25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-2296
A SMALL TURBINE WITH DIFFUSER ADAPTED TO LOW WIND SPEED

Cíntia Rodrigues Bispo Santos
George Stephane Queiroz de Oliveira
Faculty of Mechanical Engineering, Institute of Technology, Federal University of Pará, Av. Augusto Correa, N 1, Belém, PA, 66075-900, Brazil.
cintiaarbs@gmail.com, george.oliveira@itec.ufpa.br

Vera Carlice Lopes Pereira dos Reis
Faculty of Mechanical Engineering, Institute of Technology, Federal University of Pará, Av. Augusto Correa, N 1, Belém, PA, 66075-900, Brazil.
veracarlicedosreis@gmail.com

Diego Felipe Boneterre Miranda
Faculty of Mechanical Engineering, Institute of Technology, Federal University of Pará, Av. Augusto Correa, N 1, Belém, PA, 66075-900, Brazil.
diego.boneterre9@gmail.com

Jerson Rogério Pinheiro Vaz
Faculty of Mechanical Engineering, Institute of Technology, Federal University of Pará, Av. Augusto Correa, N 1, Belém, PA, 66075-900, Brazil.
jerson@ufpa.br

Erb Ferreira Lins
Faculty of Mechanical Engineering, Institute of Technology, Federal University of Pará, Av. Augusto Correa, N 1, Belém, PA, 66075-900, Brazil.
erb@ufpa.br

Abstract. *The use of diffusers around wind turbines, especially small ones, is important because it can maximize the kinetic energy extracted from the wind. In isolated regions, turbines with diffuser are indeed required due to typically low wind speeds. Regions like this are commonly found in the Amazon and are characterized by difficulty in accessing electricity. This work concentrates on a method to design a small wind turbine able to attend the conditions and characteristics of low wind speeds, typically found in Amazon. A study of a turbine shrouded by a diffuser is made in this work. In this sense, a numerical analysis is carried out in this paper, in which a small diffuser is designed. We verified an increasement of the velocity profile through the rotor, under the influence of the diffuser, which provides improvements on the turbine performance.*

Keywords: *wind turbine, diffuser, renewable energy.*

1. INTRODUCTION

In recent years, researchers worldwide have implemented small systems capable of serving communities not assisted by the conventional electric power. Wind energy is a viable alternative in places with good wind potential for generating electricity in a renewable way. In the world scenario, wind energy has reached a stage of maturity that places it as a participant in the energy matrix in several countries where the natural resource is available, with a significant participation in the world matrix in the coming decades.

The use of wind energy disseminated in the literature, occurs through the conversion of the kinetic energy contained in the winds into rotational kinetic energy and finally into electric energy by means of an electric generator. The amount of kinetic energy contained in a moving air mass depends on the wind speed, the area swept by the turbine rotor, and the specific mass of the air (Hansen, 2008). Thus, in the coastal and mountainous regions the highest incidence of winds is used for this energy conversion. However, in the case of isolated regions, it is necessary to study wind turbines that produce electricity through low wind speeds.

Therefore, the use of turbine with diffuser is an efficient alternative, since it increases the electric power production capacity. This technology causes an increase of the flow velocity due to the increase of mass flow through the rotor (Rio Vaz et al., 2014).

2. MATERIAL AND METHODS

The aerodynamic optimization of the turbine blades is performed using Rio Vaz et al. (2014) approach applied to rotors without diffuser. This method corresponds to a more general optimization technique than the classic Glauert method (1926), considering the use of Joukowsky's theory with a Rankine vortex. Thus, the mathematical model using the expression established in the work of Wilson and Lissaman (1974), which is based on Joukowsky's theory, for the local power coefficient is:

$$Cp = \frac{P}{\frac{1}{2}\rho V_0^3 A} = \frac{b^2(1-a)^2}{b-a} \tag{1}$$

The angle of flow, ϕ, is obtained by:

$$\phi_{opt} = tan^{-1}\left[\frac{(1-a_{opt})}{(1+a'_{opt})x}\right] \tag{2}$$

The optimal twist angle is given by:

$$\beta_{opt} = \phi_{opt} - \alpha \tag{3}$$

Once all the equations for chord and twist angle distributions have been defined, the rotor can be evaluated using a new model of wind turbine performance analysis with diffuser developed by Rio Vaz et al. (2014).

2.1 Numerical analysis

Computational fluid dynamics (CFD) is used to analysis the flow around the diffuser. The modeling considers incompressible flow. Therefore, the equations assume the following form:

$$\nabla . u = 0 \tag{4}$$

$$\rho\frac{\partial u}{\partial t} + \rho\nabla.(u \times u) = -\nabla p + \nabla . T + f \tag{5}$$

where u is the velocity vector, ρ is the specific mass of the fluid, p is the pressure relative to an arbitrary reference pressure, T is the tensor of viscous stresses, and f is the body force acting on the fluid. These equations, added by the boundary conditions, contain all the information to obtain the fields of velocity and pressure for the flow of a fluid in a determined space domain. However, its solution, or approximation by numerical methods, is hampered by the presence of turbulence. Thus, the RANS (Reynolds Average Navier Stokes) type of turbulence is inserted.

$$\rho\frac{\partial \kappa}{\partial t} + \rho\mathbf{U}.\nabla\kappa = \nabla.\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\nabla\kappa\right] + P_k - Y_k + G_k \tag{6}$$

$$\rho\frac{\partial \omega}{\partial t} + \rho\mathbf{U}.\nabla\omega = \nabla.\left[\left(\mu + \frac{\mu_T}{\sigma_\varepsilon}\right)\nabla\varepsilon\right] + P_\omega - Y_\omega + D_\omega + G_\omega \tag{7}$$

This is the turbulence model called $K - \omega$. The variables refer to the production, destruction, cross-diffusion and generation of the variables of interest (Menter, 1994). Despite the use of wind turbines of even simpler models, such as that $K - \omega$ applied in Phillips et al. (2008), the use of a more refined model as the model $K - \omega$ seems to be adequate. In this project, the model $K - \omega - SST$ (Shear Stress Transport - Menter, 1993, 1994) has been used, which has also been widely used in the modeling of wind turbines (Jafarin and Kosasih, 2014). The geometry of the set used deals with a cutting plane containing the profile of the diffuser, but not the structure of the blades, as seen in the Fig. 1.

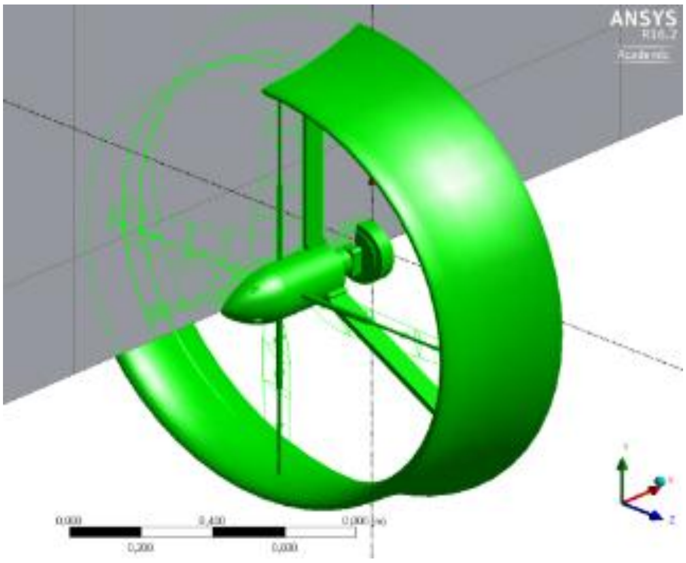

Figure 1. Geometry of the studied structure.
Available from: Authors

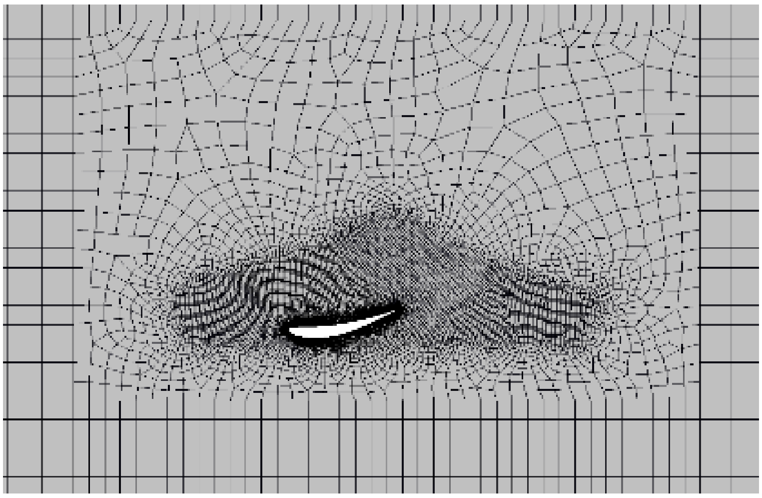

Figure 2. Detail of the mesh used in the vicinity of the diffuser profile (the number of finite volumes is reduced for visualization only).
Available from: Authors

Table 1. Number of finite volumes and nodes in the meshes used.

	Volumes	Nodes
Mesh 1	85002	85708
Mesh 2	143427	144326
Mesh 3	577046	289114

3. RESULTS AND DISCUSSION

The following figures show the velocity and turbulent kinetic energy for the turbulence model, when the most refined mesh is used. By performing a quantitative analysis, we can make use of the velocity field in the internal region of the diffuser. The flow through the rotor, under the influence of the diffuser, causes an increase of the kinetic energy.

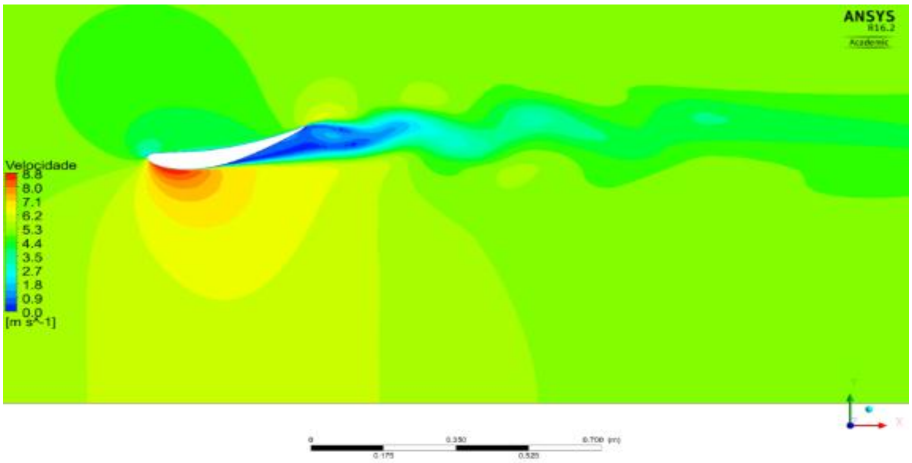

Figure 3. Model speed magnitude.
Available from: Authors

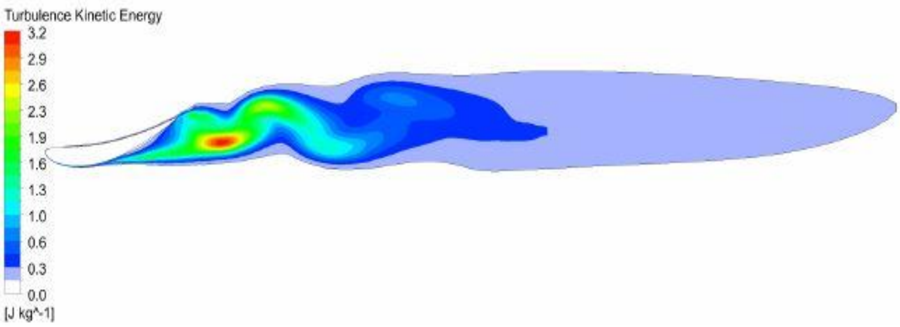

Figure 4. Kinetic turbulence field in the vicinity of the diffuser profile.
Available from: Authors

The analysis is important to identify the position where the rotor needs to be placed into the diffuser, as well as the velocity profile along the radial direction at the same position. With graphics presented above can be seen the ideal position for the turbine location.

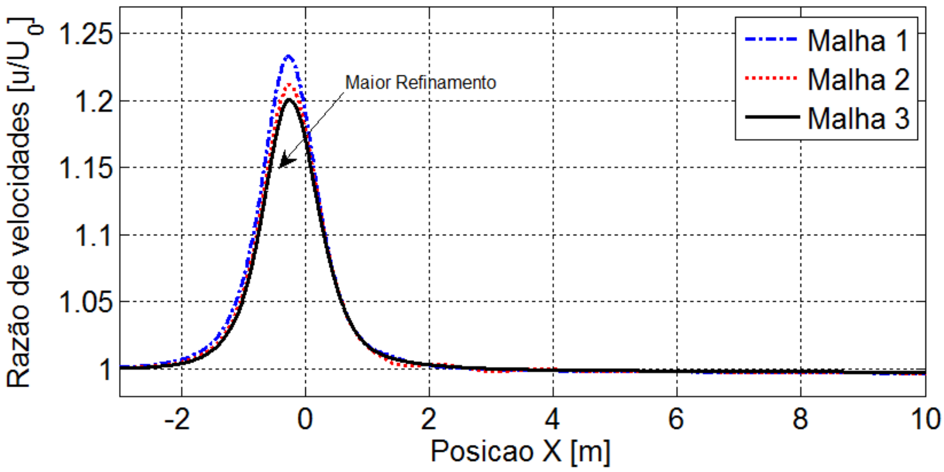

Figure 5. Speed ratios for three tested meshes.

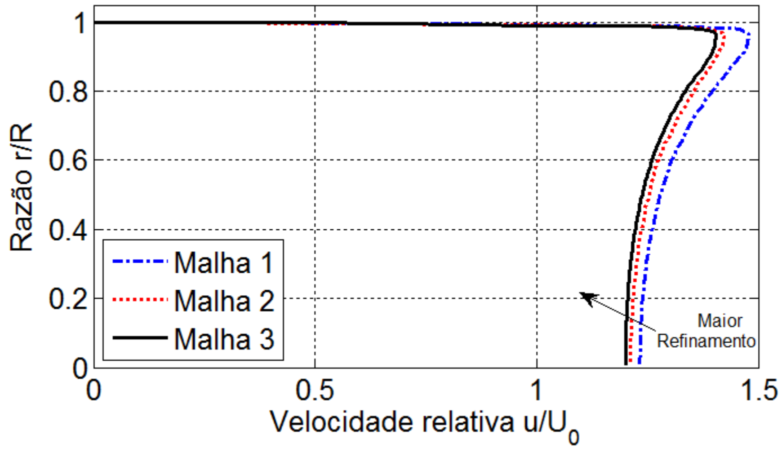

Figure 5. Radial velocity profiles along the maximum speed position in the three meshes tested

The minimum speed of the fluid through the rotor is about 20 % greater than the free flow velocity. The maximum speed is about 50 % higher, and it occurs in the region of the blade tip, where the forces of on the profile maximize the torque generated. The velocity fields between the profiles of different meshes differ in magnitude, but their variation is similar. Also, there is coherence in the direction of greater refinement (increasing the number of finite volumes), which allows us to infer which profile speed best suited for very refined meshes.

4. CONCLUSION

In this work, the study of wind turbines adapted to low wind speeds is important, mainly because the Amazon Region presents typically isolated areas. So then, improvements on the turbine performance by means of a diffuser is really important to the region. Regarding the diffuser, it can enhance the turbine power coefficient 2 times when compared to a bare one.

5. REFERENCES

Glauert, H., 1983. *The elements of aerofoil and airscrew theory*. Cambridge University Press.

HANSEN, M. O., 2008. *Aerodynamics of Wind turbines*. 2nd edition.

Jafari, S. A. and Kosasih, B., 2014. “Flow analysis of shrouded small wind turbine with a simple frustum diffuser with computational fluid dynamics simulations”. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 125, pp. 102-110.

Menter, F. R., 1993. “Zonal two equation kw turbulence models for aerodynamic flows”. In *23rd fluid dynamics, plasmadynamics, and lasers conference*, p. 2906.

Menter, F. R., 1994. “Two-equation eddy-viscosity turbulence models for engineering applications”. *AIAA journal*, Vol. *32*, No. 8, pp. 1598-1605.

Rio Vaz, D. A. T. D., Mesquita, A. L. A., Vaz, J. R. P., Blanco, C. J. C. and Pinho, J. T., 2014. “An extension of the blade element momentum method applied to diffuser augmented wind turbines”. *Energy conversion and management*, Vol. 87, pp. 1116-1123.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.