

Low-Cost Composite Materials and Structures for Aircraft Applications

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Abstract

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 realized. The results of the survey show 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. Initial acquisition costs of composite airframe components are affected by high material costs and complex certification tests which appear to discourage the widespread use of composite materials for aircraft applications. Material suppliers have performed very well to date in developing resin matrix and fiber systems for improved mechanical, durability and damage tolerance performance. The next challenge for material suppliers is to reduce material costs and to develop materials that are suitable for simplified and inexpensive manufacturing processes. The focus of airframe manufacturers should be on the development of structural designs that reduce assembly costs by the use of large-scale integration of airframe components with unitized structures and manufacturing processes that minimize excessive manual labor.

Introduction

The application of high performance composite materials to military aircraft can be traced back almost three decades to the F-14 (US Navy) and F-15 (US Air Force) fighters, which use boron/epoxy skins in their empennages. Since then the use of composite materials in military and transport aircraft has increased. Initial applications of composite materials to aircraft structures were in secondary structures such as fairings, small doors and control surfaces. As the technology matured, the use of composite materials for primary structures such as wings and fuselages has increased. A comprehensive list of current aircraft with a significant use of composite materials in the airframe is shown in Figure 1. As indicated in Reference 1, the aircraft industry chooses to use composite materials not only to reduce weight, but also because these materials are corrosion and fatigue resistant. The limiting factor in the widespread application of these materials has been their high cost compared to conventional metals. The

application of composite materials for each of the aircraft listed in Figure 1 are reviewed in the present paper with respect to the following:

• 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)	MiG-29, Su series
• Bomber (US)	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,

Figure 1. Aircraft composite materials usage surveyed.

1. The typical weight fraction of composite structures in military, transport and general aviation aircraft
2. Factors influencing the use of composite materials
3. Payoffs associated with the applications reviewed
4. Factors limiting the use of composite materials
5. Technology developments in progress to remove the limitations
6. Potential role for composite materials in future airframes.

The following paragraphs describe the results of this review.

Combat Aircraft

The trends in the use of composite materials for US Fighter aircraft are shown by three examples in Figure 2. 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 Figure 3. 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. 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 Fiberite's 977-3 toughened epoxy system 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.

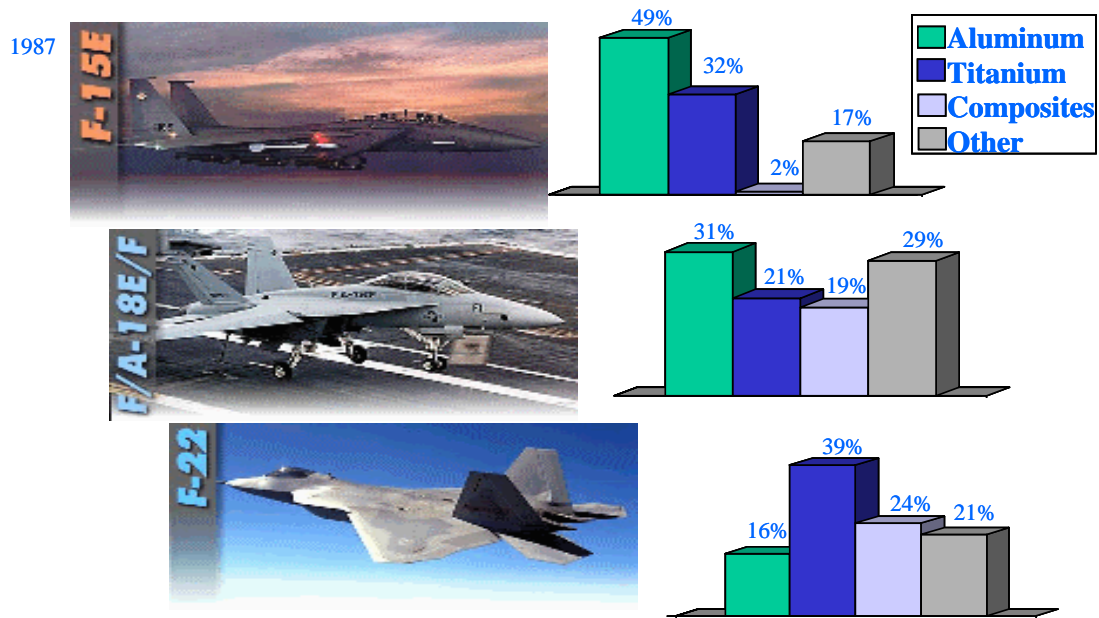


Figure 2. Materials usage trends in US fighter aircraft.

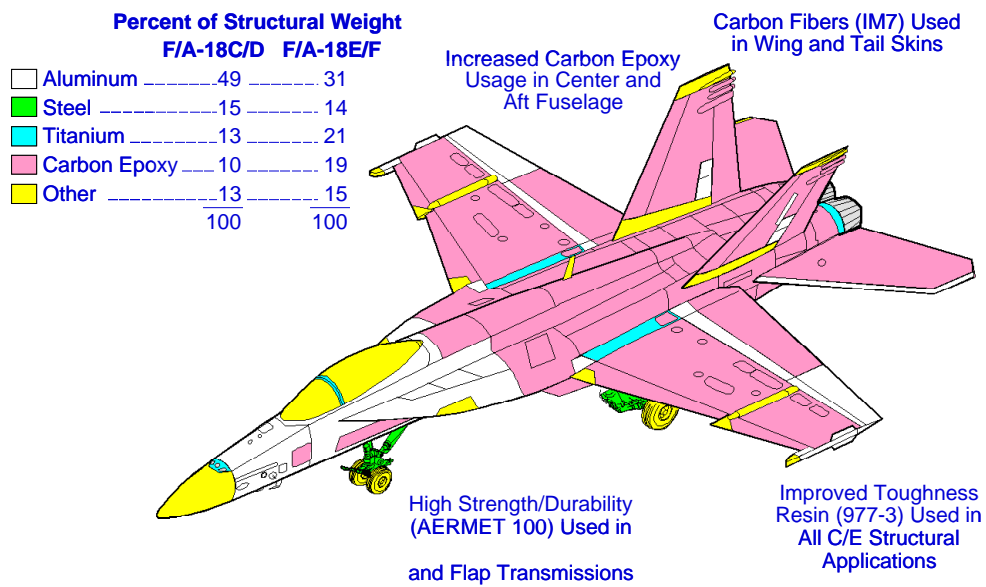


Figure 3. Materials distribution for the F-18 E/F aircraft.

The Eurofighter Typhoon is shown in a cutaway view in Figure 4, and uses composite materials in the wing skins, forward fuselage, flaperons and the rudder. Eurofighter's exterior skins are made of Hexcel's 8552 toughened epoxy and constitute 70% of the wetted area. Overall, 40% of the Eurofighter's structural weight consists of carbon-fiber composite materials. The proportion of composite parts in Dassault's combat aircraft has grown steadily over the years, from 7 percent on the first Mirage 2000 fighters, to over 26 percent on the Rafale. Other fighters built by European companies such as the Saab Gripen, and EADS' newly developed "light" fighter Mako use composite materials extensively in the 20-25% weight percent range.



Figure 4. Cutaway view of the Eurofighter Typhoon structure.

The composites applications trend over the years in US and European combat aircraft is summarized in Figure 5. As shown in the figure, the composite fraction of the structural weight for fighter and attack 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. Based on the prevalent applications seen by composites in combat aircraft, this limit is an indicator of lack of confidence in composite applications in highly 3-D loaded fuselage and wing substructures such as the main spars, and bulkheads e.g. the wing and landing gear attach bulkheads. Manufacturing and structural demonstration of innovative concepts in these areas is the next step if the 30 percent barrier is to be broken. Affordability is also a 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 can exceed the \$/lb saved ceiling for an aircraft. Therefore, cost reduction strategies for heavily loaded substructure need to be developed.

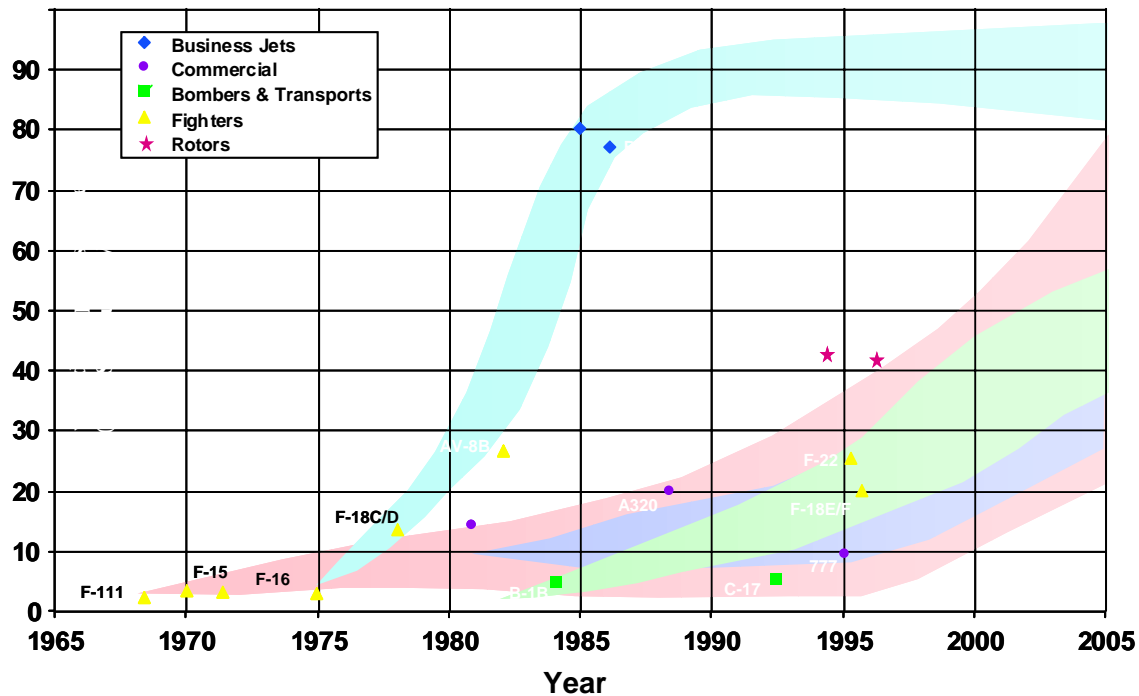


Figure 5. Composite Application Trend in US and European Combat Aircraft

Another feature to note in Figure 5 is the weight fraction of composites in the B-2, which seems to have broken the 30 percent barrier. This in spite of being a heavy lift class of aircraft where, as will be shown later, the limiting composites percent weight is even lower than for fighter/attack category of combat aircraft. Figure 6 illustrates the extent of carbon fiber and glass fiber composites usage on the B-2 that results in the high weight fraction. For the B-2, stealth or minimizing the radar cross-section was the primary driver and as such carbon fiber composites were extensively used in the primary structure to offset the weight penalty from radar absorbing materials applied to the exterior. Due to the lower density of composites compared to metals, the volume fraction of the airframe that is composite is considerable and may exceed 60 percent. Of special note in the case of the B-2 is that stealth performance requirements dictate significantly increased usage of composites.

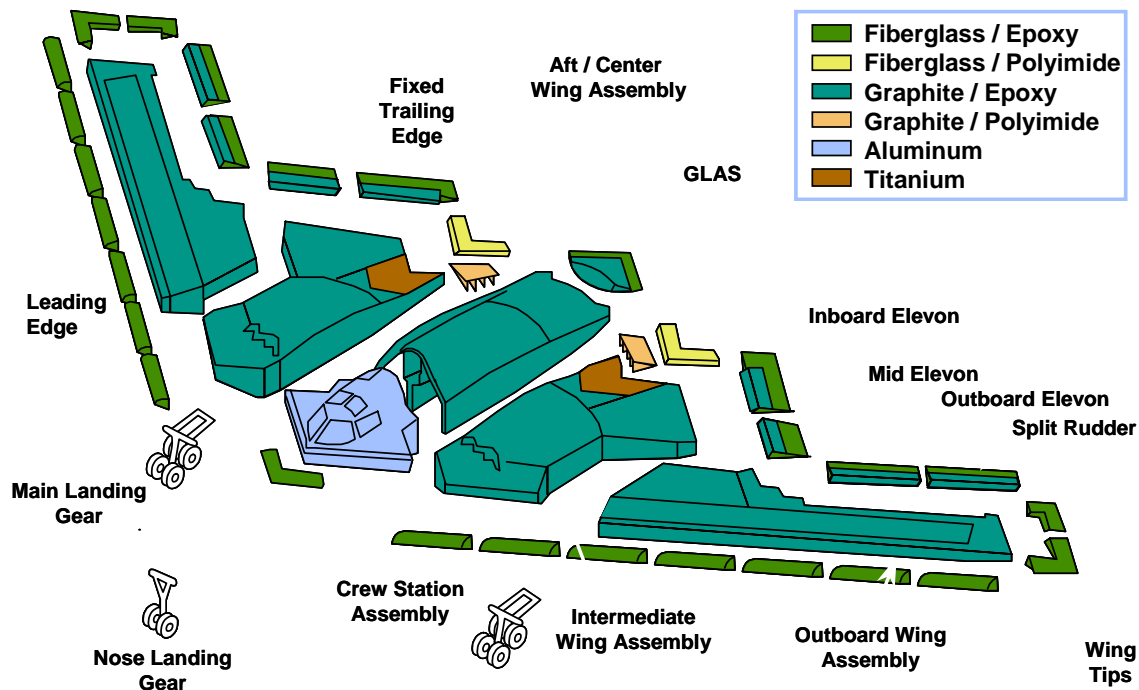


Figure 6. Application of Composites in the B-2 Bomber

Transport Aircraft

Operating efficiency and economy with passenger comfort are paramount in commercial transport aircraft. Reduced airframe weight pays off in fuel economy and, therefore, reduces Direct Operating Costs (DOC) for the operators. Several NASA Research and Development Programs (e.g. Advanced Composites for Energy Efficiency) have demonstrated the DOC savings potential of carbon fiber polymer matrix composites. In addition, NASA programs have recognized the need to reduce associated manufacturing costs so that the increased initial acquisition costs do not offset the DOC savings attained with composite structures. NASA's Advanced Composites Technology program developed prototype composite wing and fuselage structures for commercial transports using integrated design and manufacturing concepts that would lower the costs of such structures.

The first significant application of composites in commercial transports, however, was in Europe in 1983 when Dasa Airbus introduced an all composite rudder for the A300 and A310, followed in 1985 by a much more complex vertical tail fin. The metal vertical tail had about 2,000 parts excluding fasteners, whereas, the composite vertical had less than 100 parts. As a consequence, the composite vertical was not only lighter but also lower cost than the metal vertical because of the reduced part count and assembly costs. The composite parts combined with other design efficiencies led to reduced fuel consumption- a major attraction for the airlines. Currently the A300-600 airframe is 4.5% composites by weight.

The weight and manufacturing cost savings for the A300 vertical fin and, subsequently, a carbon fiber epoxy/honeycomb core sandwich elevator for the A310 had proven so impressive that Airbus used composite materials for the entire tail structure of the A320. In addition, composites were also used in the A320's fuselage belly skins, fin/fuselage fairings, wing fixed leading/trailing-edge bottom access panels and deflectors, trailing edge flaps and flap track fairings, spoilers, ailerons, nosewheel/mainwheel doors, main gear leg fairing doors, nacelles,

interior and carbon brakes. The floor panels were also made of glass fiber reinforced polymer matrix composites. These composite structures in the A320 airframe, shown in Figure 7, added up to 5.5 tons, or 28 percent of the total weight.

A320 composite structures

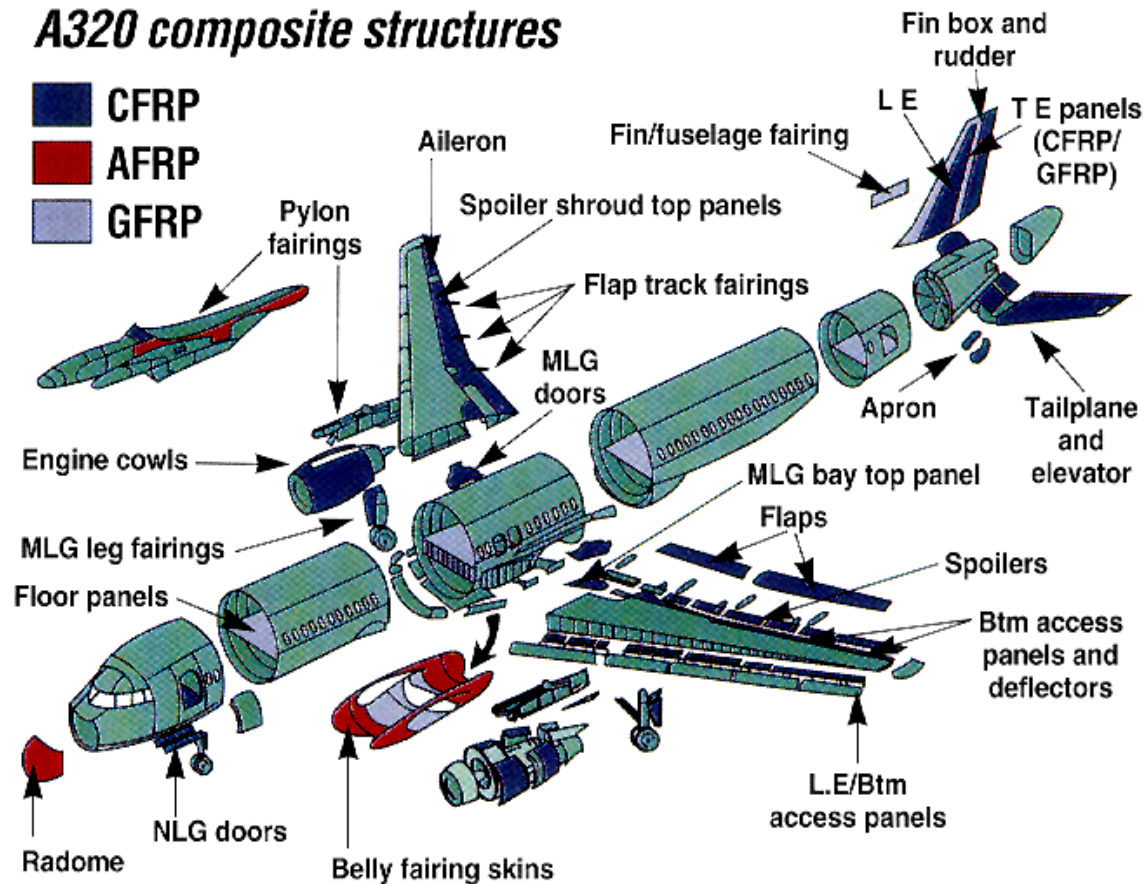


Figure 7. Composite Materials Applications on Airbus A320

Almost 4.5 tons of composites are used on the A340, a large-capacity, twin-aisle, medium-to-very long range aircraft. The A340 composite horizontal stabilizer incorporates an integral, load-leveling fuel tank that permits center of gravity control for best cruise efficiency. Although composites constitute only about 13 percent of the aircraft's total weight, the A340 scored a first in triple type certification by Europe's Joint Aviation Authorities, the US Federal Aviation Administration and Transport Canada. The A340-500 and A340-600 prototypes are targeting addition airframe elements for composites applications. These include the rear pressure bulkhead, the keel beam, and the fixed leading edge of the wing, which is especially significant since it involves the first large scale use of a thermoplastic matrix composite component on a commercial transport. The thermoplastic leading edge offers a 20 percent weight savings with reduced fabrication time and improved damage tolerance.

The A-3XX design under development is expected to rely on composite structures to achieve the promised 18 to 20 percent reduction in operating costs- a main selling point for the model. Composites are envisioned for the entire outer wing, i.e., outboard of the outboard engine, and the fuselage skins (mainly GLARE) in addition to the tried and tested applications on the previous models.

In the US, the most significant use of composites in commercial transports has been on the Boeing 777. Composite structures make up 10 percent of the structural weight of the B-777. Figure 8 shows the various composite structural elements used in the B-777. Corrosion and fatigue resistance with weight savings and improved damage tolerance were the main drivers for these applications. The composite empennage alone saves approximately 1500 lb over similar aluminum structure. The composites usage trend for commercial and military (C-17) transports is summarized in Figure 9. In the case of transport aircraft where cost and reliability are the predominant factors, composite applications seem to be leveling off at 20 percent of the structural weight a ceiling lower than for combat aircraft. The barrier in this case is set by the affordability of the airframe since initial acquisition cost plays a major role in airlines' selection of a particular model.

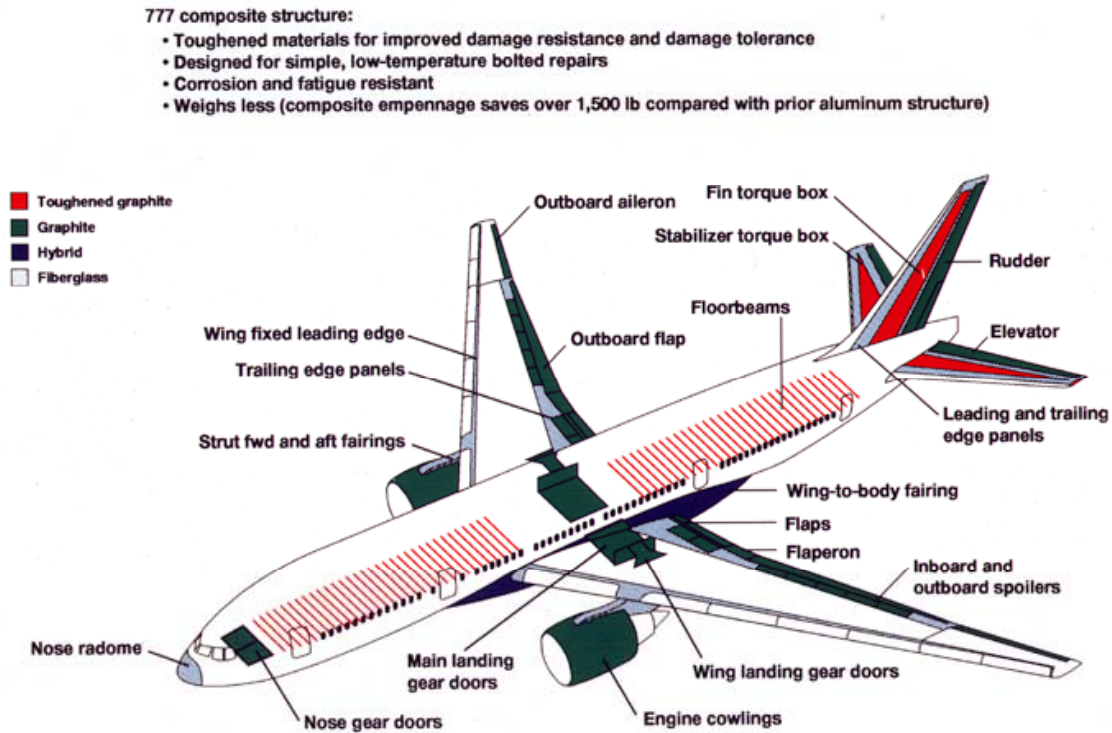


Figure 8. Boeing 777 Composite Usage

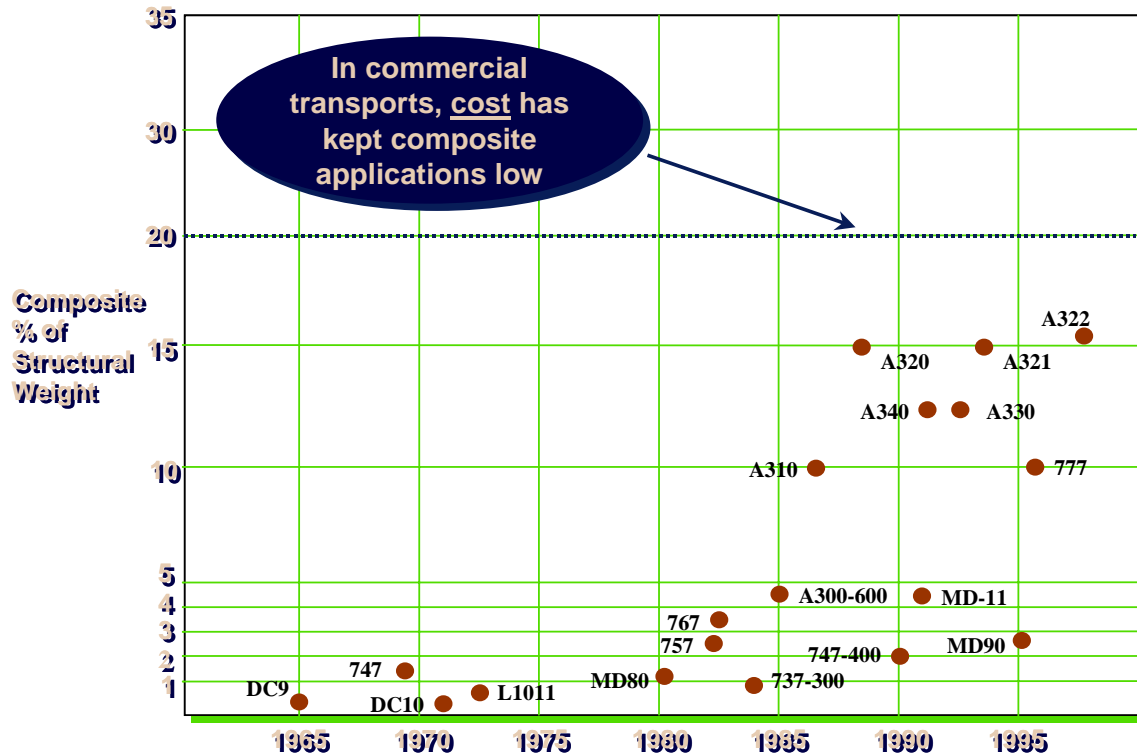


Figure 9. Composite Usage Trends in Commercial Transports and General Aviation Aircraft

Helicopters

The strength-to-weight advantage of composites is vital to maximizing 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 tiltrotor V-22 Osprey. The main design driver for these composite applications is weight savings. Stiffness tailorability and radar absorbing properties are a significant contributor 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 syntactic foams and bonded assembly technology played a major role in increasing composites usages in helicopters.

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 10. Composites usage in the V-22 is approximately 50 percent of the airframe weight. 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.

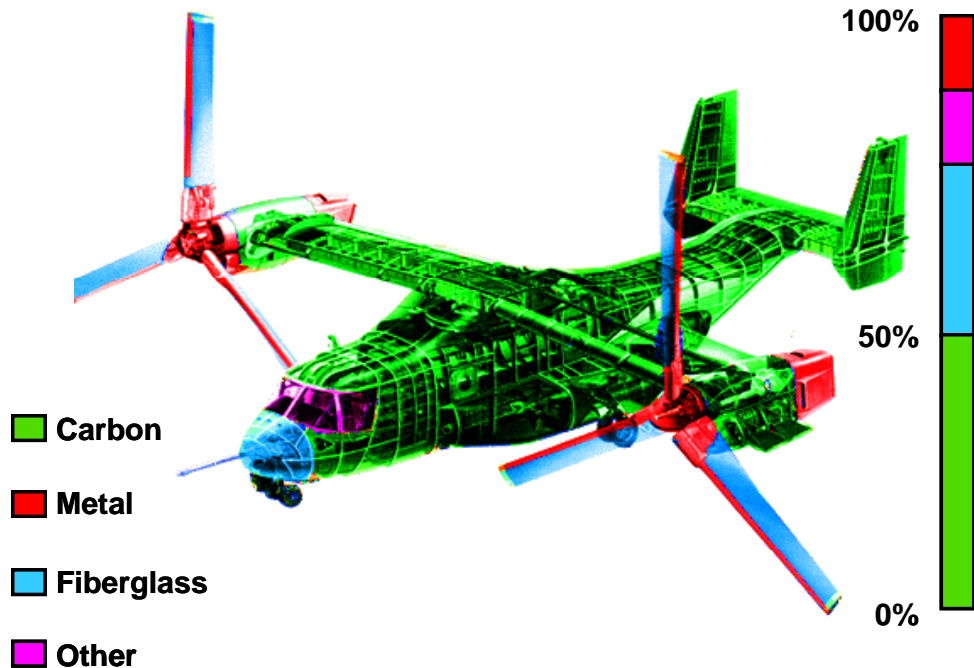


Figure 10. V-22 Material Application

The RAH-66 composites applications consist of the tail rotor shroud, main and tail rotor blades, exhaust doors, lower tail cone, dome and vertical and horizontal stabilizers. The Bell/Agusta BA609 consists of a third generation composite wing structure and is heavily influenced by the DMLCC- BW wing program. The BA609 demonstrated low cost and defect free bonded assembly.

Composite engine air intake ducts with integral heating systems are used on the GKN-Westland EH101 and Super Lynx 300 helicopters. The inlet duct's aerodynamic shape is very complex, transitioning from a rectangular to a ring shaped cross-section and is difficult to fabricate with metals. Metallic construction requires several parts with joints and multiple fasteners. A composite duct on the other hand can be manufactured as one-piece, thus saving weight and assembly costs.

The Eurocopter Tiger has carbon/glass hybrid prepreg engine fairings, glass prepreg blades and a fuselage, cockpit and tail boom built from Carbon prepreg.

Conclusions

For increased future applications of composites in aircraft structures lowering their costs is essential. The affordability lesson learned from a survey of US and European aircraft are as follows:

1. Unitize and integrate multiple parts to reduce fabrication costs in the early stages of the design process. One such example taken from the US Air Force Composites Affordability Initiative (CAI) program is shown in Figure 11.

2. Simplify design and apply automation to reduce variable fabrication costs
 - Replace lightly loaded integral stiffeners with Syncore sandwich construction
 - Utilize fiber placement, performs, and other innovative material forms to reduce manual lay-up
 - Design for efficient manufacturing processes such as fiber placement and RTM
3. All aspects of the design and manufacturing processes must be addressed to achieve lower cost composite structures.

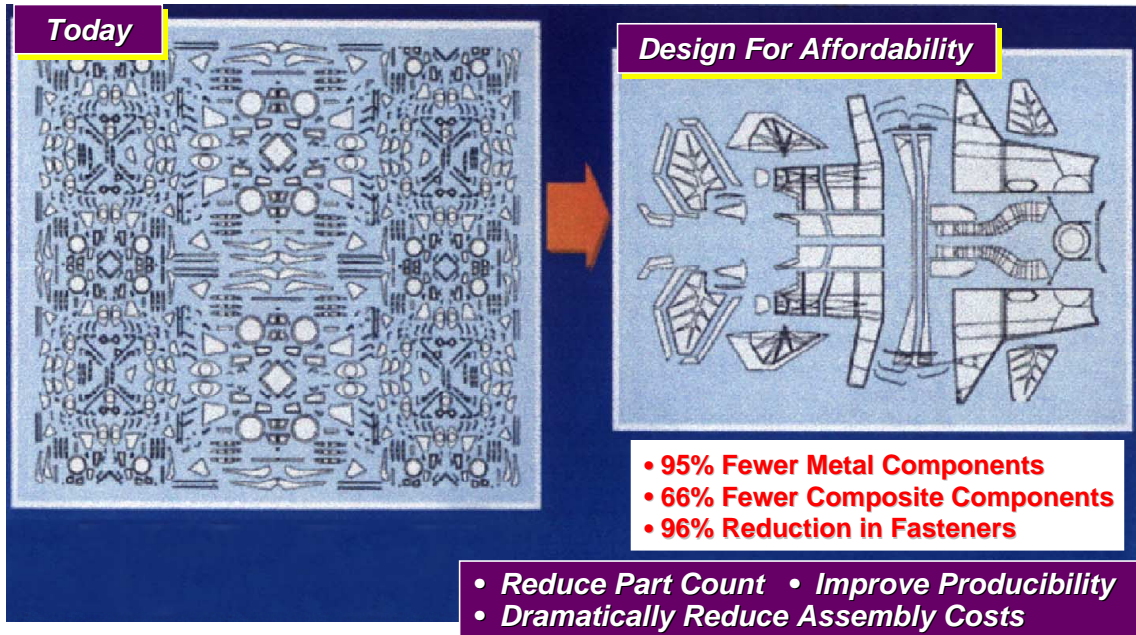


Figure 11. Unitized Structure for Affordability

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QUESTION/ANSWER FORM

LOW COST COMPOSITE STRUCTURES

Name of Author Ravi Deo

Paper Number 1

Name of Discussor Samy Amin, Pratt & Whitney, Canada

Question: Any plans to look at composite applications in gas turbine engines?

Answer: Not that I am aware of at this time.

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