Eera Deepwind'2017, 14th Deep Sea Offshore Wind
R&D Conference, 18 - 20 January 2017

POLITECNICO
MILANO 1863

Wind Tunnel Wake Measurements of Floating Offshore Wind Turbines

I. Bayati, M. Belloli, L. Bernini, A. Zasso

Politecnico di Milano, Department of Mechanical Engineering

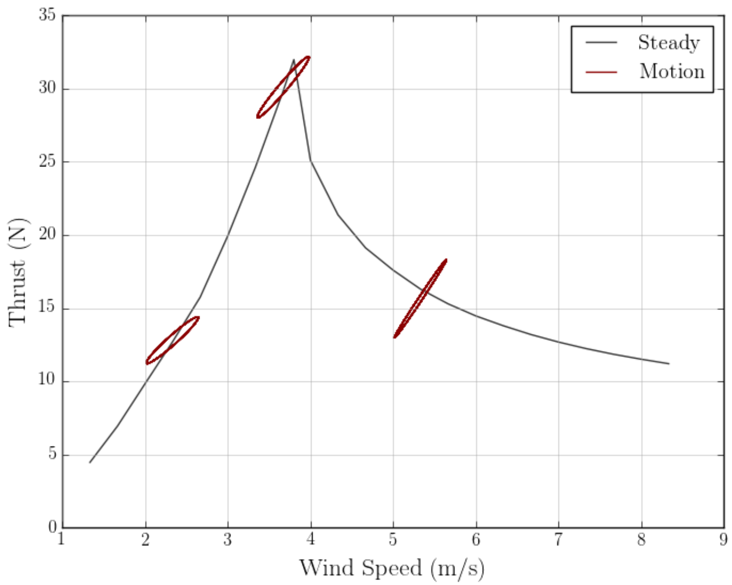
Presentation's outline

- 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



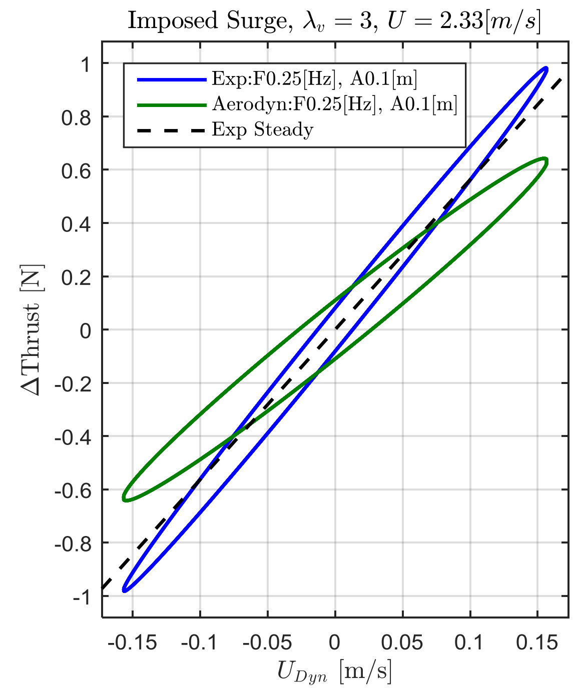
LIFES50+

Ongoing analysis of unsteady aerodynamics of FOWTs @ PoliMi

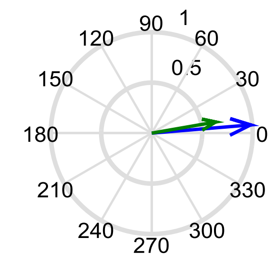
From experiments, unsteadiness depends on:

- Tip Speed Ratio
- "Wake Reduced Velocity" V_w^*

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



$V_w^* = 4$



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

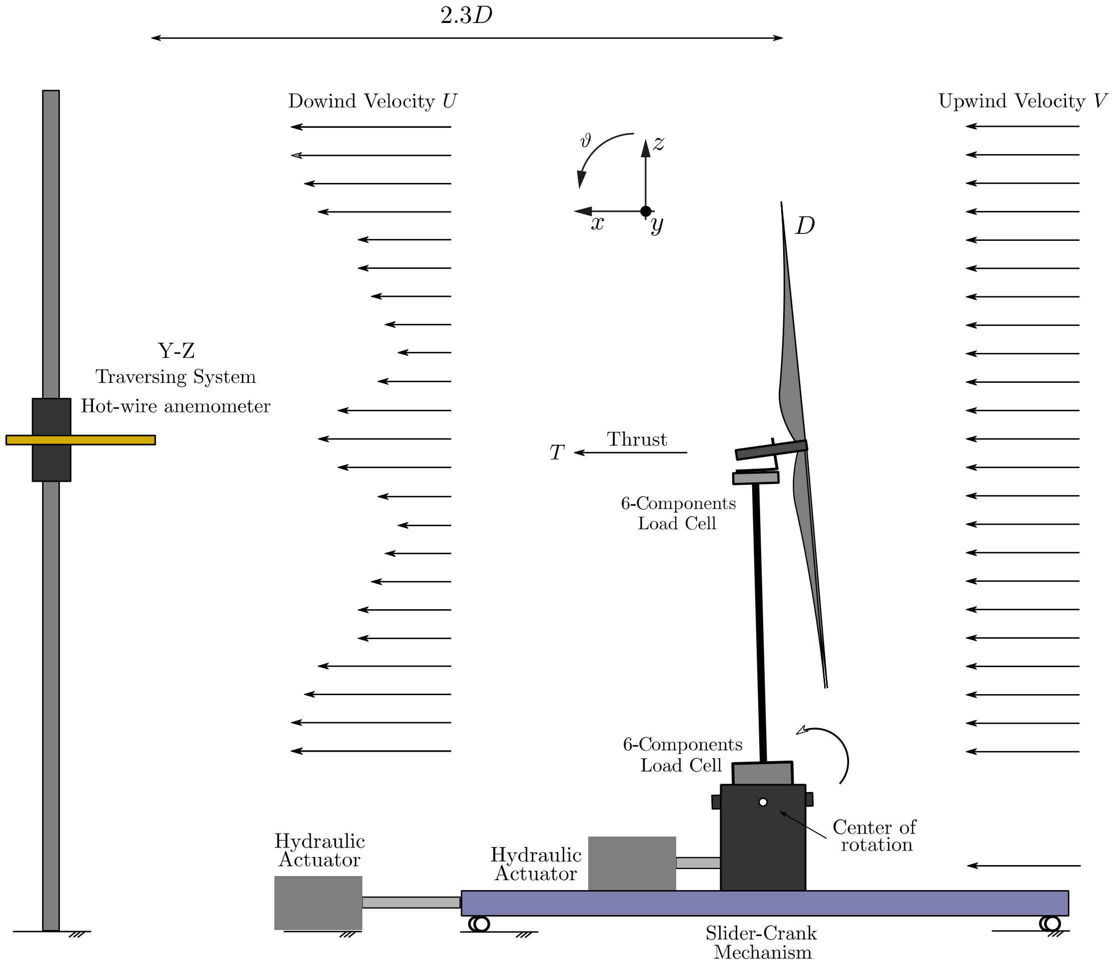
- Downwind Hot-wire anemometer
- Upwind Pitot Anemometer
- 6 Components balances
- Imposed Surge Motion

Tests

- **2D Map** (*Y-Z* plane)
    - @ Rated
- **1D Map** (*Y*, Hub's height)
    - @ Below Rated
    - @ Rated
    - @ Above Rated

    +

    - Different Amplitudes & frequencies

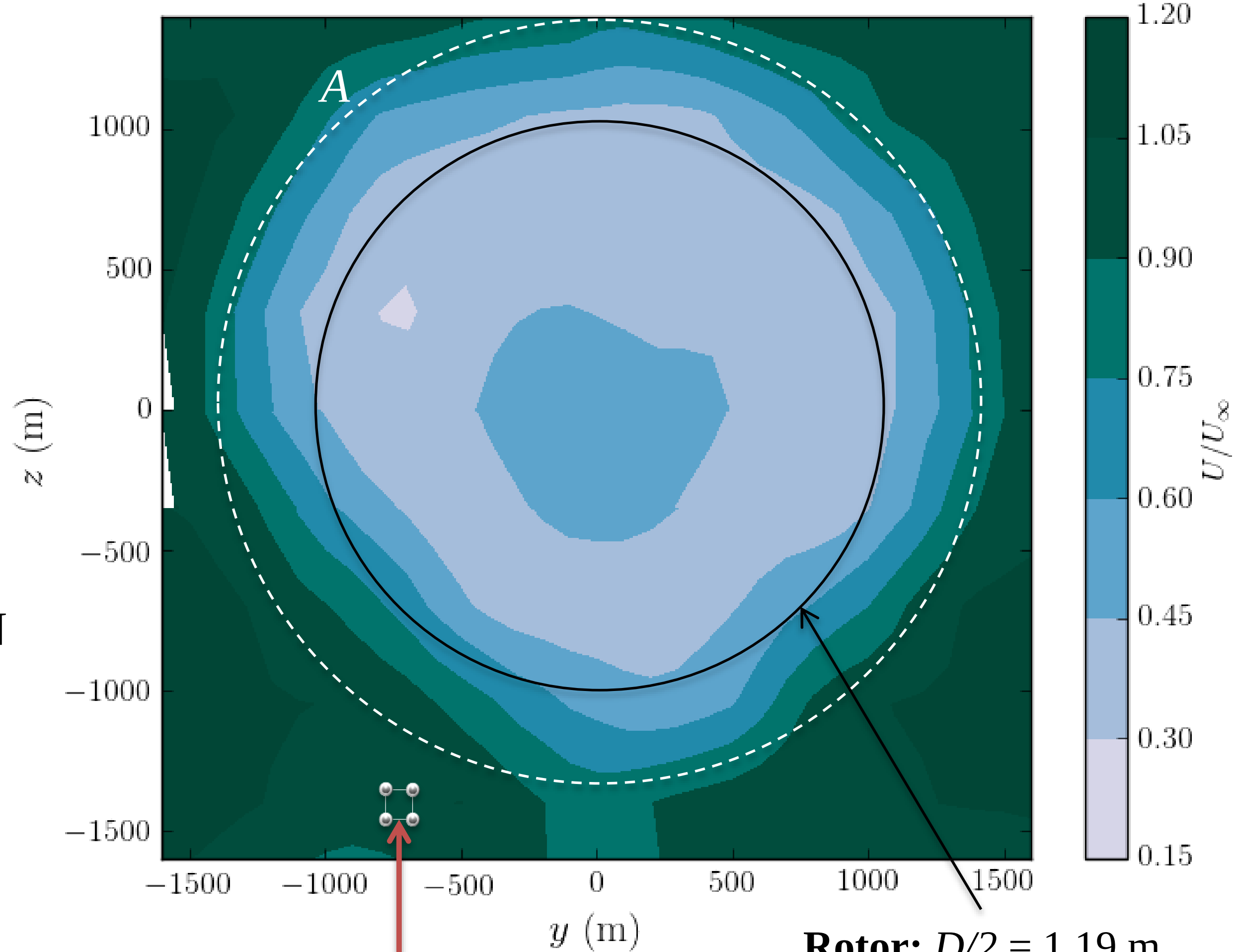


Steady 2D map @ Rated Wind Speed

- Wind speed *U*=3.67 m/s
  scale factor (1/3)
- Rotor Diameter D =2.38 m
  scale factor (1/75)
- Expected/measured
  Thrust ≈ 28 N
  scale factor (1/50594)
- Recomputed Thrust ≈ 28 N
  from wake deficit

$$T = \int_A \rho U (U_\infty - U) dA$$

(Mass conservation + Momentum loss)

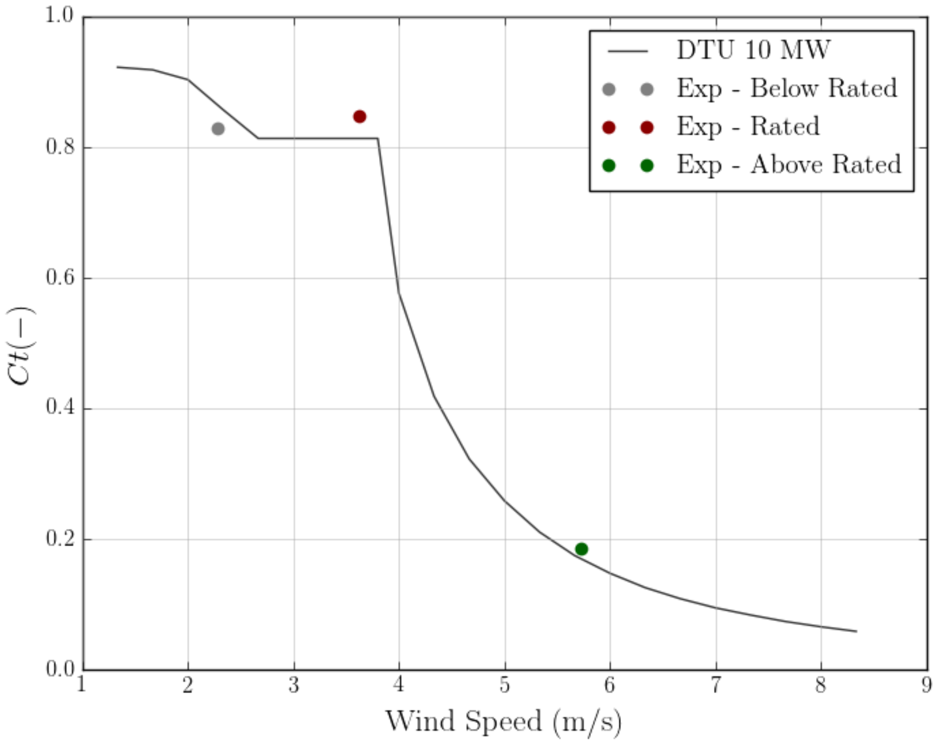


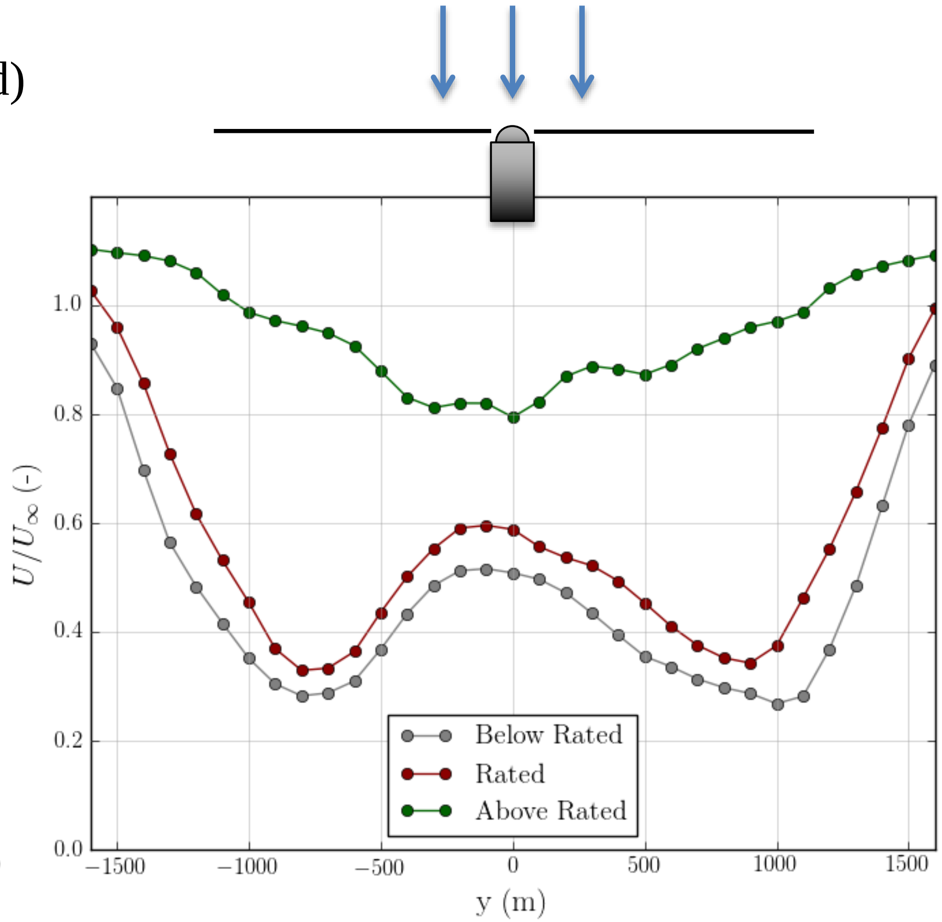
Meshgrid unit 0.1 x 0.1 m

Rotor: *D/2* = 1.19 m
(1/75 DTU 10 MW)

No Motion: the effect of *Ct* on the mean wake velocity

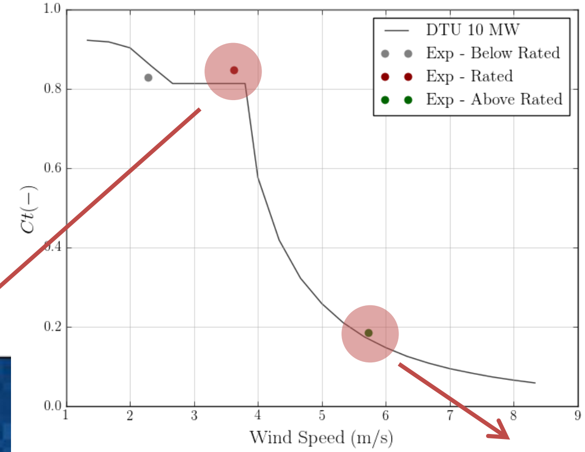
- High *Ct* = great momentum loss (Below/Low Rated)
- Low *Ct* = low wake deficit (Above Rated)



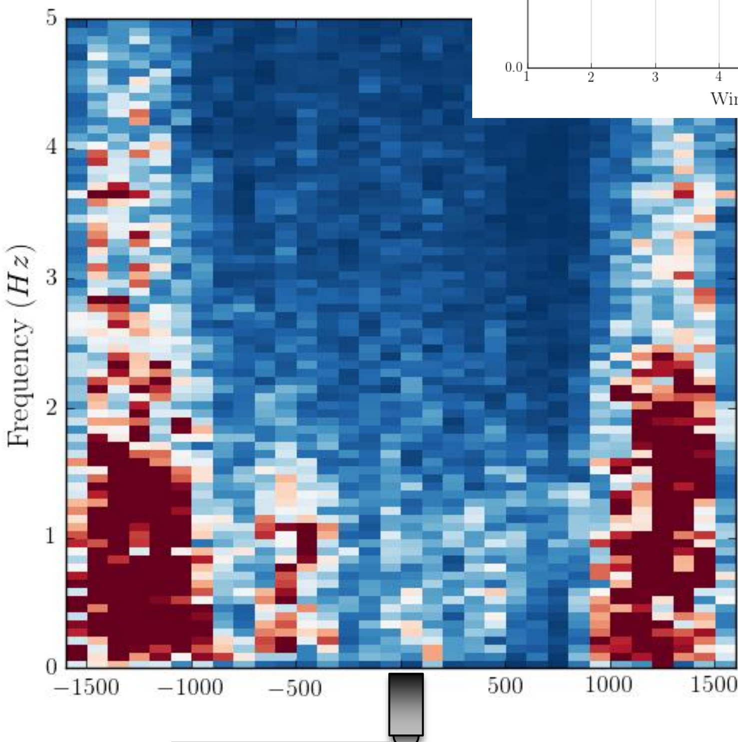


I. Bayati, M. Belloli, L. Bernini, A. Zasso

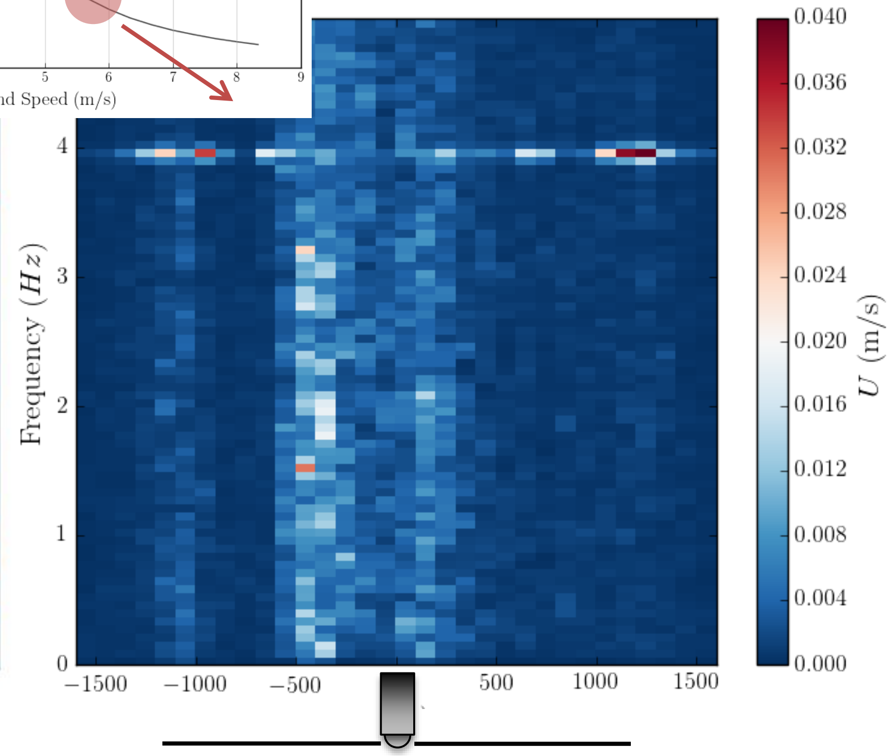
No Motion: turbulence in the wake



- Higher turbulence
- Tip vortices

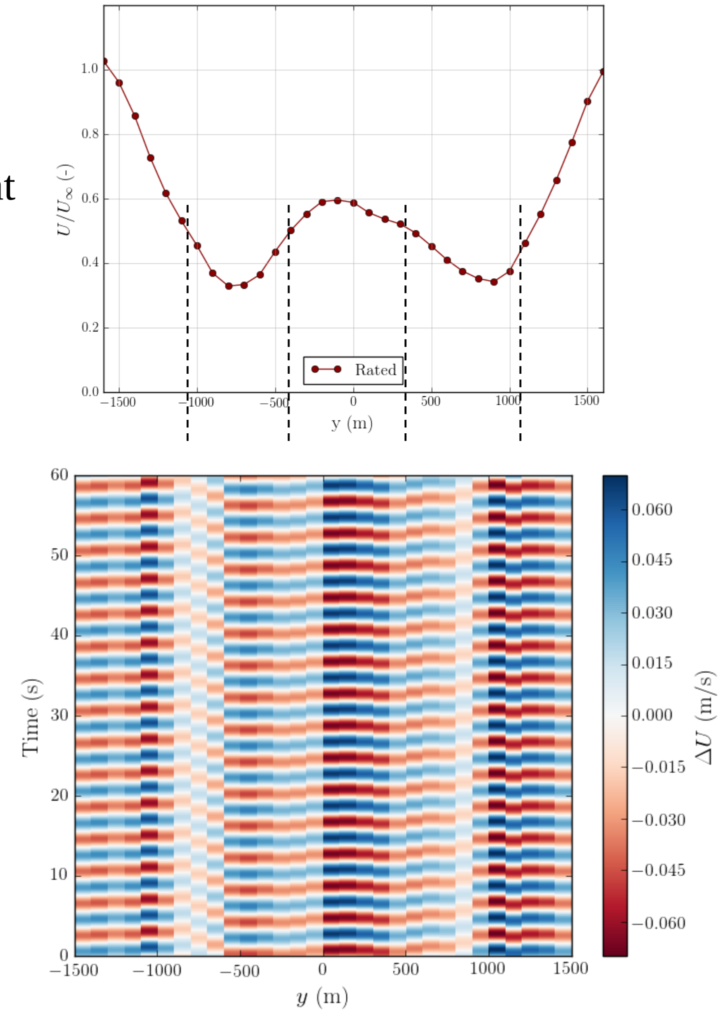


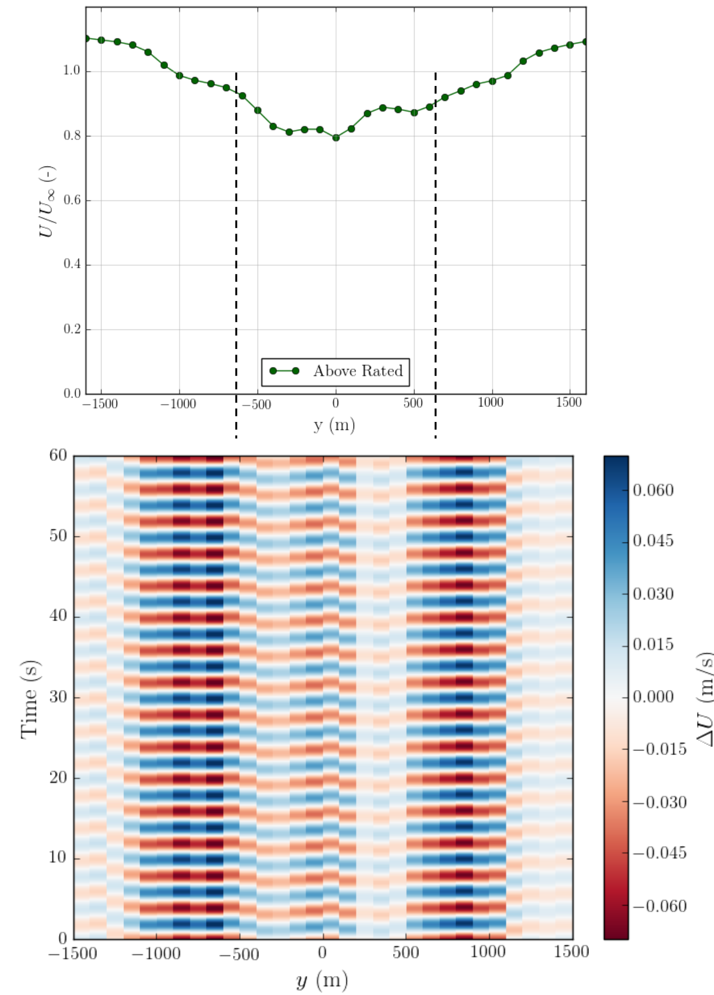
- Lower turbulence
- Clear visibility of the rotational frequency (4 Hz)



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*

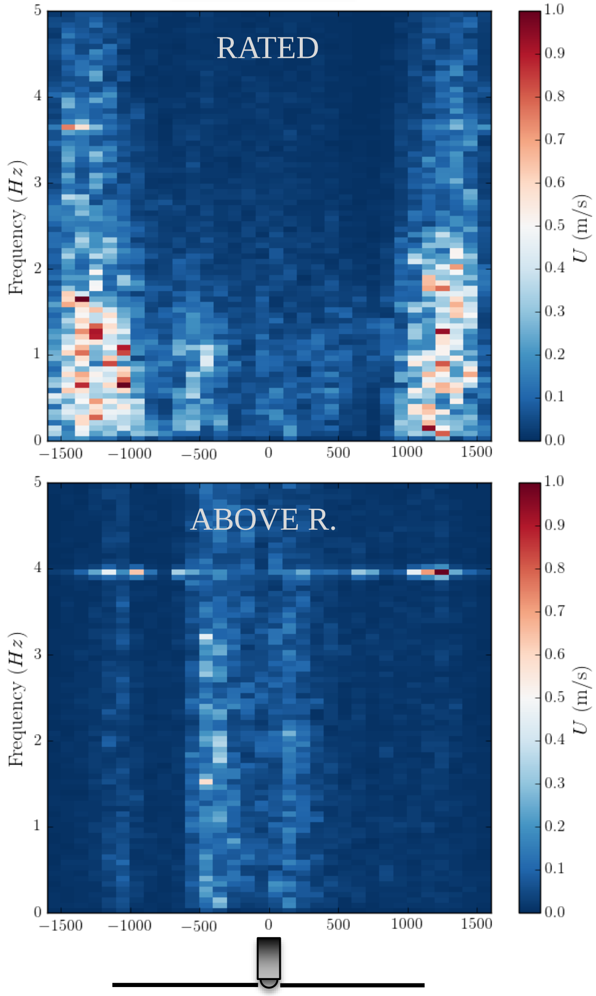




Imposed Motion: Surge frequency in the wake

- **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)

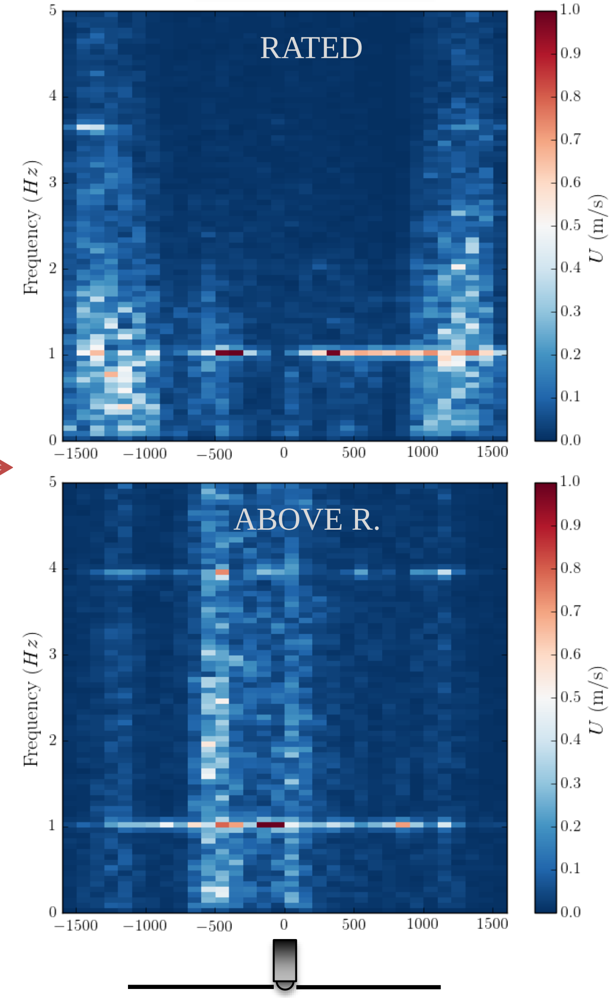
NO MOTION



Freq. **1 Hz**
Amp. 30 mm

Full Scale:
- Period. 25 s
- Amp. 2.2 m

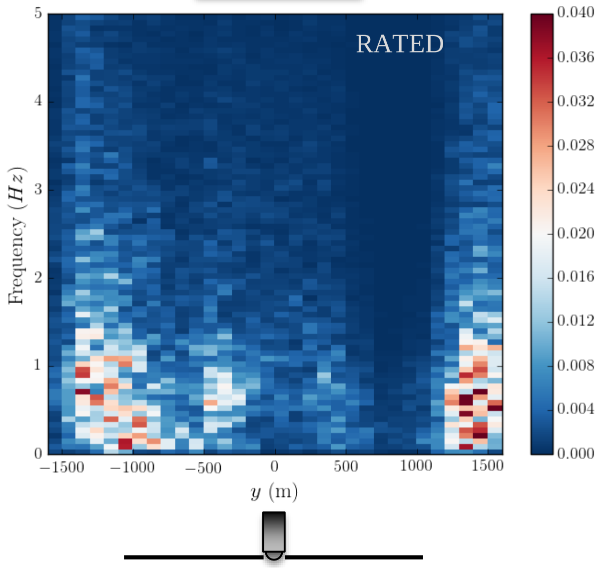
SURGE MOTION



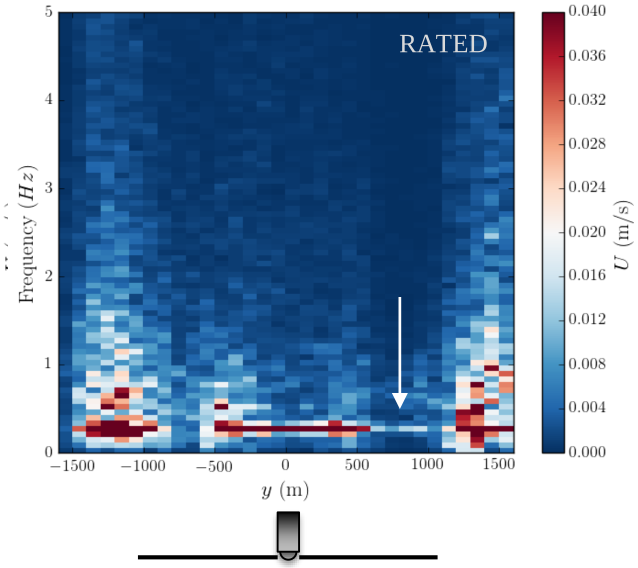
Imposed Motion: Surge frequency in the wake (Changing V_w^*) @Rated

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

NO MOTION



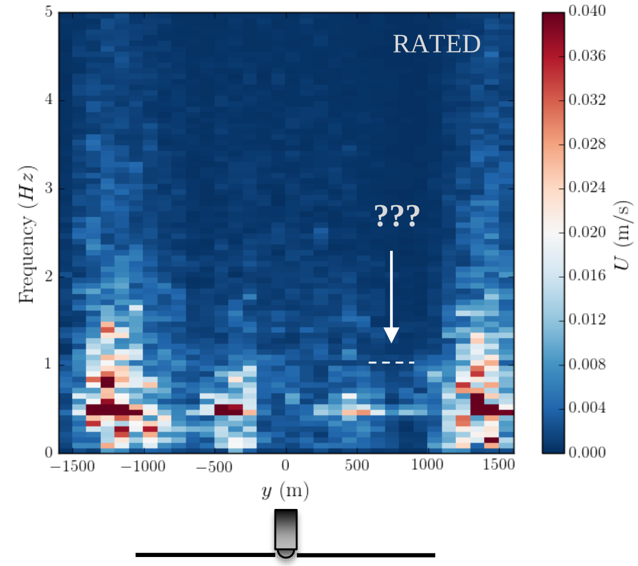
SURGE MOTION $\boldsymbol{V_w^*}$=4



Freq. **0.25 Hz**
Amp. 100 mm

Surge frequency visible in the wake

SURGE MOTION $\boldsymbol{V_w^*}$=1



Freq. **1 Hz**
Amp. 30 mm

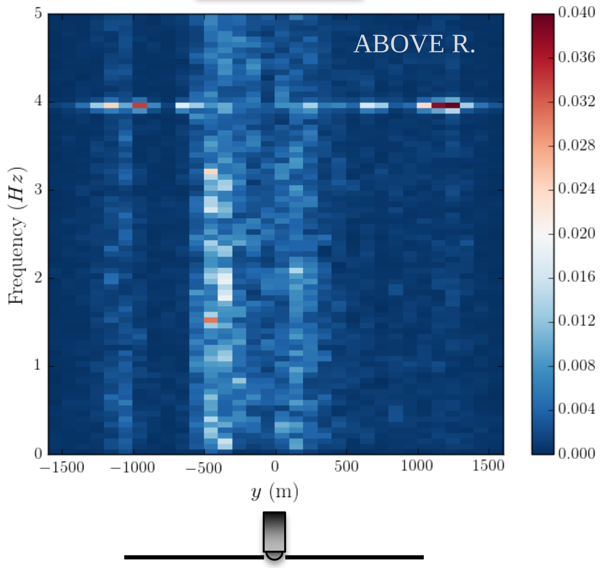
…missing Surge frequency in the wake!!

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

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

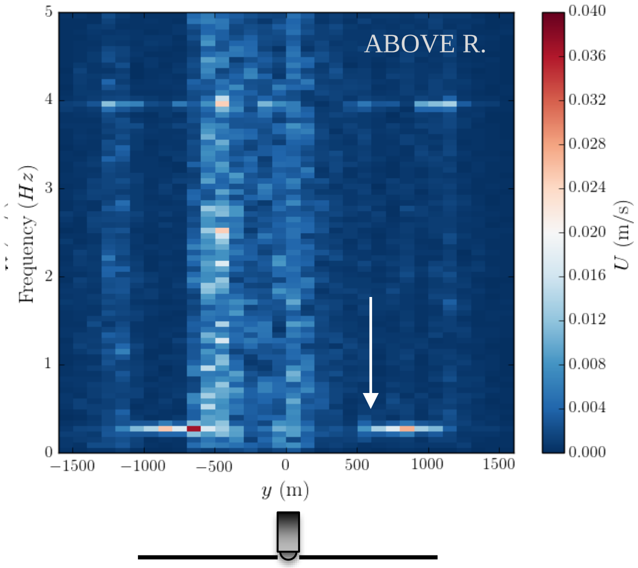
This dependency on $\boldsymbol{V_w^*}$ is however affected by the corresponding steady spectral content (Ct)

NO MOTION



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

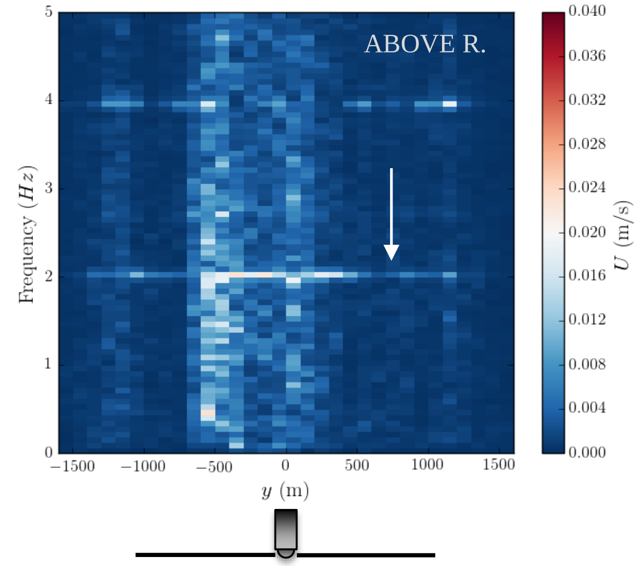
SURGE MOTION
$\boldsymbol{V_w^*}$**=9**



Freq. **0.25 Hz**
Amp. 100 mm

Surge frequency visible in the wake

SURGE MOTION
$\boldsymbol{V_w^*}$**=1**



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 Ct on the mean wake velocity

- No Motion: visible turbulence in the wake linked to the aerodynamic efficiency (Ct)

- 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 (Ct)

- 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

Full Scale			**Wind Tunnel**			V_W^*
U (m/s)	Amp x_0 (m)	Period T (s)	U (m/s)	Amp x_0 (m)	Frequency f (Hz)	(-)
7	7.5	100	2.3	0.1	0.25	≈ 4
	2.25	25		0.03	1	≈ 1
	1.125	12.5		0.015	2	≈ 0.5
11	7.5	100	3.6	0.1	0.25	≈ 6
	2.25	25		0.03	1	≈ 1.5
	1.125	12.5		0.015	2	≈ 0.8
16	7.5	100	5.3	0.1	0.25	≈ 9
	2.25	25		0.03	1	≈ 2.2
	1.125	12.5		0.015	2	≈ 1