COMPOSITE MATERIALS REVOLUTIONISE AEROSPACE ENGINEERING

Aerospace engineering is changing. Aeroplanes have traditionally been made out of metal – usually alloys of aluminium; now however, engineers are increasingly working with carbon fibre composites. Tim Edwards, a structural engineer at Atkins, describes the making of composite wings and the take-up of them across the aerospace industry.

Fibrous composite materials were originally used in small quantities in military aircraft in the 1960s, and within civil aviation from the 1970s. By the 1980s, composites were being used by civil aircraft manufacturers for a variety of secondary wing and tail components such as rudder and wing trailing edge panels. However, it is with the advent of the latest generation of airliners, such as the Airbus A380, the world’s largest passenger aircraft, that these materials have been deployed extensively in primary load-carrying structure. The A380 uses composite materials in its wings, which helps enable a 17% lower fuel use per passenger than comparable aircraft.

CIVIL AIRCRAFT MANUFACTURERS NOW Reconnaissance planes such as the U-2 and the SR-71 Blackbird have been using composites since the 1960s. The SR-71’s entire wing structure and tailplane (other than the rudder) are made from a matrix of carbon fibres reinforced with epoxy resin. The aircraft uses a type of composites called “unidirectional composites”, which are lightweight and very strong. However, the manufacturing processes are time-consuming and expensive. The first generation of the SR-71 was produced in 1964.

As the use of composites has increased, so too has the use of advanced composites, which are stronger and lighter than traditional composites. Advanced composites are made from carbon fibres, which are much stronger than traditional fibres such as glass or aramid. Carbon fibres are used in aerospace applications because they are lightweight, strong, and durable.

The Airbus A380, the world’s largest airliner, used composite materials extensively in primary load-bearing structure, allowing for lighter, stronger, and more fuel-efficient aircraft. By using composites, Airbus was able to achieve a 17% lower fuel burn per passenger compared to comparable aircraft. This is because composite materials have a higher strength-to-weight ratio than metals, allowing for lighter aircraft.

MANUFACTURING COMPOSITES

When applied to aircraft structures, composites are generally supplied in unidirectional (UD) form: thin (~0.125 – 0.25 mm thick) sheets or tapes of parallel fibres that have been pre-impregnated with resin that has yet to set. This form of the material is ideal for the manufacture of structures that require high strength, low weight, and ease of fabrication.

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of thin plates that are used so extensively in airframe structures. Manufacturers use tape-laying machines to lay down layers, or plies, of this material, one on top of the other, to form a single piece sub-components. By laying successive plies in different directions, the strength and stiffness of the component can be tailored to match the demands of the engineer; allowing adequate structural properties to be attained for minimum weight.

Modem tape-laying machines can fabricate an entire wing in one piece, eliminating the fasteners that are routinely used in metallic designs, and thus saving manufacturing cost and further reducing overall weight. To complete the manufacturing process, the component is cured within an autoclave, which subjects the component to pressure at an elevated temperature to consolidate and harden the layers of plies into a single monolith of carbon/epoxy laminate.

**AIRFRAME USAGE**

In order to derive maximum benefit from the use of carbon composites, it is essential to direct the fibres in the direction of the main stress. For example, the wing of an aircraft bends during take-off, landing and flight, meaning that it is subject to stress across its span. To support this, engineers orient up to 60% of the fibres along the wing skin and the sparwise internal stiffeners.

In addition, wing skins are subject to parallel stresses known as their ‘stresses’ – to combat this, plies are directed at 45°. Component sizes inside the wing, such as spars and ribs that are designed to bear shear stress, are made up to 80% of 45° plies. In this way, the direction at which the plies are laid ensures that material volume, and hence weight, is kept to a minimum consistent with adequate strength.

**THE DESIGN CHALLENGES**

The foregoing description of carbon composites might lead one to question whether all of this is too good to be true – surely this wonder material must have some Achilles’ heel? Indeed, there are several obstacles to achieving the low weight and low cost that the headline figures promise. Engineers are overcoming the difficulties progressively through improved design and novel manufacturing processes, but the current state of development sees engineers of all disciplines searching for the best answers.

Structural engineers are faced with worries regarding damage tolerance and delamination, but they must also contend with the less forgiving nature of the new materials when compared with metals. Metals have the desirable quality that they exhibit plasticity under high loads they undergo permanent deformation (as they bend or stretch) before they break. As a result, a metallic structure can absorb everyday small impacts (leading to dents) with very little reduction in its basic strength. Plasticity allows loads in highly stressed regions to be re-distributed to regions of lower stress, ensuring that any stress concentrations inherent in a design do not lead to premature structural failure.

Carbon/epoxy composites, by contrast, exhibit little or no plasticity. Consequently, small in-service impacts tend to create local breakdowns of the epoxy matrix, leading to a weakening of the laminate in the area of the impact. In addition, stress concentrations in a composite design can cause sudden structural failure at high load, the process would be incremental with a similar design in metal because the load would be redistributed.

Structural engineers combat this lack of damage tolerance by assuming much lower stress values than theoretically necessary when they are designing, and they have had to accept an increase in the complexity of their strength calculations to accommodate the greater sensitivity of CFRP at high loads.

**MANUFACTURING CHALLENGES**

Manufacturing engineers are, similarly, wrestling with unfamiliar difficulties. Problems with wrinkling of the fibres in the fabrication process, resulting in a loss of stiffness and strength in the finished component, are addressed only by imposing strict constraints on the geometry of the final structure. The spectre of void formation in the laminate caused by a lack of consolidation of the plies during the curing process – reminiscent of Swiss cheese – creates further geometric constraints. As a consequence, engineers working with composites have realised that designing with manufacture specificity in mind is equally as important as designing for the strength/weight ratio. These issues are a small selection from a list that includes topics such as:

- **Schematic showing the ribs within a wing**
- **Schematic showing shear forces on the spar**

**MANUFACTURING PROCESSES**

Carbon/epoxy composites for aerospace use are generally fabricated in a laminated form. The epoxy resin requires curing (hardening) through the application of heat, which subjects the component to an increasing temperature necessary to cause the resin to set. **Figure 3.**

Aircraft wings are also collaborating with this a step further, engineers are now effectively choosing the laminate to achieve consolidation to avoid the formation of inter-lamina spaces or ‘voids’. Pressure is applied to the laminate to achieve consolidation.

The predominant manufacturing approach for aerospace structures employs ‘pre-preg’. Pre-preg material is supplied in rolls or tape, and comprises fibres in woven UD form pre-impregnated with uncured epoxy resin. The material is usually stored in refrigeration to prevent premature curing of the resin at room temperature. The material is cut and laid up in a tool (mould) by machine, but must then be vacuum bagged by hand prior to the curing process. The cure takes place at a post-cure temperature – a pressured oven – that subjects the embryonic component to the pressure required to ensure consolidation and the temperature necessary to achieve hardening of the epoxy.

Manufacturing and production engineers are searching for ways of reducing the costs and times to produce composite components. Pre-preg materials are generally more expensive, both to buy and to store, than are the component parts (carbon fibre and epoxy resin) singly. Autoclaves are expensive pieces of equipment, and their presence increases the floor space occupied by a factory equipped for pre-preg production. For these reasons alternative forms of the raw materials and manufacturing processes are being sought.

Engineers are directing increasing interest at the use of ‘non-crimp’ fabric (NCF). NCF is dry carbon fibre material, which is cheaper than pre-preg. However, the absence of resin leaves the fibres free to separate from one another, making the material impossible to store or to work with. To hold the dry fibres together they are tightly stitched to form the fibre into a fabric that holds together and makes it workable, yet retains the strength and stiffness advantages of UD pre-preg.

In terms of the manufacturing process there is an on-going research effort throughout the industry to eliminate autoclaves. The heated mould tool is one means of achieving the elevated temperature necessary to cure the resin without the use of a separate oven, but this approach still leaves the issue of laminate consolidation unresolved. Vacuum bagging allows a pressure of up to one atmosphere to be applied to the laminate, although this falls short of what can be achieved in an autoclave. For this reason the geometries of component that can utilise this production approach may be restricted. Hopefully the money that is being invested in research in this area will enable such technology to be used in an increasing range of aerospace components.
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**NEXT GENERATION COMPOSITE WING (NGCW) RESEARCH PROGRAMME**

The project was launched in May 2008 and has over £103 million of funding allocated to it by its various industry partners, and the Government’s Technology Strategy Board, Regional Development Agencies and Devolved Administrations.

This investment will enable engineers to develop wing box performance analysis tools that will give a better understanding of how they can use composite materials to best advantage in the wing. By developing standard tools that can be used to test the potential performance of composites, engineers also hope to open the doorway to the increased use of composites in other industries.

The areas of research that will be undertaken in this programme focus, naturally, on the use of CFRP in civil aircraft wing structures, but the studies also encompass the interaction of the structure with the aircraft system as a whole. Aero-elastic tailoring is one example of such interaction. Another example relates to the fuel system. The wing is generally employed to carry fuel, and carbon composite wing structures can be more susceptible to damage from high fuel pressures than metallic counterparts due to the possibility of de-lamination. Thus, design of the fuel system to moderate maximum fuel pressures allows a reduction in the weight of a composite wing structure.

**APPLICATIONS**

Following the Airbus lead with its A380, a number of current large aircraft development programmes are looking to use composites more extensively within the wings and fuselage. The Boeing 787 ‘Dreamliner’, for example, may eventually be made of as much as 50% composite materials. This revolutionary aircraft uses a novel process of ‘winding’ composite layers, like the winding of a cotton reel, in the composite layers, like the novel process of ‘winding’ revolutionary aircraft uses composite materials. This be made of as much as 50% for example, may eventually.

The Boeing 787 ‘Dreamliner’, large aircraft development its A380, a number of current Following the Airbus lead with its intelligent way.

**FUTURE USES**

The environmental case for developing our understanding and increasing our exploitation of composites is compelling. The Stern Review, 2006, identified that 1.6% of global greenhouse gas emissions come from aviation but that the demand for air travel will rise with our income.

To combat the environmental threat that aviation poses, the Advisory Council for Aeronautical Research in Europe in 2002 laid out targets to reduce the emission of CO2 (an important greenhouse gas) from an aircraft by 50% by 2050. The reduction of airframe weight through the extensive use of carbon composites is one of a range of technologies that must be deployed to meet such a challenging target.

**BIography – Tim Edwards**

Tim Edwards is Chief Structural Engineer in the Aerospace division of the engineering consultancy Atkins. The company’s Aerospace division works with clients, including Airbus and Rolls-Royce, on the design and analysis of aircraft structures and aerodynamics. His composite experience includes work on the carbon composite outer wing box structures for the Airbus A400M, certification of the Airbus A380 and, more recently, research work under the Next Generation Composite Wing programme. He completed an undergraduate apprenticeship with British Aerospace and graduated in aeronautical engineering from Imperial College.

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