Scaled wind turbine setup in turbulent wind tunnel
MoWiTO 1.8 (Model Wind Turbine Oldenburg 1.8 m)

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Motivation

• Interaction of turbulent wind w/ wind turbine in controlled wind tunnel environment:
  • Loads
  • Aerodynamics
  • Control

• Scaling objectives:
  1. Representative aerodynamic response in turbulence
  2. Realistic characteristic curves
  3. Characteristics Re insensitive
Scaling: Global Parameters

Parameters

- Based on NREL 5MW
- Keep design TSR (~7.5)
- Scaling parameters:
  - Length scaling
    \[ n_L = \frac{D_{scaled}}{D_{reference}} = \frac{1.8 \text{ m}}{126 \text{ m}} = \frac{1}{70} \]
  - Time scaling
    \[ n_T = \frac{n_{scaled}}{n_{reference}} = \frac{600 \text{ rpm}}{12.1 \text{ rpm}} = 49.6 \]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rated values</th>
<th>Scaling factor</th>
<th>Reference</th>
<th>Scaled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revolutions</td>
<td>1 * n_T</td>
<td>12.1 rpm</td>
<td>600 rpm</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>n_L^5 * n_T^3</td>
<td>5 MW</td>
<td>363 W</td>
<td></td>
</tr>
<tr>
<td>Wind speed</td>
<td>n_L * n_T</td>
<td>11.4 m/s</td>
<td>8.1 m/s</td>
<td></td>
</tr>
<tr>
<td>Reynolds number</td>
<td>n_L^2 * n_T</td>
<td>~10^7</td>
<td>~10^5</td>
<td></td>
</tr>
</tbody>
</table>
Scaling: Aerodynamics

Exchange of airfoils

Root airfoil exchange

<table>
<thead>
<tr>
<th>Original</th>
<th>Scaled</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>DU 99–W–350</td>
<td>SG6040</td>
<td>0.25 R–0.32 R; 35% thickness</td>
</tr>
</tbody>
</table>

Tip and midspan airfoil exchange

<table>
<thead>
<tr>
<th>Original</th>
<th>Scaled</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>NACA 64618</td>
<td>SG6041</td>
<td>0.7 R–1 R; 18% thickness</td>
</tr>
</tbody>
</table>

Chord scaling:

\[
\frac{c_L(\alpha)c(r)}{R} = \text{const.}
\]
Blade design

- Carbon fiber with foam spar
- Composite blade weight $\sim 160 \text{ g}$ ($m_{\text{blade NREL 5MW}} / 70^3 = 52 \text{ g}$)
- Glued on metal inlet
  - Flapwise strain gauge
  - Pitch motor housing
  - Pitch bearing shaft surface
- First eigenfrequency $\sim 39 \text{ Hz}$
Objective 1: Aerodynamic response in turbulence

TurbSim wind file + NREL 5 MW

FAST Sim at 7 rpm

Results upscaling

Scaled wind + Scaled turbine

FAST Sim at 490 rpm

Myb [MNm]

Time [s]

5MW FAST + Scal. FAST

Angle of Attack [°]

Time [s]

0.67 R
Turbine key facts

• **Sensors and actuators:**
  • Strain gauges at blade root (flapwise)
  • Strain gauges at tower base (fore–aft, side–side)
  • Torque meter with encoder
  • Individual pitch motors
  • Real time control and data acquisition

• **Operation:**
  • 400 – 600 rpm
  • Rated wind 8.1 m/s
Nacelle layout

- Motor boards
- Amplifiers (24 ch)
- Slip Ring
- Gear box
- Generator
- Torque meter w/ encoder
- CANopen distribution board
- Flapwise strain gauge
- Individual pitch motor
- Generator
Wind Tunnel at University Oldenburg

- WindLab; Dimensions (H x W x L) 3 x 3 x 30 m³
- Open test section or closed test section
- $V_{\text{Wind}}$ up to 42 m/s (closed) or 30 m/s (open)
Active Grid

20 split axes with flaps in each, horizontal and vertical, direction

80 servomotors driving the axes

Reproduce turbulent wind patterns, e.g. based on free field measurements
Aerodynamic characterisation in wind tunnel

![Graph showing aerodynamic performance parameters](image-url)
Objective 2: $C_p$ and $C_t$ characteristic

- Slope matches
- Offset due to difference in glide ratio of profiles

- Good match
  Error bars indicate influence of $\pm 0.1$ m/s in reference wind
Objective 3: Influence of Reynolds number

![Graphs showing the influence of Reynolds number on different parameters.](image-url)
Experiments: Turbulent Inflow
Experiments: Turbulent Inflow

- Turbulent protocol based on free field measurement
- Mean wind velocity 5.7 m/s
- Turbulence intensity 10.4 %

[Images and graphs showing data trends over time]
Summary

• Introduction of test setup:
  • Model wind turbine (D=1.8 m)
    – Fully equipped with sensors
    – Blade aerodynamics and loads scalable to NREL 5 MW turbine
  • Wind tunnel with active turbulence grid
    – Reproduceable turbulent patterns

• Planned experiments:
  – Engineering models (e.g. dyn. inflow)
  – Turbulent inflow (temporal/spatial)
  – PIV investigations
  – Controller testing
Acknowledgements

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