Chapter 3
Advanced Polymers in Aircraft Structures

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3.1 Introduction

Engineering materials can be classified as composites, metals, nonmetals, and ceramics. Metals lose their strength at much higher temperatures than polymer materials. Considering ceramic materials, they have the potential to have a high temperature, thermal expansion characteristics, and good strength, but the only drawback is their brittleness so that they cannot be employed for the development of structural materials. Therefore, composite materials come into existence in view of the shortcomings of all materials. Recently, polymer composite materials have been the major choice of all aircraft design engineers because they can meet the high-performance requirement and ability to design material characteristics. This

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M. C. Kuşhan et al. (eds.), *Materials, Structures and Manufacturing for Aircraft*, Sustainable Aviation, https://doi.org/10.1007/978-3-030-91873-6_3

material provides excellent strength to weight ratio, wear resistance under severe environmental conditions, ability to meet intensive dimensional stability, moderate thermal expansion characteristics rapid growth cycle, and excellent fracture and fatigue resistance. In the sectors like military, with the use of polymer composite materials to produce fighter aircraft frames, significant amounts of weight loss have been achieved [1–3]. In addition, polymer composites found about 80% of recent vehicles for satellites, including many important satellite components such as, cylinder support structures antennas, hive structures, solar array substrates, instrument panels, and so on. Solid boosters of the space shuttle contain 30 tons of graphite-reinforced epoxy composites even the growth of micron-thickness films will ultimately enable some types of spacecraft, such as solar cells [4]. The material used in the manufacturing of the structural parts has to carry the load, which is acted upon the frames of the aircraft starting from the takeoff till the landing. In U.S. F14 and F15 fighter planes, the composite material was used for the first time before 30 years in the skin of empennages [5]. Now the primary and secondary parts of the aircraft polymer composite material include wings, center wing box, flap track panels, landing gear doors, engines cowlings, horizontal tailplane, tail cone, outer flaps, upper deck floor beams, vertical tailplane, etc. as shown in Fig. 3.1 [6]. Some of the metals like nickel-metal alloys are replaced with the carbon fiber–reinforced composite in the application of high-pressure turbines components like jet engine fan blades which were resulted in 5% reduction in fuel consumption than other comparable engines [7]. Researchers had proved that traditional materials are having many of the drawbacks and large amount of money is wasted in maintenance, repair, and operation of aircraft, whereas the composites material is providing excellent strength and other properties which will last for larger period. Even some of the researchers were also discovered that metals are facing so many problems in manufacturing complex design shapes; however, matrix and reinforced composite can be

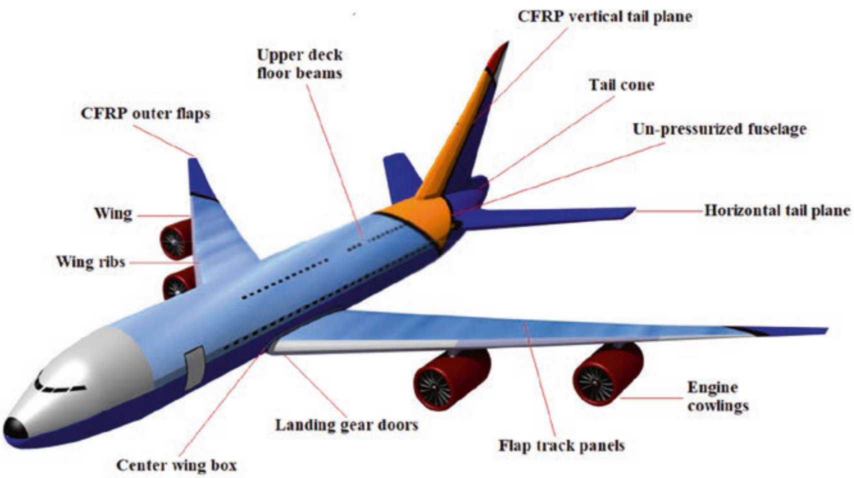

Fig. 3.1 Aircraft components produced from polymer composite materials

Table 3.1 Composite materials used in various aircraft

Type of the aircraft	Name of the aircraft
Fighter aircraft	AV-8B, F16, F14, F18, YF23, F22, JSF, UCAV, Europe Harrier, GR7, Gripen JAS39, Mirage 2000, Rafael, Eurofighter, Lavi, EADS Mako, Mig29, Su series
Bomber/ transport aircraft	KC135, C17, 777, 767, MD11, A320, A340, A380, Tu204, ATR42, Falcon 900, A300–600
General aviation	Piaggio, Starship, Cirrus SR 20, and SR22
Rotary aircraft	V22, Eurocopter, Comanche, RAH66, BA609, EH101, Super Lynx 300, S92

manufactured in any type of critical shape and they are more appropriate than the metals. The prime role of the matrix and the reinforced material is that it can be effortlessly mold in any type of complex shape and can hold good strength, mechanical properties, and stiffness. As the composite materials are the hybrid materials obtained from the combination of two or more materials which will provide advanced properties that is the reason the utilization of composite material in aerospace industry is reached up to more than 50% [8–10]. In the past, the composite material was used by only military aircraft but due to the technological development, it is used in commercial planes also. Presently, composite material has become an excellent replacement for metal components. Taking the example of Airbus 320, the use of composite material has reduced the weight of the airplane up to 800 kg and more than 20% of the airframes were made of composite material [11]. Even some of the well-known examples where composite material was used like in European fighter plane, Harrier AV-8B, A320, A380, rotor hubs and blades of helicopter, propeller, Boeing 787, etc. Table 3.1 depicts a type of aircraft whose components are made with the help of composite materials, which are given subsequently. Presently the polymer composite materials are widely used in fighter planes for the manufacturing of the parts like the wing skins, flappers, forward fuselage, and also other parts that are labeled in Fig. 3.1. The percentage distribution of the composite material is like 40% for the structural parts, 75% for the exterior parts, etc. [12, 13]. The use of polymer-based composite is rapidly increasing in the aviation parts related market instead of metal as the maintenance costs reduce. This review will focus on various types of polymer composites in the field of aviation, components, and manufacturing process, etc.

3.2 Polymer Composites in Aircraft

Polymer composite materials are the materials in which one compulsory element is a polymer. It is a type of composite in which the fibers or other small particles are inserted into it and that insertion of the fibers is called as reinforcement. The selection of the matrix and the reinforcement mainly depends on the type of application, properties, manufacturing process, and cost-effectiveness. The polymer matrix composites are the most innovative composites. This type of composite consists of fiber-reinforced polymer thermosetting or thermoplastic, also the materials can be molded in many shapes and dimensions, the classification of thermoplastic and thermosetting polymer matrix is as shown in Fig. 3.2 with their structure [14–16]. The commonly used thermoplastic and thermosetting polymer matrices are listed below:

- PEEK (poly-ether-ether-ketone)
- PEI (Polyetherimide)
- PPS (Polyphenylene sulfide)
- Polyester
- Vinyl ester
- Epoxy

In recent times, the polymer composite is in more demand due to its improved mechanical and tribological properties with more amount of weight saving. This composite has the fastest processing cycle and even at very high temperature polymer composite material cannot be stretched or compressed also excellent fracture and fatigue resistance. The unwavering urge of the aircraft manufacturers and industry to improve the enactment of military and commercial aircraft pointers to improvement of better high-performance structural materials. Among the current aircraft components, composite materials are a type of material that plays an important role. Due to the outstanding rigidity, strength, density ratio, and excellent physical characteristic polymer composite are in the focus of aircraft parts or component manufacturing industry. The most common type of fibers used in the aviation is the carbon and glass fiber. Carbon fiber is having improved properties than the glass fiber but the only drawback is the cost. Carbon fiber–reinforced plastics (CFRP) are the primary and most significant material used in aerospace sector at the earliest. Now in the latest models of thin and wide structure civil aircraft, more than 50% of the construction components are led by their excellent rigidity, strength, and weight

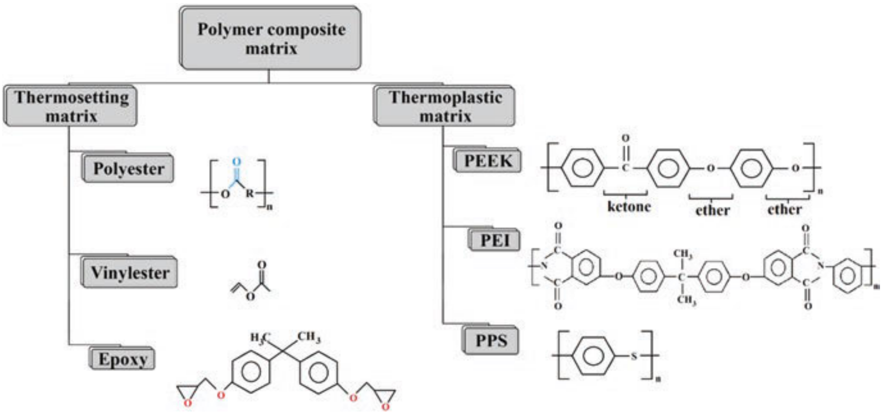

Fig. 3.2 Classification of thermoplastic and thermosetting polymer matrix

ratio. Now the major focus of the manufacturing industry is to prepare the thin-ply fiber from the spread tow fibers. The fibers are permeable to low density and strong uniform fiber–matrix reaction. The primary markets for these components were racing cars and sports-related equipment, but now there is an attraction toward the aircraft industry. The CFRP material is being employed for the inside seats of Airbus A350 aircraft by aircraft overhaul and maintenance firm Hong Kong Aircraft Engineering [13–19].

3.3 Structural Components in Aircraft

Aircraft manufacturers, which allow the production of composite structures for the future of the aircraft, contribute to the correction of the current production of the aircraft. The advantages of using composites in construction applications have been identified in many technical studies. Currently, technology development programs are being implemented to correct known shortcomings and make necessary improvements. The aircraft's parts were made using various materials and assembled using bolts, nuts, screws, rivets, and special adhesives. The design of the aircraft is designed in such a way that it can carry loads and withstand various stresses. Each part of the aircraft had different forms of complex loads. The layout of the aircraft is mostly made based on the wing structure. The aircraft can be steered around the transverse, longitudinal, and vertical axis by deflecting the control surface. These controls represent the pilot's articulated or moving landing surfaces to the aircraft's position during takeoff, flight, and landing. They can be operated either by the pilot or by connecting to the chain using foot pedals and a control stick or steering wheel. The important components of an aircraft were listed subsequently:

3.3.1 Engine Fan Blades

Composite material is currently found in many commercial applications of turbofan engines shown in Fig. 3.3 due to its low cost, enhancement in efficiency, and less weight. Recently, the composite fan blade manufacturing is the greatest innovation in the aircraft industry. As carbon fiber is mostly chosen by the design engineer for the manufacturing of composite material. The main reason to prefer the carbon fiber in the fan blade is its weight, durability, and efficiency. This carbon fiber–reinforced composite blades are used because they have the ability to withstand usual fatigue without failure and can be easily retained and repair. The use of polymer composite has reduced the weight of the engine fan blades up to 159 kg along with enhancement in mechanical and tribological properties [20, 21]. The strength of the engine fan blades mainly depends on the fiber orientation, only the specific direction of the fiber orientation will give the higher strength and this decision depends on the designer. Presently, the fibers with unidirectional tow are normally used by holding

Fig. 3.3 3D sketch of engine fan blades

Table 3.2 Properties of a recommended polymer matrix composite [24]

Properties	Value
Tensile strength	99.3 MPa
Tensile modulus	4090 MPa
Elongation at yield	4.4%
Fracture toughness	3.51 MPa-m$^{1/2}$
Density	1.272 g/cc
Viscosity	1900 cP at 129–149°C
Moisture absorption at equilibrium	3.1%

the layer together for some preferred performance. The composite fan blades can be worked in the higher temperature also by using proper epoxy resin. There is a huge enhancement in the engine performance due to the use of fiber reinforcement composite in the manufacturing of blades. Some of the researchers had done the 3D modeling analysis by using the design software and it is concluded that comparing with the materials like carbon fiber, glass fiber, and aluminum alloy carbon fiber had shown less stress with more safety material [22]. As the advantages of the composite materials were focused but they are having some drawbacks in the form of vibration damping, but this drawback can also be overcome by some of the researcher and observed that by adopting the piezoelectric vibration damping can considerably diminish vibration of aircraft engine composite fan blades [23]. The properties of a recommended polymer matrix composite for the manufacturing of airplane engine fan blades are given in Table 3.2.

3.3.2 Brackets

Aircraft component manufacturing is now becoming a challenge to manufacture the parts with more amount of weight saving. As all the parts from the main body to small components all are replaced with the composite material. Focusing on the aircraft brackets as shown in Fig. 3.4, they support the structure as they are employed to hold the two components one above the other. Brackets used in aircraft are employed for many types of applications like fuel tank, fuselage frame installation, engine mounts, and landing gears. Considering the molded bracket, the polymer used for manufacturing is PEEK (poly-ether-ether-ketone), which has reduced the weight up to 40% with cost-effectiveness and presently employed in the Bombardier's C-Series, Global, and Learjet aircraft. Also, the manufacturing cost is also reduced as there is no extra machining and painting process due to the complex shape of the mold, similarly decrease of scrap and manufacturing cycle time. The brackets of the aircraft are of three types and can be used according to the category of application like class A, class B, and class C. Class A brackets are in the primary structure, for removing the structure class B is used, and for the attachment of the tertiary structure class C. Till now many books are published to give the advantages and disadvantages of the composite material but steps to design the composite material for specific type of component manufacturing is yet not published. So, for this reason, focus is on the finite element analysis (FEA), by using FEA prediction can be done for the material failure and strength [25–27]. The researcher named Mun et al. had prepared a design model for the design and analysis of composite material as it works on the following three steps like analysis, discretization, and laminated modeling. This model will give the exact recognition of stress sharing on certain areas and will help to develop the superior composite material and structure [28, 29]. Properties that are used to check the bonding of composite material for the brackets are shear bond strength, flexural strength test, and polymerization contraction stress [28].

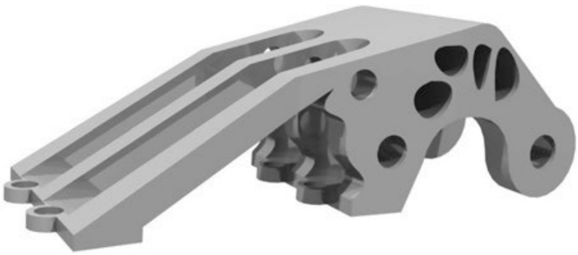

Fig. 3.4 Bracket used in aircraft

3.3.3 Interiors

Interior of the aircraft must have to promote the maximum safety and comfort for the passengers. The need to build airplane composite interior which will provide lightweight, airy, and comfortable with cost reduction. The interior of the aircraft includes electrical panels, seating arrangement, galleys, aircraft structure, entertainment devices, cabin avionics, etc. The future of composite material in the aircraft industry for the application of interior components is going on increasing in regional aircraft, general aviation, commercial aircraft, military aircraft, and helicopters. The introduction of composite window frames and the application of composite thermoplastic applications to aircraft interior had developed styles that directly affect the flexibility of composites in the aircraft industry. As compared to the glass fiber, carbon fiber–reinforced composite observed highest demand in the application like window frames and seat components as shown in Fig. 3.5 [30, 31]. In case of turbulence or at the time of emergency landing the upper storage, compartment may subject to highly dynamic loads so to overcome this drawback one of the researchers Heimbs et al. prepared a model, which will correlate the simulation and experimental data with the help of numerical method to manufacture the interior components of the airplane [32]. The most widely used resins for the applications of aircraft interior are CYCOM 2400-1, CYCOM 6070, CYCOM 2265, CYCOM 2290, CYCOM 919, and MTM 82S. Table 3.3 gives the properties of two of them, while Fig. 3.6 shows the yearly growth of composites in aircraft interior [33–35].

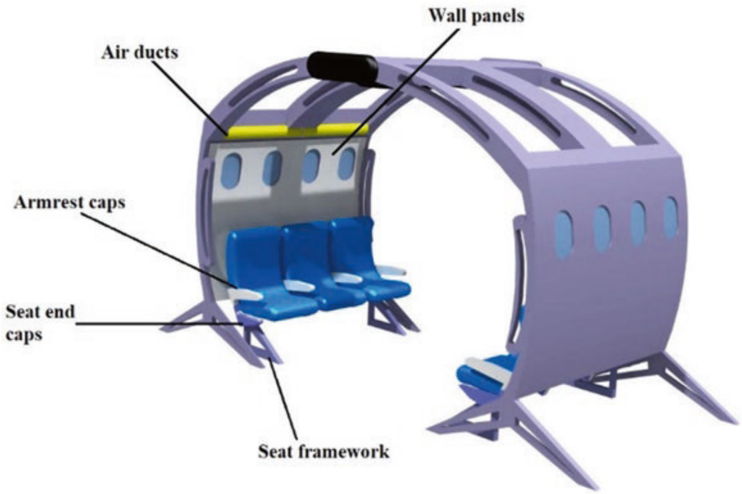

Fig. 3.5 Interior of an airplane

Table 3.3 Some resins for the application of aircraft interior components [33]

(CYCOM 6070) Phenolic composite laminates, glass				
Properties	Test temperature	7781/1581 Fiberglass fabric 8HS	120/220 Fiberglass fabric 4HS	Test method
0° Tensile strength (MPa)	−55°C	507	428	ASTM D 638
	24°C	414	369	
	82°C	352	407	
0° Compressive strength (MPa)	−55°C	407	507	ASTM D 695
	24°C	338	479	
	82°C	273	397	
0° Flexural strength (MPa)	55°C	493	579	ASTM D 790
	24°C	486	490	
	82°C	445	438	
0° Flexural modulus (GPa)	−55°C	27	25	ASTM D 790
	24°C	25	25	
	82°C	26	24	
(CYCOM 2400-1) Autoclave cured laminate				
Properties	Glass style 7781	Carbon 3K T650 8HS	Test method	
0° Tension strength (MPa)	441	924	ASTM D 638	
0° Tension modulus (GPa)	24.8	64.1	ASTM D 638	
0° Compression strength (MPa)	524	717	ASTM D 695	
0° Compression modulus (GPa)	28.3	61.4	ASTM D 695	

3.3.4 Nacelles

The nacelle is an important part of the aircraft as shown in Fig. 3.7, which is also called as covering, as it is separate from fuselage which grips the fuel or other equipment with engine. The nacelles boost airflow and safeguard the engine. Also, it supports to diminish noise and contributes to aircraft braking through integrated thrust reversers. The structure that environs the aircraft engine has fate in its inherent complexity as the shape of the aircraft nacelle is smooth. Composite nacelles are especially design to decrease the weight of the aircraft with improved engine fuel economy and supporting noise regulation. Presently most of all the aircraft are now employing composite nacelles due to its excellent properties and benefits. There are three main components of the nacelle like fan cowl, thrust reverser, and inlet. The fan base is the central part of the nacelle and it is generally prepared as a couple of hinged doors with or next to a pylon. The fan cover door engine affords access to the looking after of the assembled systems on the fan case. In most recent jet engines, the gearbox assembly is organized on a next to the fan case. That arrangement describes the region below the fan. The inlet is also the most advanced part of the

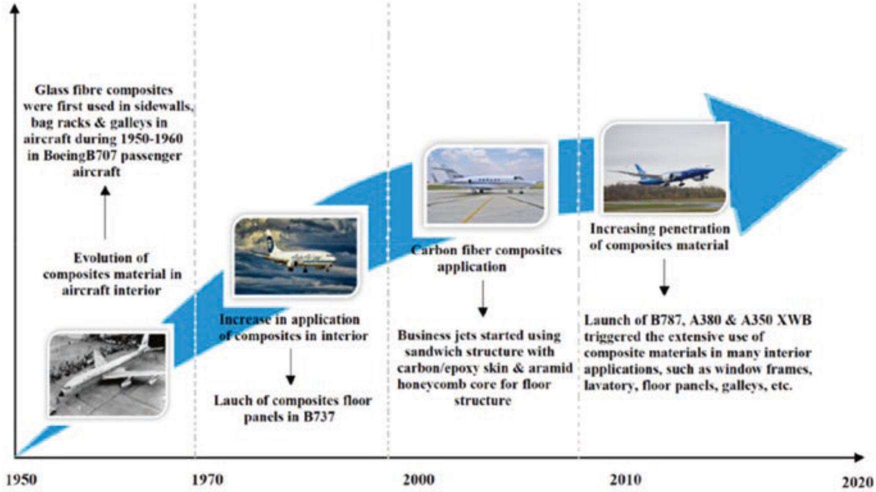

Fig. 3.6 Yearly growth of composites in aircraft interior

Fig. 3.7 3D sketch of nacelles used in aircraft

nacelles as it is connected to the engine fan case. As the inlet geometry is aerodynamically adapted to cruise conditions, it can operate in high angles of protruding engine axes in airflow next to kin. The main function of the inlet is to deliver air directly to the engineer. The last and very important part of the nacelle is the thrust reverser which helps to diminish the landing distance of the airplane. It is also used to reduce the wear of the tires and provides excess power to the pilot at the time of stopping the plane in wet and icy platform [36–39]. So, some of the researchers like Dudziak et al. revealed in his research that the structure of the airplane nacelles is design in such a way that the high temperature will not affect the components as the design is made of solid laminated structure and it is part in two sections like sandwich structure in the rear part and solid laminated structure in the front part [40].

The two important resin mostly used for nacelles manufacturing are bismaleimides and polyimide its properties are given in Table 3.4.

3.3.5 Wings

The main and important part of the airplane is wing shown in Fig. 3.8 as it has to govern the rolling and pitching action so it has to be created by different types of components. The structure of the wing is commonly hollow from the inside. At present, wings are made of composite material carbon fiber fabric that is coated and molded with resin. However, the way these materials are placed varies according to the work. To create the wing, design engineers use digital simulation and modeling software, to check the number of possible formations to create a digital arrangement paperback of layers. According to the National composite center (NCC), there may be 14,000 possible combinations of laying and cutting for a single wing skin with 150 layers. The wing of the airplane is also called as airfoil that makes a lift when moving speedily in air. By considering different types of aerodynamic properties the designer had prepared different types of wings. These types of wings are available with many a type of shapes and can be attached in many types of the angles to the main frame of the airplane. At the time of takeoff, the wings of the aircraft lift it into the air. The special design of wings for any aircraft depends on many factors including weight and size of the aircraft, use of airplanes, desired rate of climb, desired speed in landing and flight, and takeoff. The wings of the aircraft are often of full-size design. This means that they are constructed in such a way that they do not require any outward bracing. They are supported internally by structural

Table 3.4 Mechanical properties of resin used to manufacture nacelles [41, 42]

Properties	Value
Bismaleimides	
Tensile strength at 25°C	85 MPa
Tensile modulus	3.63 GPa
Flexural strength	
25°C	143 MPa
150°C	87 MPa
180°C	72 MPa
Flexural modulus at 25°C	4 GPa
Elongation	3%
Polyimide	
Modulus of elasticity	500 MPa
Compressive strength	25,000 MPa
Shearing strength	70 MPa
Tensile strength	300 MPa

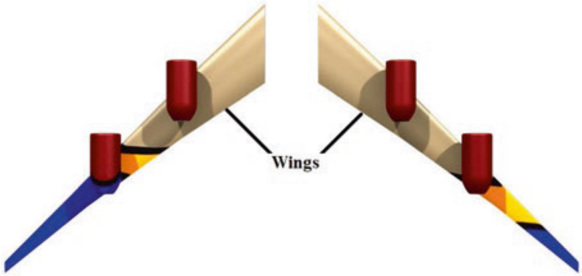

Fig. 3.8 3D design of an aircraft wings

Table 3.5 Properties of resin used for wings [48]

Properties	Value
Tensile strength	70 MPa
Tensile modulus	3.1 GPa
Tensile elongation	6.3%
Flexural strength	139 MPa
Fracture modulus	3.2 GPa
Fracture elongation	3.3%
Fracture toughness	0.9 MPa.m$^{1/2}$
Elastic shear modulus	1.2 GPa
Cured resin density	1.22 g/cm^3

members and plane skin. So, there are nine types of wings like rectangular, tapered, elliptical, delta, ogive, trapezoidal, swept back, forward, and variable swept wing as it can be used according to the type of application [43–46]. Some of the researchers are working on the fluttering speed due to variation in fiber arrangement angle, thickness of fiber, and differences in material, hence concluding that by making the computational efficient probabilistic flutter model better results can be achieved [47]. Table 3.5 gives detail about the resin properties of CYCOM 890 used for the manufacturing of aircraft wings.

3.3.6 Fuselage

The fuselage is the central and very important part of the airplane where the seating of the passenger is arranged as shown in Fig. 3.9. The part looks like central tube-shaped that's why it is called as fuselage; also, it can hold all the parts of the airplane together. The fuselage is very long and hollow to reduce the weight of the airplane, the exact shape of the fuselage dependents on the application for which that aircraft is used. If we consider passenger airplane then long fuselage is employed to transfer number of passengers at one time, likewise to reduce the drag associated with high-speed streamlined fuselage is used and for fighter planes slim fuselage is used

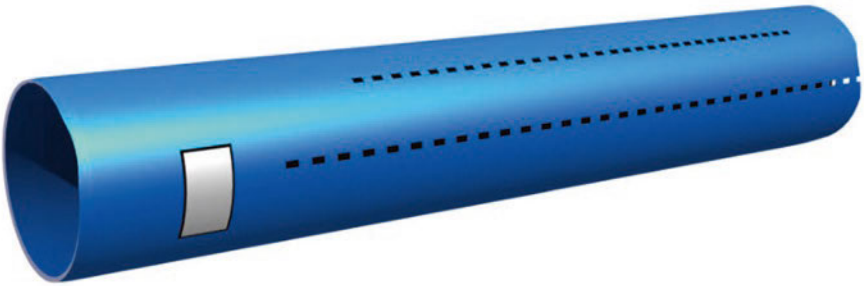

Fig. 3.9 Fuselage of an airplane

[49–52]. According to the size of the fuselage for particular application, the door size also changes. As the passenger aircraft has a smaller door as compared to the fighter aircraft, so at the time of considering the loads, smaller doors can transmit the load around the door. Pressure and volume are the main important things that work consequently in aircraft. If the fuselage is depressed because of the pressure difference, the floor will be loaded and if the fuselage is pressurized, there will be no compressive load on the floor. The basal frame of the fuselage hardly has diverse spaces; this is entitled double-bubble fuselage [53]. A researcher like Quadman et al. provided a method for calculating the post-bucking and buckling load stiffness of orthotropic sheets at the junction of compression and shear, and this proposed method is used to estimate the reverse factors and is used to design the airplane fuselage structure of this concern [54]. Presently, the airplane fuselage is made of carbon fiber–reinforced polymer composite to improve all the properties with cost-effectiveness.

3.3.7 Empennage

Empennage is commonly known as the tail assembly of an aircraft. From Fig. 3.10, all the parts like vertical stabilizer, horizontal stabilizer, elevators, trim tabs, and rubber of the tail section were clearly shown. The horizontal and vertical stabilizers are fixed but the elevator, rubber, and trim tabs are movable which is used to control the vertical/horizontal rotation of an aircraft and it is operated by the pilot. In some aircraft, a cockpit is a unit used to control the overall trim of the aircraft, so that the entire horizontal surface of the tail can be installed and adjusted. These designs are commonly referred to as stabilizers, flying tails, or tail boards. Aircraft tail, directions, and balance mechanism, as well as a tool for the control panel and maneuvering on the aircraft. The stress that occurs in an empennage is removed like the stress in a wing. Flexural, torsional, and shear strengths created by the loaded air pass from one element to another. Every element absorbs some of the stress and it will be shared with other element. As the stress exceeds its limit, then it starts transmitting

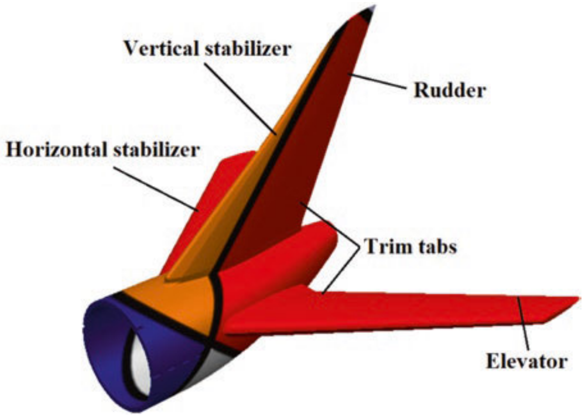

Fig. 3.10 Empennage of an airplane

to the fuselage section. Recently, the aircraft component manufacturing companies are now focusing on the new version of the empennage made of composite material for the existing aircraft. As the scientists conclude in their research, empennage elements made of composite materials show a significant improvement in the laboratory conditions of using composites in comparison with secondary structures. They are considered one of the horizontal stabilizers for decorating the Boeing 737 and Douglas DC-10 and a stabilizer of lateral stability in the vertical position. It is made of a composite stabilizer, which weighs 92.53 kg, which reduces the weight by 22% compared to metals [55].

3.4 Manufacturing Processes for Aircraft Composites

The manufacturing of composite plays a very important role at the time of designing any type of component. From the point of view of manufacturing modern fiber-reinforced composites, the main thing is to recognize that both the material and structure are made at the same time. Any defects that occur during the manufacturing process directly affect the strength and rigidity of the material and structure. Many of the manufacturing process have come into existence from the last three decades like automated tape-layup process, resin transfer molding, automated fiber placement, vacuum-assisted resin transfer molding, pultrusion, filament welding, autoclave, etc. All of the above methods have numerous things in common: that the reinforcements have been placed in the desired shape, in the tool or mold, the resin and fibers placed under high temperature and pressure to cure the resin, and the shape that will be removed from the product after the resin has cured.

3.4.1 Automated Tape Layup

The most well-founded automated manufacturing techniques for a composite are automatic tape lying. In this process, the unidirectional tapes are loaded at a partial slope and the delivery of different sizes using the loaded roller system is subject to the complexity of the fabricated part. The process diagram is as shown in Fig. 3.11 where the tapes are partially pre-bonded with adhesive resin from thermoplastic continuous strands in one direction. Further, tapes are wrapped around the reel so that they fit into the construction system. The forage unit pulls the tape from the roll and places it in the desired position on the robotic work platform or semifinished component. There, the glue is melted by heating with a laser to increase the grip. In this process, step-by-step, high-intensity continuous fiber structures are established by automated fiber placement. The single wide tape is up to 300 mm which may generally use to manufacture the part-like skin of airplane wings. The researchers, Comer et al., presented in their study that by using the automated tape layup process, the enhancement in the mechanical properties was obtained when compared to the autoclave process [56].

3.4.2 Resin Transfer Molding

It is a low temperature and low-pressure method, where the thermosetting resin is transfer into the closed mold to obtain superior quality of surface finish with improved dimensional accuracy of the composite. The process diagram is as shown in Fig. 3.12 where the mold is traditionally coated with a gel, if necessary. The mold is sealed and the reinforcement is located in the mold. Further, the resin is inserted under pressure using special inserted tools and the part is treated with mold. Reinforcement may be in the form of pattern cut roll stock material. The preform is a reinforcement that is made into a precise shape in a specific method and can be speedily molded. This process can be done under atmospheric temperature; also, the

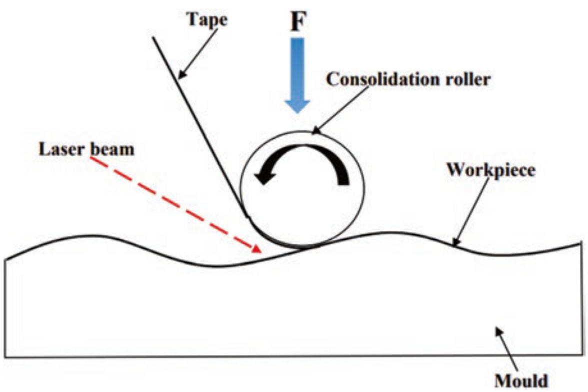

Fig. 3.11 Automated tape laying process

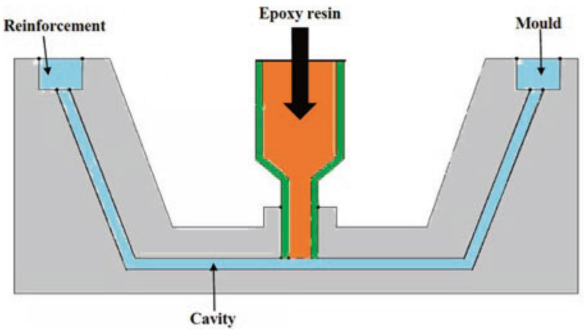

Fig. 3.12 Resin transfer molding

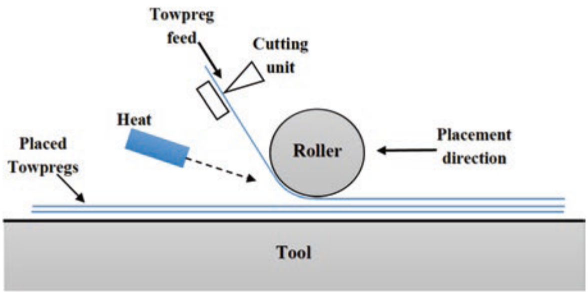

Fig. 3.13 Automated fiber placement

heated molds are necessary to accomplish fast curing time and product stability. The clamp can be completed with a circumferential clamp or press clamp [57].

3.4.3 Automated Fiber Placement

Automated fiber placement is an industrial method as shown in Fig. 3.13 that prescribes the precise placement of continuous fiber tapes for the manufacturing of multilayered composite products. In this process, usually 3–13 mm width narrow strip of tape is feed for the product to be manufactured. Tapes are fed into the head through a tape feeding system, which consists of multiple bobbins or spools with tape. These spools typically have around 1000 m of tape per bobbin. These tapes are properly placed by AFP machines according to a computer program, which is defined to provide optimal alignment of the fibers based on the expected operating load of the part being manufactured to the final product. The tape-laying head is connected to a robot, which directs the head to the correct position during the process. This process is generally used in the application related to the aircraft industry like fuselage tubs, cows with small edges, and many small/large structural parts [58].

3.4.4 Vacuum-Assisted Resin Transfer Molding

Vacuum-assisted resin transfer molding procedure as shown in Fig. 3.14 makes practice of vacuum to support resin flow in the fiber layers that are enclosed inside a mold tool protected by a vacuum bag. It is usually a top open molding device employed for the manufacturing of composite parts. In this process, the vacuum bag is placed to the top of the mold tool to regulate the continuous flow of low-pressure resin flow from one side to the other side. The composite fiber contours are compressed under the vacuum bag when the vacuum extracts air from the preform and the vacuum-assisted resin transfer molding machine on-ratio of the metered and mixes the degassed air-free resins. This process provides 60–70% fiber to resin proportion with a near-zero pore content. The most important application associated with this process is the parts manufactured like landing gears doors of airplane, turbine blades, fuselage area, etc. [59, 60].

3.4.5 Pultrusion

The pultrusion process is an extremely automated continuous fiber laminating process that produces high fiber block shapes with a fixed cross section. Having a high fiber block area is an excellent process for the production of structural components that give greater strength to the weight ratio. The process is as shown in Fig. 3.15 begins with the backing of carbon and glass fiber as a reinforcement in the form of roving. The material is drawn into the in-feed region where it is precisely formed to the required shape and capped with a resin matrix. The resin matrix can be used like epoxy, polyester, or vinyl ester for this process. Further, the impregnation reinforcement is pulled into the hot extrusion dye from the in-feed region. The cured profile that exits the die is indorsed to cool before turning and the towing units pull against each other. Puller units rotate by hand-over-hand motion, requiring a return stroke to pull smoothly at a constant speed rather than pulling force. From the pulling

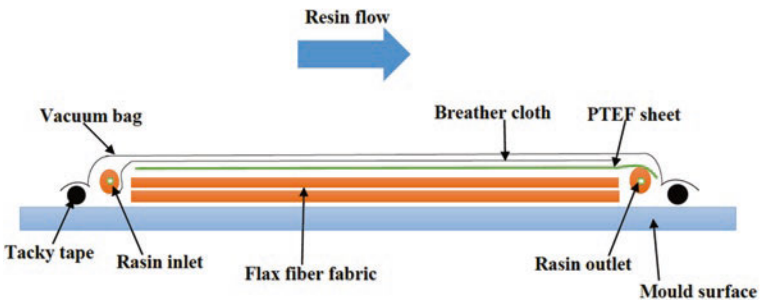

Fig. 3.14 Vacuum-assisted resin transfer molding

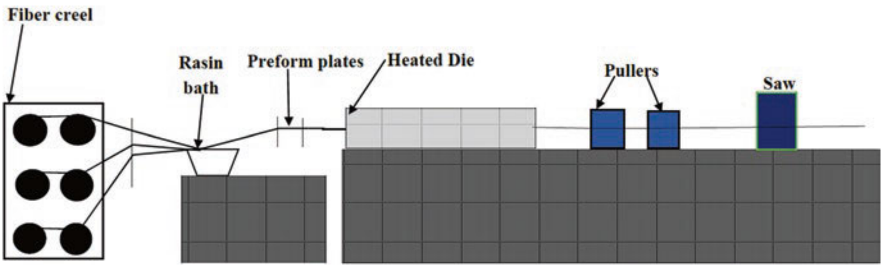

Fig. 3.15 Pultrusion process

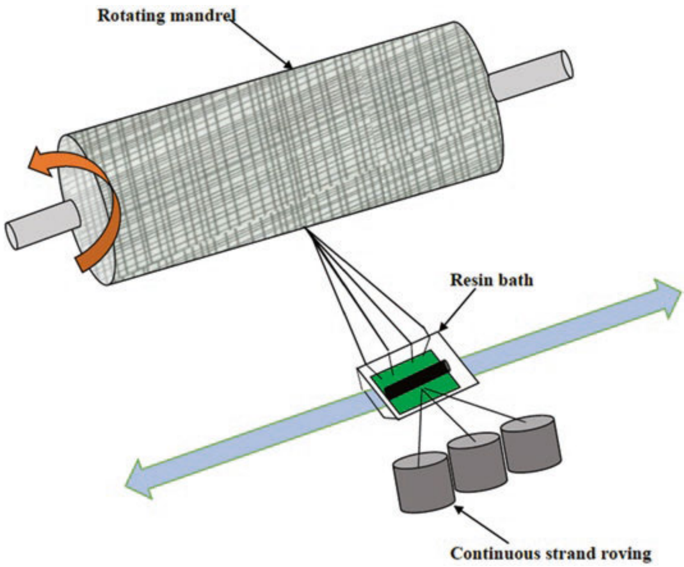

Fig. 3.16 Filament winding process

units, the profile is seen in the flying cutoff where it is cut to the necessary length [61, 62].

3.4.6 Filament Winding

The filament winding process is as shown in Fig. 3.16 produces hollow structures of unbelievable strength. In this process, the cross-weaving lines of the glass, carbon, or other fiber are added into the resin matrix, this process is used to manufacture the products that are suitable for various aircraft and other related applications. This process consists of two main components like fixed steel mandrel and carriage arm which will rotate horizontally up and down. With the help of the traveling arm comprises of winding center which includes glass, carbon, or the mixture both are allocated on the mandrel. As the mandrel rotates, the rowing's form a composite surface on the mandrel. The particular orientation of the composite matrix is determined by the travel speed of the vehicle and the rotational speed of the mandrel, both of which are automatic. The fibers are embedded in a resin and then reinforced with fiber to form the final composite material before facing to the mandrel. The disadvantage of using a filament winding is that the mandrel is often encircled to the windings. If the cladding is made of metal or polymer, then it is used as a real problem and can be an integral part of the project, but more often than not the development has been chipped off, as the parts are eventually dismantled [63, 64].

3.4.7 Autoclave Process

In today's many applications, autoclave processes as shown in Fig. 3.17 and injection molding machines are the most often used a necessary process for the aviation industry. These processes use a pre-impregnated unidirectional plies or woven cloths that can be partially cured. The only drawback is that the prepreg can be stored in the freezer to prevent the resin from escaping. Several layers of prepreg are applied to the surface using a predetermined fiber orientation to create the desired thickness, and then coated with a layer of separation film, breathing cloth, and using a vacuum cleaner bag or silicon pressure on the bag. The air escapes from the bag to create a vacuum, and the instrument, which is heated under high temperature and pressure to cure the resins. In this process, number of layup is done and after every three to four layers there is a need to remove the air which is accumulated in the layers. This removal of air prevents the layer or the material from delamination as well as determines the thickness and dimensions. The correct shape of the cycles and the appropriate hydrostatic pressure of the hand, while the curing time, are the two main requirements for succeeding good results. As compared to other processes

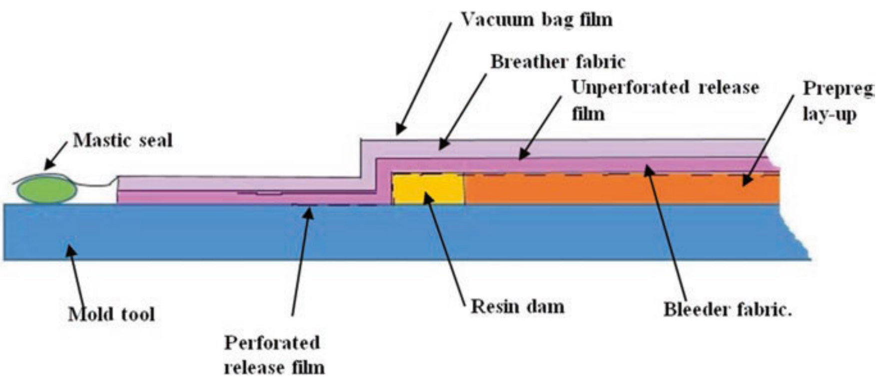

Fig. 3.17 Autoclave process for composite manufacturing

the efficiency of the machine is quite less, as more time and labor are required for bagging, stacking, and disassembling process. In addition, in the capital, the costs will be huge, and this will not limit the use of large buildings in which these costs may be required [65–67].

3.5 Conclusions

In this review article, the important thing that display is the proper selection of polymer for certain application is really important as the airplane has to sustain various types of loads and related properties when it is in running condition. As for the designing of aircraft wings, proper selection of material is very essential otherwise there is a problem with the fluttering speed. Even the fiber orientation will play a very important role at the time of manufacturing engine fan blades to diminish the vibration-related problems. The fuselage is the central part of the airplane so it should be designed in such a way that it has to carry the whole weight of the passengers. The manufacturing process for the development of aircraft components is already discussed in detail; the proper selection of the manufacturing process depends on the type of part to be manufactured. As aviation is the most advanced engineering branch so the two important things that should be considered while designing or selecting the polymer are reliability and safety. There is always a need to make polymer composite material that will provide unique properties with cost-effectiveness, because the designing of aircraft or its component is always a challenge as it requires tremendous care otherwise the significances will be hazardous and extreme.

3.6 Future Scope

In this review article, all the polymer components related to the aircraft applications are discussed in detail with their properties. By reviewing the article, the importance of composite materials is highlighted in the field of the aircraft industry. The next future of composite is bright and challenging which will present the products with extra lightweight and more efficient. In coming years, the whole aircraft will be manufactured with composite only instead of metals. At present, some of the aircraft parts are made of metals and some of the composite, which has directed to the production of important constituents by the practice of bonding and curing processes that completely restrict the practice of fasteners. In upcoming years, the focus is not only on the strength and life of the composite but also on the cost reduction. There is a need to develop the extra smart composite material so it can be used in any sort of application and also it can be fabricated in a very complex shape.

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