High-fidelity analysis of a small-scale floating wind turbine under prescribed sway

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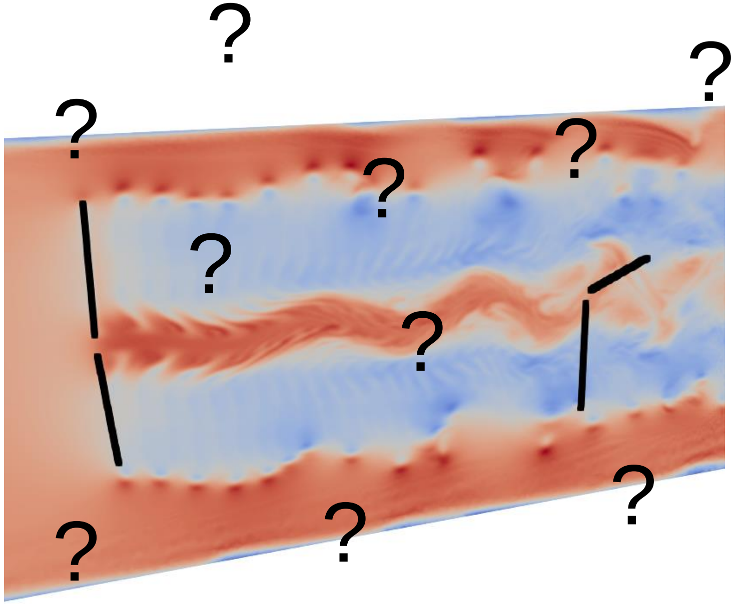
Floater motion – New complexities

The rotor will experience local and global wind velocities perturbations

Floating turbines are free to move at the foundation

The perturbations will be convected downstream to the following turbines



As a function of the motion:

- **What happens to the wake?**
- **How fast does it recover?**
- **What frequencies are transported?**

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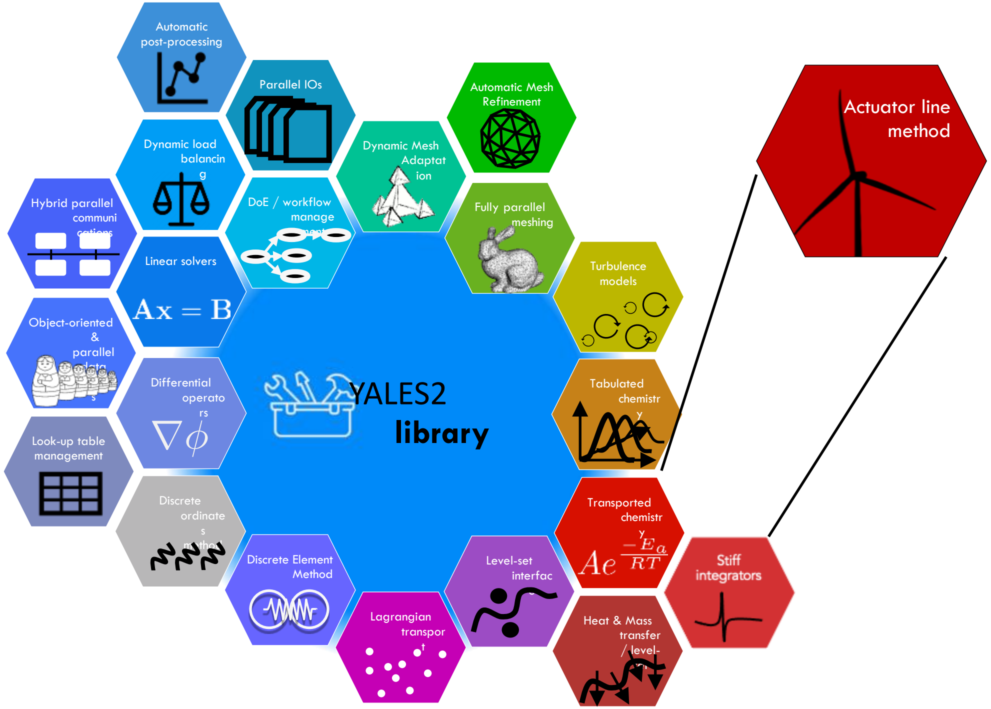
www.coria-cfd.fr



- **High-fidelity tool for the simulation of multiphysics phenomena**
- **Collaborative development**
  - Academic labs
  - HPC experts
  - Industrial partners
- **High performance on large HPC machines**
- **Many solvers and libraries**, including for example:
  - Combustion & multi-phase flows
  - Particle physics
  - Heat transfers
  - Automatic and dynamic mesh refinement
  - High-order numerics
- See https://www.youtube.com/user/CoriaCFD/videos

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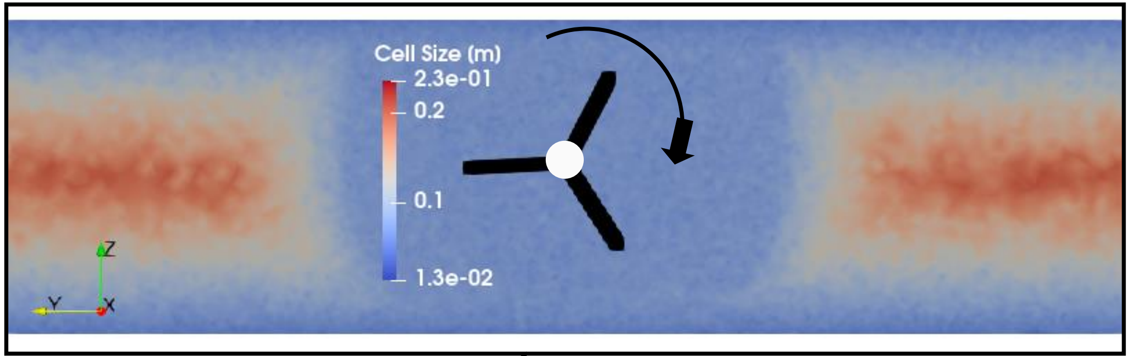
Setup – OC6 Phase III

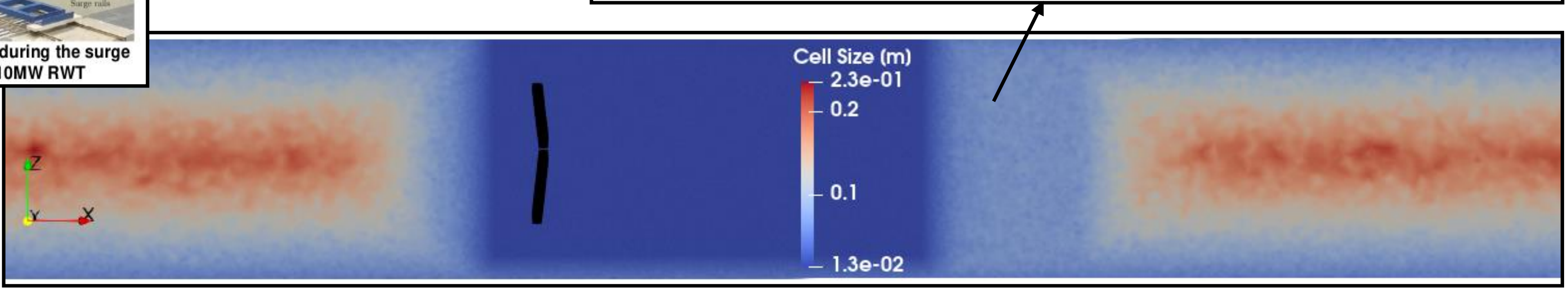
Figure 1: Polimi wind tunnel during the surge tests with scaled DTU-10MW RWT

Source: OC6 Phase III definition document

Turbine model:

- Small-scale 1:75 scaled version of the DTU 10-MW RWT (Bak et al, 2013)
- **The nacelle was not included**
- The turbine rotates clockwise
- Rotor closer to top than bottom





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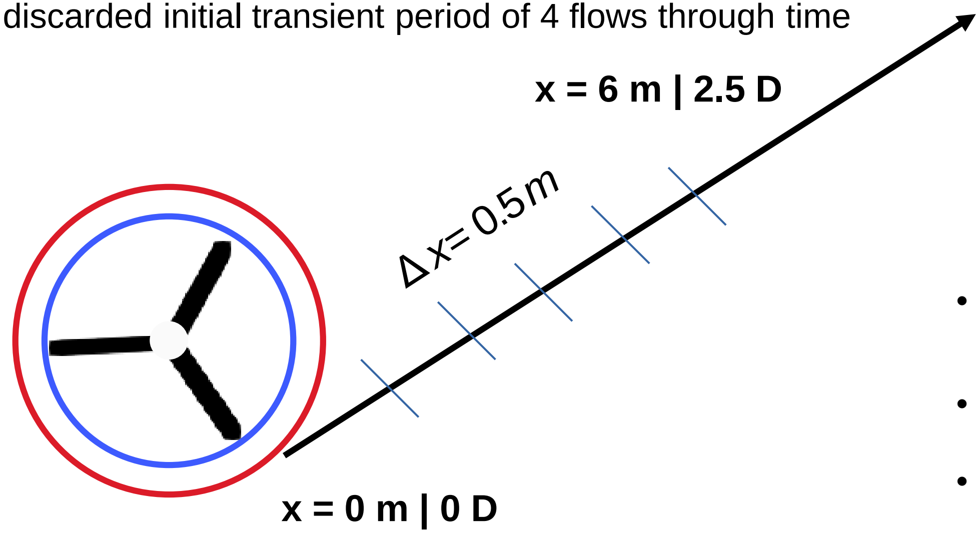
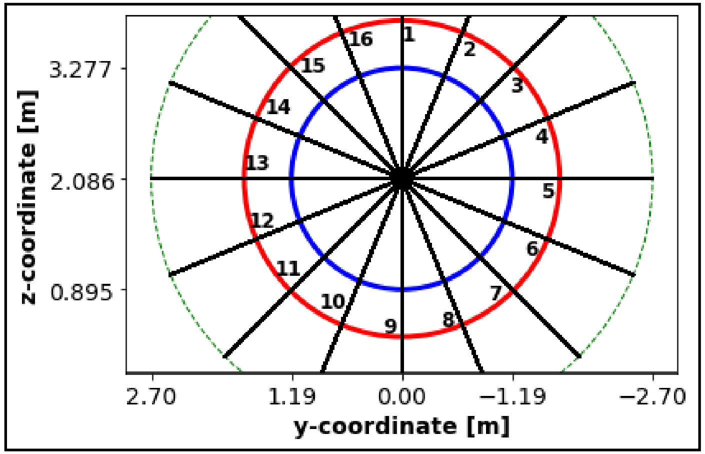
Data extraction and post-processing

- The data was extracted from radial probes fixed at several positions downstream from 0 m to 6 m with a step of 0.5 m
- The data was accumulated for 20 motion periods after a discarded initial transient period of 4 flows through time





- 16 probes were used with a radial discretization of 193 points (to match the cell size)
- The blue circle delimits the turbine radius – R = 1.19 m
- The red circle delimits the analyzed region which was limited by the top wall – R = 1.7 m

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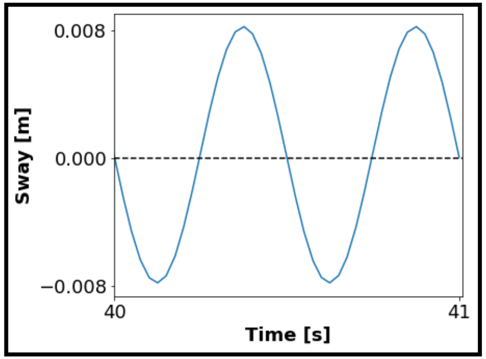
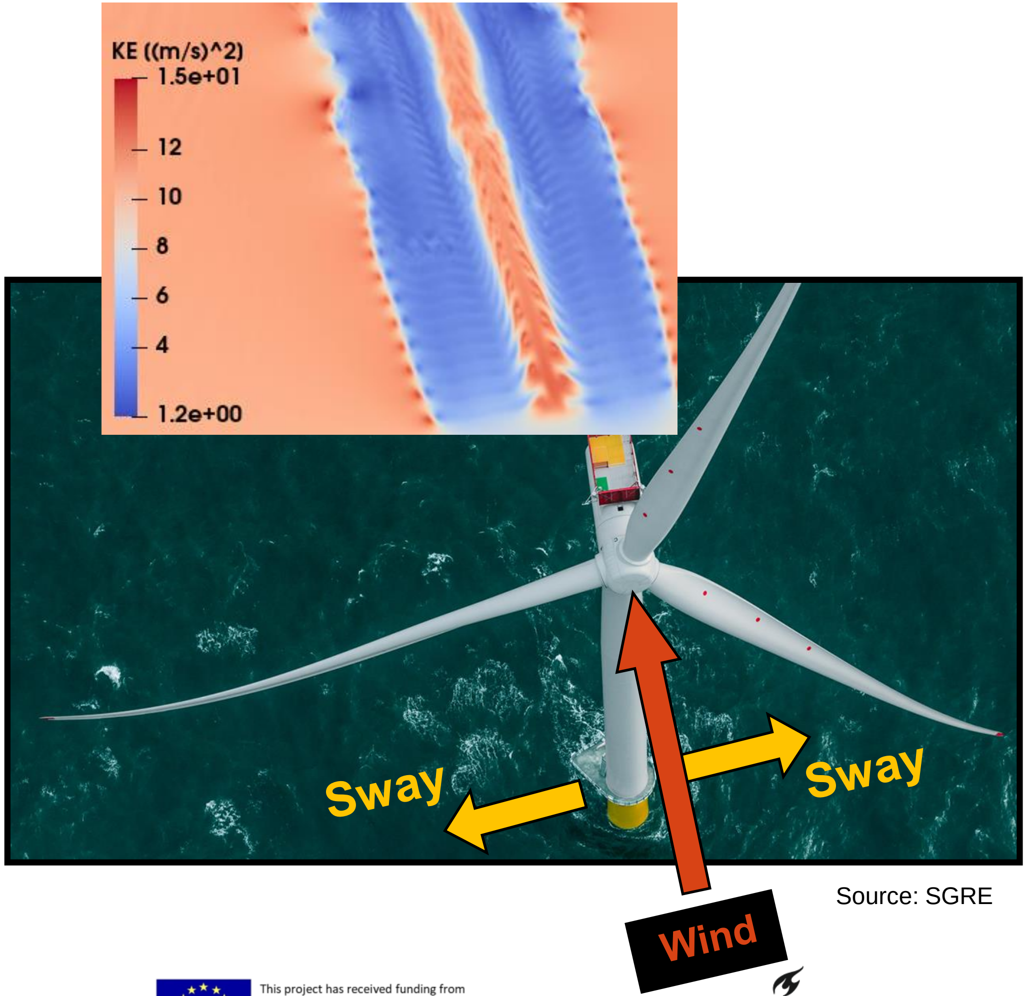
Sway motion analysis

Sway motion

It was decided to focus on a single case for this presentation with:

- **Amplitude = 0.008 m** → 0.6 m in full-scale
- **Frequency = 2 Hz** → 0.08 Hz in full-scale





Source: SGRE

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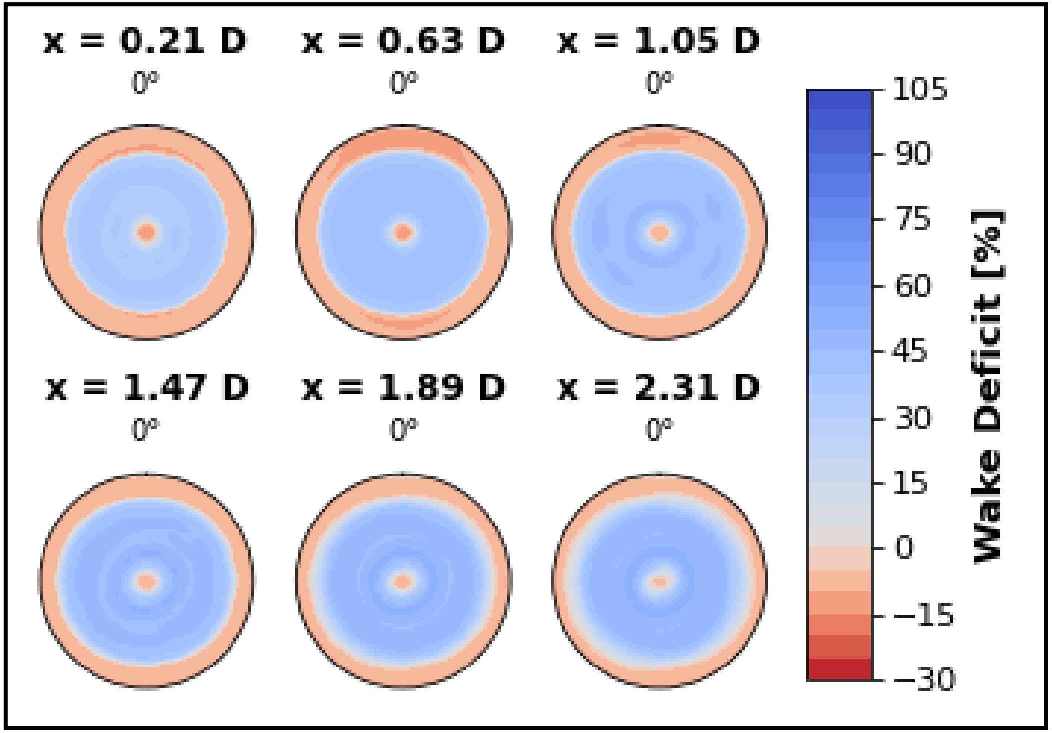
How does the wake deficit/recovery look like?

Time-averaged wake deficit – Streamwise velocity

- The probes were averaged over time and their points were interpolated in space to produce a polar plot of the wake deficit
- The absence of nacelle induces momentum from the centerline which likely speeds-up the recovery
- **At x = 0.63 D,** there appears to be an acceleration of the flow which is larger on top, probably due to the closer proximity to the wall
- **At x = 1.89 D and x = 2.31 D,** it can be seen that the wake becomes elliptical and rotates anti-clockwise, contrary to the rotational velocity
- If we plot the average wake deficit now...



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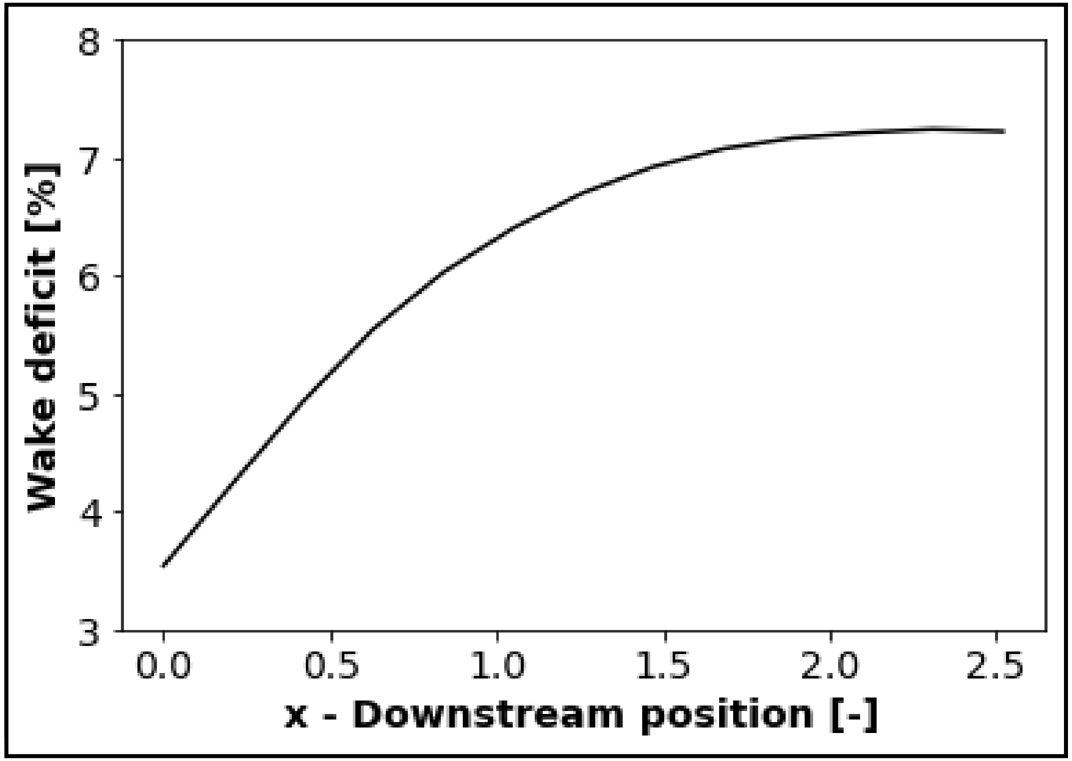

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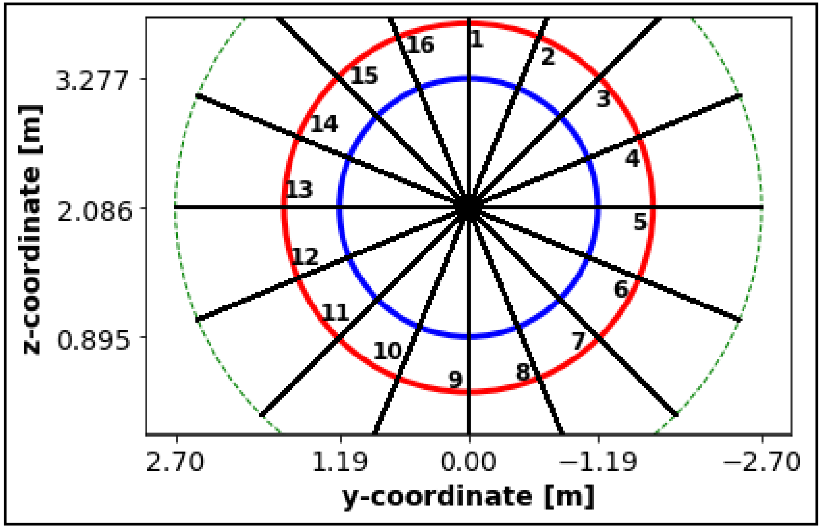
What frequencies are present at each radial and downstream position?

Azimuth-averaged amplitude spectra

- For each radial probe at a certain distance downstream, the amplitude spectra of points at the same radial distance were averaged
- Therefore an average of 16 amplitude spectra was computed to represent that that very radial position – azimuthal average
- This azimuth-averaged spectra were plotted as a function of the radial and downstream positions



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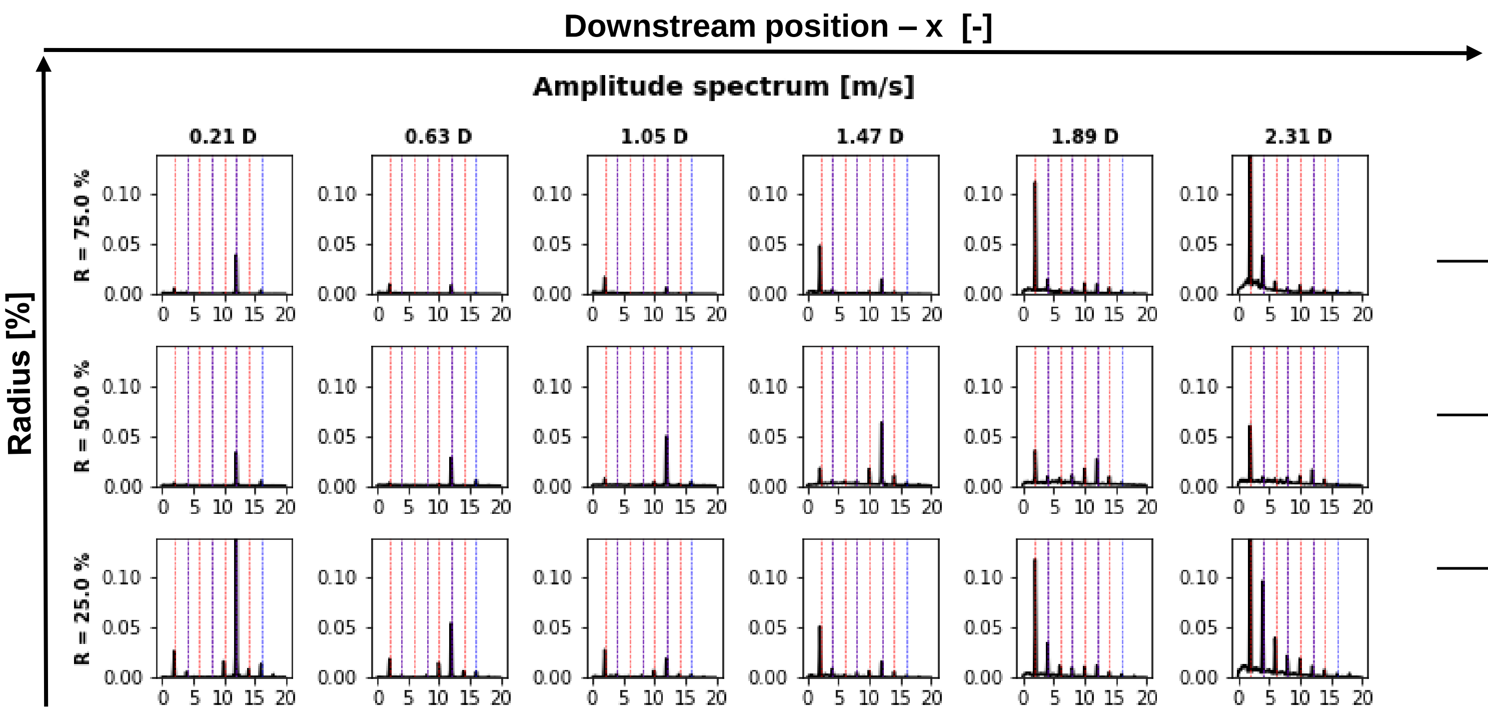
Azimuth-averaged amplitude spectra [m/s]



The frequency content tends to go from 3P to fs → can this be related to the wake recovery?

→ **3P** peak fades and **fs** rises

→ **3P** peak rises but then fades away while **fs** rises

→ **3P** peak fades and **fs** rises along with its harmonics

Red lines - multiples of the prescribed sway frequency, fs = 2 Hz | Blue lines – multiples of the rotational frequency, P = 4 Hz
Purple lines - superposition of the previous

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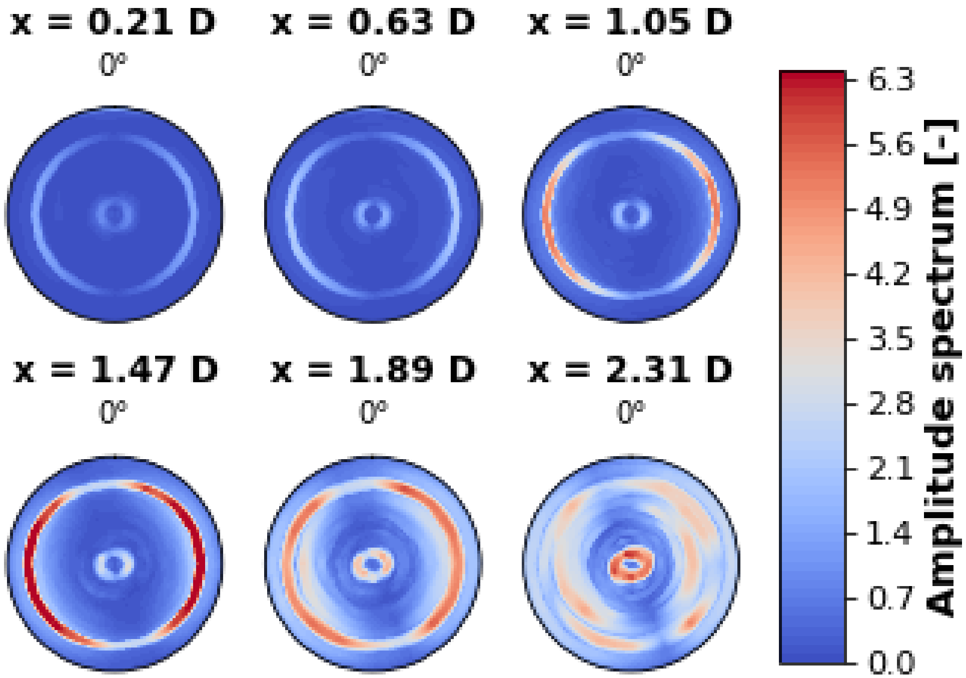
Where in the wake do we see the effect of the sway motion?

Streamwise velocity amplitude spectra at **fs** in space

- It was decided to plot amplitude spectrum value at the sway frequency for every point in each radial probe
- The amplitude spectrum is normalized by the maximum sway velocity
- **Up to x = 1.47 D,** the amplitude of the oscillations builds up in a ring and then starts spreading to the whole wake
- **In the very near wake,** the sway frequency is almost negligible
- Now if we calculate the average value of the amplitude spectrum as a function of the downstream position for **fs** and **3P**...



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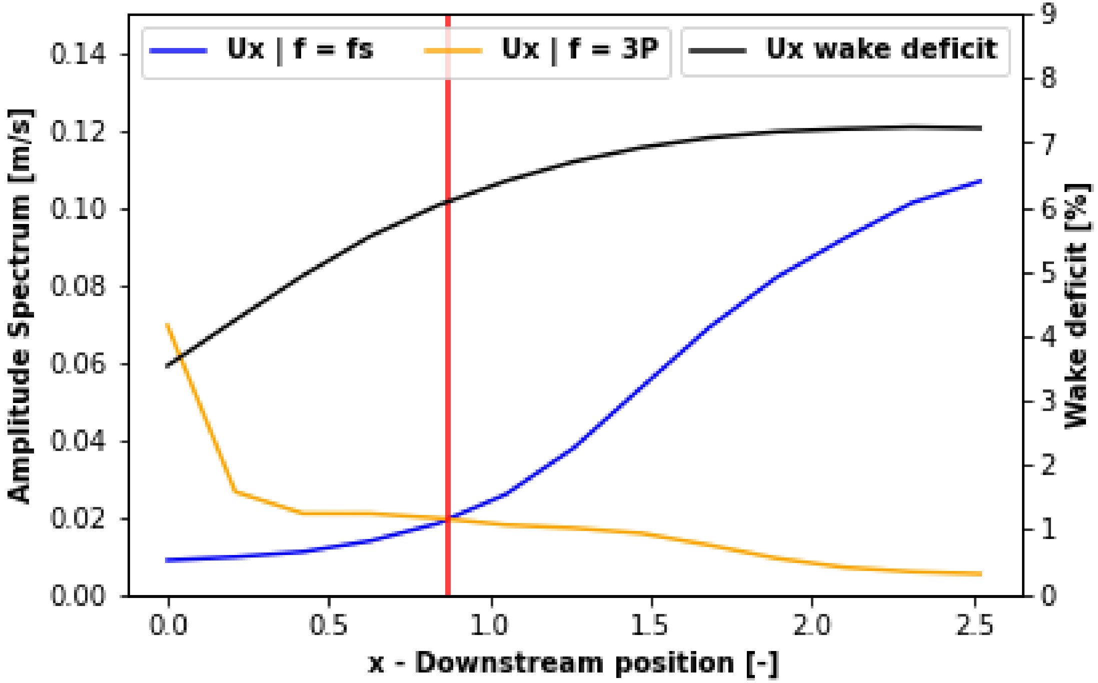
Streamwise velocity amplitude spectra at the sway frequency and 3P frequencies

- Indeed, there appears to be a frequency shift at around x = 0.86 D where the dominant frequency content is no longer **3P** but becomes **fs**
- The slope of the wake deficit appears to start decreasing once the sway frequency content becomes dominant over 3P



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Conclusions and future work

- In the very near wake, the wake seems to be insensitive to the sway motion
- As the wake develops, the wake starts experiencing the sway motion itself in that:
  - It oscillates increasingly at the sway frequency
  - The average wake becomes elliptical
- Notably, a frequency shift between **3P** and **fs** is identified as the wake develops
- The paper will address more amplitudes and frequencies as well as the remaining DOFs – heave, roll and yaw
- The ultimate goal is a full assessment of the impact of each DOF

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Q&A

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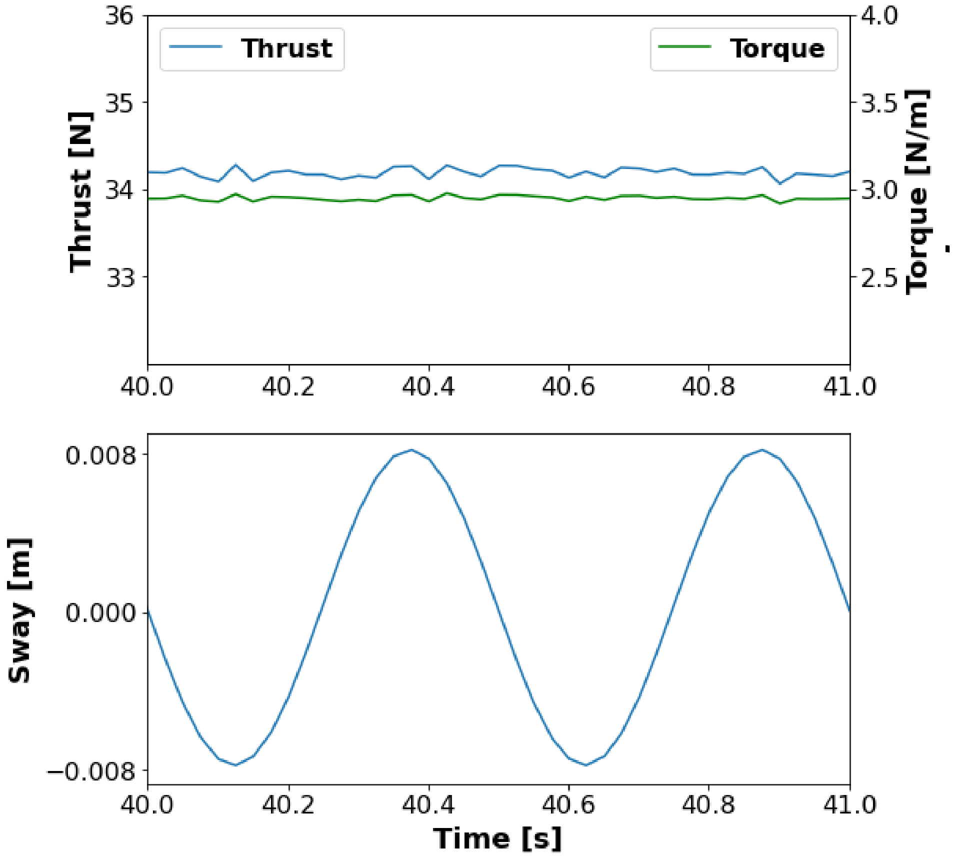
Sway motion



- The sway motion seems to have a negligible impact on the thrust and torque experienced by the turbine
- Let’s see what happens in the wake!

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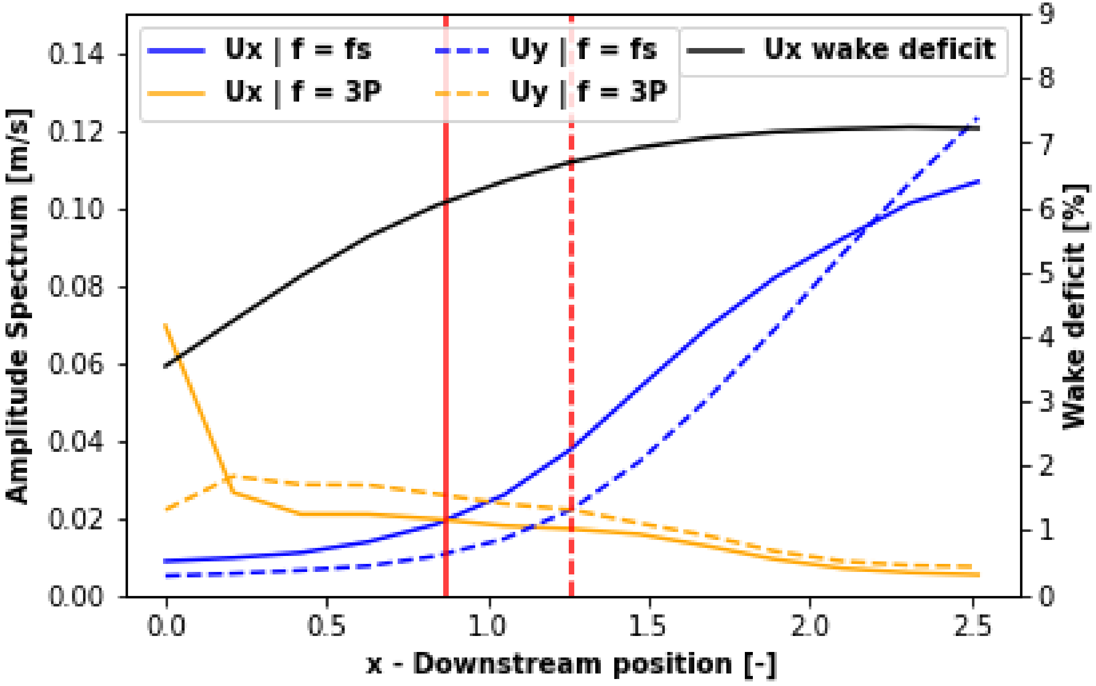
Streamwise velocity amplitude spectra at the sway frequency – 2 Hz

- The amplitude spectrum at the sway frequency fs and the 3P rotor frequency were averaged over the analyzed wake region for each position downstream and plotted in the figure on the right
- The full lines refer to the streamwise velocity Ux
- The dashed lines refer to the transversal velocity Uy – in the sway direction
- Comparing fs in blue with 3P in yellow, one can identify the points were the frequency content of the wake changes



Notes:

Main characteristics:

LES, Incompressible

Actuator line

Static polars

Prescribed motion was validated for surge and pitch in yet to be published paper

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Notes:

Velocity sampling

Fetch local velocity at future position of the blade, to avoid vortex core from previous force projection

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