CFD Analysis of Tapered Wing with NACA 64-210 at the Tip and NACA 64-215 at the Root

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Abstract: ***The primary investigation in the aerodynamics is to study how the objects fly in the air. Study of lift and drag forces are the important forces to be considered in the aircraft wing design. In this research we focus on the comprehensive study of tapered 3D unsymmetrical airfoil wing. Tapered wing is modeled in CATIA V5 considering NACA 64-210 at the tip and NACA 64-215 at the root. Computational Fluid Dynamics is carried out using ANSYS Fluent R20. Reynolds number 5.8x10^6(50m/s) is considered, which resembles the subsonic speed. Pressure and velocity distribution over the 3D tapered unsymmetrical wing surface is studied. Lift and drag forces are determined at various angles of attack, the results are tabulated and graphs are drawn for lift force versus different angles of attack and drag force versus different angles of attack. Study reveals that results clearly justify the Ludwig Prandtl boundary layer theory where pressure and velocity are inversely proportional.***

Keywords: CFD Analysis, NACA 64-215, NACA 64-210, Lift Coefficient, Drag Coefficient, Tapered Wing

1. Introduction

Airfoil sections have been developed during 1800s. Mainly the study of airfoil sections depends on boundary layer theory developed by Ludwig Prandtl, in his theory he said that fluid flowing over an object is divided and flows as two regions i. laminar region i.e. outside flow region. ii. The region near to the object, due to surface friction the flow to moving slowly. This in turn causes the air to flow at different velocities at the lower and upper surface of the object that comes in the flow of air. [1].Figure 1 shows the transverse cross-section of the aircraft wing is called airfoil which obeys the boundary layer theory [2, 3].

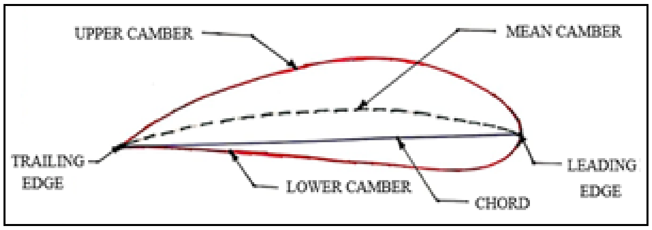

Figure 1: Cross-section of the Aircraft Wing

The airfoil function is to sling the entire weight of the aircraft in the air. The airfoil is designed in such a way that when it moves with specified speed produces an aerodynamic force which is useful to lift the aircraft in the air due to the velocity between the airfoil and the air called relative velocity. The lift is the force produced due to the difference in the pressure on the upper and lower surface of the wing or airfoil. Drag force is shear force (parallel) which is acting opposite to the aircraft forward motion direction resulting in the more utilization of energy to overcome the sheer force or drag force [4]. Vinayak Chumber et al, carried out study on various National Advisory Committee for Aeronautics (NACA) profiles to find the lift and drag coefficients and concluded at the end that high coefficient of lift is generated for higher angle of attack and simultaneously it experiences the higher drag force. [5].

Chandrakant Sagat et al. carried out both CFD and Experimental analysis at subsonic speeds and he was concluded that for a particular angle of attack that to at 12 degree the lift coefficient starts decreasing with small amount of increase in the drag coefficient. [6]. Jon Leary carried out CFD analysis on wind turbine blades to see the behavior of lift and drag coefficient. [7].Bhosle O et al. plotted the graph of angle of attack Vs coefficient of lift and angle of attack Vs coefficient of drag, the same he was repeated for various angles of attack. [8]. Ankan Dash, concluded in his research that lift coefficient increases with decrease in the drag coefficient upto critical angle of attack, after certain angle of attack it reverses. [9].Eleni et al. Considered NACA 0012 for lift and drag coefficient variation study at Reynolds number 3.0 x 10^{6}for dissimilarviscid turbulence models namely realizable k-ε, Spalart-Allmaras, and SST models and arrived that experimental results were better matching the SST model results. [10]. Arnav Kulshreshtha et al. conducted CFD analysis on various NACA profiles for the study of lift coefficient and drag coefficient for various angle of attacks. They concluded that for different operations different airfoil shapes have their own advantages. But for the common and general use it was better to use NACA 2412 profile because ratio of lift coefficient and drag coefficient reduces with increasing angle of attacks. [11]

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Construction of Tapered Wing Profile

The aircraft wing is modeled in CATIA V5 considering NACA 4412 airfoil with predefined coordinates [12]. S. Senthil kumar et al modeled tapered aircraft wing in CATIA V5 with NACA 65-210 airfoil coordinates [13]. Guguloth Kavya and B.C Raghukumar Reddy were modeled aircraft wing in ProE with spars and ribs [14] Kakumani Sureka and R Satya Meher have modeled aircraft wing in CATIA V5 R20 CAD software using NACA 64-215 airfoil coordinates [15]. From these literature surveys I concluded that CATIA V5 is the best CAD tool to model the taper wing. Airfoil NACA 64-210 at the tip and NACA 64-215 at the root are used to build the tapered wing and the basic size requirements are considered from [16] and the coordinates to generate the airfoil are taken from [17]. Initially coordinate points are generated as shown in the Figure 1; spine is created by joining the points as shown in the Figure 2.

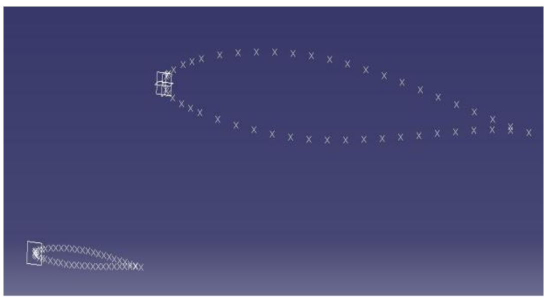

Figure 2: Generation of Coordinates at root and tip with predefined macros in CATIA V5.

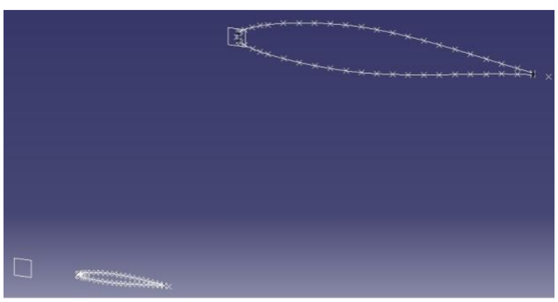

Figure 3: Airfoil shape creation using spline in CATIA V5

Wing surface is created by joining the two airfoil's one at the root and another at the tip as shown in the Figure 3.

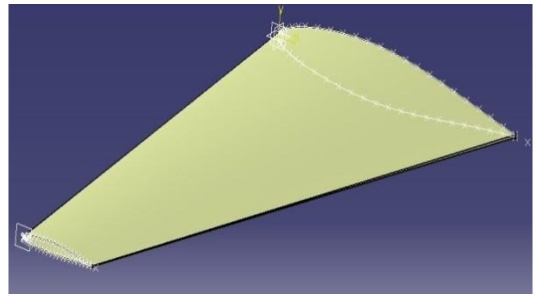

Figure 4: Wing surface connecting root and tip sections

2. Results and Discussions

Super computers have enhanced the use of simulation in the industry in the field of fluid dynamics. NASA Ames Research Center (Moffett Field, California), has involved in the development of wing using CAD tools and validation by CFD analysis. In the field of aerodynamics the problems solved by using numerical methods have been validated by wind tunnel testing and real flights which helps in the evolution of complex aircraft models. We can use number of software's in the CFD analysis [16, 17, 18, 19].

The purpose of CFD analysis is to understand the distribution of pressure and velocity on the tapered wing surface. Since most of the existing literature focuses on 2D airfoil, but our research focuses on 3D unsymmetrical wing CFD analysis considering pressure, velocity on both upper and lower surfaces at different angle of attack. Variation of lift and drag forces also determined on the entire wing surface at different angle of attack at the subsonic speed (50m/s)i.e Reynolds's number $5.8x10^{6}$.

Velocity distribution on the Tapered Wing Surface at various angles of attacks

Below figures shows the velocity distribution of 3D unsymmetrical wing profile analyzed using ANSYS fluent at different angle of attack.

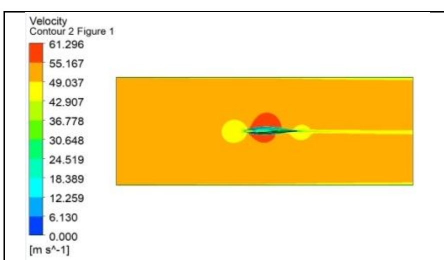

Figure 5: AOA at 0^{0}

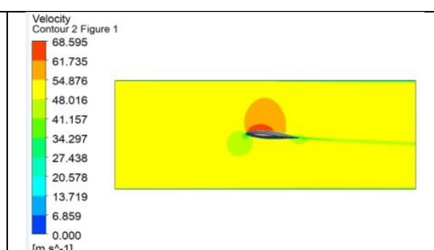

Figure 6: AOA at 3^{0}

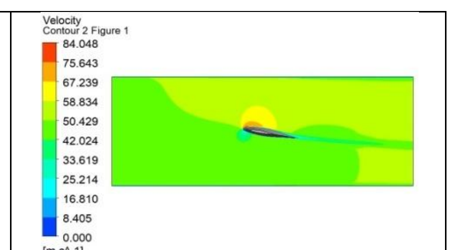

Figure 7: AOA at 5^{0}

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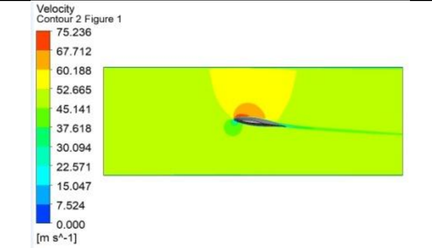

Figure 8: AOA at 8^0

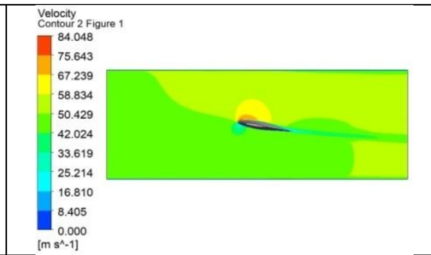

Figure 9: AOA at 10^0

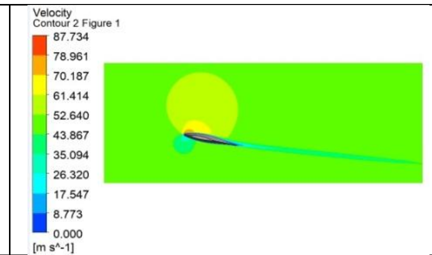

Figure 10: AOA at 12^0

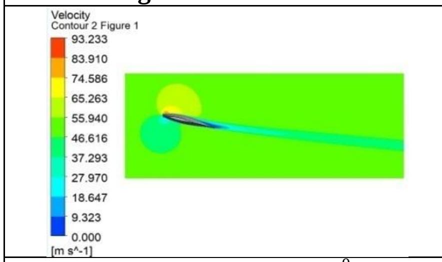

Figure 11: AOA at 14^0

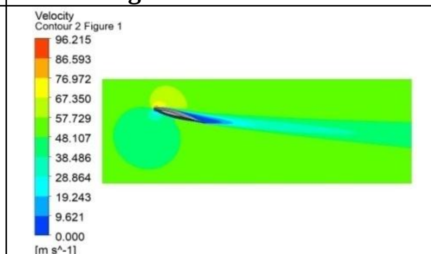

Figure 12: AOA at 16^0

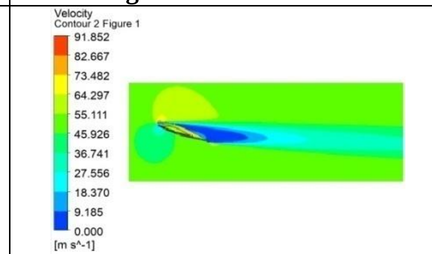

Figure 13: AOA at 18^0

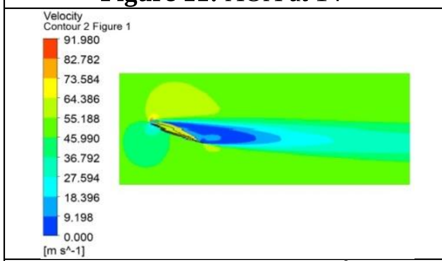

Figure 14: AOA at 20^0

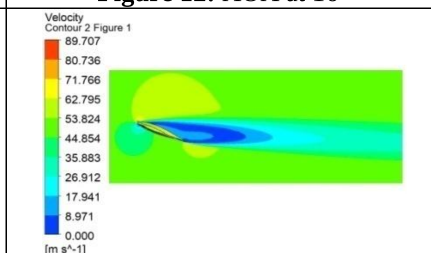

Figure 15: AOA at 22^0

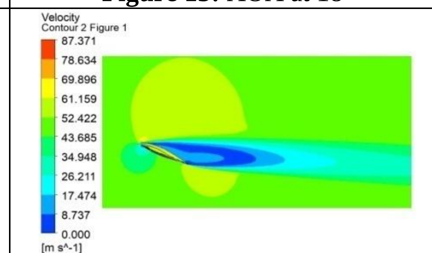

Figure 16: AOA at 24^0

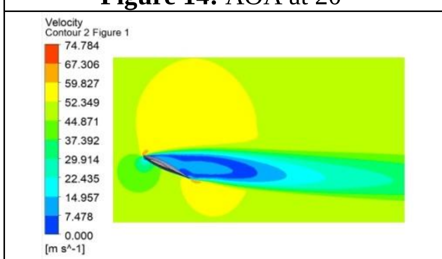

Figure 17: AOA at 26^0

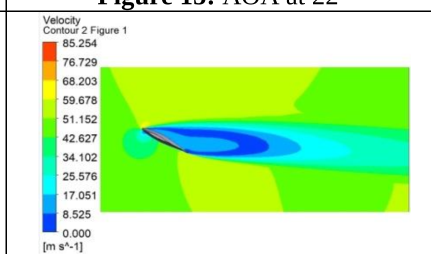

Figure 18: AOA at 28^0

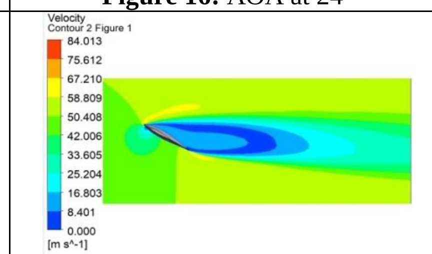

Figure 19: AOA at 30^0

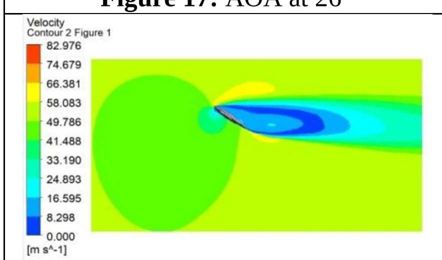

Figure 20: AOA at 32^0

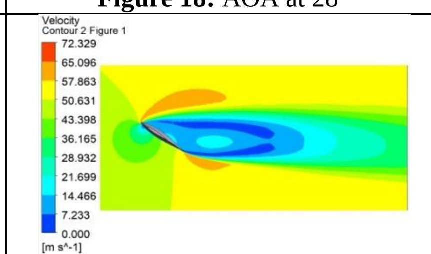

Figure 21: AOA at 34^0

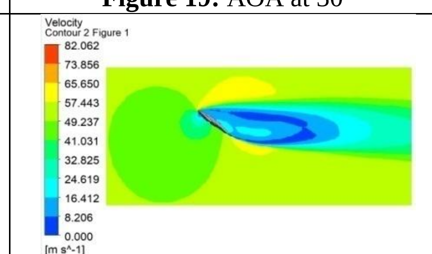

Figure 22: AOA at 36^0

Pressure distribution on the Tapered Wing Surface at different angle of attack

Below figures shows the pressure distribution of 3D unsymmetrical wing profile analyzed using ANSYS fluent at different angle of attack.

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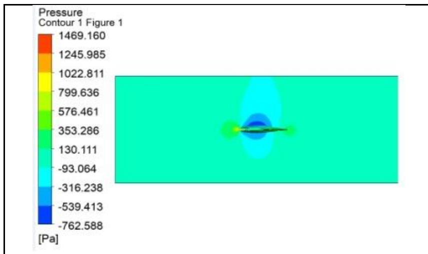

Figure 23: AOA at 0^0

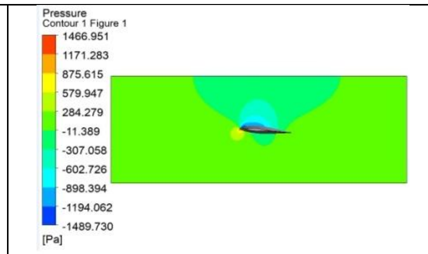

Figure 24: AOA at 3^0

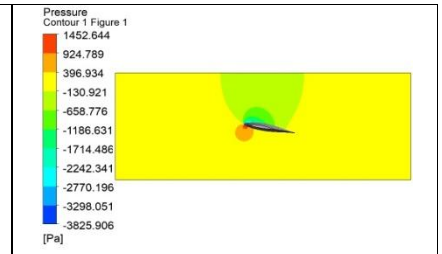

Figure 25: AOA at 5^0

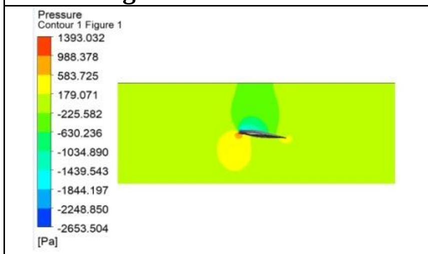

Figure 26: AOA at 8^0

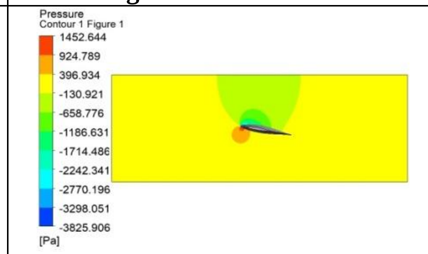

Figure 27: AOA at 10^0

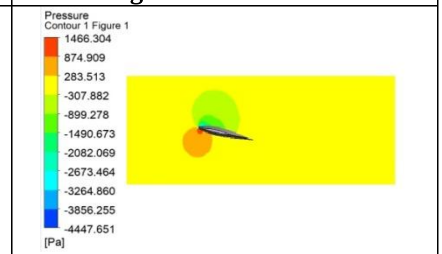

Figure 28: AOA at 12^0

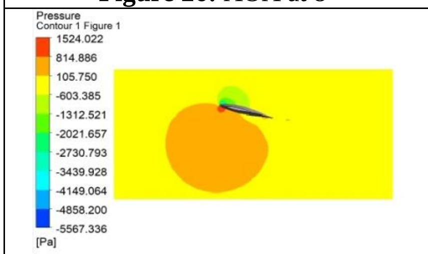

Figure 29: AOA at 14^0

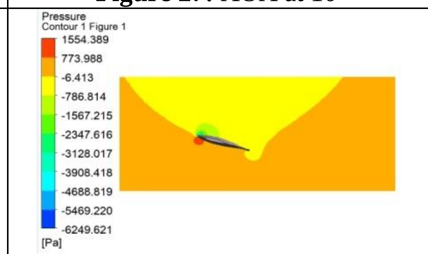

Figure 30: AOA at 16^0

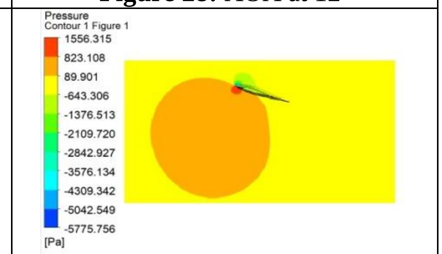

Figure 31: AOA at 18^0

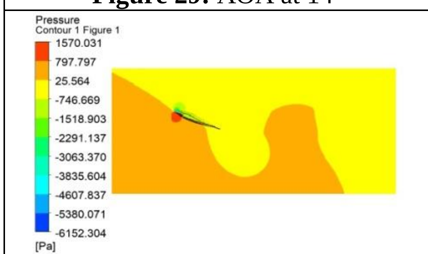

Figure 32: AOA at 20^0

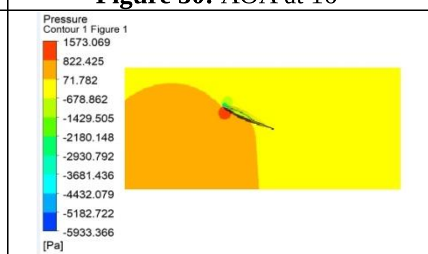

Figure 33: AOA at 22^0

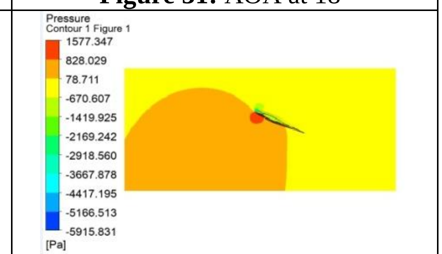

Figure 34: AOA at 24^0

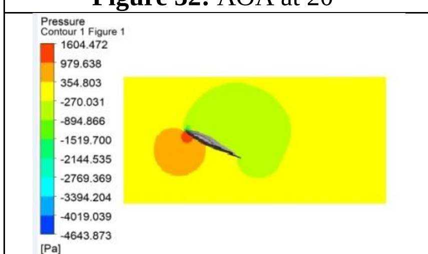

Figure 35: AOA at 26^0

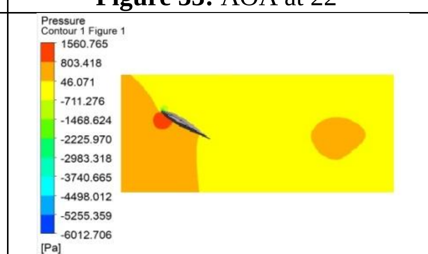

Figure 36: AOA at 28^0

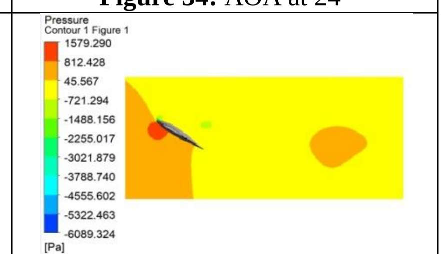

Figure 37: AOA at 30^0

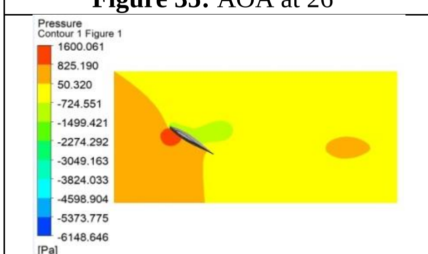

Figure 38: AOA at 32^0

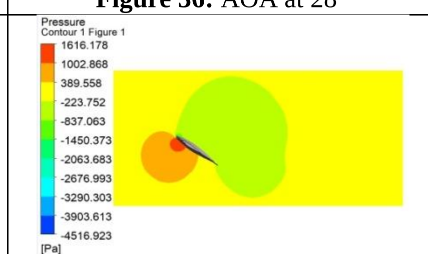

Figure 39: AOA at 34^0

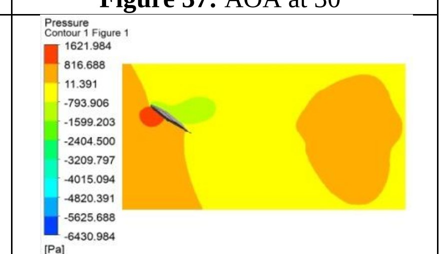

Figure 40: AOA at 36^0

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Lift and Drag forces of 3D unsymmetrical wing profile

Table 1: Lift and Drag force details at different Angles of attack

Angle of Attack	Drag Force	Lift Force	Angle of Attack	Drag Force	Lift Force
0	150.78	753.42	20	2115.53	7500.00
3	300.11	4340.96	22	2351.90	7849.00
5	380.00	5500.00	24	2694.80	7927.00
8	496.15	6361.89	26	3143.00	7988.40
10	668.88	6500.00	28	3466.60	8057.40
12	819.43	6800.00	30	3904.50	8276.80
14	1049.27	7000.00	32	4417.50	8584.20
16	1353.05	7200.00	34	4918.30	8613.60
18	1712.56	7300.00	36	5100.00	8500.00

The below Figure 41, Figure 42 and Figure 43 shows the variation of lift and drag forces takes place with respect to different angles of attack.

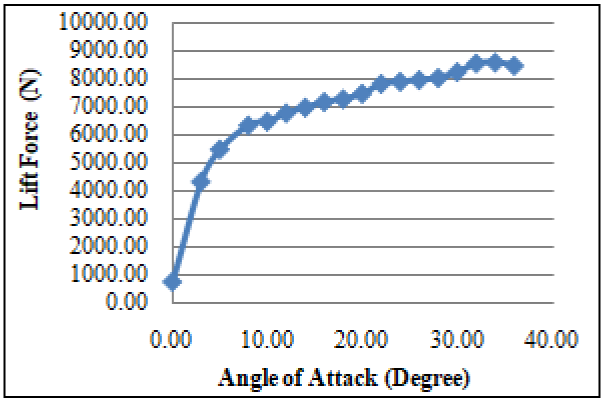

Figure 41: Lift Force Vs Angle of Attack

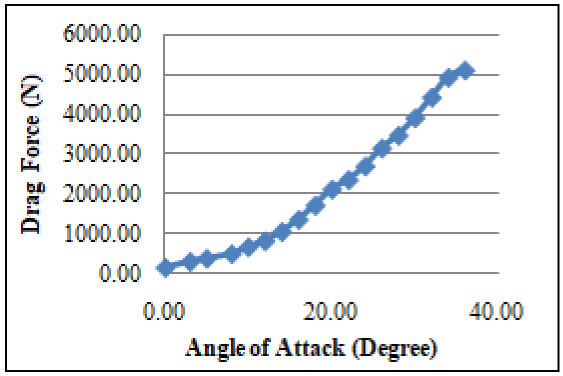

Figure 42: Drag ForceVs Angle of Attack

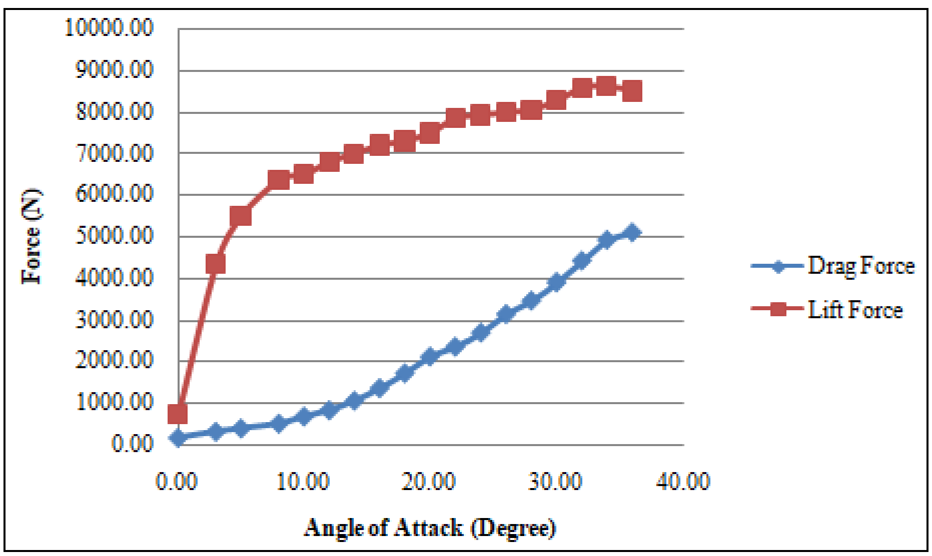

Figure 43: Lift Force and Drag ForceVs Angle of Attack

3. Conclusions

Literature related to aerodynamic characteristic analysis using CFD involves 2D airfoil only. In this research work 3D tapered unsymmetrical wing is considered. Tapered unsymmetrical wing is modeled in CATIA V5 R19 using NACA 64-210 at the tip and NACA 64-215 at the root. CFD analysis is carried out to test whether 3D wing obeys Ludwig Prandtl boundary layer theory. Reynolds number $5.8x10^6$(50m/s) is considered, which resembles the subsonic speed. The results arrived reveals that pressure distribution on the top wing surface is less. Whereas pressure distribution on the lower surface of the wing is large due to which lift is

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generated. Velocity distribution on the top surface is larger compared to lower surface of the wing. We found the average lift and drag forces on the entire 3D tapered unsymmetrical wing. From the above table it is very much clear that at 34^0angle of attack lift force is maximum that is 8613.60N and 4918.30N moderate drag force is experienced. After 34^0angle of attack lift force reduces and drag force keeps on increasing, same is shown in the graph. In future CFD analysis is carried out for different Reynolds number.

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