Design and Analysis of Archimedes Aero-Foil Wind Turbine Blade for Light and Moderate Wind Speeds

Dr S. Srinivasa Rao[#1] Kota Shanmukesh[#2], M K Naidu[3,] Praveen Kalla[4]
[1,3,4] Associate Professor, [2] Postgraduate student
Department of Mechanical Engineering, MVGR College of Engineering (A)
Vizianagaram, Andhra Pradesh., India
[2]*Shanmukesh.kota@gmail.com*

Abstract — the paper focused on Archimedes wind turbine adopted for household domestic electricity generation. The design and analysis of Archimedes aero-foil wind turbine (AAWT) will be described below. The wind turbine is a converter which converts the kinetic energy into rotational energy or mechanical energy then convert it into electrical energy. Wind turbines classified into two type's i.e. Horizontal axis wind turbine (HAWTs) and Vertical axis wind turbine (VAWTs). Archimedes wind turbine (AWT) is a new type of Horizontal axis wind turbine comprising three circular blades which are wrapped around each other and then expanded. This special design ensures that more air is drawn into the turbine. AAWT is an enhanced form of AWT introducing aero-foil profile to the blade. The ultimate objective of this paper is the torque comparison of Archimedes aerofoil wind turbine with an Archimedes spiral wind turbine. The design of a new wind turbine blade has done by introducing NACA 6409 by using CREO software package and the computation fluid dynamics (CFD) analysis was used to estimate the torque characteristics of the AAWT blade. From the CFD analysis, it is concluded that the torque obtained by AAWT is more at light and moderate wind speeds which means more suitable for urban areas.

Keywords — *Archimedes wind turbine, aerofoil, Computational Fluid Dynamics (CFD), Fluent, Torque,*

*****

I. INTRODUCTION

Wind energy is an abundant resource in comparison with other renewable resources. Moreover, unlike the solar energy, the utilization could not be affected by the climate and weather. It is a source of renewable power which comes from air current flowing across the earth's surface. Wind turbines act as a converter which extracts kinetic energy from wind and converts it into usable power which can provide electricity for the home, farm, school or business applications on small (residential), medium (community), or large scales. A wind turbine consists of several main parts, i.e. the rotor, generator, control system and so on. The rotor is driven by the wind and rotates at a predefined speed in terms of the wind speed so that the generator can produce electric energy output. A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine. A vertical axis wind turbine has its shaft normal to the ground. Power of a wind turbine depends on wind speed and blade design, in order to extract the maximum kinetic energy from wind, researchers put many efforts into the design of effective blade geometry. The orientation of the shaft and rotational axis determines the first classification of the wind turbine.

In the early stage, the aerofoil shapes of aeroplane wings were used for wind turbine blade design. Selection of aerofoil shape is the most crucial of the wind turbine design as ultimate responsibility for the maximum conversion of kinetic energy into rotational energy. In India, an average wind speeds are 3 ms^{-1} at 20m height; therefore Archimedes wind turbine is perfect for low and medium wind speeds. A focus is now being made on the Archimedes wind turbine is a new type of wind turbine, consisting of three circular blades. These are wrapped around one another, as coils and then expanded, creating a three-dimensional conical turbine. Unlike old-fashioned HAWTs, which use the lift force to take power from wind energy, the Archimedes spiral wind turbine uses both the lift and drag force. This special construction guarantees that wind is drawn into the turbine with an effective angle of 60 degrees and the wind is being turned 90 degrees by the coils [2].

There are few relevant types of research in attempting to improve performances of Archimedes wind turbine. In 2009, Timmer and Toet carried out fundamental research to examine the potential and optimal power output of the Archimedes spiral small wind turbine [3]. The highest efficiency measured in their study was 12%. Lu *et al*. [4] recently developed a design method for the Archimedes spiral wind turbine blade and performed a numerical simulation using ANSYS CFX. In 2014, Kyung Chun Kim, Ho Seong Ji investigated the aerodynamic performance of Archimedes wind turbine by using CFD analysis, 2D Particle image velocimetry (PIV) method is used to examine CFD results in the near field of the blade [5]. From the literature survey, it is observed that the study of Archimedes wind turbine with an aerofoil blade does not explore more. In this present work, an attempt is made to study the torque characteristics of the Archimedes aerofoil wind turbine blade with an aerofoil, NACA aerofoil profile is considered for analysis of Archimedes wind turbine blades and validation of the present work is done by comparing the paper [6].

In this study, Design of Archimedes aerofoil wind turbine blade of actual size of 1500 mm diameter and 1500 mm length has done by CREO 2.0 and commercially available software ANSYS Fluent is employed to predict the aerodynamic performance such as torque, power, lift & drag force, velocity and pressure distribution, according to wind condition using RANS model with a k-omega Shear Stress Transport (SST), based on Finite element method (FEM)

II. DESIGN OF ARCHIMEDES AEROFOIL WIND TURBINE

Figure 1 shows a schematic diagram of the Archimedes spiral wind turbine having three blades are connected to each other at 120^0 and symmetric arrangement around the shaft. The outer diameter of the Archimedes spiral wind turbine blade is 1500 mm, the thickness is 5 mm and the length is 1500 mm [4].

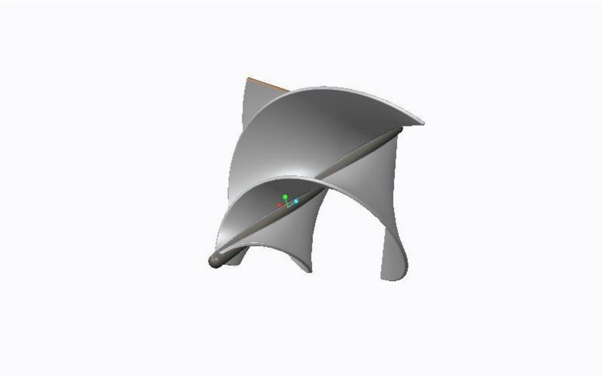


Fig 1 - Geometrical model of Archimedes wind turbine (AWT)

III. AEROFOIL ON AWT BLADE

An important design function of aerodynamic characteristics was a selection of aerofoil. The shape of the aerodynamic profile is decided for blade performance. Even minor changes in the shape of the profile can significantly affect the power curve and noise level. In order to extract the maximum kinetic energy from wind, have to put more effort into the design of effective blade geometry. A rotor blade may have different airfoil length in different sections in order to increases the efficiency, so the modern blades are more complex and efficient comparing to early wind turbine blades. The choice is based on comparing lift and drag ratios over different aerofoils.

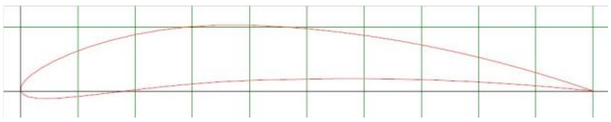


Fig 2 - NACA 6409 aerofoil profile

Dimensions of the aerofoil taken from the NACA website and scaled to AAWT dimensions by using MATLAB program and

The design of the blade has done by using NACA 6409 aerofoil shape by CREO 2.0. Modelling of Archimedes aerofoil wind turbine blade is very complex since the shape of aerofoil varies with spiral length. The final design of the Archimedes wind turbine with an aerofoil has shown in fig 3

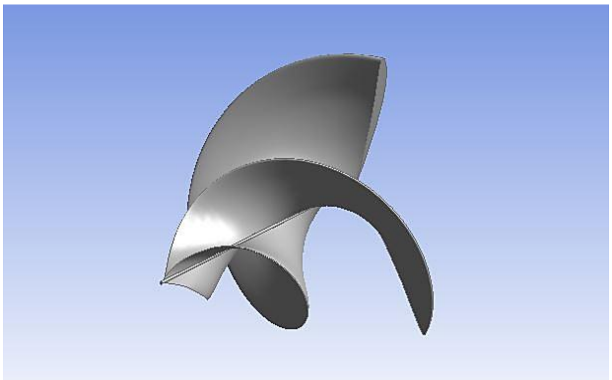


Fig 3- Geometrical model of Archimedes aerofoil wind turbine (AAWT)

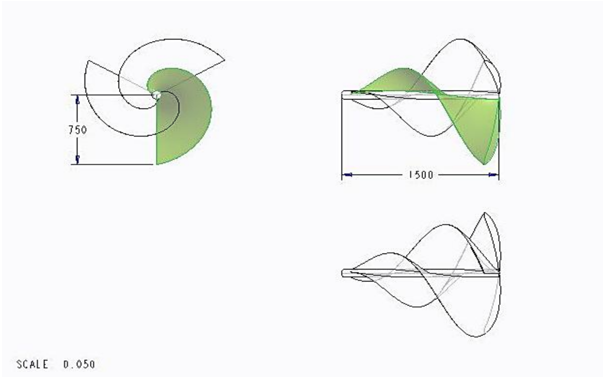


Fig 4- Views of AAWT

IV. METHODOLOGY RESULTS

The aerodynamic performance of wind turbine blade can be examined by Computational fluid dynamics (CFD) which is one of the divisions in fluid mechanics. Computational fluid dynamics (CFD) is a division of fluid mechanics that uses numerical approaches and algorithms to solve and analyze problems that involve fluid flows. Computers are used to execute the calculations required to simulate the interaction of liquids and gases with surfaces defined by the boundary condition. CFD enables scientist and engineers to achieve numerical experiments, i.e. Computer simulations in a virtual flow laboratory. CFD is quicker and definitely inexpensive. A considerable reduction of time and expenses for solving the problems as compared to traditional approaches.

A. Computational Method

CFD FLUENT consists of so various turbulence model in which Shear Stress Transport (SST) k-ω turbulence model has been used to forecast the separation of flow which is two equation-based model. SST k-ω turbulence model uses the benefit of both k-ε and k-ω turbulence model where k is turbulence kinetic energy, ε is the rate of dissipation of the turbulent kinetic energy and ω is the specific rate of dissipation

B. Mesh Generation

In order to build the computational domain and generate the mesh, the commercially accessible software "ANSYS Meshing tool" is used to build a wind tunnel model and generate an amorphous mesh around the blade in the computational domain. As shown in the figure, a 3D AAWT blade is placed inside of an imaginary wind tunnel with inlet and outlet conditions. Number of nodes on tunnel and rotor (AAWT) after meshing are 241,835 and 39,084 and total nodes are 280,919 fine mesh and hex-dominant method

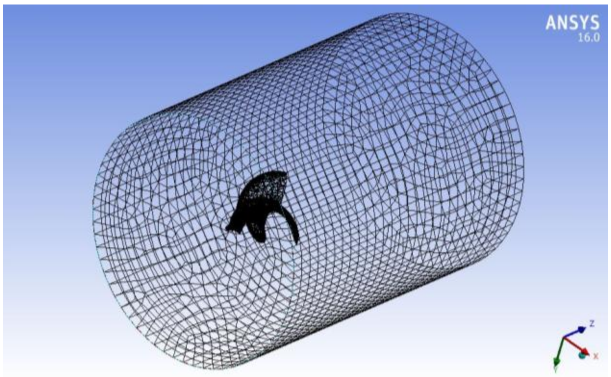


Fig 5 - Meshing of stationary and rotary domain

C. C. Boundary Setup

In this analysis, the boundary conditions are
Inlet wind speed – 1, 3, 5, 7, 9, 11, 13, 15 in ms-1
Rotor angular speed – 100, 200, 300, 400, 500 in rpm
Outlet condition – Atmospheric pressure
Wall – No slip condition
Fig 6 shows Outlet (A) where the flows leaves, walls (B) acts as boundary which restricts flow, Inlet (C) where fluid flow enters toward wind turbine blade.

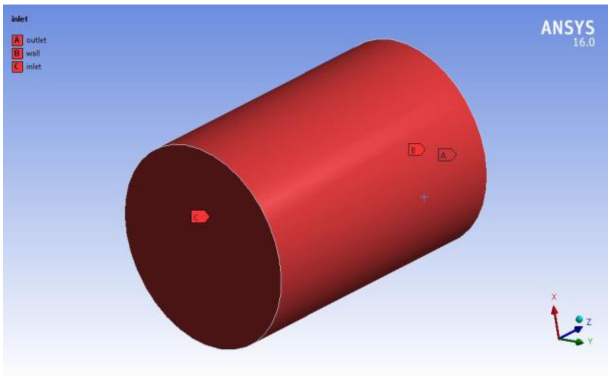


Fig 6 - Boundary condition set up on Fluent

V. RESULTS CONCLUSION

Initially, a 3D CFD analysis is carried out at a wind speed of 1 to 15 ms^{-1} in an interval of 2 ms^{-1} and rotor speed is 100 to 500 rpm an interval of 100 respectively. The wind speed is assumed to be uniform.

Table 1- Data obtained from CFD analysis

S.No	Wind speed (ms^{-1})	Torque(AWT) N-m	Torque (AAWT) N-m
1	1	0.31	0.34
2	3	2.88	3.20
3	5	8.05	9.05
4	7	15.85	17.92
5	9	26.26	29.85
6	11	39.31	44.86
7	13	54.99	63.07
8	15	73.30	84.06

The results obtained from the Archimedes aerofoil wind turbine with NACA 6409 9% aerofoil profile has compared with Archimedes spiral wind turbine. Above table 1 represents the data obtained from the CFD Fluent. In fig 7, yellow curve indicates torque of AAWT and red is AWT at different wind speeds, results show that torque increased from around 10% - 15% at low speed and more than 15% at moderate speed.

Flow direction is from left to right, because of the spiral and aerofoil shape, the velocity increased from the leading edge at the inner side of the blade that means the flow of fluid

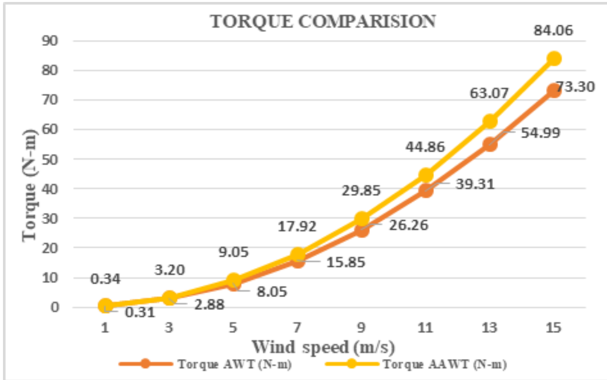


Fig 7- Torque comparison

accelerates of the blade and highest velocities have detected at the end tip of the blade as shown in fig 8.

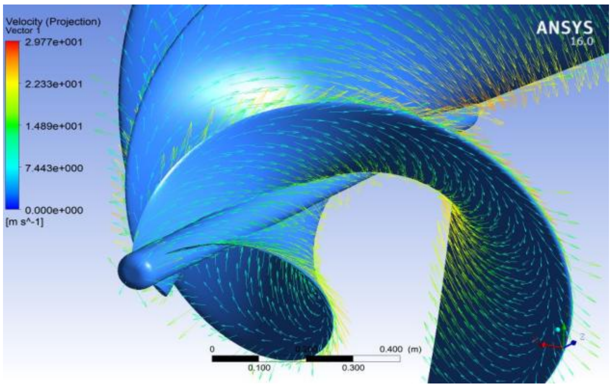
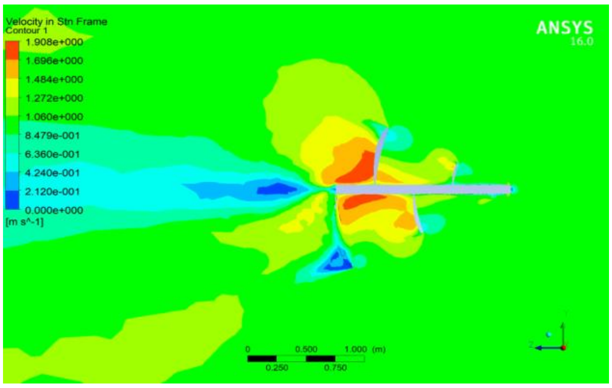
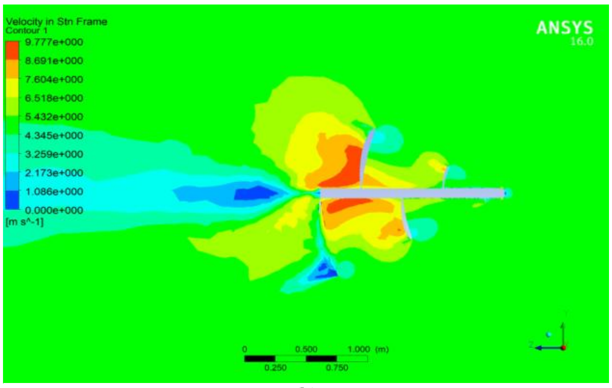


Fig 8 - Direction of flow filed over turbine blade

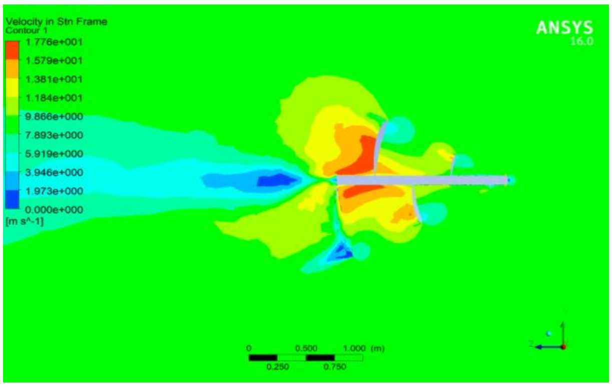
To find out aerodynamic characteristics of the Archimedes aerofoil wind turbine, velocity contours in fig 9 shows that the velocity field at the central portion of the blade increased. Above fig 8 also shows that the direction of flow on blade represents the anticlockwise direction of the rotor. The maximum pressure has found around the blade and lowest was at the back edge. The pressure distribution of the AAWT has shown in fig 10. When the blade is rotating, a pressure difference is more inside between the pressure side and suction side than the pressure difference in AWT thus leads to generate more torque. When the wind speed rises the pressure difference becomes increases means more energy can be extracted. From all the cases pressure is negative at the end of the blade causes thrust force can be generated by a wind turbine blade.



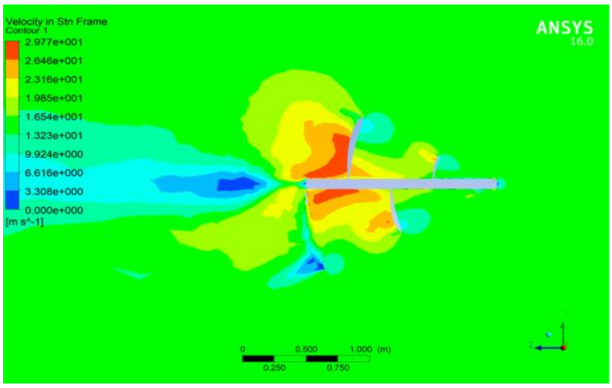
(a)



(b)

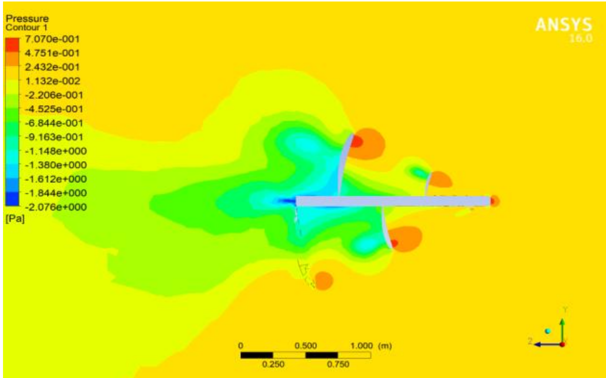


(c)

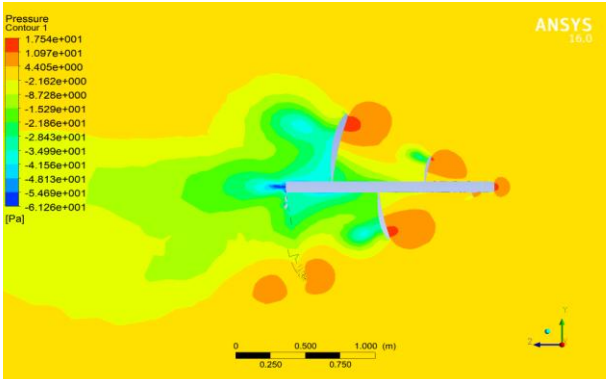


(d)

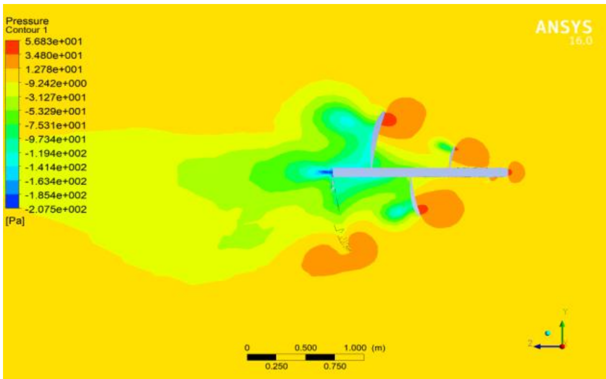
Fig 9 - Velocity fields obtained by CFD simulations:
(a) 1 ms^{-1} (b) 5 ms^{-1} (c) 9 ms^{-1} and (d) 15 ms^{-1}



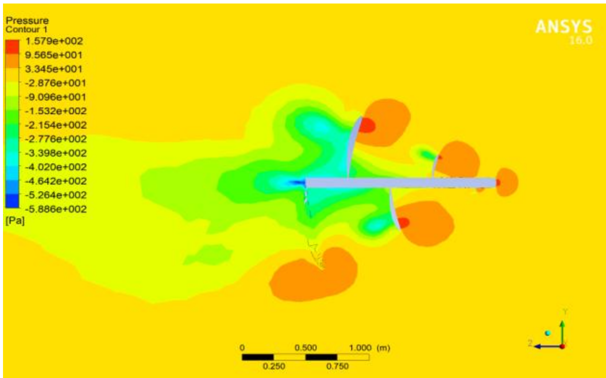
(a)



(b)



(c)



(d)

Fig 10 - Static pressure contours obtained by CFD simulations:
(a) 1 ms^{-1} (b) 5 ms^{-1} (c) 9 ms^{-1} and (d) 15 ms^{-1}

VI. CONCLUSION

To investigate the torque characteristics of the Archimedes aerofoil wind turbine, CFD has been on the Archimedes aerofoil wind turbine and Archimedes wind turbine at different wind and rotor speeds summarized as

1. Using aerofoil to an Archimedes wind turbine blade fairly increases the torque at a lower speed nearly 15 % than AWT which suggests it is more suitable for low and moderate wind speeds
2. It shows that power is the function of wind speed and design parameters of wind turbine blade
3. The Archimedes aerofoil wind turbine was able to extract more power than other wind turbines at lower and moderate speed
4. There is no need for electronic yawing equipment because use both lift and drag force which reduces the cost
5. According to the CFD results, Archimedes aerofoil wind turbine looks getting more promising power than another wind turbine including Archimedes spiral wind turbine

VII. REFERENCES

[1] Han Cao "Aerodynamics analysis of small horizontal axis wind turbine blades by using 2D and 3D CFD modelling" May 2011.

[2] Drs. M. Mieremet, Kyung Chun Kim, Dr Joon Ho Back, Ho Seong Ji, "The aerodynamic method of the Archimedes wind turbine" Power Solution 27th may 2014, unpublished

[3] Timmer, W.A.; Toet, S. "Verslag van de Metingen aan de Archimedes in de Lage-Snelheids Windtunnel van" DNW; TU Delft: Delft, The Netherlands, 2009.

[4] Kyung Chun Kim, HoSeongJi, Yoon Kee Kim, Qian Lu, JoonHoBaek and RinusMieremet, "Experimental and numerical study of the aerodynamic characteristics of an Archimedes spiral wind turbine blade" Energies 2014, 7:7893–7914. doi:10.3390/en7127893

[5] Raju Kumar, Priyanka Jhawar, Sanjay Kalraiya "A CFD Analysis of a Wind Turbine Blade Design at Various Angle of Attack and Low Reynolds Number " International Journal Scientific Research and Engineering Trend Vol. 2, Issue. 5, Sep 2016

[6] Shashank Chaudhary, Shubham Jaiswal, Richa Nanda, "Comparison of torque characteristics of Archimedes wind turbine evaluated by analytical and experimental study", International Journal of Mechanical and Production Engineering, Vol – 4, Aug 2016

[7] Ho Seong JI, Joon Ho Baek "An aerodynamic performance study on a small wind turbine with 500 w class through wind tunnel experiment", International Journal of Renewable Energy, Vol.1, 2016

[8] Bhusan S Patil, Hitesh R (2015) "Computational fluid dynamic analysis for wind turbine blade at various angle of attacks and different Reynolds number", Internation conference on Computational Heat and mass transfer - 2015, Procedia Engineering 127 (2015) 1363 – 1369

[9] Arman Safdari and Kyung Chun Kim, "Aerodynamic and structural evaluation of horizontal Archimedes Spiral Wind Turbine" Journal of Clean Energy Technologies, Vol. 3, No. 1, January 2015

[10] Yoon Kee Kim and Qian Lu "A multi-prong study on aerodynamic characteristics of Archimedes spiral-type wind turbine blade" unpublished

[11] ANSYS FLUENT 2012 User Guide.