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Reducing blade manufacturing cost of Vertical Axis Wind Turbines while maintaining aerodynamic performance

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Abstract

Vertical axis wind turbines (VAWTs) can be built in tight arrays with alternating directions of rotation to increase global performance. However, VAWT farms are economically not yet competitive compared to horizontal ones. This work is focused on ways to improve global profitability by using low-cost large-series production technologies, as well as reviewing the materials used for blade production. Knowing the performance of such designs under operating conditions is crucial. The methodology proposed here, combining structural and aerodynamic analysis, allows to look for new structural designs capable of reducing the manufacturing costs while ensuring performance of the turbine.

Manufacturing and Engineering for Low-Cost Metal Blades

The idea to design a new low-cost blade, capable of being manufactured by using large-series production technologies, makes sense when it is considered together with the construction of large farms of counter-rotating VAWT (Figure 1).

So the approach to follow should be, on the one hand, investigating arrangements of turbines for optimized wind farms, and, on the other hand, designing a metal blade that is cheaper but still light and stiff enough to compete with its fibre-reinforced counterparts. Competitive in this case means: equal performance (turbine energy production, emissions), decreased cost (materials, manufacturing process) and increased sustainability (production energy, recycling, lifetime).

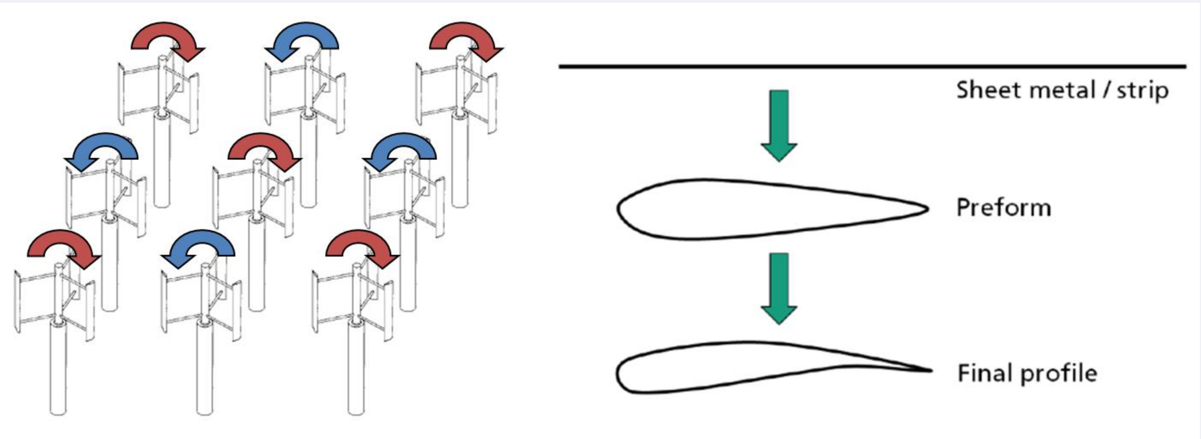

Figure 1 Group of counter-rotating VAWTs (left) and proposed manufacturing steps (right)

Wind turbine blades are currently made of fibre-reinforced materials, which are quite costly (up to 30 % of the turbine cost). The use of metal could facilitate the production process of the whole turbine and would additionally have advantages with respect to issues like robustness, sustainability and recycling. The proposed manufacturing process is a combination of roll forming for a preform geometry and hydroforming as a calibration step (Figure 1).

The methodology proposed here, combining stress and aerodynamic calculus, allows to look for new structural designs capable of reducing manufacturing costs while ensuring aerodynamic performance. The followed workflow is detailed in Figure 2.

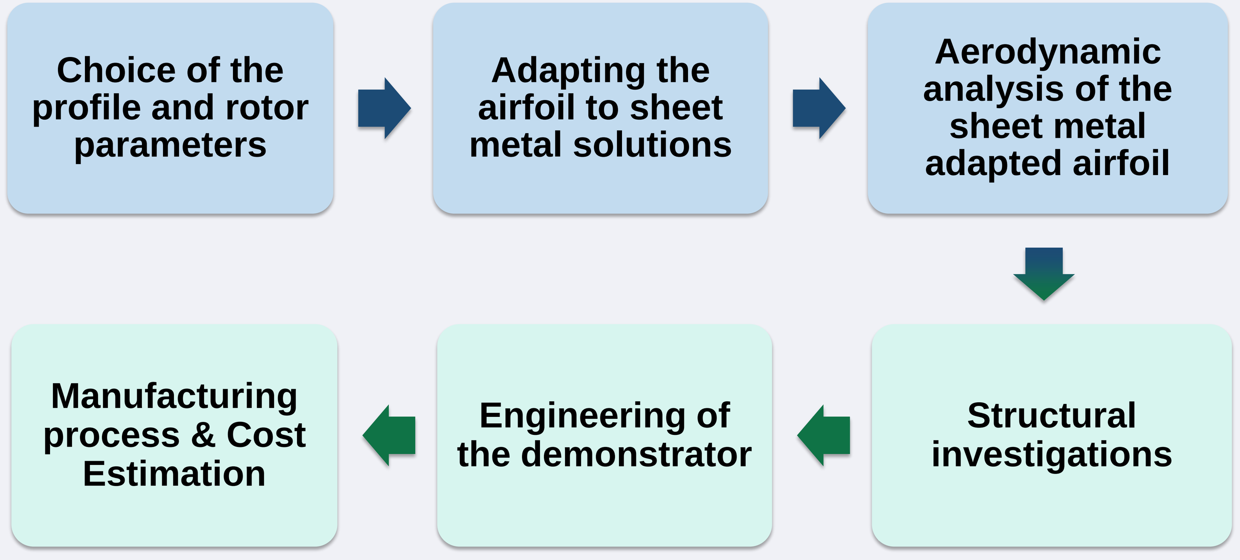

Figure 2 Workflow followed for the design of the low-cost blades.

Aerodynamic Analysis of the Blades

- Non-symmetrical profiles offer higher potential to be used as part of the VAWT. That is the reason why the S2027 was the preferred option for this design. Further analyses about remaining turbine design parameters (Table 1) were conducted following standard procedures for VAWT.

Table 1 Turbine main characteristics.

Diameter	2.4 m
Blade Chord Length	180 mm
Blade length	3.0 m
Max rpm	240

- Airfoil geometry should be adapted keeping in mind manufacturing constrains. Thus, the trailing edge initially defined as sharp without any radius should be adapted. Four different designs were proposed and studied by means of CFD computations; a trailing edge with a small radius was revealed as the best option.

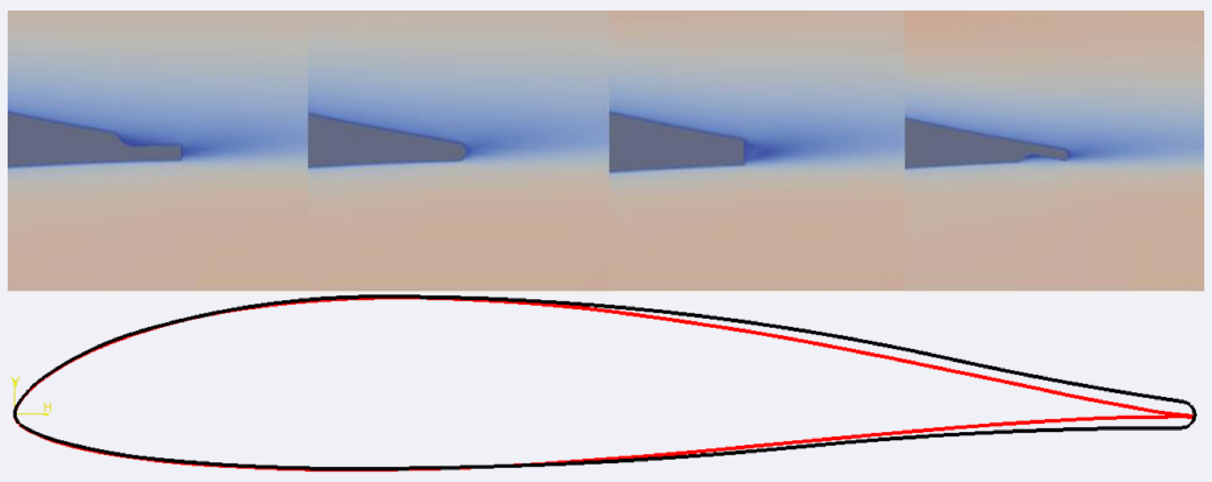

Figure 3 Velocity plots for the different trailing edge shapes (upper part) and black sheet metal adapted profile in comparison with the red original S2027 (lower part)

- CFD computations for the 3D blade at different angles of attack were performed in order to estimate more realistic aerodynamic coefficients, by considering some three-dimensional effects over the pressure distribution or tip effects.

Structural and Manufacturing Analysis of the Blades

- Inertial forces are dominant (90 % for a steel blade) but aerodynamic forces also have to be considered for load cycle/fatigue calculations. The number of rotations during the lifetime can sum up to 10^8, resulting in considerable fatigue.

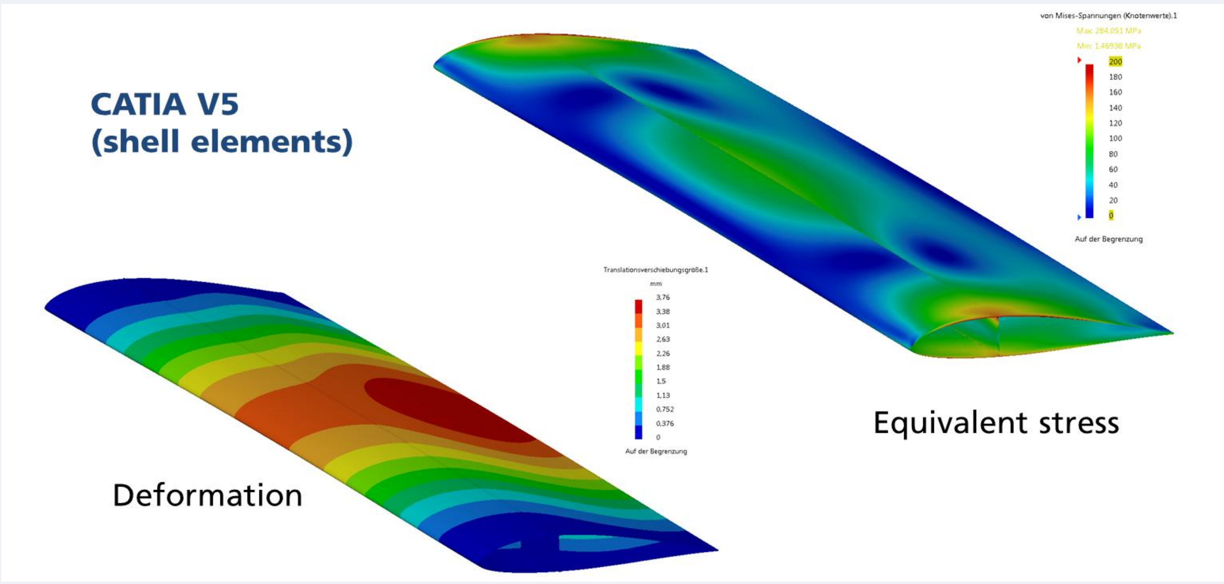

Figure 4 Deformation and equivalent stress maps obtained for a blade made of 1.4404

- Structural studies carried out at operational conditions (Table 1) show that:
  - ✓ Blade bending length (between the struts) should be limited to 1.5 m for limiting the (exponential) increase of the equivalent stress.
  - ✓ Thickness of 1.0 mm seems to be a good compromise between blade mass and deformation / equivalent stress.
  - ✓ Perpendicular inner reinforcements slightly help to reduce the deformation differences between upper and lower profile surface.
  - ✓ Using different metal materials (Figure 5) won't have a big influence on the deformation; max. equivalent stress decreases with the E-modulus.

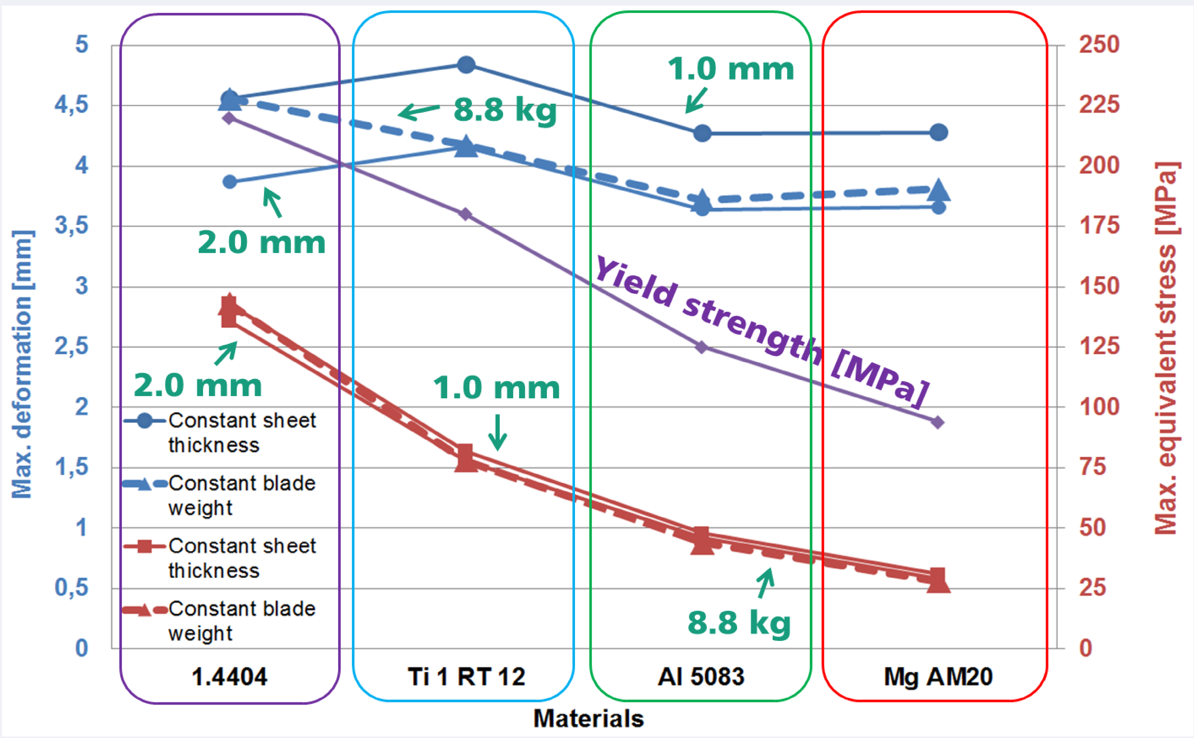

Figure 5 Influence of material choice and sheet thickness on maximum blade deformation and equivalent stress

- When choosing the material questions of production (price, formability) are more important. Stainless steel has the advantages of a high corrosion resistance, availability, relatively low costs, well-examined forming behavior and good fatigue durability. Dual phase steels offer a further cost reduction potential when combined with an anti-corrosion coating.

Table 2. Cost analysis and comparison for blade manufacturing

	Metal prototypes	Metal series	GFRP series
R&D, Tooling cost	121 €	20 €	6 €
Material cost	43 €	10 €	72 €
Manufacturing cost	33 €	5 €	210 €
Sum (per blade)	**197 €**	**35 €**	**288 €**

- The series manufacturing process combination of roll and hydroforming offers a flexibility for future rotor designs (curved blade axes, varying cross sections). The bottleneck is the hydroforming process, where the press closing force is limited as well as the maximum achievable blade length.

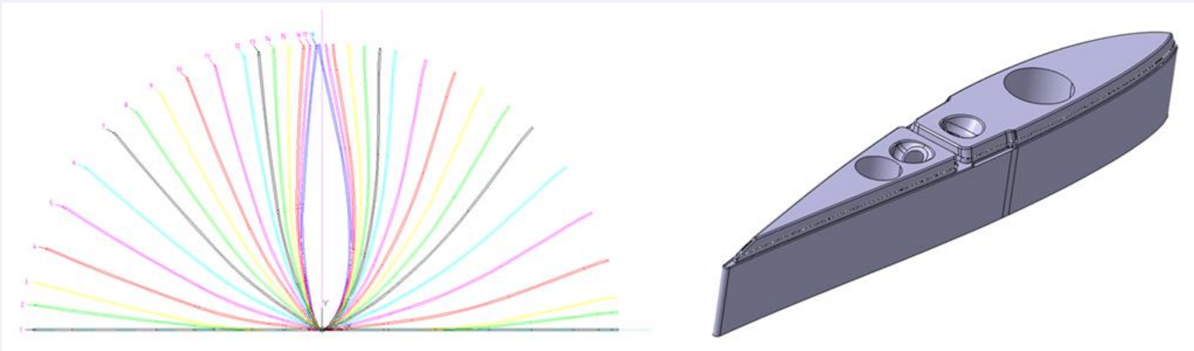

Figure 6 Roll forming profile flower (left) and possible hydroforming sealing stamp (right)

Conclusions

The approach followed in the present work has shown that it is possible to build a competitive metal blade for small to medium size VAWTs.

The summarised results suggest that the best a priori option could be a blade in 3.0 m length at a chord of 180 mm, made of stainless steel in 1.0 mm sheet thickness and with a perpendicular sheet as inner reinforcement. This design has a moderate deformation and a tolerable stress level combined with a minimum amount of material and associated manufacturing costs. First estimations show that at mass use and production (economies of scale), such metal blades have a 90 % reduction potential in their production costs compared to fibre reinforced (GFRP) ones for single turbines.

In conclusion, by making use of mass production and performance enhancement using farms of counter-rotating turbines it is possible to maintain the same turbine performance that can be achieved with traditional composite blades as well as improve global profitability. By building a demonstrator, these theoretical results will be verified in practice.

References

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