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DEVELOPMENT AND NUMERICAL ANALYSIS OF A SIMPLIFIED AERODYNAMIC PAD FOR HORIZONTAL LOW-POWER WIND TURBINES WITH IMPLEMENTATION OF AERODYNAMIC TECHNIQUES

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Abstract. *The increase in energy demand coupled with the possibility of reducing the supply of conventional fuels and the growing concern with the preservation of the environment has encouraged the scientific community to research and develop new technologies applied to alternative sources of less polluting energy. The aerodynamic profile type is one of the most important design parameters in wind turbine analysis. The influence of the profile on the power coefficient of the wind turbine is determined by the so-called aerodynamic performance L/D , which is the quotient between the lift and the drag force. This dependence is clearly seen when the wind turbine is lost, since the L/D ratio is drastically reduced and the power coefficient is similarly reduced. The improvement of the power coefficient of the aerodynamic blades is based on the use of aerodynamic techniques that promote modifications and insertions of wing devices, allowing a new configuration to the original geometry. Improvements in aerodynamic performance achieved a better 7.0% final torque performance and 6.8% power for a 6° blade angle of blades of small E-387 Eppler wind turbines through the use of techniques aerodynamics.*

Keywords: *Aeronautical devices of high capacity, wind energy, energy demand, aerodynamic performance.*

1. INTRODUCTION

The great dilemmas of today are the question of energy and its use, which has not yet reached a satisfactory level since the huge global demand and the fact that nonrenewable sources of origin have been consolidated decades ago.

When it comes to power generation, it is desirable that the largest possible distribution occurs, covering the maximum of residences and industrial sectors, and the greater efficiency in its use and generation. In this scenario, wind energy presents itself as an alternative source with growth in potential scale and applicability in developed and emerging countries (PEREIRA, 2015).

Although wind generation is advantageous, according to Sangho (2006), it is necessary to improve the efficiency of the generation process, which is still unsatisfactory, since it requires a considerable area of wind incidence to present an efficiency that justifies the cost of implantation. For small wind turbines, the efficiency can be increased with the use of some devices used in aeronautical airfoils, these being able to be combined or acting individually in the improvement of the efficiency of generation of energy.

According to Pereira (2015) and Sangho (2006), the efficiency of wind turbines depends on the geometric factors related to their architecture, such as step, rotation, wind speed, atmospheric conditions, density, power and turbulence intensity. This influence of the profile on the aerodynamic coefficient of performance, given as the quotient between the drag (L) and the drag force (D). The present project aims to present a numerical analysis of the influence of aerodynamic techniques on blades of small wind turbines in order to improve the efficiency of torque conversion power.

2. METHODOLOGY

2.1 Wind turbines

Wind turbines or wind turbines are machines that draw kinetic energy from the wind and transform it into mechanical energy. For Almeida and Silva (2011), the wind turbines can be classified in terms of the axis around which the blades of the turbines turn and their power, being:

- Horizontal axis wind turbines (HAWT);
- Vertical axis wind turbines (VAWT);

And regarding its nominal power:

- Small Porte (up to 50kW of power);
- Medium Porte (power of 50 to 1000kW);
- Large Porte (above 1MW of power);

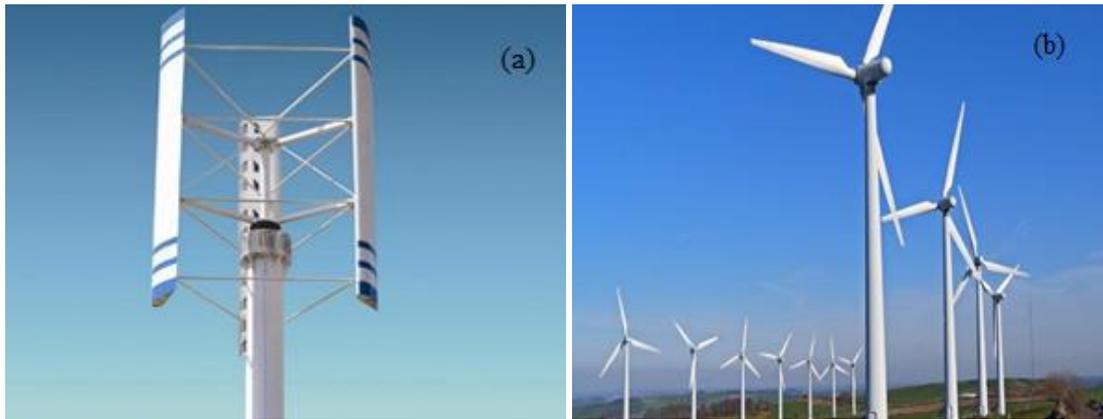


Figure 1. Wind turbine with vertical axis (a) and horizontal axis (b).
Available from: <https://www.portal-energia.com/vantagens-desvantagens-da-energia-eolica/>

Fig. 1 (a) shows a wind turbine model with a vertical axis and Fig. 1 (b) a wind turbine model with a horizontal axis. In both models the generation of electric energy occurs through coupling of the axes with generators by the conversion of the kinetic energy available in electric energy.

The propellants are components responsible for capturing the kinetic energy of the wind and transforming it into mechanical energy, having a direct influence on the overall performance of the system (BENITO, 2012).

2.2 Aerodynamic profile

An aerodynamic profile is a section obtained by a cross-section of the blade with the function of producing a pressure difference aimed at a certain aerodynamic effect (RODRIGUES, 2004). On the profile (Fig. 2) lift forces are generated, perpendicular to the incident wind, causing the blade to move, and the force of resistance (or drag) with the mass of air, acting in the opposite direction to the movement. The force produced comes then the pressure difference created between the high-low pressure region.

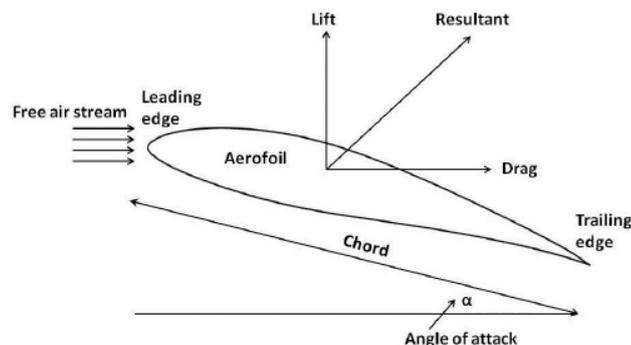


Figure 2. Forces acting on an aerodynamic profile.

Available from: https://www.researchgate.net/figure/Forces-acting-on-a-typical-aerofoil-section-of-axial-flow-fan-blade_fig2_262535527

2.3 Profiles used in aerogenerators

The cross sections of the blade of a wind turbine are in the form of airfoils whose width and blade length are directly related to aerodynamic performance, the maximum desired power, among other properties. Thus, it is important to study aerodynamic concepts related to airfoils, in order to achieve higher wind energy production (MANWELL *et al* 2002). The airfoils can be classified according to the angle of incidence, velocity of flow and the turbulence or Reynolds number.

The selection of an aerodynamic profile for wind turbines is based on the search for a profile that has a high coefficient of drag and low drag coefficient. These coefficients vary according to the angle of attack and are related by means of the CL / CD expression. In this way, we look for profiles that have higher values in the relation between lift and drag (BASTIANON, 2008).

The ideal aerodynamic coefficients are obtained by very thin profiles, in which they are not sufficiently resistant to withstand the efforts that will be submitted. Thus, it is necessary to reconcile the aerodynamic parameters with the structural resistance of the blade to be constructed (BASTIANON, 2008). The structural strength is directly linked to the geometry of the blade, as well as the materials used for its construction. Thus, it is necessary to calculate the existing shoveling efforts under various specific conditions, as in extreme cases during their lifetime. Also, one should take into account, at the time of selecting a profile, its cost of manufacturing (BASTIANON, 2008).

2.4 Aerodynamic techniques

The reduction of the induced drag forms of a profile is generated by the use of aerodynamic techniques that generate the wing modification, improving aerodynamic efficiency (L / D ratio). The main drag reduction devices are shown in Fig. 03.

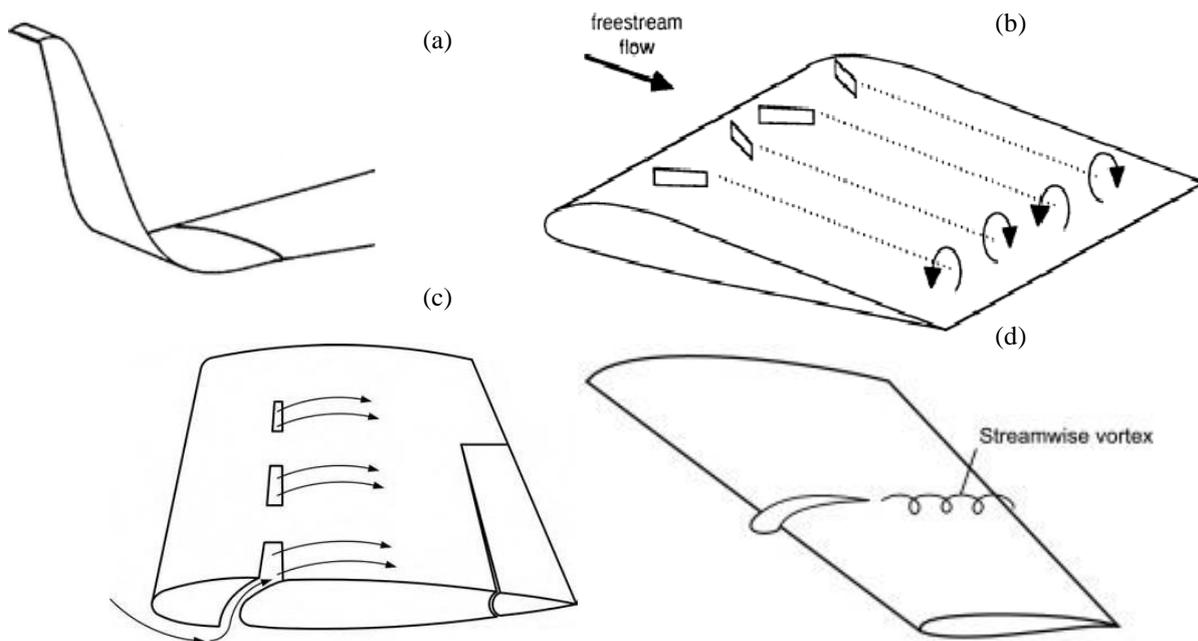


Figure 3. Winglet (a) vortex generator (b) Slat (c) e Stall fence (d).

Available from: <http://www.zoombd24.com/aircraft-high-lift-devices-slats-slots-and-flaps-types-and-working-principles/>

Fig. 3 presents aerodynamic techniques or devices in the aeronautical industry used in the optimization of the torque and power gain in the turbine rotor.

2.5 Market research

The aerodynamic profile used in the optimization study was raised through market research, presented in Tab. 1, for low power wind turbines and their technical parameters.

Table 1. Low-power wind turbines on the market.

Models	Pot. Nominal (kW)	Pot. (kW)	Voltage (V)	Rotation (rpm)	Rotor diameter (m)	Weight (kg)
1	2	2,2	48	134	2,25	24
2	2	2,5	48	400	3,2	100
3	0,4	0,6	12/24	-	1,7	-
4	0,5	1	24	600	2,5	30,3
5	1	2	60	500	3,1	60
6	2	3,2	120	450	3,8	85
7	3	4,5	180	340	4,9	182
8	0,4	0,43	12	-	1,17	5,9
9	0,16	0,3	12/24	-	1,17	5,9
10	1	-	24	740	2,46	35
11	0,42	-	24	1100	1,38	12,5
12	0,4	0,6	12	-	1,25	5,5
13	3	4,5	110/220	-	4,8	71

The Tab. 1 presents the main models of the market, analyzing the parameters presented to establish the conditions and geometric aspects of the turbine used in the analysis.

3. RESULTS AND DISCUSSIONS.

3.1 Survey of operational parameters

The analysis of the average speed of the wind where the wind turbine will be installed is one of the main parameters, being employed in the potential and economic viability for the implementation of the project. The average wind speed that will be adopted in our study was based on data provided by an automatic station of the National Institute of Meteorology (INMET), Campina Grande - Paraíba.

In addition to the wind speed, data such as the maximum and minimum temperature and the maximum and minimum pressure at the place where the turbine will be installed are shown in Table 2.

Table 2. Operating parameters per station

Seasons	Average temperature (°C)	Average speed (m/s)	Average pressure (hPA)
Spring	23,34	4,35	952,80
Summer	24,66	4	950,91
Autumn	24,45	4,20	951
Winter	21,70	4,92	954,62
Average	23,53	4,36	952,33

According to Tab. 2, the final average value found for wind speed is a low value for wind power generation, thus justifying the proposal of this work to analyze an aerodynamic profile that presents good yields at low speeds.

3.2 Selection of aerodynamic profile

The aerodynamic profile type was based on the wind turbine power coefficient determined by the high value in the relation between the drag coefficient and drag coefficient, angle of attack α and Reynolds number ranging from 100,000 to 500,000. The aerodynamic profiles selected for study are from different families, these being the profiles of models E-387, MH 106, S 8036 and SG-6040.

3.3 Establishment of profile

The selected profiles are suitable for use at low flow velocities, using free software of aerodynamic simulation, *Javafoil*, to evaluate the behavior of the profiles for certain Reynolds numbers and angles of attack.

The use of *Javafoil* was used to analyze the behavior of the profiles for the support, drag and momentum generated around the axis itself. The aerodynamic efficiency (L/D) was also calculated in order to validate the first criterion of selection of the profile more suitable for our shovel.

Table 3. Preliminary *Javafoil* parsing results.

Perfil	$C_{l\text{ máx}}$	$\alpha/C_{l\text{ máx}}$	$C_{d\text{ máx}}$	$\alpha/C_{d\text{ máx}}$	L/D	α
E-387	1,12	10°	0,08	12°	105,76	6°
MH-106	0,90	9°	0,019	10°	57.69	7°
S-8036	1,21	12,5°	0,043	12,5°	75.9	7°
SG-6040	1,33	14,3°	0,062	14,5°	86,5	6°

The Tab. 3 presents the results of the aerodynamic profiles involved. According to Tab. 03 the profiles with the best L/D ratio present better power coefficient, which in turn decreases the radius of the wind turbine. The angle of attack (α) must be small (between 6° and 8°) to generate optimum pressure gradient in the promotion of maximum torque.

Fig. 4, is presented as suitable for use and analysis in small turbines, based on the results of Tab.3.



Figure 4. Eppler profile 387.

Available from: <http://airfoiltools.com/airfoil/details?airfoil=e387-il>

The geometric parameters used in the simplified blade construction are presented in Tab. 4.

Table 4. Project specifications

Profile	E-387
Rope	0,30m
Rotor diameter	3m
Shovel wingspan	1,5m
Rotation	300rpm
Number of blades	3
Average speed	4,36 m/s
Average temperature	23,53°C
Average pressure	952,33h Pa

3.4 Conceptual design

With the aid of CAD software, the basic design of the profile modeled as a rectangular paddle was established, Fig. 4, without profile variation.

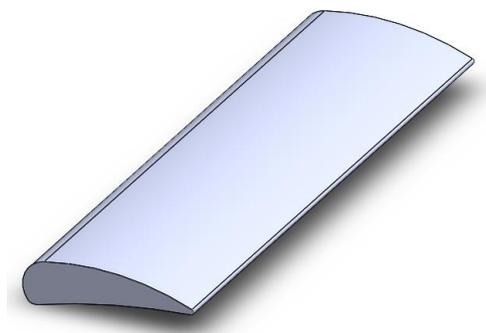


Figure 4. Design I - Simplified shovel

3.5 Conceptions with the use of aerodynamic devices.

Three conceptions were developed that involve the use of aerodynamic devices for analysis. The aerodynamic *slat*, Fig. 5 (a), is a slit-shaped aerodynamic device at the leading edge that softens the air flow in order to increase the flow velocity and allow the air to exit more tangentially the geometry, allowing the use of a greater critical angle.

The vortex generators, Fig. 5 (b), are small laminar devices to produce a suitable change or correction in the airflow.

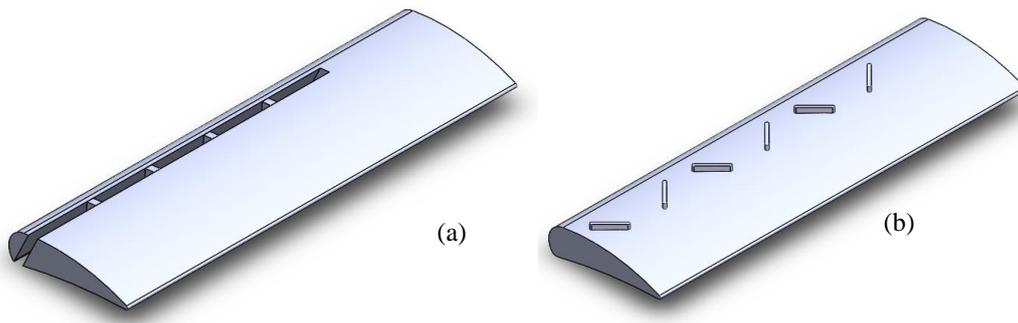


Figure 5 (a) Design II - Simplified Shovel with Slats. (b) Conception III - Simplified blade with vortex generators.

Vortex generators are generally of rectangular or triangular geometry, with about 80% of the height of the boundary layer, and run in lines of the wider space near the thickest part of the wing. The vortex generators are positioned obliquely so as to have an angle of attack relative to the local airflow.

After the conceptions generated, a fourth design was developed based on the combination of the conceptions expressed by Fig 5 (a) and 5 (b), giving rise to Fig. 6.

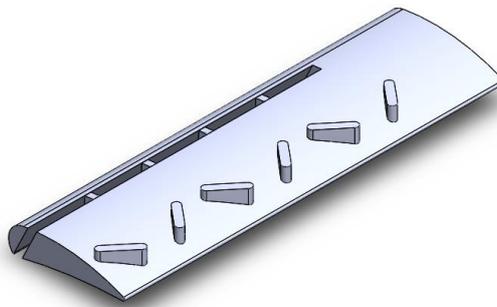


Figure 6. Design IV - Simplified blade with power generators and Slats.

3.6 Numerical analysis

With the conceptions generated, CFD analysis was started to quantify the torque and power gain with the implementation of aerodynamic devices. The numerical analysis was performed in ANSYS Academic Software Workbench.

Tab. 5 presents the parameters used in the simulations.

Table 5. Configuration parameters established for the simulations

Analysis state	Static
Mesh	Mobile Structured
Residue of convergence	1E-8
Turbulence model	k- ω SST
Pressure-speed coupling	COUPLED
Rotation method	To change speed profile
Current speed	4,36 m/s
Rotation speed	300 m/s
Fluid	Air

3.7 Results

The results obtained after numerical analysis are presented for all conceptions developed. For all conceptions, the pressure profiles were analyzed at distances of 0.25 m, 0.75 m and 1.25 m from the edge, Fig. 7.

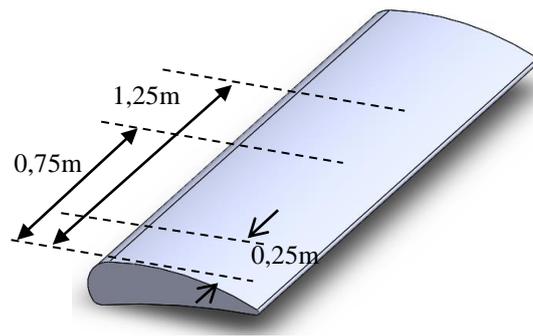


Figure 7. Points of analysis for the pressure gradient.

The design I presents variation of the pressure gradient, Fig. 7, along the length of the blade, presenting a maximum pressure of 51.94 Pa for a distance of 0.25 m from the edge, 300.8 Pa for a distance of 0.75 m from the edge and 877.1Pa for a distance of 1,25 m from the edge.

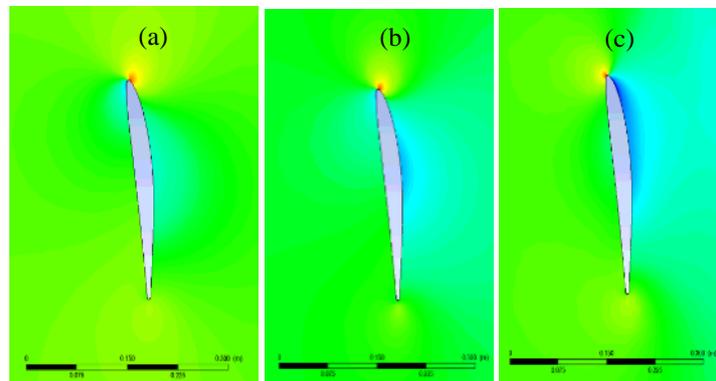


Figure 8. Pressure distribution along the simplified shovel at 0.25 m (a), 0.75 m (b) and 1.25 m (c).

According to Fig. 8 as the distance from the edge is increased, the pressure gradient increases, increasing the formation of the mat and the drag. Figure II shows a variation of the pressure gradient, Fig. 9, along the length of the blade, presenting a maximum pressure of 24.4 Pa for a distance of 0.25 m from the edge, 215.6 Pa for a distance of 0.75 m from the edge and 639.6 Pa for a distance of 1.25 m from the edge.

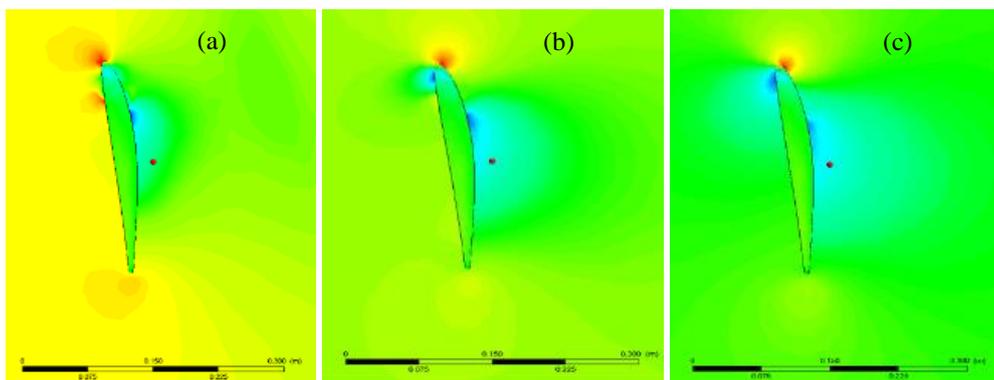


Figure 9. Pressure distribution along the simplified shovel with Slat at 0.25 m (a), 0.75 m (b) and 1.25 m (c).

As Fig. 9 shows, as the distance from the edge increases, the pressure gradient increases, increasing the formation of the mat and the drag, however, when compared to Fig 7, the use of Slats promotes the reduction of drag in up to 27.01%. Design III shows a variation of the pressure gradient, Fig. 10, along the length of the blade, presenting a maximum pressure of 46.7 Pa for a distance of 0.25 m from the edge, 290.1 Pa for a distance of 0.75 m from the edge and 894.8 Pa for a distance of 1,25 m from the edge.

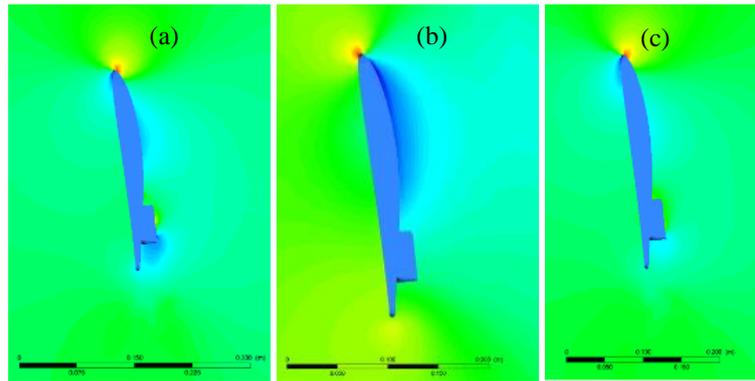


Figure 10. Pressure distribution along the simplified blade with vortex generators at 0.25 m (a), 0.75 m (b) and 1.25 m (c)

As Fig. 10 shows, as the distance from the edge increases, the pressure gradient increases, increasing the formation of the belt and drag, however, when compared to Fig 7, the use of vortex generators promotes the reduction of maximum drag of 3.11%. Design III shows a variation of the pressure gradient, Fig. 11, along the blade length, presenting a maximum pressure of 42.21 Pa for a distance of 0.25 m from the edge, 289.7 Pa for a distance of 0.75m from the edge and 750.1 Pa for a distance of 1.25m from the edge.

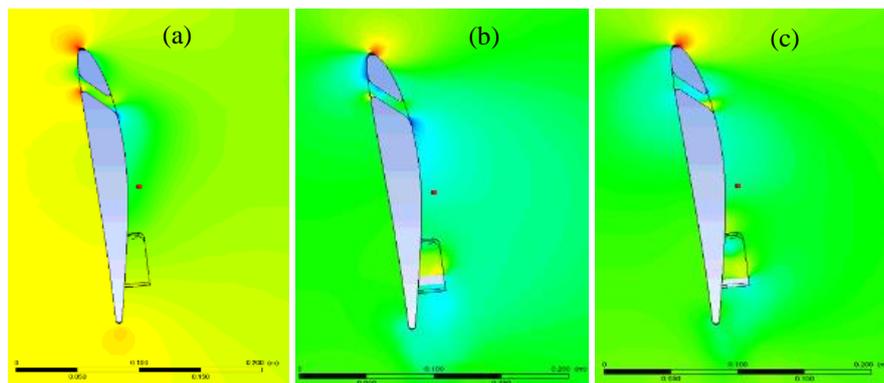


Figure 11. Pressure distribution along the simplified shovel with Slat and vortex generators at 0.25 m (a), 0.75 m (b) and 1.25 m (c)

As Fig. 11 shows, as the distance from the edge increases, the pressure gradient increases, increasing the formation of the belt and drag, however, when compared to Fig 7, the use of vortex generators promotes the reduction of maximum drag of 14.47%. In addition to the analysis of the pressure gradients, the torque generation behavior, expressed in Tab. 6, was analyzed.

Table 6 - Results obtained by the application of aerodynamic techniques.

Parameters	Concepcion			
	I	II	III	IV
Number of elements	4.281.524	3.449.170	2.192.611	3.517.759
Torque generated by a shovel (N.m)	4,43	4,48	4,60	4,81
Power generated by a blade (kW)	0,14	0,15	0,17	0,18
Total power (kW)	0,42	0,45	0,51	0,57

The Tab. 6 show a comparative between the design's development. The design IV, although presenting a smaller reduction in drag compared to the design II, promotes an increase in torque and power per blade. The increase in torque is 16.67%, raising the total power (kW) by 26.67%.

4. CONCLUSIONS

The development of research aimed at aerodynamic profile optimization through the addition of aerodynamic devices presents as a possibility to improve the power extracted in low power turbines with residential application. The addition of aerodynamic devices such as Slats and vortex generators (design IV) allows the power gain in the order of 26.67% and a drag reduction of 14.47%. The addition of Slats (Conception II) promotes a reduction of 27.01% in trawling, but the increase in power is 7%. The combination of the two devices presented even better results than using only one device alone.

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