IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 10, April 2025

Impact Factor: 7.67

CFD Analysis of Double Wedge Airfoil

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Abstract: *This study presents a Computational Fluid Dynamics (CFD) analysis of a double wedge airfoil to evaluate its aerodynamic performance across various flight conditions. Using the Navier-Stokes equations and turbulence models like k-ε, simulations were performed for both incompressible and compressible flows. Results indicate that at low angles of attack, the airfoil achieves moderate lift and low drag, while higher angles lead to flow separation, increasing drag and reducing lift. In supersonic regimes, the airfoil exhibits efficient lift with minimal shock wave effects. The study underscores the influence of angle of attack, Mach number, and Reynolds number on lift and drag, offering insights for optimizing airfoil design in high-speed aerospace applications*

Keywords: Double wedge aerofoil, CFD simulation, coefficient of drag(Cd),Coefficient of lift (Cl), supersonic flow

I. INTRODUCTION

Airfoils are critical aerodynamic structures[1] designed to generate lift while minimizing drag, playing a central role in aviation, propulsion systems, and even biological and marine applications. Their shape enables pressure differences across surfaces[2], facilitating efficient motion through air or water. With the growing emphasis on supersonic and transonic flight, aerodynamic analysis of specialized airfoils like the double wedge has become increasingly important. Unlike subsonic airfoils, double wedge airfoils are optimized[3] for high-speed regimes due to their sharp leading edges and symmetric geometry.

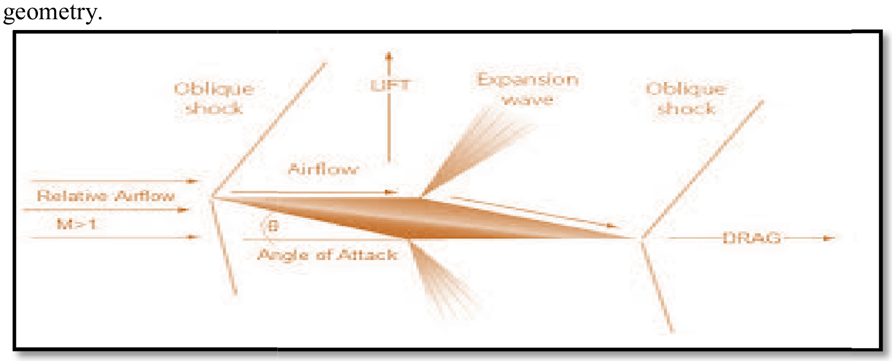

Fig.1:Typlical representation of expansion fans and oblique shock wave on airfoil.

This study investigates the aerodynamic performance[4]a of a double wedge airfoil by analysing lift and drag coefficients across varying angles of attack (5°–15°) and Mach numbers. The airfoil geometry was modeled in SolidWorks, and simulations were conducted using ANSYS to evaluate its behaviour under different high-speed flow conditions, contributing to the development of efficient airfoil designs[5] for supersonic applications.

II. METHODOLOGY

The research followed a structured methodology beginning with a comprehensive literature review to understand existing work related to aerodynamic performance, shock wave behavior, and airfoil characteristics under various flow conditions[6]. This helped in identifying the scope of the study and provided a foundation for selecting key parameters for analysis.

Following the literature review, critical aerodynamic parameters [6] such as angle of attack, Mach number, oblique and normal shock properties, and shock wave angles were identified using standard aerodynamic tables and analytical methods. These parameters were essential in framing the scope of the analysis and in understanding how they influence aerodynamic forces.

To establish a baseline, analytical calculations were performed for the case where the angle of attack was zero degrees. This served as a reference point for comparison with the computational results obtained later in the study.

The next phase involved the geometric modeling of a double wedge airfoil using SolidWorks. The airfoil design was created in 3D to enable accurate and detailed simulations. Once the model was finalized, CFD simulations were carried out using ANSYS Fluent. These simulations covered a range of angles of attack (from 5° to 15°) and Mach numbers within the transonic and supersonic regimes. The simulations aimed to capture flow characteristics such as shock wave formation, flow separation[7], and to compute key aerodynamic coefficients—namely the coefficient of lift (Cl) and coefficient of drag (Cd).

Finally, the results from the CFD simulations were compared with the initial analytical calculations to validate the simulation model. The data were then analyzed to establish the dependencies between various parameters, such as angle of attack, Mach number, Cl, and Cd. This analysis provided insights into the aerodynamic behavior of the double wedge airfoil and highlighted the key factors affecting its performance in high-speed flow[8] conditions.

A)Analytical Modeling

The analytical modeling phase of this study was undertaken to establish baseline aerodynamic characteristics of the double wedge airfoil at an angle of attack (AoA) of 0°, under supersonic flow conditions. This involved defining the geometry, performing lift and drag calculations using shock and isentropic relations, and determining aerodynamic coefficients.

1. Geometry Definition:

The double wedge airfoil considered in this analysis is symmetric, with the following geometric parameters:

Chord length (c): 1000 mm

Leading wedge angle (α): 12°

Trailing wedge angle (β): 12°

Thickness (t): 174 mm

2. Lift Calculation:

For a symmetric double wedge airfoil at zero angle of attack, theoretical aerodynamic analysis dictates that the coefficient of lift (Cl) is zero due to symmetry[9]. Hence, Cl=0.

3. Drag Calculation:

The drag calculation[11] was performed under the following flow conditions:

Mach number (M_1) =2.0

Altitude (h): 16,700 meters.

Angle of attack (AoA): 0°

Half wedge angle (θ): 6°

Length of each side of the airfoil: 0.5 m

The altitude and Mach number was chosen as cruising altitude and speed of the Airfoil.

Using the oblique shock chart ($\theta - \beta - M$ relation),

For θ=6°, M_1=2.0,

We got β=35.24°

We know that

$$M_{n1} = M_1 \times \sin\beta$$
$$= 2.0 \times \sin 35.24°$$
$$=1.15$$

From normal shock table at M_{n1}=1.15

$M_{n2} = 0.8750, \frac{P_2}{P_1} = 1.3763,$

We know that

$$M_2 = \frac{M_{n2}}{\sin(\beta-\theta)}$$

$$= \frac{0.8750}{\sin(35.24-6)} = 1.737$$

From isentropic table,

For M_2=1.737

Mach angle ϑ_2=18.981

P2/p02=0.1937 , $\frac{P_2}{P_{02}} = 0.1937$

$$\vartheta_3 = \vartheta_2 + 2\theta = 18.981 + 12$$
$$= 30.981$$

From isentropic table

For

$\vartheta_3 = 30.981$

$$\frac{P_2}{P_0} = 0.0981$$

Drag per unit area is given by D=(P_2 -P_3)×t

$$= P_2 \times [1 - (P_3/P_2)] \times t$$

$=1.3763\times0.911\times10000\times [1 - \frac{\frac{P3}{P0}}{\frac{P_2}{P_{02}}}] \times\sin(6°)$

=1.3763×0.911×10000× [1-0.0981/0.1937] ×sin(6°)

=643.50 N

Coefficient of drag Cd= D/($\gamma P_1 M_1^2$ C/2)

=643.50/(51016/2)

=0.0252

These results provide a baseline for comparison with CFD simulations and help validate the model's performance in supersonic conditions.

B) ***Numerical modeling***

1. ***Geometry Creation***

The double wedge airfoil geometry was created in SolidWorks by sketching a 2D profile and converting it into a surface model. The airfoil features a wedge length of 1 meter and a wedge angle of 12 degrees. To ensure accurate CFD analysis, the computational domain was sized with a length of 22 meters and a width of 10 meters, allowing sufficient space for flow development and shock wave capture.

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Volume 5, Issue 10, April 2025
Impact Factor: 7.67

Fig.2: Model of airfoil with domain

2. Meshing

The mesh for the simulation was generated using the ANSYS Meshing tool to ensure high-quality and accurate results. A face meshing technique was employed, dividing the entire computational domain into eight distinct faces. Each face was individually meshed to enhance grid quality, especially around the airfoil where flow gradients are expected to be high.

Total Nodes: 66,010

Total Elements: 64,980

This structured meshing approach ensured refined grid resolution near the airfoil boundaries, improving simulation accuracy. The mesh was carefully designed to balance computational efficiency and precision, making it well-suited for capturing key aerodynamic phenomena in the CFD analysis.

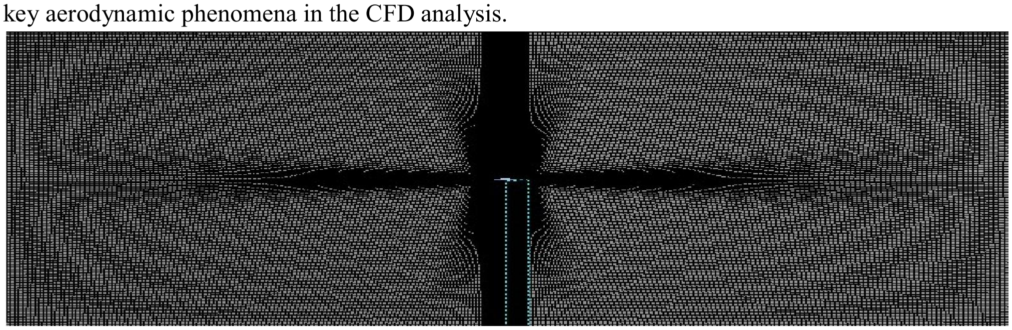
Fig.3 Mashed domain

III. ANALYSIS

The solution converged after 291 iterations, and the results were used to generate graphical representations of the aerodynamic performance of the double wedge airfoil. The computed values of the drag coefficient (Cd) and lift coefficient (Cl) were extracted from the simulation data and compared with the theoretical values derived from analytical formulas. The close alignment between the theoretical and simulated values of both Cd and Cl confirms the reliability and consistency of the simulation results, validating the accuracy of the computational model.

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Coefficient	Value by formula	Value by Simulation
Cd	0.0252	0.0267
Cl	0	0

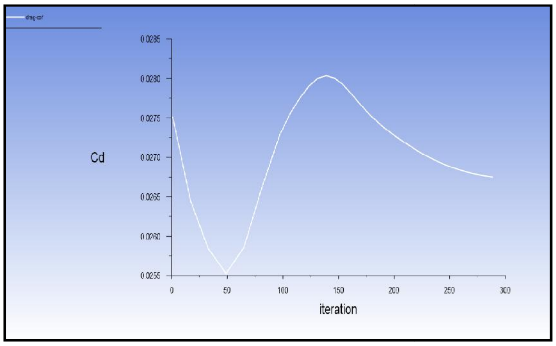

Fig.4 Plot of Cd v/s titrations

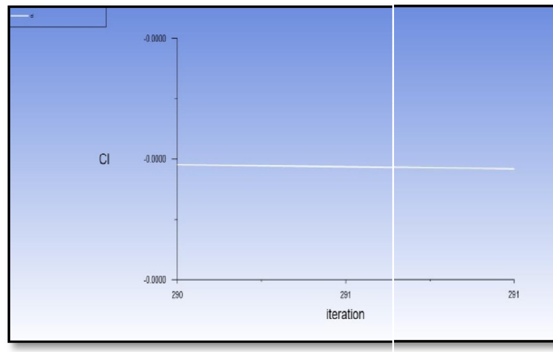

Fig.5 Plot of Cl v/s titrations

Fixed AOA with Varying Mach Numbers

At a fixed angle of attack (0°), increasing Mach number resulted in pronounced effects on the velocity and pressure distribution around the airfoil. At Mach 1.5, the velocity was highest on the backward face due to an expansion fan, while the front face saw lower velocity and higher pressure due to shock waves. As the Mach number increased to 2.5 and 3.5, the expansion and shock effects became more intense, leading to higher velocity and lower pressure backward face, and stronger shock waves and increased pressure on the front face.

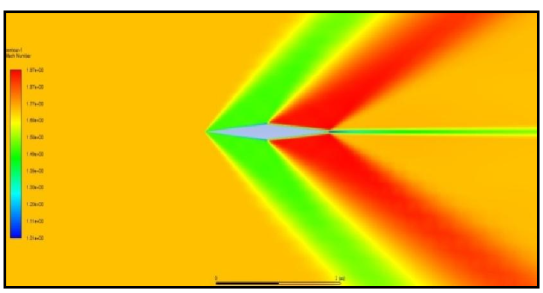

Fig.6 Velocity Contour at M=3.5 AOA= 0

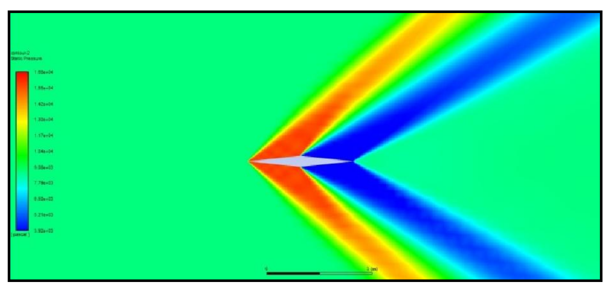

Fig.7 Pressure Contour at M=3.5 AOA= 0

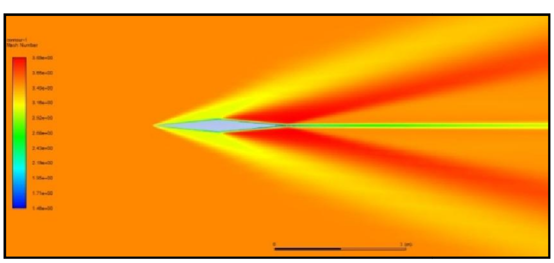

Fig.8 Velocity Contour at M=3.5 AOA= 0

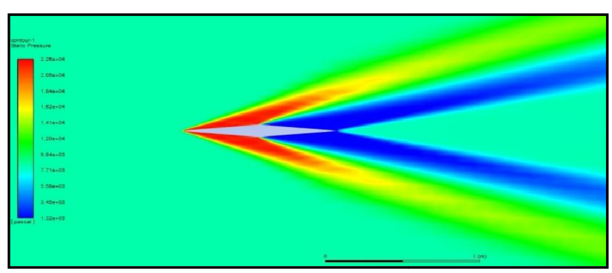

Fig.9 Pressure Contour at M=3.5 AOA= 0

Fixed Mach Number with Varying Angles of Attack (AOA)

When the Mach number was fixed at 2 and the angle of attack varied, the pressure and velocity distributions showed notable changes. At lower AOAs (0°–6°), the shock wave formation remained similar across the upper and lower surfaces. As the angle of attack increased, the upper surface became more streamlined with the flow, and expansion fans formed, leading to an increase in velocity and a decrease in pressure. At higher AOAs (12°–90°), flow separation occurred, and a detached shock wave formed, causing the airfoil to behave like a blunt body with significant flow detachment and pressure increase at the leading edge.

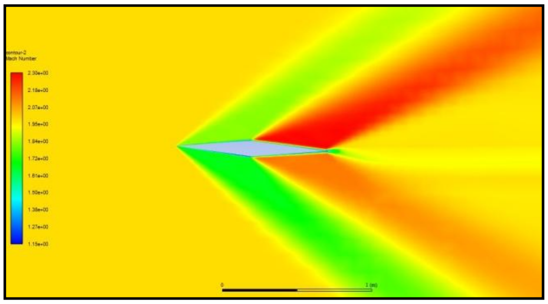

Fig.10.velocity Contour at M=2 AOA= 2

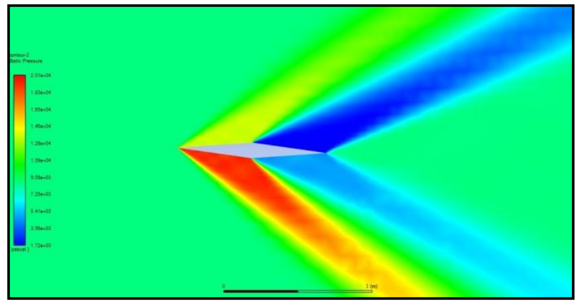

Fig.11 Pressure Contour at M=2 AOA= 2

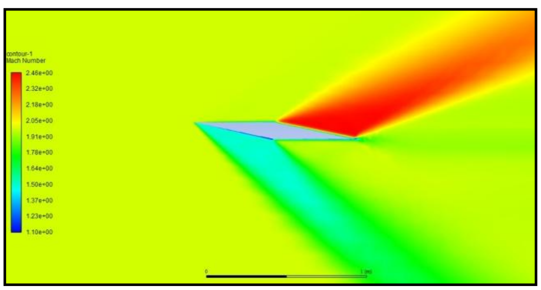

Fig.12 Velocity Contour at M=2 AOA= 6

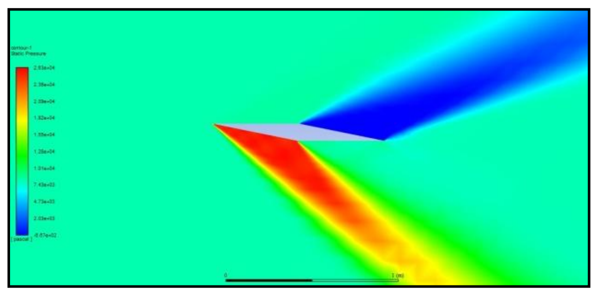

Fig.13 Pressure Contour at M=2 AOA= 6

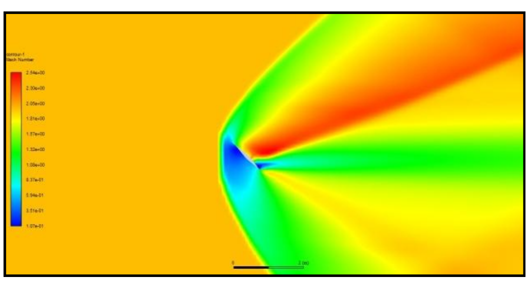

Fig.14 Velocity Contour at M=2 AOA= 45

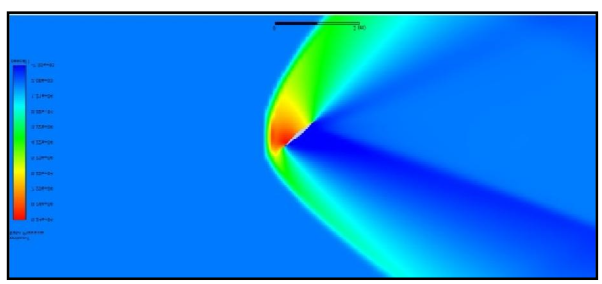

Fig.15 Pressure Contour at M=2 AOA= 45

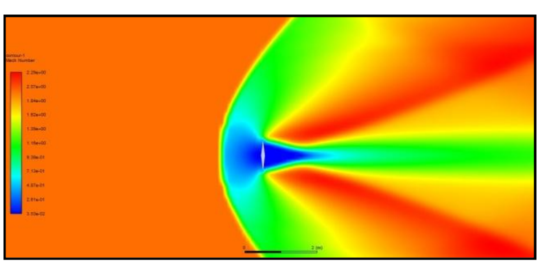

Fig.16 Velocity Contour at M=2 AOA= 90

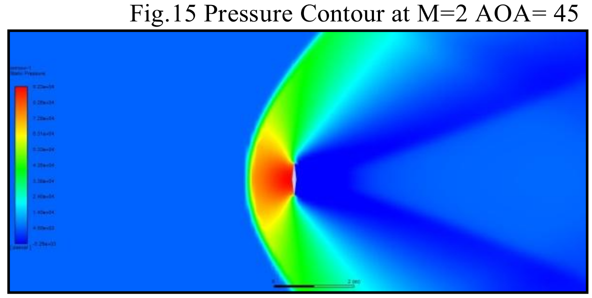

Fig.17 Pressure Contour at M=2 AOA= 90

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IV. Results

Coefficient of Lift (Cl) vs. Angle of Attack (AoA):

At small angles of attack (0° to 12°), the coefficient of lift (Cl) increases linearly with AoA. This is because lift is directly related to the angle at which airflow strikes the airfoil, creating a higher pressure difference between the upper and lower surfaces as AoA increases, resulting in increased lift. As AoA continues to rise, the relationship between Cl and AoA becomes less linear. The airfoil generates more lift, but this increase is less efficient. Eventually, flow separation begins, marking the stall point, where the coefficient of lift reaches its maximum before rapidly decreasing due to turbulent wake formation.

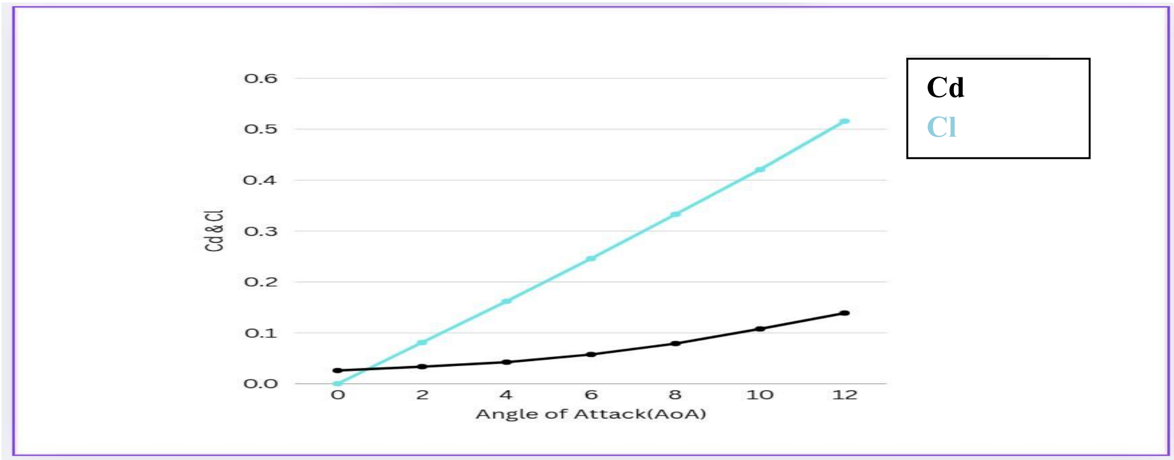

Fig.18 Graph between Cd & Cl and AoA

Coefficient of Drag (Cd) vs. Angle of Attack (AoA):

At low AoA, the coefficient of drag (Cd) is relatively low, especially with smooth (laminar) flow over the airfoil. As AoA increases slightly, drag begins to rise due to the increase in pressure drag associated with greater lift generation. As AoA increases further, drag increases due to both pressure and frictional drag. The airflow becomes more turbulent, and boundary layer separation may occur, increasing drag. At high AoA, approaching the stall point, drag increases significantly due to flow separation and the formation of a turbulent wake, known as stall drag or drag rise. The drag coefficient increases dramatically near and after the stall point. coefficient increases dramatically near and after the stall point.

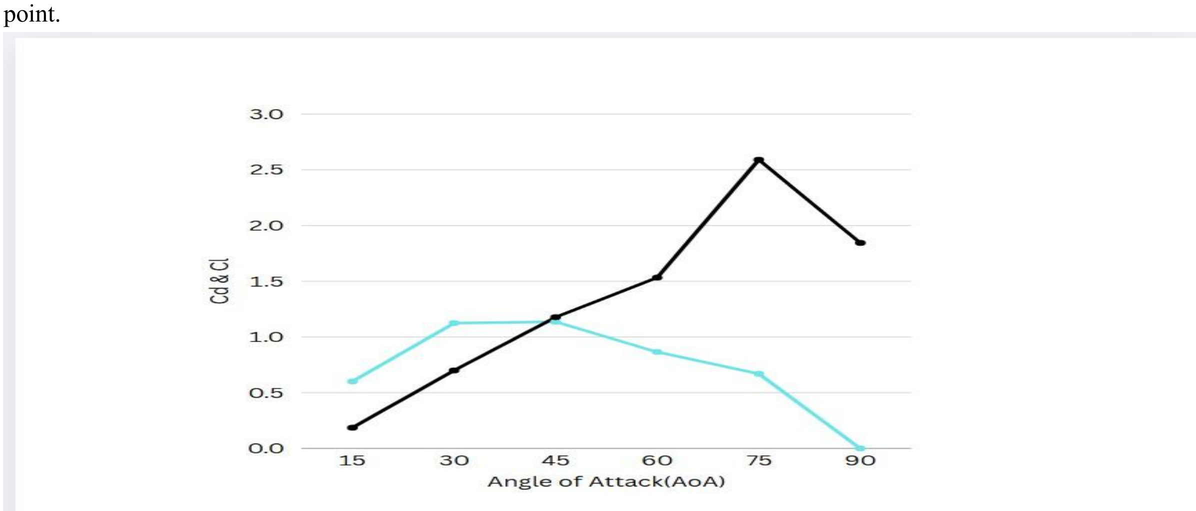

Fig.19 Graph between Cd & Cl and AoA

Variation in Cd and Cl with mach no.

The variation in the coefficient of drag and coefficient of lift with Mach number is shown in the graph. We observe that the coefficient of lift remains constant across the entire range because the angle of attack is zero at all Mach numbers. Meanwhile, the coefficient of drag increases with increasing Mach number, as indicated in the graph. As the Mach number increases beyond 1, the flow around the body accelerates, and the drag caused by shock waves changes. In the supersonic regime, the drag typically decreases because the shock waves move farther away from the body, reducing the pressure drag component. At supersonic speeds, the drag is largely dominated by wave drag caused by the shock waves. As the Mach number increases, the shock wave structure becomes more stable and less disruptive to the overall flow, which can lead to a decrease in drag.

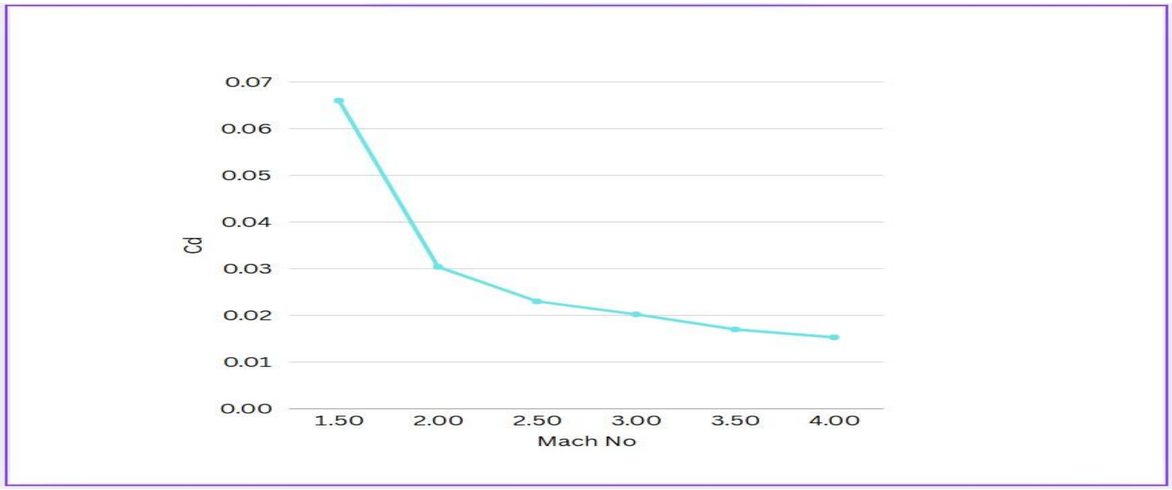

Fig.20 Graph between Cd and Mach No.

V. CONCLUSION

This study demonstrates that both Mach number and angle of attack significantly influence the aerodynamic performance of a double wedge airfoil. At a fixed angle of attack, increasing the Mach number intensifies shock and expansion effects, impacting pressure and velocity distribution. When Mach number is constant and AoA increases, lift rises linearly up to the stall point, beyond which flow separation leads to reduced lift and increased drag. The drag coefficient also increases with Mach number due to stronger shock waves but may stabilize at higher speeds due to more streamlined shock structures. Overall, the CFD results align well with theoretical expectations, validating the airfoil's behaviour in supersonic regimes.

REFERENCES

[1]. Anderson, J.D. (2010). *Fundamentals of Aerodynamics* (5th ed.). McGraw-Hill.

[2]. Liepmann, H.W., and Roshko, A. (1957). *Elements of Gasdynamics*. Wiley.

[3]. L. A. Mitchell, D. W. Young, "Optimization of Double Wedge Airfoil for Solar-Powered Aircraft," *Renewable Energy*, 2022, pp. 1027-1033

[4]. L. H. Bragg, A. P. Hughes, "Shock Wave Interactions and Their Effects on the Aerodynamic Performance of Airfoils," *AIAA Journal*, 2001, pp. 2093-2101.

[5]. Miele, A., and Miele, L. (1997). "Optimal Design of Wedge Airfoils for Supersonic Flow." *Journal of Aircraft*, 34(4), 490-498.

[6]. Sukumar, K., & Tiwari, P. (2012). *Aerodynamic Characteristics of a Double Wedge Aerofoil in Subsonic and Supersonic Flow Regimes*.

[7]. P. M. Morse, J. M. Maza, "Analysis of Shock Wave Interaction with Boundary Layer and Flow Separation on Airfoils," *Journal of Fluid Mechanics*, 2010, pp. 42-53.

[8]. P. H. Jones, S. D. Williams, "Shock-Wave Dynamics and Their Effect on Airfoil Aerodynamics at Supersonic Speeds," *Journal of Fluid Mechanics*, 2018, pp. 210-219.

[9]. C. M. Merino, R. T. Johns, "CFD Analysis of Lift and Drag on Airfoils with Varying Angles of Attack," *Computers and Fluids*, 2012, pp. 127-138.

[10]. Report 1135, national advisory committee for aeronautics,1953, ames aeronautical lab, moffett field, calif.

[11]. Devasurya, ashwanth(2022) Analytical study of double wedge aerofoil for supersonic applications. , Volume-2 IJARSCT Journal,2581-9429