

rising adoption of composites signify innovations in the aerospace industry

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Abstract

Composites are becoming increasingly important in the aerospace industry. At least 30-40 per cent of modern airframes are now made of composites, and this percentage is increasing rapidly due to technological advances in the field. The use of composites for primary structures such as fuselages and wings has grown significantly in transport aircraft. In fact, composites comprise 53 per cent of the A-350, the first Airbus with both wing and fuselage structures made primarily of carbon fiber-reinforced polymer.

Apart from increased strength at lower weights, composites also meet fatigue and damage tolerance, gust alleviation, and low noise footprint requirements.

Modern manufacturing methods are used to realize the large structures of transport aircraft. Common applications of composites include fuel tank sealing, fairings, and wing boxes.

This white paper examines the challenges and advantages of using composites in airframe manufacture, as opposed to aluminum and other alloys such as aluminum-lithium. It also looks at ways and means to ensure that safety and durability are not compromised by the use of composites. The prime objective of this paper is to highlight problem areas in composites and encourage readers to understand and write white papers on such topics.

Limitations of Metal

Aluminum, the current mainstay of airframes, is prone to fatigue and corrodes faster than some composites. Beach marks, or minute striations, are the first signs of fatigue, and sometimes are not visible to the naked eye.

To prevent air disasters, critical stress zones on aluminum airframes are routinely checked for cracks with a host of checks and other non-destructive tests (NDTs). Suitable repair schemes are adopted to enhance the aircraft's life cycle.

Compression stresses enhance fatigue life in metal, therefore methods such as cold working, interference fit, torque tightening, and shot peening have become popular. However, the advances in metallurgy have ensured that ride comfort and acoustics in metallic aircrafts are difficult to improve further. Similarly, the scope for weight reduction is very limited. For instance, Aluminum-lithium is approximately 10 per cent lighter than standard aluminum, but lithium is expensive, and the alloy requires extreme care during machining.

The Evolution of Composites

Advanced composite materials started replacing aluminum alloy components in airframes from the early 1970s. Composites have been used in military aircraft since the late 60s and with increasing adoption at Airbus and Boeing, the usage of composites in airframes has increased significantly; some modern aircraft use over 50 per cent composites:

While composites have their advantages over other conventional metals, the main benefits they bring are increased strength and major weight reduction.

	AIRBUS 350	BOEING 787
Composites	53%	50%
Aluminum	19%	20%
Titanium	14%	15%
Steel	6%	10%
Miscellaneous	8%	5%



Composites have their share of issues, but their correct usage can bring about a major reduction in weight without losing strength. Their aero-elastic tailoring capability also allows structural engineers to cut further weight. This tailoring capability along with reduction of number of joints reduces regular metal fatigue areas and weight. Aluminum, being isotropic, does not allow tailoring options.

Ride comfort can be enhanced by using smart materials embedded between layers of composites. However, the

smart materials still remain at concept levels and a lot needs to be done to use these on aircrafts. Composites used as sandwich material also help contain acoustics, but problems including moisture ingress still need to be addressed.

Composites are also vulnerable to impact damage, which could be caused due to tool drops in the shop floor, debris on the runway or the impact from hailstorms or bird-hits. Nevertheless, modern composites can be designed to withstand such impacts.

Present Analysis Tools

Packages such as Siemen's LAP and Fibersim analyze and design some of these laminates. Analysis of the composite parts is possible using NASTRAN, a finite element analysis program.

Non-linear problems like contact or geometric non-linearity are addressed using ABAQUS, which can also be used to simulate smart structures.

Many of these packages support manufacturing methods such as Automated Fiber Placement (AFP) with Automated Tape Laying (ATL) and fully automated Resin Transfer Molding (RTM) processes. They also help in material procurement, automatic cutting of plies, tool development, assembly Jig design and quality control.

Evolving Knowledge about Composites

While composites add tremendous value to an airframe in terms of weight reduction and durability, there are certain factors that one must understand when working with them. A number of factors still require further study and refinement. Some of the factors that can be taken into consideration are

Stability

Stability of panels is one of the prime drivers in aircraft design and panels are stiffened with longitudinal and transverse frames. Stability is also affected by stacking sequence and in-service damages. Robust concession methodologies and repair methods need to be explored further. Growth of delamination under compressive stress using fracture mechanics approach is a useful tool for analysis. Studies on suitable stacking sequence and modeling methodologies are also required.

Environmental effects

Environmental effects reduce the strength of the panels in hot and wet conditions. Therefore, suitable factors are taken into consideration and used in the design. These are arrived at by testing samples for the designed component.

Impact damage

Delamination is frequently caused by objects impacting the material surface during manufacturing, service and maintenance. Low energy impacts are most dangerous, since they do not produce visible damage on the surface (BVID - Barely Visible Impact Damage), but cause buried delamination between layers, which is often slight and difficult to detect. Suitable damage tolerance philosophy needs to be evolved to prove the adequacy of design.

Lightning strike

Lightning strikes can cause concentrated damage to the structure. A slight gap between a wing skin fastener and the hole it fits into could start sparking as the electricity passes through the gap. Inside the wings, any gap along the edges where wing skin meets internal structural spars could cause a spraying out of electrons during a lightning strike - a phenomenon called Edge Glow. An electric charge passing through the airplane could create a spark inside the wing, potentially causing a fuel tank explosion and destroying the aircraft.

This can be checked by ensuring that the initial lightning strike is dispersed quickly around the airframe to prevent concentrated damage. Equipment can be shielded from Electro-Magnetic Interference (EMI) disruption by embedding a thin metal mesh or foil in the outer layers of the composite fuselage and wings. Electro-Magnetic Interference (EMI), Electro-Magnetic Capability (EMC), Radio Frequency Interference (RFI) shielding protects sensitive circuits from both external and internal EMI. Fasteners must be fitted precisely and sealed on the inside to ensure a snug, spark free fit, and the edges sealed with non-conducting glass fiber. Finally, a nitrogen-generating system (NGS) that reduces flammable vapor in the wing tanks by filling the space above the fuel with inert gas, prevents the possibility of sparks reaching them.

Aero elastic tailoring

Aero elastic tailoring allows molding of components to improve aerodynamic and structural performance of the aircraft while reducing weight. The use of co-cured or co-bonded joints also helps cut weight.

Gust alleviation method

To get better ride comfort, sensors are connected wirelessly to a central data processor. An active gust alleviation system uses sensors to measure turbulence at the nose, and instantly adjusts movable wing surfaces to counter it.

Part count

Using composites helps cut the number of joints, and thus parts and fasteners. Depending on the manufacturing techniques adopted by the Original Equipment Manufacturer (OEM), it also helps prevent fuel and cabin pressure leakage.

Manufacturing techniques

Resin Transfer Mold (RTM), Automatic Tape Laying (ATL) and Automatic Fiber Placement (AFP) methods are used in manufacturing composites for aerospace.

Repairs

Common damages such as dents, gouges, thickness and height deviations, porosity, displaced plies, bubbles, resin starvation splintered plies, resin accumulation and bridging can occur after manufacturing. Impact damage during service and maintenance can occur, and damage due to lightning is also possible. Suitable repair techniques and analysis procedures exist, though a few additional methods need to be evolved.

Reinforcement

Additional transverse and longitudinal layers are placed at frame/rib stations and stiffener locations to improve notch and bearing strength of the skin where fastening is required. Sufficient pitch, edge distances, ply drops, stacking sequence rules are followed. Titanium and steel fasteners are used to avoid galvanic corrosion.

T-pull and T-shear

Co-cured and co-bonded stiffeners need sufficient attention to the design of the foot of stiffeners to avoid peak stresses at the toe. The shear peaking and peel effect at the ends of stiffeners also need sufficient attention.

Corner bending

Corner bending moment in spar causes inter-laminar tension and inter-laminar shear. A detailed study is required to prevent de-laminations.



Safety and health hazards

The release of toxic combustion products from composites in aircraft fires demands the use of personal protective equipment and particle filtration masks.

Composite panel material used in aircraft interiors must comply with strict heat release rate regulations. Epoxies are highly inflammable and thus cannot be used in composites for large surface areas such as interior panels-partitions, stowage bins, galley walls, and

ceilings. Phenolics are currently the thermoset resin of choice for aircraft interiors because of their low heat release rate.

Temperature effects

When two dissimilar materials are used, temperature stresses have to be taken into account while designing the part. Similarly, during the fabrication of a part, the tool used may induce warping because of difference in thermal expansion between component and the tool.

Failure Theories

Composites are subject to matrix-controlled and fiber-controlled theories. This can lead to either matrix or fiber failures or both. Suitable theories are to be used based on testing to predict failures. Theories such as

Tsai-Hill, Tsai-Wu, maximum strain theories or maximum stress theories and Puck are all used based on the requirements of design intent.

Engineering Requirements

Engineers and engineering firms that deal with composites must have a thorough understanding of the processes and attributes listed below:

- Mature design practices
- Extensive tests and analysis
- Robust survey techniques
- Damage tolerance philosophy
- Progressive failure models to predict impact damage
- Techniques to optimize impact performance and understanding bearing bypass methods, as well as the use of co-cured/co-bonded/bolted joints
- Use of new materials like resin infused composites with non-crimped fabrics, woven fabrics
- Geometry, stiffness degradation, and modeling of impact damage zones
- Effect of impact damage in simple laminates, sandwich panels and stiffened panels
- Systems to monitor and locate damage in structures in service
- Knowledge of PAM CRASH – physics-based simulation software
- Preventing damage caused by lightning strikes
- Good understanding of aerodynamics, structures and controls and aero elasticity, as well as related software
- Understanding of smart structures and gust alleviation
- Knowledge of tooling, manufacturing, repair methods and non-destructive testing
- Knowledge of cutting methods, shelf life, inspection procedures and safety precautions
- Different repairs like scarf joints rework schemes of various deviations
- Different categories and airworthiness requirements

Composites are expensive to repair, and some of them absorb moisture. Rapid technological advances are chipping away at these challenges, and some modern commercial aircrafts use as much as 50 per cent composites. Given the rapidly changing field and application, as well as the specialized knowledge required, it is important – when working with composites - to partner with an engineering firm which has extensive domain expertise.



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Author Profile



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N.S. Dwarakinath specializes in Finite Element Method (FEM), Fatigue and Damage Tolerance (F&DT), dynamics, and classical solutions for metallic and composite structures. He is well conversant in Nastran and Elfini, as well as in developing codes to solve problems in aero-structures.

Mr. Dwarakinath has a Bachelor of Engineering degree in Mechanical Engineering from U.V.C.E, Bangalore. He also has a Master of Technology degree in Engineering Mechanics from IIT, Chennai.

Mr. Dwarakinath comes with an impressive 37 years of experience in the field of aero-structures. He has previously worked for Hindustan Aeronautics Limited (HAL) in Bangalore, heading the stress, F&DT, and dynamics group at the Aircraft Research and Development Centre. His profile comprises the development and analyses of fuselage, undercarriages and other different aircraft components. Mr. Dwarakinath has also been responsible for providing testing support for ground and flight tests for fighter and trainer aircraft.

Mr. Dwarakinath is credited with the following achievements:

- QuEST Technical Excellence Award for his work on the development of undercarriages for helicopters
- ‘Approver’ status in HAL from Centre for Military Airworthiness and Certification (CEMILAC) and the Directorate General Civil Aviation (DGCA)
- ‘Approver’ status in CADES from Centre for Military Airworthiness and Certification (CEMILAC) and the Directorate General Civil Aviation (DGCA)
- Publisher of a number of papers in international and domestic journals
- Lifetime membership of ISAMPE

At QuEST, his role includes:

- Working for GKN regarding A400M and A350s
- Working with Hyde concessions
- Training and mentoring engineers

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About QuEST Global

QuEST Global is a focused global engineering solutions provider with a proven track record of over 17 years serving the product development & production engineering needs of high technology companies. A pioneer in global engineering services, QuEST is a trusted, strategic and long term partner for many Fortune 500 companies in the Aero Engines, Aerospace & Defence, Transportation, Oil & Gas, Power, Healthcare and other high tech industries. The company offers mechanical, electrical, electronics, embedded, engineering software, engineering analytics, manufacturing engineering and supply chain transformative solutions across the complete engineering lifecycle.

QuEST partners with customers to continuously create value through customer-centric culture, continuous improvement mind-set, as well as domain specific engineering capability. Through its local-global model, QuEST provides maximum value engineering interactions locally, along with high quality deliveries at optimal cost from global locations. The company comprises of more than 7,000 passionate engineers of nine different nationalities intent on making a positive impact to the business of world class customers, transforming the way they do engineering.



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