

# CFD Analysis of Variation in Pressure Coefficient for NACA 4412 Aerofoil

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**Abstract:** For the analysis of wind turbine blade, NACA 4412 aerofoil profile is used in this paper. The aerofoil geometry and field boundary was developed using GAMBIT 2.4.6 and CFD analysis was performed using FLUENT 6.3.26 at various angles of attack  $1^\circ$ ,  $6^\circ$ ,  $10^\circ$  and  $15^\circ$  respectively. The contours of pressure coefficient are plotted using viscous model as inviscid.

**Keywords:** Aerofoil, CFD analysis, angle of attack, pressure coefficient.

## 1. Introduction

Aerodynamics is a branch of fluid dynamics concerned with studying the motion of a fluid over a body. Understanding the motion of fluid flow over an object helps to determine the various forces acting on the body. For the design of an aircraft, missile, wind turbine blade or any other aerodynamic object, the primary consideration will be an aerofoil and the flow across it. Modern day problems associated with aerodynamics are complex and is solved with the help of computational fluid dynamics (CFD).

CFD is the use of applied mathematics, physics and computational software which visualize and determine the fluid flow over a body. The most commonly used CFD software is ANSYS, which enables us to analyse various problems related to fluid flow with the help of numerical analysis.

## 2. Background

An aerofoil is any structure which produces an aerodynamic force when air flow around it. This aerodynamic force find various applications such as in the cross section of an aircraft wing, wind turbine blades and turbine blades in a jet engine. Aerodynamic force has two components, namely, the lift and the drag. Lift force is the component of aerodynamic force that is perpendicular to the oncoming air flow direction while drag force is the force component parallel to the flow direction.

When an aerofoil is placed in a streamline of fluid or air flow, the leading edge of the aerofoil splits the incoming stream of air such that it passes above and below the aerofoil. The aerofoil is designed in such a way that the velocity and pressure of the air on the lower surface of the air remains the same compared to the upper surface. The pressure on the upper surface of the aerofoil is less than that on the lower surface. This causes the aerofoil to move from a high pressure region to a low pressure region producing the aerodynamic lift.

According to Bernoulli's theorem, the velocity on the upper surface of the aerofoil increases due to reduction in pressure. The faster the aerofoil moves in the streamline, higher will be the aerodynamic lift. Rather than the velocity of the aerofoil, there are other parameters which define the lift produced. Such a parameter is the angle of attack.

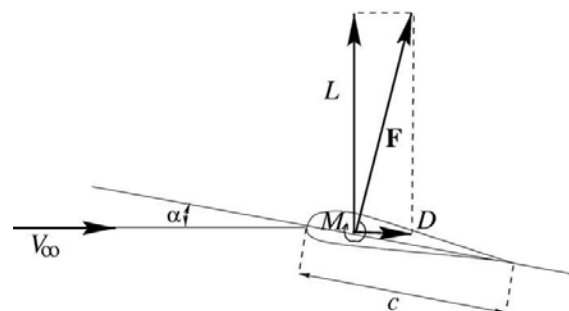


Figure 1: Definition of lift and drag [1]

Angle of attack (AOA) is the angle between the oncoming air and the reference line, usually the chord line of an aerofoil. The chord line is obtained by joining the most forward point on the leading edge of the aerofoil to the rearmost point on the trailing edge. The chord length is the length of the chord line. As angle of attack increases, there is a rapid increase in the lift force whereas, the drag force along with the drag coefficient increases gradually up to a critical value of angle of attack called the stalling angle of attack. Beyond this point the drag force increases readily. The stalling angle of attack is

15° for most aerofoils. The coefficient of lift increases up to this stalling value of angle of attack and then decreases.

### 3. Theoretical Analysis

The pressure coefficient is a dimensionless number which describes a relative pressure of an entire fluid flow field. Every point in the fluid flow field has its own unique value of pressure coefficient,  $C_p$ . Hence the pressure coefficient can be used to determine the values of pressure at critical locations around the aerofoil.

$$C_p = (P - P_\infty) / (\frac{1}{2}\rho_\infty V_\infty^2)$$

Where:

$P$  = pressure at the point at which the pressure coefficient is determined

$P_\infty$  = free stream pressure

$\rho_\infty$  = free stream fluid density

$V_\infty$  = free stream fluid velocity

For incompressible steady flow the pressure coefficient can be further simplified as

$$C_p = 1 - (V/V_\infty)^2$$

While we consider the value of  $C_p$ , we could see that the values never go beyond one and when the value of  $C_p$  is equal to one, it indicates that the pressure at the point of evaluation would be equal to the stagnation pressure. Also when the value is equal to zero, it denotes the free stream pressure.

Lift force is the component of aerodynamic force that is perpendicular to the oncoming air flow direction while drag force is the force component parallel to the flow direction.

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

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

Where,

$C_L$  = the coefficient of lift

$C_D$  = the coefficient of drag

$\frac{1}{2} \rho A V^2$  = dynamic pressure

The lift and drag force can be obtained by determining the values of dynamic pressure, coefficient of lift and coefficient of drag.

### 4. Design and Simulation

For analysing the flow over an aerofoil, the coordinates of the aerofoil vertices were imported into the GAMBIT software and a field boundary was created across the aerofoil. Quadrilateral structured meshing was used to complete the design meshing procedure as shown in fig. 2. Grid independence study was performed so that there is maximum number of cells in the mesh within the geometrical tolerance. The intensity of meshing was increased towards the aerofoil so as to obtain maximum accuracy.

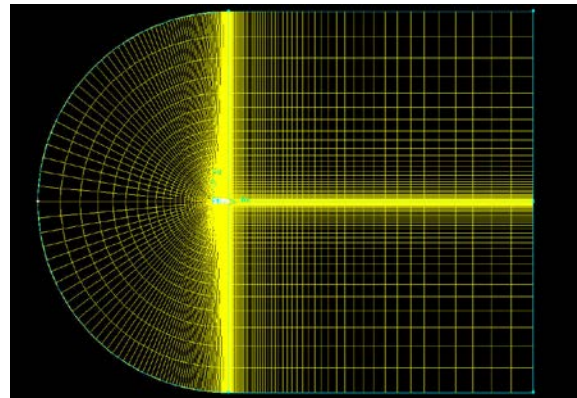


Fig 2: Completed meshed boundary of the aerofoil

Various inputs and boundary condition were considered for simulation of the aerofoil in ANSYS FLUENT which are discussed in table 1.

Table No. 1 Input and boundary condition

| No. | Input                 | Value                          |
|-----|-----------------------|--------------------------------|
| 1   | Velocity of flow      | 0.15 Mach or 50 m/s            |
| 2   | Operating temperature | 288 K                          |
| 3   | Operating pressure    | 101325 Pa                      |
| 4   | Model                 | Inviscid                       |
| 5   | Density of fluid      | 1.225 kg/m <sup>3</sup>        |
| 6   | Kinematic Viscosity   | 1.7894e-05 kg s/m <sup>2</sup> |
| 7   | Length                | 1 m                            |
| 8   | Angle of attack       | 1°, 6°, 10°, 15°               |
| 9   | Fluid                 | Air as ideal                   |

### 5. Results and Discussions

The experiment that we have performed in this paper is about the variation in the pressure coefficient by changing the angle of attack. The angle of attacks that we have considered here are 1°, 6°, 10° and 15°. As the angle of attack is increased, the pressure coefficient on the upper surface of the aerofoil goes on decreasing.

The pressure coefficient on the upper surface of the aerofoil has a negative value because the gauge pressure is taken as zero. The aerofoil is of such a design that the upper surface has a lower pressure coefficient on comparison with the lower surface. The pressure on the lower surface of the aerofoil is almost equal to the free stream pressure. According to Bernoulli's theorem, we know that an object will move from a high pressure region to a low pressure region. The proper lift in the aerofoil is due to this theorem.

The XY plot and contours of pressure coefficient for various angles of attack is as shown in the following figures.

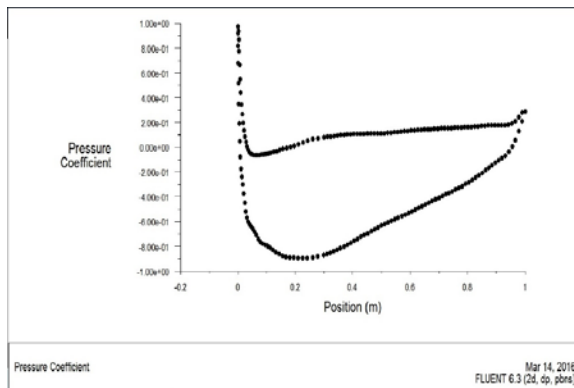


Fig 3: XY plot of pressure coefficient at AOA 1

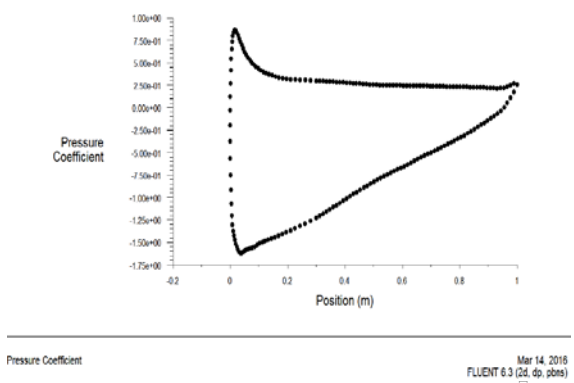


Fig 4: XY plot of pressure coefficient at AOA 6

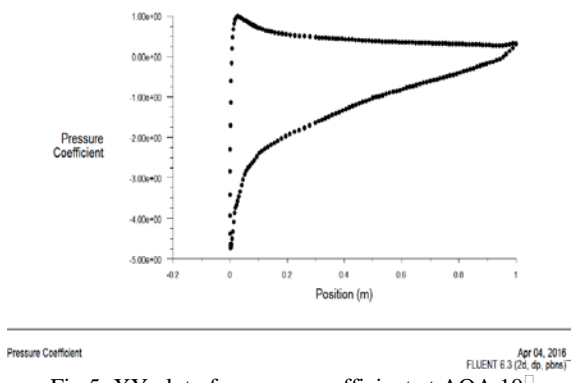


Fig 5: XY plot of pressure coefficient at AOA 10

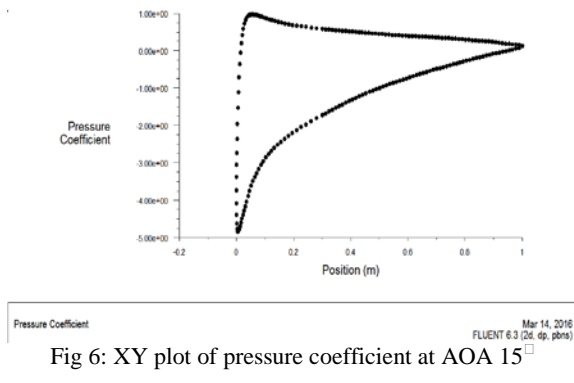


Fig 6: XY plot of pressure coefficient at AOA 15

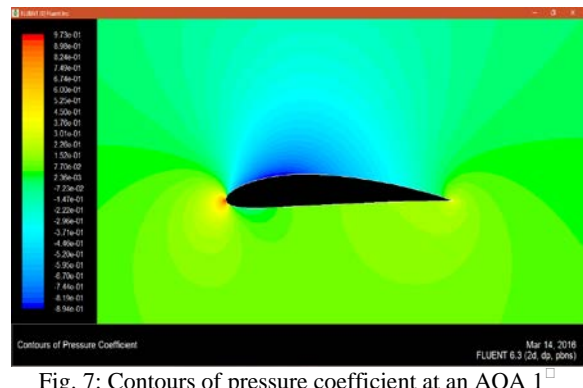


Fig. 7: Contours of pressure coefficient at an AOA 1

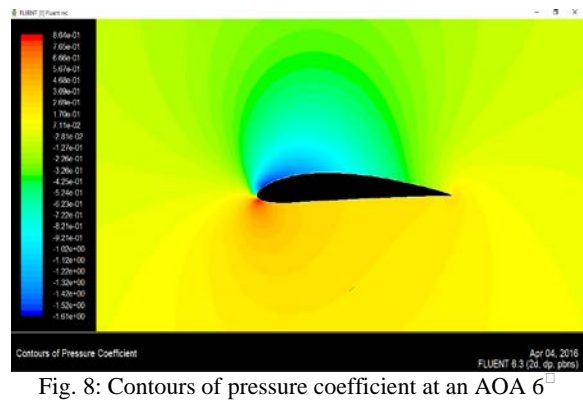


Fig. 8: Contours of pressure coefficient at an AOA 6

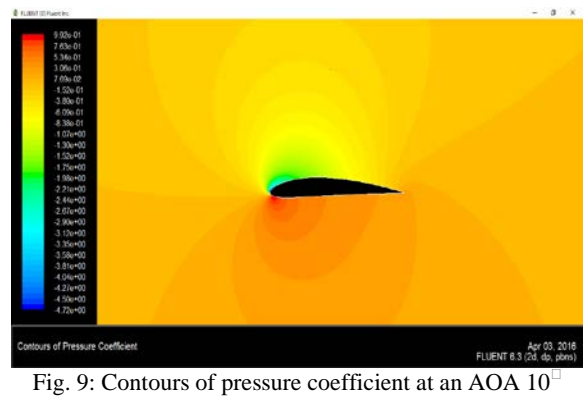


Fig. 9: Contours of pressure coefficient at an AOA 10

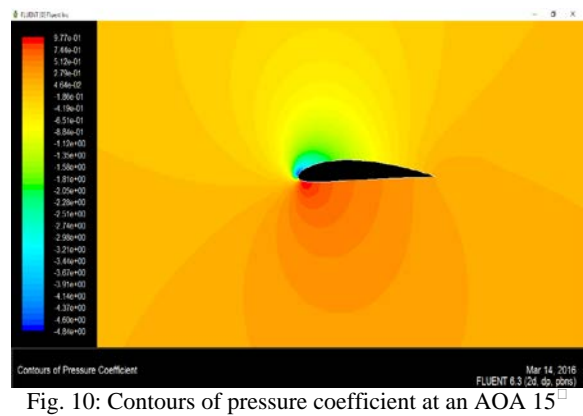


Fig. 10: Contours of pressure coefficient at an AOA 15

## **6. Conclusion**

From the study that has been conducted on NACA 4412 aerofoil we could conclude that a higher pressure coefficient was observed in the lower portion of the aerofoil that remained almost constant, whereas the upper surface of the aerofoil exhibited a much lower pressure. As the angle of attack of the aerofoil was increased there was a rapid increase in the lift force.

## **7. References**

- [1] Mr. Mayurkymar kevadiya, "CFD Analysis of Pressure Coefficient for NACA 4412", International Journal of Engineering Trends and Technology (IJETT) – Volume 4 Issue 5 - May 2013, Page 2041
- [2] MD. Safayet Hossain, Muhammad Ferdous Raiyan, Mohammed Nasir Uddin Akanda, Nahed Hassan Jony, "A comparative flow analysis of NACA 4412 and NACA 6409 aerofoil", International Journal of Research in Engineering and Technology
- [3] Karna S. Patel, Saumil B. Patel, Utsav B. Patel, Prof. Ankit P. Ahuja, "CFD Analysis of an aerofoil", International Journal of Engineering Research Volume No.3, Issue No.3, pp : 154-158.
- [4] S.Kandwal, Dr. S. Singh, "Computational Fluid Dynamics Study of Fluid Flow and Aerodynamic Forces on an Airfoil", IJERT, Vol. 1 Issue 7, September – 2012.