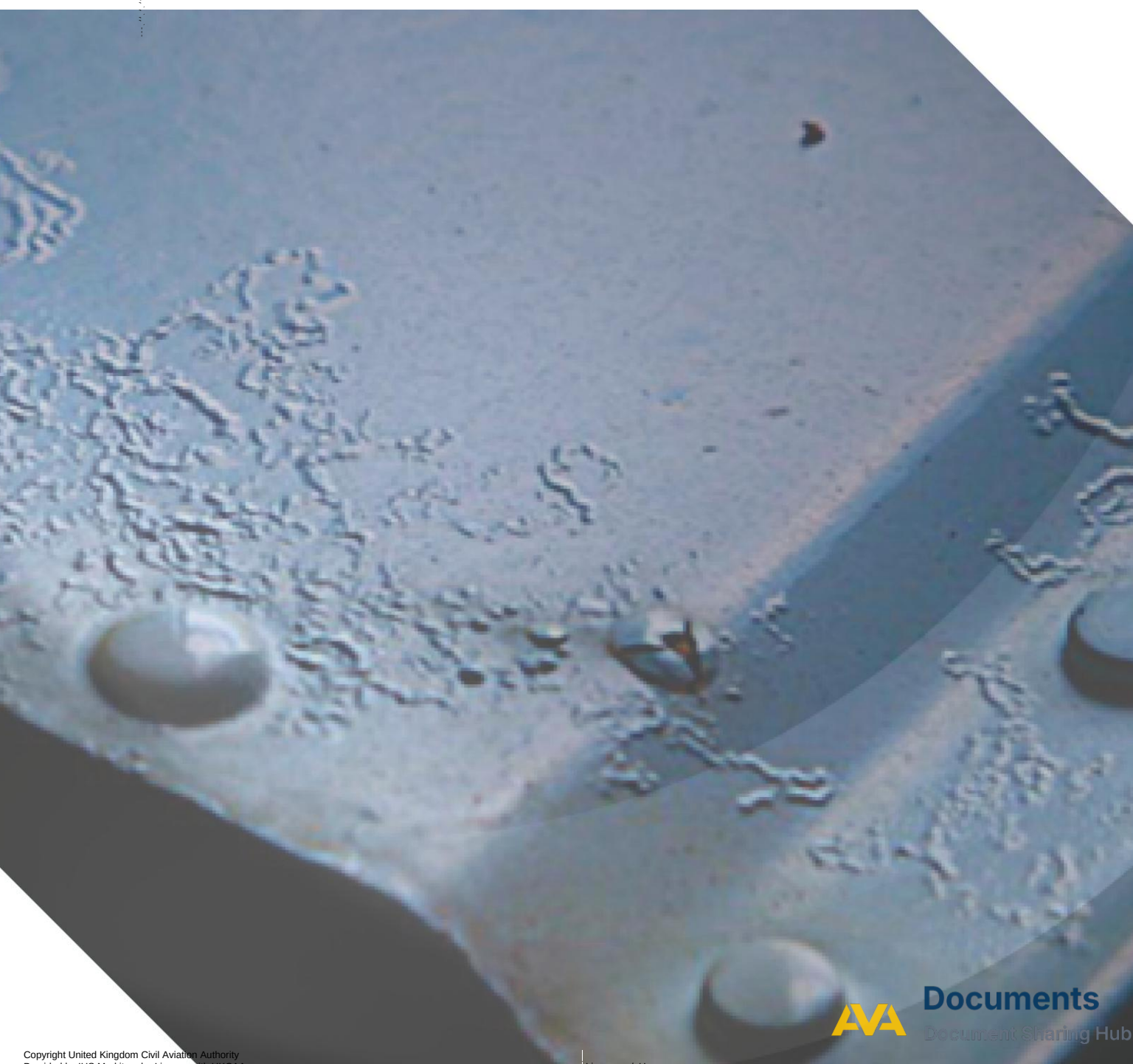


# Corrosion and Inspection of General Aviation Aircraft

CAP 1570



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## Chapter 1

# Introduction

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- 1.1 All designers, maintainers, inspectors and owners have a part to play in preventing aircraft being adversely affected by metallic corrosion. They must think about different types of corrosion and those factors that need to be considered during design, design approval and subsequent maintenance. Pilots, aircraft owners and inspectors should also be aware of the possible effects that corrosion might have on an aircraft, what to look for during their routine checks and the potential safety impact if corrosion is overlooked.
- 1.2 Aircraft designers and inspectors should also be aware of the relevant corrosion protection, inspection and related inspection access design requirements of BCAR Section S, EASA CS-VLA and Acceptable Means of Compliance, (that achieve an equivalent level of safety), when undertaking design approval and acceptance inspections respectively – references are included in the following text.
- 1.3 General guidance is provided in this publication on the design, assembly and inspection of various parts of an aircraft structure. Those areas that because of their remoteness, complexity or boxed-in nature and are not readily accessible during routine maintenance or require attention in the light of operational experience are highlighted.
- 1.4 Corrosion can result in a significant decrease in the thickness of original load bearing material that can lead to a loss of structural integrity and potentially to catastrophic failure. In the case of more highly stressed parts, finding and rectifying corrosion damage can help to prevent the early initiation of fatigue cracking from corrosion pits that can also lead to premature structural and catastrophic failures. This has been observed in aluminium alloy forgings and light aircraft landing gear components, where a mixture of exfoliation and pitting corrosion on the flash line initiated stress corrosion cracking that then lead to corrosion fatigue, normal fatigue and exfoliation.
- 1.5 Routine in-service inspections that lead to the early detection of corrosion and consequent rectification can also prevent more costly, extensive and invasive repair actions later. This can be achieved on Primary structures that are not concealed and can be easily inspected for condition in-service.
- 1.6 Deterioration of aircraft structure may arise from various causes and can affect all parts of the structure according to the design of the aircraft and the uses to which it is put. This publication should be read in conjunction with the appropriate manufacturer's publications, where provided i.e. OEM Standard Practices and

the Maintenance Programme for the aircraft concerned. In addition further information on corrosion can be found as referenced in chapter 14.

- 1.7 Although guidance may be given in publications as to suitable opportunities for inspecting normally inaccessible structures (e.g. when a wing tip is removed permitting access to the adjacent wing structure) experience should indicate to the operator further opportunities for such inspections which can be included in the Maintenance Programme. Apart from the airworthiness aspects, these combined inspections could often be to the operator's advantage, since they could reduce or remove the need for future dismantling that might otherwise be dedicated to periodic corrosion driven inspections. Thus when access has been gained to a part of the airframe which is normally inaccessible, advantage should be taken of this dismantling to inspect all parts of systems and structures thus exposed.
- 1.8 When evidence of corrosion is found it is critical that the full extent and nature of the corrosion be established and repaired, even if these means additional access, dismantling or a special inspection technique to facilitate such deeper inspection and subsequent rectification actions.
- 1.9 The presence of corrosion in aircraft will lead to deterioration in the aircraft's structure which may eventually lead to catastrophic failure. It is therefore essential that any signs of corrosion are detected in the earliest stages of its development, assessed and addressed as appropriate. Development of corrosion over time is influenced by a variety of factors as will be described subsequently.
- 1.10 Prevention is always better than cure, and by ensuring suitable corrosion protection on individual detail parts prior to and during assembly the onset of corrosion can be prevented or significantly delayed.

Note: Whilst this publication contains guidance principally aimed at General Aviation Aircraft, the content can also be seen as more widely relevant to non-GA types which are similarly vulnerable to corrosion. Accordingly a number of the corrosion examples described and associated photographs that follow involve non-GA types.

## Chapter 2

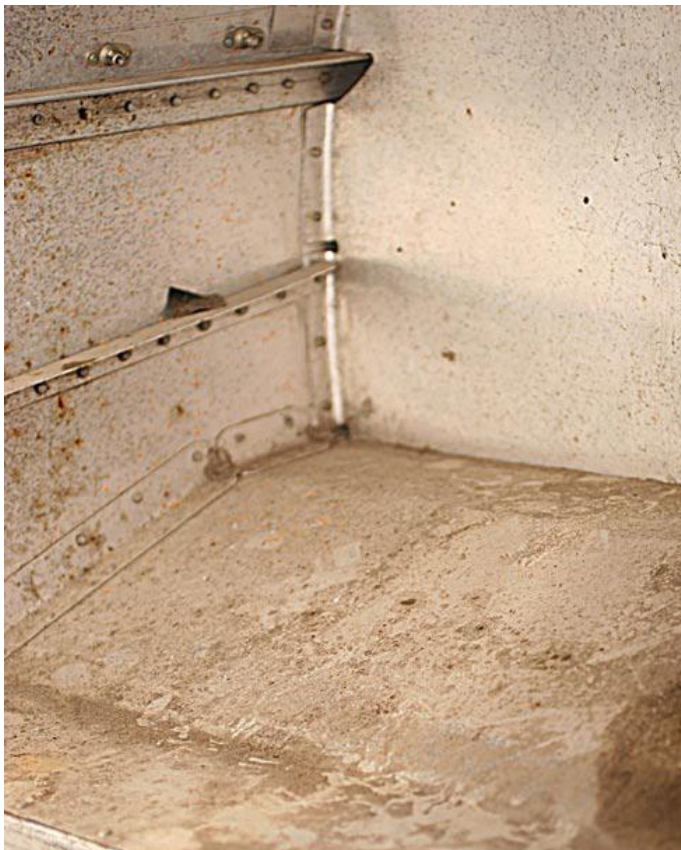
# Theory of corrosion

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The following text has been extracted from the US Department of Transportation, Federal Aviation Administration (FAA), Flight Standards Service FAA-8083-30 Aviation Maintenance Technical Handbook, Chapter 6 Aircraft Cleaning and Corrosion Control (2008) - the FAA text has not been revised save for spelling changes to UK English and in order to provide correct cross-references in the text to embedded photographs and diagrams.

- 2.1 Metal corrosion is the deterioration of the metal by chemical or electrochemical attack. This type of damage can take place internally as well as on the surface. As in the rotting of wood, this deterioration may change the smooth surface, weaken the interior, or damage or loosen adjacent parts.
- 2.2 Water or water vapour containing salt combines with oxygen in the atmosphere to produce the main source of corrosion in aircraft. Aircraft operating in a marine environment, or in areas where the atmosphere contains industrial fumes that are corrosive, are particularly susceptible to corrosive attacks.

Photograph 1. Direct chemical attack in a battery compartment

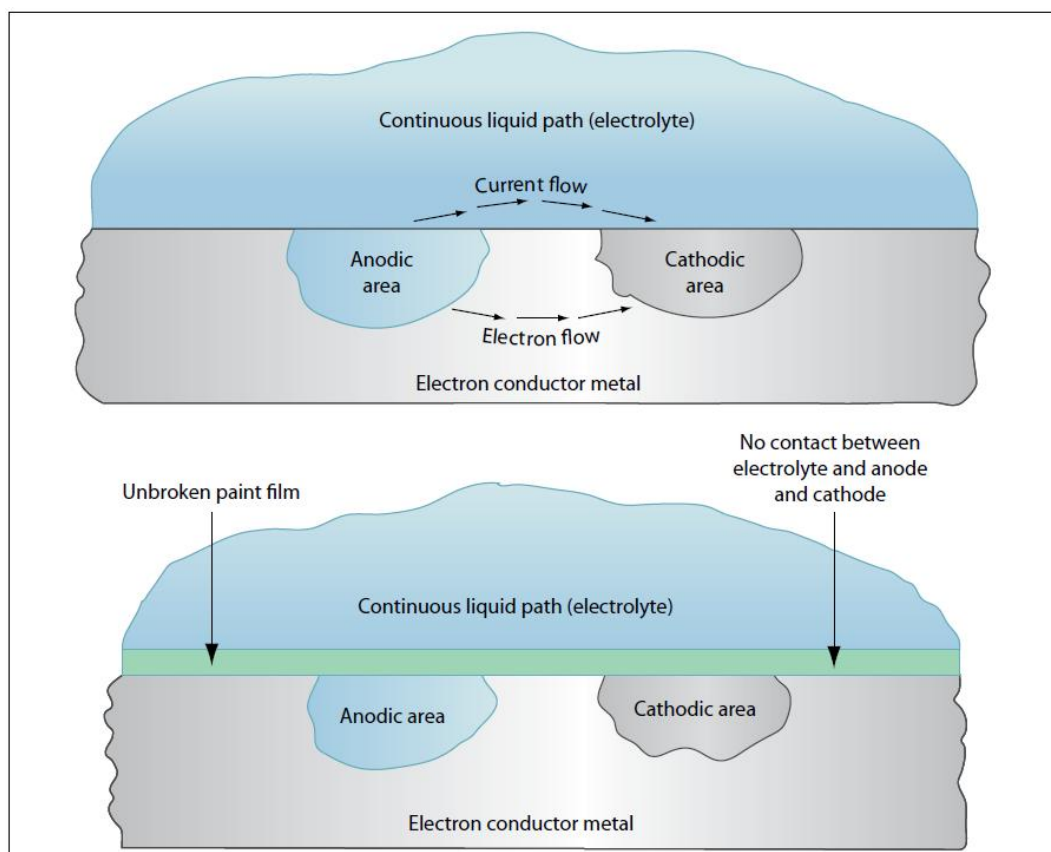


- 2.3 If left unchecked, corrosion can cause eventual structural failure. The appearance of corrosion varies with the metal. On the surface of aluminium alloys and magnesium, it appears as pitting and etching, and is often combined with a grey or white powdery deposit. On copper and copper alloys, the corrosion forms a greenish film; on steel, a reddish corrosion by-product commonly referred to as rust. When the grey, white, green, or reddish deposits are removed, each of the surfaces may appear etched and pitted, depending upon the length of exposure and severity of attack. If these surface pits are not too deep, they may not significantly alter the strength of the metal; however, the pits may become sites for crack development, particularly if the part is highly stressed. Some types of corrosion burrow between the inside of surface coatings and the metal surface, and can spread until the part fails.

## Types of Corrosion

- 2.4 There are two general classifications of corrosion that cover most of the specific forms: direct chemical attack and electrochemical attack. In both types of corrosion, the metal is converted into a metallic compound such as an oxide, hydroxide, or sulphate. The corrosion process always involves two simultaneous changes: The metal that is attacked or oxidized suffers what may be called anodic change, and the corrosive agent is reduced and may be considered as undergoing cathodic change.

Diagram 1. Electrochemical attack



## Direct Chemical Attack

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- 2.5 Direct chemical attack, or pure chemical corrosion, is an attack resulting from a direct expo-sure of a bare surface to caustic liquid or gaseous agents. Unlike electrochemical attack where the anodic and cathodic changes may be taking place a measurable distance apart, the changes in direct chemical attack are occurring simultaneously at the same point. The most common agents causing direct chemical attack on aircraft are:
- Spilled battery acid or fumes from batteries;
  - Residual flux deposits resulting from inadequately cleaned, welded, brazed, or soldered joints; and
  - Entrapped caustic cleaning solutions. [Photograph 1]
- 2.6 With the introduction of sealed lead-acid batteries and the use of nickel-cadmium batteries, spilled battery acid is becoming less of a problem. The use of these closed units lessens the hazards of acid spillage and battery fumes.
- 2.7 Many types of fluxes used in brazing, soldering, and welding are corrosive, and they chemically attack the metals or alloys with which they are used. Therefore, it is important to remove residual flux from the metal surface immediately after the joining operation. Flux residues are hygroscopic in nature; that is, they absorb moisture, and unless carefully removed, tend to cause severe pitting.
- 2.8 Caustic cleaning solutions in concentrated form should be kept tightly capped and as far from aircraft as possible. Some cleaning solutions used in corrosion removal are, in themselves, potentially corrosive agents; therefore, particular attention should be directed toward their complete removal after use on aircraft. Where entrapment of the cleaning solution is likely to occur, use a noncorrosive cleaning agent, even though it is less efficient.

## Electrochemical Attack

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- 2.9 An electrochemical attack may be likened chemically to the electrolytic reaction that takes place in electroplating, anodizing, or in a dry cell battery. The reaction in this corrosive attack requires a medium, usually water, which is capable of conducting a tiny current of electricity. When a metal comes in contact with a corrosive agent and is also connected by a liquid or gaseous path through which electrons may flow, corrosion begins as the metal decays by oxidation. [Diagram 1] During the attack, the quantity of corrosive agent is reduced and, if not renewed or removed, may completely react with the metal, becoming neutralized. Different areas of the same metal surface have varying levels of electrical potential and, if connected by a conductor, such as salt water, will set up a series of corrosion cells and corrosion will commence.

- 2.10 All metals and alloys are electrically active and have a specific electrical potential in a given chemical environment. This potential is commonly referred to as the metal's "nobility." [Diagram 2] The less noble a metal is, the more easily it can be corroded. The metals chosen for use in aircraft structures are a studied compromise with strength, weight, corrosion resistance, workability, and cost balanced against the structure's needs.
- 2.11 The constituents in an alloy also have specific electrical potentials that are generally different from each other. Exposure of the alloy surface to a conductive, corrosive medium causes the more active metal to become anodic and the less active metal to become cathodic, thereby establishing conditions for corrosion. These are called local cells. The greater the difference in electrical potential between the two metals, the greater will be the severity of a corrosive attack, if the proper conditions are allowed to develop.
- 2.12 The conditions for these corrosion reactions are the presence of a conductive fluid and metals having a difference in potential. If, by regular cleaning and surface refinishing, the medium is removed and the minute electrical circuit eliminated, corrosion cannot occur. This is the basis for effective corrosion control. The electrochemical attack is responsible for most forms of corrosion on aircraft structure and component parts.

Diagram 2. The galvanic series of metals and alloys.

| <b>+ Corroded End (anodic, or least noble)</b>                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------|
| Magnesium<br>Magnesium alloy<br>Zinc                                                                                               |
| Aluminum (1100)<br>Cadmium<br>Aluminum 2024-T4<br>Steel or Iron<br>Cast Iron<br>Chromium-Iron (active)<br>Ni-Resist Cast Iron      |
| Type 304 Stainless steel (active)<br>Type 316 Stainless steel (active)                                                             |
| Lead-Tin solder<br>Lead<br>Tin                                                                                                     |
| Nickel (active)<br>Inconel nickel-chromium alloy (active)<br>Hastelloy Alloy C (active)                                            |
| Brass<br>Copper<br>Bronze<br>Copper-nickel alloy<br>Monel nickel-copper alloy                                                      |
| Silver Solder<br>Nickel (passive)<br>Inconel nickel-chromium alloy (passive)                                                       |
| Chromium-Iron (passive)<br>Type 304 Stainless steel (passive)<br>Type 316 Stainless steel (passive)<br>Hastelloy Alloy C (passive) |
| Silver<br>Titanium<br>Graphite<br>Gold<br>Platinum                                                                                 |
| <b>- Protected End (cathodic, or most noble)</b>                                                                                   |

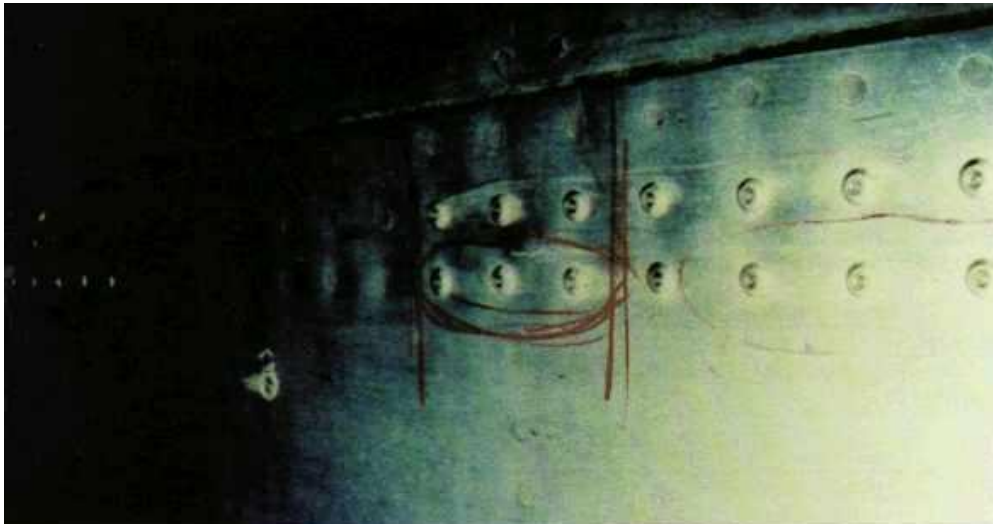
## Chapter 3

# Types of corrosion

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- 3.1 Corrosion comes in many forms, (as is discussed in more detail in Section 3.2 below), and can be found on the surface and therefore can be penetrating inside the material; thus the removal of the surface products of corrosion followed by re-protection may not always be effective. Minor corrosion on the surface may hide more significant corrosion within the material structure, this can be true of intergranular corrosion, pitting corrosion as well as stress corrosion cracking. Once the surface is penetrated the reduction in strength due to loss of material can be disproportionate to the reduction in thickness of the metal as the corrosion initiates cracking mechanisms. Voids in structural joints that could allow water /condensate ingress leading to corrosion should be prevented. Means must be provided to allow inspection of Primary Structures in order to ensure that a satisfactory continued airworthy condition is maintained.
- 3.2 Initial presentation of exfoliation corrosion in components made from aluminium alloy extrusion, plate and bar may show itself as slight dark lines along the grain direction. Exfoliation corrosion is specific to wrought aluminium alloys and occurs due to developed grain structure 'flat pancake grains', this grain structure is not developed in any other metallic material. It is a form of intergranular corrosion. These lines are not to be confused with machining marks, as these corrosion marks will be along the axis of the material and not around the circumference. Left untreated this will develop into full scale Exfoliation or surface eruptions and material flakes. Component thickness will increase, as the grain separation forces the material apart, before complete structural failure occurs. Quilting or pin cushioning occurs because the volume of aluminium alloy corrosion is significantly greater than the metal volume. This is a phenomenon that is seen with aluminium alloy structures.
- 3.3 When general surface corrosion occurs within faying/fastened structures where layers of material are nested together in a joint, a similar characteristic quilting or pin cushion effect can be observed where the surface bulges and distorts outwards between the fasteners due to the expanding pressure of corrosion products.

Photograph 2. Pin cushion effect at a fuselage lap joint – in more extreme case and more particularly with countersunk fasteners the fastener heads can either pull through or fail entirely



- 3.4 It may not be possible to determine the deterioration of material strength in Aluminium Alloy Primary Structure items, when assessing the extent of sub-surface corrosion using any known methods i.e. x-ray, ultrasound, and thus component replacement may be the only safe solution. Suitably effective individual part corrosion protection applied both before and during assembly can help to delay if not prevent corrosion in joints.
- 3.5 The following content is generally reflective of the typical types of corrosion as found with aluminium alloys, which tend to be more commonly used in the construction of light aircraft, however it should be borne in mind that most non-noble metals can corrode. Alloys including titanium alloys and steels can similarly be prone to corrosion. Even “non-corroding”/stainless types can corrode when exposed to particularly aggressive environments, (industrial chemical/saline etc., atmospheres under severe corrosion conditions), and stainless steel may also be prone to cracking when subjected to higher temperatures. Note that corrosion symptoms may present slightly differently in these other materials when compared to corrosion of aluminium alloys indeed it should be noted that different classes of alloy (2000 series, 6000 series, 7000 series) differ greatly in their corrosion resistance.

## Anodic (Galvanic) corrosion

- 3.6 This form of corrosion arises when two dissimilar metals are in contact in the presence of an electrolyte, (usually present in the form of precipitation and condensation combined with atmospheric pollutants and spillages). Aluminium alloy is by its very nature of being an alloy, is comprised of dissimilar metals, (mainly aluminium, plus copper, magnesium and manganese), therefore any exposure of that base alloy material to water in service without suitable protection will produce corrosion which will not necessarily be restricted to the

surface where powder-like white or grey deposits can be observed. Note that carbon fibres in contact with aluminium can also set up a galvanic cell and an interlay material such a glass fibre / epoxy scrim on the surface of the carbon composite can be successfully employed as a barrier layer. Surface protection can generally assist in prevention, but using the same material in contact in a joint or a more careful choice of the materials that are closer on the electrochemical scale is generally seen as an effective preventative measure - it is not always feasible or practical to prevent dissimilar metal on metal contact when constructing traditional metallic fastener joined structures made of metals or carbon fibre reinforced materials. Joint protection provided by using a "surplus of approved jointing compound" for the prevention of joint internal voids as a preventative of water ingress into joint by capillary action can be employed.

Photograph 3. Aluminium alloy fitting attachments used to mount carbon fibre composite flying surfaces to fuselage - absence of paint / interfacing GRP shim has allowed aluminium on carbon contact creating a galvanic cell with the aluminium "sacrificed".

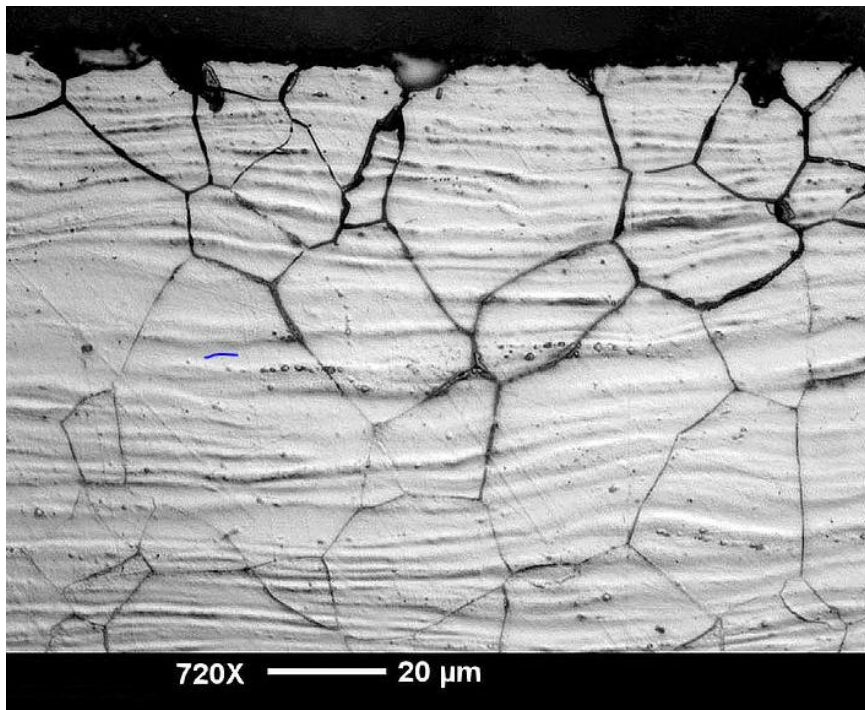


## Intergranular Corrosion

- 3.7 This form of corrosion usually presents itself as cracking and tends to accelerate with the passage of time. A combination of chemical and electrolytic actions attack the material along the grain boundaries when the surface protective coating is damaged allowing moisture and corrosive agents to enter. A series of protective barriers comprising paint, primer and using a clad aluminium sheet or plate material (i.e. a near pure aluminium outer clad layer) can help to protect the base structural material. All exposure of the Aluminium Alloy base metal from drilling or sheared edges produced during initial assembly, will remove or bypass the clad surface protection applied by the material manufacturer, and breaches in the cladding should be suitably re-protected from corrosion preferably by anodising or as a minimum by acid etch painting to be applied before final assembly with the use of, where applicable, an approved joint sealant. After final assembly, it is advisable that all joints should be sprayed with an acid etch primer, this will have the advantage of protecting newly formed rivet tails, exposed bolt threads and by leaching into any unprotected gaps/surfaces. This should prevent the capillary action of water condensate occupying those

potential voids, and has the additional benefit of providing a suitable keying surface for subsequent additional painting.

Photograph 4. Intergranular corrosion in austenitic cold rolled stainless steel<sup>1</sup>



## Filiform surface corrosion

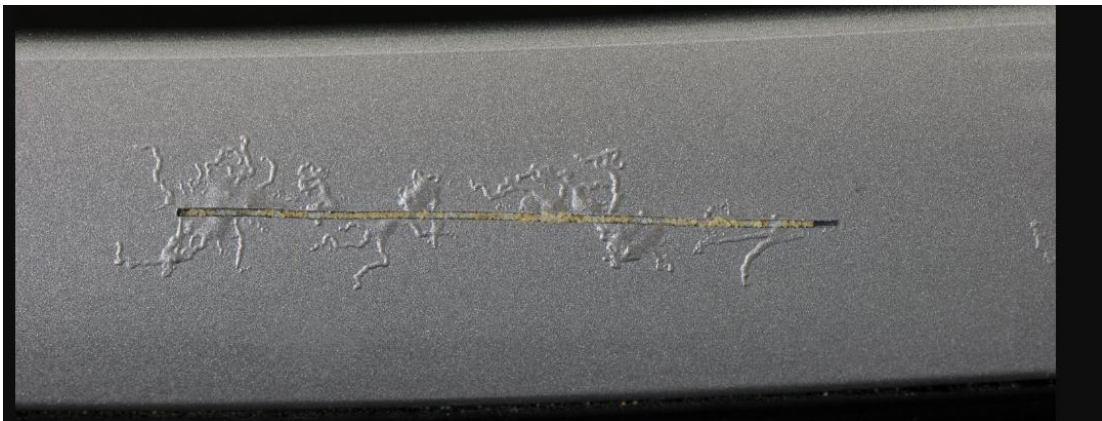
- 3.8 In this case the corrosion presents as random threadlike filaments under the paint often with the paint bulging in blisters raised by the corrosion products. Cracks or damage to the paint allow corrosive moisture ingress and surface localized active corrosion cells. More severe in high humidity, marine and industrially polluted environments.

<sup>1</sup> [https://commons.wikimedia.org/wiki/File:Intergranular\\_corrosion.JPG](https://commons.wikimedia.org/wiki/File:Intergranular_corrosion.JPG)

Photograph 5. Filiform corrosion example<sup>2</sup>



Photograph 6. Filiform corrosion spreading from scribe on painted aluminium after complete accelerated corrosion testing<sup>3</sup>



## Pitting or General Surface Corrosion

- 3.9 As the name implies the former involves the creation of localized pits / small holes in the material surface which can be deep and significant to structural integrity whilst the latter corrosion form starts with a more widely dispersed uniform surface etching that dulls the surface and can progress to generate a rougher or frosted surface appearance.
- 3.10 Corrosive agents create a local electrolytic cell when the protective surface coating is no longer in a good condition particularly in conjunction with unclean surface conditions that help to harbour moisture / corrosive medium. Pitting traps the electrolyte within the pit and the composition of the electrolyte will change as the corrosion progresses. With the change in electrolyte composition the

<sup>2</sup> FAA-8083-30 Aviation Maintenance Technical Handbook, Chapter 6 Aircraft Cleaning and Corrosion Control (2008)

<sup>3</sup> [https://commons.wikimedia.org/wiki/File:Filiform\\_corrosion\\_on\\_painted\\_aluminum.jpg](https://commons.wikimedia.org/wiki/File:Filiform_corrosion_on_painted_aluminum.jpg)

corrosion can accelerate and/or change form to stress corrosion cracking or corrosion fatigue.

Photograph 7. GA aircraft empennage structure – surface and pitting corrosion of tailplane internal rib section found after accident damaged parts were removed for component replacement.



Photograph 8. Pitting seen on vintage aircraft engine crankshaft<sup>4</sup>



## Stress Corrosion Cracking

- 3.11 Presents generally as cracking only, (usually fast crack growth), especially in higher strength alloy materials with negligible corrosion product. This phenomenon arises due to a combination of high tensile stresses, (standing

<sup>4</sup> Photo credit – Malcolm McBride LAA