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Evolution of Aerospace Materials: A Review

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Abstract - *The choice of materials used to construct an aircraft is of paramount importance due to several factors, such as safety, structural integrity and weight optimization. In this article, the evolution of materials that are particularly used in the aerospace industry since the beginning of last century is reported. This report will review the different materials that have been used in the aerospace industry since its inception. They include, but are not limited to, metals, plastics, composites, ceramics and glasses. With the development of new materials technology, aerospace engineering has quickly become one of the fastest growing industries and it is only set to continue to grow exponentially with innovations like 3D printing and nanotechnology. Alongside other industries like automobile engineering and locomotive manufacturing, aerospace engineering has benefited from such developments which have also helped increase space travel.*

Research is being conducted on materials that are designed to have excellent properties, including high strength/weight ratio, easy manufacturability, and corrosion and heat resistance. These materials would be suitable for aircrafts and offer a variety of benefits.

Key Words: Aerospace materials, Composites, Aircrafts, Aero engines and Additive manufacturing

1. INTRODUCTION

Aerospace materials have been either developed for or are expected to be used in future aerospace-related applications. These materials carry the loads exerted on the airframe during various flight operations and can withstand high temperatures, radiation, and other extreme conditions. The aerospace industry is faced with a variety of performance, strength, heat resistance, and fatigue resistance requirements that must be met by any materials used for the product. The inspection of these materials requires a lot of research and consideration before being approved for use by the company. The following table [1] represents the features of aircraft structure that include their applicability according to requirements and their effects.

1.1 Timeline of evolution

The aircraft materials have undergone an overwhelming phase of change since the takeoff of the first designed aircraft to the skies. This section will provide the timeline of the aerospace materials.

- **Period of wood**

In 1857, a French Naval officer, Félix du Temple de la Croix, received a flying machine patent. By 1874, he developed a lightweight steam-powered monoplane that flew short distances after take-off from a ski jump. It was finally, in December 1903, when the first controlled, powered, and sustained flight, called "Wright Flyer" took place near Kitty Hawk, North Carolina. This aircraft was made by the Wright Brothers. The materials involved in the construction of the Wright Flyer were:

a) Lightweight aluminum engine,

b) Giant spruce wood as the construction material, and

c) Timber for wing structures and fabric and dope that covered them

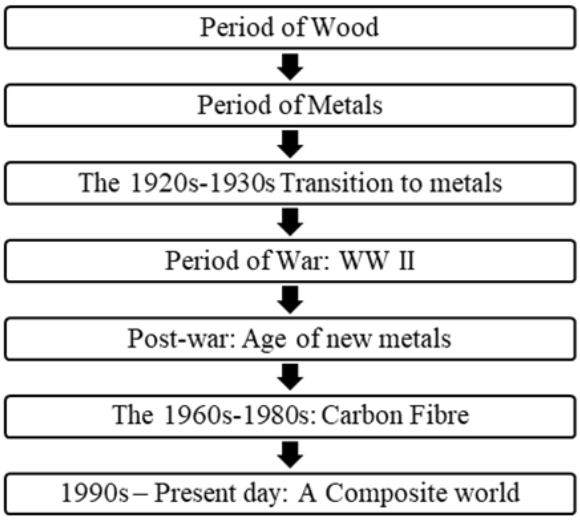

Figure 1: Evolution of materials

- *Advantages of wood, timber, and fabric*

The weight of materials while making aircraft is very important as the propulsion is dependent on that. So, the first aircraft was made using wood as it was lightweight and strong. The coefficient of thermal conductivity of the wood is very low. This means that practically, wood does not expand against heat. Due to their light-weightiness, the loss of energy due to friction is also significantly low in woods. Additionally, wood is an electrical insulator and the tensile strength of wood with 0.6/cm^3 specific gravity is 100 N/mm^2. Thus, they have very good shock-resistant properties and can bend without fracture.

The woods used in the early aircraft making were Sitka spruce, birch, ash, Douglas fir, mahogany, balsa, pine, and Gabon.

In fabrics, cotton and linen material were used for covering aircraft to reduce drag. Also, these fabrics were light as well as easy to apply.

Following is given a conventional aircraft structure made of wood. [2]

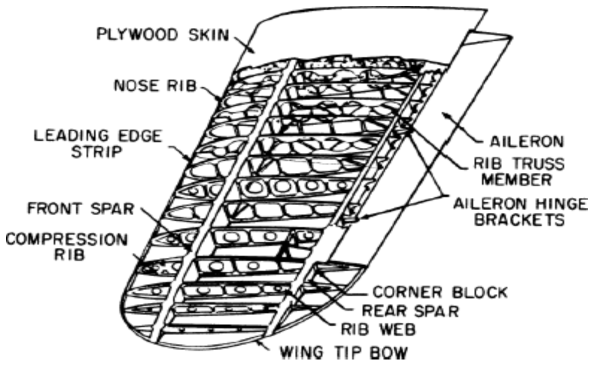

Figure 2: Aircraft wing made of wood

- *Drawbacks of wood, timber, and fabric*

Since wood is a hygroscopic material, they undergo shrinkage due to moisture. Biotic agents like mold fungi, bacteria, and insects, and Abiotic agents like sun, wind, water, certain chemicals, and fire cause their deterioration and destruction. Maintenance of aircraft is very difficult and costly. Additionally, aircrafts made of wood are prone to fuel leaks.

For fabrics, the major disadvantage is their flammability and lack of durability.

❖ Period of metals

Until 1915, it was thought that airplanes could only fly with light materials such as wood, struts, tension wires, and canvas. In 1915, Hugo Junkers, a German Aircraft designer built "J-1 Blechesel", a monoplane that was the first successful all-metal airplane. Materials used in the construction were:

1. Wide sheet steel panels and
2. Additional sheets of corrugated steel

In 1919, Junkers built F 13, the world's first all-metal transport aircraft, an advanced cantilever-wing monoplane for 4 passengers. Materials used were:

1. Aluminum alloy (duralumin) structure,
2. Corrugated and stressed duralumin skin, and
3. Circular cross-section duralumin spars with transverse bracing for building wings

- *Advantages of Metals*

Aluminum and its alloys started to be used because they are lightweight and strong. High-strength aluminum alloys (primarily alloy 7075) were used to strengthen the airframe structures. Aluminum is highly resistant to corrosion and thus it can be left unpainted.

Steel is stronger and stiffer than aluminum, but it is also heavier. So, it was chosen to be used for certain components like landing gear. Their hardness and resistance to heat make them an ideal candidate to be used on the skin surface of the aircraft. Typically, steel comprises around 11-13 percent of the materials used in an aircraft.

Steel is also used in wing root attachments because it has high stiffness, strength, toughness, and fatigue resistance.

The following graph [3] shows the strain and stress relationship of Aluminum and Mild Steel.

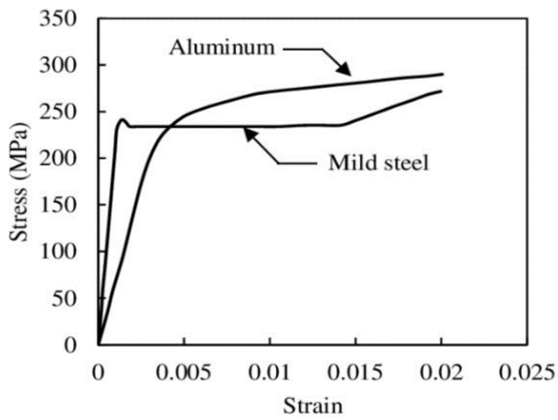

Figure 3: Stress-Strain curve

- *Drawbacks of Metals*

At high temperatures, aluminum loses strength and thus is very unsuitable for making the skin surface of an aircraft. Aluminum requires a costly and lengthy welding process. Because of its malleability, it can be more easily dented and scratched.

Steel is an alloy of iron due to which it is more susceptible to corrosion. The maintenance cost is high because of the painting required to make it corrosion-resistant. At high temperatures, steel loses its properties. The expansion rate with changing temperatures is high for steel which can be disastrous for the structure. Buckling is also a major issue for steel structures.

❖ The 1920s-1930s: Transition to metals

An American innovator Howard Hughes, found that monoplanes' frames made with aluminum alloys were capable of withstanding extraordinary pressures and stresses. The main reason behind choosing Aluminum was its lightweight design that reduced weight and thus made aircraft a more fuel-efficient design.

In 1925, Henry Ford, acquired the Stout Metal Airplane Company, utilizing the all-metal design principles proposed by Hugo Junkers, and founded the Ford Trimotor. The main aim was to design safe and reliable engines for airline travel. A few years later, Henry Ford's Trimotor NC8407 became the first airplane flown by Eastern Air Transport. This marked metals as the primary material for domestic aircraft as well as military applications with the onset of World War II.

The most significant model launched in this period was Douglas DC-3 that had its first flight in 1935. Even today DC-3 continues to fly in active commercial and military service. It is an all-metal aircraft and the materials used were primarily: steel and aluminum alloy.

- *Advantages of Metal alloys*

Nickel alloys can resist high temperatures and corrosion. They have high toughness and high creep resistance properties. They have extremely low levels of expansion at cryogenic temperatures of 500°F and above due to which they can retain their shape and strength at elevated temperatures too. They are used to make the turbines of airplane engines because engines are exposed to immense heat. In addition to this, nickel alloys can also be found in the exhaust valves, thermostat rods, tanks, and piping for liquefied gas storage.

The following figure [4] represents various series of aluminum alloys used in the aircraft industry. 2xxx, 6xxx, and 7xxx are different series of Al-alloys.

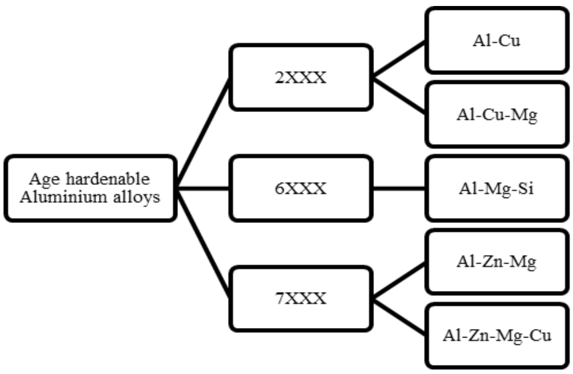

Figure 4: Aluminum alloys

- *Drawbacks of Metal alloys*

Aluminum alloys warp at high temperatures. Unlike Steels, they do not glow red before melting. Aluminum alloys have a lower fatigue limit than steel and will thus continually weaken with repeated stress. That is why they are rarely used in fabrication applications where high fatigue rates are required.

❖ **Period of war: WW II**

By the 1930s, wood was no longer used and all-metal aircraft were produced for their durability. Imperial Airways (today as British Airways), progressed in the air travel industry with advertisements of luxury and adventure to cross borders. With the outbreak of World War II, those borders were sealed off. In 1939, the company was ordered to operate from a military standpoint at Bristol Airport. The Boeing P-26 "Peashooter", the first all-metal and low-wing monoplane fighter aircraft entered the war with the United States Army Air Corps. The metals used were duralium and steel.

Later, Plastics entered the scene during World War II when the replacement of metal parts for rubber parts in U.S. aircraft began because Japan limited metal trade with the US. Thus, plastics of higher grades began to replace electrical insulators and mechanical components such as gears, pulleys, and fasteners. Further, aluminum parts started to be replaced with plastics because of their lightweight and thus being more fuel-efficient.

- *Advantages of Plastics*

To overcome the limitation that metals and their alloys had, plastics came into the picture.

The weight of materials when making aircraft is very important. Aluminum and other metals were heavier. Plastics were chosen because they were durable and lightweight. Acrylic and polycarbonate plastics were used for ventilation ducting and seals to the landing gear.

An aircraft encounters chemically harsh environments in its day-to-day operations. Plastics provide longevity to the aircraft as they are resistant to many corrosive chemicals.

Thermal insulation usually goes hand in hand with electrical insulation in materials. Thermal conductivity is reduced by the use of plastics.

The report [5] published on Grand View Research, gives statistics on plastics in the aerospace sector globally.

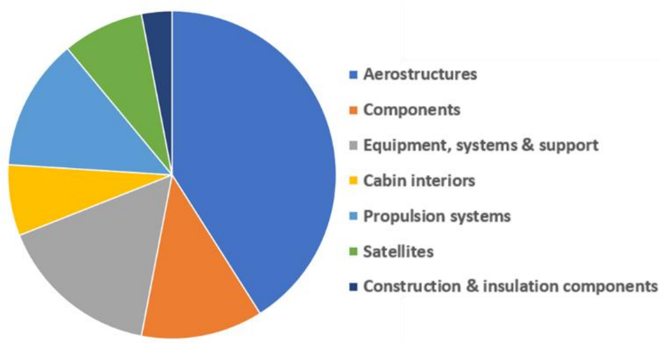

Figure 5: Usage of plastics

- *Drawbacks of Plastics*

High temperatures are a limitation of all organic polymers. Generally, the useful temperature varies from about 65 °C (150 °F) to about 370 °C (700 °F). There is a development of higher temperature polymers going on. But, polymers with service temperatures above 120 °C (250 °F) are very costly. The correlation between service temperature limit and polymer cost is almost linear. Reinforcement with fiberglass or other particulate fillers is a cost-effective way to raise both service temperature and stiffness appreciably.

Flammability is another drawback for plastics. Flame retardants such as chlorine and bromine compounds which are added to plastics make them self-extinguishing and difficult to ignite. However, once they are ignited, their burning produces toxic gases which are more hazardous. This is the reason that today, environmentalists are opposed to any materials containing chlorine or bromine.

Low-temperature brittleness is another limitation of plastics. The toughness of plastics reduced severely below the brittleness temperature.

Creep formation is the slow but steady deformation of materials under sustained loads. And plastics have the limitation of creep under sustained loading.

Additionally, Plastics have comparatively lower resistance to wear and abrasion. Plus, Ultraviolet, gamma-ray, and nuclear radiation resistance are limited for most plastics.

The property of static accumulation of electricity proves to be undesirable sometimes. Plastics are great electrical insulators. They can hold a good amount of static charges that arise from mechanical friction.

Another problem is their difficulty of repair compared to metals. A cracked metal can be welded. Many times, the weld is stronger than the parent metal. The process of welding is fairly old and thus familiar. Repair for plastics requires much greater skill compared to that of metals.

❖ Post-war: Age of new metals

Titanium began to be seen as an appealing option by engineers because of its strength-to-density ratio and resistance to corrosion, fatigue, and high temperatures.

In the late 1950s, Titanium was being used in parts like engines and sections that were exposed to high temperatures. However, Titanium being limited in resources skyrocketed the cost of production.

Today, Military aircrafts such as the F-22, F/A-18, C-17, F-35, and the UH-60 Black Hawk helicopter use large amounts of titanium for their production.

- *Advantages of the new Metals*

Although expensive, Titanium has excellent properties including high strength, high-temperature resistance, and high corrosion resistance. Titanium is commonly used in a variety of different parts of an aircraft both on the exterior and in the engine. It is being used in the wings and landing gear as well as the housing, fan blades, and pumps within the engine. In the present situation, the costs of titanium make it not feasible to be used for widespread uses like throughout the aircraft.

The higher oxidation resistance and strength retention of Titanium aluminide at high temperatures make them better suited for gas turbine engines and rocket propulsion systems. The titanium aluminides give high-temperature strength to the structural materials.

Shape-memory alloys can remember their shape after being plastically deformed. These alloys rebuild back to their original shape by heating or some other external stimulus provided the deformation they experience is within a recoverable range. The process of deformation and shape recovery is expected to be repeated many times. This makes these shape-memory alloys to be used in flight control systems. These alloys are being evaluated for several aircraft systems that would benefit from the shape-memory effect, such as control surfaces and hydraulic systems. The most common shape memory alloy is nickel-titanium, in which the titanium content is 45 to 50 percent.

- *Drawbacks of the new metals*

Titanium is extremely expensive, both in raw materials and processing. That is why its common use has been limited to that of the military, aerospace, medical devices, high-stress components like connecting rods in engines and railway applications, as well as expensive sports cars.

Designers face difficulty in the casting of Titanium. Titanium can not be easily cast, unlike iron and aluminum.

It must be noted that titanium is generally more expensive than other types of metals. When compared to steel, iron, aluminum, etc., one must expect to pay more for titanium. This is because of its rarity. Titanium is rarer than other metals due to which it has a very high selling price.

❖ THE 1960s-1980s: Carbon fiber

The first lightweight composite materials to be found in aircraft was Glass fiber-reinforced plastic or fiberglass.

It was used in rotor blades for helicopters such as the Bölkow Bo 105, the BK 117, and the Gazelle SA 340 in the 1960s and 1970s.

In the 1960s, Rolls Royce developed Compressor blades of the RB211 jet engine which was made of carbon fiber, due to its brittleness and unique fatigue behavior.

In the 1960s, Fibrous composite materials were originally military aircraft. From the 1970s, they were used in civil aviation too.

In 1975, the AS350 Écureuil helicopter presented the main rotor-head in glass fiber composite, which significantly reduced the number of parts with a highly integrated design.

In the 1980s, composites began to be used in secondary wing and tail components such as wing trailing edge panels and rudders.

- *Advantages of Carbon Fiber*

One of the greatest advantages of carbon fiber for aerospace applications is its lightweight. Weight decides the fuel consumption of any aircraft. So, the designer aims to have as light an aircraft as possible. Lighter aircraft require less fuel. In other words, lighter aircraft can travel more distances in the same amount of fuel than heavier aircraft.

The strength-to-weight ratio of carbon fiber is incredible. Carbon fibers have high tensile strength which implies that they are resistant to breakage under tension. This property of carbon fibers makes them improve aircraft crash survivability.

Metals are prone to corrosion. No such problem exists in the case of carbon fibers. They have good resistance against chemical exposure as well. Thus, using carbon fibers increases the longevity of aircraft.

The following graph [6] gives information on the Tensile Modulus and Tensile Strength of different carbon fibers used in aerospace industries.

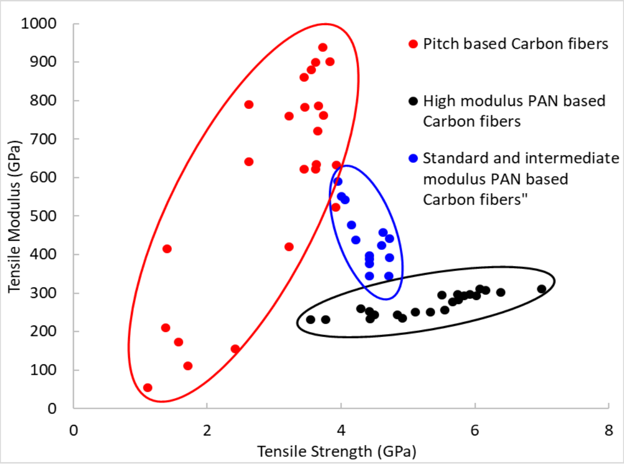

Figure 6: Tensile Modulus versus Tensile Strength for Carbon fibers

One of the properties of metals is that they change their length depending on the temperature of their surroundings. The aircraft parts are subjected to incredibly drastic temperature changes in aerospace right after the take-off till landing. In such cases, changes in the dimension of metals are not favorable. Carbon fibers do not expand and contract dramatically. That is why they offer more durability.

Carbon fibers allow the alignment of the glass fibers of thermoplastics to suit specific design programs. Glass-reinforced polymers are the most resistant to deforming forces when the polymers fibers are parallel. While they are weakest when the force being exerted is perpendicular.

- *Drawbacks of Carbon fiber*

One of the advantages of carbon fibers is that they do not break easily. This turns into a drawback because it is hard to look for damage to the internal structure. Additionally, their repairs are much more costly and difficult.

Airplanes fly up in the air and thus are often subjected to lightning strikes. The disadvantage of carbon fibers is that they do not conduct electricity. When Airplanes experience lightning strikes, their outer shells must be able to conduct electricity to dissipate electricity from lightning strikes. This mechanism protects the inside of the plan. To overcome this drawback, currently, carbon fibers are embedded with conductive metal wire, foil, and mesh to have better conductivity.

Also, the resins used in composite material weakens at lower temperatures, making it important to take extra precautions to avoid fires. Additionally, fires that involve composite materials are expected to release toxic fumes and micro-particles into the air which can cause health risks. On the other hand, Temperatures above 300 degrees can cause structural failure.

- **1990s-Present day: A composite world**

The production of new aircraft has seen an increase in the percentage of composites in their structure material.

Boeing 787 Dreamliner contains composites as 50% of its materials and took off for the first time on December 15, 2009. The carbon 'sandwich' composites and advanced carbon laminate are the major structural elements of Boeing's 787 Dreamliner.

In response to the Boeing 787 Dreamliner, Airbus proposed the A350 design in 2004 which had its first flight on 14 June 2013. The A350 XWB widebody jetliner is made of more than 50% composites, and it is 25% more fuel-efficient than its aluminum counterparts.

Airbus has manufactured a helicopter, Tiger HAD which consists of 80% composites in its aircraft frame. The first flight of Tiger was on 27 April 1991.

The NH90, introduced in 2007 by Airbus, comprises 90% of composites.

Metals have not become obsolete, and aluminum, aluminum-lithium, steel, and titanium are used for making some parts. Aluminium-lithium uses lithium, which is the world's lightest metal, to decrease the weight of aluminum and improve its strength, toughness, corrosion resistance, and forming characteristics at the same time.

The graph which is given below [7], gives information on the percentage of composites used in military and civil aircraft.

Some of the famous fighter aircraft that use composites are:

1. U.S.' AV-8B, F16, F14, F18, YF23, F22, JSF, UCAV, Bomber ' B2
2. Europe' Harrier GR7, Gripen JAS39, Mirage 2000, Rafael, Eurofighter, Lavi, EADS Mako
3. Russia' MIG 29, Su series

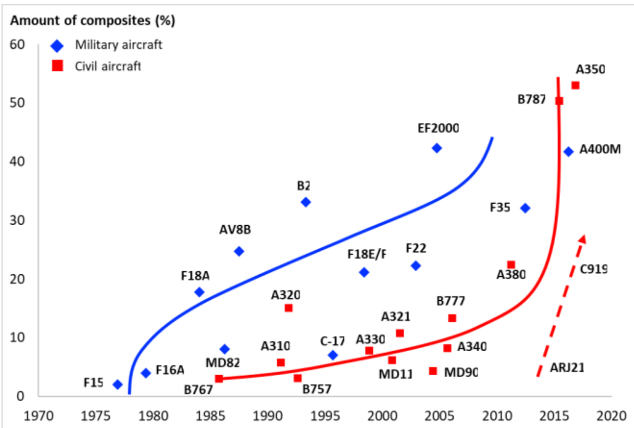

Figure 7: Applications of composites

Some of the famous military/civil aircraft that use composites are:

1. U.S.' KC135, C17, 777, 767, MD11
2. Europe' A320, A340, A380, Tu204, ATR42, Falcon 900, A300-600

- *Advantages of Composites*

Compared to metals, composites are extremely strong. The high strength of carbon fibers is very crucial for making structural components of aircraft such as floor beams, wings, and stabilizers.

They have high strength and are lightweight at the same time. Using composites, the weight reduction is seen up to 20 to 50%. They also provide higher strength at a lower weight.

Composites resist damage from moisture and corrosion as they do not react with them. Thus, composites give aircrafts durability. This in turn reduces the need for maintenance and repair because of moisture damage. Again, this reduces cost.

It is easier to mold composites into a variety of complex shapes, without using high-pressure tools. This is also why it is comparatively easier to assemble the structural components made of composite materials.

Also, composites are poor conductors of heat and electricity. This makes them suitable for the making of insulator parts.

- *Drawbacks of Composites*

Following are the current challenging areas of composites that require more research and development.

1. Manufacturing

The composite designs adopt the philosophy of metal design and use the same factor of safety of 1.5 to determine the ultimate design load from the limit load in current times. Composite parts are inherently more susceptible to variations in manufacturing processes than metal parts. The factors that contribute to these variations are a bulk factor, fiber alignment, tooling set up, humidity fluctuation, equipment control, etc. That is why this increased sensitivity of composites lowers production yields.

2. MRO - Maintenance, repair, and overhaul

The requirements of Maintenance, repair, and overhaul (MRO) of composites are very different from those of metals.

Challenges with their MRO is due to:

a) The inhomogeneous nature of composites causes defects.

b) Some defects are initiated during manufacturing and in-service.

c) Inspection requires the use of several NDT(Non-Destructive Testing) methods.

d) New developments offer improvements but still require validation and certification.

3. Functional composites

Following are the areas in terms of functionality of composites that require more research:

a) Self-healing

b) Sensing

c) Morphing

d) Lightning protection

e) Energy storage

4. Safety

The level of safety that is needed for aviation is still not completely fulfilled by the use of composites. Carbon fiber composites pose a challenge in terms of safety. They are more brittle than metals as well as complex to analyze.

The brittleness of composites is not very important to compare with the aluminum aircraft in a catastrophic accident like an aircraft at cruising speed flying into the side of a mountain. But this makes an important difference in survivable incidents, like aborted landings, hard landings, and field landings. The Airbus A300 crash in Queens in Nov 2001 and the Team Phillips catamaran are some classic examples.

Following are the future challenging areas of composites:

1. Carbon fiber availability

a) The usage of carbon fiber is growing in many industry sectors and the growth rate is accelerating globally.

b) Along with, the aerospace sector, the wind and automotive sectors too are expanding their use of carbon fiber.

c) The carbon fiber demand for these four planes: Boeing 777, Boeing 787, Airbus A380, Airbus A350 are expected to reach 23,000 and 24,000 tonnes annually.

2. Recycling

a) 3000 tonnes of carbon-fiber-reinforced polymers (CFRP) scrap are produced annually. Around 6000 to 8000 commercial planes are expected to reach their end-of-life by 2030.

b) Both landfill and incineration disposal of CFRP scrap are not optimal.

c) That is why work needs to be carried out for the development of methods that can be used to recycle carbon fibers out of CFRP.

3. Materials development

a) The surge in the use of composites has involved the development of new and improved manufacturing methods.

b) Future applications will require more developments in material properties.

c) For example, the fuselage of the Boeing 787 is made of CFRP. For Boeing to scale this down to produce a new 737 with a composite fuselage, it would require the use of a tougher composite material. Otherwise, hailstones can potentially penetrate the fuselage.

2. Space: Outside Earth

World War II presented in front of the world the need for lighter and more fuel-efficient aircraft. Further, the nations turned their attention to the skies and beyond. The space program of the 1960s brought together distinguished minds to drive mankind out into space beyond the atmosphere. Now, vehicles that can carry people and fuel against the massive gravitation of Earth were required. Need for materials that could break the Earth's atmosphere, carry a large amount of fuel, while insulating the inner of the vehicles from extreme temperatures rose. NASA scientists chose plastics, specifically Kevlar and nylon for the spacecraft. Layers of nylon and other insulators were used inside the spacecraft to protect the crew from the extreme temperatures of space. Currently, research is being carried out for making reusable spacecraft that can carry repeated launch, orbit, deorbit, and atmospheric reentry.

3. The future chapter

A constant challenge in the aerospace industry is reducing the weight of aircraft. The ultimate goal is to lower fuel consumption and associated CO_2 emissions. The aim is to provide more economical and "greener" air transport. The materials must be lightweight as well as they need to be rigid and strong enough to withstand intense mechanical stress. The strength of materials used should be such that they can withstand impact from hailstones and bird strikes.

Following is a short description of some new composite materials developed recently.

3.1 Phenolic

Phenolic composites are the first modern resin developed. They have good chemical, heat, and fire resistance. They are extensively used in aircraft cabins. For a passenger aircraft, these composites account for 80 – 90% of the interior furnishings. They are used as either a single skin laminate or as sandwich material.

3.2 Epoxy

Epoxy resins are reactive prepolymers and polymers which contain epoxide groups. For an aircraft, they are used in making fuselage, wing and tail fin components, control surfaces, and doors. They have excellent strength, lighter weight, as well as durability, and flame retardancy. Due to this, they are also used in spacesuits.

3.3 Polyester

Polyesters are the most commonly used matrix. They are typically combined with glass fiber to create glass reinforced polyester (GRP). They are used in making wind turbine blades and other cost-critical applications.

3.4 Kevlar

Aramid fibers are lightweight, tough, heat-resistant, and strong synthetic fibers. Kevlar, created by Stephanie Kwolek, is DuPont's name for Aramid fibers. It is naturally yellow and is available as dry fabric and prepreg material. Kevlar 49 (high stiffness) and Kevlar 29 (low stiffness) are the two kinds of Aramid fibers that are used in the aviation industry. Aramid fibers offer high resistance to impact damage which makes them best to use for impact-prone areas. Although, their general weakness in compression and hygroscopy and difficulty in drilling and cutting are disadvantageous to the structures. Kevlar is generally used in Military ballistic and body armor.

Mechanical strength			
	CNT	**Steel**	**Aluminium**
Young's Modulus (Tpa)	0.8 to 1.4	0.3	0.7
Tensile Strength (GPA)	63	2	0.3
Density (g/cm3)	1.4	8	2.7
Electrical properties			
	CNT	**Copper**	**Silver**
Resistivity (cm)	1	17	1.55
Thermal properties			
	CNT	**Diamond**	
Thermal conductivity	3000	2000	

raphene

Graphene was discovered in 2004 by the two professors, Andre Geim and Kostya Novoselov (Nobel Prize Winners in Physics in 2010). It consists of a single layer of carbon atoms bound in a hexagonal pattern. It is a million times thinner than paper as well as 100-300 times stronger than steel. It is used in making solar sails because of its great mechanical strength and lightness. A successful experiment regarding the use of graphene in microgravity to build cooling systems for satellites was conducted in 2017 by Leonardo, an Italian aerospace company with the National Research Council and the universities of Cambridge and Brussels. It has a tensile strength of 130GPa. Researches show that it will be strong enough to make a space elevator tether. If that will be possible then, lots of costs and risks in space exploration will be reduced.

3.6 Aerogel

Aerogel was developed by Samuel Stephens Kistler at College of the Pacific in Stockton, CA, USA. They are nano porous light materials consisting of an open-cell network. Silica aerogels show the most incredible physical properties among the class of aerogels. They possess lower density, thermal conductivity, refractive index, and dielectric constant than any solids. These properties make them useful for applications related to insulations. According to Ref [15], they have been used in providing insulation for a Mars rover.

3.7 Ceramic matrix composites (CMCs)

Ceramic matrix composites are composites where ceramics are used as both the reinforcement and the matrix material. They have excellent thermal properties and improved mechanical properties. This makes them perfect candidates for application in the hot section of the aero engines.

3.8 Metal matrix composites (MMCs)

Metal matrix composites consist of hard reinforcing particles embedded within a metal matrix phase. Usually, aluminum, magnesium, or titanium matrices are used. And oxide, nitride, or carbide are used as reinforcement. They are lightweight structural materials and are used in highly loaded surfaces such as helicopter rotor blades, turbine fan blades, and floor supports. Carbon Nanotubes: Carbon nanotubes are composed of a single atomic layer of carbon in a cylindrical configuration. It can be single-walled or multiple-walled. The following table [10] gives a comparison between the properties of carbon nanotubes and other conventional materials. Based on these properties, aircraft designers are now expecting it to be used in the shielding of large-scale aircraft.

3.9 4D printing

Today, all around the world, research is underway into 4D printing and 'digital materials'. The term 4D printing means 4-dimensional printing. The 4D printing technique will create three-dimensional objects by using bioprinting, active origami, or shape-morphing systems through computer-programmed deposition of material. This will make the material change shape by themselves according to the outside forces like water, movement, or temperature change. A leading aerospace company called Airbus is already testing the technology for an air inlet that could even form the entire cabin.

4. Conclusion

Composite materials are quickly becoming one of the most desirable options for use in modern aircraft due to their ability to be used for a wide array of structural applications, including wings, fuselages, and control surfaces. It is an area that has been greatly enhanced by recent developments in composite materials, processing techniques, and tooling systems.

Future aerospace materials research should be focused on developing composites that are not only strong and cost-effective but also environmentally conscious and sustainable.

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Table 1. Features of aircraft structures

Requirement	Applicability	Effect
Light-weight	All aerospace programs	• Semi-monocoque construction Thin-walled or stiffened structure • Use of low-density materials: • wood b. Al-alloys c. Composites • High strength/weight. High stiffness/weight
High reliability	All aerospace programs	• Strict quality control • Extensive testing for reliable data • Certification: Proof of design
Passenger safety	Passenger vehicles	• Use of fire-retardant materials • Extensive testing: Crashworthiness
Durability - Fatigue and corrosion Degradation: Vacuum Radiation Thermal	Aircraft Spacecraft	• Extensive fatigue analysis/testing Al-alloys do not have a fatigue limit!!! • Corrosion prevention schemes • Issues of damage and safe-life, life extensive • Extensive testing for required environment • Thin materials for high integrity
Aerodynamic performance	Aircraft Reusable spacecraft	• Highly complex loading Thin flexible wings and control surfaces a) Deformed shape-aeroelasticity b) Dynamics c) Complex contoured shapes d) Manufacturability: N/C Machining: Molding
Multi-role or functionality	All aerospace programs	• Efficient design • Use: composites with functional properties
Fly-by-wire	Aircrafts, mostly for fighters but also some in passenger aircrafts	• Structure-control interaction • Aero-servo-elasticity • Extensive use of computers and electronics • EMI shielding
Stealth	Specific Military aerospace applications	• Specific surface and shape of aircraft a) Stealth coatings
All weather operation	Aircraft	Lightning protection, erosion resistance