Numerical and Experimental Analysis of Aerofoil for Unmanned Air Vehicle (UAV)

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Abstract- *In this work ,NACA 0006 aerofoil was analysed. The analysis carried out was by varying wind velocities and angles of attack of NACA 0006 aerofoil model. Analysis is performed experimentally in the wind tunnel testing facility and similarly CFD analysis is performed to obtain various parameters such as C_l (coefficient of lift), C_d (coefficient of drag) & C_p(coefficient of pressure).We have fabricated NACA 0006 aerofoil model using composite material and its size considering the experimental setup dimensions. The nature of the graphs of comparative analysis were found to be similar. Similarly, for NACA 0012 aerofoil we have performed CFD analysis and obtained velocity and pressure contour. On the basis of CFD and experimental results we can conclude that NACA 0006 aerofoil has better coefficient of lift and coefficient of drag , on this basis we can say that NACA 0006 aerofoil comparatively can be a substitute for various UAV application.*

Keywords- Coefficient of drag, Coefficient of lift, Computational Fluid Dynamics, NACA 0006 , NACA 0012

I. INTRODUCTION

The Unmanned Aerial Vehicle (UAV) is an aircraft with no human aboard. UAV has various applications such as surveillance, product delivery, agricultural, photography and defence. The aerofoil plays an important role in flight and control of the UAV. Referring to the literature review it is found that NACA 0006 aerofoil hasn't yet been used for the UAV applications. NACA 0012 which is used for the various applications is compared experimentally and analytically. NACA 0006 aerofoil is tested with the help of Wind Tunnel Testing facility. ANSYS is used to obtain pressure and velocity contours which eventually is used to obtain coefficient of drag and coefficient of lift.

Aerofoil Nomenclature - The geometry of every airfoil can be described by certain terms such as Leading edge, Trailing edge, Chord Length, Camber, Mean Camber line, Thickness and Angle of Attack.

Figure 1 shows aerofoil nomenclature.

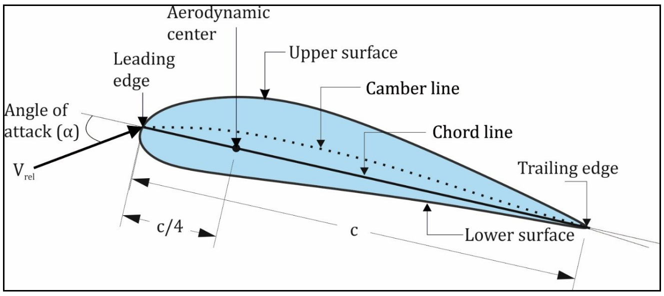

Figure 1: Aerofoil Nomenclature

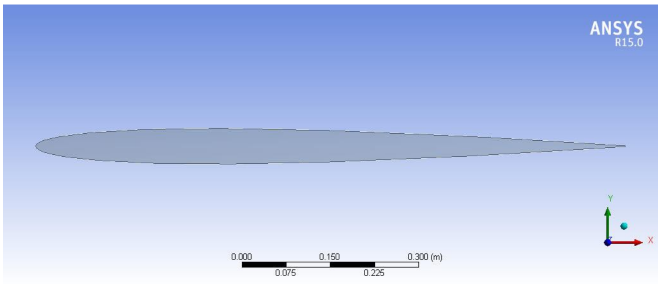

Figure 2: Aerofoil of NACA 0006

Figure 2 shows the aerofoil profile of NACA 0006. The coordinates were imported from NACA websites into excel sheets and later imported into ANSYS via .txt file. The geometry is formed and aerofoil profile is generated.

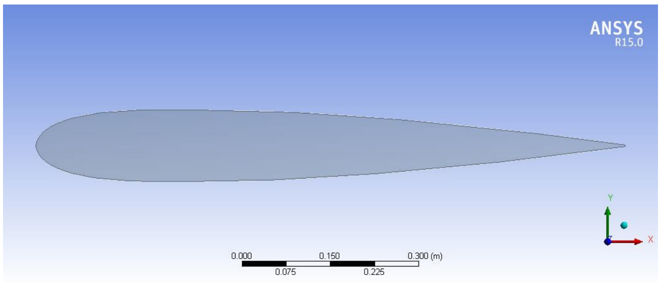

Figure 3: Aerofoil of NACA 0012

Figure 3 shows the aerofoil profile of NACA 0012.
Based on the research conducted as a part of the literature survey it's decided to work on estimating the possibility of using an aerofoil for a UAV. We accomplished this by simulating the airflow around NACA 0012 and NACA0006.

Because of more scope is involved to carried out research of these aerofoil due to good stability conditions.

II. OBJECTIVE

- To determine co-efficient of drag and co-efficient lift for NACA 0012 airfoil numerically.
- To determine co-efficient of drag and co-efficient lift for NACA 0006 airfoil numerically and experimentally.

III. METHODOLOGY

Numerical and experimental

The theoretical method involves testing of our NACA 0006 model. The model will have varied holes with extended steel tubes. The wind tunnel testing facility is utilized, our model is placed in the testing facility. Under various speeds the model is put under test , the parameters such as coefficient of drag and coefficient of lift are calculated.

The manometric values for different holes present on the model are noted down i.e. h_i & h_∞ . Further calculations to obtain parameters such as C_n , C_p ,C_l for various angles of attack and velocity of wind. We later plot graphs such as Cl v/s x , Cd v/s x , Cl v/s AOA(Angle of Attack) & Cd v/s AOA.

hi (in cm) - manometric port in cm
h∞ (in cm)- static pressure in cm
$\Delta h = h_i - h_\infty$ (manometric port pressure difference)
$\Delta p = \rho h \Delta h$
$Cp = \Delta p/q_\infty$
x - location of the pressure points on aerofoil

c = chord length
$q_\infty = \frac{1}{2} \rho_{air} v_\infty^2$
Cd- coefficient of drag
Cl – coefficient of lift
Cd = Cn sinα
Cl = Cn cosα , α-angle of attack.

Figure 4: Low speed wind tunnel facility

ANSYS Part

It involves ANSYS. Initially we import co-ordinate points from the NACA site to obtain accurate profile. The co-ordinates obtained are accordingly customized corresponding to the required standards of ANSYS. Profile is created by importing this .txt file. All the points are joined and surface is created. As it is external flow it is advised to create an external boundary to visualize the flow of fluid. The fluid we consider here is air.

We use Boolean option to separate the external boundary with the airfoil. This is done to ensure proper meshing on the boundary. Meshing is done to obtain precise results after applying boundary conditions. The input for this model analysis is air.

Variation of parameters such as velocity of air and angle of attack is done. The varying velocities of air considered in metre per second are 5m/s , 10m/s and 15m/s. The varying angle of attacks in degree are 2°, 5° , 10° & 15 °.

We have increased the size of the boundary and meshing of the boundary too much better refined comparatively. NACA 0012 for 15m/s we have obtained contours at angle of attack 2°, 5° , 10° & 15 °.Similarly for NACA 0006 too we obtained the same.

Model Description

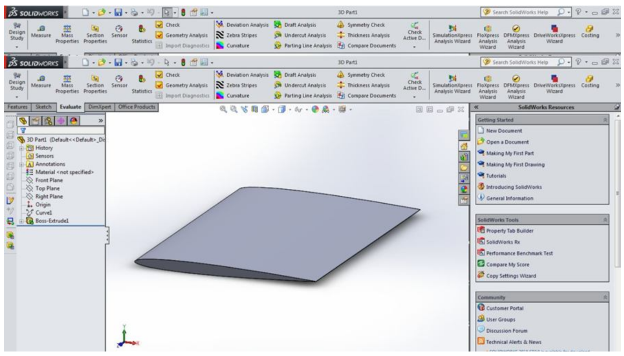

Figure 5: 3-D model of NACA 0006

Figure 5 shows a 3D model of NACA 0006 designed in Solid works.

The description of the testing model is standard profile of NACA 0006 aerofoil profile with its total length 300mm , cord length 200mm and the thickness 11.1mm. Pitot tubes are connected from the inner side of the model with respective marked points/holes on the surface of the model.
Figure 6 shows the fabricated model of NACA 0006 along with aluminum supports which are used in experimental analysis.

- Mould material – Mild Steel
- Hardener Resin – LY550
- Glass Fiber – Satinweave 300GSM & chopstand mat 600GSM
- Steel Tubes – 6 Tubes of 1.5mm diameter

Figure 6: Fabricated model of NACA 0006

WIND TUNNEL TESTING

The model fabricated is according to the testing facility dimensions. The aerofoil has various ports present in it and respective connections are provided to obtain manometric readings at the facility. The wind speeds of 8m/s, 10m/s, 12m/s, 14m/s and 16m/s are blown over the model

The manometric readings for different angles of attack are noted down from -15 degrees to 20 degrees.

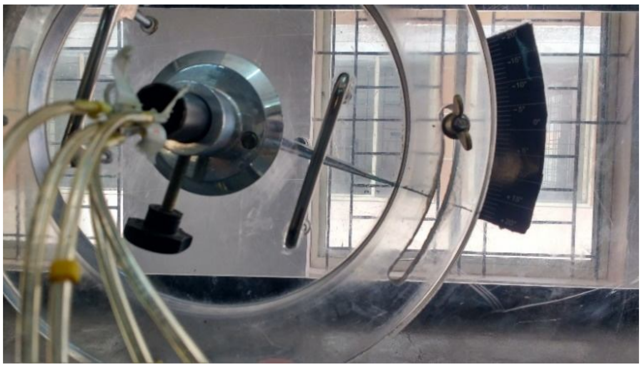

Figure 7: Model at 20 degree angle of attack

Figure 7 shows the experimental setup of the wind tunnel testing along with the model of NACA 0006 at 20 degree of angle of attack.

To obtain parameters mainly such as coefficient of lift (cl) , coefficient of drag (cd) angles of attacks are changed. The tables are obtained for various angles of attack and wind velocities. The calculations for further steps are done using formulas to calculate coeffiecient of pressure, x/c ratio i.e port distance from leading edge to chord length.

Table 1: 0-degree angle of attack

Velocity (m/s)	Speed (rpm)	Port no. 1 (in cm)	Port no. 2 (in cm)	Port no. 3 (in cm)	Port no. 4 (in cm)	Port no. 5 (in cm)	Port no. 16 (in cm)
8.4	331	8.2	8.6	8.7	8.8	8.7	8.6
10.1	411	8	9	8.9	9	8.9	8.9
11.8	453	7.9	9.1	9	9.1	9	9
13.9	526	7.8	9.4	9.2	9.3	9.3	9.2
16	597	7.7	9.7	9.6	9.6	9.6	9.4
18	662	7.5	10.1	9.9	9.9	9.8	9.7

Table 2: 2-degree angle of attack

8.4	331	8	8.9	8.8	8.8	8.8	8.9
10.1	389	8	9	8.9	9	8.9	9
11.8	451	7.9	9.4	9.2	9.2	9.2	9.1
13.9	513	7.7	9.7	9.5	9.4	9.4	9.2
16	595	7.6	10.1	9.9	9.9	9.8	9.5
18	654	7.4	10.5	10.3	10.2	10	9.6

Table 3: Experimental

Port No.	h_i (in cm)	h_∞ (in cm)	$\Delta h = h_i - h_\infty$	$\Delta p=\rho h\Delta h$	$C_p=\frac{\Delta p}{q_\infty}$
1	8	8.7	0.7	68.67	1.58
2	8.6	8.7	0.1	9.81	0.227
3	8.5	8.7	0.2	19.62	0.454
4	8.6	8.7	0.2	9.81	0.227
5	8.5	8.7	0.2	19.62	0.454
6	8	8.7	0.7	68.87	1.58
7	8.6	8.7	0.1	9.81	0.227
8	8.5	8.7	0.2	19.62	0.454
9	8.6	8.7	0.2	9.81	0.227
10	8.5	8.7	0.2	19.62	0.454

h_i= manometric port in cm
h_∞= static pressure in cm
Δh= manometric port pressure difference
$\Delta p=\rho h\Delta h$
$C_p=\frac{\Delta p}{q_\infty}$

Table 4:

Port No.	x	$\frac{x}{c}$	$D(\frac{x}{c})$	Cpl	Cpu	ΔCp = Cpl - Cpu	$C_n=\Delta Cp * D(\frac{x}{c})$
1	30	0.15	0.115	0.4539	0.9079	0.454	0.05221
2	60	0.3	0.15	0.2269	-0.4539	0.227	0.03405
3	90	0.45	0.15	0	-0.2269	0.227	0.03405
							Cn= 0.0401

x - location of the pressure points on aerofoil
c = chord length
$q_\infty = \frac{1}{2}\rho_{air}v_\infty^2$ =0.5*1.225*10.1 = 6.18625
Cd- coefficient of drag
Cl – coefficient of lift
Cd=Cn sinα = 0.0401* sin (10) = 0.00696329192
Cl=Cn cosα = 0.0401* cos (10) = 0.03949079089

MESHING

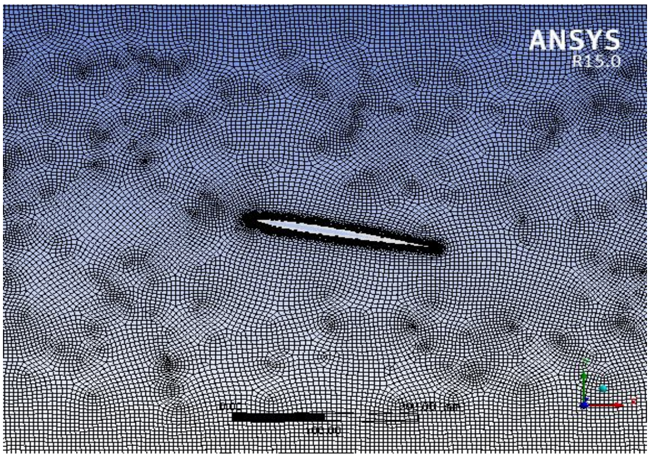

Figure 8: Meshing for 10° angle of attack of NACA 0006

The aerofoil point coordinates were imported and the model was meshed for various angles of attack. The boundaries were created similar to the wind tunnel testing facility utilized to obtain values in the theoretical testing of NACA 0006 aerofoil.

Table 5: Meshing elements

Number of nodes in the mesh	**51675**
Number of elements in the mesh	**50176**
Number of iterations for generating mesh	**306**
Air density	**1.225 kg m-3**

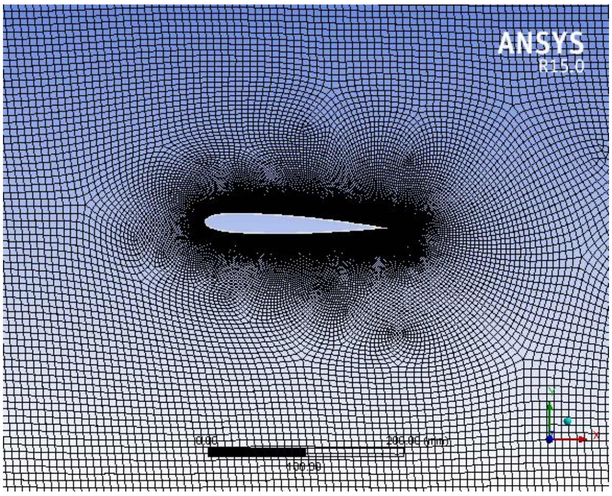

Figure 9: Meshing for 0° angle of attack of NACA 0012

Table 6: Meshing elements

Number of nodes in the mesh	**53021**
Number of elements in the mesh	**51026**
Number of iterations for generating mesh	**329**
Air density	**1.225 kg m-3**

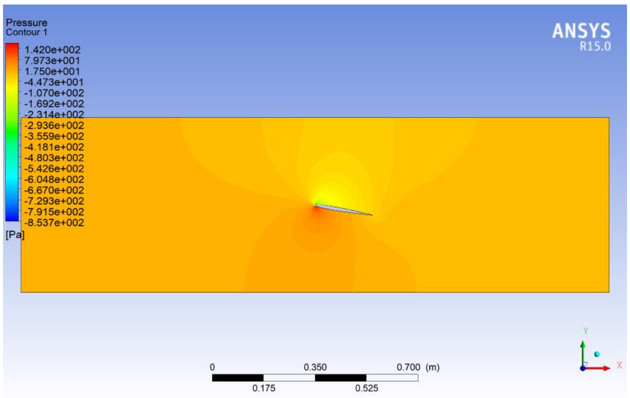

Figure 10: Pressure contour for wind 15m/s and 10° angle of attack for NACA 0006

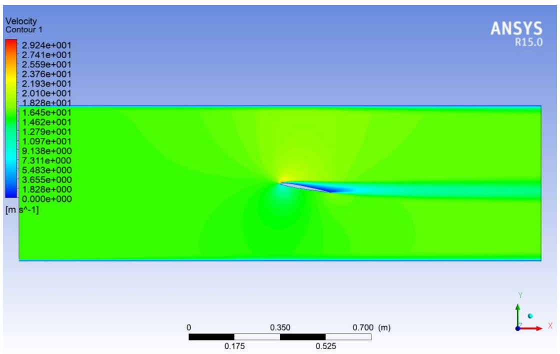

Figure 11: Velocity contour for wind 15m/s and 10° degree angle of attack for NACA 0006

The velocity in figure 12 and pressure contours in figure 13 shows us the variation and range of the respective parameters along with the representing colours at the various sites of the aerofoil(here). The detailed version contours help us visualize the variation clearly. We can observe in the pressure contour that the pressure is maximum at the leading edge especially at the lower surface of the aerofoil. It is observed that the due to varied angle of attack the upper surface of the aerofoil is getting lesser effect of pressure due to its lack of direct airflow contact. Similarly, in the detailed velocity contour the effect of wind velocity is maximum at leading edge of the aerofoil and the upper surface due to the virtue of its position experiences lesser velocity effects.

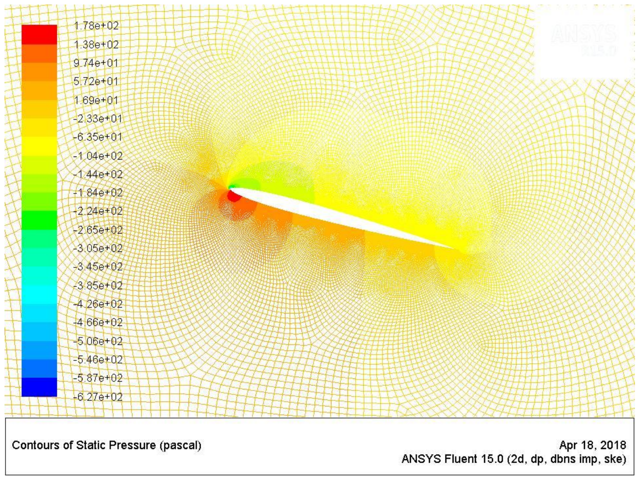

Figure 12: Detailed Pressure contour for wind 16m/s and 10° angle of attack of NACA 0006

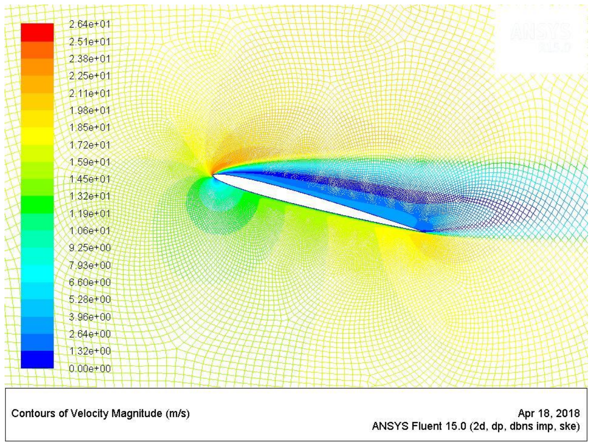

Figure 13: Detailed Velocity contour for wind 15m/s and 10° degree angle of attack for NACA 0006

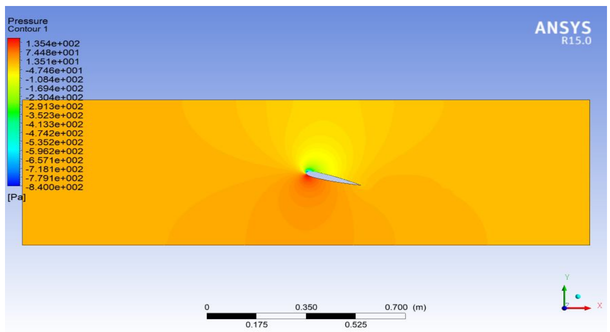

Figure 14:. Pressure contour for wind 15m/s and 10° degree angle of attack for NACA 0006

Figure 14 shows pressure contour for wind 15m/s and 10 degree angle of attack.We can see the effect of pressure at the leading edge and variation along the profile of the aerofoil.

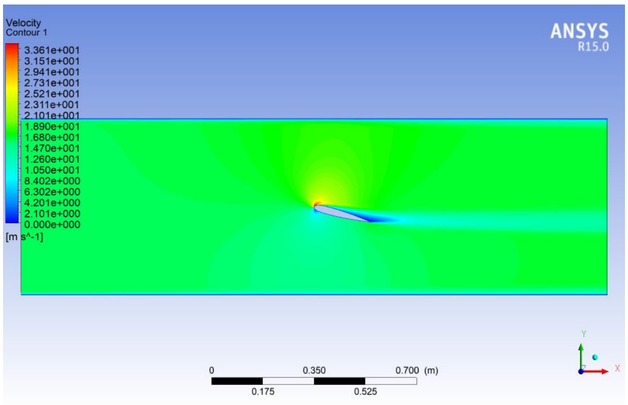

Figure 15: Velocity contour for wind 15m/s and 10° degree angle of attack for NACA 0012.

Figure 15 shows pressure contour for wind 15m/s and 10 degree angle of attack.We can see the effect of pressure at the leading edge and variation along the profile of the aerofoil.

We can also observe these effects in the detailed contours in figures 16 and figure 17. Later in figure 18 and figure19 the comparitive results of the CFD analysis of the NACA 0006 aerofoil and the experimental results of the wind tunnel testing.

The graphs ae plotted for coeffiecient of drag and lift on the y axis and the angle of attack on the x axis respectively on two different graphs.

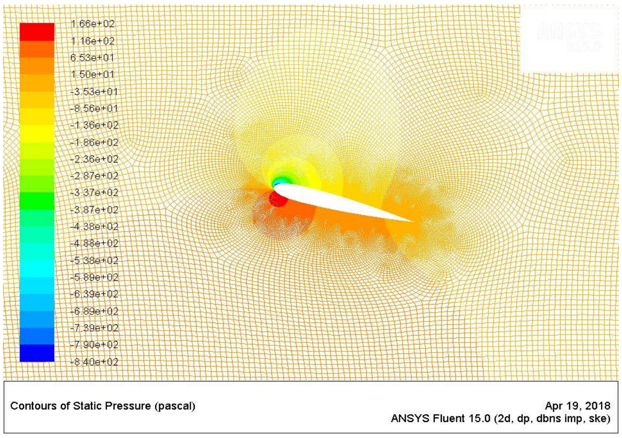

Figure 16: Detailed pressure contour for wind 16m/s and 10° angle of attack of NACA 0006

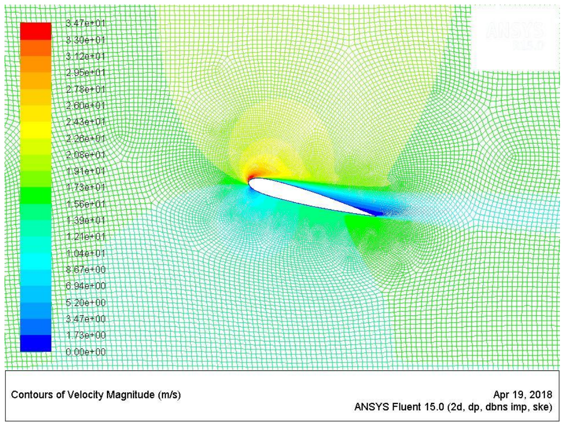

Figure 17: Detailed velocity contour for wind 16m/s and 10° angle of attack of NACA 0012

COMPARISON BETWEEN EXPERIMENTAL AND CFD RESULTS

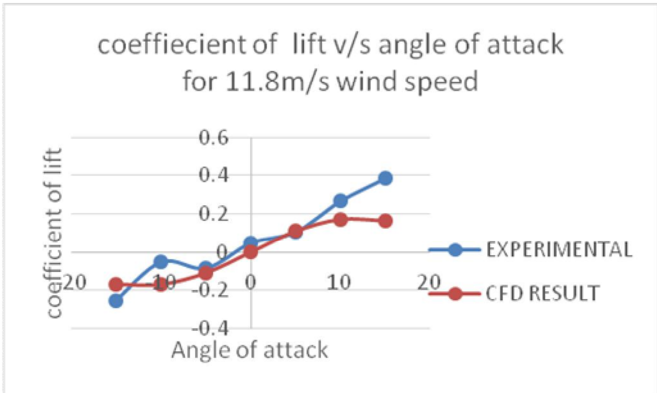

Figure 18: coeffiecient of lift v/s angle of attack for 11.8m/s wind speed

The figure 18 shows us the comparison of CFD result and experimental result for the parameter coeffiecient of lift against angle of attack. It can be observed that the nature of the graphs that CFD and experimental results' naute matches.

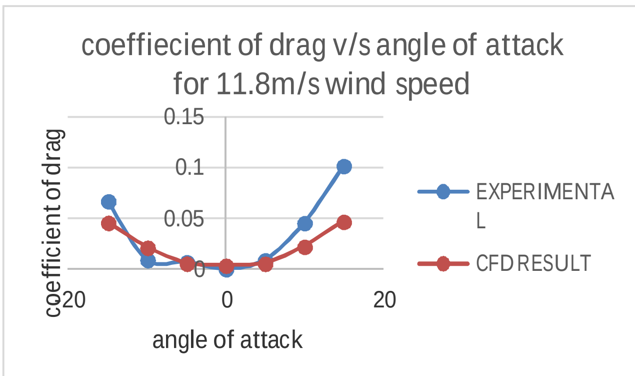

Figure 19: coefficient of drag v/s angle of attack for 11.8m/s wind speed

The results are ploted for both ANSYS and wind tunnel for various angles of attack and correspondingly coefficient of lift and coefficient of drag. The nature of the graphs obtained for comparisons for coefficient of lift were possessing the same nature of graph and similarly the nature of graph.

IV. APPLICATIONS

Symmetric aerofoil are predominantly used in UAV’s (Unmanned Aerial Vehicle) :

Symmetric aerofoils have varied applications but are predominantly used in the UAV’s. As we need large lift and less drag, symmetric aerofoils are useful.

- Reaching remote places: These aerofoils are basically having large flight time thus travelling farther distances where man cannot reach e.g. hilly areas.

- The NACA 0006 aerofoils can be used in surveillance over a large area:

Surveillance will be an ideal sector of application for NACA 0006.

- The NACA 0006 can be used at low values of flow Reynolds number.

V. CONCLUSION

- The graphs obtained from the comparison from the ANSYS and wind tunnel testing show similar nature of graph.
- Lift of NACA 0006 is higher than NACA 0012 and drag of NACA 0006 is lower than NACA 0012
- UAV take off time is less & runway distance is less too.
- NACA 0006 will act as a good substitute for NACA 0012 application.

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