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Research Article

AERODYNAMIC INVESTIGATION OF FLOW PARAMETER OVER NACA 4415 AIRFOIL BY COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

In this paper CFD analysis of NACA 4415 airfoil has been analyzed with the fluent software 6.3.26. During the CFD analysis the angle attack was taken 12^0,14^0,16^0 and 18^0 respectively and Reynolds number was selected 1000000 and 1500000. It was found that the lift coefficient increase with increase of angle of attack, but after 16^0 there was adverse pressure gradient at trailing edge over come this situation.
The Reynolds number was varied but no significant change was notice.

INTRODUCTION

The NACA airfoil shape for aircraft wings developed by the National Advisory Committee for Aerodynamics (NACA). The shape of the NACA airfoil is described using a series of digits following the word "NACA". The parameter in the numerical code can be entered into equation to precisely generate the cross section of the airfoil and calculate its properties.

The NACA four-digit wing sections define the profile as per the below Performa

1. First digit describes the maximum camber as percentage of the chord.
2. Second digit describes the distance of maximum camber from the airfoil leading edge in termss of percents of the chord.
3. Last two digits describe the maximum thickness of the airfoils as percent of the chord

Example for cambered airfoil, The NACA airfoil 4415 has a maximum camber of 4% located 40% (0.4 chord) from the leading edge with a maximum thickness of 15% of the chord.
Rotor blade design is a key element in determining the efficiency of a wind turbine. A crucial precursor to a final rotor blade design is to select one or more 2D airfoil sections to form a smooth blade profile. A wind tunnel study of a 2D airfoil (NACA 4415), typical of an airfoil used by wind turbine rotors, is compared with predictions made by our Panel Flow add-on.

Airfoil Terminology
The various terms related to airfoil are defined below:

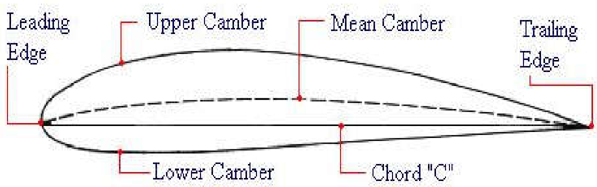

Figure 1 Airfoil terminology

- Upper surface -The suction surface (a.k.a. upper surface) is generally associated with higher velocity and lower static pressure.
- Lower surface -The pressure surface (a.k.a. lower surface) has a comparatively higher static pressure than the suction surface. The pressure gradient in between these two surfaces contributes to the lift force generated for a given airfoil.
- The leading edge – It is the point at the front of the airfoil that has maximum curvature (minimum radius).
- The trailing edge – It is defined similarly as the point of maximum curvature at the rear of the airfoil.
- The chord line - It is the straight line connecting leading and trailing edges. The chord length, or simply chord c, is the length of the chord line. That is the reference dimension of the airfoil section.

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- The mean camber line or mean line is the locus of point's midway between the upper and lower surfaces. Its shape depends on the thickness distribution along the chord;

Lift and Drag

When a solid body is placed in a fluid flow and a nonsymmetrical situation occurs the direction of the forces on the body does not coincide with the direction of the flow. This principle makes flying possible. Discussion of lift and drag starts usually with the introduction of an airfoil.

The resultant aerodynamic force F on an airfoil can be resolved into a lift force L perpendicular to the direction of undisturbed flight and a drag force D in the direction of flight. In steady level flight the drag is balanced by the thrust of the engine, and the lift equals the weight of the aircraft. These forces are expressed no dimensionally by defining the coefficients of lift and drag:

$$C_L = \frac{F_L}{\frac{1}{2}\rho A U^2}$$

$$C_D = \frac{F_D}{\frac{1}{2}\rho A U^2}$$

Where

F_D and F_L = lift and drag force

C_L = lift coefficient

C_D = drag coefficient

ρ = density of the fluid

A = reference area

U = velocity of the undisturbed flow

LITERATURE REVIEW

Lanzafame at al. [1], has done Evaluation of the radial flow effects on micro HAWTs through the use of a transition CFD 3D model - Part II: Post processing and comparison of the results.

Morshed at al. [2], has analyzed four different profile objects - a symmetrical airfoil (NACA 0015), a cambered airfoil (NACA 4415), a cylinder and a sphere. This object has been tested in a sub sonic wind tunnel

Azeez and poul [3], has done CFD Analysis of NACA 63-018 Airfoil at Different Reynolds-Number

Umapathi and Soni [4], has done Comparative Analysis of Airfoil NACA 2313 and NACA 7322 Using Computational Fluid Dynamics Method

Kevadiya and Vaidya [5], has done CFD analysis on NACA 4412 air foil of wind turbine blade

Agrawal and Saxena [6], has done analysis of wings using airfoil NACA 4412 at different angle of attack

Islam at al. [7], has done Experimental evaluation of aerodynamics characteristics of a base line airfoil

Katam [8], In this research results from a joint effort coupling numerical simulation and wind tunnel testing to investigate this flow regime

METHODOLOGY

Mesh Generation

To perform the CFD analysis it is necessary to obtain the mesh file of the airfoil. Depending upon the complexity of airfoil, mesh type may be chosen as described below:

Types of Mesh

1. Structured Meshes
2. Unstructured Meshes
3. Hybrid Meshes

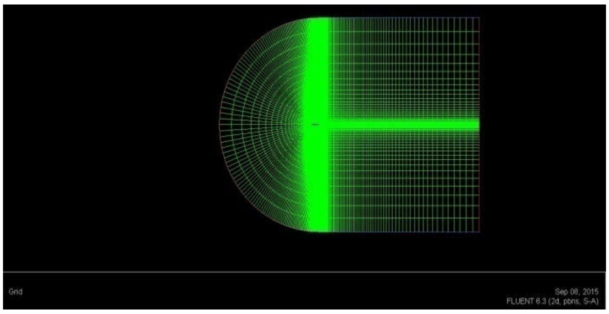

Figure 2 Upstream side of the airfoil C type topology

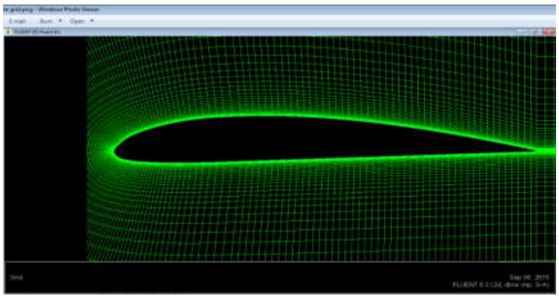

Figure 3 Full view of Airfoil

Simulation

Here the boundary condition, solver parameter and turbulence model parameters according to the problem has been set, after which the FLUENT will be used for whole input data and for calculation purpose.

Post Processing

Contours for fluid flow analysis over the airfoil have been plotted. To identify the separation point over the surface of airfoil data digitizer software "WINDIG" is used.

Assumptions

- The flow is 2D.
- Pure air is considered.
- Process is adiabatic and isothermal.
- Gravitational force is not considered.
- Pure dry air is considered for analysis purpose.

Boundary Condition

S.No	Zone	Type
1	Far field 1	Velocity inlet
2	Far field 2	Velocity inlet
3	Far field 3	Pressure outlet
4	Airfoil	Wall

Value of Velocity Inlet

TABLE - Velocity Inlet Components

Reynolds Number = 10,00,000		
Angle	X–component (m/s)	Y –component(m/s)
12^0	14.288	3.037
14^0	14.176	3.5345
16^0	14.044	4.027
18^0	13.895	4.514

TABLE - Velocity Inlet Component

Material Properties

TABLE - Material Property

Reynolds Number = 15,00,000		
Angle	**X –component(m/s)**	**Y –component(m/s)**
12^0	21.439	4.557
14^0	21.267	5.302
16^0	21.069	6.04
18^0	20.844	6.772

RESULT AND DISCUSSION

Numbers	Properties	Value
1	Density	1.225 Kg/m³
2	Viscosity	1.7894×10^{-5} Kg/m-s

Results for Coefficient of Lift Vs Flow time at Diffent angle of attack and Reynolds number

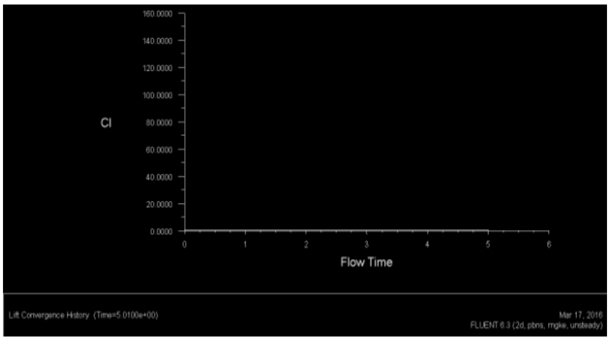

Figure 4 AOA = 12^0 and Re = $12x10^5$

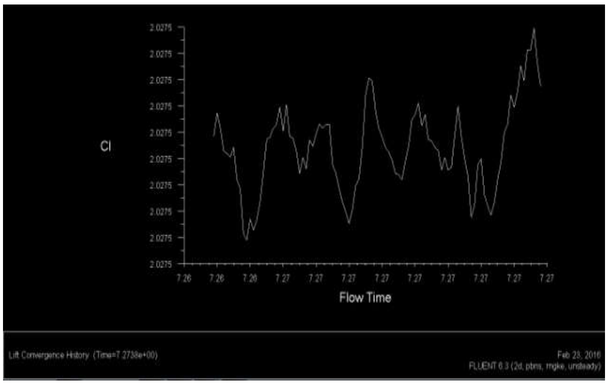

Figure 5 AOA = 12^0 and Re = $15x10^5$

Fig. 4 and Fig. 5 Shows convergence of Coefficient of lift at 12° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.7825 and 2.0277 respectively with the initial value of No. of mesh elements 15650.

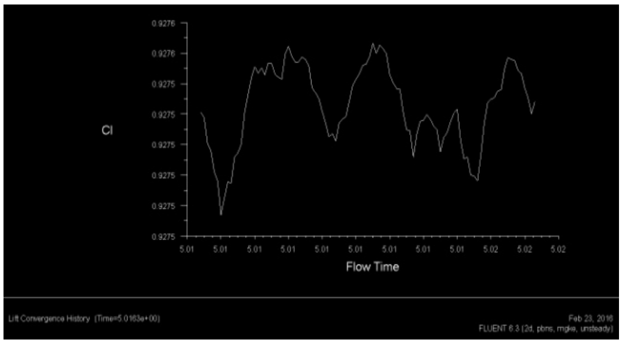

Figure 6 AOA = 14^0 and Re = $10x10^5$

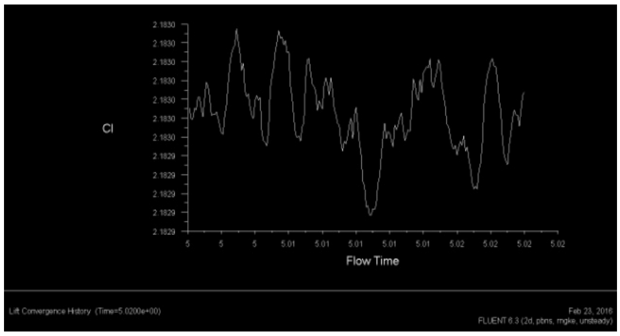

Figure 7 - AOA = 14^0 and Re = $15x10^5$

Fig. 6 and Fig. 7 Shows convergence of Coefficient of lift at 14° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.927 and 2.0275 respectively with the initial value of No. of mesh elements 15650.

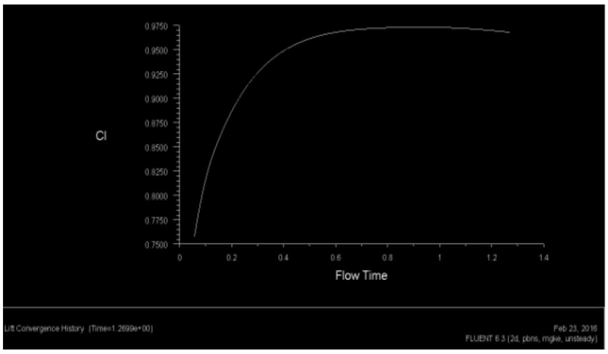

Figure 8 AOA = 16^0 and Re = $10x10^5$

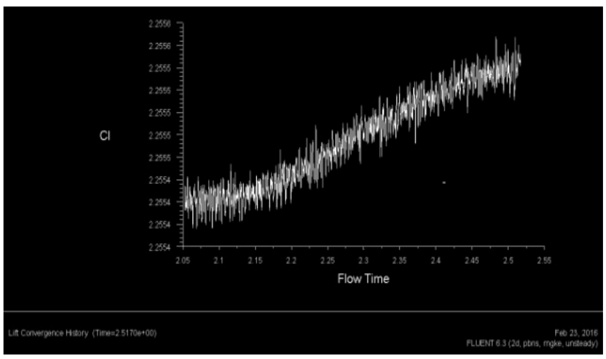

Figure 9 AOA = 16^0 and Re = $15x10^5$

Fig. 8 and Fig. 9 Shows convergence of Coefficient of lift at 16° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.96 and 2.255 respectively with the initial value of No. of mesh elements 15650

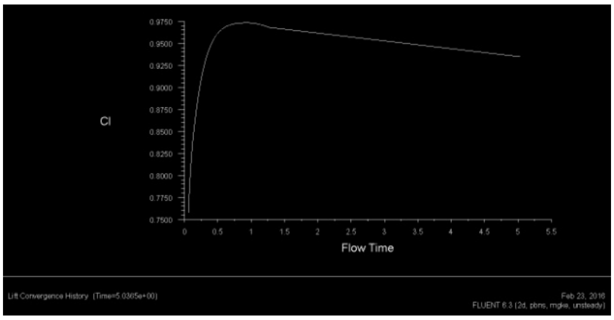

Figure 10 AOA = 180 and Re = 10x105

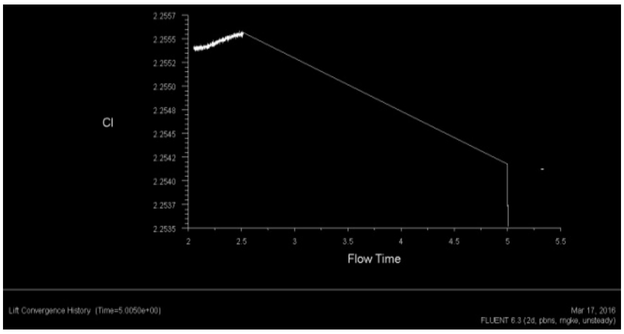

Figure 11 AOA = 180 and Re = 15x105

Fig. 10 and Fig. 11 Shows convergence of Coefficient of lift at 18° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.925 and 2.25 respectively with the initial value of No. of mesh elements 15650

Results for Coefficient of Drag Vs Flow time at Diffent angle of attack and Reynolds number

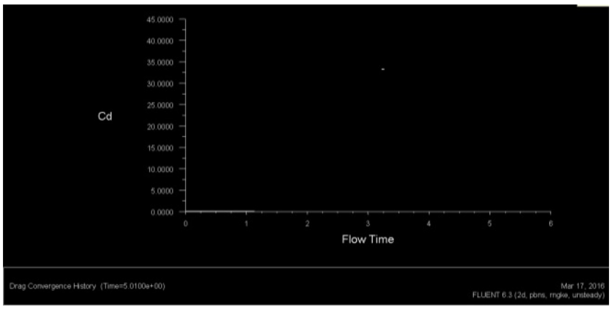

Figure 12 AOA = 12^0 and Re = $10x10^5$

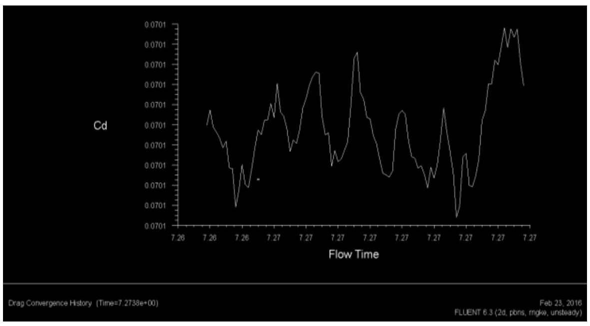

Figure 13 AOA = 12^0 and Re = $15x10^5$

Fig. 12 and Fig. 13 Shows convergence of Coefficient of drag at 12° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.031 and 0.071 respectively with the initial value of No. of mesh elements 15650.

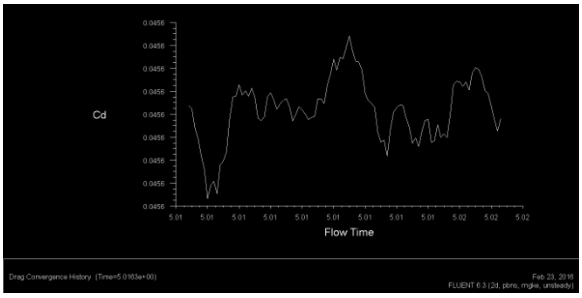

Figure 14 AOA = 14^0 and Re = $10x10^5$

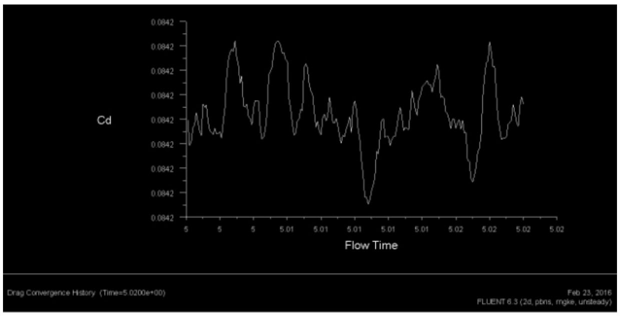

Figure 15 AOA = 14^0 and Re = $15x10^5$

Fig. 14 and Fig. 15 Shows convergence of Coefficient of drag at 14° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.045 and 0.084 respectively with the initial value of No. of mesh elements 15650.

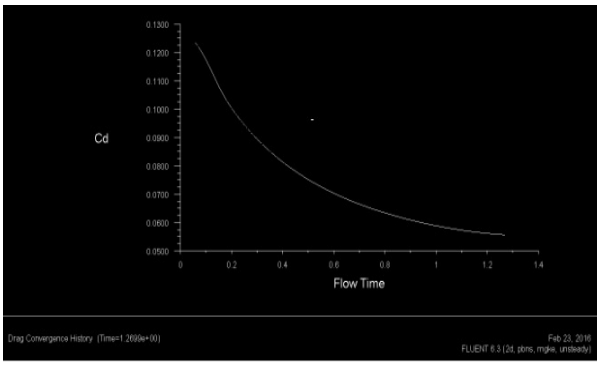

Figure 16 AOA = 16^0 and Re = $10x10^5$

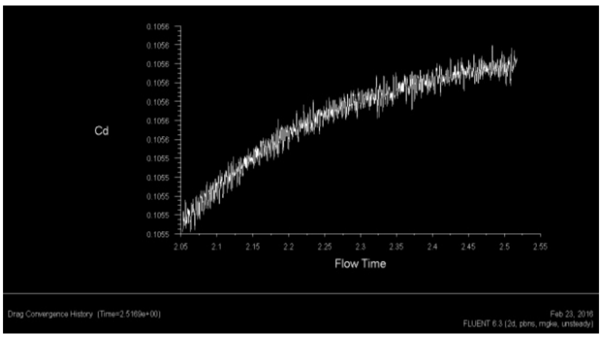

Figure 17 AOA = 16^0 and Re = $15x10^5$

Fig. 16 and Fig. 17 Shows convergence of Coefficient of drag at 16° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.059 and 0.105 respectively with the initial value of No. of mesh elements 15650.

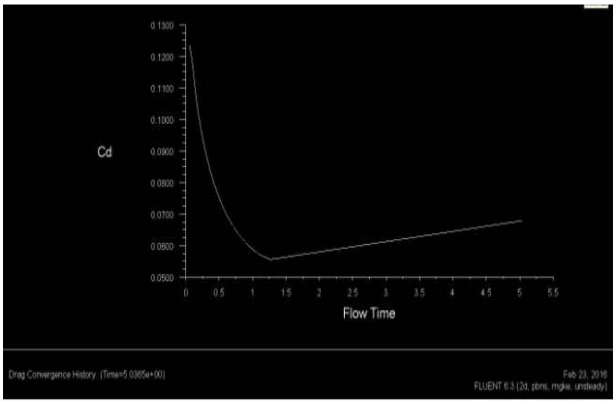

Figure 18- AOA = 18^0 and Re = $10x10^5$

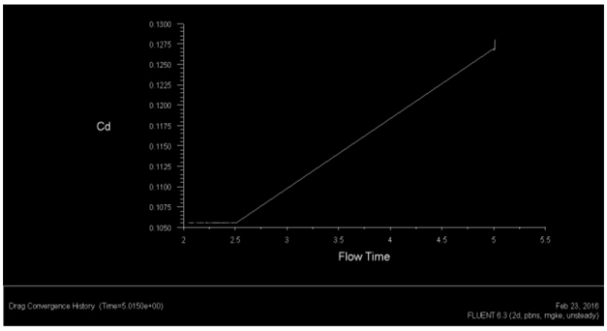

Figure 19- AOA = 18^0 and Re = $15x10^5$

Fig. 18 and Fig. 19 Shows convergence of Coefficient of drag at 18° angle of attack and 1000000 & 1500000 Reynolds number and their values are 0.065 and 0.112 respectively with the initial value of No. of mesh elements 15650.

Observation Table

Table- Coefficient of Lift (C_l) and Coefficient of Drag (C_D) at Different angle of attack for 1000000 Reynolds Number

S.No.	**Angle of attack (∝)**	**Coefficient of Lift (C_L)**	**Coefficient of Drag (C_D)**
1	12^0	0.7825	0.031
2	14^0	0.927	0.045
3	16^0	0.96	0.059
4	18^0	0.925	0.065

Table - Coefficient of Lift (C_l) and Coefficient of Drag (C_D) at Different angle of attack for 1500000 Reynolds Number

S.No.	Angle of attack (∝)	Coefficient of Lift (C_L)	Coefficient of Drag (C_D)
1	12^0	2.027	0.071
2	14^0	2.0275	0.084
3	16^0	2.255	0.105
4	18^0	2.25	0.112

From the above Figure and table**,** it has been concluded that between angle of attack (α) 12° to 16° the value of coefficient of lift increased and also increased the value of coefficient of Drag but after 16^0 angle of attack the value of coefficient of lift decreased for both the Reynolds number and value of coefficient of drag continue to increased. So critical angle of attack in our experiment it is found at 16º. At this critical angle of attack the coefficient of lift is 2.255 which is highest for both the Reynolds number.

CONCLUSIONS

From the above experiment the following conclusion is made.

1. Coefficient of lift and drag are calculated for NACA 4415 airfoil series at the different angle of attack 12^0,14^0,16^0, 18^0 for Reynolds number 1000000 and Reynolds number 1500000
2. The coefficient of lift was found to increase up to 16^0 after that the reduction in coefficient of lift was observed
3. The coefficient of drag was found increase up to 18^0 angle of attack continuously.
4. The maximum value of coefficient of lift was found 0.925 and 2.225 for Reynolds number 1000000 and 1500000 respectively.
5. The maximum value of coefficient of drag was found 0.065 and 0.112 for Reynolds number 1000000 and 1500000 respectively.

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