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PERFORMANCE ANALYSIS OF A VERTICAL AXIS WIND TURBINE

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Abstract: The increase of environmental awareness and with the shortage of fossil fuels, wind energy is becoming more important than ever. As the market for wind energy grows, wind turbines and wind farms are becoming larger. The shape of the turbine blades plays a crucial role in determining the efficiency and power output of the turbine, as well as its noise and vibration levels. The objective of the project is to Performing a computational fluid dynamic analysis on a single Vertical Axis Wind Turbine (VAWT) with two different blade profiles, elliptical and parabolic. To perform the CFD analysis, a 3D model of the VAWT with the elliptical and parabolic blade profiles was created using a space claim design (CAD) software. The model was then imported into a CFD software package, which used numerical methods to simulate the flow of air around the turbine blades. Examine parameters that affect the performance of these models, such as pressure, velocity, and the way in which the turbine force is projected onto the flow field.

***Index Terms* – Wind Energy, turbine blades, elliptical blades, parabolic blades, CFD.**

I. INTRODUCTION

Day by day, pollution levels and sea levels have been increased. So, renewable energy sources around the world have been increasing to reduce energy costs and protect the world. To overcome this, wind turbines are designed to generate electrical energy. A wind turbine is an electrical device that converts the energy from the wind into electricity. These turbines are available in different types, sizes, and shapes. So, the types of wind turbines are horizontal-axis wind turbine & vertical axis wind turbine. This article discusses an overview of one of the types of wind turbine namely vertical axis wind turbine or VAWT.

1.1 What is Vertical Axis Wind Turbine or VAWT?

The Vertical Axis Wind Turbine is a type of wind turbine and it is most frequently used for residential purposes to provide a renewable energy source to the home. This turbine includes the rotor shaft and two or three blades where the rotor shaft moves vertically. So, this turbine movement is related to the spinning of coins on the edge. In this turbine, the generator is placed at the bottom of the tower whereas the blades are covered around the shaft.

The vertical axis wind turbine working principle is that, the rotors in the turbine revolve around a vertical shaft by using vertically oriented blades. So, they generate electricity by using wind power. The wind operates the rotor which is connected to the generator, so the generator converts the energy from mechanical to electrical. Vertical axis wind turbine components are blade, shaft, bearing, frame & blade support.

1.2 Vertical-Axis Wind Turbine Block Diagram

The below fig1 shows the block diagram of a vertical axis wind turbine is shown below. The output energy generated from this can be used by any type of load. Here, the automatic lighting system is used as a load. This block diagram includes a Vertical Axis Wind Turbine (VAWT), gearbox, generator, battery, LDR circuit and LED.

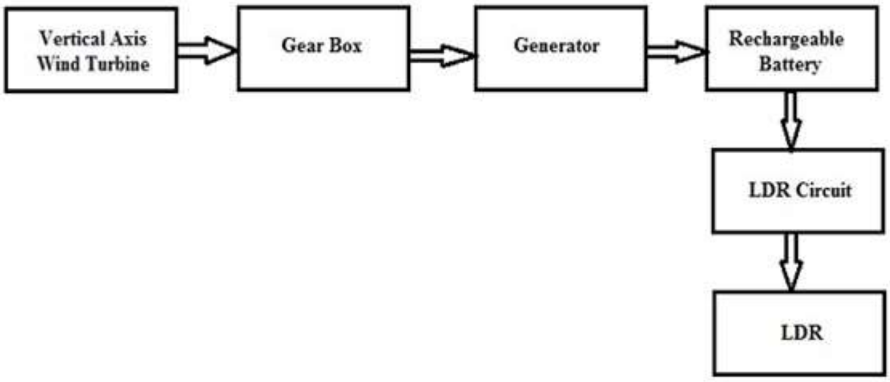

Fig 1: Vertical Axis Wind Turbine Block Diagram

1.2.1 Vertical Axis Wind Turbine

The type of Vertical Axis Wind Turbine used in this system is darrieus VAWT.

1.2.2 Gear Box

A gearbox in a wind turbine is mainly used to enhance the rotating speed from a low sped shaft to a high-speed shaft connecting through an electrical generator. Gears within the gearbox of a wind turbine are subjected to severe cyclic loading because of uneven wind loads that are stochastic within the environment.

1.2.3 Generator

The generator in the wind turbine converts the energy from mechanical to electrical. These generators are a bit strange as compared to generators used in electrical grids.

1.2.4 Rechargeable Battery

The output electric energy generated by the generator will be stored in the rechargeable battery of the wind turbine.

1.2.5 LDR Circuit

The LDR circuit is used to turn ON/OFF the light.

II. LITERATURE REVIEW

Ghatage, Swapnil et al, A system for the conversion of kinetic energy of wind into thermal energy has been developed which can replace relatively expensive electro-mechanical equipment. The system consists of a vertical axis wind turbine (VAWT) which is coupled with the shaft of a stirred vessel. In the present work, computational fluid dynamic (CFD) simulations have been performed for the flow generated in a stirred tank with disc turbine (DT). The predicted values of the mean axial, radial and tangential velocities along with the turbulent kinetic energy have been compared with those measured by laser Doppler anemometry (LDA). Good agreement was found between the CFD simulations and experimental results. Such a validated model was employed for the optimisation of drag-based VAWT. An attempt has been made to increase the efficiency of turbine by optimising the shape and the number of blades. For this purpose, the combination of CFD and experiments has been used. The flows generated in a stirred tank and that generated by a wind turbine were simulated using commercial CFD software Fluent 6.2. A comparison has been made between the different configurations of wind turbines. Results show that a provision in blade twist enhances the efficiency of wind turbine. Also, a wind turbine with two blades has higher efficiency than the turbine with three blades. Based on the detailed CFD simulations, it is proposed that two bladed turbines with 30° twist shows maximum efficiency

Cuevas-Carvajal, N., et al, Wind power is one of the main sources of renewable energy. New applications of this technology are currently under development through small vertical axis wind turbines, allowing energy production in small spaces even at low wind speeds. Therefore, creating an effective turbine design methodology tailored to these operating conditions has been the subject of extensive research. The Savonius-type vertical axis wind turbine is one of the most widely used due to its low cost and easy manufacturing. Several works have examined the effect of various geometric parameters on the performance of the Savonius-type wind turbine. However, there are no published overarching conclusions about these works. Thus, this paper aims to review and discuss in a concise way experiments and simulations carried out by several authors evaluating the effect of some geometric parameters on the maximum power and torque coefficient of Savonius vertical axis wind turbines. The paper also discusses additional experiments that should be performed in future work.

Alaimo, Andrea, et al, in this paper a new bucket configuration for a Savonius wind generator is proposed. Numerical analyses are performed to estimate the performances of the proposed configuration by means of the commercial code COMSOL Multiphysics® with respect to Savonius wind turbine with overlap only. Parametric analyses are performed, for a fixed overlap ratio, by varying the slot position; the results show that for slot positioned near the blade root, the Savonius rotor improves performances at low tip speed ratio, evidencing a better starting torque. This circumstance is confirmed by static analyses performed on the slotted blades in order to investigate the starting characteristic of the proposed Savonius wind generator configuration.

Rezaeiha, Abdolrahim et al, Accurate prediction of the performance of a vertical-axis wind turbine (VAWT) using Computational Fluid Dynamics (CFD) simulation requires a domain size that is large enough to minimize the effects of blockage and uncertainties in the boundary conditions on the results. It also requires the employment of a sufficiently fine azimuthal increment (dθ) combined with a grid size at which essential flow characteristics can be accurately resolved. The current study systematically investigates the effect of the domain size and azimuthal increment on the performance of a 2-bladed VAWT operating at a moderate tip speed ratio of 4.5 using 2-dimensional and 2.5-dimensional simulations with the unsteady Reynolds-averaged Navier-Stokes (URANS). The grid dependence of the results is studied using three systematically refined grids. The turbine has a low solidity of 0.12 and a swept area of 1 m2. Refining $d\theta$ from 10.0° to 0.5° results in a significant (≈43%) increase in the predicted power coefficient (CP) while the effect is negligible (≈0.25%) with further refinement from 0.5° to 0.05° at the given λ. Furthermore, a distance from the turbine center to the domain inlet and outlet of 10D (D: diameter of turbine) each, a domain width of 20D and a diameter of the rotating core of 1.5D are found to be safe choices to minimize the effects of blockage and uncertainty in the boundary conditions on the results.

Alaimo, Andrea, et al ,To analyze the complex and unsteady aerodynamic flow associated with wind turbine functioning, computational fluid dynamics (CFD) is an attractive and powerful method. In this work, the influence of different numerical aspects on the accuracy of simulating a rotating wind turbine is studied. In particular, the effects of mesh size and structure, time step and rotational velocity have been taken into account for simulation of different wind turbine geometries. The applicative goal of this study is the comparison of the performance between a straight blade vertical axis wind turbine and a helical blade one. Analyses are carried out through the use of computational fluid dynamic ANSYS® Fluent® software, solving the Reynolds averaged Navier–Stokes (RANS) equations. At first, two-dimensional simulations are used in a preliminary setup of the numerical procedure and to compute approximated performance parameters, namely the torque, power, lift and drag coefficients. Then, three-dimensional simulations are carried out with the aim of an accurate determination of the differences in the complex aerodynamic flow associated with the straight and the helical blade turbines. Static and dynamic results are then reported for different values of rotational speed.

N.C. Batista et al, made the study and development of an air foil capable to self-start is a very complex task. The new air foil presented in this paper is called EN0005. Before its design was developed, several other blade solutions with better known profiles were used, such as, trapping vortex cell systems, thick blades, and modified profiles. The need to get a more suitable blade profile to the VAWT in development and the need to contribute to the scientific community with another innovative solution was felt. The new profile developments started with a base profile that is continually modified by moving each segment of the profile surface. For each modification the effects of those modifications to the wind turbine performance are tested by applying the methodology that will be explained in the next section. The upper surface is a high lift surface with a slight orientation in the desired movement of the blade. This high lift surface is essential when the wind turbine is working at both low and high TSR. The nose of the blade is in a lower position in relation to the line chord and it has a tip formation in the front to increase de wind flow over the body and to reduce the drag forces when the blade is in the upstream zone. In the lower surface of the blade profile the first 20% of the length has high lift properties that are essential when the wind turbine is working at high TSR. The last 80% of the surface finishes in a cup form, which is essential to increase the drag forces of the profile when the wind turbine is stopped and the blade is in the downstream zone of the rotor. In order to assess the performance of the new air foil EN0005, a comparison to other better known and studied air foils is going to be presented. The air foils chosen in this paper for the comparison are the NACA0018 and the NACA4418.

III. MATERIALS

The materials used for building a Vertical Axis Wind Turbine (VAWT) vary depending on factors such as the turbine's size, design, and intended application. Some of the commonly used materials for VAWTs are listed below:

- Blades: Blades are typically made of lightweight materials such as aluminium, fiberglass, or carbon fiber composites. These materials have high strength-to-weight ratios, which makes them ideal for creating the curved shapes required for VAWT blades.
- Shaft and Bearings: The shaft and bearings are critical components of the VAWT. They are typically made of high-strength materials such as steel or titanium alloys, which can withstand the high torque and bending stresses generated by the rotating blades.
- Tower: The tower supports the VAWT and must be strong enough to withstand the weight of the turbine and the forces generated by wind. Towers can be made of steel, aluminium, or reinforced concrete, depending on the turbine's size and the intended application.
- Generator: The generator converts the rotational energy of the turbine into electrical energy. Generators for VAWTs can be made of a variety of materials, including copper, aluminium, and rare earth metals.
- Electrical Components: The electrical components, such as wiring, transformers, and inverters, are typically made of copper and other conductive materials.

Overall, the materials used for VAWTs must be strong, lightweight, and able to withstand the harsh conditions of the wind environment. Advancements in materials science and engineering are continuing to improve the performance, efficiency, and cost-effectiveness of VAWTs, and may lead to the development of new materials and designs for the technology..

IV. MODELLING TECHNOLOGY

Space Claim's 3D direct modelling technology is primarily expressed through its user interface in four tools: pull, move, fill, and combine:

- Pull contains most creation features found in traditional CAD systems, determining its behaviour through users' selection and though the use of secondary tool guides. For example, using the Pull tool on a face by default offsets the face, but using the Pull tool on an edge rounds the edge.
- Move repositions components and geometry, and can also be used to create patterns (often called arrays).
- Fill primarily removes geometry from a part by extending geometry to fill in the surrounding area. Popular uses include deleting rounds and holes from a model. Space Claim Engineer also includes more specialized tools for model preparation
- Combine performs Boolean and splitting operations, such as merging parts and subtracting parts from each other.

These functions were developed in the modelling kernel ACIS [5] licensed to Space Claim by Systems.

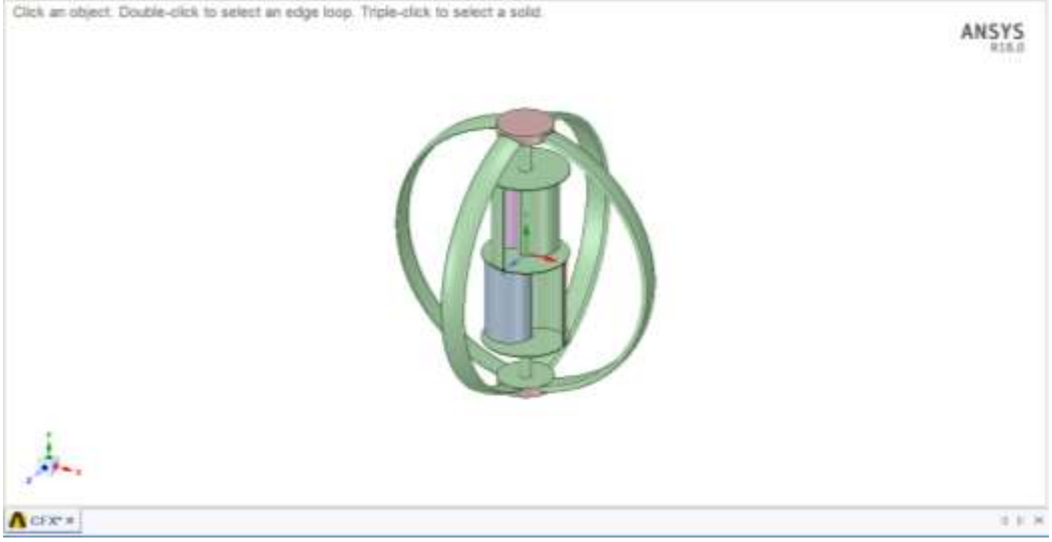

Fig 2: Savonius-Darrieus wind turbine geometry

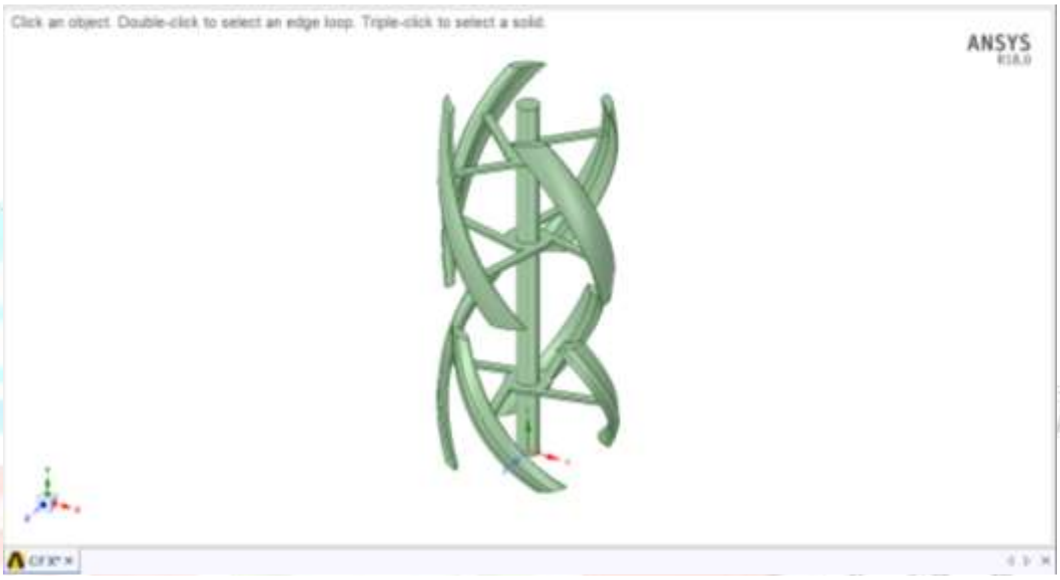

Fig 3: Parabolic-Elliptical blade VAWT geometry

The above figures 2 and 3 show the geometric models of Savonius-Darrieus wind turbine and Parabolic-Elliptical VAWT.

Meshing:

Mesh generation is the practice of creating a mesh, a subdivision of a continuous geometric space into discrete geometric and topological cells. Often these cells form a simplified complex. Usually, the cells partition the geometric input domain. Mesh cells are used as discrete local approximations of the larger domain. Meshes are created by computer algorithms, often with human guidance through a GUI, depending on the complexity of the domain and the type of mesh desired. A typical goal is to create a mesh that accurately captures the input domain geometry, with high-quality (well-shaped) cells, and without so many cells as to make subsequent calculations intractable. The mesh should also be fine (have small elements) in areas that are important for the subsequent calculations.

Meshes are used for rendering to a computer screen and for physical simulation such as finite element analysis or computational fluid dynamics. Meshes are composed of simple cells like triangles because, e.g., we know how to perform operations such as finite element calculations (engineering) or ray tracing (computer graphics) on triangles, but we do not know how to perform these operations directly on complicated spaces and shapes such as a roadway bridge. We can simulate the strength of the bridge, or draw it on a computer screen, by performing calculations on each triangle and calculating the interactions between triangles.

A major distinction is between structured and unstructured meshing. In structured meshing the mesh is a regular lattice, such as an array, with implied connectivity between elements. In unstructured meshing, elements may be connected to each other in irregular patterns, and more complicated domains can be captured. This page is primarily about unstructured meshes. While a mesh may be a triangulation, the process of meshing is distinguished from point set triangulation in that meshing includes the freedom to add vertices not present in the input. "Faceting" (triangulating) CAD models for drafting has the same freedom to add vertices, but the goal is to represent the shape accurately using as few triangles as possible and the shape of individual triangles is not important. Computer graphics renderings of textures and realistic lighting conditions use meshes instead.

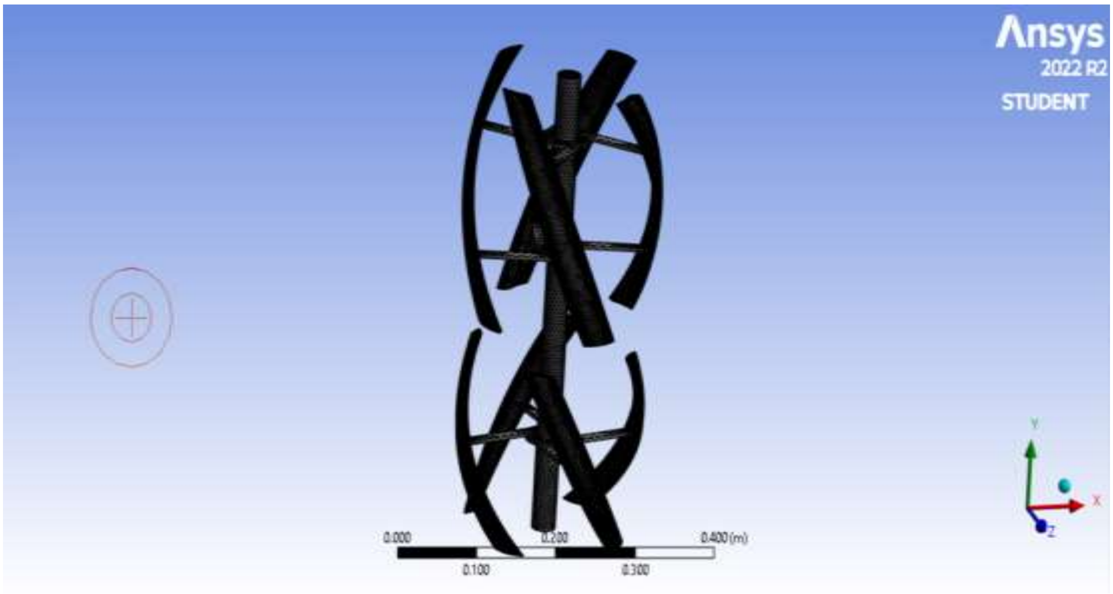

Fig 4: Parabolic-Elliptical blade VAWT meshing

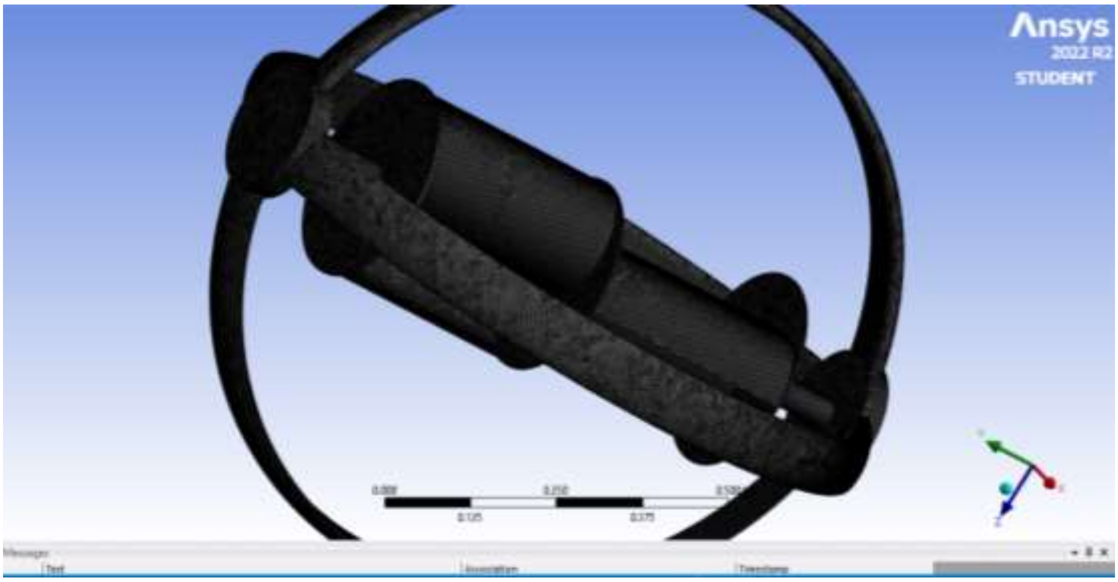

Fig 5: Savonius-Darrieus wind turbine meshing

The above figures 4 and 5 show the meshing of Parabolic-Elliptical VAWT and Savonius-Darrieus wind turbine.

IV. RESULTS AND DISCUSSION

Fig 6 and Fig 7 below show the velocity variations at different planes of a savonius wind turbine in CFX tool.

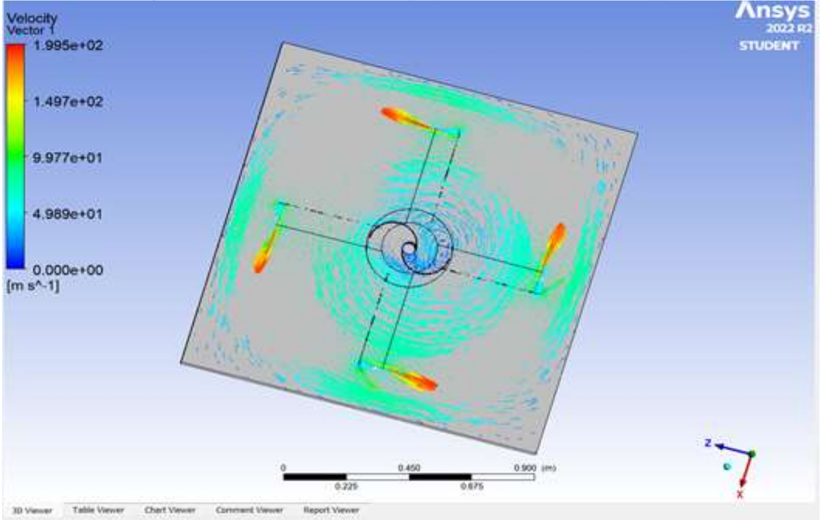

FIG 6: VELOCITY IN CFX

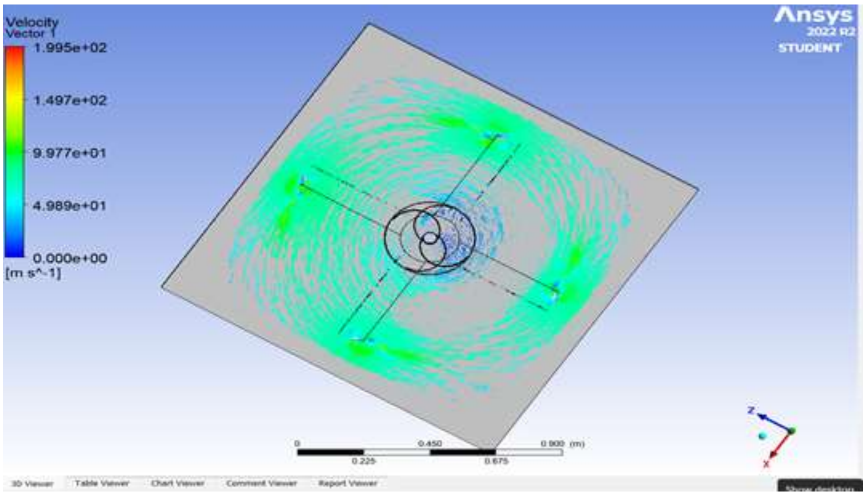

Fig 7: Velocity in CFX

Fig 8 shows pressure variation of a savonius wind turbine in CFD tool

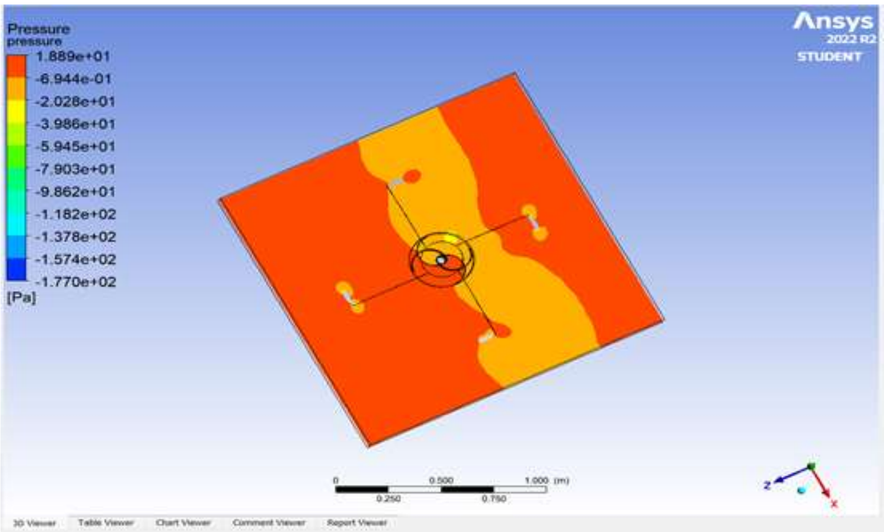

Fig 8: Pressure contours in CFD

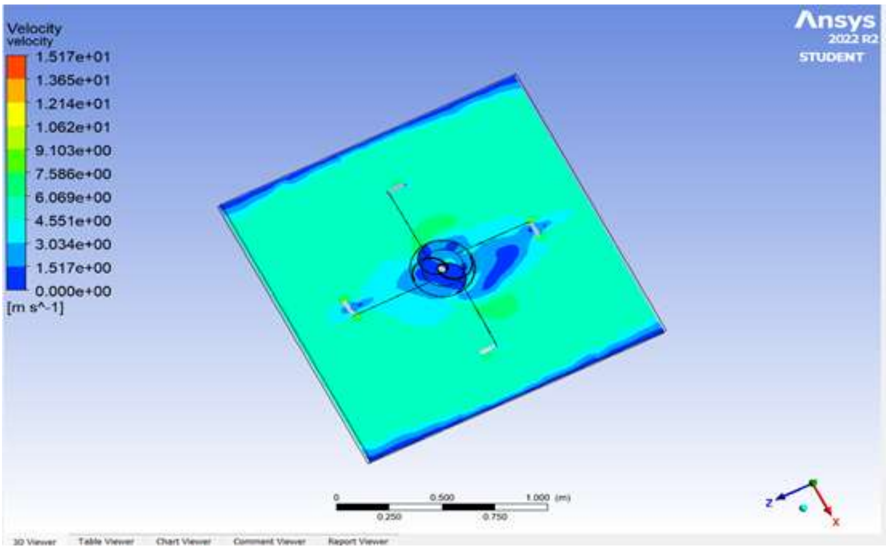

Fig 9: Velocity contours in CFD

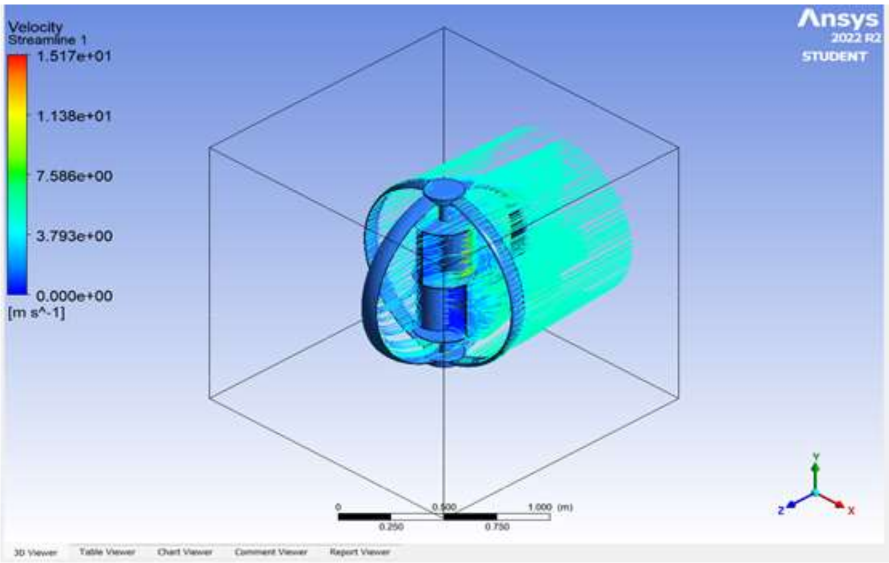

Fig 10: Streamline contours in CFD

V. CONCLUSION

The vertical axis wind turbine, which has two different types of air foil profiles, attains a higher velocity than standard vertical axis wind turbine under the same conditions. The VAWT section with a parabolic blade profile can capture more air, allowing it to rotate even at lower wind speeds. The VAWT section with an elliptical air foil profile helps to accelerate the rotation of the parabolic air foil since the elliptical profile is more streamlined and attains higher velocities.

Vertical Axis Wind Turbines have the potential to capture wind from any direction since the rotor is perpendicular to the ground. This makes them more efficient in areas with turbulent wind conditions or frequent changes in wind direction. VAWTs are generally quieter than HAWTs since the blades rotate at a slower speed, resulting in less noise pollution. VAWT having parabolic and elliptical airfoil profiles attain higher velocities than standard VAWT but less velocity than Savonius-Darrieus hybrid VAWT operating under same conditions but both have higher velocities than the standard VAWT design.

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