POD analysis of the wake dynamics of an offshore floating wind turbine model

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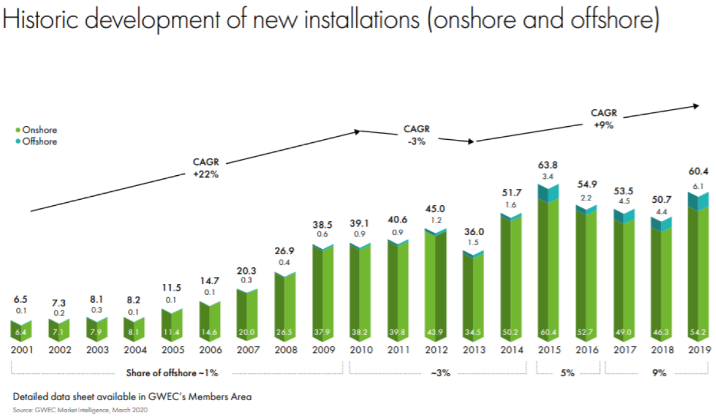
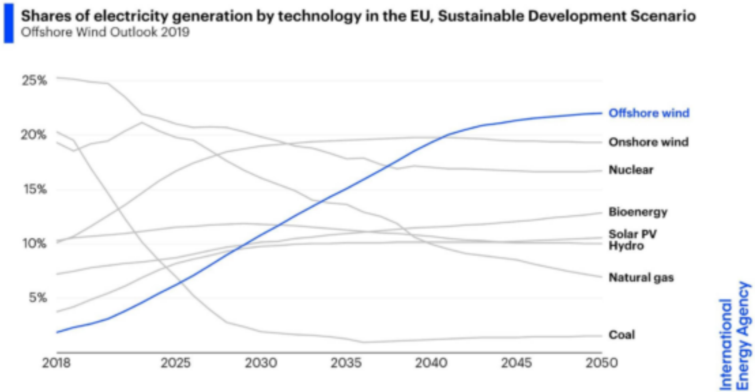
Offshore VS onshore wind power



- More and more installations, more and more offshore in proportions
- *"Offshore WP capacity has to be multiplied by 15 up to 2040 and becoming a trillion dollars market"* (AIE)

Source: GWEC

Offshore VS onshore wind power



- First share of electricity generation in the EU in 2045-2050

Source: IEA

Floating VS fixed offshore wind power

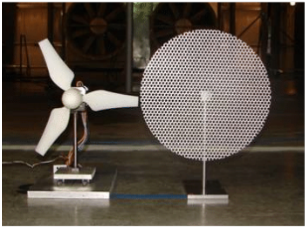
Motivations to consider floating offshore wind power

- Same advantages as offshore wind power
- Wider space in deep waters
- More power in deep waters
  $\rightarrow$ **Load factor of 65 %** [Scotland]
- Better acceptance of residents
- Easier to build (in port, then carried), less expansive
- Less disturbance of the marine ecosystem

Difficulties

- Engineering challenge
- Motions of the structure

Objectives

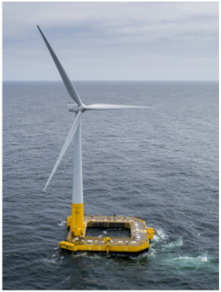


Porous disk model

[Charmanski et al. (2014)]

SCALING →

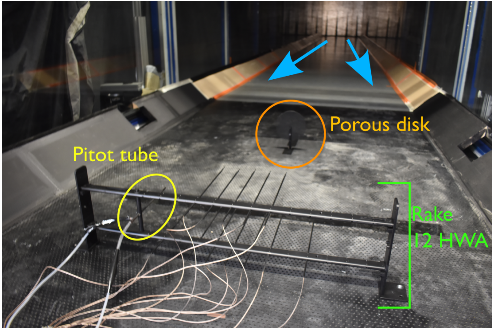
BL height
Sampling freq.
Spatial dim.

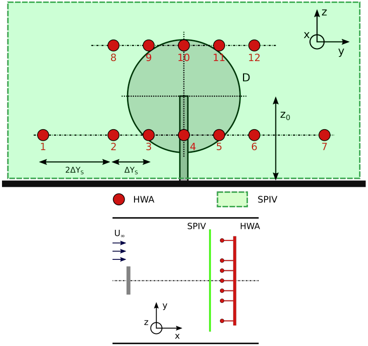


Prototype

- Realistic flow conditions
  - Boundary layer height
  - Turbulence
  - **Spatio-temporal dynamics**
- Use of realistic velocity fields as inputs of aeroelastic codes

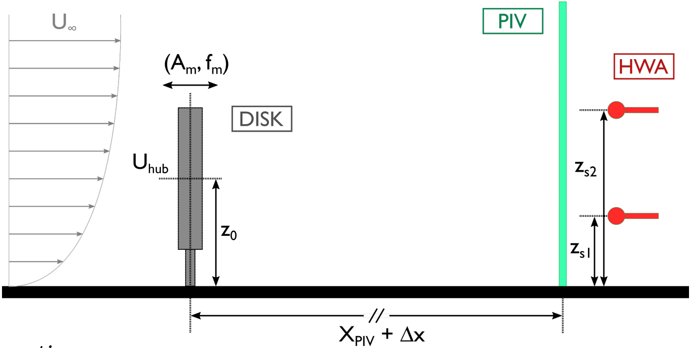
Experimental set-up





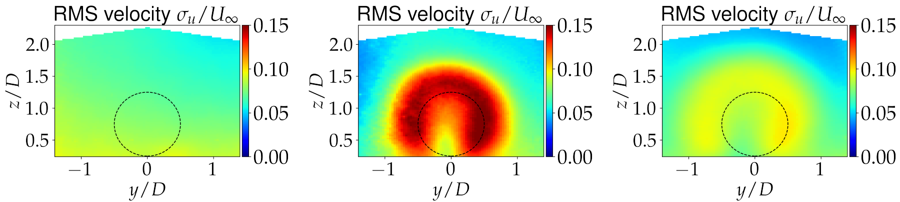
- Free-stream $U_\infty = 4.0$ m/s, BL height $\delta = 0.6$ m, Reynolds $Re_\delta = 2\ 10^5$
- Porous disk diam. $D = 0.16$ m, hub height $z_0 = 0.12$ m
- Synchronized measurements:
  - Stereoscopic PIV $y - z$ *[F_s = 14.1 Hz, large range $3D \times 2D$]*
  - 12 hot-wire sensors *[F_s = 15 kHz, 2 heights: $z_{sj}/D = 0.47$ and 1.25]*

Surge-motion and parametric space



- *Surge motion:*
    - amplitude $A_m \pm 0.01$ m
    - frequencies $f_m = [0,\ 2,\ 3,\ 3.75]$ Hz
- *2 streamwise positions of the PIV + HWA:* $X_{PIV}/D = 4.6$ and 8.1
- *3 streamwise shifts Δx for energy budgets*
- *documentation TBL*

Mean wake - Effect of the PIV position X_{PIV}



TBL $\quad$ $X/D = 4.6$ $\quad$ $X/D = 8.1$

RMS streamwise velocity u_{RMS}/U_0 for 2 streamwises position in the wake

- Increase of the wake radius w.r.t X
- Decrease of the turbulence intensity w.r.t X
- Slight shift of the wake center due to a small negative $\overline{V}$
  $\longrightarrow$ large structures upstream

Proper Orthogonal Decomposition

Objective: decompose the velocities snapshots as,

$$\mathbf{u}(\mathbf{x},t) \approx \sum_{i=0}^{N_m} \boldsymbol{\Phi}_i(\mathbf{x})\ a_i(t)$$

with,

- $\boldsymbol{\Phi}_i(\mathbf{x})$ *spatial modes*
- $a_i(t)$ *temporal modes*

The POD approach is based on the correlation matrix

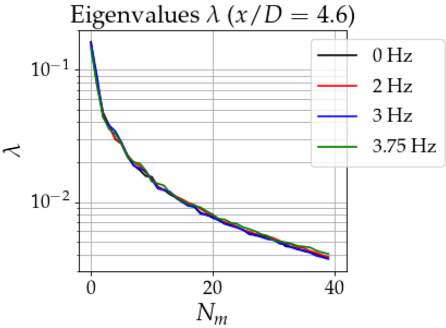
$$\mathcal{R}_{ij} = \frac{1}{N_t}\ < \mathbf{u}'(\mathbf{x},t_i), \mathbf{u}'(\mathbf{x},t_j) >$$

The POD eigenvalues are obtained as

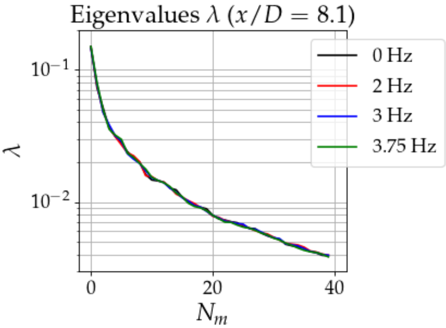
$$\mathcal{R}a_i = \lambda_i a_i$$

Sirovich (1987)

Eigenvalues



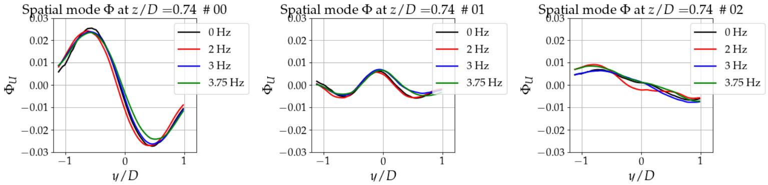
$x/D = 4.6$



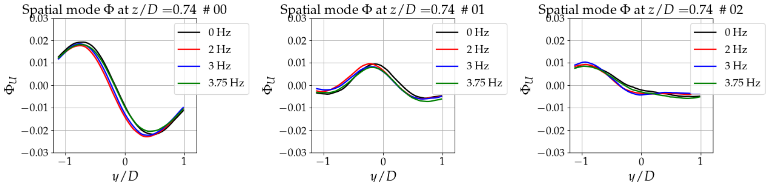
$x/D = 8.1$

- Slow convergence of the eigenvalues due to the turbulent boundary layer and its interaction with the wake

Spatial modes



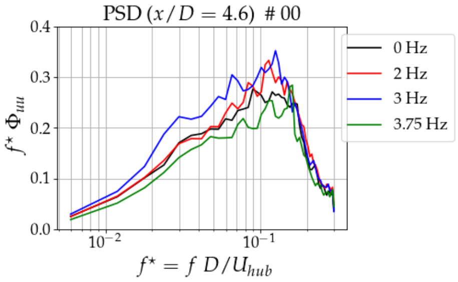
$X/D = 4.6$



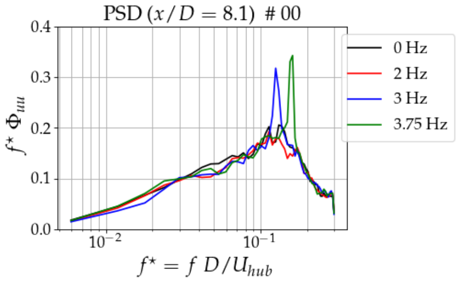
$X/D = 8.1$

- No significant effect on the spatial modes

Temporal modes - Surge motion frequency f_m



$x/D = 4.6$



$x/D = 8.1$

Premultiplied PSD of the temporal POD modes for different surge motions

- Structured dynamics of the wake for $x/D = 4.6$
- Particular behavior of the wake for $x/D = 4.6$ and $f_m = 3$ Hz.
- Larger variations between surge motions $x/D = 8.1$
- Multiple peaks at $x/D = 8.1$

Conclusions

Realistic experimental conditions for floating wind turbines

- properly scaled boundary layer
- realistic surge-motion

Importance of the dynamics behavior of the flow

- Difficulty for the modes to converge due to the TBL
- The main difference resides in the **temporal modes**
- ▶ modeling of floating WT wakes using generated dynamics

Perspectives for the database

- Reconstruction of the database using stochastic estimation
- Energy balance in the wake

SHAKE THE FUTURE.

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Questions ?