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Original Article

Design and Performance Comparison of Two Spiral Wind Turbines Using Numerical Modelling

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Abstract *- This study examines the efficacy of Horizontal Axis Wind Turbines (HAWTs) with spiral shapes, aimed at overcoming challenges related to urban wind energy collection. This structure, unlike conventional turbines, demonstrates the capacity to function well without dependence on precise wind direction, rendering it suitable for highly populated regions with fluctuating wind patterns. This paper details the design and performance assessment of a Spiral Wind Turbine (SWT) with a logarithmic spiral blade configuration. A comparative analysis was performed via simulations between the proposed logarithmic spiral arrangement and a traditional Archimedean spiral design, both limited to the same projected area. The Logarithmic Spiral Wind Turbine (LSWT) demonstrates superior performance over the Archimedes wind turbine in wind energy applications, exhibiting an efficiency differential of roughly 8%.*

Keywords *- Logarithmic spiral turbine, Archimedean spiral design, Spiral, HAWT, Urban environment.*

1. Introduction

Energy poses one of the most significant challenges for developing nations striving toward sustainable progress, with the global population expanding rapidly. Researchers are exploring new energy sources to decrease dependence on fossil fuels. Despite their harmful environmental effects, fossil fuels remain a critical foundation for human advancement, and their consumption is rising steadily.

This growing reliance has led to numerous ecological problems, including the greenhouse effect, rapid climate change, and ozone layer degradation. To address these issues, renewable energy presents a viable and eco-friendly solution tailored to the unique natural resources of each country. The development and widespread use of green technologies and improved production methods are essential in this transition. Wind energy offers a pollution-free alternative for electricity generation [1].

Wind energy has emerged as a critical resource and a more environmentally friendly option than many traditional energy sources. It is an alternative to nuclear power, oil, coal, and natural gas and stands out as one of the most sustainable energy sources globally. Unlike solar power, wind energy is not dependent on daylight, making it a reliable option.

The technology behind wind turbines is well-developed, producing no air or water pollution. Once a turbine is installed, its environmental impact is minimal, with virtually no operating costs. Overall, the adoption of wind energy for power generation has seen rapid expansion worldwide.

Nomenclature (Units)	
C_D	Coefficient of Drag
F_N	Normal force [N]
r	Turbine radius [mm]
F_D	Drag force [N]
C_L	Coefficient of Lift
S	Spiral Pitch [mm]
F_T	Tangential force [N]
F_L	Lift force [N]
R	Resultant force [N]

The wind turbine's power is contingent upon the wind's velocity and its blades' design. Extensive scholarly investigations have been directed towards optimising blade geometries to enhance the efficiency of kinetic energy extraction from the wind. Wind turbines are predominantly categorised according to their shaft and rotational axis alignment. Initially, the aerodynamic profiles utilised in constructing aircraft wings were repurposed to design wind turbine blades, as selecting a suitable aerodynamic shape is of paramount importance for effective energy conversion [2].

In India, the average wind speed is about 3 m/s at a height of 20 m [3]. The Archimedes wind turbine is a viable option for decentralised wind energy production, especially on rooftops in cities. This novel turbine is ideal for residential and commercial buildings in densely populated areas because it is specifically made to operate effectively in low wind speed conditions.

The Archimedes wind turbine is composed of three interlinked helical blades, forming a spatial arrangement that is similar to a three-dimensional conical structure.

Archimedes' wind turbine uses all the forces incident on its blades for power generation [3]. The force distribution on the Archimedes wind turbine's spiral blade configuration is shown in Figure 1. Owing to its higher efficiency and compactness, it is suitable for rooftop applications.

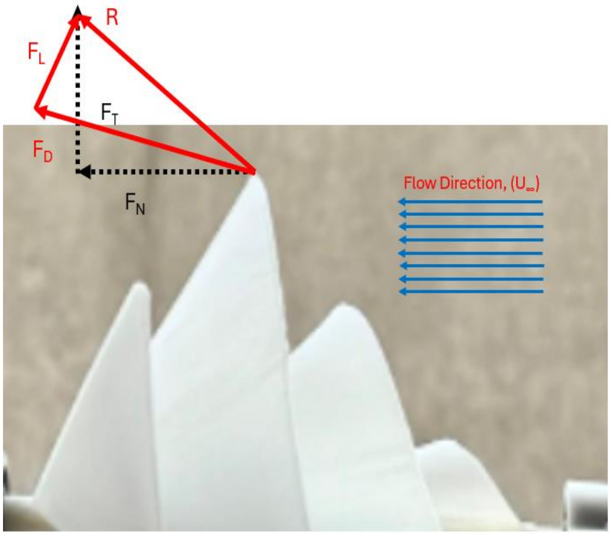


Fig. 1 Forces acting on the rotor of the SWT

Another notable advantage of SWT is the ability to adjust to wind direction. Due to its unique design, electronic yawing mechanisms are rendered unnecessary. Furthermore, due to its relatively reduced rotating speed, the turbine functions at a diminished noise level compared to all other wind turbines [4]. Consequently, the SWT is the optimal choice for installation near urban areas with significant noise issues because of its comparatively lower noise levels.

The preceding study in the scientific review seeks to assess and enhance the efficacy of wind turbines. In their study, Kim and co-researchers [5] applied Computational Fluid Dynamics (CFD) along with Particle Image Velocimetry (PIV) to investigate the performance of a reduced-scale model of the spiral wind turbine. The results indicated that it attains its peak power production. The SWT's capabilities and optimal performance attributes were also analysed using laser methodologies.

The spiral wind turbine achieved a highest power coefficient of 0.26 when exposed to a range of wind velocities, according to a computational study by Ebrahimi and Ghassemi [6] using ANSYS-CFX. TSR = 2.5 is the tip speed ratio. By demonstrating improvements in Archimedes screw turbine design, Robert Ward Harding [7] increased operational range and efficiency. In contrast to traditional turbines, which have trouble at low wind speeds, the new cupped flighting increases efficiency by 9–10% at design flow and sustains performance from 5% to 110% of design flow. For increased power generation, it uses a three-phase permanent-magnet AC servo motor. These developments establish a new standard for Archimedes spiral turbines by enabling consistent, effective operation under a variety of circumstances.

Kyung Chun Kim [8] assessed the ASWT aerodynamic performance using experimental Particle Image Velocimetry (PIV) and Computational Fluid Dynamics (CFD) approaches. Unsteady CFD closely matches experimental data, revealing complex flow patterns. The turbine demonstrates high urban efficiency with a power coefficient (Cp) of 0.25, emphasising the value of combined experimental and numerical analyses.

Mustafa Jeleel [9] thoroughly investigated the Archimedes spiral versus wind-driven propellers. Turbines and found the ASWT to consistently outperform the propeller turbine in output power and efficiency across varying wind attack angles and velocities. The ASWT's higher power coefficient (Cp) and superior energy conversion make it an additional efficient option for small-scale wind energy applications.

Although the Archimedes wind turbine produces adequate power when the wind speed is low, there is still a lot of scope to improve its aerodynamic efficiency. However, Increased energy capture and better flow dynamics may result from structural and blade profile refinement. These factors must be optimised to improve adaptability in a variety of wind conditions, especially in intricate urban settings.

The Logarithmic Spiral Wind Turbine, a new and innovative design, has been introduced to overcome these performance limitations. However, with a more optimised spiral geometry based on the logarithmic curve, this sophisticated configuration expands on the aerodynamic concepts of the Archimedes model. In comparison to the Archimedes turbine, the Logarithmic Spiral Wind Turbine blades produce higher drag and lift forces because of their larger surface area and more advantageous orientation with respect to the wind flow.

Improved interaction with incoming wind is made possible by the logarithmic design's increased surface area and curvature, which leads to higher torque generation and more efficient momentum transfer. However, when taken as a whole, these improvements result in increased energy output and overall efficiency. The logarithmic spiral turbine is a more practical option for urban renewable energy systems than the Archimedes turbine, according to comparative performance evaluations, especially in low to moderate wind regimes.

2. Geometric Configuration of Spiral Wind Turbine Blades

Three helically twisted blades evenly spaced around a central axis make up the SWT. Together, the blades form the turbine rotor, each of which contributes to rotational motion. By effectively directing airflow, this arrangement is designed to capture wind energy and transform kinetic energy into mechanical power. The main geometrical parameters defining the turbine design are the following, as shown in Figure 2. The opening angle of the turbine, which is the angle formed between the central axis and the terminal edge of the blade at the exit point; the radius (r), which is the distance from the rotational axis to the blade tip at the outlet; and the spiral pitch (s), which is the axial distance covered in one complete helical turn. This investigation explores the capabilities of the SWT, analysed through a multifaceted lens utilising the logarithmic and Archimedean principles and exploring how shifts in the opening angle affect its efficacy. It showcases unique designs of spiral profiles, notably the Archimedean spiral, Figure 3(a) and logarithmic spiral, Figure 3(b). The study highlights the SWT with a logarithmic profile and the one defined by an Archimedean profile. The critical distinction between the logarithmic and Archimedean spirals is found in the spacing between the successive turns. In a logarithmic spiral, these distances increase geometrically in a geometric progression, whereas in the Archimedean spiral, they remain uniform.

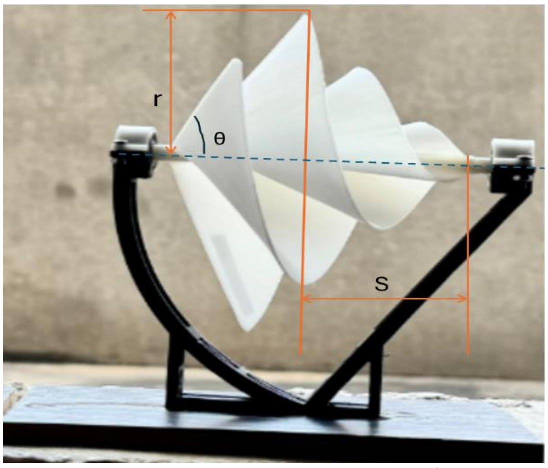
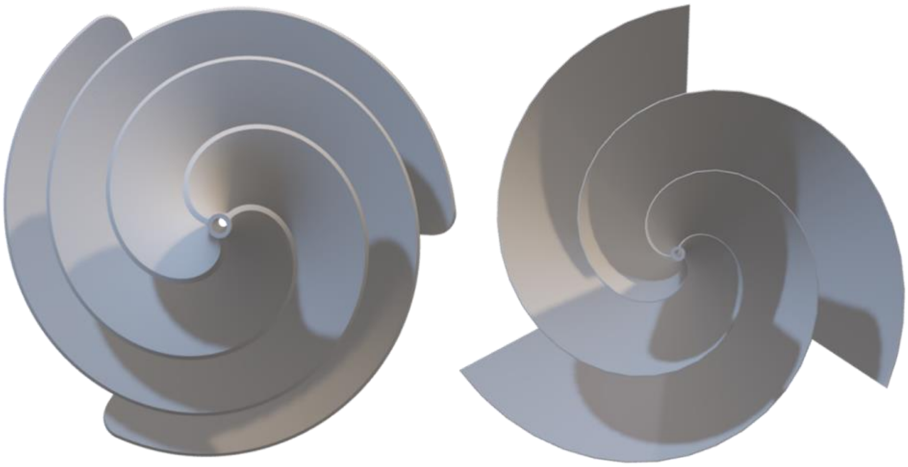


Fig. 2 Design parameters and geometry of SWT


(a) Archimedean spiral **(b) Logarithmic spiral**
Fig. 3 Model comparison of spiral wind turbine designs

The following equation represents the Archimedean spiral.

$$r = a + b\theta$$

And the equation for the logarithmic spiral is given by,

$$r = p \times e^{q\theta}$$

Constants p and q are included in the parametric form of the spiral, where r will be the radius measured from the central point and θ is the angle of rotation. The opening angle, which was measured at the blade's terminal point, was always set at 60° for every turbine configuration under study. The novelty of the work lies in exploring the performance of Logarithmic SWT vis-à-vis the Archimedes wind turbine.

3. Design of Logarithmic Spiral Wind Turbines

Figure 4 shows the Logarithmic spiral wind turbine, characterised by three blades arranged at an angle of 120 degrees apart. The outside diameter of the Logarithmic spiral wind turbine blade is 1500 mm, with a thickness of 5 mm and a length of 1500 mm. The Logarithmic wind turbine was designed and modelled using Fusion 360. Modelling the Logarithmic spiral wind turbine blade is difficult due to the continuous variation in shape along the spiral length. This variation necessitates specific adjustments to maintain aerodynamic performance and structural reliability throughout the blade. Advanced CAD techniques and a thorough understanding of aerofoil dynamics are essential for integrating these complex geometries. As a result, the modelling process is meticulous and time-intensive, highlighting the intricate nature of the blade's design.


Fig. 4 Geometrical model of logarithmic wind turbine

4. Methodology

The Computational Fluid Dynamics (CFD) approach was used to analyse the aerodynamic performance of wind turbine blades by considering the specified boundary conditions using numerical methods that solve fluid flow equations. In this controlled digital environment, researchers analyse the air flow parameters. CFD facilitates more effective CFD offers a more effective and economical alternative to conventional experimental testing, facilitating rapid performance evaluations while diminishing the need for extensive wind tunnel testing and physical prototypes.

4.1. Computational Method

CFD FLUENT provides many turbulence models, including the Shear Stress Transport (SST) k-ω model, which predicts flow separation. This dual-equation model integrates the pros of k-ε and k-ω turbulence models.

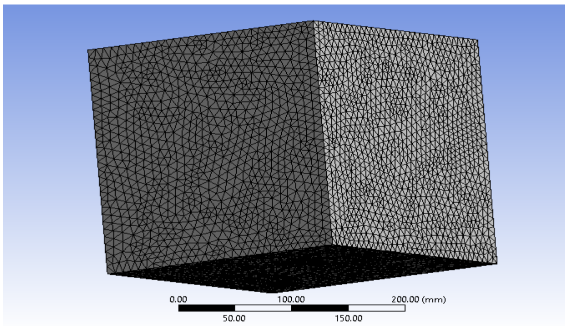


Fig. 5(a) Mesh generation for test section

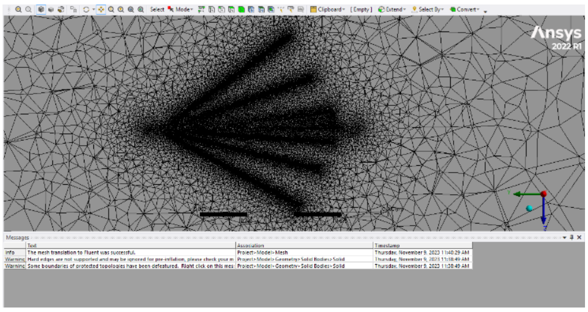


Fig. 5(b) Mesh generation for logarithmic wind turbine

4.2. Mesh Generation

The computational field is constructed, and the mesh is generated using the commercially available software "ANSYS Meshing tool" to create a test section. Figure 5(a) model and create the amorphous mesh in the computational area around the blade. The figure illustrates that a three-dimensional Logarithmic Wind Turbine Figure 5(b) blade is positioned inside an imaginary test section that defines inlet and outlet conditions.

The meshing element size for the logarithmic wind turbine was 1mm, and the test section element size was 3mm. After meshing, the total number of nodes on the tunnel and rotor of the Logarithmic Wind Turbine is 241,835 and 39,084, respectively, totalling 280,919 nodes. A fine mesh with a hex-dominant method was employed. The boundary conditions are an inlet wind speed of 5 m/s and an outlet condition of atmospheric pressure.

4.3. Mesh Quality

The graph (Figure 6) compares the quality of Tetrahedral (Tet4) and Wedge (Wed6) elements based on "Element Metrics." Tetrahedral elements show a strong concentration in the high-quality range (0.75 to 1.0), with peaks at 0.88 and 1.0, indicating most Tetrahedral elements are well-formed and of high quality. Few Tetrahedral elements fall below 0.50, suggesting that low-quality elements are rare.

In contrast, Wedge elements have a more varied distribution, with many elements falling in the lower-quality range (0.25 to 0.50). Peaks occur at 0.25 and 0.38, reflecting a higher number of low-to-medium quality elements. Some Wedge elements still reach the high-quality range (0.75 to 0.88), though fewer than Tetrahedral.

Overall, Tetrahedral elements demonstrate better quality, while Wed6 elements have more variation and include a more significant proportion of lower-quality elements.

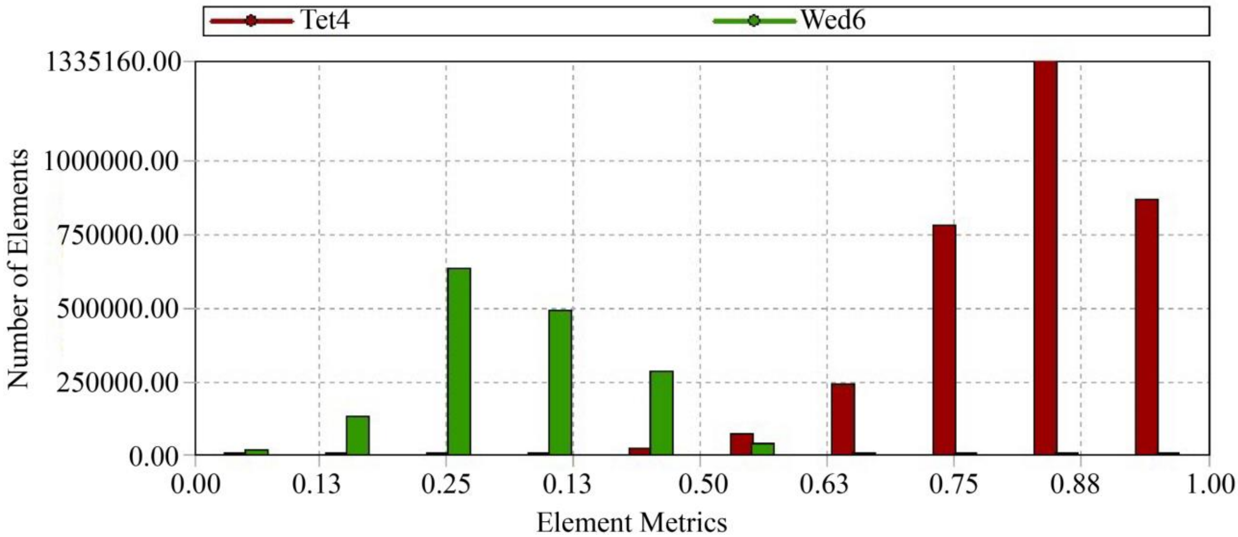


Fig. 6 Element quality

The graph compares Tetrahedral (Tet4) and Wedge (Wed6) elements based on "Element Metrics" and "Number of Elements".

1. Tetrahedral elements are heavily concentrated in the lower metric range (0.13–0.25), showing a strong positive skew. The element count decreases sharply as metrics increase, with a long right tail, indicating most elements have lower metric values.
2. Wedge also displays positive skewness, but it is less extreme. More elements are distributed between 0.13 and 0.25, and the decline in element count is more gradual than Tet4.

Both distributions are right-skewed, with most elements having low metric values. The skewness is more pronounced for Tetrahedral, while Wedge shows a smoother, less dramatic drop-off in element count.

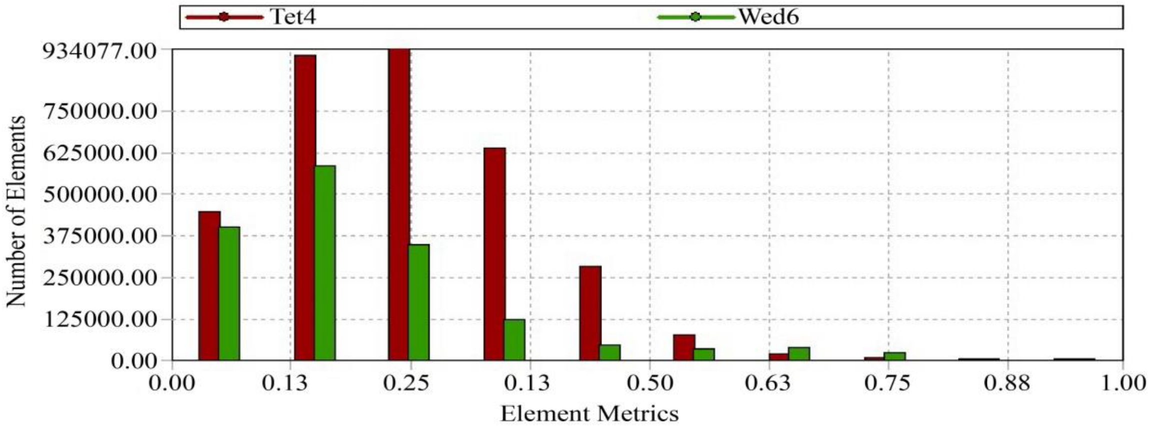


Fig. 7 Skewness

The graph compares Tet4 and Wed6 elements based on "Element Metrics" and "Number of Elements" to assess orthogonality. Both element types are clustered toward higher metric values (0.63–1.0). Tet4 shows consistent peaks at 0.75, 0.88, and 1.0, indicating strong geometric quality and high orthogonality. Tet4's concentration near 1.0 suggests that most elements are well-formed with ideal alignment. While Wed6 also displays many high-quality elements, its distribution is more spread out, indicating greater variability in orthogonality.

In summary, both element types exhibit good orthogonality, but Tetrahedral elements have a more pronounced concentration of high-quality elements.

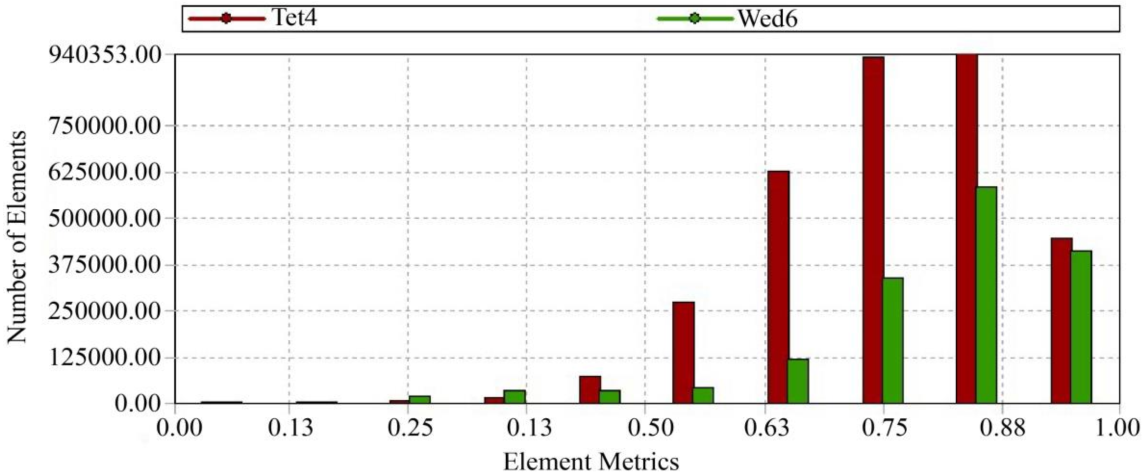


Fig. 8 Orthogonal

5. Results

5.1. Mesh Convergence

A mesh independence study has been carried out for the logarithmic spiral wind turbine model in order to ensure the precision and dependability of the CFD simulations. As seen in Figures 9(a), 9(b), and 9(c), respectively, three distinct mesh sizes—7 mm, 5 mm, and 3 mm—were examined. In each case, the resultant vector magnitude of the x-, y-, and z-directional forces was used to calculate the total force acting on the turbine. Table 1 shows the corresponding forces at different mesh sizes.

Table 1. Total force at various mesh sizes

Mesh Size (mm)	Total Force (N)
7	11.1455
5	11.2253
3	11.7796

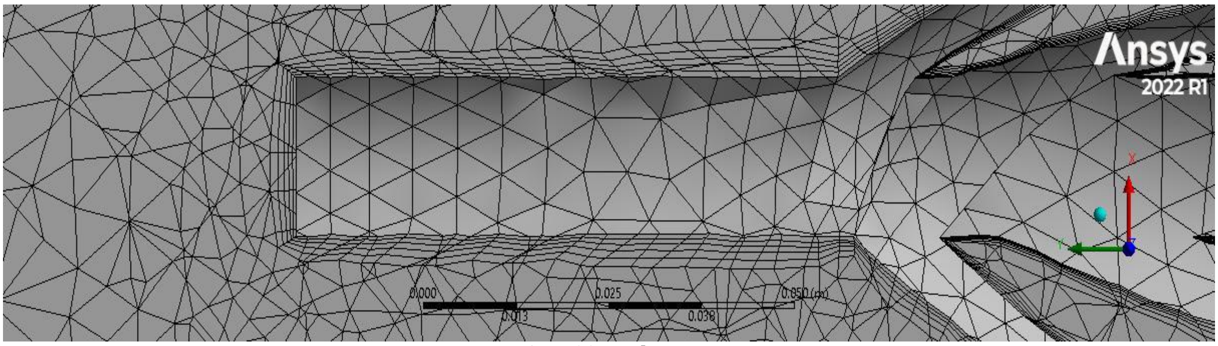


Fig. 9 (a) Mesh 7mm

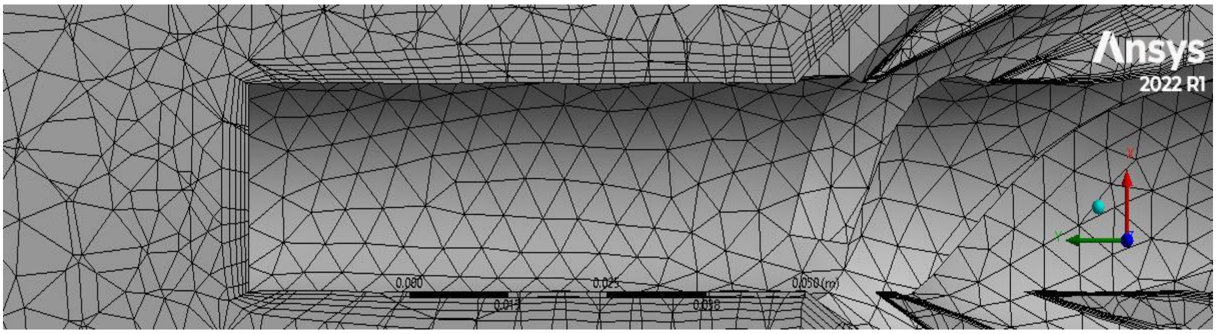


Fig. 9 (b) Mesh 5mm

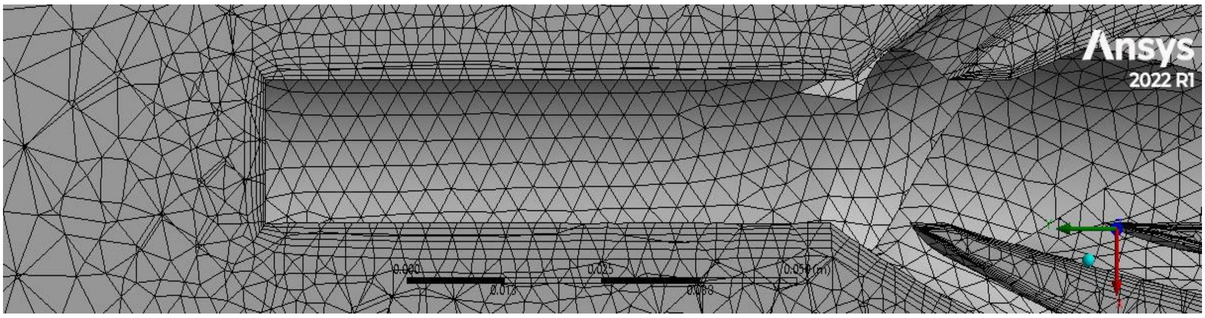


Fig. 9 (c) Mesh 3mm

The force difference between the 5 mm and 3 mm mesh sizes is found to be less than 5%, suggesting that the results have nearly converged. In order to balance computational efficiency and solution accuracy, the 5 mm mesh was chosen for additional analysis, even though the 3 mm mesh offers marginally greater accuracy.

This mesh independence validation ensures the reliability of the derived drag characteristics, which verifies that additional mesh refinement has no discernible impact on the aerodynamic force results used to evaluate the drag coefficient.

5.2. Solution

A three-dimensional CFD analysis was carried out at a wind velocity of 5 m/s, assuming a uniform wind profile. The flow was directed from left to right. Due to the helical configuration of the aerofoil, the velocity increased along the internal surface of the blade from the leading edge, suggesting that the descending motion of the fluid contributes to blade acceleration. The highest velocities were observed near the blade tips.

To investigate the aerodynamic functioning of the logarithmic wind turbine further, the velocity profile was examined in Figure 10. The results indicate a velocity increase toward the central region of the blade. Additionally, the flow direction around the blade aligns with the rotor's anticlockwise rotation, highlighting the effective aerodynamic behaviour of the turbine under operational conditions.

Initially, a three-dimensional CFD analysis is conducted at a wind velocity of 5 m/s, presuming a uniform wind profile. The flow is directed from left to right; due to the helical configuration of the aerofoil, the velocity experiences an increase from the leading edge on the internal surface of the blade, indicating that the fluid's descent contributes to the acceleration of the blade, with the peak velocities observed at the distal tip of the blade. To examine the aerodynamic properties of the Logarithmic spiral Wind Turbine, the velocity profile, as shown in Figure 10, shows that the velocity field increases toward the blade central region. In addition, the figure shows that the blade's flow direction corresponds to the rotor's anticlockwise spin.

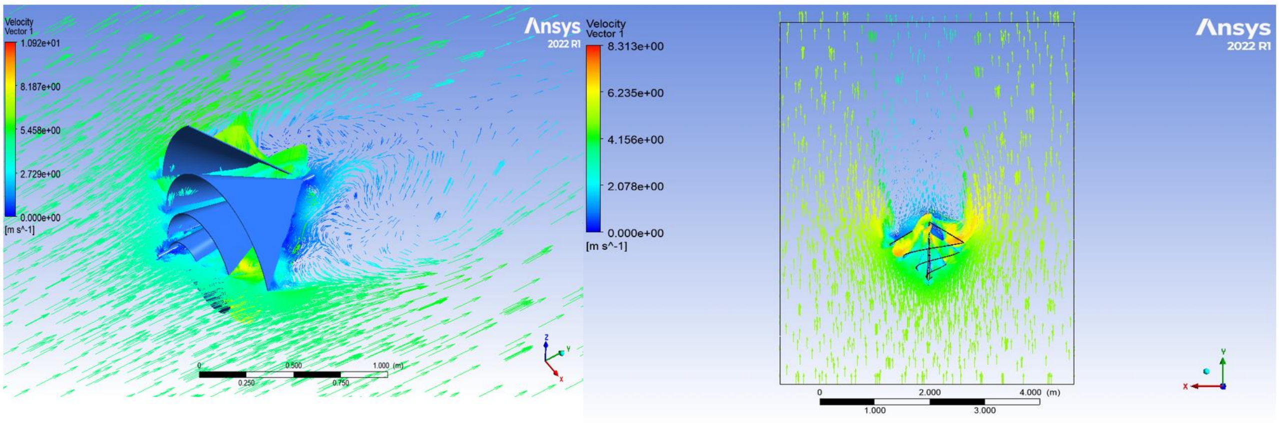


Fig. 10(a) The direction of the flow field over a turbine blade

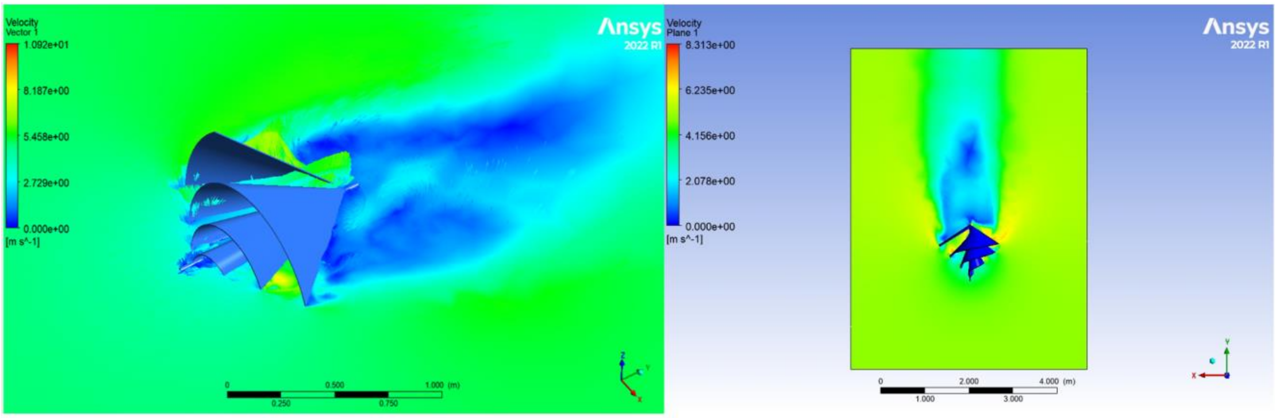


Fig. 10(b) CFD simulated velocity field

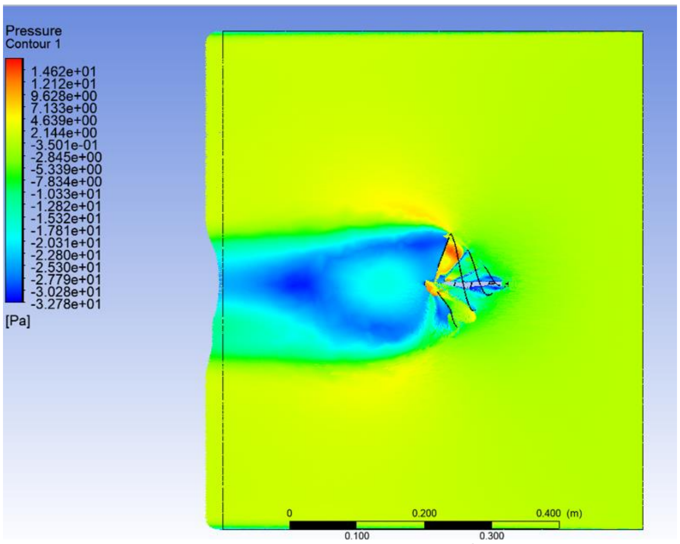


Fig. 11 CFD simulated pressure field

The simulation showcases a wake region trailing the turbine, where the velocity diminishes compared to the heightened speed observed in front of it. A pressure disparity is created across the turbine rotor as a result of fluid dynamics interacting with the rotor and the inertia of the air. A zone of high pressure develops in advance of the turbine, while a low-pressure zone manifests behind it. The peak pressure is around the blade, whereas the lowest point is registered at the trailing edge.

As illustrated in Figure 11, the pressure distribution indicates that the pressure differential between the blade's pressure side and suction side is more significant than that observed in a conventional Aerofoil Wind Turbine (AWT).

This increased pressure differential leads to a rise in torque. Furthermore, as wind velocity escalates, the pressure disparity becomes even more evident, facilitating improved energy capture.

5.3. Comparison between Archimedes Wind Turbine and Logarithmic Wind Turbine

According to the literature published by the manufacturer of the Archimedes Wind Turbine, the power produced by the turbine is 34.66 Watts, which is shown in Figure 12. From the computational modelling of the Logarithmic Wind turbine, it is observed that the power generated by the turbine is 56.063 Watts. The available power for a wind turbine of 1.5 m diameter and a wind speed of 5 m/s is 130.261 Watts. This makes the Archimedes Wind Turbine 35% efficient, while the Logarithmic Wind Turbine is 43.0389% efficient. Hence, it may be concluded that the Logarithmic profile is 8.0389% more efficient.

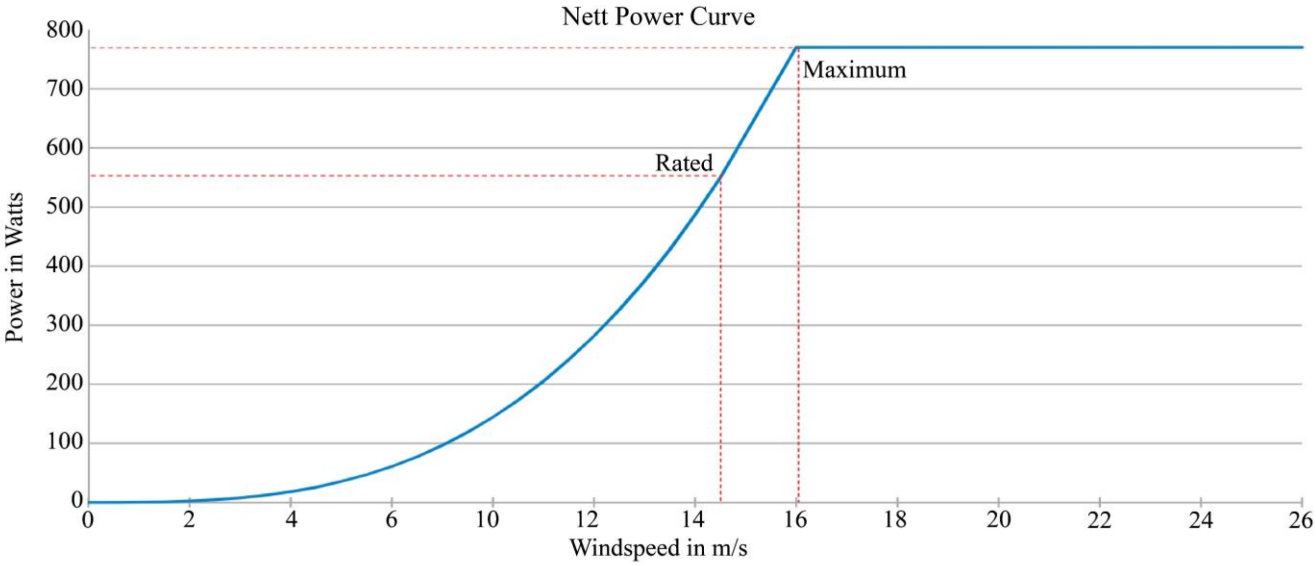


Fig. 12 Net power curve of Archimedes wind turbine [11]

The coefficient of drag plays a major role in evaluating wind turbines' aerodynamic performance. According to the specifications provided by the manufacturer, the Archimedes wind turbine's coefficient of drag is 0.39. In contrast, the Logarithmic Spiral Wind Turbine has a drag coefficient of 0.48, which is obtained from the simulation analysis. This increase in the drag indicates a greater ability to harness wind forces, which would significantly improve the aerodynamic performance and energy conversion efficiency of the logarithmic spiral design, representing a noteworthy advancement in wind turbine design.

6. Conclusion

This study examined the aerodynamic behaviour and energy performance of a wind turbine designed with a logarithmic spiral blade profile, specifically developed for small-scale wind energy applications, such as those in urban rooftop settings. The turbine's profile design is optimised to maximise energy capture in low-speed conditions.

The key conclusion are as follows:

1. The Logarithmic Spiral Wind Turbine demonstrated a greater drag force,
2. allowing for enhanced aerodynamic interaction with the wind.
3. Computational simulations indicate that the logarithmic Wind Turbine achieved an 8.0389% increase in power output efficiency in comparison with the Archimedes Wind Turbine.
4. The unique spiral design and increased blade surface area resulted in superior energy extraction and torque, which improved power generation at low wind speeds.
5. Due to its compact size and higher efficiency, the Logarithmic Spiral Wind Turbine is well-suited for limited spaces such as rooftops and urban areas.

References

[1] Peter Zhang, and Stefan Gsanger, *Small Wind World Report*, World Wind Energy Association, pp. 1-11, 2012. [Publisher Link]

[2] A.P. Schaffarczyk, *Introduction to Wind Turbine Aerodynamics*, Springer International Publishing, pp. 1-315, 2020. [Google Scholar] [Publisher Link]

[3] Ho Seong JI et al., "The Aerodynamic Performance Study on a Small Wind Turbine with 500W Class through Wind Tunnel Experiments," *International Journal of Renewable Energy Sources*, vol. 1, pp. 1-6, 2016. [Google Scholar] [Publisher Link]

[4] Kyung Chun Kim et al., "Experimental and Numerical Study of the Aerodynamic Characteristics of an Archimedes Spiral Wind Turbine Blade," *Energies*, vol. 7, no. 12, pp. 7893-7914, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[5] Shashank Chaudhary et al., "Comparison of Torque Characteristics of Archimedes Wind Turbine Evaluated by Analytical and Experimental Study," *International Journal of Mechanical and Production Engineering*, vol. 4, no. 8, pp. 75-78, 2016. [Google Scholar] [Publisher Link]

[6] Sahand Ebrahimi, and Mohammad Aref Ghassemi, "Numerical Aerodynamics Analysis of the Archimedes Screw Wind Turbine," *International Journal of Multidisciplinary Sciences and Engineering*, vol. 9, no. 10, pp. 12-15, 2018. [Google Scholar] [Publisher Link]

[7] Robert Ward Harding, and Robert Charles Fillerup, "Archimedes Screw Turbine Generator," *U.S. Patent US20140265337A1*, pp. 1-14, 2014. [Google Scholar] [Publisher Link]

[8] Kyung Chun Kim et al., "Aerodynamic Characteristics of Horizontal Axis Wind Turbine with Archimedes Spiral Blade," *ASME International Mechanical Engineering Congress and Exposition*, vol. 56321, pp. 1-6, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ayad T. Mustafa, and Haider A. Jaleel, "A Comparison Study between Archimedes Spiral Turbine and Propeller Turbine with Wind Attack Angle Effect," *2nd International Conference on Materials Engineering & Science*, Baghdad, Iraq, vol. 2213, no. 1, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[10] Sudip Sapkota et al., "Design, CFD Analysis and Modelling of Archimedean-Spiral Type Wind Turbine," *Proceedings of IOE Graduate Conference*, vol. 6, pp. 1-10, 2019. [Google Scholar] [Publisher Link]

[11] Archimedes Wind Turbine, Respect, pp. 1-15. [Online]. Avaliable: https://thearchimedes.com/images/pdf/AWM%20brochure%20Respect%202023%20HQ%20compressed.pdf