Model Building and Scaled Testing of 5MW and 10MW Semi-Submersible Floating Wind Turbines

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Motivation for INNWIND.EU model test

- Software validation: Coupled models with varying fidelity
- Investigation of methods to incorporate aerodynamics
- Comparison to other experiments
- Public set of experimental data with generic model
- Experience for further model test in INNWIND.EU
• Ecole Centrale de Nantes/France (LHEEA)
• Duration: 4 weeks, October-November 2014
• Platform: OC4-DeepCWind Design
• Rotor: Froude-scaled rotor/
Ducted fan (HIL)
• Scaling: 1:60 (10MW)
1. Aerodynamic scaling
   – Experimental scales
   – Froude-scaled rotor
   – Ducted fan (HIL)
2. Platform model:
   – Manufacturing
   – Mass distribution
3. Mooring system adaptation
4. Sensor systems
5. Wave tank
6. Test cases
7. Conclusion
Aerodynamic Scaling

1. Correct Froude-scaling of
   - Rated rotor speed $\Omega$
   - Wind speed $v_0$
   - Thrust force $F_{thrst}$

2. Set thrust coefficient $c_T$ through blade pitch angle $\theta$ s.t.

   $$F_{thrst} = \frac{1}{2} \rho \pi R^2 c_T \left( \frac{\Omega R}{v_0}, \theta \right) v_0^2$$

   for the given rotor radius $R$.

- Assessment of different scales possible.

Froude-scaling:

<table>
<thead>
<tr>
<th>Property</th>
<th>Scaling Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>$\lambda$</td>
</tr>
<tr>
<td>Mass</td>
<td>$\lambda^3 \frac{\rho_{fresh}}{\rho_{salt}}$</td>
</tr>
<tr>
<td>Velocity</td>
<td>$\sqrt{\lambda}$</td>
</tr>
<tr>
<td>Force</td>
<td>$\lambda^3 \frac{\rho_{fresh}}{\rho_{salt}}$</td>
</tr>
</tbody>
</table>

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Aerodynamic Scaling

- Froude-scaled rotor
- Constant rpm

- Ducted fan
- Real-time controlled (HIL)
- No wind generator necessary
Froude-scaled Rotor

- **Froude-scaling**: High Reynolds mismatch
- **How to get realistic rotor performance**: Higher rotor solidity (increase blade chord, i.e. airfoils Reynolds)

Scaled thrust can be obtained.
Froude-scaled Rotor

Control hardware:
- Supervisory control
- Pitch-torque control law

Remote Control Unit:
- Management of experiment
- Data logging and visualization

Optical encoder for azimuth readings
Shaft strain gages
Pitch actuator
Torque actuator
Optics for control unit
Electronics board for blade strain gages signal conditioning

Pitch actuator control units,
Torque actuator with torque/speed control

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Ducted Fan

Wind

Demanded thrust

Platform states

Waves

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Ducted Fan

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Aerodynamic damping
Platform model

Fabrication:
- Struts: carbon fibre
- Lower columns: wood
- Upper columns: PVC
- Central column: Carbon fibre-reinforced PVC
- Ballast: dumbbell disks
- Assembly: Inserted threads & screwed connections
Platform model

Mass distribution:

- CAD model
- Verification through pendulum tests
- Tuning with ballast

\[ T = 2\pi \sqrt{\frac{I}{mgL}} \]
Mooring System

- OC4 lines had to be **shortened** by 1.5m due to wave tank dimensions
- Depth of basin 0.5m **deeper** than scaled depth
Sensors

- Wave tank (optical measurement, waves, wind)
- Platform (Fairleads, accelerations)
- Rotor
Sensors: Onboard

**Platform**
- Sampling rate 100Hz, 16bit res.
- Accelerometer & gyroscope
- Fairleads force transducers
- Onboard storage and wireless transmission

**Wind turbine**
- Sampling rate 250Hz
- Tower base force transducer
- Shaft torque-meter
- Blade strain gages
- Rotor speed and azimuth
- Blade pitch angle
Sensors: Wave Tank

Wave tank
- 2 anemometers
- 3 wave probes
- Video motion capture

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Wind & Wave Tank

Wind
- Outlet of 3x3m
- Adjustable position
- Mean Turbulent Intensity below 5%
- Wind speeds 0.5...15m/s

Waves
- 50x30x5m
- Reg./irreg. waves, adjustable wave dir.

[Courbois, A. (2013)]

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Test Cases

- System ID (free decay, static mooring displacement)
- Regular waves, irregular waves
  - w/ wind
  - w/o wind
- Extreme wave conditions
- Sensitivity tests (wind speed, mooring lines)

<table>
<thead>
<tr>
<th>Sea State #1</th>
<th>Hs (m)</th>
<th>Tp (s)</th>
<th>Wind (m/s)</th>
<th>Hs (m)</th>
<th>Tp (s)</th>
<th>Wind (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,052</td>
<td>0,820</td>
<td>1,043</td>
<td>0,039</td>
<td>0,710</td>
<td>0,9</td>
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<tr>
<td>Sea State #2</td>
<td>0,073</td>
<td>0,969</td>
<td>1,267</td>
<td>0,055</td>
<td>0,839</td>
<td>1,1</td>
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<tr>
<td>Sea State #3</td>
<td>0,092</td>
<td>1,088</td>
<td>1,699</td>
<td>0,069</td>
<td>0,942</td>
<td>1,5</td>
</tr>
<tr>
<td>Sea State #4</td>
<td>0,137</td>
<td>1,327</td>
<td>2,683</td>
<td>0,103</td>
<td>1,149</td>
<td>2,3</td>
</tr>
</tbody>
</table>
Conclusions

- Generic OC4 model with two methods for aerodynamics successfully tested
- Adjustable mass distribution
- Two scales tested
- Partly wireless data transmission
- Complete set of test data will be published on WWW.INNWIND.EU
- Tool validation is ongoing

**Recommendations:**
- Identify rotor properties in open jet w/o recirculation, perform comparison cases with closed wind tunnel
- Perform „sensitivity“ tests on model properties
- CAD „supervision“ advisable
Outlook: Scaled Simulation Model

Small-scale model:

- Hydrodynamic coefficients scaled
- Blade polars for small-scale rotor
- Valid position of reference wind speed measurement in open jet
- Reconstruction of irregular wave field
Thank you!

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Results: Free-decay

Ptfm-Pitch:

W/o cables

W cables