SHAKE THE FUTURE.

Étude en soufflerie atmosphérique du sillage d'une éolienne flottante

Sandrine Aubrun,

Professor in Centrale Nantes

Research lab on Hydrodynamics, Energetics and Atmospheric Environment (LHEEA)

GDR EOL-EMR Day, November 25, 2021

FLOATEOLE project

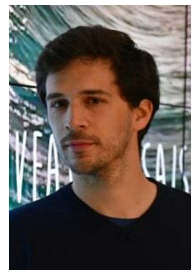
Experimental characterization of the wave impact on the unsteady aerodynamical behavior of floating wind turbines

- 2017-2022
- Grant 164k€
- Funders / Supports

FLOATEOLE project

L’équipe-projet

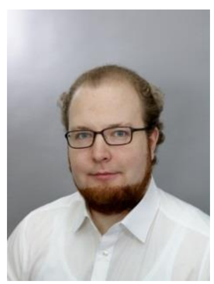
Sandrine AUBRUN
Prof. ECN, éq. SEMREV+



Boris CONAN
MCF ECN, éq. DAUC

Yves PERIGNON
IR CNRS, éq. SEM-REV+

Jean-Marc ROUSSET
IR ECN, éq. SEM-REV+



Benyamin SCHLIFFKE
Doct. Éq. DAUC/SEMREV+

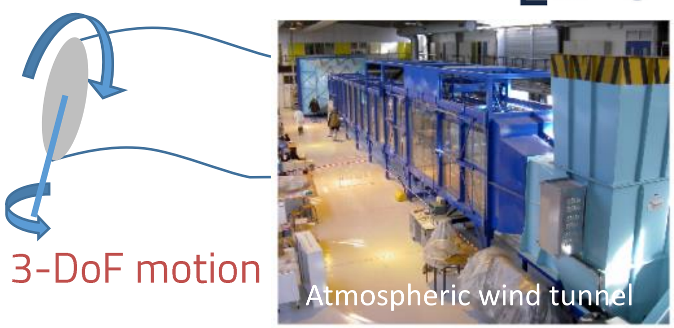
Antonin HUBERT
Doct. Éq. DAUC/SEMREV+

Post-doc
2022

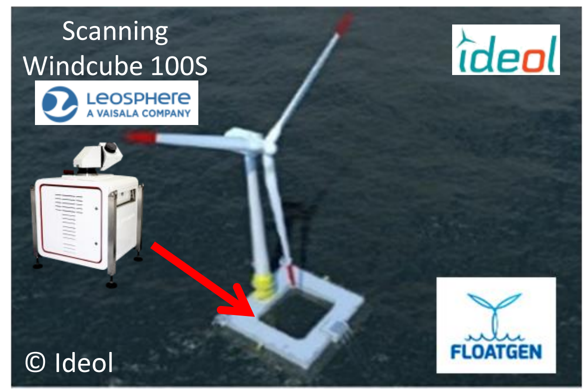
Methodology

- Multidisciplinary approach to study the wind – wave – structure coupling
- Experiments performed in controlled and real conditions (wind tunnel and sea test site, respectively)

Aerodynamic behavior under floater motion emulation



Wind resource and wake through LiDAR measurements



Scientific and technical challenges :

- Does the floater motion have an impact on the wind turbine wake development?
- Can the signature of the motion be found in the wake?

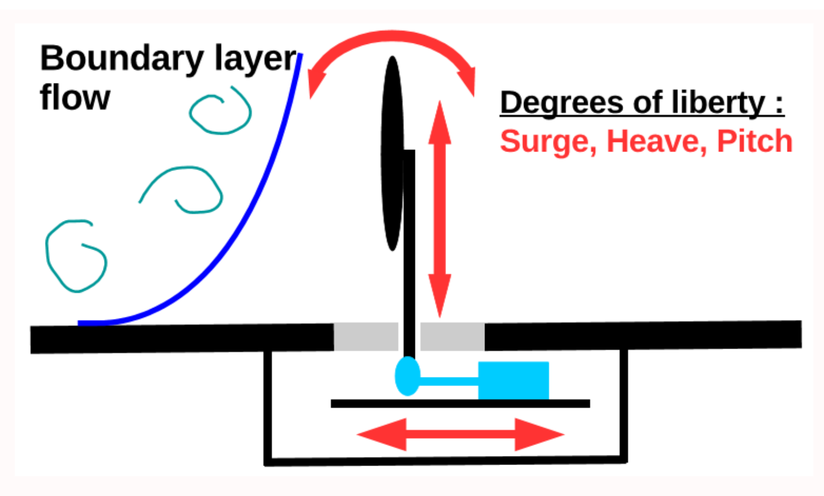
- Wind tunnel testing: Floater motion emulation at very reduced scale
- Sea testing: scanning LiDAR measurement on floating structures

Technical challenges

- **Wind tunnel experiments**

- Design a motion system that can emulate the floaters movements in different sea states
- From idealised to extreme cases
- For a reduction scale of 1:400

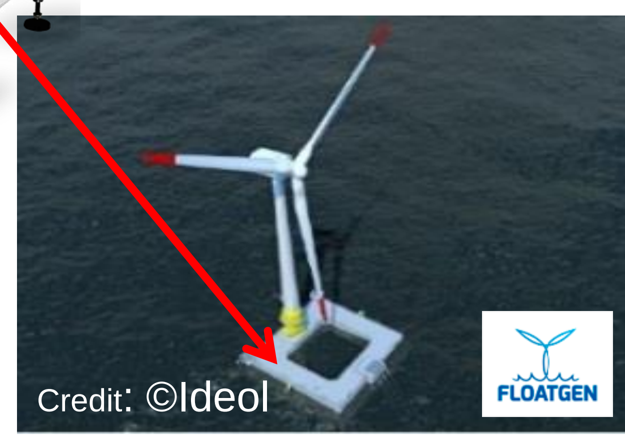
- => High accelerations



- **Onsite experiments**

- Mitigate the influence of floater motions on the LiDAR measurements
- Stabilizing platform
- Control of the scanning head

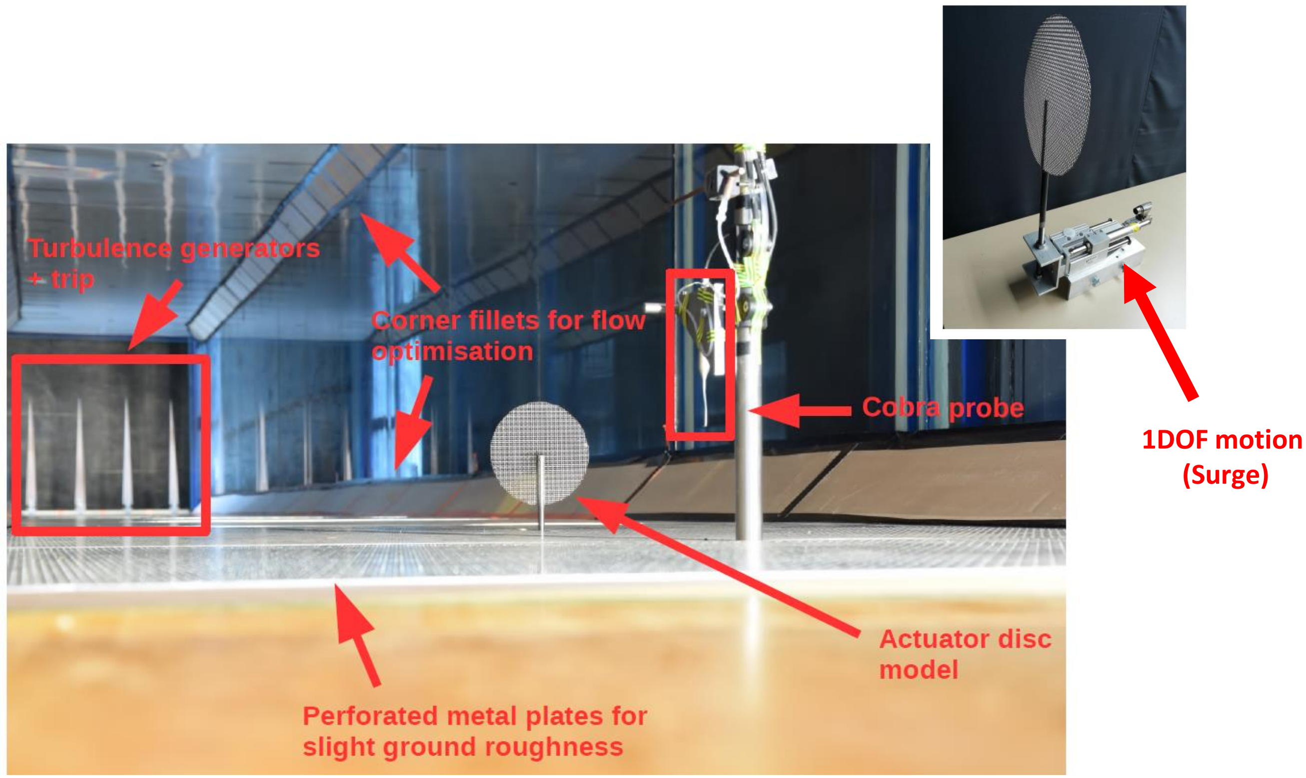
Scanning Windcube



Experimental set-up

Wind tunnel testing: Floater motion emulation at very reduced scale

Set-up in the atmospheric wind tunnel (Centrale Nantes/LHEEA)



Reduction scale 1:500

(No possible Reynolds similarity)

+

Far-wake

=

Actuator disc model (porous disc)

Ben Schliffke's PhD work

Experimental set-up

Wind tunnel testing: Floater motion emulation at very reduced scale

Set-up in the atmospheric wind tunnel (Centrale Nantes/LHEEA)

Reduction scale 1:500

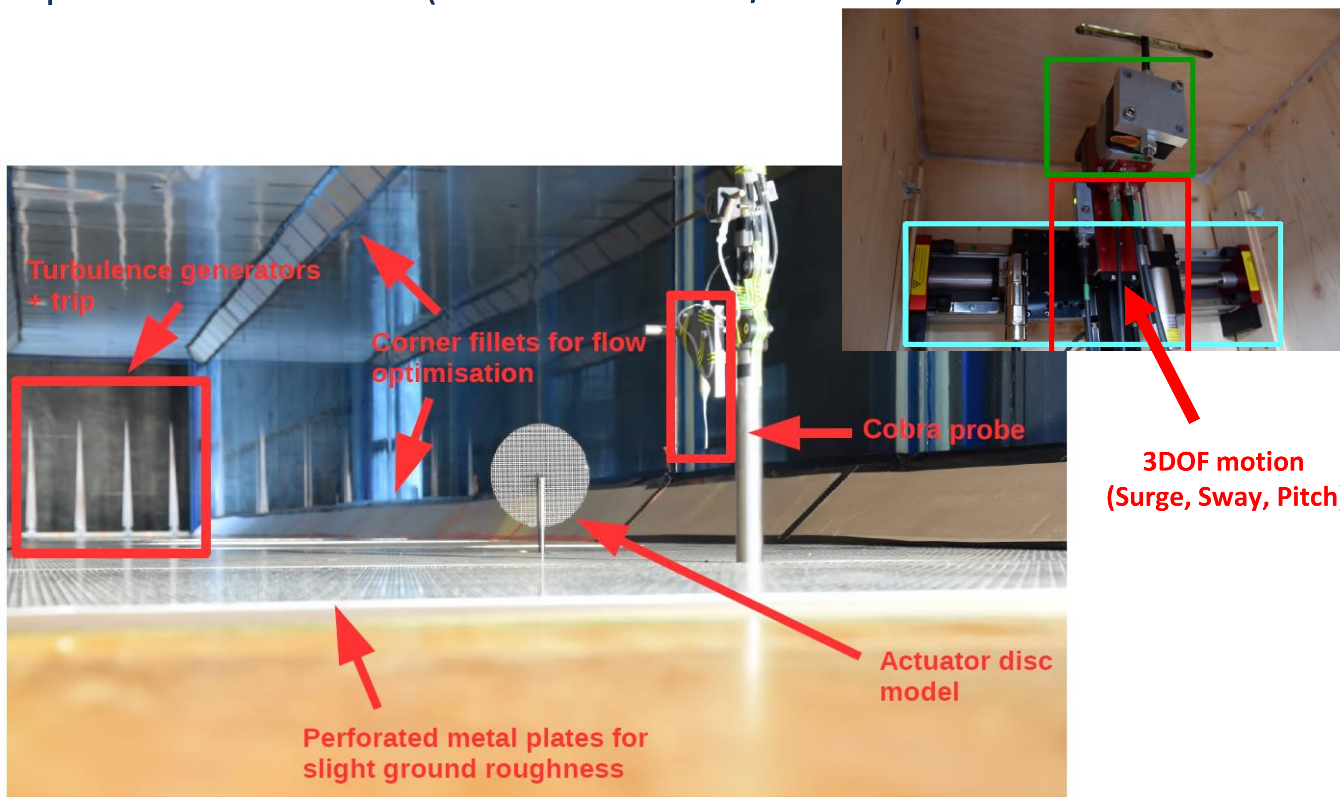
(No possible Reynolds similarity)

+

Far-wake

=

Actuator disc model (porous disc)



Ben Schliffke's PhD work

Experimental set-up

Scaling driven by wind tunnel capacities

Scaling factor	Value
Geometric	$\Lambda_L = 500$
Kinematic	$\Lambda_v = 2.5$
Time	$\Lambda_t = 200$
Frequency	$\Lambda_f = 0.005$

Scaling driven by disc aerodynamics

$$f_{red} = \frac{f.D}{U_{ref}} = St_D$$

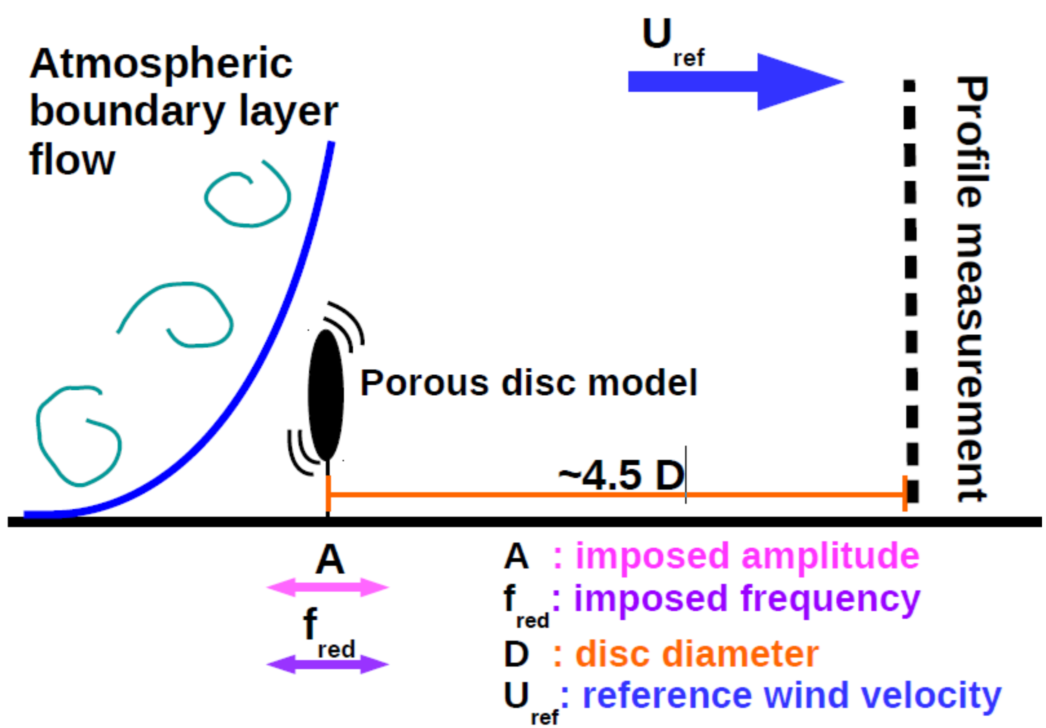
Surge specifications

$\Rightarrow$ Characteristic $A = L = 0.125D$

=> Characteristic $f_{red} = \frac{f.D}{U_{ref}} = 0.1$

Floating Wind turbine scaling

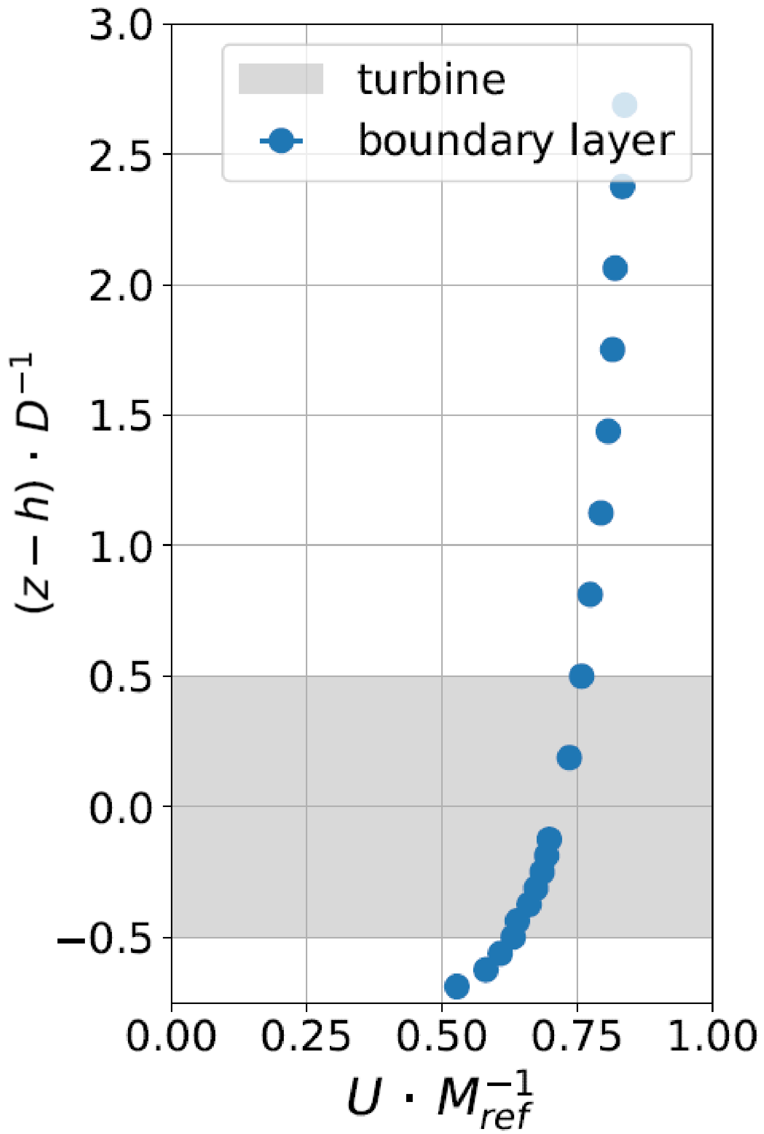
	Full scale	Wind tunnel	Name
Rotor diameter	80 m	16 cm	D
Nacelle height	60 m	12 cm	h
Char. floater surge motion	10 m	2 cm	L
Char. floater surge freq.	0.01 Hz	2 Hz	f_s



Ben Schliffke's PhD work

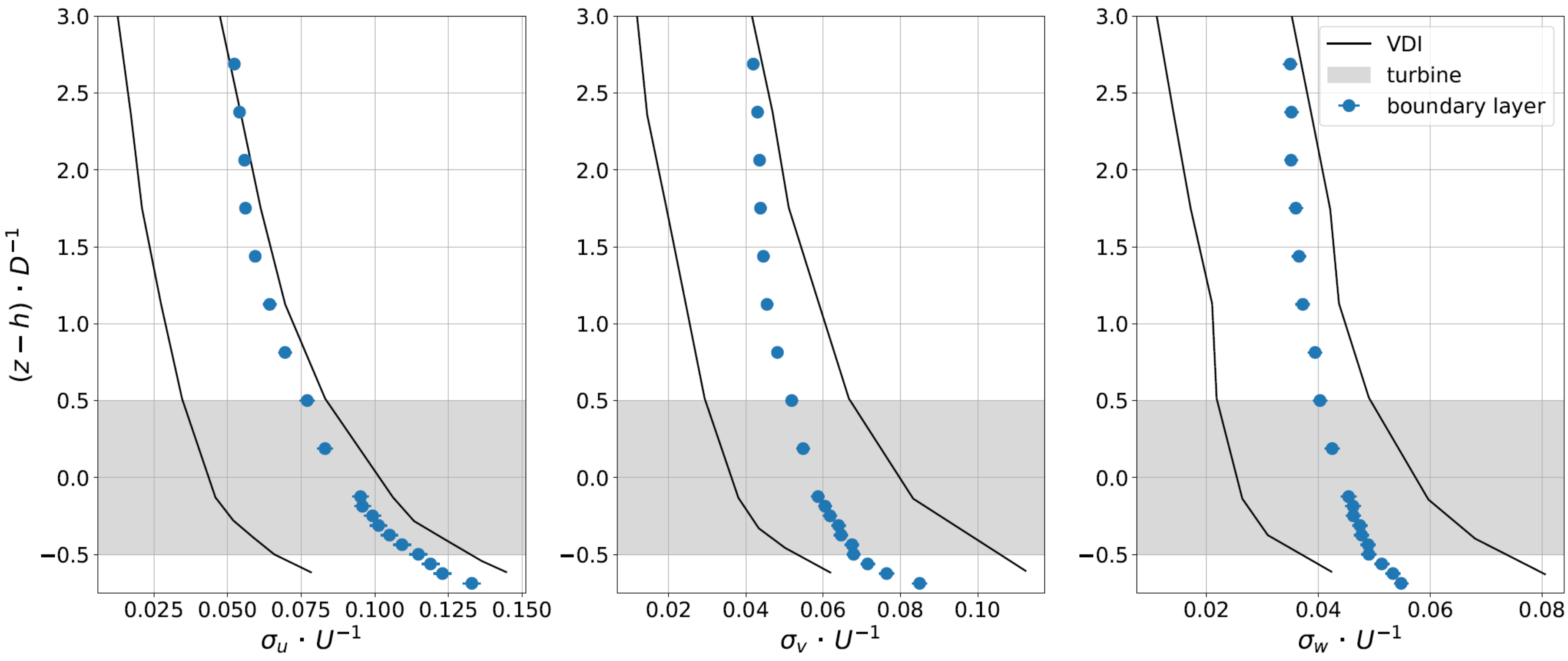
Modelled atmospheric boundary layer

Roughness class	Target values	Modelled
Type of terrain	ice, snow, water surface	water surface
z_0 $[m]$	10^{-5} to 5×10^{-3}	5.5×10^{-6}
α	0.08 to 0.12	0.11
d_0 $[m]$	≈ 0	0



LHEEA CENTRALE NANTES
cnrs

Modelled atmospheric boundary layer



LHEEA CENTRALE NANTES

cnrs

Atmospheric boundary layer specifications

VDI 3783 versus IEC guidelines

Table: Comparison of VDI Guideline 3783 (VDI, 2000) for a modelled offshore boundary layer and IEC 61400-3 design load cases for offshore wind turbines (IEC, 2009). The reference height is the nacelle in this table. For neutral stratification.

Quantity	VDI Guideline 3783	IEC 61400-3	**Modelled**
I_{ref}	-	12%	-
I_u	5% – 10%	$I_{ref} \cdot (0.75 \cdot V_{hub} + b) \vert b = 5.6m/s$	$\approx 9\%$
α	0.08 – 0.12	0.14	0.11
validity of α	entire profile	rotor swept area	entire profile
stratification	neutral	no mention	neutral

- IEC 61400-3 overestimates turbulence intensity (especially at lower velocities; see the following slide) and α compared to the VDI.
- Calculating α according to IEC with our data results in $\alpha = 0.12$
- Calculating I_u according to IEC with our (rescaled) data results in $I_u \approx 22\%$

LHEEA CENTRALE NANTES cnrs

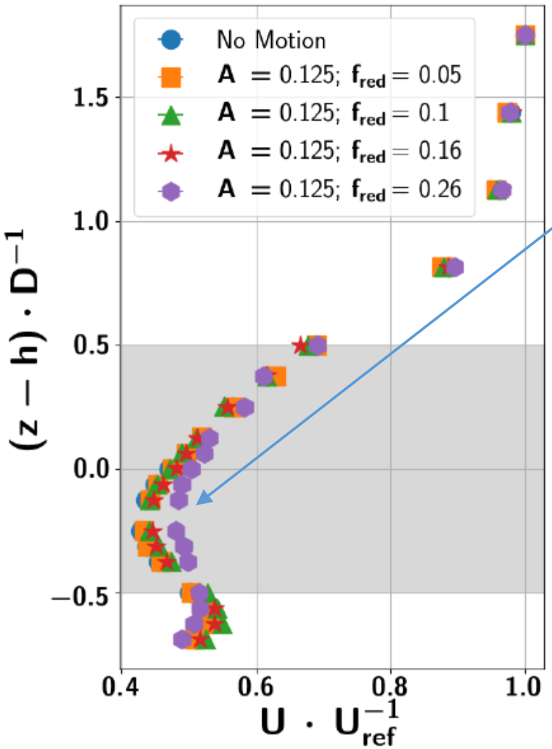
Mean velocity profiles

Impact of platform motions on far-wake properties

Imposed frequency-varying

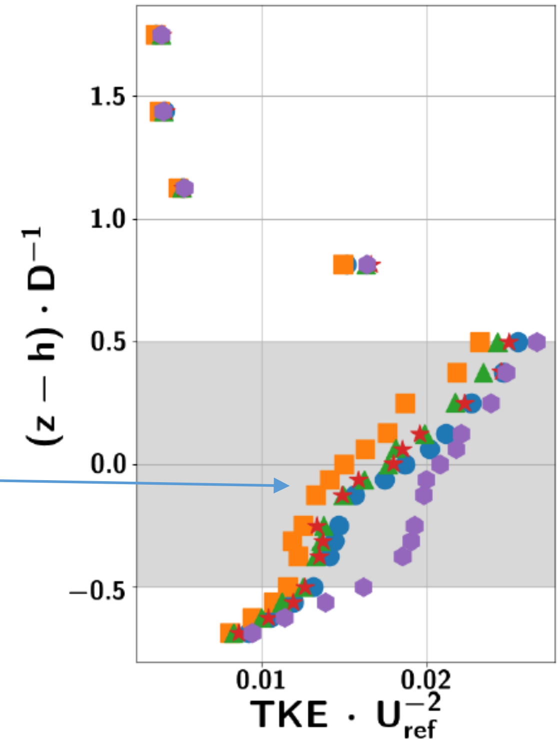
Surge motion (fore-aft translation)

Vertical profiles of the
Mean normalised velocity



Vertical profiles of the
mean velocity not
significantly changed by
the imposed motion

Vertical profiles of the
normalised turbulent kinetic energy (TKE)



- the turbulent kinetic energy is disturbed in the rotor-swept-area
- Most of the frequencies of motion correspond to a loss of TKE when compared to the no motion reference case

4.6D downstream

Ben Schliffke’s PhD work

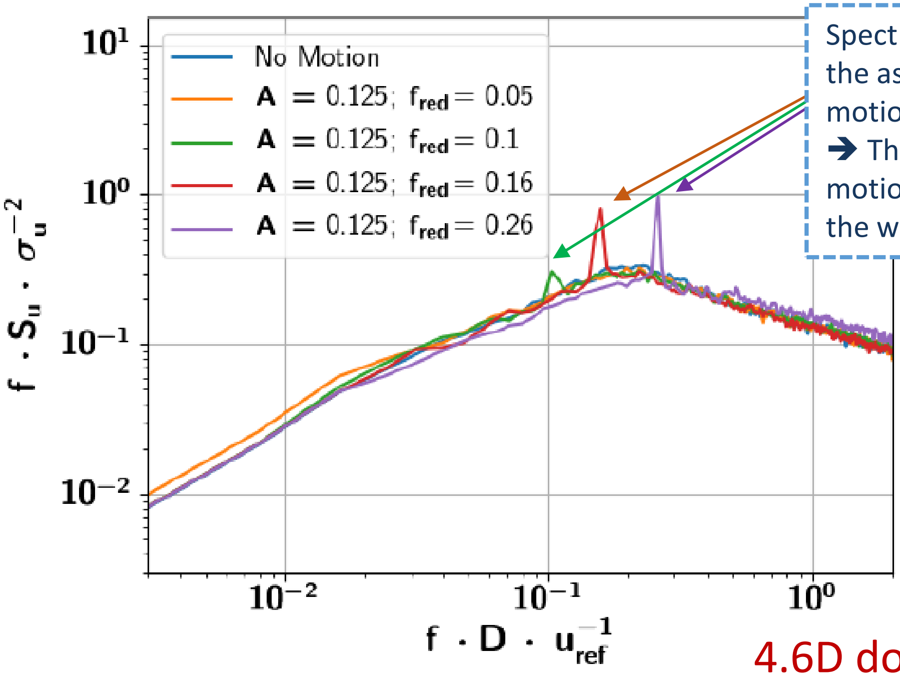
Velocity fluctuation spectra

Impact of platform motions on far-wake properties

Imposed frequency-varying

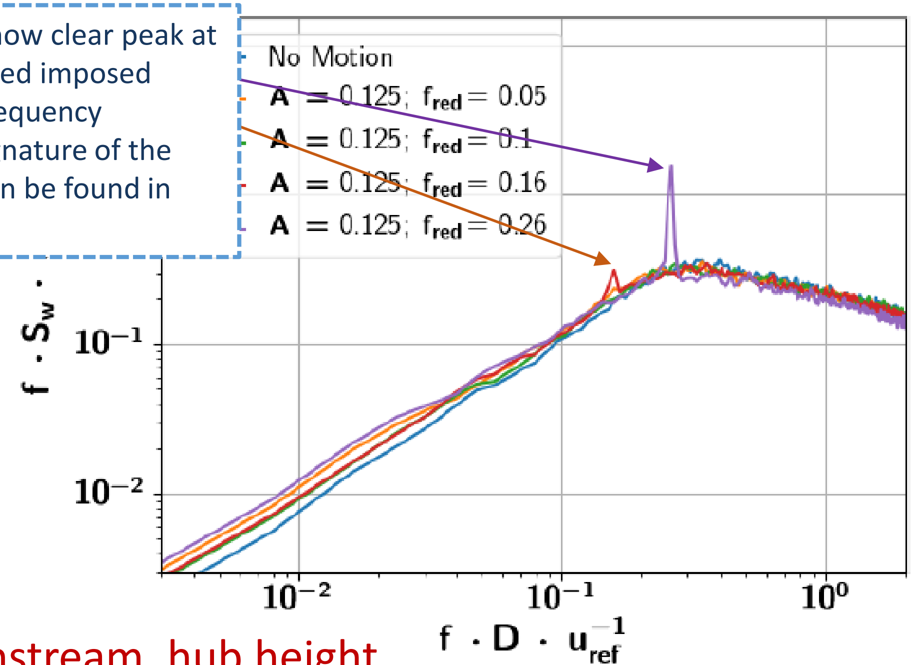
Surge motion (fore-aft translation)

Spectra of the longitudinal velocity component **u**



Spectra show clear peak at the assigned imposed motion frequency
➔ The signature of the motion can be found in the wake

Spectra of the vertical velocity component **w**



4.6D downstream, hub height

LHEEA CENTRALE NANTES cnrs

Ben Schliffke's PhD work

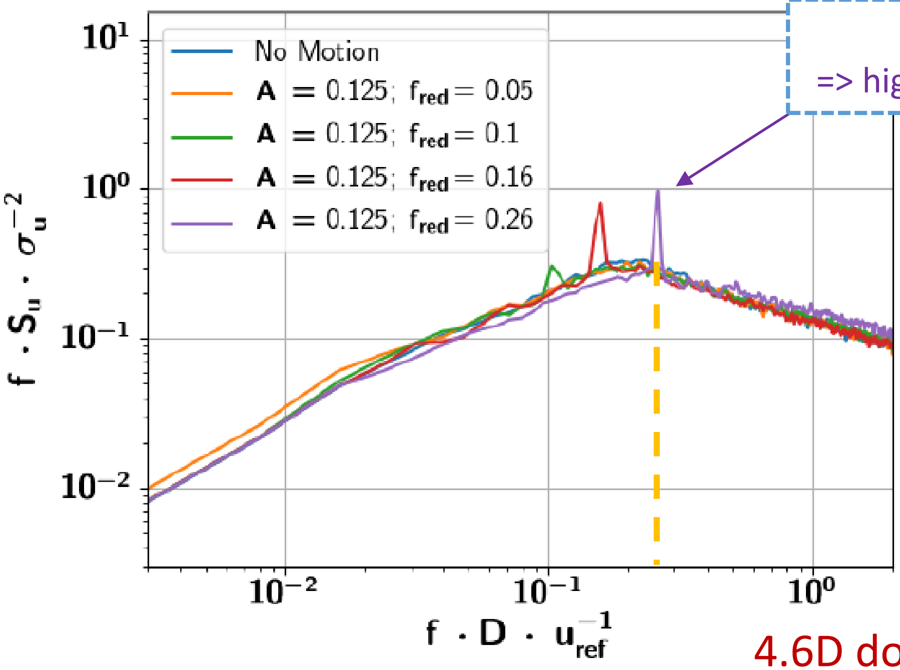
Velocity fluctuation spectra

Impact of platform motions on far-wake properties

Imposed frequency-varying

Surge motion (fore-aft translation)

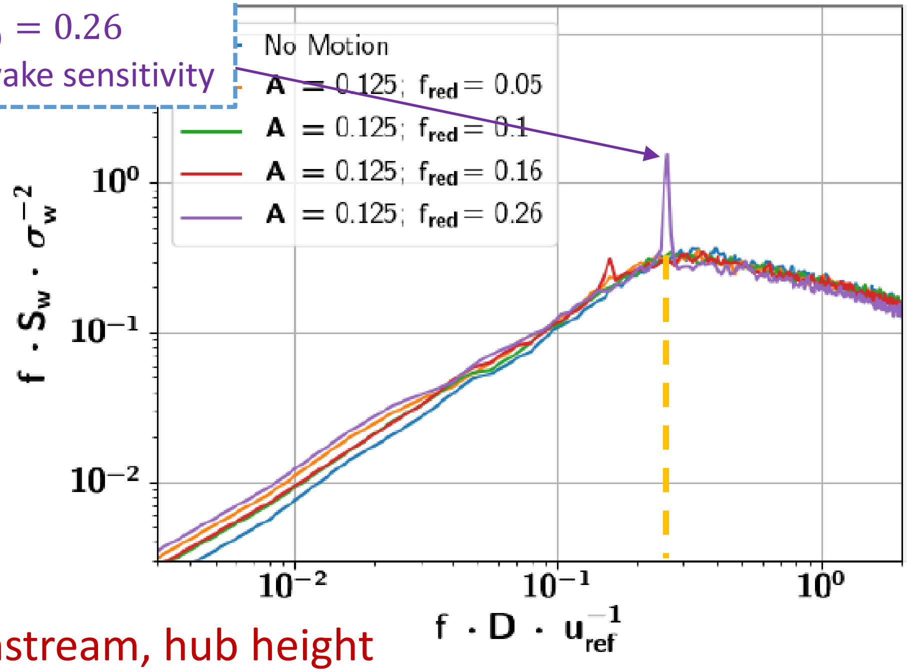
Spectra of the longitudinal velocity component **u**



$St_D = 0.26$

=> high wake sensitivity

Spectra of the vertical velocity component **w**



4.6D downstream, hub height

LHEEA CENTRALE NANTES cnrs

Ben Schliffke's PhD work

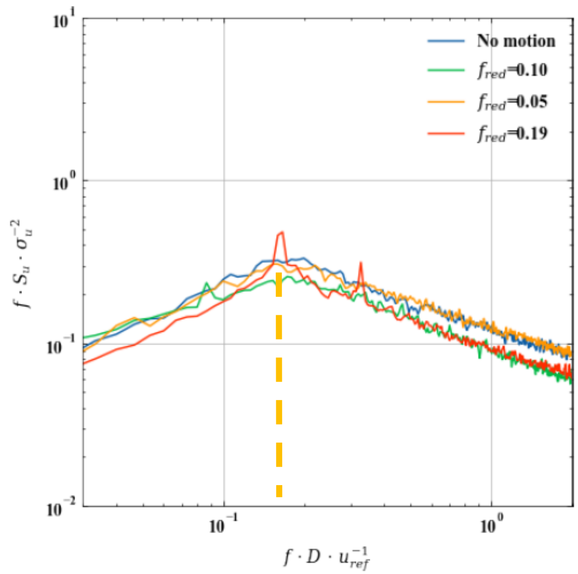
Velocity fluctuation spectra

Impact of platform motions on far-wake properties

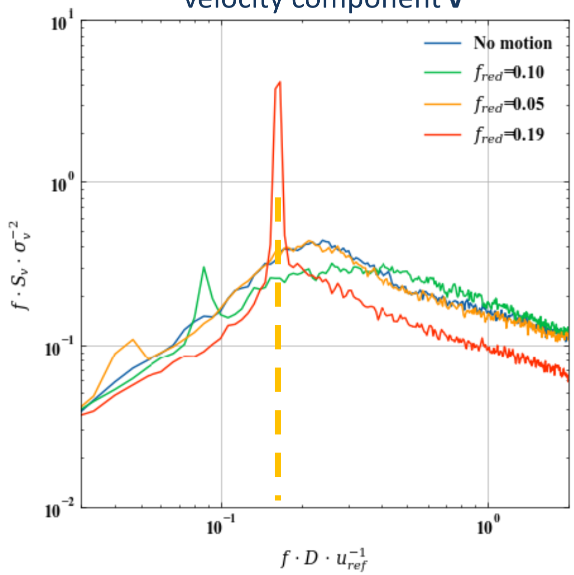
Imposed frequency-varying

Sway motion (side-to-side translation)

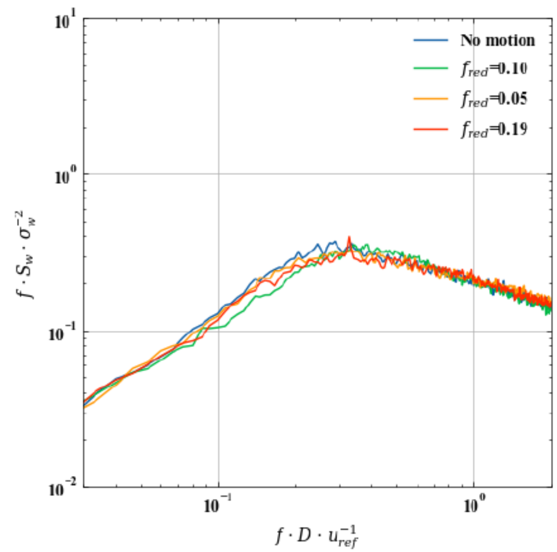
Spectra of the longitudinal velocity component **u**



Spectra of the vertical velocity component **v**



Spectra of the vertical velocity component **w**



4.6D downstream, hub height

LHEEA CENTRALE NANTES cnrs

Ben Schliffke's PhD work

Conclusions

Idealised Motions

- Can the signature of the harmonic motion be found in the far-wake? **Yes!** (if the motion is sufficiently strong and depends on the motion frequency)
- Is this indicative of faster wake recovery? **Yes, but only a little…**

Next steps

- Regular and irregular 3DOF motions (surge, sway, pitch or roll)
- Wake meandering characterisation
- Wake interactions of two floating wind turbines

LHEEA CENTRALE NANTES cnrs

Final comments on the project strategy

Wind turbine far-wake characterisation

Wind tunnel experiments

- Controlled environmental conditions
- Separate the contribution of motions & physical mechanisms to the wake modifications
- Challenges to work a reduced scale
- Upscaling?

Full scale measurement

- Uncontrolled and constantly changing environmental conditions
- Huge technical challenges in offshore conditions (equipment integrity and measurement reliability)
- But real life!

LHEEA CENTRALE NANTES cnrs