Investigating the influence of tip vortices on deflection phenomena in the near wake of a wind turbine model

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Introduction

- Wake of wind energy turbines operating in steady yaw deflected
- Downstream turbines in wind farm may experience partial/full aerodynamic influence by wake of upstream turbines → power losses, wake induced loads (Kim et al., 2015)
- Bartl et al. (2018) investigate active yawing to increase total power output of multiple turbines
- Burton et al. (2011) describes induced velocity (normal to rotor plane) as main reason for wake deflection
- Eriksen and Krogstad (2017) implement non-yaw phase-locked measurements → equal distribution of tip vortices in the wake
- Purpose of study: investigating tip vortex interaction, determine influence on wake deflection

Measurement methods

- Measurements in closed-loop wind tunnel at NTNU (test section 11.15x2.71x1.80m)
- Inflow conditions: u_∞=10ms^{-1} , TI=0.23%
- Wind turbine model: 3-bladed rotor (d=0.89m, 0.94m hub height), NREL S826 airfoil, long nacelle due to optical RPM sensor and torque meter, 12.9% blockage
- Optimal TSR λ=6, RPM=1280min^{-1}
- Wake measured with TFI Cobra probe (4-hole Pitot tube), traversed at hub height (-0.8D to 0.8D), 13 lines (1D to 4D downstream)
- Phase-locking by coupling sampling frequency (10240Hz, oversampling ratio 4) to rotational speed
- Points measured for t=40s (~850 rotor revolutions)

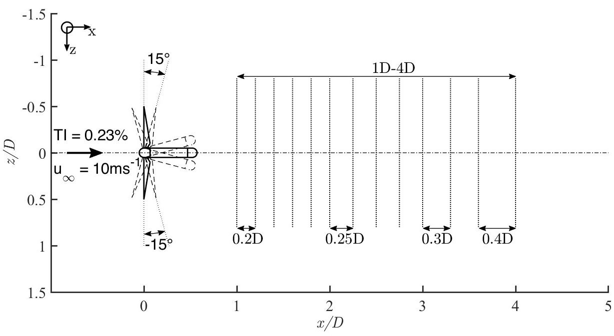

Figure 1: Measurement setup in the wind tunnel test section. Dotted lines indicate Cobra probe traversing.

Results

- Experiments successful: non-yaw reference case confirmed earlier results by Eriksen and Krogstad (2017), wake deflection is detected (Figure 2), phase-locked averaged data gives overview over position and behavior of tip vortices
- Total kinetic energy leads to conclusions about vortex core size and behavior (Figure 4)
- Paterns of vortex interaction are observed to be asymmetric with respect to yaw angle
- Earlier interaction observed for negative yaw
- Sizes of vortex cores tend to be the same for reference case, vortices shed upstream ~4 times bigger than downstream ones
- Differences in size and interaction starting position directly related: outer turbulent region of big vortices connect with each other, forcing vortices to wrap around each other
- Early vortex interaction leads to earlier dissolving into less energetic turbulent structures

Conclusions

- Vortices shed on upstream side are bigger, interact earlier, dissolve faster
- Dissolving can be used to prevent heavy loads on downstream turbines
- Wake spreading on upstream side more distinct
- Actual influence on wake deflection not determined
- Further studies to investigate vortex strength, spin, wrapping process needed

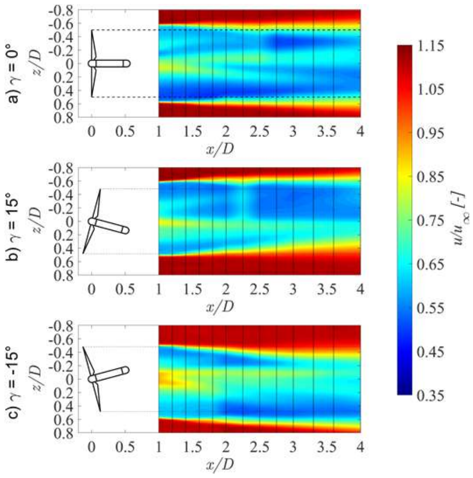

Figure 2: Interpolated normalized streamwise velocity. a) non-yaw reference case, b) positive yaw angle, c) negative yaw angle

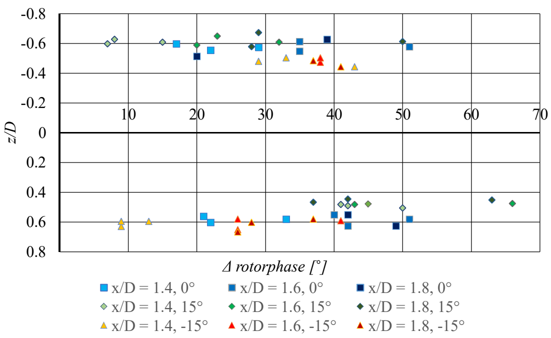

Figure 3: Vortex core sizes in degrees for three downstream positions, left and right side of the wake.

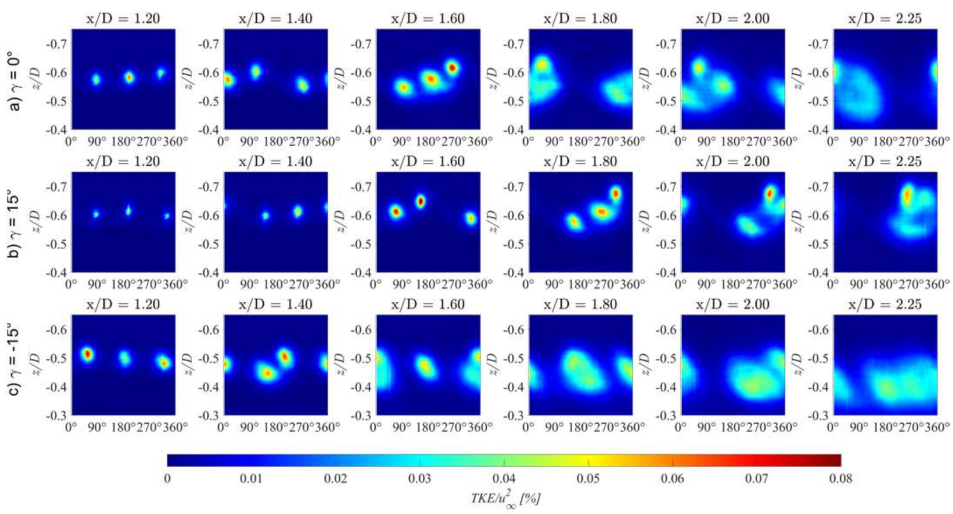

Figure 4: Normalized total kinetic energy at selected downstream positions, left side of the wake. a) non-yaw reference case, b) positive yaw angle, c) negative yaw angle

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