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A Detailed Study: CFD Analysis of NACA 0012 at Varying Angles of Attack

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Abstract: This work reflects the study and detailed analysis of NACA 0012 airfoil at different angles of attack with a constant value of Reynolds Number. The geometrical designing of the airfoil is done using FreeCad and the computational analysis is carried out using Simflow 4.0- OpenFoam Interface. The analysis is fully based upon the concepts of FEM and CFD. The velocity is kept constant with various angles of attack. CFD methods are reliable source of analysis and hence can be replaced with the experimental wind tunnel methods. Boundary layer approaches were taken into consideration using the meshing techniques. The main purpose of this work is to study the symmetric profile of NACA 0012 with varying angles and the behaviour of 0012 at specific conditions. At the end, various graphs are plotted depicting the relationship of Angle of Attack with other dimensionless quantities.
Keywords: NACA 0012, Freecad, Simflow 4.0, CFD, Aerodynamic characteristics

I. INTRODUCTION

It is a fact that when a body is kept in a fluid, resultant force is developed. This resultant force is mainly known as resistance which resists the motion of a body in fluid. The resultant force is divided into components out of which the component normal to the motion of body is far greater when compared to the component actually resisting the motion. The aircraft in flight fully depends upon such type of body used in its wings. Airfoil, a 2D cross-sectional area of a wing, when kept in a fluid experiences motion. The fluid can be air for flight purposes or water/liquid for experiment point of view. The air gets bifurcated into two streams, i.e., upper and lower. Pressure distribution arises on upper and lower surfaces of an airfoil. The difference in pressure is the main cause for the aerodynamic forces Lift and Drag. There is an immense growth seen in the analysis and CFD for solving the aerodynamic concerns within given time. During the analysis, the flow i.e., air over the airfoils play a major role that is taken into count while designing any type of air vehicles or objects. CFD gives an idea about the qualitative and quantitative information of a fluid flow with the help of numerical and analytical approaches. The steps of analysis include the statement, modelling, meshing, discretization, solvers, simulation, post processing etc. Simflow 4.0 is an open software which is taken into use by technical graduates and students for the CFD approaches. It helps in solving problem statements referring to heat transfer, turbulences, numerical approaches, and structural computations. Simflow 4.0 supports the entire process of CFD, i.e., from CAD to the post processing. The present literature reflects the characteristics shown by NACA 0012 airfoil at 5,8,11,13 degrees Angle of Attack using velocity contours. Also, the relationship between Lift, Drag and Moment coefficients with AOA are analysed using graphs.

II. KNOWING THE AIRFOIL AND ITS TERMINOLOGIES [1,3]:

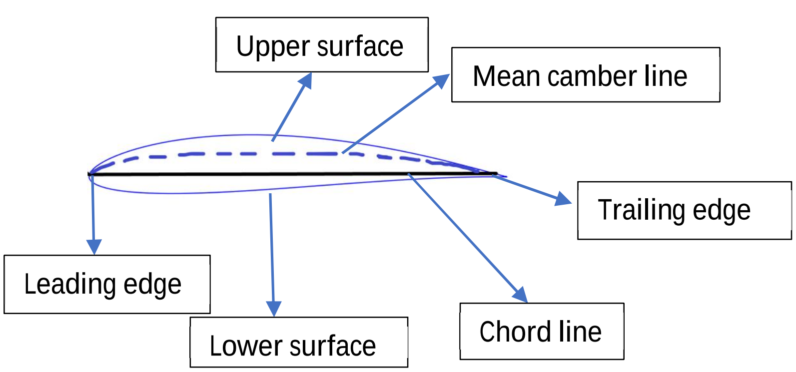

Fig1: Airfoil Nomenclature

1) Lift: It is the aerodynamic force which is perpendicular to the flow direction.
2) Drag: It is the other component of aerodynamic force which is parallel to the flow direction.
3) AOA: The angle formed between chord line and the relative wind (Free stream velocity) is known as Angle of Attack.
4) Reynolds number: The ratio of Inertial force to viscous force is known as Reynolds number. It also gives details about the flow

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Note [5]:

Lift Coefficient is given by: $Cl = \frac{L}{\frac{1}{2}\rho v^{\wedge}2A}$

where L= Lift, v= velocity at inlet, ρ = density of air, A= area of airfoil

Drag Coefficient is given by: $Cd = \frac{D}{\frac{1}{2}\rho v^{\wedge}2A}$

where D= Drag, v=velocity at inlet, ρ = density of air, A= Area of airfoil

III. DESIGN AND MESH OF NACA 0012 AIRFOIL

The airfoil NACA 0012 which is symmetrical in shape has the maximum thickness of 12% of the chord. The reason being symmetrical is the maximum camber as a percentage of the chord length and position of the maximum camber in tenths of the chord is having the value zero.

Table1: Geometry of NACA 0012

Radius [m]	25
Tail length ratio [-]	1.5
Tail angle [deg]	0
AOA [deg]	5, 8, 11,13

The airfoil coordinates were imported from the NACA airfoil database into the designing software "FreeCad". Here shown is the modelled airfoil and the complete mesh structure of 0012.

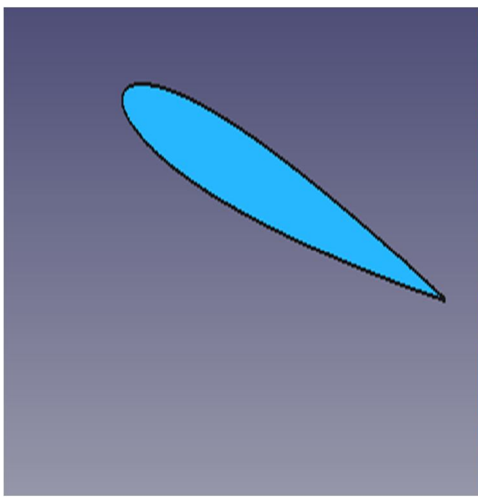

Fig2: Modelled design of NACA 0012 using FreeCad

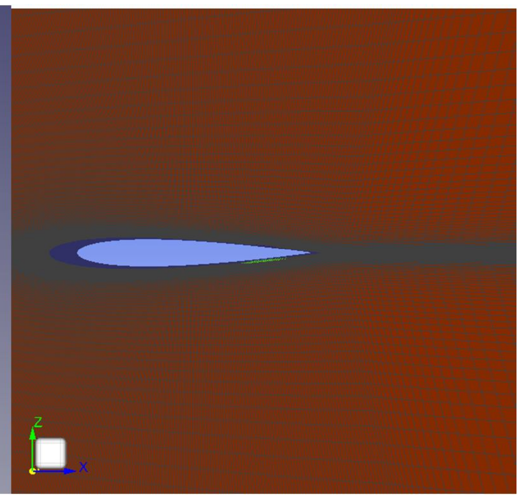

Fig3: Enlarged Mesh of 0012 using SimFlow

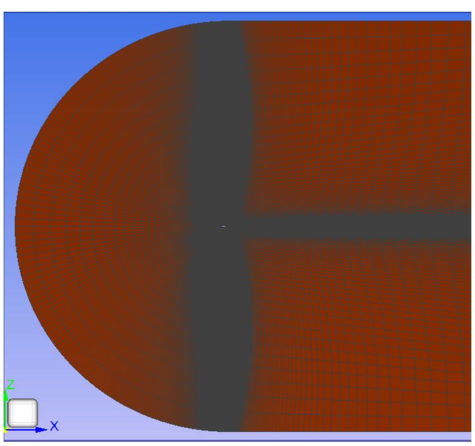

Fig4: C structured mesh of 0012

Property	Value
Surface Cell Thickness [m]	2e-04
Cell count	60183
Min surface cell length[m]	2e-03
Max surface cell Length [m]	2e-08

Table2: Mesh details of 0012

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IV. INPUTS AND BOUNDARY CONDITIONS

NACA 0012 is used for computational flow analysis at varying angles of attack (5,8,11,13 degree). Turbulence model is created using certain types of mathematical models to get the turbulence levels of airfoil. RANS equation uses a two-equation model named as K-ω model. Here k is kinetic energy and ω is specific rate dissipation. The two-equation model is amalgamated with SST (Shear Stress Transport). The fluid flow is considered to be steady and incompressible. The transport model is taken as Newtonian having kinematic viscosity as 1.5e-5 m^2/s. The solver used is SIMPLE.

Quantity	Convection
U	Linear upwind
k	upwind
w	upwind

Table3: Convection

Quantity	Type	Intensity/ Mixing length
K	Turbulence intensity inlet	0.05 [-]
w	Turbulence intensity mixing length	0.07 m

Table4: Inlet boundary conditions

Inputs	Values
U (velocity at inlet)	90 m/s
Fluid medium	Air
Operating pressure	101325 Pa
Chord length	1m
Angles of Attack	5,8,11,13
Model	Realizable K-ω model

Table5: Operating conditions

V. RESULTS AND DISCUSSION

A. Velocity Magnitude Contours at 5°, 8°, 11°, 13° Angles of Attack.

The contours show the stagnation point at the leading edge where the fluid velocity is almost zero. On the upper surface of the airfoil, the fluid velocity accelerates whereas the lower surface experiences low velocity. This is because of the existence of high pressure at lower surface and low pressure at upper surface. The differential pressure is the reason for the lift generation.

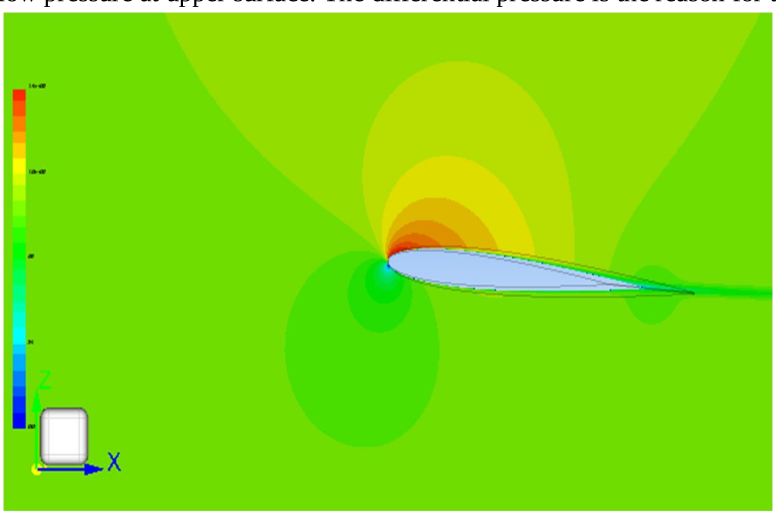

Fig5: NACA 0012 at 5°

Fig6: NACA 0012 at 8°

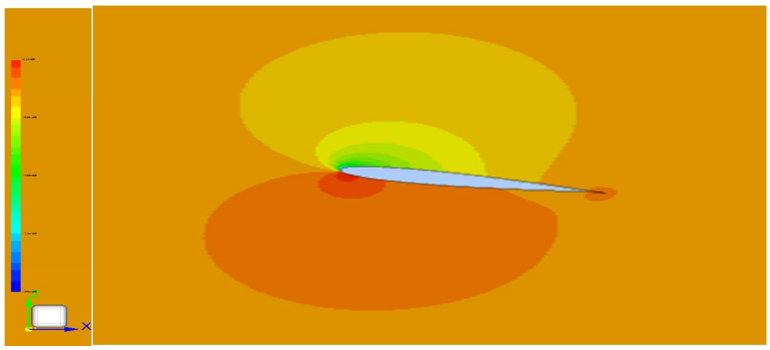

Fig7: NACA 0012 at 11°

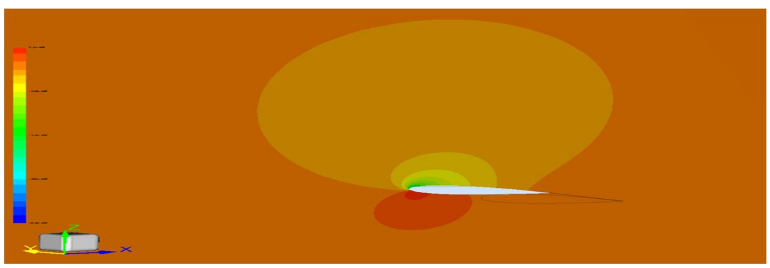

Fig8: NACA 0012 at 13°

B. Graph Profiles (Cm, Cd, Cl vs Time) FOR 5°, 8°, 11°, 13° angles of attack

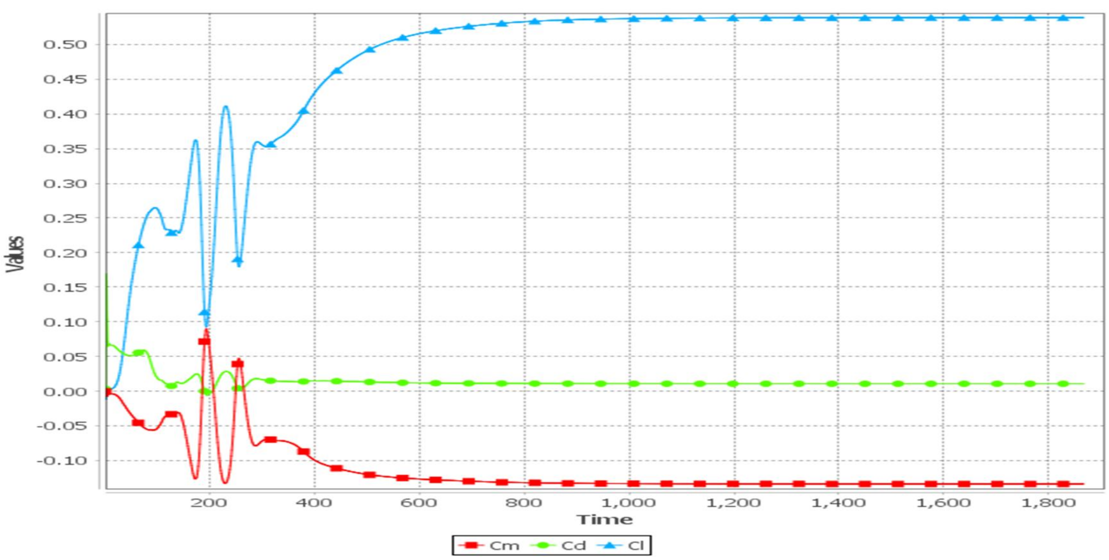

Fig9: Plot at 5°

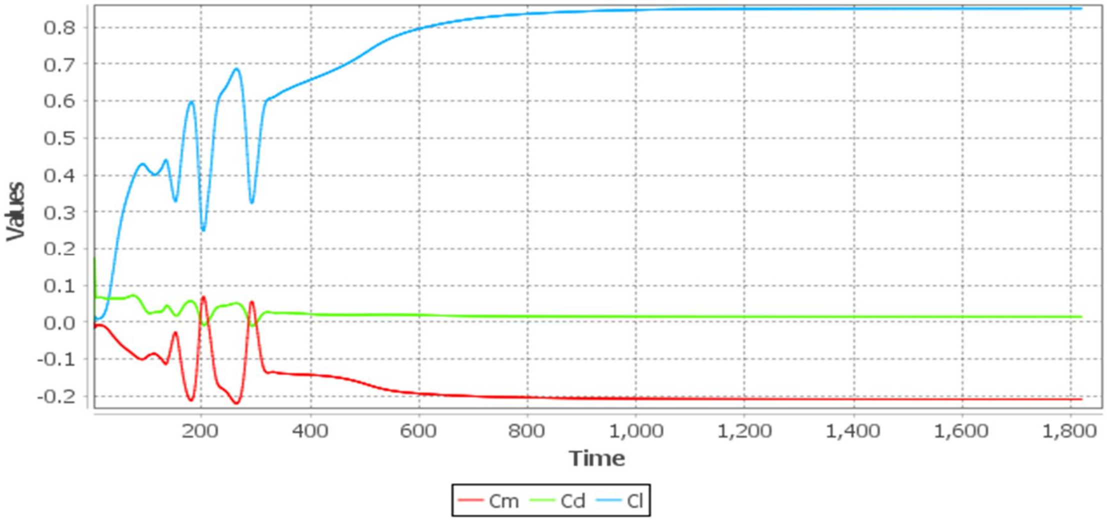

Fig10: Plot at 8°

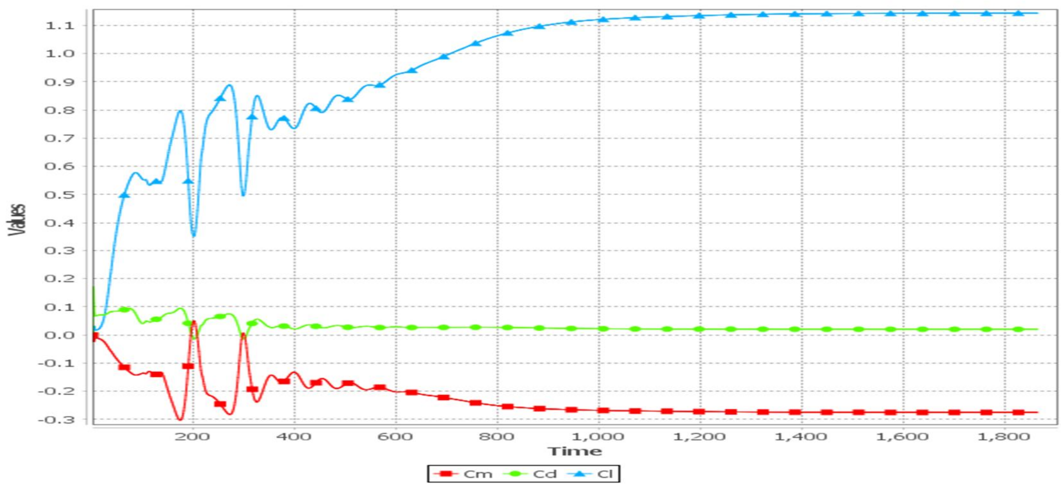

Fig11: Plot at 11°

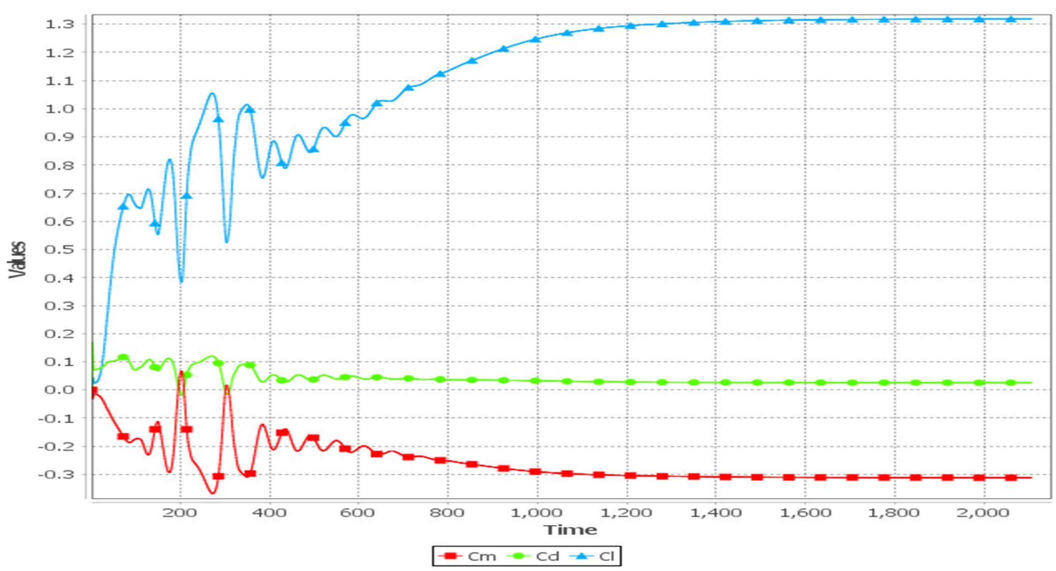

Fig12: Plot at 13°

From the figures 9,10,11,12, we can calculate Lift coefficients with varying angle of attacks.

Angles	Cl	Cd	Cl/Cd
5°	0.55	0.01	55
8°	0.9	0.021	42.85
11°	1.2	0.03	40
13°	1.32	0.036	36.66

Table6: Cl, Cd, Cl/Cd at various angles

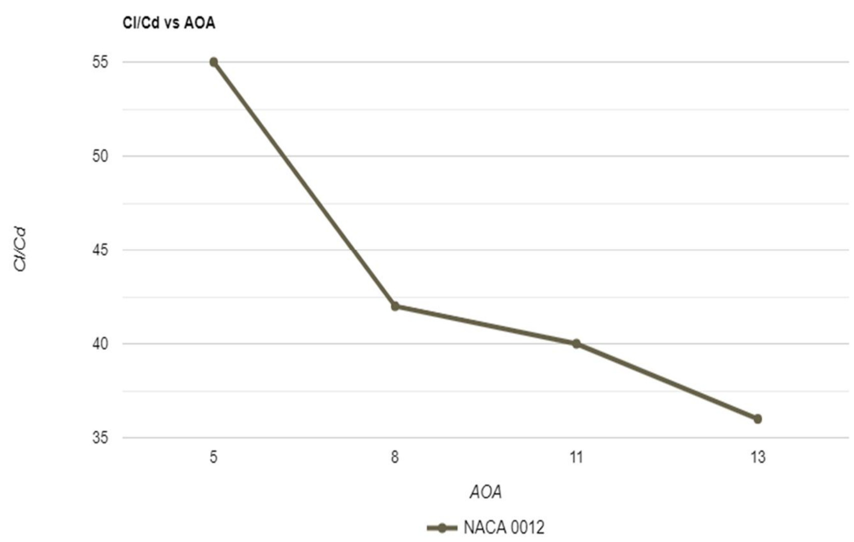

Fig13: Cl/Cd vs AOA plot

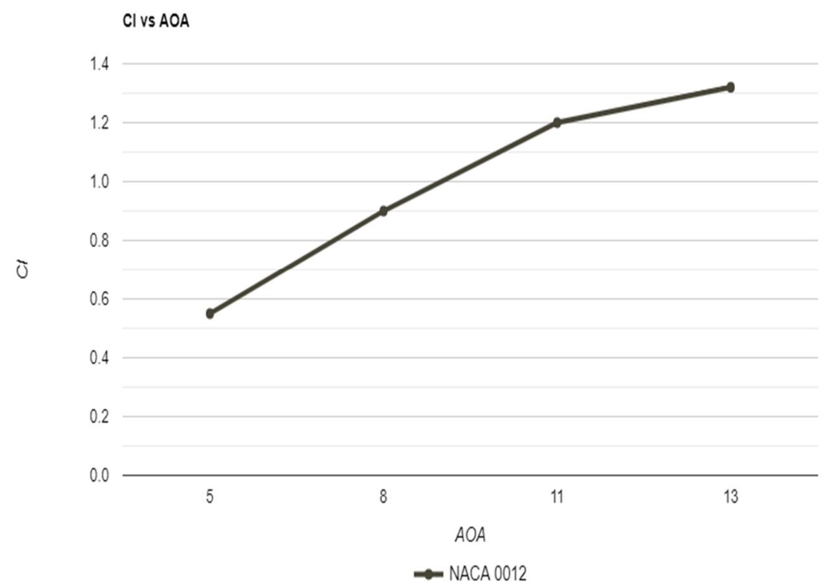

Fig14: Cl vs AOA

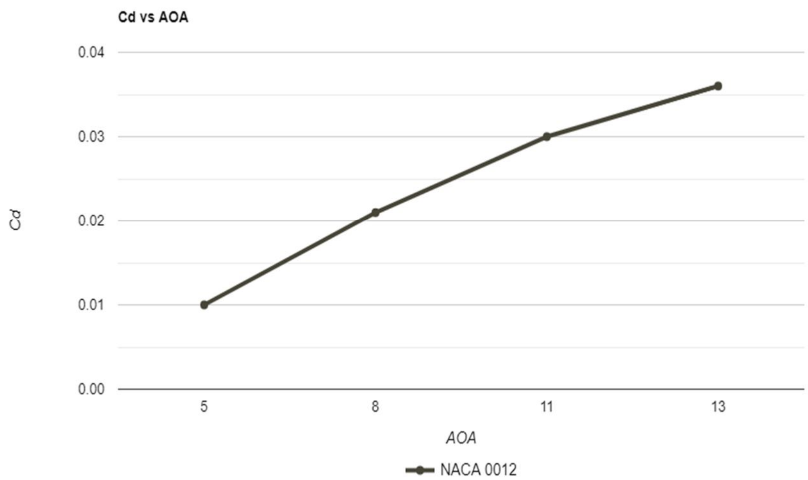

Fig15: Cd vs AOA

VI. CONCLUSION

From the table 6, it is concluded that as angle of attack increases, there is an increase in lift and lift coefficients. With varying angle of attack, drag and drag coefficients also increases but on a low scale as compared to lift and its coefficients. As the pressure generated is low on upper surface and high on lower surface, the lift is generated upwards. This gives high velocity on upper surface and low velocity on lower surface due to inverse proportionality with pressure. At a certain point, there is a sudden decrease in lift with varying AOA which is termed as critical/stalling condition. Maximum lift coefficient for NACA 0012 is 1.32. Performance using Simflow 4.0 is encouraging and is accurate in terms of results.

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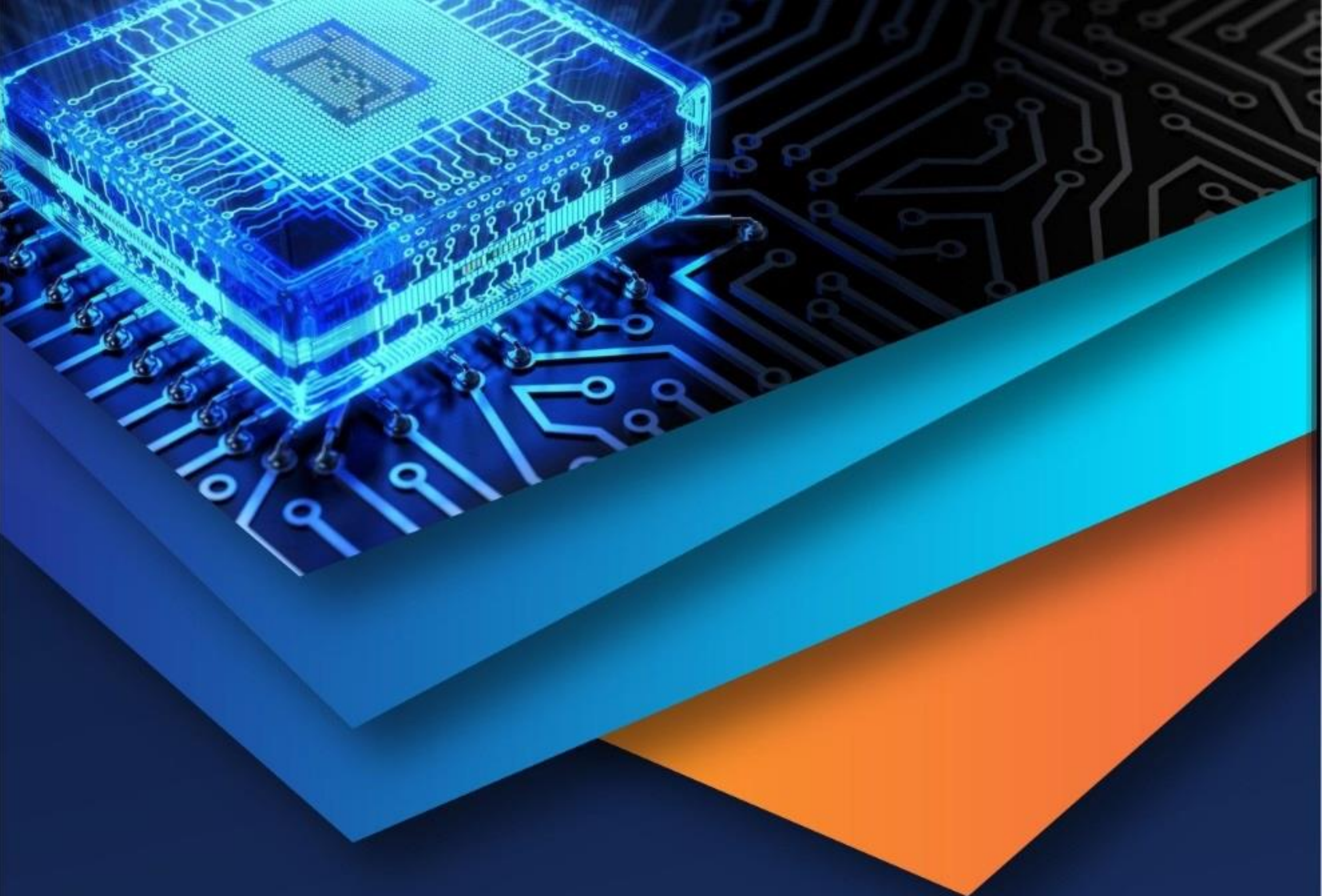

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