A Detached-Eddy-Simulation study

Proper-Orthogonal-Decomposition of the wake flow behind a model wind turbine

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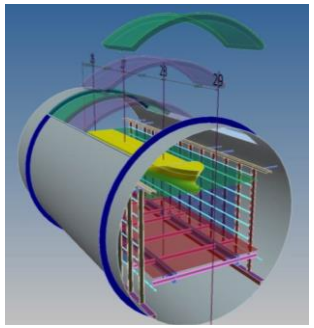
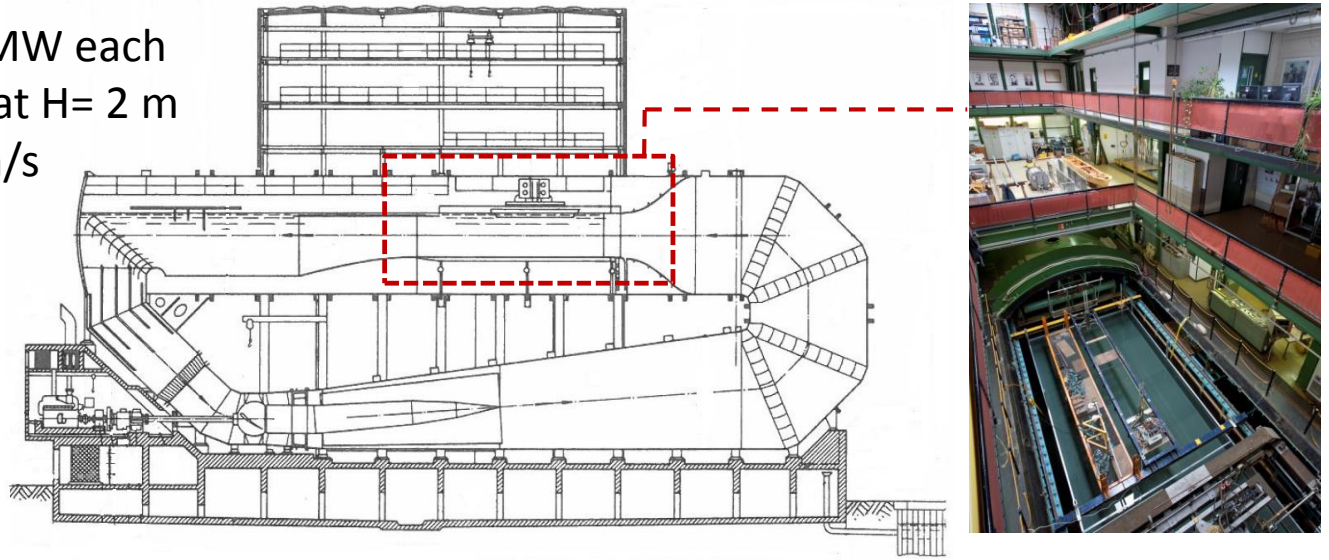
Introducing the UT2 (Circulating tank 2) at the TU Berlin

- One of the biggest circulating water tanks worldwide
- Built in 70´s and recently renovated
- Suitable for studies of ship properties as well as of floating wind turbine models



- Drive: 2 motors, 1.6 MW each
- Pump: Q = 60000 l/s at H= 2 m
- Flow speed up to 9 m/s



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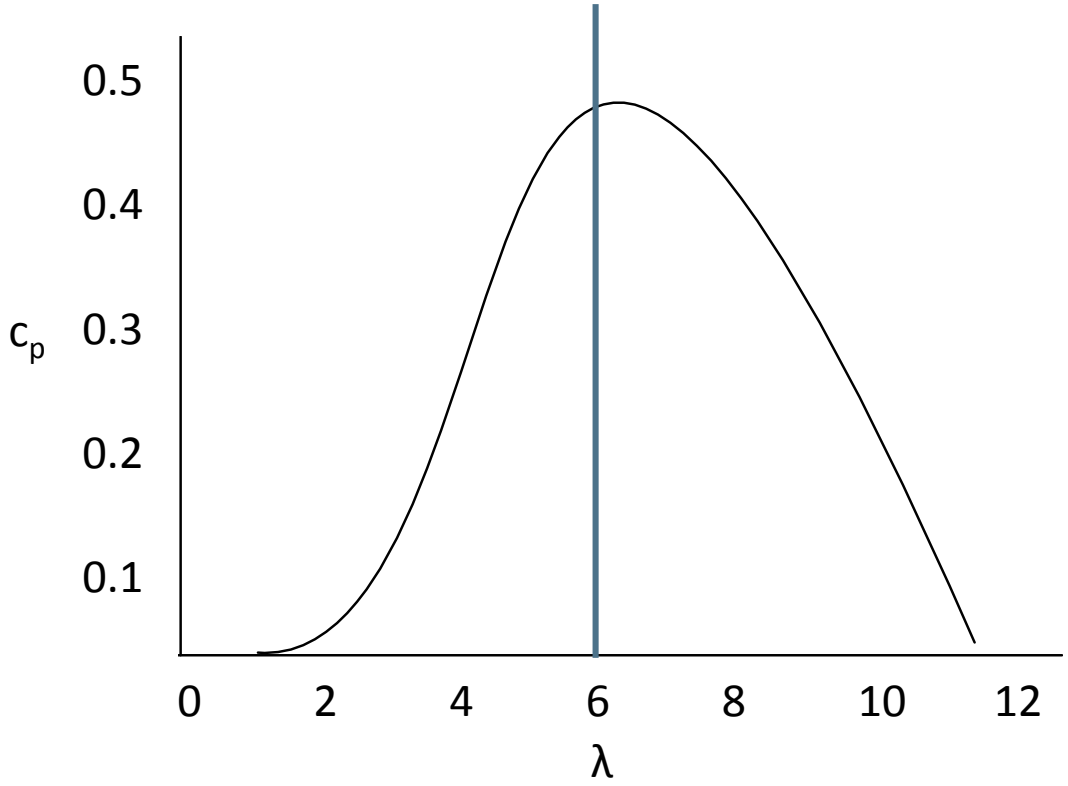
Real problem in the wind park optimization?

(1)

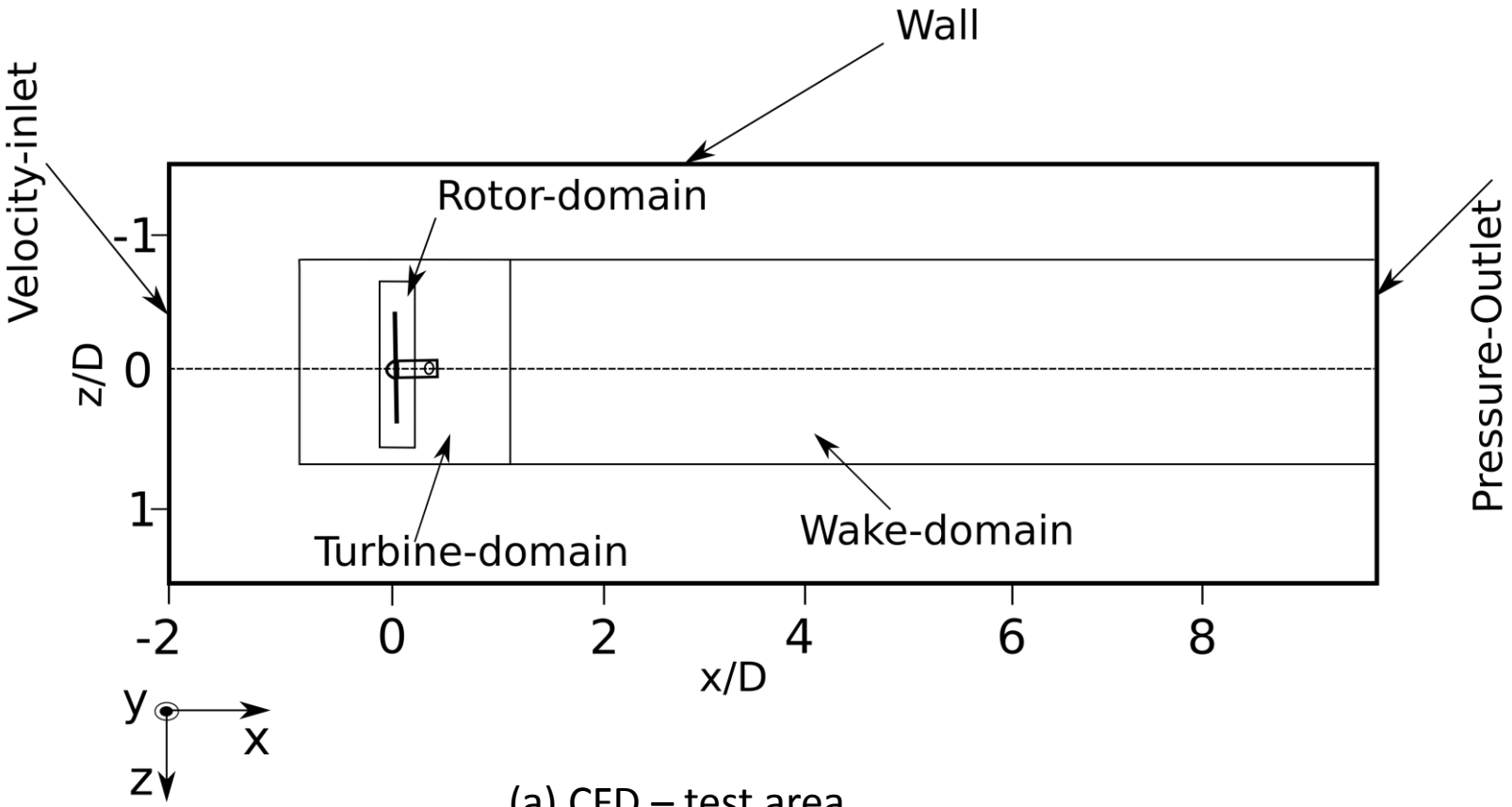
LDA-Experiment conditions

(a) Test wind turbine

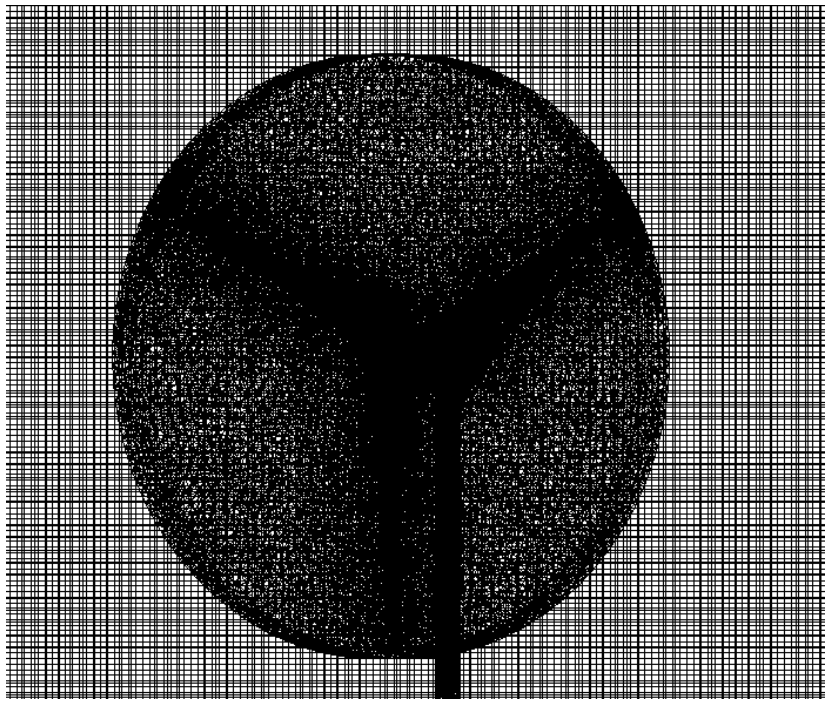


(b) Tip speed ratio

Simulation conditions

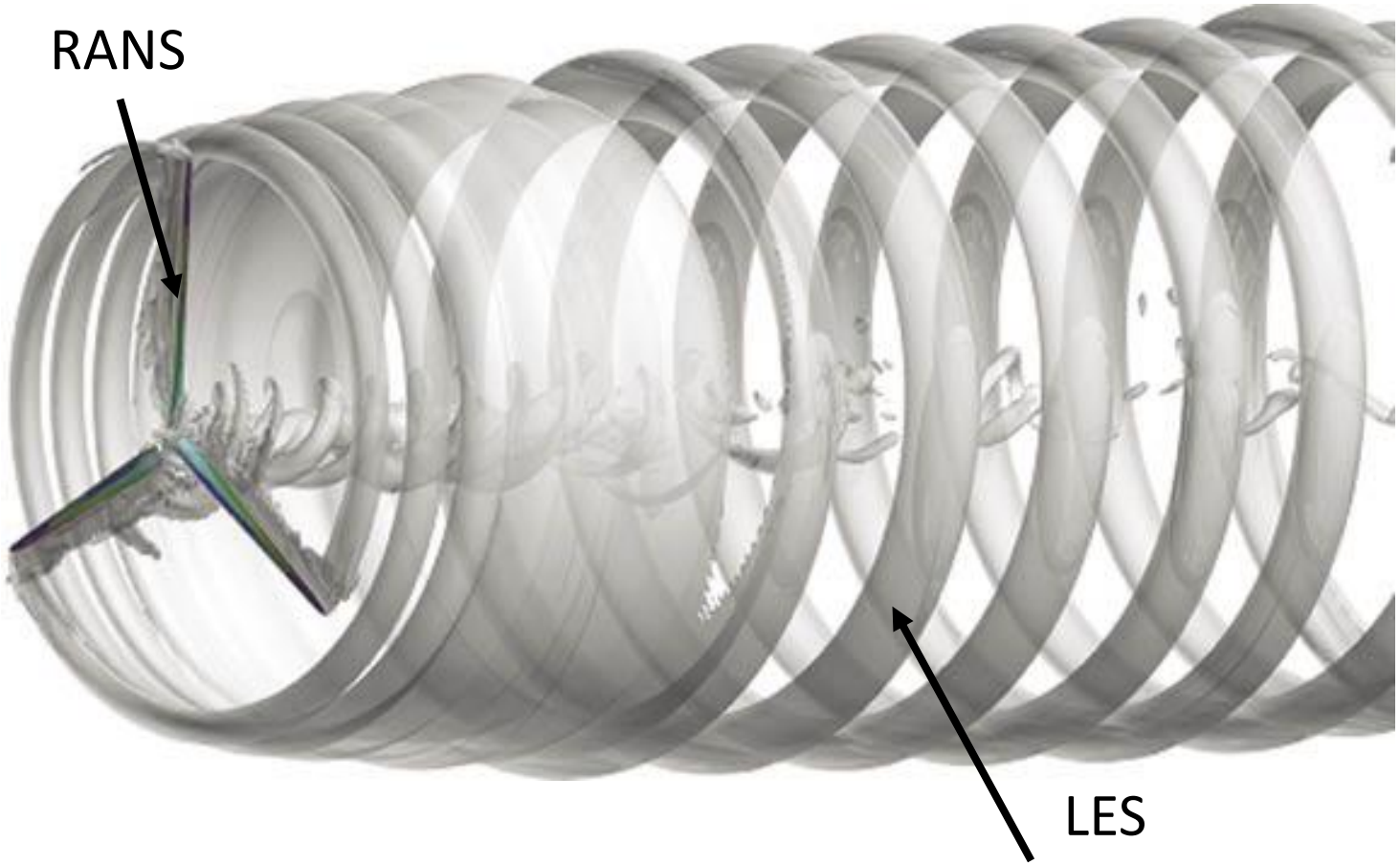


(a) CFD – test area



(b) Sliding mesh and grid size

Detached-Eddy-Simulation (DES)

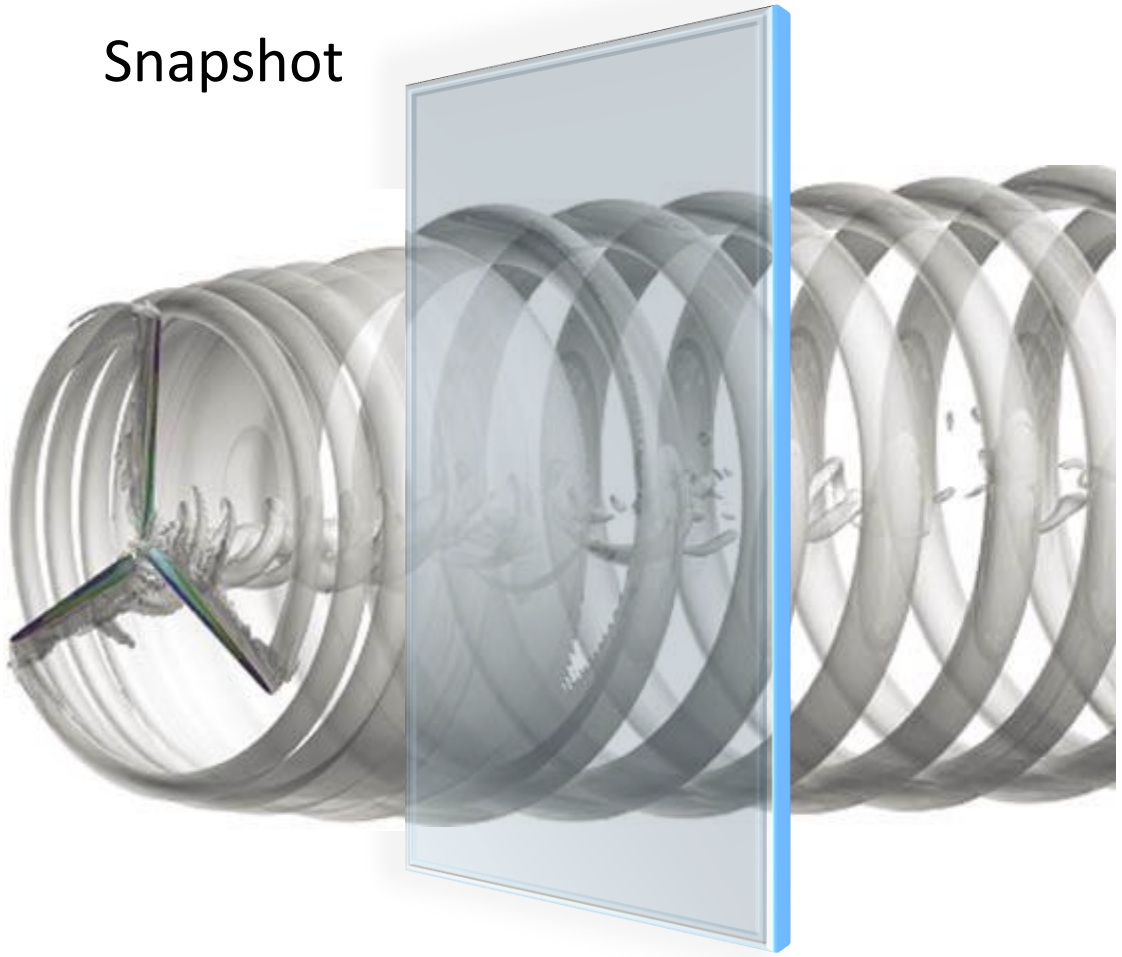


(2)

CFD Methods	Simulation properties
Reynolds-**A**veraged-**N**avier-**S**tokes	Mean values
Large-**E**ddy-**S**imulation	Large eddies

Proper-Orthogonal-Decomposition (POD)

Snapshot



(2)

S:

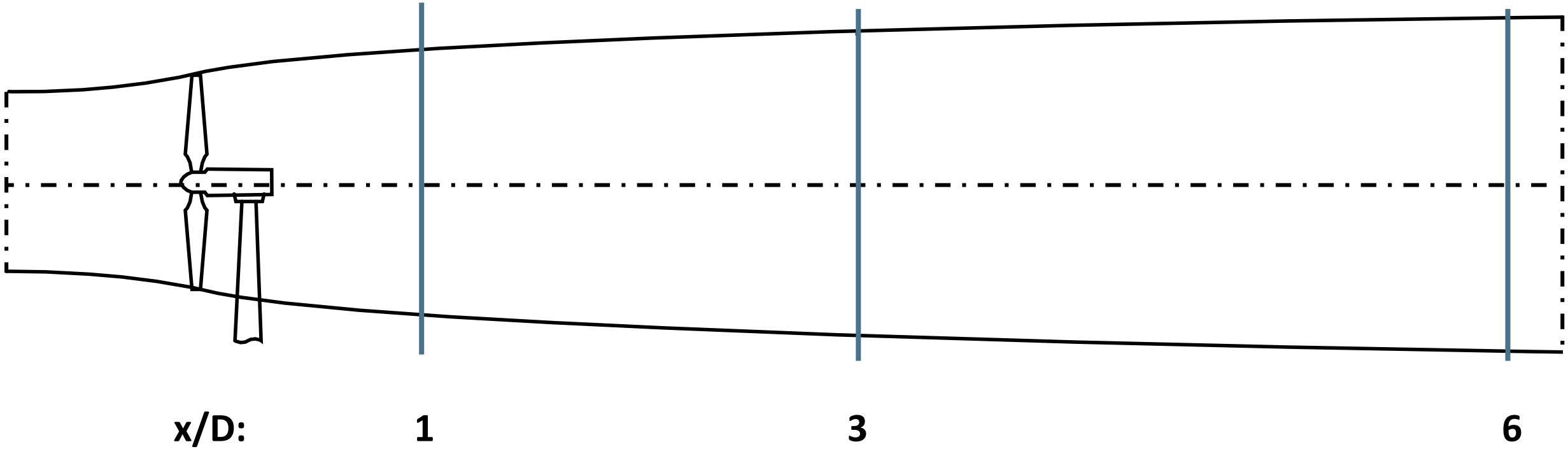
Time information

Spatial information

Snapshot 1 | Snapshot 2 | … | Snapshot n

$$S = U \cdot \Sigma \cdot V^T$$

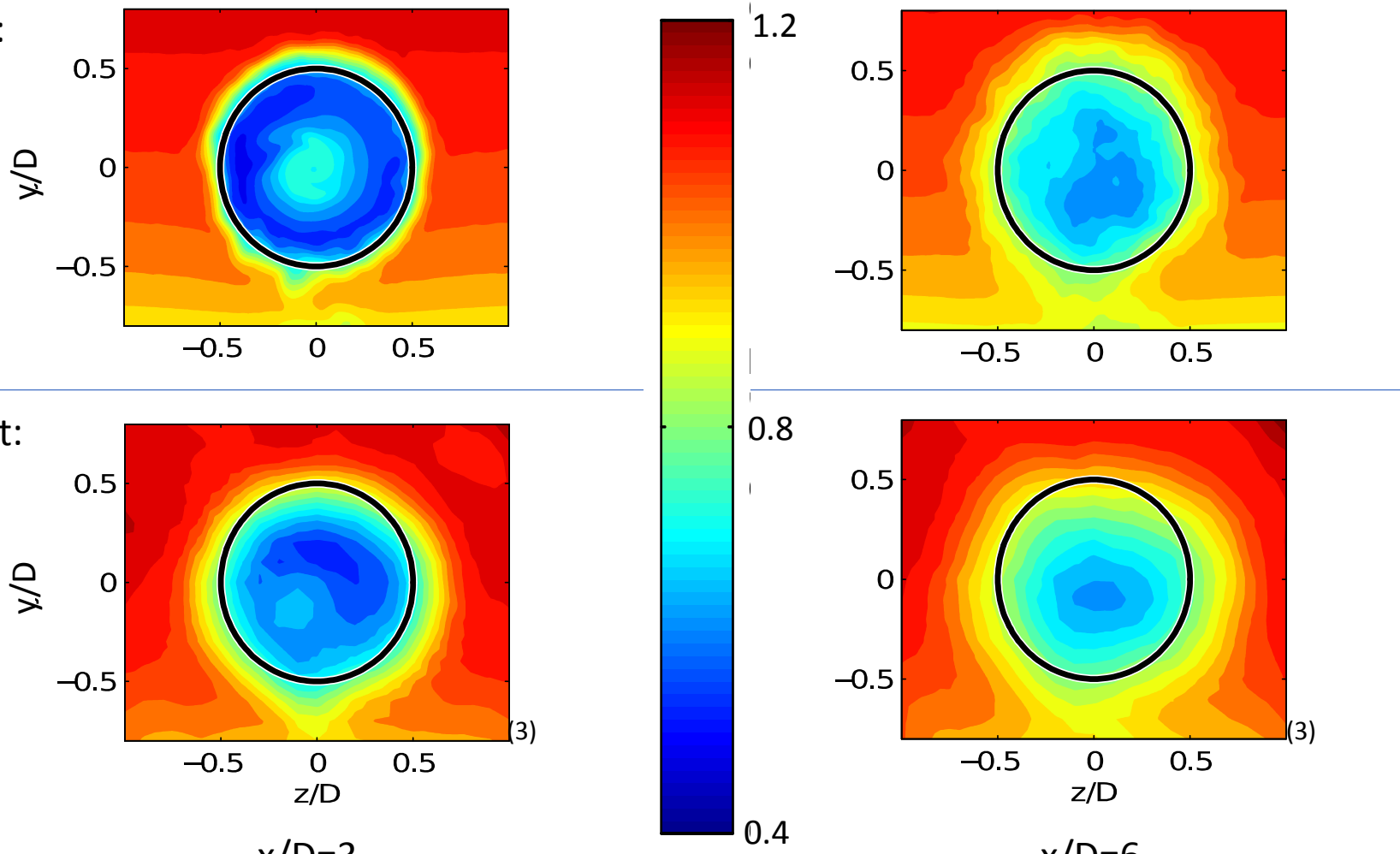
Operating points in the wake flow



Normalized streamwise velocity $u^* = \bar{u}/u_{ref}$

DES-Simulation:

LDA-Experiment:



Position: x/D=3 x/D=6

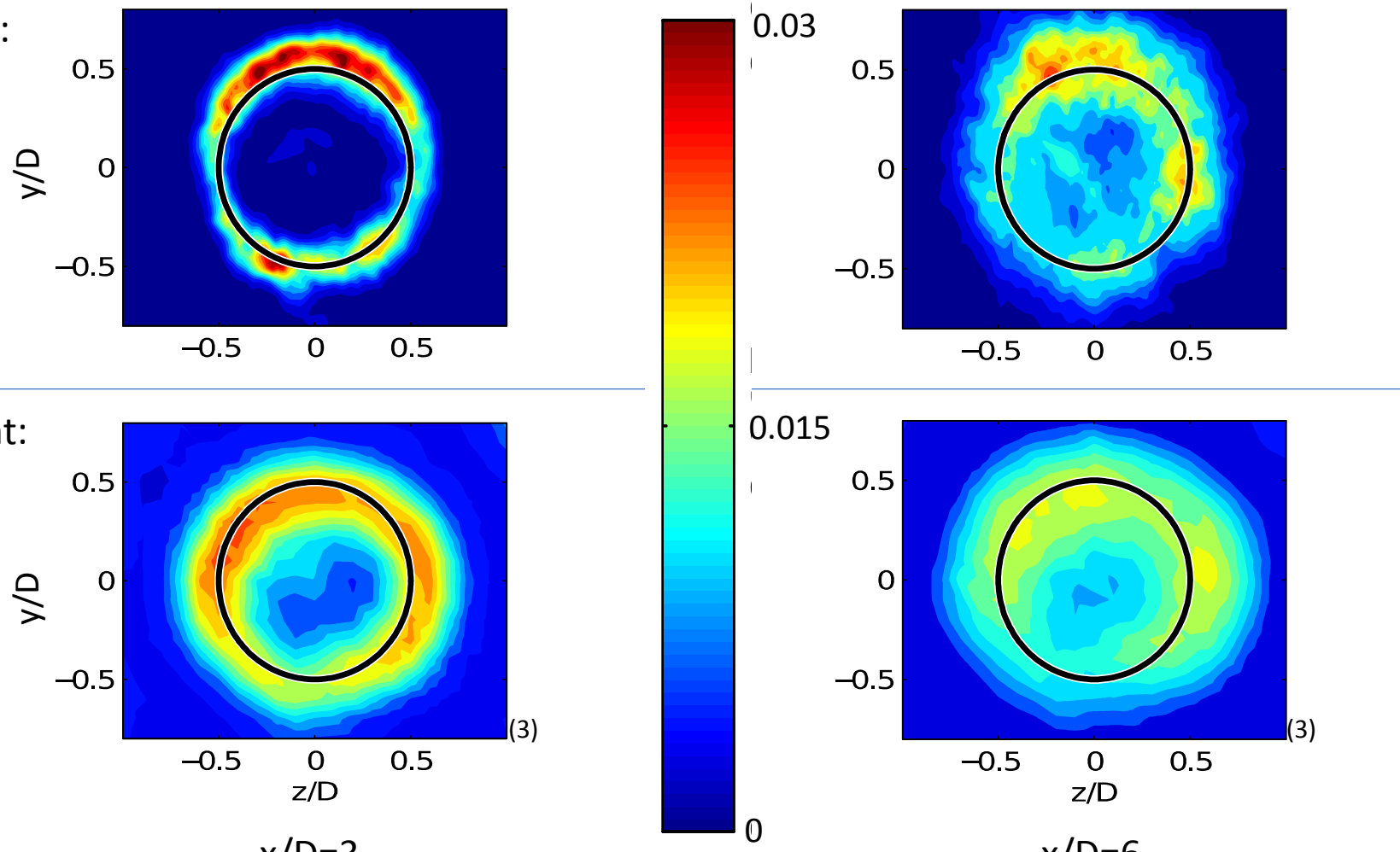
Note:

Direction of the streamwise velocity = Main wind direction

Normalized turbulence kinetic energy $k^* = \bar{k}/u_{ref}^2$

DES-Simulation:

LDA-Experiment:



Position: x/D=3 x/D=6

Note:

$$k = \frac{1}{2} \cdot \sqrt{\overline{u'^2} + \overline{v'^2} + \overline{w'^2}}$$

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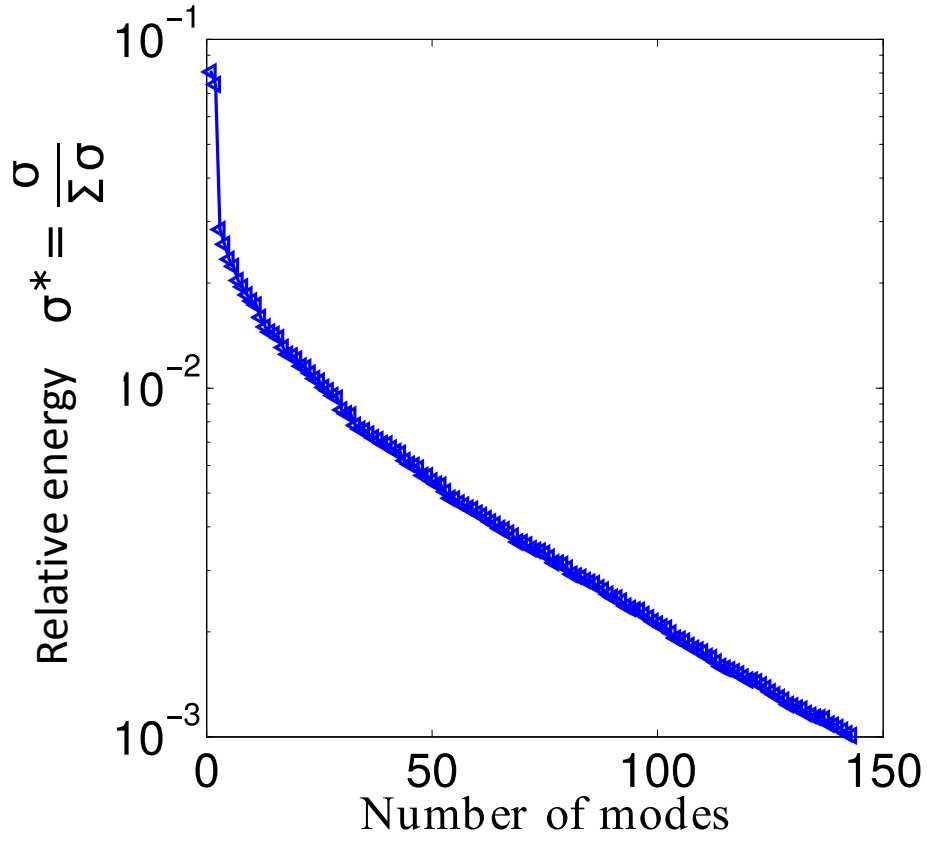
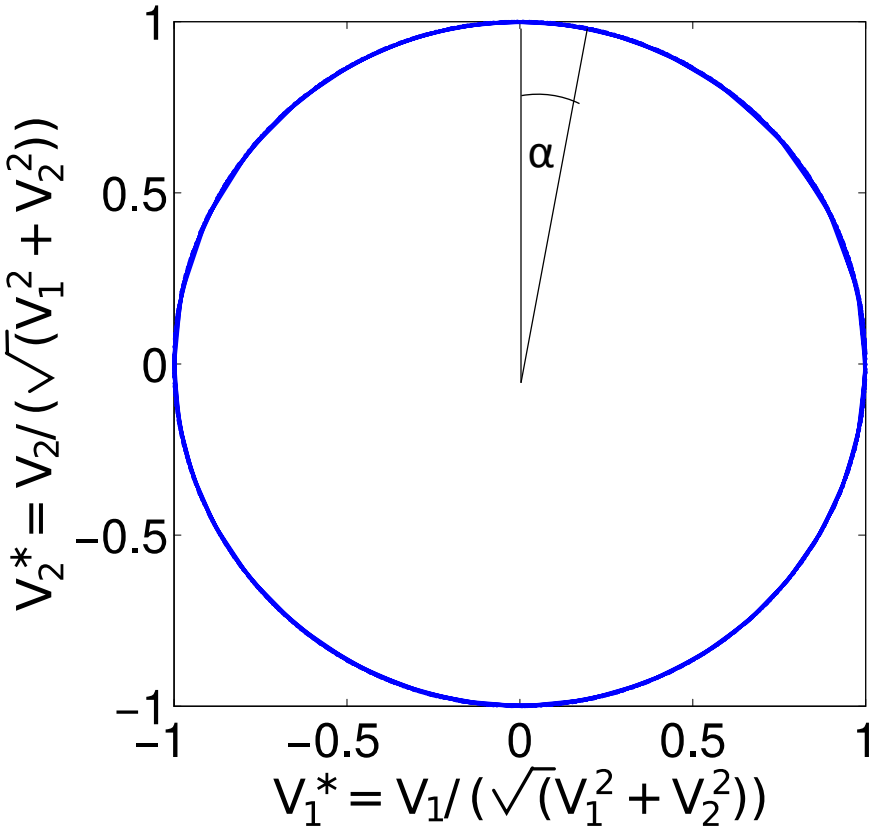
Shear flow information

POD of the flow field in x/D=1

$$S = U \cdot \Sigma \cdot V^T$$



(a) Eigenvalues or POD-Modes

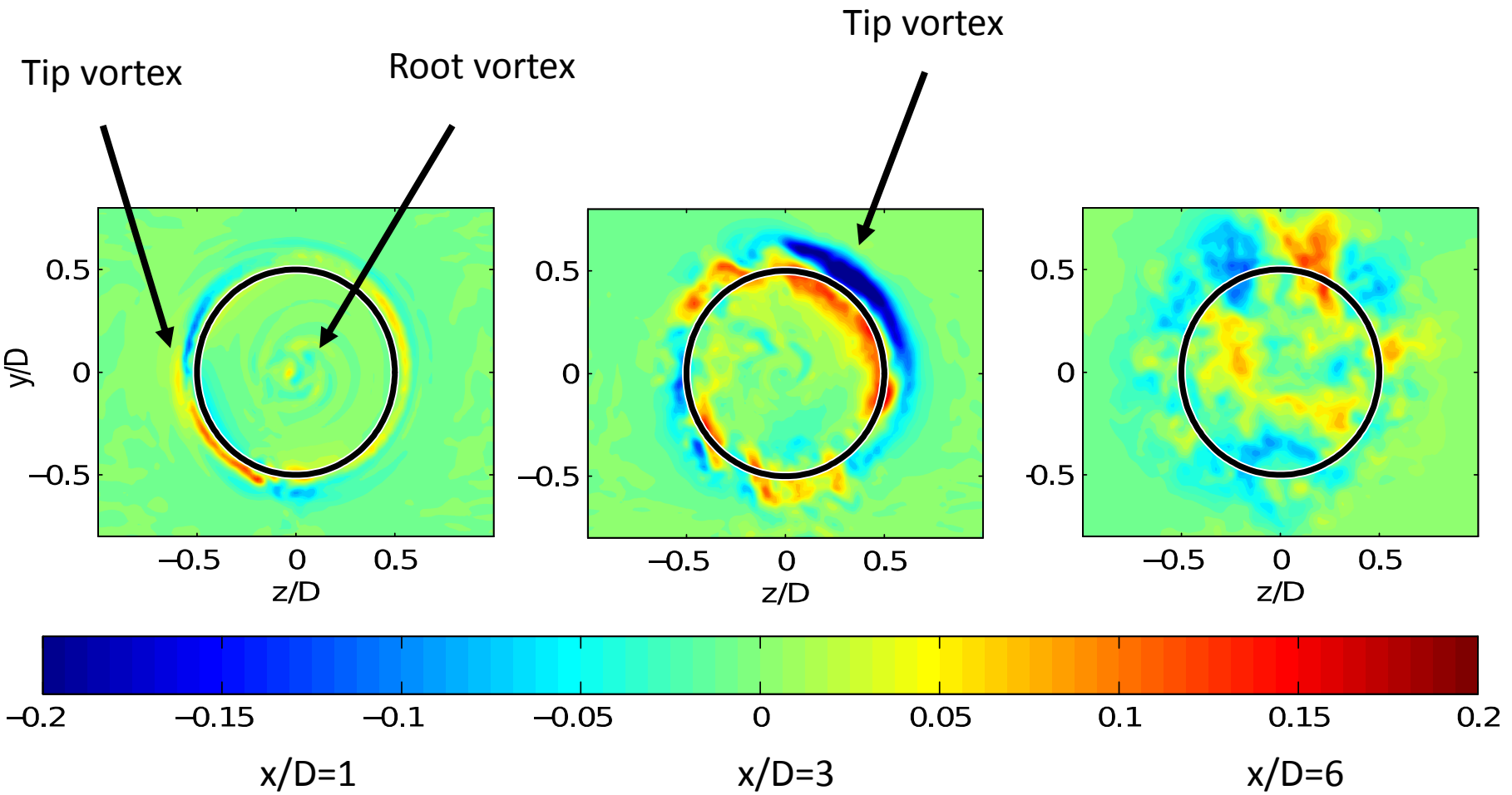


(b) Phase angle

Note:
POD-Modes: Different characteristics which describe the energy influence of the flow field.

Note:
Phase angle of a velocity signal:

Normalized coherent streamwise velocity $\tilde{u}^* = \tilde{u}/u_{ref}$ (coherent motions)

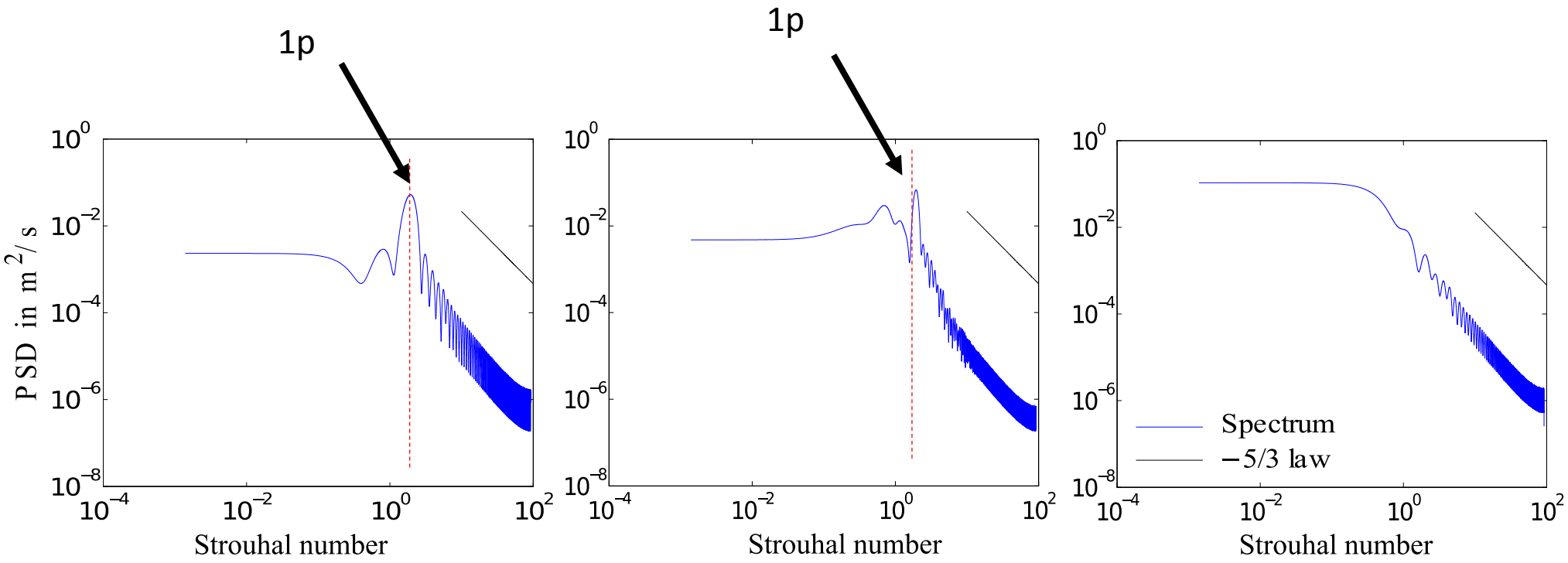


Note:

Coherent motions: Large eddies with an important influence of the flow field.

$$u = \tilde{u} + u' + \bar{u}$$

Fluctuation loads (significant frequencies)

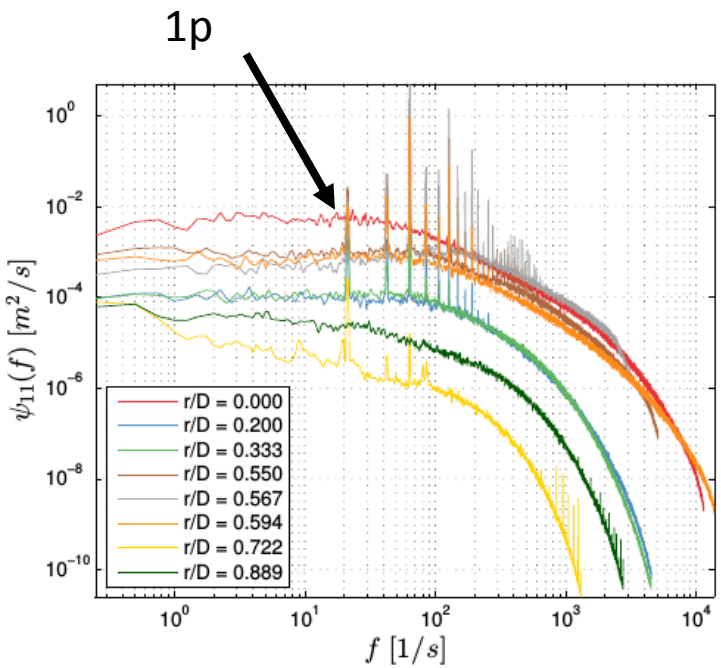


x/D=1 x/D=3 x/D=6

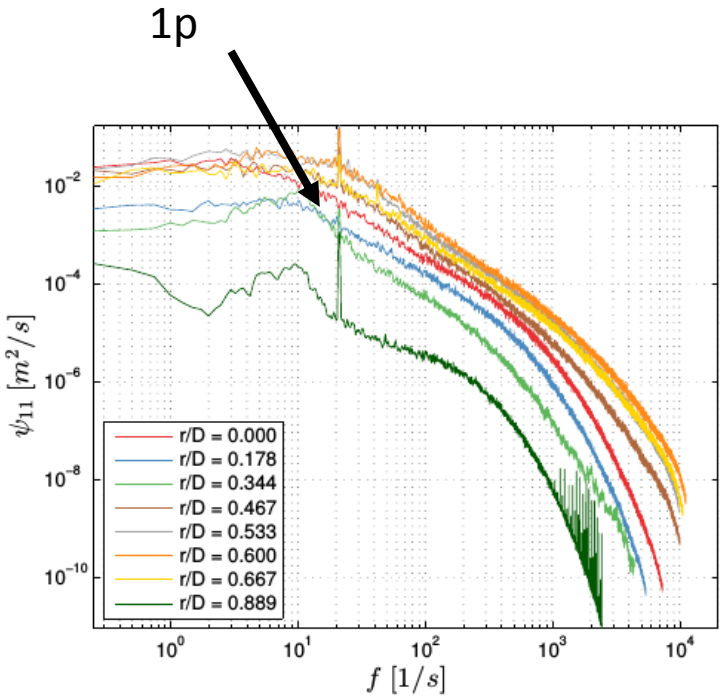
Note:

1p: Interaction between the rotation frequency of one blade and the tower.

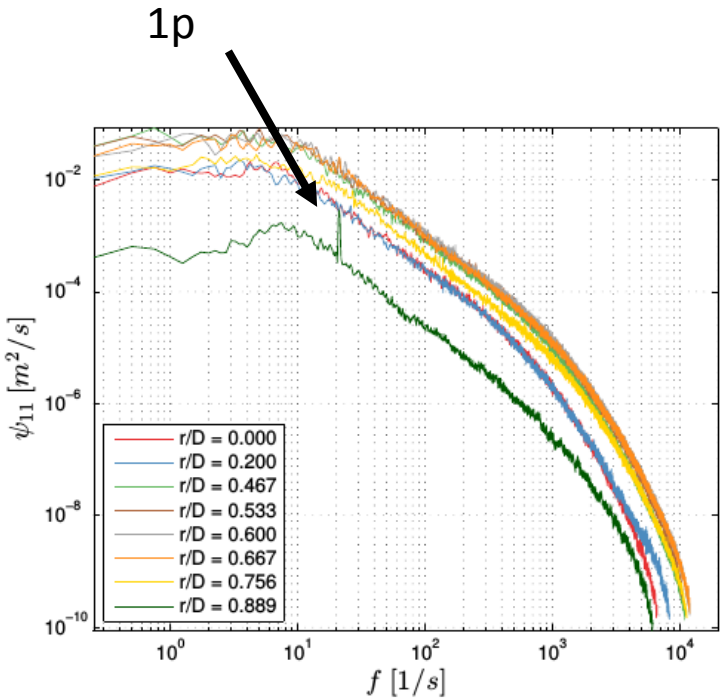
Validation of the frequency



x/D=1



x/D=3



x/D=5

(4)

Conclusion

1. DES and POD
    a. Velocity components, turbulence kinetic energy
    b. Coherent motions (tip vortex, root vortex)
    c. Fluctuation load (1p frequency)
2. Future studies
    a. Different inflow/boundary conditions
    b. Wake flow analyses for more than one turbine
    c. Optimization of the wind park planning

Thank you for your attention…

…Questions?

References:

(1) http://www.envision-energy.com/2016/08/17/optimizing-energy-production/ 14.01.2018

(2) https://www.windpowerengineering.com/simulation/seeing-the-unseeable-in-a-rotor-wake/ 14.01.2018

(3) Bartl, J., Mühle, F., Schottler, J., Sætran, L. Peinke, J., Adaramola, M. and Hölling M. [2017], Experiments on wind turbine wakes in yaw: Effects of inflow turbulence and shear. *Manuscript submitted to Wind Energy Science.*

(4) Eriksen, P. E. [2016] Rotor wake turbulence: An experimental study of a wind turbine wake, *Doctoral thesis at NTNU 2017*: 2017:34, isbn: 978-82-326-1408-0