1. MOTIVATION

• Less energy extraction of downwind turbines in a wind farm
• Increased material fatigue on downwind rotors due to additional turbulence in the rotor wake
• Need for experimental data on second turbine wake for computational wake models
• Optimization of wind farm development with wake models

2. OBJECTIVES

• Quantify the difference in mean velocity and turbulence intensity between the first and second turbine wake
• Influence of turbine separation distance \( S/D \) on mean velocity \( U_M/U_{\infty} \) and turbulence intensity \( u'/U_M \) in the wake behind two turbines

3. EXPERIMENTAL SETUP

• Wind tunnel test section of 2.0m (height) x 2.7m (width) x 12.0m (length)
• Wind tunnel inflow speed of \( U_{\infty}=11.5 \) m/s

Fig. 1. Experimental setup and axial measurement stations downstream of the second model turbine at 1D, 3D and 5D

• Power coefficient \( C_P \) measured by torque sensor
• Turbine tip speed ratio \( \lambda \) acquired by RPM sensor
• Two separation distances \( S/D=3 \) and \( S/D=5 \) investigated
• Wind turbines operated at design tip speed ratio \( \lambda_{Tu1}=6 \text{ resp. } \lambda_{Tu2}=4 \)
• Mean velocity and turbulence intensity measurements by means of hot wire anemometry at three axial measurement stations in the wake

4. RESULTS

4.1. TURBINE POWER CHARACTERISTICS

Fig. 2. Power curves of the second model wind turbine operated unobstructed, \( S/D=3 \) downstream and \( S/D=5 \) downstream of the first turbine

Fig. 3. Normalized mean velocity \( U_M/U_{\infty} \) in the wake behind the array of two model turbines separated \( S/D=3 \): (a) 1D downstream; (b) 3D downstream; (c) 5D downstream

Fig. 4. Turbulence intensity \( u'/U_M \) [%] in the wake behind the array of two model turbines separated \( S/D=3 \): (a) 1D downstream; (b) 3D downstream; (c) 5D downstream

Fig. 5. Comparison of the normalized mean velocity \( U_M/U_{\infty} \) behind one unobstructed turbine, two turbines separated \( S/D=3 \) and two turbines separated \( S/D=5 \): (a) 1D downstream; (b) 3D downstream; (c) 5D downstream

Fig. 6. Comparison of the turbulence intensity \( u'/U_M \) [%] behind one unobstructed turbine, two turbines separated \( S/D=3 \) and two turbines separated \( S/D=5 \): (a) 1D downstream; (b) 3D downstream; (c) 5D downstream

5. CONCLUSIONS

• Evident asymmetries in mean velocity and turbulence intensity profiles in close distances behind the second turbine rotor
• More uniform and symmetrical flow field further downstream in the wake
• Significantly higher turbulence intensities behind two turbines than behind one unobstructed turbine
• Considerably higher velocity deficits in the near wake behind the second turbine compared to the wake behind one unobstructed turbine
• Hardly any influence of turbine separation distance \( S/D \) on velocity and turbulence profiles in the wake
• Velocity profile at five rotor diameters behind the second turbine is already very similar to the velocity distribution behind the first turbine
• Higher symmetry and uniformity in velocity and turbulence intensity profiles behind the second turbine than behind the first turbine

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