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### PERFORMANCE ANALYSIS OF A HORIZONTAL WIND TURBINE EMPLOYING NUMERICAL SIMULATION

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**Abstract.** *Wind energy has always been a source of energy used by man, since ancient times with Dutch windmills and sailboats, but only nowadays has become the focus of great study. Given the economic viability of its use for large-scale electric power generation, the abundance of propitious regions in the Brazilian territory and its sustainable character, indispensable in the present day. There is thus the need to develop new technologies and components that optimize and at the same time reduce their cost, goals that inevitably use CFD tools. In this way, the objective of this work is to provide a detailed analysis of the performance of a large-scale horizontal axis wind turbine by the torque, power and pressure distribution coefficients using a CFD tool based on the Finite Volume method (Ansys Fluent 18.1<sup>®</sup>) for the resolution of the RANS equations. The mesh quality validation was given by the Grid Convergence Index (GCI), which analyzes how far the results are from the asymptotic solution (exact) for the mesh used.*

**Keywords:** *Wind Turbine, CFD analysis, Aerodynamic Performance*

#### 1. INTRODUCTION

We know the rapid growth that the sector of electric power generation through wind and solar sources in Brazil is going through, in a country rich in renewable resources such as wind and sunlight only today there has been an effective investment in such sectors. Unfortunately, however, the Brazilian industry does not keep pace with this, leaving almost the entire task of supplying components such as towers, generators, and especially blades, the focus of this study, to foreign firms. These factors lead to an increase in the costs of the components, consequently in the costs of installing the parks and electricity generation, resulting in a limitation in growth rates, which could be even greater. In this scenario, the development of new technologies for the area appears as a solution to this demand.

A key part of the process of generating electric energy through wind, the wind turbine blade is the component that interacts directly with airflow that moves at a relative velocity by transforming the kinetic energy contained in the innumerable particles of moving air into mechanical energy. In this case, in the form of rotational movement through the lift force that arises as the flow passes through the aerodynamic profiles that form the blade generating the torque that is transmitted to the gearbox that multiplies the number of rotations and then delivers to the generator that transforms the mechanical energy in electric energy. Thus, the power developed by the blade depends directly on the aerodynamic profiles used, consequently of the generated torque, the area swept by the rotor, the wind speed and the specific mass of the air. Factors such as the power and torque developed are intrinsically linked to the aerodynamic profiles that make up the blade and require experimental or computational procedures for its determination. In this way the CFD analysis becomes indispensable in the validation of new blade geometries, where the torque coefficient, the lift force and the pressure distribution to which the blade is submitted, of prime importance for the later development of the modeling of composite that will be used in the blade.

#### 2. COMPUTATIONAL PROCEDURE

For the development of the blade geometry, the Theory of Blade Elements with losses calculated by Schmitz (1955/56) was used, resulting in a blade with the following parameters:

Table 1. Blade Characteristics

CHARACTERISTIC	VALUE
Rotor area	7,853.98 m <sup>2</sup>

<b>Length</b>	48,7 m
<b>Maximum Chord</b>	3,4 m
<b>Tip speed ratio</b>	10
<b>Rated speed</b>	11,0 m/s
<b>Rotation speed</b>	21,0 RPM



Figure 1. Blade in CAD enviroment.

For the use of the Finite Volume method in the simulation of the blade in interaction with the air flow, the following equations of conservation of continuity (1), conservation of momentum (2) and conservation of energy (3) must be solved:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (1)$$

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u U)}{\partial x} + \frac{\partial(\rho v U)}{\partial y} + \frac{\partial(\rho w U)}{\partial z} = -\frac{\partial P}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right),$$

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho u V)}{\partial x} + \frac{\partial(\rho v V)}{\partial y} + \frac{\partial(\rho w V)}{\partial z} = -\frac{\partial P}{\partial y} + \mu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right),$$

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho u W)}{\partial x} + \frac{\partial(\rho v W)}{\partial y} + \frac{\partial(\rho w W)}{\partial z} = -\frac{\partial P}{\partial z} + \mu \left( \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) \quad (3)$$

$$\frac{\partial}{\partial t} \left[ \rho \left( e + \frac{V^2}{2} \right) \right] + \Delta \left[ \rho \left( e + \frac{V^2}{2} \right) \vec{V} \right] = \rho \dot{q} - \frac{\partial(uP)}{\partial x} - \frac{\partial(vP)}{\partial y} - \frac{\partial(wP)}{\partial z} + \rho \vec{f} \cdot \vec{V} \quad (3)$$

These equations was solved with the aid of the Fluent/Ansys version 18.1 program with the turbulence model K -  $\omega$  SST, residue of 10<sup>-4</sup> and on a personal computer with Intel Core i7 4.2 GHz processor with 16 GB of RAM. The simulations are developed using a control volume corresponding to 1/3 of the rotor, ie a slice with an angle of 120° with an upstream distance of 140.0 m and downstream of the blade of 240.0 m with the respective radius of 140.0 and 240.0 m as shown in the following figure:

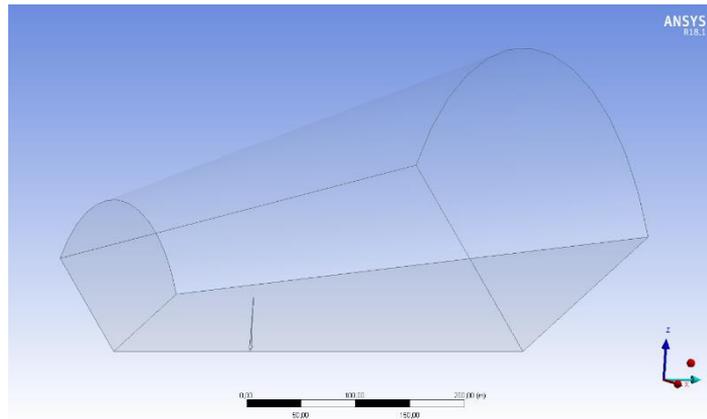


Figure 2. Control volume used in the simulations with the blade inside.

The simulations are developed using different structured and unstructured hybrid meshes in permanent and three-dimensional studies, with the stationary blade with the flow moving at a velocity of 11.0 m / s and rotation of 2.2 rad / s. Here we have three refinement levels meshes as shown in Table 2.

Table 2. Mesh parameters.

Mesh	Volume number	Processing time in hours
Fine mesh (1)	4.878.103	26
Medium mesh (2)	2.380.044	13
Coarse mesh (3)	1.695.485	6

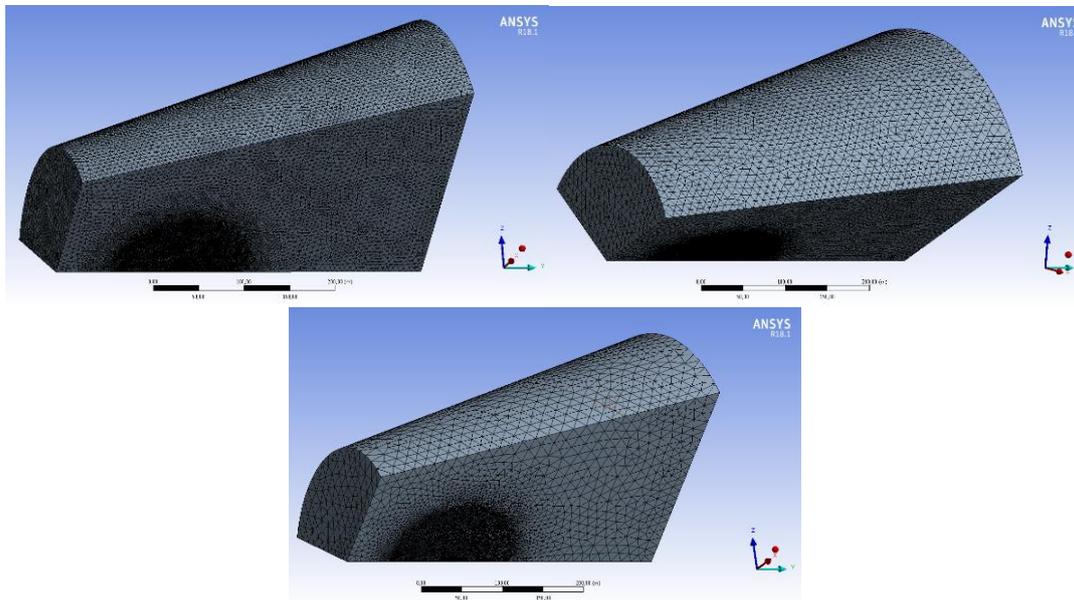


Figure 3. From left to right and from top to bottom: Fine mesh (1), medium mesh (2) and coarse mesh (3).

### 3. RESULT AND DISCURSION

Table 3 shows the results obtained for the torque coefficient of the coarse (3), medium (2) and fine meshes simulated in this work. The mesh quality evaluation was done using the Grid Convergence Index (GCI) method and the results are presented in Table 4.

Table 3. Torque coefficient (CT) and power coefficient (CP) for the three meshes.

	CT	CP
Exact values	0.02096	0.20957
Fine mesh (1)	0.02143	0.21431
Medium mesh (2)	0.02196	0.21965
Coarse mesh (3)	0.01808	0.18082

Table 4. Results of the GCI method to evaluate mesh convergence.

$R_{(\text{grid refinement ratio})12}$	1,11969
$R_{(\text{grid refinement ratio})23}$	1,27025
$P$ (order of computational method)	3,14625
Relative Error <sub>12</sub>	2,49%
Relative Error <sub>23</sub>	55,96%
Safety Factor	1,25
GCI <sub>12</sub>	0,02770
GCI <sub>23</sub>	1,63771

From the simulations with the most refined meshes, it was possible to obtain the pressure distribution on the surface of the blade, a crucial factor for the subsequent modeling of the composite fibers. Figure 4 shows such distribution, in Pa, for the lower and upper faces of the blade.

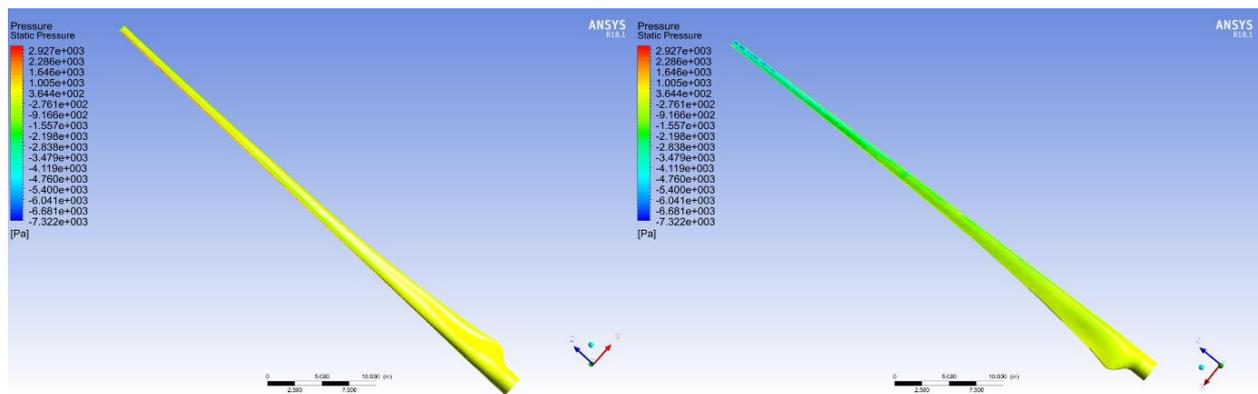


Figure 4. Pressure distribution, in Pa, obtained by simulation of the fine mesh (1).

#### 4. CONCLUSIONS

The simulations resulted in a wide range of data that, through validation by the mesh convergence index (GCI) method, prove the effectiveness and good performance of this unprecedented horizontal blade geometry. Data such as torque coefficient, pressure coefficient and pressure distribution can now be used to characterize it, being now able to model the composite material and its fiber directions that make up its structure for later manufacture and availability in the domestic market of wind turbines.

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