

A REVIEW OF RESEARCH AND TECHNOLOGY DEVELOPMENT ON THE ARCHIMEDES SCREW WIND TURBINE

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ABSTRACT

Wind energy is a renewable energy source that offers both environmental and socio-economic benefits. However, its implementation in low-wind areas remains challenging. The Archimedes Screw Wind Turbine (ASWT) is a horizontal-axis wind turbine that forms a three-dimensional conical structure shaped like an elongated spiral, resembling a seashell. This study aims to provide a comprehensive overview of ASWT research progress, including its advantages, limitations, and development opportunities. The method used is a narrative review by gathering and comparing results from previous studies on the design and performance of ASWT. The findings indicate that the Archimedean spiral profile results in better aerodynamic performance compared to the logarithmic spiral profile, with a power coefficient (C_p) value reaching 0.2668 at an opening angle of 60° . The optimal aspect ratio (AR) is found in the range of 1.0-1.1 to balance aerodynamic efficiency and structural strength. The use of NACA type airfoil profiles improves performance compared to S and FX-type airfoils and shows effectiveness at low wind speeds with minimal noise levels. Furthermore, the configuration of angles ($\alpha_1 = 30^\circ$, $\alpha_2 = 45^\circ$, $\alpha_3 = 60^\circ$) is identified as the most effective arrangement, yielding a maximum power coefficient (C_{pmax}) of 0.234 at a tip speed ratio (TSR) of 1.5. Additionally, the addition of a brimmed shroud is proven to increase the C_p value by approximately 3.6 times compared to turbines without a shroud. Overall, ASWT holds significant potential for urban applications, but further research is still needed to encourage the adoption of this technology in the renewable energy transition.



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I. INTRODUCTION

Wind power is widely recognized as one of the most promising technologies in the transition toward low-carbon energy systems [1], [2]. Wind energy represents one of the cleanest energy sources and has currently become the second-largest contributor among renewable energy resources [3]. Beyond its role in energy generation, wind power offers substantial social, public health, and environmental benefits while significantly reducing dependence on fossil fuels [4]. Based on the orientation of the rotational axis, wind turbines can be broadly classified into two categories that its Horizontal Axis Wind Turbines (HAWT), which employ rotors with axes aligned parallel to the wind direction, and Vertical Axis Wind Turbines (VAWT), whose rotors rotate about an axis perpendicular to the incoming wind flow [5]. VAWTs offer several advantages, including enhanced resistance to strong wind conditions due to their inherent stalling mechanism, which improves operational safety during high wind events [6]. In addition, they tend to operate more quietly and feature designs that eliminate the need for yaw control systems. However, these advantages are offset by limitations in self-starting capability [7]. The vertical shaft configuration of VAWTs allows the transmission system and generator to be positioned at ground level, facilitating maintenance. Nevertheless, this configuration often requires complex blade pitch control mechanisms. In contrast, HAWTs represent the most commercially successful turbine type to date and predominantly rely on aerodynamic lift to achieve high power conversion efficiency.

Drag-based turbines, such as certain VAWT configurations, generally exhibit lower efficiency compared to lift-based HAWTs. Moreover, HAWTs are typically designed to operate optimally under relatively high wind speeds, usually exceeding 6 m/s, to attain maximum efficiency [8], [9], [10], [11], [12]. Despite their technological maturity, the implementation of wind turbine systems remains challenging in regions characterized by highly fluctuating wind patterns and limited installation space, particularly in urban environments [13]. One promising innovative solution is the Archimedes Screw Wind Turbine (ASWT), a horizontal-axis turbine featuring a three-dimensional conical structure with an elongated spiral geometry resembling a seashell [14], [15]. This unique design enables the ASWT to operate effectively at low wind speeds, making it particularly suitable for urban and built-environment applications [16]. Although the ASWT demonstrates considerable potential, its practical implementation and technological development remain relatively limited. Research on ASWTs is still fragmented, and comprehensive literature reviews consolidating existing findings are scarce. A systematic review is therefore required to map the evolution of ASWT design concepts, performance optimization strategies, and key technical challenges reported across previous studies. This review aims to provide a comprehensive understanding of the current state of ASWT research and technology, highlighting its advantages, limitations, and future development prospects. The outcomes of this study are expected to serve as a valuable scientific reference for researchers, academics, and practitioners, supporting the advancement of more efficient and practical ASWT applications in the future.

II. THEORETICAL REFERENCE

This study adopts a Narrative Review approach to examine the development of research and technological advancements related to the Archimedes Screw Wind Turbine (ASWT). The review process was conducted in a systematic manner, encompassing several key stages, including the definition of eligibility criteria, identification of data sources, study selection, data extraction, and data synthesis. Through this approach, the review aims to provide a comprehensive overview that captures the evolution and current state of ASWT research.

II.1 ELIGIBILITY CRITERIA

Studies focusing on the development, performance, and technological innovation of the Archimedes Screw Wind Turbine (ASWT) constitute the primary scope of this review. Research addressing technical aspects of other wind turbine types, such as Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT), was included as supporting literature to enrich and contextualize the discussion. Only publications that meet established academic standards were considered. Consequently, non-scholarly articles, duplicate publications, and studies lacking robust methodological foundations were excluded from the analysis.

II.2 DATA SOURCES

The literature reviewed in this study was obtained through systematic searches of reputable and indexed academic databases. The sources include international peer-reviewed journal articles, conference proceedings, and other scholarly works that satisfy the defined academic eligibility criteria.

II.3 DATA SYNTHESIS

The analysis was carried out by categorizing the selected studies into key thematic areas, such as turbine design, performance characteristics, and structural or aerodynamic modifications. Findings from different studies were subsequently compared to identify common trends, methodological consistency, and notable discrepancies. The results of this comparison are presented in summary tables to facilitate clarity and readability. The overall synthesis is articulated through a structured narrative, supported by tables, figures, and illustrative materials, thereby providing a systematic and comprehensive understanding of the development of ASWT technology.

III. DISCUSSION

III.1 INTRODUCTION TO THE ARCHIMEDES SCREW WIND TURBINE

The Archimedes Screw Wind Turbine (ASWT) is a wind turbine featuring spiral-shaped blades based on Archimedean geometric principles, a concept originally introduced by the ancient Greek mathematician Archimedes [17], [18]. The overall configuration of the ASWT is illustrated in Figure 1. In its common design, the turbine consists of three blades symmetrically arranged at 120° intervals. These blades form a three-dimensional conical structure with an elongated spiral geometry resembling the shell of a marine mollusk. Owing to this spiral configuration, the ASWT is inherently capable of aligning itself with the incoming wind direction without the need for any yaw control mechanism [15], [19], [20].

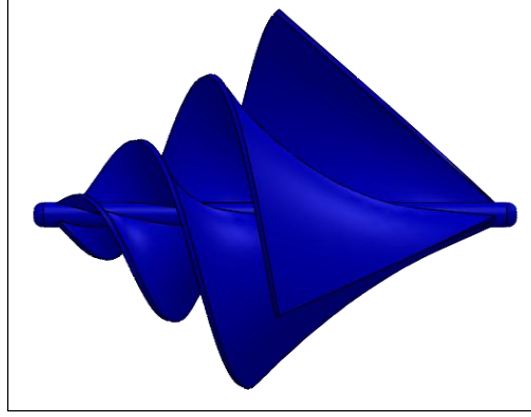


Figure 1: ASWT Turbine.
Source: Authors, (2026).

In addition to its distinctive geometry, the ASWT exhibits several notable advantages. The turbine is able to harness a combination of aerodynamic lift and drag forces to generate power, allowing it to operate effectively across a range of flow conditions. Another key advantage is its capability to perform efficiently under low wind speed conditions, with a minimum cut-in speed of approximately 2.5 m/s [16], [21]. Given the characteristics and potential outlined above, a thorough understanding of ASWT research development methodologies becomes essential for tracing the progression of knowledge related to its aerodynamic behavior and technological evolution. Such understanding is critical for the optimization of ASWT design and for enhancing its practical application in real-world wind energy systems.

III.2 RESEARCH DEVELOPMENT METHODS FOR ASWT

Research on the development of Archimedes Screw Wind Turbines (ASWT) generally follows a systematic workflow that begins with geometric modeling, proceeds through numerical simulation and experimental validation, and concludes with result documentation and analysis. The initial stage typically involves the construction of a three-dimensional reference model using computer-aided design software such as SolidWorks, OpenSCAD, or CATIA. Following the modeling phase, the research advances to analytical stages involving numerical simulation and experimental investigation. The methodological scope varies across studies. Some investigations adopt a single-track approach, relying solely on numerical simulations or exclusively on experimental testing. Numerical simulations commonly employ Computational Fluid Dynamics (CFD) techniques to virtually predict flow behavior and aerodynamic performance. These analyses are typically conducted using specialized software packages such as ANSYS Fluent, ANSYS CFX, or STAR-CCM+. In contrast, experimental investigations aim to obtain direct physical measurements. Common experimental methods include performance testing in wind tunnel facilities, flow visualization and quantification using Particle Image Velocimetry (PIV), and final validation through field testing under real operating conditions. Upon completion of these analyses, the resulting data are expected to address the predefined research objectives [22-25]. In this context, the present review paper is structured to provide a comprehensive understanding of research trends and technological developments related to ASWTs. The discussion encompasses aerodynamic aspects, including performance analysis in terms of torque and power output, force generation mechanisms, the influence of angle of attack, and the interpretation of flow simulation results. Furthermore, technological development aspects are examined, covering blade geometry optimization, evaluation of performance augmentation strategies, and comparative performance assessments against other wind turbine designs. Through this review, potential optimization opportunities are identified, and existing research gaps are highlighted, thereby offering valuable directions for future ASWT research.

III.3 AERODYNAMICS OF THE ASWT

III.3.1 Velocity Triangle and Aerodynamic Forces Acting on the ASWT

To determine the torque and power generated by the ASWT, the angular momentum equation is applied to a predefined control volume, as adopted in previous studies [14] and expressed in Equation (1) [14] :

$$\frac{\partial}{\partial t} \int_{CV} (r \times V) \rho dV + \int_{CS} (r \times V) \rho V \cdot \hat{n} dA = \sum (r \times F) \quad (1)$$

Equation (1) represents the angular momentum balance for a control volume. Under the assumption of steady-state conditions, the first term in Equation (1) becomes zero because it is time-independent. Consequently, Equation (1) can be simplified to Equation (2) [14] :

$$\int_{CV} (r \times V) \rho dV \cdot \hat{n} dA = \sum (r \times F) \quad (2)$$

The continuity equation for a fixed control volume is expressed as shown in Equation (3) [14] :

$$\frac{\partial}{\partial t} \int_{CV} \rho dV + \int_{CV} \rho W \cdot \hat{n} dA = 0 \quad (3)$$

Assuming steady-state flow and constant density, the first term in Equation (3) vanishes. The second term represents the total mass flow rate through the control volume. Accordingly, Equation (3) can be simplified to Equation (4) [14] :

$$-\dot{m}_{in} + \dot{m}_{out} = 0 \quad (4)$$

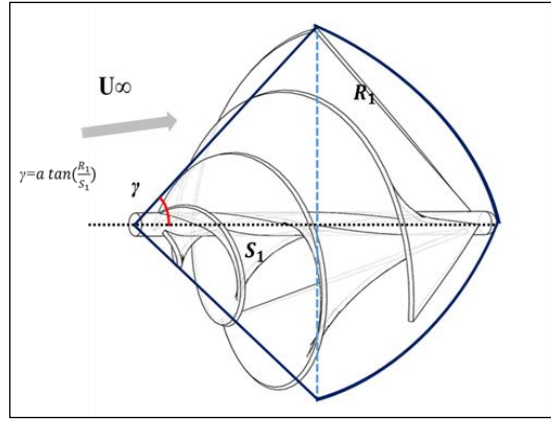


Figure 2: Shape parameter ASWT.
Source: [14].

In developing the governing equations, several geometric parameters must first be defined, namely γ , R_1 , R_2 , and S_1 , as illustrated in Figure 2. Here, γ denotes the angle between the rotation axis and the blade tip. R_1 represents the vertical distance from the outer blade tip to the rotational axis, while R_2 corresponds to the vertical distance from the inner blade tip to the rotational axis. Meanwhile, S_1 is defined as the horizontal distance between the leading blade tip and the root of the spiral blade. Based on these geometric parameters, the inlet and outlet mass flow rates can be expressed using Equations (5) and (6), respectively [14] :

$$\dot{m}_{in} = \rho U_{\infty} \sin \gamma \times \pi \left(\frac{R_1 + R_2}{2} \right) S_1 \quad (5)$$

$$\dot{m}_{out} = 3\rho A_{out} W_{\theta} \quad (6)$$

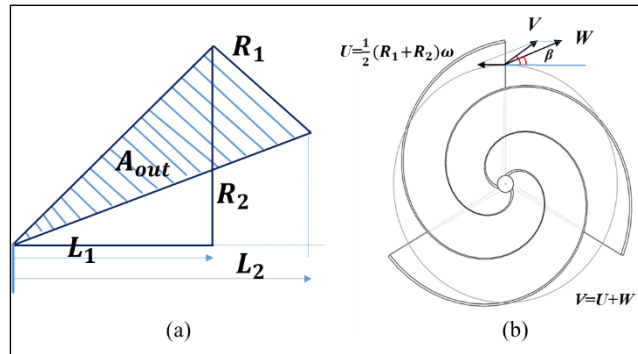


Figure 3: Definition of A_{out} , U , V and W
Source: [14].

Here, W_{θ} denotes the tangential component of the relative velocity. The velocity triangle analysis for the ASWT begins with estimating the outlet area and its geometric relationships, as illustrated in Figure 3(a). In this figure, L_1 is defined as the distance from the center of the rear face to point x , which is perpendicular to the outer blade tip, while L_2 represents the distance from the same center to point x , perpendicular to the inner blade tip. Based on this configuration, the total outlet area (A_{out}) is obtained by summing its two constituent areas, A_1 and A_2 , as expressed in Equations (7) and (8) [14] :

$$A_{out} = A_1 + A_2 \quad (7)$$

$$A_{out} = \frac{1}{2} R_1 L_1 - \frac{1}{2} R_2 L_1 + \frac{1}{2} (R_1 - R_2) (L_2 - L_1) = \frac{1}{2} (R_1 - R_2) L_2 \quad (8)$$

The velocity triangle at the blade outlet is illustrated in Figure 3(b), where W denotes the relative velocity, V the absolute velocity, and U the tangential velocity. In this context, β is defined as the angle between W and U . The outlet mass flow rate ($\dot{m}_{out}$) can therefore be written as Equation (9) [14] :

$$\dot{m}_{out} = 3\rho A_{out} W_{\theta} = 3\rho \cdot \frac{1}{2} (R_1 - R_2) L_2 \times W \cos \beta = \frac{3}{2} \rho (R_1 - R_2) L_2 \times W \cos \beta \quad (9)$$

Since $\dot{m}_{in} = \dot{m}_{out}$, the following relationship is obtained:

$$\rho U_{\infty} \sin \gamma \times \pi \left(\frac{R_1 + R_2}{2} \right) S_1 = \frac{3}{2} \rho (R_1 + R_2) L_2 \times W \cos \beta \quad (10)$$

$$\therefore W = \frac{\pi U_{\infty} \sin \gamma (R_1 + R_2) S_1}{3(R_1 + R_2) L_2 \times \cos \beta} \quad (11)$$

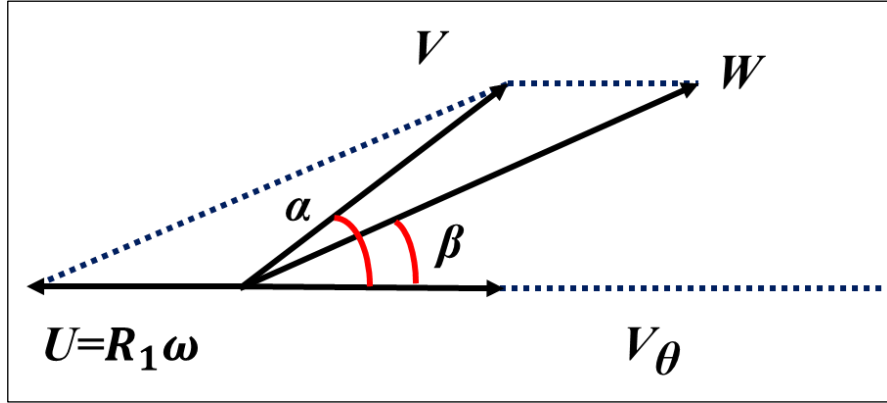


Figure 4: Triangle velocity at outlet boundary blade.
Source: [14].

Figure 4 illustrates the velocity triangle composed of U , V , and W , where α is defined as the angle between the absolute velocity V and its tangential component V_{θ} . The absolute velocity V can be expressed as follows [14] :

$$V^2 = W^2 + U^2 - 2WU \cos \beta, V_{\theta} = V \cos \alpha \quad (12)$$

Based on Equation (12), the angle α can be defined using Equation (13) [14] :

$$V \sin \alpha = W \sin \beta \rightarrow \sin \alpha = \frac{W}{V} \sin \beta \quad (13)$$

$$\therefore \alpha = \sin^{-1} \left(\frac{W}{V} \sin \beta \right) \quad (14)$$

The moment exerted by the blade on the fluid is equal in magnitude and opposite in direction to the shaft torque. This relationship is expressed in Equation (15) [14] :

$$T_{shaft} = \int_{CS} (r \times V) \rho V \cdot \hat{n} dA = \int_{CS} (rV \cos \alpha) \rho (V \cos \alpha) dA = 3\rho V^2 \cos^2 \alpha \int_0^L r dA \quad (15)$$

Finally, the torque generated by the blade can be expressed as Equation (16):

$$\therefore T_{shaft} = 3\rho V_{\theta}^2 \times \frac{(R_2 - R_1)}{6L_1(L_2 - L_1)} \times [R_2(2L_2^3 + L_1^3 + L_1L_2^3) - L_1R_1(L_1 + L_2)^2] \quad (16)$$

Power is defined as the product of torque and angular velocity and is expressed as follows [14] :

$$Power = T_{shaft} \omega \quad (17)$$

After the power expression is defined in Equation (18), as illustrated in Figure 5, the analysis of wind-blade interaction requires two complementary perspectives: the plan view (top view) and the elevation view (side view). In the plan view analysis, the calculation is based on changes in angular momentum resulting from the interaction between the incoming wind and the ASWT blades. The aerodynamic lift force (F_L) and drag force (F_D) generated on the blade are decomposed into components parallel and perpendicular to the wind direction, yielding four force components: F_{LX} , F_{LY} , F_{DX} , and F_{DY} . The resultant aerodynamic forces acting on the ASWT blade can therefore be expressed as:

$$F_X = F_{LX} + F_{DX} \quad (18)$$

$$F_Y = F_{LY} + F_{DY} \quad (19)$$

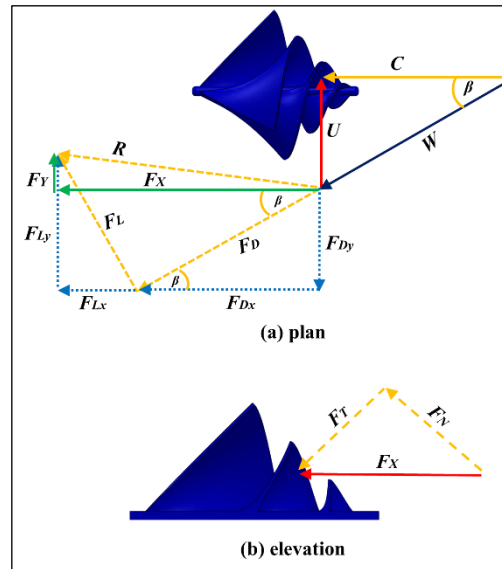


Figure 5: Aerodynamic Forces Affecting the Spiral Blade on an ASWT.
Source: [27].

The force component perpendicular to the wind direction (F_y) is responsible for driving the rotational motion of the ASWT. Meanwhile, as observed in the elevation view, the force component F_x is further resolved into two components: the tangential force (F_T), which directly contributes to power generation, and the normal force (F_N), which acts as a compressive or tensile load on the ASWT blades. Consequently, the power generated by the ASWT arises from the combined effect of the F_y component in the plan view, which produces rotational torque, and the tangential force F_T in the elevation view, which contributes directly to energy conversion. This aerodynamic interaction pattern occurs repeatedly as the wind traverses successive 120° angular positions corresponding to each of the three spiral blades of the ASWT [25-28].

III.3.2 Angle of Attack in ASWT

The angle of attack is defined as the angle between the direction of the relative airflow and the chord line of the turbine blade profile. This parameter plays a critical role in determining both the aerodynamic forces acting on the blade and the resulting power output of the turbine [29-36]. As illustrated in Figure 6, measurements are conducted within an axisymmetric observation plane that distinguishes between the windward (front) side and the sheltered (lee) side of the blade, enabling a comprehensive assessment of the flow dynamics around the rotating blade [37], [38].

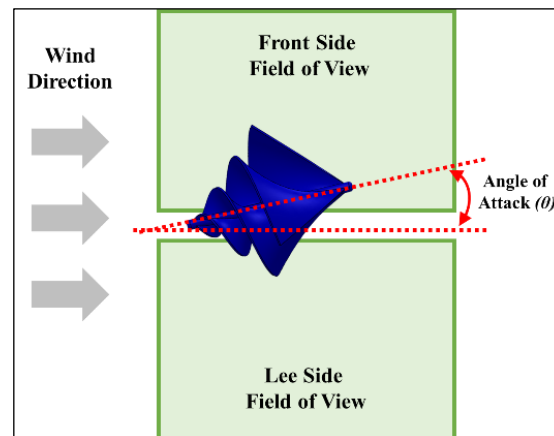


Figure 6: Angle of attack on ASWT.
Source: [37].

In the study conducted by [37], although various factors such as Reynolds number and free-stream turbulence can influence the near-wake structure of turbine blades, the analysis specifically focused on the effect of the angle of attack. To investigate the influence of wind direction on the flow field, comparisons were made between the mean velocity field and the instantaneous velocity field at different blade phase angles. The results indicate that the wake velocity decreases as the angle of attack increases. Mean velocity measurements reveal that the low-velocity region downstream of the blade expands with increasing angle of attack. Within the near-wake region behind the blade, no flow separation was observed, as the incoming airflow continues to pass through the rotating blade system. Regions of high shear were found to form around the blade tip vortices, and their size increases as the angle of attack becomes larger. The tip vortices generated by each blade are clearly observable at blade phase angles ranging from 0° to 120° . At lower angles of attack, the spacing between these vortices remains relatively uniform; however, as the angle of attack reaches approximately 15° , the vortex spacing becomes increasingly irregular.

III.3.3 Velocity and Pressure Contours in ASWT

Velocity contours are widely employed in the literature to visualize the flow velocity characteristics around wind turbine blades [39-43]. To investigate the aerodynamic behavior of the ASWT, Figure 7 presents the mean velocity fields obtained from airflow simulations conducted at three different wind speeds. In wind turbine systems, a turbulent wake state may occur due to variations in wind speed or direction, or as a result of changes in blade orientation (pitching). Such flow behavior is more clearly observed at lower wind speeds, as shown in Figure 7. The highest velocities are observed near the outermost region of the rotor within the simulation domain. Between successive spiral blade sectors, recirculation zones with relatively low velocities are formed. Furthermore, due to the spiral geometry, the flow velocity gradually increases from the leading edge of the blade toward the inner side of each blade level.

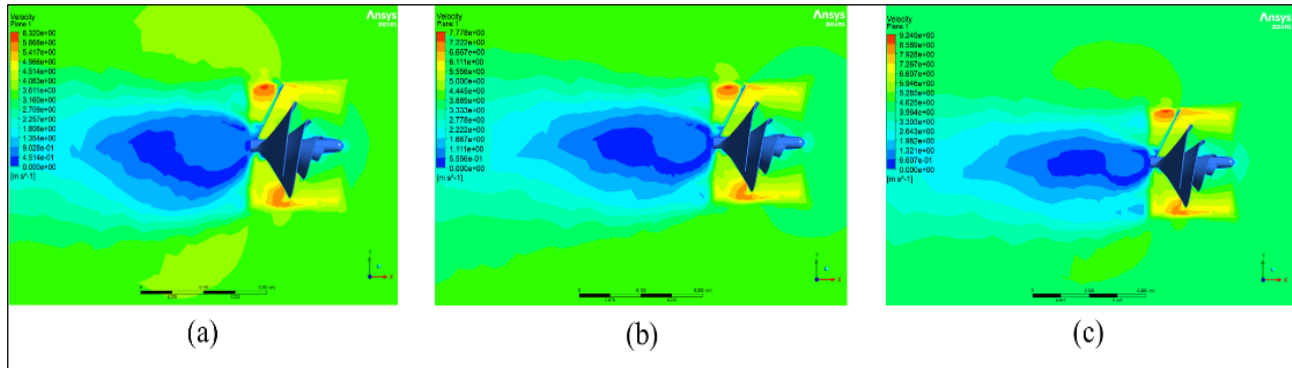


Figure 7: Ensemble-averaged velocity field and pressure distribution under steady-state conditions: (a) 3.5 m/s at 300 rpm, (b) 4.0 m/s at 400 rpm, and (c) 4.5 m/s at 500 rpm.

Source: [46].

The visualization also indicates that the airflow is partially obstructed by the conical hub and the rotor, leading to the formation of circumferential acceleration zones downstream of the rotor, which in turn reduce the pressure near the walls of the rotating domain. Meanwhile, the wake region is clearly identified behind the rotor hub, characterized by lower flow velocities. From a geometric perspective, the blade twist angle is larger near the root than at the tip. Visually, the longer velocity vectors near the blade tip indicate higher flow velocities compared to those near the blade root. In addition, all three velocity contour plots demonstrate that the flow velocity in the central region is significantly lower than that near the blade periphery. This observation suggests that stronger flow near the blade tip is highly advantageous, as it exerts force on the blade at a larger moment arm, thereby enhancing torque generation [44-46]. The streamline velocity distribution shown in Figure 8 further confirms that the lowest flow velocities occur in the central region and near the rotational axis. In contrast, the highest velocities are observed near the blade tips, where the tip speed is substantially greater than that in the mid-span region. Wind flow impinging on the blade tips generates torque, causing the turbine blades to rotate in the direction opposite to the incoming wind flow [47], [48].

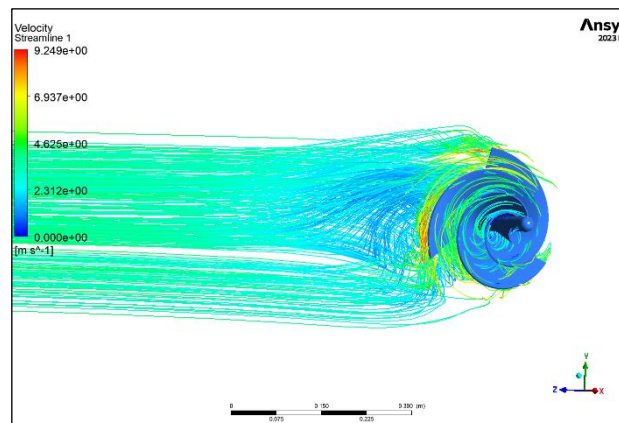


Figure 8: Streamline velocity.

Source: [47].

Pressure contours provide a graphical representation of the pressure distribution around turbine blades as obtained from fluid flow simulations [49-53]. As shown in Figure 9, the pressure contours on the front and rear sides of the turbine blades indicate that the pressure on the blade's pressure side is higher than that on the suction side. The locations of maximum and minimum pressure are predominantly found near the blade edges. The pressure difference between the pressure side and the suction side is the primary driving mechanism that induces blade rotation [47], [54], [55].

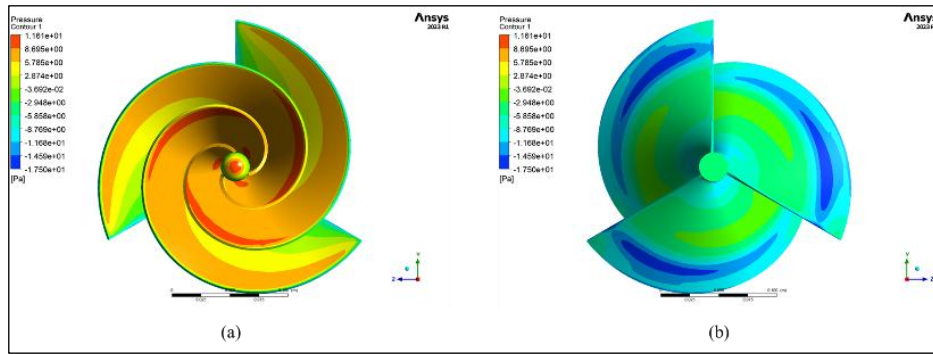


Figure 9: Pressure contours on the blade surfaces: (a) pressure side and (b) suction side.
Source: [47].

As illustrated in Figure 10, an increase in flow velocity leads to a corresponding increase in this pressure difference. The highest pressure difference occurs near the blade tip, while the pressure variation in the mid-span region remains relatively small. This finding indicates that the majority of the extractable energy originates from the region near the blade tip, which is consistent with the operating principles of most horizontal-axis wind turbines (HAWTs) [47], [56], [57].

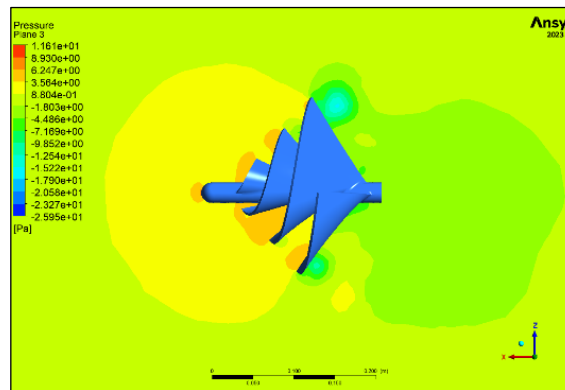


Figure 10: Pressure contours.
Source: [47].

III.4 DEVELOPMENT OF ASWT TECHNOLOGY

III.4.1 Effect of Spiral Geometry on ASWT

The Spiral Wind Turbine (SWT) is a type of wind turbine that typically consists of three blades helically wrapped around a single main shaft and symmetrically arranged with respect to the axis of rotation [58], [59]. This configuration enables the SWT to redirect the incoming airflow, thereby enhancing the utilization of the wind's kinetic energy [13], [60]. The main design parameters of the SWT are illustrated in Figure 11. Among these parameters, the spiral pitch (S) represents the axial distance traveled by a blade over one complete spiral rotation. The turbine radius (r) denotes the radial distance from the rotational axis to the blade tip at the outlet side, while the turbine opening angle (θ) describes the angle formed between the rotational axis and the blade tip at the outlet section [61].

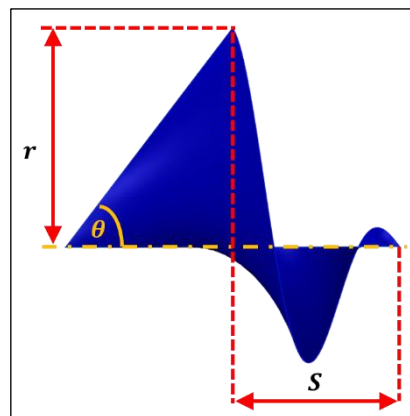


Figure 11: ASWT design parameters.
Source: [61].

Based on these design parameters, variations in spiral geometry play a crucial role in determining the aerodynamic characteristics and overall performance of the SWT.

Figure 12(a) presents a spiral wind turbine with a logarithmic spiral profile, whereas Figure 12(b) shows a turbine with an Archimedean spiral profile. The primary distinction between these two configurations lies in the winding characteristics of the spiral. In the logarithmic spiral, the spacing between successive turns increases progressively, while in the Archimedean spiral, the spacing remains constant along the spiral length [61], [62]. These variations in spiral profiles provide a clear basis for comparing the influence of spiral geometry on the performance of Spiral Wind Turbines.

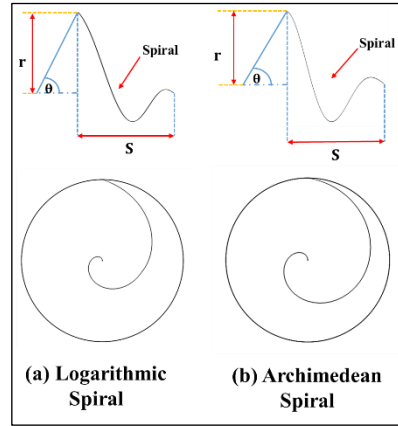


Figure 12: Spiral profile models.
Source: [61].

According to the study conducted by [61], the performance of a shell-shaped spiral wind turbine with logarithmic and Archimedean spiral profiles was evaluated under varying opening angles (θ) and tip speed ratios (TSR). The results demonstrated that the turbine with an Archimedean spiral profile exhibited superior performance compared to the logarithmic profile, particularly at an opening angle of 60° , where the maximum power coefficient (C_p) of 0.266825 was achieved at a TSR of 2.5.

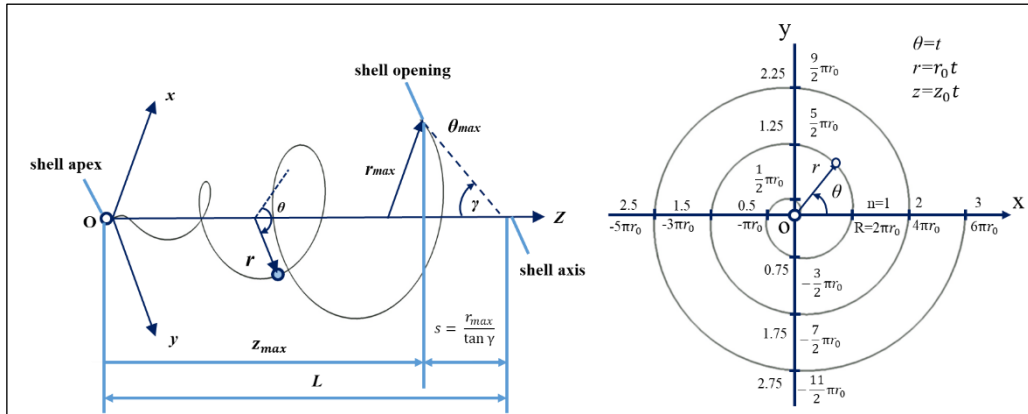


Figure 13: A seashell-shaped turbine modeled on an Archimedean conical spiral.
Source: [15].

To further examine the characteristics of the SWT with an Archimedean spiral profile, the geometric parameters of the turbine are presented in Figure 13. The three-dimensional spiral curve is generated using parametric equations expressed in a cylindrical coordinate system [15]. The governing equations employed to construct the spiral geometry are given as:

$$\theta = t \quad (20)$$

$$r = r_0 t \quad (21)$$

$$z = z_0 t \quad (22)$$

Where θ denotes the spiral rotation angle, t is the parametric variable, r represents the radial distance of the spiral, and z corresponds to the axial distance along the shell axis. The Archimedean spiral lying in the r - θ plane is defined by Equations (20) and (21), while Equation (22) describes the axial extension of the spiral along the z -axis, thereby introducing a conical component to the geometry. The resulting three-dimensional spiral curve originates at $r = 0$ and $\theta = 0$ at the defined coordinate origin (the shell apex) and terminates at $r_{\max}$ and $\theta_{\max}$ at the shell opening. For given initial values of r_0 and z_0 , a set of (r, z) points forming the conical spiral can be obtained as a function of the spiral rotation angle θ . However, the value of r_0 is constrained to ensure that all spiral configurations achieve the same maximum radius $r_{\max}$, which is necessary to guarantee equal input power among different turbine designs. The shell opening angle (γ), defined as the angle between the shell opening and the shell axis, is also incorporated into the rotor design. The number of conical spiral turns (n) and the turbine aspect ratio (AR) are illustrated in Figure 13 and defined as follows:

$$n = \frac{\theta_{\max}}{2\pi} \quad (23)$$

$$AR = \frac{L}{D} \quad (24)$$

Where the aspect ratio (AR) is the ratio between the turbine length (L) and the turbine diameter ($D = 2r_{\max}$). The turbine length (L) is obtained from the sum of the maximum axial extension of the conical spiral ($z_{\max}$) and the projected distance along the shell axis ($s = r_{\max}/\tan \gamma$) [15]. From this analysis, it can be concluded that the spiral geometry is not merely an aesthetic feature, but a critical design parameter that directly influences turbine efficiency. The SWT with an Archimedean spiral profile demonstrates superior performance, achieving a power coefficient of $C_p = 0.266825$ at an opening angle of 60° , compared to the logarithmic spiral profile. Consequently, the Archimedean spiral configuration has become the more dominant design reference in the development of Spiral Wind Turbines.

III.4.2 Aspect Ratio in ASWT

The geometric parameters of the ASWT rotor are illustrated in Figure 14. Understanding the aspect ratio as part of the rotor's geometric characteristics provides a fundamental basis for evaluating how its variation influences turbine performance. The aspect ratio (AR) is one of the key parameters that plays a significant role in defining both the geometric configuration and the operational performance of the rotor. As expressed in Equation (24), the aspect ratio is defined as the ratio between the turbine length and its outer diameter. This derived parameter offers deeper insight into the optimal geometric configuration of the rotor and has been widely adopted in previous studies [15], [63-68]. Based on earlier investigations, the influence of aspect ratio variation on the power-generating capability of ASWTs can be clearly identified through the following findings.

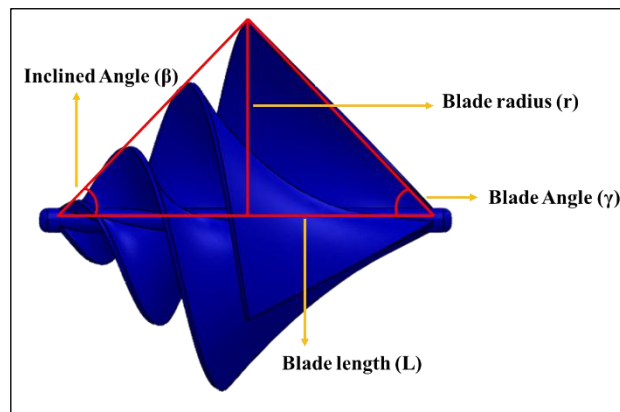


Figure 14: Geometric parameters of the ASWT.

Source : [69].

Study [69] examined five turbine models incorporating three different aspect ratios ($AR = 1.5, 1.25, \text{ and } 1.0$), designed using both forward elongation and backward elongation configurations. The experimental results identified the model with $AR = 1$ and forward elongation as the most optimal configuration. This model achieved a maximum power coefficient (C_p) of 0.249 at a tip speed ratio (TSR) of 1.413 . In general, the forward elongation configuration was found to enhance the power coefficient at lower TSR values, making it particularly suitable for low wind speed environments where effective operation at low rotational speeds is required. Conversely, reducing the aspect ratio below unity was not recommended, as it tended to induce vibrations and flow instabilities that negatively affect efficiency and reduce bearing lifespan. On the other hand, the $AR = 1$ model with backward elongation exhibited a higher torque coefficient, which can be attributed to the larger blade flow interaction area. This configuration provides improved self-starting capability and higher initial (starting) torque. In a separate investigation [70], four ASWT models with different geometric configurations were evaluated. ASWT 1 had a diameter of 55 cm and a length of 60 cm , resulting in an aspect ratio of 1.1 . ASWT 2 maintained the same diameter of 55 cm but had a shorter length of 50 cm , also yielding an aspect ratio of 1.1 . ASWT 3 featured a diameter and length of 50 cm , corresponding to an aspect ratio of 1.0 , while ASWT 4 had a diameter of 45 cm and a length of 50 cm , producing an aspect ratio of 0.9 . These variations were implemented to assess the influence of geometric changes on the aerodynamic performance of the turbine. The results demonstrated that increasing the rotor aspect ratio significantly improved the power coefficient. Among the tested models, ASWT 1 ($D = 55 \text{ cm}$, $L = 60 \text{ cm}$, $AR = 1.1$) achieved the highest power coefficient, reaching a maximum C_p value of 0.17 . Overall, the comparative analysis of the four models revealed a consistent trend indicating that rotor geometry variations have a direct and measurable impact on aerodynamic performance. Therefore, the selection of an appropriate aspect ratio in ASWT design is crucial for balancing aerodynamic efficiency and structural integrity. Research findings indicate that aspect ratios exceeding 1.1 do not provide optimal performance. Conversely, aspect ratios below 1.0 tend to introduce flow fluctuations and mechanical vibrations, which reduce efficiency and shorten component lifespan. The optimal aspect ratio range for ASWTs lies between 1.0 and 1.1 , where the highest power coefficients are consistently achieved.

III.4.3 ASWT Blade Profile Geometry

Airfoil selection is a critical aspect of wind turbine blade aerodynamic design. The airfoil profile has a pronounced influence on blade performance, where even minor geometric modifications can result in substantial changes in aerodynamic behavior as well as the level of noise generated [71-76]. To maximize the extraction of wind kinetic energy, an optimized blade geometry is required. As illustrated in Figure 15, one example of a blade profile employing an airfoil is presented. Modern rotor blades are generally designed with varying airfoil profiles along the blade span in order to enhance operational efficiency. This approach leads to more complex blade geometries, yet significantly improves performance compared to earlier generations of wind turbine blades. Airfoil selection is typically based on comparative evaluations of lift-to-drag ratios among established airfoil profiles [20], [77-79].

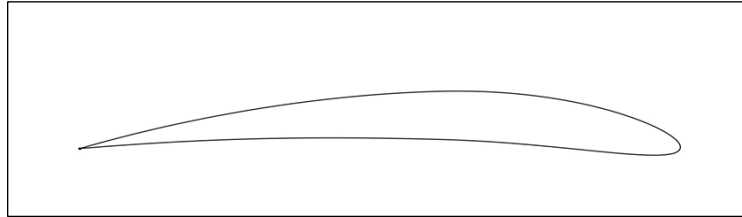


Figure 15: NACA 6409 Profile.
Source : [80].

An understanding of the role of airfoil geometry in improving blade efficiency provides the basis for further investigation into how airfoil shape affects overall turbine performance, particularly in ASWT designs. A study conducted by [25] analyzed the influence of airfoil implementation on ASWT performance by comparing four design configurations. The initial configuration consisted of a conventional ASWT with standard specifications, including a blade thickness of 3.5 mm, a pitch-to-diameter ratio ($2s/D$) of 0.28, a constant pitch of 70 mm, blade angles of $\alpha_1 = 30^\circ$, $\alpha_2 = 45^\circ$, and $\alpha_3 = 60^\circ$, and outer and inner shaft diameters of 25 mm and 15 mm, respectively. The second configuration involved a modified ASWT in which the blade thickness was reduced to 2 mm and the blade angles were adjusted to $\alpha_1 = 25^\circ$, $\alpha_2 = 50^\circ$, and $\alpha_3 = 60^\circ$, while maintaining the same pitch and $2s/D$ ratio. In the third stage, the ASWT design focused on variations of the pitch-to-diameter ratio ($2s/D$) to identify the most efficient configuration, with values modified from the baseline 0.28 to 0.22, 0.24, 0.26, 0.30, 0.32, and 0.34. The final stage introduced airfoil-based ASWT designs (AASWT), representing an advanced level of aerodynamic refinement through the application of various airfoil profiles to the modified ASWT geometry. In this phase, three airfoil families (S, FX, and NACA), each comprising five profile variants, were evaluated using the previously identified optimal $2s/D$ ratio to assess the influence of micro-scale aerodynamic characteristics on overall turbine performance. The results indicated that the AASWT employing the NACA 4401 airfoil achieved the best performance, reaching a maximum power coefficient (CP) of 30.45% at a tip speed ratio (λ) of 2. This design exhibited a 26.88% efficiency improvement compared to the conventional ASWT and a 6.47% increase relative to the modified ASWT. Consistent with these findings, several studies have investigated the application of NACA airfoil profiles in ASWT designs to evaluate performance responses under varying wind speed conditions. Research by [20] focused on AASWT performance by comparing the torque characteristics of an ASWT equipped with a NACA 6409 airfoil against a conventional ASWT. Computational fluid dynamics (CFD) analysis was employed to estimate blade torque characteristics. The results demonstrate a torque increase of approximately 10–15% at low wind speeds and more than 15% at moderate wind speeds, indicating that the NACA 6409 airfoil blade design performs effectively under low to moderate wind conditions. In another study, [81] reported that ASWTs modified with the NACA 2412 airfoil profile produced lower noise levels and exhibited improved suitability for low wind speed operation. These findings were supported by both wind tunnel experiments and field tests, which confirmed enhancements in torque output and aerodynamic efficiency. Overall, these results indicate that the application of NACA-type airfoil profiles in ASWT blades yields superior performance compared to S and FX profile types. Furthermore, ASWT designs incorporating the NACA 6409 airfoil demonstrate effective operation under low to moderate wind speeds, while NACA airfoil configurations also contribute to reduced noise levels relative to conventional blade designs.

III.4.4 Effect of Blade Inclination on ASWT Performance

Analyzing the influence of blade inclination on ASWT performance requires a clear understanding of how variations in blade angle alter turbine behavior. Figure 16 provides an initial conceptual illustration that clarifies the role of blade inclination in the ASWT rotor. A study conducted by [82] investigated the effect of blade inclination on ASWT performance using two distinct approaches: variable blade-angle configurations and uniform blade-angle configurations across the rotor. The variable configurations consisted of ($\alpha_1 = 15^\circ$, $\alpha_2 = 30^\circ$, $\alpha_3 = 45^\circ$) and ($\alpha_1 = 30^\circ$, $\alpha_2 = 45^\circ$, $\alpha_3 = 60^\circ$), while the uniform configurations included ($\alpha_1 = \alpha_2 = \alpha_3 = 30^\circ$), ($\alpha_1 = \alpha_2 = \alpha_3 = 45^\circ$), and ($\alpha_1 = \alpha_2 = \alpha_3 = 60^\circ$). Among all tested configurations, the stepped blade-angle arrangement ($\alpha_1 = 30^\circ$, $\alpha_2 = 45^\circ$, $\alpha_3 = 60^\circ$) emerged as the most effective, achieving a maximum power coefficient (C_{pmax}) of 0.234 at a tip speed ratio (TSR) of 1.5. The analysis revealed that rotors with larger blade angles dominate the incoming flow through a stronger interaction over the swept area, thereby widening the operational TSR range and shifting the peak performance toward higher TSR values. This configuration generated higher thrust forces and increased force fluctuations due to enhanced drag associated with more upright blade orientations. These effects intensified flow blockage and produced more pronounced pressure patterns around the rotor. In contrast, rotors with smaller blade angles presented a gentler interaction surface to the incoming flow. As a result, the freestream was able to pass through the rotor with minimal disturbance, leading to a weaker blockage effect and reduced energy extraction. While this condition supported more stable tip-vortex structures, it was also associated with slower wake recovery compared to rotors with larger blade angles. At higher blade inclinations, stronger and more coherent hub vortex structures were observed, indicating a more aggressive momentum exchange between the blades and the flow.

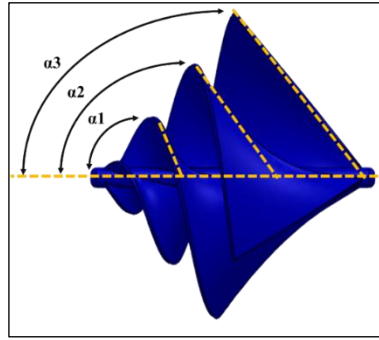


Figure 16: Schematic view of the ASWT rotor.
Source : [82].

Consistent with the findings of [82], the study by [27] examined the combined effects of blade thickness and blade angle on ASWT performance. The results demonstrated that stepped blade-angle configurations provide superior performance, with the combination of $\alpha_1 = 25^\circ$, $\alpha_2 = 50^\circ$, and $\alpha_3 = 60^\circ$ and a blade thickness of 2 mm identified as the optimal arrangement for the modified ASWT. Additional studies further broaden the understanding of blade inclination effects on ASWT performance. Research by [83] analyzed the lift coefficient (C_L) and drag coefficient (C_D) of ASWTs employing a Fibonacci-based blade arrangement with opening angles of $\alpha_1 = 35^\circ$, $\alpha_2 = 45^\circ$, and $\alpha_3 = 65^\circ$. The investigation was conducted under turbulent airflow conditions at a Reynolds number of 1200, ambient pressure of 1 atm, and wind speeds of 5.5 m/s and 15 m/s. The results indicated that at a wind speed of 5.5 m/s, increasing the blade opening angle led to higher lift coefficients. Conversely, at a wind speed of 15 m/s, larger blade angles resulted in increased drag coefficients, as a greater portion of the wind was intercepted by the turbine. However, the occurrence of unstable aerodynamic responses in these simulations was identified as a general limitation in wind turbine design. Nevertheless, a contrasting trend was reported by [84], who evaluated blade inclination angles (β) ranging from 50° to 65° at 5° intervals using computational simulations validated by experimental measurements. The results showed that the maximum power coefficient ($C_{P_{\max}} = 0.22$ at $TSR = 1.72$) and the maximum torque coefficient ($C_{T_{\max}} = 0.24$ at $TSR = 0.62$) were both achieved at a blade angle of 50° . These findings indicate that increasing blade inclination beyond this value leads to a reduction in maximum power coefficient, revealing an inverse relationship between blade angle and peak power performance under certain operating conditions. Overall, these findings suggest that larger blade opening angles in ASWTs can significantly enhance turbine performance under specific configurations and operating regimes. By expanding the effective wind capture area and strengthening aerodynamic interactions, appropriately inclined blades are capable of generating higher power and torque coefficients. However, excessive blade inclination may induce increased drag and flow instability, underscoring the importance of optimizing blade angle to balance aerodynamic efficiency and flow stability.

III.4.5 Augmentation for ASWT Performance Enhancement

The Archimedes Screw Wind Turbine (ASWT) has been further developed through the incorporation of augmentation devices such as shrouds or flow channels to enhance its aerodynamic performance, as illustrated in Figure 17. Turbines equipped with such structures are commonly referred to as Shrouded Archimedes Screw Wind Turbines (SASWT). The shroud functions by generating a low-pressure region downstream of the rotor, which accelerates the incoming airflow and draws a larger volume of air through the turbine. In addition, the shroud acts as a flow concentrator, increasing both the mass flow rate and the momentum of the air entering the rotor [85-87]. The resulting increase in pressure differential across the rotor leads to a higher airflow throughput and, consequently, greater power output. Despite the substantial performance gains, SASWTs face notable challenges, particularly the significantly higher thrust forces acting on the rotor compared to open (unshrouded) turbines [85], [86], [88], [89]. These elevated structural loads require the use of stronger blade materials, which inevitably increases the initial construction cost. Nevertheless, the improvements in efficiency and power output position SASWTs as a promising solution in wind energy development. It is important to note that although the shroud enhances turbine performance, it does not directly generate energy. In power coefficient (C_p) calculations, the shroud is typically excluded from the rotor area, ensuring that the C_p value remains below the Betz limit. Accordingly, the shroud is regarded as a passive enhancement device that amplifies pressure and flow rather than a power-producing component [85-88].



Figure 17: Shrouded Archimedes Spiral Wind Turbine (SASWT) layout.
Source: [90].

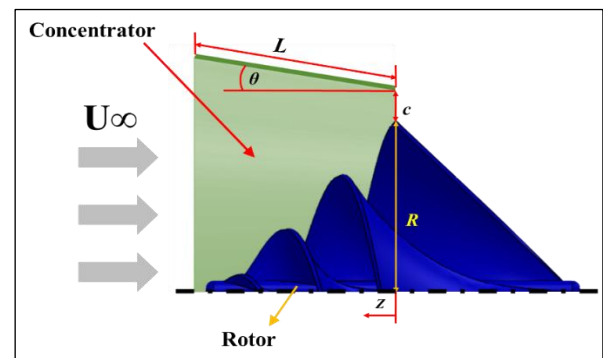


Figure 18: Shrouded Archimedes Spiral Wind Turbine (SASWT) layout.
Source: [90].

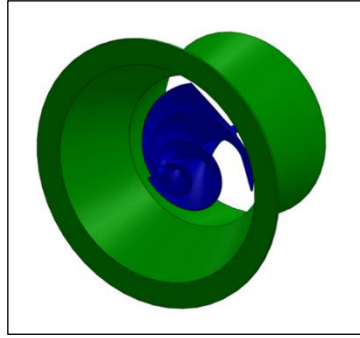


Figure 19: Illustration of the concentrator design with a flange at the ASWT inlet.
Source: [91].

Augmentation devices such as concentrators have been shown to significantly improve ASWT performance. A study by [90] evaluated the optimal configuration of an ASWT equipped with a concentrator and compared its performance to that of a bare ASWT. The concentrator design parameters are presented in Figure 18. The results demonstrated that the optimal configuration characterized by a concentrator position of $0.1D$ upstream of the rotor, a concentrator angle of 20° , a tip clearance of $0.05D$, and a concentrator length of $0.6D$ achieved a maximum power coefficient of 0.311 at a TSR of 2 .

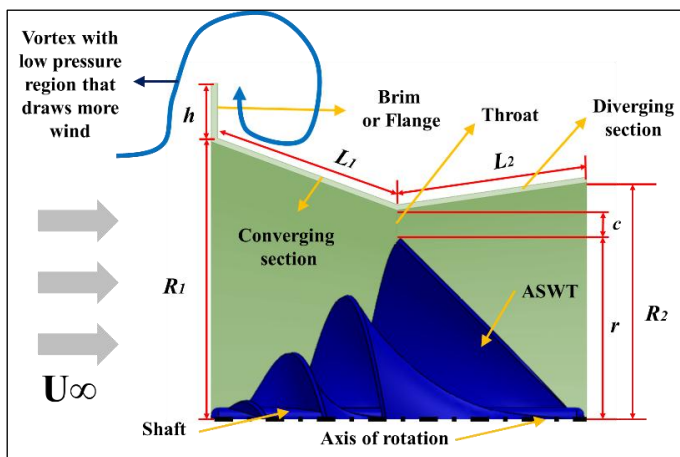


Figure 20: Design parameters of the concentrator with a flange at the ASWT inlet.
Source: [91].

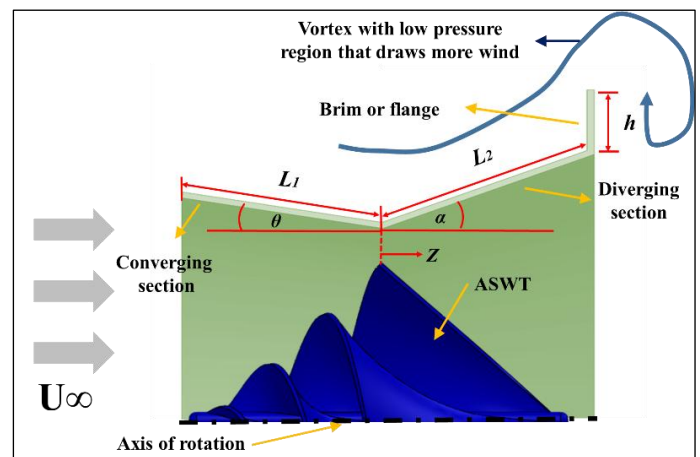


Figure 21: Design parameters of the concentrator with a flange at the ASWT outlet.
Source : [92].

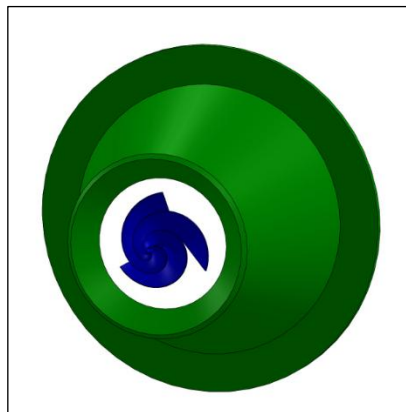


Figure 22: Illustration of the concentrator design with a flange at the ASWT outlet.
Source: [92].

The effectiveness of concentrator-based augmentation can be further enhanced by incorporating a flange, as reported in [91]. In this study, ASWT performance was improved by designing a concentrator with an inlet flange, as illustrated in Figure 19. The flange design parameters are shown in Figure 20. Using a turbine with a diameter of 250 mm, the optimal configuration yielding the highest C_p was obtained at $L_1 = 180$ mm, $L_2 = 152$ mm, $R_1 = 250$ mm, $R_2 = 137.5$ mm, and $h = 75$ mm. Under these conditions, the ASWT achieved a maximum C_p of 0.502 at a TSR of 2.5 , representing an approximately 2.58 -fold increase compared to the bare ASWT ($C_p = 0.195$). Beyond inlet-mounted flanges, performance enhancement can also be achieved by repositioning the flange at the outlet. A study by [92] numerically investigated the performance of an ASWT equipped with an airflow channel designed to improve energy harvesting efficiency in urban environments characterized by low wind speeds.

Figure 21 presents the concentrator parameters with an outlet flange, while Figure 22 illustrates the configuration. The findings revealed that the optimized channel geometry significantly increased the power coefficient. The optimal parameters were identified as $L_1 = 0.2191D$, $L_2 = 1.658D$, $\theta = 45.51^\circ$, $\alpha = 22.2^\circ$, $h = 0.3457D$, and $Z = -0.296D$. With this configuration, the maximum power coefficient reached 0.967 at a TSR of 3.25, corresponding to an approximately 3.6-fold improvement compared to the bare ASWT ($C_p = 0.2668$ at TSR = 2.5).

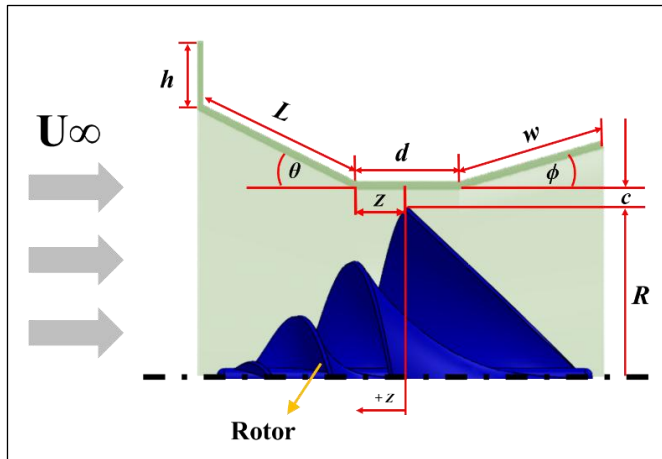


Figure 23: Wind lens design parameters for the ASWT.
Source: [88].

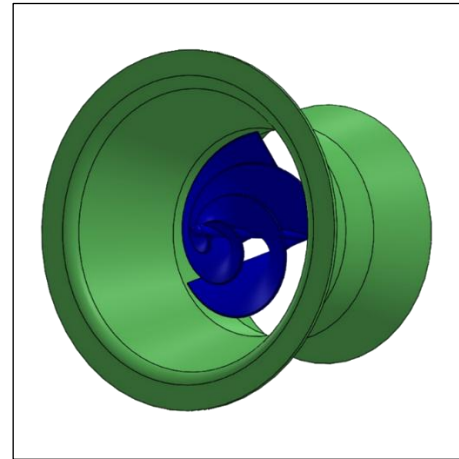


Figure 24 : Illustration of the wind lens design for the ASWT.
Source: [88].

To further optimize performance, the geometry and configuration of wind-lens systems have been extensively investigated. Figure 23 presents the design parameters of a wind lens applied to an ASWT, with the corresponding illustration shown in Figure 24. The study by [88] systematically optimized wind-lens parameters, including diffuser length and angle, duct length, and flange height, to maximize the performance of a Shrouded Archimedes Spiral Wind Turbine (SASWT). The optimal configuration was obtained with $Z = 0.1D$, $\phi = 20^\circ$, $c = 0.05D$, a diffuser angle of 15° , and a concentrator length (L) of $0.6D$. Additionally, the optimal values for duct length (d), flange height (h), and diffuser length (W) were each $0.3D$. This configuration yielded a maximum power coefficient of 0.49 at a TSR of 3, representing a 2.1-fold increase relative to the ASWT without a wind lens. As a further advancement, [93] introduced three key contributions: (i) the use of a cylindrical enclosure to fully cover the turbine, (ii) the implementation of a simplified Maximum Power Point Tracking (MPPT) strategy, and (iii) the integration of protective electronic circuitry. The results indicated that the enclosure not only enhanced turbine efficiency but also reduced visual impact by obscuring the rotating blades an important advantage for individual users concerned with the aesthetic aspects of wind turbine installations. In summary, the incorporation of augmentation devices such as concentrators, concentrators with ducts, concentrators with ducts and flanges, and wind-lens systems consistently enhances ASWT performance by increasing pressure differentials and accelerating the incoming airflow. These mechanisms lead to substantial and measurable improvements in the power coefficient. For instance, an optimized shroud configuration with parameters $L_1 = 0.2191D$, $L_2 = 1.658D$, $\theta = 45.51^\circ$, $\alpha = 22.2^\circ$, $h = 0.3457D$, and $Z = -0.296D$ was shown to achieve a maximum C_p of 0.967 at a TSR of 3.25 approximately 3.6 times higher than that of a bare ASWT ($C_p = 0.2668$ at TSR = 2.5).

III.4.6 Comparison between ASWT and other Wind Turbine Types

Several studies have demonstrated that the effectiveness of newly developed wind turbine designs can be systematically evaluated through direct comparisons with similar configurations or alternative turbine types. In a study conducted by [94], a dual-turbine system combining a Savonius turbine and an Archimedes Screw Wind Turbine (ASWT) was developed. Both turbines had a diameter of 20 inches and were mounted on a 4.5 m tower. Experimental results showed that the ASWT produced higher voltage output and rotational speed than the Savonius turbine. The ASWT achieved an average voltage of 7.04 V with a power output of 5.10 W, whereas the Savonius turbine generated only 2.70 V and 1.23 W. When operated simultaneously, the hybrid system produced an average voltage of 9.73 V and a power output of 6.32 W [94]. In another study, [95] performed a comparative numerical investigation of four different wind turbine types using ANSYS 16.0 based on Computational Fluid Dynamics (CFD), under a constant wind speed of 5 m/s and identical rotor swept areas. The simulation results indicated that the ASWT exhibited the highest performance, achieving an aerodynamic efficiency of 30.3%, a maximum power output of 6.55 W, and a rotational speed of 398 rpm. One of the key advantages of the ASWT lies in its ability to operate efficiently under low wind speed conditions, in contrast to Horizontal Axis Wind Turbines (HAWTs) and conventional Vertical Axis Wind Turbines (VAWTs), which typically require higher wind speeds to reach optimal performance [25], [27], [96]. The spiral blade geometry of the ASWT promotes smoother airflow behavior and a more uniform pressure distribution along the blade surface. This characteristic contributes to reduced aerodynamic noise and enables the turbine to initiate operation at wind speeds as low as approximately 2.5 m/s [27], [73], [88], [91], [97-101]. These combined features make the ASWT particularly well suited for urban environments, where wind speeds are generally low and highly turbulent. Moreover, the ASWT offers significant design flexibility and operates effectively at low Tip Speed Ratios (TSRs), enhancing its resistance to turbulence effects. Unlike HAWTs, ASWTs can employ a larger number of blades arranged at closer spacing, which improves wind energy capture efficiency. Further performance enhancement can be achieved through multi-turbine configurations. A study by [98] revealed that counter-rotating ASWT arrangements in both parallel and tandem configurations improved aerodynamic efficiency by 3.53% and 2.56%, respectively, compared to a single ASWT. Such configurations are particularly advantageous in urban settings, as they maximize energy density within limited spatial constraints.

IV. CONCLUSION

Considering its technical characteristics and environmental benefits, the Archimedes Screw Wind Turbine (ASWT) demonstrates strong potential as a future renewable energy solution. ASWT offers several inherent advantages, including self-starting capability, the absence of yaw mechanisms and tall towers, and ease of integration with augmentation devices. These features make ASWT particularly suitable for urban environments that require compact, low-noise turbines capable of operating under low wind-speed conditions. Recent research developments and innovations indicate that the selection of spiral geometry has a direct influence on turbine performance. ASWT equipped with an Archimedean spiral profile consistently outperforms logarithmic spiral configurations, achieving a maximum power coefficient (CP) of 0.2668 at a blade opening angle of 60° . In addition, aspect ratio (AR) values exceeding 1.1 are found to be suboptimal, while AR values below 1.0 tend to induce flow instability, vibration, and performance degradation, potentially shortening component lifespan. The optimal AR range is identified between 1.0 and 1.1, which provides a balance between maximum power output, structural stability, and operational durability. Performance enhancement in ASWT is not governed solely by aspect ratio. The application of airfoil-based blade profiles has been shown to significantly improve turbine efficiency. ASWT blades employing NACA airfoil profiles demonstrate notable performance gains compared to conventional blade designs, while also contributing to noise reduction. In particular, the NACA 6409 airfoil exhibits effective operation under low to moderate wind-speed conditions.

Beyond blade geometry, the blade opening angle also plays a crucial role in improving ASWT performance. Larger opening angles expand the effective wind capture area and enhance aerodynamic forces, resulting in increased torque and power output. The blade inclination configuration ($\alpha_1 = 30^\circ, \alpha_2 = 45^\circ, \alpha_3 = 60^\circ$) emerged as the most effective arrangement, achieving a maximum power coefficient (C_{pmax}) of 0.234 at a tip speed ratio (TSR) of 1.5. The results indicate that rotors with larger blade angles tend to dominate the flow by providing a stronger capture area, thereby extending the operational TSR range and increasing the TSR at peak performance. However, this configuration also generates higher thrust forces along with increased fluctuations, primarily due to the elevated drag associated with a more upright blade orientation relative to the incoming flow. Further performance improvements can be achieved through external modifications. The integration of augmentation structures, such as brimmed shrouds, has been reported to dramatically increase the power coefficient, with performance gains reaching up to 3.6 times compared to a bare ASWT configuration. Nevertheless, to fully realize the potential of ASWT technology, continued research efforts are required. These should focus on advanced design optimization, full-scale experimental validation, and comprehensive techno-economic analyses under real-world operating conditions. Collaboration among academic institutions, industry stakeholders, and governmental bodies will be essential to accelerate the adoption of ASWT technology as part of the global transition toward sustainable energy systems.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Bayu Ardiansyah Maskub Putra.

Methodology: Bayu Ardiansyah Maskub Putra.

Investigation: Bayu Ardiansyah Maskub Putra.

Discussion of results: Bayu Ardiansyah Maskub Putra, Nazaruddin Sinaga, Eflita Yohana.

Writing – Original Draft: Bayu Ardiansyah Maskub Putra.

Writing – Review and Editing: Bayu Ardiansyah Maskub Putra, Nazaruddin Sinaga, Eflita Yohana, Mochammad Shodiq.

Resources: Bayu Ardiansyah Maskub Putra.

Supervision: Nazaruddin Sinaga, Eflita Yohana.

Approval of the final text: Bayu Ardiansyah Maskub Putra, Nazaruddin Sinaga, Eflita Yohana, Mochammad Shodiq.

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