

TWO-DIMENSIONAL ANALYSES BASED COMPUTATIONAL FLUID DYNAMICS ON NACA 4412 AIRFOIL

ABSTRACT

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In this study, we focus primarily on assessing the aerodynamic effect on NACA 4412 2D airfoil across the six geopolitical zones in Nigeria. The performance of an airfoil of a wind turbine blade is influenced by aerodynamic characteristics and aerodynamic effects. This involved the selection of a suitable airfoil for wind turbine blade design calculations. The blade profile of the NACA 4412 airfoil is considered for these studies. The airfoil geometry was created using Ansys gambit 2.4.6 which was later exported to Ansys Fluent 6.3.26 for Computational Fluid Dynamics CFD analysis across the six geopolitical zones in Nigeria. The result of computational analysis based on Q-blade as shown in the figure implies that the airfoil is optimum at 60 angle of attack. The computed net lift and drag forces for North-east, North-west, North-central, South-south, South-west and South-east are given as 148.26N, 222.66N, 138.26N, 110.36N, 76.35, 90.07N (Lift Force) and 2.817N, 4.230N, 2.627N, 2.0967N, 1.451, 1.711N (Drag force) respectively. From the simulation, the result obeyed the fundamental law of fluid mechanics and the Bernoulli principle whereby at the leading edge there is higher static pressure than that on the trailing edge which is negligible. The velocity component shows that air must travel more distance per unit of time on the lower surface of the blade than on the upper surface. The airfoil is a second-order downwind and normal to the incoming airflow.

Keywords: Airfoil, Coefficient of lift, Coefficient of drag, Reynolds number and Angle of attack.

INTRODUCTION

An airfoil is a cross-section body or object that when placed in an airstream produces a useful aerodynamic force such as lift or drag force either to increase lift and minimise drag or vice versa P.J Manga *et. al.*, (2022a). The following are examples of an airfoil the cross sections of wings, propeller blades, windmill blades, compressor and turbine blades in a jet engine, and hydrofoils P.J Manga *et. al.*, (2022b). The basic geometry of an airfoil is shown in Figure 1.

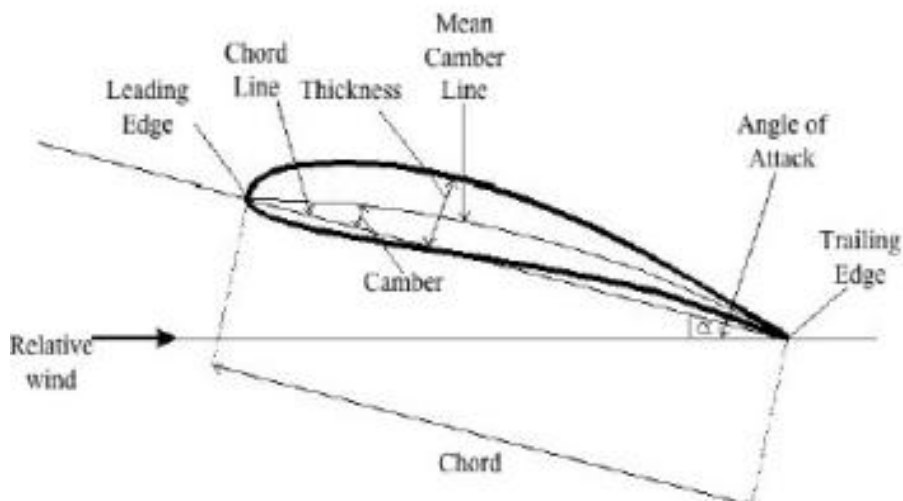


Figure 1: 2D airfoil's geometry

LIFT AND DRAG

Lift and Drag force is the component of forces that arise as a result of pressure differences according to Bernoulli law P.J Manga *et. al.*, (2023a). The lift force acting on a body is that component of a force that is perpendicular to the undistributed wind stream or the force on the body that acts in a direction normal to the aero flow direction P.J Manga *et. al.*, (2023b). The lift will only occur if the fluid blends in a circulatory flow about the body such as that which exists about a whirling cylinder S Kandwal *et. al.*, (2012). This reduced the static pressure with an increase in the velocity of the body. The velocity beneath will slow down which will give an increase in static pressure. On this note a normal upward force is created by the airfoil of a wind turbine blade called the Lift Force P.J Manga *et. al.*, (2023a).

$$Lift_force = 1/2 * \rho * A * V^2 * CL \quad 1$$

The drag is that component of force produced by an airfoil when placed in the path of an airstream. This force acts on a body in an oncoming flow and is defined as the force that is in a direction parallel to the direction of the undistributed airstream flow Nathan Logsdon (2006).

$$drag_force = 1/2 * \rho * A * V^2 * C_d \quad 2$$

For a wind turbine to perform its desirable goal the lift force must be higher than the drag force at a lift-to-drag ratio of 27.54. At these ratios, the wind turbine is set for efficient extraction of wind energy at 6° angle of attack. If the angle of attack increases to some certain value, the lift force decreases with a rapid increase in drag force. Perhaps, it is important to know that the angle of attack plays an important role in determining the aerodynamic effect of a wind turbine blade. Lift and drag are presented in the figure below Mr Monir *et. al.*, (2012).

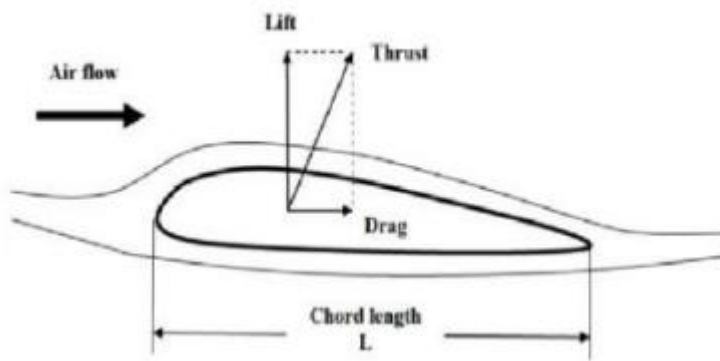


Figure 2: Forces on a stationary rotor blade in the airstream.

AIRFOIL DESCRIPTION

An airfoil simply refers to a two-dimensional cross-section shape of a wing or wind turbine blade whose purpose is to either generate lift or minimize drag when exposed to a stream of fluid. The word is an Americanization of the British term aerofoil which is derived from two Greek words Aeros ("of the air") and Phyllon ("leaf"), or "air leaf".

The NACA **four digits** of sectional airfoil define the wind turbine blade profile by www.airfoiltools.com:

- I. One digit describing the maximum camber as a percentage of the chord
- II. One digit describing the distance of maximum camber from the airfoil leading edge in tens of per cent of the chord
- III. Two digits describe the maximum thickness of the airfoil as a per cent of the chord.

MODELLING AND SIMULATION

NACA 4412 airfoil is used for this study which was selected using an airfoil design workshop and Q-blade for optimization and assessing its aerodynamic effect. Ansys Gambit Software was used for structural analysis and meshing of the wind turbine blade. The figure below shows the un-grid structural meshing of the airfoil and geometry of the 2D airfoil P.J Manga *et. al.*, (2023b).

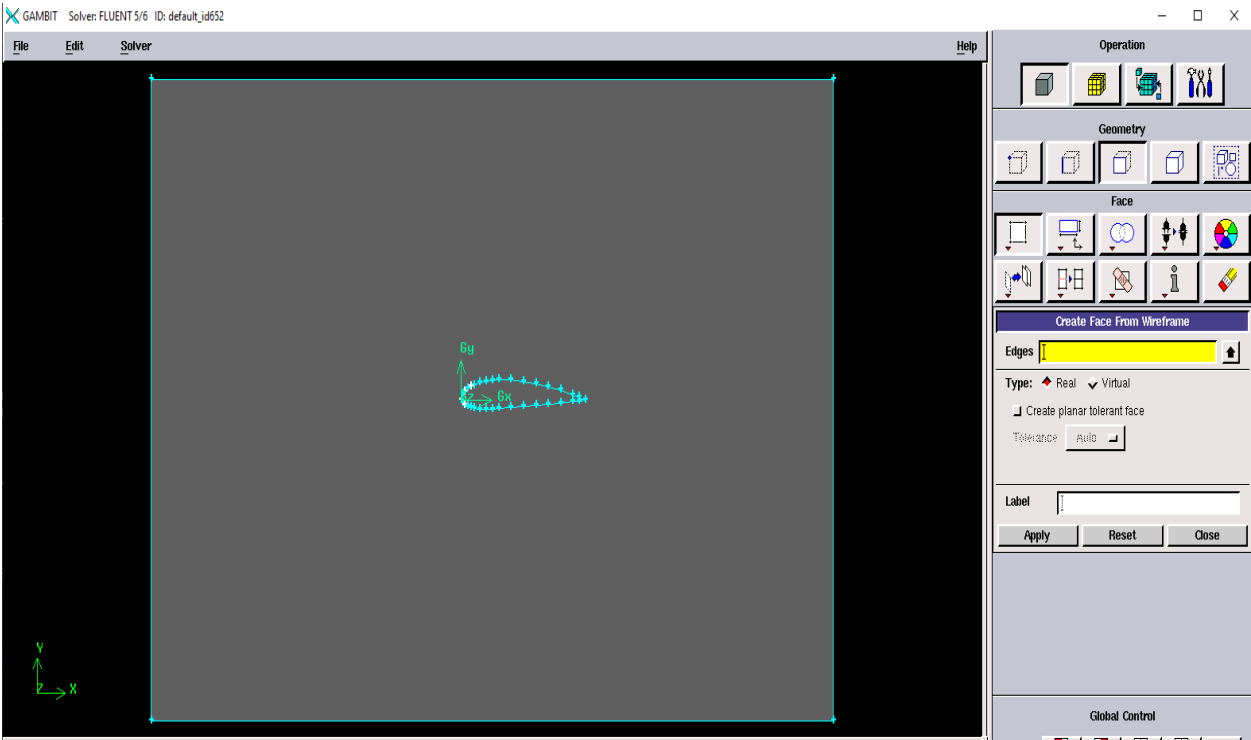


Figure 3: Geometry of Airfoil created in GAMBIT

The airfoil (Blade) geometric was generated using Ansys Gambit which was later exported to Ansys Fluent for structural analyses under a set of parameters which are given below by P.J Manga *et. al.*, (2022a).

Table 1: Definition of simulation parameters for NACA 4412 airfoil continuum

Solver	Pressure
Viscous Model	Spalart – Allmaras
Density (kg/m^3)	1.223
Viscosity ($kg/m - s$)	1.7889
Turbulent viscosity ratio	10.0
Inlet Velocity	North-east is 10.2m/s, North-west is 12.5m/s, North-central is 8.99m/s, South-south is 8.8m/s, South-west is 7.32mls and South-east is 7.95m/s.
Chord length	0.1m
Momentum	Second order downwind
Pressure velocity coupling	Simple

From the flow contours across North-Central, North-West, North-East, South-East, South-West and South-South, on the leading edge, the static pressure is high with negligible or little static pressure on the trailing edge. The fundamental law of fluid mechanics and Bernoulli Principle stated that due to pressure differences on both the upper and lower surface of the blade. The airflow will experience some “forces” while on the upper surface of the 2D airfoil, there is low static pressure.

Figure 4-6 shows that the simulated airfoil was designed at 6° angles of attack with the spalart-allmaras model. The pressure acting on the upper surface of the airfoil indicates that the air that flows on the down

surface of the blade must move more distance per unit of time than the air that flows on the upper surface of the blade. the airfoil is downward and normal to the incoming airflow.

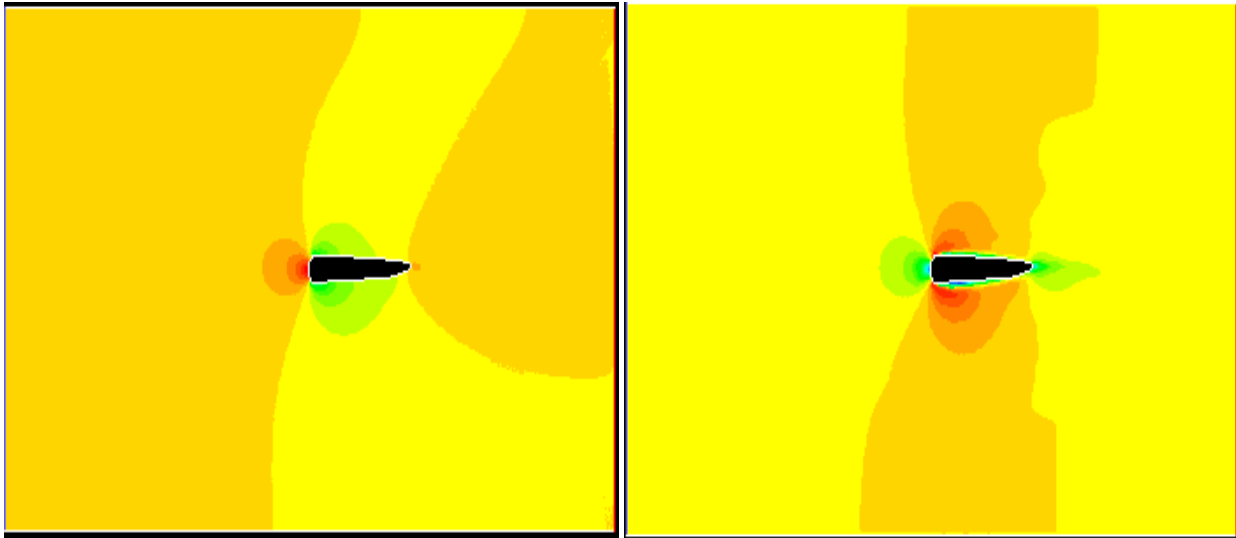


Figure 4: Contour Flow of Static Pressure and Velocity for North-Central

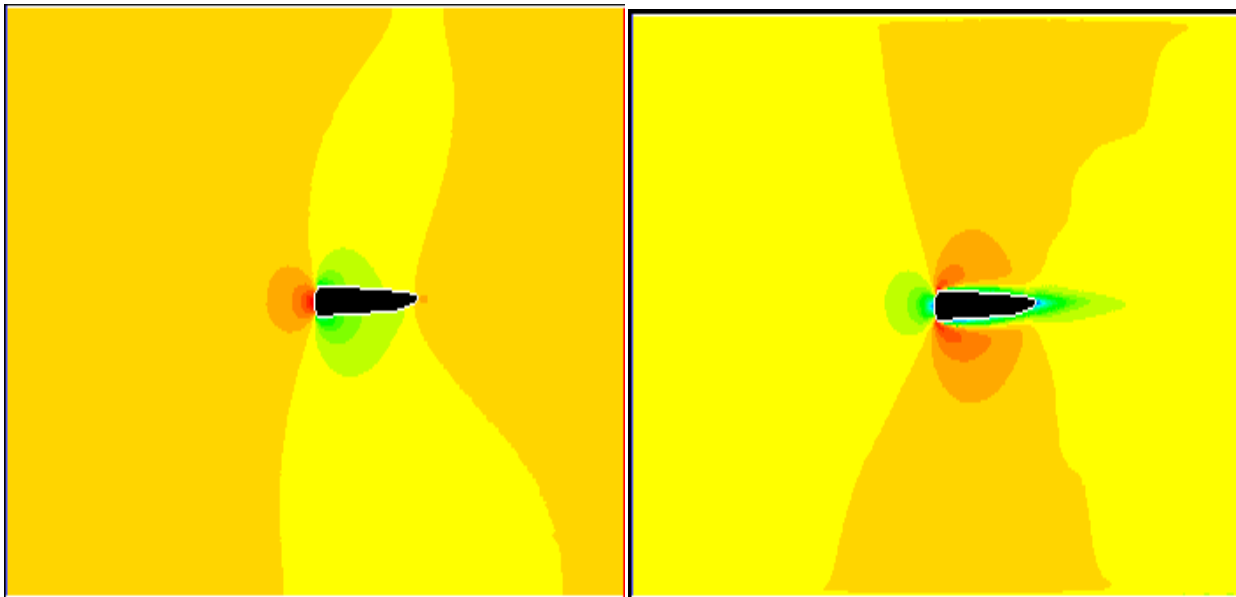


Figure 5: Contour Flow of Static Pressure and Velocity for North-East

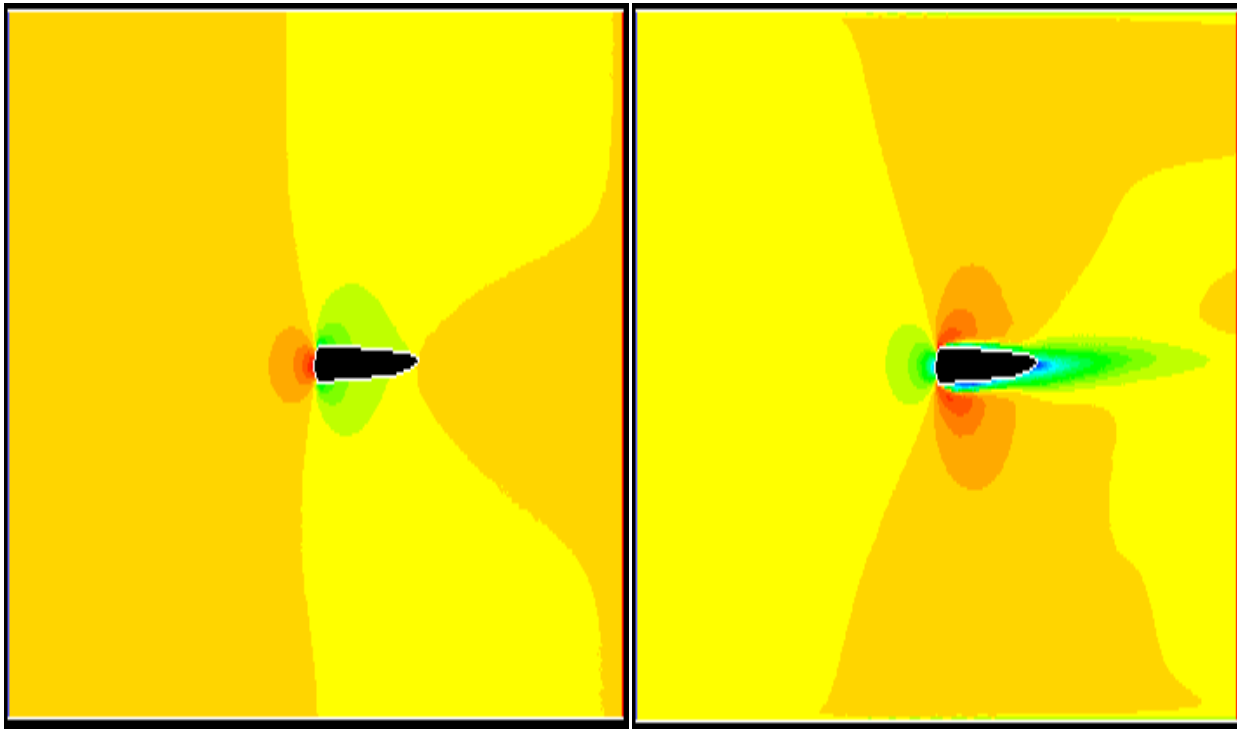


Figure 6: Contour Flow of Static Pressure and Velocity for North-West

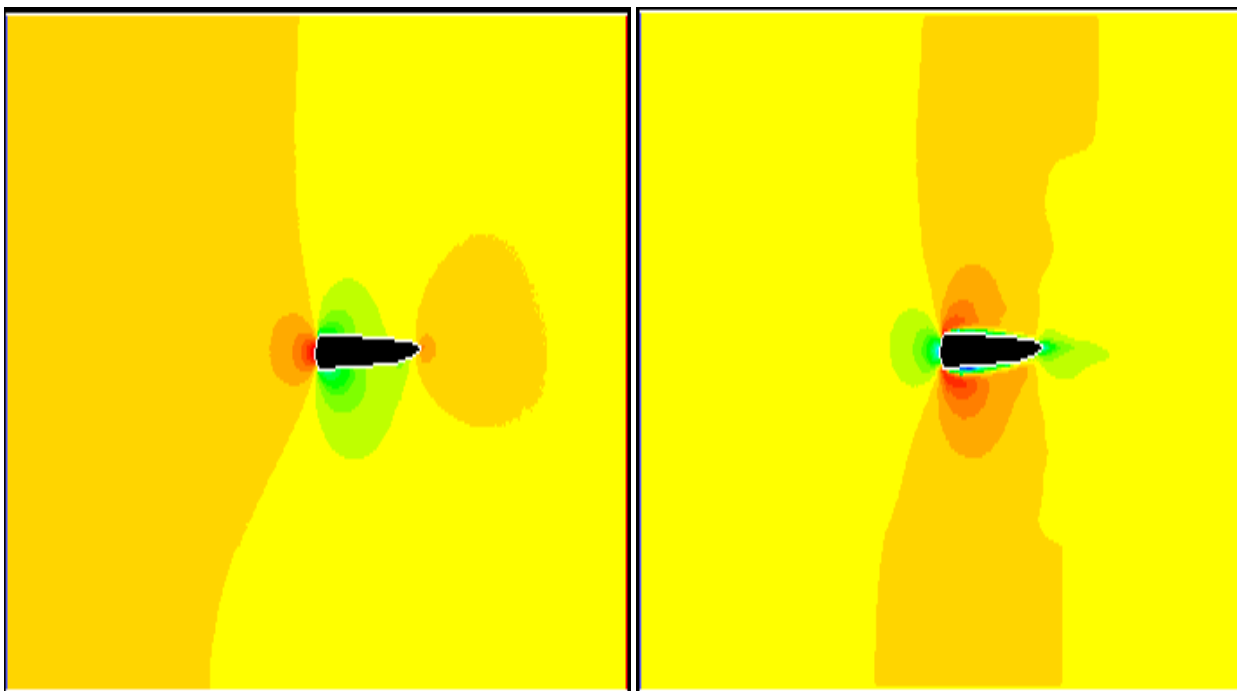


Figure 7: Contour Flow of Static Pressure and Velocity for South-East

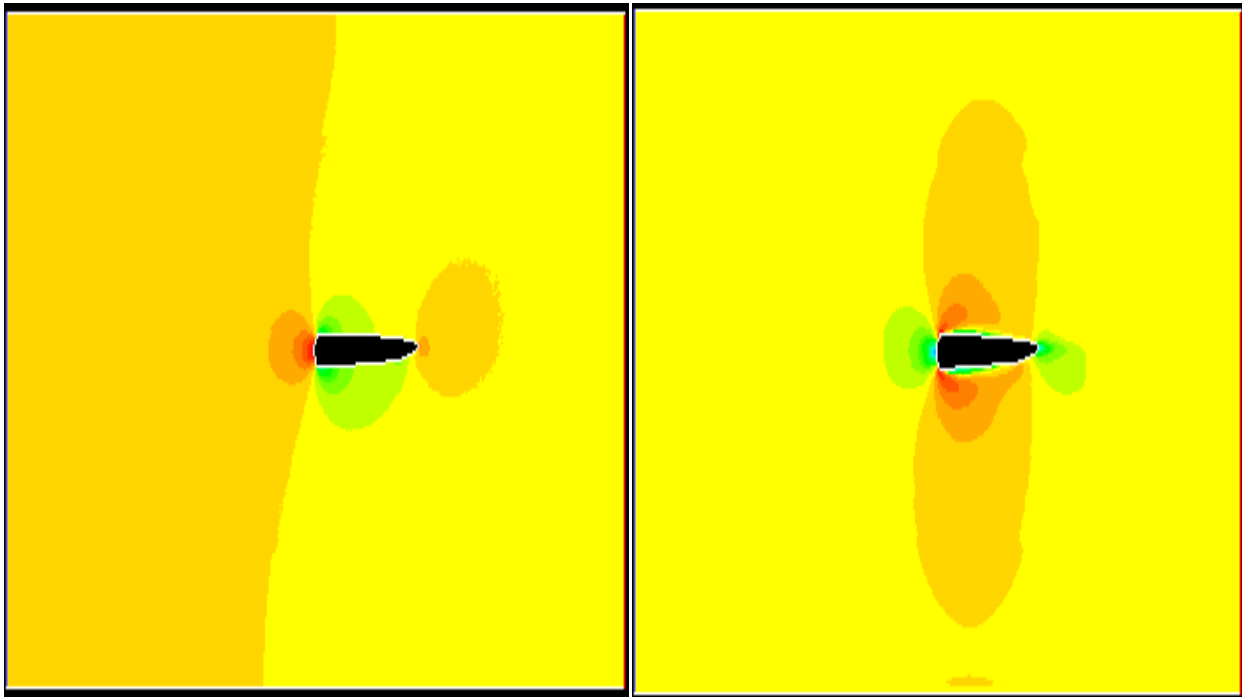


Figure 8: Contour Flow of Static Pressure and Velocity for South-South

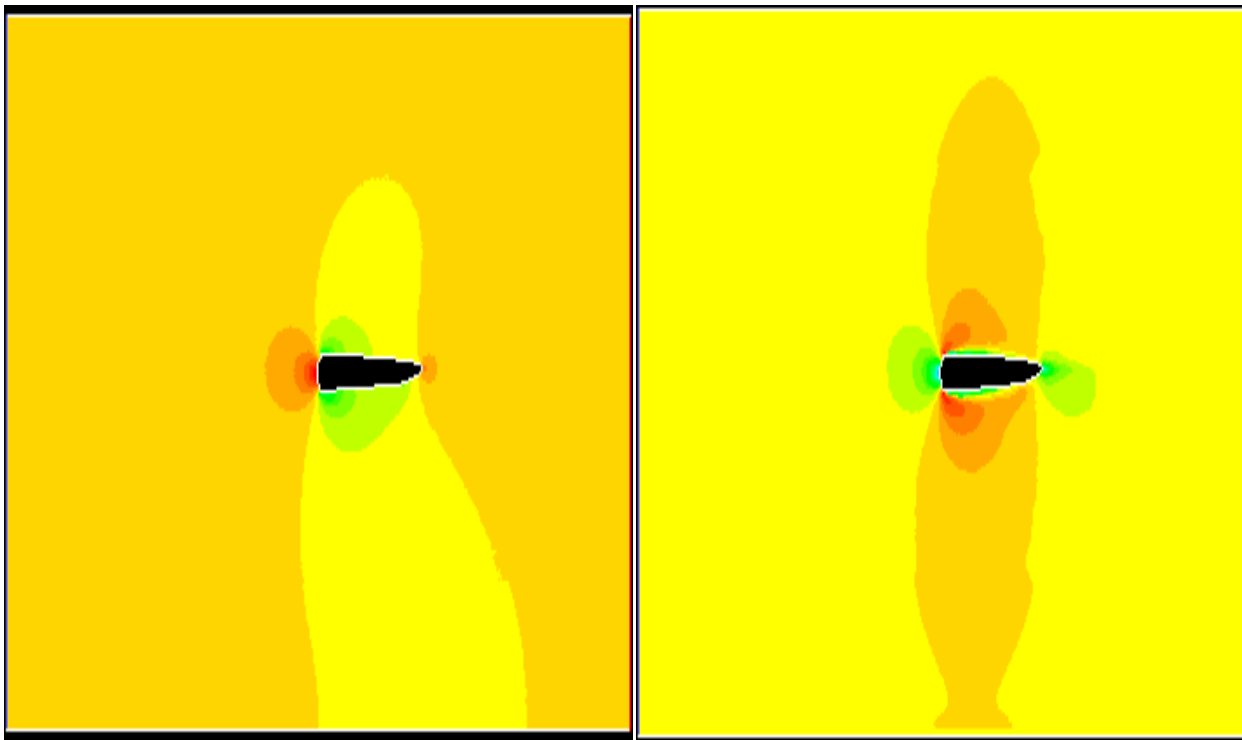


Figure 9: Contour Flow of Static Pressure and Velocity for South-West

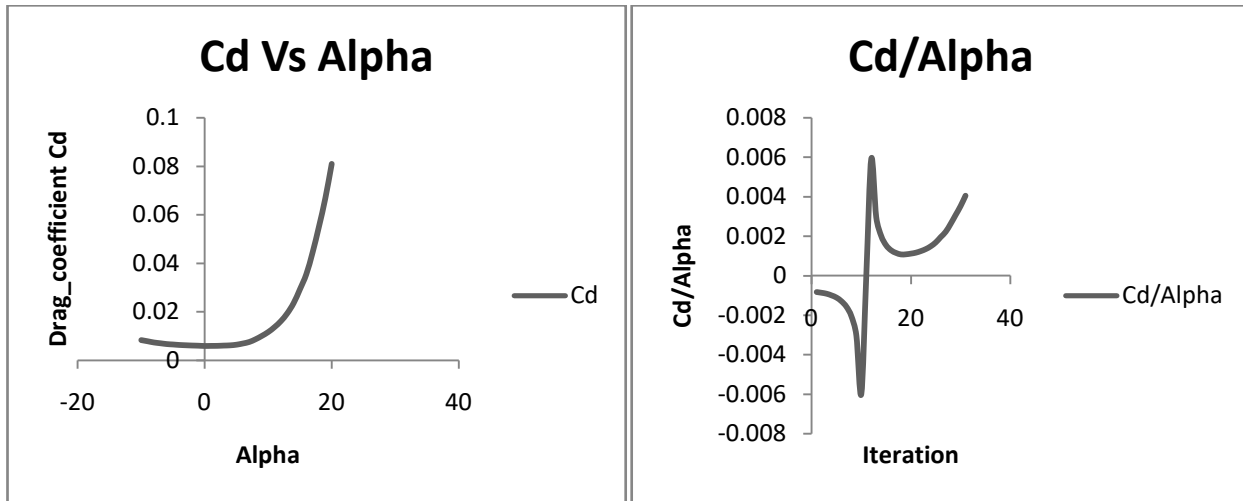


Figure 10: Computed Cd on Q-blade at 0 - 40° angle of attack and iteration.

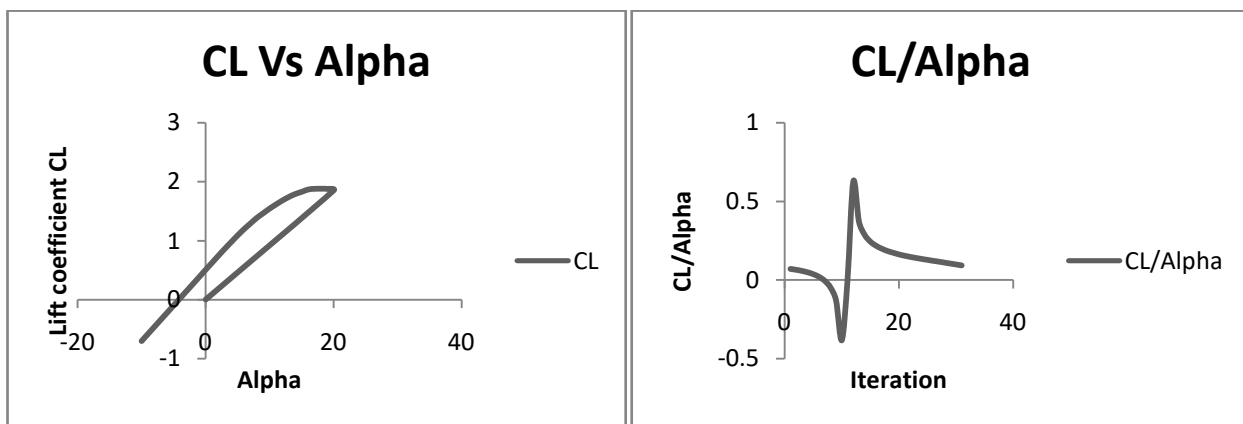


Figure 11: Computed CL on Q-blade at 0 - 40° angle of attack and iteration.

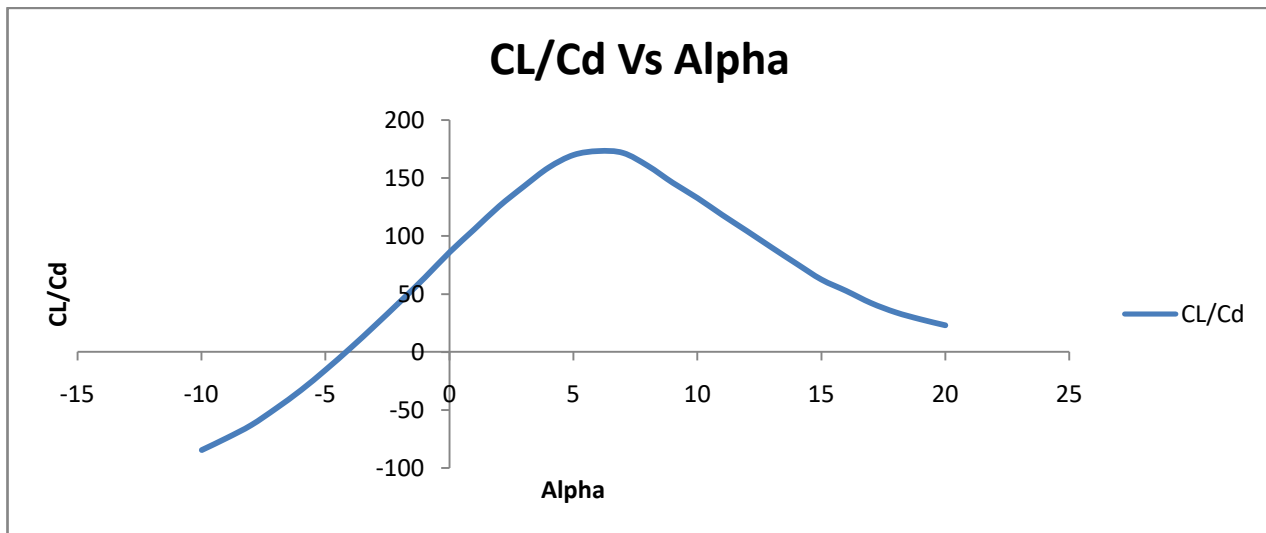


Figure 12: Computed CL / Cd based on Q-Blade at 0 – 40°

Figure 10-13 shows that at 6° angle of attack, the airfoil is optimum for efficient extraction of wind energy by the rotor blade machine. This implies that at each certain value of the angle of attack, the lift force will increase to an optimum value whereby any further increase in the angle of attack the drag force will be built up associated with a decrease in lift force.

CONCLUSION

The coefficient of Lift and drag is calculated for this NACA 4412 series for the angle of attack 0° to 40° . The coefficient of the Lift/Drag ratio increases with an increase in the Angle of attack up to 6° . Followed by a decrease in the Lift/Drag ratio as the angle of attack increases above 6° .

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