NAVAIR 01-1A-509-1
TM 1-1500-344-23-1
TO 1-1-689-1

TECHNICAL MANUAL

CLEANING AND CORROSION CONTROL

VOLUME I
CORROSION PROGRAM AND CORROSION THEORY

This publication supersedes NAVAIR 01-1A-509/TM 1-1500-344-23, dated 1 May 2001 and NAVAIR 16-1-540/TM 1-1500-343-23/TO 1-1-689, dated 1 Sep 2000.

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CHAPTER 1
INTRODUCTION

This volume was prepared under the technical cognizance of the
Materials Engineering Division, NAVAIR North Island, San Diego, California.

1-1. OVERVIEW. Prevention and repair of corrosion damage to aircraft and avionic systems continues to be an ever increasing cost and safety burden for military aircraft. Equipment is routinely exposed to changes in temperature and pressure, varying humidity levels, dust, dirt, ultraviolet light, aircraft fluids, and environments that promote corrosion. Increasing environmental and safety restrictions, which limit traditional corrosion control materials, are also a significant factor in the safe and economic operation of aircraft and avionics.

1-1.1. The Cleaning and Corrosion Control manual was established jointly by the Navy, Air Force, and Army as a combined effort to consolidate and coordinate corrosion control best practices for aircraft and avionics.

1-1.2. This volumized set of corrosion manuals combines and replaces the former Aircraft Weapons Systems Cleaning and Corrosion Control (NAVAIR 01-1A-509/TM 1-1500-344-23) and Avionics Cleaning and Corrosion Prevention/Control (NAVAIR 16-1-540/TO 1-1-689/TM 1-1500-343-23) manuals.

1-2. PURPOSE. The purpose of this manual is to provide information on materials and procedures to prevent, control, and repair corrosion damage to aircraft and avionics on land or at sea.

1-3. SCOPE. The material in this manual contains basic corrosion prevention and corrective maintenance information to be used at Organizational, Intermediate, and Depot levels.

1-4. ARRANGEMENT OF MANUAL.

1-4.1. OVERVIEW OF ALL VOLUMES. The NAVAIR 01-1A-509/TM 1-1500-343-23/TO 1-1-689 series of manuals is arranged as shown in Table 1-1.

1-4.1.1. A complete set of manuals to perform aircraft cleaning and corrosion control functions consists of Volumes I, II, and IV (replaces NAVAIR 01-1A-509/TM 1-1500-344-23).

1-4.1.2. A complete set of manuals to perform avionics and electronics cleaning and corrosion control functions consists of Volumes I, III, and IV (Navy and Army) or Volumes I, III, and V (Air Force) (replaces NAVAIR 16-1-540/TM 1-1500-343-23/TO 1-1-689).

Table 1-1. Outline of Manual - All Volumes

VOLUME	TITLE	BRIEF DESCRIPTION
I	Corrosion Program and Corrosion Theory	This volume provides overall program information and explains what corrosion is, why it occurs, the forms it can take, and how to recognize it.
II	Aircraft	This volume provides cleaning and corrosion control procedures for aircraft.
III	Avionics and Electronics	This volume provides cleaning and corrosion control procedures for avionics and electronics.
IV	Consumable Materials and Equipment for Aircraft and Avionics	This volume lists approved materials and equipment for cleaning and corrosion control, and provides ordering information.
V	Consumable Materials and Equipment for Avionics	This volume was prepared at the request of the Air Force. It lists approved materials and equipment for cleaning and corrosion control, and provides ordering information, for avionics only.

Table 1-2. Outline of Volume I

CHAPTER	TITLE	BRIEF DESCRIPTION
1	Introduction	This chapter explains the purpose, appropriate usage, and the responsibility for changes to this manual. Also, this section presents the scope and outline of this volume of the manual, and an overview of the entire volumized manual.
2	Corrosion Programs	This chapter outlines the corrosion control and preventive maintenance program requirements, and provides general safety information.
3	Corrosion Theory	This chapter explains what corrosion is, why it occurs, the various forms it can take, and how to recognize it.
	Glossary	The glossary defines terms commonly used by personnel performing aircraft and avionics cleaning and corrosion control.

1-4.2. ARRANGEMENT OF VOLUME I. Volume I consists of three chapters and a glossary, arranged as shown in Table 1-2.

1-5. RELATED PUBLICATIONS. A listing of related publications is provided in Chapter 1 of each volume of this manual, as applicable.

1-6. USAGE AND CONFLICTS.

1-6.1. Supervisory and maintenance personnel shall use this manual as a guide for all corrosion control and maintenance efforts. Contractors who maintain and repair corrosion for military aircraft and avionics shall also comply with the requirements of this manual.

1-6.2. This manual shall be used in conjunction with and in support of the appropriate Army Technical Manuals (TMs), Technical Bulletins (TBs), Department of the Army Pamphlets (DA PAMs), Navy Maintenance Instruction Manuals (MIMs), Navy Structural Repair Manuals (SRMs), Maintenance Requirement Cards (MRCs), or Air Force Technical Orders (TOs).

1-6.2.1. In the case of a conflict between this manual and other Navy manuals, this manual shall take precedence; however, maintenance activities shall contact the appropriate Cognizant Field Activity (CFA)/ Fleet Support Team (FST) for immediate resolution of the conflict.

1-6.2.2. The Army and Air Force specific systems/ components manuals shall take precedence over this manual.

1-6.3. WORDING. The following definitions are adhered to in preparing this manual.

1-6.3.1. Shall is used when a procedure is mandatory.

1-6.3.2. Should is used when a procedure is recommended but not mandatory.

1-6.3.3. Will indicates future action but does not indicate a mandatory procedure.

1-6.3.4. May is used only when a procedure is optional.

1-6.4. SYMBOLS (WARNINGS, CAUTIONS and NOTES). The following definitions apply to WARNINGS, CAUTIONS and NOTES found throughout the manual.

1-6.4.1. WARNING. An operation or maintenance procedure, practice, condition, or statement, which if not strictly observed, could result in injury to or death of personnel, or long term health hazards to personnel.

1-6.4.2. CAUTION. An operating or maintenance procedure, practice, condition, or statement, which if not strictly observed, could result in damage/destruction of equipment or loss of mission effectiveness.

1-6.4.3. NOTE. An operating procedure, practice, or condition which is essential to emphasize.

1-6.5. SERVICE DESIGNATIONS. Since this is a tri-service manual, not all sections apply to all services. Information within the text that does not apply to all three services is designated after the paragraph number as follows: (N) NAVY ONLY, (A) ARMY ONLY, or (AF) AIR FORCE ONLY. Large sections that are service specific are included as appendices in the appropriate volume.

1-7. REPORTING ERRORS AND IMPROVEMENT RECOMMENDATIONS.

1-7.1. GENERAL. All activities using this manual are invited to submit recommended changes, additions, or deletions.

1-7.2. SPECIFIC REPORTING REQUIREMENTS. Recommended changes, additions, or deletions shall be reported as follows:

1-7.2.1. Navy personnel should submit recommended changes to the appropriate technical services facility using the reporting system outlined in OPNAVINST 4790.2.

1-7.2.2. Air Force personnel should refer to TO 00-5-1 to report changes.

1-7.2.3. Army personnel should submit completed DA 2028/2028-2 forms to Commander, U.S. Army Aviation and Missile Command, ATTN: AMSAM-MMC-MA-NP, Redstone Arsenal, AL 35898-5220. Changes may also be submitted electronically via the Army website, https://amcom2028.redstone.army.mil, or via email to: 2028@redstpme/army.mil.

1-8. MANUAL CHANGE PROCEDURES.

1-8.1. RESPONSIBILITY. This manual is a tri-service document, coordinated by the Materials Engineering Division, Naval Air Depot North Island, Code 4.9.7, San Diego, CA. The following activities are responsible for maintaining this document: the Naval Air Systems Command, the Air Force Corrosion Program Office, and the U.S. Army Aviation and Missile Command. As necessary, representatives from these activities shall meet to review proposed engineering and logistical changes to this manual. Changes are approved by all services, except for service-specific information.

1-8.2. PROCEDURES. The Navy is the lead service for publication of this manual; therefore, the following Navy publication change procedures apply:

1-8.2.1. Revisions. Volumes will be updated periodically by the issuance of a revision, which is a complete replacement of all pages with all change information incorporated.

1-8.2.2. Routine Changes. Between revisions, routine changes may be issued in the form of corrected pages to a portion of the existing manual. They consist of replacement change pages for that section of the manual affected by the change.

1-8.2.3. Rapid Action Changes. Changes may be issued as a formal Rapid Action Change (RAC) or an Interim Rapid Action Change (IRAC). IRACs are issued as naval messages to expedite the release of urgent and essential operational and maintenance change information. Army and Air Force program managers are responsible for retransmittal of IRACs to the appropriate service addressees.

1-9. REQUISITIONING AND AUTOMATIC DISTRIBUTION.

1-9.1. Procedures to be used by Naval activities and other Department of Defense activities requiring NAVAIR technical manuals are defined in NAVAIR 00-25-100.

1-9.2. To automatically receive future changes and revisions to NAVAIR technical manuals, an activity must be established on the Automatic Distribution Requirements List (ADRL) maintained by the Naval Air Technical Data and Engineering Service Command (NATEC). To become established on the ADRL, notify your activity central technical publications librarian. If your activity does not have a library, you may establish your automatic distribution requirements by contacting the Commanding Officer, NATEC, Naval Air Station North Island, P.O. Box 357031, Bldg. 90 Distribution, San Diego, CA 92135-7031. Annual reconfirmation of these requirements is necessary to remain on automatic distribution. Use your NATEC assigned account number whenever referring to automatic distribution requirements.

1-9.3. If additional or replacement copies of this manual are required with no attendant changes in the ADRL, they may be ordered by submitting requisitions to the Commanding Officer, Naval Supply Systems Command, Naval Logistics Library, 5801 Tabor Avenue, Philadelphia, PA 19120-5099.

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CHAPTER 2
PREVENTIVE MAINTENANCE PROGRAM

2-1. OVERVIEW. Investigations during the past ten years have identified corrosion as a major factor in electronics failure in the field. As much as 30% to 40% of military avionic failures are due to the corrosion process. This is despite steady improvements in reliability of avionic systems fielded to date and outlines the need for an effective preventive maintenance program.

2-2. CORROSION PREVENTION PHILOSOPHY. Corrosion and environmental conditions are natural phenomena that adversely affect equipment in field service. Although never totally eliminated, the problems these factors cause can be minimized so that they are less severe and better controlled. This can be achieved by understanding equipment failure mechanisms and development/utilization of corrosion control technology.

2-2.1. As a general rule, maintenance personnel should assume corrosion is ongoing, regardless of visible physical evidence. The aim of corrosion prevention is to enable systems to perform satisfactorily for a specified time period. In other words, maintenance efforts should allow equipment to approach its maximum lifetime.

2-2.2. The general workflow diagram, in Figure 2-1, defines procedures followed to implement a corrosion preventive maintenance program. This process is designed to indicate the sequence of events needed to implement and maintain an effective corrosion prevention and control program.

2-3. PREVENTIVE MAINTENANCE. The two most important factors in preventing corrosion, and the only ones which can be controlled by field personnel, are the removal of the electrolyte and the application of protective coatings. Since the extent of corrosion depends on the length of time electrolytes are in contact with metals, aircraft corrosion can be minimized by frequent washing. If noncorrosive cleaners are used, the more frequently a surface is cleaned in a corrosive environment the less the possibility of corrosive attack. In addition, by maintaining chemical treatments and paint finishes in good condition, corrosion can be minimized. The degradation of non-metallic materials can be minimized by avoiding the use of unauthorized maintenance chemicals and procedures. In addition, when repair or replacement of non-metallic materials is required, only approved materials shall be used. Dedication to proper preventive maintenance practices maximizes equipment reliability.

2-4. AIRCRAFT PREVENTIVE MAINTENANCE PROGRAM.

2-4.1. The prevention and control of corrosion on aircraft and related equipment is a command responsibility. Each command must place special emphasis on the importance of the corrosion control program and lend its full support to ensure that corrosion prevention and control receives sufficient priority to be accomplished along with other required maintenance.

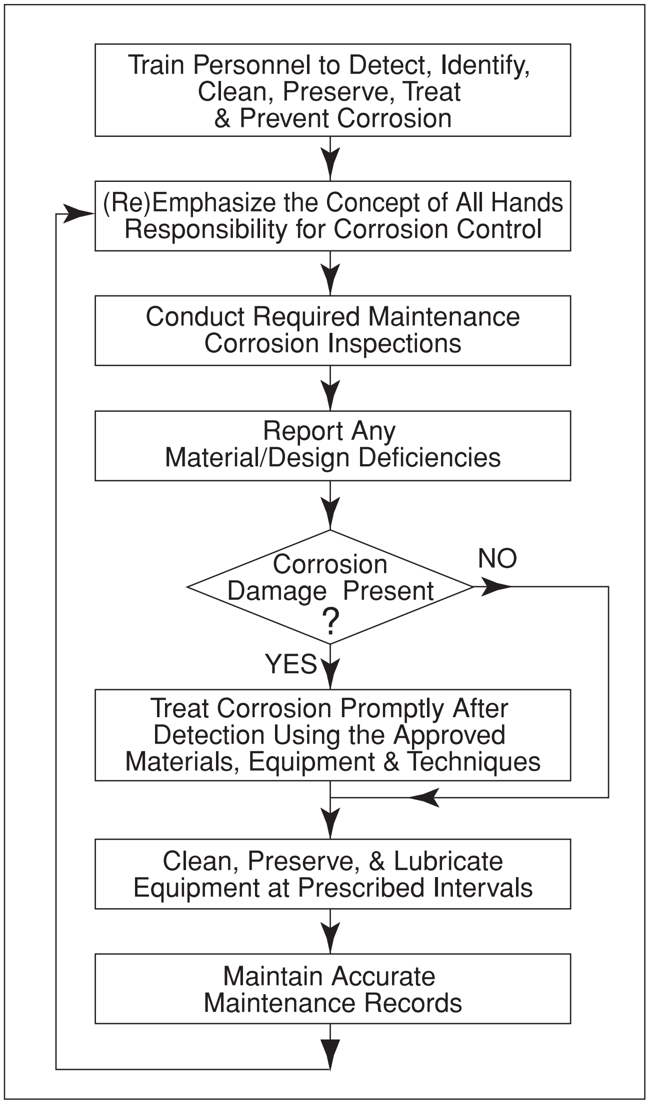

Figure 2-1. Corrosion Prevention Program General Workflow Diagram

2-4.2. Aluminum and magnesium alloys found in aviation equipment will normally begin to corrode if salt deposits, other corrosive soils, or electrolytes are allowed to remain. In order to prevent corrosion, a constant cycle of cleaning, inspection, operational preservation, and lubrication must be followed. Prompt detection and removal of corrosion will limit the extent of damage to aircraft components. An effective preventive maintenance program requires cleaning, lubrication and preservation, as well as corrosion removal, paint removal, surface treatment, sealing, and painting. A disciplined preventive maintenance program includes:

a. Regularly scheduled aircraft washing as specified by parent service organization directives;

b. Using clean water with low chloride content for aircraft washing and rinsing (chloride content should be less than 400 parts per million, approximately the same limit as that for potable water);

c. Regularly scheduled cleaning or wipe down of all exposed unpainted surfaces, such as landing gear struts and actuating rods of hydraulic cylinders as specified by parent service organization directives, with a compatible fluid or lubricant;

d. Keeping low-point drains open;

e. Inspection, removal, and reapplication of corrosion preventative compounds (CPCs) on a scheduled basis;

f. Earliest detection and repair of damaged protective coatings; and

g. Using padded panel racks to store panels/parts for aircraft and equipment during maintenance and using protective measures to prevent abrasions/ scratches resulting from placement of parts, tools, or tool boxes on wings, fuselage or other aircraft surfaces.

2-5. AVIONICS PREVENTIVE MAINTENANCE PROGRAM.

2-5.1. PROGRAM REQUIREMENTS. Successful avionic cleaning and corrosion prevention/control efforts depend on a coordinated, comprehensive preventive maintenance program. Everyone involved in maintenance, repair, and operation of avionic systems must be concerned with corrosion, cleaning, inspection, prevention, and treatment. Specifically, avionic corrosion prevention/control is everyone's responsibility. Each command must place special emphasis on the corrosion control program and lend their full support. This ensures the program receives sufficient priority to be accomplished along with other required maintenance. The goal of a preventive maintenance program is to halt corrosion before significant decline in equipment performance occurs. As such, it is important to recognize the difference between prevention of corrosion and repair of damage caused by corrosion. A preventive maintenance program at the Organizational/Unit and Intermediate Maintenance Activities should:

a. Reduce the maintenance time spent repairing corrosion damage.

b. Improve avionic system reliability, durability, and service life.

c. Make the military avionics community aware of the extent of the problem.

d. Report any deficiencies with materials and processes associated with corrosion control.

2-5.2. APPLICABLE GUIDELINES. All activities responsible for the maintenance of military aircraft and avionic systems shall establish a corrosion prevention/ control program. The type of program depends on the conditions or environments to which the aircraft/avionic systems are exposed. Those aircraft and avionic systems exposed to salt-air and tropical environments require the most stringent corrosion prevention and control programs.

2-5.3. MAINTENANCE FUNCTIONS. Experience has shown that all activities have a corrosion problem. This is regardless of whether the equipment is an installed avionic system, ground support equipment, or missile system. Accordingly, corrosion control efforts by all hands is mandatory. This must be a day-to-day requirement to prevent corrosion before it starts. Figure 2-2 depicts the basic maintenance functions.

2-6. CORROSION CONTROL PROGRAM. All activities responsible for aircraft maintenance shall establish corrosion control programs as required by the parent service organization. This program shall be structured as required by OPNAVINST 4790.2 (Navy), TO 00-20-1 (Air Force), or AR 750-59 (Army) and ensure that personnel receive hazardous material/waste handlers training. The type of program depends upon the environment to which the aircraft may be exposed. At sea, where conditions are normally the most severe, aircraft are exposed to salt spray, ship stack gases, and

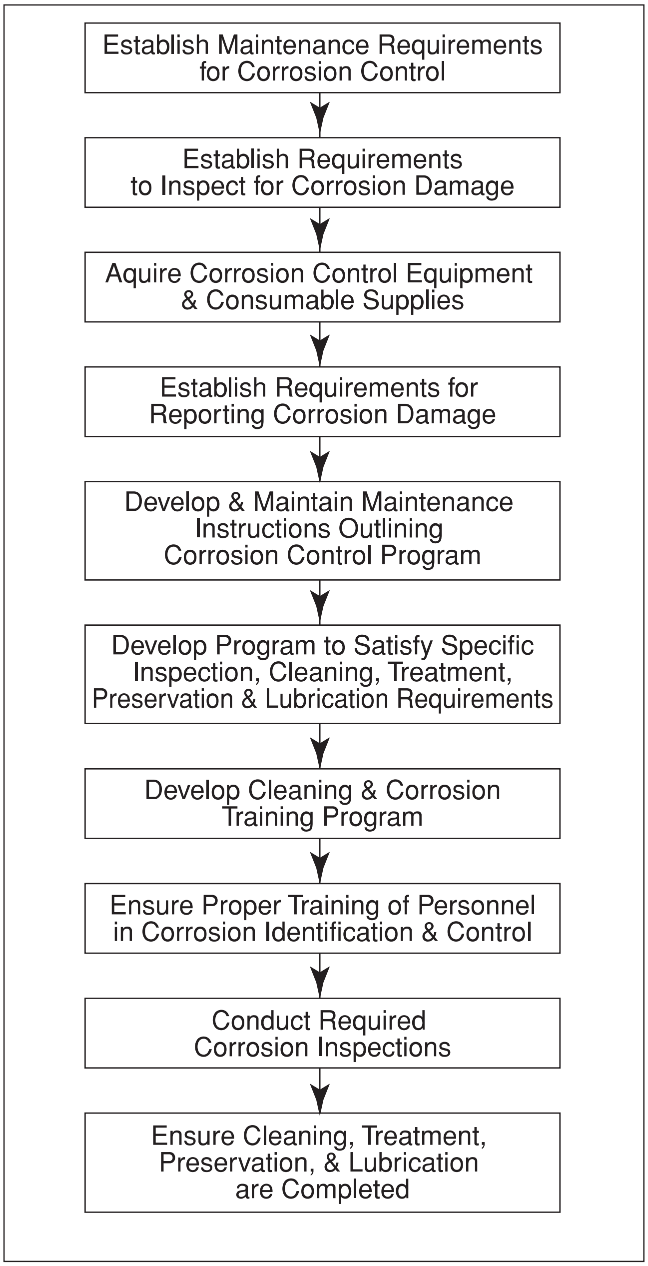

Figure 2-2. Basic Maintenance Functions

aircraft engine exhausts. Land-based aircraft may be exposed to industrial gases, salts, rain, mud, and, near salt water, mists containing sea salts. A comprehensive corrosion control program shall consist of either a Corrosion Control Work Center or a Corrosion Control Team with personnel trained in the prevention, early detection, reporting, and repair of corrosion damage. Such a program requires a dedicated effort by all maintenance personnel to prevent corrosion before it starts. These efforts will improve the operational readiness of equipment and minimize costly repairs.

2-6.1. TRAINING. Personnel performing maintenance on aircraft shall be trained in basic corrosion control skills as established by the parent service organization. Personnel shall be fully aware of the reasons for the corrosion control program. Without such training and understanding, further damage or additional problems may result.

2-6.2. TRAINING AND QUALIFICATION REQUIREMENTS. Personnel responsible for corrosion control maintenance and treatment shall receive the following training.

a. Supervisors and corrosion control personnel shall attend basic corrosion control courses established by the parent service organization.

b. Cleaning and repair personnel shall be trained in inspection, identification, cleaning, treatment, preservation, lubrication, hazardous material handling/ hazardous waste disposal, and proper documentation reporting.

c. Supervisors shall ensure maximum use of in-service and on-the-job-training.

2-6.3. MAINTENANCE. An effective corrosion control program shall include thorough cleaning, inspection, preservation, and lubrication, at specified intervals, in accordance with Volumes II and III of this manual. Check for corrosion damage and integrity of protective finishes during all scheduled and unscheduled maintenance. Early detection and repair of corrosion will limit further damage. When corrosion is discovered, treat corrosion as prescribed in Volumes II and III as soon as possible and use only approved materials, equipment, and techniques. Only affected areas shall be repaired. All maintenance personnel shall report corrosion promptly, in accordance with directives established by the parent service organization.

2-7. CORROSION-RELATED FAILURE DATA FEEDBACK.

2-7.1. Since corrosion prevention and control for aircraft and avionics is a continuing concern, it is vitally important that corrosion problems are properly reported. Problems can be corrected and improvements made to prevent reoccurrence in future equipment design. Identification of the specific causes and extent of corrosion problems is essential. Improved equipment performance and maintenance assistance (personnel, equipment, materials, and procedures) are dependent on this data.

2-7.2. MAINTENANCE AND READINESS DATA COLLECTION. All activities using this manual are required to use the current maintenance data collection system(s) of the parent service organization. This will enable a record of corrosion-related failures to be submitted to the appropriate technical services facility for analysis. Reporting personnel shall identify/report corrosion discrepancies in accordance with OPNAVINST 4709.2 (Navy), TO 00-20-2 (Air Force), or DA PAM 738-750/DA PAM 738-751 (Army).

2-8. SAFETY. Safety is everyone's business and concern.

2-8.1. RESPONSIBILITY OF SUPERVISORS.

2-8.1.1. Work center supervisors shall receive the following training in accordance with parent service directives:

a. The recognition and elimination of hazards;

b. Occupational safety and health;

c. The safety of the individual;

d. Accident investigation and reporting; and

e. The inspection and maintenance of personal protective equipment (PPE).

2-8.1.2. Supervisors shall ensure that all corrosion control personnel are informed of:

a. Current safety procedures;

b. Characteristics of materials to which they will be exposed; and

c. Required protective clothing to ensure safety of personnel.

2-8.1.3 In addition, supervisors shall ensure that an adequate supply of safety equipment is in a ready-for-issue condition, and that the personnel under their control are given, and use, appropriate protective equipment to prevent accidents, injuries, and occupational illness.

2-8.2. RESPONSIBILITY OF PERSONNEL. Maintenance personnel shall use appropriate equipment while exposed to hazardous conditions, and shall report to the supervisor any protective equipment that is broken, damaged, defective, or inadequate. No one shall use protective equipment that is not in a satisfactory and serviceable condition. Personnel shall comply with occupational safety and health requirements, including medical examinations, respirator training and fit testing, and use of protection for eyes, ears, head, skin, and feet.

2-8.3. MATERIALS HANDLING. Many of the materials and procedures outlined in this manual are potentially hazardous to personnel and potentially damaging to aircraft, especially with improper use. When using any chemicals, such as paint removers, detergents, conversion coatings, and solvents, follow the correct procedures with appropriate protective gear to prevent personnel injury and aircraft damage. Read the appropriate warnings and cautions in this manual prior to use of any hazardous materials. Misuse of certain materials can damage parts or cause corrosion which may lead to catastrophic failure. Refer to DoD 6050.5-LR, Hazardous Materials Information System, or the appropriate parent service organization documents for the handling, storage, and disposal of hazardous materials. Refer to local directives and policies pertaining to hazardous waste management. When in doubt, contact the local safety office, industrial hygienist, bioenvironmental engineer, or regional medical center.

2-9. MATERIALS.

2-9.1. Consumable materials and equipment listed in Volumes IV and V shall be used for corrosion control. These materials and equipment have been approved only after extensive testing to prove their ability to perform properly and effectively without damaging any of the metallic or nonmetallic materials used in aircraft.

2-9.2. Only those materials listed in this manual shall be used for cleaning or corrosion control of aircraft components. When several methods or materials are listed, the preferred one is listed first, with alternates following. Materials listed in other manuals shall be used only when required procedures are not covered by this manual. When approved materials are not available, substitutions shall only be made by the appropriate Aircraft Controlling Custodians (ACC) or System Program Manager (SPM).

2-9.3. Materials or processes considered to be an improvement over existing ones, after local laboratory analysis and evaluation, shall be forwarded to the Aircraft Controlling Custodians (ACC) or System Program Manager (SPM) for submission to the parent service organization for further evaluation.

CHAPTER 3
CORROSION THEORY

3-1. OVERVIEW.

3-1.1. Maintenance of military aircraft and avionic equipment requires knowledge of why metals corrode and materials degrade. The theory lies in the definition and description of mechanisms that cause equipment to fail in field service. Corrosion is the chemical or electrochemical deterioration of a material. This deterioration is complex in nature because of the various types of corrosion, the frequent simultaneous presence of several types of corrosion, and the design characteristics and maintenance/environmental factors that make aircraft and avionic systems susceptible to corrosion.

3-1.2. Corrosion can cause complete failure of equipment or undesirable changes in electrical characteristics. It is a process that is active on a 24 hour basis. Equipment does not necessarily have to be installed, operated, or resident in a particularly harsh environment. Some form of corrosion will take place even in near ideal environments. All personnel should recognize that corrosion is the natural continuing process of materials returning to their normal state. Inadequate corrosion prevention and control will ultimately affect equipment life cycles, downtime, and overall system reliability.

3-2. PURPOSE. The purpose of this chapter is to provide maintenance personnel with the background knowledge necessary to understand the causes of corrosion.

3-3. SCOPE. This chapter is an introduction to corrosion theory: the causes of corrosion and the factors which influence its development. The theory of corrosion and the factors influencing corrosion of aircraft metals are described. The types of corrosion and how to recognize them are discussed.

3-4. DEFINITION OF CORROSION. Corrosion is the electrochemical deterioration of a material or its properties due to its chemical reaction with the surrounding environment. This reaction occurs because of the tendency of metals to return to their naturally occurring state, usually oxide or sulfide ores. For example, iron in the presence of moisture and air will return to its natural state, iron oxide or rust. Aluminum and magnesium form corrosion products that are white oxides or hydroxides. When a water solution containing soluble salts is present, corrosion of many alloys can occur easily at ambient temperatures. This type of corrosion can be effectively treated by maintenance personnel as discussed in this manual. Corrosion can also occur in the absence of water but only at high temperatures, such as those found in gas turbine engines. However, the most common type of corrosion (and the one that can be most effectively treated by maintenance personnel) is electrochemical corrosion.

3-5. CHEMICAL DEFINITIONS.

3-5.1. ATOM. The smallest unit of an element, made up of a positively charged nucleus surrounded by a system of negatively charged electrons. There are over 100 elements, including metals (such as aluminum, magnesium, gold, platinum, iron, nickel, titanium, cadmium, chromium, copper, silver, lead, beryllium, zinc), and non-metals (such as carbon, boron, sulfur, chlorine, hydrogen, oxygen, nitrogen, and helium).

3-5.2. ELECTRON. A negatively charged subatomic particle. An electric current occurs when electrons are forced to move through metal conductors. Electrons flow through liquid solutions only in the presence of ions.

3-5.3. ION. An atom or group of atoms or molecules which has acquired a net electric charge by gaining (negative ion) or losing (positive ion) electrons. When ions are forced to move through liquid solutions, an electric current can occur. Ions cannot move through metal conductors.

3-5.4. ELECTROLYTE. A liquid (usually water) solution containing ions. Sea water is an electrolyte: an aqueous (water-based) solution whose major components are sodium and chloride ions. Electrochemistry is the branch of science concerned with chemical reactions at surfaces in contact with electrolytes.

3-6. THEORY OF CORROSION. All metals will corrode to some extent in a natural environment. When a metal corrodes, the atoms lose electrons and become positively charged. In solution, the positively charged metal ions can combine with negatively charged ions to form corrosion products, such as metallic chlorides, oxides, hydroxides, and sulfides.

3-6.1. Four conditions (illustrated in Figure 3-1) must exist before metal corrosion can occur.

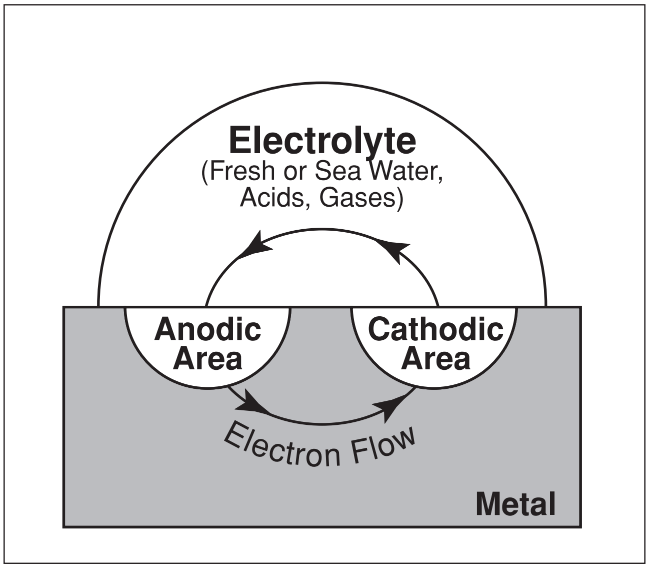

Figure 3-1. Simplified Corrosion Cell

a. A metal which has a tendency to corrode must be present (the corroding metal is called the anode);

b. A dissimilar conductive material (the cathode), which has less tendency to corrode than the anode, must be present (a dissimilar metal may be a different metal, a protected part of the same metal, or conductive plastic);

c. A conductive liquid (electrolyte) must connect the anode and cathode (so that ions can carry electric current between them); and

d. Electrical contact between the anode and cathode (usually in the form of metal-to-metal contact) must exist so that electrons can move between the anode and the cathode.

3-6.2. The elimination of any one of the four conditions will slow or stop corrosion. For example, a paint film on a metal surface will prevent the electrolyte from connecting the anode and cathode, thereby stopping the electric current (see Figure 3-2). A change in the electrolyte can also affect the rate of corrosion. Two connected dissimilar metal parts placed in distilled water corrode very slowly due to a lack of ions in solution to conduct the electric current; in sea water the corrosion reaction is accelerated by a factor of 1000 or more (see Figure 3-3).

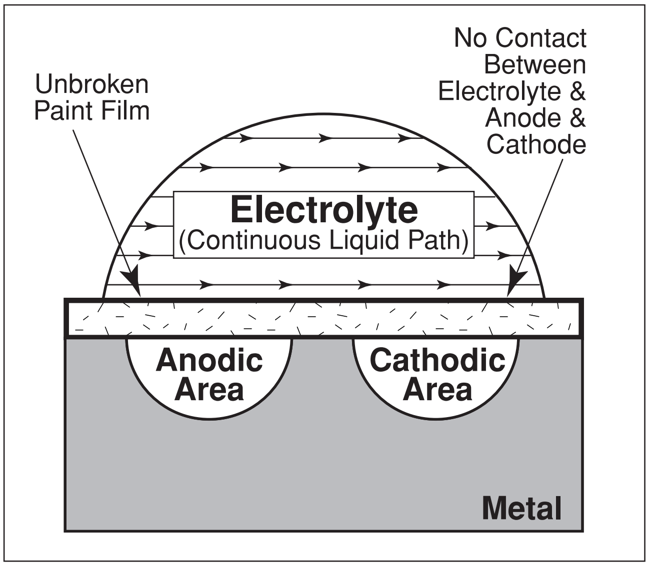

Figure 3-2. Elimination of Corrosion by Application of an Organic Film to a Metal Surface

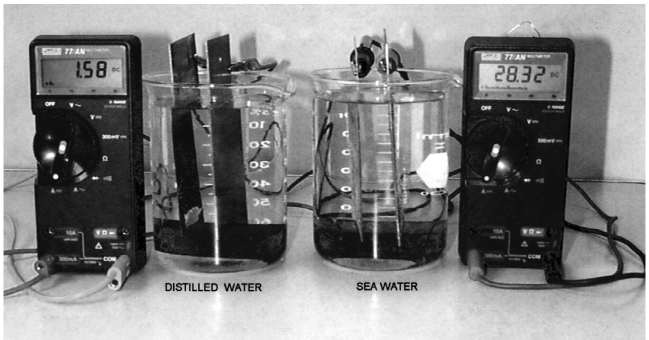

Figure 3-3. Effect of Sea Water on Galvanic Corrosion

3-7. DEVELOPMENT OF CORROSION. All corrosive attack begins on the surface of the metal. If allowed to progress, corrosion can penetrate into the metal. If corrosion begins on an inside surface of a component (for example, the inner wall of a metal tube), it may go undetected until perforation occurs.

3-7.1. When corrosion products form, they often precipitate onto the corroding surface as a powdery deposit. This film of corrosion products may reduce the rate of corrosion, if the film acts like a barrier to electrolytes. Some metals (such as stainless steel and titanium), under the right conditions, produce corrosion products that are so tightly bound to the corroding metal that they form an invisible oxide film (called a passive film) which prevents further corrosion. However, when the film of corrosion products is loose and porous (such as those of aluminum and magnesium), an electrolyte can easily penetrate and continue the corrosion process, producing more extensive damage than surface appearance would indicate.

3-7.2. Paint coatings can mask the initial stages of corrosion. Since corrosion products occupy more volume than the original metal, the paint surfaces may become blistered, flaked, chipped, or appear lumpy.

3-8. FACTORS INFLUENCING CORROSION. Factors which influence metal corrosion and the rate of corrosion are outlined below.

3-8.1. TYPE OF MATERIAL. The best time to prevent corrosion is at the design stage. Proper material selection is critical for the protection of equipment against harmful environmental effects. Most pure metals are not suitable for aircraft construction and are used only in combination with other metals, and sometimes non-metals, to form alloys. The metals most commonly used in aircraft construction are aluminum, steel, titanium, and magnesium. Cadmium, nickel, chromium, and silver are sometimes used as protective platings. Metals have a wide range of corrosion resistance. The most active metals (those which tend to lose electrons easily), such as magnesium and aluminum, corrode easily and are listed at the top of Figure 3-4. The most noble metals (those which do not lose electrons easily), such as gold and silver, do not corrode easily and are listed at the bottom of Figure 3-4.

3-8.2. HEAT TREATMENT AND GRAIN DIRECTION. Most alloys are made up entirely of small crystalline regions called grains. When heat treated during manufacturing or repair, heavy sections of metals do not cool uniformly and, as a result, tend to vary in chemical composition from one part of the metal to another. This can cause corrosion if one area is more active than another. Alloys which are fabricated by rolling, extruding, forging, or pressing have properties which depend highly on direction (parallel to grain elongation vs. cross grain). Corrosion can occur on surfaces of those regions which are less resistant and also at grain boundaries, resulting in the formation of pits and intergranular corrosion. For example, exposed end grains corrode much more easily than flattened elongated surfaces in sheet stock. This explains why exfoliation occurs at the edge of aircraft skin sections or next to countersunk fasteners.

3-8.3. DISSIMILAR METALS. When two dissimilar metals make electrical contact in the presence of an electrolyte, the rate at which corrosion occurs depends on the difference in their activities, that is, their positions in Figure 3-4. The greater the difference in activity, the faster corrosion occurs. For example, magnesium would corrode very quickly when coupled with gold in a humid atmosphere. But aluminum would corrode very slowly, if at all, in contact with cadmium. A flashlight battery is an example of galvanic corrosion put to practical use. In Figure 3-5, the zinc battery casing steadily corrodes, supplying a steady flow of electrons, but only when the switch is closed. When the switch is open, there is no corrosion because electrons are not able to leave the zinc anode.

3-8.4. ANODE AND CATHODE SURFACE AREA. The rate of corrosion also depends on the size of the parts in contact. If the surface area of the corroding metal (the anode) is smaller than the surface area of the less active metal (the cathode), corrosion will be rapid and severe. But, when the corroding metal is larger than the less active metal, corrosion will be slow and superficial. For example, an aluminum fastener in contact with a relatively inert monel structure may corrode severely, while a monel bracket secured to a large aluminum member would result in a relatively superficial attack on the aluminum sheet (see Figure 3-6).

3-8.5. PRESENCE OF ELECTROLYTES. Electrically conducting solutions are easily formed on metallic surfaces when condensation, salt spray, rain, or rinse water accumulate. Dirt, salt, acidic stack gases, and engine exhaust gases can dissolve on wet surfaces, increasing the electrical conductivity of the electrolyte, thereby increasing the rate of corrosion.

3-8.6. ELECTROLYTE CONCENTRATION. In the same way that metals can corrode when exposed to different concentrations of oxygen in an electrolyte, corrosion will also occur if the concentration of the electrolyte on the surface varies from one location to another. This corrosive situation is known as a concentration cell.

3-8.7. AVAILABILITY OF OXYGEN. When some of the electrolyte on a metal surface is partially confined (such as between faying surfaces or in a deep crevice), metal in this confined area corrodes more rapidly than other metal surfaces of the same part outside this area. This type of corrosion is called an oxygen concentration cell or differential aeration cell. Corrosion occurs more rapidly than would be expected because the reduced oxygen content of the confined electrolyte causes the adjacent metal to become anodic to the metal surfaces exposed to the air.

Figure 3-4 . Galvanic Series of Metals and Alloys in Sea Water

ANODIC - High Corrosion Potential

- Lithium
- Magnesium Alloys
- Zinc (plate)
- Beryllium
- Cadmium (plate)
- Uranium (depleted)
- Aluminum Alloys
- Indium
- Tin (plate)
- Stainless Steel 430 (active)
- Lead
- 1010 Steel
- Cast Iron
- Stainless Steel 410 (active)
- Copper (plate)
- Nickel (plate)
- AM 350 (active)
- Chromium (plate)
- Stainless Steels 350, 310, 301, 304 (active)
- Stainless Steels 430, 410 (passive)
- Stainless Steel 13-8, 17-7PH (active)
- Brass, yellow, Naval
- Stainless Steel 316L (active)
- Bronze 220
- Copper 110
- Stainless Steel 347 (active)
- Copper-Nickel 715
- Stainless Steel 202 (active)
- Monel 400
- Stainless Steel 201 (active)
- Stainless Steels 321, 316 (active)
- Stainless Steels 309, 13-8, 17-7 PH (passive)
- Stainless Steels 304, 301, 321 (passive)
- Stainless Steels 201, 316L (passive)
- Stainless Steel 286 (active)
- AM355 (active)
- Stainless Steel 202 (passive)
- Carpenter 20 (passive)
- AM355 (passive)
- Titanium Alloys
- AM350 (passive)
- Silver
- Palladium
- Gold
- Rhodium
- Platinum
- Carbon/Graphite

CATHODIC - Low Corrosion Potential

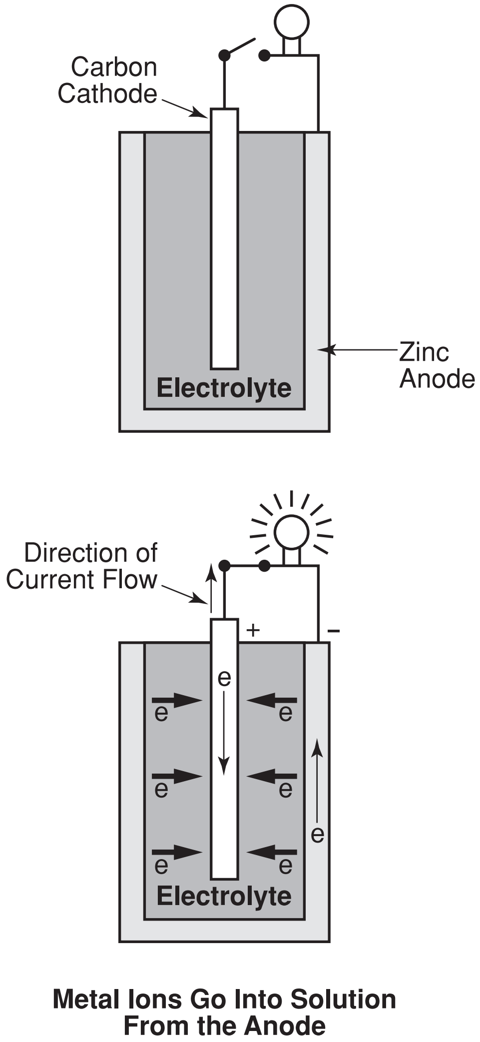

Figure 3-5. Galvanic Corrosion in a Flashlight Battery

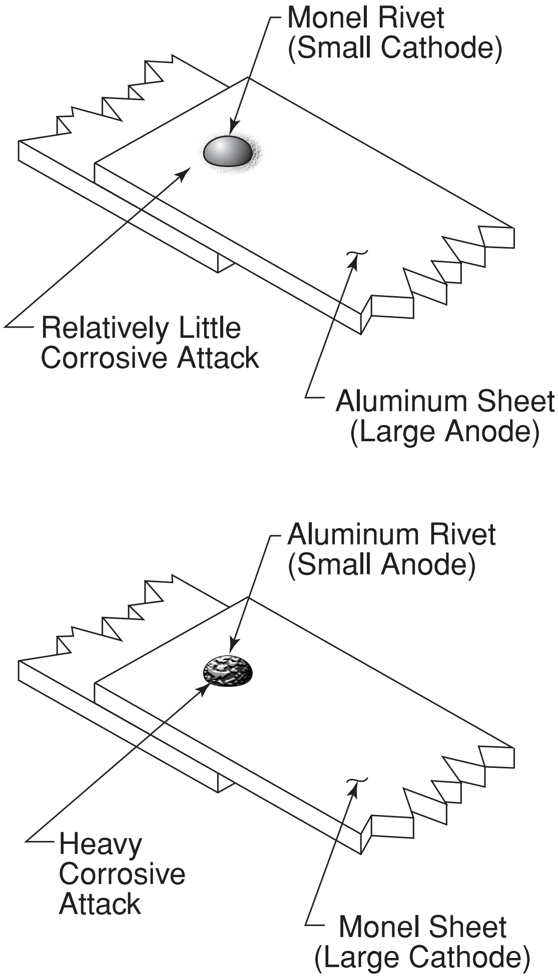

Figure 3-6. Effect of Area Relationship in Dissimilar Metal Contacts

3-8.8. TEMPERATURE. Higher temperature environments tend to produce more rapid corrosion due to accelerated chemical reactions and, in humid environments, higher concentration of water vapor in the air. In addition, nightly drops in temperature can cause greater amounts of condensation, leading to increased corrosion rates.

3-8.9. BIOLOGICAL ORGANISMS. Bacterias, molds, fungi, and other living organisms (some microscopic) can grow on damp surfaces. Once they are well established, the area tends to remain damp, increasing the possibility of corrosion. Their presence can cause the areas they occupy to have different oxygen and electrolyte concentrations. In addition, acidic wastes are secreted, which cause corrosion.

3-8.10. MECHANICAL STRESS. Many alloys used in aircraft construction are sensitive to a form of corrosion known as stress corrosion cracking. Manufacturing processes such as machining, forming, welding, or heat treatment can leave residual mechanical stresses in aircraft parts. The addition of in-service stresses to residual stresses can cause corrosion to proceed more rapidly than would be expected in normal service.

3-8.11. LENGTH OF EXPOSURE. As time passes, metals naturally tend to corrode. In some cases, the corrosion process occurs at the same rate, no matter how long the metal has been exposed to the environment. In other cases, corrosion can decrease with time, due to the barrier formed by corrosion products, or increase with time if a barrier to corrosion is being broken down.

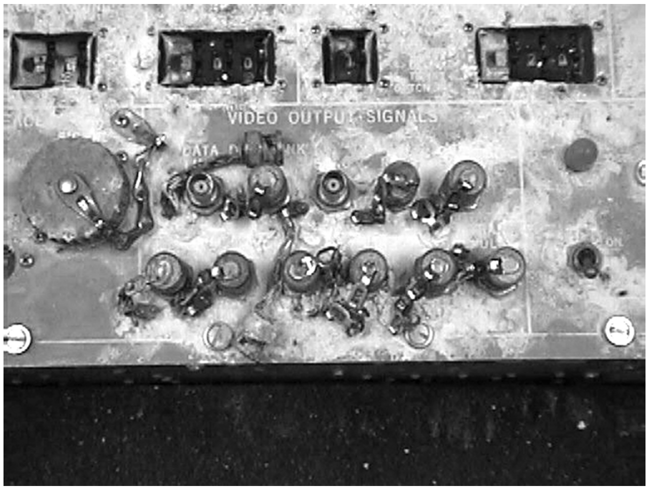

Figure 3-7. Surface Corrosion on Frequency Test Set

3-9. TYPES OF CORROSION. Corrosion is catalogued and typed in many ways. Occasionally, different names are used for the same type of corrosion. The common types of corrosion are described below.

3-9.1. UNIFORM SURFACE CORROSION. Uniform surface corrosion is probably the most common type of corrosion. It results from a direct chemical attack on a metal surface that proceeds uniformly over the entire exposed surface (see Figure 3-7). The metal gradually becomes thinner and eventually fails. On a polished surface, this type of corrosion is first seen as a general dulling or etching of the surface and, if the attack is allowed to continue, the surface becomes rough and possibly frosted in appearance. An example is the etching of metals by acids. The discoloration or general dulling of metal created by exposure to elevated temperatures is not considered to be uniform surface corrosion. Coating/sealing the exposed surface will protect it from this type of attack. Also, corrosive elements may be removed through air movement and drain holes.

3-9.2. GALVANIC CORROSION. Galvanic corrosion occurs when different metals are in contact with each other and an electrolyte, such as sea water. It is usually recognizable by the presence of a buildup of corrosion deposits at the joint between the metals. For example, aluminum skin panels and stainless steel doublers, riveted together in an aircraft wing, form a galvanic couple if moisture and contamination are present. Figure 3-8 shows galvanic corrosion of magnesium adjacent to steel fasteners. The potential for galvanic corrosion is greatest when the two metals are well separated from each other in the galvanic series (see Figure 3-4) and are in electrical contact.

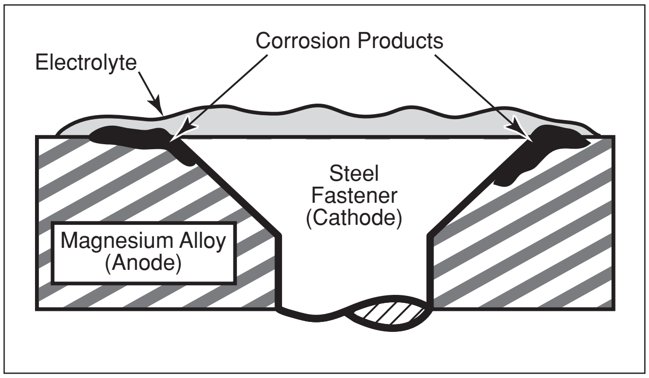

Figure 3-8. Galvanic Corrosion of Magnesium Adjacent to Steel Fastener

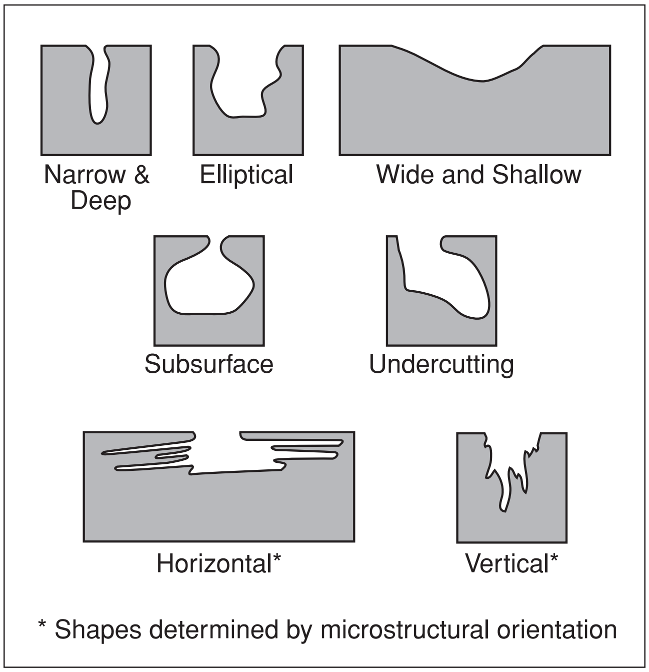

Figure 3-9. Variations in the Cross-Sectional Shape of Corrosion Pits

3-9.3. PITTING CORROSION. Pitting is a form of extremely localized attack that results in holes in the metal (see Figure 3-9). Pits can be isolated, or so close together that they look like a rough surface. Pits are often difficult to detect because of their small size and because they may be covered with corrosion products. Pitting is usually first noticeable as a white or gray powdery deposit, similar to dust, which blotches the surface. When the deposit is cleaned away, tiny pits or holes can be seen in the surface. Most pits develop and grow downward (in the direction of gravity) from a horizontal surface. Pitting failures are commonly caused by electrolytes containing chloride or chlorine-containing ions (such as seawater). Stainless steels are most susceptible to pitting damage, although aluminum, magnesium, and copper are often attacked (see Figure 3-10).

3-9.4. INTERGRANULAR CORROSION. Intergranular corrosion is an attack on the grain boundaries of the metal. A highly magnified cross section of any commercial alloy (see Figures 3-11 and 3-12) shows the granular structure of the metal. It consists of quantities of individual grains, each having a clearly defined boundary, which chemically differs from the metal within the grain. Frequently the grain boundaries are anodic (tend to corrode more easily) to the metal within the grain. When an electrolyte is present, rapid selective corrosion of the grain boundaries occurs. High strength aluminum alloys, which depend on precipitated phases of alloying elements for strength, are particularly susceptible to intergranular attack. Figure 3-13 shows how intergranular corrosion progresses in 7075-T6 aluminum alloy adjacent to steel fasteners. In this example, the grain boundaries are anodic to both the metal grain and the steel fastener.

3-9.5. EXFOLIATION CORROSION. Exfoliation (see Figures 3-14 and 3-15) is an advanced form of intergranular corrosion where the surface grains of a metal are lifted up by the force of expanding corrosion products occurring at the grain boundaries. The lifting up or swelling is visible evidence of exfoliation corrosion. Exfoliation occurs on extruded, rolled, wrought, and forged high strength aluminum and magnesium parts. This type of corrosion most often occurs on extruded sections of metal and is found primarily in aluminum sheet around steel fasteners. Its prevention involves separating the aluminum and steel by a barrier, such as zinc-chromate primer or sealant.

3-9.6. CREVICE CORROSION. Crevice corrosion is one of the most familiar types of corrosion. Field experience shows that this type of corrosion may occur in any crevice where a stagnant solution has pooled. Crevices are usually located at gasket surfaces, lap joints, and under bolt or rivet heads. Crevice corrosion occurs because the environment of the local area is very different from the larger environment. As a result, the metal surfaces, even though they may be the same metal, have different activities, and corrosion occurs inside the crevice. This kind of corrosion can also occur when a surface is covered by a foreign material. Methods to minimize crevice corrosion include closing the crevice


Figure 3-10. Pitting of an Aluminum Wing Assembly

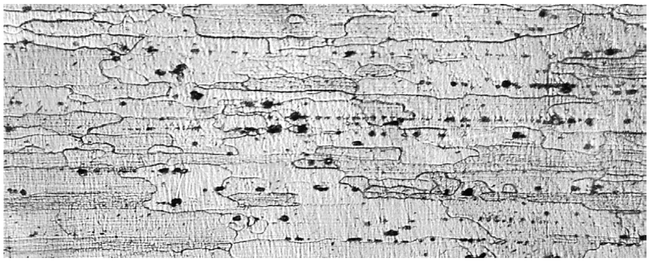
Figure 3-11. Cross-Section of 7075-T6 Aluminum Alloy


Figure 3-12. Scanning Electron Micrograph of a Corroding Aluminum Surface

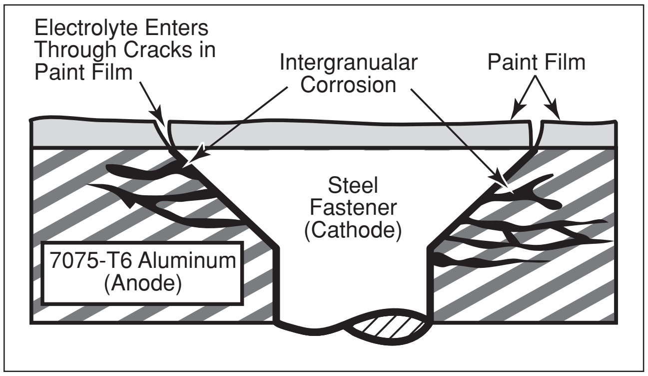

Figure 3-13. Intergranular Corrosion of 7075-T6 Aluminum Adjacent to Steel Fasterner

Figure 3-14. Extreme Example of Exfoliation at Edge of Sheet

by welding, sealant, or soldering, and use of nonabsorbent gaskets (such as Teflon).

3-9.6.1. Oxygen Differential Cells. Electrolyte in contact with metal surfaces will normally contain dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse into the solution, thereby creating a difference in oxygen concentration between two points. Typical locations of oxygen differential cells are under either metallic or non-metallic deposits (dirt) on the metal surface and under faying surfaces such as riveted lap joints. Oxygen cells can also develop under gaskets, wood, rubber, plastic tape, and other materials in contact with the metal surface. Corrosion will occur at the area of low oxygen concentration (anode) as illustrated Figure 3-16, View A. Alloys such as stainless steel, which owe their corrosion resistance to surface passivity, are particularly susceptible to this type of crevice corrosion.

3-9.6.2. Active/Passive Cells. Metals which depend on a tightly adhering passive film, such as the oxide film on corrosion resistant steel, are prone to rapid corrosive attack by active/passive cells. The corrosive action usually starts with a deposit of dirt or salt which

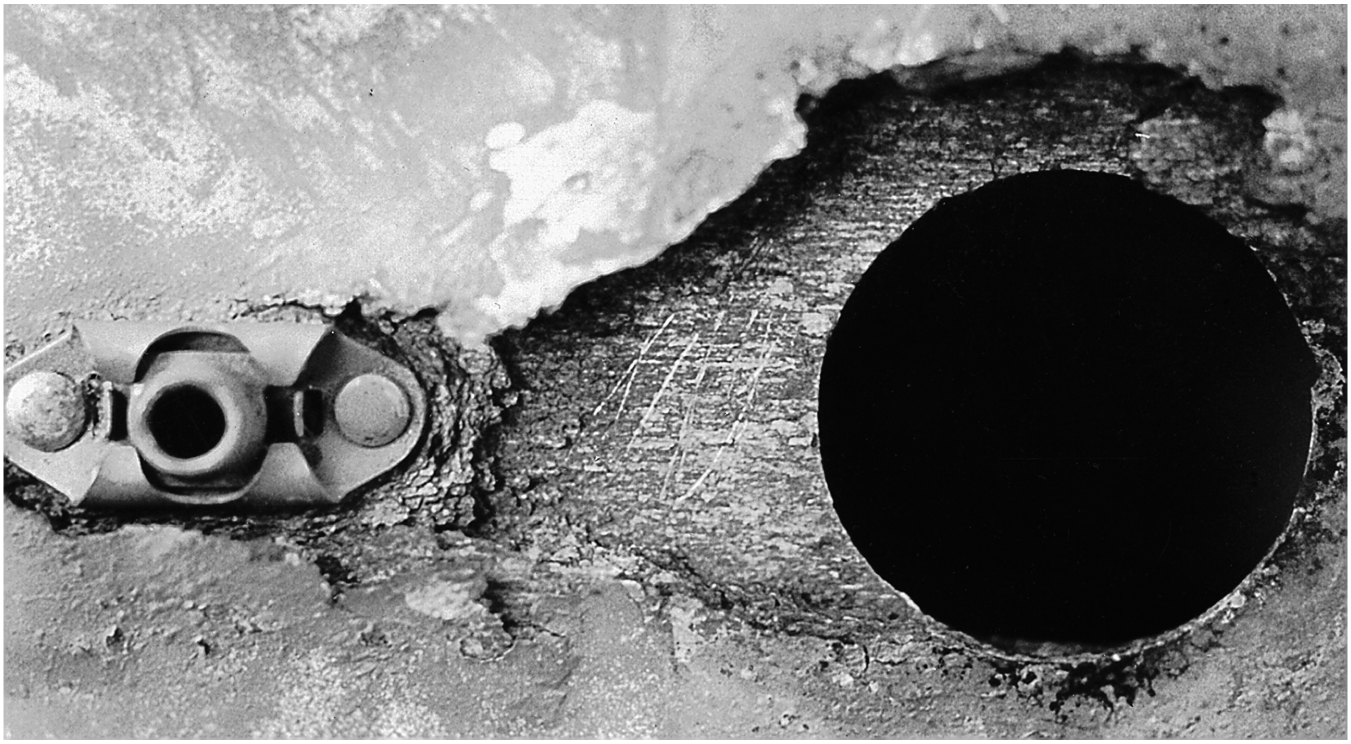

Figure 3-15. Exfoliation Adjacent to Fasteners

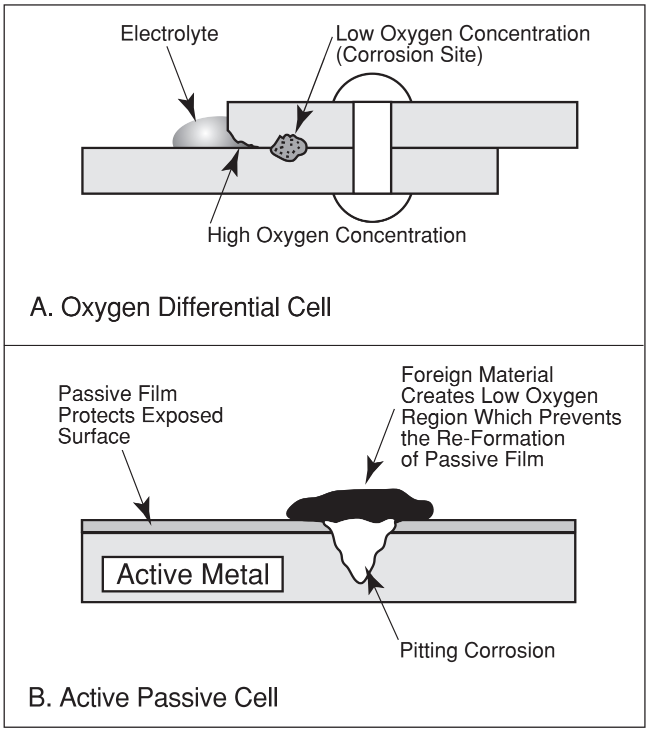

Figure 3-16. Crevice Corrosion Mechanisms

creates an oxygen differential cell. The passive film is then broken in the area of the salt deposit and the more active metal beneath the passive film will be exposed to corrosive attack. This small anodic area will then corrode rapidly due to the much larger area of the surrounding cathode (passive film). The result is rapid pitting of the surface, as illustrated in Figure 3-16, View B.

3-9.7. FILIFORM CORROSION. Filiform corrosion is a form of crevice corrosion which occurs on metal surfaces having a thin (~4 mils) organic protective coating. It is recognized by its characteristic wormlike trace of corrosion products beneath the coating (see Figure 3-17). Filiform corrosion is unusual because it only affects surface appearance, but does not weaken or destroy the base metal. Filiform corrosion occurs when the relative humidity of the air is between 65 and 90%, and the air temperature is between 70° and 100°F. It starts at breaks in the coating system, such as scratches and cracks around fasteners and seams, and proceeds underneath the coating, due to the diffusion of water vapor and oxygen from the air through the coating (see Figure 3-18). Filiform corrosion can attack

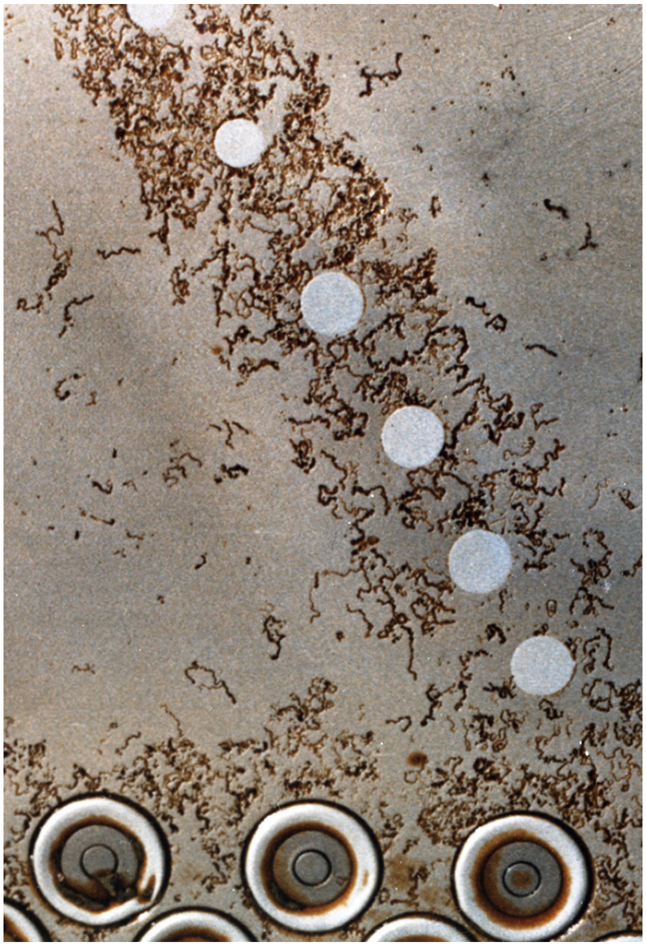

Figure 3-17. Filiform Corrosion Found Under Paint Coating on a Magnesium Panel

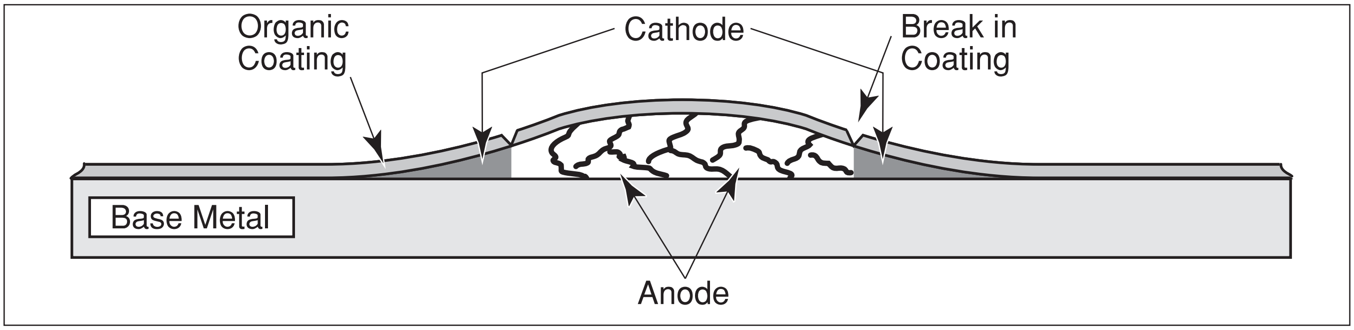

Figure 3-18. Schematic of the Development of Filiform Corrosion on an Aluminum Alloy

steel, magnesium, and aluminum surfaces and may lead to more serious corrosion in some locations. Filiform corrosion can be prevented by storing equipment and aircraft in an environment with a relative humidity below 65%, by using coating systems having a low rate of diffusion for oxygen and water vapors, by maintaining coatings in good condition (prompt touchup around fasteners), and applying corrosion preventive compounds (CPCs) when the coating is damaged.

3-9.8. <u>EROSION CORROSION</u>. Erosion corrosion is the increase in the rate of attack on a metal due to the action of a corrosive fluid against the metal surface. Generally the movement is rapid, and wear or abrasion occurs with the corrosion. Erosion corrosion is characterized by grooves, gullies, waves, rounded holes and/or valleys in the metal surface. Metals that are soft (copper, lead) or metals that depend upon the development of a protective surface film (aluminum, stainless steel) are susceptible to erosion corrosion damage. Equipment exposed to moving fluids (e.g. heat exchanger tubing, pumps, propellers, impellers) are also susceptible.

3-9.9. <u>STRESS CORROSION</u>. Also called stress corrosion cracking (SCC). Stress corrosion (Figure 3-19) is the intergranular or transgranular cracking of a metal caused by the combined effects of constant tensile stress (internal or applied) and corrosion. Internal or residual stresses may be produced by welding, cold working, forming, and heat treatment operations during the manufacture of a part. Stresses remain concealed in the part unless stress relief operations are used. Other hidden stresses are induced in parts when press or shrink fits are used and when slightly mismatched parts are clamped together with rivets and bolts. All these stresses add to those caused by applying normal loads to parts in operation. Stress corrosion is normally localized and appears in the form of cracks. During SCC, the metal is unattacked over most of its surface, while fine cracks progress through the interior of the part. Cracking is generally perpendicular to the applied stress. Metals have threshold stresses below which stress corrosion cracking will not occur. This threshold stress varies from metal to metal, is different for different tempers of the same metal, and is different for each of the three directions in which stress can be applied. In aircraft, high strength steel parts (e. g. landing gear) and high strength aluminum parts are particularly susceptible to stress corrosion.

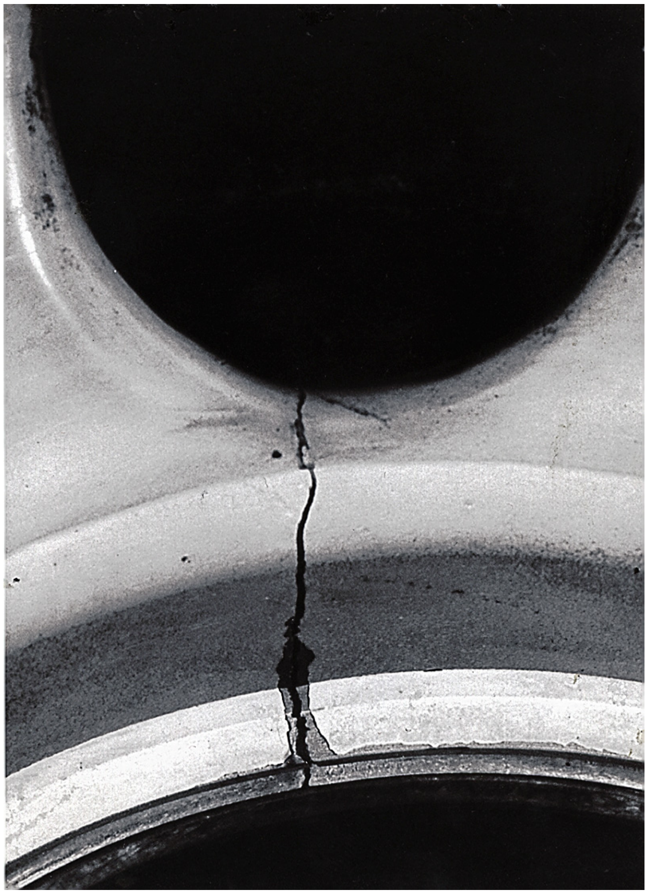

Figure 3-19. Cracking (Typical of Stress Corrosion or Corrosion Fatigue)

3-9.9.1. <u>Associated Hazards</u>. Stress corrosion cracking is an extremely dangerous type of failure because it can occur at stress levels far below the rated strength of a metal, starting from what appears to be a very minor corrosion pit. This type of failure can be catastrophic and occur without warning. Parts can completely sever in a split second or they can crack slowly. The rate of cracking and the stress limit is very unpredictable in operating service. For example, 7075-T6 aluminum alloy can fail by stress corrosion cracking when subjected to a stress which is only 10% of its rated strength.

3-9.9.2. <u>Causes</u>. Specific environments have been identified which cause stress corrosion cracking of certain alloys. Salt solutions, sea water, and moist salt laden air may cause stress corrosion cracking of heat treatable aluminum alloys, stainless steels, and some titanium alloys. Magnesium alloys may stress corrode in moist air. Stress corrosion can be prevented by placing an insulating barrier between the metal and the corrosive environment, or by applying protective coatings and/or water displacing corrosion preventive compounds. Stress relief operations during fabrication of parts will help, because it lowers the internal stress level of the part. Shot peening a metal increases resistance to stress corrosion cracking by creating compressive stresses on the surface, which must be overcome by an applied tensile stress before the surface sees any tension load. Changing the alloy (for example, replacing an aluminum 7075-T6 part with one made from 7075-T73 or –T76 alloy) can greatly increase resistance to SCC.

3-9.10. CORROSION FATIGUE. Corrosion fatigue (see Figure 3-19) is the cracking of metals caused by the combined effects of cyclic stress and corrosion. No metal is immune to reduction in its resistance to cyclic stress if the metal is in a corrosive environment. Corrosion damages the metal by pitting, followed by crack formation in the pitted area due to cyclic stress. The crack is propagated predominantly in the fatigue mode, in which the rate of cracking is controlled by the stress concentration in the main cross section, the physical properties of the metal, and the presence of corrosion products on the crack face. Fracture of a metal part due to corrosion fatigue occurs when the remaining cross-sectional area is unable to carry the applied loads. Like stress corrosion, corrosion fatigue is normally localized and appears in the form of cracks. The metal is generally unattacked over most of its surface, while the crack progresses through the part. Cracking is generally perpendicular to the applied stress. Protection of all parts subject to cyclic stress is particularly important, even in environments that are only mildly corrosive. Preventive measures include reducing the stress on the part, using corrosion inhibitors, and applying a metallic coating (e.g. chromium, cadmium, or ion vapor deposition (IVD) aluminum) to the part.

3-9.11. FRETTING CORROSION. Fretting corrosion occurs at contact areas between materials under load subject to repeated vibration. The relative motion needed to produce fretting is extremely small (sometimes as little as 10^{-8} cm). The corrosion products increase the wear of the surface, and the wear exposes more bare metal surface to be corroded. The overall effect is greater than the single effects of corrosion and wear added together. Fretting has the general appearance of galling, in which chunks of metal are torn from the surface with corrosion at the torn areas or ragged pits (see Figure 3-20). Although fretting corrosion can take place on any metal, aluminum, stainless steel, and titanium alloys are most susceptible. These metals depend on an oxide surface film to inhibit further corrosion. With rapid movement under pressure at the interface, the oxides are removed and rapid oxidation occurs. Moisture does not appear to increase the corrosion; in fact, it tends to slow down the reaction. Fretting corrosion is normally encountered in heavily loaded static joints which are subject to vibration, such as landing gear component attachment areas having lug holes with slight press fits, slip fit bushings with very close tolerance bolts passing through the bushings, wing root access panels or wing-to-body fairings, and engine blade roots. Practical means of reducing fretting corrosion include reducing the amount of relative motion at the surface, adding a lubricant at the interface to reduce friction and seal out oxygen, increasing the surface hardness of the part, and increasing the overall hardness of one or both contacting metals.


Figure 3-20. Fretting Corrosion

3-9.12. HOT CORROSION. Also called high temperature oxidation. Corrosion in the absence of water can occur at high temperatures, such as those found in turbine engine combustors, turbine sections, and afterburners. When hot enough, metals can react directly with the surrounding gases, producing oxide scale (see Figures 3-21 and 3-22). Contaminants, such as chlorides and sulfates, can accelerate the hot corrosion reaction by reducing the melting point of the metallic oxide and promoting its vaporization. High temperature ceramic coatings can reduce this type of corrosion but are usually applied only by the manufacturer due to the highly specialized equipment required for application.

3-10. METALS AFFECTED BY CORROSION. No metal has perfect environmental integrity and is totally resistant to corrosion. As a result, all metals will corrode sooner or later. The characteristics of corrosion on aircraft metals are summarized in Table 3-1. The

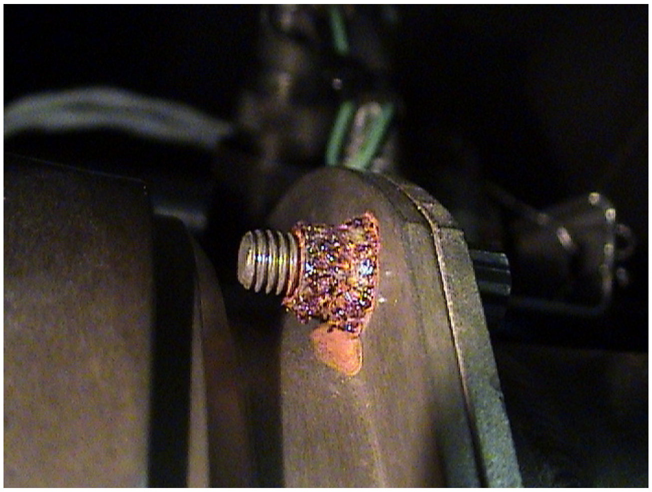

Figure 3-21. Hot Corrosion on Fasteners

Figure 3-22. Hot Corrosion on Engine Components

following paragraphs discuss the corrosion characteristics of commonly used aircraft metals.

3-10.1. ALUMINUM. Aluminum and aluminum alloys are the most widely used materials for aircraft construction. In addition to its uses in aircraft structure, aluminum and aluminum alloys are widely used in equipment housings, chassis, mounting racks, supports, frames and electrical connector shells. Aluminum is highly anodic, as evidenced by its position in the galvanic series table. It is anodic to most other metals, and, when in contact with them, galvanic corrosion of the aluminum will occur. Aluminum alloys are subject to pitting, intergranular corrosion, and stress corrosion cracking. In some cases, the corrosion products of a metal in contact with aluminum are corrosive to aluminum. However, the formation of a tightly adhering oxide film offers increased resistance under mild corrosive conditions. The corrosion product of aluminum is a white to gray powdery material (aluminum oxide or hydroxide) which can be removed by mechanical polishing or brushing with abrasives (Figure 3-23). Therefore, it is necessary to clean and protect aluminum and its alloys against corrosion. Since pure aluminum is more corrosion resistant than most alloys, aluminum sheet stock is often covered with a thin layer of nearly pure aluminum called cladding or alclad. However, in a marine environment, all aluminum surfaces require protection. Cladding is easily removed by harsh treatment with abrasives and tooling, exposing the more corrodible alloy surface. Chemical conversion coating, paints, and corrosion preventive compounds are the main methods of protection.

3-10.2. ANODIZED ALUMINUM. Some aluminum parts are protected with an electrochemically applied oxide coating called anodize. Aluminum oxide film on aluminum is a naturally occurring protective film, and anodizing merely increases the thickness of the oxide film. When this coating is damaged in service, it can be only partially restored by chemical surface treatment. Unnecessary destruction (e.g. nicks and scratches) of the anodized surface must be avoided.

3-10.3. MAGNESIUM. Magnesium alloys are the lightest structural metals used for aircraft and missile airframes. Magnesium alloys are used extensively throughout avionic systems as antennas, structures, chassis, supports, and frames (radar). Magnesium is also used extensively for transmission and gearbox housings. These alloys are highly susceptible to corrosion when the metal surface is exposed to the environment without a protective finish. The corrosion products are white powdery snow-like mounds (see Figure 3-24). The deposits have a tendency to raise slightly and the corrosion spreads rapidly. When the white puffy areas are discovered, it requires prompt treatment or the corrosion will penetrate entirely through the structure. The natural oxide-carbonate film formed on magnesium alloys does not provide sufficient corrosion protection even in the mildest environment. The rate of corrosion of a magnesium alloy increases when the alloy is immersed in water or periodically subjected to moisture. Corrosion may also be accelerated by dissimilar metal couples and when conductive contaminants are dissolved in the water. Corrosion of magnesium alloys can be greatly diminished by the use of the proper protective finish, such as magnesium conversion coating and paint. Some magnesium parts in current aircraft have been originally protected by anodizing processes. Coatings

Table 3-1. Effects of Corrosion on Metals

ALLOYS	TYPE OF ATTACK TO WHICH ALLOY IS SUSCEPTIBLE	APPEARANCE OF CORROSION PRODUCT
Aluminum Alloy	Surface pitting, intergranular, exfoliation, stress corrosion and fatigue cracking, and fretting	White to gray powder
Magnesium Alloy	Highly susceptible to pitting	White, powdery, snowlike mounds, and white spots on surface
Carbon & Low Alloy Steel (4000-8000 series)	Surface oxidation and pitting; surface and intergranular corrosion	Reddish-brown oxide (rust)
Stainless Steels (300-400 series)	Crevice corrosion; some pitting in marine environments; corrosion cracking; intergranular corrosion (300 series); surface corrosion (400 series)	Rough surface; sometimes a red, brown, or black stain
Titanium Alloy	Highly corrosion resistant; extended or repeated contact with chlorinated solvents may result in degradation of the metal's structural properties. Cadmium plated tools can cause embrittlement.	No visible corrosion products at low temperature. Colored surface oxides develop above 700° F (370° C)
Cadmium (used as a protective plating for steel)	Uniform surface corrosion	From white powdery deposit to brown or black mottling of the surface.
Chromium (plate)	Pitting (promotes rusting of steel where pits occur in plate)	No visible corrosion products; blistering of plating due to rusting and lifting
Nickel-base Alloy (Inconel, Monel)	Generally has good corrosion resistant qualities; susceptible to pitting in sea water	Green powdery deposit
Electroless Nickel (used as a plating)	Pitting and flaking of surface plating	Nickel does not corrode, but promotes corrosion of aluminum base metal where pits occur in the plating
Copper-base Alloy, Brass, Bronze	Surface and intergranular corrosion	Blue or blue-green powdery deposit
Silver	Will tarnish in presence of sulfur	Brown to black film
Gold	Highly corrosion resistant	Deposits cause darkening of reflective surfaces
Tin	Subject to whisker growth	Whisker-like deposits

Figure 3-23. Aluminum Surface Corrosion Products

Figure 3-24. Magnesium Corrosion Products

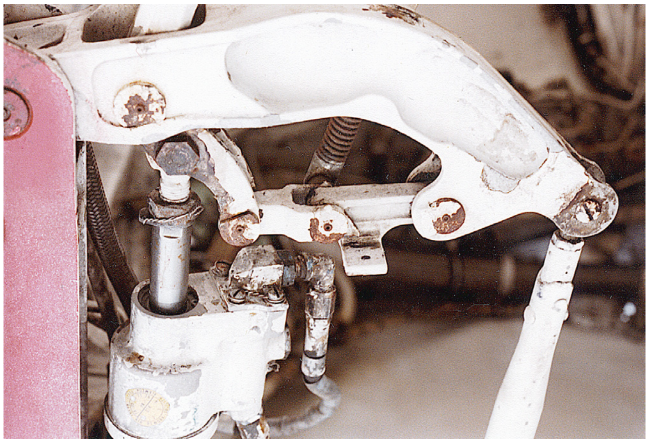

Figure 3-25. Steel Corrosion Products

Figure 3-26. Color Changes in Titanium Due to Heating

of this type are thicker than those applied by immersion or brush on conversion coating. Anodized finishes cannot be restored in the field. Care should be taken to minimize removal of these coatings.

3-10.4. STEEL. Ferrous (iron) alloys are used to manufacture many aircraft components and massive structures and assemblies in aircraft ground support equipment, such as missile gantries, silo crib structures, frames and bodies of trailers and vans, and lesser structural parts such as brackets, racks, and panels. Iron and steel are also used as component leads, magnetic shields, transformer cores, brackets, racks, and general hardware in avionic systems. If unprotected, ferrous alloy surfaces (with the exception of stainless steels) are easily corroded in the presence of moisture. Corrosion of steel is easily recognized because the corrosion product is red rust (Figure 3-25). When ferrous alloys corrode, a dark corrosion product usually forms first. When moisture is present, this coating is converted to red rust, which promotes further attack by absorbing moisture from the air. Ferrous alloy surfaces of structures or assemblies are normally painted, or plated with nickel, tin, or cadmium and painted, to prevent corrosion.

3-10.5. STAINLESS STEEL. Stainless steels, or corrosion resistant steels (as they are more properly described) are alloys of iron containing large amounts of chromium and nickel. Stainless steels are used for gears, bearings, and high strength bolts, and for mountings, racks, brackets, and hardware in avionic systems. The main reason for the existence of stainless steels is their resistance to corrosion. Stainless steels are much more resistant to common rusting, chemical action, and high temperature oxidation than ordinary steels, due to the formation of an invisible oxide film, or passive layer, on the surface of these alloys. Corrosion and heat resistance are the major factors in selecting stainless steels for a specific application. However, it should be well understood that stainless steels are not the cure-all for all corrosion problems, due to service conditions which can destroy the oxide film on their surfaces. Stainless steels are susceptible to crevice corrosion and stress corrosion cracking in moist, salt laden environments. Exposure to saltwater can cause pitting. The corrosion product of stainless steel is a roughened surface with a red, brown, or black stain. Corrosion treatment of stainless steel should be limited to cleaning. Stainless steels can cause galvanic corrosion of almost any other metal with which they are in contact if proper techniques of sealing and protective coating are not used. Stainless steels may be magnetic or non-magnetic. The magnetic steels are identified by numbers in the American Iron and Steel Institute (AISI) 400 Series (e.g. 410, 430). These steels are not as corrosion resistant as the non-magnetic steels, which are identified by numbers in the AISI 300 Series (e.g. 304, 316).

3-10.6. TITANIUM. Titanium and titanium alloys find numerous uses in aircraft, engines, and missiles at temperatures up to 1000°F (540°C). Above 1000°F, titanium readily absorbs gases from the surrounding air and becomes very brittle. Under certain conditions, chlorides and some chlorinated solvents may induce stress corrosion cracking of certain titanium alloys. Titanium and its alloys are highly corrosion resistant. An oxide film forms on their surfaces almost immediately upon contact with air, which is extremely adherent to the surfaces and provides a protective barrier. This is identical to the way aluminum forms a protective oxide film on its surface. Even at temperatures approaching 1000°F, titanium retains its strength and corrosion resistance. When titanium is heated, oxides having

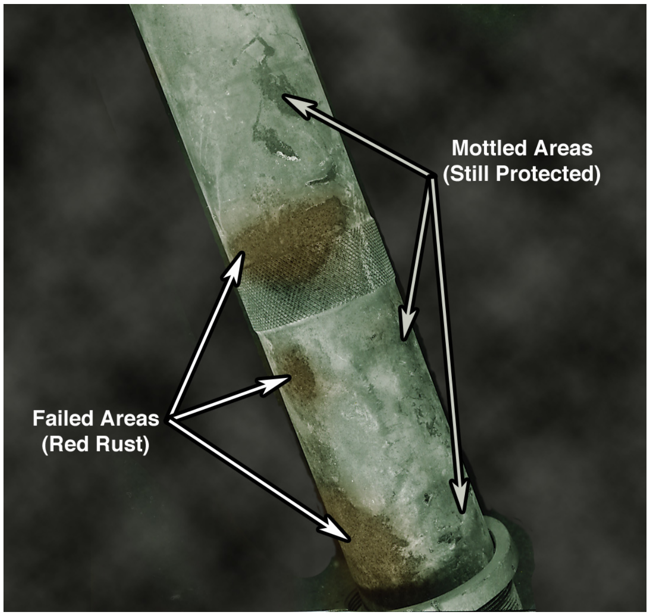

Figure 3-27. Cadmium Plated Surface Conditions

different colors form on the surface (see Figure 3-26). A blue oxide coating will form at 700° to 800°F (370° to 425°C), a purple oxide at 800° to 950°F (425° to 510°C), and a gray or black oxide at 1000°F (540°C) or higher. These are protective discolorations and should not be removed. Since titanium is the less active member (cathodic) of most dissimilar metal couples, it can greatly accelerate corrosion of a dissimilar metal coupled to it. Electrical insulation between titanium and other metals is necessary to prevent galvanic corrosion of the other metal. Titanium in contact with a corroding metal can absorb hydrogen and become brittle. Frequent inspection of such areas is required to insure that insulation failure has not allowed corrosion to begin.

3-10.7. CADMIUM. Cadmium is used as a coating to protect steel hardware, such as bolts, washers, and screws, and as plating on electrical connectors. It is used as a plating on high strength steel parts (e.g. landing gear) to improve resistance to corrosion fatigue. Cadmium may also used to provide a compatible surface when a part is in contact with other materials. Cadmium, when coupled with steel, is anodic and protects the steel by galvanic action. Corrosion on cadmium is evident by white to brown to black mottling of the surface. When cadmium plate shows mottling and cracks in the coating, the plating is still performing its protective function as an anodic material (see Figure 3-27). The cadmium plate on iron or steel is still protecting the base metal until signs of rust begin to appear. Even then, any mechanical removal of corrosion products should be limited to metal surfaces from which the cadmium has been depleted. Care should be taken not to remove undamaged cadmium plate adjacent to the corroded area.

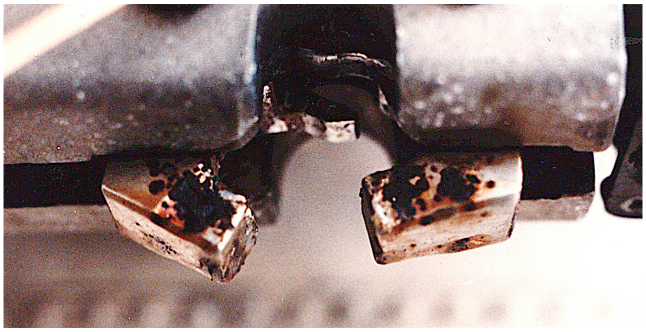

Figure 3-28. Failed Chromium Plate

3-10.8. CHROMIUM. Chromium is used as a protective plating. Chromium plating is also used to provide a smooth, wear-resistant surface and to reclaim worn parts. When corrosion resistance in a marine environment is required, a nickel under-coat is used. The degree of protection is dependent upon plating thickness. Chromium forms a continuous oxide coating that can be polished to a high luster and still protect not only itself but any underlying metal. Chromium coatings contain cracks, and corrosion may originate at the base metal below these separations. Figure 3-28 shows the results of a failed chromium plate.

3-10.9. NICKEL. Nickel is important as a plating metal, an additive to stainless steel, and a base for nickel alloys. Pure nickel is used as an electroless coating and is subject to pitting corrosion. Flaking of the nickel coating can also occur when an underlying metal corrodes. When added to stainless steel alloys, the stress corrosion resistance increases with nickel contents above 10%. Nickel based alloys are used in high temperature areas (engines, afterburners), but they are subject to hot corrosion attack and embrittlement when sulfur containing gases are present.

3-10.10. COPPER AND COPPER ALLOYS. Copper and copper-based alloys (brass and bronze) are considered corrosion resistant, with corrosion usually limited to staining and tarnish. Copper and copper-based alloys are generally used in avionic systems as contacts, springs, leads, connectors, printed circuit board (PCB) conductors, and wires. Generally, changes in surface conditions are not dangerous and should ordinarily have no effect on the part. Copper corrosion is evidenced by the accumulation of blue or blue-green

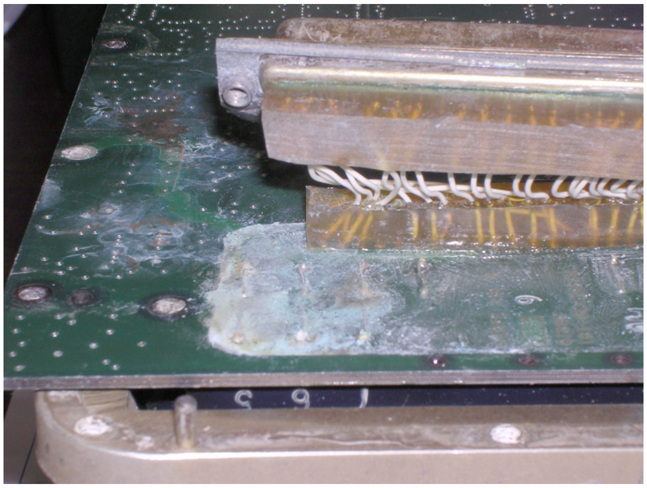

Figure 3-29. Corroded Circuit Card

corrosion products on the corroded part (see Figure 3-29). Sometimes copper or copper alloy surfaces tarnish to a dull gray-green color (patina) and the surface will remain relatively smooth. This discoloration is the result of the formation of a fine-grained, airtight copper oxide crust. This crust offers good protection for the underlying metal in ordinary situations. However, exposure of copper and copper alloys to moisture or salt spray causes the formation of blue-green salts, indicating active surface corrosion, which should be removed. When coupled with most metals used in aircraft construction, copper is the less active metal and greatly accelerates corrosion of iron, steel, aluminum, and magnesium. Examples are usually found in electrical components and in areas where copper bonding strips or wires are fastened to an aluminum chassis or structural components. Protective paint coatings are seldom required because of the inherent resistance of the metal. However, paint finishes may be applied for decorative purposes or if the normal tarnish or green patina on the copper is objectionable.

3-10.11. SILVER. Silver is used as a plating material over copper in waveguides, miniature and microminiature circuits, wires, contacts, high frequency cavities, tank circuits, and RF shielding. Silver does not corrode in the ordinary sense, although it will tarnish in the presence of sulfur. The tarnish appears as a brown to black film. The tarnish is silver sulfide and may or may not be detrimental to circuit electrical characteristics, depending on the application. When silver is plated over copper there can be an accelerated corrosion of the copper. This occurs through galvanic action at pinholes or breaks in the silver plating. One example of this is the deterioration of silver plated copper wire. This problem is compounded because the wire insulation prohibits detection of breaks in the silver plating until damage is extensive. This “red plague” is readily identifiable by the presence of a brown-red powder deposit on the exposed copper. Silver plating over nickel plate does not exhibit the red plague phenomenon.

3-10.12. GOLD. Traditionally considered the best coating for corrosion resistance and solderability, gold is used on printed circuits, semiconductors, leads, and contacts. Gold is usually applied in a thin layer over nickel, silver, or copper. Gold is a noble metal (pure metal in nature) and does not normally corrode; however, a slight deposit will appear as a darkening of reflecting surfaces. Tarnish removal is critical on gold components because of the very thin coatings used. Gold plated over silver or copper in thin layers accelerates corrosion over the less noble metals (silver or copper). This occurs at pores or pinholes in the gold. This corrosion is readily identified as darkening of the silver or blue-green deposits on the copper. "Purple plague" is a brittle gold-aluminum compound formed when bonding gold to aluminum. The growth of such a compound can cause failure in microelectronic interconnection bonds.

3-10.13. TIN. The use of tin in solder is a well-known application. However, tin plating is also common on avionic RF shields, filters, crystal covers, and automatic switching devices. Tin has the best combination of solderability and corrosion resistance of any metallic coating. However, tin has a tendency to grow “whiskers” on tin plated wire and other plated applications.

3-11. DEGRADATION OF NON-METALS. Non-metallic materials (plastics, elastomers, paints and adhesives) are not subject to electrochemical corrosion, since ions are not easily formed from non-metallic materials and since the electrical conductivity of non-metals is extremely low. The degradation of non-metals depends on the chemical makeup of the material and the nature of the environment. In general, aircraft non-metallic materials are selected for their performance properties (flexibility, transparency, strength, electrical resistance). Also, resistance to heat, impact, abrasion, ultraviolet radiation, moisture, ozone and other detrimental gases, as well as operational fluids such as hydraulic fluid, lubricants, cleaners, and deicing fluids, must be considered. However, the use of unauthorized maintenance chemicals and procedures can accelerate degradation. In almost all cases, the deterioration of a nonmetallic material permits moisture intrusion. This creates physical swelling, distortion,

Table 3-2. Effects of Deterioration on Nonmetals

MATERIAL	TYPE OF ATTACK TO WHICH MATERIAL IS SUSCEPTIBLE	APPEARANCE OF DETERIORATION
Acrylic	UV light, moisture, solvents	Discoloration, cracking
Adhesive	Dirt, UV light, solvent, moisture	Cracking, peeling
Ceramic	Extreme heat	Discoloration, cracking
Cloth	Dry rot, mildew	Discoloration, tears, dust
Conformal coating	Moisture, scratchess	Peeling, flaking, bubbling
Cork	Moisture, mildew, dry rot	Discoloration, dust, peeling
Elastomer	Heat, UV light, excessive cycling	Cracks, crazing, discoloration
Encapsulation	UV light, moisture	Cracking, peeling, disbonding
Felt	Moisture, mildew	Discoloration, looseness
Glass	Heat, mechanical damage (broken)	Cracked, discolored
Laminates	UV light, moisture, solvents	Discolored, disbond, delamination
Paint	Moisture, heat, humidity	Bubbles, peeling, cracking
Plastic	UV light, heat, abrasion	Discoloration, cracks, deformation
Polymers	Extreme heat, solvents	Discoloration, deformation
Potting Compounds	UV light, moisture, heat	Discoloration, cracks, deformation
RTV (noncorrosive)	Moisture, UV light, heat	Peeling, debonding, discoloration
Sealants	Moisture, UV light, heat	Peeling, debonding, discoloration

mechanical failure through cracking, and altering of electrical characteristics. The most common nonmetals used in aircraft systems and their modes of deterioration are listed in Table 3-2. Examples of nonmetallic deterioration are discussed in the following paragraphs.

3-11.1. GRAPHITE/CARBON FIBER COMPOSITES. Graphite or carbon fiber composites are materials which consist of reinforcing fibers in a matrix made of organic resin, usually epoxy. They are an important class of aviation materials because of their high strength-to-weight ratios and high stiffness. Composite materials are found in aircraft structure, connectors, enclosures, EMI seals and gaskets. Since carbon is the least active metal in the galvanic series, it will accelerate the corrosion of any aircraft metal to which it is coupled. Insulation between graphite or carbon epoxy composites and other metals is necessary to prevent dissimilar metal attack on the attached part.

3-11.2. ENCAPSULANTS AND CONFORMAL COATINGS. Encapsulants and conformal coatings are used to envelop an avionic component, module or assembly. These materials are considered nearly as effective as hermetic sealing. Typical materials used for this purpose are epoxy, polyurethane, silicone rubber, acrylic, and varnish. Because these materials are organic, they are susceptible to moisture, varying temperature, and fungus. Moisture accumulates when incorrect repair procedures cause imperfections and bubbles, or when the coating is applied too thick. High temperatures may cause corrosive vapor to outgas from encapsulants and conformal coatings. This problem is of special concern if a circuit component burns on a conformal coated circuit board. These gaseous vapors can penetrate under circuit board coatings and cause major corrosion damage.

3-11.3. POTTING COMPOUNDS. Potting compounds are used to encase a part or component, such as in an electrical connector. Generally, potting compounds are considered to be a good seal against moisture when correctly applied. Problems occur when potting compounds are cured too quickly, not mixed properly, or the surface is not cleaned completely. Aging of certain potting compounds can cause the potting compound to harden and become brittle, or soften and revert. Usually, the process of potting involves the use of a mold to form the potting compound. These molds are made of plastic and may become the source of moisture intrusion. All molds should be removed after the potting compound has cured (refer to Volume III).

3-11.4. LAMINATE CIRCUIT BOARDS. Laminate circuit boards typically use encapsulants or conformal coatings as sealers. In some cases, the laminate is not sealed along the edge or at the contact tabs. This allows the laminate board to absorb moisture and delaminate. Overcleaning with abrasive materials may damage the resin surface of the laminate board. High temperatures caused by the burning of a circuit component may char the laminate surface and increase moisture intrusion.

3-11.5. RUBBERS AND ELASTOMERS. Rubbers and elastomers are used for insulation, seals, gaskets, caps, tubing, films, and coatings. Natural rubber, silicone rubber, and polyurethane are normally susceptible to attack by fungi, microbes, ozone and ultraviolet light. Polyurethane and silicone rubber are to some extent permeable to moisture.

3-11.6. TAPES. Some pressure sensitive tapes are effective moisture barriers. Problems arise with cloth or paper-based tapes. These materials absorb moisture and support fungal attack. This is particularly true when wicking action takes place on the cloth or paper material. Some tapes deteriorate and outgas, emitting an acid that is corrosive to metals.

3-11.7. OILS. The lubricants used in some electronic equipment are capable of minimizing moisture intrusion and corrosion attack. However, at high temperatures and pressures, oils can chemically react with impurities to produce acids. Oil can hold a limited amount of water. Excess water will separate from the oil if the holding capacity is reached at a given temperature.

3-11.8. MATERIAL INCOMPATIBILITY OF NONMETALLICS. The complexity of modern aircraft and avionics makes it difficult to predict what problems may result from reactions between materials. Incompatibility of materials can cause deterioration of the nonmetallic substances. This may result in the release of chemicals or gases that react with other components. In some cases, cleaning solutions, high temperature, or lubricants will cause a reaction in nonmetallic substances. Common examples of nonmetallic materials incompatibility are as follows:

3-11.8.1. Solvents. Some encapsulants, conformal coatings, and acrylic plastics soften or dissolve when they come in contact with cleaning solvents.

3-11.8.2. Heat. The heating of conformal coatings for removal or repair may outgas corrosive vapors onto metal components. Shrinkage elastomers (heat-shrinkable tubing) can damage adjacent circuitry when heat guns are applied to shrink the tubing. Certain oils (such as silicones) and greases “creep” as temperature increases. This causes contamination of adjacent surfaces, degradation of organic coatings, and attraction of particulates.

3-11.8.3. Acid Creation. Some commercial conformal coating strippers contain acids that attack PCB laminates and discolor or corrode copper. Certain room temperature vulcanizing (RTV) silicone sealants contain acetic acid that is highly corrosive to metal components (a list of authorized RTV silicone sealants is provided in Volume III). Degradation of polyvinylchloride (PVC) gives off acid fumes that are corrosive to most materials used in avionics. Some solid film lubricants contain uninhibited molybdenum disulfide which, with moisture and heat, may form sulfuric acid.

3-11.8.4. Form Change. Some potting compounds revert to liquid form under certain conditions. This reversion causes a maintenance problem and reduces the moisture protection in electrical connectors.

3-11.8.5. Oil and Lubricants. Application of conformal coatings, adhesives, and paint finishes is difficult when silicone oil film is present on base material. Some solid film lubricants containing graphite are corrosive. Graphite and moisture will promote galvanic corrosion in many metals. Some lubricants will attack neoprene, plastics, rubber, organic materials, and most paints.

3-11.8.6. Plastics. Plastics can be damaged by solar heating and cosmic radiation. The damage is a visible darkening, discoloration, or color fading of the plastic. Lower pressures and vacuum can cause outgassing and loss of plasticizers/ flexibilizers. This can cause a change in structural properties such as loss of strength. The damage is appears as embrittlement and crazing of the surface, as well as loss of electrical properties.

3-12. EFFECTS OF ENVIRONMENT ON CORROSION. Corrosion of aviation equipment occurs in both natural and man-made environments. In addition, the aircraft operational and maintenance environment contributes to unique corrosion conditions.

Natural conditions in the environment which affect the corrosion process are moisture, temperature, salt atmospheres, ozone, sand, dust, and solar radiation. Corrosion may also be promoted by biological sources, including animals, insects, and microorganisms. Man-made conditions, which also affect the corrosion process, include industrial pollution, manufacturing operations, packaging, storage conditions, and shipment. By understanding these conditions, maintenance personnel will be better able to prevent aircraft damage.

3-13. NATURAL ENVIRONMENTS.

3-13.1. MOISTURE. Moisture is present in air as a gas (water vapor) or as finely divided droplets of liquid (mist or fog). It often contains contaminants such as chlorides, sulfates, and nitrates, which increase its corrosive effects. Moisture enters all areas of an aircraft that air can enter. Enclosed areas which are not sealed allow air to enter and leave as the pressure between the interior and exterior changes. These pressure differences occur when the aircraft changes altitude, when atmospheric pressure changes, and when the temperature of air inside an enclosed area changes.

3-13.1.1. Condensed Moisture. Moisture will condense out of air when the air becomes too cool to hold all of the moisture in it. The dew found on aircraft after a cool night is the result of condensation. Condensed moisture usually evaporates as the surrounding air warms, but leaves contaminants, including salts, behind. This can result in the build-up of soils and salt contamination. Condensed moisture and its contaminants can also be trapped in close fitting wettable joints, such as faying surfaces. Some gasket and packing materials will absorb several times their weight in water and, when heated, can transmit this retained moisture into the sealed area. Moisture can accumulate in such areas through successive cycles of warming and cooling. In addition, moisture can be drawn along poor bond lines by capillary action (wicking). Temperature and humidity conditions can vary widely in separate sections of aircraft depending on the success of environmental sealing, condensation, and location near heat-generating equipment.

3-13.1.2. Effect of Moisture. Electrolyte formation results from condensation of moisture. All non-metals absorb some moisture, which may cause changes in dimensional stability, dielectric strengths, ignition voltages, and volume insulation resistances. In general, organic matrix composites are adversely affected by moisture and may suffer a loss of strength and stiffness from exposure. Hermetic sealing (liquid and vapor proof at normal temperatures and pressures) is recommended for moisture-critical items such as capacitors and quartz crystals.

3-13.2. SALT ATMOSPHERES. Salt forms a strong electrolyte when dissolved in water, which causes rapid corrosion of unprotected metal surfaces. The primary source of the world's salt is the ocean, which is 3.5% to 3.9% salt. Normal sea winds can carry from 10 to 100 pounds of seasalt per cubic mile of air. Since dissolved salts are strong electrolytes, it is easy to understand why corrosion is such a severe problem in shipboard and coastal environments.

3-13.3. OZONE. Ozone is a particularly active form of oxygen which is formed naturally during thunderstorms, by arcing in electrical devices, and by photochemical reactions in smog. When ozone is absorbed by electrolyte solutions in contact with metals, it increases the rate of corrosion. It also oxidizes many nonmetallic materials, being particularly harmful to natural and certain types of synthetic rubber. Rubber seals stored near welding equipment have experienced complete degradation.

3-13.4. SOLAR RADIATION. The two ranges of solar radiation most damaging to materials are ultraviolet (the range that causes sunburn) and infrared (the range that makes sunlight feel warm). On earth, maximum solar radiation occurs in the tropics and equatorial regions, but considerable damage occurs in the temperate zones as a result of solar heating, photochemical effects, and combinations of these two phenomena. Non-metals, especially organic and synthetic materials, are strongly affected by sunlight. Both natural and synthetic rubber deteriorate rapidly when exposed to sunlight. After extended exposure, plastics darken, paints lose their protective characteristics, polymers undergo marked decreases in strength and toughness, and colors fade, removing essential color coding. Most electronic equipment is housed in enclosed structures and is protected from solar radiation. Extra care must be taken in the selection and surface treatment of parts, such as cables and harnesses, that are exposed to exterior environments.

3-13.5. TEMPERATURE. High temperature either improves or impairs the performance of avionic equipment, depending on conditions. Corrosion and other harmful processes (outgassing, decomposition) increase as temperature rises. However, moderate increases in temperature may prevent condensation.

Most fungus growth is inhibited by temperatures above 104°F (40°C). Low temperatures pose no real threat of corrosion except that as temperature drops relative humidity rises. The greatest problem in extremely low temperatures, as in polar regions, is the shrinkage of seals and gaskets. This results in leakage and embrittlement of organic materials. If temperatures vary sufficiently, moisture may condense to form liquid water in the equipment. Similarly, the introduction of cooling air may cause condensation. If moisture intrusion occurs, subsequent freezing can cause the entrapped moisture to expand, resulting in structural damage.

3-13.6. PRESSURE. Most military equipment is intended for service in low pressure (high altitude) environments. These environments create the familiar corona, arcing, and poor cooling problems in avionic equipment. Another problem is that of cyclic low and high pressures. These varying pressures create leaky seals and cause breathing. Breathing promotes condensation and creates a corrosive environment. Low pressure also causes outgassing (loss of volatile components, such as plasticizers) of plastics and other organic materials. Very low pressure causes changes to the physical and chemical properties of some materials.

3-13.7. SAND, DUST, AND VOLCANIC ASH. Some of the least recognized contributors to corrosion are sand, dust, and volcanic ash. They often contain a number of tar products, ashes, and soot. Sand, dust and volcanic ash are hygroscopic and, when present on internal or external surfaces of aircraft or electronic parts, can absorb and hold moisture. This provides an electrolyte for corrosion and the growth of fungus. The presence of sand, dust or volcanic ash may also affect the operation of electrical contacts, prevent proper action of rotating motor-drive devices, and cause malfunctions of indicating instruments. Sand and dust are extreme problems in the deserts, since dry, powdery sand and dust are easily carried by wind. During sandstorms, they can penetrate sealed equipment as well as internal areas of airframes. In arid regions such as deserts, small sand particles are often blown as high as 10,000 feet by the siroccos (hot, dust laden winds). Sand and dust on surfaces can cause an abrasive action when the surfaces are moved or vibrated. This removes the protective oxide coatings and leaves the metal exposed. Volcanic ash contains chlorides and sulfates, which are extremely corrosive in the presence of moisture. Although small amounts of sand, dust, or ash may be unnoticed by operating personnel, they may be sufficient to initiate or promote corrosion.

3-13.8. CLIMATE. Warm, moist air, normally found in tropical climates, tends to accelerate corrosion. Cold, dry air, normally found in arctic climates, tends to reduce corrosion rates. Corrosion does not occur in very dry conditions. For this reason, desiccants are used in shipping containers to produce very dry local environments. The operational climate extremes have always been considered in aircraft design. However, certain areas within an aircraft, such as the cockpit and air conditioned equipment bays, may be subjected to climatic conditions very different from external areas of the aircraft. Relatively warm, dry air that has been cooled by air conditioners, thus reducing its ability to hold moisture, and ducted into interior areas of the aircraft, can release sufficient moisture to accelerate corrosion. It is imperative, therefore, to consider not only the operational environment but also the environments in which the equipment will be fabricated, transported, reworked, or repaired.

3-13.8.1. Desert. The hot, wind-swept desert creates a severe maintenance problem because powdery dust can penetrate even supposedly sealed components. High daytime temperatures, high humidities (in areas such as the Persian Gulf), ultraviolet radiation, and fine dust are the four most serious, destructive elements of the desert climate. Nonmetallic materials suffer the most damage from the hot desert climates, where air temperatures during the day may reach 124°F (50°C). Temperatures inside closed containers may be 100°F (38°C) higher than external air temperatures.

3-13.8.2. Temperate Zones. The temperate or intermediate climate zone encompasses most of the North American and European continents. These areas at various times of the year may approximate the extremes of polar, desert, or tropical temperatures and humidity. The temperate zone temperatures range from -25° to 59°F (-32° to 15°C) in the winter and from 59° to 125°F (15° to 52°C) in summer. The relative humidity also fluctuates between five and 100%. The most critical areas are coastal locations: during the warm periods of the year the relative humidity approaches 100% at night and the air has high concentrations of salt. Moisture from this salt-laden air can condense on equipment during early evening and morning hours, thereby causing serious corrosion. Because of its relatively mild temperatures, the temperate zone is also the most heavily populated. Consequently, the smoke, smog, ozone, and corrosive fumes associated with heavy industry are also present.

3-13.8.3. Tropics. The greatest challenge to the aircraft industry is the design of equipment that is protected from corrosion and deterioration in the heat and humidity that prevails in the tropics. Even though they encompass only a small portion of the earth's land area, the tropics demand the greatest amount of consideration from the standpoint of corrosion treatment and control. The tropical environment is sustained by long periods of heavy rainfall, during which as many as 100 inches of rain may fall. Relative humidities of up to 100% at ambient air temperatures of 85°F (29°C) pose formidable threats of corrosion. When high humidity and temperature conditions are combined with salt-laden air, the corrosive environment becomes extremely severe. Extended periods of high heat and humidity contribute to rapid corrosion of metals, cracking and flaking of rubber and plastic materials, and deterioration of seals. Equipment, whether stored or in use, requires special protective containers and frequent preventive maintenance. Many items become covered with fungi in a matter of hours. For effective operation of electronic equipment in the tropics, special efforts must be made. The critical combination of high temperatures, condensation, high relative humidity, and contaminants such as salt and sand may cause catastrophic failure of equipment. Intensive preventive maintenance and the best possible protective techniques are necessary for aircraft and their components.

3-14. BIOLOGICAL CORROSION.

3-14.1. ANIMAL AND INSECT DAMAGE. Damage to aircraft and aircraft subsystems may be caused by insects, birds, and various small animals, especially in tropical environments. Equipment in storage is most susceptible to this type of attack. Insects and small animals may enter through vent holes or tears in packaging and sometimes build nests. They like to feed on various organic materials, such as polyethylene, insulation, and wire coatings, which can result in system or equipment failure. Another type of damage can occur when electrical insulation, varnishes, and circuit board coatings are eaten by insects. When bare wires or circuit components are exposed, more areas become available for corrosion and shorting to occur. Moisture absorbed by nests plus excretions from animals may cause corrosion and deterioration that goes unnoticed until equipment is put to use and fails. Damage may also occur when organic materials, such as upholstery, are shredded for nests or consumed as food.

Figure 3-30. Biological Growth on Helicopter Wall

3-14.2. MICROORGANISMS. Microbial attack, as the term is used in this manual, includes the action of bacteria, fungi, or molds. Microorganisms are nearly everywhere and outnumber all other types of living organisms. Those organisms causing the greatest corrosion problems are bacteria and fungi (see Figure 3-30). Damage resulting from microbial growth can be caused by: (1) the tendency of the growth to hold moisture, which then causes corrosion; (2) digestion of the substrate as food for the microorganism; or (3) corrosion of the surface beneath the growth by secreted corrosive fluids. Modern avionic equipment, because of complexity, dense packaging, and higher sensitivity, is more susceptible to damage from microbes than earlier systems. Condensed moisture can provide conditions that promote the growth of molds, bacteria, and fungi. Once established, these growths continue to absorb and hold moisture. Acid secretions from the microorganisms are strong electrolytes. These electrolytes corrode the underlying metal. Some nonmetals provide nutrients that can accelerate growth. The presence of bacteria and fungi can readily be identified by damp, slimy, and bad smelling growths. These vary in color from black, bluegreen, green, to yellow. Table 3-3 lists some common materials and the corresponding effect of moisture and fungi.

3-14.2.1. Bacteria. Bacteria may be either aerobic or anaerobic. Aerobic bacteria require oxygen to live. They can accelerate corrosion by oxidizing sulfur to produce sulfuric acid or by oxidizing ammonia to produce nitric acid. Bacteria living adjacent to metals may promote corrosion by depleting the oxygen supply or by releasing metabolic products. Anaerobic bacteria, on the other hand, can survive only when oxygen is not

Table 3-3. Effects of Moisture and Fungi on Various Materials

PART OR MATERIAL	EFFECT
Fiber: washers, supports	Moisture causes swelling that causes the support to misalign, resulting in binding of supported parts. Destroyed by fungi.
Fiber: terminal strips, insulators	Moisture forms electrical leakage paths, causing flashovers and crosstalk. Insulating properties are lost. Destroyed by fungi.
Laminated plastics: terminal strips, boards, switchboard panels, tube sockets and coil forms, and connectors	Moisture causes insulating properties to be lost. Leakage paths cause flashovers and crosstalk. Delamination occurs and fungi grow on surface and around edges. Expansion and contraction under extreme temperature changes.
Molded plastics: terminal boards, switchboards panels, connector, tube sockets and coil forms	Machined, sawed, or ground edges of surfaces are supporters of fungi, causing shorts and flashovers. Fungal growth reduces resistance between parts mounted on plastic to such an extent that the parts are useless.
Cotton linen, paper, and cellulose derivatives: insulation, coverings, webbing, belting, laminations, dielectrics	Moisture causes loss or impairement of insulating and dielectric properties, causing arcing, flashovers, and crosstalk. Destroyed by fungi.
Wood: cases, houses and housings, plastic fillers, masts	Dry rot, swelling, and delamination are caused by moisture and fungi.
Leather: straps, cases, gaskets	Moisture and fungi destroy tanning and protective materials, causing deterioration.
Glass: lenses, windows	Fungi grow on organic dust, insect track, insect feces and dead insects. Dead mites and fungal growth on glass obscure visibility and corrode nearby metal parts.
Wax: for impregnation	Fungi-inhibiting waxes that are not clean support the growth of fungi, cause destruction of insulating and protective qualities, and permit entrance of moisture that destroys parts and unbalances electrical circuits.
Metals	High temperature and moisture vapor cause rapid corrosion. Fungus and bacterial growth produce acid and other products that speed corrosion, etching of surfaces, and oxidation.This interferes with the operation of moving parts, screws, and causes dust between terminals, capacitors, plates or air condensers, which in turn may cause noise, loss in sensitivity, and arc-overs.
Metal, dissimilar	Metals may have different corrosion potentials. When moisture is present, one of the metals (anode) corrodes.
Soldered joints	Residual soldering flux on terminal boards holds moisture, which speeds up corrosion and growth of fungi.

present. The metabolism of these bacteria requires them to obtain food sources by oxidizing inorganic compounds such as iron, sulfur, hydrogen, and carbon monoxide. The resultant chemical reactions cause corrosion.

3-14.2.2. Microbial Growth Requirements. Fungi make up one class of microorganism that feeds on organic matter. Low humidity levels will inhibit the growth of most species of fungi and bacteria. Ideal growth conditions for most fungi and bacteria are temperatures between 68° and 104°F (20° and 40°C) and relative humidities between 85 and 100%. It was formerly believed that microbial attack could be prevented by applying moisture-proof coatings to nutrient materials or by drying the interiors of compartments with desiccants. However, some moisture-proof coatings are attacked by microorganisms, especially if the surface on which they are used is already contaminated. Some microorganisms can survive in spore form for long periods while dry, and can become active when moisture is available. When desiccants become saturated and unable to absorb moisture in the affected area, microorganisms can begin to grow. Dirt, dust, and other airborne contaminants are the least recognized contributors to microbial attack. Unnoticed, small amounts of airborne debris may be sufficient to promote fungal growth.

3-14.2.3. Microbial Nutrients. Since fungi, bacteria, and other microorganisms are classified as living, it was previously thought that only materials derived from living organisms could provide food for microorganisms. Thus, wool, cotton, feathers, and leather are known to be microbial nutrients. To a large extent this rule of thumb is still valid, but the increasing complexity of synthetic materials makes it difficult, if not impossible, to determine from the name alone whether a material will support growth of microorganisms. Many otherwise resistant synthetic materials are rendered susceptible to microbial attack by the addition of chemicals, which change the properties of the material. In addition, different species of microorganisms have different growth requirements. The service life, size, shape, surface smoothness, cleanliness, environment, and species of microorganism involved all determine the degree of microbial attack on the affected item.

3-15. MAN-MADE ENVIRONMENTS.

3-15.1. INDUSTRIAL POLLUTANTS. Carbon from internal combustion engine exhaust, nitrates from agricultural fertilizers and industrial processes, ozone from electrical motors and welding operations, sulfur dioxide from engine exhaust and industrial and ship smoke stacks, and sulfates from automobile exhaust are significant pollutants. Corrosive solutions form when these contaminants are absorbed by condensed moisture. Many of the fumes and vapors emitted by ships and from factories can greatly accelerate metal corrosion. Industrial atmospheres may exist over large areas, since wind may carry these corrodents many miles from their source. The combination of these pollutants contributes to the deterioration of non-metallic materials and severe corrosion of metals.

3-15.2. MANUFACTURING, ASSEMBLY AND REPAIR. During the manufacture, assembly, or repair of aircraft and subsystem components, many factors that might lead to corrosion may be introduced. The use of unsuitable materials and improper material processing can cause corrosion. Shearing or hole-punching operations on some metal alloys, especially high-strength aluminum, may introduce stresses that eventually lead to corrosion. Assembly or repair of avionic components in areas contaminated by fumes or vapors from adjacent operations (such as welding, paint spraying, and solvent cleaning) may result in entrapment of fumes in the equipment and may cause corrosion. Air conditioned avionic shops are inherently lower in temperature than surrounding spaces. In shops without humidity control, the air conditioning system can create condensation. This is of particular concern after working hours because the absence of shop personnel (body heat) and the lack of heat generated by operating various equipment create lower temperatures. Thermostats should be adjusted to prevent excessive cooling and condensation after working hours.

3-15.3. SOLDER FLUX CORROSION. The simple task of soldering a component in a circuit board can cause corrosion, often due to failure to remove flux residues. Most metals exposed to the atmosphere develop a thin film of oxide. This film is not visible and solder alone cannot dissolve it. During soldering operations, the addition of flux removes the oxide film and prevents further metal oxidation. Although most flux is burned away during the soldering process, some residues remain and must be removed. Residues from solder fluxes can degrade circuitry by causing solder joints to corrode, causing corrosive flux vapors that settle on adjacent components, reducing insulation resistance, changing the resistivity of the solder joint, and attracting dirt and other contaminants that may absorb moisture. Refer to ANSI/J-STD-001 for general solder information. Refer to ANSI/J-STD-004, -005, -006 for solder flux requirements for securing connections in electrical or electronic equipment. Refer to NAVAIR 01-1A-505 (Navy), TO 1-1A- 14 (Air Force), or TM 55-1500-323-24 (Army) for additional information on solder fluxes and soldering techniques.

3-15.4. EQUIPMENT HANDLING. Equipment removed from aircraft for maintenance or inspection may be exposed to various environments. Equipment that requires handling or protection against the environment should be preserved and packaged accordingly. In some cases, special containers are furnished for the purpose of protecting the equipment. Where containers or special packaging are not furnished, steps shall be taken to provide the protection required. For example, a printed circuit board (PCB) that has been repaired but not coated with conformal coating requires protection against electrostatic discharge and contaminants. It should be placed in an antistatic bag and transported using a covered antistatic tote tray or fast pack from the repair station to the test bench. Components with conductive coatings shall be protected from abrasion, damage, and electrostatic discharge. Corrosion that develops as a result of improper handling or inadequate packaging, storage, and shipment is extremely destructive. Some of the same design characteristics that support corrosion in equipment on board aircraft also lead to deterioration in inadequately packaged, stored, and shipped components. All uninstalled avionic equipment should be preserved and stored in shock

Table 3-4. Effects of Airframe Fluid Intrusion

TYPE OF FLUID	EFFECT
Engine Fuel	Softening or swelling of some polymers.
Hydraulic Fluid	Lack of coating adhesion; introduction of insulative films on electrical connector contacts.
Lubricants	Attacks some seal and gasket materials.
Dielectric Coolant	Attacks organic seals.
Anti-icing Fluid	Increased condensation and attack on electrical wiring.
Aqueous Contaminants (free water, urine, condensation, desiccants)	Increased condensation causing pooling of fluids in bilge areas; corrosive attack of unprotected bimetallic couples; introduction of insulative films on electrical connector contact surfaces.
Maintenance Fluids (solvents, detergents, cleaners, strippers)	Softening and/or reduced adhesion of some organic coatings and cracking of some wire insulation.

and moisture resistant packaging with an active desiccant. The following unacceptable conditions should be corrected:

a. Equipment with a high replacement rate that is kept unprotected.

b. Equipment moved on an open flat bed vehicle between the removing/installing activity and the repair shops that is unprotected.

c. Equipment exposed to the environment awaiting transfer to the repair shop or depot activity that is unprotected.

3-15.5. PACKAGING. Packaging is intended to protect equipment or components against corrosion, deterioration, and physical damage during transportation and storage. Avoid the use of unsuitable materials, or corrosion attack may occur as a result of improper packaging materials. Proper packaging techniques are not necessarily limited to the manufacturing or shipping activity but concern the shop technician as well. Certain woods, cottons, foams, and papers absorb moisture and are susceptible to mold and fungus attack. These materials, and shredded newspaper, excelsior, and fiberboard, may emit acidic vapors. Corrosive vapors are not only a product of wood but other incompletely cured organic materials such as glues, paints, varnishes, resins, and preservatives. Outgassing (decomposition) of organic materials such as adhesives, gaskets, sealants, wire insulation, sleevings, tubing, plastics, and circuit board varnishes also may produce corrosive organic acid vapors. When corrosive vapors are released in a confined space or in a piece of avionic equipment, serious corrosion attack will occur in the presence of moisture. Instructions for proper packaging are given in MIL-STD-2073-1.

3-15.6. STORAGE. Even traces of corrosive vapor in packages containing aircraft parts may result in serious corrosion. Moreover, the natural breathing of packages may introduce moisture into the parts and equipment. Some packing materials have been known to decompose and emit corrosive vapors during periods of prolonged storage. Avionic equipment should not be stored in wooden boxes, fiberboard containers, or vented containers, especially during air shipment. Refer to NAVAIR 15-01-500 (Navy), TM 743-200-1 (Army), or T.O. 1-1-17 (Air Force) for additional storage information.

3-15.7. SHIPMENT. During shipment, materials such as plastics and lubricants are often exposed to environments that were not considered during the design stage. Materials shipped by air are subjected to changes in atmospheric pressure and can lose volatile components by outgassing. The vibration and mechanical shocks associated with shipment by truck can damage protective coatings or platings. Shipment by ocean vessel may expose the equipment to corrosive marine environments, vibrations and shock from engines or sea conditions, and residual corrosive vapors from previous shipments. Equipment should be properly packaged in accordance with MIL-STD-2073-1 to minimize damage during shipment. Packaging damaged during shipment should be repaired as soon as possible.

3-15.8. AIRCRAFT FLUIDS. Many fluids can be present in various areas of an airframe. Table 3-4 lists the types of fluid intrusion and the possible effects. Some of these fluids are corrosive to metals, while others are destructive to seals. The destruction of seals may lead to fluid penetration into areas that are considered protected. Some fluids are from external sources, while others are present due to internal leaks or servicing spills.

3-15.9. OPERATIONAL AND MAINTENANCE ENVIRONMENT. All personnel should familiarize themselves with their local environment, such as moisture, temperature, atmospheric pressure, salt, water, sand, and dust. The type of aircraft, aircraft mission, and ground operations also influence the rate of corrosion.

3-15.9.1. Type of Aircraft. Fixed-wing and rotary-wing aircraft have some airframe flexibility, which results in seal deterioration. This allows moisture/fluid intrusion. Vulnerable areas include gaskets on access doors/panels; fuselage flexure points; vents, ducts, and static pressure sensors; equipment bay door and electromagnetic interference (EMI) gaskets; radome and antenna seals; and opening for steps.

3-15.9.2. Effects of Aircraft Mission. A number of field corrosion problems are a result of the mission of the aircraft. For example, during a search and rescue (SAR) operation, helicopter flights are performed with the doors and windows open for optimum visibility. This causes water to enter the cabin, bilge areas, and lower mounted avionic equipment. During low-level over water flights involved in anti-submarine warfare (ASW), moisture is introduced into aircraft via the fine ocean spray prevalent at lower altitudes. This moisture saturates wiring harnesses, connectors, antennas, waveguides, and switches, and causes frequent equipment failure. Flight operations in tropical environments can produce conditions that support the growth of fungus and other microorganisms.

3-15.9.3. Protection of Aircraft During Ground Operations. Equipment can also be damaged during maintenance periods. Many problems are encountered while aircraft are parked. In general, the majority of aircraft ground time is spent with the aircraft opened up or unbuttoned. It is often necessary for canopies and access panels to be open during certain maintenance functions. This produces situations where moisture, rain, or ocean spray may soak cockpit and internal avionic components. Inspection and timely corrosion control is essential for proper operation and full life cycle. Maintenance operation time varies widely between types of equipment and depends largely on reliability and troubleshooting time. Most front-line combat aircraft average 1 to 2 hours per day in flight operations. In some cases, aircraft may be nonoperational for extended periods while waiting for spare parts. This increases the vulnerability of the entire system to corrosion. Some of the potential problems associated with increased maintenance operation time are as follows:

a. The avionic system(s) involved may be open (radomes up, equipment bay doors open, canopies raised) for extended periods.

b. Maintenance may damage seals and the locking integrity of fasteners, scratch protective finishes, and otherwise impart wear and tear to the aircraft.

c. Components may be moved several miles and exposed to the environment between the removing/installing activity and the repair shops.

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GLOSSARY

A

A-SCAN - A data presentation method for ultrasonic inspection. Data is displayed on a cathode ray tube (CRT). Sound energy amplitude is plotted on the vertical axis and distance (or time of flight) on the horizontal axis.

Abrade - To prepare a surface by roughening through sanding or mechanical means.

Accelerator - A compound that hastens a reaction, especially one that reduces the curing or hardening time of compounds.

Acetic Acid - A clear, colorless organic acid with a distinctive sharp odor (e.g. vinegar). Sometimes used as a solvent.

Acidic - Acid forming or having acid characteristics.

Active Metal - A metal ready to corrode, or being corroded.

Additive - A substance added in small amounts to something else for a particular purpose. For example, substances are added to fuel and lubricants to prevent corrosion, gum formation, varnishing, sludge formation, or knocking.

Adhesion - The chemical and/or mechanical bonding of a material to a surface.

Adhesion Promoter - A material applied to a surface to chemically enhance the adhesion of a paint or sealant to the surface.

Adhesive - Substance capable of holding materials together by surface attachment. Adhesive is a general term for glue, cement, or paste.

Aeration Cell - An electrolytic cell in which the driving force results from a difference in the amount of oxygen in solution from one point to another. Corrosion is accelerated in areas where the oxygen concentration is least; for example, in a stuffing box or under packing.

Aerobic - A process which occurs in the presence of oxygen.

Air Curing - Thermosetting or curing at ordinary room temperature without the addition of heat.

Aircraft Controlling Custodian - Navy command responsible for specific aircraft (AIRLANT, AIRPAC, CNAVRES, CNATRA, or NAVAIR).

Alkaline - Having a pH of more than 7.

Alloy - A combination of two or more metals.

Anaerobic - A process which occurs in the absence of oxygen.

Anion - A negatively charged ion that migrates toward the anode in an electrolyte. The chloride ion in sea water is an anion.

Anode - The positively charged electrode of an electrolytic cell at which oxidation or corrosion occurs. It may be a small area on the surface of a metal or alloy, such as that where a pit develops, or it may be the more active metal in a cell composed of two dissimilar metals, (i.e., the one with the greater tendency to go into solution).

Anodize - Application of a protective oxide film on a metal (such as aluminum) through an electrolytic process. This layer provides protection from corrosion and is a good base for paint.

Anodic Protection - Formation of a protective film on metals by externally applied anodic current. A potentiostat is used to maintain the potential difference between the metal and a reference electrode. At somewhat higher values of potential, the current drops to a very low value, the metal becomes passive, and corrosion is greatly reduced.

Application Time - The length of time after mixing that sealant remains suitable for application to the substrate.

Aqueous - Relating to, like, containing, or dissolved in water.

Assembly Time - The maximum length of time after mixing or thawing that sealant remains suitable to assemble parts, including final tightening of fasteners, to assure proper sealing.

Atomization - The formation of tiny droplets of liquid, as in the paint spraying process.

Austenitic - A form of stainless steel that is essentially nonmagnetic and not hardenable by heat treatment. Austenitic stainless steels have the highest corrosion resistance of any of the steel alloys.

B

Base Compound - The major component of a two-part curing-type sealant that contains the polymer (usually referred to as Part B).

Bilge - The lowest point of an aircraft's inner hull. This area is where cable runs, wire bundles, coaxial cables, lights, and antennas are typically installed.

Bleeding - A defect in which pigment from a lower coat of paint diffuses into an upper coat and discolors it.

Brush Coat - The thin coating of sealant usually applied over fasteners, seams, and various parts and small openings.

C

Capillary Action - The action by which the surface of a liquid, in contact with a solid, is raised or lowered. This is caused by the relative attraction of the liquid molecules for each other (surface tension) and those of the solid. The "wicking" of a fluid up a cloth is an example of capillary action.

Carbonize - To reduce or convert into carbon, usually by high heat or partial burning.

Cathode - The negatively charged electrode of an electrolytic cell, where the action of the corrosion current causes a reduction reaction. This results in the nearly complete elimination of corrosion.

Cation - A positively charged ion of an electrolyte which migrates toward the cathode. Metallic ions, such as iron or copper, are cations.

Cathodic Protection - Corrosion protection achieved by supplying electrons to the metal to be protected. The source of the protective current may be a sacrificial metal, such as magnesium, zinc, or aluminum, which creates a galvanic coupling. The current may also be supplied by a power source (rectifier, generator, or battery) attached to an appropriate anode and the metal to be protected. As the current passes to the metal, corrosion is suppressed.

Catalyst - The component of a two-part curing-type sealant that causes the polymer to react.

Caustic Embrittlement - Aluminum and its alloys are rapidly attacked by even dilute alkali solutions. The result of the combined action of tensile stress and corrosion due to the alkali solution causes caustic embrittlement.

Cavitation - The sudden formation and collapse of low pressure bubbles in a liquid stream by means of mechanical forces. Cavitation is often encountered around propellers, rudders, struts, and in pumps.

Cell - In corrosion processes, a cell is a single unit of electrolysis that is responsible for corrosion. It consists of an anode and a cathode immersed in an electrolyte and electrically joined together. The anode and cathode may be two separate metals or dissimilar areas on the same metal.

Chalking - Deterioration of an organic coating during exposure to the environment that results in a powdery, chalky residue on the painted surface.

Channel Seal - A seal formed by injecting a noncuring sealant material into a groove machined in one faying surface of the mating or overlapping structure after assembly.

Checking - Fine cracks in a surface film due to excessive shrinkage of the film or expansion of the surface.

Chemical Conversion Coating - A chemical treatment of a metal surface, such as aluminum or magnesium, which results in a protective (corrosion resistant) layer on the metal's surface. Types of application include immersion, brushing, or spraying with the selected chemical solution. Coatings covered by MIL-C-5541 are examples. The protective layer also greatly enhances paint adhesion

Chlorides - Certain compounds of chlorine that are extremely corrosive. Most pitting corrosion is associated with chlorides. Many varieties are present in seawater and contribute to making seawater corrosive.

Clean - Free from dirt or pollution.

Clear Water - Colorless water containing no visible suspended particles.

Combustible Liquid - Any liquid capable of igniting and burning at or above 100°F, but below 200°F.

Concentration Cell - An electrolytic cell consisting of an electrolyte and two electrodes of the same metal or alloy that develops a difference in potential as a result of a difference in concentration of ions (most often metal ions) or oxygen at different points in a solution.

Conformal Coating - A closely adhering moisture and gas barrier applied to circuit boards to prevent corrosion and breakdown of electrical insulation.

Corona - A faint glow adjacent to the surface of an electrical conductor at high voltage.

Corrosion Fatigue - A reduction in the ability of a metal to withstand cyclic stress due to its exposure to a corrosive environment.

Corrosion Rate - The speed of corrosion attack. It is usually expressed in terms of weight loss per unit of time or depth of penetration per unit of time.

Couple - Two or more metals or alloys in electrical contact with each other. These usually can act as the electrodes of a cell if they are immersed in an electrolyte.

Cracking - (1) Breaking of a metal or alloy in a brittle fashion along a narrow path or network. (2) Localized breaking of a paint film to expose the underlying material.

Crazing - The formation of surface cracks, often as a fine network, that changes the properties of the film. Crazing does not usually penetrate into the underlying surface.

Crevice Corrosion - Corrosion occurring within a crevice. The crevice may be formed at the mating surfaces of two or more parts of the same or different metals, or by a metal and nonmetallic material. Stainless steel and aluminum alloys are particularly susceptible to crevice corrosion. Crevice corrosion is an example of concentration cell corrosion.

Critical Avionic Components - Miniature or microminiature circuits, including the components, printed circuit boards, tunable coils, tuned circuits, and devices with gold/silver plated connectors or contacts.

Critical Humidity - The relative humidity, under a specific set of conditions, at which a metal or an alloy will begin to corrode. In the presence of hygroscopic (moisture absorptive) solids of corrosion products, the critical humidity will be lowered. For example, steel will not corrode if the relative humidity is less than 30% in a marine atmosphere.

Cure - The process by which a coating or sealant is converted from the liquid to the solid state. Enamel paints cure; lacquers do not cure.

Cure Rate - The length of time required for a coating or sealant to obtain the minimum hardness required by the specification.

D

Deionized Water - Water which has had various organic and inorganic materials removed by means of an ion exchange process.

Deposit Attack - When foreign material (dirt, corrosion products) is deposited on the surface of a metal, it may shield the metal from the oxygen necessary to regenerate a protective oxide layer. An oxygen concentration cell is formed, and serious corrosion may result.

Desiccant - A drying agent which acts by absorbing moisture.

Distilled Water - Water which has had various organic and inorganic materials removed by means of an evaporation and condensation (distillation) process.

Dry to Tape - The drying time required to allow a coating the ability to resist marring by adhesive tape.

Durability - Ability of components to function and sustain stresses in field service for a specified period of time with economical maintenance. This is measured in terms of minimum acceptable failure free lifetime (MFL) and expected maximum lifetime (EML) including repair (avionics components), and mean time between failure (MTBF) (aircraft components).

E

Elastomer - A synthetic material with the elastic properties of natural rubber.

Electrochemical Corrosion - Corrosion which occurs when current flows between cathodic and anodic areas on metallic surfaces.

Electrode - A metal or alloy that is in contact with electrolyte and serves as the site where electricity passes in either direction between the electrolyte and metal.

Electrolysis - Chemical changes, especially decomposition, in the solution or electrolyte due to the passage of an electric current. Its relation to corrosion arises only if the corrosion process alters the make-up of the electrolyte.

Electrolyte - Any substance which, in solution or when fused, disassociates into electrically charged ions that render the liquid capable of conducting a current. Soluble acids, bases, and salts, such as sea water, are electrolytes.

Electromagnetic Interference (EMI) - Radiation generated from electromagnetic fields which are produced by radar antennas, Radio Frequency (RF) antennas, shipboard transmitters, certain poorly designed avionics units, electric motors, and lightning and other natural effects. This type of radiation can interfere with aircraft avionics systems causing electrical malfunctions.

Electromotive Force (EMF) Series - A list of elements according to their standard electrode potentials. The more negative the potential the greater the tendency of the metal to corrode. A hydrogen gas electrode is the standard reference and its potential is designated as zero. All potentials are positive or negative with respect to the hydrogen electrode. This series does not indicate rates of corrosion.

Electronic Countermeasure - An offensive or defensive tactic using electronic or reflecting devices. It is used to reduce the military effectiveness of enemy equipment involving electromagnetic radiation.

Electronic Warfare - Warfare directed at the electronic capabilities of the enemy, to detect and prevent hostile use of the electromagnetic spectrum. Electronic warfare includes electronic countermeasures and counter countermeasures.

Electrostatic Spraying - A system of applying a coating in which the coating droplets from an air, air-assisted airless, or airless spray gun are given an electrical surface charge. These electrically charged droplets are attracted to an electrically grounded workpiece.

Embrittlement - Severe loss of ductility in a metal alloy that results in a sudden, brittle fracture.

Emulsion - One liquid dispersed throughout a second liquid with which the first liquid will not mix to form a homogeneous solution.

Enamel - A paint having a high gloss finish.

Encapsulant - The general term describing materials used to encase or fill a void to prevent the entrance of moisture or fungus. Conformal coatings, fungus-proof coatings, and potting compounds are all forms of encapsulants.

Epoxy - A type of paint or resin, adhesive, or plastic noted for high mechanical strength, good adhesion, and resistance to solvents, acids, alkalis, and corrosion.

Ester/Diester Oils - Oils containing synthetic materials known as esters or diesters, which are chemically formed by the reaction of an alcohol and an acid. Examples include jet engine oil (MIL-PRF-23699) and hydraulic oil (MIL-PRF- 83282). These synthetic oils can attack certain plastics and paints.

Erosion Corrosion - Accelerated attack of a metal due to the relative movement between a fluid and the metal surface.

Etching - The use of a chemical solution or primer to prepare a surface for priming or bonding by removing a layer of the base metal.

Exfoliation - The separation of a material in flakes or layers.

Expected Maximum Lifetime (EML) - The expected maximum period of time over which an avionics system, subsystem, module or component performs satisfactorily. This includes acceptable availability, operation, and support cost (specified number of repair cycles).

Extrusion Grade Sealant - A higher viscosity (8,000 - 16,000 poise) sealant designed for application by extrusion by a sealant gun. This grade is usually used for forming fillets and sealing vertical surfaces. Usually designated as a Class B sealant.

F

Fairing - A shape that produces a smooth transition from one angular direction to another.

Fatigue - The tendency of a material to fracture under repeated cyclic stressing.

Faying Surface - The common surface between mating parts.

Faying Surface Seal - A preassembled seal installed between two mating surfaces, used to prevent corrosion. In combination with fillet seals, faying surface seals prevent a leak path from extending through a faying surface into an interior area.

Feathering - To spread out (as paint) especially around the edges of a particular area in order to blend in with adjoining matter and leave no clear lines of distinction.

Filiform Corrosion - Corrosion that develops under coatings on metals, and appears as fine ragged hairlines, usually wavy or curved and randomly distributed.

Fillet Seal - A primary seal applied at the meeting of two adjoining surfaces and along the edges of faying surfaces as a continuous bead after part assembly. It can be applied over, along the edges, and between mating parts.

Film - A thin layer of material that may or may not be visible to the eye.

Fish-Eyes - Craters distinguished by a center which consists of a uniform flat painted region, surrounded by a depression, followed by a ridge of paint. Fish-eyes are caused by undispersed fluid globules in the paint or by airborne droplets that are deposited on the painted surface.

Flammable Liquid - Any liquid having a flash point of 100°F or less.

Flashpoint - The minimum temperature at which a liquid gives off an ignitable vapor.

Flat - A surface with minimal reflection. Flat is the opposite of gloss.

Fretting Corrosion - Corrosion which occurs at the interface of two mating surfaces, under load and subjected to vibration and slip. The relative motion between the two surfaces is extremely small.

Fungus - A group of parasitic lower plants that feed on dead or decaying organic matter. Includes molds, mildews, smuts, mushrooms and some bacteria.

G

Galvanic - A chemical reaction involving two dissimilar metals which produces direct current electricity.

Galvanic Corrosion - The accelerated corrosion of a metal that is associated with the flow of electrons from a less active metal in the same solution and in contact with the more active metal.

Galvanic Couple - A closed electric circuit of two connected dissimilar metals joined by an electrolyte.

Galvanic Series - A list of metals and alloys arranged in order of their tendency to corrode in a given environment. The galvanic series is a more accurate predictor of galvanic relationships than the electromotive force (EMF) series.

Gloss - The degree to which a surface reflects light. Gloss is the opposite of flat.

H

Hazardous Material - A material which may pose a threat to human health or the environment when improperly handled or disposed of.

Hazardous Waste - Waste which is characterized by the Environmental Protection Agency (EPA) as 1) ignitable, 2) corrosive, 3) reactive, or 4) toxic, as defined in 40 CFR 261, or is a listed hazardous waste identified in that regulation.

Hydrogen Embrittlement - Loss of ductility of a metal caused by the absorption of hydrogen ions. Hydrogen may be generated as a by-product of corrosion or through various manufacturing operations (cleaning, plating). High strength steel alloys are most susceptible to hydrogen embrittlement.

Hygroscopic - The property of readily absorbing and retaining moisture.

I

Impingement Attack - A form of erosion corrosion that is associated with turbulent flow of a liquid, as at the entrance of a condenser tube or around bends in a pipe line. Air bubbles can accelerate impingement attack.

Inhibitor - A chemical substance or mixture which, when added in small amounts to a solution, markedly decreases corrosion.

Inorganic Coating - A coating composed of matter other than of plant or mineral origin (e.g. electroplate, chemical conversion, anodize, phosphate or oxide).

Integral Fuel Tank - A load carrying structure of an aircraft that is completely sealed to provide fuel containment. It may exist as a cavity in a wing and/or the fuselage.

Ion - An electrically charged atom, group of atoms, or molecule. The sign of the charge is positive in the case of cations and negative in the case of anions.

L

Lacquer - A paint that contains a synthetic resin and forms a film after solvent loss. The film is susceptible to attack by the same or similar solvents used in the lacquer.

Local Cell - A cell in which the driving force is due to a difference in potential between areas on a metal or alloy surface immersed in an electrolyte. The potential difference may be due to inclusions, lack of homogeneity, or varying concentration of the solution with respect to oxygen or metal ions.

M

Malfunction - Failure to function correctly, especially a failure causing a flight safety situation, a mission abort, or a failure to accomplish mission.

Matte Surface - A surface with a dull finish, as in the case of an etched or sandblasted surface.

Microbes - Microscopic living plants or organisms, such as germs or bacteria.

Mil - One thousandth of an inch.

Mill Scale - The heavy oxide layer formed during hot fabrication or heat treatment of metals. The term is most frequently applied to the scale of mixed iron oxides on iron and steel.

Minimum Failure Free Lifetime (MFL) - The minimum period of time that an avionics system, subsystem, module or component performs satisfactorily without failure.

Mottling - Appearance of spotting or blotches of different color or shades of coloring.

N

Nitrates - Compounds including certain combinations of nitrogen and oxygen. Present in many industrial pollutants.

Noble Metal - A metal usually found as uncombined metal in nature, characterized by excellent corrosion resistance and high cost. Also called precious metals. Platinum, gold, and silver are noble metals.

Noncritical Avionics Components - Any avionic component that is not critical to the function of the aircraft, such as tubes, tube sockets, resistors, mechanical devices, knobs, various macroelectronic components and hardware.

Non-Destructive Inspection - An inspection method used to check the soundness of a material or a part without impairing or destroying the serviceability of the part. Examples are ultrasound, x-ray, and liquid penetrant.

O

Orange Peel - A surface bumpiness or waviness that resembles the skin of an orange. Orange peel is often caused by poor leveling and is a common defect in both spray and roll applied painted surfaces.

Organic Coating - A coating composed of matter derived from living organisms or carbon containing compounds (e.g. paint, lacquer, plastic, grease, preservative).

Outgassing - Emission of a gas during the cure or decomposition of organic material, usually increased in rate by higher temperatures.

Overspray - Sprayed paint that misses the area being painted and falls upon the surrounding surface.

Oxidation - (1) A chemical reaction in which the atoms in an element lose electrons. Any corrosion process involves oxidation of the metal in a true chemical sense. (2) The combination of a metal with oxygen which produces oxides, e.g. the scaling of steel at high temperatures.

Ozone - A triatomic (O_3) form of oxygen formed naturally from diatomic oxygen by electric discharge or exposure to solar ultraviolet radiation. The generation of the ozone layer in the upper atmosphere helps to minimize/ reduce the amount of harmful ultraviolet radiation produced by the sun. Ozone is an unstable, powerfully bleaching, poisonous oxidizing agent used to purify and deodorize air and sterilize water.

P

Passivation - The process or processes that cause a metal to become inert to a given corrosive environment. Passive metals have a very low corrosion rate.

Peel - A method of separating a bond of two materials, where the flexible material is pulled from the mating surface at a 90° or 180° angle.

Phantom Gripe - An intermittent malfunction or failure which cannot be verified/identified for corrective action.

pH - A term used to express the effective hydrogen ion concentration of a solution. Values range from 0 to 14. A pH of 7 indicates a neutral solution. Values lower than 7 indicate an acidic solution, while values greater than 7 indicate a basic solution.

Pitting - A form of extremely localized attack that eventually results in holes in the metal. Pits may vary from deep cavities of small diameter to relatively shallow depressions. Pits may be isolated or so close together that they look like a rough surface.

Plasticizer - A chemical added to rubber or resins to impart flexibility and keep them soft and pliable.

Polyethylene - A thermal plastic (softens with heat) characterized by high impact strength and high electrical resistivity. One of several plastics used for wire coating, it is also used to create film and sheets for packaging.

Polyurethane - A type of paint or resin known for its toughness, flexibility, weather resistance, chemical resistance, and abrasion resistance. Commonly used to make topcoats.

Pot Life - The usable or sprayable life of a coating or sealant after mixing has occurred.

Potentiostat - An electronic device that maintains a metal at a constant potential with respect to a reference electrode.

Potting Compound - A poured material which cures to a hard rubberlike consistency and creates a seal. It adds moisture resistance and vibration resistance to the item.

Powder Coating - A coating that is applied to the surface as a dry, finely ground powder and then heated above its melting point so that the powder particles flow together or cure.

Primer Coat - The first coat of a protective paint system. Originally applied to improve adherence of succeeding coat(s), it now usually also contains a corrosion inhibitor.

R

Relative Humidity - The ratio (expressed as a percent) of the actual moisture content of the air relative to the maximum moisture content of the air fully saturated at the same temperature.

Retarders - A solvent added to a paint to slow down its evaporation rate.

Reversion - The process in which a cured material reverts toward its precured condition, e.g. a cured potting compound reverts to a sticky, liquid-like consistency.

Room Temperature Vulcanizing (RTV) - A process for treating or curing of synthetic rubber or plastic materials which occurs at room temperature.

S

Sacrificial Anode - A metal that is anodic to the metal being protected. It corrodes preferentially when galvanically coupled to the protected metal and is consumed (sacrificed) during protection.

Seal - An adhesive agent, such as sealant, used to close or secure parts to prevent leaks. Seals may also be created by compressive interference, such as O-rings, plugs, and interference fit fasteners.

Sealant - A continuous thick film, with low cohesive strength, which prevents the passage of liquids or gasses.

Shelf Life - The length of time an unopened container can be stored at the recommended storage temperature and still retain the properties required by the specification.

Solvent - A liquid substance capable of dissolving or dispersing another substance.

T

Tack-Free Time - The length of time required for a curing sealant to lose its surface tackiness.

Thixotropic - A property of certain gels to liquefy when shaken or stirred and then return to a hardened state upon standing.

Titration - A method or process of determining the concentration of a dissolved substance by adding to it a standard reagent of known concentration in carefully measured amounts until a reaction (color change or electrical measurement) is completed.

Top Coat -The final paint film applied to a surface.

Total Environment - The circumstances and conditions which surround and influence the equipment. The total environment includes manufacturing, storage, shipping, mission, maintenance, and repair.

U

Ultraviolet (UV) Light - Light of a wavelength band shorter than visible light but longer than X-ray radiation. Longer wavelength UV from the sun causes sunburn. Shorter wavelength UV from unfiltered UV lamps can damage unprotected eyes.

Unacceptable Response - A detrimental abnormality in system performance.

Undesirable Response - A tolerated interruption of normal performance.

Uniform Surface Corrosion - Corrosive etching of metal involving only the surface.

V

Viscosity - The degree to which a fluid resists flow under an applied force.

Void Seal - A seal used to fill holes, channels, and other voids in a fuel tank. The void seal provides continuous sealing, while a fillet seal would be interrupted by structural gaps.

Volatile Organic Compound (VOC) - Compounds in paints and solvents that dissolve into the air. VOC content is restricted in many materials due to environmental regulations.

W

Water Spotting - The change in surface appearance resulting from the action of water standing on the paint film or substrate. Spotting usually is caused by water sensitivity of the coating, although the defect can be the result of dissolved material deposited as water evaporates.

Wet Edge - The ability of a wet coating to blend smoothly together in the overlap areas during application.

Wet Installed Fastener - Fasteners that have sealant applied to the shank and under the head prior to installation to provide a corrosion barrier and secondary seal.

Wrap Around - The phenomenon by which electrically charged paint droplets curve around the rear side of the object being painted.

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