AERODYNAMIC DAMPING OF A HAWT ON A SEMISUBMERSIBLE

Effect of aerodynamic loading on the motions of the OC4-semi in waves

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How MARIN is helping developers of floating wind turbines?
- Model-tests
- Simulations

From ‘concept design’ to validated model ‘Model of the model’
- Example of the OC4-semisubmersible
- Sensitivity to change in inertia
- Sensitivity of the model to rotor force coefficients

Conclusions

Further work
FLOATING WIND AT MARIN

Model tests

Wind set-up  MSWT  Concept  Model tests

Waves + Wind

Numerical studies

Scaled wind

Scaled thrust

CFD for wind set-up, blades

aNySiM + PHATAS FAST (+ 2nd order)

My objectives:
• R&D: What does matter for the floater?
• BU: Verification => Concept study
‘MODEL OF A MODEL’

- A concept design evolves before and after the model-tests (different mass distribution, different turbine, etc...)
- A turbine is available for model-testing in wave and wind (but the actual wind turbine may be slightly different)
- While modeling wind & waves, a new scaling approach is followed (‘performance scaling for the rotor’). This has an impact on the aerodynamic performance of the turbine.

⇒ Use model-test data to calibrate a numerical model = ‘Model of the model’
⇒ What is the influence on the motions of a OFWT of all these differences?
**MODEL OF THE OC4 SEMISUBMERSIBLE**

- **Differences?**
  - (Design) OC4-SEMI
  - (Built) OC5-SEMI

⇒ “Model of the model”

<table>
<thead>
<tr>
<th>Designation</th>
<th>Symbol</th>
<th>Unit</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>OC4 Calculated</td>
</tr>
<tr>
<td>Draft</td>
<td>T</td>
<td>m</td>
<td>20.0</td>
</tr>
<tr>
<td>Mass</td>
<td>M</td>
<td>ton</td>
<td>14,260</td>
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<tr>
<td>Centre of Gravity above keel</td>
<td>KG</td>
<td>m</td>
<td>9.96</td>
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<tr>
<td>Longitudinal metacentric height</td>
<td>GMₗ</td>
<td>m</td>
<td>7.34</td>
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<tr>
<td>Roll radius of gyration in air</td>
<td>kₓₓ</td>
<td>m</td>
<td>32.07</td>
</tr>
<tr>
<td>Pitch radius of gyration in air</td>
<td>kᵧᵧ</td>
<td>m</td>
<td>32.94</td>
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<tr>
<td>Yaw radius of gyration in air</td>
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<td>m</td>
<td>31.83</td>
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<tr>
<td>Natural pitch period (moored)</td>
<td>T₀</td>
<td>s</td>
<td>25.1</td>
</tr>
<tr>
<td>Natural heave period (moored)</td>
<td>Tₜ</td>
<td>s</td>
<td>17.0</td>
</tr>
</tbody>
</table>
CALCULATION PROCESS & POST-PROCESSING

- Potential Flow
  - Mesh
    - DIFFRAC OC4
  - Damping estimates
  - Damping decay tests
- Equation of motions
  - aNySIM OC4-semi
  - Quadratic transfer functions
- Post-processing
  - aNySIM OC5-semi
  - Added-mass Potential dpg Wave load RAOs
  - Time-series Plots
  - Spectral Plots
Load case:
• Long-crested waves
• JONSWAP $H_s = 7.1 \text{ m} \ T_p = 12.1 \text{ s}$

Comparison of simulations for:
A. $OC5 = \text{calibrated model}$
B. $OC4 = \text{original 5MW}$
C. $\text{Measurements}$
• Operational sea, head waves
VERIFICATION OF HYDRODYNAMIC RESPONSE

- Operational sea, head waves

- Response in wave energy range (1\textsuperscript{st} order) are similar
VERIFICATION OF HYDRODYNAMIC RESPONSE

- Operational sea, head waves

- Response in low frequency range (2\textsuperscript{nd} order) are different
- Difference at resonance (surge, heave & pitch)
COMPARISON: MODEL OF THE MODEL

• OC5 Calibrated / OC4 Design / Model-test data

• Surge resonance peak of simulations are different and much smaller than in the model-test data.
COMPARISON: MODEL OF THE MODEL

- OC5 Calibrated / OC4 Design / Model-test data

- Pitch resonance peak are different:
  - OC4 < model-test
Load case:
• Co-linear waves and wind
• JONSWAP Hs = 7.1 m Tp = 12.1 s
• Wind speed V = 13 m/s
• Rotor fixed rpm = 12.1
• Blade pitch angle = 1 deg
=> TSR = 6.156

Comparison of simulations for:
A. OC4 design (XFOIL @ FS)
B. OC5 model (UMaine @ MS)
C. OC5 model (ECN RFOIL @ MS)
• Operational sea + steady wind, head waves

• Response in wave energy range (1\textsuperscript{st} order)
VERIFICATION OF RESPONSE IN WIND & WAVES

- Operational sea + steady wind, head waves

- Response in low frequency range (2\textsuperscript{nd} order)
COMPARISON: MODEL OF THE MODEL

- OC5 Calibrated / OC4 Design / Model-test data

⇒ Less damping for the model-tests than the simulations
⇒ Effect mainly visible at resonance (slow drift $2^{nd}$ order response)
COMPARISON: MODEL OF THE MODEL

- OC5 Calibrated / OC4 Design / Model-test data

=> Less damping for the ‘Model of the model’ than the ‘Design’ case
• OC5 Calibrated / OC4 Design / Model-test data

Correlation of pitch moment at tower foot and pitch motion
Parallel wind and wave, no yaw

Thrust acts mainly on
- Surge
- Pitch

Test in a basin at scale 1/50 with a re-designed rotor that mimics the full scale rotor \( \{C_t, (C_p)\} \) for a range of TSR

What are the \( \{C_l, C_d\} \)?
- Optimization = vary \{C_l, C_d\} to match measured \{C_t, C_p\}

- Optimization on \{C_l, C_d\}
  - To match \{C_t, C_p\}
  - Of the experiments

- Check performance curve

- Look at effects on the motions of the floating foundation
• Simulation of a pitch decay test in steady wind (13 m/s)

=> More damping for the ‘Model of the model’ than the model-test
LOOK AT EFFECT OF $\{\text{CL, CD}\}$ ON THE RESPONSE

- Simulation of a pitch decay test in steady wind (13 m/s) with other {Cl, Cd}

- Surge (and heave) are identical
- Less damping with RFOIL than UMaine
LOOK AT EFFECT OF \{CL,CD\} ON THE RESPONSE

- Operational sea + steady wind (13 m/s), head waves
- **RFOIL** versus **UMaine** coefficients

- Surge and heave are identical
- Different amplitudes of pitch resonance peak
- Less damping with **RFOIL** than **UMaine**
CONCLUSIONS

Lessons learnt:

- OC5 and OC4 behave in similar ways (small differences)
- ‘Model of the model’ => learn about main physics at play
- Response to 2nd order wave loads in surge and pitch
- Rotor loads acts primarily on resonance peaks
- Aerodynamic damping is mainly effective on surge and PITCH

- Level of damping (aero + hydro) is important to know if a numeric model is conservative or not
- Further work necessary on the determination of the damping:
  - Horizontal (hydrodynamics)
  - Pitch (aerodynamics)
- Also on the wave loads (surge)
THANK YOU

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