Floating offshore wind turbine loads and motions in the unstable atmospheric conditions

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Outline

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- Background
- Højstrup spectral model parametric study
- Results – coupled SIMO-RIFLEX on OC3-Hywind
- Conclusion
- Future work
Motivation

- Initial study from the master thesis project ‘A study of the coherences of turbulent wind on a floating offshore wind turbine’
Background

- Højstrup spectral model: derived based on Kaimal spectral model, especially developed for unstable diabatic conditions:

\[ S(n) = S_L(n) + S_M(n) \]

- Parameters: boundary layer height \( z_i \), Obukhov-length \( L \), height \( z \)

- In combination with Davenport coherence:

\[
Coh_i(n) = \exp \left[ -\frac{n}{u} \sqrt{(C_i^y d_y)^2 + (C_i^z d_z)^2} \right]
\]
Højstrup spectral model – parametric study

Variation in L

Variation in $z_i$

Benchmark: $z_i=1000$ m, $L=-100$ m
Simulations

- Turbulence box generation using MATLAB®

<table>
<thead>
<tr>
<th>Load case</th>
<th>Spectral model</th>
<th>( z_i ) (m)</th>
<th>( L ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Højstrup</td>
<td>700</td>
<td>-50, -90, -180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-50, -90, -180</td>
<td></td>
</tr>
<tr>
<td>Kaimal</td>
<td>700</td>
<td>( \infty )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>( \infty )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decay coefficient (Davenport Coherence)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_u )</td>
</tr>
<tr>
<td>Value</td>
</tr>
</tbody>
</table>

- Coupled SI MO-RI FLEX® simulations on the OC3-Hywind

| Wind speed | 8, 11.4, 15 ms\(^{-1}\) |
| #seed      | 6                          |

<table>
<thead>
<tr>
<th>Wave</th>
<th>JONSWAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H_s )</td>
<td>6 m</td>
</tr>
<tr>
<td>( T_p )</td>
<td>12 s</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Results – Turbulence Intensity

- 40% TI difference between neutral (Kaimal) and very unstable (Højstrup $L=-50$ m), considering the same $z_i$
- 14% TI difference between $z_i = 700$ m and $z_i = 1000$ m, considering the same $L$
Results – DEL tower top yaw torsion

65% difference between neutral (Kaimal) and very unstable (Højstrup L=-50m)
Results – DEL tower base side-side bending

37% difference between neutral (Kaimal) and very unstable (Højstrup L=-50m)
Results – DEL blade root flap-wise bending

24% difference between neutral (Kaimal) and very unstable (Højstrup L=-50m)
Results – platform yaw motions

- Graphs showing platform yaw motions at different wind speeds for different heights and wind turbine locations.
  - $z_1 = 1000$ m
  - $z_1 = 700$ m

Legend:
- Hojstrup L=-50 min
- Hojstrup L=-90 min
- Hojstrup L=-180 min
- Kaimal min
- Hojstrup L=-50 mean
- Hojstrup L=-90 mean
- Hojstrup L=-180 mean
- Kaimal mean
- Hojstrup L=-50 max
- Hojstrup L=-90 max
- Hojstrup L=-180 max
- Kaimal max
Results - other DEL and motions

- Tower base fore-aft bending DEL: 7% difference between neutral (Kaimal) and very unstable (Højstrup L=-50) conditions
- Blade root edge-wise bending DEL: 3% difference between neutral (Kaimal) and very unstable (Højstrup L=-50) conditions
- Other platform motions mode variations were not noticeable (except for roll, despite its small magnitude of -0.3° to 0.6°)
Limitations – Davenport decay coefficients

- A modified Davenport coherence by Cheynet et. al (2018) for vertical coherence:

\[ \text{Coh}_i(d_z, n) = \exp \left[ -\sqrt{\left( \frac{c_1^i f d_z}{\bar{u}} \right)^2 + \left( \frac{d_z}{l_2} \right)^2} \right] \]

- \( l_2 = \frac{\bar{u}}{c_2^i} \), proportional to a typical length scale of turbulence

- Decay coefficient depending on stability conditions \((-2 < z/L < -0.2)\) derived from FINO1 data:

<table>
<thead>
<tr>
<th>Decay coefficient</th>
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</thead>
<tbody>
<tr>
<td>( c_1^u )</td>
</tr>
<tr>
<td>( c_1^v )</td>
</tr>
<tr>
<td>( c_1^w )</td>
</tr>
<tr>
<td>( c_2^w )</td>
</tr>
<tr>
<td>11+1.8exp(4.5 z/L)</td>
</tr>
<tr>
<td>7.1+3.4exp(6.8 z/L)</td>
</tr>
<tr>
<td>3.5+0.7exp(2.5 z/L)</td>
</tr>
<tr>
<td>0.05+0.13exp(5 z/L)</td>
</tr>
</tbody>
</table>
Conclusions

- The addition of low-frequency component in Højstrup model increases the spectral energy and TI
  - L and $z_i$ are the parameters driving the TI
  - OC3-Hywind DELs for tower top yaw torsion showed a variation up to 65% for the different load cases. Also up to 37% for tower base side-side bending

- Højstrup spectral model was developed based on onshore measurement

- The importance of selecting a proper wind model representative for offshore environment in the OWT simulations, particularly for unstable conditions
Future work

- Simulations using spectral & coherence model as derived in the study of (Cheynet et al., 2018) using data from FINO1 measurement platform. This is only verified for vertical separations.

- New measurements from the COTUR project will hopefully provide new information on coherence for horizontal separations.

- Simulations using modified Mann spectral tensor model (Chougule et al., 2018) – with the possibility of deriving parameters from offshore data into the models.

- Comparing various floater models and rotor sizes (Bachynski & Eliassen, 2018).
Thank you 😊