Wind Tunnel Wake Measurements of Floating Offshore Wind Turbines

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Presentation’s outline

• Motivations and goals

• Ongoing analysis of unsteady aerodynamics of FOWTs @ PoliMi

• Experimental Setup and Tests

• Results

• Conclusions
Motivations and goals

- Support side activity of LIFES50+ project
- Hybrid tests in Wave Basin
- Understanding unsteady aerodynamics due to platform’s motion
  - Calibration of numerical models
  - Imposed Surge motion @ different amplitudes and frequencies
Ongoing analysis of unsteady aerodynamics of FOWTs @ PoliMi

From experiments, unsteadiness depends on:

- **Tip Speed Ratio**
- **“Wake Reduced Velocity”** $V_w^*$

$$V_w^* = \frac{U}{f \cdot D}$$

- $V_w^*$  
  - $N$ of rotor **diameters** $D$ “travelled” by the air with a **drift (mean) velocity** $V$ within **one cycle** of **platform motion** of **frequency** $f$

$V_w^* > 5$  
Quasi-steady behaviour

$V_w^* < 5$  
Non-linear behaviour: the rotor re-enters its wake
Experimental Setup and Tests

**Experimental Setup**

- Downwind Hot-wire anemometer
- Upwind Pitot Anemometer
- 6 Components balances
- Imposed Surge Motion

**Tests**

- **2D Map** (Y-Z plane)
  - @ Rated

- **1D Map** (Y, Hub’s height)
  - @ Below Rated
  - @ Rated
  - @ Above Rated
  - Different Amplitudes & frequencies
Steady 2D map @ Rated Wind Speed

- Wind speed $U = 3.67$ m/s
  scale factor (1/3)

- Rotor Diameter $D = 2.38$ m
  scale factor (1/75)

- Expected/measured Thrust $\approx 28$ N
  scale factor (1/50594)

- Recomputed Thrust $\approx 28$ N
  from wake deficit

$$T = \int_A \rho U (U_\infty - U) dA$$
(Mass conservation + Momentum loss)
**No Motion: the effect of $C_t$ on the mean wake velocity**

- High $C_t = $ great momentum loss (Below/Low Rated)
- Low $C_t = $ low wake deficit (Above Rated)
No Motion: turbulence in the wake

- Higher turbulence
- Tip vortices

- Lower turbulence
- Clear visibility of the rotational frequency (4 Hz)
Imposed Motion: Wake dynamic component at the frequency of the imposed motion

- Mean wake velocity influences the entity of wind oscillation at surge frequency $f$
Imposed Motion: Surge frequency in the wake

- **Same operational conditions**

- **Normalization** of the FFT by the maximum peak amplitude

- Clear evidence of the **surge motion frequency** $f$

- Rotational frequency still evident (where present from no motion)
Imposed Motion: Surge frequency in the wake (Changing $V_w^*$) @Rated

Towards quasi-steady dynamic conditions (higher $V_w^*$), Surge frequency more visible in the wake…

![Graphs showing surge frequency in the wake for different $V_w^*$ values](image)

Surge frequency visible in the wake

$V_w^* = \frac{U}{f \cdot D}$

Freq. 0.25 Hz
Amp. 100 mm

Freq. 1 Hz
Amp. 30 mm

...missing Surge frequency in the wake!!
Imposed Motion: Surge frequency in the wake (depending on $V_w^*$) @ Above rated

This dependency on $V_w^*$ is however affected by the corresponding steady spectral content ($Ct$)

$$V_w^* = \frac{U}{f \cdot D}$$

Freq. $0.25$ Hz
Amp. $100$ mm
Surge frequency visible in the wake

Freq. $2$ Hz
Amp. $15$ mm
Surge frequency still visible in the wake
Conclusions and on-going work

• No motion, steady 2D map @ rated: correspondence between force measurements and wake deficit analysis

• No Motion: visible effect of $C_t$ on the mean wake velocity

• No Motion: visible turbulence in the wake linked to the aerodynamic efficiency ($C_t$)

• With Motion, different wave reduced velocity $V_w^*$ test cases:
  • Towards quasi-steady dynamic conditions (higher $V_w^*$), Surge frequency more visible in the wake
  • This dependency on $V_w^*$ is however affected by the corresponding steady spectral content ($C_t$)

• Overall confirmation of the dual dependency of the unsteadiness on the steady aerodynamic efficiency and the wake reduced velocity $V_w^*$

• Measurements at different downwind distances
### Imposed Motion: Test Matrix, different $V_w^*$ test cases

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<thead>
<tr>
<th>🅿️ Full Scale</th>
<th>🅿️ Wind Tunnel</th>
<th>$V_w^*$</th>
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</thead>
<tbody>
<tr>
<td>$U$ (m/s)</td>
<td>Amp $x_0$ (m)</td>
<td>Period $T$ (s)</td>
</tr>
<tr>
<td>7</td>
<td>7.5</td>
<td>100</td>
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<tr>
<td></td>
<td>2.25</td>
<td>25</td>
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<td>12.5</td>
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<td>11</td>
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