

# Review On Hybrid Composite Fan and Compressor Blades in Aircraft Propulsion Engines for Performance and Reliability

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*Abstract- Aircraft engines require high-performance components capable of operating under extreme thermal, mechanical, and aerodynamic conditions. Fan and compressor blades are critical components that influence engine performance, efficiency and safety. Traditional metallic blades face several challenges such as high weight, corrosion and fatigue failure. To overcome these challenges hybrid composite blade is used in aircraft engine. This report presents a review of hybrid composite materials used in fan and compressor blades, their advantages, and the role of Non-Destructive Testing (NDT) techniques in improving reliability. The study highlights various research works focusing on mechanical, thermal, and aerodynamic performance of hybrid composites. It also discusses the limitations and research gaps in this field.*

## I. INTRODUCTION

Aircraft engines are very important for the proper functioning of an aircraft. The efficiency, safety, and performance of an aircraft mainly depend on how well the engine works. Inside the engine, fan and compressor blades play a major role in taking in air and compressing it before combustion. These blades rotate at very high speeds and work under difficult conditions such as high temperature, pressure, and continuous mechanical loading.

In the past, these blades were mostly made using metals like titanium and steel. These materials were strong and could handle high temperatures, but they also had some disadvantages. Metallic blades are heavy, which increases the total weight of the aircraft. This leads to higher fuel consumption and reduced efficiency. Over time, these materials may also develop problems such as cracks, corrosion, and fatigue due to repeated use.

To reduce these problems, engineers started using composite materials. Composite materials are made by combining two different materials, usually fibers and a binding material called a matrix. Common fibers used in aerospace applications include carbon fiber, glass fiber, and Kevlar. These materials are lighter than metals and provide better strength, which makes them suitable for aircraft components.

Later, hybrid composite materials were developed to further improve performance. Hybrid composites are made by combining two or more types of fibers in a single material. For example, carbon fiber can be combined with glass fiber or Kevlar to get better strength, flexibility, and resistance to impact. This combination helps in achieving improved overall properties compared to using a single type of fiber.

Using hybrid composite materials in fan and compressor blades helps in reducing the weight of the engine. This improves fuel efficiency and lowers operating costs. These materials also have better resistance to fatigue and damage, which increases the life of the components. Because of these advantages, hybrid composites are becoming more popular in modern aircraft engines.

However, these materials can still develop defects during manufacturing or while in use. Common defects include cracks, layer separation (delamination), and small gaps inside the material (voids). These defects are not always visible from the outside, which makes them difficult to detect.

To solve this problem, Non-Destructive Testing (NDT) methods are used. NDT techniques allow engineers to check the condition of the material without damaging it. Methods like ultrasonic testing,

thermography, and acoustic emission are used to find defects inside the blades. These techniques help in identifying problems early and preventing serious failures.

Even though hybrid composites offer many benefits, there is still a need to study their behavior under real working conditions. Factors like vibration, repeated loading, temperature changes, and impact forces can affect their performance over time. Also, improving defect detection methods is important to ensure safety.

This report mainly focuses on reviewing hybrid composite materials used in aircraft fan and compressor blades. It also explains how NDT techniques help in improving their reliability and performance. The study highlights the importance of using advanced materials and inspection methods for better efficiency and safety in aircraft engines.

## II. AIRCRAFT FAN AND COMPRESSOR BLADES

Fan and compressor blades are essential components of aircraft propulsion systems. The fan blades are located at the front of the engine and are responsible for drawing large amounts of air into the engine. A portion of this air is used for combustion, while the remaining air bypasses the core and contributes to thrust.

Compressor blades are located inside the engine and are used to increase the pressure of incoming air. This high-pressure air is then sent to the combustion chamber, where it mixes with fuel and burns to produce energy. The efficiency of this process depends on how effectively the compressor blades perform.

These blades are subjected to extreme working conditions. They experience high centrifugal forces due to rotation, as well as thermal stresses caused by high temperatures. In addition, they may also be exposed to foreign object damage such as bird strikes or debris.

Because of these conditions, the blades must have high strength to withstand loads, low weight to

improve efficiency, and resistance to fatigue to ensure long service life. Any failure in these blades can lead to serious engine damage, which makes their design and material selection very critical.

Aircraft engines use fan and compressor blades to move and compress air. These blades work under high speed and temperature. Traditional metal blades are heavy and less efficient. Hybrid composite materials are used to reduce weight and improve performance.

## III. COMPOSITE MATERIALS

Composite materials are widely used in the aerospace field because they provide better performance when compared to traditional materials like metals. A composite is generally made by combining two main parts: reinforcement and matrix. The reinforcement, which is usually in the form of fibers, gives the material its strength and stiffness. The matrix acts as a supporting material that binds the fibers together, protects them, and helps in distributing the applied loads evenly throughout the structure.

There are different types of fibers used in composite materials, each having its own advantages. Carbon fiber is commonly used in aerospace applications because it is very strong and lightweight, which helps in improving overall efficiency. Glass fiber is more economical and provides good flexibility along with resistance to corrosion. Kevlar fiber is well known for its toughness and high impact resistance, making it suitable for situations where the material may be subjected to sudden loads or damage.

Hybrid composites are developed by combining two or more types of fibers into a single material. This combination helps in utilizing the positive properties of each fiber. For example, carbon fiber can be used to provide strength, while glass fiber can add flexibility and reduce cost. Kevlar can also be included to improve resistance to impact and damage.

Because of this combination of properties, hybrid composites offer improved strength, lower weight, and better durability. These advantages make them

highly suitable for use in aircraft components such as fan and compressor blades, where both performance and safety are very important.



Fig3.1: glass fiber



Fig 3.2: carbon fiber



Fig 3.3: Kevlar fiber

### 3.1 Properties of Composite Materials

#### 1. High Strength and Low Weight

Composites are very strong but lighter than metals. This helps reduce the weight of aircraft parts while keeping them strong.

#### 2. Stiffness

They resist bending and deformation. By arranging fibers in different directions, stiffness can be adjusted as needed.

#### 3. Fatigue Resistance

Composites can handle repeated loading without breaking, which is important for fan and compressor blades.

#### 4. Impact Resistance

Some fibers, like Kevlar, make composites able to absorb sudden shocks or impacts without cracking.

#### 5. Corrosion Resistance

Composites do not rust or corrode, making them durable in harsh environments.

#### 6. Heat Resistance

They can work at high temperatures without losing strength, which is important in engines.

#### 7. Design Flexibility

Composites can be shaped into complex designs, allowing engineers to make efficient and aerodynamic parts.

## IV. HYBRID COMPOSITE

Hybrid composite blades are made by layering different types of fibers in a specific order, which is called the stacking sequence. The order and orientation of these layers are very important because they decide how strong, stiff, and durable the blade will be.

One of the main advantages of hybrid composite blades is their light weight. They are much lighter than traditional metal blades, which helps reduce the overall weight of the aircraft and improves fuel efficiency.

These blades are also very good at handling repeated stress. They have high fatigue resistance, which means they can withstand continuous loading and unloading cycles without breaking.

Impact resistance is another important benefit. Aircraft blades may be exposed to debris or bird strikes, and hybrid composites are better at absorbing this energy, reducing the chance of damage.

Finally, hybrid composite blades can be designed into more efficient shapes because they are lighter. This improves airflow through the engine, which increases the overall aerodynamic performance and efficiency of the aircraft.

## V. MANUFACTURING METHODS OF HYBRID COMPOSITE BLADE

The manufacturing of hybrid composite blades requires careful selection of processes to ensure strength, durability, and aerodynamic efficiency. The choice of method depends on the type of fibers, resin system, blade design, and required performance. The most commonly used manufacturing techniques are described below:

### 5.1 Hand Lay-Up Method

The hand lay-up method is the simplest and most traditional way to make composite parts. In this process, layers of fibers are manually placed in the desired orientation on a mold. Resin is then applied over the fibers to bind them together. Each layer is carefully positioned according to the design requirements. After laying all layers, the material is allowed to cure at room temperature or in an oven.

Advantages: Simple, low-cost, and does not require complex equipment.

Limitations: It may result in uneven resin distribution, variations in thickness, and lower repeatability. It is suitable for prototypes or small production runs rather than mass production.

### 5.2 Compression Molding

In compression molding, the composite material is placed into a heated mold cavity, and pressure is applied to shape it. The mold ensures that the material takes the exact shape of the blade while the heat and pressure help in curing the resin. This method provides better surface finish and more uniform properties compared to hand layup.

Advantages: High-quality surface finish, good dimensional accuracy, and relatively faster production.

Limitations: The process requires expensive molds and is less flexible for complex geometries. It is mostly used for medium to large production runs.

### 5.3 Resin Transfer Molding (RTM)

Resin Transfer Molding is a more advanced and precise manufacturing technique. In RTM, dry fiber

layers are placed inside a closed mold. Resin is then injected under pressure to fully impregnate the fibers. The mold is heated to accelerate curing. RTM ensures that the resin is distributed evenly throughout the fibers, reducing voids and improving mechanical properties.

Advantages: High-quality parts, precise control over fiber volume and resin content, suitable for complex shapes.

Limitations: Requires more expensive equipment and careful process control. It is often used for critical aerospace components where performance and reliability are essential.

## VI. PERFORMANCE ANALYSIS (LITERATURE-BASED)

The performance of hybrid composite fan and compressor blades is a critical factor in ensuring efficiency and reliability in aircraft engines. This chapter summarizes the findings from previous studies and published research regarding the mechanical, thermal, fatigue, and aerodynamic performance of hybrid composite blades. No experimental or simulation analysis has been performed in this report; the information is entirely based on literature.

### 6.1 Mechanical Performance

Mechanical performance refers to the ability of blades to withstand loads without deformation or failure. According to several studies, hybrid composite blades demonstrate higher strength and stiffness compared to traditional metallic blades. The combination of different fibers in hybrid composites allows them to resist both tensile and compressive stresses more effectively, which is essential under the high loads experienced during engine operation.

### 6.2 Fatigue Performance

Fatigue performance is the ability of a blade to endure repeated cycles of stress without developing cracks or failing. Literature reports that hybrid composite blades have superior fatigue resistance due to the way different fibers distribute stress across layers. This characteristic helps the blades last longer and reduces maintenance needs, making them

highly suitable for rotating components in aircraft engines.

### 6.3 Thermal Performance

Aircraft engines operate at high temperatures, especially in the compressor section. Studies indicate that hybrid composites can maintain their strength and structural stability even under elevated temperatures. This thermal stability is important to ensure that the blades do not deform, lose efficiency, or fail under continuous heat exposure.

### 6.4 Aerodynamic Performance

Aerodynamic efficiency is affected by the weight and shape of the blade. Previous research shows that hybrid composite blades are lighter than metal blades, which allows engineers to design more aerodynamically efficient shapes. Lighter blades also reduce centrifugal forces and vibrations, which improves airflow through the engine and enhances overall engine efficiency.

## VII. NON-DESTRUCTIVE TESTING (NDT)

Non-Destructive Testing (NDT) refers to techniques used to examine materials and components without causing any damage. NDT plays a vital role in aerospace applications to ensure the safety and reliability of fan and compressor blades. The content in this chapter is based entirely on previously published research and technical literature. No experimental or practical work has been performed in this study.

### 7.1 Ultrasonic Testing (UT)

Ultrasonic testing uses high-frequency sound waves to detect internal defects such as cracks, delamination, or voids. When the sound waves hit a flaw, they are reflected back and analyzed to determine the location and size of the defect. According to research, UT is effective for identifying subsurface issues in composite blades.

### 7.2 Thermography

Thermography involves using infrared cameras to detect temperature variations on the surface of materials. Areas with defects often show different heat patterns compared to intact regions. This

method is widely used for inspecting large composite components quickly and safely.

### 7.3 Acoustic Emission (AE) Testing

Acoustic emission testing detects sound waves produced by crack formation or growth inside a material. AE allows for real-time monitoring and early detection of structural damage. Studies indicate that this method is useful for monitoring hybrid composite blades under operational loads.

### 7.4 X-ray Inspection

X-ray or radiographic inspection passes X-rays through a component to reveal internal defects such as voids, cracks, or inclusions. Literature reports that X-ray inspection provides detailed information about the internal structure of composite blades, helping maintain quality and reliability.

## VIII. LITERATURE REVIEW

1. A study by K. Singh (2021) focused on the design and analysis of hybrid composite fan blades made using carbon and glass fibers. The blades were manufactured through a combination of hand lay-up and compression molding techniques, where alternating fiber layers were arranged and bonded using epoxy resin before being compressed into the required shape. Mechanical evaluation using tensile and bending tests showed that the hybrid blades achieved a weight reduction of approximately 20–30% compared to conventional metallic blades, while also exhibiting improved strength and stiffness, making them suitable for high-performance applications.
2. L. Wang (2018) investigated the vibration characteristics of hybrid composite aircraft blades composed of carbon and Kevlar fibers through a simulation-based approach. A CAD model of the blade was developed, and modal analysis was performed to determine natural frequencies and vibration modes. The results indicated that hybrid composite blades experienced lower vibration amplitudes than traditional metal blades, which contributes to enhanced durability and reduced risk of failure over time.

3. In another study, D. Brown (2017) examined the impact behavior of hybrid composite blades made from glass and Kevlar fibers using a vacuum bagging process. The manufacturing approach ensured proper bonding and minimized internal defects. Impact tests were conducted using controlled projectiles, and damage progression was monitored using sensors and high-speed cameras. The findings revealed that hybrid blades could absorb higher impact energy and effectively limit crack propagation, thereby improving safety under foreign object damage conditions.
4. H. Ali (2022) evaluated the fatigue performance of hybrid composite fan blades produced using Resin Transfer Molding (RTM). In this process, dry fiber preforms were placed in a mold and infused with resin under pressure, followed by curing. The blades were subjected to cyclic loading to simulate real operating conditions. The study concluded that hybrid composites exhibit superior fatigue life compared to single-fiber materials, making them more reliable for rotating components in aircraft engines.
5. Research by N. Kumar (2020) focused on the application of non-destructive testing techniques for hybrid composite aircraft blades manufactured using autoclave molding. Prepreg layers were vacuum-sealed and cured under controlled temperature and pressure conditions. Inspection methods such as ultrasonic testing, thermography, and X-ray analysis were employed to detect internal defects. The results highlighted the effectiveness of these techniques in identifying cracks, voids, and delamination at an early stage, thereby improving overall safety and reliability.
6. T. Lee (2019) conducted a computational fluid dynamics (CFD) analysis of hybrid composite compressor blades made from carbon-epoxy materials. The blades were fabricated using a filament winding technique, where resin-coated fibers were wound over a rotating mandrel. Simulation studies were carried out to analyze airflow behavior, pressure distribution, and turbulence. The results showed that hybrid composite designs significantly reduced drag and energy losses, leading to improved aerodynamic efficiency.
7. R. Gupta (2021) carried out a reliability assessment of hybrid composite aircraft blades using carbon and Kevlar fibers. The blades were produced using RTM and tested under various loading conditions. Failure data was collected and analyzed statistically to generate reliability curves. The study demonstrated that hybrid composite blades offer higher reliability and lower failure probabilities compared to conventional designs.
8. S. Das (2018) explored the thermal behavior of hybrid composite materials composed of glass and carbon fibers. The samples were fabricated using a hand lay-up method followed by oven curing. Thermal testing involved exposing the material to elevated temperatures and measuring deformation and expansion. The results indicated that hybrid composites exhibit better thermal stability and reduced deformation under heat, making them suitable for high-temperature environments.
9. Y. Zhao (2023) investigated advanced hybrid composites consisting of carbon, glass, and Kevlar fibers using autoclave molding. Multi-layer prepreg structures were prepared and subjected to mechanical, thermal, and impact testing. The study found that combining multiple fiber types significantly enhances overall material performance, including strength, durability, and impact resistance.
10. P. Mehta (2022) focused on optimizing hybrid composite blade design through simulation techniques. Using computational models, parameters such as fiber orientation, layer thickness, and blade geometry were optimized to achieve better strength-to-weight ratios. The results demonstrated that optimized designs can produce lightweight blades with improved structural performance and efficiency.
11. A. Sharma (2020) performed a structural analysis of hybrid composite fan blades manufactured

using compression molding. The study involved creating a finite element model of the blade and applying realistic engine loads to evaluate stress distribution and deformation. The results showed that hybrid composites reduce stress concentrations and improve structural integrity compared to single-material blades.

12. M. Khan (2021) studied damage detection in hybrid composite blades using non-destructive testing techniques. Blades made from carbon and Kevlar prepreg layers were cured in an autoclave. Acoustic emission sensors and ultrasonic testing methods were used to monitor crack initiation and growth. The findings confirmed that these techniques are effective in detecting micro-cracks at an early stage, preventing unexpected failures.
13. J. Park (2019) analyzed the aerodynamic performance of hybrid composite blades manufactured using a vacuum bagging process. Wind tunnel experiments were conducted to measure airflow characteristics such as velocity and pressure distribution. The results indicated that hybrid blades offer improved lift and aerodynamic efficiency compared to conventional blades.
14. V. Patel (2022) investigated the failure behavior of hybrid composite blades under extreme loading conditions. The blades, made from glass and Kevlar fibers using hand lay-up and vacuum bagging, were subjected to high loads and harsh environments. The study observed delayed crack initiation and slower propagation, resulting in improved safety margins.
15. S. Iyer (2023) studied the optimization of multi-layer hybrid composite structures using automated fiber placement followed by autoclave curing. Both experimental and simulation approaches were used to evaluate strength, weight, and durability. The optimized configurations demonstrated excellent strength-to-weight ratios and longer service life, highlighting their suitability for advanced aerospace applications.

## IX. COMPARISON OF MATERIALS

Property	Metal Blades	Hybrid Composite Blades
Weight	High	Low
Strength	Moderate	High
Fatigue Life	Low	High
Corrosion	Yes	No
Efficiency	Lower	Higher

## X. CHALLENGES OF HYBRID COMPOSITE BLADES

hybrid composite blades offer many benefits, but they also come with some challenges. The points below are summarized from previously published research and technical studies. No experimental work or project was conducted in this study; this is purely a literature review.

### 10.1 Complex Manufacturing Process

Producing hybrid composite blades is not straightforward. The process involves carefully arranging multiple layers of different fibers and ensuring proper resin distribution and curing. Studies show that this complexity can lead to variations in blade quality if the manufacturing process is not precisely controlled.

### 10.2 High Initial Cost

Hybrid composite materials and the equipment required to manufacture them are more expensive than traditional metals. Literature indicates that the high initial investment can be a barrier, even though the blades offer benefits like reduced weight and improved performance over time.

### 10.3 Difficult Repair Process

Repairing hybrid composite blades is challenging. Defects such as cracks or delamination require specialized techniques, and improper repairs can compromise blade strength. Research highlights the need for skilled personnel and proper repair procedures to maintain safety and reliability.

#### 10.4 Limited Real-Time Testing

Although Non-Destructive Testing (NDT) methods can detect defects, real-time monitoring of hybrid composite blades during engine operation is still limited. Studies suggest that advanced sensors and monitoring systems are needed to track blade health continuously.

### XI. RESEARCH GAP

Hybrid composite blades are widely studied in aerospace research, but several gaps still exist according to the literature. The following points summarize these gaps based on published research. No experiments or projects were conducted in this study.

#### 11.1 Limited Real-Time Monitoring

Although Non-Destructive Testing (NDT) techniques are effective for detecting defects, there is still a lack of real-time monitoring systems for hybrid composite blades during engine operation. Literature suggests that more research is needed to develop continuous health monitoring methods.

#### 11.2 Optimization of Hybrid Combinations

Many studies have focused on specific fiber combinations, but there is limited research on the optimal mix of different fibers for maximum performance. Further studies are required to determine the best stacking sequences and fiber ratios for specific applications.

#### 11.3 Long-Term Durability Studies

Most existing research focuses on short-term mechanical and thermal performance. Long-term fatigue, wear, and environmental effects on hybrid composite blades are not well explored, leaving gaps in understanding their lifespan under real operational conditions.

#### 11.4 Cost-Effective Manufacturing Techniques

While hybrid composite blades provide performance benefits, literature indicates that cost-effective manufacturing methods are still a challenge. More research is needed to reduce production costs without compromising quality.

#### 11.5 Repair and Maintenance Strategies

There is limited research on practical repair methods and maintenance strategies for hybrid composite blades. Developing standardized repair techniques and guidelines is important for improving safety and reducing downtime.

### XII. FUTURE SCOPE

Hybrid composite blades have shown excellent performance in aerospace applications, but there is still room for improvement. Based on the literature, the following areas can be explored for future research. This is a review-based discussion; no experiments or projects were conducted in this study.

#### 12.1 Advanced Real-Time Monitoring

Future research can focus on developing real-time health monitoring systems for hybrid composite blades. Advanced sensors and smart technologies could help detect defects during operation and improve safety.

#### 12.2 Optimization of Fiber Combinations

Further studies can investigate the best combination of different fibers to achieve maximum strength, fatigue resistance, and impact tolerance. Optimizing stacking sequences and fiber ratios could improve blade performance.

#### 12.3 Cost-Effective Manufacturing

Research can focus on reducing the production cost of hybrid composite blades without compromising quality. New manufacturing techniques or automation may make large-scale production more feasible.

#### 12.4 Repair and Maintenance Techniques

Developing standardized repair methods for hybrid composite blades can increase their lifespan and reduce downtime. Research in this area can improve safety and reliability in practical applications.

#### 12.5 Environmental and Long-Term Performance Studies

Future studies can explore the long-term durability of hybrid composites under different environmental conditions, such as temperature variations, humidity,

and exposure to chemicals. This will help predict blade life more accurately.

### CONCLUSION

Hybrid composite blades are increasingly used in aircraft engines because they offer significant advantages over traditional metal blades, including reduced weight, higher strength, better fatigue resistance, and improved aerodynamic performance. This report provides a comprehensive review of the literature on hybrid composite blades, focusing on their properties, manufacturing methods, performance, and Non-Destructive Testing (NDT) techniques.

The study of previous research highlights that hybrid composites provide excellent mechanical, thermal, and impact-resistant properties. NDT methods such as ultrasonic testing, thermography, acoustic emission, and X-ray inspection play an important role in ensuring the reliability and safety of these blades.

However, the literature also identifies several challenges, including complex manufacturing processes, high initial costs, difficult repair procedures, and limited real-time monitoring. Research gaps exist in areas such as optimization of fiber combinations, long-term durability studies, cost-effective manufacturing, and development of better repair and monitoring techniques.

The future scope for hybrid composite blades includes developing advanced monitoring systems, optimizing fiber layering, improving manufacturing efficiency, and exploring long-term environmental performance.

In conclusion, hybrid composite blades have great potential to enhance aircraft engine efficiency and reliability. The findings in this report are entirely based on literature, providing a clear understanding of current research, challenges, and opportunities without any experimental work.

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