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EXPERIMENTAL STUDY OF DIFFUSERS APPLIED TO DAWTS

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Abstract. *The search for generation of alternative energy systems for remote regions has been increased in Brazil. The wind power generation attracts great interest due to the wind potential of the country coast. However, some technological barriers have retarded the progress of some low-cost technologies, mainly those of small wind systems such as the aerogenerators, which in general are imported and not adapted to the characteristics of low wind velocity conditions. Therefore, it has been undertaken an experimental study of airfoil-shaped diffusers aiming to obtain the best results for efficiency in Diffuser Augmented Wind Turbines adapted for low wind velocities existing in Brazil's North region.*

Keywords: *Diffusers. Wind turbines. Renewable energy*

1. INTRODUCTION

The development of new technologies for renewable energy use has been stimulated in Brazil. Such behavior is due to environmental impacts caused by two main sources responsible for power generation in the country: fossil fuels that drive combustion engines coupled to generators, and water, which generates energy through large hydroelectric plants. In the Amazon region, for example, many communities still suffer the lack of electricity, due to the distances from the power transmission lines already installed, and the low consumer demand for the high investments required. The rise of the Brazilian industry has resulted in a significant growth in energy consumption, showing that is necessary more investment in alternative energy sources, especially the renewable ones. These facts show the need to develop low cost for the care of small and medium energy demands in isolated regions technologies (Wiener and Koontz, 2010).

Wind energy is usually obtained through the use of wind turbines. These equipment are machines that extract energy from the wind by aerodynamic effects acting on the wind rotor. The blades of modern wind turbines use specially profiles developed to be equivalent to those used in aircraft wings. To design a wind rotor airfoils are used with its lift and drag coefficients which change varying the angle of attack. These profiles have different dimensions and angles over the blades in order to provide the best aerodynamics and efficiency (Hansen, 2008).

In locations that have low wind speeds, the use of diffusers coupled to turbines is a useful and effective alternative. The diffusers are devices installed around the turbine, which aim to increase the flow velocity through its rotor plane, increasing the extraction of kinetic energy from the wind. As the electric power generated is proportional to the cube of the incident velocity in the turbine rotor, a small increase in the wind velocity causes a significant increase in the generation of electricity, justifying the use of such devices around the conventional turbines (Hansen, 2008).

The use of diffusers in wind turbines is not as widespread as in the industrial environment, when compared to traditional turbines. It is because there is a significant additional cost for making the diffuser and the structure that supports it. In Brazil there is a great potential for the use of wind energy, however many of the equipment used in these systems, although manufactured in Brazil, still use imported technologies and their aerodynamic characteristics, in general, are not appropriate to the local wind conditions (Silva and Filgueiras, 2003). The state of Pará is bathed by the Atlantic Ocean to the northeast, and studies conducted by Friade and Pinho (2000) have shown that the wind potential in this region is interesting for wind power generation, especially for use of small systems.

Thus, this paper proposes the development and manufacture of aerodynamic diffusers with airfoils to be used in DAWTs, having as the main goal the experimental survey of diffusers efficiency in order to obtain better results in the design of efficient wind turbines.

2. WIND TURBINES WITH DIFFUSERS

The study of wind turbines with diffusers, known as Diffuser Augmented Wind Turbines (DAWTs) was started around the 20s, when the benefits of using diffusers in turbines were discussed for the first time. However, the application of diffusers and existing models at the time made the use of these equipment economically unviable. Most work has examined a parameter named speed-up factor, or simply speed ratio. This ratio, in the presence of the turbine, is defined by the ratio between the effective velocity along the turbine and the incident speed. For the case in which the flow is evaluated only around the diffuser, the speed ratio is defined by the ratio between the speed in the x direction of an effective reference plane and the incident speed.

Betz (1929) recognized the potential of wind turbines with diffusers and was the first to develop a theory for DAWTs where assumed that the static pressure at the diffuser exit plane would be equal to the ambient pressure. Another restriction imposed by their theory was that the ratio between the diffuser exit area and the area of the rotor plane, called area ratio, should be small, leading to small speed ratios. From these findings, the idea of using diffusers in turbines was abandoned until 1950, when Sanuki (1950) published experimental results of a DAWT indicating a power increase of 88% over the Betz limit. The increase in power of a wind turbine results from two main mechanisms: increasing the mass flow and turbulent flow with external mixing. To improve the efficiency of a DAWT, some concepts have been used alone or in combination, such as: vortex generator, cylindrical obstruction and creating diffuser effect (Phillips, 2003).

Regardless of the authors who have studied the power gain in wind turbines, everyone agrees that this increase in efficiency is achieved with rotors 'channeled' or 'pipeline'. Such gain is done by means of two effects: a) reduction in blade tip losses and b) an increase in the axial velocity of the rotor obtained by the control of the turbulent wake (Lilley and Rainbird, 1957). This work indicates that a DAWT can produce twice as much power as compared turbine without diffuser with the same rotor diameter. They also suggest that the presence of a flap (similar to the element used in aircraft to control aerodynamic lift of the wings) in the diffuser exit plane would minimize the problem of flow separation which occurs due to the increase of the opening angle of the diffuser.

3. METHODOLOGY

To perform an evaluation of airflow along aerodynamic diffusers with airfoils and rectangular section, without the presence of turbines, three diffusers with distinct geometric dimensions and adjustable angles of attack of the airfoils have been used in order to evaluate the distribution of velocities within each diffuser varying their angle of attack, as well as comparing the speed distributions in each.

The equipment, instruments and materials used in the experimental survey are: wind tunnel, Pitot tube, micromanometer and balsa wood. The wind tunnel is a facility that aims to simulate the effect of air flow over or around solid bodies. The airflow speed in the wind tunnel is controlled by a frequency inverter, which varies the fan rotation that moves the air. The wind tunnel cross section used in this paper is 300 x 300 mm². The Pitot tube is the sensor which provides the flow velocity of a fluid from measurements of the static and stagnation pressures. The difference between these two pressures is called dynamic pressure. The Pitot tube used in this study is the L-type with 5 holes having a diameter of 7 mm, length of 310 mm and error laid down in ± 2%. Digital micromanometer is a device designed to measure small differences in pressure. They operate according to the principle of piezoelectricity, measuring pressure by means of a voltage generated in a piezoelectric crystal. The micromanometer operating range is 0-18 m/s, with an uncertainty of 0.25% reading indicated for speed measurement and acquisition rate of 4 Hz. Balsa wood is the material used in the construction of airfoils and diffusers fairing structures used in the experiment. Figure 1a shows the profiles cutting and Fig. 1b the diffuser assembly.

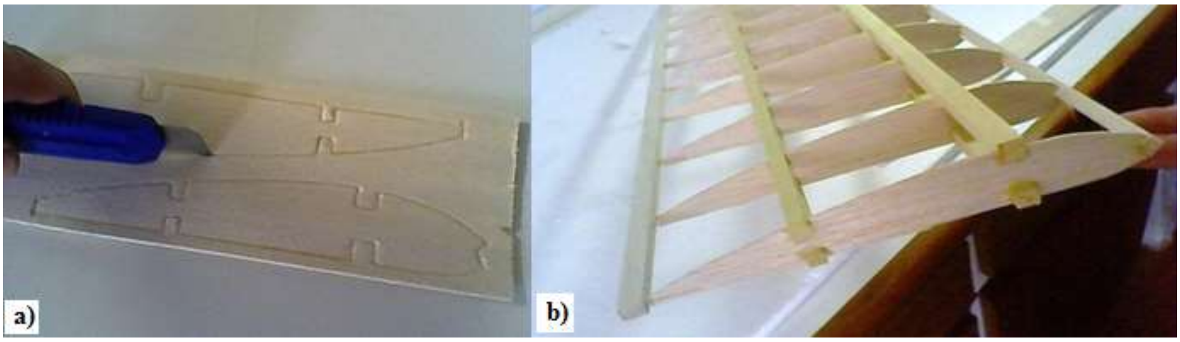

Figure 1. (a) Corte dos perfis aerodinâmicos e (b) Montagem para alinhamento dos perfis aerodinâmicos

3.1 Selection of the measurement points.

For the tests, it is necessary to adopt a distribution point velocity measurements along each diffuser. In order to provide standardized measurements, it has been used a spacing of 150 mm from the exit of the wind tunnel, and a spacing of 15 mm between each acquisition point on the diffuser (Fig. 2), since these points were repeated in the other diffusers.

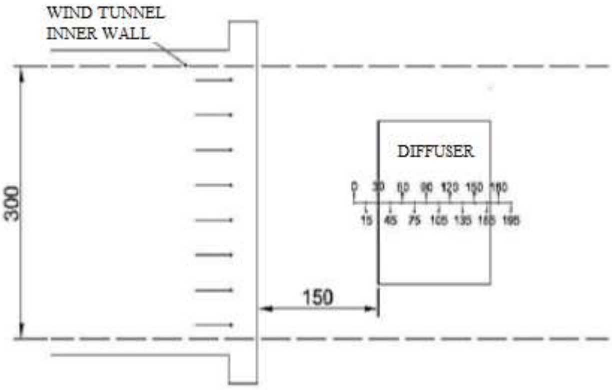

Figure 2. Distance between the diffuser and the wind tunnel exit

3.2 Mapping airflow at the wind tunnel exit

The wind velocity measurements were performed with diffusers positioned externally to the wind tunnel, due to its cross section (300 mm x 300 mm) is small compared to the size of the diffusers. As the flow over the diffusers is evaluated externally to the wind tunnel, it was necessary to map the region of influence of this flow to verify whether it would remain uniform as they moved away from the exit of the wind tunnel. For this purpose, three velocity profiles were measured along the x axis, from the wind tunnel exit without the presence of the diffuser, with a spacing of 150 mm between each profile, with a total distance of 450 mm, as shown in Fig. 3.

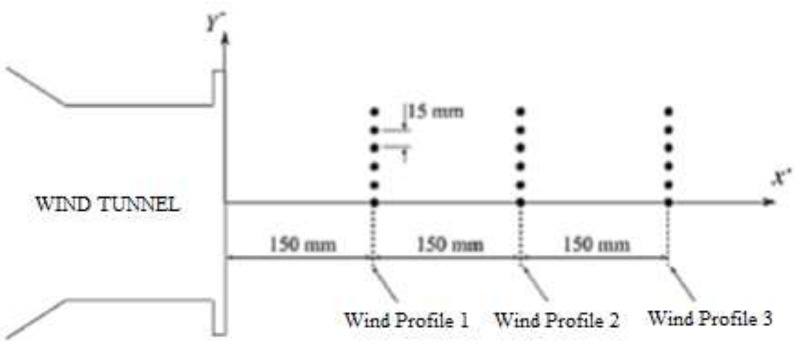

Figure 3. Velocity profiles outside the wind tunnel

3.3 Diffusers dimensions and airfoils.

The diffusers used in this experiment were built in reduced scale due to the geometric constraints of the wind tunnel (300 mm x 300 mm). Their dimensions (all in millimeters) can be seen in Fig. 4.

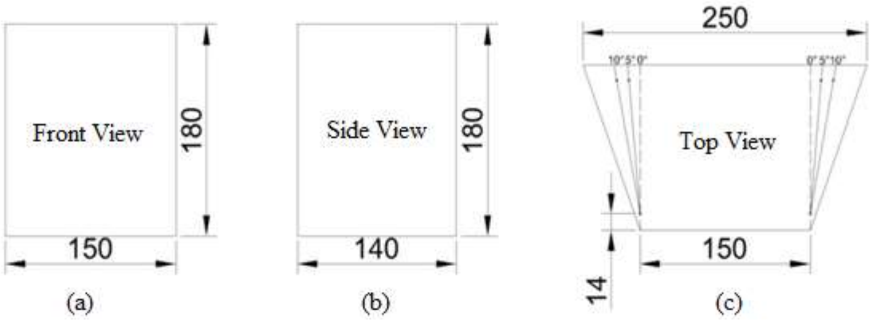

Figure 4. Diffuser dimensions

The variation of the angle of attack in each profile is 0°, 5° and 10°, as shown in Fig. 5. This change aims to find an angle to the diffuser that offers a higher flow rate during the test. For this work, three fairing airfoils diffusers with the same dimensions and rectangular section were used as shown in Fig. 5. The only difference is on the airfoils chosen, shown in Fig. 6.

Figure 5. Variation of the profiles angles of attack

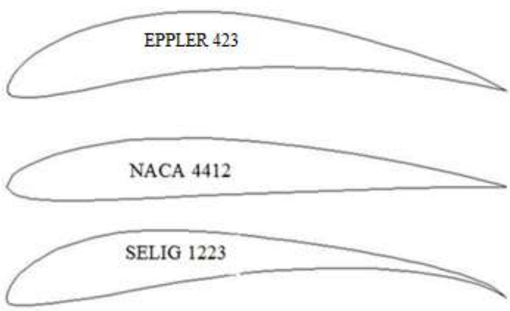

Figure 6. Airfoils used in the diffusers

4. VELOCITIES MEASUREMENT ALONG THE DIFFUSERS

For speed measurements, each diffuser was positioned in front of the wind tunnel at a distance of 150mm. The support that maintains the diffuser in the desired position (Fig. 7a) was constructed for it to be rigid enough to minimize vibration (transverse displacement) of the diffuser when the wind tunnel was in operation, especially at high speeds. The diffusers have their axes aligned with the axial wind tunnel longitudinal axis, with the purpose of maintaining the air flow parallel to the longitudinal axis of each diffuser, as shown in Fig. 7b. Incident speeds upstream, inside and downstream of the diffuser will be evaluated in this experiment. The displacement in the longitudinal direction of the Pitot probe was made manually, with a sufficiently resistant mounting to the effects of fluid flow, thus having an acquisition data satisfactory to the experiment.

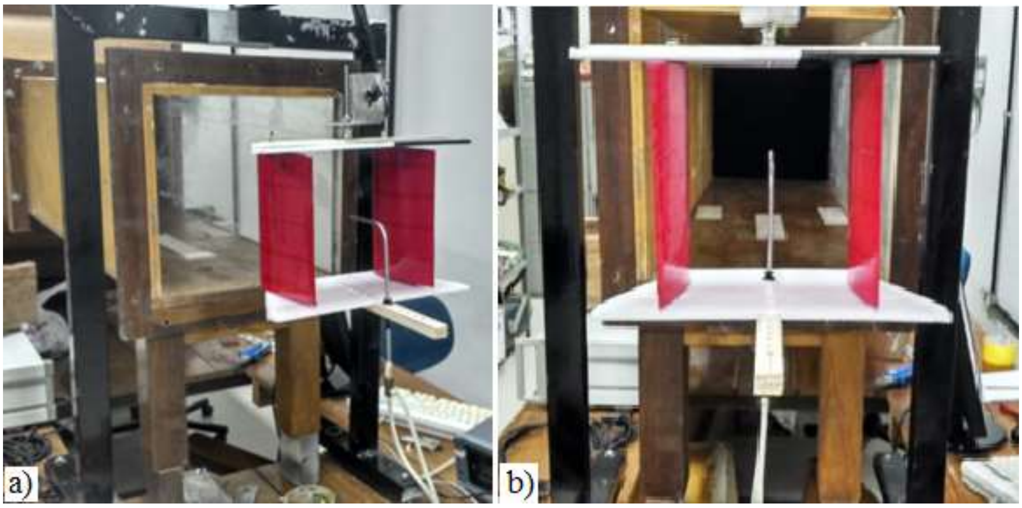

Figure 7. (a) Diffuser positioned at the wind tunnel exit and (b) aligned with the axial wind tunnel longitudinal axis

For each diffuser, the speed measurements were initiated upstream of the diffuser through the internal region, and terminating downstream of the diffuser. The Pitot probe has been moved in the longitudinal direction to the next measuring point. Each time it was necessary to move the pitot probe within the diffuser. The speed readings made by micromanometer were performed on samples of 250 measurements at a rate acquisition 4 Hz and sent directly to the microcomputer for a spreadsheet. At each point a speed domain was used for the experimental survey, 6.0 m/s. This speed value was used because it is an intermediate value between 4.05 m/s 9,05m s which are the values used in the sensitivity analysis. This value of speed (6 m/s) was also used because it is a compatible value to low wind speed incidents in the coastal regions of northern Brazil. The total acquisition time for the speed measurements was approximately 25 hours.

5. RESULTS

To analyze the flow at the exit of the wind tunnel was necessary to conduct a mapping in order to verify the possible disturbances. The results show the velocity distribution along the y-axis away 150, 300 and 450 mm from the exit of the wind tunnel set to 4 and 9 m/s. The Fig. 8 show the three velocity profiles plotted simultaneously, so as to compare the measured velocities and the region in which they are shown uniforms.

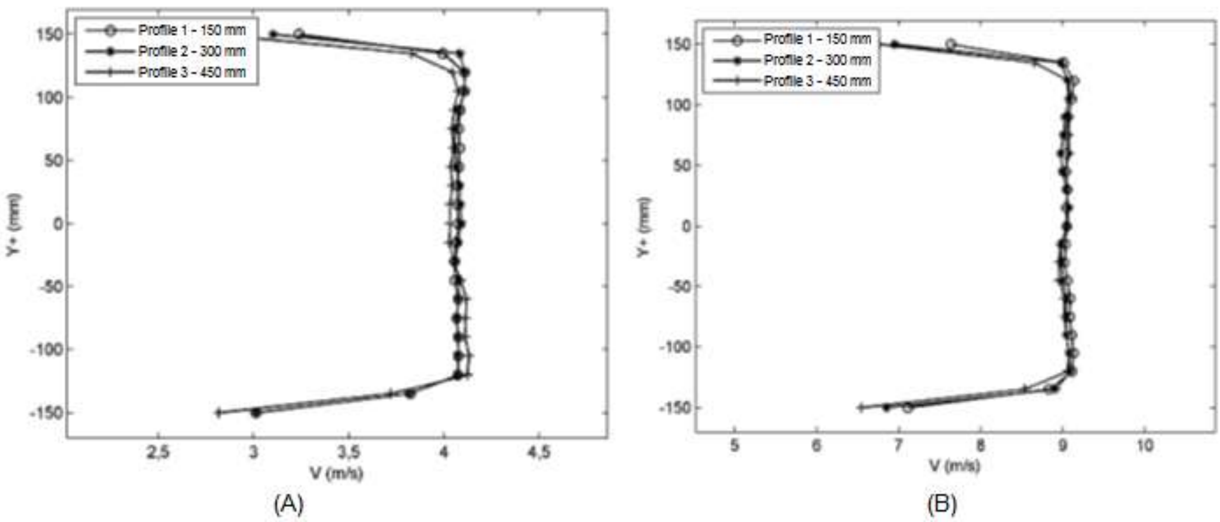

Figure 8. Wind profile outside the wind tunnel in the three points measured for (A) V_0 = 4 m/s and (B) V_0 = 9 m/s

These results have shown an uniformity in the flow in the exit of the wind tunnel over a distance of 450 mm, was also noticed that the speed remained constant so that this flow configuration becomes satisfactory for the purpose of this work.

The velocities results obtained are presented in Fig. 9 where the x-axis was maintained according to the actual distances in the axial direction and the y-axis contains the values of the velocity ratio. The left vertical lines, x (mm) = 30 and right x (mm) = 165, represent the plans inlet and outlet of the diffuser, respectively. Figure 6 shows the results obtained for each diffuser, using an average speed of 6 m/s.

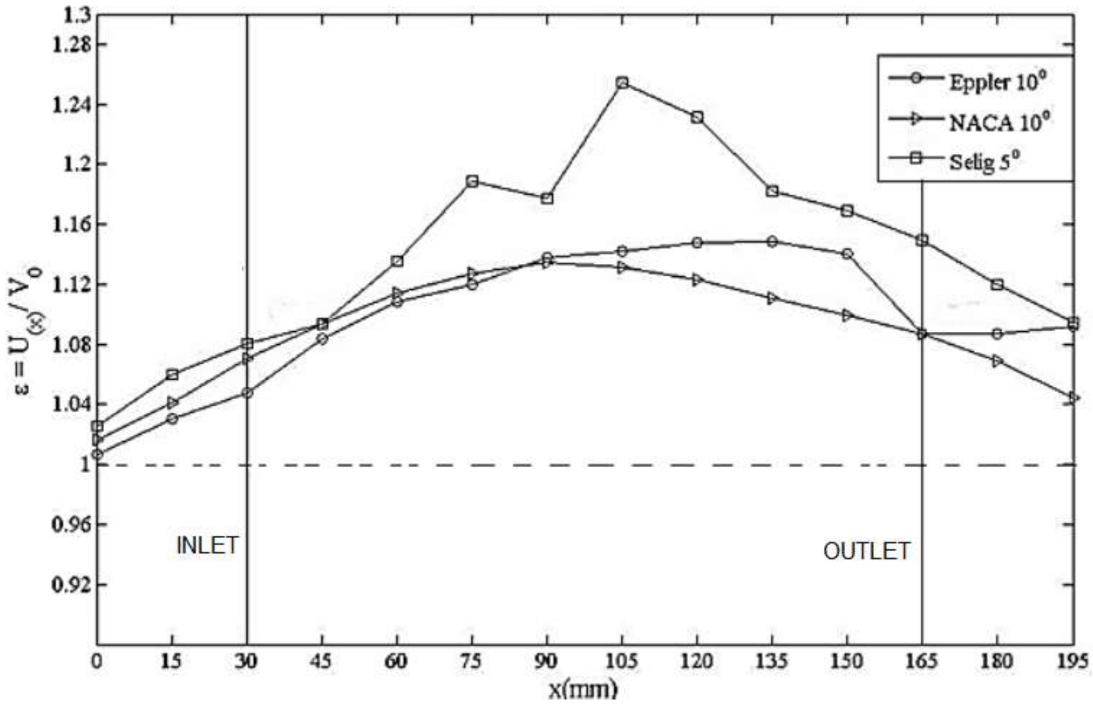

Figure 9. Comparing the velocity ratio results of the diffusers for V_0 = 6m/s

The horizontal dotted line represents the absence of a diffuser, showing that any point above this line indicates an increase in speed as well as points below this line represent a reduction in the incident speed. The three diffusers have shown an increase in speed, each with its own special features, which are discussed below.

The diffuser fairing with NACA 4412 profile with an angle of 10 degrees, showed a uniform and well-defined behavior, on the other hand, was the one with the lowest speed ratio (1.13), which resulted in an increase of 13% in velocity.

The diffuser fairing EPPLER 423 profile at an angle of 10° showed a sharp decline after reaching the maximum speed ratio (1.15), this is justified due to a high angle of attack in a high lift profile, which causes a disturbance in the flow. Despite these fluctuations, the diffuser showed an intermediary speed ratio, providing a 15% increase in speed.

The diffuser fairing profile SELIG 1223 with 5 ° angle got more prominence, increasing speed by 26%, however had a behavior with some oscillations, what do not directly interfere in the results. These oscillations are due profile having characteristics of high lift and can be minimized by increasing the measurement points.

6. CONCLUSION

The main objective of this work is to develop an experimental study of diffusers applied to DAWTs and describe the behavior of the air flow inside these diffusers. The experimental study presented in this work is of great importance towards to the development of information on airfoil parameters facing the efficient design of wind turbines with nozzles, operating at low wind speeds, especially in locations as existing in Amazon region, where the average speed is around 4-6 m/s.

In all diffusers tested in this work there was obtained a significant increase in the rate of airflow, where the diffuser fairing with the profile SELIG 1223 provided the best result, which enabled a 26% increase in the rate of airflow therein. The EPPLER 423 profile presented an intermediate behavior between the profiles that were tested, with a 16% increase in the rate of airflow. Although the profile NACA 4412 have shown stable behavior as the measured velocities, it has presented the lowest speed ratio, about 14% increase in the airflow.

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8. RESPONSIBILITY NOTICE

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