Vortex interaction in the wake of a two- and three-bladed wind turbine rotor

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1 Motivation

- Two-bladed turbine concepts are experiencing new attention for offshore applications.
- Main advantages of two-bladed rotors are reduced weight and lower costs.
- Disadvantages, such as increased noise and distracting visual impact, are of less relevance in the offshore environment.
- However, the effect on wake dynamics due to blade reduction is not well understood.
- Wake deficit and turbulence are a main cause for lower farm production and increased fatigue.

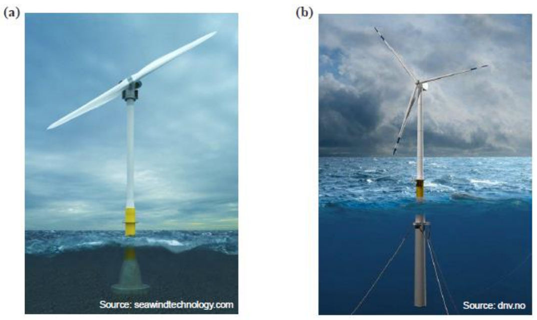

Figure 1: Offshore wind turbine concepts: **(a)** *two-bladed and* **(b)** *three-bladed rotor concept*

2 Methods

- Model-scale wind turbines (D_{Rot}=0.90 m) in a wind tunnel test section of *1.8m x 2.7m*
- Two Cobra probes *TFI Series 100* for measurement of the velocity vector in the wake
- Synchronized measurements with the rotational speed allow for phase-averaging

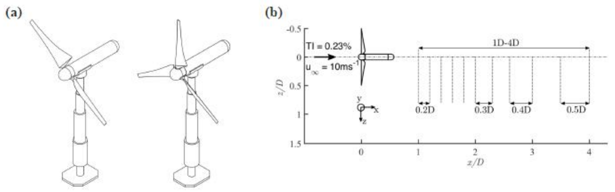

Figure 2: **(a)** *Sketches of the turbine models,* **(b)** *Reference coordinate system and wake measurement stations*

3 Operating conditions

3.1 Rotor design

- Optimised airfoil *Opt* is used for the two-bladed rotor, *NREL S826* airfoil for three-bladed rotor.
- Both airfoils have similar lift and drag characteristics, but higher peak lift and lower drag for *Opt*.
- Chord and twist distribution are obtained by minising induction according to BEM theory.

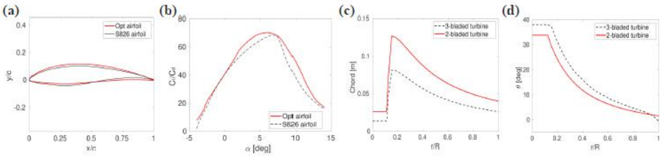

Figure 3: Comparison of the two rotors' design: **(a)** *airfoil geometry,* **(b)** *lift/drag coefficient C_l/C_d vs α,* **(c)** *chord length vs radius r/R,* **(d)** *twist angle θ vs radius r/R.*

3.2 Turbine performance

- Measured *power coefficient C_P at* design tip speed *λ=6* very similar for both rotors.
- Improved airfoil performance increases power production for the two-bladed rotor at *λ>5*.
- Both rotors have almost identical thrust characteristics C_T at *λ=6*.

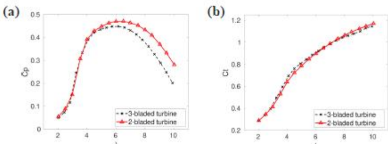

Figure 4: Comparison of the rotors' experimentally measured **(a)** *power C_P and* **(b)** *thrust coefficient C_T*

4 Results

4.1 Time-averaged streamwise velocity

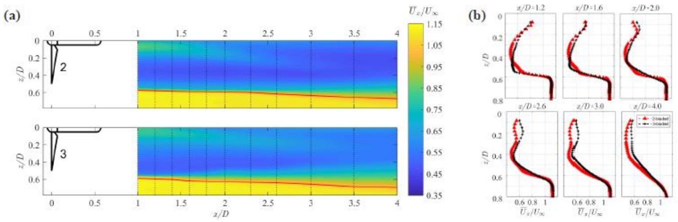

Figure 5: Comparison of the time-averaged streamwise velocity: **(a)** *Contours in the wake behind the two- and three-bladed rotor.* **(b)** *Cross-sectional cuts at selected downstream locations*

4.2 Time-averaged total kinetic energy

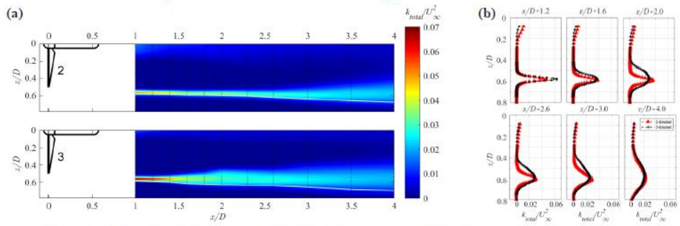

Figure 6: Comparison of the time-averaged total kinetic energy: **(a)** *Contours in the wake behind the two- and three-bladed rotor.* **(b)** *Cross-sectional cuts at selected downstream locations*

4.3 Phase-averaged turbulent kinetic energy

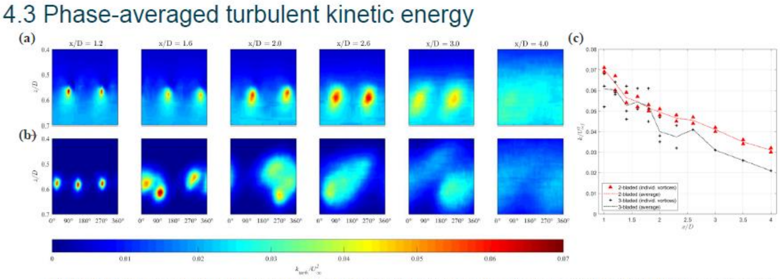

Figure 7: Comparison of the phase-averaged turbulent kinetic energy measured in the wake behind the **(a)** *two-bladed and* **(b)** *three-bladed rotor.* **(c)** *Maximum turbulent kinetic energy extracted from the single vortex cores.*

4.4 Phase-averaged vorticity

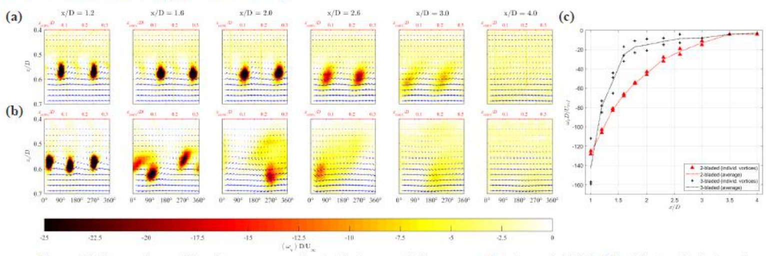

Figure 8: Comparison of the phase-averaged out-of-plane vorticity measured in the wake behind the **(a)** *two-bladed and* **(b)** *three-bladed rotor.* **(c)** *Maximum vorticity extracted from the single vortex cores.*

5 Conclusions

- Velocity deficit behind two-bladed rotor initially smaller (*x/D=1*), but larger further downstream (*x/D=4*).
- Phase-averaged results reveal an interaction and decay of the tip vortices in the wake of the three-bladed rotor, while the two-bladed rotor's vortices continue to move downstream in an ordered helix.
- In a stable atmosphere, this could cause a lower power output and higher fatigue loads on a downstream turbine in a wind farm.
- However, the influence of a variation in solidity and the consequential change in tip speed ratio have not been chosen to investigate in this experiment.
- These parameters can potentially affect the wake development significantly and will be studied in future research.

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