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EXPERIMENTAL OBSERVATIONS ON EFFICIENCY DIFFERENCE BETWEEN HELICAL AND STRAIGHT BLADED VERTICAL AXIS WIND TURBINES

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Abstract. While in operation, the straight bladed vertical axis wind turbines (VAWTs) are affected by the variations in loadings that result in torque and power oscillations. This problem is considered to be solved by adopting helical blades. However, the way this solution affects the turbine's efficiency is not entirely clear thus this aspect was studied and the results are presented in this paper. Four small scale VAWTs were investigated. A set consisting of one straight bladed turbine and one helical bladed turbine was tested. The airfoil used for this case was the symmetrical NACA 0018. Except for the helical angle, the two turbines were defined by the same key parameters that refer to the: swept area, aspect ratio, solidity, chord length, number of blades, airfoil type and pitch angle. The results revealed that the helical turbine was more efficient than the straight bladed one, generating 53% more power at 12 m/s. Another set of helical and straight bladed versions was tested, this time based on the asymmetrical FX 63-137 airfoil camber out mode. Contrary to the first case, here the straight bladed turbine was more efficient than the helical version, generating 2 times more power at 11 and 12 m/s.

Keywords: *asymmetrical airfoil, efficiency, experimental analysis, symmetrical airfoil, wind energy.*

1. Introduction

Vertical axis wind turbines are known to be characterized by variations of loadings on the blades while in action that cause fluctuations in torque and power coefficients. Aside from the loadings issue, VAWTs are known to be less efficient when compared to horizontal axis wind turbines. The loadings problem is considered to be solved to a certain degree by adopting helical blades. However the efficiency of this version when compared to that of the straight blades is not entirely clear.

The helical blades are characterized by the helical angle Λ that can take different values (Figure 1). There are papers that focus on how this angle affects the turbine's performance. McIntosh et al [1] developed a Lagrangian based free vortex model for analyzing the performance of helically bladed VAWTs based on the symmetrical NACA 0021 airfoil. The results showed that by increasing the helical angle, the efficiency decreases. According to the study, when compared to the straight bladed VAWT ($\Lambda = 0°$) a helical angle equal to 50° lowers the power coefficient by approx. 0.1. On the other hand, a helical angle of 30° drastically reduces the amplitude of the loading variation.

Scheurich [2] studied three VAWT types: with straight blades, with curved blades and with helical blades all defined by the NACA 0015 airfoil. The study was based on the Vorticity Transport Model. Like McIntosh et al [1], Scheurich writes that the helically bladed turbine was characterized by a lower variation of the power component but unlike McIntosh, the author points out a higher efficiency for the helically bladed VAWT over the curved bladed turbine followed by the straight bladed one [3].

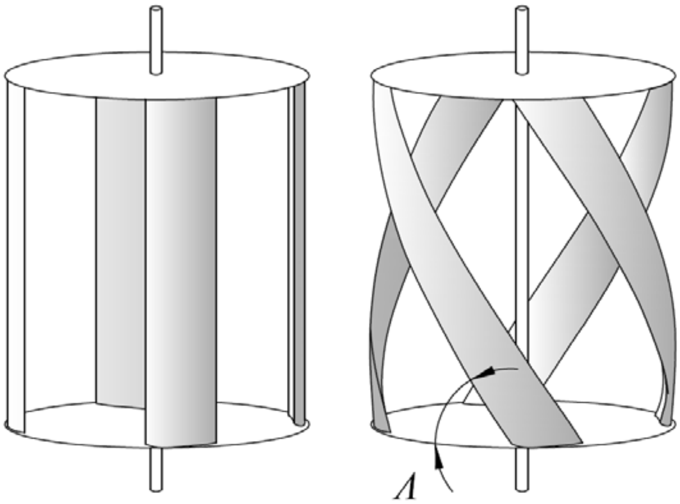

Figure 1. Straight and helically bladed turbines.

As from the sources above it is unclear which version would be more efficient, this aspect was analyzed and the results presented in this paper. Various sets of experiments were ran that involved four small scale wind turbines, two of which had straight blades and the other two of helical blades. Two airfoils were considered: the symmetrical NACA 0018 airfoil as it is a common choice for VAWT applications and the asymmetrical FX 63-137 airfoil that is among the recommended versions proposed by Bostan et al. [4]. Except for the airfoil types, the turbines were defined by the same key parameters and were subjected to the same wind conditions.

2. Methodology

2.1. Theoretical considerations

The turbines' performance was compared in terms of generated power and not power coefficient as it is usually done, thus the parameters that could influence their productivity were kept the same except for the helical angle. The definitions and roles of the parameters are given below.

The power output *P* of a wind turbine can be calculated with the relation:

$$P = \frac{1}{2} \cdot C_p \cdot \rho \cdot A \cdot U^3 \quad (1)$$

where ρ is the air density, A – the turbine's swept area, U is the wind speed and C_p is the power coefficient which is a non-dimensional value of turbine's efficiency. One can notice that the power output is directly proportional to the swept area. In order to remove that as an influence factor the turbines were built with the same swept area.

For a straight bladed VAWT the swept area is confined by a rectangle, where one side is the turbine's height and the other is its diameter. The ratio between the height and diameter is called the rotor's aspect ratio – *AR*, which also influences the turbine's efficiency [5 - 7]. As for the swept area, the compared turbines had the same aspect ratio.

The cross section of a wind blade is characterized by the special aerodynamic shape called airfoil. Nowadays a large variety of airfoils are used, both symmetrical and asymmetrical. The line under which the symmetry is considered is called the chord *c* which connects the airfoil's leading and the trailing edges. This is a particularly important feature when it comes to efficiency thus the blades of the turbines that were compared were defined by the same airfoil type.

For a specific swept area and aspect ratio, one can choose different values for the airfoil's chord length *c*, this way determining the turbine's solidity *σ*. The solidity is defined as the ratio between the blades area and turbine's swept area. The area of a straight blade is calculated by multiplying the chord length *c* and the blade's length *L* which in this case is equal to its height *h*. Thus the solidity *σ* of a straight bladed wind turbine can be calculated with the relation:

$$\sigma = (N \cdot c \cdot L)/A = (N \cdot c)/D \tag{2}$$

where *N* – number of blades; *D* – turbine's diameter. Once the swept area, the blade number and the aspect ratio are set, to change the solidity one can use the chord length *c*. Like the properties described above, the solidity greatly influences the turbine's power coefficient. Moreover, it influences the turbine's tip speed ratio (TSR). The tip speed ratio or rapidity *λ* is the ratio between the tangential speed of the blade and the wind speed. The graph presented in the Figure 2 shows the power coefficient dependence on the solidity determined with different chord lengths. The figure depicts a study of a straight bladed turbine of the height and diameter equal to 6 m and was done using the QBlade software. It can also be noticed that different solidity values induce different tip speed ratios.

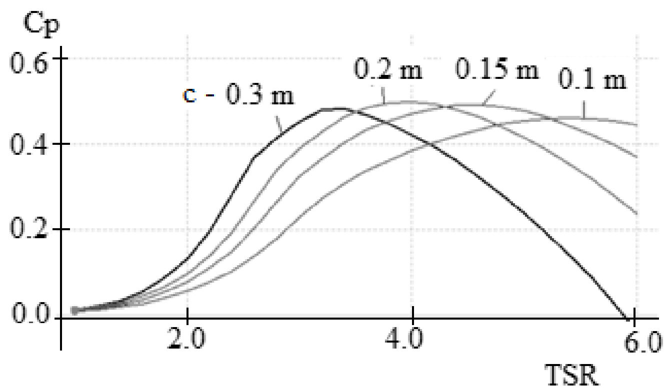

Figure 2. Power coefficient dependence on chord length.

The solidity affects the turbine's self-starting abilities, where a higher solidity is more convenient in this regard [8].

Most of the modern wind turbines have three blades. This option is selected by taking into account aspects like efficiency, structural loads and economic reasons [8-9]. Each of the turbines analyzed in this paper had three blades.

The pitch angle *β* is the angle between the chord's line and blade's tangential velocity vector *v*. The angle *β* can take null, positive or negative values (Figure 3). When designing a VAWT the optimal fixed pitch angle has to be determined as it affects the turbine's efficiency [10]. In order to cancel its influence, the turbines that were analyzed had the same fixed pitch angle.

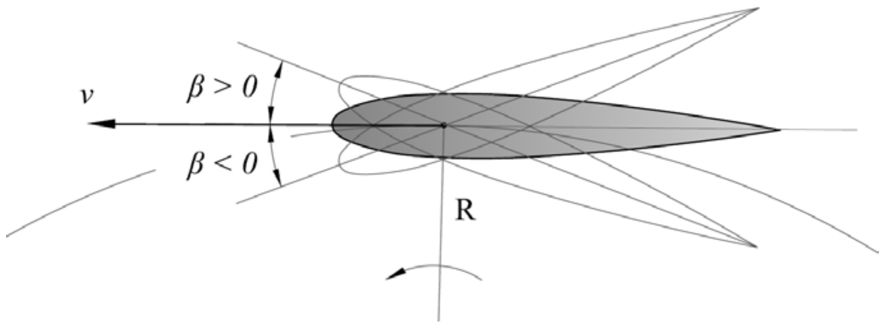

Figure 3. Pitch angle of the rotor's blade.

2.2. Experimental setup

The experimental setup consisted of two main components: the wind tunnel and the small scale wind turbine. The wind tunnel Gunt ET 220 that was used for the analysis was designed for studying a particular embedded horizontal axis wind turbine. In order to study VAWTs, the embedded turbine was removed along with the protection fences. The outer diameter of the tunnel is 610 mm which limits the size of the turbines that can be analyzed. The maximum wind speed varied between 11.5 and 12.5 m/s.

The wind turbine was designed in a way that allows simple blade change so different types of blades can be easily attached to the turbine's struts. This way the fixed tower, the supporting struts that define the diameter, the electric generator and electrical load remained the same whereas the different sets of blades that were attached formed different turbines (Figure 4).

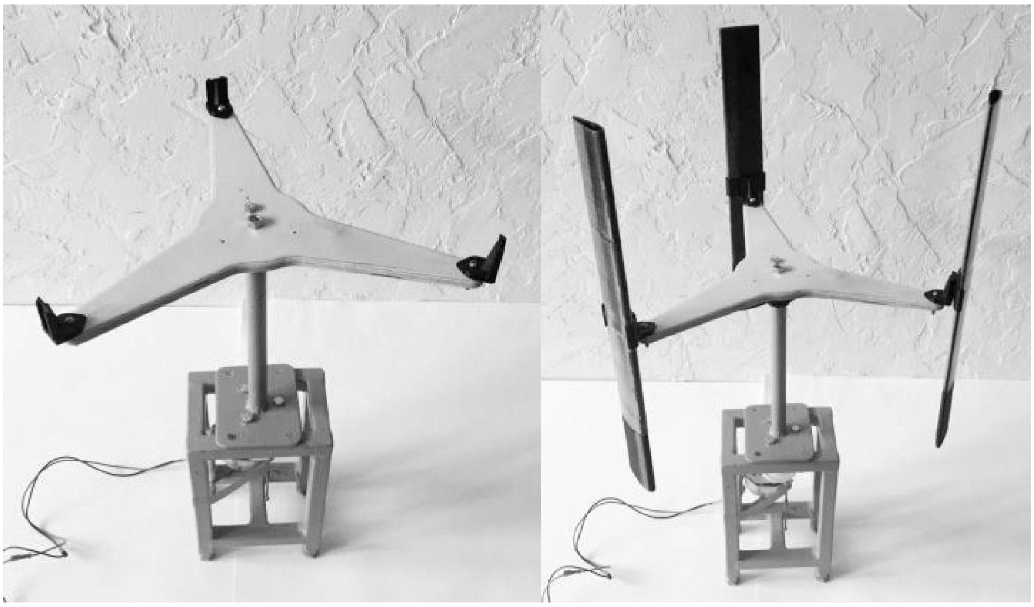

Figure 4. Experimental VAWT that allows changing different set of blades.

Four sets of three blades each were prepared. Two sets consisted of straight blades and other two of helical blades, all of which were obtained by 3D printing. As the work volume of the 3D printer was limited, segments of blades were printed and then glued together so that they formed an entire blade with the necessary length. For better rigidity, the blades were then taped so that it preserved the original aerodynamic shape.

Two airfoil types were considered: the symmetrical NACA 0018 airfoil and asymmetrical FX 63-137 airfoil. One straight bladed turbine and one helical turbine had blades defined by the NACA 0018 airfoil. These two were tested together and their performance compared. The other turbines had blades defined by the asymmetrical airfoil FX 63-137 and were tested together. The chord length and the pitch angle were the same for all cases – 0.05 m and 0° respectively. The turbines had the height and the diameter equal to 0.4 m. These dimensions were chosen by taking into account the size limitations imposed by the tunnel's diameter. Given these values, all turbines had the same swept area – 0.16 m^2 and aspect ratio – 1.0. The turbines' parameters are listed in the Table 1.

The rotors were tested under different wind speeds, ranging from 7 m/s to 12 m/s. The power produced by the three phase generator was measured using a specially designed platform based on NI Elvis II which included the RELab module and a computer that ran a LabView application (Figure 5). The alternating current from the generator was converted into direct current by using a rectifier. The voltage and current produced were measured by involving the system's variable load resistance.

Figure 5. Data acquisition system NI Elvis II RELab.

The device determines the power output once every few seconds (number that can be specified exactly). In our case data was collected once every 7 seconds which is the recommended time interval.

Table 1

The turbines' parameters

The parameter		*Helical blades*	*Straight blades*
Rotor's height, (m)	*h*	0.4	0.4
Rotor's diameter, (m)	*D*	0.4	0.4
Number of blades, (/)	*N*	3	3
Blade's length, (m)	*L*	0.434	0.4
Helical angle (°)	*Λ*	67	0
Chord length, (m)	*c*	0.05	0.05
Swept area, (m^2)	*A*	0.16	0.16
Solidity, (/)	*σ*	0.375	0.375
Aspect ratio (/)	*RA*	1	1
Pitch angle, (°)	*β*	0	0
Airfoil types	NACA 0018 / FX 63-137		

3. Results

First the straight and helically bladed turbines based on symmetrical NACA 0018 airfoil were tested. Three measurements have been taken for every wind speed and the average value was calculated. The results obtained are depicted graphically in Figure 6. The observed trends favored the helically bladed turbine which showed better results than the straight bladed version. At 12 m/s the helical turbine generated 48% more power than the straight bladed one, at 11 m/s it generated 53 % more and at 10 m/s the helical turbine produced 4 times more energy. As for lower wind speeds the turbines showed little or no performance at all, only the results for higher wind speeds are shown.

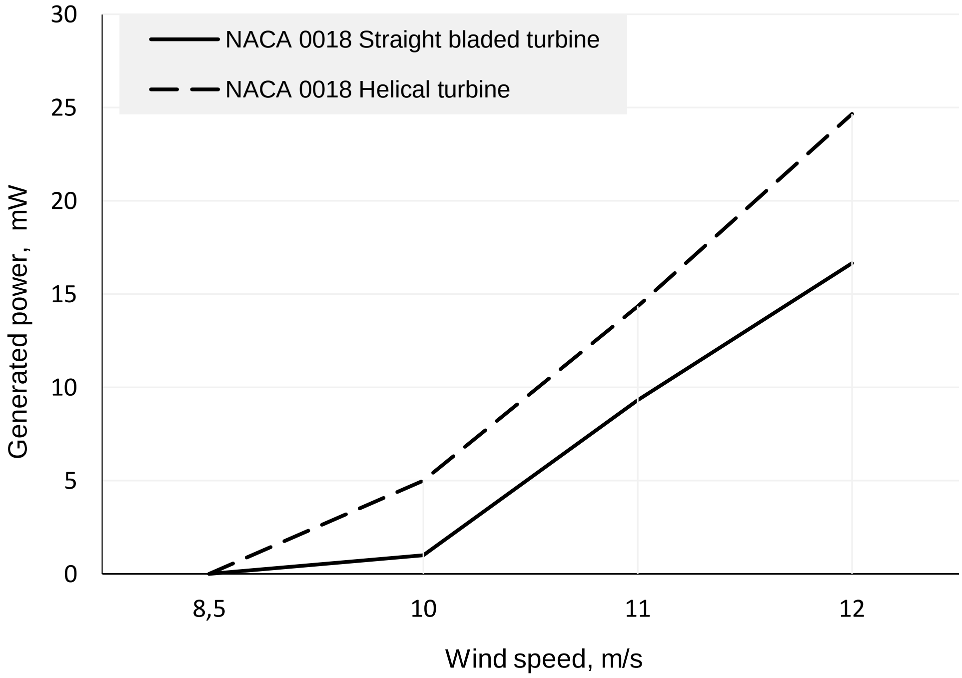

Figure 6. The performance of straight bladed and helical turbines based on NACA 0018 airfoil.

Second, the straight and helically bladed turbines based on the asymmetrical FX 63-137 airfoil were tested.

The asymmetrical airfoils can be positioned in two modes relative to the turbine's axis: airfoil's curvature (camber) oriented radially inward or outward (Figure 7). For this specific airfoil the inward curvature mode performed poorly compared to the outward orientation mode thus the last option was further adopted.

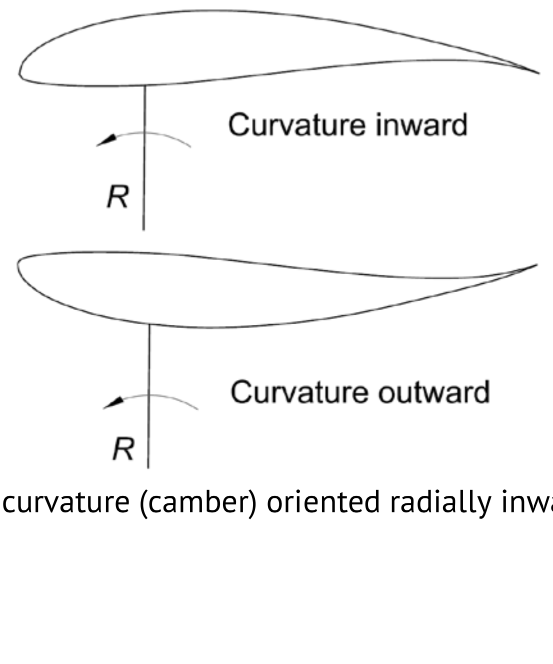

Figure 7. Airfoil curvature (camber) oriented radially inward and outward.

The Figure 8 depicts the power generated by the two turbines. Unlike the previous case, the straight bladed turbine showed better results than the helical one. Thus at 11 and 12 m/s it generated 2 times more power than the helical version. However at 10 m/s the helical turbine showed slightly better performance as for the NACA 0018 case.

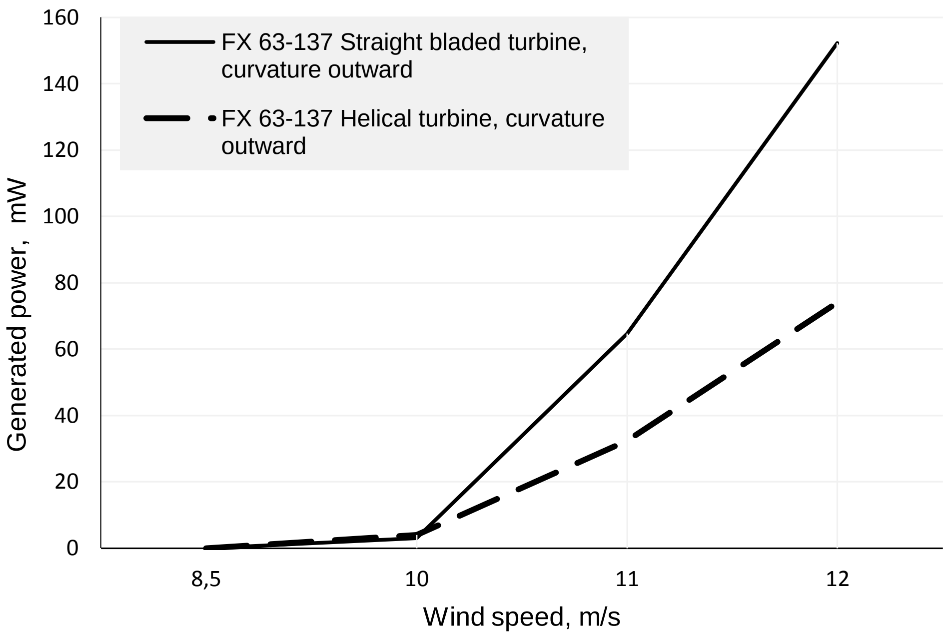

Figure 8. The performance of straight bladed and helical turbines based on FX 63-137 airfoil.

It was calculated that the wind turbines were operating for a Reynolds number that varied up to an average of 40000. The value was calculated using the relative wind speed.

4. Conclusions

Four small scale vertical axis wind turbines were tested: two turbines with blades of helical shape and the other two with blades of straight shape. Two airfoils were considered: the symmetrical NACA 0018 airfoil and the asymmetrical FX 63-137. Except for the airfoil type and helical angle, all turbines were characterized by the same key parameters that refer to the: swept area, solidity, aspect ratio, chord length, number of blades and pitch angle.

One straight bladed turbine and one helical bladed turbine based on NACA 0018 airfoil were tested and the generated power compared. The helical version was more productive than the straight bladed one generating 48% more power at 12 m/s and 53% more power at 11 m/s.

Another set of two turbines was tested, this time the asymmetrical FX 63-137 airfoil curvature (camber) outward mode was adopted. Contrary to the NACA 0018 case, here the straight bladed turbine was more efficient, generating 2 times more power at 11 and 12 m/s.

According to these results, the helical angle could be considered as an efficiency optimization solution but its effectiveness will depend on the adopted airfoil. Also it cannot be asserted that the helical configuration is more efficient than the straight bladed version or vice versa as this depends at least on the airfoil type. However, the helical blades advantage in terms of cyclic loads pointed out by different studies is not to be disregarded.

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