R E P O R T

Composite Materials in the advanced manufacturing

Introduction:

Materials make up every aspect of our world and have been critical throughout history in advancing both technological and cultural development, from the tools of the Bronze Age to the silicon driving the Information Age. The ability to effectively develop and deploy breakthrough materials technologies has always been inextricably tied to national prosperity and influence on the world stage. At no time has this been more evident than with the current imperative to secure a sustainable energy future.

Energy availability and the impact of energy consumption on the environment will be the delineating factor of major economic and security issues for decades to come. The effectiveness and practicality of many critical energy solutions will depend on advancements in materials and their manufacturing processes.

Achieving a markedly higher standard of fuel economy at an affordable cost and reduced environmental impact is a pivotal challenge for both the personal and mass transportation industries in the Clean Energy Age. Success will depend on the effective deployment of advanced materials innovations in nearly every system of the cars, trucks, airplanes, and other modes of transportation that have come to define modern commerce and quality of life.

Composite material is a material that consists of strong carry-load materials which are embedded in a somewhat weaker material. The stronger material is commonly referred to as reinforcement and the weaker material is commonly referred to as the matrix. The reinforcement provides the strength and rigidity that is needed and which helps to support the structural load.

The matrix or the binder helps to maintain the position and orientation of the reinforcement and is somewhat more brittle.

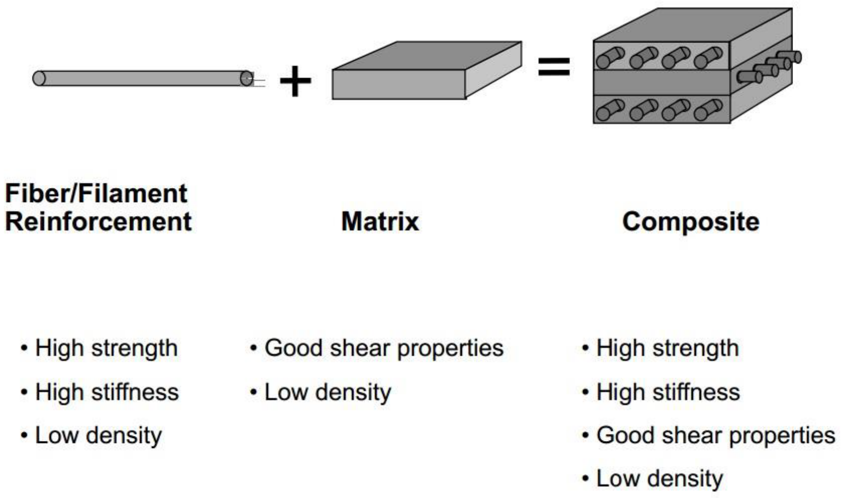


Fig. 1.Main composition of Composites

The matrix is the continuous phase of the composite. Its principal role is to give the shape to the structure. Therefore, matrix materials that can be easily shaped and then hold that shape are especially useful.

The matrix is the component of the composite that first encounters whatever forces might be imposed.

The principal role of the reinforcement is to provide strength, stiffness and other mechanical properties to the composite. Structural properties, such as stiffness, dimensional stability, and strength of a composite laminate, depend on the stacking sequence of the plies. The stacking sequence describes the distribution of ply orientations through the laminate thickness. As the number of plies with chosen orientations increases, more stacking sequences are possible.

Main Applications of composite materials in the industry:

Composite materials contain construction, marine goods, aerospace, transportation, sporting goods, and further newly infrastructure, with construction and transportation being the biggest. Generally, more costly but high act continuous carbon-fiber composites are used somewhere light weight along with high stiffness and strength are required, and in fewer demanding applications where weight is not as critical then considerable lower cost fiber-glass composites are used.

1. Aerospace Applications

Aircraft applications are the maximum significant uses of composites. Unlike other vehicles, commercial aircraft, essential to lay greater stress on safety and weight. They are realized by using materials through great specific properties. A modern civil aircraft designed as to encounter the several criteria of power and safety. As a result of forward-thinking technology that has gone beyond the design and application the glass and carbon reinforced hybrid composites are the best preferred materials.

2. Wind Power Generation

The applications of composite materials are used in wind power generation because the wind power engineering is a significance region of energy generation because of its resource saving and ecologically safe. The power monetary value mainly is determined substantially by simple power element blades. At present-day hybrid fibers (carbon, glass) are largely used for fabrication of the blades.

3. Automobile/Transportation Sector

In spite of the potential benefits and many advantages of lighter weight and high durability resulting from corrosion resistance, advanced composites are not used widely in automotive applications. There must be some step's should be taken on a global level to make advanced composites material attractive for some wide-spread use in trucks, cars etc. and all other automobile applications. The main cause which is a barrier for composite material is its high cost of raw and fabricated material, since the existing material used is of law cost.

4. Nanotechnology

The Composite materials have a wide range of applications in the field of Nanotechnology. The Nanocomposites is a resourceful conception having fillers on a nanometer scale isolated in the resin. Because of the diffusion of very small fillers, flame retardance and inflexibility of the resin improves significantly with the addition of only a tiny quantity of fillers. Nanocomposite materials are greatly used in automotive, electronic parts and in industrial equipments etc.

5. Marine Applications

In marine applications ships are under unbroken attack, both from the elements of nature and the enemy. The huge majority of ship hulls are created from common carbon steels, that are noticeably vulnerable to corrosion, but they also make different thermal and electromagnetic signatures simply noticeable from long distances.

6. Hybrid Thermoplastic Application

Thermoplastic composites which used for mass producing lightweight structural parts because it has long held potential properties. On the other hand thermoset constructed composites, which undergo time consuming chemical cross linking throughout processing; thermoplastic based composites are typically treated using simply heat and pressure.

7. Civil Construction

From the previous decade, largely in several countries, the research and development of totally hybrid Fiber Reinforced Polymer FRP structures in civil engineering has developed. All the structural elements have been made with Hybrid Fiber Reinforcement Plastics (Glass, Carbon) GFRP & CFRP. The all HFRP solution was chosen for this bridge due to its heavily corrosive atmosphere someplace the bridge is surrounded through the ocean. It is believed that the inventive materials can be competitive to other conventional materials in the close future when life cycle cost of the material is taken into account; there is a vital requirement for research and development of this revolutionary technology.

8. Telecommunication Applications

Telecom industries felt the need of explore the innovative product category known as hybrid cable because the reason behind that the requirement of power transmission along with data transmission are increasing in telecommunication industries. Hybrid aerial, underground cable is advanced and versatile cabling solution inside constructed power transmission required for network equipments with Optical Fiber Cable OFC. Hybrid Composite Cable is requirement of a period, primarily to support for Power transmission for always ON (Interrupt free) telecom needs.

9. Orthopedic Aids

People who were born with physical imperfections or who obtain disability, Orthotics and Prosthetics support by correct them with artificial supports. Prosthesis is an artificial replacement for a misplaced part of the body. Bio-medical prosthetic gimmick are artificial substitutes that are used in the human body to utility such as original parts. Materials intended for such prosthetic aids must non-toxic, chemically and biologically stable and have adequate mechanical reliability and strength to withstand physiological loads.

Composite material has been known as the innovative class of synthetic bio-materials. A vital improvement has been the usage of carbon fiber reinforced polymer matrix for composite limb. The reintegration industry is moving in the direction of composite material, as they are light- weight, comfortable to work with and more durable such as lighter prosthesis needs less energy consumption for the period of running, walking and other activities, weight is very important in an artificial leg.

10. Electronics and Electrical

The composites are fitted with high quality electric insulation, spark-free and good antimagnetic agents. They also have good adhesion toward glue & paint. Composite also possess selfextinguishing qualities due to which it is used for the construction of distribution pillars, link boxes and profiles for the separation of current-carrying phases to prevent short circuits etc.

11. Chemical Industry

The composite materials are one of the most popular materials used in chemical industry due to its various advantages of being light in weight, have better resistance against fire and show resistance to chemicals. Composite grips the wide use in chemical industry are used in the manufacturing of structural supports, storage tanks, exhaust stacks and blowers, columns, pumps, reactors etc. for acidic and alkaline environments.

12. Nuclear Industry

Composite materials are used widely in nuclear industries due to its nuclear fuels require good specific fission gas retention properties. Due to use in metal matrices, ceramic fuels are used at a great level from last few years. The ceramic fuels used in fast reactors have been sensibly successful in stainless steel matrix as used in plutonium uranium dioxide solid solution in steel cermets.

Composite materials applications in aerospace industry

There is a revolution underway in commercial aircraft manufacturing today and it can be summed up in one word: *composites*. There are many good reasons for aircraft manufacturers to use composites and for airlines to want composites to be used in their fleets.

Composite materials are becoming more important in the construction of aerospace structures.

Aircraft parts made from composite materials, such as fairings, spoilers, and flight controls, were developed during the 1960s for their weight savings over aluminum parts. The air transport industry has widely adopted carbon fibre reinforced plastics (CFRPs) as its composite materials of choice for airframe structures, engine nacelles and fan casings, floorboards and interior parts. Since first-generation CFRPs began appearing in civil aviation applications in the 1970s, major changes have taken place in the way CFRPs are made, their properties and the uses to which they are put in commercial aircraft. These changes are exemplified by the Boeing 787, the first airliner that is more than 50 per cent-composed of CFRP structures; and the Learjet 85, the first business jet with both fuselage and wing built primarily from carbon composites.

Applications of composites on aircraft include:

- ✓ Fairings
- ✓ Flight control surfaces
- ✓ Landing gear doors
- ✓ Leading and trailing edge panels on the wing and
- ✓ stabilizer
- ✓ Interior components
- ✓ Floor beams and floor boards
- ✓ Vertical and horizontal stabilizer primary structure on
- ✓ large aircraft
- ✓ Primary wing and fuselage structure on new generation
- ✓ large aircraft
- ✓ Turbine engine fan blades
- ✓ Propellers

New generation large aircraft are designed with all composite fuselage and wing structures and the repair of these advanced composite materials requires an in-depth knowledge of composite structures, materials, and tooling.

The primary advantages of composite materials are their high strength, relatively low weight, and corrosion resistance.

Many composite materials achieve relatively greater strength characteristics compared with traditional metallic materials, reducing aircraft weight and thus reducing fuel cost per passenger carried. Composites are more resistant than metal to fatigue from repeated take off/landing cycles, resulting in fewer costly inspections over the aircraft’s lifespan and more time spent in the air making money.

Several types of composites are commonly used in the aerospace industry. For example, composites were first used for military aircraft during World War II. Nowadays, they are used for private jets and modern commercial aircrafts in the aerospace industry.

Basic Families of Composite Structure:

There are two basic types of composite structures:

- ➢ ***Sandwich***: Thin, high strength skins are separated by, and bonded to lightweight honeycomb cores, the thicker the core the stiffer the panel with minimal weight increase.

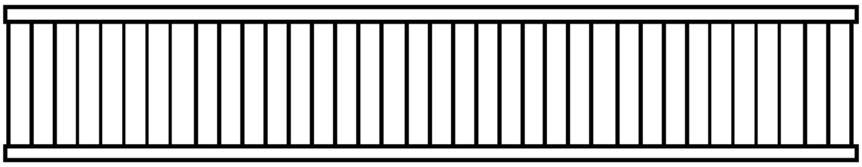


Fig.2. Sandwich structure.

- ***Solid Laminate***: assembled so that the fibre orientation provides most of the desired mechanical properties and the solid matrix largely determines the environmental performance.

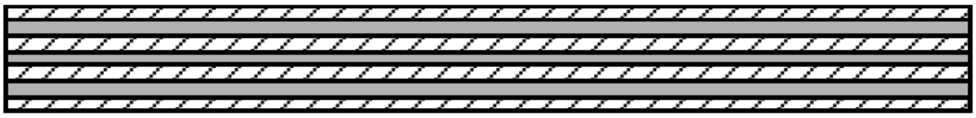


Fig.3 . Solid laminate structure.

It is important to note that the three most common existing types of composites are ***reinforced with fiberglass**, **carbon fibre** and **aramid fibre**.*

It is also interesting that each of these types has subtypes which provides for a wide variety of composites.

Fiberglass: is a fibre reinforced polymer made of a plastic matrix reinforced by fine fibres of glass. It is a lightweight, extremely strong and robust material. Although strength properties are somewhat lower than carbon fibre and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive.

Carbon-Fiber-Reinforced Polymer: is an extremely strong and light fiber-reinforced polymer which contains carbon fibers. Advantages include its high strength and corrosion resistance. Disadvantages include lower conductivity than aluminum; therefore, a lightning protection mesh or coating is necessary for aircraft parts that are prone to lightning strikes. Another disadvantage of carbon fiber is its high cost.

The composite may contain other fibers, such as aramid, e.g. Kevlar, Twaron, aluminum or glass fibres, as well as carbon fibres.

Aramid Fiber: *(Kevlar® is DuPont's name for aramid fibers)* is a class of heart-resistant and strong synthetic fibres. They are used in aerospace and military applications, for ballistic rated body armour fabric and ballistic composites, in bicycle tires, and as an asbestos substitute.

Every year the aerospace industry uses a higher proportion of advanced composite materials in the construction of each new generation of aircraft.

Back in the 1950s, when the most common composited of fibreglass was first used in the Boeing 707 passenger jet, composites accounted for 2% of the structure. By contrast, composites on the 787 account for 50% of the aircraft's structural weight and composites make up about 25% of the total airframe of the Airbus A380.

Boron: Boron fibers are very stiff and have a high tensile and compressive strength. The fibers have a relatively large diameter and do not flex well; therefore, they are available only as a prepreg tape product. Boron fibers are used to repair cracked aluminum aircraft skins, because the thermal expansion of boron is close to aluminum and there is no galvanic corrosion potential.

Ceramic Fibers are used for high-temperature applications, such as turbine blades in a gas turbine engine. The ceramic fibers can be used to temperatures up to 2,200 °F.

Matrix Materials:

Thermosetting Resins:

- ✓ Polyester Resins
- ✓ Vinyl Ester Resin
- ✓ Phenolic Resin
- ✓ Epoxy
- ✓ Polyimides
- ✓ Polybenzimidazoles (PBI)
- ✓ Bismaleimides (BMI)

Thermoplastic Resins:

- ✓ Semicrystalline Thermoplastics
- ✓ Amorphous Thermoplastics
- ✓ Polyether Ether Ketone (PEEK)

<u>The advantages & disadvantages of composites in aerospace industry:</u>

Composite materials are used more and more for primary structures in commercial, industrial, aerospace, marine and recreational structures.

Advanced composites do not corrode like metals – the combination of corrosion and fatigue cracking is a significant problem for aluminium commercial fuselage structure.

Composites today have a wide array of benefits in the aerospace and defence industry. Resulting fuel efficiency gained by an aircraft is becoming increasingly important with today's soaring fuel prices. Other positive attributes include excellent fatigue and corrosion resistance and good impact resistance.

Composite usage has increased across aerospace and defence verticals, and some segments are expected to grow significantly in the next 20 years.

Going forward, the total composite market is anticipated to quadruple at a compound annual growth rate of 7.3 %, reaching US $30 billion by 2026.

Main 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 fibreglass plays a roll.

Main disadvantages of composites materials:

1. Some higher recurring costs,
2. Higher nonrecurring costs,
3. Higher material costs (High cost of fabrication of composites),
4. Non-visible impact damage,
5. Repairs are different than those to metal structure (Repairing process of composites is complex as compared to that for metals),
6. Isolation needed to prevent adjacent aluminium part galvanic corrosion.
7. Composite material structure has more complex mechanical characterization than a metal structure,

Composite materials maximize weight reduction – as they typically are 20% lighter than aluminum and are known to be more reliable than other traditional metallic materials, leading to reduced aircraft maintenance costs, and a lower number of inspections during service.

A Federal Aviation Administration Advanced Materials Research Program report found that for every pound of weight saved on a commercial aircraft, there is a US $100-300 cost saving over the service life of that aircraft.

The Boeing 787 Dreamliner, with its widespread composite use in primary structures, will result in an aircraft that is 10,000 lb lighter and burns 20 % less fuel than a comparably-sized all aluminum aircraft. This shows that fibre composite use in aircraft results in significant weight savings, increased payload capacity and reduced fuel burn, allowing airlines using these aircraft to remain profitable in the face of rising fuel costs.

<u>Composites in aircraft production:</u>

Advanced composites play a key role in aerospace innovation. Airbus has pioneered the use of composites and other advanced materials in aircraft design and manufacturing, resulting in an industry-leading product line of economical and environmentally-friendly jetliners – from the single-aisle A320 Family to the 21st century A380 flagship (Fig. 4).

The latest development in the field of aerospace materials arises from the use of application-specific materials.

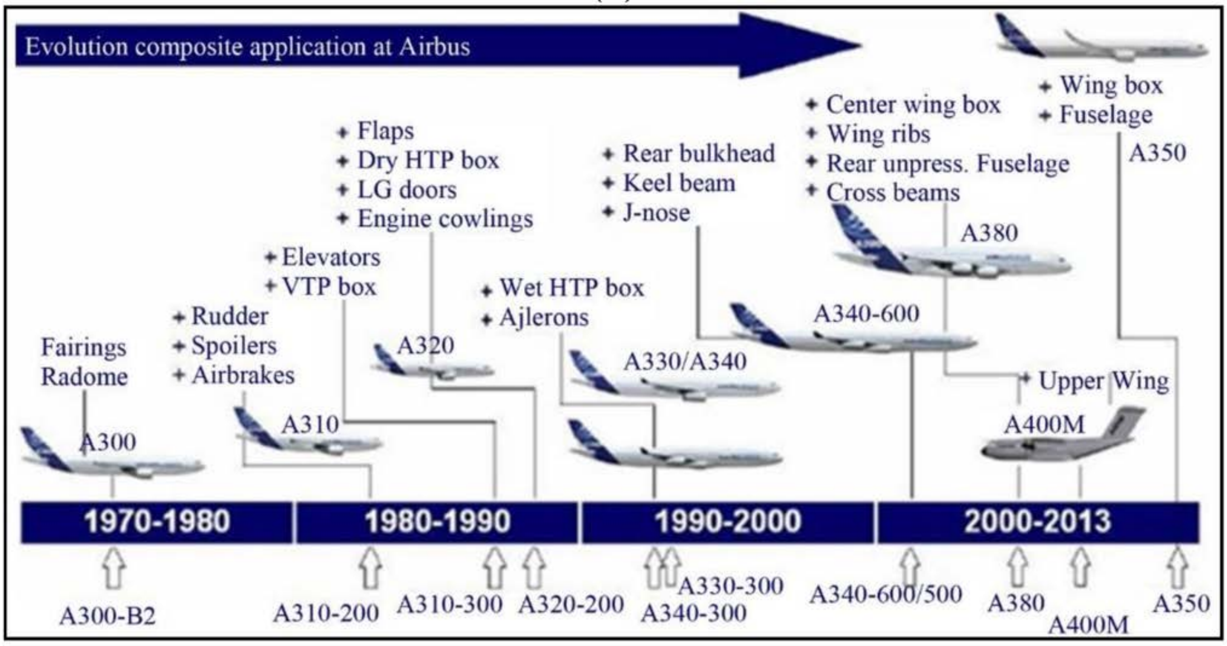


Fig.4 .Evolution composite application at airbus.

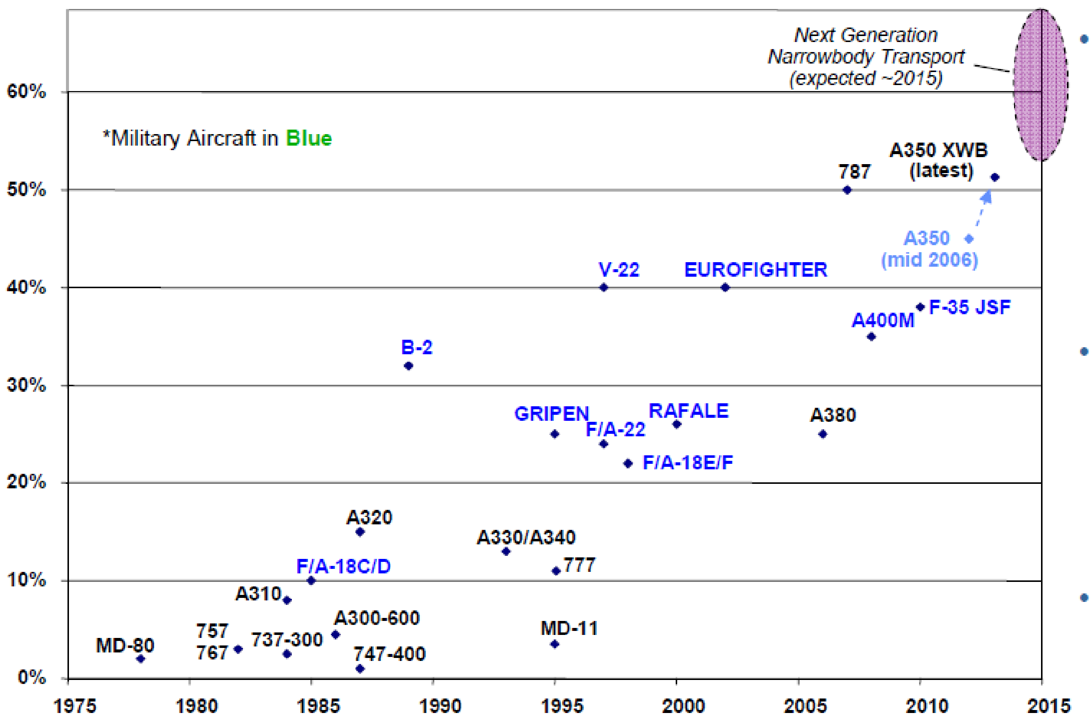


Fig.5. Aircraft Composite Content for Select Airframes % of structural weight.

Military aircraft designs were early adopters of composites (Fig. 5):

- ✓ Performance oriented
- ✓ Less cost sensitive
- ✓ Unique requirements (e.g. radar signature suppression)

The latest commercial designs, led by the B787, A380, and A350 XWB, feature significantly greater composite content.

Airbus recently announced that it has added a hybrid composite/metal fuselage to the A350XWB design (Fig.6).

Fig.6 . A 350XWB

Plane manufacturers have been increasingly using composite materials instead of traditional ones like aluminum, half of the weight of Boeing's latest plane, the 787, comes from composites (Fig.7)

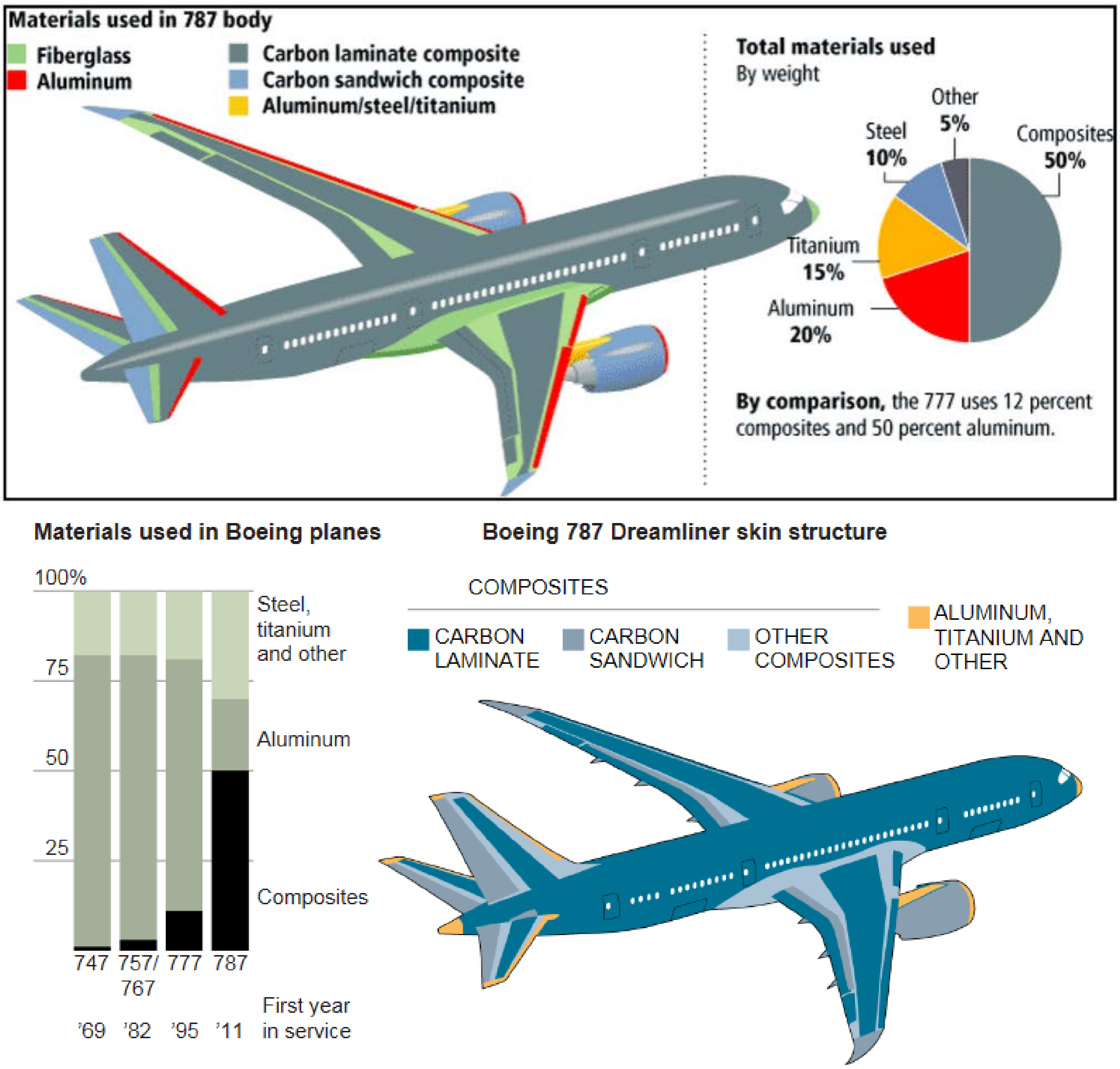


Fig.7. Composite materials application in B787.

Application development of composite materials in aircraft construction:

Growth in the use of composite materials in regional commercial airframes steadily increased in recent years, largely in response to airlines' concern about the ever-increasing cost of fuel. Chris Red, president of Composites Forecasts and Consulting LLC (Mesa, AZ, US), estimated that a mere 0.45 kg of weight savings reduces annual fuel expenses (at $3/gal) by US$185 to US$360 per year for a regional turboprop and US$175 to US$432 per year for jets, dependent on aircraft size and annual flight hours. He estimated that one less kilogram of weight on a single-aisle aircraft could save from US$330 to US$990 per year, per aircraft. Some of the savings will be earned by increased use of composites in passenger cabins. Although the composite interiors market is fairly mature — glass and carbon fiber composites have been used to reduce the weight of interior components for more than three decades — Red claimed there is "still plenty of room for improving weight, durability, aesthetics and functionality." Composites currently represent only 20-25% of total interior weight, but could increase to 30-40% in 10 years. Emerging interiors applications, says Red, could drive annual production volumes up an additional 60% by 2023.

To obtain the collection of data, an assessment of the percentage of total manufacturer empty weight of production commercial aircraft, with more than 100 passengers, from Boeing, Airbus, McDonnell Douglas, and Bombardier's CSeries was made and a tendency curve created from these data (Figures 8 and 9)

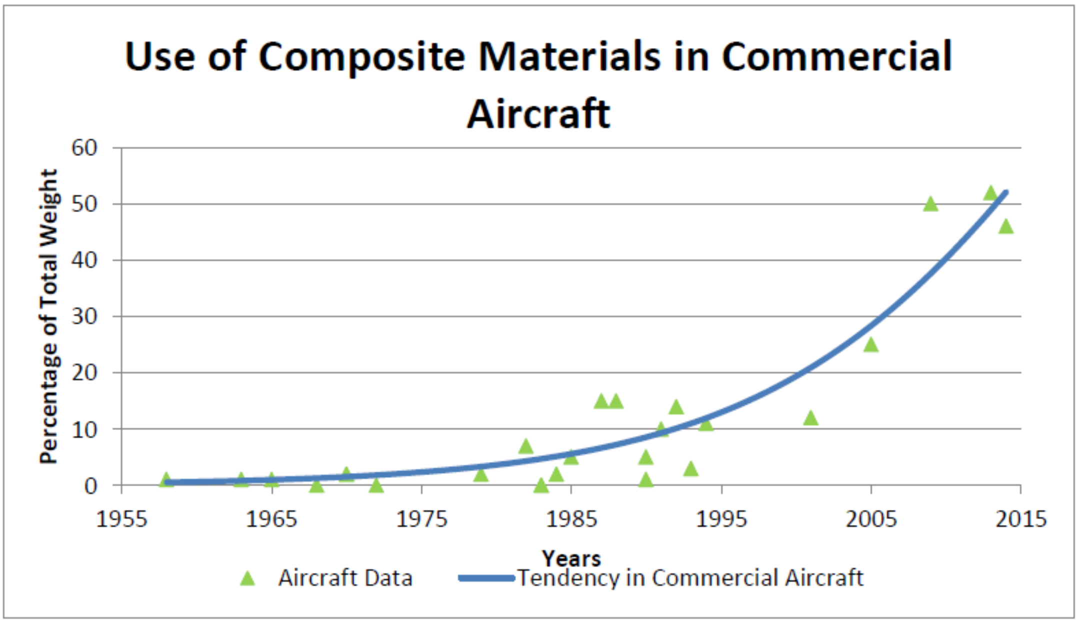


Fig.8 . Historical tendency of the use of composite materials in aircraft as percentage of total weight.

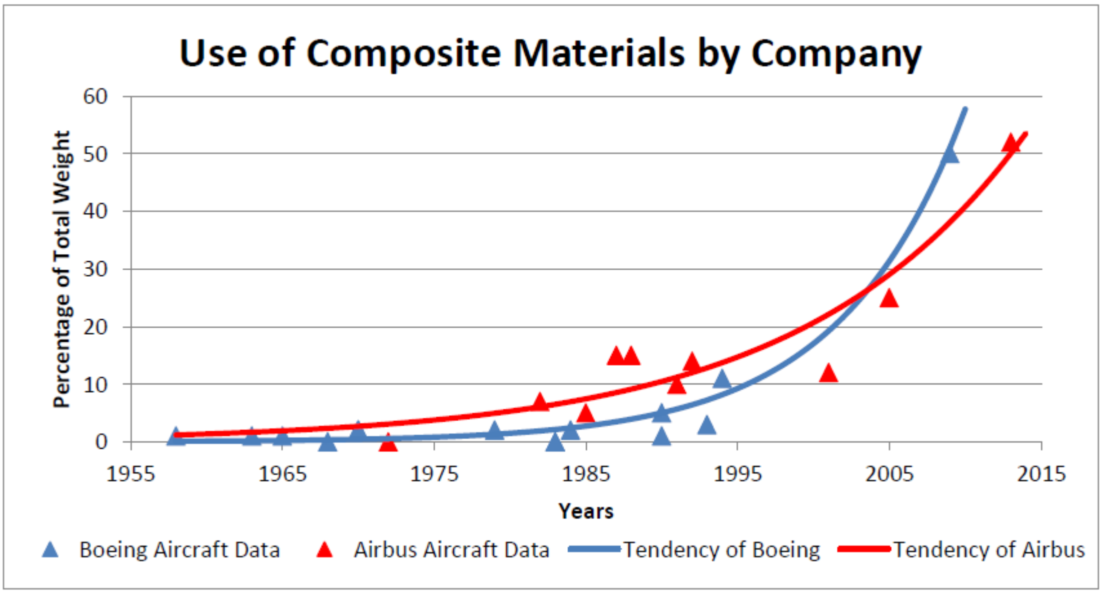


Fig.9 . Comparison between the historical tendencies of Boeing and Airbus. To note that McDonnell Douglas aircraft data are included in Boeing's.

From the above figures presented, one can see that, in fact, the use of composite materials have experienced an exponential growth in the commercial sector of the aeronautical industry, and so, one can conclude that currently composite use is in its exponential phase of growth. Throughout the years, Boeing has been quite conservative as to use composite materials in a large scale, with the exception of the new generation 787, jumping from some 11% of total weight in the 777 to around 50% in the 787. To note that there is a 15 year gap between the two aircraft. The reasons for this jump have to do with technology maturation that was achieved in Boeing during the Sonic Cruiser program and with certain conclusions that arose from the internal Airplane Creation Process Strategy ACPS initiative to produce an aircraft in half the time and half the cost. On the contrary, Airbus has, throughout the years, applied composite materials to its aircraft in an increasing manner, thus resulting in a less steep tendency curve. To note that in each new generation of aircraft, Airbus has used composite materials more extensively than Boeing.

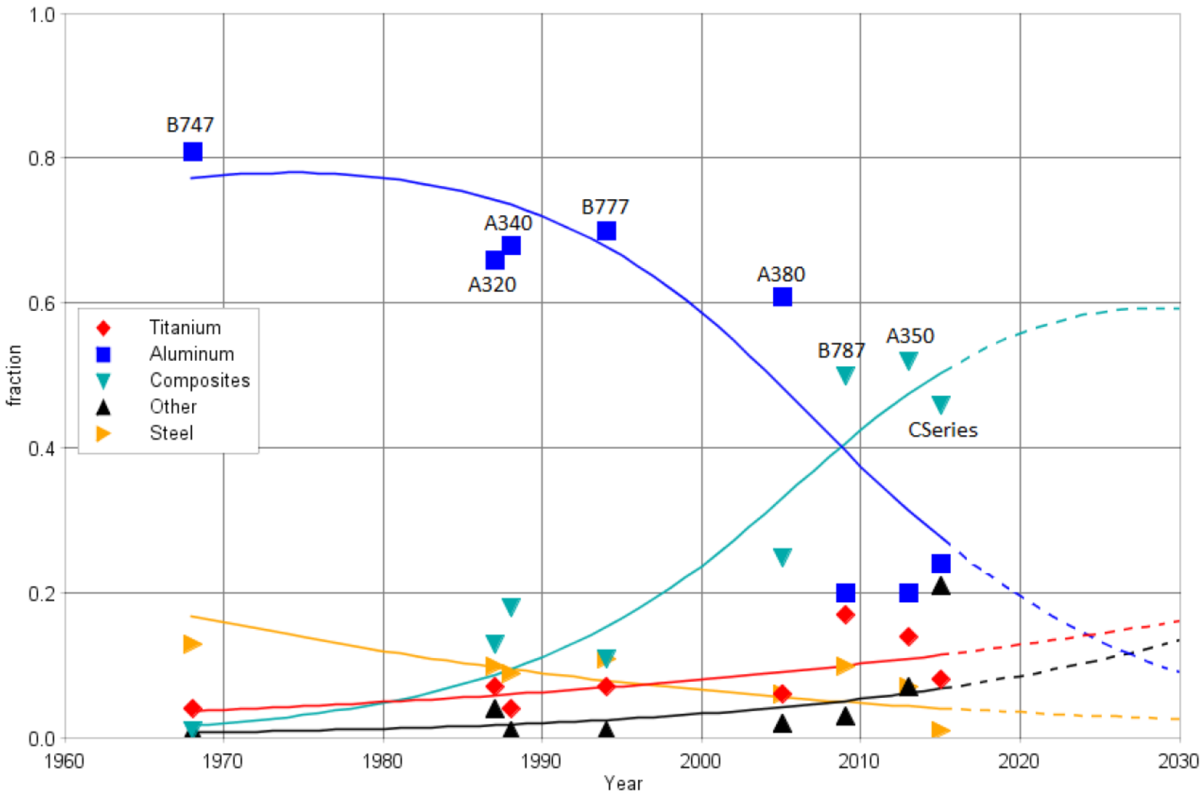


Fig.10 . Tendency of the mix of materials used in aircraft construction.

From figure 10, Composite materials are expected to reach a maximum of 60% of total aircraft weight, as assumed previously, by the year 2030. Then, and as said, the 70% value appears as an ultimate value admitting that in this time span technology breakthroughs will occur that allow this value. So, it must be seen as a hypothetic scenario.

Composite Repair challenges:

Damage to composite components is not always visible to the naked eye and the extent of damage is best determined for structural components by suitable Non Destructive Test (NDT) methods. Alternatively the damaged areas can be located by simply tapping the composite surface and listening to the sound. The damaged areas give a dull response to the tapping, and the boundary between the good and damaged composite can easily be mapped to identify the area for repair.

Awareness of and inspection for composite damage should be included in the regular maintenance schedules for composite structures. Particular attention would be made to areas which are more prone to damage.

Repairs to aircraft structures are controlled and should be carried out according to the Aircraft Structural Repair Manual (SRM). For other applications the repaired components would normally be expected to meet the original specification and mechanical performance requirements.

The next flow chart gives the main key stages for composite repair.

The main in-service defect types:

- Impact damage

- Ballistic damage
- Moisture ingression
- Chemical attack
- UV damage & weathering
- Erosion or abrasion
- Fatigue

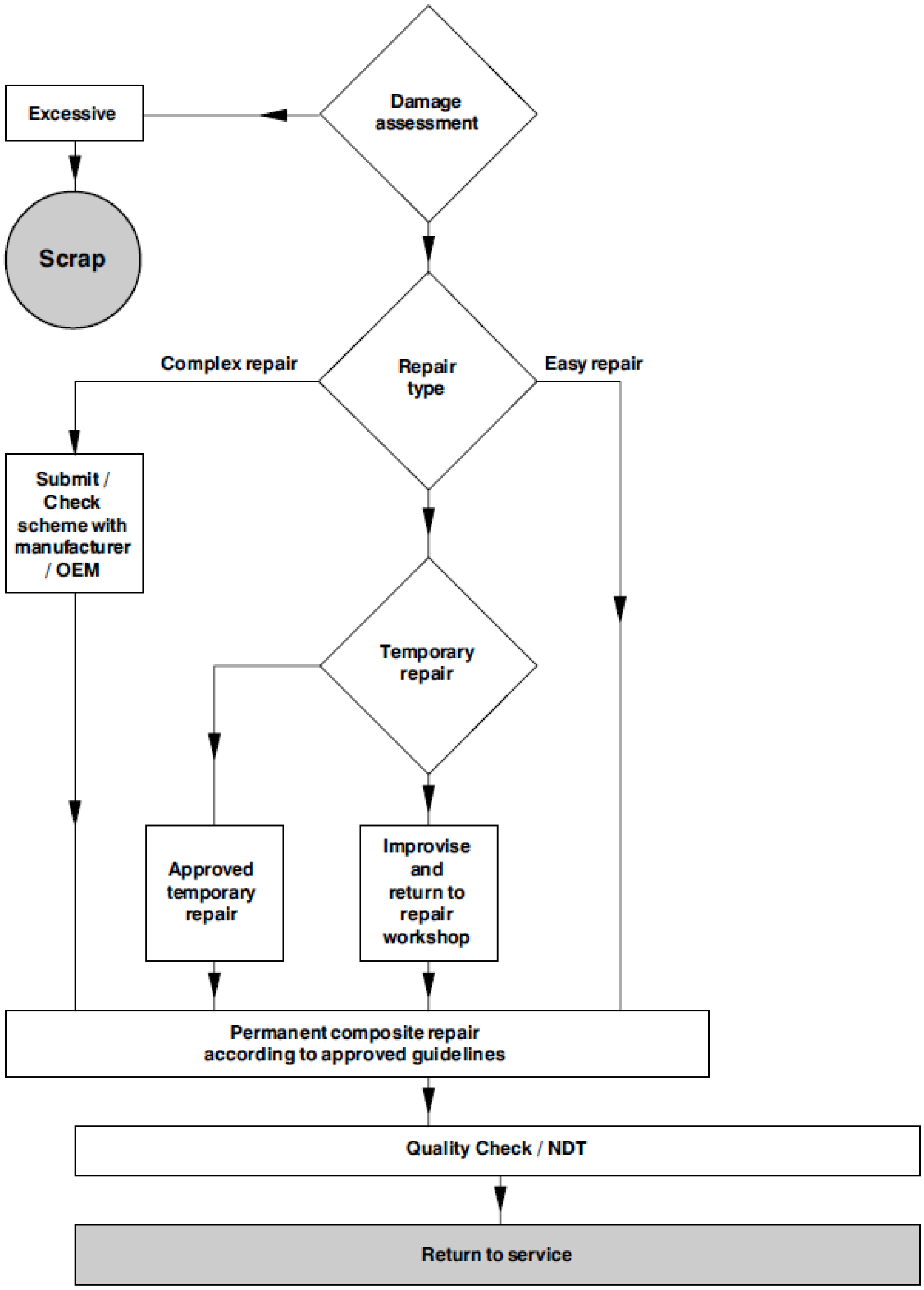


Fig.11 . flow chart of the main key stages for composite repair

The main Nondestructive Inspection (NDI) of Composites with comparison (Fig.12)

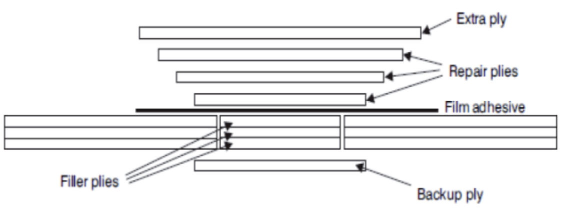
Method of Inspection	Type of Defect							
	Disbond	Delamination	Dent	Crack	Hole	Water Ingestion	Overheat and Burns	Lightning Strike
Visual	X (1)	X (1)	X	X	X		X	X
X-Ray	X (1)	X (1)		X (1)		X		
Ultrasonic TTU	X	X						
Ultrasonic pulse echo		X				X		
Ultrasonic bondtester	X	X						
Tap test	X (2)	X (2)						
Infrared thermography	X (3)	X (3)				X		
Dye penetrant				X (4)				
Eddy current				X (4)				
Shearography	X (3)	X (3)						

Notes: (1) For defects that open to the surface
(2) For thin structure (3 plies or less)
(3) The procedures for this type of inspection are being developed
(4) This procedure is not recommended

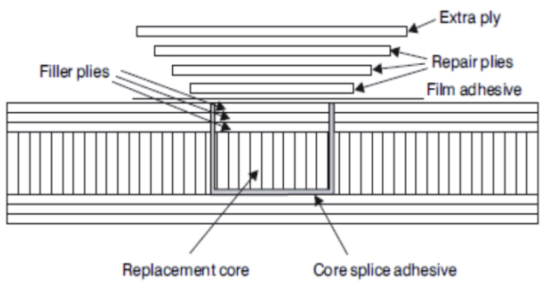
Figure .12. *Comparison of NDI testing equipment.*

There are two basic types of composite repairs:

- ***Bonded repairs***: Various types of bonded repairs are possible: resin injection, core replacement, structural repairs using Prepreg and adhesive film, bonding plates and wire mesh replacement, etc.



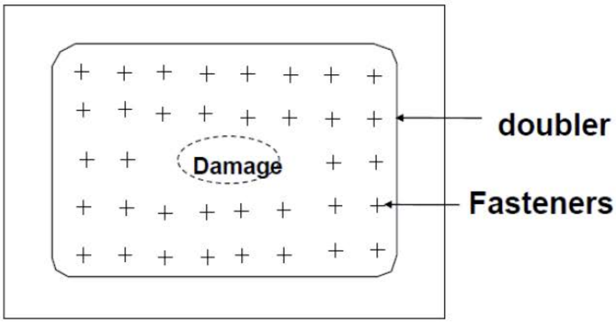
Typical laminate bonded repair

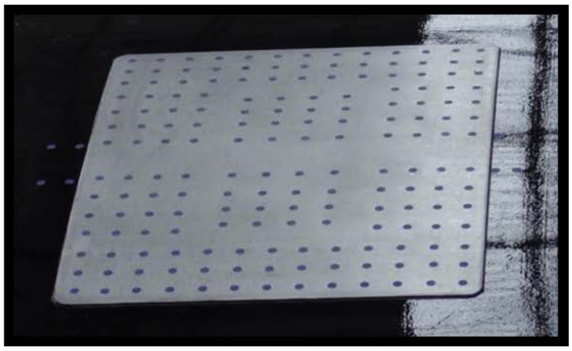


Typical sandwich panel bonded repair

Figure .13. Bonded repairs.

- ***Bolted repairs***: The basic concept of the bolted repair is that the damaged area is covered by a doubler which is mechanically joined to the structure using fasteners.





Example of bolted repair

Basic elements of a bolted repair

Figure .14. Bolted repairs.

The choice between the two types of repairs (which is not a Part 145 decision) is associated with advantages and disadvantages in both case (e.g., bonded repairs provide more uniform stress distribution but require a more rigid process regarding control and time, etc.). In general terms non-critical repairs may be bonded or bolted, while critical repairs will be bolted. The bonded repair dominates today and in order to perform such repairs the Part 145 AMO shall be specifically organised in terms of process control, facilities and equipment.

The increasing use of composites in commercial aircraft is ***creating debate about the best way to repair these materials.***

Repairing the composite parts that have been produced for jet airliners up to now is a well-established art, but repairing reinforced plastic fuselages is likely to be, as they say, a whole new ball game. With both leading commercial jet airframers now having adopted composites for the fuselages of their latest aircraft – the Boeing 787 and Airbus A350 XWB – airframers, regulators and repairers are facing a major repairs challenge.

Fuselages are typically monolithic wound or tape laid structures with various thicknesses and may have complex curvatures, as in this B787 nose section. This constitutes a new level of challenge for composite repairers.

There are uncertainties surrounding the repair of these internally-pressurised, humanity-containing tubes that are arguably the most safety-critical part of an aircraft and simply cannot be allowed to fail or be compromised. Fuselages are very different from the planar thin-skinned, honeycombcored structures that have been the mainstay of aircraft composite repair shops to date. They have pronounced curvature and utilise monolithic laminate that can be thick in some places. Being generally filament wound or tape laid they rely, for at least part of their integrity, on long continuous fibres. And, most significantly, they are engineered to withstand constantly repeated cycles of elevated internal pressure.
Clearly, with structures that are protecting occupants flying six miles high, repairs must be qualitatively beyond reproach, offering the highest levels of assurance. However, given the variability inherent in this supremely tailorable class of materials, plus the diverse skill levels of repair technicians, achieving this consistently is difficult.

The aerospace and automotive industries have a long track record in developing, manufacturing and repairing metallic structures. Static strength, yield, and fatigue are well-known degradation mechanisms in metals. Previously, composites were used as secondary structures because they did not affect the flight safety of the vehicle, making their extended service time performance less critical. Now that the aerospace industry is moving to primary loaded composite structures, long time degradation behavior will be critical. Composites are highly process sensitive and allow local properties to be tailored to meet the design specific requirement.

The aerospace industry has experience with composite repairs as secondary structures, but much work is required to develop the same confidence for primary safety of flight critical composite structures compared to the earlier nonstructural applications.

Whilst earlier Boeing and Airbus aircraft are approximately 10 to 15 per cent built of composite materials in terms of their total structural weights, the A380 is approximately 20 to 25 per cent composite materials". He says both the 787 and A350 are approximately 50 per cent constructed of composite materials, including aircraft surfaces like fuselage barrels.

The thin plastic skin on Boeing's 787 Dreamliner is an engineering marvel, a mix of carbon fibers and epoxy molded into large barrel-shaped sections that are then baked at up to 350 degrees in giant ovens.

But while airlines love how this lightweight concoction saves fuel, the recent fire on a 787 at Heathrow Airport in London ***provides the first test of how difficult and costly it will be to repair serious damage***. It's happening at a pivotal moment for Boeing, which is eager to show that even significant damage to a carbon-composite plane like the 787 can be repaired as quickly and effectively as in the old aluminum models. Each day a jet remains grounded costs an airline tens of thousands of dollars.

In September 2011, the US Government Accountability Office (GAO) released a report on the "status of the FAA's actions to oversee the safety of composite airplanes" (GAO-11- 849 Aviation Safety). The study was necessary, it said, because "although composites are lighter and stronger than most metals, their increasing use in commercial airplane structures such as the fuselage and wings has raised safety concerns".

The GAO report also identified four central safety-related concerns with the repair and maintenance of composites. These were:

- *limited information on the behaviour of aircraft composite structures;*
- *standardisation of repair materials and techniques;*
- *training and awareness;*
- *technical issues related to the unique properties of composite materials.*

Significantly too, the airworthiness authorities remain wary of bonded repairs and have been loath to certify them. Boeing and Airbus may be somewhat overoptimistic in claiming that they either have answers to all these points or are well on the way to having them. Both assert that composite fuselages are in any case tougher than those of metal and will be more resistant to damage. However, experience suggests that some damage will inevitably occur, especially to lower fuselage sections which are vulnerable to impacts from baggage loaders, catering carts and other service vehicles. When this does happen, aircraft operators will require access to repair schemes that are fully developed, approved and certified.

However, for *the Federal Aviation Authority (FAA) and European Airworthiness and Safety Administration (EASA), the main reason for withholding certification of bonded repairs is the lack of certainty over bond quality*.

The difficulty at present with a repair bond is knowing exactly what strength you've got. There‘s no sure way of testing a bond's strength without breaking it, and one has to rely on coupon or sample tests, which might not be fully representative."

Limited information

The GAO report admits that its concerns over the limited information on the behaviour of composite structures ***as they age or when they are damaged*** "are partly attributable to the limited in-service experience with composite materials used in the airframe structures of commercial airplanes" and therefore, "less information is available on the behavior of these materials than on the behaviour of metal". The report suggested that "more empirical data would help better predict the behaviour of damaged composite structures through more robust models or analytical methods". Reliable damage behaviour predictions are considered vital as they help form the basis for a new aircraft's design or maintenance programme.

The FAA has already issued an aircraft fatigue damage rule intended to help address "concerns related to limited information on how composite structures age and fatigue". The regulation, "Aging Airplane Program: Widespread Fatigue Damage, 75 Fed. Reg. 69746 (2010)", requires that "all manufacturers take a proactive approach to managing risk related to widespread fatigue damage by requiring the demonstration of the validity of the structural maintenance programme by test or service experience, in an effort to reduce the FAA's current practice of issuing airworthiness directives after an incident," according to GAO. As a result of attempts to increase the predictability of composite structures' behaviour Reichen believes that additional regulatory requirements are on the horizon. "I imagine that the FAA is going to mandate more and longer testing on the static fatigue testing aircraft used for certification similar to the already performed fatigue testing requirements, but under more stringent rules, including expanding non destructive testing (NDT) on the fleet leader aircraft," he says.

Another method for achieving greater industry- wide availability of data on the behaviour of ageing and damaged composite structures might be the implementation of a composite behavior data sharing and database development initiative, as part of an industry collaborative decision-making effort. But this option faces considerable limitations.

"The two main players are only going to share data when it is mandated by local authorities. Advanced know-how in composites manufacturing and behaviour represents a competitive advantage in the market and therefore sharing would not be very much appreciated by the manufacturers," explains Reichen. "The operators will accumulate most of the information anyway as usual; the question will be how this information is captured, funnelled back, validated, standardized and analysed for the most accurate results, in order to extrapolate the most accurate potential future results for the damage and fatigue behavior of the surveyed aircraft structures."

Limited standardisation

GAO also reported that "composite materials and repair techniques are less standardised than metal materials and repairs". This is due, in part, to business proprietary practices and the relative immaturity of the application of composite materials in airframe structures. As well as a repair technician potentially confusing materials or processes, which may result in improper repairs, the GAO report cautioned that "less standardisation can have a negative economic impact for airlines and repair stations because a repair facility might have to keep a large stock of repair materials and parts in house, which creates an inventory and storage challenge. Composite materials generally need to be stored at a specific temperature, and the materials also have shelf lives (i.e. expiration dates)".

These issues are being addressed by the Commercial Aircraft Composite Repair Committee (CACRC), whose stated mission is "to reduce the cost of maintaining composite structures through standardisation of materials technique and training". Boeing, an active member of the committee, reports that a standardisation effort such as that supported by CACRC can provide significant benefits to the MRO industry. "An industry standard guideline would decrease the amount of time necessary to obtain regulatory approval for repairs," says a spokesperson. "This would then reduce cost to an airline or MRO." CACRC's 'Repair Technique Task Group' is currently active in the development of standard repair process documents from current best practices, and a number have thus far been produced. Another CACRC task group is the 'Analytical Design Group', which is active in the development of a standard repair design and analysis document, "a guide of generally accepted stress analysis methods used for the design and evaluation of composite repairs for approval submission". "The intent of the document is to provide best practices for the development of a repair to be submitted to an airworthiness authority," says the Boeing spokesperson. "This will be beneficial to aircraft maintenance and repair because it will provide a better understanding of repairs design requirements to composite structure." The problem of limited standardisation has also been, in part, proactively addressed at the aircraft manufacturing level. In the case of the 787, the aircraft was "designed from the start with the capability to be repaired in exactly the same manner that airlines would repair an airplane today — with bolted repairs". Boeing states: "The ability to perform bolted repairs in composite structure is service-proven on the 777 and offers comparable repair times and skills as employed on metallic airplanes. In addition, airlines have the option to perform bonded composite repairs, which offer improved aerodynamic and aesthetic finish. These repairs are permanent, damage tolerant, and do not require an autoclave. While a typical bonded repair may require 24 or more hours of airplane downtime, Boeing has taken advantage of the properties of composites to develop a new line of maintenance repair capability that requires less than an hour to apply. This rapid composite repair technique offers temporary repair capability to get an airplane flying again quickly, despite minor damage that might ground an aluminium airplane."

Level of training and awareness

The GAO study's training concerns centre on whether repair technicians receive sufficient training and whether all those who come into contact with composites "are aware of and can appreciate the differences between metal and composite materials".

This issue is being addressed by the CACRC's 'Training Task Group', whose purpose is to develop standard curricula for non-NDT inspectors, technicians, and engineers. "The curricula were first developed in the mid 1990s," according to Boeing. "The training task groups' goal is to modularise the current curriculum into manageable training blocks. The first is a basic repair training curriculum that is non-equipment specific and then can be used as a method to meet initial training requirements. This curriculum will be referred to as the basic composite repair training programme. We have drafted a qualification /certification standard that would give training providers a method to issue an industry accepted certification of basic repair skills, knowledge, and abilities. The new document would refer to the curriculum document." The items to be developed are an advanced course curriculum that adds to the basic skill set, a metal bond repair curriculum, and, finally, a curriculum development guideline for the hardware specific repair that will be in aThe CACRC's curricula appear likely to receive the endorsement of a relevant and influential regulator, since "the task group has worked closely with the FAA". With regard to the availability of personnel competent enough to actually deliver the training on the contents proposed in these curricula, the Boeing' spokesperson says that "there are several training providers who would be able to provide the basic composite repair certificate training. However, an industry accepted basic repair certification would reduce the time required to train new employees."

On the differences between traditional metals and composites, Reto Inderbitzin, claims manager at Global Aerospace Underwriting Managers in Zurich, says that "in many cases mechanics and engineers still lack the necessary skills", with "proficiency in this discipline not yet that well developed". Inderbitzin draws attention to a specific example. "Composite aircraft encountering a lightning strike quite often record small dark holes on the skin and these need to be repaired as soon as possible, otherwise there is an increased risk of moisture infiltration," he says. "The problem is that even pilots conducting ramp checks may not have the competence to detect such damages as threatening. There is a need for an increased know-how as to the behavior of composites in the maintenance side of the business as well as in the piloting side."

Technical concerns

Another category of concern raised in the GAO report relates to the "challenges in detecting and characterising damage in composite structures, as well as making adequate composite repairs". The study noted that impact damage to composite structures is unique in that it may not be visible or may be barely visible, making it more difficult for a repair technician to detect than damage to metallic structures. A long term solution could involve applying evolved protective skins. The US

National Aeronautics and Space Administration (NASA) is funding a research programme whose goal is "the development of potential concepts for protective skins which enable natural laminar flow and a significant weight reduction in the aircraft's primary structure". Vicki Johnson, a principal investigator at Cessna Aircraft who is overseeing the project, says a protective skin is needed to absorb impact damage and to provide environmental protection.

The current and future challenges with composite materials:

- Human factor: New skills will be demanded from the maintenance personnel, Composite repair skills will be demanded, with all the necessary background education like gluing, carbon and composite cloth handling. Know-how in vacuum and heat treatment techniques for curing of repairs and more NDT skills to verify repairs will be needed as well."
- Manufacturing:
  Prepreg and autoclave cure has traditionally been the standard for aerospace- necessary to guarantee ultimate quality.
  Not appropriate for very large scale structures and preparation and cycle times are long.
  With build rates rising to satisfy demand, the OEMs needed to find a way, without compromising quality, to increase production line and eliminate autoclave. This produced two trends:
  Automated production: Automated tape laying, automated fibre placement. Cure can either be done in or out of an autoclave as long as an appropriate materials is used, examples of usage are B 787 nose and A 350 fuselage panels.
  Out of autoclave processing: Process involves laying up of dry fabric and introduction of resin either in wet of film form using a vacuum to pull it through the fabric.(e.g. Infusion..)
- Maintenance, repair and overhaul (MRO) requirements of composites are different from those metals.
- Shorter track record of use than metallic structures, many MRO companies therefor do not have much experience of maintaining composite structure.
- Parts are designed to cope with typical defects/damage (although given variations in microstructure in composites, even this can be difficult) but non-destructive testing is required to pick up damage/growth beyond these limits.

  The specific challenges with maintenance:
  - Specific defect types due to inhomogeneous nature of composites.
  - Defects are initiated during manufacturing as well as in-service.
  - Inspection regime usually involves use of several NDT techniques.
  - New and developments in existing techniques offer improvements in current state of the art, but these need to be validated and certified.
- Carbon fibre availability:
  Global usage of carbon fibre is growing in many industry sectors and the growth rate is accelerating.

The aerospace sector is not the only sector increasing use of carbon fibre. There massive expansion in the wind and automotive sectors too. Although current producers are increasing production and new producers are coming online at high rate, aerospace grade fibres are the most expensive to produce and need to be certified before use therefore increase production may be limited.

- Recycling:
  3000 tones CFRP (carbon fibre reinforced plastics) scrap produced annually, 6000 to 8000 commercial planes expected to reach end-of-life dismantlement by 2030.
  Therefore work has been done to develop methods that can be used to recycle carbon fibres out of CFRP.
  There is currently no real market for the recycled product that is produced.

- Materials development:
  The recent increase in the use of composites has involved the development of new/improved manufacturing methods.
  These manufacturing techniques are now allowing us to develop parts that are testing the limitations of the materials used. Future applications will require developments in materials properties.

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