Applications Of Composite Materials In The Aviation Industry

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Abstract- *Composite Materials such as Carbon Fiber Reinforced Plastics (CFRP), Glass Laminate Aluminium Reinforced Epoxy (GLARE) are now being used extensively in the aviation industry due to their versatility and their mechanical properties. The use of composites as structural materials has many advantages due to their ability to sustain different flying environments and their pertinent (ad hoc) applications for the very purpose. The leading companies in the commercial aviation industry such as Airbus and Boeing have been using the composite materials such as CFRP and GLARE for the manufacturing of commercial aircrafts such as Airbus A380 (the largest passenger carrying commercial jetliner in the world), Airbus A350 and Boeing 787 Dreamliner for quite some time now. The composite materials decrease the weight of the aircraft thereby increasing the flying time, they increase the fuel efficiency and the number of flights possible with a single aircraft over a span of some years also increases due to the use of composite materials. The nature of operation and the response of the composite materials under different loading conditions, the response to various stresses have been represented. The advantages and drawbacks of the composite materials as the structural materials for aeronautical applications have been discussed in the process.*

Keywords- Airbus A350, Boeing 787 Dreamliner, Carbon Fibre Reinforced Plastics (CFRP), Composite Materials, Glass Laminate Aluminium Reinforced Epoxy (GLARE),

I. INTRODUCTION

The use of metals in the commercial aircraft applications has always posed a challenge for the aviation industry because of their weight as well as mechanical properties as the metal fuselage structures are more prone and susceptible to stress cracking due to stress concentration and fatigue failure. The high losses due to the stress concentration, fatigue failure and reduced flying time for the aircraft forced the aviation industry to look for options other than metal structures in order to increase the efficiency of an aircraft so that the flying time of the aircraft is increased and the reduction of the weight of aircraft takes place. The composite materials were just the right replacement or an answer to these shortcomings. The composite materials had an immediate impact that the aviation industry was looking for and the performance of the composites was as expected. This led to a reduction in the weight of the aircraft, an increase in the fuel efficiency and an increase in the number of flights of the aircraft. Emergence of strong and stiff reinforcements like carbon fibre along with advances in polymer research to produce high performance resins as matrix materials have helped meet the challenges posed by the complex designs of modern aircraft. The large scale use of advanced composites in current programmes of development of military fighter aircraft, small and big civil transport aircraft, helicopters, satellites, launch vehicles and missiles all around the world is perhaps the most glowing example of the utilization of potential of such composite materials.

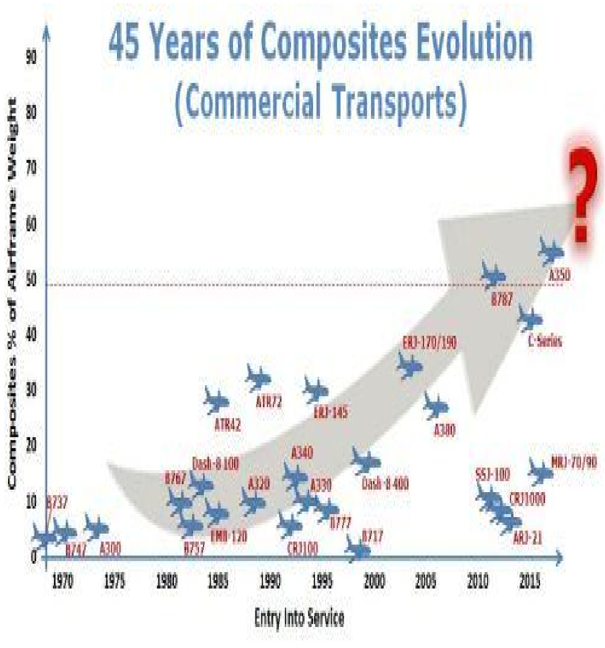

Fig. 1 Graph illustrating the evolution of composite materials in the commercial aviation

The graph illustrating the use of composite materials in the commercial aircrafts over a period of 45 years has been shown. In the phase from 2010-2015, the percentage of composites used in the modern aircrafts crossed 50% with the introduction of Boeing 787 Dreamliner and the Airbus A350

XWB. The integration of the composites with the fuselage of the aircraft really began to increase in the time period from 1980-1990 during which many aircrafts had their fuselage made of composite materials; some examples are Airbus A320 and Boeing 767, among others. The Boeing 787 Dreamliner has 50% composite composition whereas Airbus A350 XWB has 52% composite composition. It would be very interesting to see where the aviation industry goes from here on as far as the use of composites in the structure is concerned.

II. BACKGROUND

In the aerospace industry the benefits of exploiting the excellent specific strength and stiffness properties (strength and stiffness per unit weight) of composites in terms of lightweight structural design are immediately apparent. Furthermore, the laminated nature of high performance composite materials enables the designer to tailor optimum mechanical properties by orientating the fibre direction with the primary load paths. As a result, the first generations of commercial aircraft that contain large proportions of composite parts, such as the Boeing 787 Dreamliner and Airbus A350 XWB have entered into service recently. Other advantages of fiber reinforced plastics, such as the relative ease to manufacture complex shapes, and their excellent fatigue and corrosion resistance, have made FRP composites increasingly attractive in the renewable energy sector.

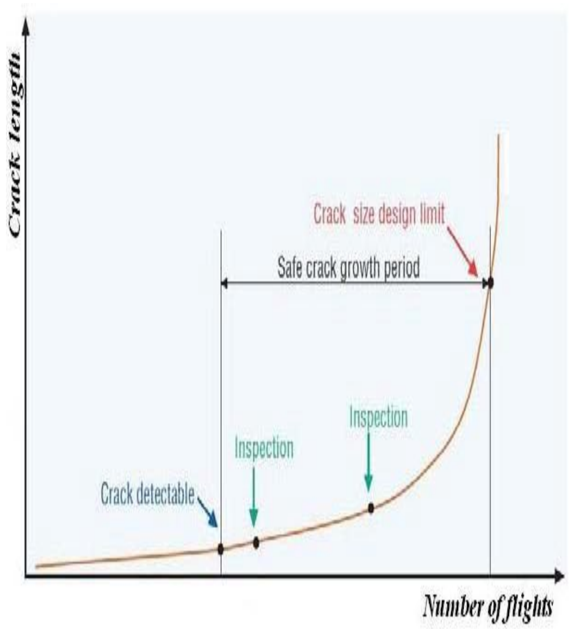

Fig.2 Graph illustrating effect of crack length on the number of fights

III. LITERATURE REVIEW

1. 'Fiber-Reinforced Polymer Composites as Structural Materials for Aeronautics' studied by Fulga Tanasa et. al.
In this paper, the nature of composite materials and behavior under specific conditions has been discussed.
2. 'Advanced composite materials of the future in aerospace industry' studied by Maria Mrazova.
In this paper, improvement in the physical properties to allow composites' application in new areas and roles for further usage in the future has been discussed.
3. 'Composite Materials in Aerospace Applications' studied by Nikhil V Nayak.
In this paper, impact damage and damage tolerance in general, environmental degradation and long-term durability has been discussed.
4. 'Composite Materials in the Airbus A380 - From History to Future' studied by Jérôme Pora.
In this paper, the composite materials used in the Airbus A380 and their properties have been discussed.
5. 'Developments to manufacture structural aeronautical parts in carbon fiber reinforced thermoplastic materials' studied by Jorge Diaz et. al.
In this paper, reinforced thermoplastic structural detail parts and assemblies have been discussed.

IV. BASIC PRINCIPLES

The basic principles that the composite materials are based on are basically a matrix and reinforcement. The matrix can be made up of plastic or epoxy resin which binds the composite together in shape. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. The reinforcement used can be carbon fibers, glass fibers or aramid fibers.

Due to the combined properties of the matrix and reinforcement, it resulted in imparting more strength to the fuselage or to the aircraft as a whole. The combined characteristics granted it lightweight, due to high specific strength and stiffness, fatigue and corrosion resistance, time and place stability, low dielectric loss, achievable low radar profile and stealth availability. So, basically we need both the matrix as well as reinforcement to impart their respective properties in the aviation industry.

V. CASE STUDY (AERONAUTICS)

The composite structure of the aircraft should be strong enough to sustain all the various forces as well as stresses that it is subjected to while it is taking off, while it is cruising at 40,000 feet above the ground at a certain velocity or at 0.95 Mach, while the turbulence occurs in the sky and while it is landing on the ground on a runway.

Now, suppose we need to select the materials for the Airbus A380, then the A380 composite structure should be strong enough to sustain the aforesaid conditions. Now, the part of the goal is to select the most appropriate material for the specific application, which would lead to the lightest possible structure. The A380 is the first aircraft ever to boast a CFRP composite central wing box, representing a weight saving of up to one and a half tonnes compared to the most advanced aluminium alloys. On the A380, the centre wing box weighs around 8.8 tonnes, of which 5.3 tonnes is composite materials.

A monolithic CFRP design has also been adopted for the fin box and rudder, as well as the horizontal stabilizers and elevators. The size of the CFRP Horizontal Tail Plane is close to the size of A320 wings.

The parts of the aircraft such as the empennage are made of CFRP, flap track fairings have carbon/glass epoxy skins, fuselage belly fairing also have carbon/glass epoxy skins, landing gear door has carbon epoxy skins, the nose gear doors have carbon fiber epoxy skins, Pylon fairing access panels have Kevlar/carbon fiber epoxy skins and Pylon aft secondary structure has carbon/glass fiber epoxy skins.

The major candidates were first reviewed before their applications in the aforesaid locations. As we have to select the best material for the most pertinent application, we cannot select an underperforming material, per se. The material has to provide the desired results against the opposing factors such as fatigue resistance, corrosion resistance, stiffness as well as stress cracking and tensile loading.

By way of comparison, the ultimate strength of aerospace grade aluminum alloys is 450MPa, whilst that of a carbon fiber would be five times higher. Glass, aramid and boron (far superior to carbon fibers, but 6 times more expensive) fibers are also used, but it seems carbon fibers have the best strength/cost ratio for primary load-bearing structure. The carbon fibers technology continues to improve by valorizing the versatility of carbon fibers and new varieties with improved modulus and strength are available.

Due to their mechanical behaviors, design criteria are different for metallic and composite structures. Numerous years of successful experiences at designing metal structure cannot be directly transferred to composite structures. First, composite materials are not isotropic like most metallic alloys. Second, the initiation and growth of damage and the failure modes are more difficult to predict analytically on composites. Due to these complications, the best practices are fully understood only by those engineers that are experienced at designing composite structures.

TABLE 1: Reinforcing fibers used in aerospace industry

Fibers	Density (g/cm3)	Modulus (GPa)	Strength (GPa)	Application
Glass (E-Glass)	2.55	65-75	2.2-2.6	Small passenger aircraft parts, radomes, rocket motor casings
Intermediate Aramid (modulus)	1.44	120-128	2.7-2.8	Radomes, some structural parts; rocket motor casings
Standard Carbon (modulus)	1.77-1.80	220-240	3.0-3.5	Widely used for almost all types of parts, satellites, antenna dishes, missiles, etc.

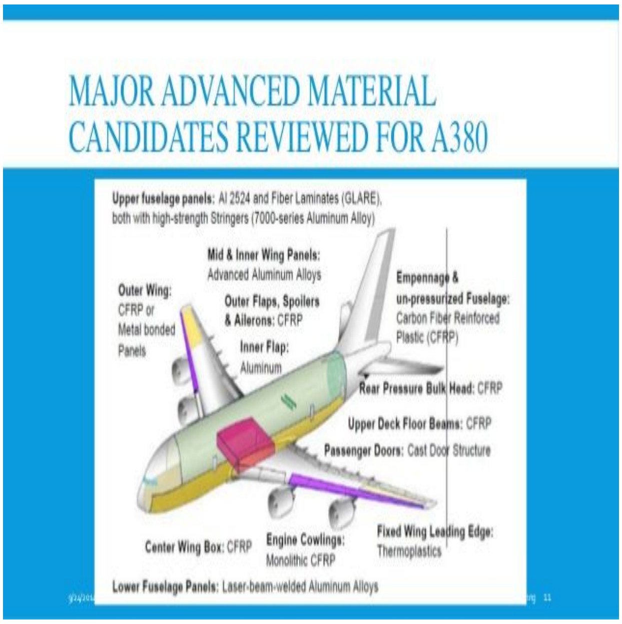

Fig.3. Major advanced material candidates reviewed for A380

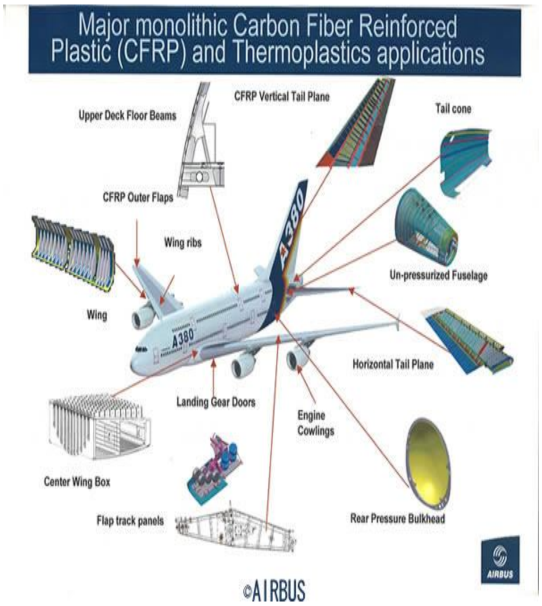

Fig.4. Major monolithic CFRP and Thermoplastics applications

VI. ADVANTAGES AND DISADVANTAGES OF COMPOSITE MATERIALS

Advantages of composite materials:

1. Weight reduction – savings in the range 20% - 50% are often quoted
2. Mechanical properties can be tailored by 'lay-up' design, with tapering thicknesses of reinforcing cloth and cloth orientation.
3. High impact resistance – Kevlar (aramid) armor shields planes, too – for example, reducing accidental damage to the engine pylons which carry engine controls and fuel lines.
4. High damage tolerance improves accident survivability.
5. 'Galvanic' - electrical – corrosion problems which would occur when two dissimilar metals are in contact (particularly in humid marine environments) are avoided. Here non-conductive fiberglass plays a roll.
6. Excellent strength-to-weight ratio.

Disadvantages of composite materials:

1. Some higher recurring costs
2. Higher nonrecurring costs
3. Higher material costs
4. Non-visible impact damage
5. Repairs are different than those to metal structure
6. Isolation needed to prevent adjacent aluminium part galvanic corrosion.

THE COMPOSITE MATERIAL COMPOSITION:

The Boeing 787 Dreamliner was one of the first aircrafts in the commercial application to have half of its structure comprising of the composite materials. The 787 Dreamliner has its entire fuselage made up of the composite materials such as Carbon Fiber Reinforced Plastic (CFRP), Carbon Laminate and Glass Laminate Aluminium Reinforced Epoxy (GLARE) or fiberglass.

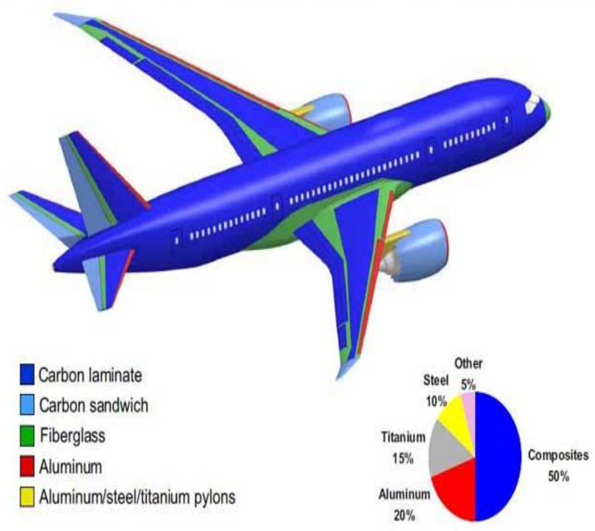

Fig.5. Boeing 787 Dreamliner has 50% of its structure made of composite materials

The recent commercial aircraft that has entered into service is the Airbus A350. The Airbus A350's structure is also made up of composite materials. As a matter of fact, 52% of its structure is made up of composite materials.

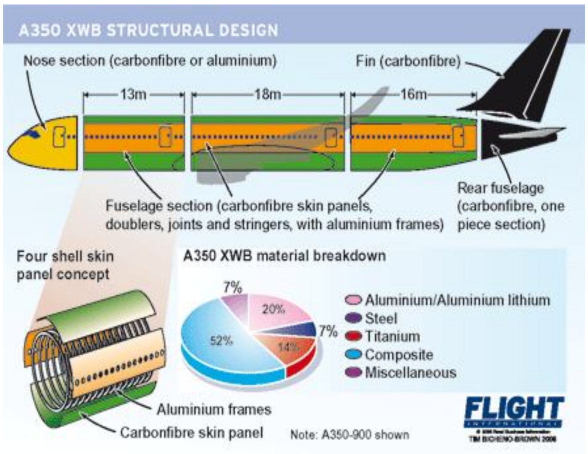

Fig.6. Airbus A350 XWB has 52% of its structure made up of composite materials

Another aircraft that uses composite materials as structural materials is the Airbus A380 – the largest passenger carrier jet in the world. Some part of its fuselage is made up of GLARE (or fiberglass), the tail of the aircraft as well as the flaps are made up of CFRP. The use of composites has a tremendous impact on the weight of the A380; there is a reduction of 15 tonnes of the weight due to the composites.

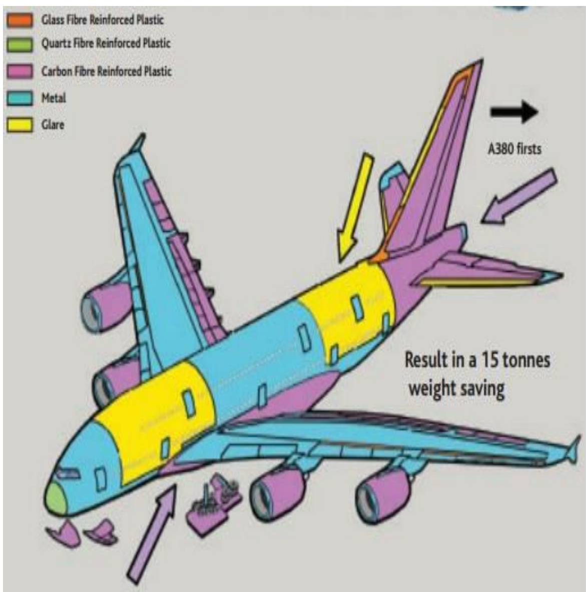

Fig.7. Composite Material Composition of the Airbus A380

Though GLARE is a composite material, its material properties and fabrication are very similar to bulk aluminium metal sheets. It has far less in common with composite structures when it comes to design, manufacture, inspection, or maintenance. GLARE parts are constructed and repaired using mostly conventional metal working techniques.

While a simple manufactured sheet of GLARE is more expensive than an equivalent sheet of aluminium, considerable production savings can be made using the aforementioned optimization. A structure properly designed for GLARE is significantly lighter and less complex than an equivalent metal structure, requires less inspection and maintenance, and has a longer lifetime-till failure, often making it cheaper, lighter, and safer in the long run.

TABLE 2: Aircraft requirements and subsequent design demands

Requirement	Design demands	Obs.
Low weight	Semi-monocoque construction Thin-walled-box or stiffened structures Use of low density materials: wood, Al-alloys, composites High strength/weight ratio, high stiffness/ weight ratio	Application area: all aerospace programs
High reliability	Strict quality control Extensive testing for reliable data Certification: proof of design	Application area: all aerospace programs
Passenger safety	Use of fire retardant materials and coatings Extensive testing: crashworthiness	Application area: passengers transport
Aerodynamic performance	Highly complex loading Thin flexible wings and control surfaces Deformed shape: aero elasticity, dynamics Complex contoured shapes: process ability, machining, molding.	Application area: all aerospace programs

Stealth	Specific surface and shape of aircraft Stealth coatings	Application in military program
All-weather operation	Lightning protection, erosion/corrosion resistance Corrosion prevention schemes Issues of damage and safe life, life extension Extensive testing for required environment Thin materials with high integrity.	Application area: all aerospace programs

VII. CONCLUSION

Composite materials are the way forward. The versatility that they provide and the fields in which they can be applied compliment each other very well.

The composites have the capability and the capacity to endure various environments in which they are applied.

The various types of composites like CFRPs, polymer matrix composites, ceramic matrix composites, glass laminate aluminium reinforced epoxy (GLARE) can sustain different flying environments and can be termed as adaptable materials.

The adaptability is with respect to the weather, different seasons, different aircrafts and spacecrafts where composites are applied.

Composite materials have some conspicuous drawbacks but the fact of the matter is that their pros outweigh their cons.

There are many advancements going on in the field of aeronautics as well as composites and more advancement will lead to more pertinent applications in the aviation sector.

The composite materials reduce the weight of the fuselage extensively because of their properties and structure. The ultimate aim of the aviation industry is to reduce the weight of the aircrafts to increase the flying time and the binder of flights the aircraft can go through. Composites play a crucial role to facilitate these needs.

The recent research in composites bodes well for the future as more research will lead to more useful applications in various fields. These are great times for the application of composites and for the world which will be ultimately benefitted by it.

REFERENCES

[1] Fulga Tanasa, Madalina Zanoaga, “Fiber-Reinforced Polymer Composites As Structural Materials For Aeronautics” International Conference of Scientific Paper Afases 2013 Brasov, 23-25 May 2013 Petru Poni Institute of Macromolecular Chemistry, Iasi, Romania.
[2] Maria Mrazova, “Advanced composite materials of the future in aerospace industry”. The Faculty of Operation and Economics of Transport. The Air Transport Department Univerzitna 1, 010 26 Zilina, Slovak Republic.
[3] JérŎme Pora, “Composite Materials in the Airbus A380 – From History to Future” Airbus, Large Aircraft Division, 1 Rond Point Maurice Bellonte 31707 BLAGNAC Cedex, France.
[4] Jorge Diaz, Luis Rubio “Developments to manufacture structural aeronautical parts in carbon fiber reinforced thermoplastic materials” EADS CASA, MTA Division/Cadiz Plant, Avda, Marconi 33, 11011, Cadiz, Spain.
[5] Nikhil V. Nayak, “Composite Materials in Aerospace Applications”, International Journal of Scientific and Research Publications, Volume 4, Issue 9, September 2014 ISSN 2250-3153.

WEBSITES

[6] www.wikipedia.org
[7] https://en.wikipedia.org/wiki/Composite_material
[8] https://en.wikipedia.org/wiki/Carbon_fibers
[9] http://aerospaceengineeringblog.com/composite-materials/