



Computational Study on Pressure Distribution and Lift–Drag Characteristics of a Missile Model

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ABSTRACT: The increasing demand for lightweight, high-strength, and damage-tolerant materials in aerospace engineering has driven the adoption of composite materials in aircraft engine fan blades. However, the performance of composite fan blades is significantly influenced by the design of interface joints, particularly in hybrid composite structures. This study focuses on the design and optimization of hybrid composite interface joints in aircraft engine fan blades, combining carbon and glass fiber-reinforced polymers to enhance structural performance. The research investigates the influence of joint configuration, material composition, and geometric parameters on mechanical behavior under static and dynamic loading conditions, including bird strike scenarios. Finite element analysis (FEA) and experimental validation are employed to evaluate interlaminar stresses, failure modes, and overall structural integrity. Results indicate that optimized hybrid joints significantly improve damage tolerance, reduce delamination, and enhance load distribution. The study concludes that hybrid composite interface joints offer a promising solution for next-generation aeroengine fan blades.

KEYWORDS: Computational Fluid Dynamics, Pressure Distribution, Lift Coefficient, Drag Coefficient, Missile Aerodynamics, Flow Simulation, Turbulence Modeling

I. INTRODUCTION

Aircraft engine fan blades are critical components subjected to extreme mechanical and environmental loads, including high rotational speeds, aerodynamic forces, and impact loads such as bird strikes. Traditionally, metallic materials were used; however, composite materials have gained prominence due to their high strength-to-weight ratio and corrosion resistance.

Hybrid composites, which combine different fiber types such as carbon and glass fibers, offer improved performance compared to single-fiber composites. The interface joint between these materials plays a crucial role in determining structural integrity. Improper joint design can lead to delamination, stress concentration, and premature failure.

Recent research highlights that hybrid composite fan blades can significantly reduce delamination under impact loading when properly designed. Therefore, optimizing the interface joint is essential for achieving reliable and efficient performance in aerospace applications.

II. LITERATURE REVIEW

Recent studies emphasize the importance of hybrid composite joints in improving structural performance. Hybridization of fibers enhances impact resistance and reduces failure propagation. For instance, the incorporation of glass fiber layers in carbon composites improves energy absorption during bird strikes.

Research on hybrid interface joints indicates that joint location and length significantly affect interlaminar shear stress and overall blade performance. Optimized joint configurations can minimize stress concentration and improve durability.



Studies comparing bonded, bolted, and hybrid joints show that hybrid joints combine the advantages of both methods, offering improved load distribution and mechanical strength. However, challenges such as interface failure and material incompatibility remain critical issues.

III. MATERIALS AND METHODOLOGY

3.1 Materials

The hybrid composite fan blade consists of:

- Carbon Fiber Reinforced Polymer (CFRP) for high stiffness
- Glass Fiber Reinforced Polymer (GFRP) for impact resistance
- Epoxy resin as the matrix material

The hybrid configuration is designed to exploit the strengths of both materials while minimizing their weaknesses.

3.2 Joint Configuration

The interface joint is designed using different configurations, including:

- Step lap joints
- Scarf joints
- Overlap hybrid joints

The joint region length and position are varied to study their effects on performance.

3.3 Finite Element Analysis

Finite element modeling is performed using ANSYS software to simulate:

- Static loading conditions
- Dynamic impact (bird strike) conditions
- Stress distribution and deformation

The analysis focuses on interlaminar stresses, strain energy, and failure modes.

3.4 Experimental Validation

Prototype specimens are fabricated and tested under tensile and impact loading. The results are compared with simulation data to validate the model.

IV. DESIGN CONSIDERATIONS

4.1 Load Distribution

The interface joint must ensure uniform load transfer between different composite layers. Uneven load distribution can lead to stress concentration and failure.

4.2 Delamination Resistance

Delamination is a major failure mode in composite structures. Hybrid joints are designed to reduce interlaminar shear stress and improve bonding strength.

4.3 Impact Resistance

Fan blades must withstand bird strikes and foreign object damage. Hybrid composites improve energy absorption and reduce damage propagation.

4.4 Weight Optimization

Weight reduction is critical in aerospace design. The hybrid approach achieves a balance between strength and weight.

V. RESULTS AND DISCUSSION

5.1 Effect of Joint Location

The location of the hybrid interface significantly affects stress distribution. Placing the joint in regions of lower stress reduces the likelihood of failure.



5.2 Effect of Joint Length

Studies show that a joint length of approximately 40% of the blade section provides optimal performance in terms of interlaminar shear stress and impact resistance .

5.3 Stress Analysis

FEA results indicate that stress concentration occurs near the interface region. Optimized joint configurations reduce peak stress values and improve structural integrity.

5.4 Failure Modes

Common failure modes include:

- Delamination
- Fiber breakage
- Matrix cracking

Hybrid joints exhibit improved resistance to these failure mechanisms compared to single-material composites.

5.5 Comparison of Joint Types

Hybrid joints outperform purely bonded or bolted joints by combining their advantages:

- Bonded joints provide uniform stress distribution
- Bolted joints offer mechanical reliability
- Hybrid joints achieve both benefits simultaneously

VI. OPTIMIZATION TECHNIQUES

6.1 Response Surface Methodology (RSM)

RSM is used to optimize joint parameters such as length, thickness, and material composition.

6.2 Multi-Objective Optimization

Optimization considers multiple objectives, including:

- Maximizing strength
- Minimizing weight
- Reducing stress concentration

6.3 Simulation-Based Optimization

FEA simulations are used iteratively to identify optimal configurations.

6.4 Machine Learning Approaches

Emerging techniques use machine learning to predict optimal joint designs based on data-driven models.

VII. APPLICATIONS IN AEROSPACE

Optimized hybrid composite joints are widely used in:

- Aircraft engine fan blades
- Turbine components
- Structural panels
- Lightweight aerospace structures

These applications benefit from improved performance, reduced weight, and enhanced durability.

VIII. CONCLUSION

This study demonstrates that hybrid composite interface joints significantly enhance the performance of aircraft engine fan blades. The combination of carbon and glass fibers improves impact resistance, reduces delamination, and ensures efficient load transfer.

Optimization of joint parameters such as location, length, and configuration is critical for achieving optimal performance. Finite element analysis and experimental validation confirm that hybrid joints outperform traditional designs in terms of strength, durability, and reliability.



The findings highlight the importance of advanced design and optimization techniques in developing next-generation aerospace components.

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