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AERODYNAMIC BENCHMARKING OF THE DEEPWIND DESIGN

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Abstract

The aerodynamic benchmarking for the DeepWind rotor is conducted comparing different rotor geometries and solutions and keeping the comparison as fair as possible. The objective for the benchmarking is to find the most suitable configuration in order to maximize the power production and minimize the blade solicitation and the cost of energy.

Different parameters are considered for the benchmarking study. The DeepWind blade is characterized by a shape similar to the Troposkien geometry but asymmetric between the top and bottom parts. The blade shape is considered as a fixed parameter in the optimization process and, because of different blade element radii, it will experience different tip speed ratios in the same operational condition. This leads to a complex optimization problem, which must be carefully analyzed in order to find a suitable parameter set.

The number of blades in the analysis is varied from 1 to 4. In order to keep the comparison fair among the different configurations, the solidity is kept constant and, therefore, the chord length reduced. A second comparison is conducted considering different blade profiles belonging to the symmetric NACA airfoil family. Finally, a chord optimization along the blade span is conducted, in order to find the optimal chord distribution to maximize the energy extraction.

Simulation Algorithm

The BE-M algorithm considered in the present work is the Double Disk Multiple Streamtube developed by Paraschivoiu improving the Single Disk Multiple Streamtube model originally proposed by Strickland.

The main input for this method are the operative conditions, blade geometry and airfoil lift and drag coefficients. In the present work, the database provided by Jacobs for NACA 0015, NACA 0018 and NACA 0021 and by Bullivant for NACA 0025 are considered. These database are provided for different Reynolds number and angles of attack lower than 30 deg: in order to overcome this limitation, the aerodynamic coefficients for higher angles of attack are derived from Sheldahl, whose reliability for lower angles of attack is questionable.

Given the DeepWind rotor size, the validation should be conducted focusing on high Reynolds numbers and therefore selecting a big rotor size wind turbine. The experimental results for the Magdalen Island 37m wind turbine by Templin are considered. The numerical results compared against experimental measures are shown in Figure 1.

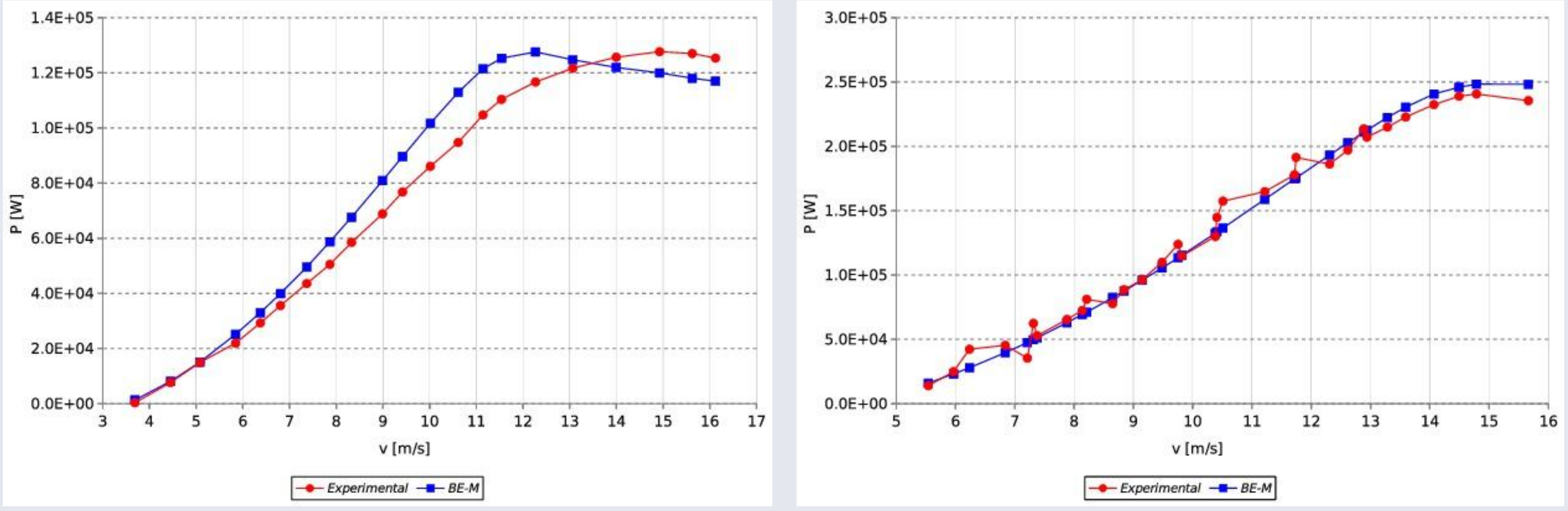

Fig. 1: Experimental vs Numerical Performance at 29.4 rpm and 36.6 rpm for Magdalen Island 37m vertical axis wind turbine.

Case Study

In the present work, the rotor architecture from the DeepWind project is considered, Figure 2. The rotor shape was optimized considering inertial and gravity forces and is kept constant in the aerodynamic benchmarking. The blade shape is shown in Figure 3. The baseline rotor configuration is characterized by the parameters reported in Table 1.

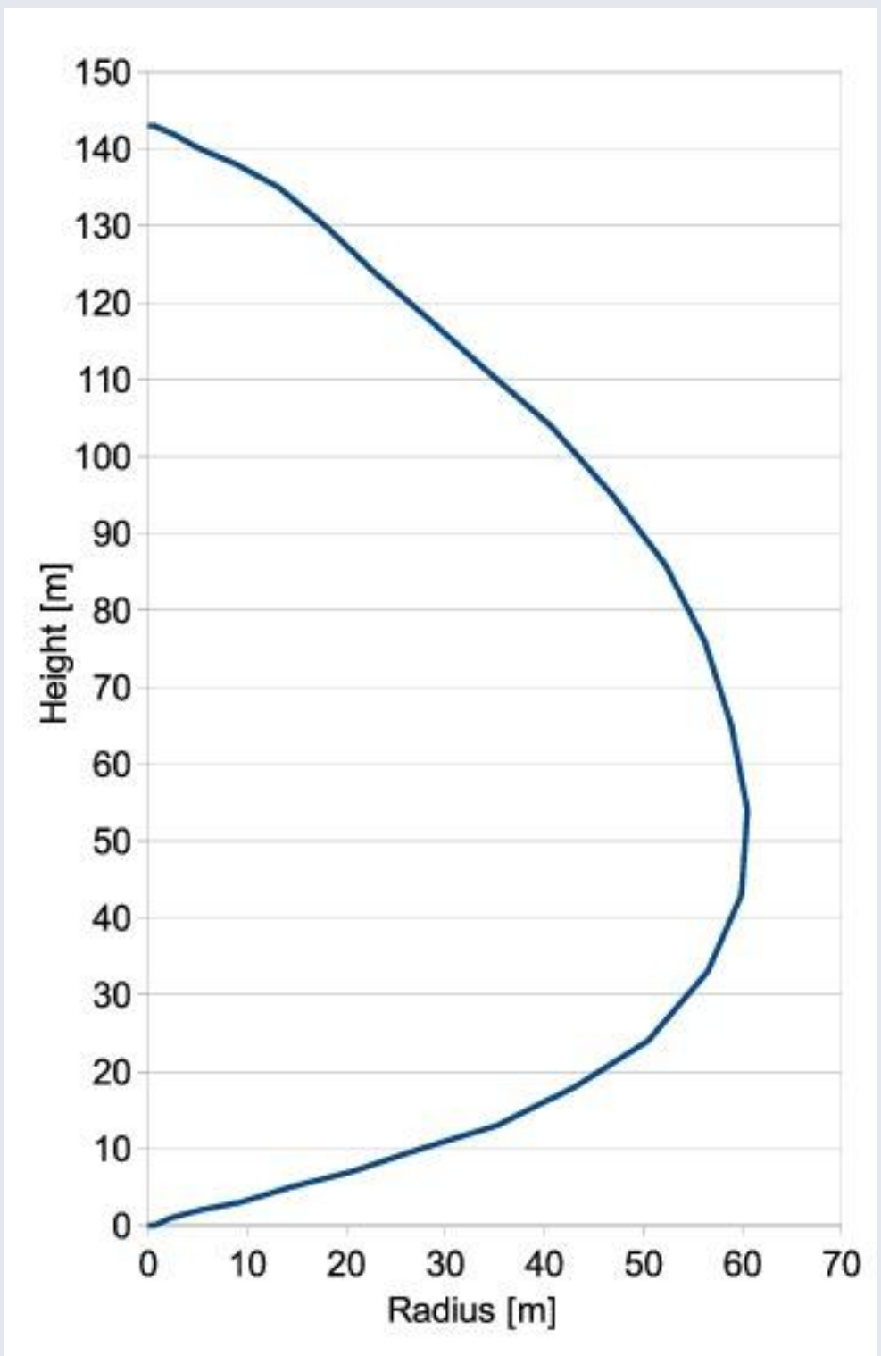

Fig. 3: DeepWind optimized blade rotor shape

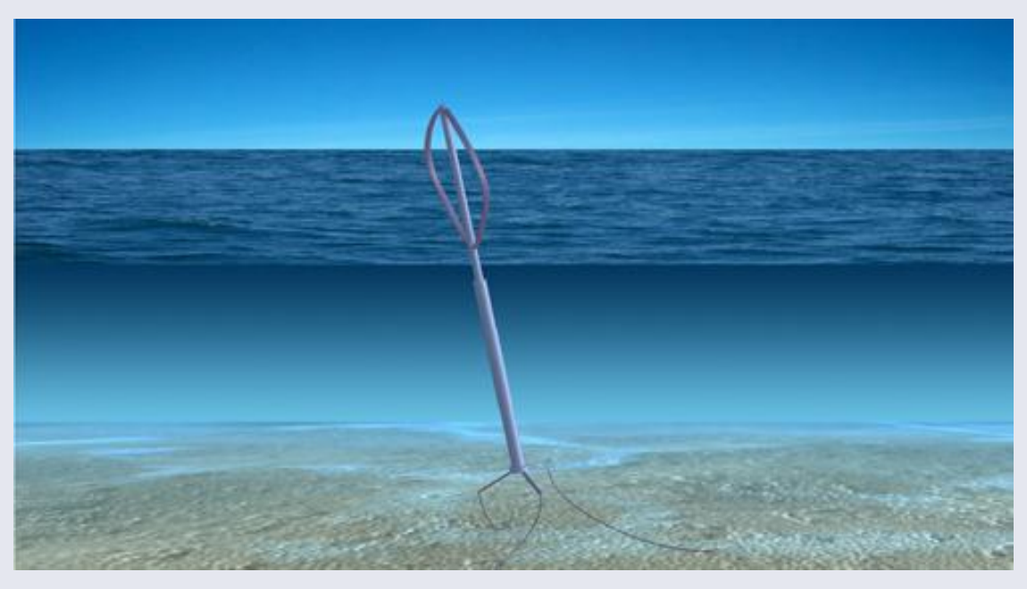

Fig. 2: DeepWind concept

Height	143 m
Radius	60.5 m
Airfoil	NACA 0018
Chord	5 m
Blade number	2
Solidity	0.165
Max. rotation speed	6 rpm

Table 1: Baseline parameters for the DeepWind project rotor

Benchmark Results

- **Number of blades**

The number of blades is object of the present investigation. The same solidity among the different configurations is considered by decreasing the chord size. The loads are represented by the thrust C_T and lateral force C_N coefficients and represent a measure of the stress in the tangential and the normal direction, shown in Figure 4.

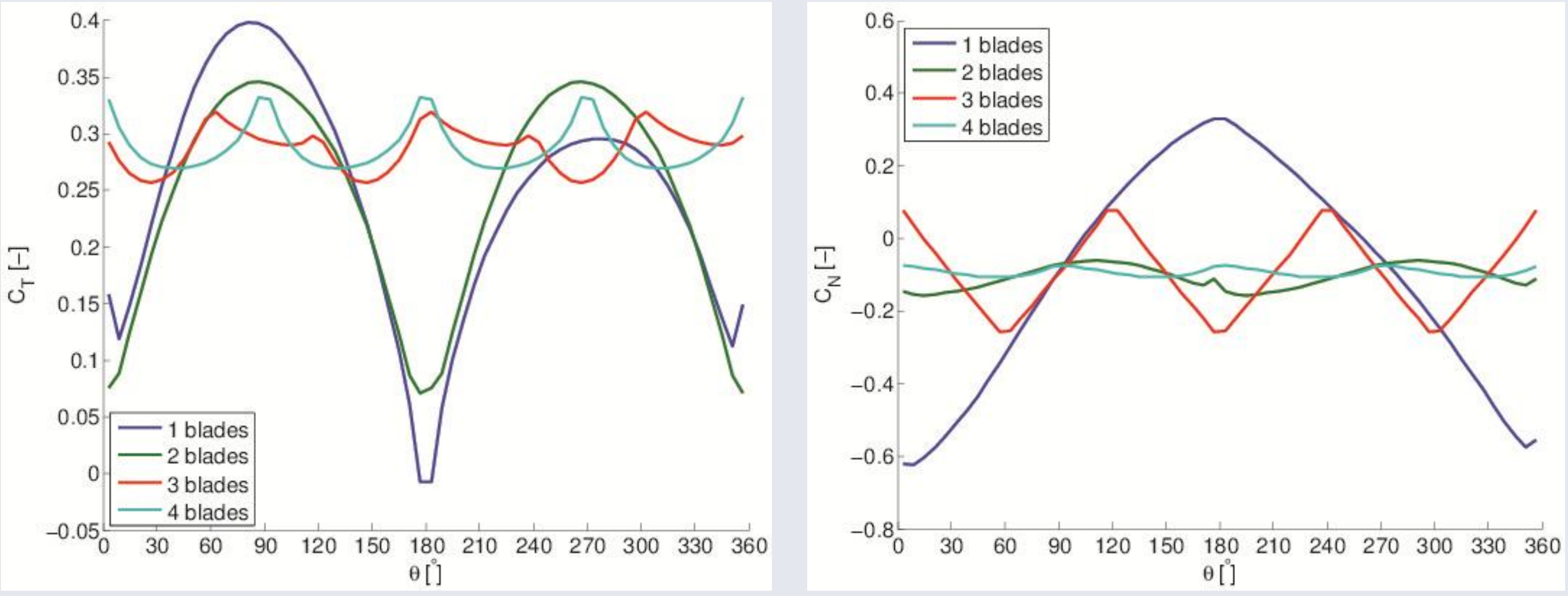

Fig. 4: Rotor thrust and lateral force coefficients computed by BE-M algorithm with respect to the different number of blade

- **Blade airfoil**

Different blade airfoils are tested with respect to the baseline configuration in order to find the highest power production and analyze the rotor loads, shown in Figure 5. The considered airfoils belong to the symmetric NACA family and their choice is limited by the availability of the aerodynamic coefficients.

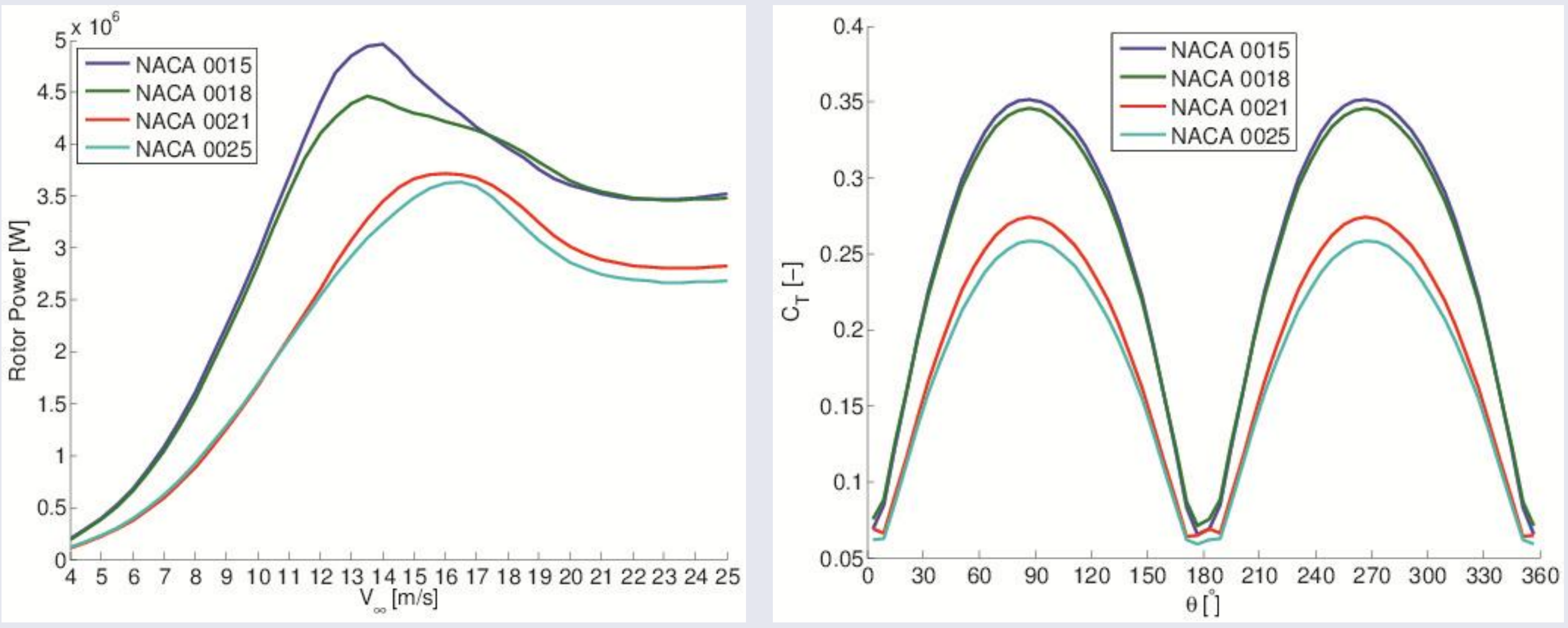

Fig. 5: Rotor performance and thrust coefficients computed by BE-M algorithm with respect to the different airfoil configurations

- **Chord distribution**

The blade is characterized by a variable radius and every blade section is operating at different tip speed ratios. The optimal chord varies along the blade span. In order to find the optimal distribution, the simulation algorithm is coupled with an optimization algorithm, a genetic code. The chord is varied between 1 m and 12 m. The optimal chord distribution and the resulting power curve are reported in Figure 6

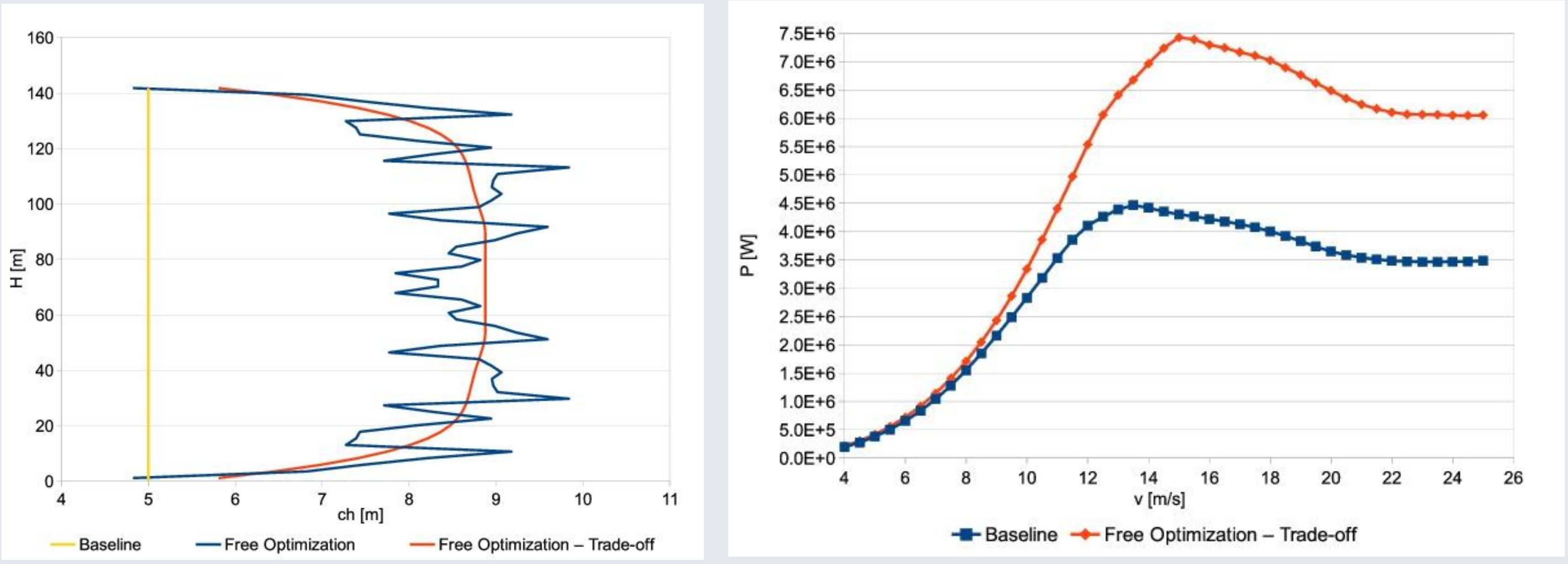

Fig. 6: Optimal chord distribution and power curves for the different configurations

Conclusions

A blade number equal to two or three is equally a good choice with respect to the rotor loads. Further reduction in the loads can be obtained by adding one more blade. However, this would increase substantially the rotor cost.

NACA 0015 and NACA 0018 are the two best alternatives from a power production point of view. Increasing the airfoil thickness would lead to a sensible decrease in the performance, however linked to a decrease in the blade loads.

A new optimal chord distribution is obtained, providing a sensibly increased power production but at the same time a substantial increase in the thrust coefficient. This very interesting result represents only the first step for the optimization procedure, which will involve additional iterations between the structural and aerodynamic analysis.

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