

# Comparative Analysis of Composite Materials for Aircraft and UAV Wing Spars

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**Abstract:** *This paper presents a comparative review of composite materials used in aircraft and UAV wing spars, with emphasis on lightweight aerospace structures [3], [4], [8]. Materials including Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), Kevlar/epoxy composites, and hybrid composites such as carbon-glass and carbon-flax systems are evaluated using findings from previous experimental and numerical studies [5], [8], [12]. The comparison focuses on important mechanical properties including strength, stiffness, fatigue resistance, fracture toughness, corrosion resistance, and structural weight reduction. The review indicates that composite materials provide significant advantages over conventional aluminium alloys in terms of strength-to-weight ratio and overall structural efficiency [9], [15], [18]. Among the materials studied, TR50 carbon fiber with an R367-2 epoxy matrix demonstrated the best overall performance due to its high strength, excellent stiffness, superior fatigue resistance, and lightweight characteristics. The study concludes that advanced CFRP systems are highly suitable for modern aircraft and UAV wing spar applications.*

**Keywords:** Aerospace Engineering, Composite Materials, Aircraft Wing Spars, UAV Structures, CFRP, Lightweight Structures, Structural Optimization, Aerospace Composites.

## 1. Introduction

An aircraft airframe is the main structural framework of an aircraft and includes components such as the fuselage, wings, empennage, and landing gear [1], [2]. These structures are designed to withstand aerodynamic loads, maintain structural stability, and support the aircraft during flight [1]. Among these components, the wing plays a major role in generating lift and maintaining flight performance [2].

Within the wing structure, the wing spar acts as the primary load-carrying member [1], [6]. It supports most of the aerodynamic forces experienced during flight and helps the wing resist bending and twisting loads [1], [7]. Because of this important function, the material used for wing spars greatly affects aircraft strength, structural efficiency, and overall weight.

Traditionally, aircraft wing spars were manufactured using metallic materials such as aluminium alloys [6], [7]. Although these materials provide good strength and durability, their higher weight limits efficiency in modern aerospace structures [6]. As the demand for lightweight and fuel-efficient aircraft continues to increase, aerospace engineers have increasingly shifted toward the use of advanced composite materials [8], [15], [19].

Composite materials, especially fiber-reinforced polymers, are now widely used in aircraft structures because of their structural efficiency and lightweight characteristics [3], [4], [12]. Materials such as Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), Kevlar/epoxy composites, and hybrid composite systems are commonly studied for wing spar applications due to their beneficial mechanical properties [5], [8], [13].

This paper presents a review and comparative analysis of different composite materials used in aircraft and UAV wing spars. The study mainly focuses on comparing important

properties such as strength, stiffness, fatigue resistance, fracture toughness, and weight reduction using information collected from previous research and experimental studies.

## 2. Methodology

This study follows a review-based comparative analysis methodology. Information related to aircraft wing spars and composite materials was gathered from previously published research papers, aerospace engineering textbooks, technical journals, and experimental studies [1], [3], [8]. The research mainly focused on widely used composite materials for wing spar applications, including Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), Kevlar/epoxy composites, hybrid composite systems, and advanced CFRP materials such as TR50 carbon fiber with an R367-2 epoxy matrix [4], [5], [8].

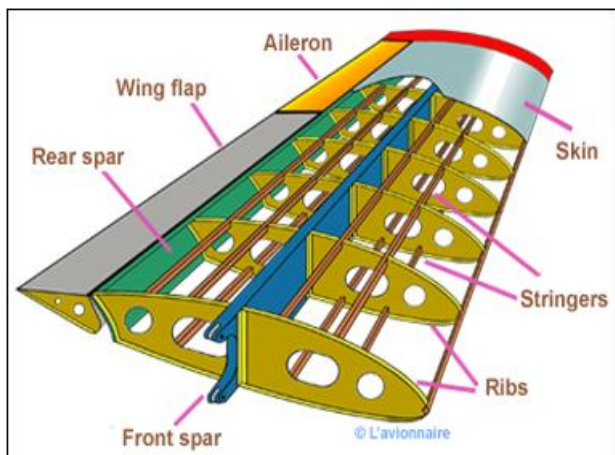
The collected information was evaluated using important mechanical and structural properties such as tensile strength, stiffness, fatigue resistance, fracture toughness, density, and weight reduction capability [3], [13], [14]. Conventional 7000 series aluminium alloys were also considered in the comparison to study the advantages and limitations of advanced composite materials in aerospace structures [6], [7]. Finally, a comparative analysis was carried out using results from previous experimental and numerical studies to determine the most suitable material system for aircraft and UAV wing spar applications based on overall structural performance.

## 3. Aircraft Wing Spar Overview

A wing spar is the main structural component of an aircraft wing that extends from the wing root to the wing tip along the span of the wing [1], [6]. It serves as the primary load-carrying member and supports the aerodynamic forces acting on the wing during flight [1]. The spar provides the required strength and rigidity needed to resist bending, shear, and

torsional stresses [6], [7]. In modern aircraft construction, wing spars function together with ribs, stringers, and the wing skin to create a lightweight yet structurally strong wing framework [1], [6].

Aircraft wings experience different types of forces during flight, including lift, drag, fuel loads, engine loads, and landing loads [2], [7]. Among the various structural components of the wing, the spar supports most of these loads and transfers them safely to the fuselage [1]. Because of its major structural function, the design and material selection of wing spars play an important role in determining aircraft performance, structural safety, and overall weight reduction.



### 3.1 Functions of a Wing Spar

One of the main functions of a wing spar is to withstand the bending loads produced during flight [1], [6]. When lift acts upward on the wings, bending forces are created along the wing structure. The spar supports these loads and helps prevent excessive bending or structural failure [6], [7]. It also provides the wing with the required stiffness and helps maintain its shape under different loading conditions.

Aircraft wings are also subjected to twisting forces caused by aerodynamic pressure and the movement of control surfaces such as flaps and ailerons [2]. Along with the ribs and wing skin, the spar helps resist these torsional stresses and maintains the aerodynamic stability of the aircraft [1], [6]. In addition, the wing spar transfers aerodynamic and structural loads from the wings to the fuselage, contributing to the overall structural stability of the aircraft.

### 3.2 Classification Based on Number of Spars

Wing spars are classified based on the number of spars used in the wing structure and the structural configuration of the spar itself [1], [6]. Different spar arrangements are selected depending on aircraft size, loading conditions, performance requirements, and manufacturing considerations.

#### 3.2.1 Single-Spar Wing

A single-spar wing contains one primary spar that carries most of the aerodynamic loads acting on the wing [1], [6]. This configuration is commonly used in lightweight aircraft, trainer aircraft, homebuilt aircraft, and unmanned aerial vehicles (UAVs) due to its simple construction and low structural weight [2], [7]. However, single-spar designs

generally possess lower torsional rigidity and reduced load-carrying capability compared to multi-spar configurations.

#### 3.2.2 Double-Spar Wing

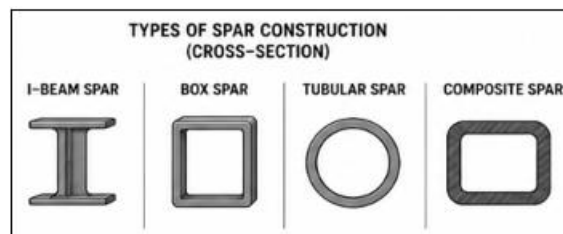
A double-spar wing consists of two main spars, commonly called the front spar and rear spar [1]. In this configuration, the aerodynamic and structural loads are shared between both spars, which improves the overall strength of the wing and increases resistance to twisting forces [6], [7]. Due to their good balance between structural strength and rigidity, double-spar wings are widely used in modern commercial and military aircraft.

#### 3.2.3 Multi-Spar Wing

Multi-spar wings use more than two spars within the wing structure and are mainly used in aircraft that experience very high aerodynamic and structural loads, such as large transport aircraft and high-performance military aircraft [6], [7]. These wing designs provide better load distribution and improved structural reliability. However, they are more complex to manufacture and usually result in higher overall structural weight.

### 3.3 Classification Based on Spar Construction

Wing spars can also be grouped based on their structural design. I-beam spars have a shape similar to the letter "I" and are commonly used because they provide good bending strength while keeping the structure lightweight [1], [6]. Box spars are built using enclosed sections with vertical webs and upper and lower panels, which gives them high torsional stiffness and better structural efficiency [6], [7]. Tubular spars use hollow circular or oval tubes and are mostly seen in lightweight and older aircraft due to their good strength-to-weight ratio.



In modern aerospace engineering, composite spars are becoming increasingly important due to their lightweight nature [8], [15], [19]. These spars are manufactured using advanced composite materials such as Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP). Compared with traditional metallic spars, composite spars provide better strength-to-weight ratio, improved fatigue and corrosion resistance, and lower overall structural weight [9], [15], [18]. Because of these advantages, composite wing spars are widely considered suitable for modern aircraft and UAV applications. However, they also involve higher production costs and more complicated repair and maintenance procedures [20].

## 4. Composite Materials Used in Wing Spars

### 4.1 Carbon Fiber Reinforced Polymer (CFRP)

Carbon Fiber Reinforced Polymer (CFRP) is known for its excellent mechanical performance, corrosion resistance, and fatigue durability [3], [4], [15], [19]. CFRP is one of the most widely used composite materials in modern aerospace structures [8], [15], [19]. It consists of carbon fiber combined with epoxy resin.

Compared with conventional aluminium alloys, CFRP provides significant weight reduction while still providing high structural strength and rigidity [9], [15], [18]. However, CFRP materials are relatively expensive and require advanced manufacturing techniques, and on top of that, damage detection and repair procedures are more complex compared to metallic structures [20].

### 4.2 Glass Fiber Reinforced Polymer (GFRP)

Glass Fiber Reinforced Polymer (GFRP) is a high-strength composite material made of continuous glass fibers combined with a polymer resin [4], [12]. GFRP offers good structural strength, corrosion resistance and lower manufacturing costs compared to CFRP [4], [12]. Because of its affordability and easy manufacturing, GFRP is commonly used in lightweight aircraft structures and UAV applications where extreme structural performance is not required [5], [12]. This material also provides good impact resistance and electrical insulation properties.

Despite these advantages, GFRP has lower stiffness and strength compared with carbon fiber composites, making it less suitable for highly loaded aerospace structures [13], [14].

### 4.3 Kevlar/ Epoxy Composite

Kevlar/epoxy composites are produced by combining Kevlar fibers with an epoxy resin matrix [4], [12]. Kevlar is well known for its high impact resistance, toughness, and fatigue durability [12], [16]. These composites are commonly used in aerospace applications where good damage tolerance and vibration resistance are required [8], [16]. Compared with many conventional materials, Kevlar/epoxy composites offer lower density and improved fracture resistance. They are especially suitable for structures that experience repeated loading and impact forces. However, Kevlar composites generally provide lower stiffness and compressive strength when compared with CFRP materials [13], [16]. In addition, their manufacturing and machining processes are often more difficult and complex.

### 4.4 Hybrid Composite Systems

Hybrid composites combine two or more different reinforcing fibers within a single composite structure to achieve balanced mechanical performance and reduced cost [5], [8]. Common hybrid systems used in aerospace structures include carbon-glass and carbon-flax combinations.

Carbon-glass hybrid composites combine the high stiffness of carbon fibers with the lower cost and improved impact

resistance of glass fibers [8], [12]. Similarly, carbon-flax composites provide lightweight characteristics and improved vibration damping properties. Hybrid composites are increasingly being investigated for aircraft wing spar applications because they offer a balance between structural efficiency, durability, and economic feasibility [8]. However, their structural behavior can be more complex due to differences in fiber properties and load distribution.

From the materials discussed so far, CFRP seems to stand out as the better overall option for wing spar applications because of its combination of high strength, good stiffness, and low weight [15], [19]. Since CFRP materials are being used more widely in modern aerospace structures, it is useful to take a closer look at one particular high-performance CFRP system: TR50 carbon fiber with an R367-2 epoxy matrix.

### 4.5 TR50 Carbon Fiber with R367-2 Epoxy Matrix

TR50 carbon fiber with an R367-2 epoxy matrix is an advanced aerospace-grade CFRP composite material system [8], [13], [15]. In this composite, TR50 acts as the reinforcing carbon fiber, while R367-2 serves as the epoxy resin matrix that binds the fibers together and helps distribute loads throughout the structure. TR50 carbon fiber is recognized for its high tensile strength and excellent stiffness [13]. Even though the fibers are extremely lightweight, they are capable of carrying very large loads without undergoing permanent deformation. Due to their crystalline carbon structure, the fibers also provide high rigidity and low thermal expansion, making them highly suitable for aerospace structures exposed to changing aerodynamic and environmental conditions.

The R367-2 epoxy matrix surrounds and supports the carbon fibers within the composite laminate. Its main role is to transfer loads between the fibers, maintain the alignment of the fibers, and protect them from moisture, environmental damage, and mechanical wear [3], [14]. The epoxy matrix also improves fracture toughness and helps the material resist crack propagation during loading [14]. Despite its advantages, the material involves higher manufacturing costs and more complex fabrication and repair procedures than traditional metallic materials [20]. However, due to its superior mechanical performance and reduced structural weight, TR50 carbon fiber with an R367-2 epoxy matrix is considered one of the most effective composite systems for advanced aerospace structures.

Which material is commonly used where?

Material	Common Spar Type	Typical Applications
CFRP	Box Spar, I-Beam Spar	Commercial aircraft, UAVs
GFRP	I-Beam Spar, Tubular Spar	Lightweight aircraft, UAVs
Kevlar/Epoxy	Box Spar, Tubular Spar	UAVs, impact-resistant structures
Carbon-Glass Hybrid	Box Spar	UAVs, medium-load structures
Carbon-Flax Hybrid	I-Beam/Box Spar	Eco-friendly lightweight UAVs
TR50 CFRP + R367-2 Epoxy	Advanced Box Spar	High-performance aerospace structures

(NOTE: The comparative values presented are based on findings reported in previous experimental and numerical studies. Variations may occur depending on material composition, fabrication techniques, and testing procedures.)

### 5. Comparative Analysis of TR50/R367-2 CFRP and 7000 Series Aluminium Alloy

Traditionally, 7000 series aluminium alloys have been widely utilized in aircraft structures because of their good mechanical strength, durability, and ease of manufacturing [6], [7]. However, the increasing need for lower structural weight, better fuel efficiency, and enhanced mechanical performance has encouraged the aerospace industry to adopt advanced composite materials for modern aircraft applications [8], [15], [19].

Among the different composite systems reviewed, TR50 carbon fiber combined with an R367-2 epoxy matrix shows outstanding mechanical properties, including high tensile strength, superior stiffness, enhanced fatigue resistance, and improved fracture toughness [13], [15]. Compared with conventional aluminium alloys, this advanced CFRP system offers lower structural weight while maintaining strong mechanical performance under aerodynamic loading conditions [8], [9], [18], [19].

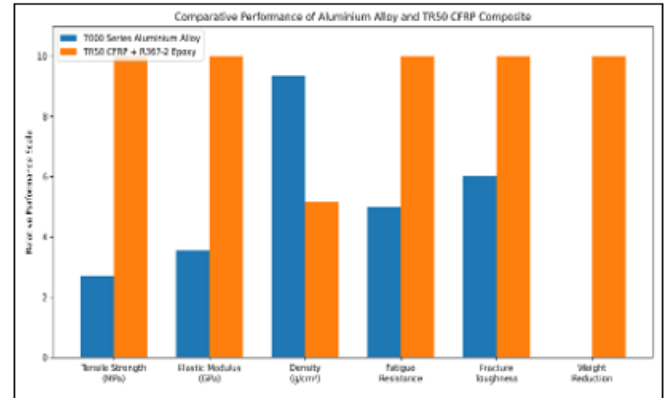
**Table 1:** Comparative Mechanical Properties of Conventional Aluminium Alloy and Advanced Composite Materials Used in Wing Spar Structures

Property	7000 Series Aluminium Alloy (7075-T6)	TR50 Carbon Fiber + R367-2 Epoxy	References
Density	~2.8 g/cm <sup>3</sup>	~1.5–1.6 g/cm <sup>3</sup>	[6], [15]
Tensile Strength	510–570 MPa	1500–2500 MPa	[13], [15]
Yield Strength	300–500 MPa	Significantly higher than aluminium alloys	[13]
Elastic Modulus	~71 GPa	~150–240 GPa	[3], [13]
Fatigue Resistance	High	Excellent	[8], [15], [19]
Fracture Toughness	Good	Excellent	[14]
Corrosion Resistance	Moderate	Very High	[4], [15], [19]
Structural Weight Reduction	Baseline	~18%–60% lower than aluminium structures	[8], [9], [18], [19]
Typical Wing Spar Usage	Conventional aircraft structures	Advanced aircraft and UAV wing spars	[6], [8]

(Note: The comparative values presented are based on findings reported in previous experimental and numerical studies. Variations may occur depending on material composition, fabrication techniques, and testing procedures.)

Table-1 presents a comparative analysis of conventional 7000 series aluminium alloy and TR50/R367-2 CFRP based on important structural and mechanical properties relevant to aircraft wing spar applications. The comparison highlights differences in density, tensile strength, yield strength, elastic modulus, fatigue resistance, fracture toughness, corrosion

resistance, structural weight reduction, and overall suitability for lightweight aerospace structures.



(Comparative Analysis of Mechanical Properties Between TR50/R367-2 CFRP and 7000 Series Aluminium Alloy)

### 6. Discussion

The results of this review show that composite materials have clear advantages over conventional metallic materials when used in aircraft wing spars [4], [8], [15], [19]. Although traditional 7000 series aluminium alloys provide good strength and durability, their higher weight reduces overall structural efficiency in modern aerospace applications [6], [7].

Among all the materials studied, CFRP showed very strong overall performance because of its balanced mechanical properties and durability under repeated loading conditions [3], [8], [15], [19]. GFRP and Kevlar/epoxy composites also offer useful benefits such as lower cost, better impact resistance, and improved fracture behaviour [12], [16]. Hybrid composites provide a good balance between performance and affordability.

The comparison further showed that TR50 carbon fiber with an R367-2 epoxy matrix performs better than conventional aluminium alloys in terms of strength, stiffness, fatigue resistance, and weight reduction [13], [15]. These properties make it highly suitable for aircraft wing spars and UAV structures where lightweight construction and structural efficiency are important.

Even though advanced composite materials are more expensive and require more complex manufacturing and repair procedures [20], their lightweight nature and improved mechanical performance make them highly effective for modern aerospace structures.

### 7. Conclusion

This review compared different composite materials used in aircraft and UAV wing spars based on important structural and mechanical properties such as strength, stiffness, fatigue resistance, corrosion resistance, and weight reduction capability [3], [4], [13]. The findings show that composite materials provide major advantages over conventional aluminium alloys in lightweight aerospace structures [8], [15], [18]. Among the materials reviewed, advanced CFRP systems demonstrated very strong overall structural

performance due to their excellent strength-to-weight ratio and superior fatigue behaviour [15], [19]. In particular, TR50 carbon fiber with an R367-2 epoxy matrix showed outstanding suitability for aircraft and UAV wing spar applications [13]. Although advanced composites involve higher manufacturing costs and more complex repair procedures [20], their mechanical efficiency and lightweight characteristics make them highly valuable for modern aerospace engineering applications [8], [18], [19].

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