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AERODYNAMIC HEATING EFFECT ON ROUGHNESS, AERODYNAMIC COEFFICIENTS AND POWER OUTPUT OF AEROGENERATORS: A DISCUSSION

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Abstract. *The aerodynamic heating effect is well known to have great impact on the design of high speed aircrafts or reentry vehicles, i.e. for supersonic or hypersonic speeds, because its effects are minimal for subsonic speed, so they are usually ignored. This work comes with the objective of checking the aerodynamic heating effects on airfoils of big wind turbines. Precisely, it is discussed if the temperature during operation of the blades can change the roughness of their airfoils, if there is uniform heating that leads to heat convection from the airfoil or if there is considerable difference in extrados and intrados temperature. The computational approach is done with numerical simulation to solve the two-dimensional, steady and turbulent form of the Reynolds-Average Navier-Stokes equations in the CFD software ANSYS CFX. It was not observed any significant performance of the cases listed, so the operation conditions of the current biggest wind turbines and the ones that will be possible developed in the next years are not expected to be jeopardized by the aerodynamic heating of the turbine blades.*

Keywords: *Aerodynamic heating, wind turbine blade, aerodynamic coefficients.*

1. INTRODUCTION

Many industrial sectors that depend on the petroleum made products felt the impacts of the oil crisis. Thus, with the increase of fuel prices in 1973 and in others crisis, the electricity generation became more expensive too. Within this reality, alternative ways to generate electric power to the conventional ones, i.e., to those which use petroleum as fuel, were proposed and developed. Therefore, the wind energy presents itself as an alternative and renewable way of generating electricity, in addition, Salles (2009) enumerates different advantages of the electric power generation from wind energy as the independence of the cost of the generated energy in relation to fuel prices.

The Brazilian National Interconnected System has an installed electric power generation capability of 151,7 GW of which 61,05 % are from hydroelectric plants, 27,09 % are from thermoelectric plants and just 6,93 % are from wind farms. However, the wind energy represents 38,9 % of the generation capacity under construction (3,60 GW) and there has been an increase of 275,71 % in the installed wind energy generation capacity since 2014. Figure 1 shows the distribution of the brazilian installed electric power generation and Fig. 2 shows the electric power generation under construction. These data show the expansion of the Brazilian wind energy generation system (ANEEL, 2017).

Another matter of interest is the continuous increase of wind turbines diameters, heights and output in order to produce more electric power. As consequence, higher wind speeds are required and higher Reynolds numbers of the flows are reached, which could induce different flow conditions from the usual ones that were not expected until that point, moreover they could induce harmful conditions that would decrease the energy output. The aerodynamic overheating of the airfoil could be one of these harmful conditions because it may change the roughness of the airfoil which may seriously affect the aerodynamics coefficients as just a little change in the value of the hardness may have a great influence over those coefficients (Ren and Ou, 2009; Li *et al*., 2010). Furthermore, the power output of an aerogenerator will also be impaired, as it is strongly related to the blades aerodynamic performance. Indeed, Khalfallah and Koliubb (2007) presented a difference of about 20 % in the power output of a small wind turbine. Seifert and Richert (1997) showed that the wind turbine could even not reach its rated power in determined conditions of surface roughness. Therefore, different conditions of surface roughness than the designed one are not desired.

Other manner of affecting aerodynamic performance of an airfoil is through heat transfer from it. Hinz et al. (2012) studied this phenomena for a static, plunging and pitching NACA 0012 airfoil by uniformly heating it and all situations leaded to a decrease in aerodynamic performance. Kim et al. (2003) and Bekka et al. (2009) studied the influence on the aerodynamic coefficients when intrados and extrados have different temperatures. Both studies shows that when the intrados is in a higher temperature than the extrados, lift is increased and drag is decreased. So, depending on the thermal configuration of the airfoil, it is possible to achieve both good or bad results.

The aerodynamic heating is widely studied for bodies in supersonic flows and it is also easy to find papers about it. This happens because the heating in that condition is very remarkable due to the high fluid speed and it can induce great deformations in the structure, leading to unavoidable mechanical failures and possible collapses. Thus, as the consequences of aerodynamic heating for the structures are minimized in subsonic flows, the subject is not studied. However, as it was approached before, the aerodynamic heating of the airfoil may change its roughness and, consequently, it may harm its aerodynamic coefficients and the power output of the wind turbine.

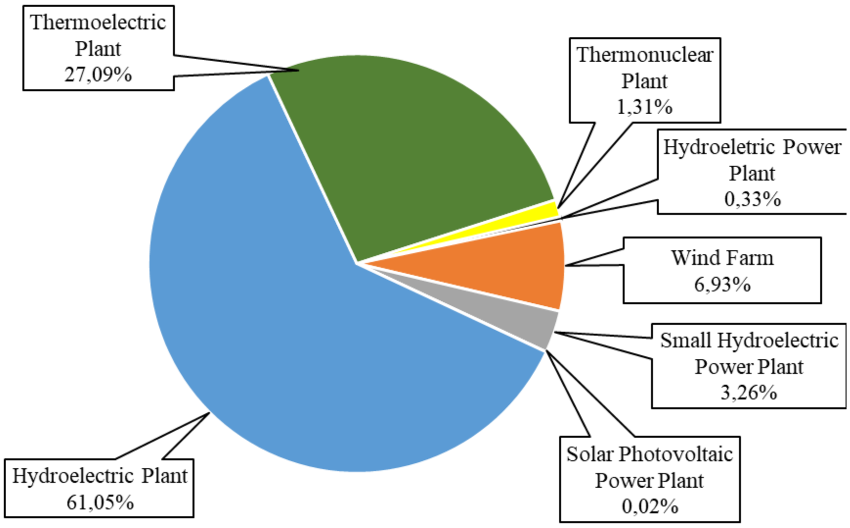

Figure 1. Installed electric power generation in Brazil (adapted from ANEEL, 2017).

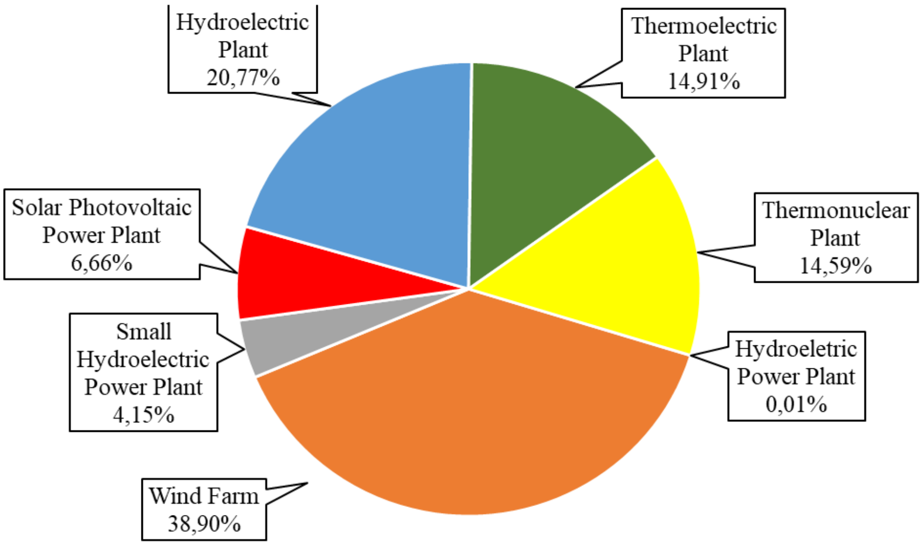

Figure 2. Electric power generation under construction in Brazil (adapted from ANEEL, 2017).

1.1 Aerodynamic heating

The study of the interaction between an air flow and a solid body is called aerodynamic and there are many consequences derived from this event. One of them is the aerodynamic heating and it is the heating of a solid body when the air flow interacts with it. The physics behind this event is the conversion of kinetic energy into heat by skin friction on the surface of the body and the intensity of that phenomena depends on the density and speed of the air. Usually, the effects of aerodynamic heating are minimal at subsonic speeds, however it is a great matter of concerning for the designing of high speed aircrafts and reentry vehicles. In addition, its effects are higher at the leading edge of the bodies but the whole body may reach the same temperature if it keeps at a constant speed (Anderson, 2010).

As an example, Anderson (2010) presents it as a blunt body that reentries the atmosphere at Mach 36 and find that the temperature of the shock layer would be around 11.000 K (Fig. 3). So, associated with this high temperature of the shock layer, a great amount of heat is transferred to the surface of the body. Depending on the flow velocity, the heat transfer can be dominated just by convective heating, by thermal radiation or both.

The current wind turbines does not operate at those great Mach numbers, indeed the Mach usually is smaller than 0,1 for the biggest ones. However, the developing trend of wind turbines is to reach heights and diameters of the rotors even higher than the current ones and, as it had already been said, these new sizes require more air speed which will influence the aerodynamic heating.

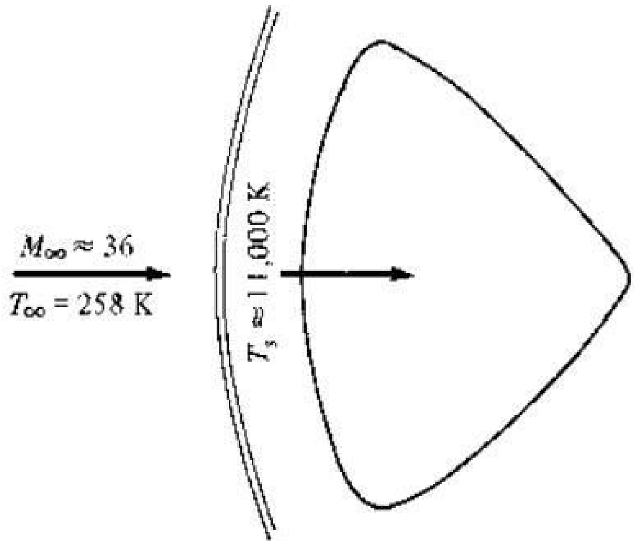

Figure 3. High temperature in the shock layer (adapted from Anderson, 2010).

2. OBJECTIVES

The main objective of this work is to discuss and to characterize the aerodynamic heating of a wind turbine airfoil, i.e. the heating of the airfoil due to the interaction of it with the air flow, in the next probable conditions of operation for the next biggest aerogenerators.

In addition, this works aims to analyze if the aerodynamic heating has a considerable influence on the surface temperature of the wind turbine blades that could jeopardize their roughness and, consequently, could also harm the aerodynamics coefficients, more specifically the lift coefficient. If that is observed, the power output (or power coefficient) of the aerogenerator can be lower than expected.

3. MATERIAL AND METHODOLOGY

In this work, it was utilized the S809 airfoil because it was specifically developed for wind turbine blades by the National Renewable Energy Laboratory (NREL), besides that it is widely used in the aerogenerator industry. The airfoil coordinates were withdrawn from NREL website (MANWELL et al., 2002; NREL, 2017).

3.1 Computational analysis

The aerodynamic heating was computationally approached and the numerical calculations were performed by solving the two-dimensional, steady and turbulent form of the Reynolds-Average Navier-Stokes equations based on finite volume method and using the CFD software ANSYS CFX. The mesh was determined through an independency study (Fig. 4) and contained $1,70 \times 10^5$ nodes of tetrahedral elements with minimum size of 1×10^{-3} m which is shown in Figures 5 and 6. The simulation used the SST *κ-ω* turbulence model along with 1 % of turbulence.

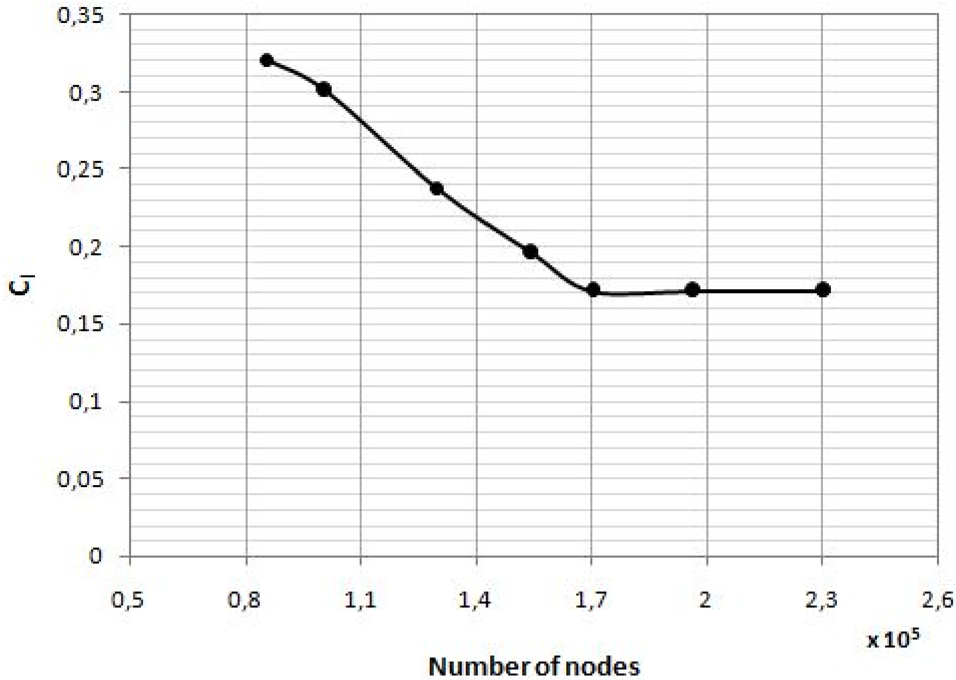

Figure 4. Independency study of the mesh.

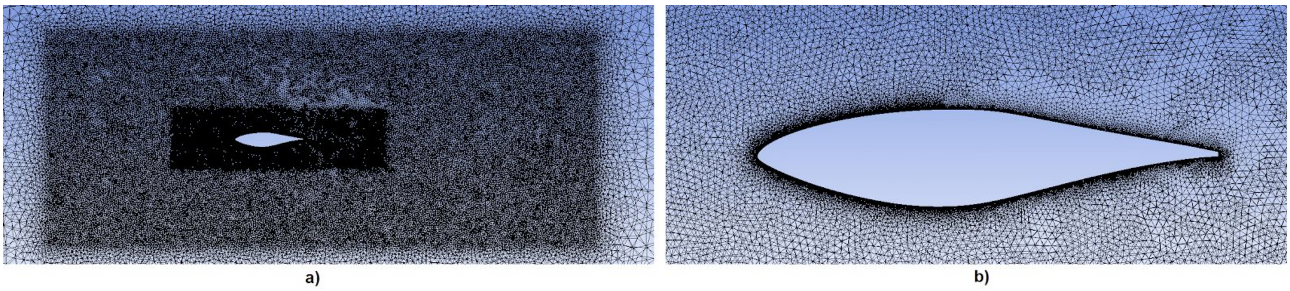

Figure 5. Two different visualizations of the mesh; a) the whole volume of control and b) a nearer region to the airfoil.

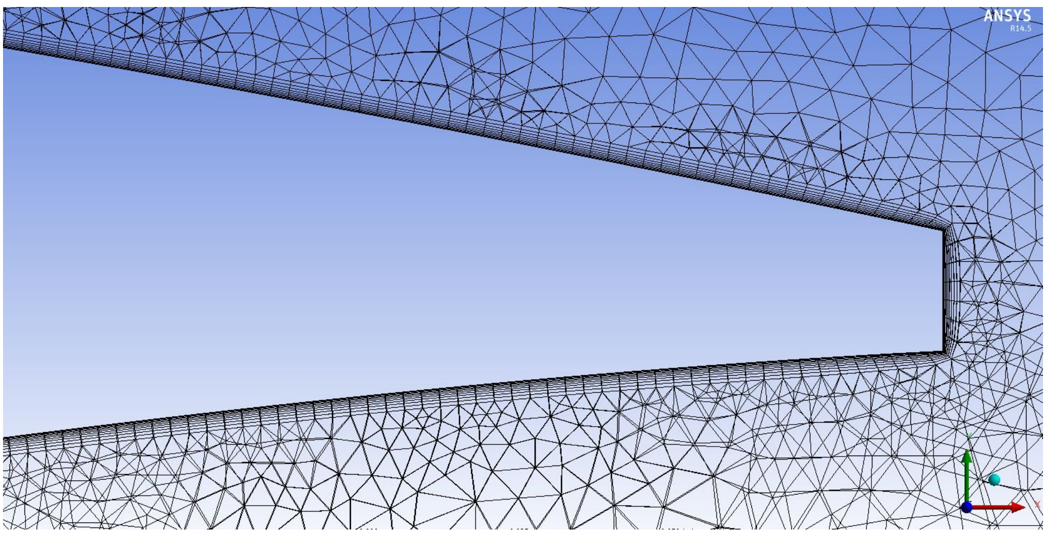

Figure 6. Close look of the mesh around the airfoil.

A search on the internet was realized in order to find the current biggest wind turbines and models as V117-4.2 MW™ from Vestas and E126 7500 kW™ from ENERCON were found. Their cut-off speed is 25 m/s, so this velocity was utilized in the simulations in order to represent the real operation of them. The chord values of the whole blades are not available, however Vestas reports that the maximum chord of its turbine blades is four meters, however this is probably just find in the blade root. Thereby two meters of chord is adopted here as mean value of chord for big turbine blades (VESTAS, 2018). Besides that, the temperature of the air utilized was the same as the mean temperature of a whole year at the wind farm *Complexo Eólico do Alto do Sertão*, located in Guanambi, Bahia, Brazil, which is 26,63 ºC and the static pressure at 550 m of altitude is 94,9 kPa (INMET, 2018). By last, the flow was set up with Cartesian coordinates in order to establish 6 º of angle of attack.

4. RESULTS AND DISCUSSION

The temperature contour with 25 m/s of flow velocity is shown in Fig. 7. It is seen that there is not a considerable difference between the extrados and intrados temperature, indeed the maximum difference between then is 0,74 K. There is no difference with the flow temperature (299,78 K), which would be approximately the designed temperature. As consequence, no changes in surface roughness will be observed due to thermal effects and none of the studied effects by Khalfallah and Koliubb (2007), Seifert and Richert (1997), Hinz et al. (2012), Kim et al. (2003) and Bekka et al. (2009) will occur.

Another simulation was performed in order to check in which flow velocity condition those phenomenons could be observed, thereby a value of 200 m/s was chosen because it lies in a condition where the compressibility effects start to be noticeable. This velocity represents a Ma of about 0,58 at the wind farm location studied here. The temperature contour in this situation is shown in Figure 8. It’s observed that the maximum difference between the extrados and intrados temperature occurs close to the leading edge and it is 56,3 K. In this situation, the effects observed by Kim et al. (2003) and Bekka (2009) could be observed, however wind velocities around 200 m/s are not and will not be expected for wind farm conditions. Accordingly, the design of wind turbines does not need to take into account probably thermal effects due to the interaction between flow and blade, i.e. aerodynamic heating.

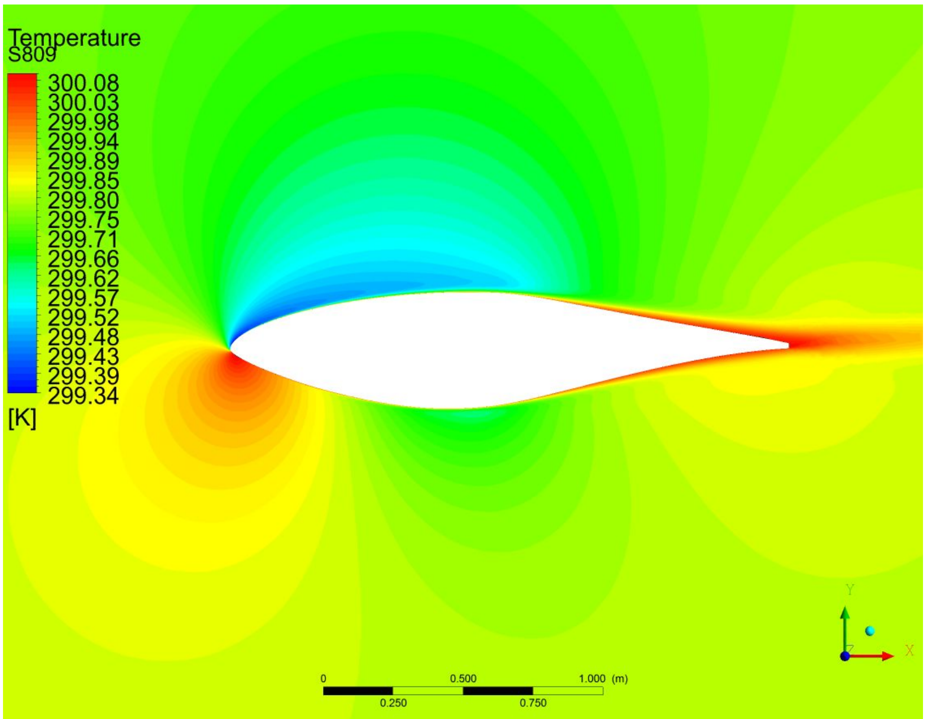

Figure 7. Temperature plot for 25 m/s of flow velocity and 6º of angle of attack.

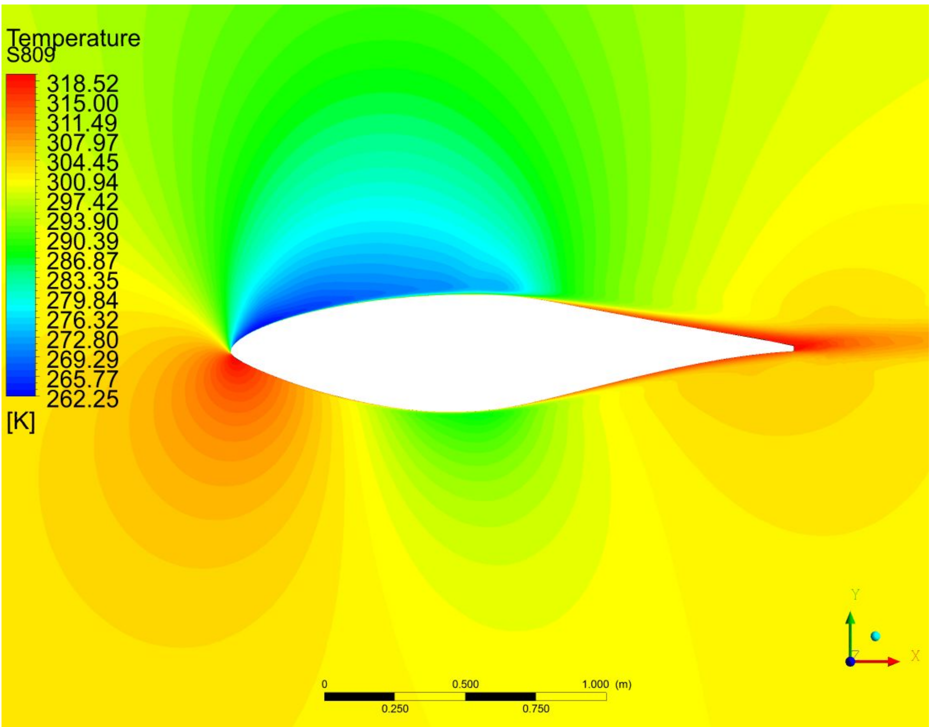

Figure 8. Temperature plot for 200 m/s of flow velocity and 6º of angle of attack.

5. CONCLUSIONS

The aerodynamic heating effects on S809 wind turbine airfoil was studied in order to comprehend if there is significant effects on aerodynamics coefficients and power output of an aerogenerator. This was realized through numerical simulations to solve the two-dimensional, steady and turbulent form of the Reynolds-Average Navier-Stokes equations in the ANSYS CFX software.

These studies did not find enough rising of temperature over the airfoil to induce changes on the surface roughness, nor other thermal effects that could alter the aerodynamic coefficients, as considerable different temperatures between intrados and extrados or heat transfer from the airfoil. These kind of effects were only met with flow velocity of 200 m/s. which are not expect conditions for wind farms. Therefore, the actuals and futures biggest wind turbines do not need to take into account thermal effects in their designing process.

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