Aerodynamics Design and Analysis of Small Horizontal Axis Wind Turbine

Satyam Singh Tiwari[1], Prof. Yogesh Yadav[2]
[1]*M.Tech Scholar, Millennium Institute of Technology, RGPV Bhopal*
[2]*Assistant Professor, Millennium Institute of Technology, RGPV Bhopal*

Abstract- **Power has been extracted from the wind over hundreds of years with historic designs, known as windmills, constructed from wood, cloth and stone for the purpose of pumping water or grinding corn. Historic designs, typically large, heavy and inefficient, were replaced in the 19th century by fossil fuel engines and the implementation of a nationally distributed power network. Energy is essential to human civilization development. With progress of economics and socialization, there is an expanding demand on renewable energy resources to secure energy supply, such as solar power, wind power, tide and wave power etc. As a clean renewable resource, wind power plays a more and more important role in modern life. Power in the wind comes from the transformation of the air that is driven by the heat of the sun, which is abundant, clean and renewable. Wind turbine technology is one of the effective means to implement this renewable resource in order to produce environmentally friendly electrical energy. As it is an intricate system it depends upon the unification of multiple engineering disciplines, which comprises of structures, aerodynamics, controls and electrical engineering.**

A wind turbine converts kinetic energy into mechanical power through a rotor, and then converts the mechanical power into electric power through a generator which is linked to the rotor with and without a gearbox. Various types of wind turbines are designed to take advantage of wind power based on the principle of aerodynamics. Depending on the wind turbine rotor orientation, there are two types of wind turbine , horizontal axis wind turbine(HAWT) and vertical axis wind turbine(VAWT).When considering installation sites, there are onshore(free standing or building mounted) and offshore wind turbines. Based on the operation scheme, wind turbine can be divided into stall regulated (fixed pitch) wind turbine and pitch controlled (variable pitch) wind turbines. According to the relative flow direction of the wind turbine rotor, horizontal axis wind turbine are either upwind or downwind turbines.

Index terms- Blade momentum theory, Computational fluid dynamics, Horizontal Axis Wind Turbine, Blade air foil.

I. INTRODUCTION

Energy is important to human civilization development. With progress of economics and socialism, there is an expanding demand on renewable energy resources to secure the supply of energy such as solar power; wind power .Wind energy is a plentiful resource in comparison with other renewable resources. In wind energy wind power is converted to electrical energy and this machine is called the wind generator. Power in the wind comes from the transformation of the air that is driven by the heat of the sun, which is abundant, clean and renewable. Unconventional wind turbines are those that differ significantly from the most common types in use. As of 2012, the most common type of wind turbine is the three-bladed upwind horizontal-axis wind turbine (HAWT), where the turbine rotor is at the front of the nacelle and facing the wind upstream of its supporting turbine tower. A second major unit type is also classified by its axis: the vertical-axis wind turbine (VAWT), with blades extending upwards that are supported by a rotating framework.

A wind turbine is a complex system which consists of several components, including a rotor, a transmission system, a generator, a nacelle, a tower and other electro-mechanical subsystems. The rotor blades are the most important components. In order to transfer wind energy into mechanical power, the blade is designed as aerodynamics geometry with nonlinear chord and twist angle distributions. The section view of a wind turbine blade is of an aerofoil shape, which is generated to high lift and low drag forces. The shape of the blade is vital as it determines the energy captured, and the loads experienced. The study of interaction between wind flows and wind turbines is wind turbine aerodynamics which plays an important role in wind turbine design and analysis.

Wind Turbine Aerodynamics

Aerodynamic performance is fundamental for efficient rotor design. Aerodynamic lift is the force responsible for the power yield generated by the turbine and it is therefore essential to maximize this force using appropriate design. A resistant drag force which opposes the motion of the blade is also generated by friction which must be minimized.

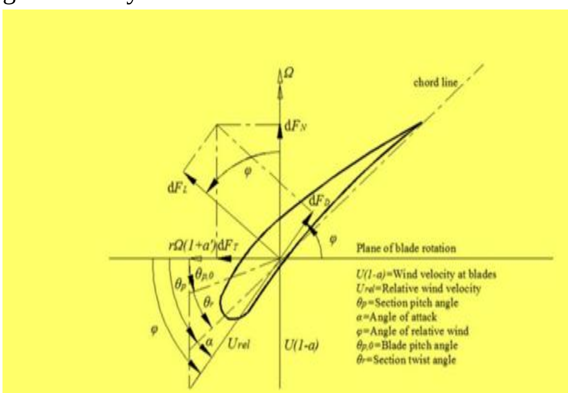

Figure 1: Schematic diagram of blade, angle of attack, pitch angle etc. [8]

It is then apparent that an aerofoil section with a high lift to drag ratio typically greater than 30, be chosen for rotor blade Coefficient of lift, Lift to Drag Ratio, Coefficient of drag.

II. LITERATURE REVIEW

Relating to the current stated work a literature survey was carried out. The summary of the reviewed papers is given below.

Kunduru Akhil Reddy et al. [2015] investigated a brief research, study, design and analysis on wind turbine. This paper evaluates the aerodynamic performance of variable speed fixed pitch horizontal axis wind turbine blade using two and three dimensional computational fluid dynamics. The primary objective of the paper is to increases the aero dynamic efficiency of a wind turbine. The blades are designed using different type of airfoils which are associated with angle of attack. The blade design is responsible for the efficiency of the wind turbine. The design of the blade is done using Q- blade software. The result indicates that the power output is determined using blade elemental theory. The power output of designed blade design is higher when compare to existing design of the blade.

M. Abid et al. [2015] analyzed the design, development and testing of a savonius and darrieus vertical axis wind turbine. This paper shows that vertical axis wind mill is more efficient when compare to horizontal axis wind mill. The darrieus turbine consists of 3 blades which can start alone at low wind speed. When savonius turbine is attached on the top of existing wind mill which provide the self-start at low wind speed. The result indicates that the darrieus vertical axis wind turbine acts as a self-starter during the testing. The function required the starting mechanism which can be provided by the combination of NACA 0030 aerofoil and savonius turbine. The high blade thickness of the NACA 0030 aerofoil will improves the self-starting capability of the turbine.

Niranjana.S.J [2015] investigated the power generation by vertical axis wind turbine. In this paper the power is generated by fixing the wind mill on the road high ways .when the vehicle is passed through the road at high speed the turbine of the wind mill rotates and generates the power sources. This analysis indicates that the vertical axis wind turbine can be able to attain the air from all the direction and produces the power of 1 kilowatt for a movement of 25 m/s. The efficiency of vertical axis wind turbine can be increases by modifying the size and shape of the blade.

Xinghui Q. and Qinkai H. [2018] have studied Load sharing characteristics of planetary gear transmission in horizontal axis wind turbines. With the increase of wind turbine size gravity becomes an important non-torque excitation source. Gravity disrupts the cyclic symmetry of the planetary gear and causes unequal load-sharing. Because of the specific operation conditions, the bedplate will tilt and lead to the offset of the gear plane and vertical plane. Taking gravity, tooth separation, backside contact and bedplate tilt angle into consideration, a rotational-translational-axial dynamic model of the spur planetary gear is developed. With two different load-sharing factor models, the load-sharing characteristics of the planetary gear in horizontal axis wind turbines are numerically investigated. The effects of gravity, ring support stiffness and bedplate tilt angle on load-sharing characteristics are systematically examined.

When planets move to certain positions, severe unequal load-sharing and backside contact are more likely to happen. Load-sharing characteristics change with the bedplate tilt angle and the ring support stiffness, and the variation trend is closely related to the occurrence of tooth separation and backside contact.

Germano D. and Ettore P. [2019] have studied Kinematic and power-flow analysis of bevel gears planetary gear trains with gyroscopic complexity. In this paper a method for the kinematic and power - flow analysis of bevel epicyclic gear trains with gyroscopic complexity. By gyroscopic complexity, we mean the possibility of the gear carrier to be a floating link as, for instance, in robotic gear wrists. Thanks to the new formulas herein deduced, the methods based on the graph representation of planetary spur gear trains have been extended to bevel gear trains. In particular, the well-known Willis equation has been modified to maintain its validity for bevel gears. The modified Willis equation was then embodied in new power ratio expressions. Under our simplifying hypotheses of absence of friction and constant angular speeds, it is shown that gyroscopic torques do not enter into power flow analysis. Two numerical examples are discussed. A fundamental step in mechanical efficiency analysis is the ascertainment of the amount of power flow through the meshing gears. Although not self-evident, due to power circulation, some meshing gears may sustain a power higher than the input one. Power circulation that usually occurs with very low transmission ratio must be detected at the early design stages in order to dimension properly meshing gears and lubricating methods. Most of the contributions are related to spur gear trains. In this case the kinematics can be studied with the classic scalar Willis equation.1 The relationship between the absolute angular speeds of bevel gear trains is not scalar and this complicates the analysis. This paper focuses on kinematic and power flow analysis of planetary trains with bevel gears. It can be considered as an attempt to extend the modus operandi of the analysis methods devised for spur gear trains to bevel gear trains.

Renewable technology which is emerging technology rapidly expands as a good option in the power generation sector. In India, due to Jawaharlal Nehru solar mission which have a target to established 20,000 MW till 2020, Wind industries expand in electricity generation. Very important role played by deregulation act of government that is electricity act 2003 technology is one of the glowing technology compare to other wind energy technology because of its high efficiency. The flow field is three-dimensional, incompressible, unsteady, turbulent, and separated to a large extent.

From the above literature review, it is clearly understood that the efficiency of wind turbine is always based on the parameters such as design and size of the blade, aspect ratio, tip speed ratio, blade angles and velocity. The power production of combined vertical and horizontal wind mill is high compare to vertical axis wind turbine and horizontal axis wind turbine. It requires less space for high generation of electricity.

III. RESEARCH OBJECTIVES

The aim of this research work is to evaluate the aerodynamics performances of variable fixed-pitch horizontal-axis wind turbine blades through two and three dimensional computational fluid dynamics (CFD) analysis.

- To analyses the aerodynamic performance of different aerofoil.
- A simulation model can be created in GAMBIT directly or imported from other CAD software packages, Such as Solid Works and Pro/Engineer.
- Conduct the analytical design for a small-scale, stall-regulated horizontal axis wind turbine blade.
- Employ optimization theory in the design method.
- Design specifically for low wind speed application (2.5 to 25m/s).
- Ensure peak performances over the selected range of wind speeds.

IV. METHODOLOGY

Geometry Setup

2D Airfoil generated in pre-processor of the Ansys FLUENT software for the front rotor blade airfoil generate with chord length 0.70m(700mm) blade length 1.5m and chord thickness is 21%of the chord length .this is NACA 0021 airfoil.

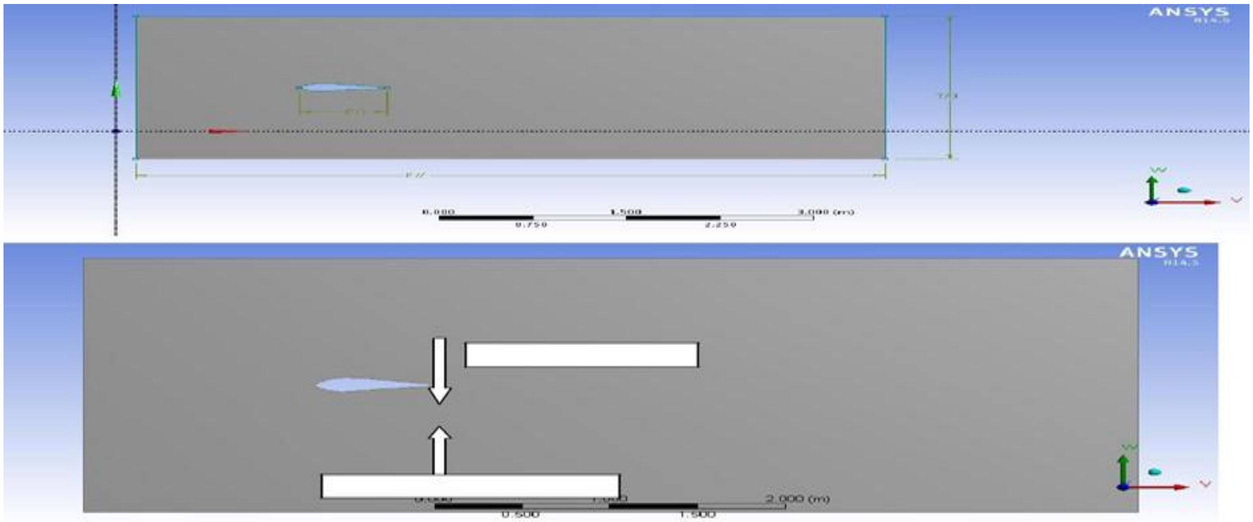

Figure 2: Blade airfoil of the Ansys fluent software

Table 1: Geometry of the Rear Rotor airfoil

Rear Rotor radius	1.5m
Rear Blade radius	1.4m
Chord length at root section	0.70m
Chord thickness	21% of the radius at 30-40% position
Chord length at tip	0.21m

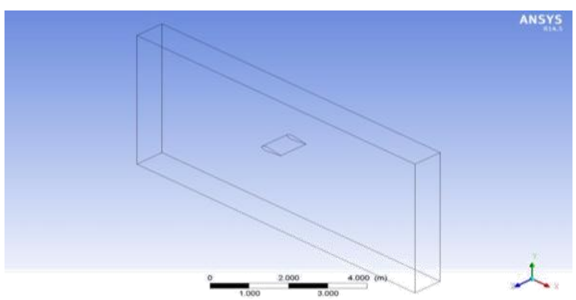

Figure 3: 3-d design of blade

Meshing

Meshing of the geometry after creating the geometry, start the meshing modeler meshing, sizing, and name selection are all of the process are held on this meshing modeler. The mesh consists of 50,000 quadrilateral cells, of which, 300 are on the aerofoil. A large number of grids around the aerofoil surface is used to capture the pressure gradient accurately at the boundary layer. This is because the adverse pressure gradient induces flow separation. Stall will occur when separation region extends. In the far-field area, the mesh resolution can become progressively coarser since the flow gradients approach zero in order to compare the experimental data with the simulation outcome under the same testing condition, the Reynolds number was set up as 1,000,000 and wind speed is 10 m/s.

Boundary Conditions

Table 2: Computational feature of the Rear rotor Airfoil on CFD

Airfoil	NACA0021
Solver	Pressure-based
Simulation	Steady simulation
Turbulent model	Spalart-Allamaras
Fluid material	Air
Boundary condition	Pressure-far-field
Temperature	300 K
Interpolating scheme	• Pressure(standard) • Density (second order upwind) • Modified turbulent viscosity (second order upwind)
Kinematic viscosity	Sutherland
pressure	101325 pa
Density	1.25 kg/m^3

V. RESULTS AND DICUSIONS

The Design of the Dual Rotating Wind Turbine blades is analyzed by using the Ansys Fluent (ICEM CFD 14.5) Software. The author has assumed the value of rear rotor diameter 3m and front rotor diameter 1m and Rated wind speed of Bhopal is 10m/s.

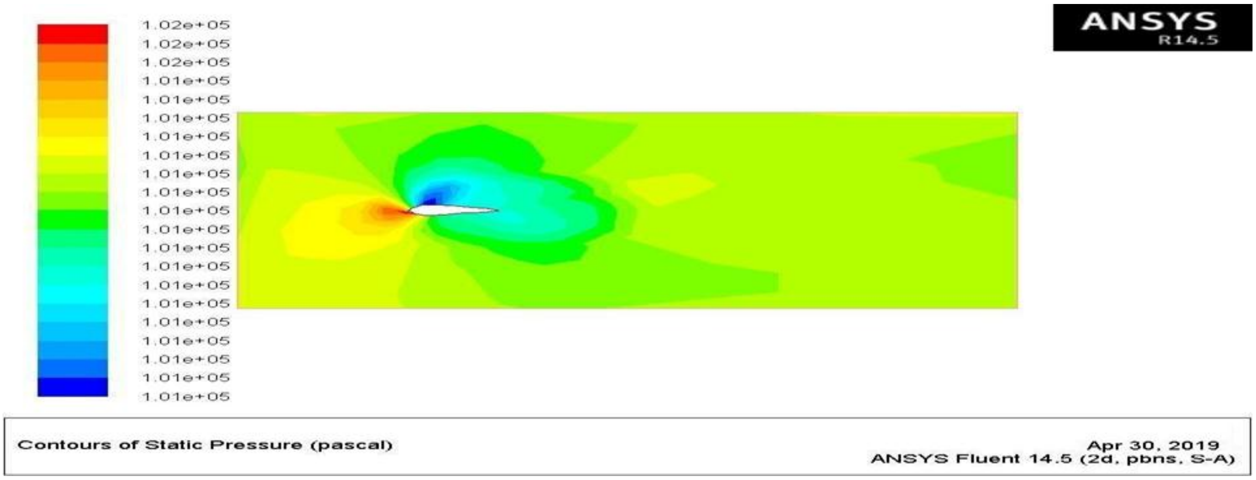

Figure 4: Pressure contour at AOA is 10 degree.

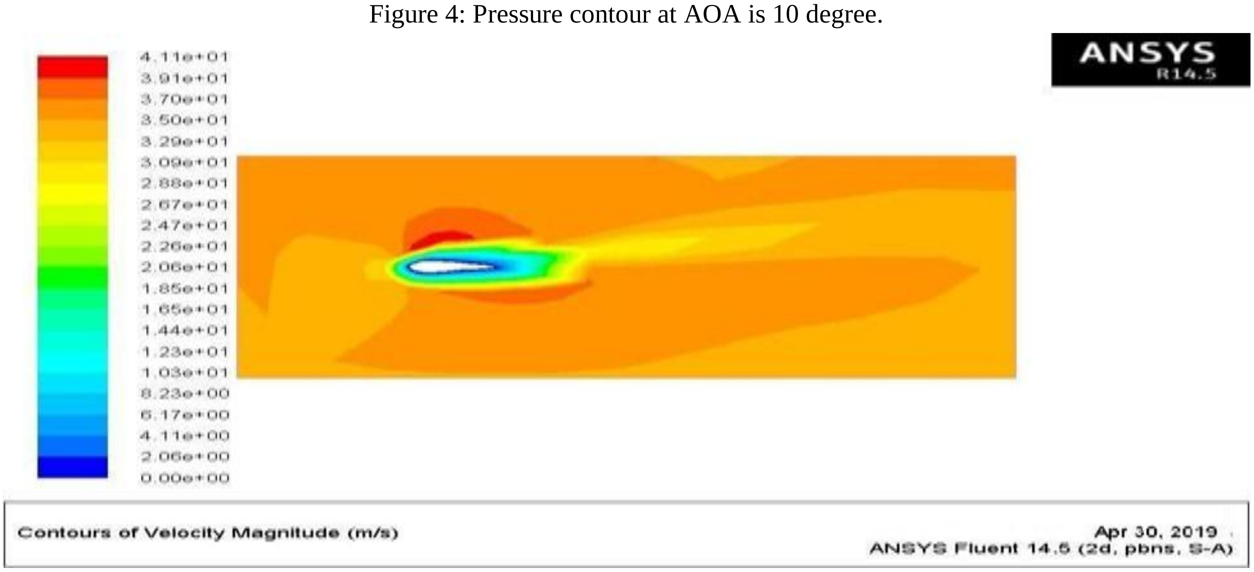

Figure 5: Velocity contour at AOA is 10 degree.

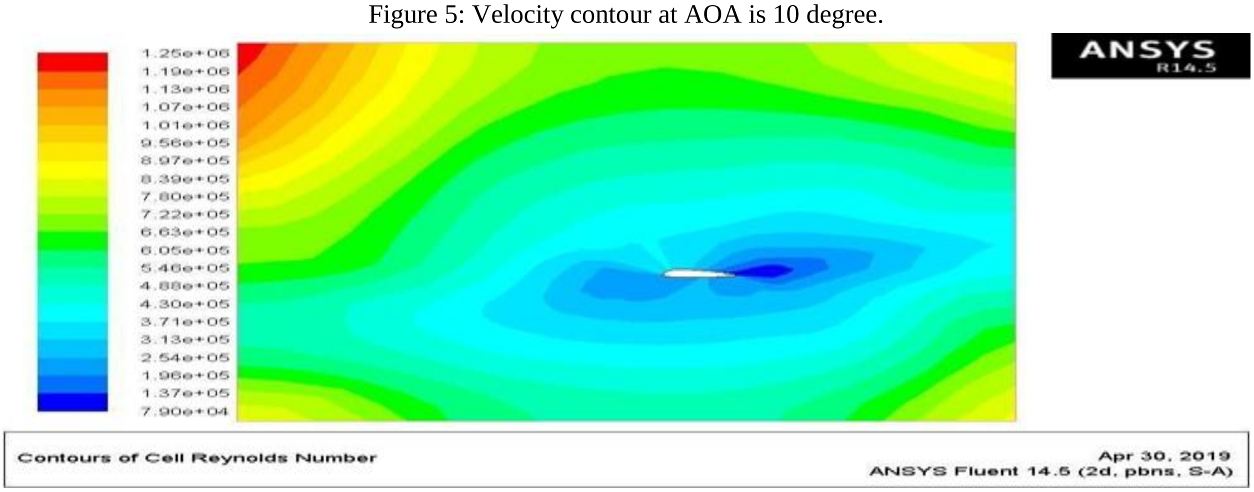

Figure 6 Reynold's number contour at AOA is 10 degree

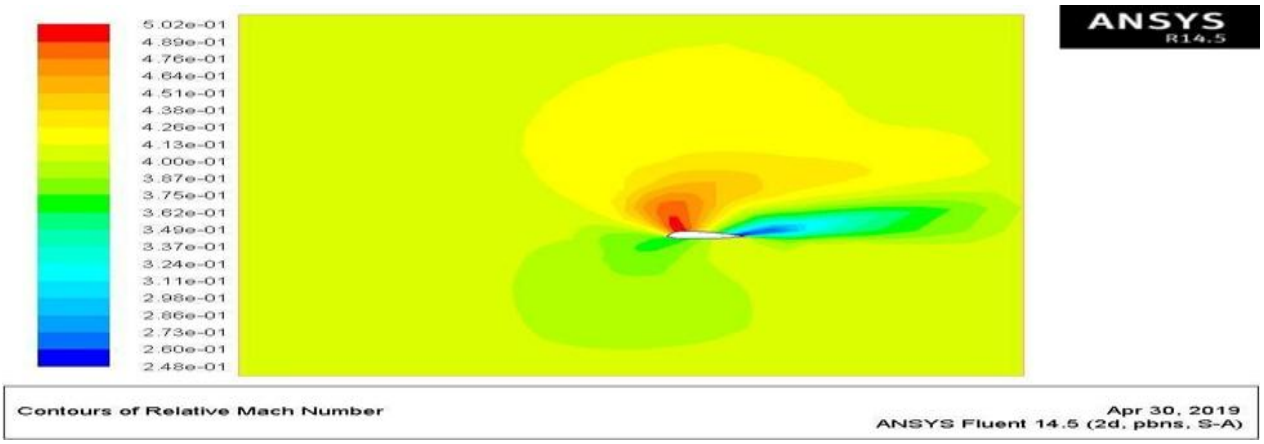

Figure 7: Relative Mach number contour at AOA is 10 degree.

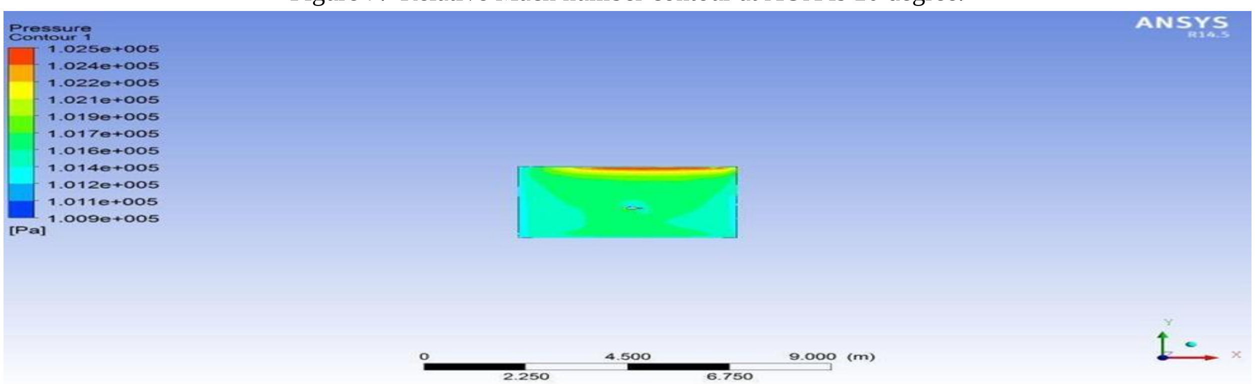

Figure 8: Pressure contour at front rotor.

Table 3: Force Calculation at ANSYS FLUENT software

	Front rotor	Rear rotor
Total Forces	103.89844N	102.69141 N
Coefficient of pressure	169.6301	17.819525
Forces on airfoil Top	7.18387 N	-1.8091N
Forces on airfoil Bottom	27.048N	13.7922N
Lift force	103.89844N	103.91016N
Drag force	31.608582N	11.1931N

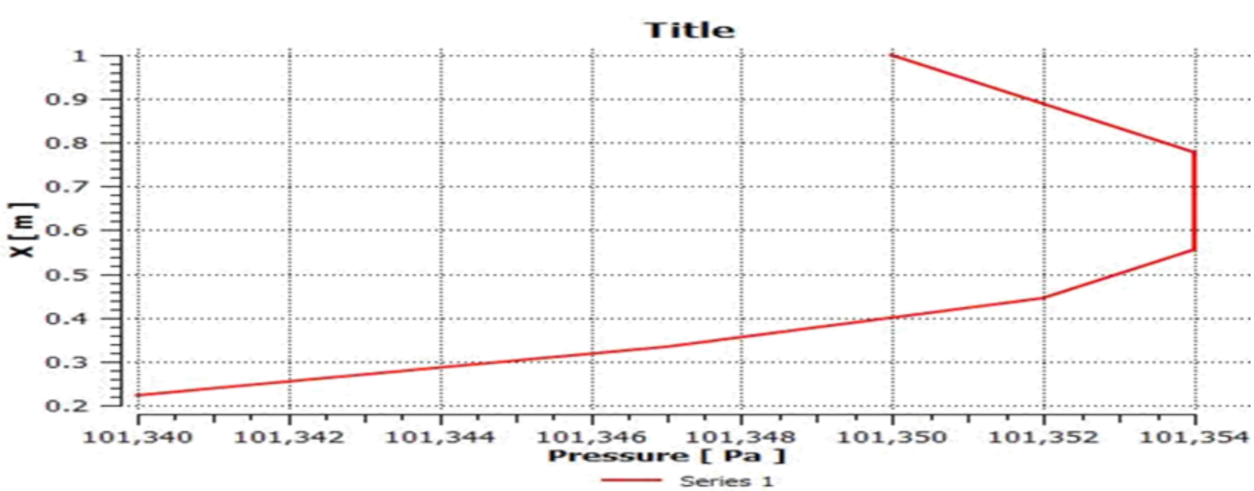

Figure 9: pressure variation flow with respect to x direction.

VI. CONCLUSIONS

An investigation of the solution space for the profile optimization enables the user to understand the influence of each design variable on the optimization objective and thus understand the progress of the optimizer during each iteration. This aids the user to select realistic design variables for the optimizer to use. Furthermore, the solution space provides insight into the most suitable optimization methods to be used. When new air foils are generated by blending shape functions, it is advisable to include basic shapes, such as triangles, amongst the air foils. This allows the optimizer to conduct localized changes to the new airfoil, as opposed to the entire foil being altered.

A 1.5 kW horizontal axis wind turbine blade design has been carried out with an existing generator and a wind speed resource. With a rated wind speed of 10m/s and a generator of 1.kW, a rotor of 1.5m radius of rear rotor and 0.5m for the front rotor and the NACA airfoil has been applied. It has been predicted to be with a power coefficient of 0.37 at the tip speed ratio of 3 based on the BEM theory. A further structure analysis and testing will be developed in the future.

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