Aerodynamic and structural aspects of swept blades in the context of wind turbine load reduction

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1. Introduction

The length of modern wind turbine blades increased considerably in the last years and consequentially the swept area of the wind turbines. As the turbines are operated at turbulent inflow conditions load control by pitching the blades is not suitable to reduce local aerodynamic loads at the blades caused by gusts, eddies, etc. Several comprehensive approaches exist like the active control of blade flaps [1] or the passive change of angle of attack by bend-twist coupling in the blades [2,3]. An advantage of bend-twist coupled blades is the automatic adjustment of the airfoils to the local inflow without any active control requirement. However, the impact of both structure and aerodynamics on the coupling has to be understood completely in order to achieve the optimal blade design. This paper investigates the coupled bend-twist behaviour of different blade shapes and compares it to that of a standard blade without coupling. Furthermore, we analyse the load changes of the turbine system for different blade settings.

2. Approach

Passive bend-twist coupling for load reduction purposes can be achieved e.g. by off-axis fibre orientation in the blade structure [2] or by changing the blade shape by means of sweeping the blade within the rotorplane [3,4], the latter of which called geometrical bend-twist coupling. First parametric studies have been performed in [4] to investigate the load alleviation of wind turbines by using swept blades. For the parametric study presented here the sweep start position along the blade length was added as an additional parameter to determine the influence of the curvature shapes regarding the aerodynamic and structural behaviour of a blade with 80m length (see Fig. 1).

To understand the behaviour of the geometrical bend twist coupling concerning structure and aerodynamics we performed aeroelastic simulations of a 7.5MW wind turbine model with a rotor diameter of 164m [6] utilizing the HAWC2 code [7]. However, to reduce the unsteady effects the simulations have been performed without turbulence or wind shear, leaving a constant wind velocity. This reduction in complexity allows us to investigate the coupling behaviour for stationary inflow conditions. Furthermore we discretised the blade model in 31 sections with coinciding positions for the structural and aerodynamic sections in order to ensure that both characteristics are analysed at the same position.

For the determination of the shape we defined several parameters to determine the exact shape of the blade. For the shape study we used the following third order function

$$f(x) = y_{max} \cdot \left(\frac{x_{tip} - x_{0s}}{x - x_{0s}}\right)^3$$

for sweeping the blade. All blades have an additional prebend that is described by the same function but has a fixed prebend eccentricity at the tip of 4.5m towards the pressure side and a starting position at distance of 9m from the blade root.

For the exact shape of the sweep the following parameters must be given according to Fig. 2:

- The sweep eccentricity at the tip, y_{max}, measured perpendicular to the pitch axis,
- the distance between the blade root and the starting point of the sweep, x_{0s},
- and the length of the blade projected on the pitch axis, x_{tip}.

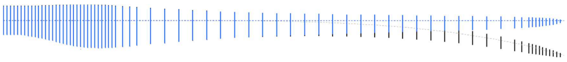

Fig. 1 Discretised model of the straight and a swept blade shape

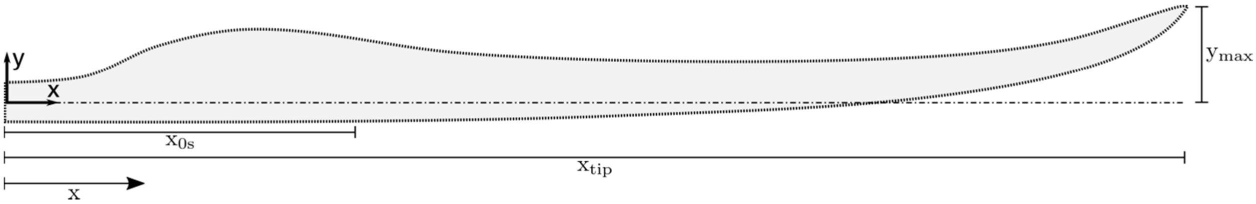

Fig. 2 Parameters for the determination of the sweep with a third order function

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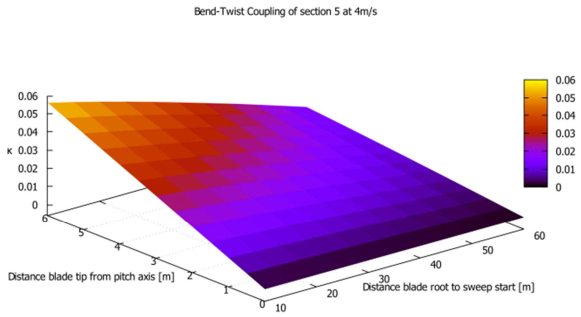

Fig. 3a Coupling coefficient at section 5 at 4m/s

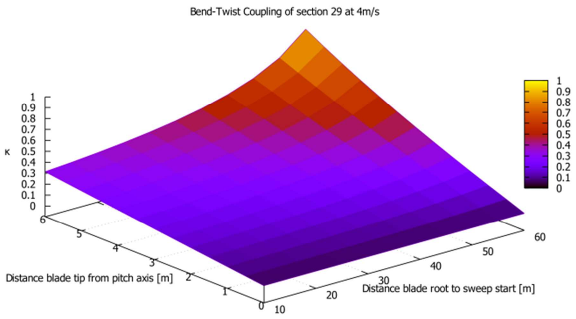

Fig. 4a Coupling coefficient at section 29 at 4m/s

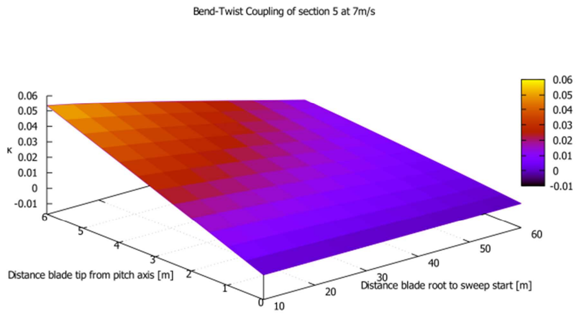

Fig. 3b Coupling coefficient at section 5 at 7m/s

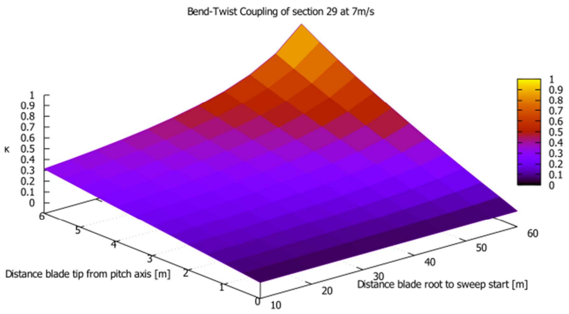

Fig. 4b Coupling coefficient at section 29 at 7m/s

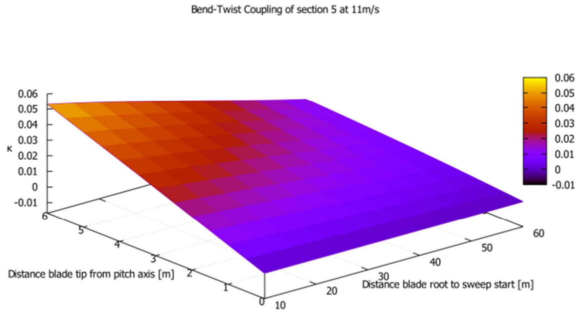

Fig. 3c Coupling coefficient at section 5 at 11m/s

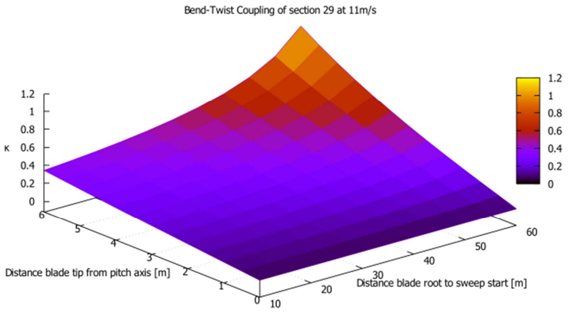

Fig. 4c Coupling coefficient at section 29 at 11m/s

3. Aerodynamic and structural characteristics

To investigate the structural behaviour we introduced a section-wise coupling coefficient

$$\kappa = \frac{M_t}{M_b}$$

which is calculated by dividing the torsional moment by the flapwise bending moment at each section. The coupling coefficient is exemplarily shown in Figs. 3-4 for one section close to the root at x = 8m (section 5) and one section close to the tip at x = 76m (section 29). The coupling coefficient is plotted against y_{max} and x_{0s} for the wind velocities 4m/s, 7m/s, and 11m/s. The coupling coefficient at section 5 shows is very low, i.e. below 0.06, for all parameters and decreases with higher wind speeds. That means the flapwise bending moment increases faster than the torsional moment at the root section.

Section 29 shows a much more significant coupling effect at different settings than the section close to the root. The coupling coefficient at the root increases the lower the distance between the blade root and the curvature start point becomes. On the contrary the coupling coefficient increases the larger the distance between curvature starting point and blade root gets. Furthermore, the coupling effect reaches at very large settings values ≈ 1 which means the torsional moment reaches a level equal to the flapwise bending moment. It is further shown that the gradient caused by the distance between the root and the curvature start point is higher than the distance of the tip with regard to the pitch axis.

In Figs. 5-6. the three different wind speeds represent operation states at different tip speed ratios λ. As section 5 which is close to the blade root shows almost no change section 29 close to the tip is highly influenced by the blade sweep.

However, it is clearly visible that the eccentricity of the blade tip has the highest influence. The distance between the blade root and the sweep start shows almost no influence at the angle of attack within tip eccentricities of ≤ 3m and a very low deviation for eccentricities > 3m.

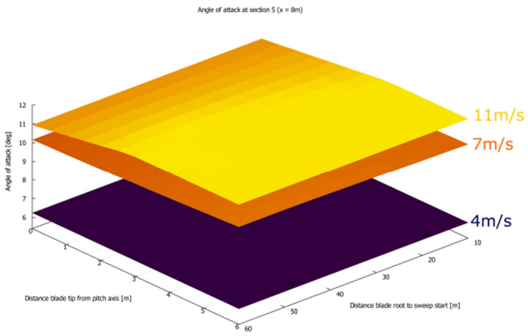

Fig. 5 Angle of attack at section 5 at different wind speeds

4. Conclusions

At the root section we investigated a very low structural and aerodynamic coupling effect.

The structural coupling coefficient at the section that is close to the tip is highly influenced by both parameters, whereas the distance between sweep start and blade root has a higher gradient than the sweep eccentricity of the blade tip. Furthermore, we have shown that the coupling coefficient can reach values of ≈ 1 which means the torsional moment is equal to the flapwise bending moment. This coupling effect also shows a high influence of the aerodynamic behaviour of the section at the tip region.

As the distance between the blade root and the sweep start shows only a very low influence of the angle of attack change at high wind speeds it is largely dependent on the sweep eccentricity of the tip.

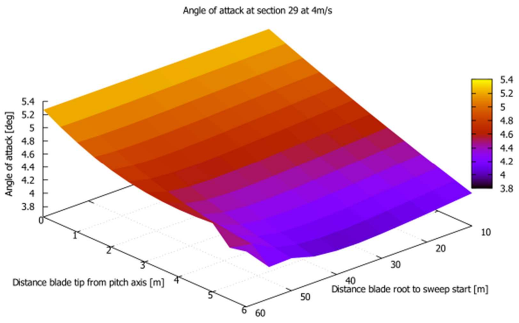

Fig. 6a Angle of attack at section 29 at λ = 10.7

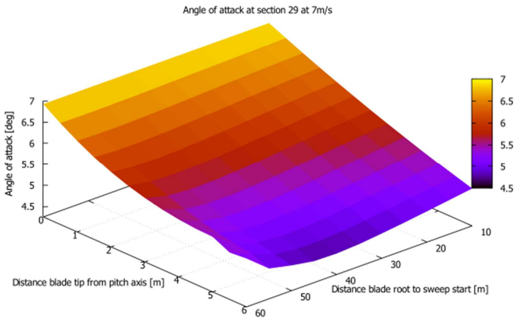

Fig. 6b Angle of attack at section 29 at λ = 8.4

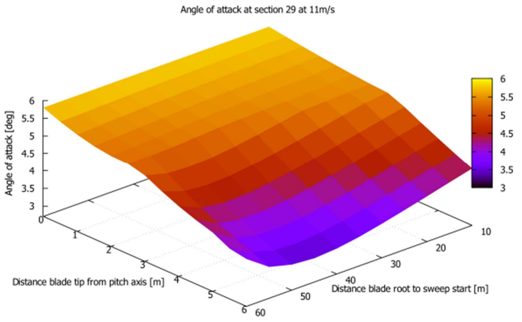

Fig. 6c Angle of attack at section 29 at λ = 7.8

5. Learning objectives

For the understanding of the coupling effect and the aerodynamic influence we analysed an 80m blade for a 7.5MW turbine in an aeroelastic simulation tool and showed the results of two different sections which are close to the root and to the tip with changing the sweep eccentricity of the tip and the distance between the blade root and the sweep start for stationary conditions. As the turbine is equipped with a power control we have chosen three different wind speeds to analyse the structural and aerodynamic effects at three different tip speed ratios including the design tip speed ratio.

The influence of geometric bend-twist coupling is variable at the root and tip of a rotor blade. Therefore the different behaviour must be considered to optimize the loading of blades by focussing the sweep introduction to the tip region of a blade.

6. References

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