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A review of Carbon Nanotube Reinforced Aluminium Composite and Functionally Graded composites as a Future material for Aerospace

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Abstract: *Material selection is a very critical issue when it comes to aerospace engineering. Materials should have good qualities like light weight, high strength and corrosion resistance with economic viability. Over the period, Aluminium blends of composite are used for variety of applications. Carbon Nanotube reinforced Aluminium composites and Functionally graded composites(FGC) are the new developments in materials engineering. Gradual but continuous variation in composition and structure over volume, results in corresponding changes in the properties of material in contrast to homogeneous mixing of CNT in case of composite. FGM promises to be more suitable in the future. This paper focuses on brief review of CNT reinforced Aluminium composite and FGM application in aerospace.*
Keywords: *Aerospace, Composites, FGM, CNT*

I. Introduction

A survey of current applications of composite materials and structures in military, transport and general aviation aircraft is presented to assess the maturity of composites technology, and the payoffs are realized[1]. The results of the survey shows that performance requirements and the potential to reduce life cycle costs for military aircraft and direct operating costs for transport aircraft are the main reasons for the selection of composite materials for current aircraft applications. Aluminium/Aluminium alloy is the most usable materials in aerospace structure due to its distinct properties as compared to other metals[2]. Reinforcement of CNT in Aluminium matrix leads to huge changes in physical as well as chemical properties like greater strength, improved stiffness, reduced density(weight), improved high temperature properties, controlled thermal expansion coefficient, thermal/heat management, enhanced and tailored electrical performance, improved abrasion and wear resistance, control of mass (especially in reciprocating applications), improved damping capabilities[3,4,5]. The application of high performance composite materials to military aircraft can be traced back to almost three decades to the F-14 (US Navy) and F-15 (US Air Force) fighters, which uses boron/epoxy skins in their empennages[6,7].

II. Composite And Functionally Graded Composites Material

Over the years, research in materials science has geared up with new innovative materials called Functionally graded materials[8]. Especially these materials show new capabilities towards thermal and chemical resistance with application of producing light weight structures. FGM also provides chance to build structures with different functionality as the requirements (needs). These developments are replacing parts of aerospace with FGM components[9,10]. Initial applications of composite materials to aircraft structures were in secondary structures such as fairings, small doors and control surfaces. As the technology developed, the use of composite materials for primary structures such as wings and fuselages has increased[11,12]. A comprehensive list of current aircraft with a significant use of composite materials in the airframe is shown in Table 1. [13,14].

TABLE 1
Composite component of Air Bus

Component	Details
Wing	Box beam skins, box beam sub-structure, winglets, Leading edge flaps/slats, ailerons/flaperons , raps & spoilers, fixed leading edges, fixed trailing edge panels, rap track fairings, actuator fairings.
Empennage	Horizontal stabilizers, skins, sub-structure, elevators, leading edges,fixed trailing edge panels,tips
Vertical stabilizer	Skins ,sub-structure, rudders, leading edges fixed trailing edge panels, ventral fins, tips.
Fuselage	Radome, forward fuselage, canopy frames (helicopters) ,mid fuselage, rear fuselage, speed brakes , tail cone, floor beams, floors rotor-domes, cabin doors (helicopters), lining and partitions, overhead baggage compartment, air ducts.
Helicopter	Main rotor blades, tail rotor blades, rotor drive shafts.
Doors and Fairings	Landing gear doors , landing gear fairings , landing gear pods, Wing-fuselage fairings, stabilizer fairings, equipment access doors.
Propulsion System	Engine fan blades ,engine casing , nozzle flaps, thrust reversers, engine nacelle and cowling, fan cowls , turbine blade containment rings, pylon fairings, fuel tanks, propeller blades.
Propulsion System	Engine fan blades ,engine casing , nozzle flaps, thrust reversers, engine nacelle and cowling, fan cowls , turbine blade containment rings, pylon fairings, fuel tanks, propeller blades.

III. MATERIAL FOR AEROSPACE

Materials are classified into the seven broad classes that are shown in figure 1; metals, ceramics, glass, elastomers, polymers, composites and FGM[15,16]. Composites and FGM are the advanced engineering Materials having high specific performance advantages in comparison with the conventional materials. In cases where high moduli of elasticity values are less important, fiberglass is the natural option because of the low cost of material[17,18]. The matrix material used with fiber glass are limited to low temperatures, such as below 121°C. Although it is not a debilitating limitation for the fiber, as its properties can still be used and maintained at temperatures beyond 426 to 482°C. Fiber epoxy composites have been used in aircraft engine to enhance the performance of the system[19]. The pilots' cabin door of aircrafts has also been made with fiber glass resin composites and these are now used in other transport systems. The boron-graphite materials were initially designed for fighter aircraft components and their use in commercial aircraft has been very limited[20,21].However, These are widely used for experimental applications. They are presently limited to secondary structures which can be used in commercial aircraft with considerable safety. The data from such experimentation on the long term effects of loads and stresses on the structure provides an input for design. Both dynamic and static conditions are combined in the turbojet engine and research has always been directed and focused towards replacement of materials[22,23]. Figure 1 shows the evolution of materials from conventional alloys to functionally graded materials used for aerospace structures.

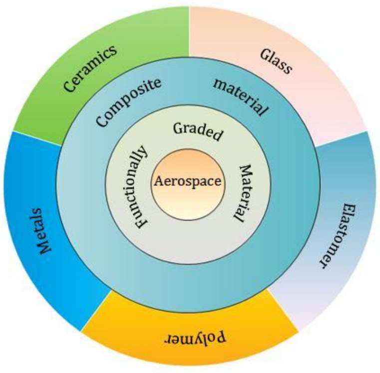

Fig.1. Material advancement for aerospace application

Application of FGM has advantages of light weight and high strength. The weight of the rotors, compressors and bearings are reduced. Initially, turbojet engines were used in fighter aircraft and later in commercial planes[24,25]. The necessity of a commercial plane is durability and heigher service life, therefore few turbofan engines are designed to meet the manifold requirements of transport sector. The performence of the engine can be improved by improving the efficiency of propulsion or reducing the weight. The notable stiffness and strengths of composites permit reduction in the number of compressor stages by higher blade loading. The use of composites in rotors, compressors and engine parts are estimated to lead to weight savings[26,27]. Figure 2(a) shows the CNT reinforced composite specimen and Figure 2(b) shows layered CNT reinforced Al functionally graded material specimen.

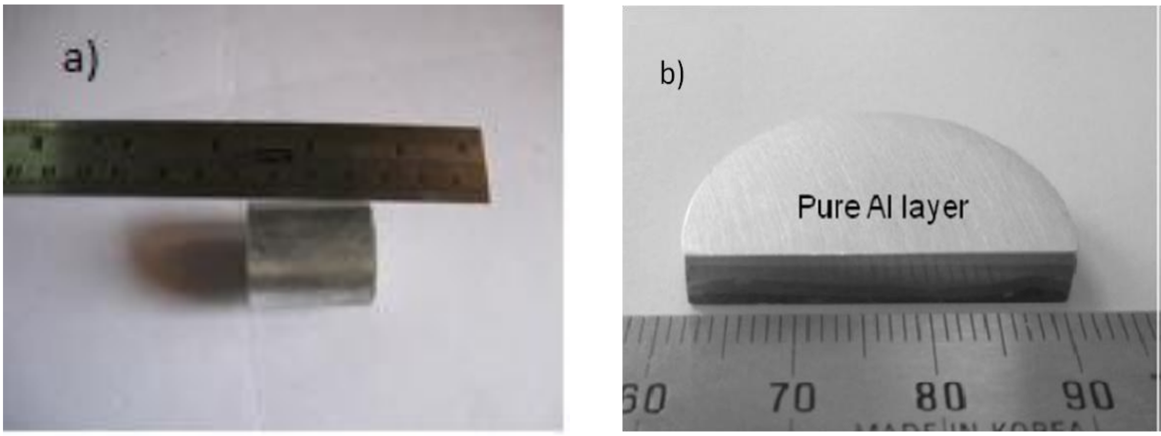

Fig.2 : (a) CNT reinforced Al composite specimen, (b) CNT reinforced Al FGM specimen

Comparison of Composite with FGM was shown in Table 2.

TABLE 2
Comparison of Composite and FGM

CNT reinforced aluminium	FGM
Increased mechanical properties	Increase in mechanical property in a range
Light weight and hard	Light weight, tough and hard
Good chemical resistance	Good chemical resistance and thermal barrier capacity

IV. APPLICATION OF COMPOSITES IN AIRCRAFT INDUSTRY

The use of fiber reinforced composites has become an attractive alternative to the conventional metals for many aircraft components mainly due to their increased strength, durability, corrosion resistance, resistance to fatigue and damage tolerance characteristics[28]. Composites also provide greater flexibility because the material can be tailored to meet the design requirements and they also offer significant weight advantages. Carefully designed individual composite parts, at present, are about 20-30% lighter than their conventional metal counterparts[29]. Although all-composite airplanes are now available in the world market, yet advances in the practical use of composite materials should enable further reduction in the structural weight of airplane. The composite materials used in aircraft industry are generally reinforced fibres or filaments embedded in a resin matrix. The most common fibres are carbon, aramid, glass and their hybrids. Commercial aircraft applications are the most important users of composites[30]. Aircraft, unlike other vehicles, need to lay greater stress on safety and weight. They are achieved by using materials with high specific properties. A modern civil aircraft must be so designed as to meet the numerous criteria of power and safety[31,32]. The composites applications trend over the years in US and European combat aircraft is summarized in table 3.

TABLE 3
Aircraft composite Materials usage

Fighter Aircraft (US)	F-16, F-14, F-18,YF-23, F-22, JSF, UCAV.
Fighter Aircraft (Europe)	Gripen JAS-39, mirage 2000, rafael,eurofighter typhoon, lavi, DASA Mako
Fighter Aircraft (Russia) Bomber (US)	MiG-29, su series B-2
Transport (US)	KC-135, C-17
Transport (US- commercial)	B-777, B-767, MD-11
Transport (Airbus, European)	A-320, A-340, A380, Tu-204, ATR42, Falcon 900, A300-600 ST
General aviation	Piaggio, Starship, premier 1
Rotary aircraft	V-22, Eurocopter tiger, comanche, RAH-66, bell/agusta BA-609, EH101, super Lynx 300, S-92.

V. CASE STUDIES

5.1Civil aircraft applications

Aeronautical engineering comprises of various distinct areas in producing vehicles capable of performing distinct flight programmes. Initially importance was given to weight, speed and power, but other parameters that influence market acceptance of the aircraft should also be considered during design[33]. Airframe design starts with evaluation of flight conditions which the aircraft will encounter. Figure 5 shows the evolution in the use of composite over the years.

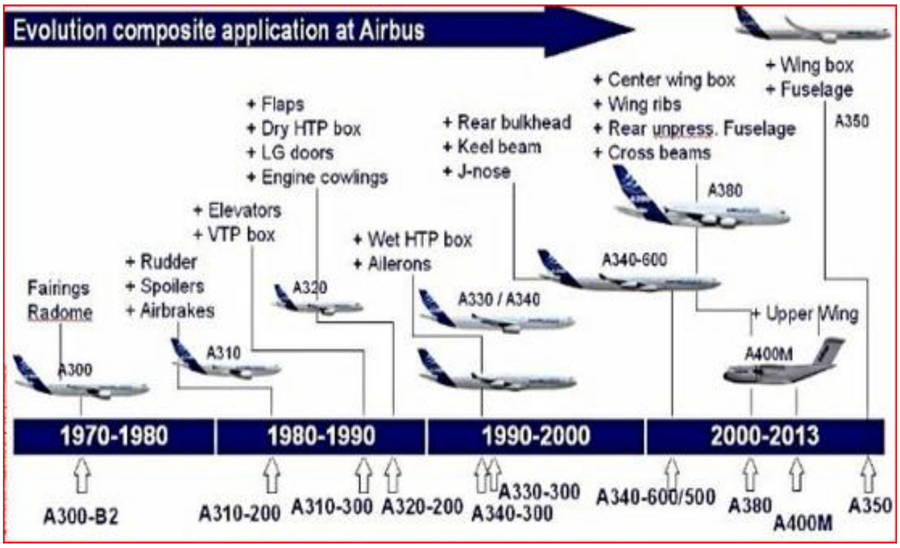

Fig. 5. Evolution in use of composite in Air bus [Courtesy: defenceaviation.com]

In recent designs, wind tunnel tests and analysis are being done to determine the lift and drag forces. Once determined, they are used to compute related factors of structural engineering. The high strength of composites and FGM allows designing of higher aspect ratio wings in aerofoil sections[34]. Figure 6 shows the percentage of forecast of composite structure uses in air bus and predicted huge market in the future grounds.

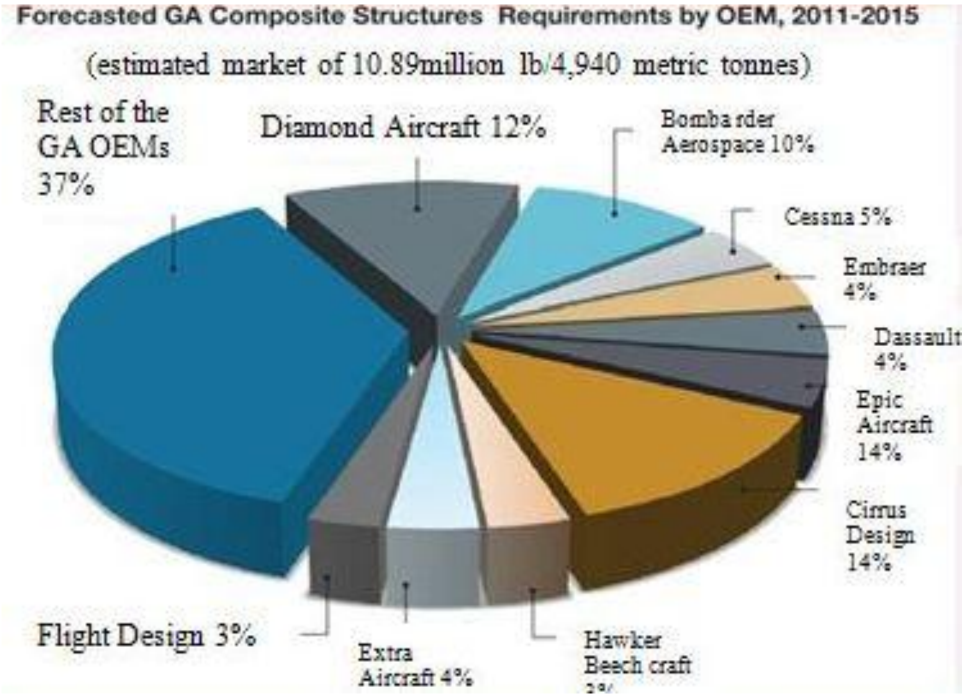

Fig. 6. Forecast of composite structure use in airbus

The selection of material naturally comes into the picture at the early stage of design itself. Airbus Industries used advanced composites on the Airbus A300 aircraft which first flew in 1972. The composite material was used in fin leading edge and other glass fiber fairing panels (as shown in Figure 7)[35]. As shown in the figure 5, the evolution of composite fraction of the structural weight for fighter and airbus aircraft seems to be leveling off at 30 percent. The payoff in combat aircraft is in performance in the form of reduced weight, increased payload and speed. Affordability is also a most important concern since costs associated with aircraft specific structural concept development, production implementation and recurring fabrication of complex composite parts with built in metal fittings and trunnions. Boeing is actively working with its global partners to find applicable best practice guidelines for the 787 program. As the newest member of the Boeing family of airliners, it is an all-new, mid-sized airplane with long range capabilities. The 787 is being made primarily of carbon fiber composite material comprising 50% of the 787's structural weight. This represents a breakthrough from today's airliners that are primarily composed of aluminium. Looking forward, cost reduction strategies for heavily loaded substructure need to be developed[28].

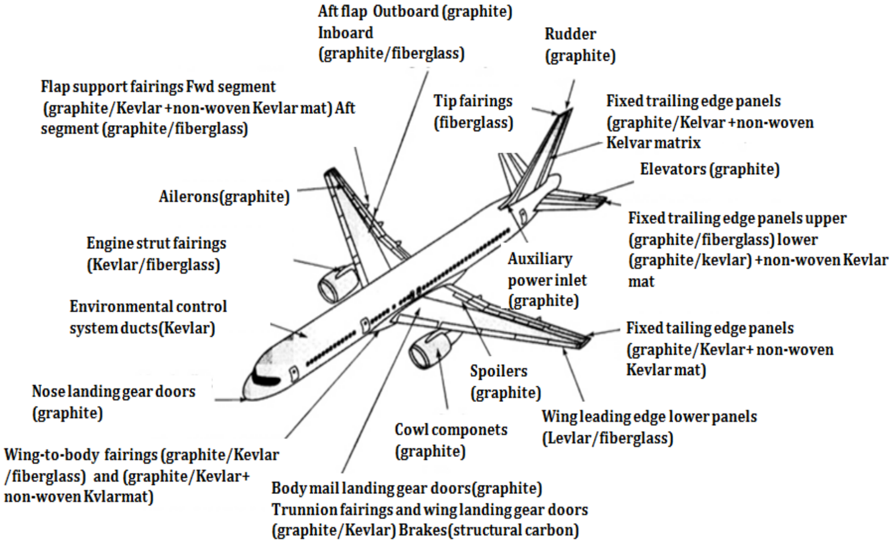

Fig. 7. Use of composite in Air bus [Courtesy: defenceaviation.com]

TABLE 4
The components used on Airbus series

Aircraft Type	Components Made of Composite Materials
Airbus A300B2/B4	Radome, fin leading edge and tip, fin trailing edge panels, cabin and cargo hold furnishings. Fairing -pylon, wing/ fuselage rear.
Airbus A310-300	Rudder, elevator, vertical stabilizer, spoilers, cowl (inlet & fan), thrust reverser, main & nose landing gear door of wing leading & trailing edge panels, nacelles. Fairings -Ion, flap track, win fuselage.
Airbus A320/A319 & A321	Aileron, horizontal and vertical stabilizer, elevator, rudder, spoilers, flaps, engine cowl, radome, landing gear doors (main & nose), floor panels, wing panels (leading & trailing edge), other access panels, nacelles, Fairings -flap track, wing/fuselage (forward & rear), and main landing gear leg.
Airbus A330	Ailerons, rudder, flaps, spoilers, elevator, horizontal and vertical stabilizer, wing panels (leading & trailing edge), landing gear doors (main & nose), nacelles,Fairings -flap track, wing/fuselage (forward & rear).
Airbus 340	Ailerons, rudder, flaps, spoilers, elevator, horizontal and vertical stabilizer, wing panels (leading & trailing edge), landing gear doors (main & nose), nacelles,Fairings -flap track, wing/fuselage (forward & rear).

5.2 Military Aircraft Applications

The trends in the use of composite materials for US Fighter aircraft are shown by the examples in Figure 8 . The percentage by weight of composite materials used initially (e.g., F-15E) was small at 2%, but this percentage has since grown to more than 25% for the F-22 which is the designated replacement for the F-15E. The F-22 has demonstrated the feasibility and benefits of introducing processes such as RTM (Resin Transfer Molding) to improve the affordability of composite materials in combat aircraft applications. The use of composite materials in the US Navy's F/A-18E/F equals nearly 20% of its structural weight in flight critical parts as shown in table 5. The choice of composite materials in the F/A-18E/F was dictated by a need to reduce weight and to improve strength, reliability and maintainability in an aircraft carrier environment.

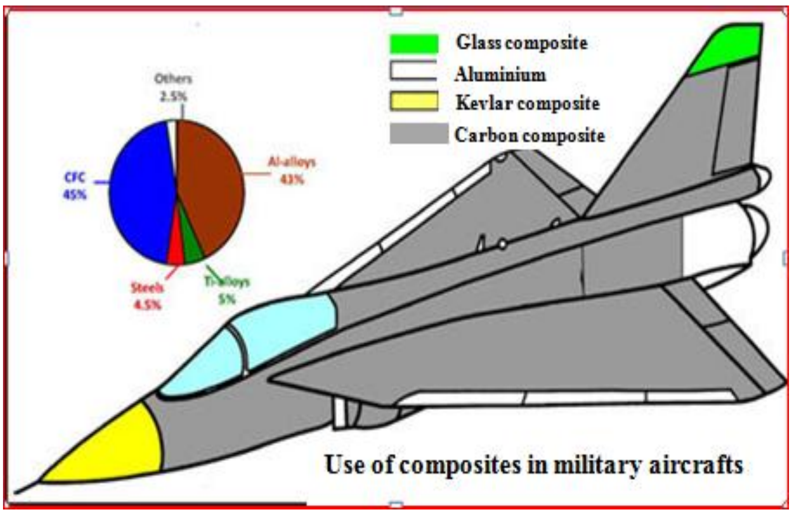

Fig. 8. The composite components used on Military aircraft [Courtesy: defenceaviation.com]

The center and aft fuselage skins and other ancillary structure, such as the speed brake and dorsal covers, are all-carbon/toughened- epoxy construction in the F/A-18E/F. Carbon fibers, such as Hexcel's IM7, with improved strength and stiffness properties are used in the wing and the tail skins. Although composite materials in general are sensitive to impact damage, toughened materials such as Fiberites 977-3 toughened epoxy system are used on the F/A-18E/F have successfully addressed this threat in operations. The AV-8B uses nearly 25% by weight of composite materials in its airframe[29].

TABLE 5
The composite components used on different Military Aircraft

Aircraft type	**Components made of composite materials**
F-14	Doors, Horizontal tail and fairings
F-15	Rudder, Vertical tail, horizontal tail and speed brake
F-16	Vertical tail and horizontal tail
F-18	Doors, Vertical tail, horizontal tail, wing box, fairings ,speed brake
B-1	Doors, Vertical tail, horizontal tail, Flats and slats
AV-8B	Doors, Vertical tail, horizontal tail, Flats and slats, Aileron, Flaps, Wing box, Body and fairings
TYPHOON	Wing, Fin ,Rudder, In-board aileron, fuselage
LIGHT COMBACT AIRCRAFT(LCA)	Wing, Fin ,Rudder, Control surface, radome

5.3 General aviation application: Helicopter

Composite materials are being used for different helicopter components as shown in figure 9. Use of advanced composites in helicopter application started way back in 1959 with the development of optimum pitch blade for the XCH-47 twin rotor helicopter of Vertol Aircraft Corporation[30].Extensive use of composites has also been made in India's Advanced Light Helicopter (ALH). In ALH, composite material is employed in whole of the secondary structure and several parts of the primary structure. The nose is made of aramid and tail section of carbon fiber reinforced plastic.

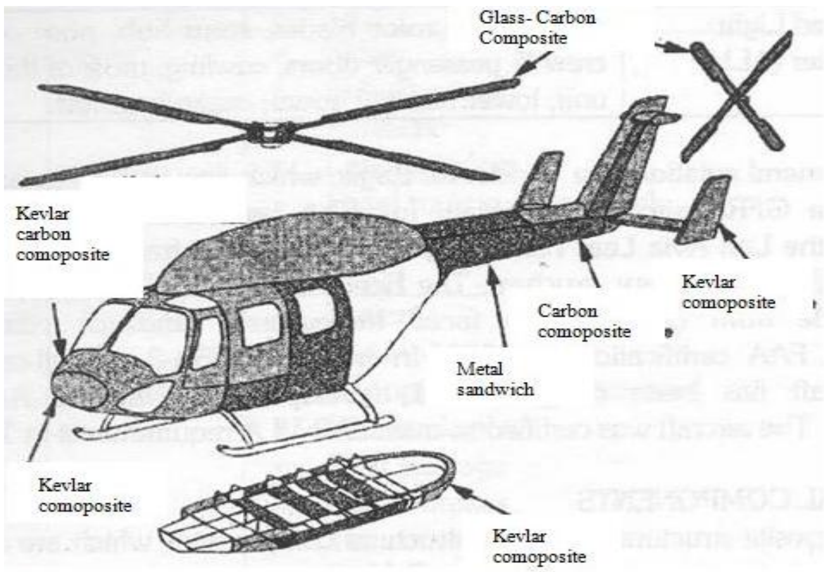

Fig. 9 . Helicopter with composite components [Courtesy: defenceaviation.com]

Rotor hub, main and tail rotor blades are made of composites. Entire cockpit is also made of composite material. The extent of composites used in the structure is about 60% by wetted area and about 29% by weight[31,32].The strength-to-weight ratio advantage of composites is vital to maximize payload in helicopter design. Boeing used composites in rotorcraft fairings in the 1950s and manufactured the first composite rotor blades for the CH-47 helicopter in the 1970s. Composites constitute key structural elements of the Boeing-Sikorsky Comanche RAH-66 helicopter and the Bell-Boeing tilt rotor V-22 Osprey. The main design driver for these composite applications is weight savings and the listed parts in table 6 [33]. Stiffness tailorability and radar absorbing properties are significant contributors to these savings. The US Army's Advanced Composite Airframe Program (ACAP) and the US Air Force funded DMLCC-BW (Design and Manufacture of Low Cost Composites- Bonded Wing) program have provided major advances in composites technology for helicopters. Development of synthetic foams and bonded assembly technology played a major role in increasing composites usages in helicopters[34].

TABLE 6
The composite components used on Helicopter

Helicopter Type	Components made of composite materials
MBB BK 117	Main rotor blades, tail rotor blades, horizontal stabilizer, vertical stabilizer.
Bell 206L	Vertical stabilizer
Bell 402	Main rotor blades
Dauphin	Main rotor blades, vertical stabilizer.
McDonnell Douglas, MD 520N	Main rotor blades, tail boom
McDonnell Douglas MD 900	Main rotor blades, fuselage mid section, tail boom, canopy frame, internal fuselage, horizontal stabilizer, vertical stabilizer

Composites played a crucial role in the development of the tilt-rotor V-22 due to its weight sensitivity. The V-22 uses composite nacelles, wing, fuselage skins, empennage, side body fairings, and doors as shown in Figure 9. Composites usage in the V-22 is approximately 50 percent of the airframe weight[35,36]. The DMLCC- BW program provided the bonded assembly technology used in the V-22. Bonded assembly virtually eliminates mechanical fastening and allows structural attachments to be integrated into the components. The ACAP program provided advances in manufacturing technology to reduce costs of the composite components. Automated fiber placement technology applications to the fuselage resulted in a 53 percent cost savings since the V-22 aft fuselage skin could be fabricated in one integral piece rather than assembly of 10 skin panels in the original design[37].

Optimise the requirements:
For increased future applications of composites in aircraft structures lowering their costs is essential. Some of the means by which it can be achieved are:

1. Unitize and integrate multiple parts to reduce fabrication costs in the early stages of the design process.
2. Simplify design and apply automation to reduce variable fabrication costs
3. Replace lightly loaded integral stiffeners with syncore sandwich construction
4. Utilize fiber placement, performs, and other innovative material forms to reduce manual lay-up
5. Design for efficient manufacturing processes such as fiber placement and Resin transfer moulding.
6. All aspects of the design and manufacturing processes must be addressed to achieve lower cost composite structures.

VI. CONCLUSION

The Advanced Composites Programme activities have proliferated encompassing number of composite applications and its presence is now being felt across the large geographical canvas of the world as well as diverse user segments. It should be an efficient, successful mechanism in infusing the knowledge component to industrial practices. Effective knowledge among the academia/research institutions, standards & certifying agencies as well as the experts from the actual users has gone a long way in reducing product development cycle time and thus reaching the value-added products to the market in time. Composites are used in peripheral structures of aerodromes. Conventional constructions of composites ought to cost much less in future and will not be a constraint. Automation along with high standard for reinforcement and matrix materials will also decrease fabrication costs, as the rejection on grounds of quality will be less. Performance, reliability and efficiency of operators alone can assure the success of any programme and the space program in particular. The potential for application of high-performance composites and functionally graded composites has revolutionized space structural technology for future needs[36,37].

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