Experimental Analysis of Wakes in Floating Wind Turbines Under Dynamic Induction Control

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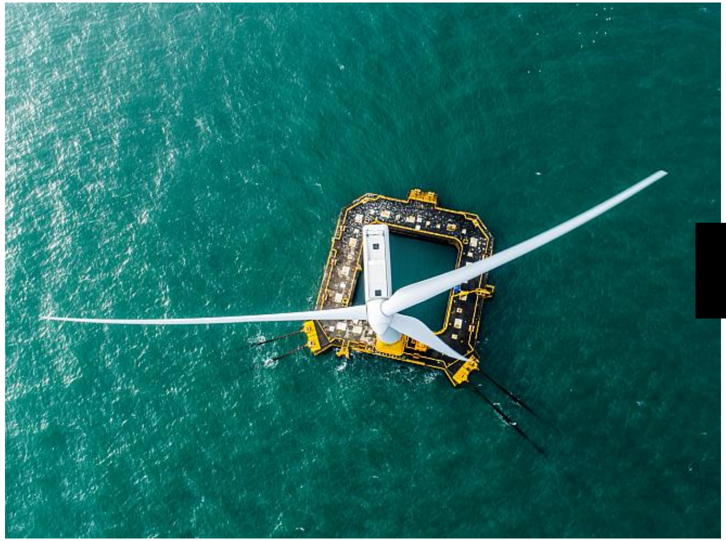
EERA DeepWind
Experimental testing and validation
January 15th, Trondheim, Norway

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Towards large floating wind farms



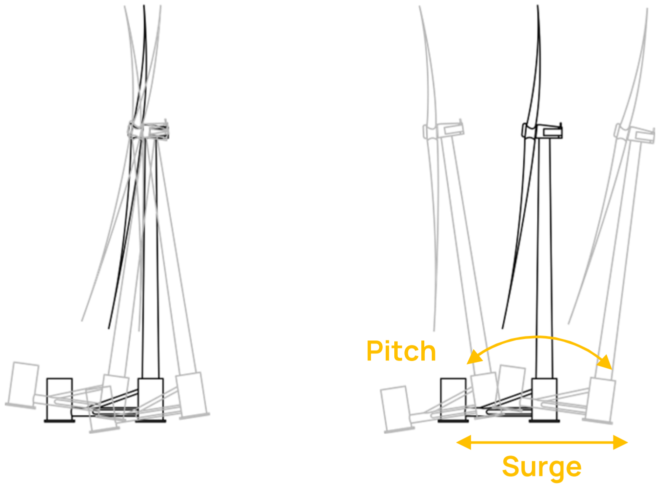
Floatgen
(1 WT, 2MW, 2018)

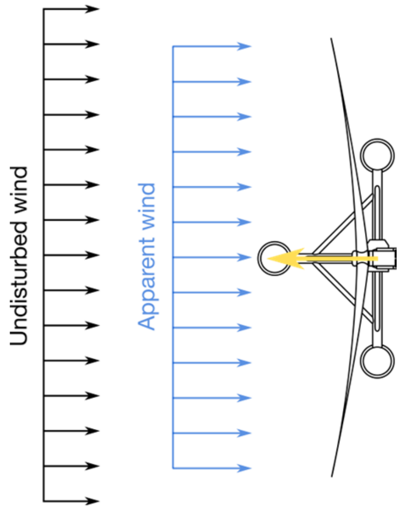
Provence Grand Large
(3 WT, 24MW, 2024)

?

Hornsea Project 2
(165 WT, 1386MW, 2022)

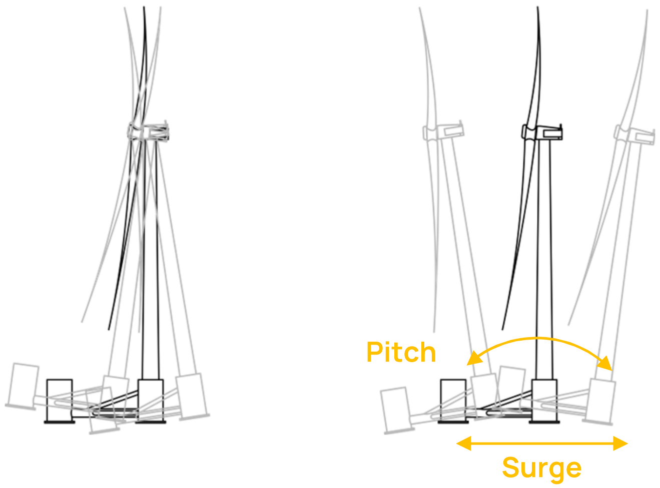
Dynamic induction and control in a floating wind turbine

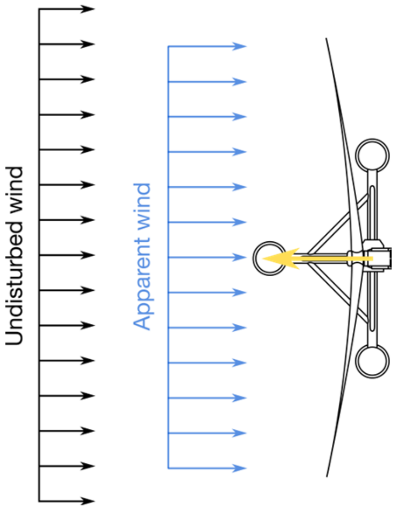




- Surge and pitch motions move the nacelle in the wind direction
- Nacelle motion causes variations in the apparent wind
- The variations in the apparent wind result in fluctuating thrust force

Dynamic induction and control in a floating wind turbine





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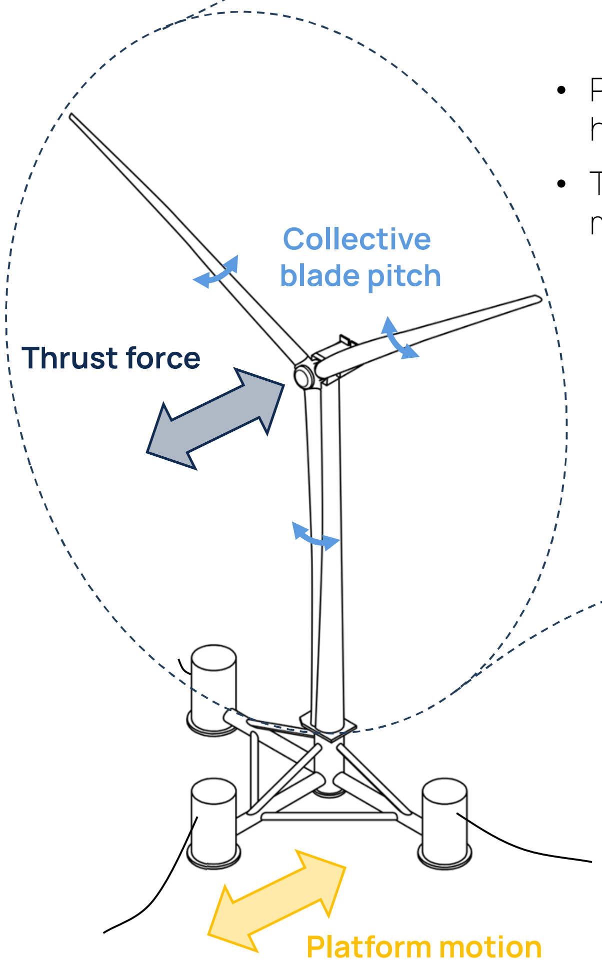
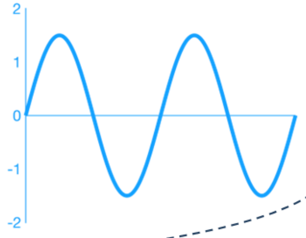
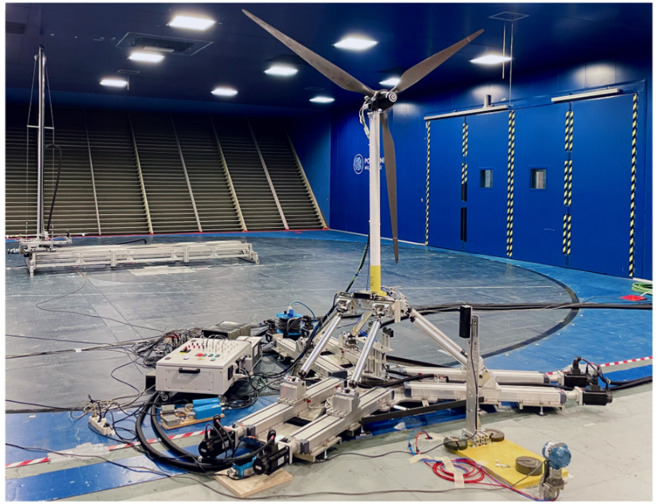


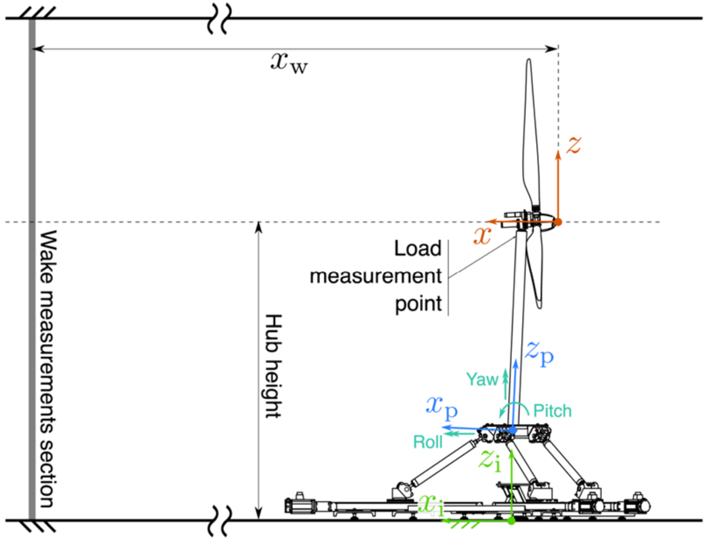
Pulsing thrust influences wake development

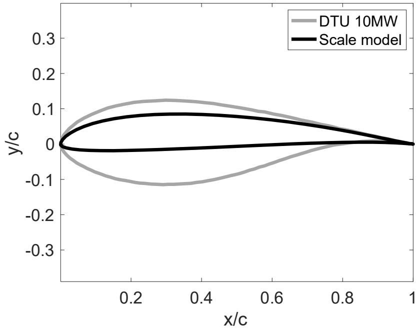
- Periodic blade pitching results in harmonic variations in the thrust force
- This pulsing thrust force causes movement in the platform

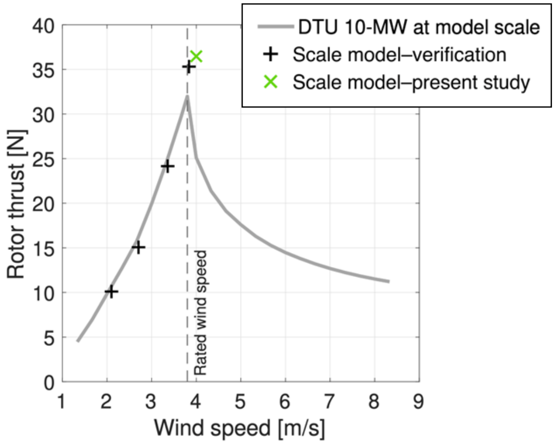


Wind tunnel experimental setup









NETTUNO Project

Wind turbine

- 1:75 scale model of the DTU-10 MW
- Same as in OC6 Phase III
- 2.4 m diameter rotor
- Performance-scaled blades
- 6-DOF robotic platform
- Near rated operation (max. thrust)

Wind tunnel

- 13.84 m x 3.84 m x 35 m
- Close-to-laminar wind (TI 1.5%)

Measurements

- 6-components aerodynamic loads at rotor
- Streamwise velocity in the wake (hot wire)

see more at: **https://nettuno-project.it**

Surge motion scenarios

Harmonic platform motion with various reduced frequencies and amplitudes

Reduced frequency $$f_\mathrm{r} = \frac{f_\mathrm{motion} D}{U}$$

0.3
0.6
1.2

0.3, 0.6: Rigid-body modes (0.02-0.04 Hz at full-scale)

1.2: Wave frequency (period of 12.5 s at full-scale

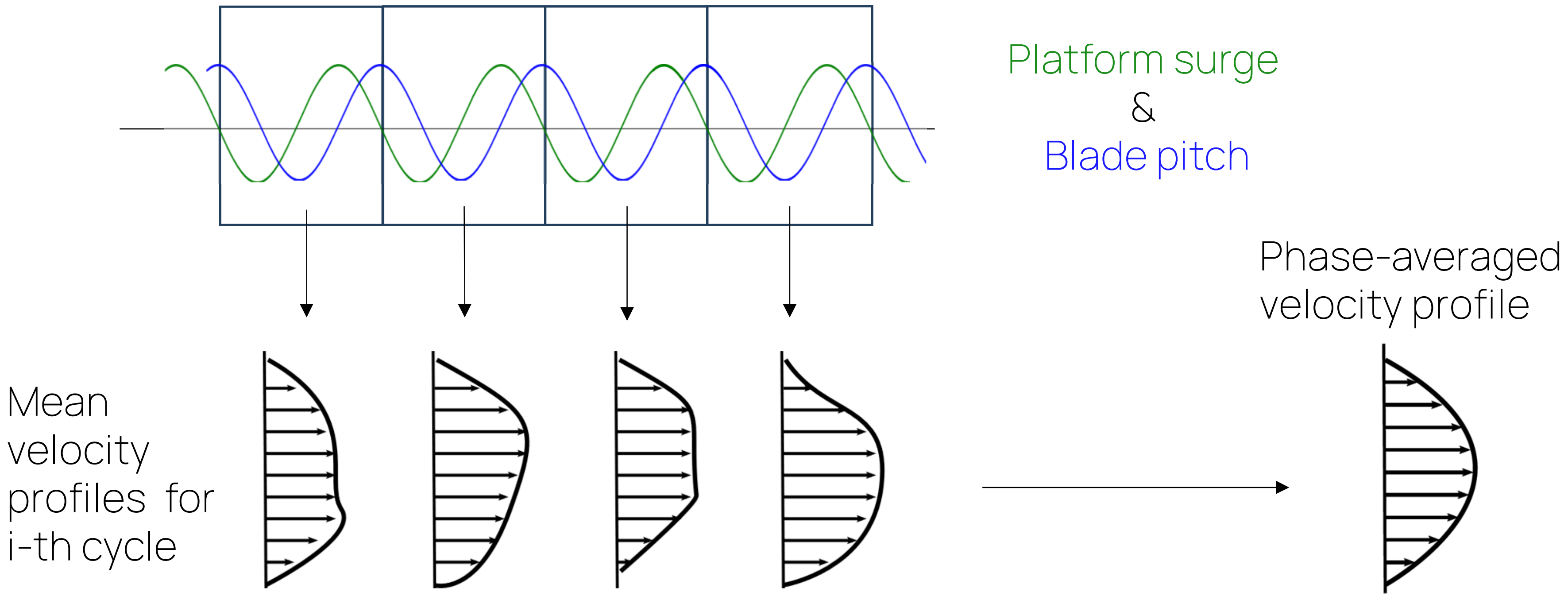
Motion amplitude

Model scale	Full scale
0.016 m	1.2 m
0.032 m	2.4 m
0.048 m	3.6 m
0.064 m	4.8 m

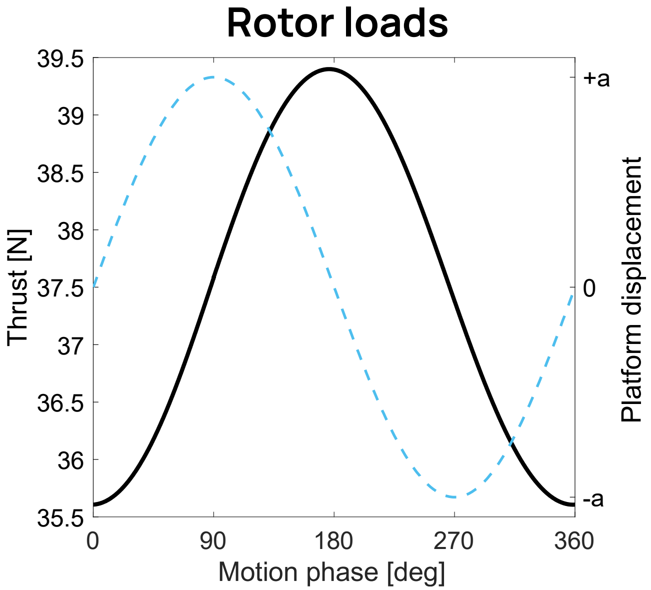
Methodology

Wake velocity were acquired over multiple cycles of platform motion

- imposed sinusoidal surge motion of the platform
- imposed sinusoidal pitching of the blades with <u>90° phase-shift</u>

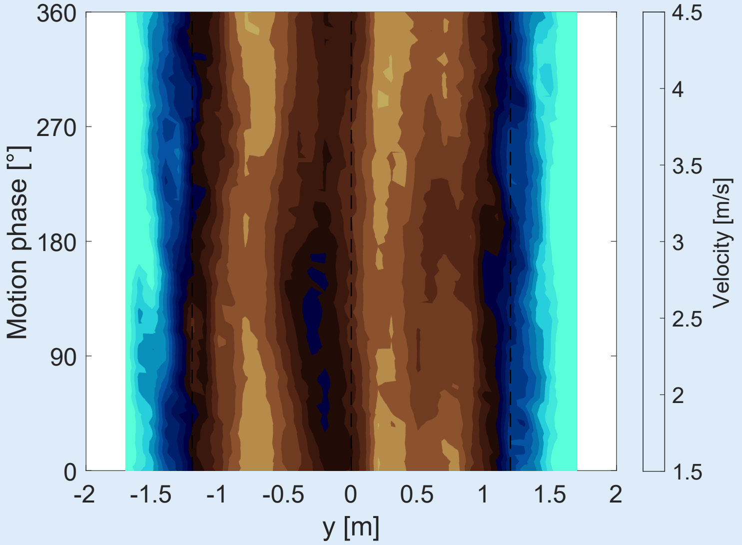


Wake with surge motion



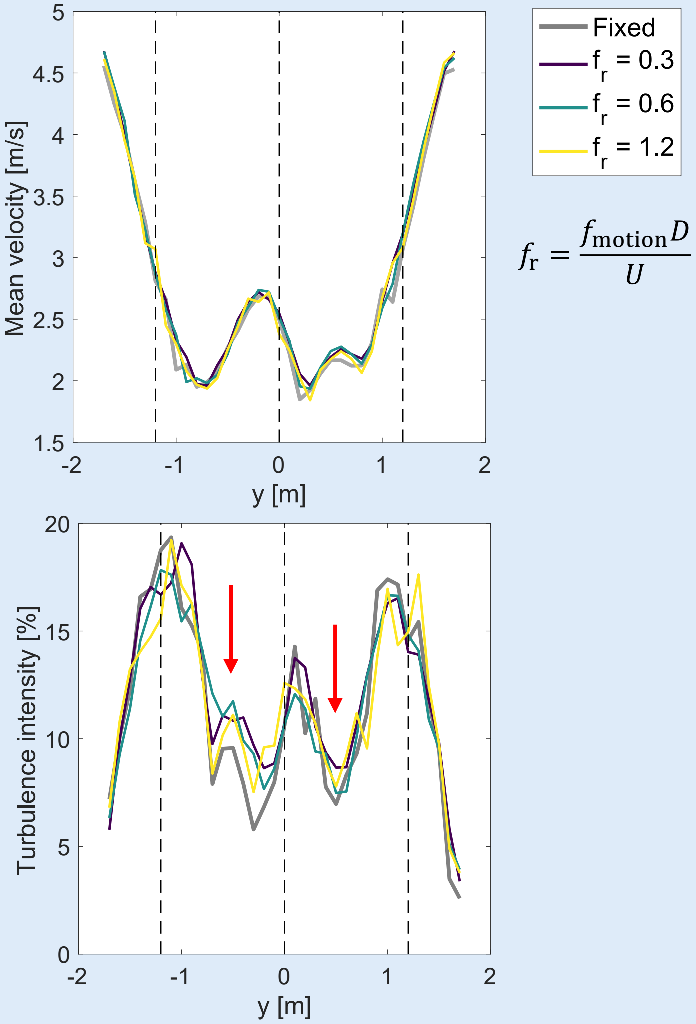
- Pulsing thrust force driven by apparent wind

Wake at 3D – Hub height



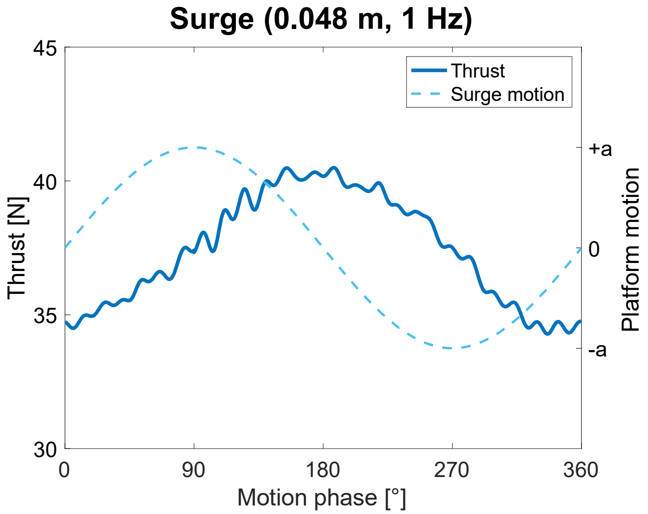
- Flow structures coherent with the platform motion
- Wake pulsing across the wake width

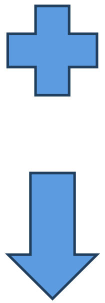
- Increase turbulence intensity in the center of the wake
- Strongest variations with $f_r = 0.6$

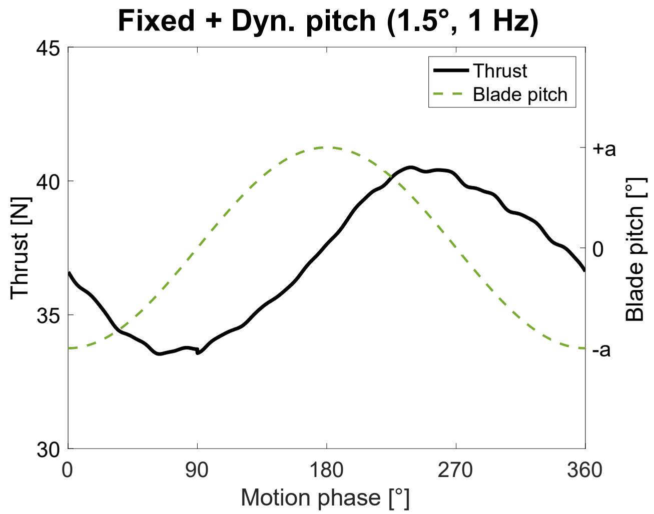


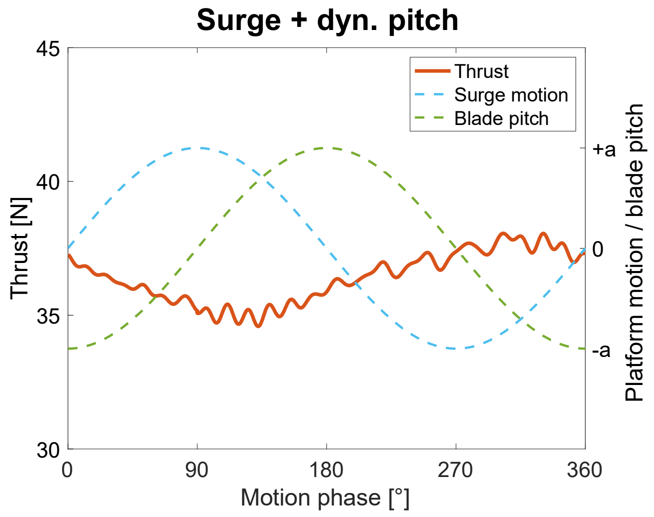
$$f_r = \frac{f_{motion} D}{U}$$

Surge motion + Dynamic blade pitch: loads









Surge (nacelle) motion

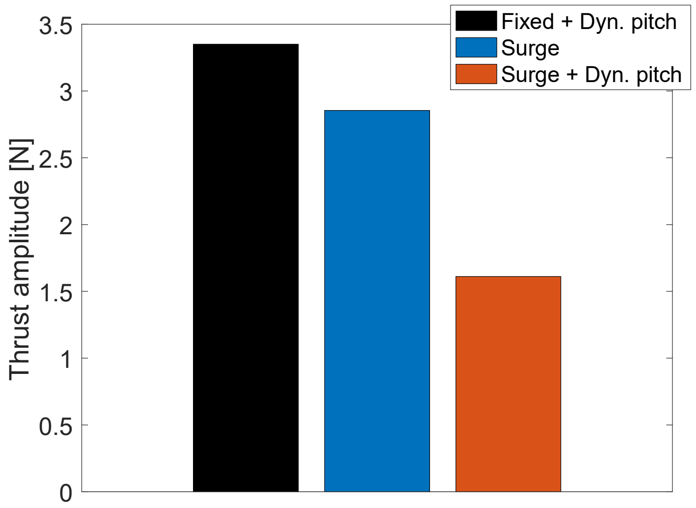
Model scale	Full scale
0.016 m	1.2 m
0.032 m	2.4 m
0.048 m	3.6 m
0.064 m	4.8 m

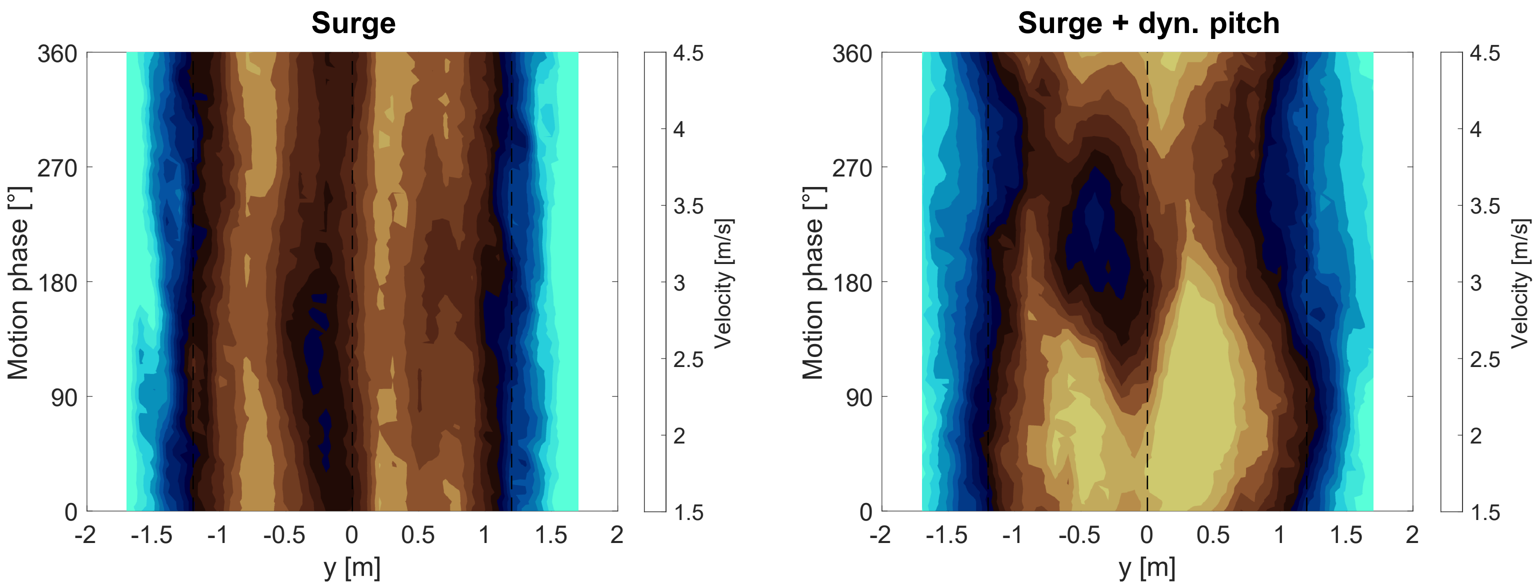
Blade pitch

- Amplitude 1.5°
- Same frequency of platform motion
- Phase shift of 90° between

Surge motion + Dynamic blade pitch: wake

Wake at 3D – Hub height



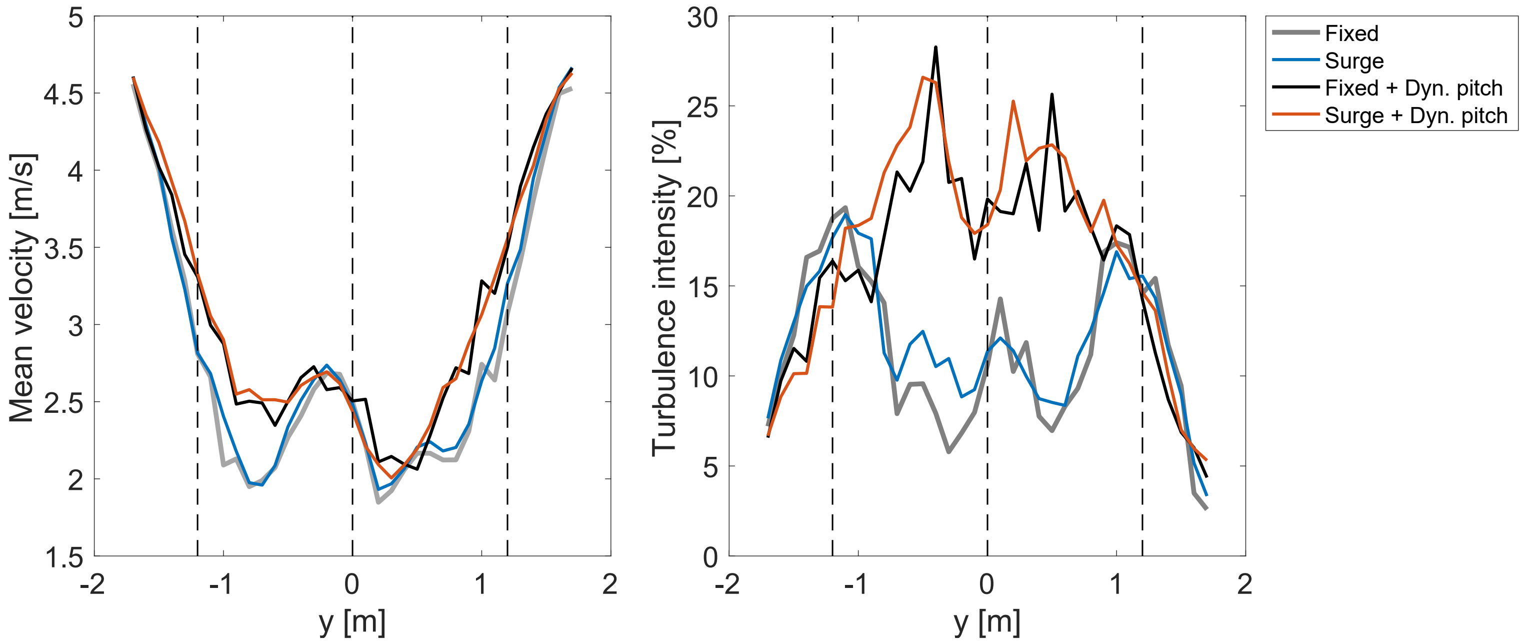


- Similar variations of thrust force with <u>separate</u> dynamic pitch and surge
- When combined, the variation of thrust force is lower due to phase-shift

Stronger wake pulsing is stronger with dynamic blade pitch

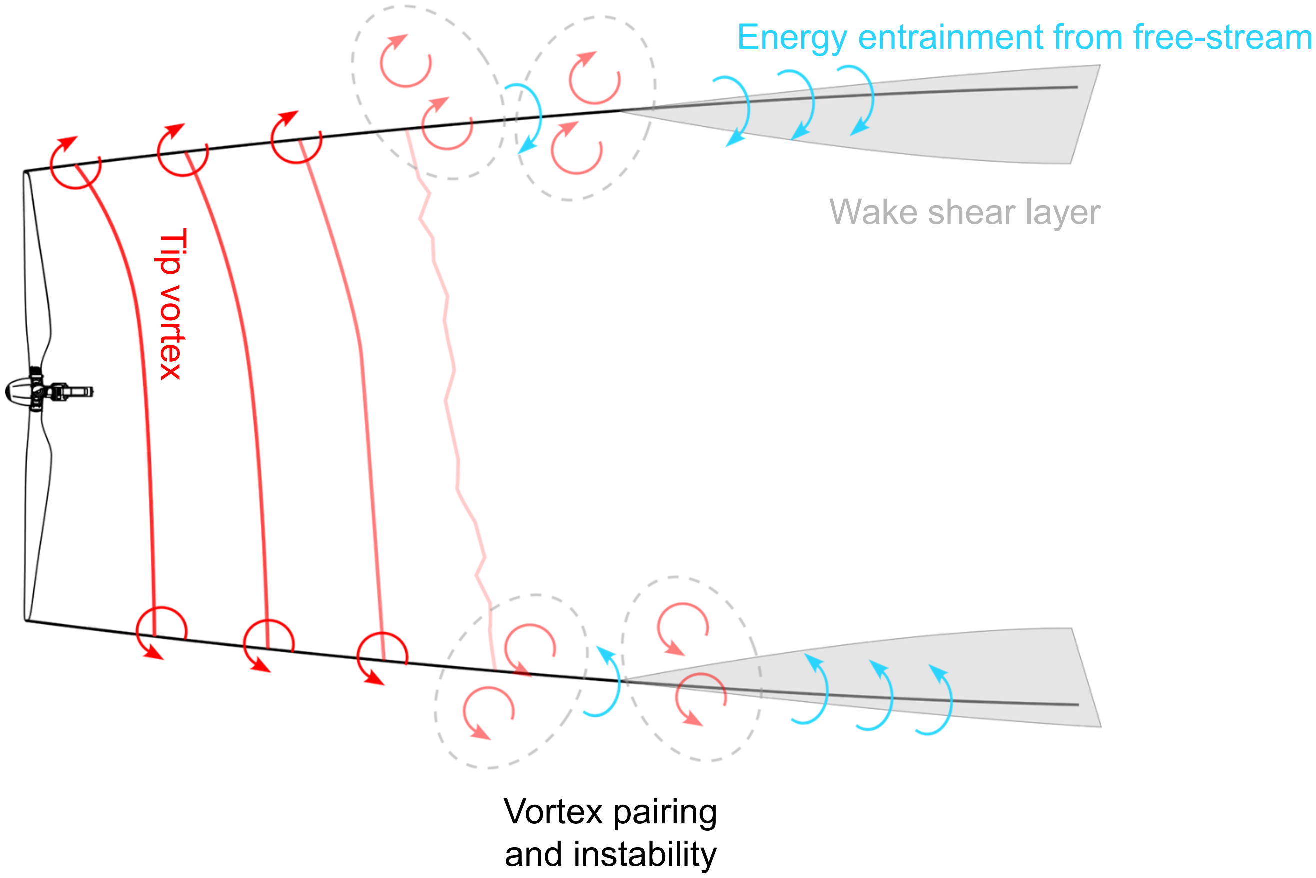
Surge motion + Dynamic blade pitch: wake

Wake at 3D – Hub height

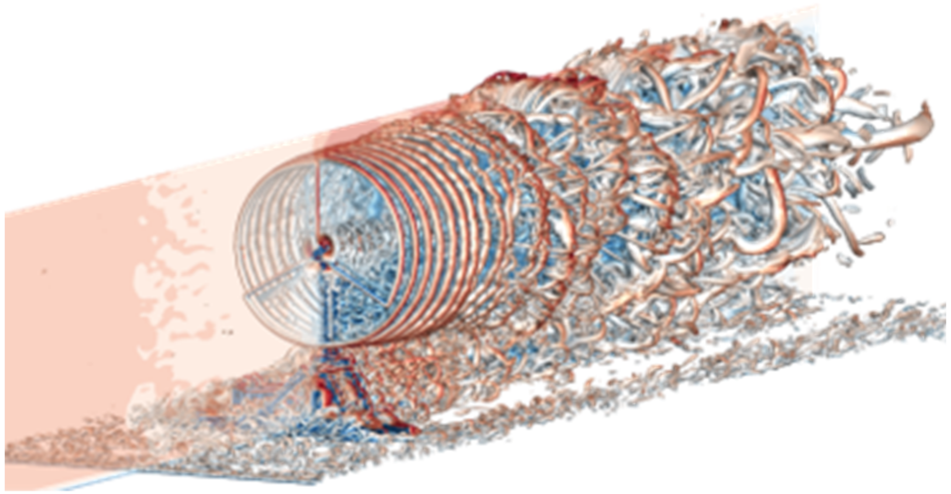


- Increased mean wind speed with dynamic blade pitch
- Surge motion has limited impact on wake recovery
- Increase TI at the center of the wake due to dynamic pitch

Wake excitation mechanism



- Near wake "shielded" by tip vortex
- Pulsing thrust force linked to fluctuating vorticity
- Higher instability of the tip vortex and more rapid decay
- ... **see our poster this evening**!



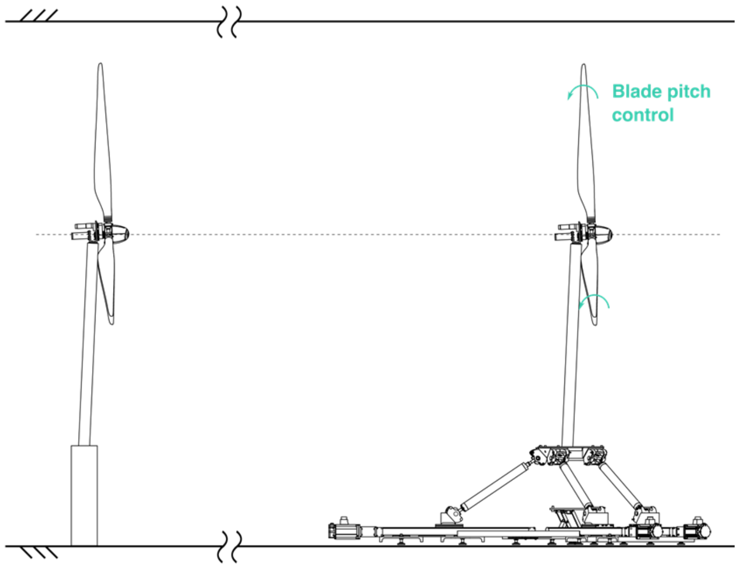
Conclusions and future work

Conclusions

- Surge motion and dynamic pith cause
  - periodic variations of thrust force
  - flow structures in the wake coherent with nacelle motion / blade pitch
- The effects on wake do not combine in a linear manner
  - **dynamic blade pitching** with platform movement → **increased wake velocity** without increasing loads
- Dynamic induction control **effective** also in floating wind turbines

Future work

- High-fidelity simulations to understand the wake excitation mechanism
  - a paper using LES has been submitted to WES
- New wind tunnel experiments:
  - increased number of scenarios with collective dynamic blade pitching
  - tests with individual dynamic blade pitching (a.k.a. Helix)
  - loads and power of a waked turbine



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