ICAS-90-1.10.3

COMPOSITE REPAIR - AN AIRLINES POINT OF VIEW

ir. Erik Moyson

Structures and Composites Engineering
Sabena Technics
Brussels, Belgium

Abstract

The increasing number of applications of composites in aircraft structures, promises the manufacturers significant cost and weight savings. But there is a considerable danger that this is being achieved at the expense of serviceability, which is essential to a maximum utilisation of the aircraft.

Repair of composite structures and components is not always evident, especially for airlines having several aircraft types of different manufacturers.

The different steps of composite repair, including maintenance and inspection, will be discussed : damage assessment, surface preparation, repair types, repair materials, taper ratio and overlap length, sequence of patch overlay.
Some of these steps are still indefinite; for others the differences between manufacturers and the potential problems for the airlines will be pictured.

To standardize repair as far as possible, and to minimize the cost of repair and maintenance, IATA formed a Composite Repair Task Force (CRTF). One of the most important achievements of the CRTF is the agreement of major original equipment manufacturers (OEM) to call out common repair materials, applicable to different aircraft types.

I. Composites in airliners

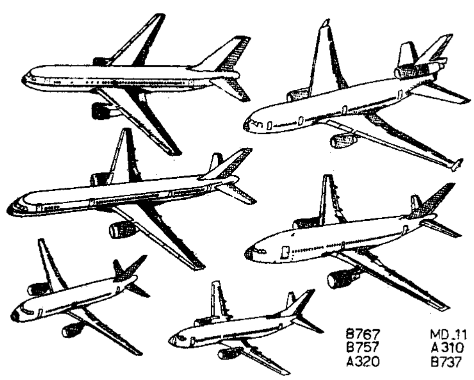

Fig. 1. Composites in airliners

Until recently, composite materials were only used in secondary and tertiary structures. In the design of modern aircraft, the use of composites is now extended to primary structures such as all composite vertical fins and horizontal stabilizers (Fig. 1.). The different composite structures of an aircraft may be constructed of GFRP, AFRP, CFRP or hybrids, and can be of sandwich, monolithic or mixed construction. Composite design accounts for high specific strength and stiffness, superior fatigue and corrosion resistance, resulting in significant weight savings.

The OEM's take also advantage of reduced manufacturing costs : good formability and design of integral structures.

However, the major concern of airlines is the serviceability of these composites.

II. Maintainability

Proper maintainability is a key factor for airlines to control operation costs.

Exterior paint stripping

There is an urgent need to evaluate alternative paint stripping methods, taking into account the total cost of stripping a complete aircraft, including repair cost incurred because of damage.

Toxicological aspects of paint strippers, environmental and economical aspects of waste disposal, will restrict the use of conventional chemical strippers in many countries in the near future.
Anyway, chemical paint stripping of composites is not acceptable because of the damage to the resin matrix. Hand sanding is the only currently unrestricted approved method for paint removal, but it is unacceptably time consuming and labor intensive when stripping the whole aircraft.

Component size

Composites lend themselves to the lay-up of "unitized structures" (Fig. 2.). This reduces part count and is favoured by OEM's. However, to an airline it causes problems if a large part has to be removed from an aircraft, only to repair a small amount of damage.

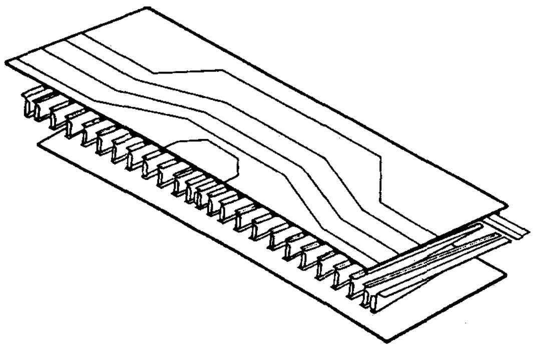

Fig. 2. Unitized structures

III. Damage

Since airliners are designed for 50,000 flight cycles, or even more, it is clear that composite materials on these aircrafts will suffer from damage, not only in flight condition but also during maintenance tasks.

Although damage growth in composites is very slow, they certainly do not have a good damage tolerance. During the design phase, the OEM's should attempt to reduce the specific sensitivity of composite materials to : environmental conditions like lightning strike, and chemical attack.
To limit impact damage, OEM's should use tougher resins. Now resin matrices are very brittle. Water uptake is also very important : up to 1 % by weight for GFRP and CFRP and - because of moisture ingress in aramid fibres - up to 3 % for AFRP.

IV. Damage assessment

Damage detection on large complicated composite structures, with sophisticated non-destructive inspection (NDI) techniques, requires a lot of manhours and high investments in special equipment and training.

It is useful to make a distinction between "non-instrumental" NDI and "instrumental" NDI.

Non-instrumental NDI

The visual inspection is the simpliest and easiest procedure. However it can only detect surface damage. Damage such as disbonding or delamination cannot be found, except on thin skin composites.

The design of composites should be such that visual inspection is sufficient for damage detection. The OEM shall demonstrate that the structural integrity is maintained when damage is not visual.

Because of delaminations or subsurface cracks, damage in composites is often larger than what is visually detectable. Therefore, after visual damage detection, additional NDI is required.

The audiosonic inspection (usually named tapping) is very simple and easy, but subjective in its interpretation. It allows mapping of disbonds or delaminations on thin skins.
The real damage size can be estimated by multiplicating the assessed damage by an "uncertainty factor", given for different composite types and structures.

Instrumental NDI

Instrumental NDI methods define the damaged area based on the sensitivity and accuracy given by the calibration standards.
Ultrasonic scanning is the best method to locate and identify damage on monolithic components. But it is only useful when performed by qualified personnel using the correct calibration standard.
The method can also be used to inspect sandwich components for disbonding.
X-ray radiography can be used to assess liquid water content or crushed honeycomb of sandwich structures.
These methods should be standardized to a high degree and - unfortunately - none of the inexpensive and portable instrumental NDI equipment is yet commercially available.

V. Surface preparation

Decontamination

Before accomplishing a repair, all contaminants must be removed, e.g. hydraulic fluid, engine oil, aviation fuel, de/anti-icing fluid...

The surfaces have to be cleaned with compatible chemicals, in order to remove contaminants and to avoid damage to the composite resin system. Therefore the OEM's should specify and standardize upon technical grade cleaning fluids and methods.

Drying

According to the SRM (Structural Repair Manual), all composites must be dried before repair. However, up to now, no simple and inexpensive instrument for measuring moisture content of CFRP is commercially available.
Until such an instrument is produced, parts must be dried under heat and vacuum for several hours. Guidance is required regarding temperature of drying and time required to be dry enough for a good repair.

Local paint stripping

Hand sanding is the only method for local paint stripping approved by the OEM's, although this process is time consuming and labour intensive.

VI. Repair types

Design characteristics

Each of the following design characteristics, related to flight safety, should be used in the description of the repairability of composite structures :

- structural importance
- aerodynamic smoothness
- heat resistance
- fire resistance
- electrical conductivity
- radar transparency
- weight and balance
- ...

These design characteristics determine allowable damage limits, repairable damage limits and applicable repair methods.
For an airline composite repair engineer, it is important to understand which design characteristics determine the given limitations, so he can design a good repair for damage beyond the limits of the SRM.

Field repair

Airlines need field repairs to allow the aircraft to make limited revenue flights to fly back to the home-base. They may be performed at an out-station, where no specific equipment is available, in a limited downtime.

Structures with relatively large damage should be repairable without any surface preparation or drying.

In-situ repair

Since there is a tendency towards "unitized structures", the OEM's shall provide in-situ repairs for damage that is likely to occur on such components. This avoids part removal and minimizes downtime.

Hot bonded prepreg repair

To avoid damage to the originally cured resin system the maximum temperature of the hot bonded prepreg repair shall be below, at least 25°C, the original cure temperature.

Furthermore, the development and use of prepregs, film adhesives and foaming films with a much lower cure temperature, such as 95°C, shall be encouraged.

Prepreg repairs are easy to carry out and have uniform properties. But they also have some disadvantages : storage at -18°C, with a shelf life of only 6 to 12 months. The purchase costs are high, especially for small quantities, as it is the case for airlines.

Cold bonded wet lay-up

Wet lay-up materials are less expensive and can be stored at room temperature.

But wet lay-up repairs require skilled people and the repairable damage limits are much smaller.

For less important components, wet lay-up repairs should be considered as permanent. Curing can be accomplished up to a maximum of 80°C, either to accelerate the cure or to achieve the properties required.

VII. Repair materials

Different designs and materials

Airlines are not only operating different types of aircraft, but aircraft manufacturers also tend to subcontract both design and manufacturing of composite structures to different subcontractors. This leads to a large number of not only aircraft specific, but also component specific materials and processes, most of them with similar objectives.
As airlines are obliged to fulfill the requirements of each OEM's SRM, this compliance with aircraft specific and component specific repair materials and processes presents a problem.

Shelf life and small quantities

Each individual airline has a fairly small consumption of composite repair materials, which normally have a shelf life of six to twelve months. It is very difficult and expensive to have all the specified materials on the shelf and within the recommended shelf life at the same time.

Therefore, the material suppliers should develop suitable packaged repair materials taking into account the need of airlines for small quantity material supply.

Material source

The true source of all materials and their original material suppliers part number shall be quoted in the material data sheet and on the package. This could save a great deal of money on research, only to find that materials were identical to others previously tested.

Incoming material testing

It does not make sense that every airline has to purchase a second roll of prepreg, only to do incoming tests, like liquid chromatography and infrared spectroscopy.

The incoming material testing should be performed by the material supplier, who should provide a "certificate of conformance" to the material data sheet.

Shelf life extension

A small number of tests should allow airlines to extend the shelf life. These tests shall concentrate only on properties most affected by possible quality reduction, and take into account the limited airline testing facilities.

Repair material substitution

It happens more than once that none of the repair materials on the qualified products list (QPL) is available.

The use of material data sheets of different repair materials for comparative purposes is unworkable .
The material data sheet lay-out and testing procedures are different for each material supplier, even for different products of the same material supplier.

Additionally, different OEM's raise their own specifications and require different performance levels for the same type of material.
Sometimes an OEM will require only the top performing materials from a batch, which may produce properties above those quoted on the material supplier data sheet.

Repair material standardization

For design purposes, OEM's will hardly be able to agree upon standardization of composite materials, because it took decades to establish a workable material data base.

But for repair purposes, the OEM's should accept each others repair materials specifications, or specify repair materials according to a worldwide accepted repair material specification.
Material suppliers will request qualification of their materials to these repair materials specifications.

Standardization of repair materials specifications is an urgent need : airlines want to be able to purchase these materials as easily and with the same clarity of definition as aluminum or steel alloys.

Repair material qualification procedure

On the longer term, the OEM's together could develop a detailed repair material qualification procedure : not only material properties shall be evaluated, but repair type specific tests shall be performed as well.

These qualification procedures should specify standardized test methods, number of specimens required, acceptance values, and will cover areas such as qualification, production control, incoming tests, shelf life extension, repair procedures and processes.

Repair materials qualification procedures can be used by the OEM's, but also by the airlines to qualify alternative repair materials themselves.

VIII. Taper ratio and overlap length

Different manufacturers use different values for taper ratio and overlap length :

OEM	Taper ratio Scarf joint (Fig. 3.b.)	Overlap length Stepped joint (Fig. 3.a.)
Boeing	50/1	.50"/ply
Airbus	50/1	
Douglas	50/1	.50"/ply
Fokker		10 mm/ply
Westland	30/1	.25"/ply
Shorts	20/1	
Saab		10 mm/ply

Fig. 3.a. Stepped joint

Fig. 3.b. Scarf joint

Because the above values do not differ too much, it should be possible to standardize to some commonly accepted values.
All SRMs tend to the conservative side, which gives a fairly large lap.

The lap length is designed according to the strain level. Since primary structure components mostly contain bolt holes, stress concentrations around those holes reduce the allowable strain.
Taper ratio's of 20/1 or 25/1 are recommended for monolithic panels. This results in a significant repair area reduction.

On the other hand, for wet lay-up repair, some OEM's enlarge the taper ratio from 50/1 to 100/1 and the overlap length from .50" to 1.00"/ply, regardless the cure temperature.

IX. Sequence of patch overlay

For airlines, there is no logical reason why OEM's have such a variety of different composite repair processes. They differ not only in materials used, but also in :
- the number of patches : two extra plies compared with the original build-up or equal number of plies as the original part;
- the kind of repair patches build-up : largest ply at the top or at the bottom.

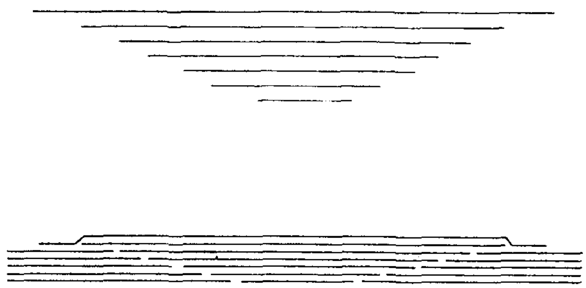

Fig. 4. Smallest ply first

Most American OEM's tend to go for the smallest ply first (Fig. 4.). If stepped correctly, each overlay has the same orientation as the layer it is repairing. OEM's claim that in a fire, it is better to have the minimum number of free edges.

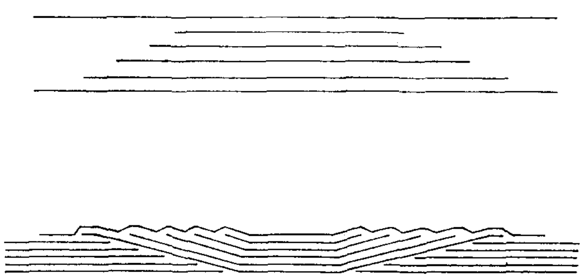

Fig. 5. Largest ply first

A major European OEM argued that the shear transfer is better if the largest ply is fitted first, and consequently put the largest ply first (Fig. 5.), but in some cases the smallest ply.
Recently this OEM stated that largest ply first and smallest ply first are both acceptable.
The latest SRM revision of their fly-by-wire aircraft gives a choice of method. This is a useful achievement for the airlines, because it allows the use of the smallest ply first method on all aircraft types.

X. IATA - CRTF

In May 1988, the International Air Transport Association (IATA) Engineering and Maintenance Advisory Sub-Committee (EMAC), decided to form a Composite Repair Task Force (CRTF).

Its objectives were twofold namely :
- to standardize the repair of composites as far as possible,
- to minimize the cost of the repair and maintenance of composites.

Task Force membership was not limited to airlines only. Major OEM's as Airbus, Boeing, Douglas and Fokker participated on an active basis, and some material suppliers were represented as well.

In two years time, the CRTF produced a document : "Guidance Material for the design, maintenance, inspection and repair of thermosetting epoxy matrix composite aircraft structures".

Repair materials

Standard data sheets for adhesives and prepregs have been proposed.
The OEM's agreed to call out in the future common repair material specifications, applicable to different aircraft types. The QPL shall contain at least three materials coming from different sources throughout the world.
This enables an airline to purchase one 250°F cure carbon prepreg to repair all the aircraft types it is flying.
On the longer term, the CRTF document proposes qualification procedures for airlines to carry out agreed tests to qualify alternative repair materials themselves.

Taper ratio and overlap length

Agreement has been reached with all OEM's on standard overlaps and taper ratio for repair joints.

CONSTRUCTION		JOINT DESIGN
Sandwich		
skin thickness	< 0.5 mm	Scarf joint, taper 50/1 or Lap joint, overlap 13 mm
	0.5-1.5 mm	Scarf joint, taper 40/1
	> 1.5 mm	Scarf joint, taper 30/1 or Stepped joint, overlap 25/1
Monolithic		Scarf joint, taper 30/1

Sequence of patch overlay

Five standard sequences of repair patch overlays have also been agreed.

Smallest ply first for stepped joints. Each ply shall be oriented in the same direction as the ply it overlaps.

For a scarf joint, both smallest ply first or largest ply first are acceptable.
Each ply shall be oriented to drawing.

For lap joints on sandwich skins, where honeycomb has been replaced and brought to the level of the skin, both smallest ply first and largest ply first are acceptable. Each ply shall be oriented i.a.w. the SRM.

Training

Training has received a great deal of attention. The document contains suggested training programs both for Repair Design Engineers and Repair Mechanics.

Training is one of the most important factors in the achievement of high quality composite repairs.

New aircraft

The IATA believes that the use of this document when purchasing new aircrafts can result in the production of better composite parts, which are more easily repairable and cost-effective in use.

The required documentation provides better repair instructions and ways of approving alternative repair materials.

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