Comparative study on the wake deflection behind yawed wind turbine models

J. Schottler$^1$, F. Mühle$^2$, J. Bartl$^3$, J. Peinke$^1$, M. S. Adaramola$^2$, L. Sætran$^3$, M. Hölling$^1$

$^1$ ForWind, Center for Wind Energy Research, University of Oldenburg, Germany
$^2$ Norwegian University of Life Sciences, As, Norway
$^3$ Norwegian University of Science and Technology, (NTNU), Trondheim, Norway

jannik.schottler@forwind.de
Motivation

Field measurements
- expensive
- limited availability
- uncontrolled boundary conditions

Experiments
- inexpensive
- controlled environment
- tunable boundary conditions
- upscaling?

Numerics
- turbulence models
- computational costs
- validation?

Validation
Wakes Experimentally

- actuator disc vs. model wind turbines
- model wind turbines are **not** standardized
  - varying blade design / geometry / control...
- how sensitive are results to facility/turbine model/...?
- experiments lack systematics and comparability
Main Idea

• Performing wake measurements with **focus on yaw misalignment** using...
  ▪ two different model wind turbines (size / blade design / geometry / ...)
  ▪ the same wind tunnel facility (NTNU Trondheim, Norway)
  ▪ the same boundary conditions (TSR, distance x/D, yaw ...)
  ▪ the same measurement technique (full plane 2d-LDA)

Goals

• identify turbine specific effects
• identify general effects
• judge effects of boundary conditions
Setup & Overview

• 2 inflow conditions
  ▶ uniform turbulent
  ▶ sheared turbulent
  ▶ (no grid)

• 3 yaw angles
  ▶ 0°
  ▶ +30°
  ▶ -30°

• 2 downstream distances
  ▶ 3D
  ▶ 6D
Setup & Overview

<table>
<thead>
<tr>
<th>Turbine</th>
<th>Rotor diameter</th>
<th>Hub diameter</th>
<th>Blockage</th>
<th>TSR</th>
<th>$Re_{tip}$</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ForWind</td>
<td>0.580 m</td>
<td>0.077 m</td>
<td>5.4 %</td>
<td>6</td>
<td>$\approx 6.4 \times 10^4$</td>
<td>clockwise</td>
</tr>
<tr>
<td>NTNU</td>
<td>0.894 m</td>
<td>0.090 m</td>
<td>13 %</td>
<td>6</td>
<td>$\approx 1.1 \times 10^5$</td>
<td>counter-clockwise</td>
</tr>
</tbody>
</table>

Wind tunnel: 2.71m x 1.81m x 11.15m (width x height x length)
Methods I - Wake center detection

\[ P^* = \sum_{i=1}^{10} \rho A_i \left\langle u_i(t) \right\rangle_{A_i,t}^3 \]

For \(-D/2 \leq z \leq D/2\)

**NTNU, ShearGrid, 6D, \(\gamma = -30^\circ\)**
3D

$u/u_{\text{ref}}$
Wake deflection II

\[ z_{\text{min}} = 0.19 \ D, \ \text{skew} \approx 3.7^\circ \]

\[ z_{\text{min}} = 0.19 \ D, \ \text{skew} \approx 3.7^\circ \]
Curled wake in yaw - a general effect?
Curled wake observed for drag disc (30mm) model wind turbines (150mm, 580mm, 890mm)
Curled Wake in yaw - towards quantification

![Diagram showing polynomial fit and minimum](image)

- Polynomial fit
- Minimum
Curled Wake in yaw - towards quantification
Curled Wake in yaw - towards quantification
Curled Wake in yaw - towards quantification

- ‘curl’ observed for all wakes where $\gamma \pm 30^\circ$
- further deflection of ‘ForWind’-wake
- tilt in opposite direction
  - different direction of rotation!
  - interaction with the ground/tower shadow

in accordance with [Bastankhah & Porté-Agel 2016]
Summary & conclusion

• wake measurements with focus on yaw misalignment
  ▶ full plane LDA data, 2 distances (3D, 6D)
  ▶ two model wind turbines, differing in size/design
  ▶ 3 different inflow conditions (no grid, uniform grid, shear grid)
  ▶ > 20 wakes total

• “potential power” approach for wake center detection
  ▶ systematic quantification/comparison of wake deflection

• curled “kidney” wake observed for all yaw cases
  ▶ general effect
  ▶ quantification / comparison
Project outlook

- Blind-Test ✓ coming up!
  - workshop held on Monday
  - 3 selected test cases of the project
  - 4 participants contributing simulations
  - results / comparisons will be published
Thank you!

Party funded by the Reiner Lemoine Foundation

jannik.schottler@forwind.de