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# The wind shielding factor for wind turbine blades stored in groups

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**SUMMARY:**
With the growing market for green – and particularly, wind – energy, larger wind turbine blades are required. This generates new engineering challenges, especially related to the transport and storage of such blades. The study presented in this paper is focused on the estimation of wind actions on large wind turbine blades during their storage in grouped arrangements. Due to the aerodynamic interference, there is a possibility that the wind action on subsequent blades in a row can be larger than on the windward-facing one. Furthermore, the complex and curved cross-section shape of the blades makes it impossible to rely on standardized data that only takes into account more basic shapes. To estimate the level of this interference, a shielding factor was established, which is the ratio of the aerodynamic coefficient of a given blade in the arrangement to the aerodynamic coefficient of either the windward blade or an isolated blade. The tested groups consisted of a total of 5 blades. Tests were done in conditions that would correspond to the 2D flow, for 2 different sections of the blade (near the base and near the tip). Aerodynamic coefficients were calculated based on the wind pressure measurements.

*Keywords: wind tunnel tests, wind turbine blades, aerodynamic interference, shielding factor*

## 1. INTRODUCTION

The goal of the wind tunnel campaign was to determine the shielding factors for a group of blades, depending on their position in the group and the spacing between the blades. This was done on two separate cross-sections, representing the part of the blade near the root and the tip. The tests were done to validate CFD simulations and therefore performed in equivalent conditions: uniform flow and smooth floor (in principle no friction) in the closed-circuit boundary layer wind tunnel at the Wind Engineering Laboratory of Cracow University of Technology (more information about the tunnel can be found in Flaga et al., 2020), used for these tests with uniform flow conditions.

## 2. EXPERIMENTAL SETUP

### 2.1. Scope and test cases

The tests investigated the effect of the following parameters for each blade of the group:

- 2 different cross-sections: near the root (airfoil 1) and near the tip of the blade (airfoil 2);
- 5 different axis-to-axis spacing arrangements (between 3.38 m and 7.88 m in full scale);
- 2 different boundary conditions (with/without a baseplate that simulates the ground);
- 4 different blades regarding their position in a row of blades (see Fig. 2 for numeration);
- 2 different wind angles of attack (0° and 180°).

In the case of airfoil 1, the 2 different measured levels were done with 2 different surface roughness types on the models – smooth at the upper level (green lines in Fig. 2) and rough at the lower level (red lines in Fig. 2) – to assess the potential Reynolds number influence. In the case of airfoil 2, the measurements at 2 different levels were done to ensure the flow was two-dimensional. A total of 160 test cases were investigated during the wind tunnel campaign. Based on the test results (measured wind pressures), two different aerodynamic coefficients were calculated for each tested case: $C_x$ – drag coefficient, or aerodynamic coefficient in the along-wind direction, and $C_z$ – lift coefficient, or aerodynamic coefficient in the across-wind direction.

### 2.2. Models for the wind tunnel tests

The models for the tests were prepared with 3D printing technique. For each of the airfoils, 2 of the models were done as proper test models with pressure sensors installed inside and the remaining 3 were just dummy models. The measurements were always done on the first (windward) blade for reference, while the other tested model was changed between positions 2-5 for each test series. A total of 30 pressure taps were installed along the circumference of airfoil 1 at each level and 23 pressure taps at each level of airfoil 2.

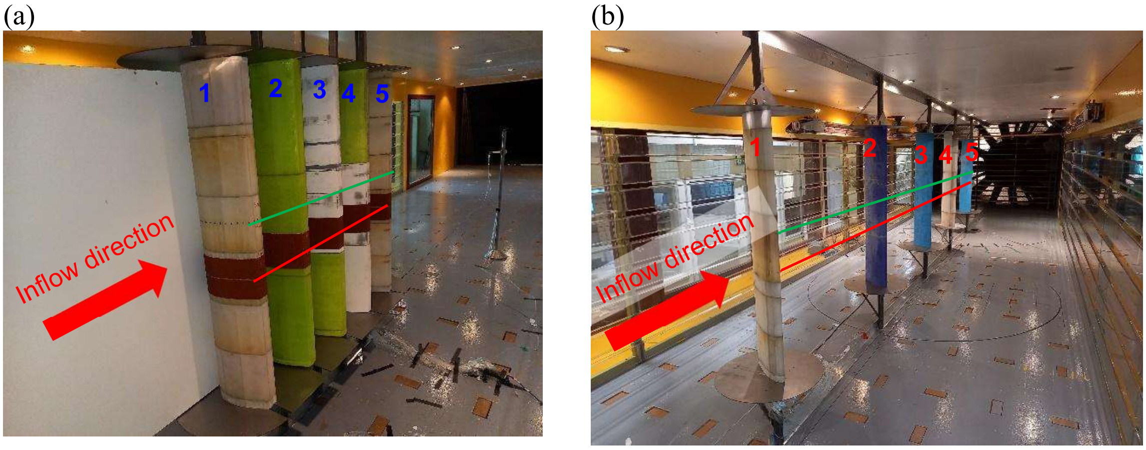

**Figure 2.** Models of airfoils in the wind tunnel working section: (a) airfoil 1, with baseplate; (b) airfoil 2, without baseplate.

The test setup was developed to model the 2D flow around the blades (Bearman, 1997); therefore, the cross-sections are constant along the whole length of the model. At both ends of the models, thin metal plates were installed as boundary disks to separate the flow detachment and mitigate the so-called ‘tip effect’. The model scales used in the tests were different for airfoils 1 and 2, as they had to account for the blockage ratio inside the wind tunnel (Antoine and Olivari, 2009). The goal was to keep the blockage ratio below 10% for reliable results. In the case of airfoil 1, a scale of 1:26.7 was used and for airfoil 2, a scale of 1:6.3 was used. Due to the dimensions of the wind tunnel and the models, the tests were done in a vertical arrangement (rather than the intended in real-life horizontal arrangement) of the blades, so that the whole system was rotated 90° about the wind axis for the purpose of the tests. The models for both airfoil types inside the working section of the wind tunnel are shown in Fig. 2. One should notice the “baseplate” which simulates the effect of the ground and, because of this rotation of the model, is placed over a vertical plane in this case.

## 2.3. Wind tunnel measurements

Each measurement that was conducted in the wind tunnel resulted in 5 000 samples for each point (20 seconds with a sampling frequency of 250 Hz). During wind tunnel tests wind velocity was stabilized at about 19.5 m/s, which corresponds with Reynolds number $2.57 \cdot 10^5$ at a smooth surface. The turbulence level was uniform along the height of the tunnel (no additional turbulence-generating elements were used) with magnitude oscillating around 4%. The reference wind pressure was measured at undisturbed airflow at the front of the model at the reference height $z_{ref} = 0.75$ m. To obtain a good measure of aerodynamic interference between the blades through a direct parameter, the shielding factors were defined, which were the ratios of the aerodynamic coefficient for a given blade to the corresponding aerodynamic coefficient of either the windward (first in the row) blade during the same measurement or the isolated blade in the corresponding test conditions.

## 3. WIND TUNNEL CAMPAIGN RESULTS

Due to a large number of test cases investigated and for the sake of brevity, only exemplary results are shown below, which outline the main comparisons of the results in Fig. 3 and Fig. 4.

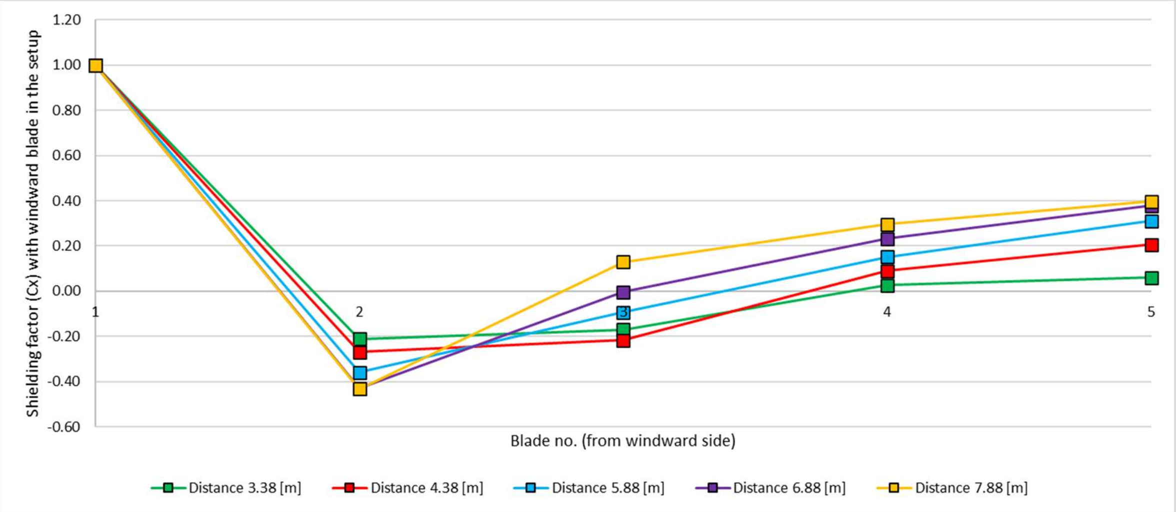

**Figure 3.** Exemplary comparison of shielding factor for $C_x$ with respect to the first blade in a row between different spacings of the blades for airfoil 1, at the smooth part, without the baseplate and for the wind angle of attack of 0°, compared against the positions of the blades in a row.

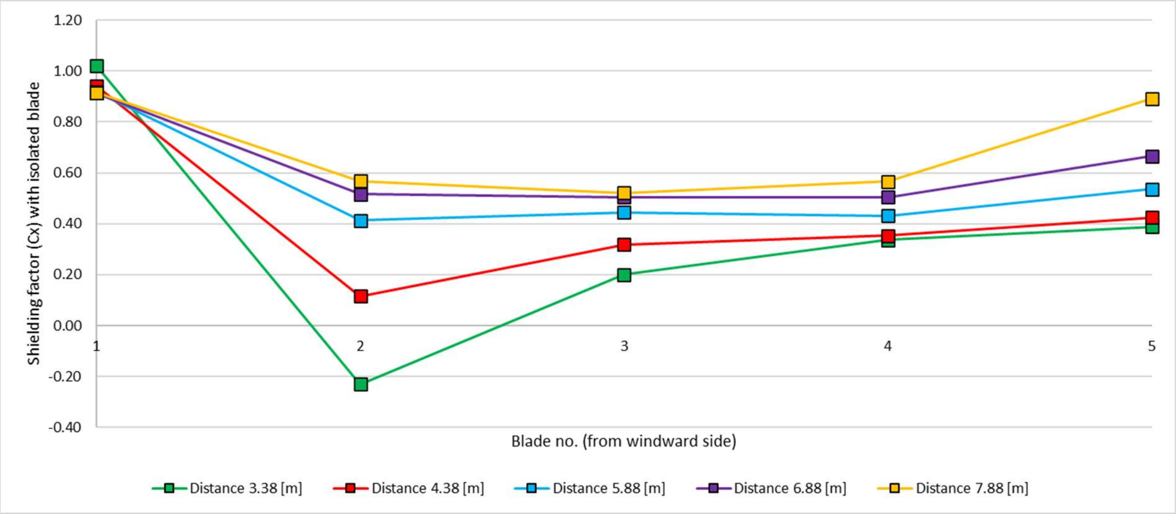

**Figure 4.** Exemplary comparison of shielding factor for $C_x$ with respect to the isolated blade between different spacings of blades for airfoil 2, at the lower measuring level, without the baseplate and for wind angle of attack of 180°, compared against the positions of the blades in a row.

## 4. CONCLUSIONS

The following main conclusions can be drawn from the studies for each of the tested airfoil types:

- The values of the shielding factor for $C_x$ differ with respect to the spacing – generally, a pattern for airfoil 1 can be observed in the case without the baseplate for rough and smooth surface, for both 0° and 180° wind angles of attack, where in most conditions for the 2nd blade in a row, the value of this coefficient will decrease with the increase of the spacing, while for the 3rd, 4th and 5th blades, it increases with the spacing;
- Furthermore, for the airfoil 1, with larger spacings between the blades, the differences between the values of shielding factor for $C_x$ for each blade in a row are larger, which is especially prevalent in the cases without baseplate;
- For blades 2-4, there is a tendency of the shielding factors to stabilize and converge into a constant (limit) value for a given spacing. This is particularly visible for airfoil 2, where the spacings between the faces of each two blades are larger, so there is more room for the flow to stabilize. It is expected that a similar pattern would be observed if there were more blades in the group (with the exception of the last blade, which is subject to different flow conditions);
- The relationships between shielding factors for airfoil 2 are different from those obtained for airfoil 1 due to the different shapes of their cross-sections. The section close to the root (airfoil 1) is closer to a circular cross-section, whereas the section closer to the tip (airfoil 2), especially at the sharp trailing edge, is more similar to a rectangular one.

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