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Analysis and Selection of Airfoil sections for Low Speed UAV's

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Abstract: Recent advancements in communications, materials technology and fabrication technology leads to improvisation in design and structural ability of economical UAV's to serve as a multipurpose utility tool in different sectors viz., scientific, civil, agriculture and military sectors. The paper describes the design and analysis of different airfoil sections which suits best for the agricultural field imaging application. The paper studies background of different airfoil sections such as NACA0012, NACA0015, NACA4412, CLARK Y, S5010 suitable for subsonic speeds. This selection process was followed by the flow analysis of the airfoil sections by using ANSYS FLUENT software. Best suited airfoil was selected and the theoretical lift and drag values were validated with experimental values of wind tunnel test.
Keywords: Airfoils, ANSYS FLUENT, Fixed Wings, Unmanned Aerial Vehicle, Wind Tunnel Test

I. INTRODUCTION

Current commercial UAVs are costly and not affordable by common people. Also, different conditions like velocity, air density, have huge impact on efficiencies of these UAVs. Airfoil selection for an UAV is the most important step in designing which plays a major role in governing the functions. Various commercial drones use different airfoils which are not suitable for all conditions. Analysis of an airfoil gives us a fair idea as to which airfoil is suitable for the specified conditions and parameters like velocity, pressures and the required function.

Governing equations and formulae list for the analysis is selected by based on the requirement, i.e,

- Chord length: 0.15m
- Velocity: 15m/s
- Medium of work: air

The analysis of various airfoils is done in ANSYS FLUENT to obtain drag and lift forces, coefficients of drag and lift. Experiment is carried out on wind tunnel to validate the results obtained from ANSYS FLUENT software. The airfoil is selected based on the lift and drag forces, stall angle. The process is concluded after choosing the airfoil and providing reasons supporting the selection of the airfoil.

The paper contributes towards various aspects and governing conditions that are to be considered while selecting an airfoil. The speed range selected for the working is low speed of about 15-20 m/s. Various airfoils were analyzed and the best among them is selected by comparing C_L and C_D. Selected airfoil can be then used in designing process.

II. INDENTATIONS AND EQUATIONS

To calculate lift and drag forces

$$\text{Lift: } C_L \times 0.5 \times \rho \times V^2 \times A \qquad \text{...... (1)}$$

$$\text{Drag: } C_D \times 0.5 \times \rho \times V^2 \times A \qquad \text{...... (2)}$$

To calculate lift and drag coefficients

$$\text{Lift coefficient: } C_L = \frac{L}{q \times A} \qquad \text{...... (3)}$$

$$\text{Drag coefficient: } C_D = \frac{D}{q \times A} \qquad \text{...... (4)}$$

Moment coefficient: $C_M = \frac{C}{q \times S}$ …… (5)

Reynolds number

$$R_E = \frac{\rho \times V \times l}{\mu} = 158373 \quad \text{...... (6)}$$

Reynolds averaged navier-stokes equations will be the governing equation used by Ansys fluent solver.

$$\rho \frac{\partial u}{\partial t} + \rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial x} \right) = -\frac{\partial p}{\partial x} + \mu \nabla^2 u \quad \text{...... (7)}$$

2.1 Abbreviation of symbols used in equations

- C_L – Lift coefficient
- C_D – Drag coefficient
- C_M – Moment coefficient
- Rho(ρ) – Density
- Mu(μ) – Viscosity
- V – velocity
- A – Reference area
- L – lift force
- D – drag force
- q – dynamic pressure
- S – wing span
- L – length

III. FIGURES AND TABLES

3.1 Figures

ANSYS FLUENT software is used to analyze the airfoils and compare them with the calculated theoretical values. The values were compared, and an airfoil is selected based on lift-drag forces and stall angle. The airfoils were analyzed for angle of attacks from 0^0 to 25^0 in step of 5^0.

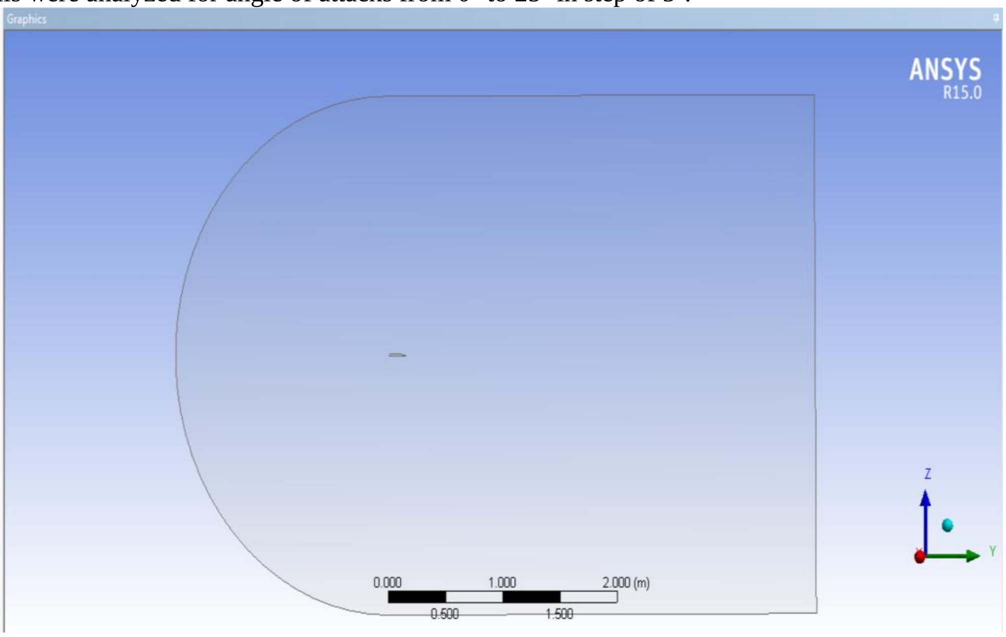

Fig.1 setting up the geometry, enclosure & Boolean subtraction of air foil from enclosure where Chord length of air foil = 0.15m, enclosure = 12.5 times the chord length.

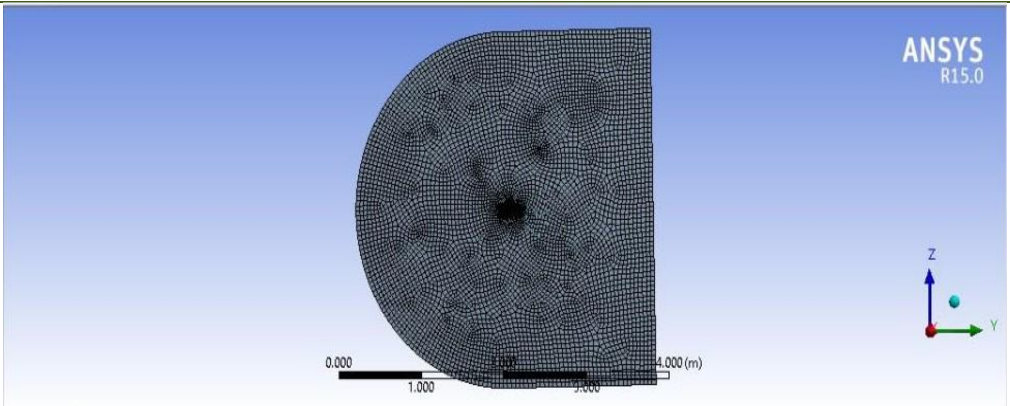

Fig. 2 meshing of airfoil where meshing type is "Sphere of Influence"

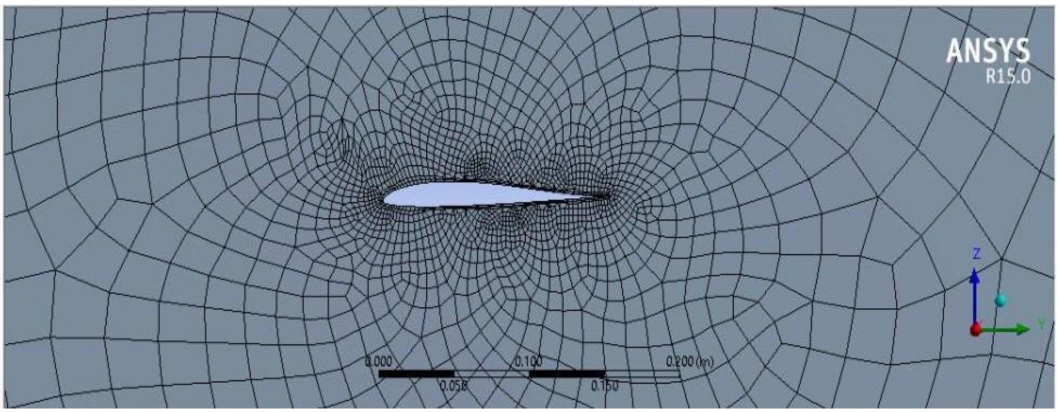

Fig. 3 meshing around airfoil with growth rate of 1.2 for 10 layers

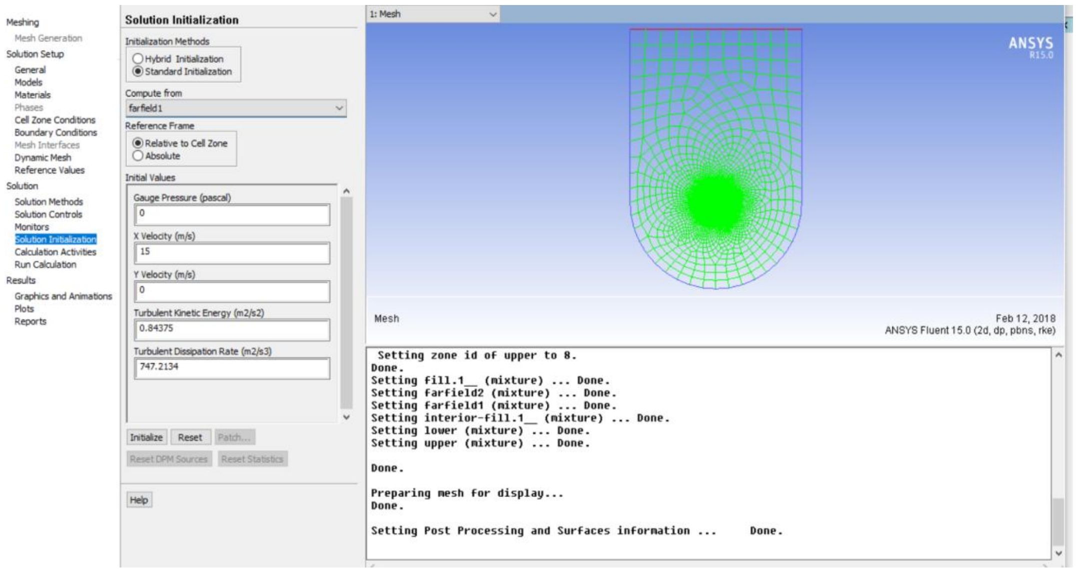

Fig. 4 solution initialization with initial velocity of 15m/s for 0° angle of attack. X axis velocity is multiplied with cosine of angle of attack where Y axis velocity is multiplied with sine of angle of attack. With angle of attack 0° Y axis becomes Zero.

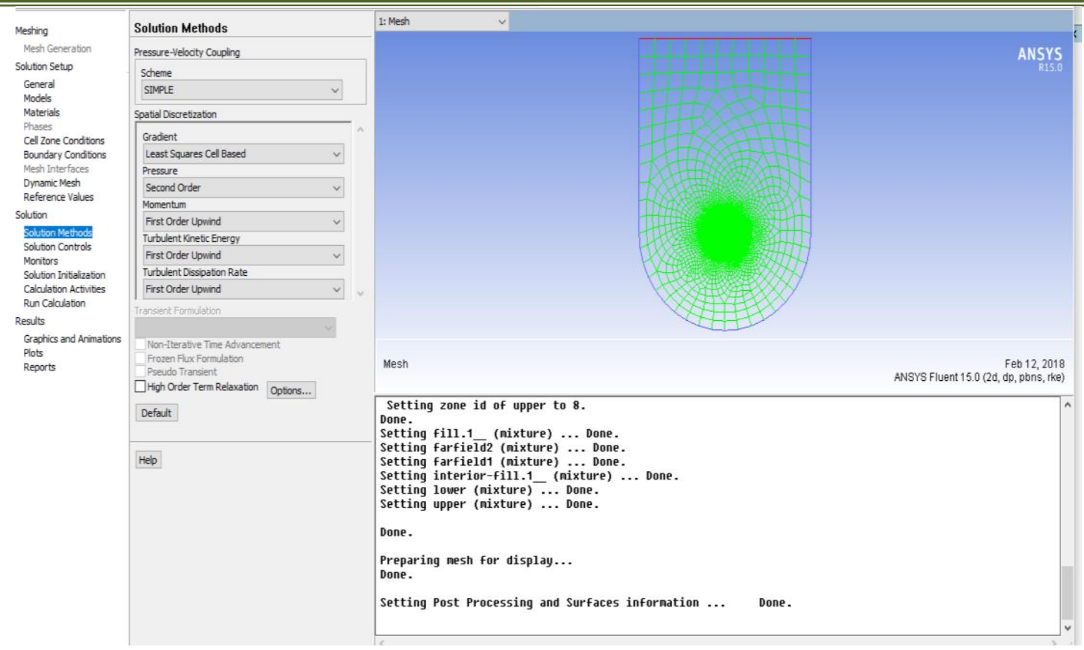

Fig. 5 Solution methods provided. The momentum is set to first order upwind which is more stable and less accurate, the solver after becomes stable then shifts to second order upwind which is more accurate.

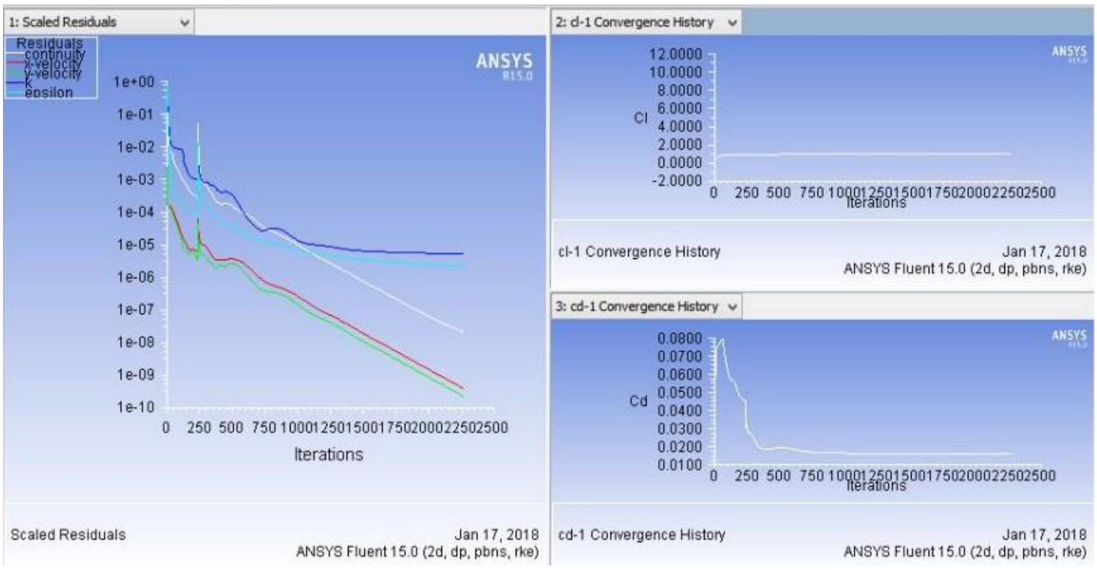

Fig. 6 Graphs for NACA 0012 airfoil at 10° angle of attack

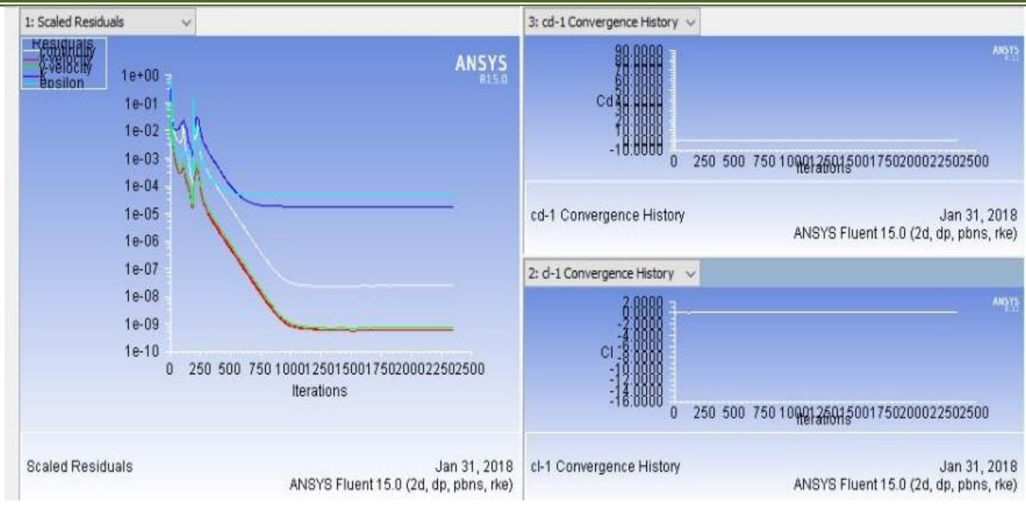

Fig. 7 Graphs for S5010 airfoil at 15° angle of attack

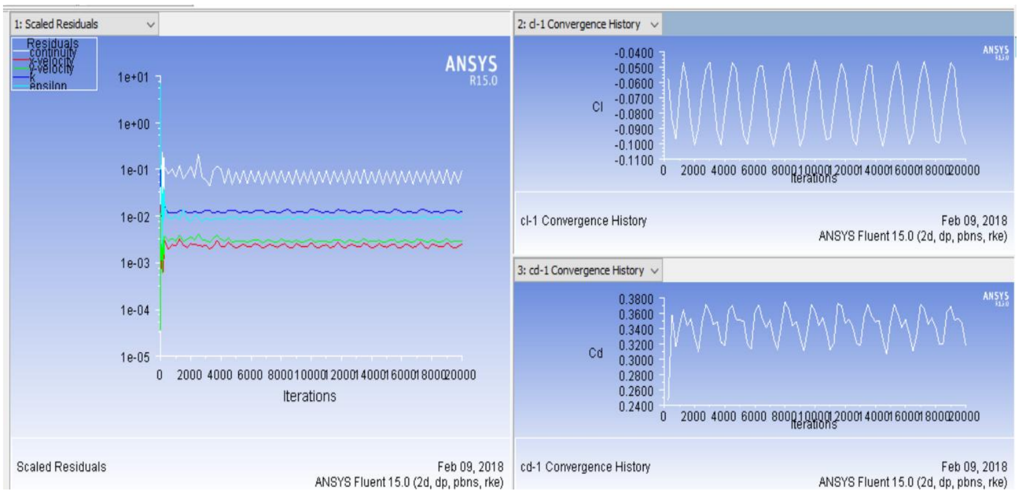

Fig. 8 Graphs for NACA4412 airfoil at 10° angle of attack.

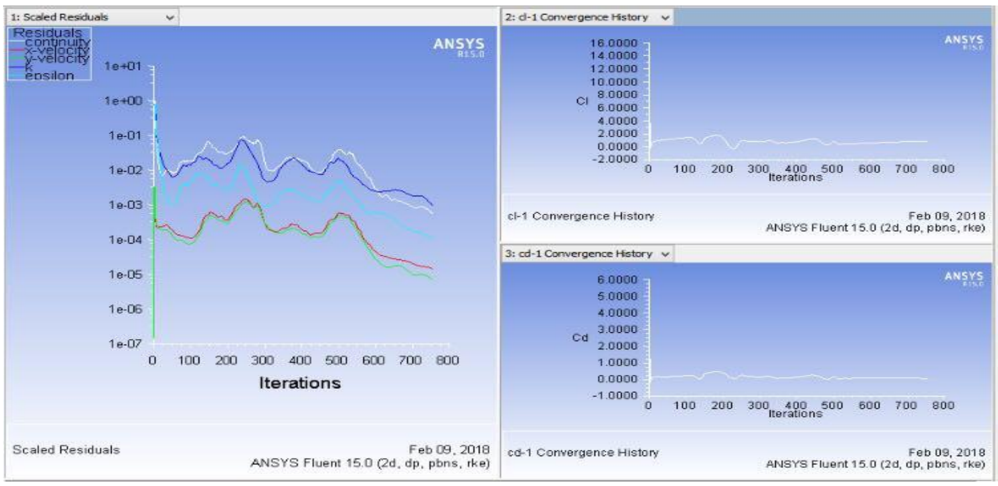

Fig. 9 Graphs for NACA0015 airfoil at 10° angle of attack

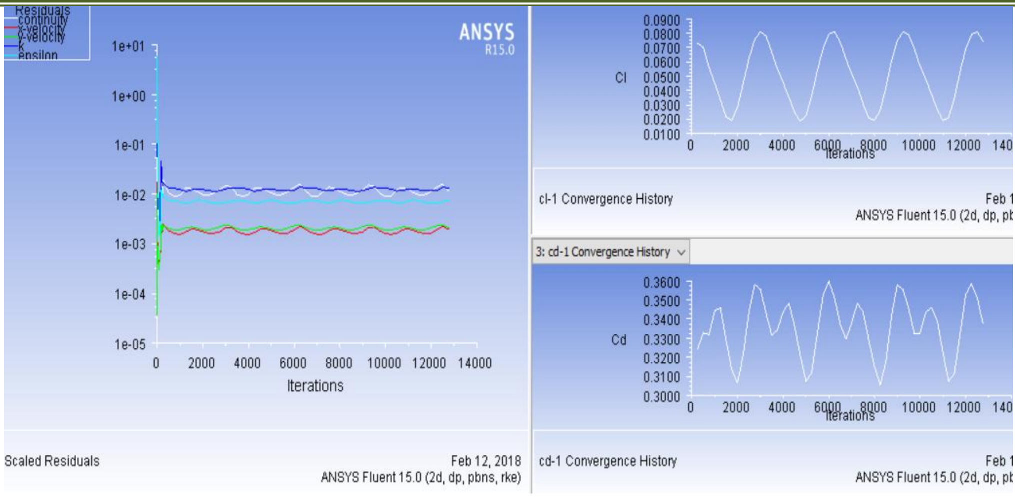

Fig. 10 Graphs for CLARK Y at 10° angle of attack

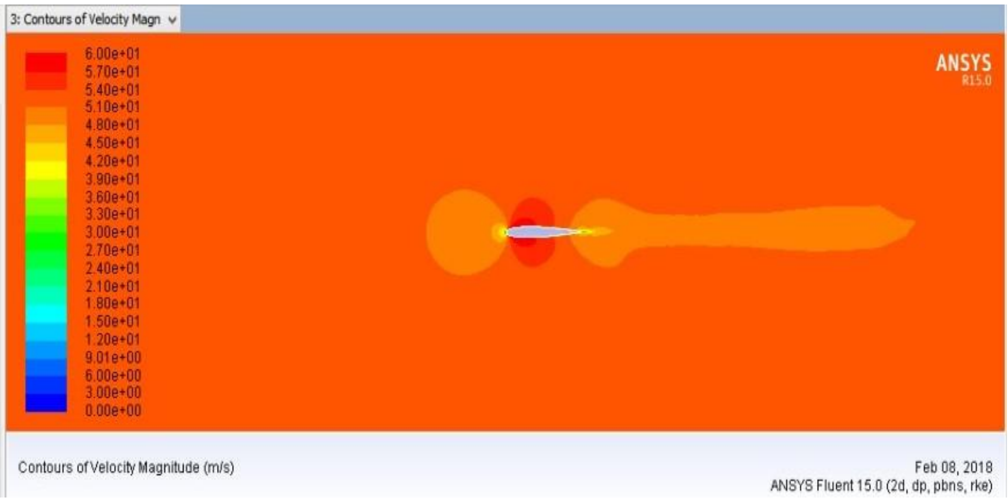

Fig. 11 Velocity contour of NACA0012 airfoil

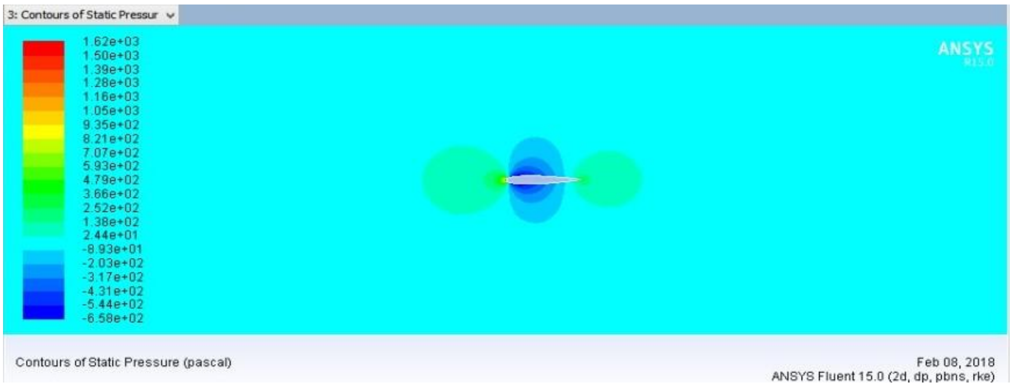

Fig. 12 Pressure contour of NACA0012 airfoil

3.2 Tables

Table for comparison of ANSYS values with the theoretical value for NACA0012 airfoil

Angle of attack	ANSYS		Theoretical		C_L / C_D
	C_L	C_D	C_L	C_D	
0	0.0015	0.00402	0	0.00463	0.3571
5	0.082	0.00516	0.086	0.00518	15.89
10	0.156	0.00930	0.158	0.00933	16.774
15	0.1822	0.02200	0.183	0.02205	8.281
20	0.155	0.04844	0.153	0.04849	3.20

Table for comparison of ANSYS values with the theoretical value for S5010 airfoil

Angle of attack	ANSYS		Theoretical		C_L / C_D
	C_L	C_D	C_L	C_D	
0	0.0122	0.00303	0.011	0.00332	4.066
5	0.0972	0.00411	0.097	0.00414	23.649
10	0.1706	0.00660	0.170	0.00652	25.8484
15	0.166	0.01853	0.165	0.01860	8.9584
20	0.104	0.06032	0.103	0.06041	1.724

Table for comparison of ANSYS values with the theoretical value for NACA0015 airfoil

Angle of attack	ANSYS		Theoretical		C_L / C_D
	C_L	C_D	C_L	C_D	
0	0.0021	0.00429	0	0.00420	0.489
5	0.090	0.00480	0.091	0.00482	18.75
10	0.167	0.00725	0.169	0.00730	23.034
15	0.219	0.014	0.216	0.01472	15.64
20	0.217	0.0285	0.215	0.02853	7.61

Table for comparison of ANSYS values with the theoretical value for NACA4412 airfoil

Angle of attack	ANSYS		Theoretical		C_L / C_D
	C_L	C_D	C_L	C_D	
0	0.065	0.00478	0.075	0.00480	13.5983
5	0.160	0.00612	0.162	0.00615	26.3414
10	0.227	0.00814	0.228	0.00814	28.009
15	0.248	0.01964	0.248	0.01966	12.61
20	0.210	0.04583	0.209	0.04584	4.559

Table for comparison of ANSYS values with the theoretical value for CLARK Y airfoil

Angle of attack	ANSYS		Theoretical		C_L / C_D
	C_L	C_D	C_L	C_D	
0	0.066	0.00382	0.063	0.00385	16.36
5	0.151	0.00482	0.152	0.00483	31.469
10	0.218	0.00550	0.217	0.0056	38.75
15	0.214	0.01567	0.215	0.01568	13.76
20	0.1574	0.03999	0.158	0.03995	3.959

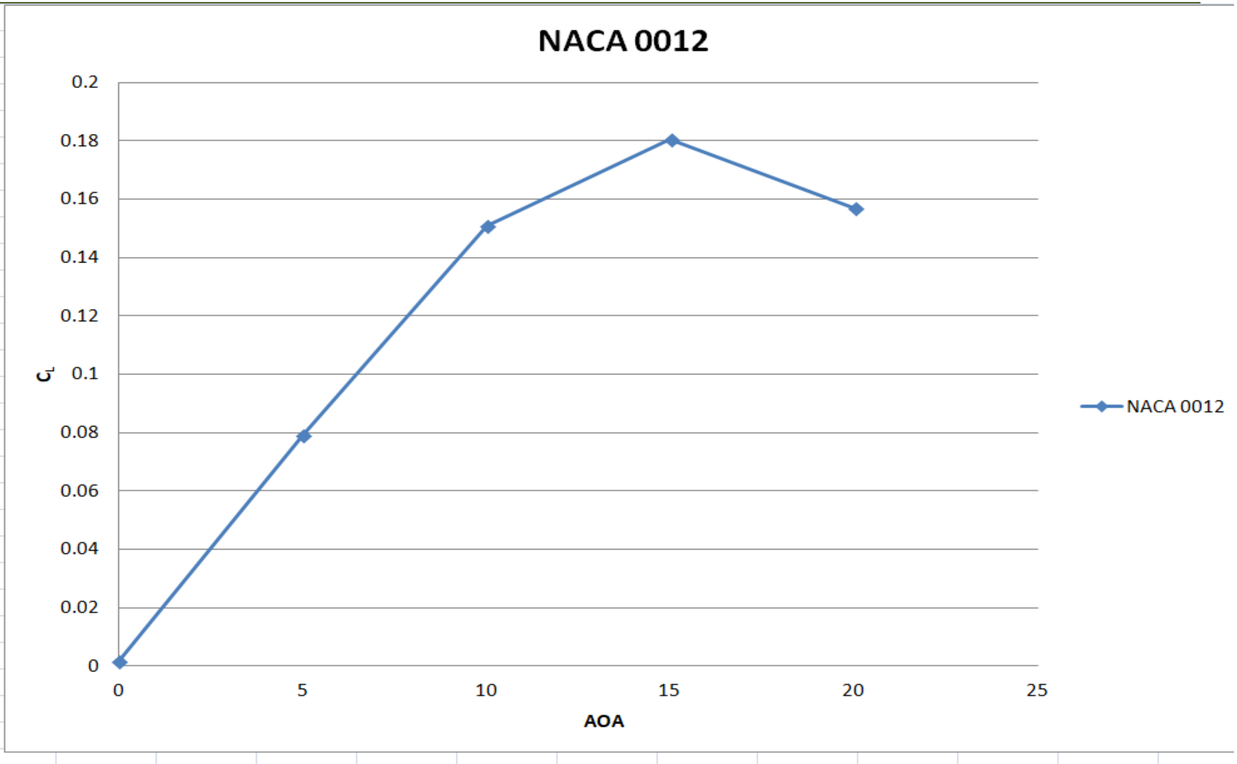

Fig. 13 Graph of lift force versus angle of attack for NACA 0012

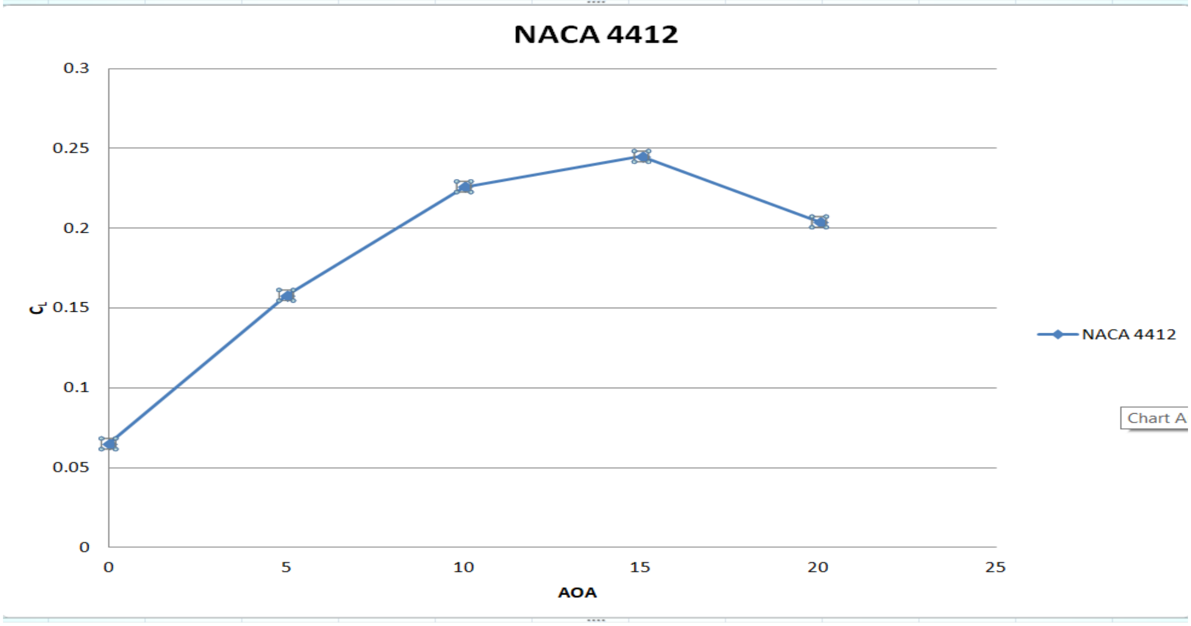

Fig. 14 Graph of Lift versus angle of attack for NACA 4412 Airfoil

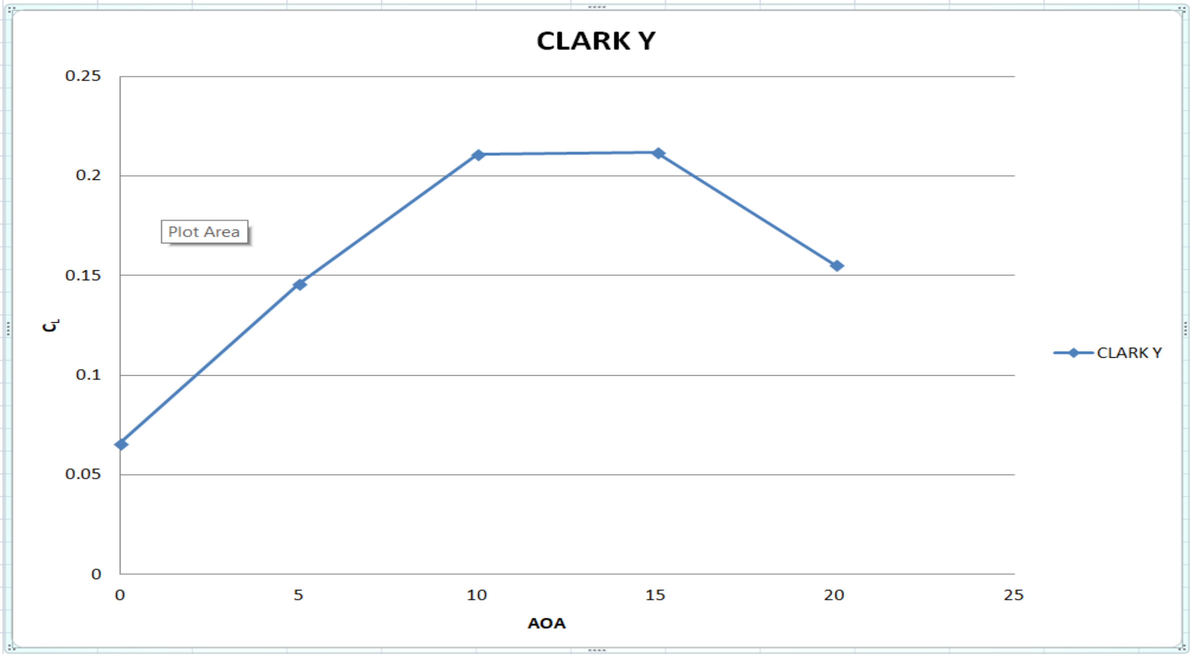

Fig. 15 Graph of lift versus angle of attack for CLARK Y airfoil

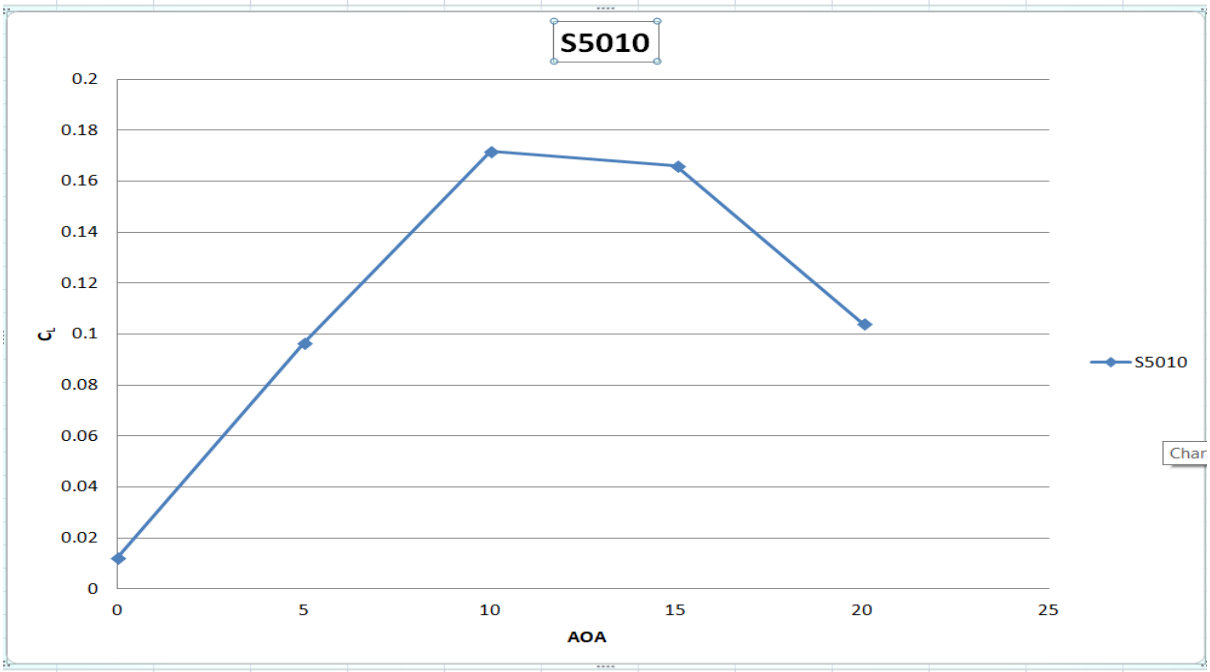

Fig. 16 Graph of lift versus angle of attack for S5010

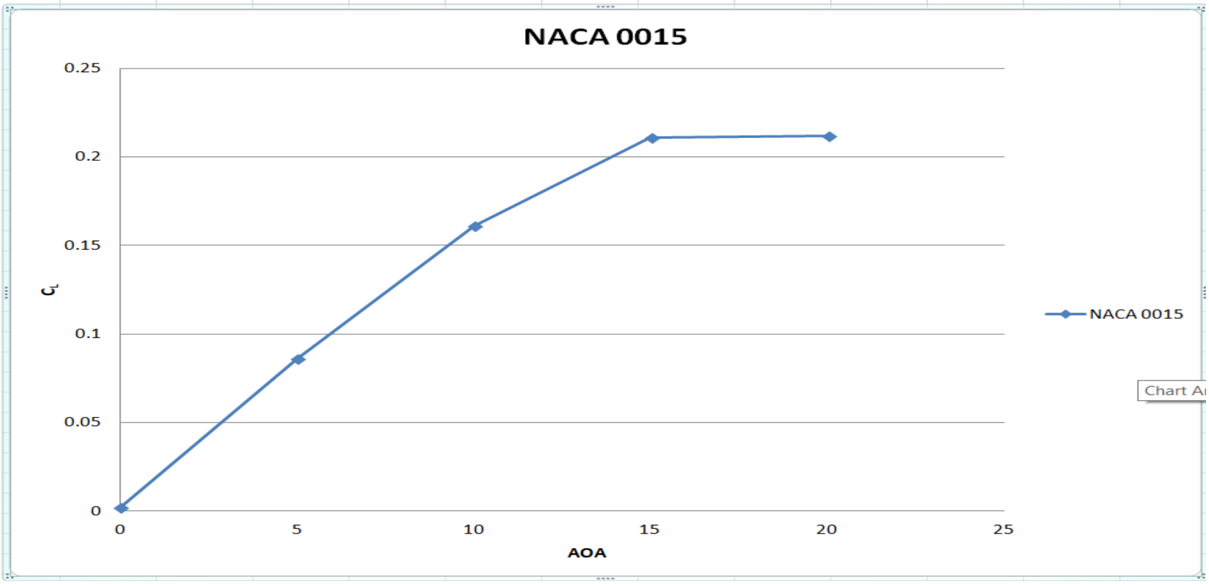

Fig. 15 Graph of lift versus angle of attack for NACA0015

IV. CONCLUSION

It is very important to analyze the airfoils before designing an UAV because analysis gives us better idea as to which airfoil is best suitable for the specified conditions.

ANSYS FLUENT analysis yields the lift and drag values for the airfoils considered, and these values are compared with theoretically calculated values. On comparison and working out the C_L/C_D ratio it is found that the NACA 4412 and CLARK Y has highest C_L/C_D ratio. Among the two airfoils CLARK Y has better C_L/C_D ratio and is selected for the specified conditions.

The graphs plotted for C_L versus Angle of attack shows the maximum lift at certain angle and later it decreases. The graph clearly shows that, the stall angle is 15^0 for most airfoils including CLARK Y. Hence CLARK Y airfoil section is selected.

The advantages of CLARK Y airfoil at 0.15m of chord length and velocity of 15m/s is that it has better lift and lesser drag forces for different angle of attacks. Angles 5^0 and 10^0 are the most common angles that an airfoil encounters during its fly, and the selected airfoil has high lift, lesser drag and an optimum C_L / C_D ratio which can carry the entire load of aircraft.

The limitation is that, weight of the UAV is not considered while calculating the C_L/C_D ratio. Hence weight of the UAV is not known during the design stage. The weight has an impact on the C_L/C_D ratio. Since the selected airfoil has better values than other airfoils even after the consideration of weight factor CLARK Y will be suitable for low speed UAV's.

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