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CFD Analysis of Diamond Shape Airfoils at Supersonic Speed

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Abstract: *The Aim of this paper is to perform aerodynamic analysis of double wedge / diamond shape airfoil of different wedge angles at supersonic speed at Mach 2.In this work, the flow over a "Diamond shaped Airfoil" in aspects of coefficient of Lift, coefficient of Drag, coefficient of pressure, and flow velocity at Mach 2 at various angle of attack was investigated. Using ANSYS Workbench, one of the top programmes for computational fluid simulation, and Ansys design workbench for modelling, we have analysed the flow parameters between three diamond-shaped airfoils with various geometry. In this paper it has concluded that the diamond shape airfoil with wedge angle 10° is experiencing lower drag compared to other two airfoils at supersonic speed.*

Keywords: Supersonic, compression, expansion, oblique shock, double wedge airfoil, Transonic, Wave drag, Shockwave, ANSYS FLUENT

I. INTRODUCTION

A supersonic airfoil is a cross-section geometry designed to generate lift efficiently at supersonic speeds. The need for such a design arises when an aircraft is required to operate consistently in the supersonic flight regime.

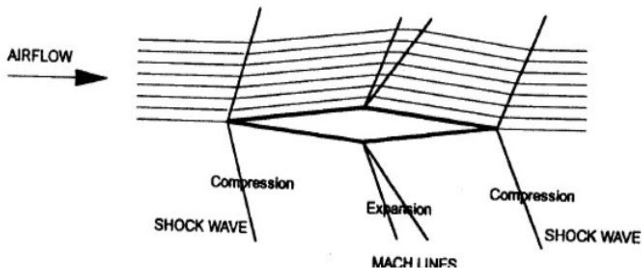

Figure.1 Supersonic airfoil

A lifting force that operates at a right angle to the airstream and a dragging force that acts in the same direction as the airstream are produced by an airfoil, sometimes referred to as an aerofoil, which is the shape of an aircraft wing.The two types of airfoils that are most frequently utilised in supersonic travel are double-wedge and bi-convex. The most basic and significant source of drag in areas of supersonic flow is wave drag. When an airfoil's Mach number exceeds 1, it is referred to as supersonic. A supersonic airfoil is made to efficiently provide lift at supersonic speeds. The leading and trailing edges of supersonic airfoils are extremely sharp, and the thin section is made of either angled planes or opposing arcs. Usually described as double wedge airfoils & a biconvex airfoil. Sharp edges on the airfoil itself prevent a disconnected bow shock from forming as it travels through the air. towards the airfoil. The wave drag is the simplest and most significant part of the drag created in the supersonic domain.

The shock waves and expansion waves produced by a double Wedge airfoil / diamond shape airfoil are linked to its supersonic properties. However, this does increase the drag that is created. The application of the airfoil is constrained by the intricate geometrical parameter variation of the double wedge airfoil. The position of the shock waves and expansion waves along the wing surface are the two key factors that must be taken into account when designing any supersonic airfoil. However, its location is influenced by the geometry of the airfoil as well as the rate and direction of the local flow across it.

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The detrimental effects of the shock waves that are created at the edges of the wing surface in a supersonic flow tend to be greatly reduced by the double wedge shape of the airfoil. Furthermore, because the bow shock tends to generate greater drag than the oblique shocks, the narrow leading edge of the airfoil frequently leads to the formation of an oblique shock/connected shock rather than the detached/bow shock. As a result, double wedge airfoils operate well at supersonic speeds but poorly at subsonic speeds due to the sharp edges that stall.Supersonic aircraft frequently employ airfoils with a diamond shape airfoils or bi convex airfoils. As an aeroplane flies faster than the speed of sound, it frequently produces shockwaves and expansion waves. When an object's Mach number is higher than 1, shock and expansion waves are created.

The objectives of this project are:

- To select supersonic airfoils and to design for different geometric dimensions.
- To model 2-dimensional supersonic airfoils as per the dimensions and wedge angles.
- To analyse the airfoils at various boundary conditions for zero AOA and determine the wave drag and coefficient of lift
- Optimize the best deign Wedge angle airfoil with minimum wave drag and maximum lift coefficient.

II. AIRFOIL DATA

For the flow analysis we have designed three different airfoils of different wedge angles.

The details of the airfoils are show below

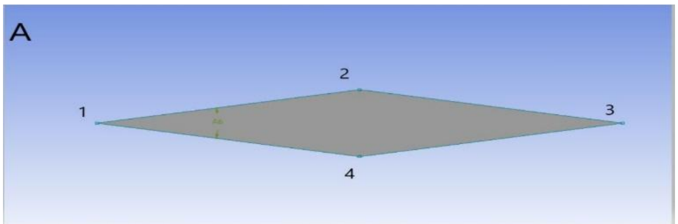

Figure 2: Double wedge airfoil /Diamond shape airfoil {wedge angle 20°}

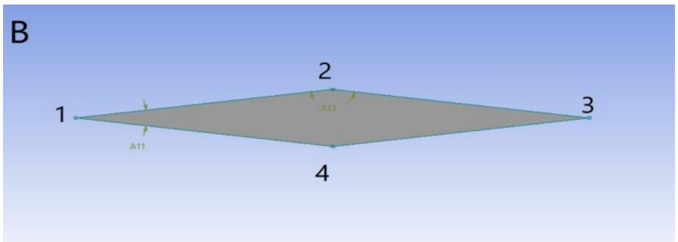

Figure 3: Double wedge airfoil /Diamond shape airfoil {wedge angle 15°}

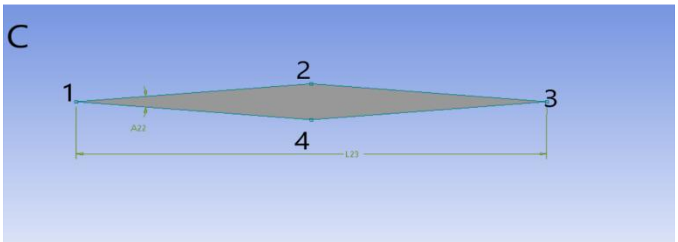

Figure 4: Double wedge airfoil /Diamond shape airfoil {wedge angle 10°}

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AIRFOIL DESCRIPTION

Airfoil name	Angle 1	Angle 2	Angle 3	Angle 4
A	20	160	20	160
B	15	165	15	165
C	10	170	10	170

III. METHODOLOGY

The modelling and analysis have been done using ANSYS FLUENT software. The wedge angles for airfoil are chosen as 20°, 15°&10°.the supersonic analysis was carried out for Mach number 2.0. A simple analysis is made on different supercritical airfoils and a conventional airfoil in ANSYS FLUENT.

1. Pre-processing stage-

Design 2 D model of double wedge airfoil / diamond shape airfoils.
These airfoil data are imported to ANSYS FLUENT (flow).
Domain is created across the airfoil for analysis.

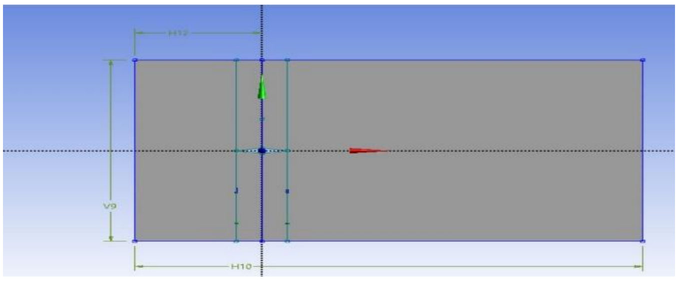

Figure 5: Domain/far field for the analysis of the airfoil

DESCRIPTION	DIMENSIONS
Type of Domain	RECTANGLE
Domain length	10 m
Domain Width	6 m

2. Meshing-

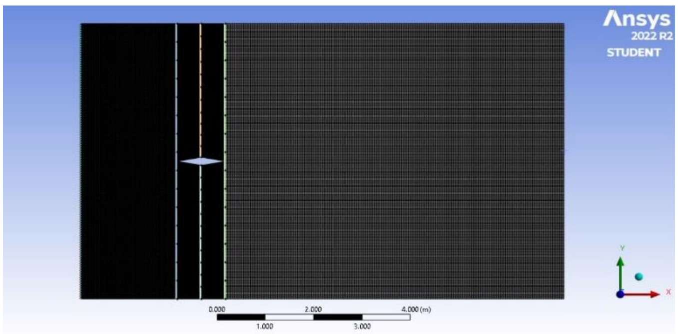

Figure 6 : Mesh created for the airfoil considered

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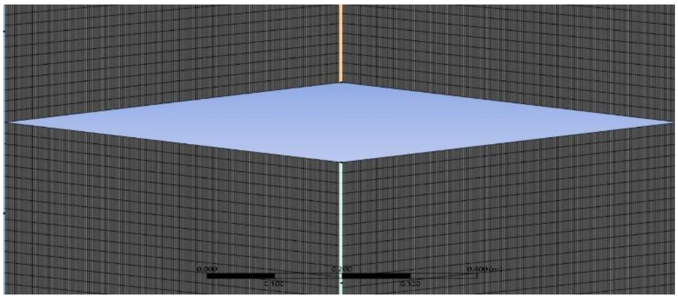

Figure 7. Structured mesh across the airfoil.

3. Simulation-

The simulation was done using FLUENT in Ansys Fluent workbench. The fluid used for simulation is air. The meshing file is imported to ANSYS FLUENT and the boundary conditions are applied.

Boundary conditions are,

BOUNDARY CONDITIONS	
Type of model	Spalart-Allmaras
Mach number	2
X Component of flow direction	1
Y Component of flow direction	0
Velocity, m/s	680.58
Pressure, bar	1.01325
Angle of attack	0
Solver type	Pressure based
REFERENCE VALUES	
Area, m^2	1
Density, kg/m^3	Ideal gas (1.176674)
Temperature, K	300
Viscosity, kg/m-s	Sutherland

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IV. RESULTS

PRESSURE CONTOURS

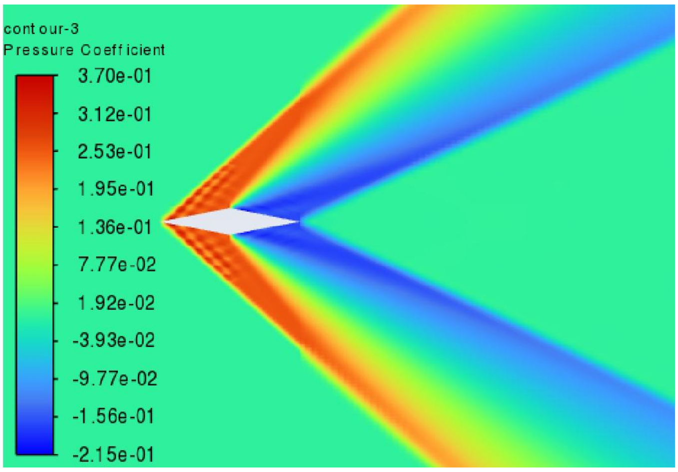

Figure 8.a: Pressure contour of Wedge angle 20 °

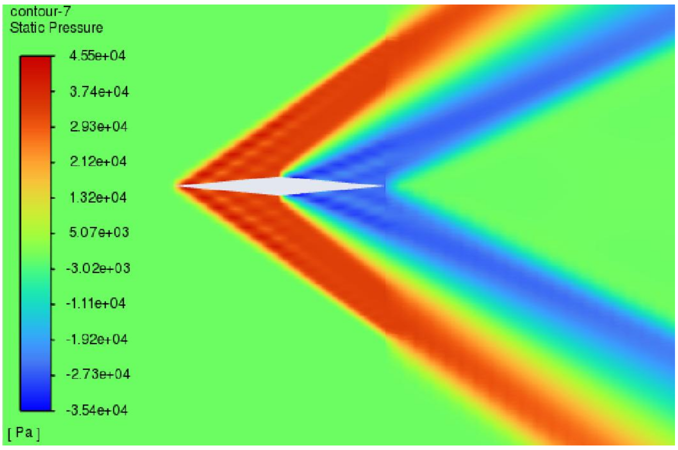

Figure 8.b: Pressure contour of Wedge angle 10 °

Figure 8: a & b are the pressure contours of different airfoils at Mach number 2 and at 0 ° Angle of attack.

The above fig shows the pressure contours of diamond shape airfoil at Mach 2. It can clearly seen that the pressure at leading edge of airfoil is maximum because of compression behind the attached oblique shock wave.

MACH NUMNBER CONTOURS

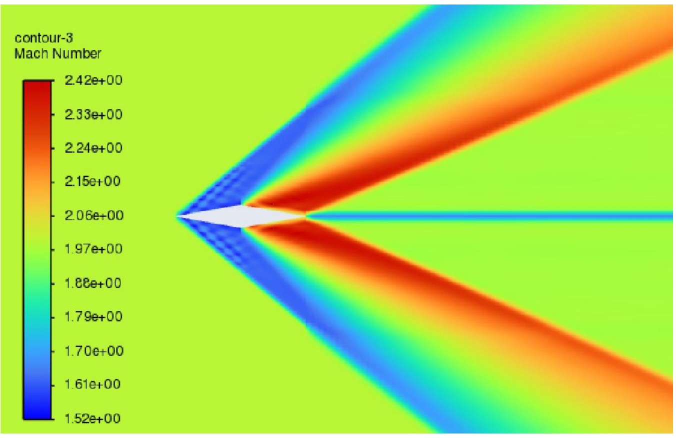

Figure 9.a: Mach No. contour of Wedge angle 20 °

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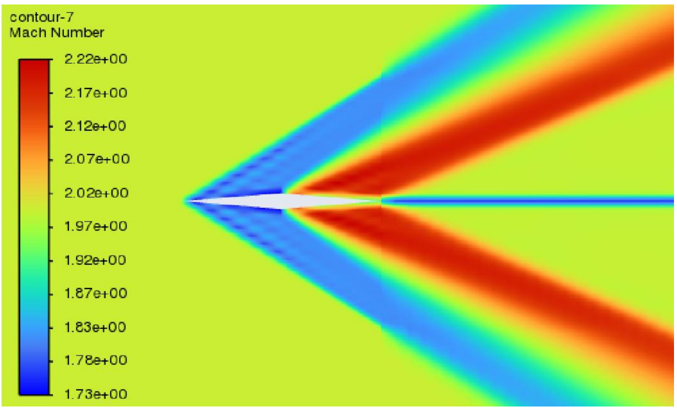

Figure 9.b: Mach No. contour of Wedge angle 10 °

Figure 9: a & b are the Mach No. contours of different airfoils at Mach number 2 and at 0 ° Angle of attack.

The above fig shows the Mach number contours of diamond shape airfoil at Mach 2. It can be clearly observed that the velocity of air passing through leading edge of an airfoil is less and suddenly velocity increases at mid chord of airfoil because of the expansion waves are generated and this accelerates the flow in same direction.

CO-EFFICIENT LIFT V/S POSITION & MACH NUMBER V/S POSITION PLOTS.

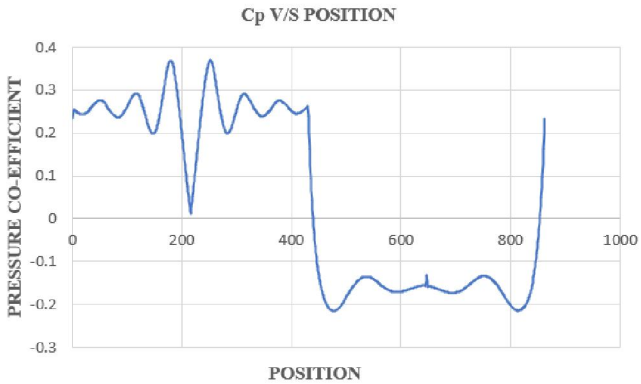

Figure 10.a: Cp vs position for Wedge angle 20°

Above figure shows the Pressure co-efficient vs chord length plot at 2 Mach number. It can be observed that sudden pressure rise is occurring at mid chord of an airfoil.

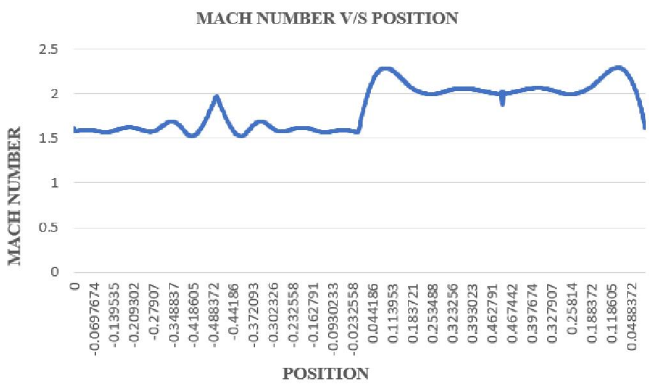

Figure 10.b: Mach no. vs position for Wedge 20°

Above figure shows the Mach No vs chord length plot. It can be observed that sudden increase in velocity is occurring at mid chord of an airfoil because of flow gets accelerated.

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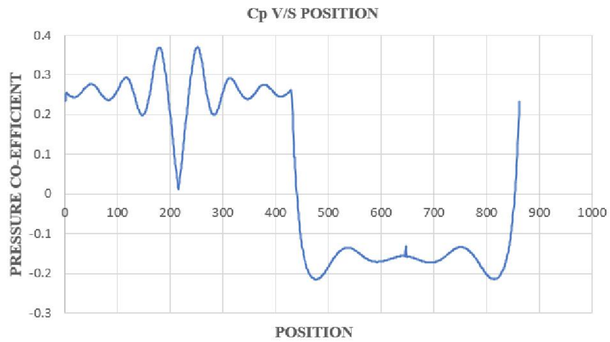

Figure 11.a: Cp vs position for Wedge angle 10°

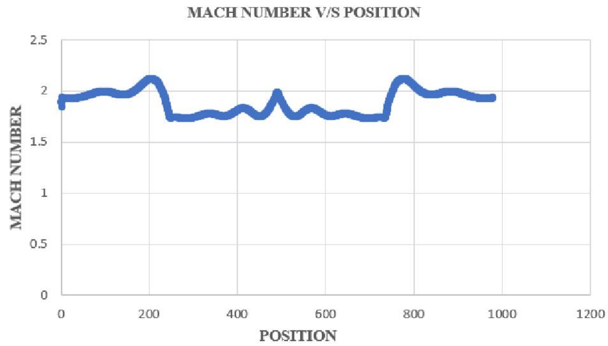

Figure 11.b: Mach no. vs position for Wedge angle 10°

CO-EFFICIENT OF DRAG V/S POSITION

Figure 12.a: Cd for Wedge angle 20°

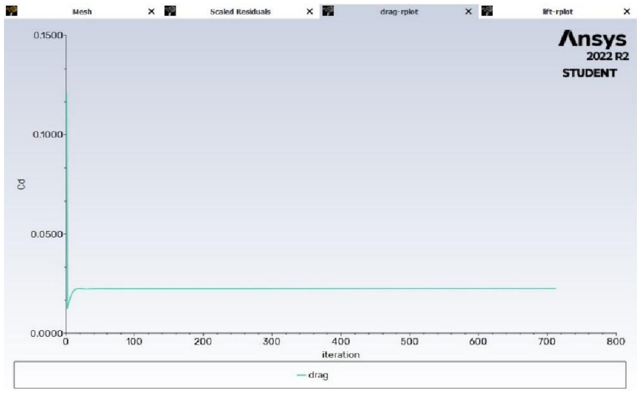

Figure 12.b: Cd for Wedge angle 15°

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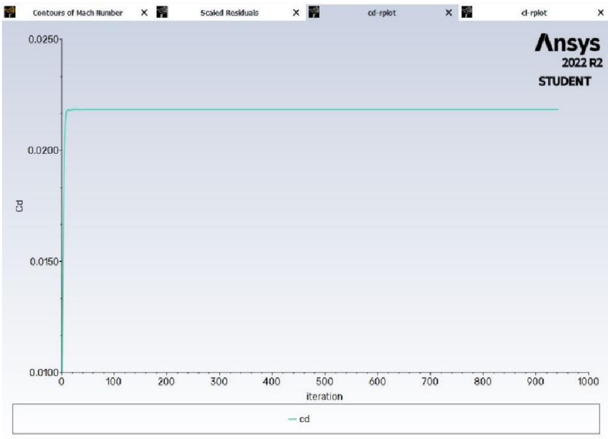

Figure 12.c: Cd for Wedge angle 10°

Figure 10: a, b & c are the drag coefficients of different airfoils at Mach number 2 and at 0 ° Angle of attack.

Wedge Angle	CD
20°	3.4986e+4
15°	2.2514e-2
10°	2.1836e-2

The above table shows co-efficient of drag values with respect to Wedge angles.

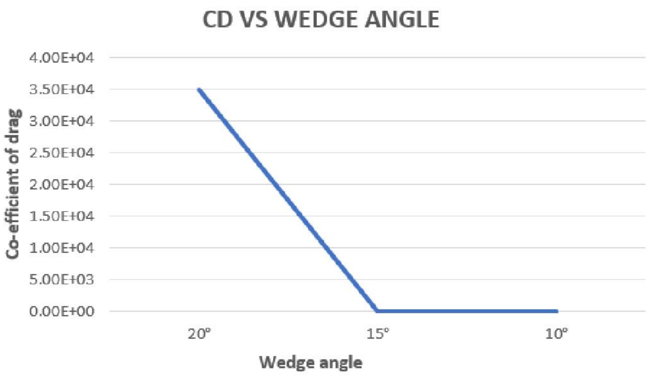

Figure 11: Co-efficient of drag vs wedge angle plot

Above figure shows the co-efficient of drag vs wedge angle plot. It can be observed that the airfoil with wedge angle 10 deg will experience lower drag when compare to other airfoils.

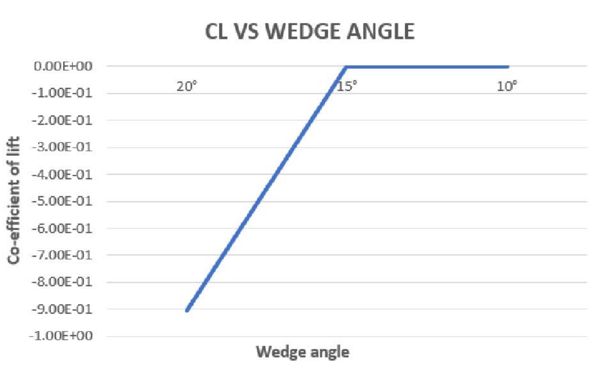

Figure12: Co-efficient of lift vs wedge angle plot

Above figure shows the co-efficient of lift vs wedge angle plot. It can be observed that the airfoil with wedge angle 10 deg will have more coefficient of lift when compare to other airfoils.

V. CONCLUSION

From this Analysis it can be concluded that Airfoil with **10°** wedge angle is experiencing the **lower drag** at supersonic speed compared to other two airfoils.

At **0-degree** AOA the attached shock for shock angle above 90o is clearly seen in fluent. Pressure Coefficient is seen to decrease with increase in Mach number after the expansion waves generated at mid chord.

Hence diamond shape airfoil with wedge angle 10 deg generates maximum co-efficient of lift at 0 AoA.

This CFD analysis of different supersonic airfoils has helps to identify the wave drag which will improve the fuel economy and NOx emissions during the operation of Jets at supersonic speeds.

VI. FUTURE SCOPE OF WORK

- Experimental Analysis of the 3D Modelled airfoil can be done at various Mach Numbers in supersonic regime.
- The work can be extended by validating the Experimental and Numerical results for the optimized airfoil.

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