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Research Article

# Influence of Solidity and Camber on Vertical Axis Wind Turbines

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**Abstract**

This paper aims to predict the performance of a VAWT using a cambered airfoil. The H-type Darrieus turbine consists of three straight blades with shape of aerofoil attached to a rotating vertical shaft. Bearing in mind the overall flow is characterized by important secondary flows, the turbulence model selected was Transition SST with non-equilibrium wall functions. Conservation equations were solved with a Third-Order Muscl scheme using SIMPLE to couple continuity and momentum equations. A parametric study has been carried out to analyze the solidity and camber effects on the non-dimensional curves so that the range of tip speed ratio of operation could be predicted as well as their self-starting behavior.

*Keywords*- VAWT; CFD; solidity; efficiency, NACA, H-Darrieus

## 1. Introduction

One advantage of vertical-axis wind turbines (VAWT) is they do not need to be oriented in the wind direction however they operate at low tip speed ratios. Then the application is limited to small consumes. This paper aims to predict the performance of VAWT. The H-type Darrieus turbine consists of three straight blades with shape of aerofoil attached to a rotating vertical shaft. The criterion on the selection of this kind of turbines, despite its reduced efficiency, is the easy manufacture in workshops.

A parametric study has been carried out to analyze the solidity and camber effects on the non-dimensional curves so that the self-starting features [1] as well as the range of tip speed ratio of operation could be predicted [2]. Analyzed the flow on the inner blade surface of an H-Darrieus vertical axis wind turbine with both straight and canted blades and different pitch angles. The work evidences that the reduction of solidity increases the range tip speed ratio.

A VAWT with airfoils NACA 7425, that are extremely cambered, is going to be tested and contrasted with the corresponding symmetric airfoil NACA0025. Also solidities ranging from 1.5 to 0.75 will be analyzed to see tendencies.

## 2. Numerical Model

The general purpose code Fluent ® v.6.2.16 was used to carry out the simulations. The governing continuity, momentum and turbulence equations

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were solved using a finite volume method. The set of equations are solved using a segregated solver.
Bearing in mind the computational cost and discretization errors, the best performance was that of the Transition SST. The near wall turbulence treatment was that of non-equilibrium wall functions because the overall flow is characterized by important secondary flows.
Transition SST model is suitable for flows ith inemediate regimes between laminar and fully developed turbulence. This model has been used by [3] in 2D simulations of VAWT.
Conservation equations were solved with a Third-Order MUSCL scheme using SIMPLE to couple continuity and momentum equations.

Table 1. Details of the H-Darrieus.

| Airfoil | NACA7425 |
|---|---|
| Shaft radius | 0.01 m |
| Rotor radius (R) | 0.05 m |
| Rotor Length (b) | 0.2 m |
| Chord (c) | 0.05 m |
| Rotor Area (A) | 0.02 m2 |
| Number of foils (N) | 3 |
| Solidity (σ) | 1.5 |

During VAWT operation, the performance depends mainly on the relative motion of the rotating blade fields and has a fundamental period which depends both on the rate of rotation and the number of blade passage. The transient study is necessary to characterize the hysteresis phenomenon. For the proposed calculations, the temporal discretization was achieved by imposing a physical time step equal to the lapse of time the rotor takes to make a 1.2º rotation. Hence, more than three revolutions were carried out to prevent the influence of the initial conditions.
The mesh has two fluid volumes, one for the rotor where the moving mesh utility is used to establish the rotation velocity [4]. The other is the environment of the rotor. Different structured meshes were built. The 2D model has nearly 44 thousand hexahedral cells for a scaled model with chord 5 cm, see figure 1 and table 1 for details.
Non dimensional parameters to be used are solidity eq. 1, Tip Speed Ratio eq. 2, momentum and power coefficients, equations 3 and 4 respectively.

$$\sigma=\frac{Z\cdot c\cdot b}{2\cdot r\cdot b} \quad (1)$$

$$TSR=\frac{\omega\cdot r}{v_\infty} \quad (2)$$

$$C_m=\frac{T}{\frac{1}{2}\cdot\rho\cdot v_\infty^2\cdot r\cdot c\cdot b} \quad (3)$$

$$C_p=\frac{T\cdot\omega}{\frac{1}{2}\cdot\rho\cdot v_\infty^3\cdot c\cdot b} \quad (4)$$

Power coefficient is the product of momentum coefficient and the TSR.

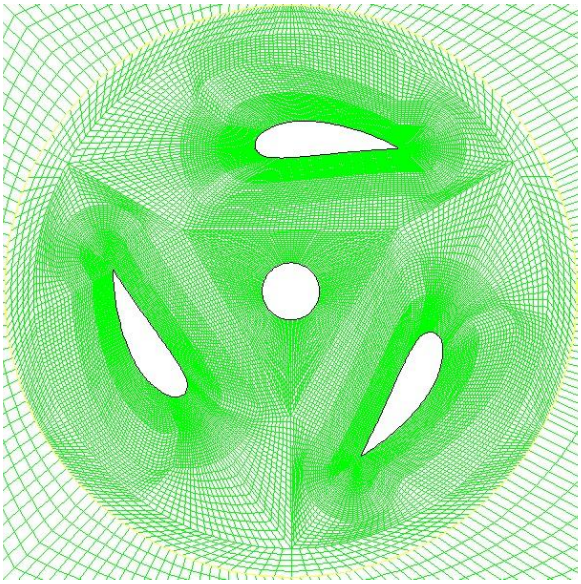

Figure 1. Mesh details.

## 3. Numerical Results

Because of transient flow, results change over time as well as the torque on the shaft, there are time steps with high values of momentum coefficients, which correspond to the favorable positions of the wind turbine, and similarly there are times with torque close to zero or even negative, corresponding to unfavorable positions, [5].

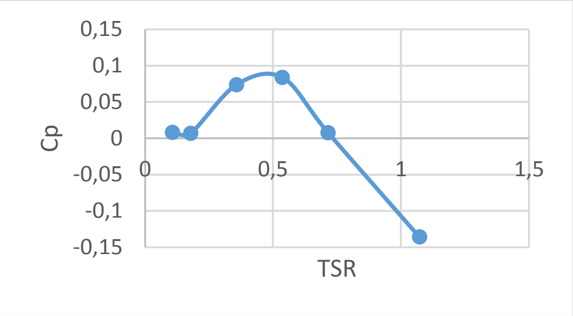


Figure 2. Averaged power coefficient versus the Tip Speed Ratio on no-symmetric NACA 7425 for an incident wind speed of 7 m/s and solidity 1.5.

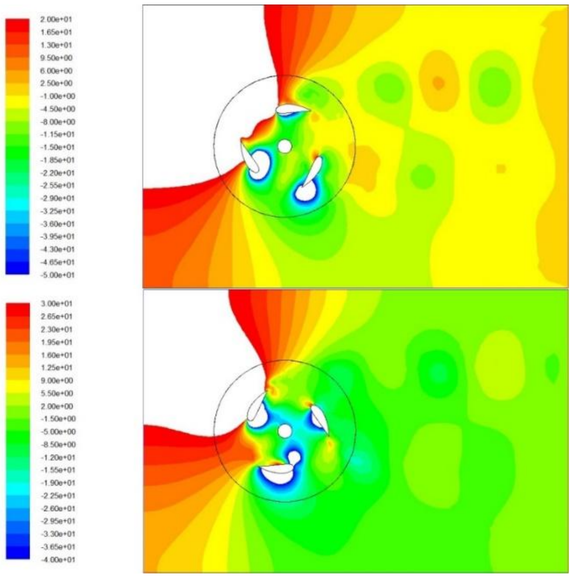

Figure 3. Contours of pressure for NACA 7425 for an incident wind speed of 7 m/s and solidity 1.5 at design conditions. (top) at minimum instantaneous power coefficient (bottom) at maximum instantaneous power coefficient.

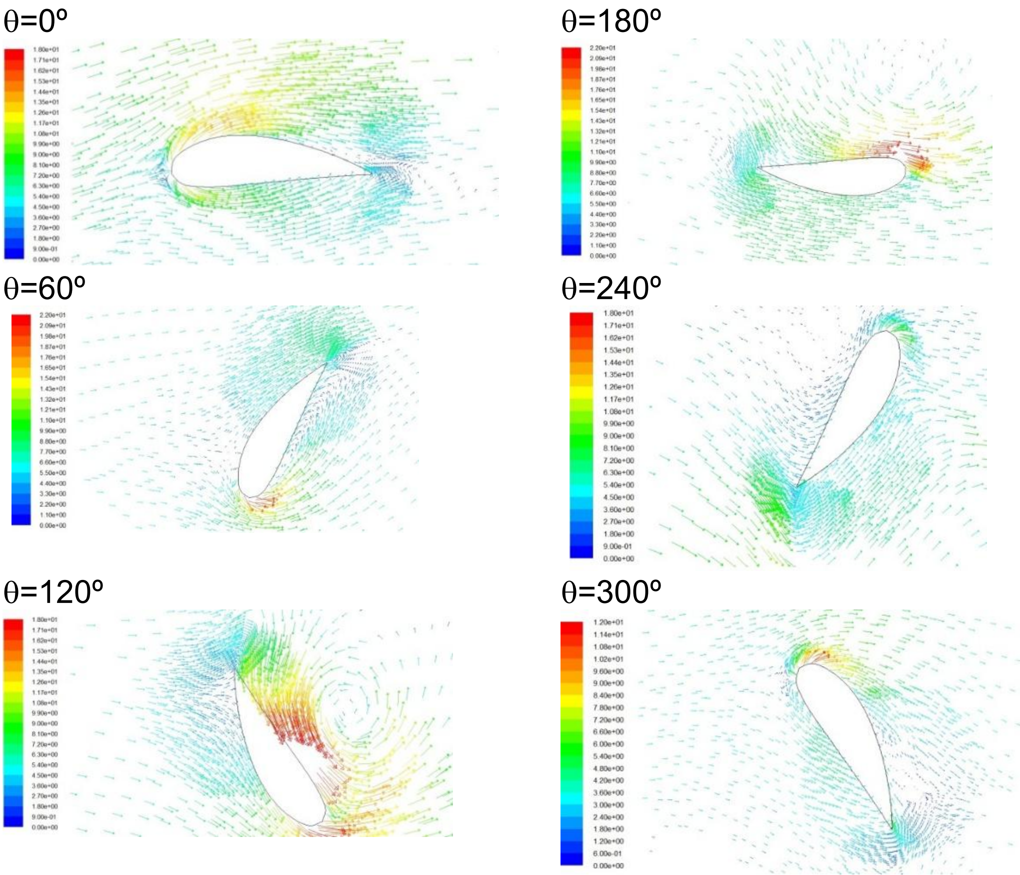


Figure 4 Velocity vectors around NACA 7425 on different positions of for an incident wind speed of 7 m/s and solidity 1.5 at design conditions at maximum instantaneous power coefficient

The averaged momentum coefficient over one revolution of the rotor multiplied by the tip speed ratio produces the averaged power coefficient and it is one

point of the characteristic curve of the wind turbine. Fig. 2 depicts a graph with the variation of Cp versus the TSR.
Fig. 3 shows pressure contours at the most unfavourable (a) and favourable (b) position. Local minimum of pressure is an evidence of recirculation zones because of the detachment of the boundary layer.
Whereas fig. 4 depict the velocity vectors around the airfoil at different tangential positions. Detachment of the boundary layer is a precursor of secondary flows in different instantaneous positions of the blades.

## 4. Influence of the Solidity

This section is devoted to the analysis of the influence of solidity. The increase of the rotor radio implies a reduction of the solidity coefficient (see eq. 1). Fig. 5 shows an increase of the operating Tip Speed Ratio maintaining the design power coefficient. This tendency corresponds with results from other authors [6, 7]. This is very important for electricity production.

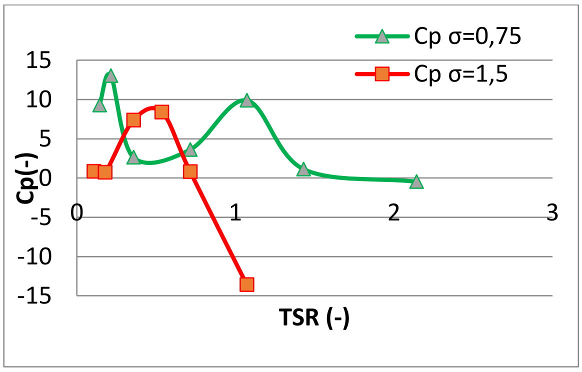


Figure 5. Averaged Power Coefficient versus TSR with NACA 7425 and two different solidities.

## 5. Influence of the Camber

Camber is involved with the degree of lack of symmetry. A VAWT with symmetric airfoils NACA0025 is contrasted with that with a strongly cambered airfoils NACA7425. Results for very low TSR are not very reliable since periodicity is difficult to achieve and a turbulence model for low Reynolds number is requested.
It is clear that the non-symmetric airfoils provide better performance than symmetric ones since NACA7425 show larger range of TSR with positive power coefficient, see fig. 6.

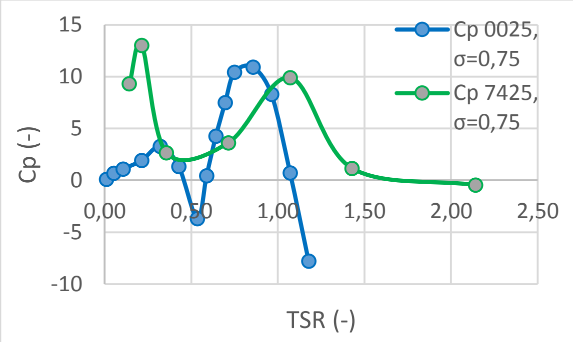


Figure 6. Averaged Power Coefficient versus TSR with NACA 0025 and NACA 7425 with solidities 0.75.

## 6. Conclusion

An H-Darrieus air turbine using non symmetric NACA airfoils has been modelled using a 2D general purpose CFD code. The flow patterns are properly analysed to identify the detachment of boundary layer on the moving airfoils.
The parametric analysis studied the effect of solidity and camber. The criteria are based on the minimum range of TSR with averaged negative power coefficient to help the self-starting. Decreasing solidity increases the range of TSR with energy production. Besides, the camber effect has a similar effect on the characteristic curves.

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