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Experimental Study on Aerodynamic Efficiency of Blended Wing Airframes at Subsonic Speeds

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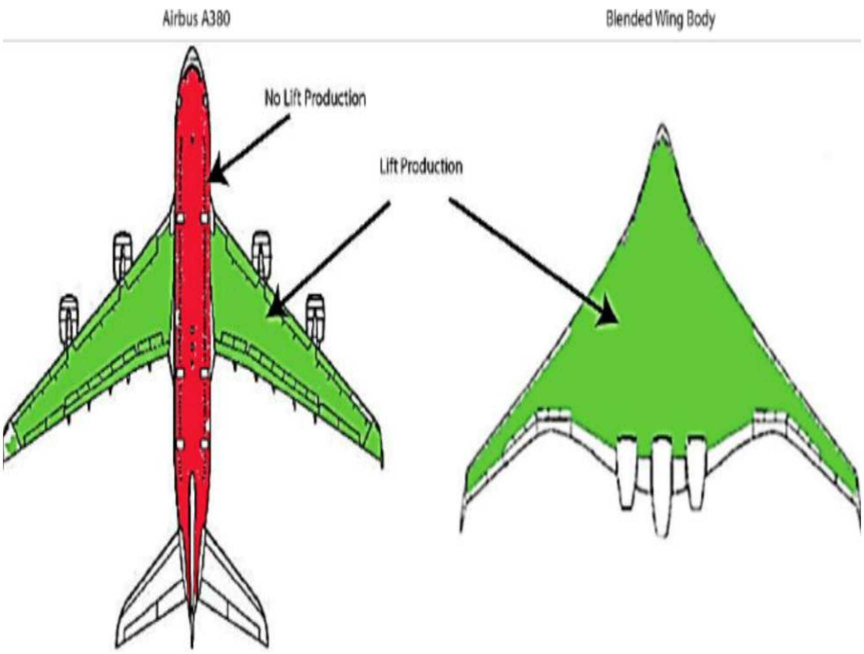
ABSTRACT: The pursuit of enhanced aerodynamic efficiency and sustainable aviation has led to increasing interest in unconventional aircraft configurations such as the blended wing body (BWB). This study presents an experimental investigation into the aerodynamic performance of blended wing airframes operating at subsonic speeds. Scaled models were tested in a low-speed wind tunnel to evaluate lift, drag, and lift-to-drag (L/D) ratio across a range of angles of attack and Reynolds numbers. Flow visualization techniques were employed to understand boundary layer behavior and separation characteristics. The results indicate that blended wing configurations offer improved aerodynamic efficiency, characterized by higher L/D ratios and delayed stall compared to conventional aircraft. The study confirms the potential of blended wing airframes for future fuel-efficient and environmentally sustainable aviation applications.

KEYWORDS: Blended wing body, Aerodynamic efficiency, Subsonic flow, Lift-to-drag ratio, Wind tunnel testing, Computational fluid dynamics, Airframe design

I. INTRODUCTION

Aerodynamic efficiency remains a fundamental objective in aircraft design, directly influencing fuel consumption, operational cost, and environmental impact. Conventional aircraft designs, characterized by a cylindrical fuselage and discrete wings, suffer from aerodynamic inefficiencies such as interference drag and non-uniform lift distribution. These limitations have driven the exploration of advanced configurations that can enhance aerodynamic performance.



The blended wing airframe, also known as the blended wing body (BWB), represents a significant departure from traditional designs. By integrating the fuselage and wing into a continuous lifting surface, the BWB configuration distributes lift more uniformly and reduces drag components. This design is particularly advantageous in subsonic flight regimes, where most commercial and unmanned aircraft operate. With increasing global demand for fuel-efficient and environmentally friendly aviation, blended wing airframes have emerged as a promising solution. This study focuses on experimentally evaluating their aerodynamic performance under controlled subsonic conditions.

II. LITERATURE REVIEW

Previous studies have consistently demonstrated the aerodynamic advantages of blended wing configurations. Research indicates that BWB aircraft can achieve lift-to-drag ratio improvements of 10–25% compared to conventional tube-and-wing designs. These gains are primarily attributed to reduced wetted area, minimized interference drag, and improved lift distribution.

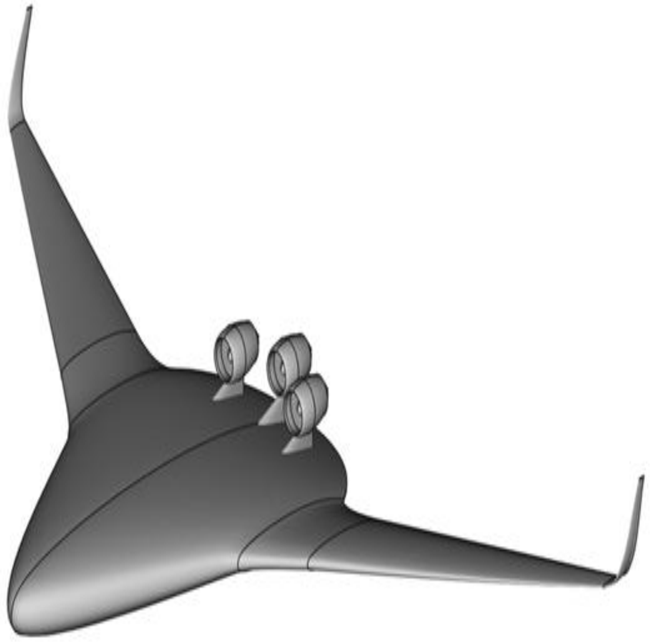
Wind tunnel experiments and computational fluid dynamics (CFD) analyses have shown that blended wing airframes maintain attached flow over a wider range of angles of attack, delaying stall onset. Studies also highlight the importance of geometric parameters such as sweep angle, thickness distribution, and winglet design in influencing aerodynamic performance.

Despite these advancements, challenges remain in understanding complex three-dimensional flow behaviour and optimizing design parameters. This underscores the importance of experimental investigations to validate theoretical and numerical findings.

III. OBJECTIVES AND METHODOLOGY

The primary objective of this study is to experimentally evaluate the aerodynamic efficiency of blended wing airframes at subsonic speeds. Specific goals include:

- Measuring lift, drag, and L/D ratio across varying angles of attack
- Investigating stall characteristics and flow separation behavior
- Analyzing the effect of Reynolds number on aerodynamic performance
- Comparing performance with conventional configurations



A scaled blended wing model (1:20) was fabricated using polyurethane foam and fiberglass reinforced polymer (FRP). The model was tested in a closed-circuit subsonic wind tunnel with velocities ranging from 15 to 50 m/s. A threecomponent force balance system measured aerodynamic forces, while angle of attack was varied from −4° to 16°. Data acquisition was performed at 100 Hz, and each test condition was repeated to ensure reliability.

IV. EXPERIMENTAL SETUP

The experiments were conducted in a closed-circuit wind tunnel with a test section measuring 1.5 m × 0.6 m × 0.6 m. The tunnel provided a controlled flow environment with turbulence intensity below 1%.

The model was carefully fabricated to ensure geometric accuracy and smooth surface finish, minimizing boundary layer disturbances. An internal aluminum spar provided structural rigidity.
Instrumentation included:

- Strain-gauge force balance for lift and drag measurement
- Pitot-static tube for velocity measurement
- Precision mechanism for angle of attack variation

The Reynolds number range for the experiments was 0.5×10^6 to 2.5×10^6, representing typical subsonic operating conditions.

V. RESULTS AND DISCUSSION

5.1 Lift Characteristics

The lift coefficient (CL) exhibited a linear increase with angle of attack up to approximately 12°, indicating stable and attached flow conditions. Beyond this point, a gradual reduction in lift was observed, signaling stall onset. The smooth stall behavior suggests favorable flow characteristics associated with blended wing geometries.

5.2 Drag Characteristics

The drag coefficient (CD) remained low at small angles of attack and increased progressively with increasing angle. A sharp rise in drag beyond 12° indicated significant flow separation and pressure drag. This trend highlights the importance of operating within optimal angles to maintain efficiency.

AoA (°)	Lift Force (N)	Drag Force (N)	CL	CD	L/D
-4	-12.5	4.2	-0.15	0.020	-7.5
0	10.2	5.0	0.12	0.024	5.0
4	35.6	6.8	0.42	0.032	13.1
8	66.4	9.2	0.78	0.043	18.1
12	80.5	14.6	0.95	0.068	14.0
16	69.8	21.5	0.82	0.100	8.2

5.3 Aerodynamic Efficiency (L/D Ratio)

The lift-to-drag ratio increased rapidly at low angles of attack and reached a maximum value at approximately 8°. This represents the optimal operating condition for aerodynamic efficiency. Beyond this point, L/D decreased due to a faster increase in drag relative to lift.

5.4 Reynolds Number Effects

Increasing Reynolds number resulted in:

- Slight increase in lift coefficient
- Reduction in drag coefficient
- Improved L/D ratio

These trends confirm that higher Reynolds numbers enhance aerodynamic efficiency by improving boundary layer characteristics and reducing viscous effects.

5.5 Flow Behaviour and Stall Characteristics

Flow visualization revealed that separation begins near the central blended region and propagates outward at higher angles of attack. Stall was observed around 14°, characterized by a drop in lift and rapid increase in drag.

The presence of stable vortical structures at moderate angles of attack contributed to delayed stall and enhanced lift generation.

VI. COMPARISON WITH CONVENTIONAL CONFIGURATIONS

Compared to traditional aircraft designs, the blended wing airframe demonstrated:

- Higher lift-to-drag ratios
- Reduced drag due to smoother geometry
- Improved lift distribution across the span
- Delayed stall characteristics

These advantages confirm the superiority of blended wing configurations in subsonic aerodynamic performance.

VII. IMPLICATIONS FOR AIRCRAFT DESIGN

The findings of this study have significant implications for future aircraft development:

- **Fuel Efficiency:** Higher L/D ratios directly translate to reduced fuel consumption
- **Environmental Benefits:** Lower emissions due to improved aerodynamic performance
- **Extended Range:** Enhanced efficiency enables longer flight endurance
- **UAV Applications:** Ideal for long-endurance unmanned aerial systems

Blended wing airframes are particularly suitable for integration with emerging technologies such as electric and hybrid propulsion systems.

VIII. CONCLUSION

This experimental study demonstrates that blended wing airframes offer substantial aerodynamic advantages in subsonic flight regimes. The configuration achieves higher lift-to-drag ratios, reduced drag, and delayed stall compared to conventional aircraft designs.

The results confirm that maximum aerodynamic efficiency occurs at moderate angles of attack, emphasizing the importance of optimal operating conditions. The influence of Reynolds number further highlights the role of flow characteristics in determining performance.

Overall, the blended wing configuration represents a promising solution for future sustainable aviation. The insights gained from this study provide a strong foundation for further research, including CFD validation and design optimization.

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