Aerodynamic Analysis of Airfoil Wind Turbine Blade Naca 4315 For Power Calculation Using Betz Limiting Theory

Mr. Sidam Yesudasu[1], Mr. B.Prasad Reddy[2], Mr. V.Satyanarayana[3]
[2, 3]Associate professor, Dept of Mechanical
[1, 2, 3] Kakinada institute of technology and science, Divili

Abstract- *With an increase energy crisis around the world it is important to investigate alternative methods of power generation in ways different than fossil fuels .few of the energy sources available all around the world at all times "wind and solar". In this thysis wind generation isconcentrated up on. The major aerodynamic properties of wind turbine were studied.The wind that cuts the wind turbine blade flows through its cross section lie on aerofoil plays an important role in power generation. so the aerodynamics of NACA 4315 aerofoil were studied. In anysis fluent an artificial wind turbine was created around the aerofoil, the inlet conditions were given the flow of the air is taken as laminar as it could decrease the complications in the results.*

The amount of power generated by a blade of infinite length having the profile NACA 4315 was calculated using the BETZ limiting theory.

I. INTRODUCTION

India contributes around 1.8% of the total global CO_2 emission. The global CO_2 emission estimated by International Energy Agency in 2010 is 30.6 Gigatonnes from which india contributes about 1.67metric tons which is 5 % more than the earlier record which was estimated in 2008. Around 80% of this emission is from the power sector. (International Energy Agency 2011)

With the major energy sources diminishing the world is looking for more and more renewable and zero emission energy sources likeSolar energy, wind energy, tidal energy, biomass etc. One of the most important sources of renewable energy is wind power. On Wind energy noted American author and Naturalist Henry David Thoreau said that "First there is the power of wind, constantly exerted over the globe. Here is an almost incalculable power at our disposal, yet how trifling the use we make of it."(Jain 2011) This is done by using wind turbines to extract kinetic energy from wind. In comparison with other renewable resources Wind energy is aprofuse resource. Climate and weather could affect the utilization of wind energy when compared to solar energy. In order to get energy from the wind, wind turbines were invented. The wind turbine converts the wind energy into electrical energy and is also called as wind generator. The use of wind energy is growing rapidly in developed countries. In India wind power began in the year 1986, the first wind farms setup in coastal areas of Gujarat, Maharashtra, and Tamil Nadu with 55KW wind turbines. The present wind power in India is estimated as 24677MW as on 31st October 2015. Floating wind turbine technologies in deep sea areas is under implementation.

Aim: The aim of this project is to study and Analyse an aerodynamics of different wind turbine blades and to evaluate the smallest possible properties affecting the power output of the turbine.

The Research work done in this thesis is three parts.

In first part of the study the fundamental relations are taken from the literature survey and by studying the standard journals and patents.

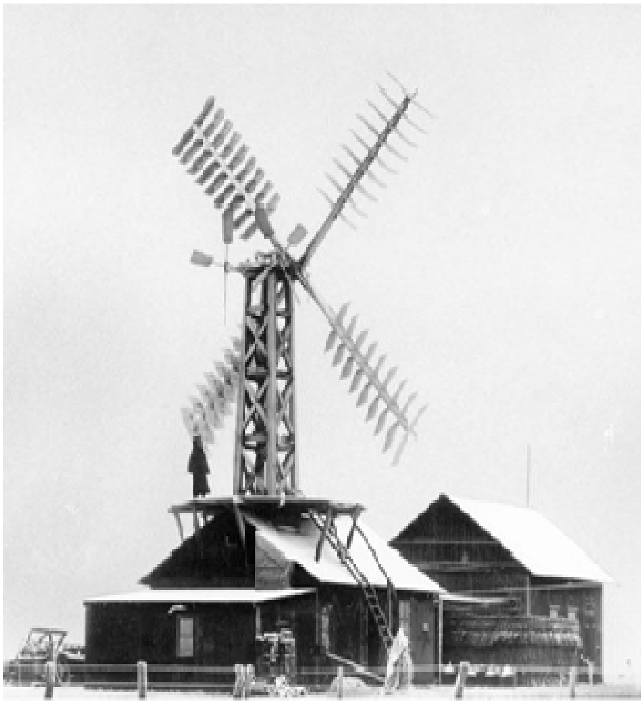
In the second part by using basic relations the design of aerofoil was done in the software. The prototype was created by using a rapid prototype machine and it was tested at different wind speeds and different wind angles to calculate the lift and drag in a wind tunnel.

In the third part of the study by using a CFD software the airflow is stimulated around the aerofoil and the phenomena of lift and drag can be known. The velocity and pressure contours generated by the fluent software can be used to calculate the percentage of mechanical output generated by the conversion of kinetic energy of the wind.

Wind Energy Growth AndHistorical Development Of Wind Turbine

The development of wind power in India began in 1986 with first wind forms being set up in coastal areas of Gujarat, Maharashtra, tamilnadu with 55 KW vestas wind turbines. In 2009-10 India‟s growth rate was highest among the other top four countries.

the potential for the wind forms in the country was first accessed by dr. jamiHossain using a GIS flat form at around 3000 GW in 2011.the revised estimation of the potential wind resource in India from 49130MW to 300000 MW ASSED AT 100 m hub height. The wind resources at higher hub heights that are prevailing is possibly even more. In 2015 the MNRE set the target for windpower generation capacity by the year 2022 at 60000MW. As of 31 October 2015 the Installed capacity of wind power in India was 24677 MW mainly spread across the south and west,north regions.



Classification of Wind Turbine:

According to differential rotational orientation of wind turbine can be classified in to horizontal axis and vertical axis wind turbines.The advantage of VAWT is the drive trains are located virtual to the ground and they can be installed very easily. VAWT can work without yaw and most of them have a blade with constant chord and no twist and it is of simple structure. When HAWT is compared with VAWT the stall control can be used because it is very difficult to incorporate aerodynamic control,such as aerodynamic brake and variable pitch. So HAWT has more power efficiency when compared with VAWT.

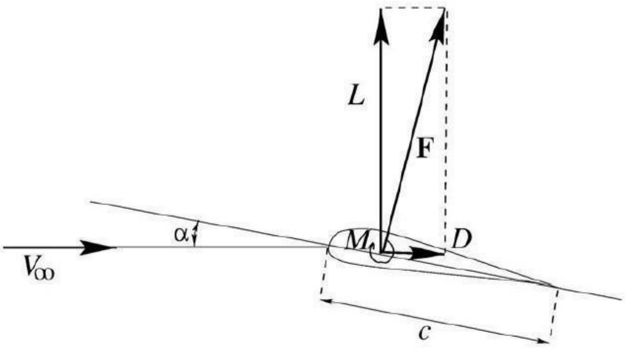
HORIZONTAL AXIS

VERTICAL AXIS

Aerodynamics of Wind Turbine

Aerodynamics of wind turbine has a crucial and challenging part for turbine energy capture. Aerodynamic performance plays a crucial role. Wind turbine blades are shaped to generate maximum power at minimum cost. Primarily the design is driven by the aerodynamic requirements, but economic means that the blade shape is a compromise to keep the cost of construction reasonable. In particular the blade tends to be thicker than the aerodynamic optimum close to root, when the stress due to bending are greatest. The design parameter of the blade element and the number of blades assigned to a rotor directly act on the performance of the wind turbine.

Lift, drag and moment coefficients:



Definition of lift and drag ratio

Betz Limiting Theory:

There are few principles on which a disc shape rotating wind energy converter works and extracts mechanical energy from a stream of moving air. Albert Betz has recognised some of these principles. Between 1922 to

1925,his works focussed on applying elementary physics laws to show that mechanical energy is extractable from an air stream which is passing through a given cross sectional area. According to Betz momentum theory the energy converter is assumed to be working in a frictionless airflow without losses. The kinetic energy of air of mass „m" moving with velocity

„v" can be expressed as $E=1/2\ mv^2$ (1)

Let the cross sectional area of the converter be „A" and the volume be „V". Then the volume flow can be expressed as

(2)

$=v*A\ m^3sec^{-1}$

If the air density is „Q",

(3)

$=QvA$ kg/s

From equation (1) and (3), we can calculate the energy or power of the air passing through cross section A, i.e. given by $P=1/2\ Qv^3A$ watt (W)

So, if the velocity of air before reaching the converter is v_1 while the velocity behind the converter is v_2. Let the area of cross sections before and after the converter be A_1 and A_2 , then the mechanical power developed by the converter is equal to the energy lost by the air stream.

$P = 1/2\ QA_1v_1^3 – 1/2\ QA_2v_2^3$
$= ½\ Q(A_1v_1^3 – A_2v_2^3)$

Therefore $P=1/2\ Qv_1A_1\ (v_1^2- v_2^2)$ i.e. $P=1/2$ $(v1^2 – v2^2)$ Watt

Since the mechanical energy produced by the converter is equal to this force,

$1/2\ (v1^2 – v2^2) = (v1-v2)\ v$"

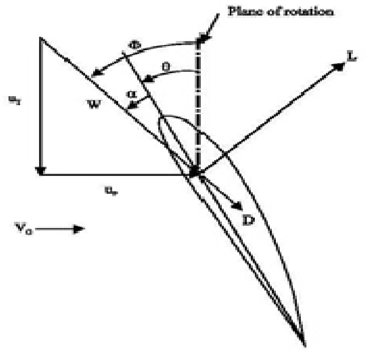
Therefore v"$= 1/2\ (v1+v2)$ m/sec

Thus the mass flow can be expressed as

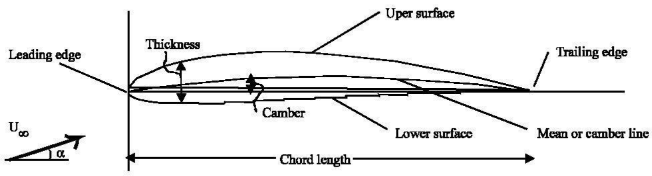
$= QAv$" $= 1/2\ QA\ (v1+v2)$ kg/sec

The power of the air stream which is flowing with a velocity of v1 through a cross section A without mechanical power being extracted from it is $P_o = 1/2\ Qv_1^3A$ Watt $(v1^2 – v2^2)$ WattV$=4.3*(\Delta h)^{0.5}$

Aerofoil: Aerofoil is the cross Section of the wind turbine blade through which the air flows. So the geometry of the aerofoil plays a important role in the conversion of the kinetic energy of the wind into mechanical energy which is converted into electrical energy by the generator. In the below figure a symmetrical airfoil is schematically shown.



Blade Element Force Velocity Diagram



In the following figure, the angles and powers of a blade section with 'r' diameter are depicted, based on the position with the wind provided. The fundamental element of the rotating component (ur) and axis component (up) is the relativistic wind vector in 'r' diameter (W). 'Θ' and 'α' are the blade connection angle and the attack angle, respectively. 'ϕ' is the angle constructed by relativistic vector and blade rotation vertical angle. It can be observed that the lift power component (CL) and drag power component (CD) are parallel to relativistic wind vector in vertical and parallel directions.

Geometrical Parameters of a Wind Turbine's blade profiles

Design Specifications of the aero foil:

Design Parameter	Value in Percentile
Camber	4.0%
Chord length	150mm
Span of the Aerofoil Section	125mm
Trailing Edge Angle	16.8°
Thickness	14%
Lower Surface Flatness	67.8%
Lower Surface Flatness	67.8%

The aerofoil curve is shown in the figure below this can be done by using coordinates and drawing the curve by plotting those points. The figure shows us the curve of the NACA 4314 aerofoil.

II. TESTING IN THE WIND TUNNEL

Designing in Solidworks

Solidworks is designingsoftware which help us to build 3D parts from simple 2D sketchesA new file is opened and part file is selected the units are set in millimetre. The tool curve through XYZ points is selected.

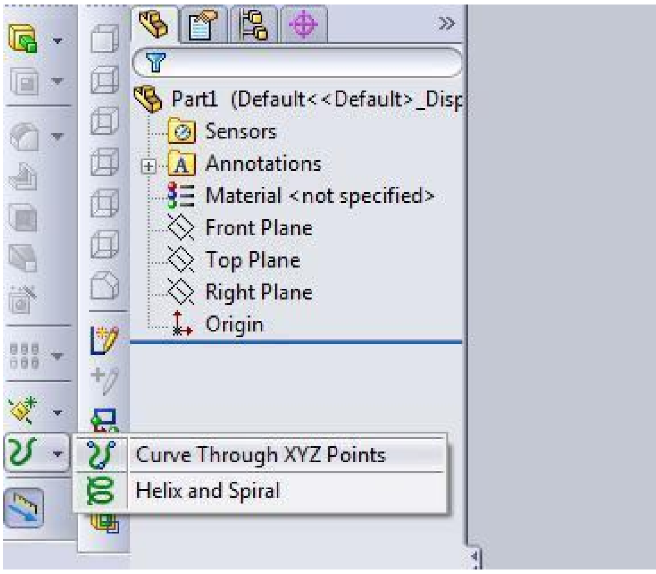
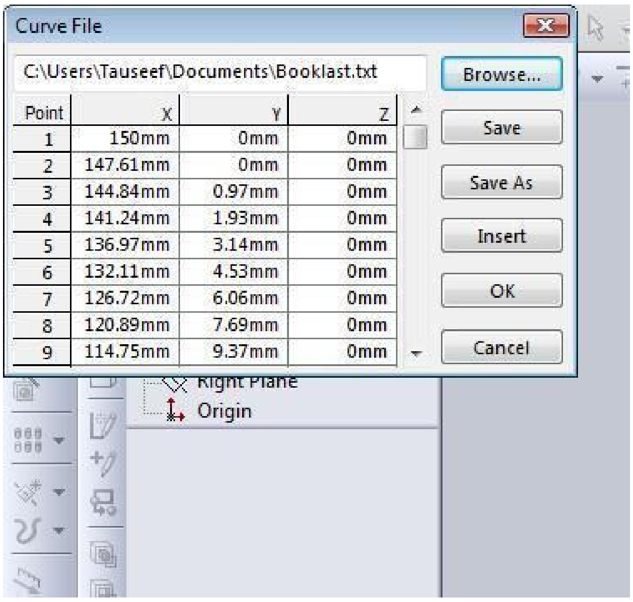
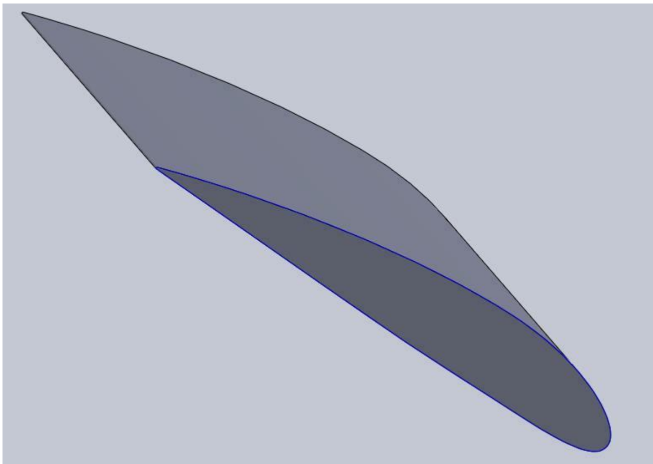


Image showing the curve through xyz points tool in solid works

The Coordinates which were saved in a text file are now selected. In solidworks coordinate system are mainly used for export and importing but they can also be used defining properties, mating and other purposes. In the below figure the coordinates are selected in the curve file have been calculated from the design specifications.



The 3D aerofoil which has been produced by the above steps is shown in the figure below.



Now the front plane is again selected and sketch mode is opened a circle of 12mm diameter is drawn on the front surface of the aerofoil. The circle is drawn to cut a hole though the aerofoil so that it fits a shaft which holds the aerofoil inside the wind tunnel.

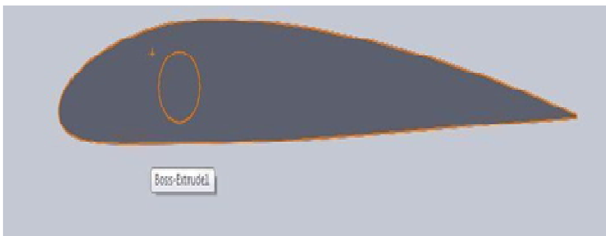
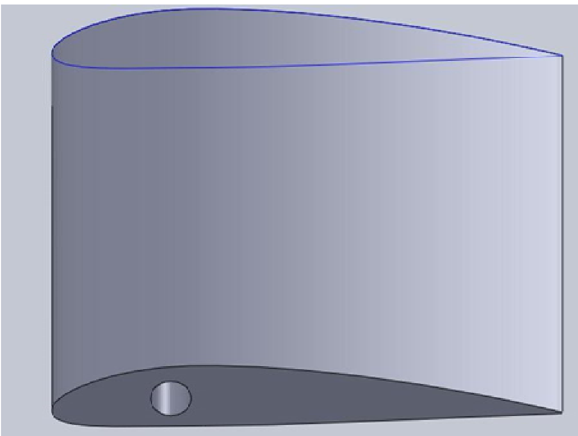


Image showing a circle being drawn on the surface of the aero foil

Extrude cut command is used to cut the hole from the aerofoil. The hole depth given was 60mm.



Rapid Prototyping of the Model:

Rapid Prototyping can be defined as fabrication of a model designed by using a CAD software in layer by layer construction. The major benefit of Rapid Prototyping is that it decreases the wastage of time in building a model from the CAD design. The schematic diagram below describes the procedures of Rapid Prototyping The process starts with designing the model in CAD software and saving it as STL file which means stereo Lithography (cooper 2001).

These STL files are sent to the pre-processor which checks the files and then transfers it into. The STl file represents the solid model in triangulated portrayal. The design developed in solidworks is given as input in the rapid prototype machine. The process was completed in 8 hours and the prototype was kept in solution to remove the supporting material on it.

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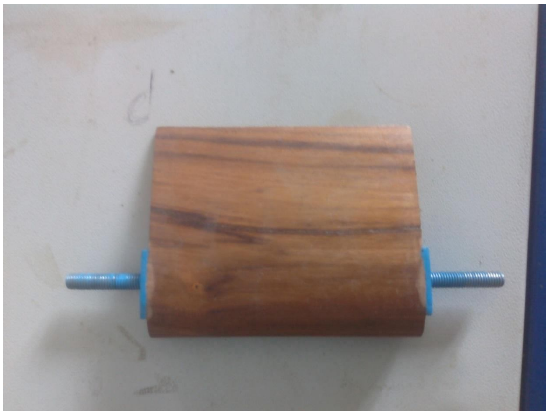
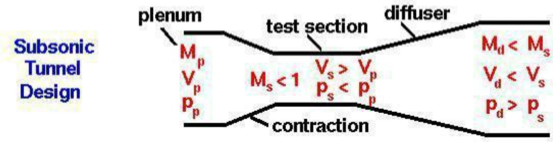


Wind Tunnel Test:

A subsonic wind tunnel is used in this experiment. A wind tunnel is a test rig based on ground designed to test the flow of air or different gases around the particles. A low speed subsonic wind tunnel work under the conditions when Mach number less than 1.



Schematic Representation of wind tunnel (National Aeronautics and Space Adminstration 2011)

Simulation of Airflow around the Airfoil using CFD

A fluid volume and mesh was created around an airfoil for analyzing in the fluent. Created a nonsymmetric 4315 airfoil.

Choose points to 60 and point size to 4 to ensure that the points are clearly visible.

Simple editing can be made in the airfoil data by using Microsoft word excel.

After all the alterations made, save the document.

Create a FLUENT template in the Project Schematicwindow.

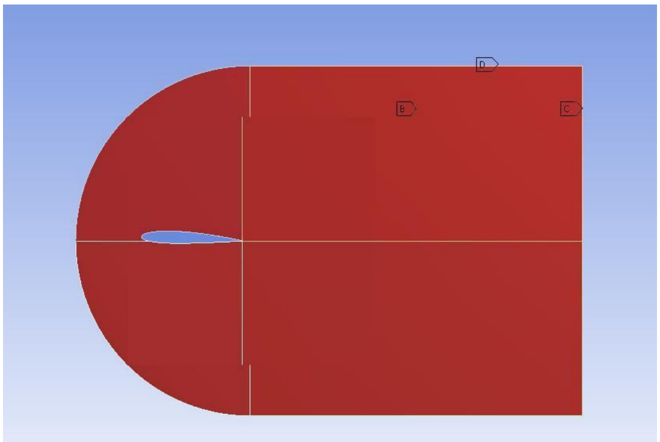
Open the project in the ANSYS.

Make sure that there are tick marks on all the options namely – Toolbox, Toolbox customization and Project Schematic.

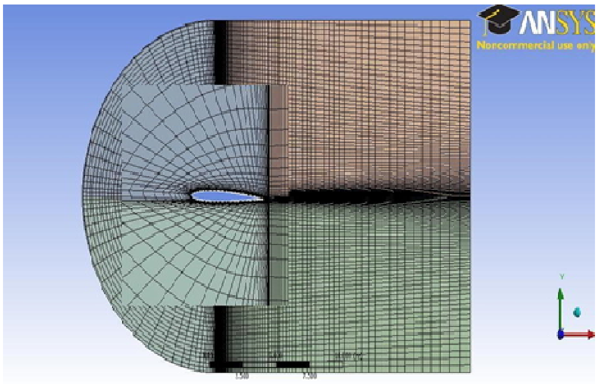
In toolbox customization under analysis systems verify that the fluid flow (FLUENT) has a check mark next to it.

Choose the option of geometry in ANSYS Design Modeler (DM).

Then the option of choosing the desired length unit will be shown on the screen, choose meter.



Aero foil inside an artificial wind tunnel designed in ANSYS



The boundaries meshed around the aero foil

III. RESULTS AND DISCUSSION

angle	CL	CD	L/D	Cm
-8	0.2	-0.11	-1.81818	-0.12
-5	0.22	-0.2	-1.1	-0.11
-3	0.25	-0.9	-0.27778	-0.12
0	0.64	0.17	3.764706	-0.24
2.5	0.98	0.2	4.9	-0.24
5	1.04	0.22	4.727273	-0.24
6.5	1.19	0.3	3.966667	-0.26
9.5	1.34	0.49	2.734694	-0.24
12	1.46	0.66	2.212121	-0.26
14	1.46	0.74	1.972973	-0.26
15	1.42	0.8	1.775	-0.26

The observations for Reynolds number 1E5

angle	CL	CD	CM	L/D
-8	-0.43	-1.95	-0.44	0.220513
-5	-0.2	-0.6	-0.22	0.333333
-2	0.82	1.98	-0.22	0.414141
0	0.95	1.46	-0.94	0.650685
2	1.15	1.66	-0.94	0.692771
5	1.2	1.8	-0.82	0.666667
8	1.3	2.8	-0.94	0.464286
10	1.35	3	-0.94	0.45
12	1.42	3.4	-0.94	0.417647
14	1.4	4	-0.94	0.35

The observations for Reynolds number 5E4

angle	CL	CD	CM	L/D
-8	-0.15	0.2	-0.17	-0.75
-5	-0.17	0.3	-0.17	-0.56667
-2	0.23	0.4	-0.17	0.575
0	0.35	0.35	-0.28	1
2	0.52	0.35	-0.23	1.485714
5	0.57	0.35	-0.29	1.628571
8	0.73	0.4	-0.27	1.825
10	0.83	0.55	-0.28	1.509091
12	0.94	0.75	-0.28	1.253333
15	0.92	0.79	-0.28	1.164557

The observations for Reynolds number 7E4

Plot of L/D ratio or Sliding Rate Vs Angle of Attack:

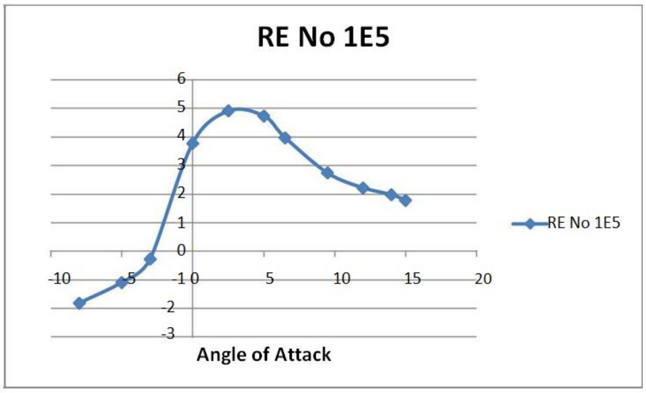
The plots for L/D vs angle of attack show results where the range of angle of attack is from -8 to +12. The graph shows that the L/D value increases till a particular value which is the optimum angle of attack and starts to fall beyond that which is knows as stalling.

For the Reynold‟s number 100,000 the optimum angle of attack is 4 degrees.

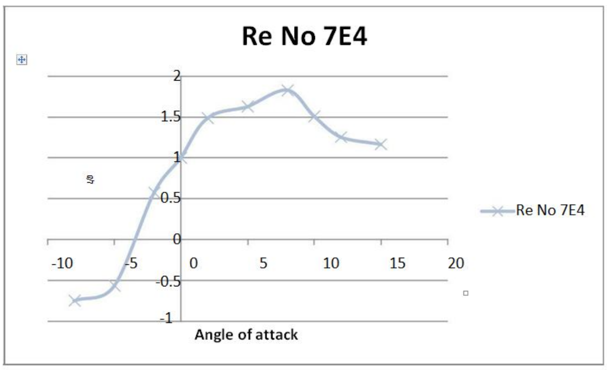
For the Reynold‟s number 70,000 the optimum angle of attack is 3 degrees.

At these angles the L/D ratio is maximum for the aerofoil. The maximum value of the sliding rate(L/D) for these Reynold‟s numbers are 4.72, 0.69 and 1.62 degrees each, which are very less when compared to the value calculated by NACA which is around

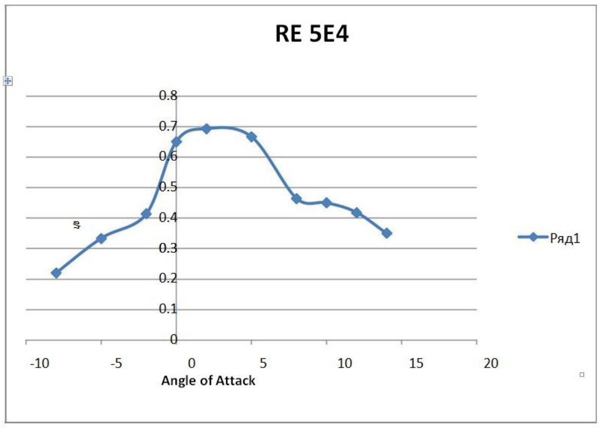
24 degrees. Because the Reynold‟s number used by the NACA was around 3,200,000 and the velocity of the wind was 20.76 m/sec. The decrease in the values of the L/D ratio might also be because of the surface roughness of the aerofoil which was minimized by painting.



Graph showing L/D vs Angle of attack for Re number1E5

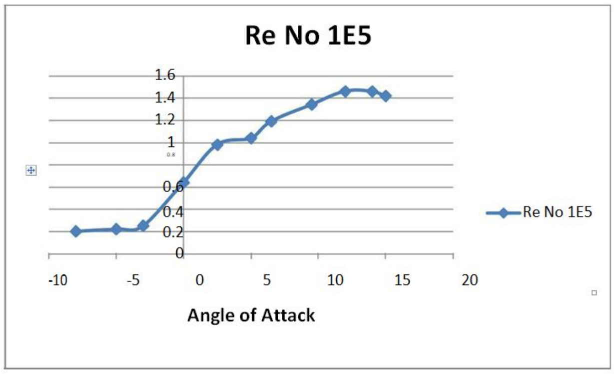


Graph showing L/D vs Angle of attack for Re number 7E4

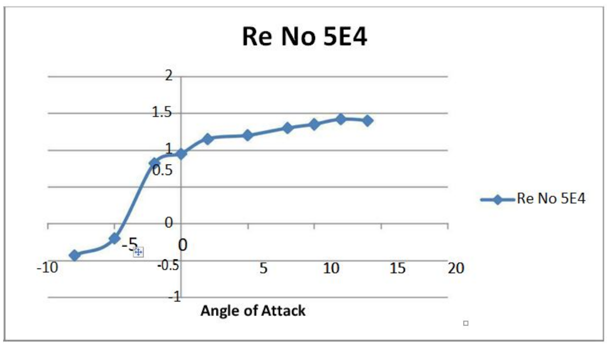


Graph showing L/D vs Angle of attack for Re number 5E4

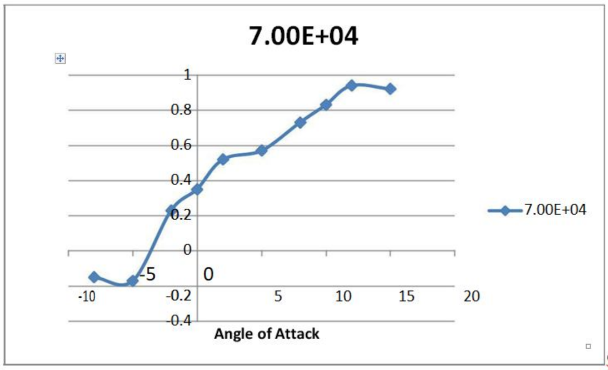
Plot of Coefficient of Lift Vs Angle of Attack: The plots for C_l vs. angle of attack indicate that the coefficient of lift of the aerofoil increases rapidly till a particular angle and then starts to decrease gradually. This phenomenon is called stall and the angle at which the stall starts is called stall angle.



Graph showing Coefficient of lift vs Angle of attack for Re number 1E5

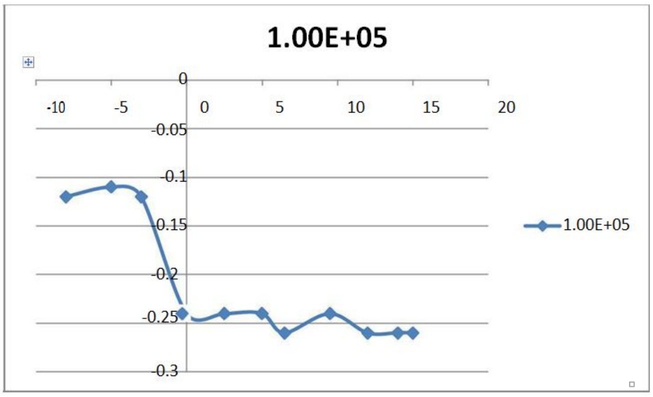


Graph showing Coefficient of lift vs Angle of attack for Re number 5E4

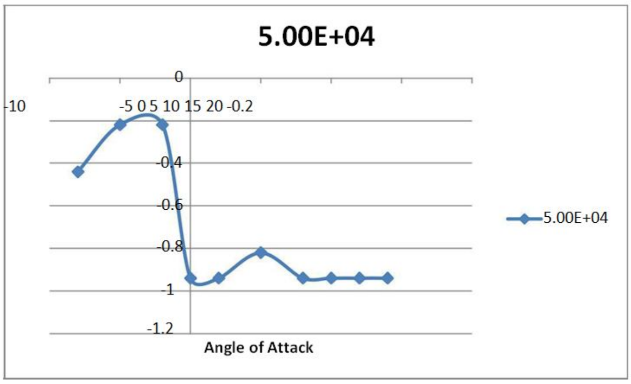


Graph showing Coefficient of lift vs Angle of attack for Re number 7E4

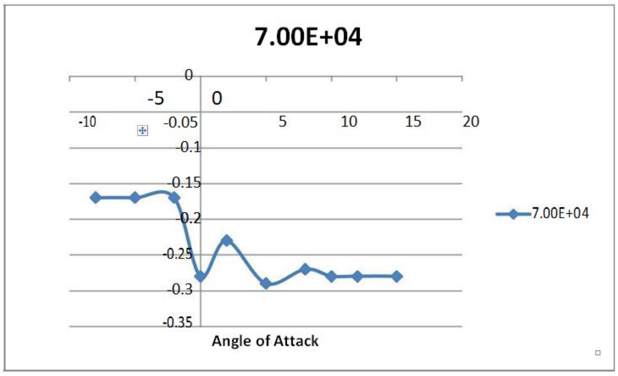
Plot of Coefficient of Moment Vs angle of Attack: The plots for C_m vs. angle of attack indicate that there is a sudden decrease in the C_m which is followed by a gradual stability in the value. Though the plots of the graph aren"t very clear due to the surface roughness but are enough to indicate the patternfollowed by the C_m



Graph showing Coefficient of moment vs Angle of attack for Re number1E5



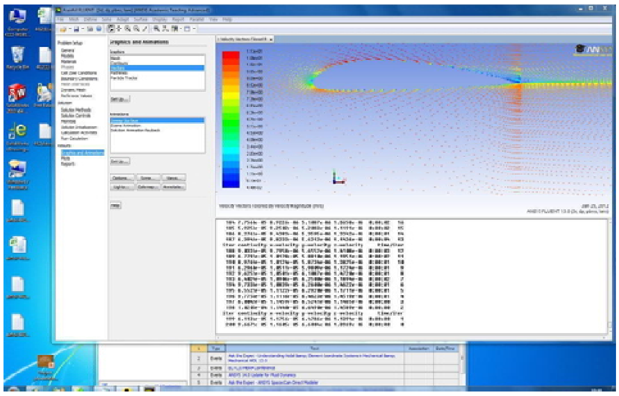
Graph showing Coefficient of moment vs Angle of attack for Re number 5E4



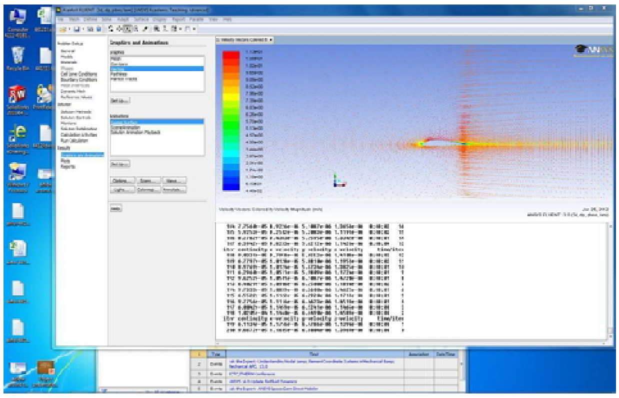
Graph showing Coefficient of moment vs Angle of attack for Re number 7E4

Fluent Results:

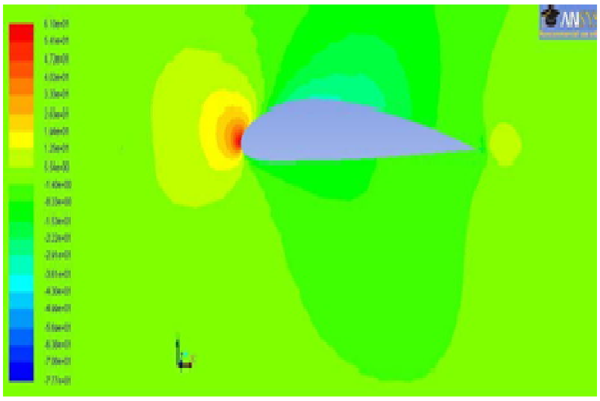
The maximum pressure is found at the leading edge of the aerofoil which is equal to $6.1x10^1 N/m^2$.



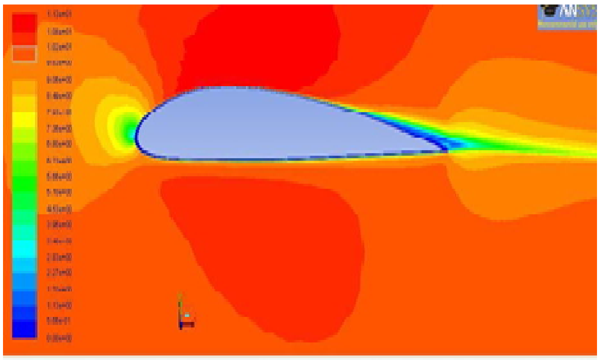
Stream lines showing air flow around the aero foil



Stream line showing the air flow around aero foil



Pressure Contour



Velocity Contour

IV. CONCLUSION

According to the research the major aims and objectives of this project which were achieved are listed below**.**The major aerodynamic properties of a wind turbine were studiedThe wind that cuts the wind turbine blade flows through its cross section(i.e. an aerofoil) which plays an important role in power generation, so the aerodynamics of different aerofoils were studiedNACA 4315 aerofoil was selected to do the research and it was worked on both software(ANSYS-Fluent) and as well as in practical in a wind tunnelThe wind tunnel test gave the values of lift and drag at different angles of attack on different Reynolds‟ number.

These values were plotted and they were compared with the plots developed by NACA in their technical reports

The plot results showed similar results as to the original ones released by NACA but the magnitude of the research values were less in comparison to the originals.

After a brief research the fact that came to light is that the NACA used high Reynolds‟ number when compared to the ones used in this project

The Reynolds‟ number depends upon the chord length and the wind velocity, the wind velocities used here were 5,7 and 10 m/sec which mimicked the wind velocity .

From the plots it was noticed that the coefficient of lift increases with increase in angle of attack till a certain value and begins to decrease as well as the coefficient of drag increases, this condition is called stall

In ANSYS-Fluent an artificial wind turbine was created around the aerofoil, the inlet conditions were given, the flow of the air is taken as lamina as it could decrease the complications in the results

The mechanism of the lift and drag of the aerofoil were explained using ANSYS, the pressure drop and increase in velocity on the upper surface, were explained using the counter plots

The vortex at the tip of the blade was identified and the its area increases with increase in angle of attack

The amount of power generated by a blade of infinite length having the profile NACA 4315 was calculated using the BETZ limiting theory.

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