DOCUMENTATION VERIFICATION AND VALIDATION OF REAL-TIME HYBRID MODEL TESTS WITH THE 10MW OO-STAR WIND FLOATER

Maxime Thys (SINTEF Ocean)  Valentin Chabaud (SO/NTNU)
Lene Eliassen (SINTEF Ocean)  Thomas Sauder (SO/AMOS)
Petter A. Berthelsen (SINTEF Ocean)
Layout

- Model testing: motivation and limitations
- Real-Time Hybrid Model testing
- OO-Star Wind Floater ReaTHM tests
- Verification
- Conclusion
Motivation for model tests

• Common to all offshore structures
  • Significant investments should be de-risked and optimized
  • Some physical effects are not modelled correctly by engineering tools yet
  • Some physical effects are not known yet

• Specific to FOWT
  • Complex coupling between wind and wave loads, structure and blade dynamics.
  → Issue: the experiments must capture these couplings correctly
Limitations of classical approaches

- Tests in wave tanks, using fans to generate the aerodynamic loading
  - Challenge 1: ensure a correct wind field above the wave field → accuracy, repeatability, traceability
  - Challenge 2: ensure a correct mass distribution of the RNA model
  - Challenge 3: Froude/Reynolds scaling conflict, and rotor re-design by "Performance scaling"
Real-Time Hybrid Model (ReaTHM®) testing
ReaTHM® testing

Strong points of ReaTHM® testing?

• Realistic and controlled rotor loads
• Possibility to test extreme conditions
• Cost-effective and flexible

Any challenges?

Multidisciplinary

How to ensure high quality testing?
OO-Star Wind Floater model tests

- Lifes50+ H2020 project (http://lifes50plus.eu/)
- OO-Star Wind Floater with DTU 10MW turbine
- Tested in Nov 2017 in the Ocean Basin at SINTEF Ocean
- Scale 1/36
- Environmental conditions of Gulf of Main (depth 130m)

Objectives:
- Concept performance verification
- Data for num. calibration
- Develop hybrid methods
OO-Star Wind Floater model tests
Verification: Stepwise approach

- General: Sensitivity study
- Substructure Verification
- Verification of complete system
Verification: Sensitivity study

- How important are each of the turbine load components for operational and parked conditions?
- Realized by use of Riflex-SIMO-Aerodyn, where rotor loads are modified one by one.
- Sensitivity to
  - aerodynamic sway, heave, pitch, and yaw
  - Gyro moments/centrifugal forces
  - Vertical and horizontal directionality
- 16 loading conditions

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>EC1</th>
<th>EC2</th>
<th>EC3</th>
<th>EC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>m/s</td>
<td>8.0</td>
<td>11.4</td>
<td>20.0</td>
<td>44.0</td>
</tr>
<tr>
<td>TI</td>
<td>%</td>
<td>12.7</td>
<td>12.4</td>
<td>9.5</td>
<td>11.0</td>
</tr>
<tr>
<td>Wind model</td>
<td>-</td>
<td>NTM</td>
<td>NTM</td>
<td>NTM</td>
<td>NTM (EWM)</td>
</tr>
<tr>
<td>Power law coeff.</td>
<td>-</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.11</td>
</tr>
<tr>
<td>$H_s$</td>
<td>m</td>
<td>2.3</td>
<td>2.5</td>
<td>3.6</td>
<td>10.9</td>
</tr>
<tr>
<td>$T_p$</td>
<td>s</td>
<td>9.7</td>
<td>9.8</td>
<td>9.9</td>
<td>16.0</td>
</tr>
<tr>
<td>Wave spectrum</td>
<td>-</td>
<td>PM</td>
<td>PM</td>
<td>PM</td>
<td>PM</td>
</tr>
</tbody>
</table>
Verification: Sensitivity study

- Influence on standard deviation for quantities of interest (DOF1-6, mooring line tensions, BM and SF)

<table>
<thead>
<tr>
<th>Removed</th>
<th>Operating (EC1-3)</th>
<th>Parked (EC4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamic sway</td>
<td>small</td>
<td>15% tension and 8% yaw and pitch</td>
</tr>
<tr>
<td>Aerodynamic heave</td>
<td>small</td>
<td>12% tension</td>
</tr>
<tr>
<td>Aerodynamic pitch</td>
<td>+18% pitch and +10% SF</td>
<td>+22% pitch and +22% BM</td>
</tr>
<tr>
<td>Aerodynamic yaw</td>
<td>-85% on yaw (small)</td>
<td>small</td>
</tr>
<tr>
<td>Vertical directionality</td>
<td>small</td>
<td>7% pitch and 15% tension</td>
</tr>
</tbody>
</table>

=> 6 actuators in two parallel horizontal planes to apply all loads except heave
Verification of Physical Substructure

- Pullout
- Decay
- Repetitions
Verification of Numerical Substructure

Physical part of the experiments emulated in SIMA for verification of
- Allocation (rotor loads->forces on actuators 1-6)
- Scaling
- Applied actuators forces
Verification of Control System

Main objectives:
• Reference tracking
• Disturbance rejection

Through:
- Chirp tests
- Following tests
Verification of Complete System: Decay

Pitch decay test without ReaTHM system and with the system in following mode

<table>
<thead>
<tr>
<th>Tn Pitch [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ReaTHM</td>
</tr>
<tr>
<td>Following</td>
</tr>
<tr>
<td>Rel. Diff [%]</td>
</tr>
</tbody>
</table>

![Graph showing pitch decay test results](image-url)
Verification of Complete System: Decay

Pitch decay test without ReaTHM system and with the system in following mode
Verification of Complete System: Repetition

Test repetition:
• DLC 1.6
• Waves: Pierson-Moskowitz
  \( H_s = 7.7 \text{m} \) and \( T_p = 12.4 \text{s} \)
• Wind: NTM 8m/s

Collinear wind and waves
Conclusions

- ReaTHM® testing is a multidisciplinary method
- Sensitivity analysis is key in the design process
- New verification and documentation methods developed for substructures and complete system
- Examples shown from Lifes50+ with OO-Star Wind Floater
- More work needed to address experimental uncertainty of hybrid tests -> Phase 2 of Lifes50+ in March 2018 (Nautilus-DTU10)
Acknowledgments

The research leading to these results has received funding from the European Union Horizon2020 programme under the agreement H2020-LCE-2014-1-640741

"The present work was part of the "HYBRID KPN" project supported by the Maritime Activities and Offshore Operations Program" (MAROFF) of the Research Council of Norway (grant No. 254845/O80).

Also, we are grateful to Dr. techn. Olav Olsen AS for the permission and contribution to set up the public 10MW semi-submersible design based on their concept of the OO-Star Wind Floater (www.olavolsen.no).
Teknologi for et bedre samfunn