Chapter 27 – REPAIRING CORROSION DAMAGE

Ronald W. Gould
Structures and Materials Performance Laboratory, Institute for Aerospace Research
National Research Council Canada
Ottawa, Ontario
CANADA

27.1 INTRODUCTION

Repair of corrosion damage requires that suspect structure can be accessed and inspected non-destructively so that the damage can be detected and quantified in terms of severity. Chapter 21 of this publication describes some of the inspection methods available as well as the quantitative success of most of these methods. This chapter illustrates how some of these methods are used in practice and the complications that arise when dealing with multi-layer, built up structure. It also reviews some of the methods available for repairing corrosion damaged structure as well as work performed at the National Research Council to develop a library of specimens of corroded aircraft structures.

27.2 REPAIRING CORROSION DAMAGE

27.2.1 Standard Practice

All aircraft must be periodically inspected for corrosion. During visual inspections an inspector looks for surface features that indicate the presence of corrosion. One such feature is known as corrosion pillowing, which occurs when corrosion products are present at the faying surfaces of lap joints or in areas of multi-layer construction. Service bulletins and maintenance manuals state that if corrosion is visually detected, then eddy current equipment should be used to estimate the percentage of thickness loss. In general, if the thickness loss in a single skin is greater than 10% [1] the joint must be repaired. This entails:

- Removing the rivets in the affected area;
- Wedging open the skins;
- Removing the corrosion products and any visible damage (e.g., pits) [2];
- Applying doublers to the affected skins; and
- Returning the aircraft to service.

For a thickness loss of less than 10% the required action varies depending on the aircraft. For some aircraft repair is not mandatory, but there must be regular inspections until the joint is repaired. However, for other aircraft the service bulletins state that if the corrosion is within specified limits, prior to flight, it, and any other visible damage, must be removed, e.g., by blending out.

The standards for safe corrosion damage repair have been developed from years of accumulated experience. The guidelines for these best practices are set out in training and repair manuals and the work is carried out by skilled personnel. Nevertheless, the nature of the work does sometimes result in unwitting damage being done, and the time spent carefully exploring the extent of the corrosion damage could be wasted if the end result is that the part must be scrapped and replaced.

Paint systems are still removed from aircraft structures before inspections are made for corrosion and fatigue damage, since there is as yet no acceptance that available NDI techniques can detect such damage

through the protective coatings [3]. To illustrate that hazards exist during paint stripping, the FAA recently added an Airworthiness Directive for B757s to the previous warning for B737s[1] [4]. These ADs followed the discovery of procedural errors (use of metal tools, resulting in scratches) when some airframes were being paint-stripped for inspection prior to maintenance. Not only are scratches a concern for fatigue damage but they are potential sites for corrosion initiation. Blending out of such scratches should be followed by the application of a protective coating since the blending (grinding/hand sanding) may extend through the original protective cladding layer.

27.2.2 Inspection Methods and Examples

Typical line inspection of operational aircraft relies on the human inspector's ability to view the surface and visually recognize faults such as 'pillowing', cracks and loose or failed fasteners. NDI techniques are not typically applied to the interrogation of individual fasteners. On the aircraft such damage is usually noticed only when the fastener head has fallen out. Often the fastener is replaced from the exterior only (blind or pop-rivet type) owing to access difficulties. This means that the condition of the inner structure is not properly assessed. Structures receiving this type of maintenance have sometimes been found to have non-existent or severely compromised inner structure. The end result can be a filled hole in the outer layer with no mechanical connection to the sub-structure. The inability of normal visual inspections to detect hidden corrosion damage has led to enhanced visual inspections, see below, and sometimes to X-radiography.

27.2.2.1 D Sight Aircraft Inspection System (DAIS)

This inspection system enables enhanced visual inspections of intact joints [5]. Figure 27-1 is a DAIS image of a lap joint that illustrates the stages in corrosion growth, detection and repair:

- Green line: this area is undamaged (green line) and shows the normal skin deformations in joints resulting from manual assembly: note also that the deformations along the body frames are typical.
- Yellow line at left: corrosion was detected and assessed to exceed the damage limits (>10% thickness loss), thereby requiring local disassembly, clean-up between the skins and application of an external doubler. The mechanical deformations resulting from this repair mean that this area can no longer be assessed simply by visual inspection of the outer surface.
- Orange line at right: a lower level of corrosion was detected (<10% loss) and the repair involved local disassembly, clean-up and reassembly with larger diameter protruding head rivets. Drilling for these rivets completely removed the countersinks in the outer skin of the original flush-head rivets. The large size of the protruding rivet heads and their spacing make future visual and NDI inspections very difficult. There is very little room to slide an eddy current probe around between the heads.
- Red line: this area suffered un-repaired corrosion damage, visible as pillowing. Either this damage had occurred since the repairs were carried out or it was present at the time and was missed by the inspection techniques employed. At the next D-check the external doubler repair (solid yellow line) was removed and replaced with a larger doubler that covered the expanded repair area, as indicated by the dotted yellow line.

[1] FAA AD 2007-19-07 for certain Boeing Model 757-200, 200PF, and -200CB series airplanes. This AD requires inspections to detect scribe lines and cracks of the fuselage skin, lap joints, circumferential butt splice strap, and external and internal approved repairs; and related investigative/corrective actions if necessary. This AD results from reports of scribe lines adjacent to the skin lap joints. We are issuing this AD to detect and correct cracks, which could grow and cause rapid decompression of the airplane.

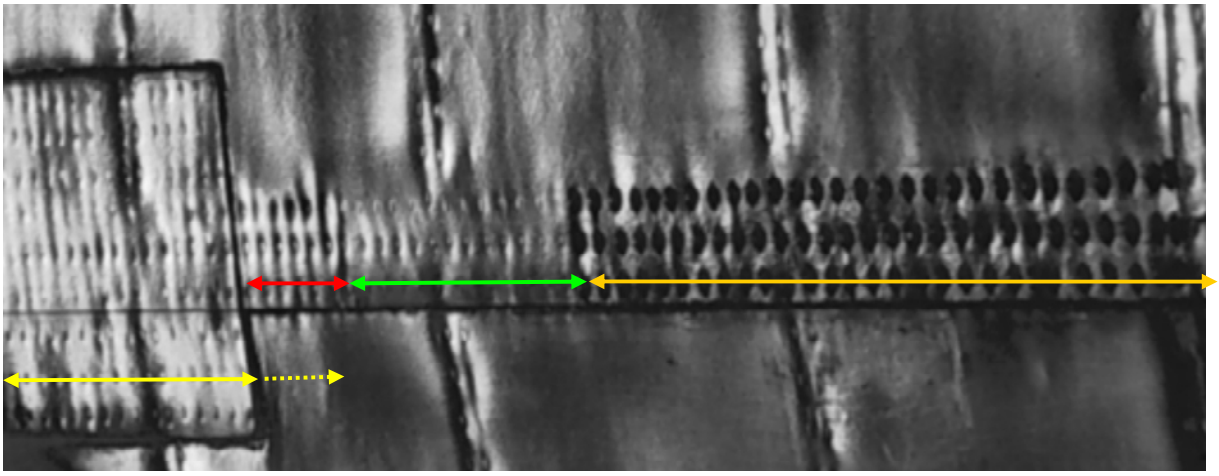
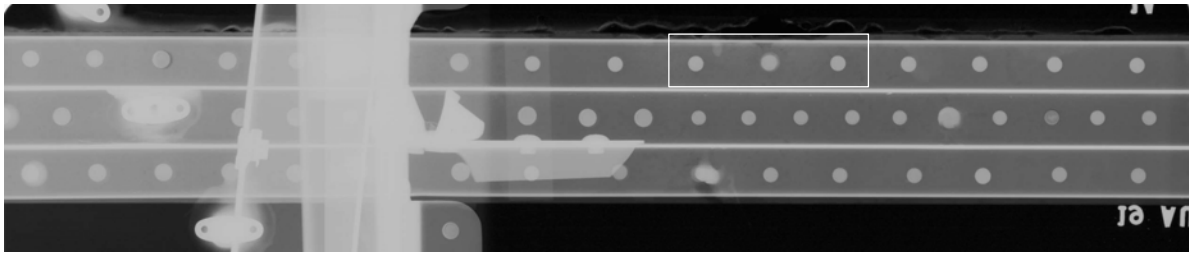


Figure 27-1: Lap Joint Corrosion and Repairs.

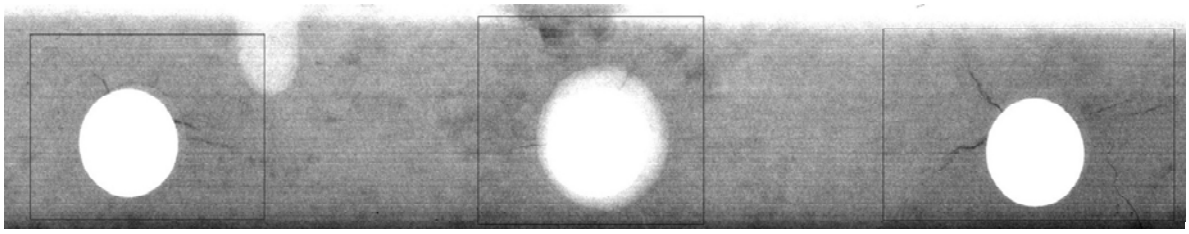
In the above illustration the rivet-to-rivet and row spacings in the joint were nominally equal, which caused the pillowing response when the skins were deformed by the accumulation of corrosion products between the fasteners restraining them. However, each manufacturer has invested heavily in the understanding of their proprietary joint designs and chosen specific rivet / rivet row spacings. These spacings directly affect the corrosion pillowing response and inspectability. For example, Airbus and Lockheed L1011 joints do not pillow, they make waves. Douglas DC-10 joints also make waves, but the view is complicated by the use of 'beauty strips' (external butt joint doublers). Douglas DC-9 longitudinal joints do not appear to pillow or make waves unless they are viewed perpendicular to the joint rather than along it as in Figure 27-1. The reason is that the DC-9 has closely spaced rivets in widely spaced rows, and corrosion product accumulation results in wave-like distortions parallel to the joint. These are almost impossible to detect when viewed along the joint.

27.2.2.2 X-Ray Inspection

X-radiography is not typically used for corrosion detection, as is mentioned also in Part 2 of this chapter. However, the pillowing forces generated by the corrosion activity in multi-layer structures can lead to tensile forces sufficient to nucleate cracks which are detectable by X-ray, Figure 27-2.



(a) Typical x-ray film of intact joint.

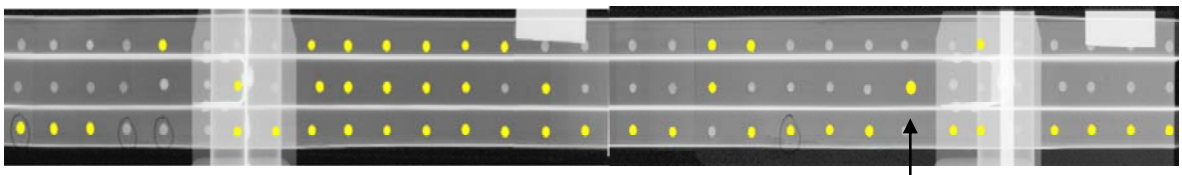


(b) Non-surface breaking cracks (enlargement of area in white box).

Figure 27-2: Corrosion-Induced Pillowing Cracks.

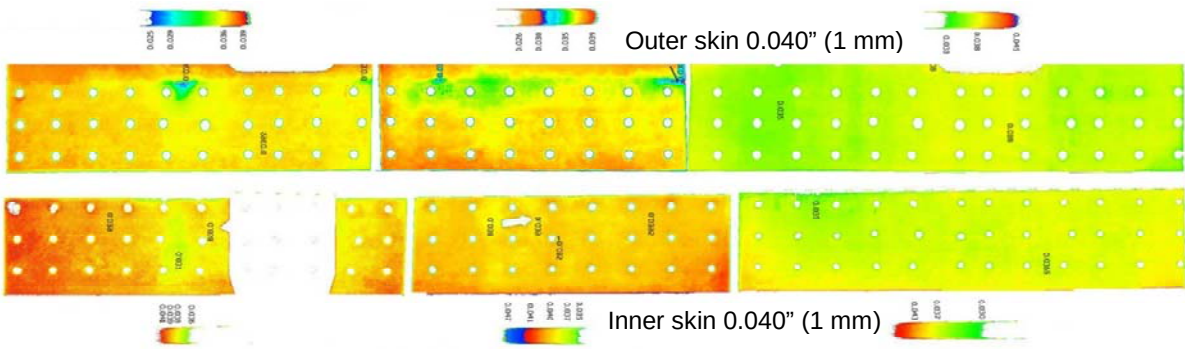
27.2.2.3 Examples of Damage Undetectable Without Detailed Inspections

Skin thickness loss and cracked rivets – Figure 27-3 shows X-ray inspection results for an intact and disassembled lap joint. The skins of the lap joint suffered only 3 – 4% combined thickness loss yet 43 of the 93 rivets in the joint, a total of 47%, were *subsequently* (during teardown) found to be fractured, including a larger diameter replacement rivet in the middle row. Fractured rivets were those that easily broke into two during teardown of the joint (shop heads machined off and rivets pressed out).



Larger diameter replacement rivet also fractured

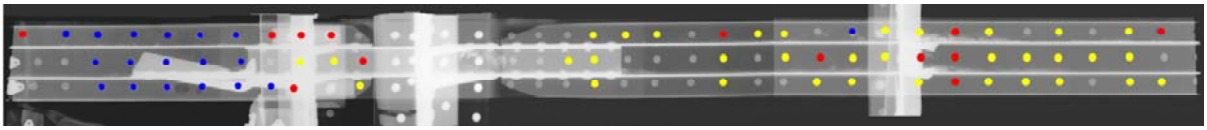
(a) Rivet condition: Yellow – fractured.



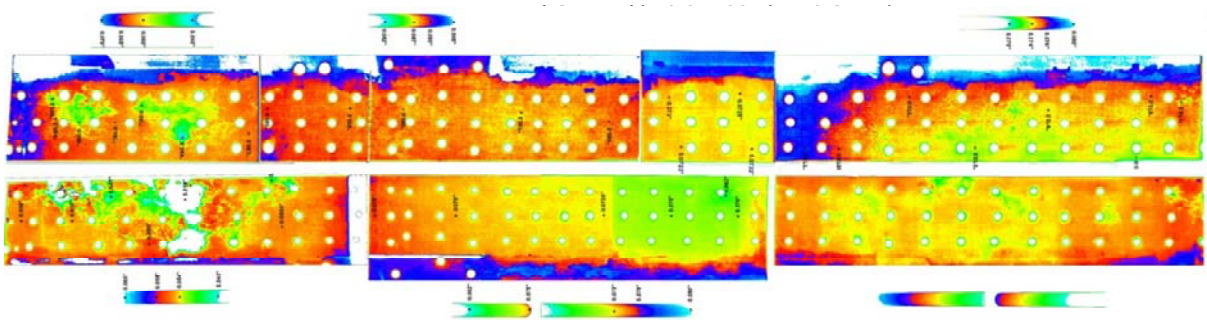
(b) False-color digitized X-ray thickness loss (calibration ramps adjacent to sections).

Figure 27-3: X-Ray Inspection Results for (a) Intact and (b) Disassembled Joint.

Figure 27-4 gives another example of X-ray inspection results for an intact and disassembled lap joint. The upper X-ray was taken before the joint was disassembled and cleaned of paint, primer, sealants and corrosion product to facilitate the thickness loss mapping of the separate skins. Both skins had been taper-machined: the outer skin from 0.07 to 0.09 inch (1.78 – 2.28 mm) and the inner skin from 0.06 to 0.08 inch (1.52 – 2.03 mm). Disassembly allowed detection of the thickness loss due to corrosion.



(a) Rivet condition: Red – Failed-in-place, Yellow – Fractured, Blue – Replaced.



Tapered Inner skin 0.06-.08" (1.5-2.0 mm)

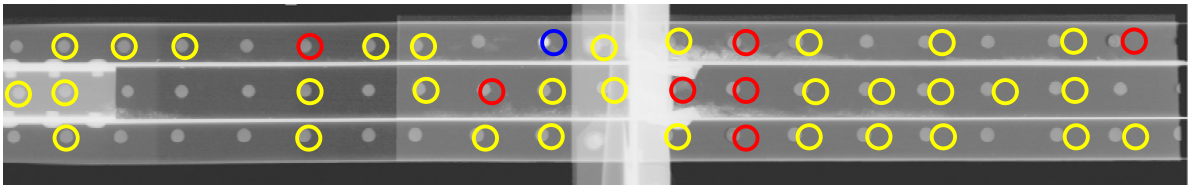
(b) False-color digitized X-ray thickness loss (calibration ramps adjacent to sections).

Figure 27-4: X-Ray Inspection Results for (a) Intact and (b) Disassembled Joint.

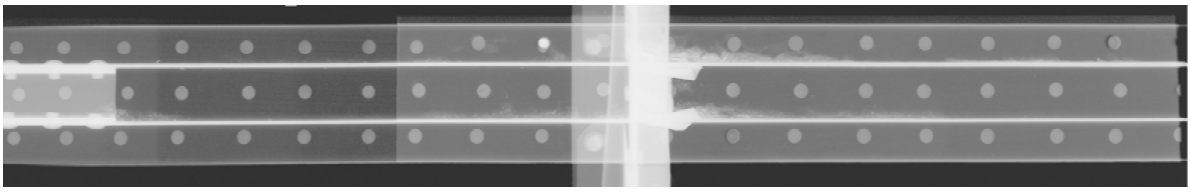
However, neither X-ray nor eddy current inspections before disassembly showed differences between intact and cracked rivets. Disassembly showed that of the 108 fasteners in the lap joint, 13 had failed, 31 were fractured, and 18 had been previously replaced − but 17 of these were installed into the severely exfoliated second layer skin and stringer (left end). A total of 57% of the fasteners in this section of lap joint were either failed or distressed.

Figure 27-5 provides a closer assessment of the fasteners at the right end of the joint shown in Figure 27-4. The key for the colored circles applied to the X-ray image of the joint in Figure 27-5(a) is:

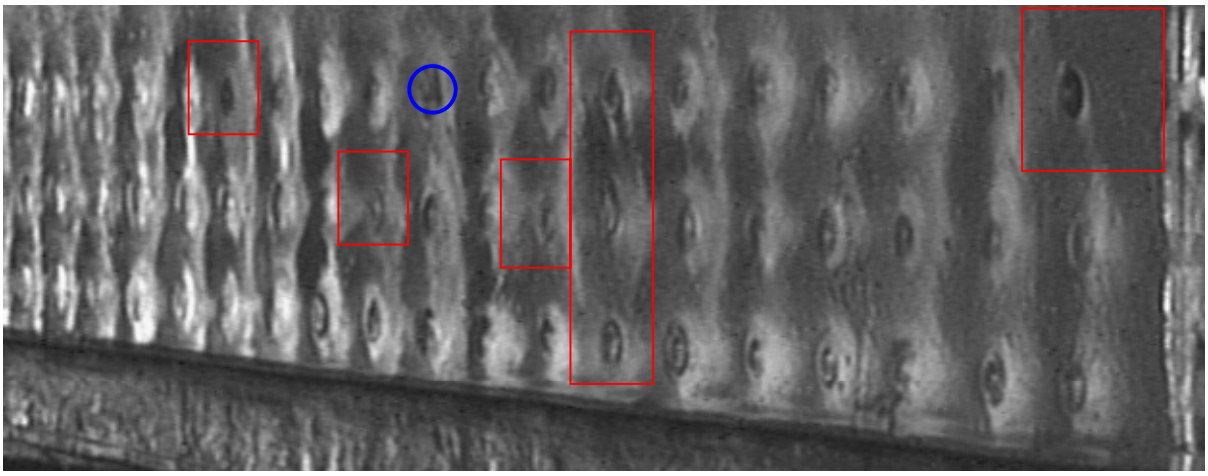
- Red – cracked around base of rivet head or head missing.
- Yellow – partially cracked.
- Blue – replacement for previously failed rivet.



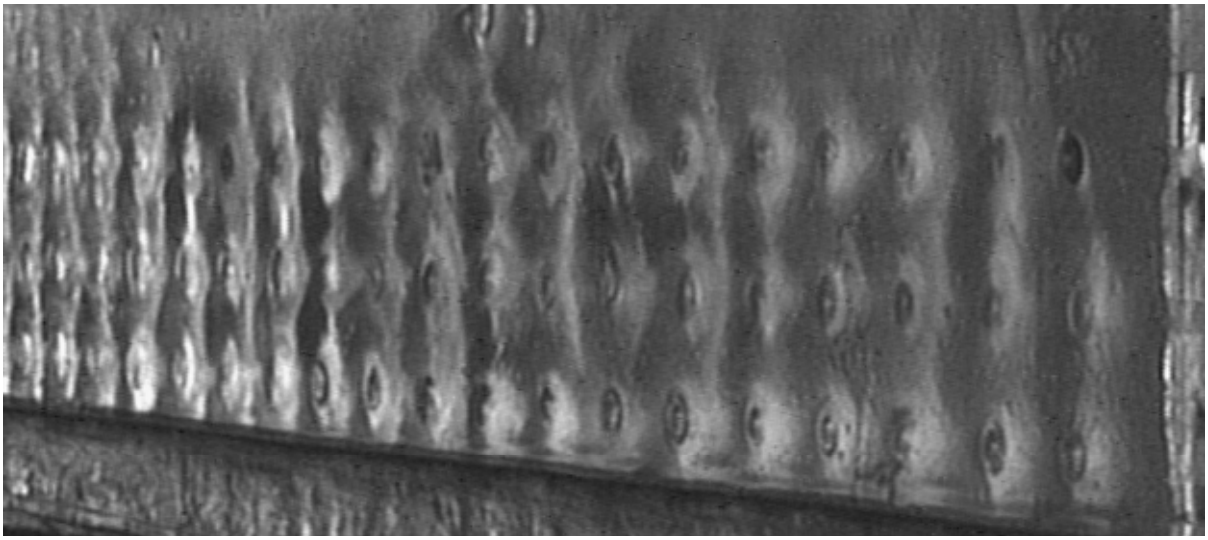
(a) Rivet damage assessment on X-Ray of intact joint.



(b) X-Ray of intact joint (same as 'a').



(c) Replaced rivet (blue circle), fractured rivets (red).



(d) DAIS view of LH end of lap joint (same as 'c').

Figure 27-5: DAIS and X-Ray Images of Left End of Joint (Figure 27-4) Showing Failed Rivets *In Situ*.

In yet another example (not shown), a lap joint with a combined average of only 8.8% thickness loss had 4 failed rivets, and a further 32 of the 48 rivets were cracked. Hence 75% of the fasteners in the lap joint section were distressed.

27.2.2.4 Corrosion Pillowing and Cracked Rivets

Figure 27-6 shows an unpainted longitudinal lap joint. One rivet head in the top row was missing (arrow) and this visible damage contributed to the selection of this joint for study. An automated eddy current scan of the joint was carried out before teardown. Scanning of the entire intact joint required the application of Teflon tape to prevent wear of the eddy current probe. After the scan the tape was peeled off, and this resulted in two additional rivet heads being released (circled). Observation of the parts of these two failed rivets showed that they had cracked and ultimately failed owing to the force created by corrosion pillowing. There was only minor corrosion on the rivet surfaces.

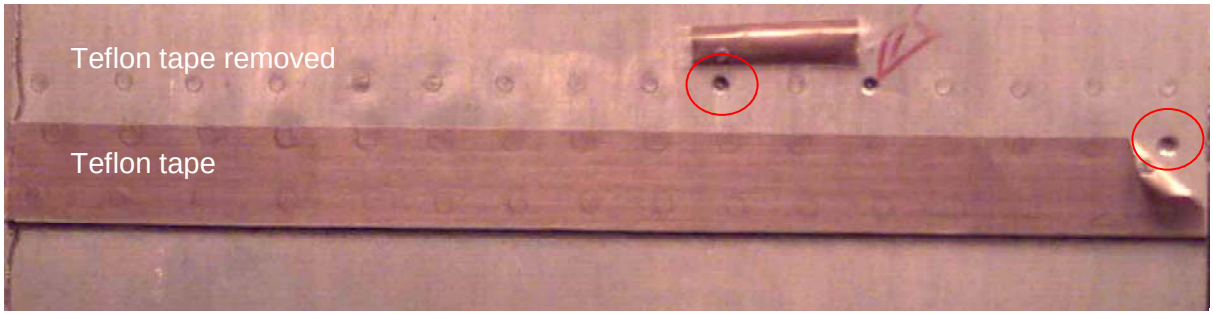


Figure 27-6: Corrosion Pillowing Induced Failure-in-Place of Rivets Discovered by Tape Peel.

During many similar eddy current scans, often on painted joints, there were numerous cases where Teflon tape removal also resulted in the discovery of rivets failed *in situ*. Neither X-ray nor eddy current inspections of the intact joints indicated any difference between undamaged, cracked or failed rivets.

27.2.3 Repair Philosophy

With increased understanding of the fatigue and corrosion behavior of a specific joint design the move can be made from the current “find and fix” philosophy to a “predict and manage” philosophy. Corrosion removal activities must balance the need to remove all detectable damage, blend the excavated area to avoid stress concentrations, permit spliced repair sections and doublers in the space available, not impede drainage, and meet OEM guidelines for minimum thickness allowables.

At times the thickness loss will be found to exceed the minimum thickness allowables and the offending part must be replaced. This is relatively straightforward. However, repair rather than replacement tends to cause the most trouble:

1) Much effort can be expended before it is discovered that the damage exceeds the allowables and the whole part will need to be replaced.

2) The real hazard with trying to save an installed part is the natural tendency to cover the repaired area in sealant, with the thought that this will prevent corrosion from reappearing. What typically happens is that not all the corrosion is removed, and so it starts again. This restart is difficult to determine because the area is totally obscured from visual or instrumented damage inspection. The sealant also forms a barrier to any future effective applications of Corrosion Prevention Compounds (CPC). Any repair must therefore consider that the conditions that led to damage were not unique, and that the repaired area is most likely to see the same environmental conditions

that led to the original damage. Drainage paths must be re-established, not blocked or rerouted, or new problems will occur. Visual and NDI records of the repair should be made for later comparison and assessment of any changes during further service.

3) Drilling out rivets always has the potential to cause elongated fastener holes. Figure 27-7 gives an example where not only were the fastener holes enlarged to the maximum size but they were almost all elongated. In addition, the skin was found to be corroded and the removal process thinned the skin by up to 37% (white areas). In this case it was deemed appropriate to attach a new skin to this damaged skin, match-drilled into the same elongated fastener holes. On the other hand, one might well consider that enlarging the replacement skin sheet size and also shifting the joint to the next stringer on the remaining original sheet should eliminate such a compromised joint.

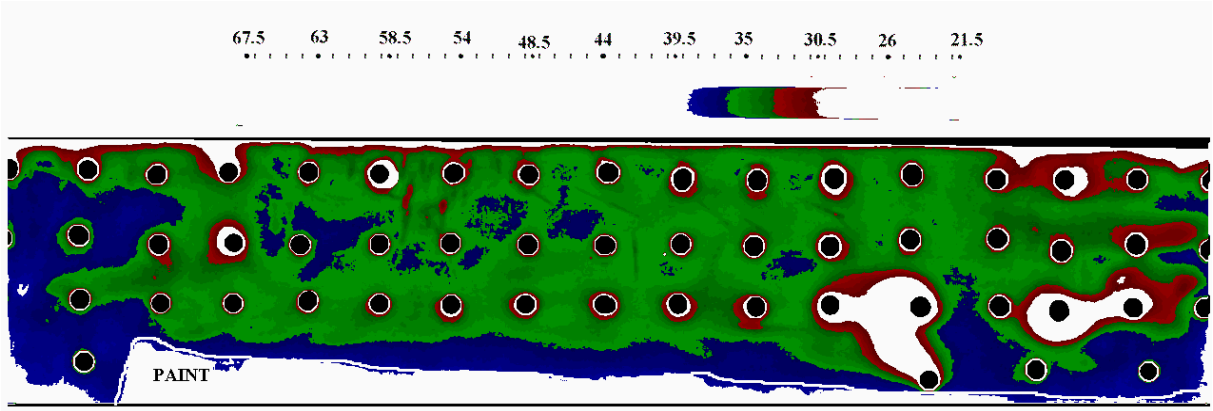


Figure 27-7: Elongated Holes from Rivet Removal and Skin Thinned by Corrosion Removal.

27.2.4 Repair and Repair Problems

Service repair instructions state that corrosion detected between layers in a joint should be removed. This is done mechanically. However, the access to accomplish this task is often limited to de-riveting a short length of joint and wedging the skins apart. This means that the maintenance operator cannot properly observe the clean-up, which will necessarily err on the side of removing too much material, i.e., including sound metal. Besides this conservatism, an incomplete understanding of the corrosion process can lead to using clean-up techniques that actually cause more damage than corrosion removal. Some examples of the problems that occur are given here.

27.2.4.1 Faying Surface Grinding Around Rivet Holes

Because corrosion product build-up permanently deforms the skins of a joint (at 6% thickness loss the forces are sufficient to exceed the yield strength of the skin material), and because of the fastener clamp-up, the deformation will occur away from the fastener holes. This means that the first contact of any corrosion removal process will be with the material closest to the fastener holes.

As shown schematically in Figure 27-8, corrosion product removal by grinding, i.e., with rigid abrasive power tools, can cause serious damage to the faying surfaces. This damage could cause high stress concentrations, increasing the risk of premature cracking. Also, if cracks have *already* initiated at the faying surfaces owing to pillowing forces (as predicted by Finite Element Analysis and found during teardowns) then grinding could smear the cracks closed and obscure them from visual and X-ray inspections. Thus faying surface corrosion products are better removed by chemical cleaning.

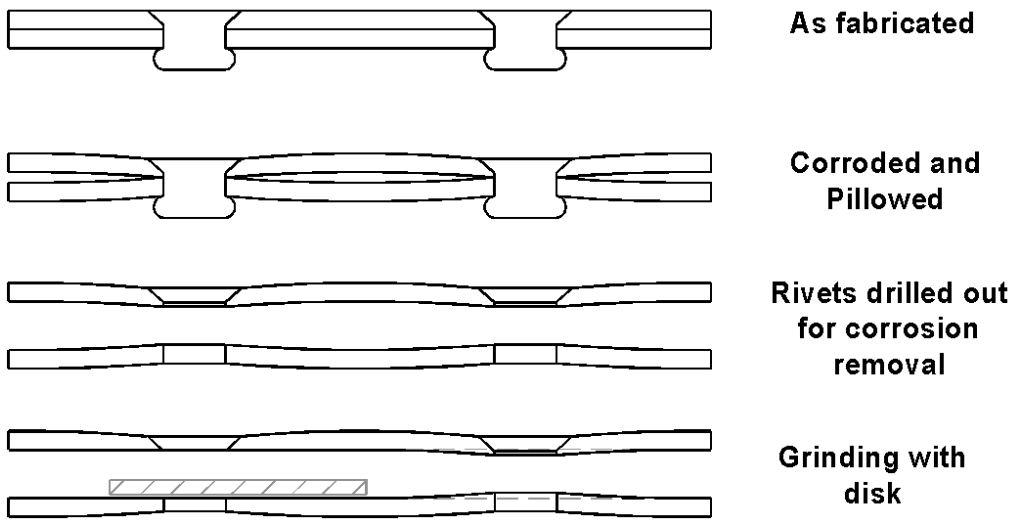
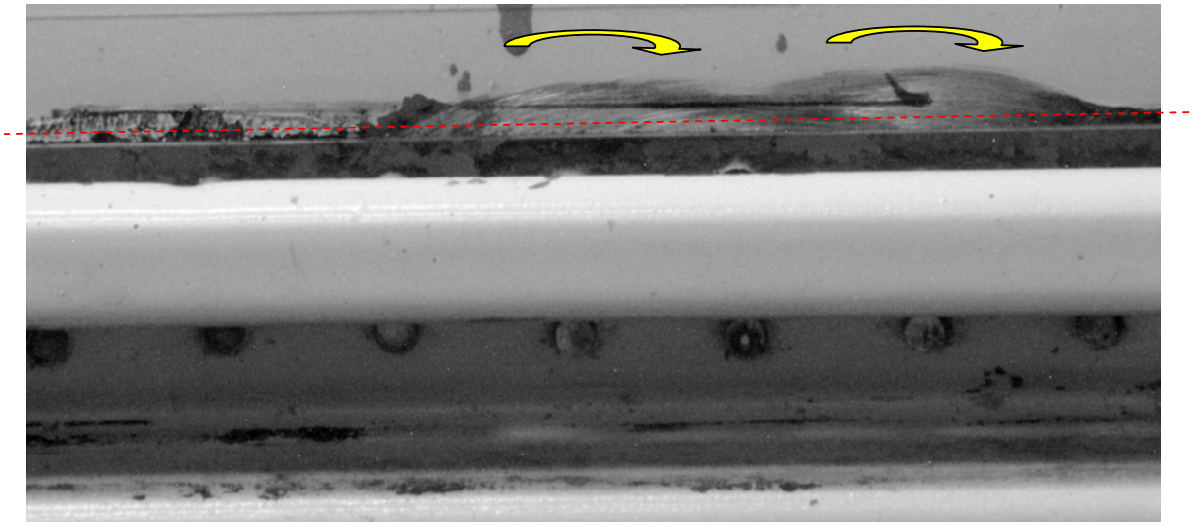
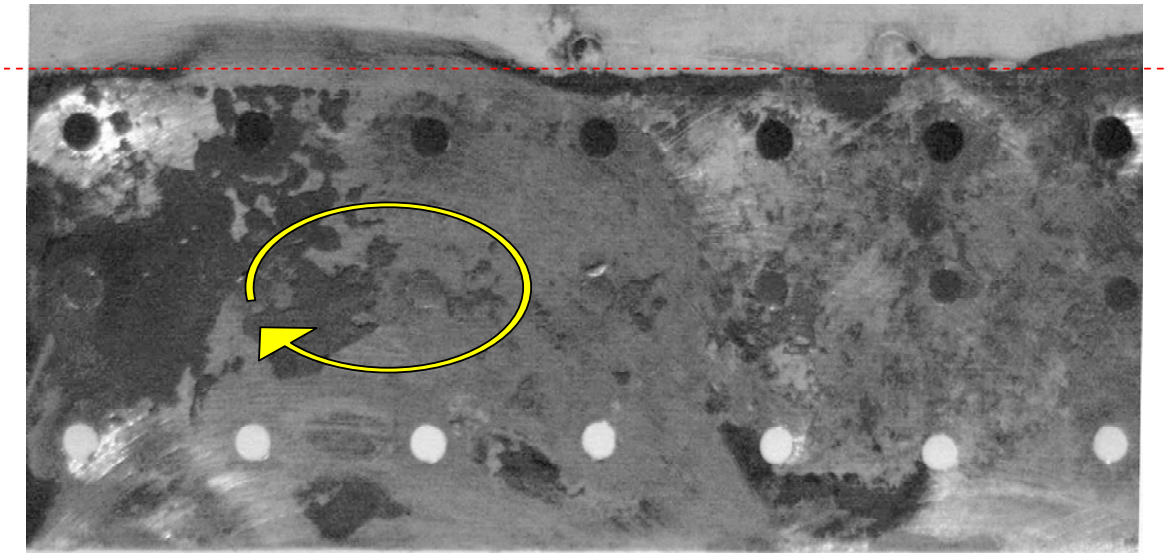


Figure 27-8: Scenario Showing how Grinding Could Remove Excessive Amounts of Material from Around Rivet Holes.

Evidence of the use of a rigid abrasive disc to remove faying surface corrosion is visible extending above the top edge of the inner skin on the inboard surface of the outer skin (red line) of the previously repaired and re-assembled joint shown in Figure 27-9(a).



(a) Rear surface of joint rebuilt after grinding for corrosion removal. Red line – Top of inner skin.



(b) First layer skin, inboard surface, disassembled, showing grinding marks. Red line denotes top of inner skin (removed).

Figure 27-9: Evidence of Grinding on Re-Assembled and Disassembled Joints.

Figure 27-9(b) shows the faying surface of the outer skin from the disassembled joint. The grinding marks indicate that the joint had been previously opened for corrosion removal, and that this was done using a motor driven rigid abrasive disc. The limited access and visibility mentioned above makes it understandable that motor driven discs of a diameter large enough to span the joint might be preferred to manual scraping/ sanding tools. This is despite the fact that there are written warnings that powered grinding operations can generate temperatures sufficient to affect the temper of the aluminum. The only recommended powered corrosion removal tools are rotary files, flap brushes (both impractical in this instance) and *flexible* abrasive discs, see the FAA and Airbus guidelines after Figure 27-10. The point often missed here is 'flexible'. The danger is the unintended damage done as a result of employing non-recommended tools and procedures owing to the difficult accessibility.

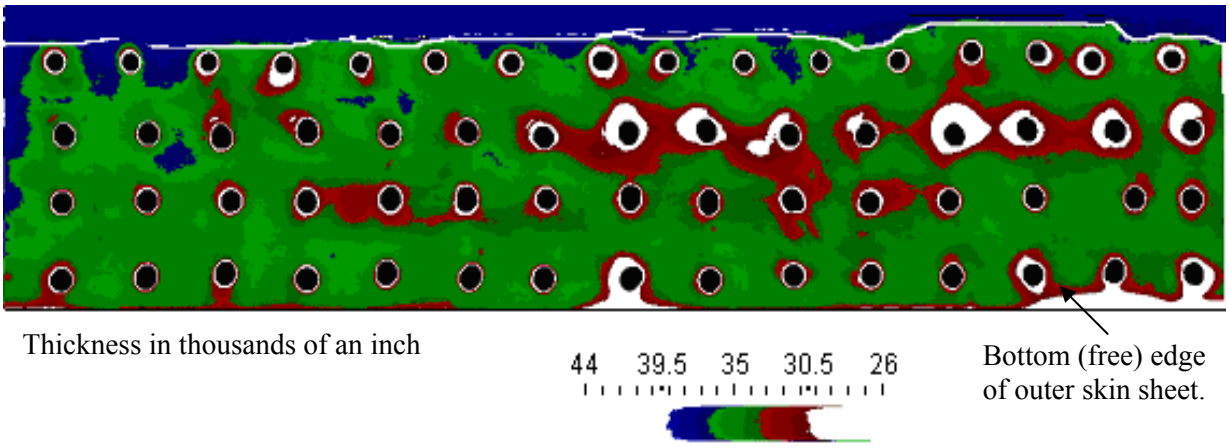


Figure 27-10: Digitized and Colorized X-Ray Thickness Loss Map for Outer Skin.

The selected removal technique, rigid abrasive disc grinding, resulted in significant skin thickness loss and produced knife-edges at fastener holes and at the free edge of the 0.038 inch (0.96 mm) thick sheet. These effects are illustrated by the digitized and false-colored X-ray thickness loss map shown in Figure 27-10: red indicates a range of 20 − 25% loss and white indicates a loss beyond the range of the calibration master. The minimum measured thickness was 0.026 inch (0.66 mm) at the bottom edge, a 34% loss.

27.2.4.2 FAA and Airbus Guidelines for Corrosion Removal

- FAA Advisory Circular AC 43.13-1B Large AC. Acceptable Methods, Techniques, and Practices – Aircraft Inspection and Repair. 9/27/01 Section 6 Corrosion Removal procedures, Pages 6-18:

  "Do not abrade or scratch any surface unless it is an authorized procedure. If surfaces are accidentally scratched, the damage should be assessed and action taken to remove the scratch and treat the area."

- Airbus A-310 STRUCTURAL REPAIR MANUAL Dec 01/97 51-74-10 Corrosion Removal Techniques – General

  1) Abrasion by hand with paper or pads is only suitable for removing light corrosion and finish work after heavy corrosion removal by other means.
  2) Wire bushing by hand or motor driven is acceptable but only with stainless steel or aluminum oxide coated brushes.
  3) Grinding is not suitable for use on aluminum alloys and high temperatures may be generated that may change the mechanical properties of the materials.
  4) Hand held rotary files are the only rigid cutting tool permitted for motorized use to remove heavy corrosion on aluminum structures. Otherwise hand scraping is prescribed.
  5) Abrasive blasting can be used to remove heavy corrosion but it is not recommended for use inside the airframe. The choice of blast media and the number of applications may be restricted.

27.2.4.3 Exterior Grinding

Exterior surface corrosion damage may be exacerbated when addressed with rigid abrasive tools and a lack of appreciation for the damage that can quickly be done. In the case illustrated in Figure 27-11 the effort to remove filiform corrosion damage around rivets succeeded only in grinding the heads off the rivets and thinning the adjacent skin, in some cases completely through the thickness. The minor damage and appearance issues were thus transformed into a completely ruined joint. As with the faying surface

corrosion removal situation, the outer surfaces are pillowed by the internal build up of corrosion products, and attempts to remove exterior surface damage must recognize the danger of removing sound material before the damaged area is cleaned up. Fortunately, this example was seen in an aircraft graveyard, but on the other hand the aircraft must have been flown to get it there.

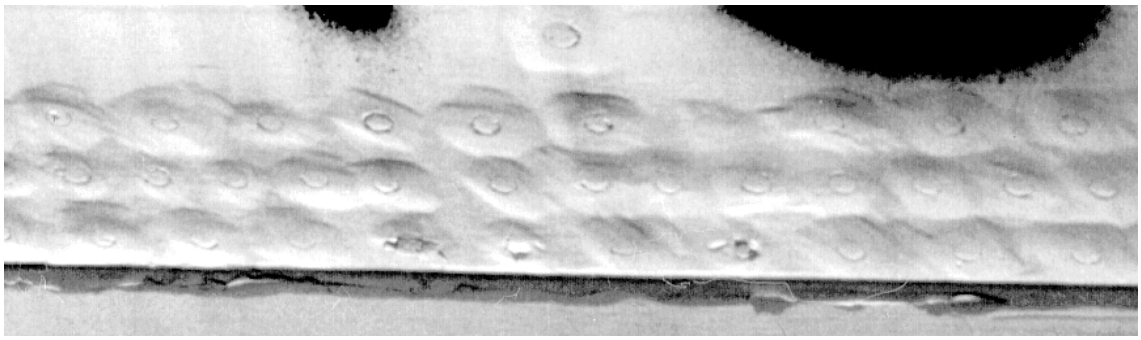


Figure 27-11: Exterior Spot Grinding.

Figure 27-12 shows a DAIS view of another lap joint that was ground externally while also suffering faying surface corrosion with resulting pillowing. The pillowing complicated the grinding action and the DAIS image illustrates the damage and thickness loss to the skin. Not only was the skin thinned, but more importantly the heads of the rivets were also damaged, in this case most notably in the middle rivet row and as shown in a normal view in Figure 27-13. Clearly, either the grinding should be done after the rivets have been removed or the rivets should be replaced after the surface has been ground.

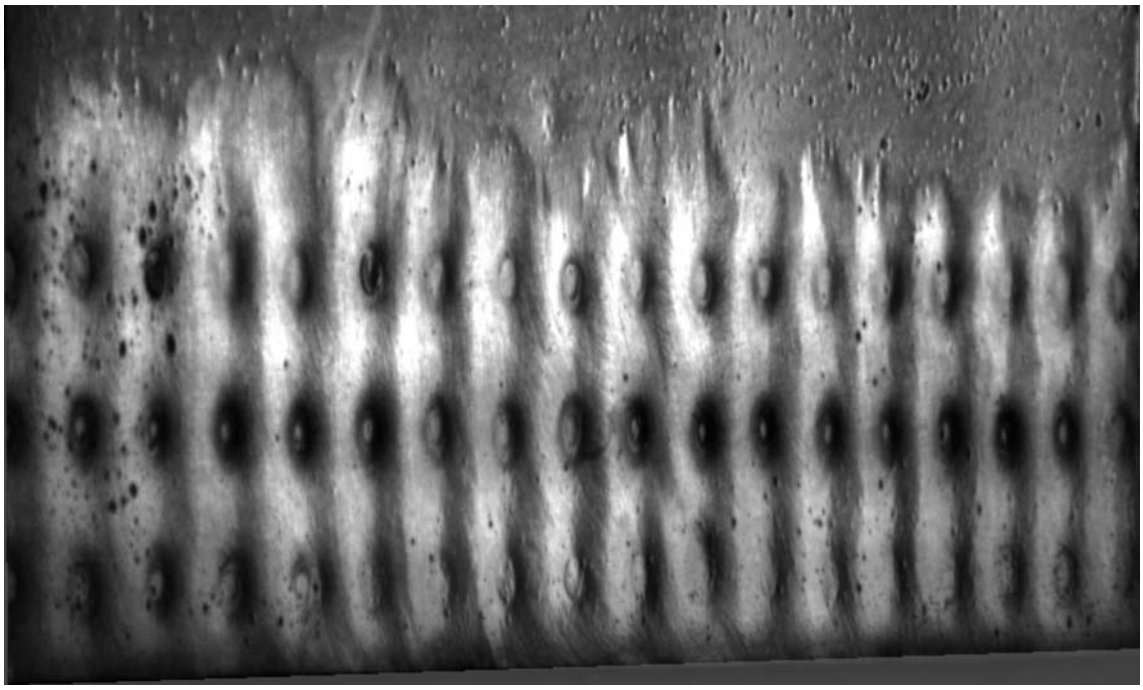


Figure 27-12: DAIS View of Pillowed Skin Suffering Surface Grinding.

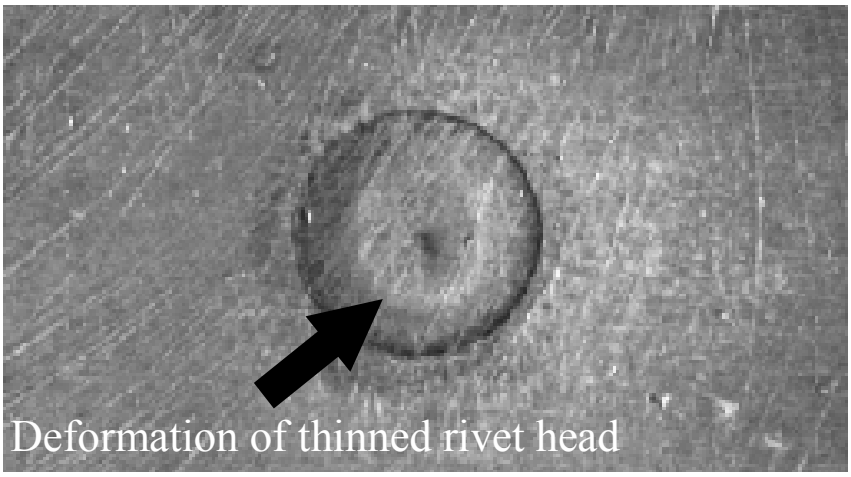


Figure 27-13: Close-Up of Grinding Damage to Rivet Head, Middle Row Rivet, Joint Shown in Figure 27-12.

27.2.4.4 Exfoliation Corrosion Removal

Wing skins machined from rolled aluminum plate tend to suffer exfoliation corrosion at edges such as stepped thickness changes and fastener holes, where the ends of the elongated grains are exposed. Following the inspection of numerous aged aircraft wings it has been noted that exfoliation damage is not always confined to these physical locations. Apart from grain and constituent particle directionality, aluminum alloys are assumed to be more or less homogeneous. However, many cases of exfoliation damage have appeared in areas well away from any fastener holes or machined edges. In two cases (KC-135 and A-300B4) the occurrence could be referred directly back to a common batch of plate material. The alloy must have contained non-uniform inclusions that became active corrosion sites when the protective coating systems degraded in service.

Figure 27-14 gives an example where severe exfoliation corrosion was removed from an upper wing skin plank. Unfortunately, the material removal and blending at two fastener holes (circled) went far beyond the allowed minimum thickness, and this resulted in the entire wing plank having to be replaced.

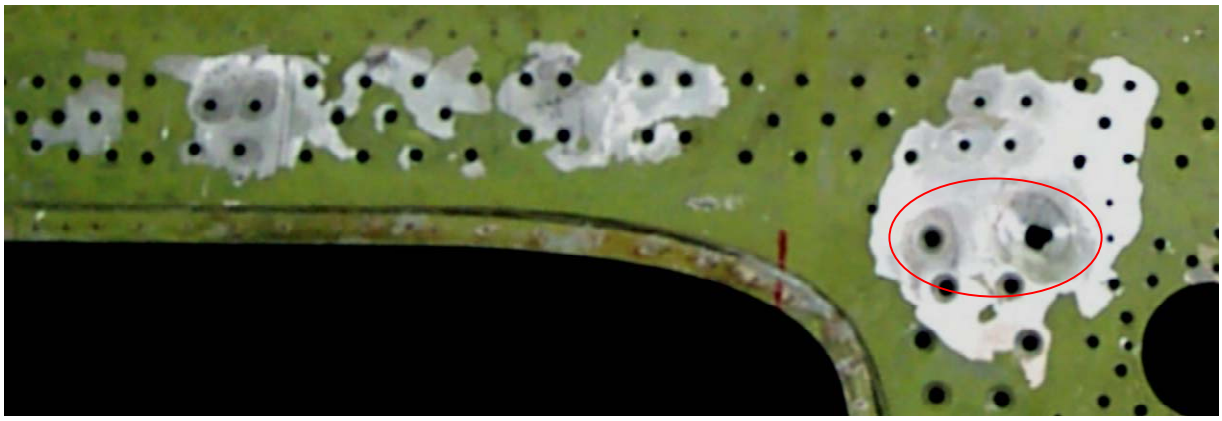


Figure 27-14: Upper Wing Skin with Exfoliation Corrosion Damage at Fastener Holes.

Another example is given in Figure 27-15. At great expense in time and effort almost every fastener site on the upper wing skin has been ground and blended-out to remove the exfoliation corrosion.

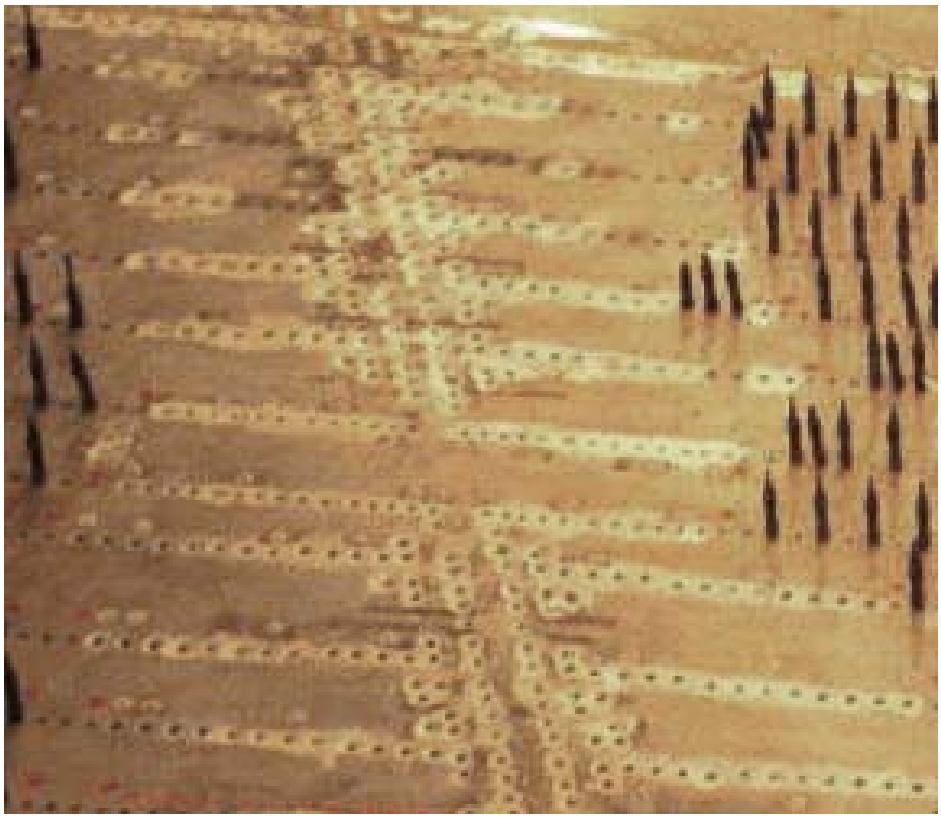


Figure 27-15: Upper Wing Skin with Multiple Sites Ground for Exfoliation Corrosion.

Testing [7] of upper wing skin material with similar levels of damage that has not been re-worked has shown that there is no decrease in load capacity or durability (compression-dominant fatigue). One might consider that more damage may be done to the structure by completely removing this form of corrosion; and that it would be better to surface grind to restore aerodynamic smoothness, followed by re-application of the protective coatings and institution of an NDI monitoring plan. This would probably be sufficient to extend the life of the part without the expense of extensive reworking.

27.2.5 Post-Repair Inspection

It seems often to be assumed that once a repair is done then no further corrosion damage will occur and thus there is no need for a follow-up inspection or monitoring program. Be that as it may, the addition of doublers and sealants to the repair makes inspection and detection more difficult.

Nevertheless, there is great value in repeated inspections specific to the repaired area to confirm corrosion abatement. Part of the above assumption is that the damaged and repaired area has been returned to a ‘zero time’ condition. This is incorrect, since not only has the structure been changed by material removal, fastener replacement, possible reinforcing doublers and the addition of sealants, but the disassembly and reassembly operations are bound to have caused some mechanical deformation. In addition, the stiffness of the repaired area will have changed, and flight loads will therefore affect the structure in ways other than expected.

A major point is to thoroughly document a repair. Yet repairs are rarely documented for their post-repair appearance or NDI response, both of which should serve as baselines for future inspections. Some examples of continuing problems after corrosion repairs are given in the remainder of this sub-section. These problems all involve sealants.

27.2.5.1 Inside Surface Corrosion

Figure 27-16 shows inside surface corrosion of an upper skin from a lap joint. This occurs more often and more severely than one might expect, for reasons given below.

Figure 27-16: View of Surface Corrosion on INBD Side of Upper Skin at Lap Joint.

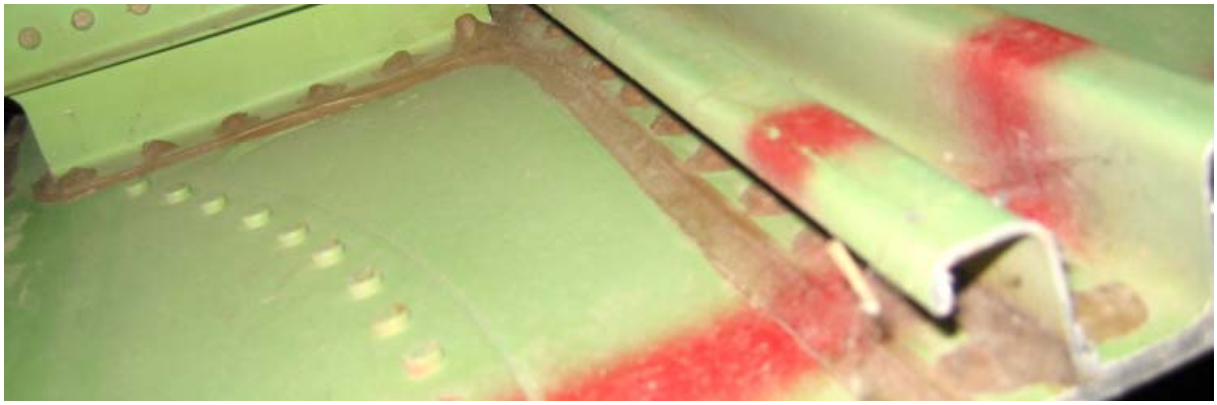
On the outside of the fuselage the lapping of sheets top-over-bottom seems sensible if you are concerned with shedding rainfall. The exterior joint edge is given a bead of sealant to restrict moisture entry, and the integrity of that sealant is easy enough to check and replace. But what about the 'rain' inside? Internal moisture condenses, collects, and runs down the inside of the skin sheets until it hits the ledge formed by the top edge of the inner skin. This edge also receives a bead of sealant but it is only seen on rare occasions, like D Checks, and age plus pressure cycling eventually defeats these edge seals.

If lap joints were oriented the other way (as some lower lobe KC-135 joints are) the moisture running down the inside would not have a ledge to collect on; and if the lower edge of the inner skin is not caulked, then any breakdown in the outer sealant bead and /or faying surface sealant layer would naturally drain (until the easily accessible outer sealant breach is fixed). Alternatively, deleting the outer sealant bead on the lower edge of a standard lap would allow drainage of moisture that has entered the joint.

27.2.5.2 Widespread Inside Corrosion

In response to the heightened awareness of how important corrosion can be for the integrity of ageing aircraft lap joints, some manufacturers mandated a comprehensive sealant program where every internal joint and fastener was potted or received additional sealant. Even the upper and lower edges of the stringer were sealed. This succeeded in only one thing: the moisture that was already in the joint was locked in, and inside corrosion was inevitable. Figure 27-17 is an example: sealants were comprehensively applied to exclude moisture intrusion in an attempt to avoid the development of crevice corrosion. The result was that every section harvested from the fuselage of this retired aircraft suffered corrosion inside the joints.

(a) Lap joint top row fasteners and stringer sealant application.



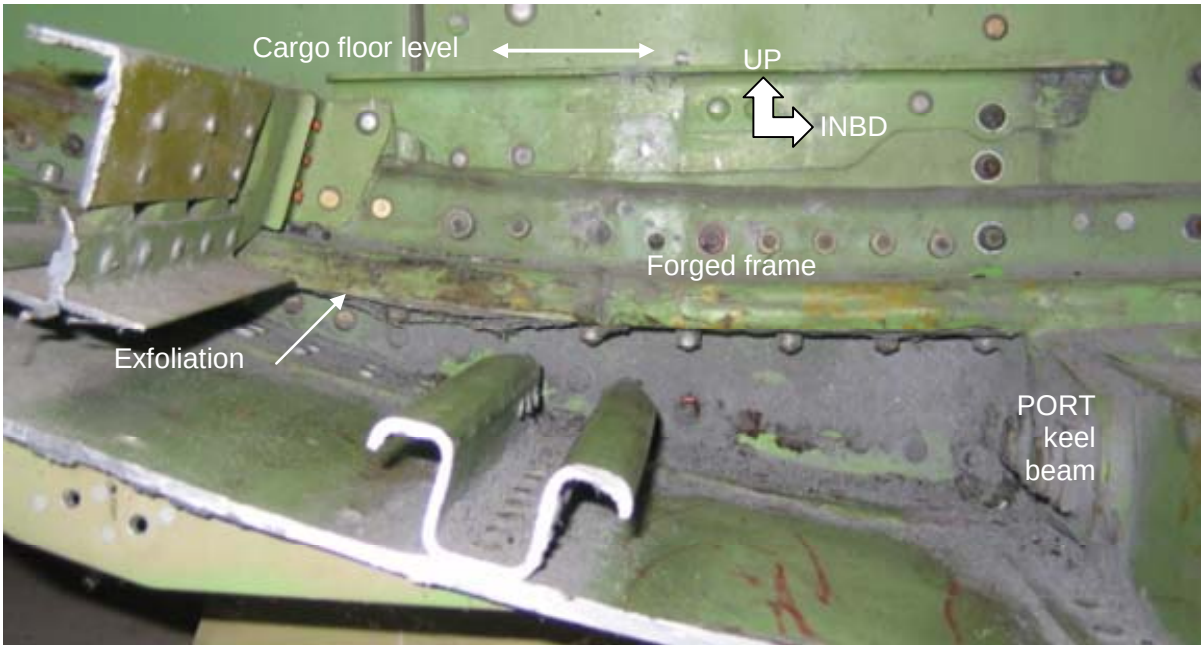
(b) View along lower surface of stringer on lap joint and body station frame attachment.

Figure 27-17: Rivet Shop Head and Stringer Edge Sealant Applications.

27.2.5.3 Exfoliation Corrosion

Figure 27-18(a) is a view of the port side of a bilge area in a fuselage where a heavy forged frame passes close to the bottom. The bottom surface of the frame has begun to exfoliate. This is a difficult location to inspect, since it is under the cargo floor and below the flange of the frame.

Figure 27-18(b) is the view of the starboard side of the frame. As may be inferred, exfoliation corrosion of the frame had been discovered previously, and following (any) remedial actions the frame was liberally covered with sealant. This prevented any later assessment of ongoing corrosion and the integrity of the frame. In fact, the area suffered significant further damage: large pieces of the frame could be pulled out from below, although the sealant was in good condition.



(a) View of area below cargo floor at fuselage frame, PORT.

(b) View of area below cargo floor at fuselage frame, STBD.

Figure 27-18: Views of Exfoliated Frame Treated with Sealant.

27.2.5.4 Other Problems with Sealants

Maintenance procedures for corrosion damage removal end with the requirement that surface protective coatings be re-applied to the cleaned area (wash primer, primer and possibly paint). There is no mention of encasing the area in sealant. Besides the problems illustrated in Figure 27-16 – Figure 27-18, the sealant would also act as a barrier thus preventing any benefit from CPC applications.

On the other hand, a sealant layer is required to be between the inner and outer fuselage skins in order to prevent fretting and achieve pressurization requirements. Care must be taken in applying a thin even layer (recommended 0.02 inch (0.5 mm) thick) otherwise the joined sheets may be deformed by any excess sealant, see Figure 27-19 and Figure 27-20. This deformation will confuse subsequent exterior visual inspections for corrosion pillowing unless the repairs are documented and subsequently referred to before re-inspection.

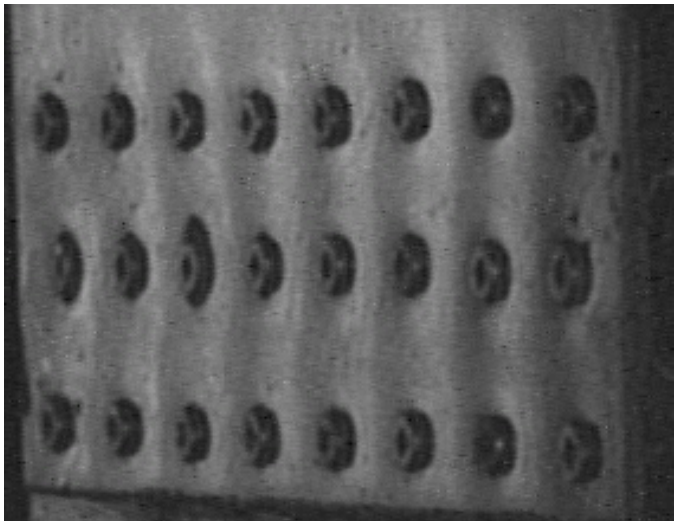


Figure 27-19: Surface Deformations from Excess Sealant in Laboratory Test Lap Joint (Non-Aerospace Fasteners).

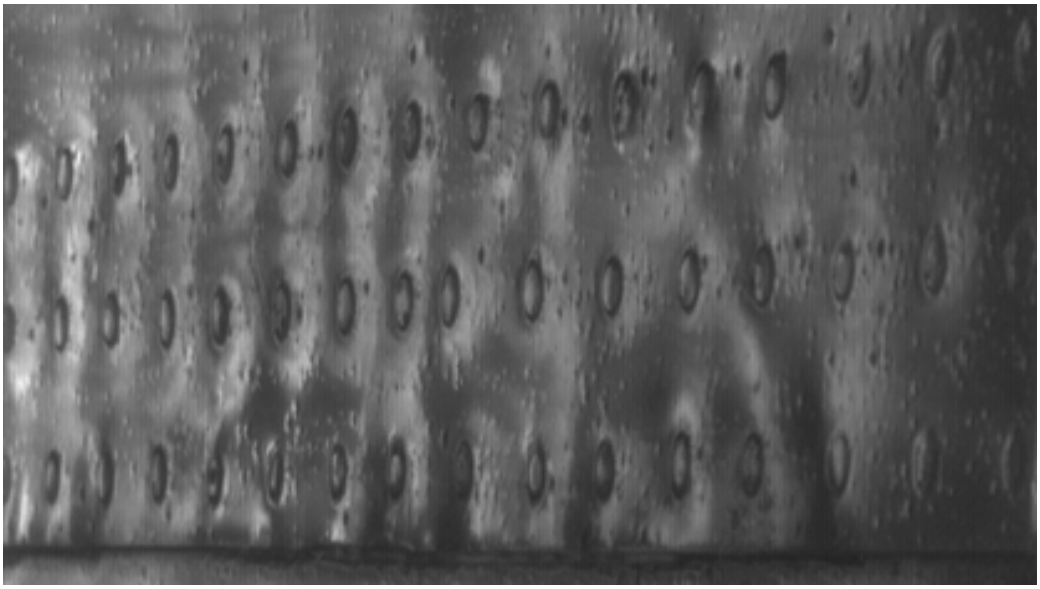


Figure 27-20: Surface Deformations from Excess Sealant in Repaired On-Aircraft Lap Joint.

27.2.6 Issues Related to New Materials and Techniques

Standard practices of material removal and replacement/reinforcement have not changed for many years, but they will have to be modified and augmented owing to the growing acceptance of bonded repairs and the substitution of composites and fiber-metal laminates for traditional patching materials.

Surface preparation is the key to successful and enduring bonding of new surfaces and will be even more of a challenge with corroded surfaces. Composite patch faying surface and edge conditions will have heightened importance because they must remain sealed and galvanically insulated from the metallic substrate.

27.2.6.1 Composite Patching

The Graphite Epoxy (Gr/Ep) framed / aluminum skinned structure shown in Figure 27-21 had the standard glass fiber insulating layer for galvanic corrosion protection. There was also a fillet seal to prevent moisture entering from the outside. However, internal corrosion took place, basically because the edge of the Gr/Ep spar was not sealed, i.e., the glass fiber layer was not wrapped around the trimmed Gr/Ep edge. The corrosion mechanism is as follows: although there was no direct contact between the graphite and aluminum, moisture accumulated internally and bridged between the ends of the graphite fibers and any scratches through the protective coatings on the aluminum skin, thereby completing the electrical circuit.

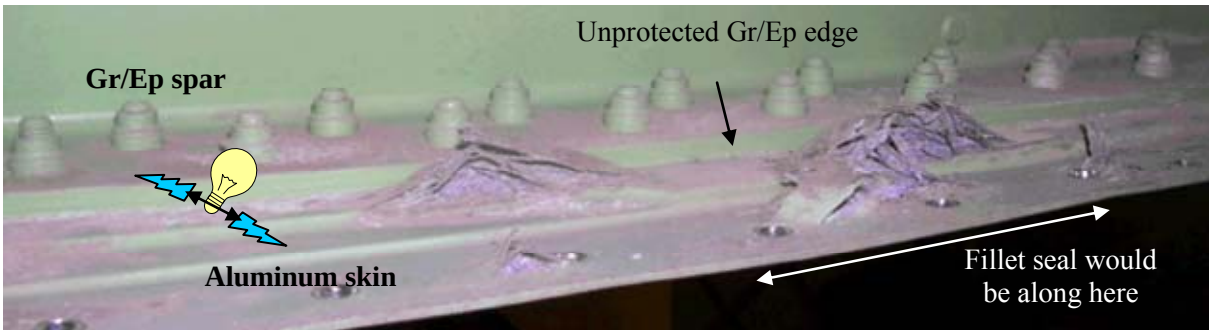


Figure 27-21: Graphite to Aluminum Connection Produces Corrosion.

The lessons are that:

a) Any graphite fiber patch repairs on metallic surfaces would have to be similarly insulated and edge sealed to prevent similar occurrences of corrosion; and

b) Routine inspections would have to include condition assessments of these features of the repairs.

27.2.6.2 Fiber-Metal Laminates

Manufacturers are looking to optimize structural weight. Lighter materials such as Glare® sheet material are being employed as replacements for aluminum sheet. Glare is a fiber-metal laminate, whereby thin sheets of aluminum are bonded to layers of glass fibers with an adhesive. Glare panels can be manufactured to large dimensions, and are used in the Airbus A380.

Glare is considered to be resistant to corrosion because the damage should penetrate only the outer aluminum layer and then stop at the adjacent fiber/epoxy layer. However, once damaged, the outer surface will become an aerodynamic smoothness issue and someone will try to clean this up, also for cosmetic reasons, see Figure 27-22.

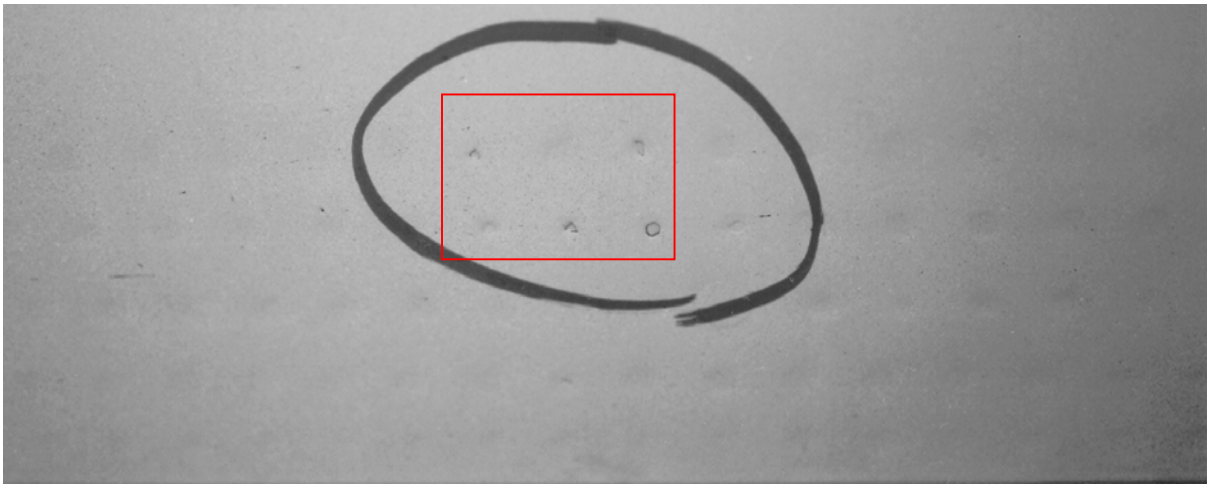
Figure 27-22: Corrosion Damage on Outer Surface of Glare Lap Joint.

Corrosion repair on the outer aluminum surfaces will require great care (no power tools!) because the metal layers are very thin, typically only 0.016 inch (0.4 mm). With such thin aluminum layers there is an increased possibility of damaging the thin fiber/epoxy layer. Epoxies will absorb moisture over time, and if the outer surface is not resealed the adhesive bond will eventually degrade and the next aluminum layer will be corroded. The protective coating systems applied to the surfaces and edges of Glare panels will have to be carefully maintained to prevent corrosion initiation.

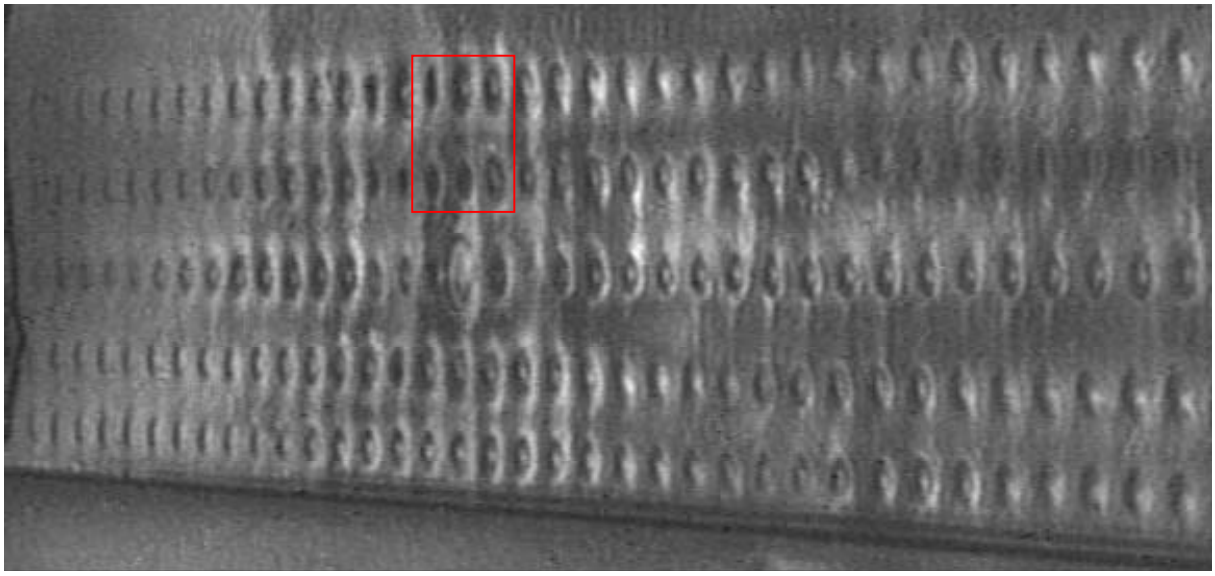
27.2.6.3 Welding

In the past, spot welding has been used (B707, KC-135 and Dassault Falcon jet) to mechanically fasten fuselage structures. Spot welding has a poor reputation – indeed, until recently any kind of welding in aluminum alloy aircraft structures was generally considered less than desirable.

In corrosion situations spot-welded structures fail differently to riveted ones. Owing to pillowing forces, cracks occur in the spot welds and grow towards the surface. The corroded and cracked areas may not be easily visible, even with enhanced techniques such as DAIS, Figure 27-23(b), until the cracks have reached the surface and gone on to crack the paint, see Figure 27-23(a). Dye penetrant or magnetic particle inspections are required to detect the surface-breaking cracks in their early stages. Besides corrosion clean-up, if feasible and necessary, repairs are made by drilling out the cracked spot welds and installing rivets.



(a) Normal view. Cracked paint aids visual detection.



(b) DAIS view shows only subtle difference between normal deformation and corrosion pillowing.

Figure 27-23: Corroded KC-135 Spot Welded Lap Joint with 4 Fractured Welds (Inside Red Boxes).

27.2.6.4 Friction-Stir Welding (FSW)

FSW is beginning to replace traditional mechanically fastened constructions especially for fuselage stringers. FSW will enable significant reduction in aircraft assembly time and may replace the installation of thousands of rivets. As an example; the use of FSW will replace 60% of the rivets that would have been required on major assemblies of the Eclipse 500 jet including the cabin, aft fuselage, wings and engine mounts.

Figure 27-24 shows a development FSW stringer to skin joint. Unlike a riveted joint FSW joining cannot tolerate traditional protective coatings already being in place. Any coatings and sealants will have to be applied to the skin, stringer and joint edges after the weld is formed. By incorporating intermittent non-welded areas the joint would allow the egress of any moisture that accumulated between the stringer and skin.

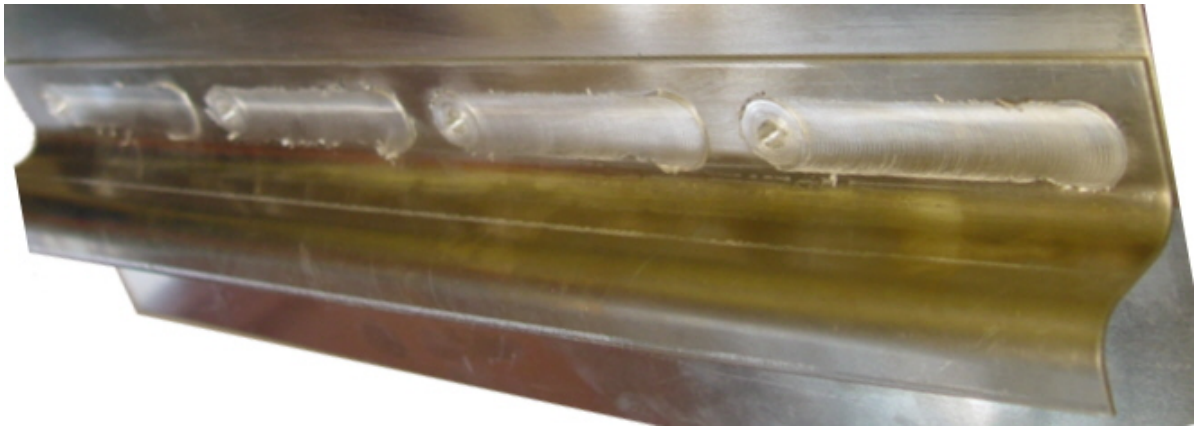
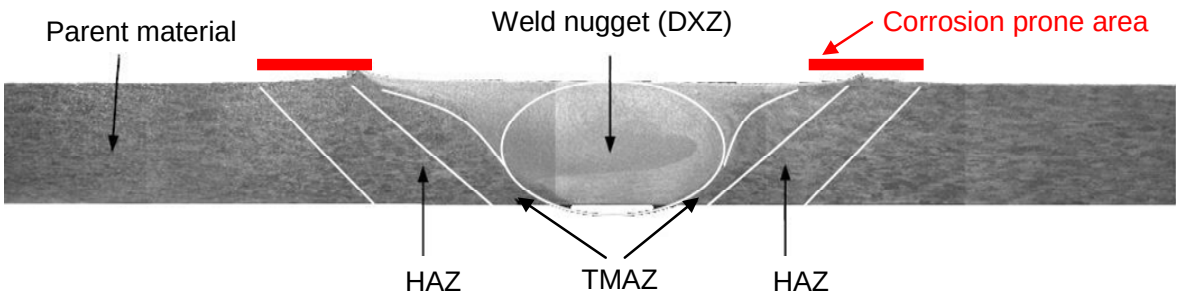


Figure 27-24: Friction Stir Welded Stringer and Skin.

A friction-stir weld is typically characterized as being comprised of three primary zones: the Heat-Affected Zone (HAZ), the Thermomechanically Affected Zone (TMAZ), and the Dynamically Recrystallised Zone (DXZ) or weld nugget. Tensile failure in transverse tensile tests most often occurs within the HAZ or the section between the HAZ and the TMAZ. Due to the change in precipitate morphology, this region is also generally susceptible to corrosion (red lines in Figure 27-25). One way to potentially improve the resulting corrosion properties is through post-weld heat ageing treatments. Another would be to coat the susceptible surface area with another, more resistant, alloy.



(a) Cross section through joint identifying regions of the weld zone.

(b) Outer surface showing exfoliation corrosion (ASTM G-34).

Figure 27-25: FSW Joint Structure and Corrosion Damage.

The main concerns that will require additional study and testing of FSW are currently related to corrosion properties, damage tolerance properties (fracture toughness), residual stresses and the long-term stability of the joints. With respect to corrosion maintenance, simply grinding to remove the corrosion will not end

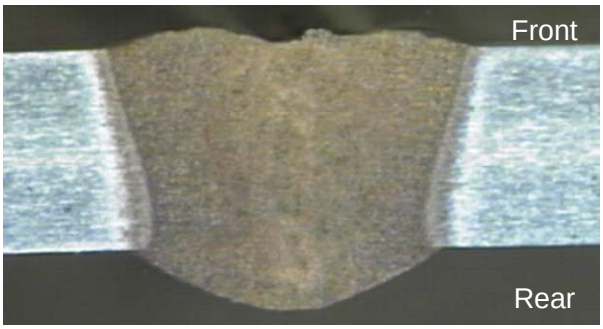
the problem. As mentioned above, it may be possible to improve the corrosion resistance of susceptible areas by re-ageing or coating following corrosion removal, although it would obviously be better and easier to use these options on new structure. On-aircraft repairs will have to be done using riveted aluminum patches, since field repair FSW will not be possible.

27.2.6.5 Laser Welding

A development laser welded skin butt joint of two equal thickness sheets is shown in Figure 27-26.

(a) Front surface.

(b) Rear surface.



(c) Cross-section.

Figure 27-26: Laser Welded Skin Butt Joint.

Laser welding may eliminate lap joints by enabling butt welds. As with FSW, there may corrosion-prone areas adjacent to the laser weld, owing to microstructural differences relative to the parent material. The welds are quite narrow, and early detection of corrosion and fatigue damage will therefore require the use of sophisticated inspection equipment. Repairs will have to be done using riveted aluminum patches, since field repair laser welding will not be possible.

27.3 CORROSION TEARDOWN METHODS

A teardown is complete disassembly of a structure in a controlled, stepwise manner that allows detailed intermittent inspections. It is necessary to know and understand the steps to be followed, and also the most

suitable inspection techniques, in order to obtain the desired information before it is lost or destroyed by the disassembly process. The real value of a technically rigorous teardown is to validate the Non-Destructive Inspections (NDI) and to provide information to aid in residual strength assessment. Sample selection for teardowns requires knowledge of the problem areas and can be aided by the damage history. Much of this information can be acquired from surveying the "Service Difficulty Reports, Notice of Proposed Rule Making and Airworthiness Directives". These can also be useful in planning the teardowns and inspections of candidate structures. In addition, some information for sample selection may be obtainable from maintenance records, if available.

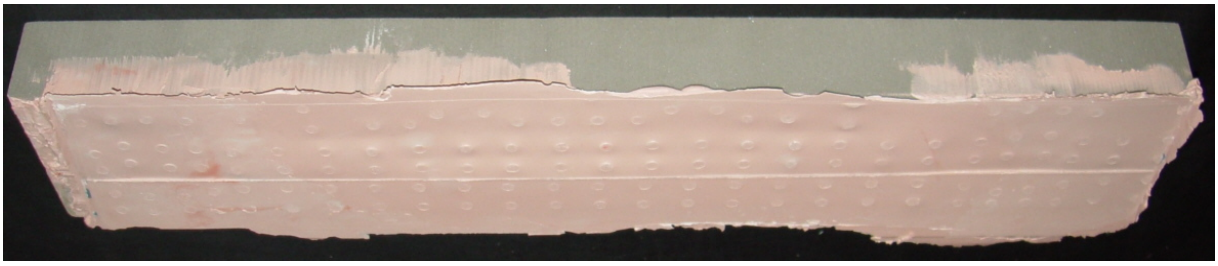
Once samples have been selected, removing them from the overall structure without additional (mechanical) damage requires suitable support equipment and skilled operators.

27.3.1 Pre-Teardown

27.3.1.1 Initial Assessment and Records

Typical means of documenting the condition of a structure are photographic records and written descriptions from initial close visual inspections. Recent advances in the precision and portability of 3-D laser measuring systems indicate their potential to quickly add metrics to the documentation, thereby enabling virtual replicas of the sample surfaces.

Physical replicas of the entire sample surfaces are impractical, and measurement data would still have to be collected. Hence surface replication is done on a smaller scale, for example parts of lap joints. Both rigid and flexible (but dimensionally stable) replicas can be, and have been, made. These provide surface topography records, e.g., Figure 27-27, which are available for investigation after teardown. For example, after disassembly it might be found useful to relate corrosion-induced pillowing (a surface topography effect) directly to internal corrosion product accumulation and any permanent deformation of the skin material.

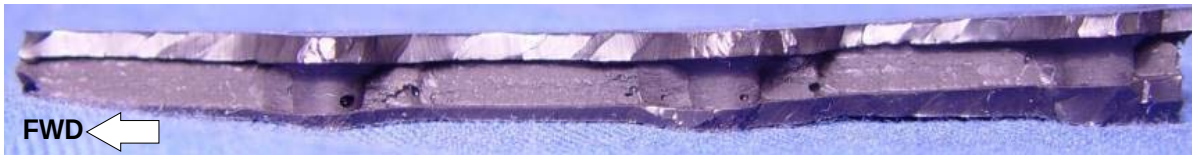


(a) Surface replica of joint discussed in Post Teardown (Figure 27-38 – Figure 27-40).

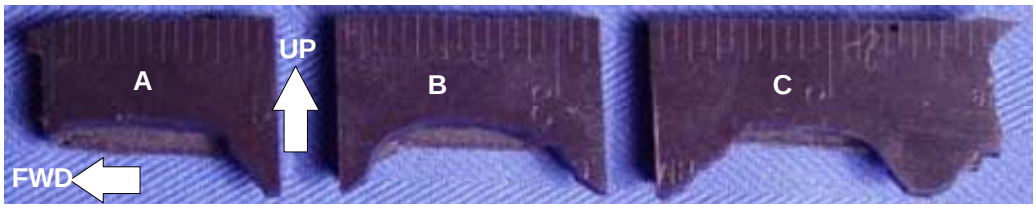
(b) Replica of a replica recreates surface for further analysis.

Figure 27-27: Replicas on Rigid Foam Backing of Damaged Fuselage Joints.

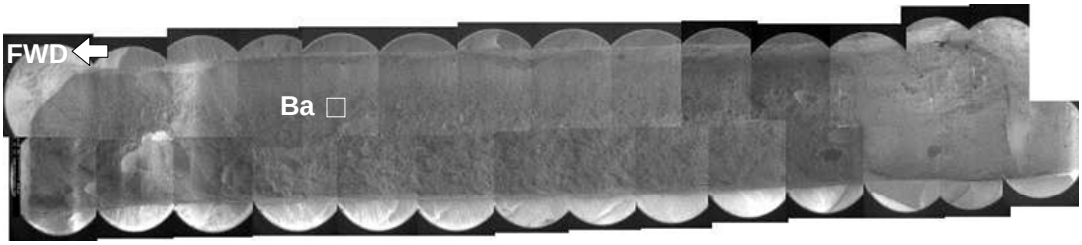
Some samples may have accessible fracture surfaces before teardown. In such cases replicas of the fracture surfaces can be made, or indeed have to be made, since sometimes it is not allowed to cut out and examine the originals if they are part of an accident investigation. Also, using replicas for detailed investigation avoids sectioning and mounting the originals for Optical and Scanning Electron Microscope (SEM) fractography. Depending on the results, which might be compromised by resolution limitations and artifacts from the replication process, one can still decide to examine the original fracture surfaces. (This will obviously be necessary if metallographic cross-sections are required.) Figure 27-28 provides an example of a fracture surface replica, its sectioning for SEM investigation, and details from this investigation.



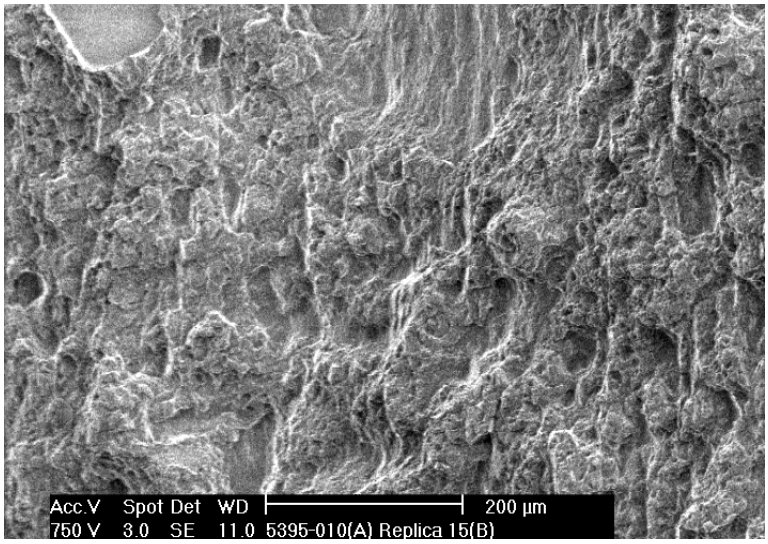
(a) Side view of replica from a fractured skin edge showing fracture surface.



(b) Skin fracture replica sectioned to fit into SEM.



(c) SEM image montage for replica section B. Note selected site Ba.



(d) SEM image of fracture surface at site Ba from failed fuselage skin replica B.

Figure 27-28: Fracture Surface Replica Analysis.

27.3.1.2 Paint and Sealant Removal

Paint and primer systems are removed either by chemical or mechanical means. Chemical strippers have been reformulated to make them more environmentally friendly. In some cases this results in lower effectiveness and increased time and effort to completely remove coatings, especially if they are multi-layered.

Dry particle blast stripping systems have advantages with respect to environmental and health considerations, and also layer by layer removal control. They are typically restricted on metallic materials to sheet greater than 0.032 inch thick (0.8 mm) and must be closely monitored. Repeat applications may be restricted to exclude damaging the surface. Sealants may mask corrosion damage and their presence will interfere with NDI inspections. Sealants are best removed by a combination of mechanical and chemical stripping. After most of the sealant has been removed mechanically, the remainder is removed by chemical softening and final mechanical removal with non-marring tools. Air-assisted hand tools have been developed to expedite bulk and final mechanical removal without damaging the substrate. These tools are especially useful for stripping sealants from inside wing fuel tanks.

27.3.1.3 Alloys and Coatings

A small sample of metallic material may be excised and used to verify the alloy and determine the presence of a protective coating (oxide or metal). This sample may also show whether the coating has deteriorated owing to mechanical damage caused by polishing or previous paint system removal.

There may be issues regarding the protective coatings on rivets, depending on their manufacture and age. For example, Alodine coated rivets have sometimes been chosen instead of anodized rivets, owing to improved electrical contact during lightning strikes. However, Alodine coatings have given paint adhesion problems ("rivet rash"). They have also been implicated in degrading NDI, specifically the reliability of sliding probe Eddy Current (EC) inspection for cracks at fastener holes [7],[8],[9]. This is because the conductivity of Alodine coated rivets could be sufficient to mask some cracks. In the light of these issues it may be prudent, during teardown, to remove some rivets with the additional goal of determining the type of coating used, since rivet types may have been mixed due to repair actions.

Corrosion Prevention Compounds (CPCs) are applied internally to large areas of ageing aircraft structures. Inspections cannot be completed with these coatings in place because they accumulate dirt and debris and obscure direct viewing of the surfaces. These will often have had multiple applications of CPCs, which bind the dirt and debris in place, and the CPCs become increasingly difficult to remove as they harden with age. Another disadvantage is that the dirt-collecting nature of CPCs discolors white-painted bilges, see Figure 27-29. This discoloration reduces the visibility of corroded areas.

(a) White paint over primer (corrosion circled).

(b) White paint coated with CPC.

Figure 27-29: Bilge Areas Below Cargo Floor (Floor Panels and Insulation Blankets Removed).

27.3.1.4 Non-Destructive Inspection

Whenever possible, reference standards for setting up and calibrating NDI techniques are made using the same alloys and material thicknesses as those in the structures to be inspected. However, this is not necessarily sufficient. A typical example is the mechanical removal of material to simulate thickness losses owing to corrosion of one or more layers of a built-up structure. Machining cannot represent the rough topography of a corrosion-damaged surface, and this may lead to difficulties in the detection and quantification of damage to the specimen. Ideally, reference standards should be developed with surface topography representative of corrosion damage and also with the inclusion of corrosion products and associated pillowing or exfoliation, if present in the specimen. This is no easy task, however.

NDI techniques are selected for their applicability to the materials and structures involved and the suspected damage. In contrast to the spot inspections made in the field on operational aircraft, samples subject to complete teardown can be inspected using automated scanning systems to produce complete Eddy Current (EC), Ultrasonic (UT) or similar maps of the parts or areas of interest. In addition, the samples can be inspected with new techniques, to aid in their development and add the results to the NDI knowledge base.

Enhanced optical systems can provide increased sensitivity for damage assessment (2 – 3 % thickness loss) and act as a control for the traditionally manual visual inspection process. For example, laser topographical mapping can quickly capture the surface deformations and, if the entire part is scanned, produce accurate 3-D models.

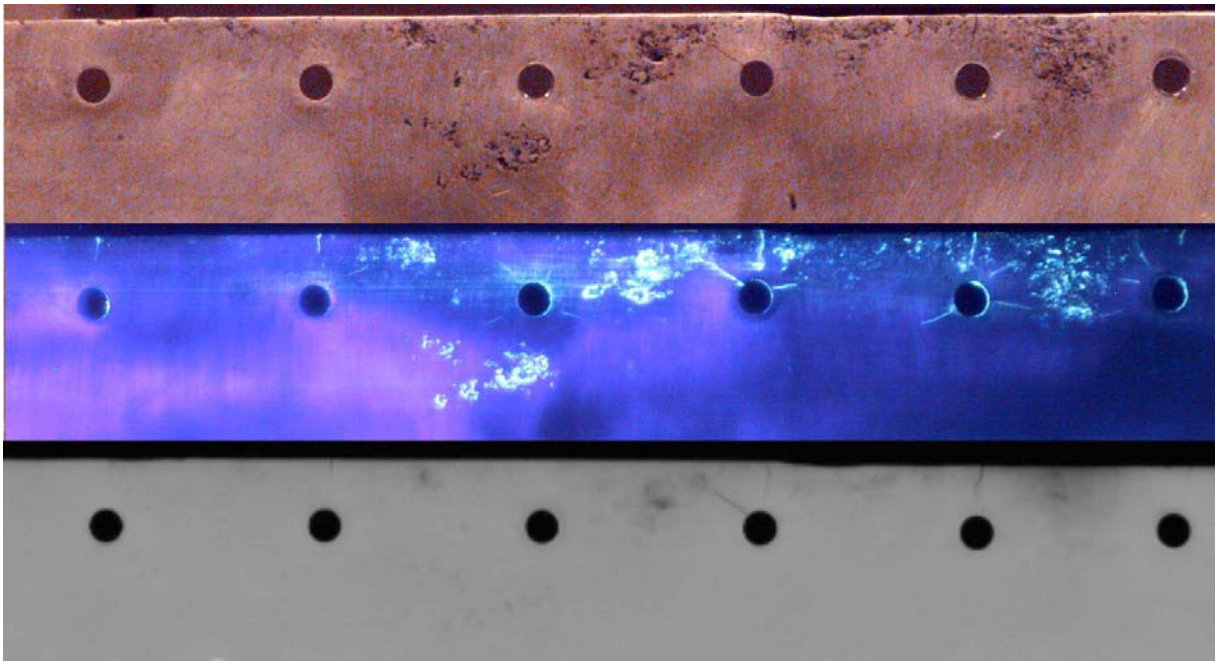
Eddy current techniques should be tolerant of air gaps when applied to multi-layer structures with suspected corrosion damage. Frequency mixing is one technique that removes the effects of any spaces between layers.

Through-transmission UT C-scan inspection can be used if samples can tolerate immersion or if a couplant squirter system is available. This technique is used primarily on wing skin samples to determine the exfoliation corrosion damage area and depth. If a sample comes from a wet wing design, the internal sealant must be removed because it attenuates the signal and may mask any corrosion damage.

X-ray inspection is not typically used for corrosion detection. However, the pillowing forces generated by corrosion in multi-layer structures may lead to tensile forces sufficient to nucleate cracks, and these can be detectable by X-rays. Both fatigue and stress corrosion cracks can occur in some structures, so more detailed investigation (part of the teardown) is often needed.

Dye penetrant inspections for cracks are affected by the presence of paint systems and sealants. Although dye penetrant is often used on in-service components and structures, the paint systems and sealants on samples must be removed. However, mechanical removal of surface corrosion products should be avoided, since the cracks may become obscured by being partially filled-in.

Figure 27-30 is an illustration of crack detection in a chemically cleaned corroded skin that contained pillowing cracks. These cracks were small and non-surface-breaking, i.e., they did not reach the outer surface of the skin. Careful disassembly and cleaning allowed these small cracks to be detected, notably by dye penetrant. Mechanical removal of corrosion products would probably have reduced the number of cracks detected by this technique.



Top: Optical, Middle: Dye penetrant, Bottom: X-ray.

Figure 27-30: Three Views of Inner Surface of a Chemically Cleaned Corroded Skin Exhibiting Pillowing Cracks.

Non-surface-breaking cracks like those illustrated in Figure 27-30 have been predicted by Finite Element Modeling (FEM) of fuselage joint designs. These radiating cracks are caused by tensile forces induced in

the skin faying surfaces when sufficient corrosion products build up between them, causing pillowing. The cracks initiate outside the fastener holes and then grow both towards and away from the holes.

27.3.2 Teardown

As stated at the beginning of this section, a teardown is disassembly in a controlled, stepwise manner. Before disassembly all measurements, documentation and non-destructive inspections that depend on, or benefit from, intact specimens should have been carried out. It is necessary to know and understand the disassembly steps to be followed, and also the most suitable inspection techniques, in order to obtain the desired information before it is lost or destroyed by the ongoing disassembly process.

27.3.2.1 Fasteners

Teardown begins with the careful removal of fasteners and visually examining their condition before and after cleaning. This can provide very useful information, because damaged fasteners on an aircraft are usually noticed only when they are severely corroded or have fallen out. Furthermore, in-service replacement typically results in damaged fasteners being destroyed by drilling out (rivets) or being discarded after disassembly (nuts and bolts).

The condition and integrity of mechanical fasteners deserves more attention. Corrosion or fretting damage on rivets, bolts and nuts controls and directs their replacement, but the source of their degradation should also be sought. For example, rivets have been found that at first sight showed corrosion on their surfaces, but with the corrosion cleaned off they were seen to have cracking problems as well, see Figure 27-31. This damage was detected only because the prescribed teardown required the upset heads to be machined off and the rivets pressed out instead of being drilled out.

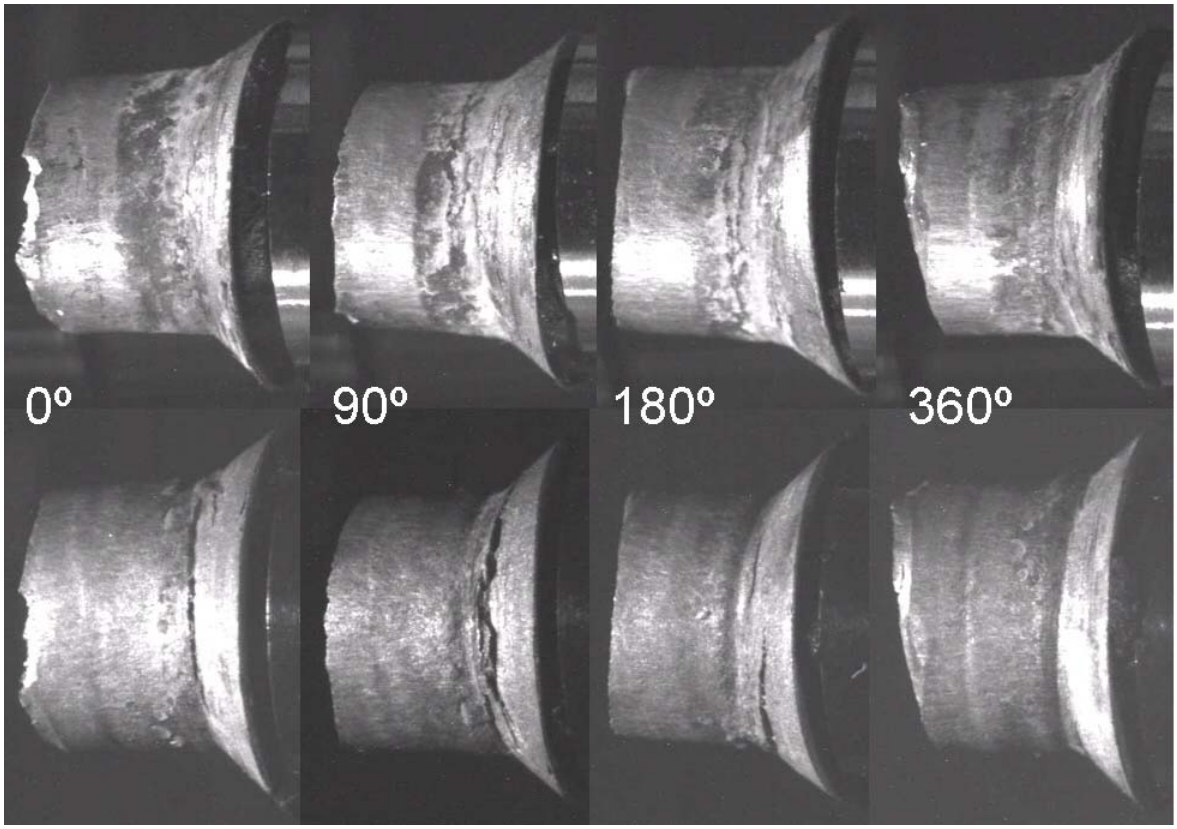


Figure 27-31: Corrosion Pillowing Induced Cracks in a Rivet (Top: As removed; Bottom: Cleaned).

27.3.2.2 Adhesives and Sealants

Structural adhesives or gap-filling sealants are often applied to the faying surfaces of fuselage skin joints. Disassembly requires care since the parts may be damaged and deformed by the tools and forces needed to wedge the layers apart. All traces of the adhesives or sealants must be removed before the exposed surfaces can be examined for damage. This removal is best accomplished by mechanically removing the bulk of the material followed by chemical dissolution and final removal with non-marring tools, as mentioned earlier. Mechanical actions that might contact the surfaces should be avoided to prevent metal smearing and obscuring any cracks from detection.

27.3.2.3 Corrosion Removal

In a teardown for corrosion damage the steps are:

a) Document the total thickness loss in the structural sample;

b) Validate the results of NDI techniques; and

c) Prepare the remaining base material for detailed analysis (coupon selection and removal).

The method of corrosion product removal should be chosen to ensure that no additional damage is done to the structure. This is especially true if cracks are to remain undisturbed. It has been proven that corrosion product removal by chemical dissolution is greatly assisted by ultrasonic vibration in an immersion tank, for example Figure 27-32.

Ultra Kleen is a mild cleaning solution designed for cleaning corrosion products off aluminum. The solution has the following composition:

$4\ (CH_3)_3COH + 3\ C_3H_8O_3 + H_3PO_4 + 2\ H_2O$

Figure 27-32: Ultrasonic Immersion Corrosion Cleaning Tank.

Rather than filling the tank with the chemical cleaning solution, the samples are placed in solution-filled bags which are then suspended in water in the tank. This minimizes the amount of cleaning solution required. Various chemical solutions can be used. To verify the selected chemical removal process, long exposure tests are required to demonstrate that no damage is done to the remaining base material, see Figure 27-33.

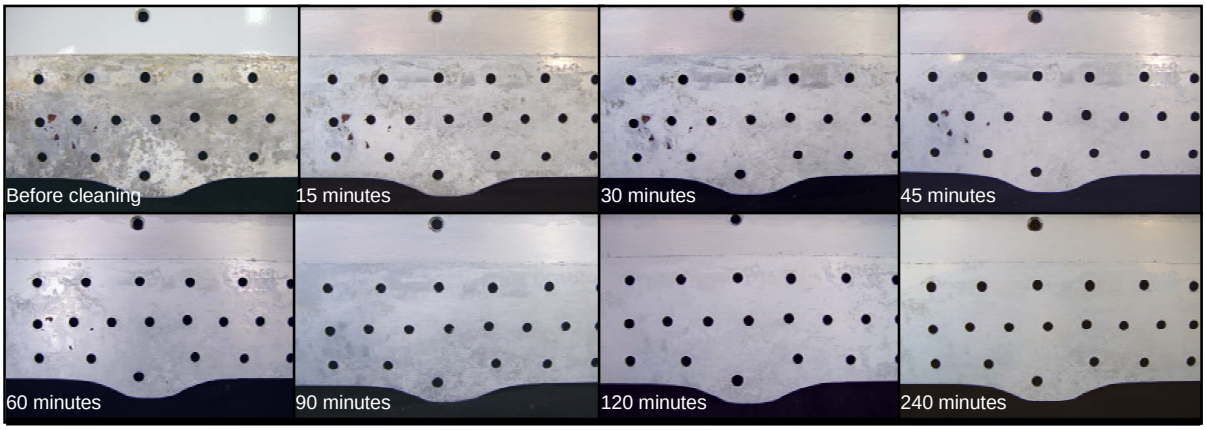


Figure 27-33: Views of Skin Surface Before and During Long Exposure Chemical/Ultrasonic Corrosion Cleaning for Corrosion Removal.

27.3.2.4 Thickness Loss

Figure 27-34 is an example of corrosion-induced pillowing from the teardown investigation of a lap joint outer skin. The pillowing was made visible by the D Sight Aircraft Inspection System (DAIS) [10], which enables enhanced visual inspections of intact joints. It was known that the joint had undergone maintenance because of corrosion. This maintenance had included removing the original flush-head rivets and re-installing with protruding-head rivets.

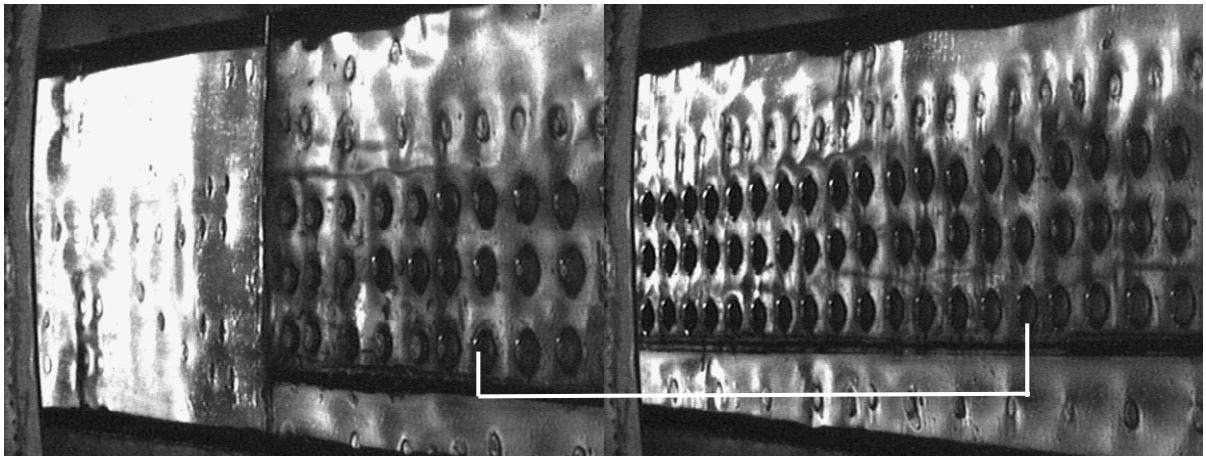


Figure 27-34: DAIS Lap Inspections on the Intact Joint (White Line Shows Specimen in Figure 27-35).

The protruding-head rivets made it impossible to inspect the intact joint by eddy current NDI. Consequently the rivets were drilled out to separate the outer and inner skins. Figure 27-35 shows the rear surface of the outer skin. The black and gray areas are the remains of faying surface sealant from the prior maintenance, which had also included applying a primer. Significantly, there was no visual evidence of corrosion at the time of the teardown. This means that the pillowing observed in the DAIS inspection, Figure 27-34, was due to corrosion product accumulation up until the maintenance action, and that the subsequent visible persistence of pillowing was due to permanent deformation of the skin.

Figure 27-35: Rear Surface of Outer Skin.

The outer skin inner surface shown in Figure 27-35 was cleaned chemically to remove the sealant and primer. This was followed by X-radiography that included a ramped master calibration tool to enable thickness measurements. The NRC/IAR NDI Analysis™ software was used to obtain the calibration and skin thickness measurements from the digitized image file of the X-ray film, Figure 27-36.

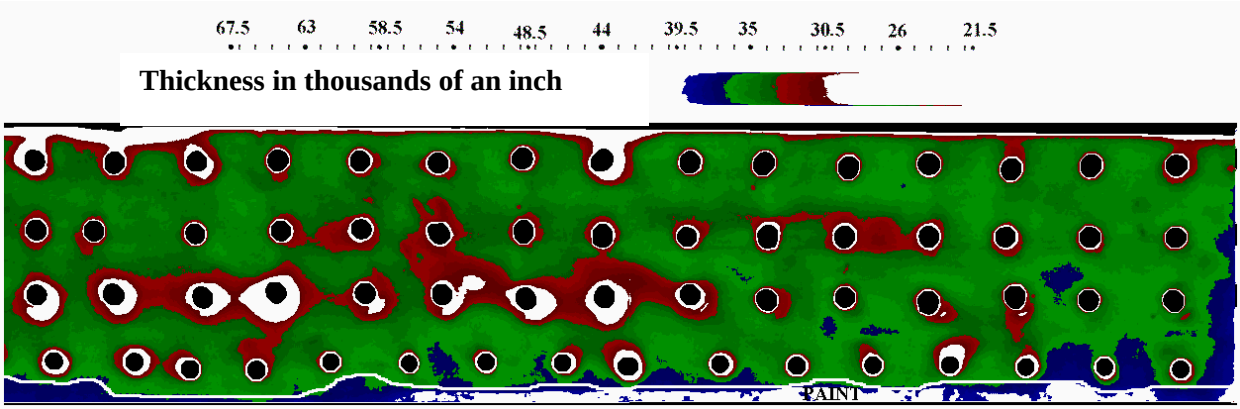


Figure 27-36: X-Ray Thickness Loss Map (Calibration Ramp at Top).

Figure 27-37 shows mechanically made thickness measurements taken nominally midway between fastener holes and also where thinning was beyond the lower limit of the X-ray calibration. The maximum thickness was 0.038 inch. The minimum thickness between fastener holes was 0.030 inch [24% loss], and the minimum thickness at the free edge was 0.026 inch [34% loss]. These losses and the pattern of losses, especially around fastener holes, compromised the skin and would have made it more prone to fatigue damage.

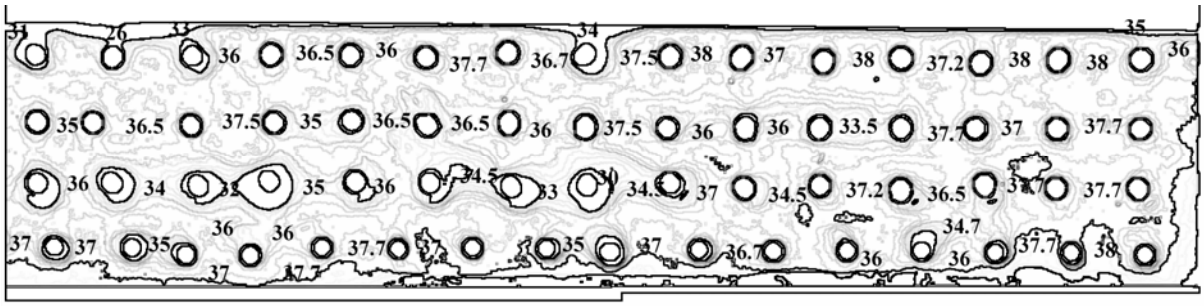


Figure 27-37: Thickness Measurement Map.

27.3.3 Post-Teardown

Acquisition, inspection and teardown information must be recorded to document the investigative methods employed. The information that is collected is rarely in a convenient format, either for archiving or presentation. A searchable database makes the job easier. It facilitates the recording of image and text information on the history, metrics, condition and teardown findings for each specimen. An example is the NRC/IAR NDI Analysis™ software used for X-radiography.

A disciplined approach is required to fully exploit the opportunities for damage assessment. A methodology is needed that accounts for the capability of each step in the teardown process and defines the sequence of steps to ensure that information is not inadvertently destroyed. The teardown process should be governed by a set of decisions and authorization procedures that include knowledge of the consequences for not following the prescribed order of events. Finally, all this must be fully understood by everyone involved in the teardown process.

27.3.3.1 When It All Goes Wrong – C141 "Corroded" Joint

Field inspection of a C-141 airframe located classic visual evidence for corrosion induced pillowing at the joint on Stringer 32 Right, see the left-hand photograph in Figure 27-38. The skin was buckled between the steel fasteners (Hi-Lok® HL19, 100°, Reduced Flush, shear bolts), and some fastener heads were being pulled through the outer skin. Furthermore, this damage was at a known corrosion site, below the sewage access port for the hospitality pallet. The right-hand photograph in Figure 27-38 shows that sealant had been added to the original protection scheme on the inner surface, indicating maintenance for corrosion damage.

Figure 27-38: A Visual Inspection of the Exterior Surface Indicated Corrosion Pillowing (left) While the Interior Showed Sealant Added (red) Indicating Maintenance for Same (right).

Laboratory DAIS and UT inspections gave the results shown in Figure 27-39. The DAIS inspection indicates corrosion-induced pillowing, and the UT inspection apparently indicates corrosion product build-up along two fastener rows below the access port. However, teardown revealed something totally different. Figure 27-40 shows that a shim had been placed along one bolt row, presumably during maintenance. Tightening of the steel bolts caused the outer skin to buckle, and where it was unsupported by the shim the fastener heads tended to be pulled through the skin. The resulting incomplete clamp-up confused the UT inspection, since air gaps were interpreted as corrosion build-up.

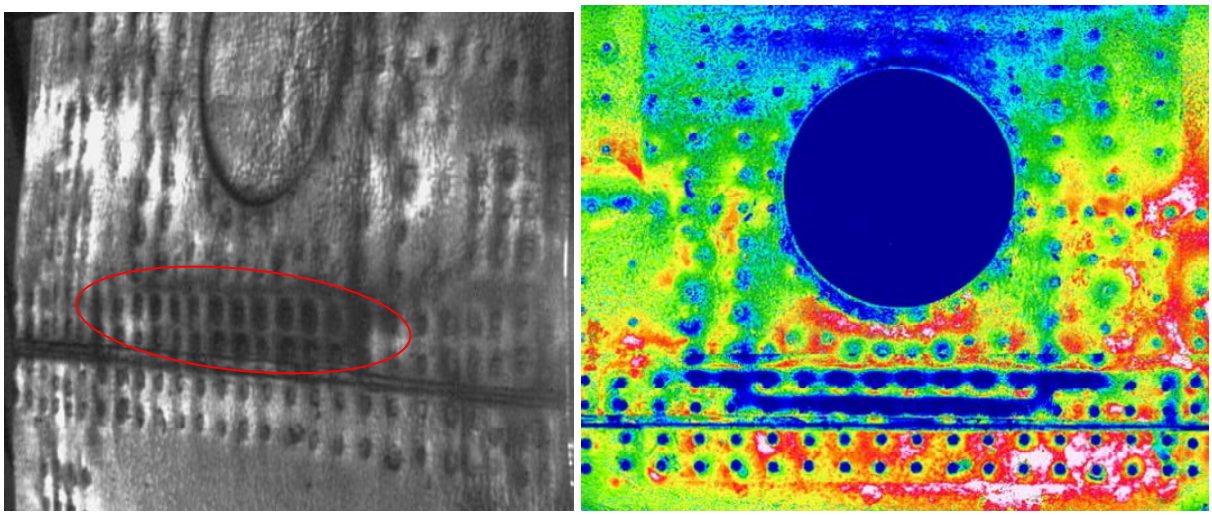


Figure 27-39: Laboratory Inspections Preceding Teardown Both DAIS (left) and UT (right) Indicated Damage in the Upper Skin of the Butt Joint.

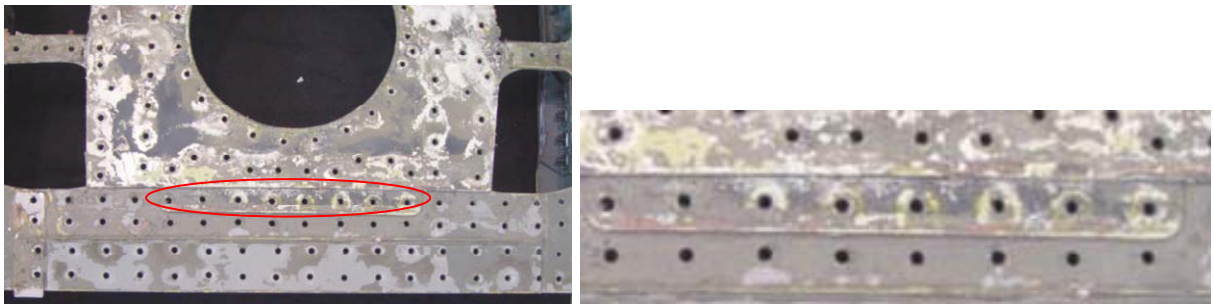


Figure 27-40: A 0.080 Inch (2.03 mm) Thick Shim In-Situ (left, circled), Enlarged (right).

27.4 CORRODED COMPONENTS AVAILABILITY

When corrosion is discovered on airframe components, it is usually assessed, more or less quantitatively, by Non-Destructive Inspection (NDI). Ideally this should enable well-founded decisions about repairing or replacing the affected parts. If repair appears to be possible, e.g., by attaching replacement materials (inserts) and/or reinforcements (doublers), the first maintenance action is to remove the damage mechanically. If the damage is assessed or turns out to be too severe, the components are removed and disposed of.

These customary procedures for repair or replacement make it virtually impossible to investigate and collect examples of as-found corrosion damage. This is unfortunate, since such examples can be valuable for:

a) Verifying NDI techniques, thereby facilitating decisions about repairs or replacements; and

b) Determining the underlying causes of corrosion.

The non-optimal alternative is to do corrosion tests on simulated structural details in artificial environments.

There is an additional problem. As aircraft fleets age there can be, and have been, situations where the original materials for some components have gone out of production, therefore being no longer available

for repair or replacement, or for serving as baselines for corrosion test evaluations of substitute materials. Collected examples of pristine original structures can provide these baselines.

Some research organizations, operators and maintenance contractors have recognized the above-mentioned usefulness of collecting examples of typical aircraft structures. By doing so, they benefit from having assemblies of the original materials, surface treatments, protective coatings, sealants, paint systems and fasteners.

If possible, both naturally damaged and pristine structures are collected. The usual sources for these original components have been wrecks and airframes Withdrawn From Use (WFU), see Figure 27-41 and Figure 27-42. Operators of new designs have been known to purchase additional airframes intended as immediate sources of spare parts, but these can also serve as sources for materials and assemblies.

A chance phone call resulted in a rush across three states to capture some of the last available B707 wings, made with discontinued 7178-T6, just days before they would have been lost to the scrap metal smelter.

Figure 27-41: Aircraft Graveyards have been Valuable Sources of Corrosion Samples.

Figure 27-42: Cut-Outs Show where Fuselage Structure was Harvested from WFU Airframes.

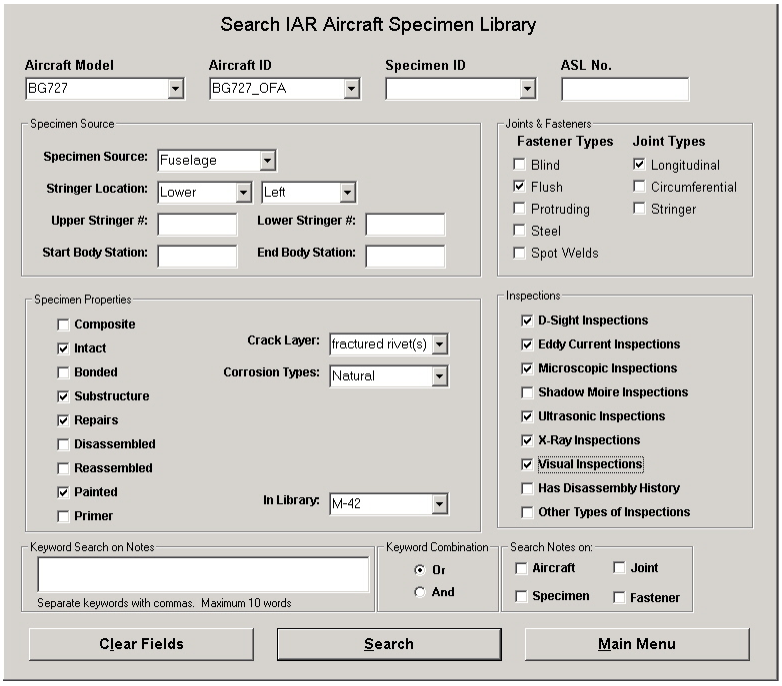
Note from Figure 27-42 that these WFU aircraft are parked in desert environments. Actually, deserts are *not* the best places to store aircraft that have been in service. It has been assumed that the arid climate minimizes corrosion activity. This may be true for the exterior surfaces, but experience has shown that the closed-off internal environments still support corrosion processes, and the high daytime temperatures may well accelerate them. Consequently, desert storage areas have proven to be productive sources of examples of service and post-service corrosion, Figure 27-43 and Figure 27-44.

Figure 27-43: Stringer and Frame Corrosion in the Crown of a Stored Fuselage Due to Moisture Remaining in Insulation Blankets (Removed).

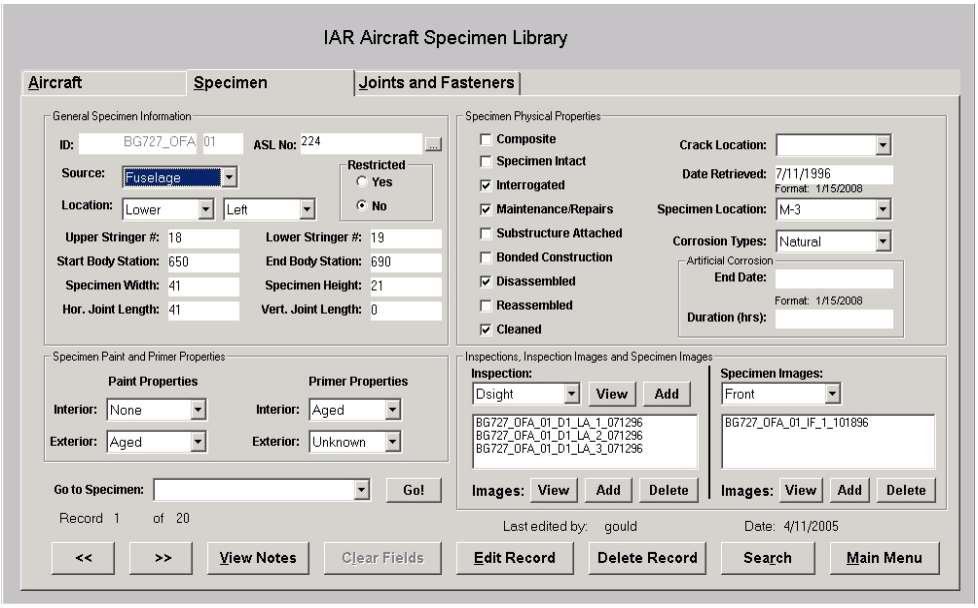
Figure 27-44: Lower Window Frame Corrosion Due to Moisture Accumulating Between Seal and Structure of Stored Airframe.

From nose to tail and top to bottom the materials, structural elements and assemblies of transport aircraft fuselages generally remain the same. The upper and lower wing skins are usually made from different alloys (7XXX upper skin, 2XXX lower skin) and they vary in thickness from root to tip. However, apart from these differences both fuselage and wing structures can be sampled for collection, i.e., it is not necessary to obtain entire airframes. Figure 27-42 illustrates that the samples can be relatively small.

Storage space is always an issue, especially when the use of collected samples is uncertain. Linking collections via databases could enable users to avoid a heavy storage burden, but still have the benefit of access to representative material, available when the need arises. Figure 27-45 shows details from a database set up by the NRC/IAR in Canada.



(a) Search pick-list has 27 parameters to choose from.



(b) Information on the parent aircraft, the condition of each specimen and detailed inspection results are all accessible through the database.

Figure 27-45: NRC/IAR Aircraft Specimen Library Database.

There are very few known collections of aircraft structure. Those that exist have been used successfully to support NDI equipment and technique verification, repair scheme development, damage characterization, and human factors studies. Figure 27-46 shows cut-outs where natural corrosion damage specimens have been extracted from a WFU aircraft wing. The labels show where even more specimens are to be harvested. Thus instead of disappearing into the "recycle-bin" the components and samples in these libraries continue to educate and serve their fleets.

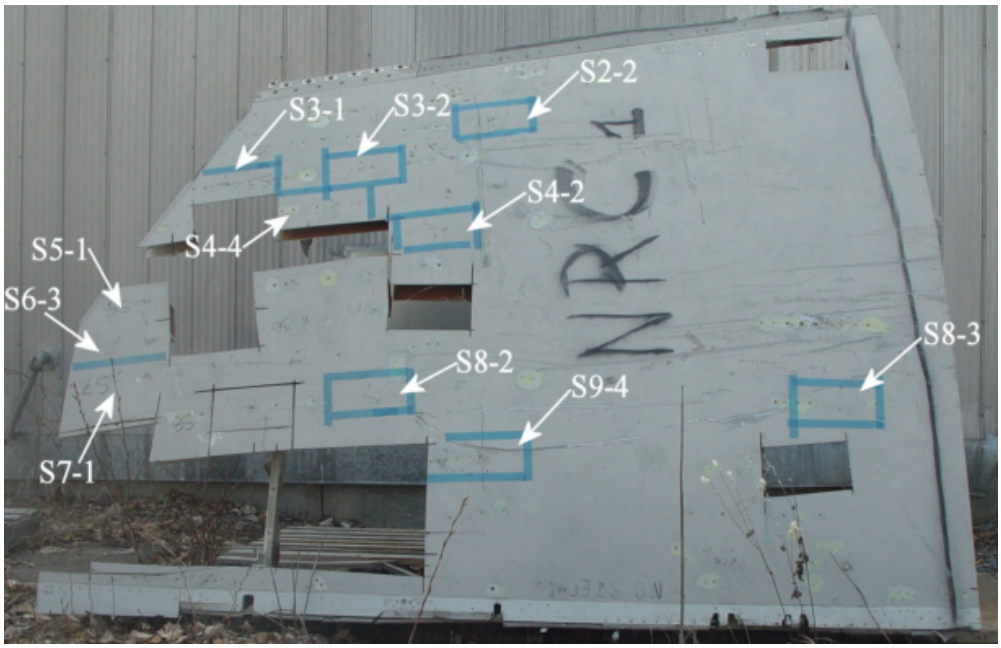


Figure 27-46: Upper Wing Section Being Harvested for Corroded and Undamaged Material.

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