



# Design and CFD Analysis of Variable Sweep Wings for Supersonic Bombers

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**Publication History:** Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03.2026; Published: 28.03.2026.

**ABSTRACT:** Variable sweep wing technology has been a cornerstone in enhancing the aerodynamic performance of supersonic aircraft operating across diverse flight regimes. This study presents the conceptual design and Computational Fluid Dynamics (CFD) analysis of a variable sweep wing configuration tailored for supersonic bomber applications. The research evaluates aerodynamic performance at multiple sweep angles corresponding to subsonic, transonic, and supersonic flight conditions. Key aerodynamic parameters such as lift coefficient, drag coefficient, lift-to-drag ratio, and shock wave behavior are analyzed using compressible flow simulations. The results are validated against wind tunnel data, demonstrating strong agreement. The findings highlight the effectiveness of variable sweep wings in balancing lift and drag requirements across flight regimes, thereby improving mission flexibility and aerodynamic efficiency.

**KEYWORDS:** Variable sweep wings, supersonic aerodynamics, CFD analysis, aircraft design, lift-to-drag ratio, shock waves, high-speed flight, wing morphing, computational simulation, bomber aircraft

## I. INTRODUCTION

Supersonic bombers play a vital role in modern military aviation due to their ability to deliver payloads rapidly over long distances while evading interception. However, designing aircraft capable of efficient performance across multiple flight regimes—ranging from low-speed takeoff to high-speed supersonic cruise—poses significant aerodynamic challenges. Fixed-wing configurations often fail to meet these conflicting requirements effectively, as low-sweep wings provide high lift at low speeds but suffer from excessive drag at supersonic speeds, while highly swept wings reduce drag but compromise lift and handling characteristics.

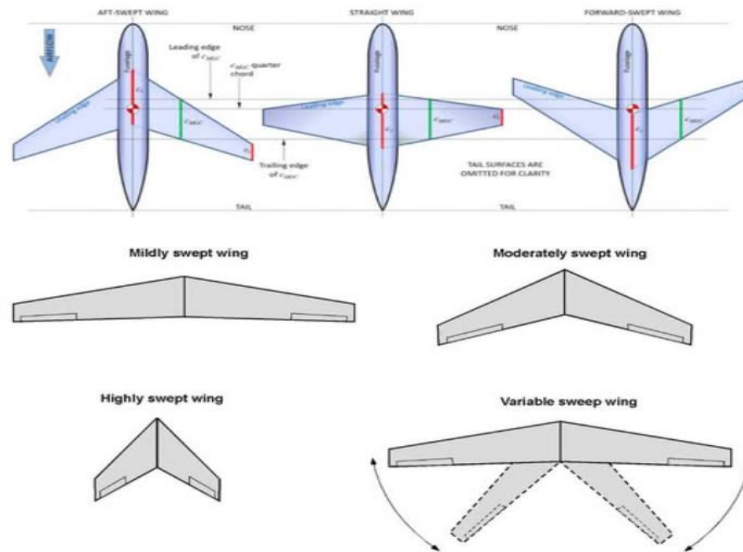
To address these limitations, variable sweep wing technology, also known as swing-wing configuration, was developed. This adaptive system allows the wing sweep angle to be altered during flight, enabling the aircraft to optimize its aerodynamic performance for different flight conditions. At low sweep angles, the wing provides increased lift for takeoff and landing, whereas high sweep angles minimize wave drag during supersonic flight.

## II. AERODYNAMIC BACKGROUND AND CHALLENGES

Supersonic flight introduces complex aerodynamic phenomena, including shock wave formation, compressibility effects, and boundary layer interactions. As aircraft approach transonic speeds, localized supersonic regions form on the wing, leading to drag divergence and shock-induced flow separation. These effects significantly increase aerodynamic drag and reduce efficiency. Wing sweep plays a crucial role in mitigating these challenges by reducing the effective Mach number normal to the leading edge. This principle delays shock formation and reduces wave drag, making swept wings essential for supersonic aircraft design. However, increasing sweep angle reduces lift and adversely affects low-speed performance, necessitating a compromise in fixed-wing designs. Variable sweep wings resolve this trade-off by dynamically adjusting wing geometry, enabling optimal performance across all flight regimes.

III. CONCEPT OF VARIABLE SWEEP WINGS

The variable sweep wing mechanism allows the wing to rotate about a pivot point, changing its sweep angle during flight. This adaptability enables the aircraft to operate efficiently under varying aerodynamic conditions. At low sweep angles (20°–25°), the wing provides maximum lift, making it suitable for takeoff and landing. Moderate sweep angles (35°–45°) are used for subsonic and transonic cruise, balancing lift and drag. High sweep angles (60°–70°) are employed during supersonic flight to minimize wave drag.



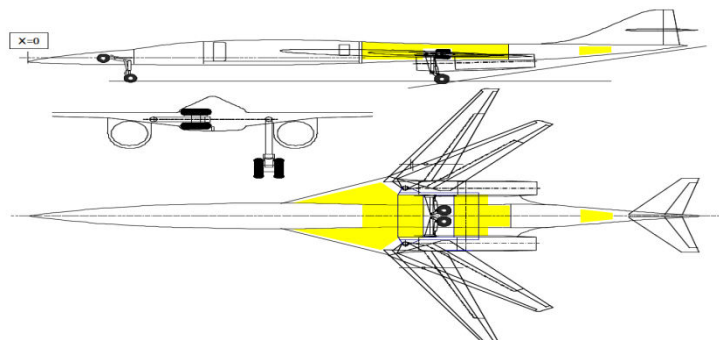
This technology has been successfully implemented in aircraft such as the B-1 Lancer and Tu-160 bombers, demonstrating its effectiveness in enhancing aerodynamic performance and mission flexibility .

IV. METHODOLOGY

The study employs a combination of conceptual design, geometric modeling, CFD simulation, and experimental validation. A trapezoidal wing planform is designed with parameters optimized for supersonic bomber applications, including low aspect ratio, thin airfoil sections, and variable sweep capability.

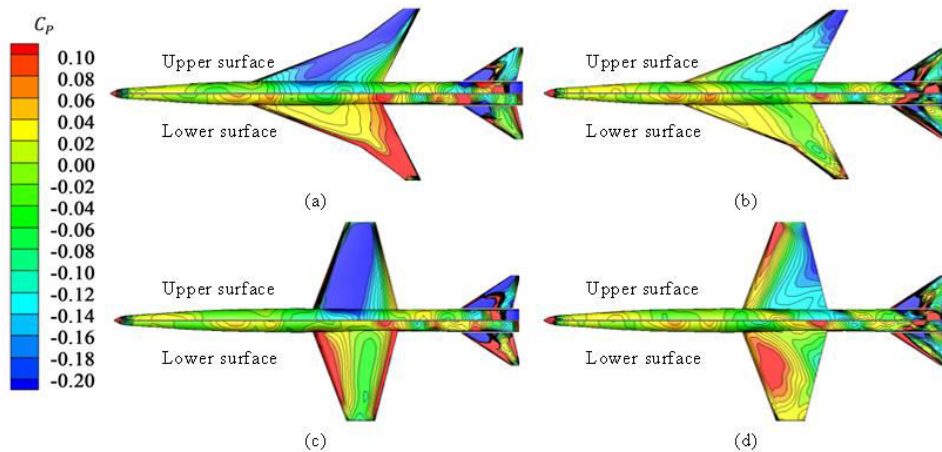
CFD simulations are conducted using compressible Navier–Stokes equations to capture the behavior of high-speed airflow. The  $k-\omega$  SST turbulence model is employed to accurately predict flow separation and shock-boundary layer interactions. An unstructured mesh with boundary layer refinement is used to ensure numerical accuracy, and a grid independence study is performed to validate the simulation results.

Three sweep configurations—25°, 45°, and 65°—are analyzed at corresponding Mach numbers representing subsonic, transonic, and supersonic conditions.



V. CFD ANALYSIS AND FLOW BEHAVIOUR

The CFD analysis provides detailed insights into the aerodynamic characteristics of variable sweep wings. At low sweep angles, airflow remains largely attached, resulting in high lift coefficients and favourable lift-to-drag ratios. As sweep angle increases, shock waves begin to form, particularly in the transonic regime, leading to increased drag. At high sweep angles, the normal component of the Mach number is reduced, weakening shock strength and improving supersonic performance. However, this configuration results in reduced lift and overall aerodynamic efficiency. Flow visualization techniques, including Mach contours and pressure distribution plots, reveal critical phenomena such as shock–boundary layer interaction and flow separation. These insights are essential for optimizing wing design and improving aerodynamic performance.



VI. RESULTS AND DISCUSSION

The results demonstrate a clear relationship between sweep angle and aerodynamic performance. At 25° sweep, the wing achieves the highest lift coefficient and lift-to-drag ratio, making it ideal for low-speed operations. At 45° sweep, transonic drag rise is observed due to shock formation, resulting in moderate aerodynamic efficiency. At 65° sweep, wave drag is reduced, enabling efficient supersonic flight, although lift and overall efficiency decrease.

Comparison between CFD results and wind tunnel data shows strong agreement, with deviations of approximately 4–6% for lift and drag coefficients. This validates the accuracy of the computational model and confirms its reliability for aerodynamic analysis. The study highlights the trade-off between lift and drag in variable sweep configurations. While low sweep angles provide high lift, high sweep angles are essential for reducing wave drag at supersonic speeds. The optimal sweep angle depends on the specific flight regime, emphasizing the importance of adaptability in aircraft design.

VII. STRUCTURAL AND DESIGN CONSIDERATIONS

Although variable sweep wings offer significant aerodynamic benefits, they introduce structural and mechanical challenges. The pivot mechanism must withstand high aerodynamic loads and ensure smooth operation during sweep transitions. Additionally, the shifting aerodynamic center affects aircraft stability and control, requiring careful design considerations.

The added weight and complexity of the sweep mechanism can offset some performance gains, making it essential to balance aerodynamic benefits with structural efficiency. Advances in materials and actuation systems have the potential to reduce these limitations and enhance the feasibility of variable geometry designs.

VIII. APPLICATIONS AND FUTURE SCOPE

Variable sweep wings remain relevant for high-speed aircraft, particularly supersonic bombers that require flexibility across multiple flight regimes. Advances in CFD, materials, and control systems have renewed interest in adaptive wing technologies. Future research may focus on morphing wing concepts that extend beyond sweep variation to



include changes in wing camber, span, and airfoil shape. Integration of artificial intelligence and optimization algorithms can further enhance aerodynamic performance and operational efficiency.

## IX. CONCLUSION

This study presents a comprehensive analysis of variable sweep wings for supersonic bomber applications, demonstrating their effectiveness in improving aerodynamic performance across diverse flight conditions. The results confirm that sweep variation significantly influences lift, drag, and shock behaviour, with each configuration offering distinct advantages for specific flight regimes. The strong correlation between CFD simulations and experimental data validates the reliability of the computational approach. Overall, variable sweep wings provide a practical solution to the challenges of supersonic aircraft design, offering enhanced performance, flexibility, and mission capability.

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