Evaluation of Experimental Wind Tunnel, RANS and LES Analysis of Wind Flow Over a Complex Terrain

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1. Introduction

A key aspect to determine the technical and economic viability for the wind power plant is the accurate assessment of the site distribution of wind speed. The correct definition of variables as the wind velocity profile and the turbulence intensity are fundamental elements for the feasibility analysis of wind farms. This work presents a study on two important tools for wind analysis, Computational Fluid Dynamics (CFD) and Wind Tunnel experiments.

This research focuses the investigation of the Atmospheric Boundary Layer (ABL) in a complex area, formed with an asymmetric hill and three other small hills. Measured wind profiles over a wind tunnel model are compared with numerical simulations of the experiment.

Numerical simulation of turbulent flow over a complex geometry is a challenge for wind engineering. Present work evaluates the numerical simulations using Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) methodology.

The topographic features of a complex area cause a change in the behavior of the wind which implies in the acceleration or deceleration of the airflow. The definition of variables such as the profile of the wind speed, the turbulence intensity and the topographic effects over the wind speed provide the key elements for the evaluation of the micro siting for wind energy. If the area is a complex terrain anemometric measurement may not be enough to analyze the assessment area. In order to fill up the uncertainty of the wind, computational and experimental studies offer the most perfect evaluation of the area. This research analyzes and compares the use the wind tunnel measurements with CFD to evaluate the complex area with asymmetric hill with their slope 34^{o}.

2. Aproach

2.1. Experimental feature: Boundary Layer Prof. Joaquim Blessmann Wind Tunnel

From the experimental simulation of a neutral Stratified ABL in the wind tunnel, it is possible to parameterize the effects of wind over complex terrain [1]. The wind tunnel simulations were developed in a main asymmetric hill included in a complex terrain using the scale of 1:1000 in Atmospheric Boundary Layer Wind Tunnel Prof Joaquim Blessmann at the Federal University of Rio Grande do Sul. The flow close to the surfaces of the hills were measured with a hot-wire anemometer. The wind measurement data can be seen in Figure 01.

The Boundary Layer Wind Tunnel of the Federal University of Rio Grande do Sul, Brazil is a closed return type wind tunnel, with a length/height ratio of the test chamber around 10, being 1.30 m wide, 0.90 m high and 9.32 m long as shown in Fig 01. The highest flow velocity in this camera with smooth uniform wind and without any obstruction exceeds 160 km/h.

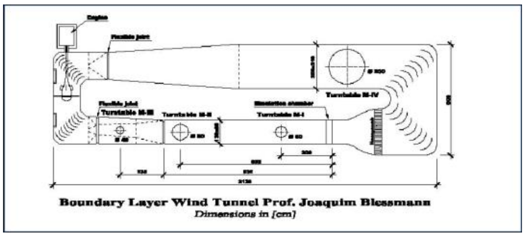

Fig 1. Boundary Layer Prof. Joaquim Blessmann Wind Tunnel

The experimental measurements in a wind tunnel to define the vertical profiles of the turbulence intensity and the wind speed were performed at upwind, in the crest and downwind in the asymmetric hill (1:1000 scale) for two types of terrain related to a power law exponent p=0,11 and p=0,23 in nine points with twenty heights as shown in Figure 02. For this purpose was used a system of hot wire anemometry. The data acquisition is performed with an anemometer Dante Dynamics system Stream Line NS. The frequency of acquisition was 2 kHz and the period of acquisition was 64 s. The Figure 02 shows the low plant related to a cross section of the model and on the right the model in tunnel chamber.

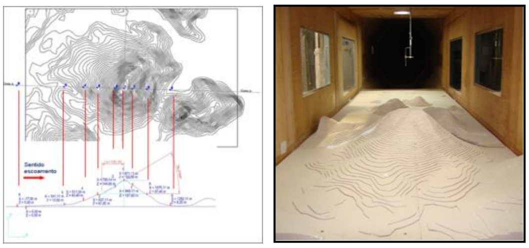

Fig 2. Model at the Boundary Layer Wind Tunnel

2.2 Numerical Methodology

The numerical simulations of the turbulent flow are evaluated using ASYS Fluent commercial code, RANS methodology, with $k-\varepsilon$ and $k-\omega$ SST turbulence models, and for LES, the Smagorinky Dynamic Model is adopted.

With the coordinates of the contours of the terrain, you can generate the surface through modeling using the software for free distribution of topographic calculations Topocal called. For discretization of the computational domain, it is used the commercial software ANSYS ICEM such as tool for generating meshes used in the simulations. The discretization is done in finite volume with hexahedral refinement controlled hill near the surface. Figure 3 illustrates the refinement of mesh elements near the surface.

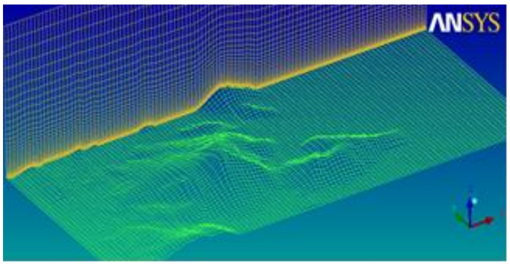

Fig 3. Surface mesh generated in ANSYS ICEM

For satisfactory results, it is necessary that the initial and boundary conditions are applied according to the physics of the problem. The input field is described by a velocity profile representing the atmospheric boundary layer. The departure is considered a free flow and the sides and the lower and upper planes are considered impermeable walls without sliding. For reproducing the profile of wind speed is programmed function that represents the velocity profile which simulates the profile of winds in the input domain. The expression that was programmed is expressed below.

$$\begin{cases} U/U(0{,}8) = 1 - \left| \left((z-0{,}8)/0{,}8 \right)^{0{,}23} \right| & 0 < z < 0{,}8 \\ U/U(0{,}8) = 1 - \left| \left((z-0{,}8)/0{,}8 \right)^{0{,}11} \right| & 0{,}8 \le z < 0{,}9 \end{cases}$$

3. Main body of the abstract: Results
   The experimental results are presented and compared, as the example results showed in this section. The experimental velocity profiles are compared with numerical results as presented in figure 4.

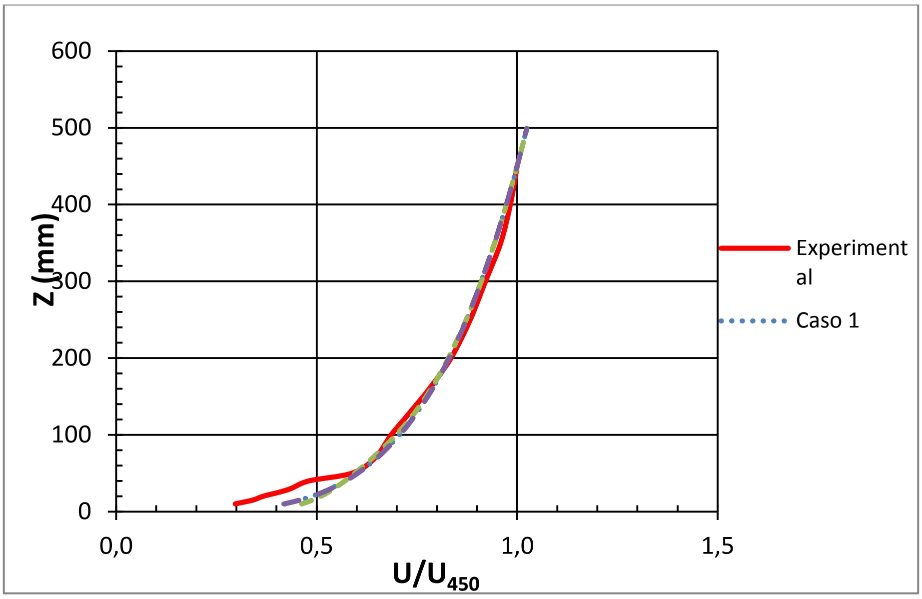

Fig 4. Example of numerical results comparing with experimental results.

Figure 5 illustrates the velocity field in the plane where the points are located in prime directive of the hill for the simulation of airflow using different models of turbulence.

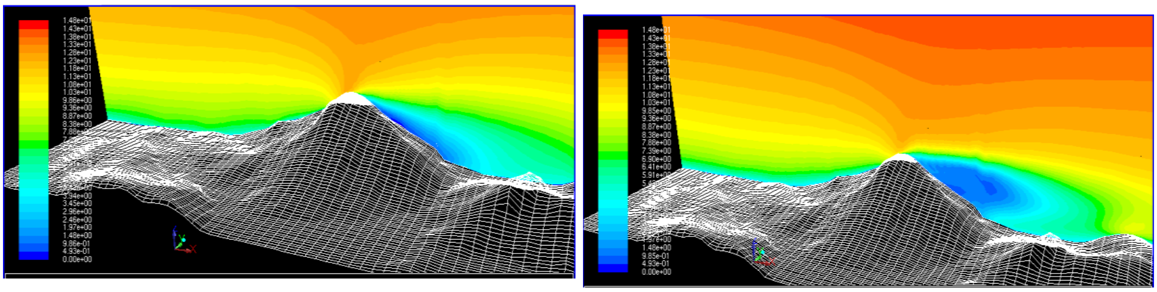

Fig 5 - Velocity field for simulation with different turbulence models.

Example of velocity vectors obtained numerically are showed at Figure 6, it is possible verify the simulation of the boundary layer detachment after the hill.

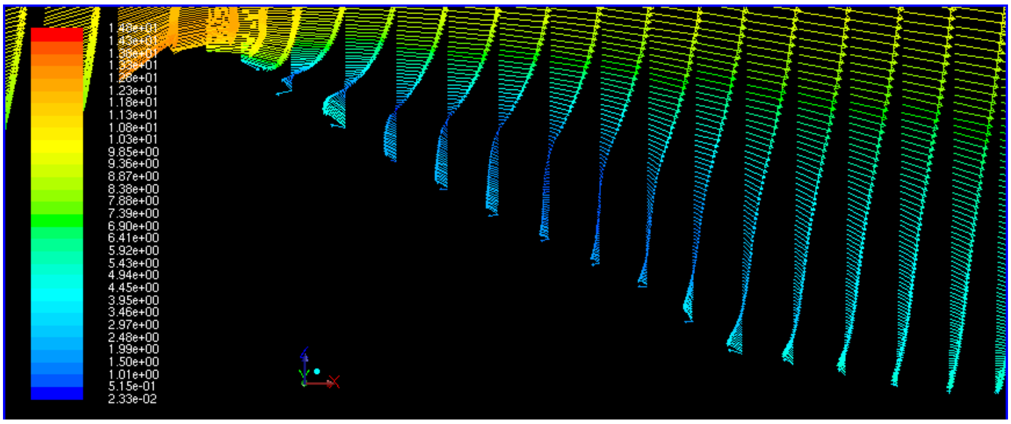

Fig 6. Velocity vectors at points 7, 8 e 9 .

4. Conclusions

The complete work will show that is possible to conclude that the wind tunnel results indicate extent and magnitude of the influence of complex terrain over the wind flow and suggest that significant changes in turbulence characteristics only occur in the wake region, close behind the crest, where is evident a shift of energy in higher frequencies. The turbulence model has important influence on results, for RANS, $k-\omega$ SST have the best fit with experimental data. LES requires significantly more computational time, but is a viable methodology to obtain more detailed information about transient and turbulent behavior of the wind over complex terrain.

5. Learning objectives

Evaluations of complex terrain Atmospheric Boundary Layer, with experimental and numerical methods are the main objective of present work. The viability, application, quality of results obtained and limitations of the Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) numerical methodologies are investigated.

6. References

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