

TITTLE:

A Review on Design Parameter Optimization of Helical Blade Darrieus Vertical Axis Wind Turbines.

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ABSTRACT:

This study provides a detailed analysis of the optimization of design parameters for Darrieus-type vertical-axis wind turbines with helical blade configurations, emphasizing the enhancement of aerodynamic performance and OE. The various parameters considered in this study included blade shape, helix angle, TSR, solidity, number of blades, blade pitch angle, aspect ratio, angle of attack, and material choice, based on their effects on power generation, torque uniformity, and starting capability. The application of CFD allows for a comprehensive analysis of fluid behavior.

INTRODUCTION:

Wind energy has become one of the most promising sources of renewable energy, primarily owing to its sustainability, environmentally friendly nature, and increasing global demand from around the world for electricity production through sustainable means. Among all the available wind turbine technologies, Vertical Axis Wind Turbines (VAWTs), especially Darrieus VAWTs, are one of the most promising. Helical-blade Darrieus VAWTs are among the most advanced models of Darrieus VAWTs that solve many problems associated with straight-blade versions, such as fluctuating torque, non-self-starting nature, and structural inefficiency.

Various parameters influence the optimal performance of helical-blade Darrieus vertical-axis wind turbines (VAWTs). The efficiency of such VAWTs can be improved by optimizing different variables, such as the blade shape, helix angle, tip speed ratio, angle of attack, aspect ratio, number of blades, and material used in construction. To enhance the aerodynamic efficiency of such VAWTs, increase the power output, reduce torque fluctuations, and improve the overall performance of these turbines, optimizing such variables is critical. The use of computational fluid dynamics (CFD) tools for such analyses has become easier.

In this review, we examined the effects of important design variables on the performance of helical blade Darrieus Vertical Axis Wind Turbines (VAWTs).

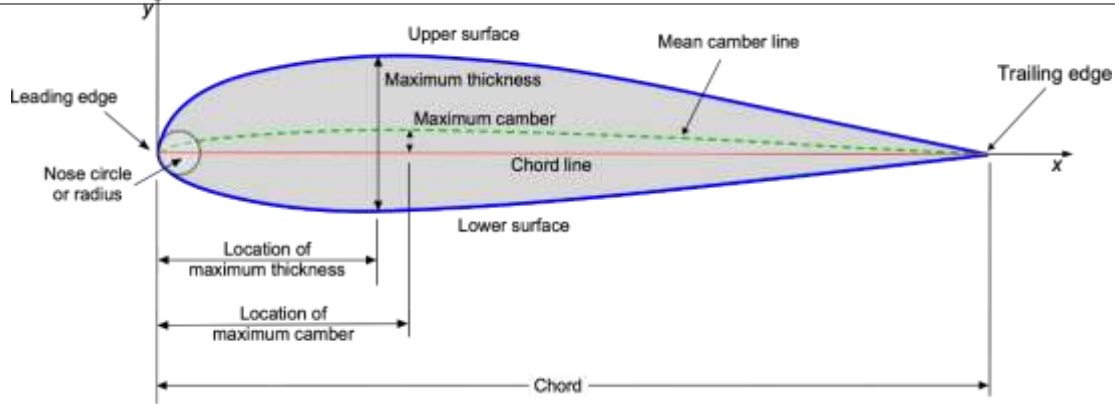
A) Blade Profile:

The airfoil shape or blade section plays an important role in calculating the efficiency and performance characteristics of the Darrieus VAWT with helical blades. As the turbine generates its power based on lift forces, the blade profile affects all significant aerodynamic factors.

- **Lift coefficient (Cl):** An increased value of lift helps achieve better energy conversion into rotor rotation.
- **Drag coefficient (Cd):** A reduced drag coefficient means fewer energy losses and greater efficiency.
- **Lift-to-drag ratio (Cl/Cd):** A large ratio guarantees excellent aerodynamic performance.
- **Autostart characteristics:** Airfoil geometry affects self-starting capabilities at low wind speed.
- **Power coefficient (Cp):** It determines the efficiency of wind energy conversion into shaft mechanical power.

It is necessary to choose the appropriate airfoil or design it for the Darrieus VAWT with helical blades to achieve high efficiency and reliability. Some common types of airfoils include symmetrical profiles (NACA 0012, NACA 0015, and NACA 0018).

Airfoil	Thickness (%)	Cl	Cd	Cl/Cd	Reynolds No.	Remark
NACA 0012	12	0.65 – 0.75	0.010 – 0.014	High	$1 \times 10^5 - 5 \times 10^5$	High Efficiency
NACA 0015	15	0.70 – 0.80	0.012 – 0.016	Good	$1 \times 10^5 - 5 \times 10^5$	Balance
NACA 0018	18	0.75 – 0.85	0.014 – 0.018	Moderate	$1 \times 10^5 - 5 \times 10^5$	Stronger
NACA 0021	21	0.80 – 0.90	0.016 – 0.022	Low	$1 \times 10^5 - 5 \times 10^5$	High Strength



B) Helix angle:

This will assist in improving the blade performance, considering that a spanwise flow will be generated. First, the smoothness of the torque output must be considered. In the case of straight blades, the variation in force causes the torque to vary; however, when helical blades are used, the effects are minimized owing to the uniformity in the application of force. In addition, for straight blades, negative torque can lead to difficulties in starting the turbine, which is not the case for helical blades.

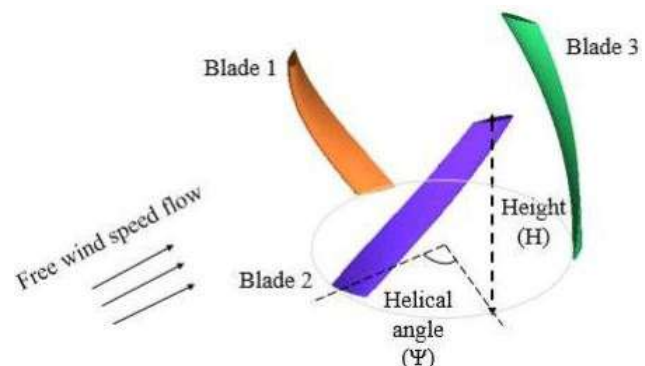
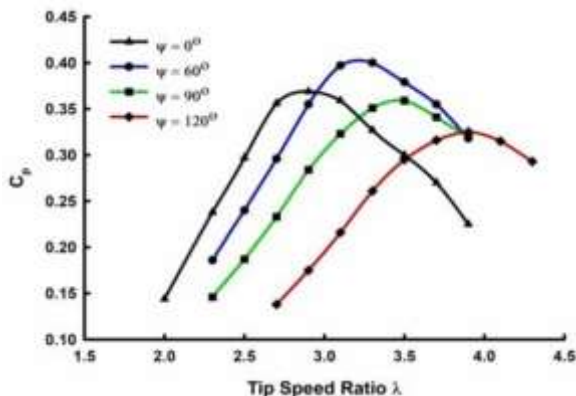
However, to optimize the blade configuration, the optimum helix angle must be used to attain maximum efficiency (C_p). The optimum helix angle of a turbine is attained at a moderate angle of the helix between 60° and 90° . This depends on turbine and blade specifications. The helix angle was calculated using the following formula:

$$\theta = \tan^{-1}\left(\frac{\pi \times D}{H}\right)$$

Where:

- D = Diameter of turbine (m)
- H = Height of turbine (m)

Helix Angle	Torque Repulsion	Self-Starting	Efficiency (C_p)	Structural Complexity	Remark
0°	30–40%	Low	0.30 – 0.40	Low	High efficiency but unstable
30°	20–30%	Moderate	0.32 – 0.42	Low	Improved stability
60°	10–20%	Good	0.35 – 0.45	Moderate	Optimal balance
90°	5–10%	Very Good	0.30 – 0.40	High	Very stable operation
$>90^\circ$	$<5\%$	Excellent	0.25 – 0.35	Very High	Lower efficiency



Coefficient of performance of VAWT for various helix angles

C) The angle of attack:

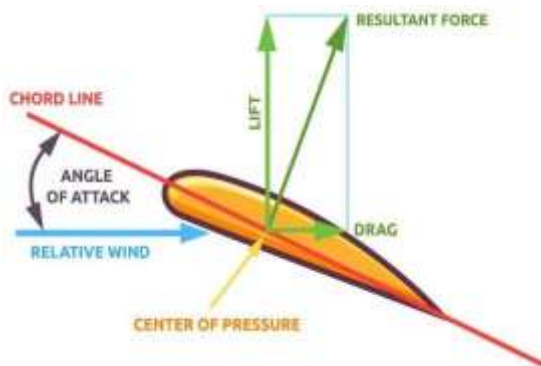
Angle of Attack (AoA): This is an important aerodynamic consideration for helical vertical axis wind turbines (VAWT), which is the difference between the relative velocity and the blade chord angle. The AoA of VAWTs varies as the blades rotate, producing complex aerodynamics. When the tip speed ratio is low, the AoA rises beyond the stall limit (approximately 15 °), causing dynamic stall and inefficiencies. Alternatively, if the tip speed ratio is high, the AoA decreases significantly, and the lift is insufficient. Ideal performance occurs if the AoA is maintained at approximately 5°-15°, where the lift is highest and drag lowest. For the helical VAWT, the AoA was distributed across the height of the blade using the blade twist.

$$\alpha = \tan^{-1} \frac{\sin\theta}{\lambda + \cos\theta}$$

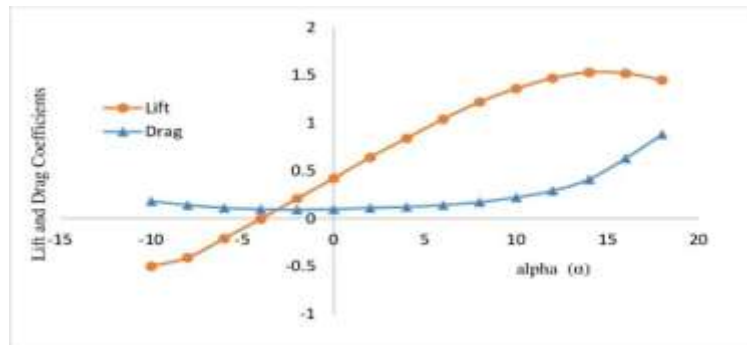
where:

- α = angle of attack
- θ = azimuth angle
- λ = tip speed ratio

AoA Range	Lift Generation	Drag	Flow Condition	Efficiency (Cp)	Remark
0°-5°	Very Low	Very Low	Attached Flow	0.10 - 0.25	Insufficient lift
5°-10°	High	Low	Stable Flow	0.30 - 0.40	Good working range
10°-15°	Very High	Moderate	Near Stall	0.35 - 0.45	Best operating region
15°-20°	Reduced	High	Stall Begins	0.25 - 0.35	Efficiency drops
>20°	Very Low	Very High	Deep Stall	0.10 - 0.20	Not recommended



Angle of Attack in airfoil



C_d and C_l vs α

D) Aspect Ratio:

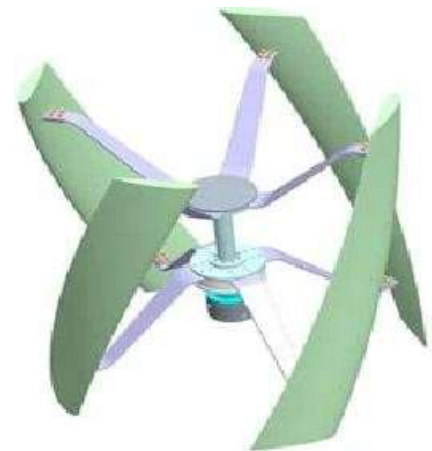
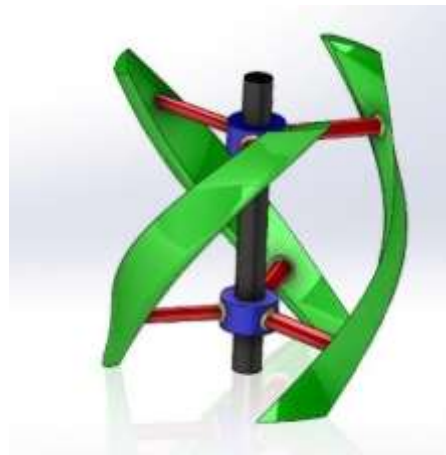
Aspect ratio in a helical vertical-axis wind turbine (VAWT) refers to the ratio between the height and the diameter of the rotor of a turbine, and is very important in determining the aerodynamic efficiency, the power output, and the structural properties of the turbine. High aspect ratio turbines whose ratio falls between 2 and 4 are relatively tall and slender, resulting in high efficiency and high-power coefficients due to better interactions between the rotor and wind. On the other hand, low aspect ratio turbines whose ratio lies between 0.5 and 1.5 have poor aerodynamic efficiencies due to increased aerodynamic losses.

Helical VAWTs have twisted blades that help to distribute load throughout the rotor's height. Therefore, an optimum ratio between 1.5 and 3 should be used.

Aspect Ratio (H/D)	Turbine Shape	Torque	Self-Starting	Efficiency (Cp)	Structural Stress	Remark
0.5 -1.0	Very Wide	High	Excellent	0.20- 0.30	Low	Good starting but low efficiency
1.0- 1.5	Wide	Moderate-High	Very Good	0.25- 0.35	Low-Moderate	Balanced torque and starting
1.5 -2.0	Moderate	Moderate	Good	0.30- 0.40	Moderate	Improved efficiency
2.0 -3.0	Tall & Slender	Moderate-Low	Moderate	0.35- 0.45	High	Optimal performance range
3.0 -4.0	Very Tall	Low	Poor	0.35- 0.42	Very High	High efficiency but structural issues

E) No of Blades:

The number of blades is a significant aspect that plays a vital role in designing helical VAWTs. This element has a significant impact on the aerodynamic performance, torque generation, and start of operation of turbines. The number of blades determines the level of solidity of the rotor, which refers to the relationship between the aggregate blade area and the swept area of the rotor. The higher the number of blades used, the higher the solidity level, torque generated, and self-starting capability, because the interaction with air would be more effective. Nevertheless, it causes greater drag and blade interaction losses, which make the helical VAWT inefficient. If there are fewer blades in such turbines, a lower solidity will help to increase the aerodynamic efficiency by reducing the drag losses; however, such devices will have less torque and self-starting capability owing to fewer interactions with the wind. Helical blades assist in the even distribution of aerodynamic loads, which allows the use of fewer blades while providing good performance. Typically, two or three blades provide the best compromise.



No. of Blades	Torque	Self-Starting	Efficiency (Cp)	Aerodynamic Loss	Structural Complexity	Remark
1 Blade	Very Low	Poor	0.20 – 0.30	Very Low	Very Low	Not practical
2 Blades	Low-Moderate	Moderate	0.30 – 0.40	Low	Low	Simple design
3 Blades	Moderate-High	Good	0.35 – 0.45	Moderate	Moderate	Best balance (most preferred)
4 Blades	High	Very Good	0.30 – 0.40	High	High	Better starting, more drag
≥5 Blades	High	Excellent	0.20 – 0.35	Very High	Very High	High torque but low efficiency

CONCLUSION:

The study underscores the significance of optimizing the design parameters to improve the efficiency of helical-blade Darrieus vertical-axis wind turbines. The efficiency, torque characteristics, and self-starting ability are highly dependent on parameters like blade profile, helix angle, angle of attack, aspect ratio, and number of blades. Although a small helix angle (generally 60°-90°) ensures smooth torque production and improved stability, symmetric airfoil blade profiles provide consistent performance under different wind speeds.

In addition, this study reveals that in order to optimize lift-to-drag ratio, thereby enhancing efficiency, it is essential to keep a good angle of attack (5°-15°). Likewise, an optimal combination of mechanical strength and aerodynamic performance was obtained when the aspect ratio was maintained at 1.5 to 3. In order to find an appropriate compromise between efficiency, torque, and mechanical simplicity, two or three blades were recommended.

Generally speaking, the application of advanced computing tools like CFD analysis has considerably enriched our knowledge about flow dynamics and performance optimization. Future studies can explore hybrid concepts, modern materials, and dynamic optimization strategies to increase efficiency and applicability.

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