Challenges in the Repair of Composite Structures

Part I

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Abstract

This two part paper discusses the development of repairs to composite aircraft structures. Through a brief history and outline of generic repair types schemes, the paper will discuss the specific requirements of composite structural repairs. A ten step guide as how to best achieve a successful composite repair is given. This leads to a description of the aircraft structure repair manual’s (SRM) typically explanation of how to conduct a composite structural repair is applied. Several areas of improvement in the SRMs are discussed, covering inappropriate and poor repair scheme design and application practices.

Introduction

Composite materials have been used in aircraft structures since the early days of aviation. As materials technology has advanced, so has the structural application of composite materials in airframes. Today, significant quantities of composite materials are used in primary aircraft structures on both military and civilian aircraft. Operational requirements need to be set so that composite structures can be maintained and repaired if damaged. This is the challenge of aircraft operators today.

Repairs to composite structures require a different perspective from their metal counterparts. Like in the manufacture of the composite structures themselves, the design and fabrication of the repair scheme are intimately related. Thus several important considerations must be understood in the entire repair process. Concern is expressed for the need to develop a repair scheme based on damage significance. The purpose of repair design is to restore structural integrity, when required, with the application of a simple repair scheme. With more complex and difficult repair schemes the chance of something going wrong is much greater. Typically when something goes wrong with a composite repair process it is usually trapped inside the repair itself and tends to be hidden from view until the repair patch falls off the aircraft during the next flight.

The aim of this paper is to describe where composite structural repairs have come from and where they are going. Part I of the paper presents the application history of composite aircraft structures and the generic types of composite repair schemes. In Part II, the repair requirements are set-out and the procedures required to complete a successful repair are stated. A guide to what typical structural repair manuals tell you to do and what they should have told you to do is discussed. The discussion in this paper is essentially directed at aircraft composite structures, but the information contained herein can be easily translated to other load bearing composite structures in the marine, civil, automotive, etc. industries.

Historical Overview
Composite materials have been used in aircraft since the dawn of human-powered flight. The Wright Flyer, Figure 1, is an excellent example of the application of the principles of composite materials in skin type structures. The cotton fabric wing skins are soaked in a resin type material (known as doping) and when dry causes the fibres to contract and form a rigid, thin and lightweight aerodynamic surface. With the fabric providing strength and stiffness, and the resin supporting the fibres. Nothing much has changed in the principle idea of composite materials since then.

Figure 1: Wright Military Flyer (circa 1908) (Photograph - author)

From the first flight at Kittyhawk, the technology did not advance for many years up until World War II. During the late 1930’s a shortage of strategic aircraft materials (namely aluminium alloy) forced the de Havilland company to study a laminated wooden structural design based on earlier successes. The resulting aircraft was the de Havilland DH-98 Mosquito fighter/bomber, Figure 2. The laminated construction of the wooden fuselage and wing skins, shown in Figure 3, is certainly the embryo of current composite laminate construction techniques. The Mosquito, or the “Wooden Wonder” as it was affectionately referred to, stunned the British War cabinet during flight trials by outclassing the current fighter aircraft of the day.
Today a number of the 1930/1940 vintage aircraft are still flown and are maintained in the early forms of composite materials. Such an example is the Douglas DC-3, where composite materials (doped fabric skins) are used on the empennage control surfaces, Figure 4.
In the 1940’s/50’s period the development of fibreglass and phenolic type resins saw a significant leap in composite materials technology. Although the material were lighter, stiffer and stronger than its doped fabric counterparts, the performance of these new materials did not meet the class of the standard aluminum alloys of the day. Thus the fibre reinforced plastic, as they become known, made their niche in the secondary and lightly loaded structures of aircraft, such as fairings on the Lockheed Neptune P-2 and Boeing 727 aircraft, Figure 5. Today, the fiberglass composites are used in much the same components on aircraft, and have particular application in radomes and antennas because of the radar energy conductivity performance.

Figure 4: Douglas DC-3

Figure 5: Structural Application of Fibreglass Composites
The current application of composite materials in military aircraft can be summarised in Table 1. The F-111 is more renowned structurally for the extensive use of adhesively bonded honeycomb core sandwich panels as primary structure, but the aircraft did introduce advanced composites into small areas of primary structures. The general application of advanced composite materials in military aircraft is typified by the distribution of these materials in the F/A-, Figure 6.

![Figure 6: McDonnell-Douglas F/A-18](courtesy of McDonnell Douglas)

Table 1: Current Application of Composite Materials in Military Aircraft

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Composite</th>
<th>Application</th>
<th>% of Aircraft Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-111</td>
<td>Glass/Epoxy &amp; Boron/Epoxy</td>
<td>Panels, fairings, etc.</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>F-14 Tomcat</td>
<td>Boron/Epoxy</td>
<td>Horizontal tail skin</td>
<td>1%</td>
</tr>
<tr>
<td>F-15 Eagle</td>
<td>Boron/Epoxy, Boron/Epoxy, Graphite/Epoxy</td>
<td>Horizontal tail skin, Vertical tail skin, Speed brake</td>
<td>1.5%</td>
</tr>
<tr>
<td>F-16 Falcon</td>
<td>Graphite/Epoxy, Graphite/Epoxy, Graphite/Epoxy</td>
<td>Horizontal tail skin, Vertical tail skin, Control surfaces</td>
<td>5%</td>
</tr>
</tbody>
</table>
Commercial aircraft have also seen a growing use of advanced composite materials in primary structure. From the simple fairing structures of the Boeing 727 (Figure 5.b) to major control surfaces and engine nacelles of the Boeing 767 and then extensive use of composite materials in primary structures on the Airbus A330/340 and Boeing 777 (Figures 7 and 8). Regional turboprop class aircraft have also adapted composite materials into their structure as shown in Figure 9 for the ATR 42. A significant quantity of composite structures is found in all of the modern business jets such as the Aerospatiale Falcon 900.

![Airbus A330/340](courtesy of Airbus Industries)
The application of composite materials in helicopters structures is also widespread and growing. Essentially their usage has been in the rotor blades and fuselage structures. Examples of the distribution of composite materials in a modern military helicopter is shown in Figure 10 for the Sikorsky Black Hawk. Whereas, the extreme use of composite materials is illustrated in the Boeing V-22 Osprey (Figure 11). The Osprey contains 59% of its structural weight in graphite/epoxy composites and a further 11% in glass/epoxy composites.
Generic Repair Schemes

The various types of repairs to composite materials have evolved around five basic repair scheme configurations since their early application into structural components. Each is briefly described:
1. **Repair Plug.** When the significance of the damage is small and the main requirement to repair is for environmental protection, a cosmetic plug repair is all that is necessary. Such repairs have been used on the very early application of composite materials in secondary structure (fibreglass reinforced plastics), such as aerodynamics fairings and antenna covers on the Neptune P-2 and F-111. In such a repair scheme the damage may not necessarily be removed, but moisture removal is still recommended. The damaged area is filled with a suitable potting compound (neat resin or mixed with chopped fibreglass) and then the damaged area is sealed with a layer of fibreglass/epoxy cloth, Figure 12.

![Figure 12: Cosmetic Plug Repair (Non-Structural)](image)

2. **Laminated Doubler.** As the structural severity of the damage increases, particularly for thin skins and honeycomb sandwich panels, some load transfer over the damaged region will be required. Such a repair scheme is both cosmetic and semi-structural, Figure 13. The damage is usually removed, as well as moisture desorption, honeycomb core is replaced or a foaming resin plug inserted, over which a doubler is adhesively bonded. The plug should be of low modulus so as not to attract significant load. The adhesively bonded doubler repair is not a new repair scheme. Such repairs to doped aircraft skins have been used (Figure 14) and are still used in many light general aviation and ultralight aircraft categories.

![Figure 13: Semi-Structural Plug/Patch Repair](image)
3. **Scarf Patch.** In relatively thin composite structures that have had their structural integrity significantly reduced by the presence of damage, a flush bonded patch repair scheme will provide the greatest strength restoration capability. Such a repair is also aerodynamic smooth. The repair process is to remove the damage and carefully scarf or step the hole out, again it is important to dry the laminate prior to applying the repair scheme. The patch, designed and cut to fit in the hole, can by either pre-cured and secondarily bonded or co-cured to the damaged area. Co-cured patches are generally stronger. A doubler patch is also included in the repair scheme as a sealing patch for the flush patch. The doubler patch is no more than 4 plies in thickness and can be of a lower modulus material, if required. Figure 15 illustrates a typical bonded scarf repair.

![Figure 15: Bonded Scarf Repair](image)

4. **Bolted Doubler.** The bolted patch repair is restricted to thicker laminated sections that require ample structural integrity to be restored. However, the full structural strength is unlikely to be achieved, but restoration of the design load carrying capacity can be designed with a bolted patch repair. The bolted patch repair can be by a semi-flush or double-lap repair scheme, depending on the design requirements, and is typical of that configuration shown in Figure 16. The repair process is to remove the damage and create a hole with circular ends, remove any moisture, drill the locating fastener holes in the parent laminate, and attach the inner, flush and outer patch panels. The patch panels and fasteners should be coated with a sealing compound and fitted wet.
5. **Resin Injection.** Current practice in the restoration of local stiffness in the presence of a delamination is to resin inject the damage. This is achieved by drilling two holes in the surface down to the delamination, one hole is used to inject a low viscous resin and the other hole acts as a vent, Figure 17. This repair method, although very simple in application, has a number of significant drawbacks\(^6_7\).

**References**

1. Internet address, [http://www2.awinc.com/users/mconstab](http://www2.awinc.com/users/mconstab).
SECTION A-A

Figure 17: Resin Injection Repair