AEOLIAN BLADES WOUND SPARS DESIGN AND MODELING PROCEDURE

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INTRODUCTION

Modern aeolian blades began to describe a more and more delicate and complicated at the same time three-dimensional geometry. Regardless of the differences with respect to the tasks of wind energy technology, blades construction has been borrowed almost without exception from aircraft technology, as well as the manufacturing techniques that primarily come from modern boat building. Blade thickness, weight and strength, in particular, are provided by the height and length of the spar box, which absorbs tensile, compressive and transverse forces. Wound spars made of fibre-reinforced composites with laminated outer shells are typical for small rotor blades of our days, while for large scale wind turbines the manufacturers prefer one or more light-weight spar webs. The paper relates to the design and modeling procedure of the wound spars, accounting a quite complex process that takes place simultaneously or at least play a decisive role in the blades external shape developing.

1. INITIAL DATA

Complicated three-dimensional geometry of the aerodynamically shaped aeolian blades mostly is described by the following parameters:

- blade length,
- cross-sections arrangement with respect to the blade radial line,
- cross-sections airfoils,
- chord length distribution,
- blade twist,
- hub connection,
- blade tip shape and
- aerodynamic brakes (if used).

Further will be tackled the example of a 4.138 m length (R) blade, component of a three-bladed fixed-pitch 10 kW rated aeolian rotor. Blade radial line passes the cross-sections through the aerodynamic pressure centers of the outlined airfoils. The connection to the hub, as is shown in fig. 1, is done through six bolts screwed on a surface that is parallel to the rotor plane of rotation. The other main geometric parameters are listed in the table 1.

Table 1. Main geometric parameters of the tackled aeolian blade.

Cross-section No.	**Airfoil**	**Local rotor radius (*r*), m**	**Chord length (*c*), m**	**Twist angle ( ), deg**
1	NACA 4430	0.414 ($0.1 \cdot R$)	0.845	36.6
2	NACA 4429	0.621 ($0.15 \cdot R$)	0.657	25.4
3	NACA 4427	1.035 ($0.25 \cdot R$)	0.438	13.9
4	NACA 4424	1.655 ($0.4 \cdot R$)	0.287	6.4
5	NACA 4419	2.690 ($0.65 \cdot R$)	0.181	1.3
6	NACA 4412	4.138 ($1 \cdot R$)	0.120	-1.6

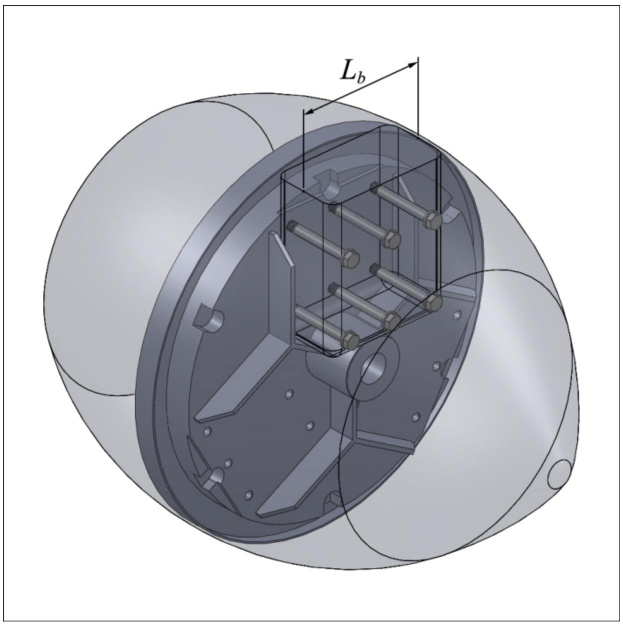

Figure 1. Blade connection to the rotor hub.

Another key parameter that directly relates to the design and modeling procedure of the wound spars too, is the placement law of the studied cross-sections towards the rotor centre of rotation. In the case presented, the subsequent local rotor radius (r) succeeds the previous in a geometric sequence (exponentially), according to the equation:

$$\boldsymbol{r = q \cdot R}\text{, where } \boldsymbol{q_{k+1} = q_k \cdot 1.585}\,. \tag{1}$$

The results are also presented in the table 1.

2. WOUND SPARS DESIGN AND MODELING PROCEDURE

Wound spars design and modeling process is conducted on the basis of the following three key elements:

1. Wound spar bottom width, predetermined by the specificity of the connection to the hub;
2. The airfoils chord length and
3. thickness, that follow the placement law of the studied cross-sections and obviously restrict the wound spar width and thickness too.

In the case presented, the wound spar bottom width (L_b) is of 0.235 m (fig. 1, 2). In the same sectional plane, the airfoil chord length (c_b) is of 0.919 m (fig. 2). Depending on the chords lengths (c) of the blade cross-sections airfoils, according to the relation (2), the wound spar widths (L) longitudinal distribution can be calculated:

$$\boldsymbol{L = \frac{c \cdot L_b}{c_b}}\,. \tag{2}$$

Once having determined the width of the wound spar tip cross-section, the spar tip thickness (l_t) can be set. In the case presented, it was set to be of 6.8 mm. Afterwards, by a reverse procedure of the relation (2), the wound spar thicknesses (l) longitudinal distribution can be calculated:

$$\boldsymbol{l = \frac{c \cdot l_t}{c_t}}\,. \tag{3}$$

where c_t is the chord length of the blade tip airfoil.

Coming again to the grip section we can find that the obtained bottom thickness is too small. The airfoil thickness let's make it bigger with a certain length q_b. Therefore, to obtain the desired thickness, along the entire blade the wound spar thickness should be widened with a consecutively increasing length (q), which is zero at the tip and maximum at the bottom cross-section:

$$\boldsymbol{q = \frac{(c - c_t)q_b}{c_b - c_t}}\,. \tag{4}$$

Thus, the effective thickness (l_q) of the wound spar cross-sections will be the amount of the thickness calculated with the relation (2), and the corresponding addition length (q), calculated with the relation (4):

$$\boldsymbol{l_q = l + q}\,. \tag{5}$$

Obviously, the wound spar edges cannot remain sharp. The longitudinal variation of the fillet radius (r) can be calculated by the same method too, starting from the desired fillet radius (r_b) of the bottom cross-section. In the case presented, r_b is set of 20 mm:

$$\boldsymbol{r = \frac{c \cdot r_b}{c_b}}\,, \tag{6}$$

thereby being finished the wound spar design and modeling procedure (fig. 3), following the development of the internal strength structure and its integration into the entire blade assembly (fig. 4). All the results are presented in the table 2.

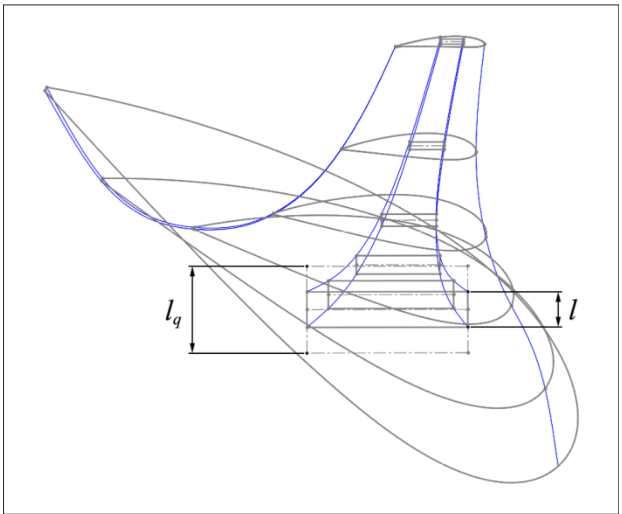

Figure 2. Wound spar raw cross-sections.

Table 2. Geometric parameters of the designed wound spar.

Cross-section No.	Width (L), mm	Thickness (l), mm	Addition length (q), mm	Effective thickness (l_q), mm	Fillet radius (r), mm
1	216.1	47.9	69.0	116.9	18.4
2	168.2	37.3	51.2	88.5	14.3
3	112.1	24.9	30.3	55.2	9.5
4	73.4	16.3	15.9	32.2	6.2
5	46.3	10.3	5.8	16.1	3.9
6	30.7	6.8	0	6.8	2.6

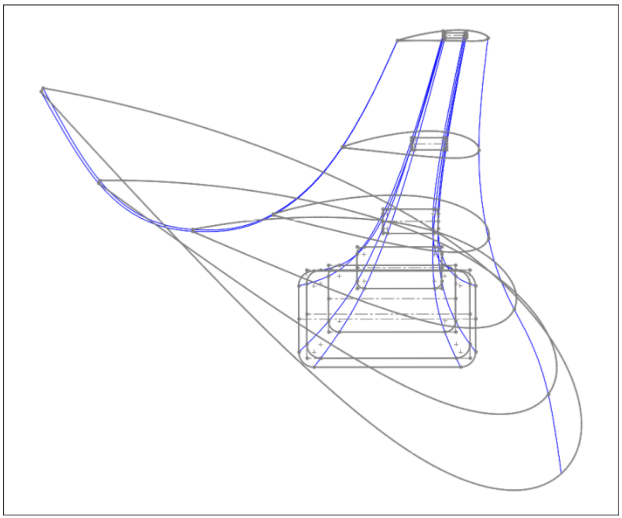

Figure 3. Gained wound spar cross-sections.

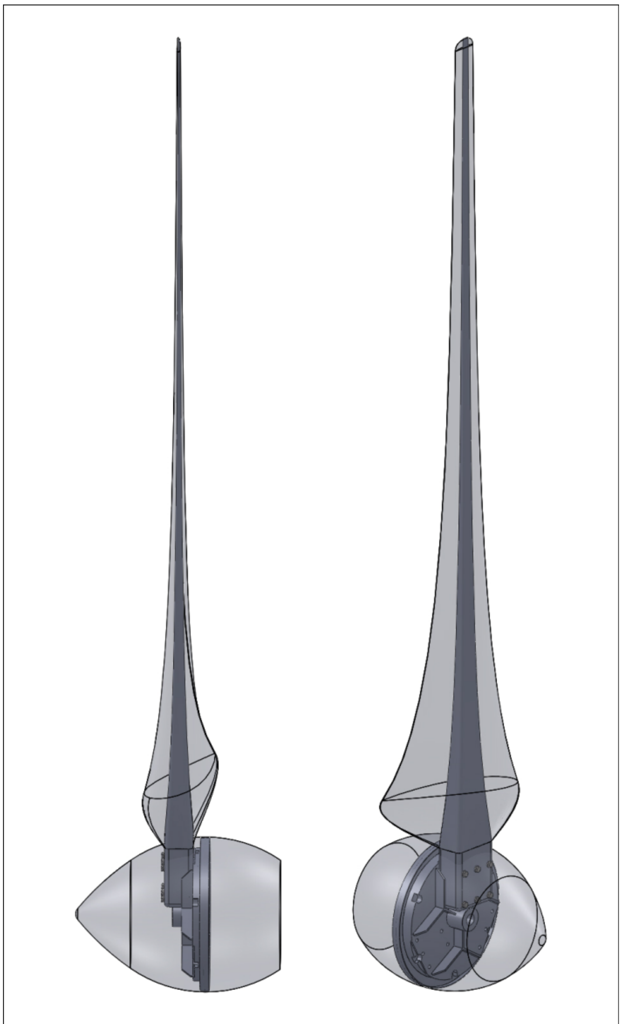

Figure 4. 3D model of the designed wound spar within the blade external aerodynamic shape.

3. FINAL REASONS

Aeolian blade outer contour is designed from aerodynamical considerations, but once being built, it must also be sufficiently strong and stiff. The rotor blades of the present-day wind turbines are made almost exclusively of glass fibre reinforced plastics and, most recently, of carbon fibre reinforced plastics. To make the blade stronger and stiffer, a wound spar or so-called webs are glued on between the blade suction and pressure sides (fig. 5). The wound spar or the webs that form a box-like structure is the most important structural part of the blade. It acts like a main beam on which a thin skin is glued defining the aerodynamic shape of the blade. Often, especially in the case of small rotor blades, the last is not carrying loads or could face only a part of the acting forces, leaving the most into account of the spar box. Thus, the integration of a strong and stiff wound spar into an efficient aerodynamic shape is a complex and always present problem solved in several ways, one being presented in the paper.

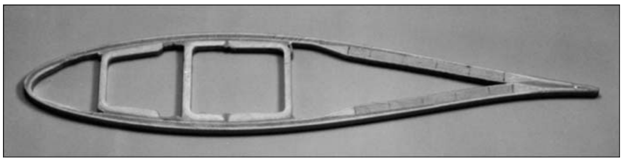

Figure 5. Modern rotor blade cross-section in laminated shell construction with spar box.

The calculus presented above is conducted on the basis of longitudinal distribution of the airfoils chords length. Since it follows a certain harmonious consecutiveness, the same compliance of the wound spar cross-sections will be obtained. The harmonious transition from one cross-section to another is the basic problem solved by the presented methodology, even more when several different types of aerodynamic profiles are used. With small nonconformity it can be applied for irregular shaped spar boxes design too.

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