Brazil Windpower 2015
conference & exhibition
1 A 3 DE SETEMBRO DE 2015
RIO DE JANEIRO - BRASIL

Optimisation Methods Applied to Wind Turbine Blade Design

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ABSTRACT

The paper presents the results of applying optimization methods in a wind turbine blade design. Master airfoils and blade geometry are optimized in a combined way in order to minimize cost of energy. Based on starting 2D geometrical blade distributions, structural parameters and several master airfoils the method allows finding blade geometries being close to the expected performance while keeping loads at reasonable levels. The proposed method iterates between blade and airfoil design in order to converge in a final optimum solution, based on applicable design drivers.

Keywords: *Airfoil design, Blade design.*

1 INTRODUCTION

Although there have been significant progress over the last 20 years, wind turbine blade design still is a key engineering challenge for wind turbine manufacturer. In this context, one blade design approach is for instance to optimize each blade section independently in terms of Annual Energy Production (AEP) and then to generate the blade geometry by creating smooth surfaces between those sections.

However, it seems that this approach does not lead to an optimum design since structural requirements are kept out of the loop [1]. Hence, and in order to provide highly competitive wind turbines, design approaches are required that optimize the blade geometry more in terms of Cost of Energy (CoE) rather than just focusing on AEP.

Besides the change in scope, design techniques have changed in the recent years. Thanks to the high computational capacity, optimization algorithms are applicable demonstrating an improvement on CoE performance

2 METHODS AND DESCRIPTION

To limit the number of design variables structural optimization is not considered explicitly in the proposed method. The approach only demands the following input variables that are schematically illustrated in Figure 1.

- Number of blade sections
- Distance r of radial sections to the blade root
- Chord distribution
- Twist distribution
- Relative thickness distribution
- Master airfoils including airfoil shape and existing or target polars
- Mass and stiffness

Chord, twist and relative thickness distributions are then parameterized using B-splines to further reduce the number of design variables. Besides, assuming these curves, the resultant geometry will be smooth, ensuring you optimize a smooth surface rather than smoothing an optimized design obtained by other techniques.

The combination of the proposed curves generates a candidate blade which is evaluated in terms of power and loads performance, with the use of aero-elastic codes. The evaluation obtains different parameters that conform a cost function, such as: AEP, blade mass, tower loads, etc. These parameters are compared with target ones, giving a final evaluation of the candidate. To optimize the blade in terms of CoE the control point coordinates are then varied within user defined boundaries using first evolutionary and then, in a second step, gradient based algorithms until the defined cost function reaches a minimum.

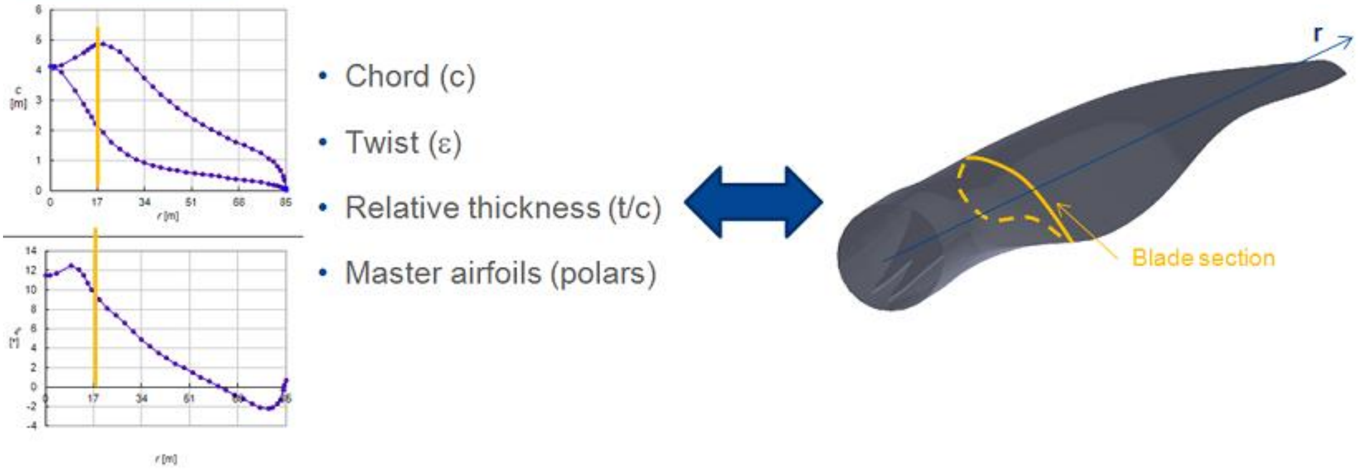

Figure 1 - Blade section definition (right) and chord, twist and relative thickness distribution as a function of the blade radius r (left)

In case the required CoE is out of reach considering the master airfoils available in the airfoil database realistic target polars are prescribed in a first design loop. In a separate design process, new airfoil designs are carried out to match the required polar performance.

One way to find efficiently the unknown airfoil geometries is to use Class-Shape-Transformation (CST) [2] methods to parameterize the airfoil geometry and to couple it with a rapid panel solver and a powerful optimizer. In the proposed method airfoils located in the outer part of the blade having a maximum thickness >> trailing edge thickness are parameterized using Bernstein coefficients (see an example in left picture in Figure 2) whereas airfoils close to the blade root with a possible trailing edge thickness closer to the order of magnitude of the maximum thickness are represented by four connected Bézier curves as proposed by Botasso [1] (as schematically illustrated in Figure 2).

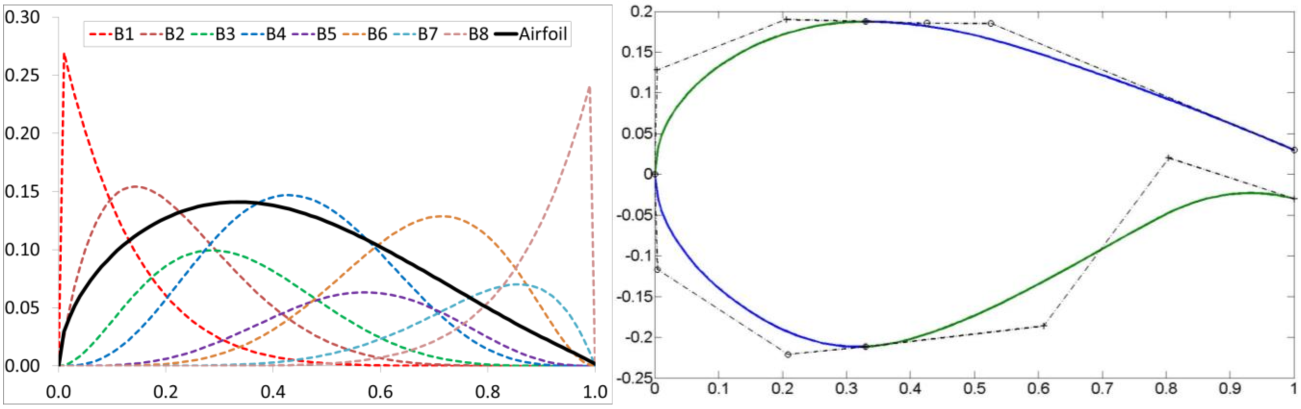

Figure 2: Parameterization method for master airfoils: left using Bernstein polynomials (only airfoil suction side is shown) and right using Bézier curves

In the following coefficients are varied to find the best compromise between the prescribed target performance considering efficiency, stall margins, behavior under turbulence inflow conditions (for clean and forced transition) and structural requirements such as geometry limits, family compatibility, maximum thickness and thickness skew.

In each optimization loop airfoil performance is evaluated automatically using the improved panel solver RFOIL [3] in combination with empirical correction factors that are supposed to match wind tunnel measurements of similar, previously measured airfoils having a similar maximum thickness and the same design Reynolds number. A more extensive work about the airfoils validation can be found in [4].

3 RESULTS

In the following some first results of the previously presented method are shown. In the first section A the results of blade optimization are shown and in the section B the results of a target airfoil approximation are highlighted.

3.1 Blade design

In Figure 3 are shown the results of an optimization run for a blade over 1250 iterations using an evolutionary algorithm. Evolutionary algorithms are convenient to explore the space of the design variable and to find the global optimum. It can be seen that the prescribed cost function is converged.

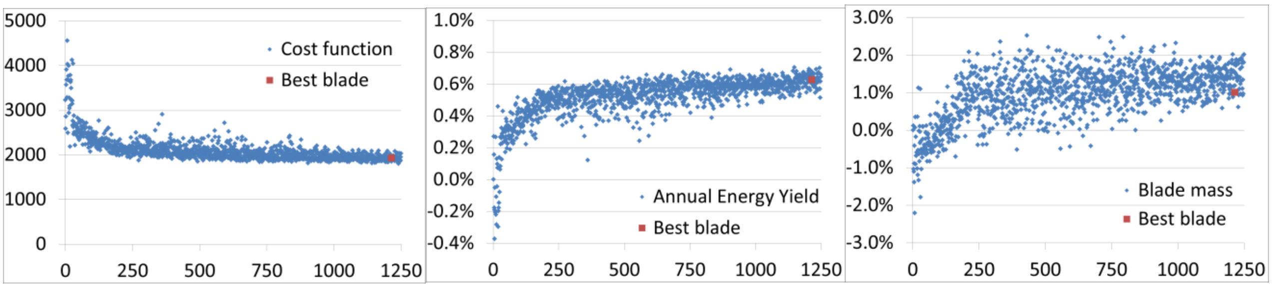

Figure 3: Cost function (left), AEY (middle) and blade mass (right) evolution during a blade shape optimization run over 1250 iterations.

3.2 Target airfoil approximation

To achieve the blade performance shown in Figure 3 a target polar was used. In a second step it was then necessary to find the airfoil providing the assumed polar values. For this purpose an existing airfoil was used to start the optimization with the objective to reduce lift and hence loads and to increase performance under rough conditions for which boundary layer transition occurs close the leading edge. In Figure 4 it can be observed that thanks to the described method, an airfoil geometry can be found satisfying to yield the desired blade performance.

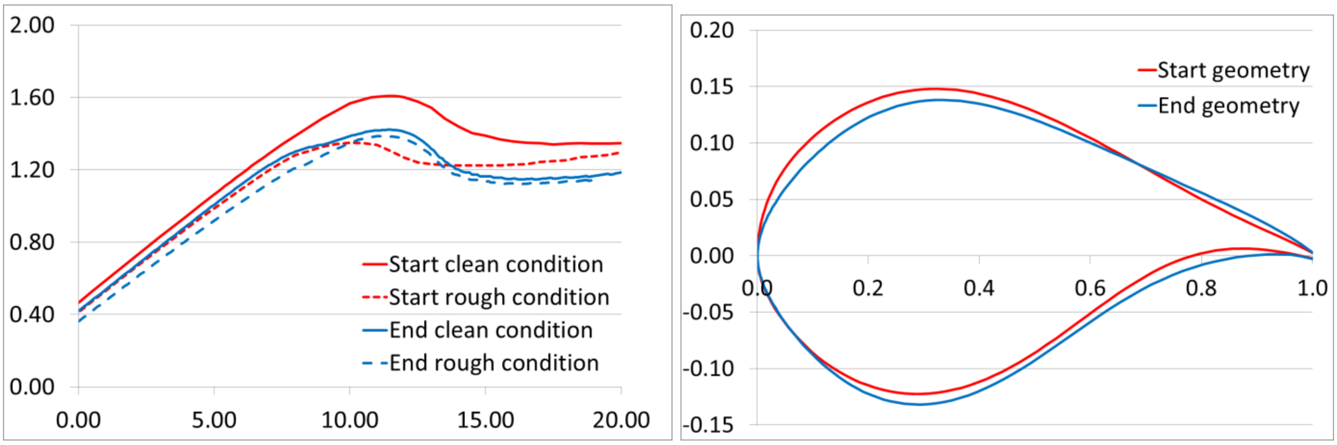

Figure 4: Comparison of starting airfoil performance (left) under clean and rough conditions (forced transition) at 7E+06 Reynolds number with an optimized low lift airfoil. Right: geometry comparison

4 CONCLUSION

This paper defines a methodology to combine airfoil and blade design in order to improve considering not only aerodynamic requirements, but also loads or structural inputs. With this transversal design, cost of energy is reduced. Besides, new design techniques as optimization methods are applied with satisfactory results.

REFERENCES

[1] Bottasso, C.L., Croce, A., Sartori, L. and Grasso, F., F ree-form design of rotor blades, *Journal of Physics*, Conf. Ser. 524 012041, 2014.

[2] Straathof, M. H., van Tooren, M. J. L., Voskuijl, M., Koren, B. , Aerodynamic shape parameterisation and optimisation of novel configurations, The Aerodynamics of Novel configurations: capabilities and future requirements. Proceedings of the 2008 Royal Aeronautical Society Annual Applied Aerodynamics Research Conference, London, 27-28 October, (2008)

[3] Timmer, W.A. and van Rooij, R.P., “SUMMARY OF THE DELFT UNIVERSITY WIND TURBINE DEDICATED AIRFOILS”, AIAA-2003-0352, 2003

[4] Canal, M., Miguel, D., New Airfoil Family Design for Large Wind Turbine Blades. AIAA-2015-0996

BIOGRAPHIES

Christian Engfer – Stuttgart, 1982. Doctoral research study in aircraft aerodynamics (2015)

He is the aerodynamic expert into Technology group inside Loads & Aerodynamics area, in Alstom Wind. He is in charge of the airfoil and blade aerodynamic design, covering the expertise of Computational Fluid Dynamics.

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