Study of Variation of Aspect Ratio of Savonius Rotor.

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Abstract –

In vertical axis wind turbines to be viable, concerns of sustainability and power production must be taken into consideration. The market for wind energy is rising at a CAGR of 6.3% during the recent decade. According to previous studies, the Savonius Turbine has the lowest power coefficient of all wind turbines; its wind direction is independent, has a good beginning torque, and produces less noise. The turbine's efficiency is additionally influenced by the design of its blades. Utilizing both numerical and experimental techniques, our study examines the power coefficient and aspect ratio of a wind turbine's vertical-axis blades (S-Rotor). This study has investigated the link between a wind turbine's aspect ratio and performance. We have used conventional ways to construct a two-blade Savonius rotor. The project attempts to make it as portable and usable as possible.

Keywords *— Aspect ratio, Low wind speed, Savonius rotor, Self- starting, Swept Area, Wind turbine.*

I. Introduction

Between 2018 and 2050, the world's energy consumption is expected to rise by close to 50%. For that we could not depend only on non-renewable energy sources [24]; some renewable alternatives are leading in this era, like solar energy, tidal energy, hydroelectric, geothermal energy [1]. One of the most important sources of renewable energy is wind power. This technique uses revolving blades to transform wind energy into mechanical power [2]. In the past, wind turbines have been used to grind grain and pump water out of the ground. In order to provide electricity for the power system, generators and wind turbines are combined today [3]. In terms of installed capacity and annual growth rates, wind power has been the energy technology with the fastest expansion in the 1990s. Around 69 % of all wind energy installations spread throughout Europe, 19 % in North America, and 10 % in Asia and the Pacific before 1999 [5]. The two types of wind turbines that are most frequently used are Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines [12]. HAWT is more widely used and more effective than VAWT, although it can only be applied in places where the wind speed is strong (>5 m/s). VAWT, on the other hand, is less commercially viable [10]. It is fascinating to note that numerous professionals were interested in enhancing VAWT because it may be applied in metropolitan places to lessen the substantial electrical load [21]. Savonius type VAWTs are ideal for application in countries near the equator with relatively low average wind speeds (between 4 and 5 m/s) [6][7]. A conventional Savonius wind turbine's basic structure is made up of two half cylinders mounted on a shaft [13]. The concave Savonius rotor blade is under attack from a pure drag force. The concave blade acts as a wind flow barrier to transform wind kinetic energy into mechanical energy, which is subsequently transformed into electrical energy by producing equipment [16]. Omnidirectional [18], running at relatively low speeds, and making less noise are a few benefits of the Savonius wind turbine. Savonius can be erected on the roofs of high-rise structures in metropolitan settings, including hotels, clinics, and business buildings [9]. the effectiveness of the Savonius turbine, whose power coefficient is less than 0.25 [11]. Performance of the Savonius turbines is influenced by several design elements, such as blade profiles such blade shape, number of blades, geometry design, and wind inlet speed [14]. We used SolidWorks to design an S-rotor and run CFD on it. In this study, the relationship between a wind turbine's aspect ratio and performance was examined, and a correlation between the aspect ratio and performance of the turbine was found.

II. Literature Review

The torque vs. rpm relationships that J. Mercier et al. [1] developed for wing rotors operating in a uniform stream have been discussed. He concluded that Savonius rotors appear to be exceptionally sensitive to curved fluid intake, whether they are being used as current meters or turbines. by examining five distinct kinds of Savonius rotors physically. The performance of the rotor is impacted by the shape of the end plates, according to O. Takenori et al. [2]. They also learned that the deflecting plate might be used as a speed limiter or safety feature. The maximum stress of a portable wind turbine blade, according to Chong et al. [3], is lower than the material's aluminum alloy (EN-AW 1200) yield strength of 2.5e+007 N/m2. To analyzing historical wind data gathered from the roofs of several WPI buildings, N. Bourabaa et al. [4] developed a wind modeling software tool named WASP. The power output of this VAWT system improved by 70% as compared to the previously completed projects.

M. Kamoji [5] investigated how Savonius' performance changed with AR increases of 0.88, 0.93, and 1.17. Savonius wind turbines with an AR of 0.88 at TSR 0.7 were found to be able to attain the highest power coefficient value of 0.165. Endplates were added to the upper and lower sides of the blade by Jeon et al. [6] to boost the Savonius turbine's effectiveness. Efficiency was shown to increase by up to 36% over Savonius without endplates. As a result, it boosts the positive torque. To predict the dynamic behavior of a standing S-shaped rotor. The forces of aerodynamics acting on the rotor were studied by Islam et al. [7]. After analyzing the pressure distribution over the surfaces of the blades, they noticed that flow divides over the front and back surfaces of the blades, and that the point of separation depends on the rotor angle. A rotor with a gap ratio of 0.21 provides positive static torque at all angles, as shown by Sawada et al. [8], who developed a Savonius rotor with two semi-circular blades and analyzed the mechanism governing its spinning. Two Savonius rotors working side by side at various separations were examined for performance using discrete vortex methods by Aldoss and Obeidat [9]. They validated their findings by contrasting the torque and power coefficients they computed with the results of their experiments. The aerodynamic performance of a Savonius rotor was studied by Fujisawa et al. [10]. Direct torque measurements and the integrated pressure assessment of torque and power performance were very consistent when the pressure distributions on the blade surfaces at different rotor angles and tip-speed ratios were examined. The aerodynamic characteristics, such as the torque and drag coefficients, of a three-bladed Savonius rotor model were studied by Rahman et al [11]. For the two-bladed Savonius rotor, they used the static coefficients for dynamic prediction to compare the results in terms of power coefficient for different tip-speed ratios with those from the experiments.

Using a constant wind speed of 3 m/s, McWilliam and Johnson et al. [12] conducted an experiment. They found that the forward-curving blade was the critical point for external flow and that the Savonius wind turbine's blade overlap ratio allowed flow from the top blade to enter the bottom blade, decreasing the negative pressure region behind the blades. By placing valves on the concave side of the blades, Saha et al. [13] produced a two-stage Savonius wind turbine. The three-stage design and the twisted-blade design outperformed a conventional Savonius wind turbine when they were put side by side to measure performance. In their study, Gupta et al. [14] contrasted three-bucket Savonius and three-bucket Savonius-Darrius wind turbines. They found that as the overlap ratio increases, the combined turbine's power coefficient decreases. The greatest power coefficient of 51% was identified in the absence of overlap. To improve the performance of the Savonius wind turbine, Altan et al. [15] employed curtains in a few experimental studies. In order to prevent the destructive torque from harming the convex blade surface of the Savonius wind turbine, they set up a curtain arrangement in front of the rotor.

III. Methodology/Experimental

A. Theoretical Background

There are two common types of wind turbines: the more common and frequently utilized Horizontal Axis Wind Turbine (HAWT), and the less common Vertical Axis Wind Turbine (VAWT). The underlying idea behind each of these turbines is the same: by using the pressure differential established on the blades, the kinetic energy from the mass flow of air is transformed into rotational energy. In order to create mechanical energy or just electrical energy, this rotational energy was first converted.

1. Bet’z Law —

According to Albert Betz, a German physicist, the maximum power that can be extracted from an air flow has a limit. It follows that wind energy can never be completely harvested because momentum and mass are both constant. The most kinetic energy that can be extracted from the wind is 59.3%, according to Betz's research. This law therefore states that no turbine can entirely extract the speed from the wind that is already flowing, and the wind will continue to flow after passing through the turbine. Since a horizontal axis wind turbine was used to calculate the Betz limit, vertical turbines are not immediately affected. The same source asserts that an ideal VAWT system might potentially surpass this theoretical constraint. It has been asserted that VAWTs, in their current configuration, are less effective than HAWTs and are less able to dominate the limit for horizontal axis turbines.

2. Tip Speed Ratio —

It is defined as –

$$\lambda = \frac{v_{tip}}{v_{\omega ind}} \quad (1)$$

where,

v_{tip} = $speed\ of\ the\ tip\ of\ the\ blades$

$v_{\omega ind}$ = $speed\ of\ the\ wind$

Power coefficient varies with tip speed ratio so does the power efficiency. The fine optimal value will result in maximum power coefficient.

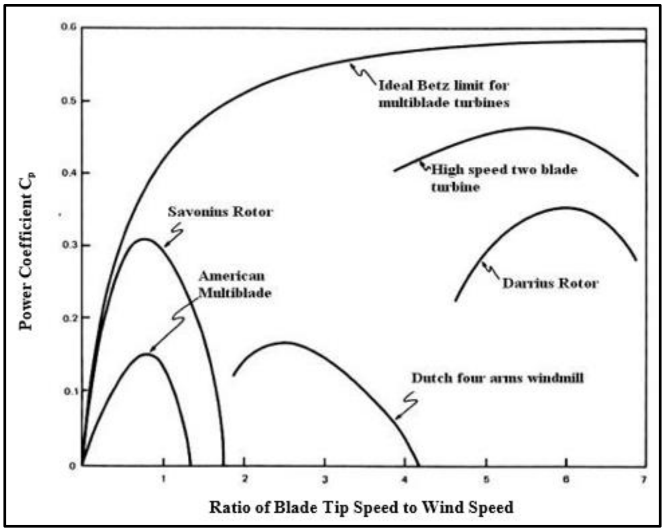

Figure 1. Different types of Turbines presenting Power Coefficient Curve

Low C_p is caused by insufficient extraction of wind energy and low tip speed ratio. In addition, a high wind tip ratio might result in low C_p and significant stresses in the blades. Having the correct tip speed ratio is essential for increasing productivity.

3. Forces involved —

Lift Force and Drag Force are two distinct types of forces that cause the wind turbines to turn. In our example, the direction of the fluid flow (wind) is perpendicular to lift forces, which are parallel to drag forces. Depending on the type of blades it is utilizing, a turbine may produce the spinning motion by lift or drag. As we learned, horizontal turbines use the lift force on their blades, whereas Savonius turbines use the drag force to push the blades.

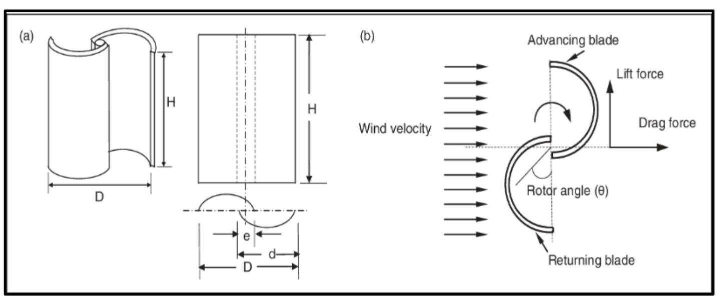

Figure 2. Drag and lift forces on turbine blades

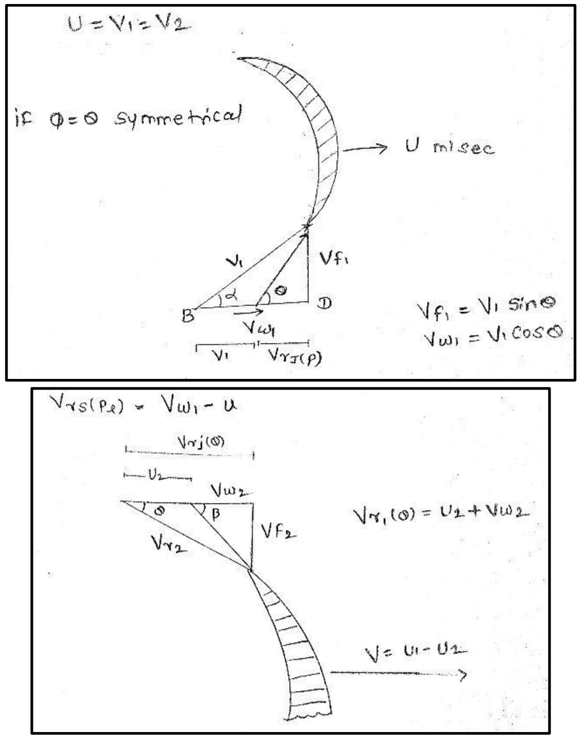

Figure 3. Velocity triangle

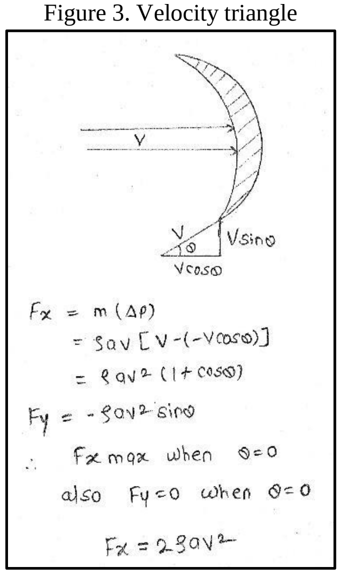

Figure 4. Velocity resolved component diagram

4. Turbulence —

Turbulence poses a serious problem for wind turbines because it causes an uneven power profile and shortens the life of the turbine blades owing to mechanical stresses. Because of the unpredictable and abrupt fluctuations in wind speed and direction, the turbine's components regularly experience problems. These components would need to be mechanically robust to endure vibrations brought on by the turbulent flow and be able to bear short peak loads whenever there is strong turbulence.

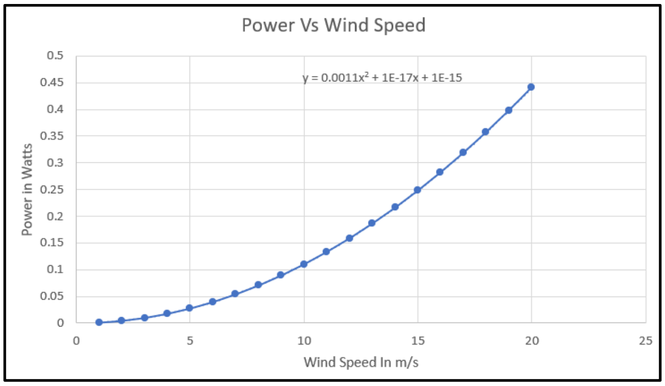

Figure 5. Power vs Wind Speed

In our project we have designed a portable Savonius rotor that can even operate at very low speed i.e., in general wind breezes come from windows outside.

B. Designing Savonius Rotor (S - shaped)

Designing a S rotor vertical axis wind turbine needs consideration of the power coefficient (C_p), tip speed ratio (λ), and aspect ratio (H/D). It is possible to represent the wind turbine's power using VAWT as

$$Power = \frac{1}{2}\rho CpAv^3 \qquad (2)$$

where,

ρ = Air Density

C_p = Coefficient of Performance

A = Swept Area of Blades

v = Velocity of wind

We define the aspect ratio as the ratio of the blades' height to the rotor's diameter once we have determined the blades' radius and height. (AR = H/D)

1. Importance of Aspect Ratio —

$$R = \sqrt{\frac{P}{\rho v^3 ARC_p}} \qquad (3)$$

In eq.3, if R increases as AR decreases. Also, rotational velocity can be derived as

$$\omega = \frac{\lambda_{cpmax} v}{R} \qquad (4)$$

In eq.4, rotational velocity (ω) is inversely proportional to R. The aspect ratio of the rotor should be as low as practical to enhance the power coefficient.

2. Working principle —

The Savonius rotor features the most straightforward two-bladed design. The Savonius turbine applies pressure to the curved blades in order to produce the torque needed to rotate the rotor. It is the most aerodynamically straightforward wind turbine to design and build, which greatly lowers its cost when compared to the aerofoil blade designs of the other VAWTs and HAWTs. The concave and convex portions of the rotor blades experience different amounts of drag, which causes the turbine to rotate.

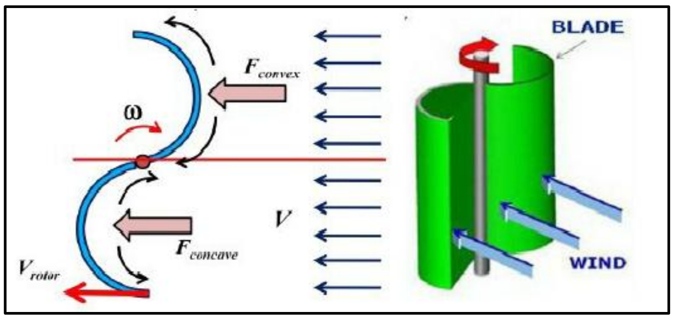

Figure 6. Working principle for Savonius Rotor

The working principle is that air is trapped in the concave part and pushes the turbine. The concave section confines the air, which accelerates the turbine. A smaller drag is generated on the convex section than on the concave one by the flow that impacts it. This turbine rotates as a result of the differential in drag force.

3. Characterization of Savonius Rotor —

Each Savonius blade is identified by its swept area (A_s). More power is gained the larger the swept area. A_s = H * D, where H is the turbine's height and D is its diameter, gives the swept area.

While the torque coefficient (C_t) measures the ratio of the rotor's actual torque to the maximum torque that may be produced by the wind. It is provided by —

$$C_t = \frac{T}{T_w} = \frac{T}{\frac{1}{4}\rho A_s\, dV^2} \quad (5)$$

The ratio of wind energy extracted to wind energy available is known as the power coefficient Cp, and its equation is as follows:

$$Cp = \frac{P\omega}{P_a} = \frac{T*\omega}{\frac{1}{2}*\rho*H*D*V^3}$$

(6)

Using these factors, we can understand different characteristics of the Savonius rotor and can analyze its performance.

C. *Project Action Plan Procedure*

The methodology of the project mainly includes six phases that are given in Fig. 7. Information gathering includes all the research reviews from different journals, conference papers, many articles, blogs, regarding Vertical Axis Wind Turbines. Then we analyzed prior solutions for this problem statement and went through refinement for a new solution or some criteria or attributes that affect the design model. By going through such theoretical concepts, we finalized to deal with Savonius VAWT. The power coefficient for the Savonius rotor's aspect ratio has been finalized and new ideas have been developed.

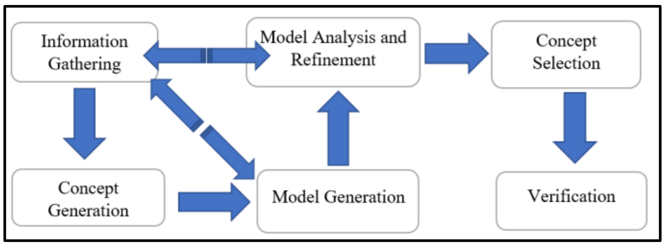

Figure 7. Applied Phases of used Methodology

We have defined our project objectives and problem statement and we found some tasks to be done in this project mandatorily. We grouped all these tasks and worked according to them.

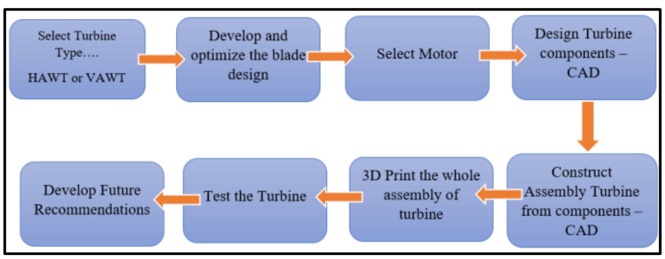

Figure 8. Tasks to be grouped

In fig 9, our project plan according to weekly and monthly basis i.e., how our project evolves with the working period of project time.

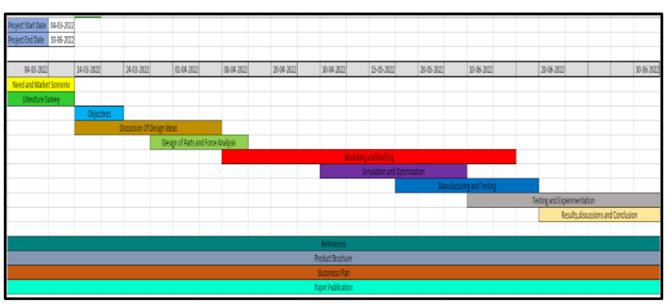

Figure 9.Planning of our work

D. CAD Model of Savonius

The classic barrel design for the Savonius rotor is simple. It includes simple two half cylinder shaped blades (eventually called a Barrel). Generally, their axis does not meet rather than set apart. We have made a portable design for the Savonius rotor such that we can dispatch it soon after work is over and can revert it too. We have designed a blade having slots to be fixed on slits provided to the shaft that has been designed.

Figure 10. Savonius Blade 1

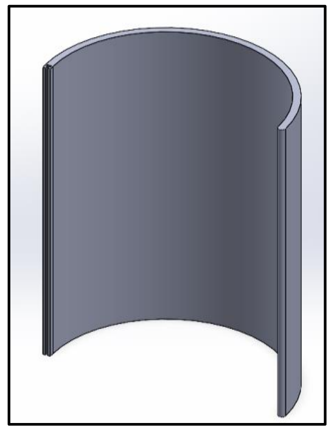

Figure 11. Savonius Blade 2

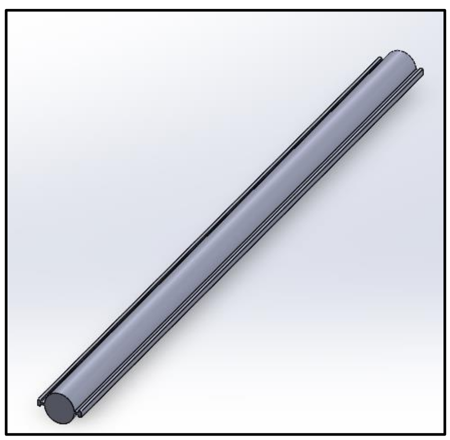

Figure 12. Shafts with slits

We have designed a Savonius 2- bladed rotor for our project. All this modeling has been done in SolidWorks. There are basic parts for Savonius rotor design like 2 slitted blades, base, shaft, cap, bearings, motor that are designed as CAD models and assembled for experimentation purposes. So, it is 3D printed.

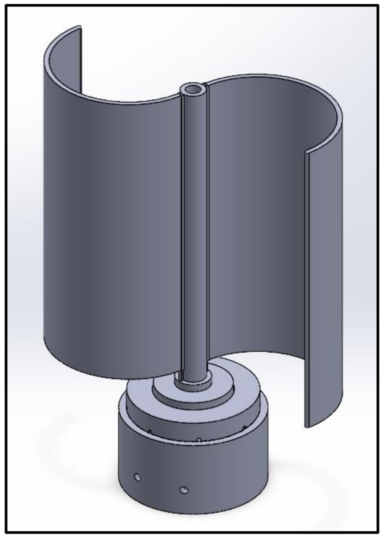

Figure 13. CAD assembly of Savonius rotor..H=12 cm, D=6cm

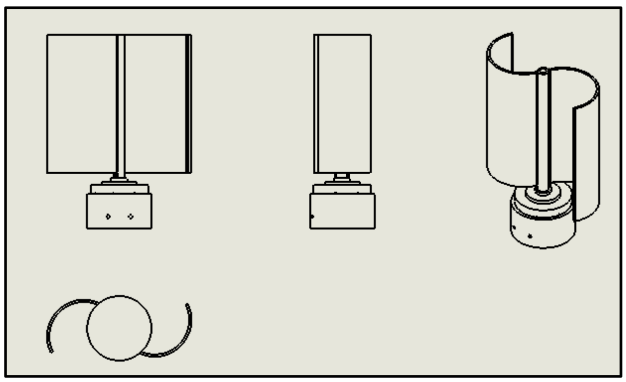

Figure 14. Different views of CAD model

By making the assembly we have further one its 3D printed model that has shown under the results section. Model is designed for 2 cases of aspect ratio that has been given in following table –

Blade	Height (H)	Diameter (D)	Aspect Ratio (H/D)
Blade 1	12 cm	6 cm	2
Blade 2	8 cm	9 cm	0.888889

Figure 15. Blades with different aspect ratios

E. CFD Simulation

Specific details of the procedures taken as well as the explanation (based on our limited comprehension of these incredibly complex software tools and mathematical models) are provided in the subsequent paragraphs.

1. Setup —

Utilizing ANSYS: Fluent, we will execute these simulations. In order to depict flow, turbulence, heat transport, and reactions for industrial applications, it "contains the vast modeling and simulation capabilities needed. Fluent features a wide range of applications, and it includes specialized models with the ability to simulate in-cylinder combustion, aeroacoustics, turbomachinery, and multiphase systems. Fig. 16 depicts project setup.

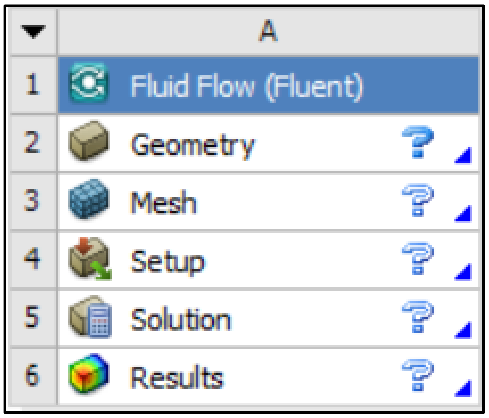

Figure 16. Ansys Fluent Project

We need either use ANSYS Design Modeler (DM) to model the geometry, which would then be meshed, or import the geometry from a CAD program (such as SolidWorks) till we can run the simulation. Software for computational fluid dynamics (CFD) operates by solving fluid dynamics equations around the geometry while conforming to the boundaries we provided. A mesh is constructed to help specify the location where these equations will be solved. Using a mesh, a tiny fraction of discrete points is created from the physical area. The mesh size, or number of points, affects how exact the solution is and also how long and how much energy it takes to solve a problem.

2. Meshing —

Determining the geometry to be simulated is the first step in the simulation process. We import the SolidWorks model for the 3D simulations, and for the 2D simulations, we recreate a 2D transverse section of the rotor using the dimensions we provided in the earlier sections.

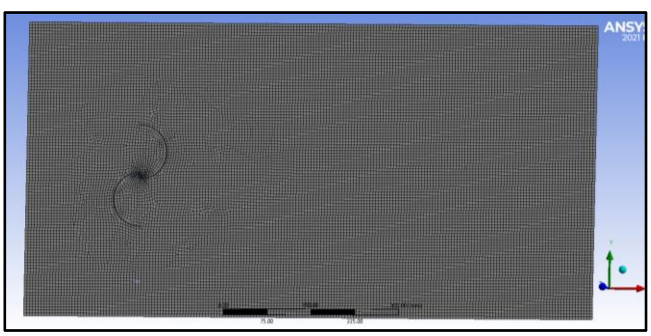

Figure 17. Meshing

Following mesh construction, the solver is where we describe the methods to be used, the boundary conditions, the turbulence model, the number of iterations, and the convergence condition. We shall use a pressure-based solver in steady time rather than a transient time solution. The output in our circumstance won't be affected by choosing between Pressure Based and Density Based because we are operating at a rather slow speed.

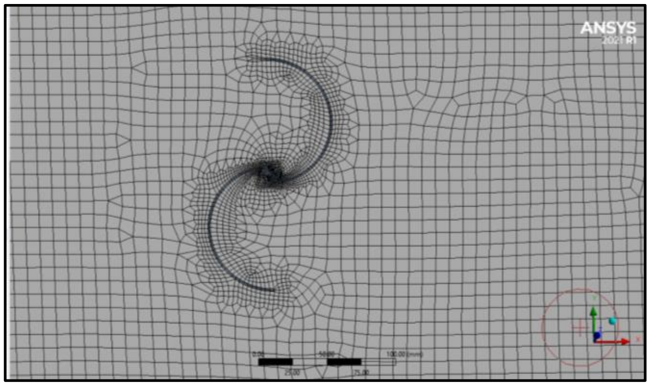

Figure 18. Rotor Mesh

It is advised to employ a density-based paradigm for extremely high speeds and a pressure-based approach for low speeds. Steady Time should be used since it converges more swiftly, according to the tutorials on which this work was based. Fig shows the residuals plot.

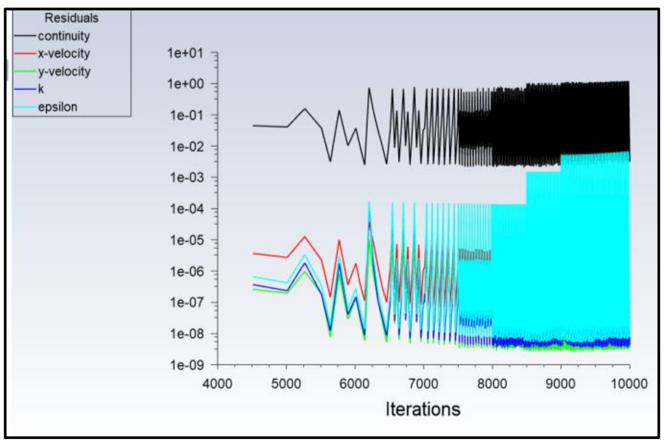

Figure 19. Scale residuals plot

We initialize the gauge pressure (the difference between the absolute pressure and the atmospheric pressure, reset at a value of zero) and the velocity (on the x, y, and z-axis) before conducting the solution.

IV. Results/Discussions

A. *Experimentation (Physical Prototype)*

We have developed Savonius turbine by two ways:
Blades using PVC material type and 3D Printed material type Savonius. First model is given in fig.10.

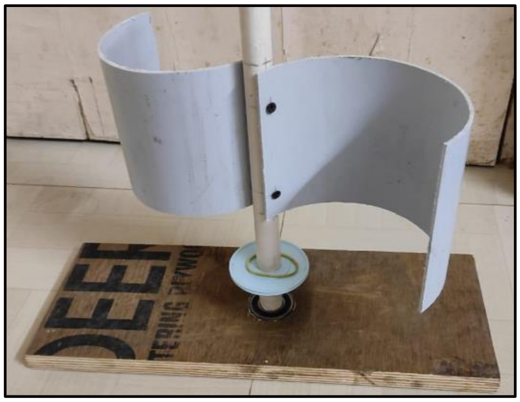

Figure 20. Model 1 - Not Portable

This model is made by us as material PVC is Common household material, easy to find, cheap, easy to work with and also its flexibility is strong, but we analyzed that it gets bulky and not really portable design as it needs more space to operate and does not fit to our problem statement. So, we decided to make it portable by reducing its required dimensions and specifications and modeled the 3D printed Savonius rotor.

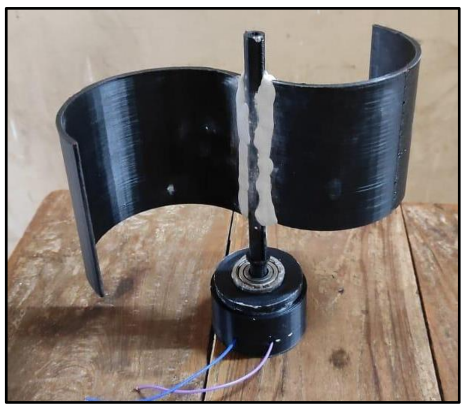

Figure 21. 3D printed model

Height (H) (in cm)	Diameter (D) (in cm)	Aspect Ratio (H/D)	Power (P) (in watt)
12	6	2	0.0059538
8	9	0.888889	0.0079384

Figure 22. Power output at 3m/s wind speed

Height (H) (in cm)	Diameter (D) (in cm)	Aspect Ratio (H/D)	Power (P) (in watt)
12	6	2	0.0165378
8	9	0.888889	0.0220504

Figure 23. Power output at 5 m/s wind speed

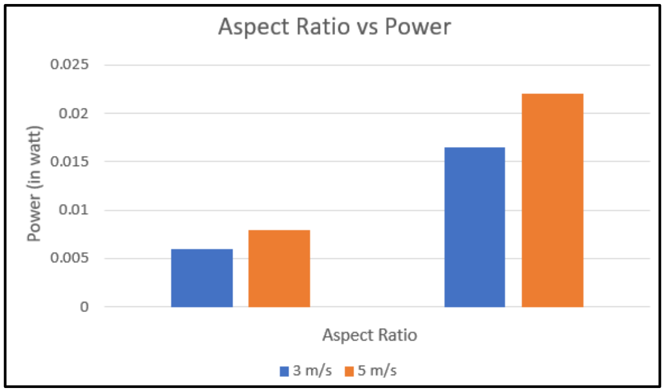

Figure 24. Aspect Ratio vs Power at different wind speeds

B. CFD Results

As seen in fig. 25, the pressure is the greatest on the concave side of the rotor blade (the receiving open cup), where the wind will be most intense and will take longer to dissipate than on the convex side. Negative pressure (vacuum gauge pressure - as compared to ambient pressure) is produced on the back of the rotor because this is a static instance with the rotor positioned in this specific position. A net force is applied to the blades as a result of the pressure differential, which causes rotation. To reach a trustworthy conclusion on the relationship between the quantity of blades and the pressure differential, the same simulation will be run at different rotor orientations and speeds.

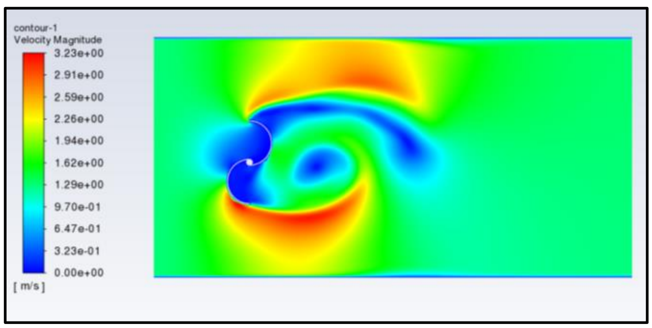

Figure 25. Velocity Contours at 5 m/s

Conditions at the velocity inlet are Normal to Boundary according to its magnitude approach. Inlet velocity is 5 m/s, while the reference frame is absolute. The intensity and length scale approach is used to specify turbulence, and the threshold value for turbulence intensity is 5%. A 1000 m scale is used to describe turbulence.

Velocity outlet conditions are given as the backflow frame reference is absolute as its gauge pressure tends to 1. It has a Normal to Boundary specification method as a backflow direction frame. We have concluded force and moment plots. It has the same turbulence intensity and turbulence length as defined for inlet conditions.

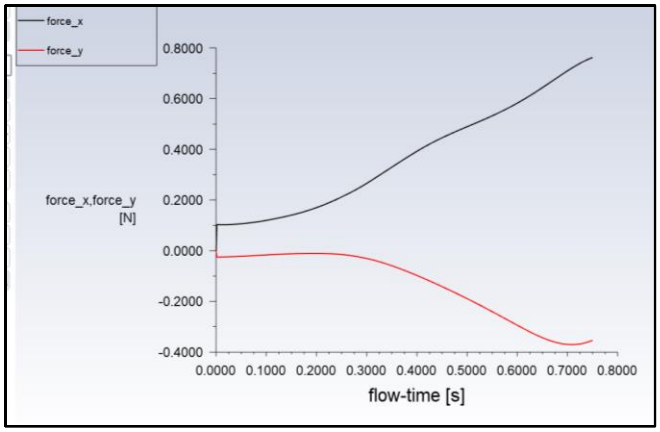

Figure 26. Force Plot

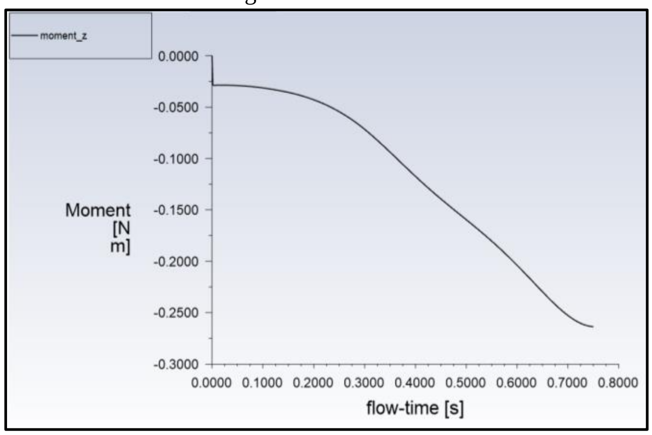

Figure 27. Moment Plot

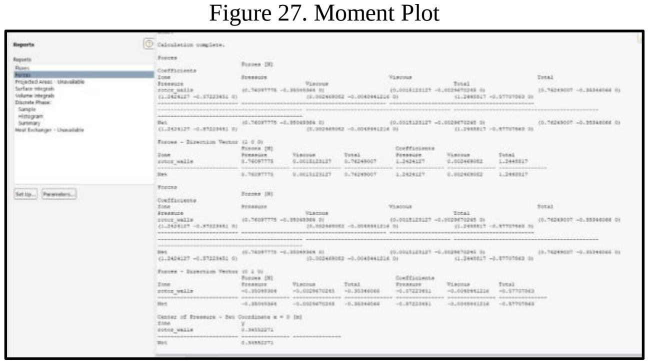

Figure 28. Forces report

Fig. 28 shows console values of forces report including direction forces, pressure forces, viscous forces, total pressure forces values are also depicted.

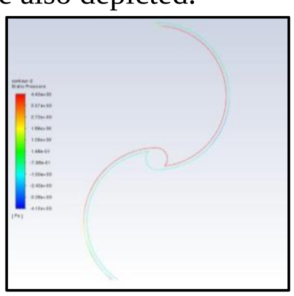

Figure 29. Static Pressure Contour

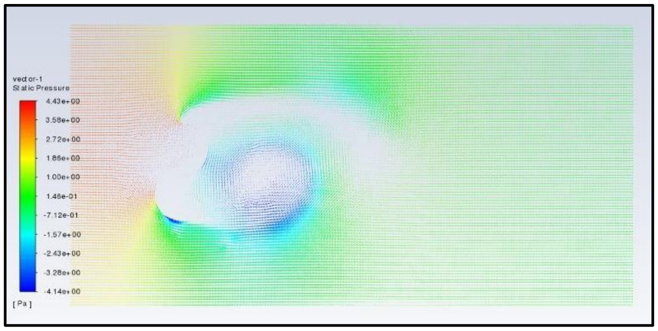

Figure 30. Relative Velocity Contour by Static Pressure

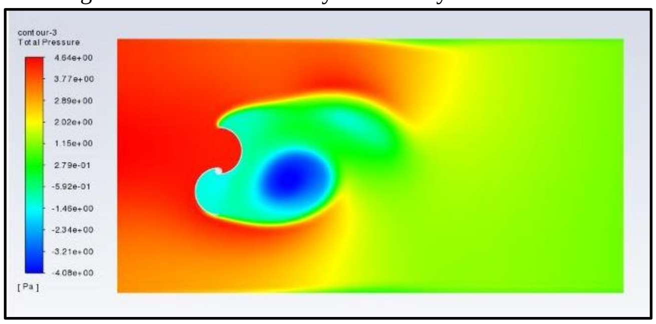

Figure 31. Total Pressure Contour

In a 2D simulation, Fig. 31 displays the total pressure contour surrounding Savonius blades. Savonius displays a moderate pressure contour and performs well.

V. Limitations

We measure only the voltage that we get and calculate its power coefficient and compare the results for both the blades specifications with different aspect ratio not to store the voltage that can be used further for electrical output. It can integrate with our future recommendations that we can use generators or batteries to store the voltage output.

VI. Future Scope

We can store the electrical energy by means of batteries so that we can use it for charging small electronic gadgets. This can be our future scope of our project that can lead to power storage capacity of this Savonius rotor can be improved further. Also, we can make its tapering blade design specially called Ice wind design at portable level that gives more output than classic barrel design.

VII. Conclusion

This research was conducted to examine the impact of aspect ratio on the Savonius turbine's power coefficient. We considered how to build Savonius to enhance its power coefficient. As a result of our analysis of many elements, such as aspect ratio and swept area, we have concluded that both values have an impact on power coefficient since a turbine with a lower aspect ratio can generate more power. Lower aspect ratio turbine blades provide more advantages than higher aspect ratio ones. advantages such as greater power coefficients and a structural benefit from a thicker blade (lesser height). Additionally, tests show that this wind turbine can function in winds as low as 3 m/s^2. Voltage, current, and generated power output all increase with wind speed. In order to increase the amount of wind that can sweep the blade's area and extract the most energy, we have improved the working by shortening the chord length. The turbine is sturdy enough to be designed for self-starting in order to provide more torque under low-speed conditions. The Savonius rotor has demonstrated its performance as a simple design, low cost, and low starting torque at low wind speed, taking into consideration low efficiency in terms of negative torque applied to the returning blade.

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