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Effect of Aspect Ratio on The Performance of Savonius Wind Turbine

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ABSTRACT
Savonius wind turbines are widely recognized for their simplicity, self-starting capability, and suitability for low wind speed applications; however, their relatively low aerodynamic efficiency remains a major limitation. One of the geometric parameters that significantly influence the performance of Savonius turbines is the rotor aspect ratio, defined as the ratio of rotor height to rotor diameter. This study investigates the effect of aspect ratio on the aerodynamic performance of a two-bladed Savonius wind turbine through experimental analysis. Two rotors with aspect ratios of 2.0 and 0.5 were designed, fabricated, and tested under controlled laboratory conditions using a variable-speed wind source. Electrical output parameters were measured using a resistive load and data acquisition system, from which the power coefficient and tip speed ratio were evaluated at different wind speeds. The experimental results show that the rotor with an aspect ratio of 2.0 consistently achieved higher power coefficients across the tested wind speeds, with a maximum power coefficient of 0.023, compared to a maximum value of 0.00917 obtained for the rotor with an aspect ratio of 0.5. The findings confirm that increasing the aspect ratio enhances the energy capture capability of Savonius wind turbines, thereby improving their overall performance. This work provides useful design guidance for small-scale and educational Savonius wind turbine applications in low-wind environments.
Keywords: Savonius wind turbine, Aspect ratio, Power coefficient, Tip speed ratio, Vertical-axis wind turbine.

Nomenclature
P=Powermeasuredinwatt(W) Cp = Power coefficient
U=the windspeed (m/s)
ω=Angularvelocityoftherotormeasuredinrad/s λ = Tip speed ratio
D=Diameteroftherotormeasuredinmeter(m) H = Height of the rotor measured in meter (m)
As=SweptareaoftheSavoniusrotormeasuredin(m2)whereAs=D.H Ar = Aspect ratio where Ar = H/D
R'=Radiusoftherotorblades PT = Wind turbine power
PAV=AvailablePower
R=Resistor

I. Introduction

The global transition toward renewable energy has intensified research into efficient wind energy conversion systems suitable for diverse environmental conditions. Among the available technologies, the Savonius wind turbine—a drag-type vertical axis wind turbine (VAWT)—has attracted considerable attention due to its simple construction, low manufacturing cost, self-starting capability, and relatively good performance at low wind speeds [1]. Despite these advantages, the Savonius turbine generally exhibits a lower power coefficient compared to lift-based turbines, which has motivated extensive research aimed at improving its aerodynamic performance through geometric and operational optimization [2]. One of the most critical geometric parameters affecting Savonius rotor performance is the aspect ratio (AR), defined as the ratio of rotor height (H) to rotor diameter (D) [3]. The aspect ratio directly influences the swept area, torque generation, and aerodynamic interaction with incoming wind flow. Consequently, numerous studies have investigated its effect on turbine efficiency, although reported optimal values vary significantly. Akwa et al. [4] conducted a comprehensive review of parameters influencing Savonius turbine performance and observed that many researchers converge on an aspect ratio close to 2.0 for favorable outcomes. Similarly, Kadam and Patil [5] and Bhayo et al. [6] reported that increasing the aspect ratio generally improves the power coefficient, recommending values not less than two. Sai and Rao [7] further suggested a design configuration in which the rotor height is approximately twice its diameter to achieve enhanced performance. Conversely, other investigations propose different optimal aspect ratios. Al-Faruk and Sharifian [8] reported that an aspect ratio of 1.0 can yield a relatively high power coefficient under certain flow conditions. Fernando [9], in a doctoral dissertation, observed a peak power coefficient of approximately 23.5% at an aspect ratio of 0.77. Experimental work by Mahmoud et al. [10], who tested aspect ratios ranging from 0.5 to 5, revealed a general trend of increasing power coefficient with increasing aspect ratio. This observation was also supported by Kadam and Patil [11], who noted a positive correlation between aspect ratio and turbine efficiency. Given these divergent findings in the literature, further empirical investigation is required to establish clearer design guidelines. This study therefore aims to contribute experimental evidence by comparing the performance of two Savonius rotors with distinct aspect ratios (2.0 and 0.5) under identical wind conditions, with the objective of identifying the configuration that maximizes the power coefficient.

II. THEFUNDAMENTALEQUATIONSOF ASAVONIUSWINDTURBINE

The swept area of a Savonius wind turbine is given by:

$A_s = H \times D$

Where*H* is the rotor height and *D* is the rotor diameter.

The aspect ratio of the rotor is defined as:

$A_r = H / D$

Where H is the rotor height and D is the rotor diameter.

The available wind power is expressed as:

$P_{AV} = \frac{1}{2} \rho A_s U^3$

where ρ is the air density, As is the swept area, and U is the wind speed.

The electrical power output of the turbine is determined using:

$P_T = V_{rms}^2 / R$

whereVrms is the root mean square voltage across the load resistance R.

The power coefficient, which represents the efficiency of the turbine, is defined as:

$C_p = P_T / P_{AV}$

The tip speed ratio is given by:

$\lambda = \omega R / U$, where ω is the angular velocity of the rotor and R is the rotor radius.

The Schematic Diagram of a Two-Bladed Savonius Wind Turbine Rotor is shown in figure 1.

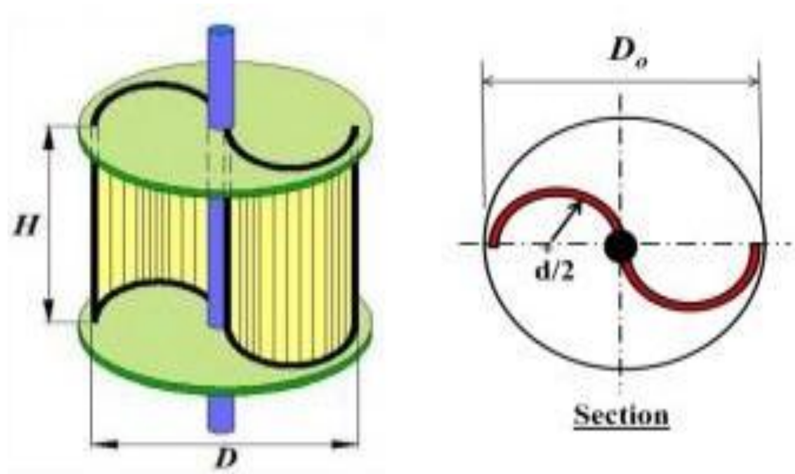

Fig.1. Schematic Diagramofa Two-BladedSavoniusWind TurbineRotor [11]

III. Methodology

The experimental setup consisted of a laboratory-scale Savonius wind turbine driven by a controlled air source is shown in figure 2. A domestic hair dryer was used as the wind blower, with the heating element disabled to avoid thermal effects. Two wind speed settings were employed, and measurements were taken at different distances between the blower and the rotor to achieve wind speeds ranging from 3.9 m/s to 11.2 m/s. Two Savonius rotors were fabricated with identical blade profiles but different aspect ratios. The first rotor had a height of 0.12 m and a diameter of 0.06 m, resulting in an aspect ratio of 2.0 as shown in figure 3 (a). The second rotor had a reduced height to achieve an aspect ratio of 0.5 as shown in figure 3(b). The turbines were coupled to an electrical generator, and the output voltage was recorded using a data acquisition system connected to a computer. A resistive load of 100 Ω was used

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throughout the experiment. The recorded voltage signals were analyzed to determine the RMS voltage, from which the electrical power output, power coefficient, and tip speed ratio were calculated for each operating condition.

Fig.2. WindTurbineconnectedtotheDataLogger,theDataLoggerconnectedtothe Computer (Display)

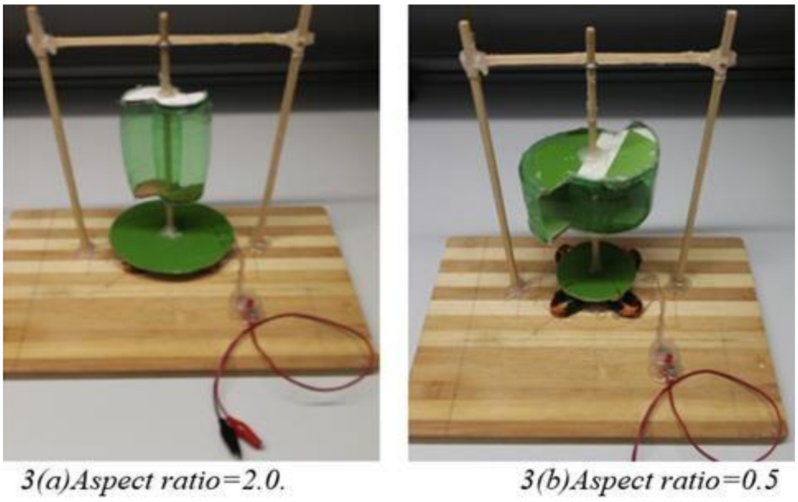

Fig.3(a)and(b)Savoniuswindturbine rotorswithan aspectratioof 2.0and 0.5

IV. RESULTS AND DISCUSSION

A. RESULTS

The results obtained from the experiment are presented in Tables 1 and 2. Table 1 shows the coefficient of power (Cp) and corresponding tip speed ratio (λ) for a rotor with aspect ratio of 2.0 at different wind speeds, while table 2 presents similar parameters for a rotor with an aspect ratio of 0.5

Table:1CP-λvaluesforarotorwith anaspectratioof 2.0

S/N	Wind speed	Coefficientofpower(CP)	Tipspeedratio (λ)
1	11.2m/s	0.005	0.747
2	5.7m/s	0.023	1.018
3	4.9m/s	0.011	0.639
4	3.9m/s	0.011	0.604

Table2: CP-λvaluesforarotorwithan aspectratioof 0.5

S/N	Wind speed	Coefficientofpower(CP)	Tipspeedratio (λ)
1	11.2m/s	0.00204	1.037

2	5.7m/s	0.00917	1.393
3	4.9m/s	0.005	1.06
4	3.9m/s	0.00339	0.966

B. DISCUSSIONS

- **.Cp - λ Characteristics for Aspect Ratio = 2.0**

Figure 4 illustrates the variation of the coefficient of power with tip speed ratio for the Savonius rotor having aspect ratio of 2.0. The results show a clear increase in Cp with increasing λ, reaching a maximum Cp of approximately 0.023 at λ ≈ 1.0. This indicates improved aerodynamic performance at moderate tip speed ratios, which are characteristics of Savonius rotors operating under low to moderate wind speeds. The observed behavior suggests that a higher aspect ratio enhances energy capture by reducing end losses and improving flow interaction along the blade height

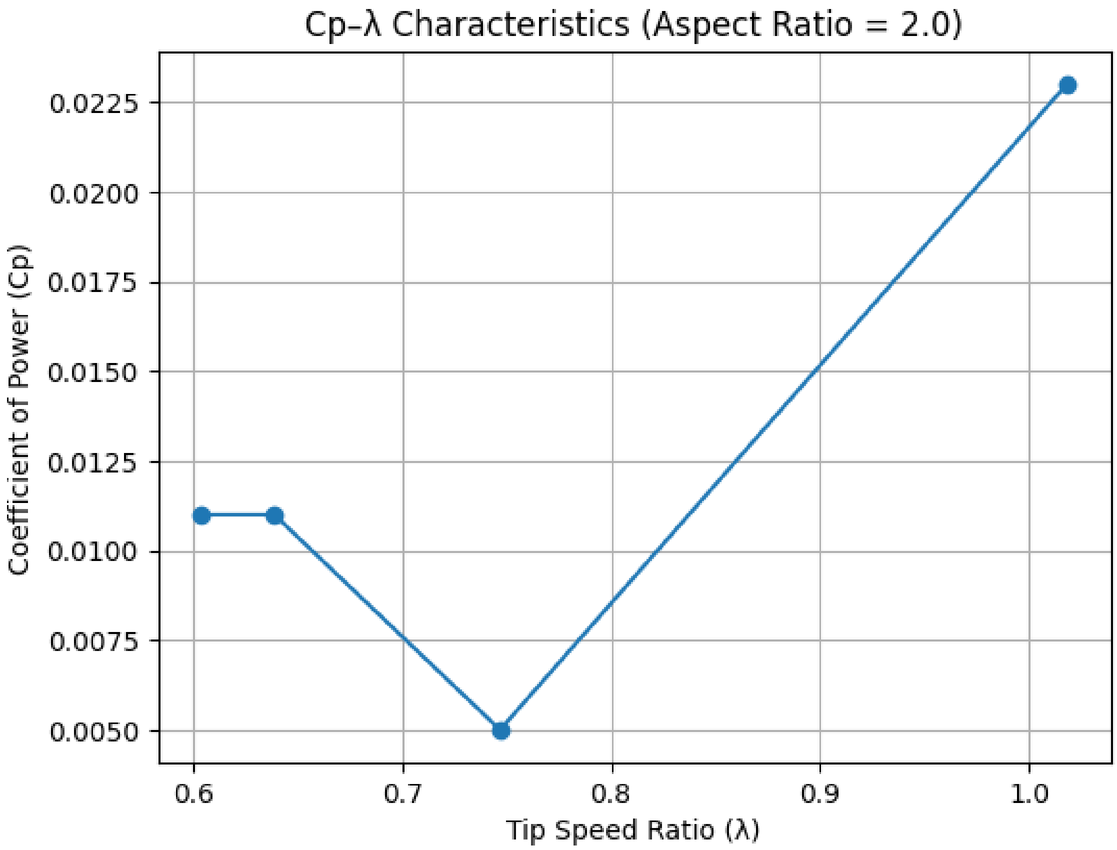

Fig. 4. Variation coefficient of power (Cp) with tip speed ratio (λ) for a Savonius rotor withan aspect ratio of 2.0

- **Cp - λ Characteristics for Aspect Ratio = 0.5**

The Cp - λ relationship for the rotor with aspect ratio of 0.5 is presented in Fig. 5. Compared to the higher aspect ratio rotor, lower Cp values recorded across the investigated range of λ. The maximum Cp obtained is approximately 0.009 at λ≈1.4. Although the rotor operates at relatively higher tip speed ratios, the reduced aspect ratio limits the effective aerodynamic interaction, leading to lower power extraction efficiency.

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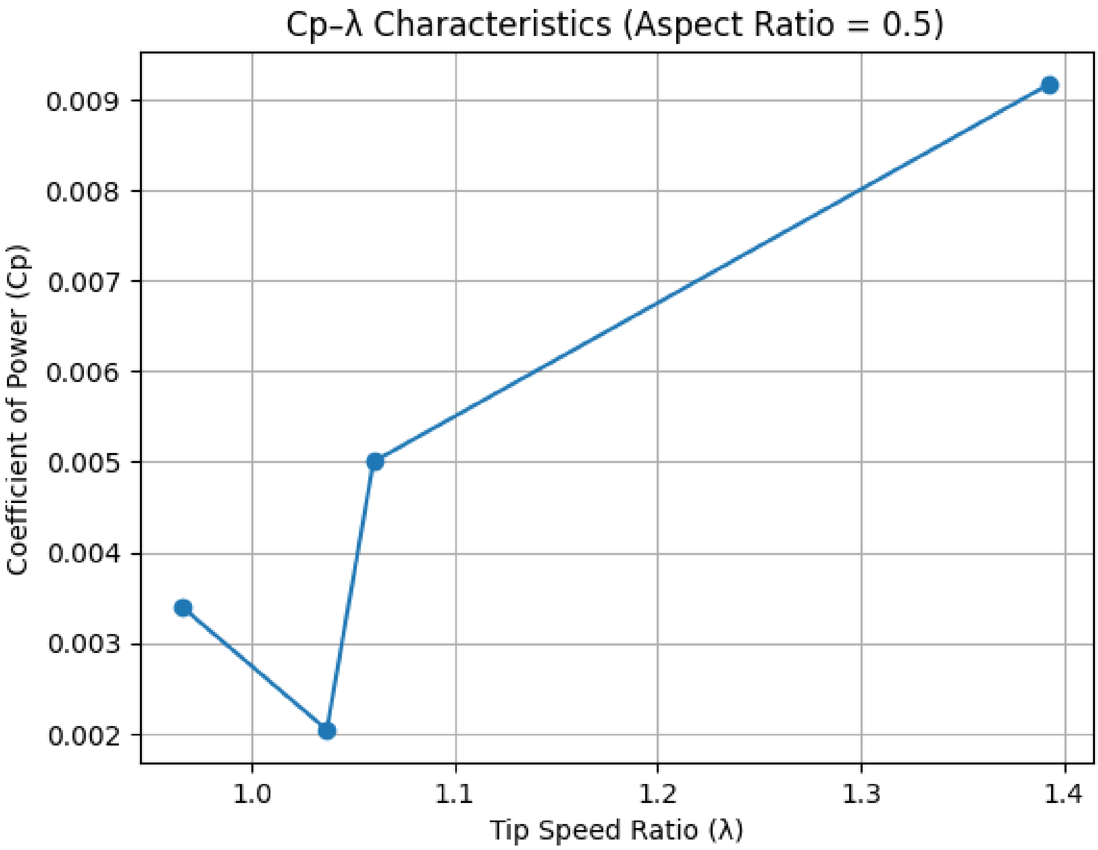

Fig. 5. Variation coefficient of power (Cp) with tip speed ratio (λ) for a Savoniusrotor with an aspect ratio of 0.5

- **Comparative Analysis of Aspect Ratios**

Figure 6 compares the Cp – λ characteristics of both rotors. It is evident that the rotor with an aspect ratio of 2.0 consistently outperforms the rotor with an aspect ratio of 0.5 in terms of coefficient of power. While the lower aspect ratio tends to operate at higher λ values, this does not translate into higher power output. This confirms that aspect ratio plays a significant role in determining the aerodynamic efficiency of Savonius rotors, with higher aspect ratios favouringimproved power coefficients. Although the absolute Cp values are lower than those commonly reported in literature, this can be attributed to small-scale experimental limitations, mechanical losses, and measurement uncertainties. Nevertheless, the relative trends observed are consistent with established Savonius rotor performance characteristics, validating the comparative analysis.

Savonius rotor with an aspect ratio of 2.0 is 0.00477 while the lowest Cp for Savonius rotor with an aspect ratio of 0.5 is 0.00204.

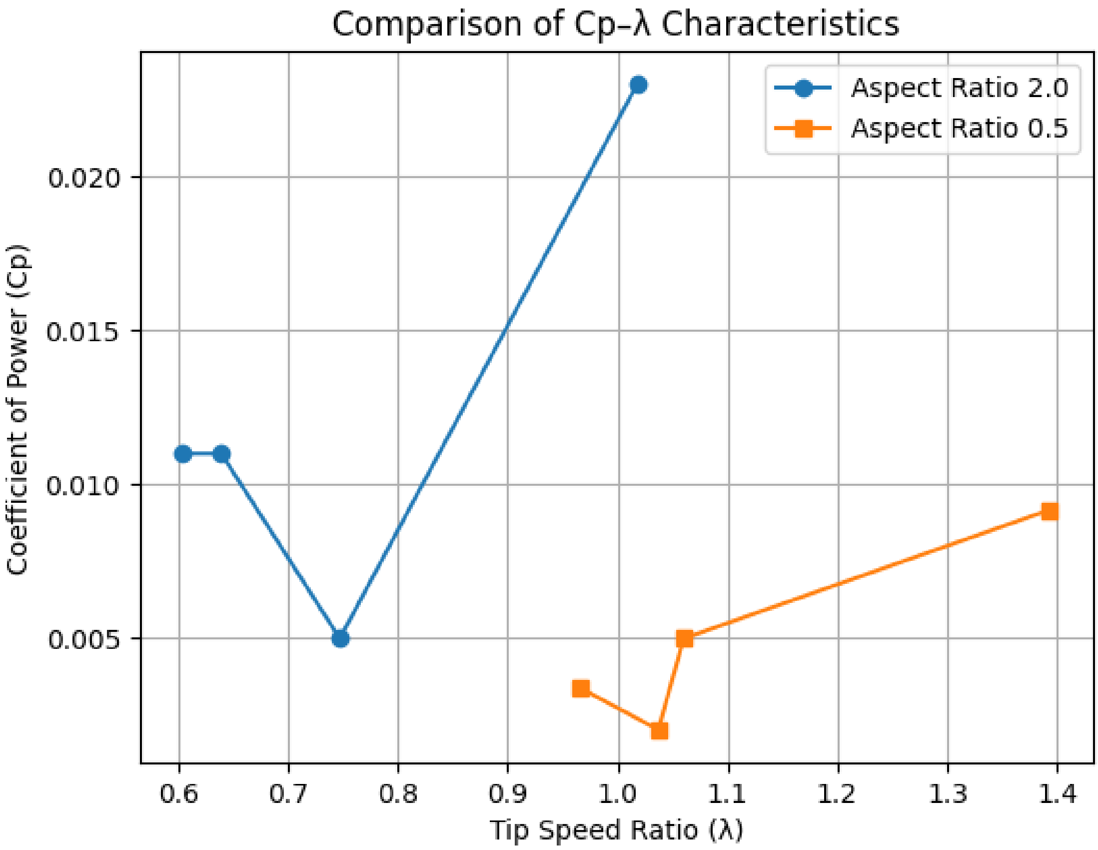

Fig.6. compares the Cp-λperformance of both rotors

Conclusion

This study experimentally investigated the effect of aspect ratio on the performance of Savonius wind turbines using two rotors with aspect ratios of 2.0 and 0.5. The results show that increasing the aspect ratio significantly improves turbine performance, as evidenced by higher power coefficients and improved Cp–λ characteristics. The rotor with an aspect ratio of 2.0 consistently outperformed the rotor with an aspect ratio of 0.5 under identical testing conditions. These findings confirm that an aspect ratio around 2.0 is preferable for achieving better efficiency in small-scale Savonius wind turbines. The outcomes of this research provide practical guidance for the design and optimization of Savonius turbines for low wind speed and educational applications.

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