# Numerical study of self-starting torque in Darius vertical axis wind turbines with J-type blades

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**ABSTRACT**

**The current study has used three-dimensional simulation of flow around the three-bladed Darrieus turbine to investigate the turbine's self-starting power. Two types of straight and helical bladed turbines, which are equipped with J-type blades are considered. The effects of various parameters including wind speed, blade height, and the tips shape of J-type blades which could be open or closed have been studied and compared with those of the turbine with conventional blades form. The flow analysis around the J-type blades determined that the vortices formed on the pressure raise the torque production. By closing the ends of the J-type blade, these vortices are prevented from exiting at the ends that leads to a substantial improvement on the self-starting and low tip speed ratios. The average torque produced by the straight and helical bladed turbines equipped with closed end J-type blades is respectively 38.5% and 21% higher than the turbines with full profile blades under self-start-up conditions, and the aforementioned percentages are 49% and 41.9% at low tip speed ratios. The positive effect of using J-type blades under self-starting conditions is more pronounced at low wind speeds and higher blade heights, which makes these blades a viable option for urban applications.**

**KEYWORDS**

**Darrieus turbine, J-type blade, Self-starting power, Straight bladed turbine, Helical bladed turbine.**

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## 1. Introduction

Generally, one of the fundamental issues with Darrieus vertical axis wind turbines (VAWTs) is the lack of self-starting capability [1, 2].

To address the self-starting issue, researchers have proposed combined Darrieus and Savonius turbines. The combination of these turbines involves utilizing the Savonius section for self-starting and the Darrieus section for high TSRs torque generation. Various studies have been conducted to optimize the combined turbines, considering factors such as the placement of the Savonius section, the number of blades, and the shape of the blades. The findings indicate that combined turbines can enhance the self-starting power but lead to reduced performance at high TSRs [3, 4].

Numerous researchers have endeavored to improve the performance of Darrieus turbines by altering the structure of turbines and blades. Investigations into helical blades, three-section blades, airfoils plus cavities, serrated leading edges, and grooved blades have provided valuable insights into improving turbine efficiency. However, they did not seem sufficient for solving the self-starting problem [5, 6].

The previous research efforts aimed to enhance their overall performance and enable self-starting capability. One approach involved using blades that could harness both driving and drag forces simultaneously. The introduction of J-shaped blades showed promise in utilizing drag forces during startup and transitioning to Darrieus turbine behavior. However, previous studies mainly focused on performance under operational conditions rather than self-starting conditions [7-9].

This research utilizes 3D simulation to compare the torque production of a J-type bladed turbine with a turbine equipped with complete blades. The study examines the self-starting torque generated by both turbine types under urban wind conditions, considering the contributions of driving and drag forces. The research also explores innovative ideas such as closing the ends of J-type blades, changing blade height, and implementing helical J-type blades, comparing their performance to turbines with complete blades during self-starting. The investigations cover various wind angles and low TSRs to assess the effectiveness of J-type blades during self-starting comprehensively.

## 2. Numerical simulation

The cross-sectional profile of the J-type blade is illustrated in Fig. 1. As evident, the J-type blade is generated by removing the pressure surface from the maximum thickness location to the blade trailing edge.

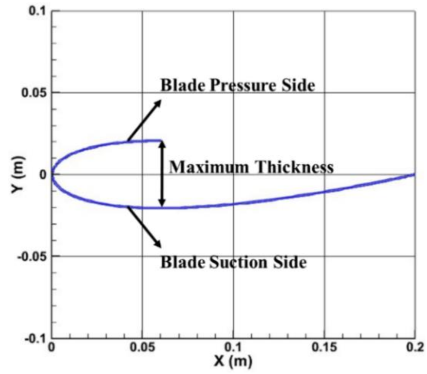


**Figure 1: J-type blade cross-sectional profile**

The complete view of the straight-bladed turbine is depicted in Figure 2. Considering urban environmental conditions, a maximum wind speed of 10 m/s is taken into account.

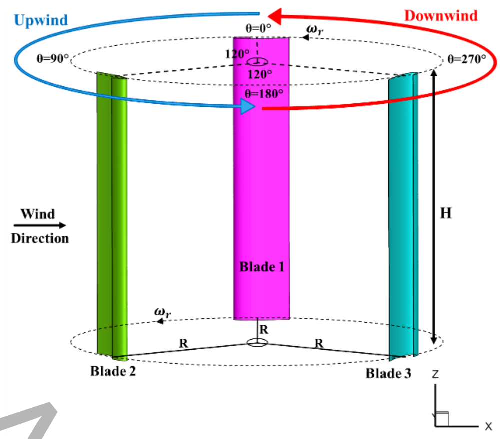


**Figure 2: 3D view of the straight J-type bladed turbine**

The URANS equations have been employed to simulate the fluid flow around the wind turbine. The k-ω SST turbulence model has been utilized to estimate the Reynolds stress tensor in these equations. In the present study, 3D turbulent incompressible flow around the turbine has been simulated using the finite volume method. The sliding mesh technique has been utilized at the interface between the rotating and stationary regions. Second-order discretization has been applied for the pressure and momentum equations.

After achieving independence in terms of computational grid and time step, it is observed that when the rotor is rotating, the results exhibit an average error of 11% with the experiments of Ref. [10]. In the self-starting condition, the results are compared with the numerical results of Ref. [6], showing an average error of 3.2%. The comparison of the results with experimental and numerical studies demonstrates a satisfactory agreement between the findings of this research and the numerical and experimental studies.

## 3. Results and Discussion

A straight-bladed turbine equipped with J-shaped blades generates higher torque than a turbine with complete blades under self-starting conditions. At wind speeds of 10 and 5 meters per second, the torque produced by the turbine equipped with J-shaped blades was 26.9% and 37.6% higher than the turbine with complete blades, respectively. These J-shaped blades appear to be a suitable option for replacing complete blades in urban wind turbine applications. For a rotor configuration where one blade is positioned at 60 degrees and the other blade is at 180 degrees, the maximum difference in torque production between the J-shaped blade and the complete blade reaches approximately 107%.

It has been shown in Fig. 3 that J-shaped blades with closed tips have higher startup power than blades with open tips, with an improvement in performance of 26.9% for the blade with an open tip and 38.5% for the blade with a closed tip compared to the complete blade. the J-shaped blade with a closed tip also exhibits better performance when the rotor has low TSRs. For a tip speed ratio of 0.5, this blade increases the average torque coefficient by 11.2% and 49.5% compared to the open-tipped J-shaped and complete blade, respectively (Fig. 4).

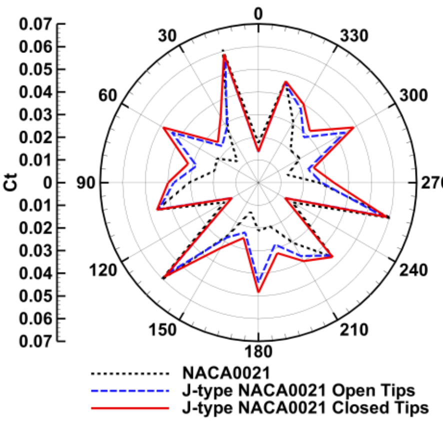


**Figure 3: Self-starting torque of straight bladed turbine equipped with open and closed end J-type blades compared to complete blades**

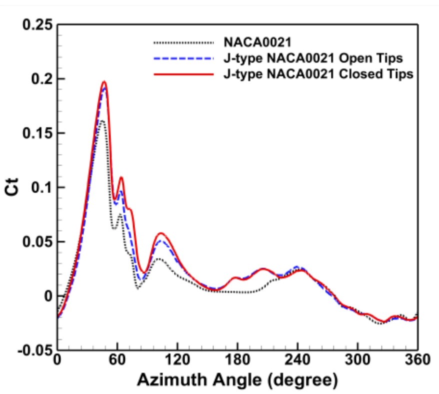


**Figure 4: Instantaneous Ct in one revolution for one blade**

## 4. Conclusion

- The straight-bladed or helical-bladed turbine equipped with J-shaped blades produces higher torque under self-starting conditions. This performance improvement is more pronounced at lower wind speeds and higher blade heights.
- It has been demonstrated that the J-shaped blade with a closed tip exhibits higher self-starting power compared to the blade with an open tip, as well as low TSRs situations.
- In a helical-bladed turbine, similar to a straight-bladed turbine, the use of a J-shaped blade with a closed tip enhances self-starting power and improves the performance at low TSRs.

## 5. References

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