How does turbulence change approaching a rotor?

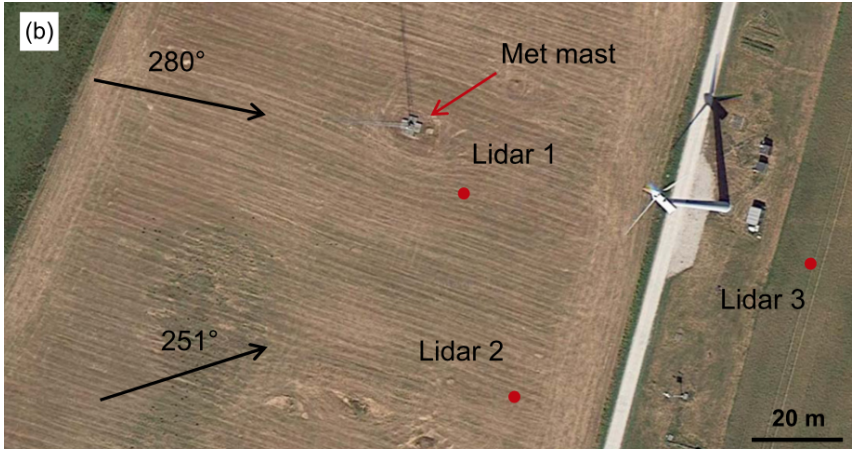
Jakob Mann, Alfredo Peña, Niels Troldborg & Søren J. Andersen

Technical University of Denmark
DTU Wind Energy, Roskilde, Denmark

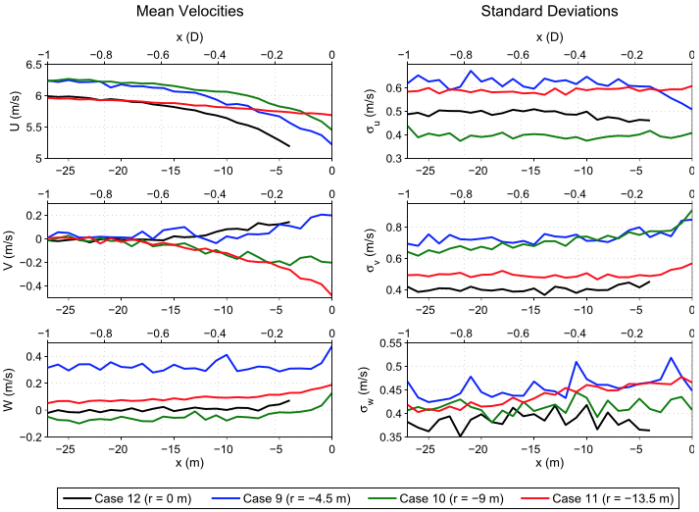
June 24, 2017, DTU Wind Energy

Induction zone experiment at DTU Wind Energy

E. Simley *et al*, *J. Renewable Sustainable Energy*, **8** 013301 (2016)

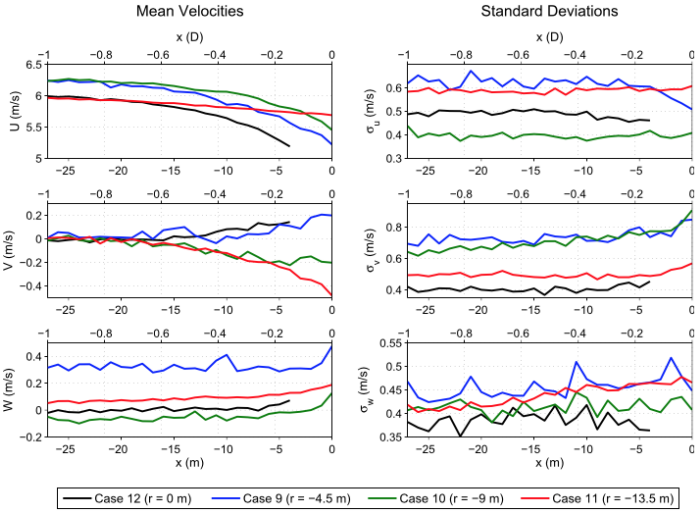


Results for mean wind and turbulence



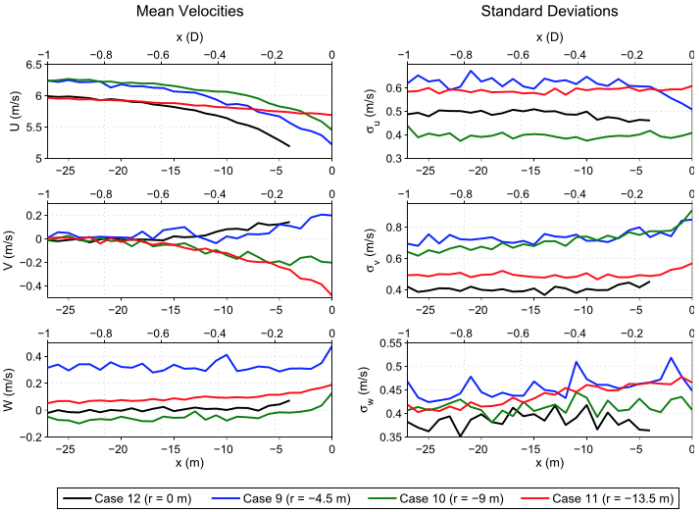
- Stagnation clear

Results for mean wind and turbulence



- Stagnation clear
- σ_u (and σ_w) almost constant

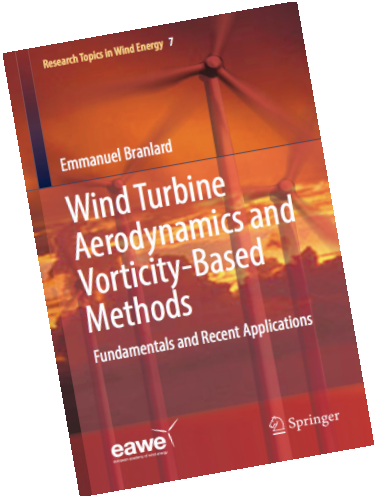
Results for mean wind and turbulence



- Stagnation clear
- σ_u (and σ_w) almost constant
- Not much statistics

Vorticity based methods

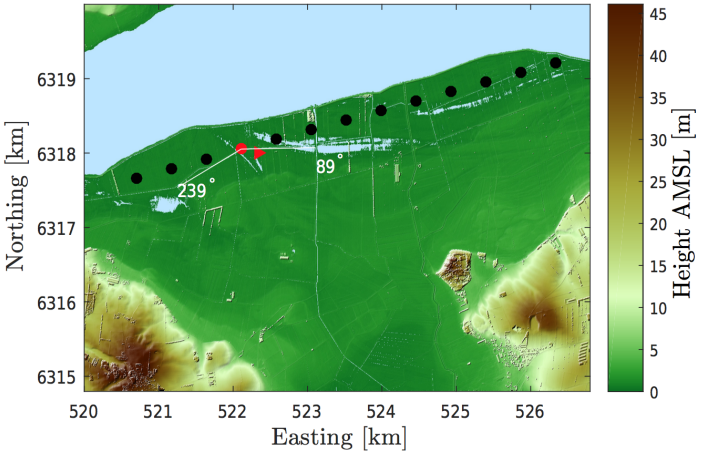
E. Branlard, 2017



- To a first approximation, the presence of the wind turbine does not affect the turbulence spectrum significantly.
- Slight decrease of energy at high frequencies implying a slight decrease of turbine loads
- Further investigations necessary to conclude whether effect is systematic.

The Nørrekær Enge Experiment

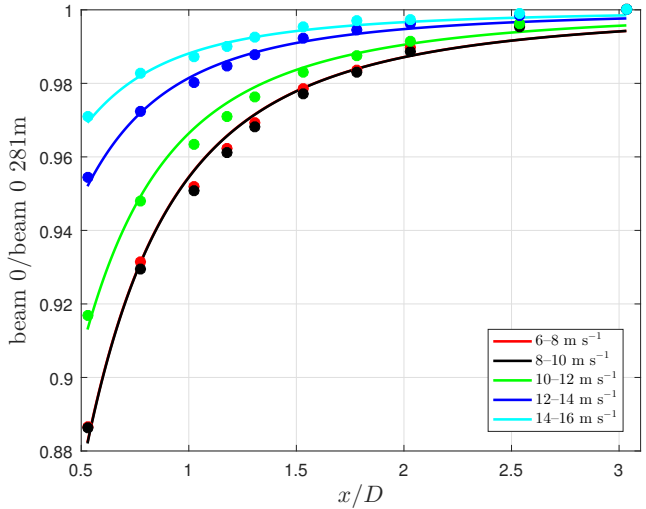
A. Peña *et al*, *Wind Energ. Sci.* **2** (2017)



- Siemens 2.3 MW-93, $z_h = 81.8$ m
- Pulse five-beam lidar on nacelle (only central beam used here)
- Ten ranges (49, 72, 95, 109, 121, 142, 165, 188, 235, and 281 m)

Induction flow measured by lidar

Nørrekær Enge



Quasi-steady fluctuations (very low frequencies)

$$f(\xi, a, U_\infty) \equiv \frac{U}{U_\infty} = 1 - a\left(1 + \frac{2\xi}{\sqrt{1+4\xi^2}}\right) \tag{1}$$

A slow fluctuation in U_∞

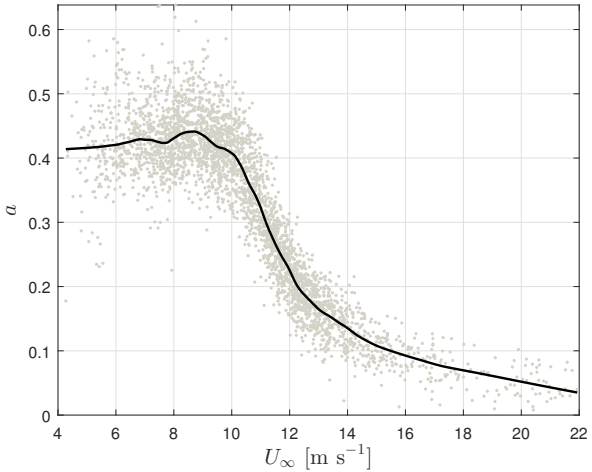
$$\frac{S(x)}{S_\infty} = \left(\frac{\partial U}{\partial U_\infty}\right)^2 \tag{2}$$

where $S(x)$ is the spectrum at a low frequency at the position x while S_∞ is the upstream, undisturbed spectrum.

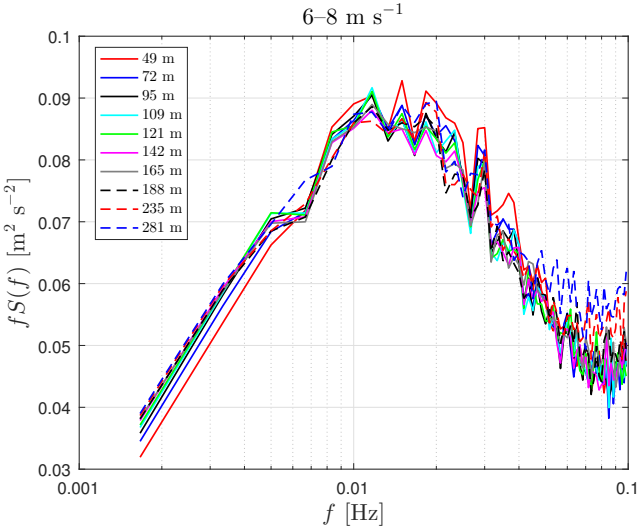
$$\frac{\partial U}{\partial U_\infty} = \frac{\partial f}{\partial U_\infty} U_\infty + f = f - \left(1 + \frac{2\xi}{\sqrt{1+4\xi^2}}\right) \frac{\partial a}{\partial U_\infty} U_\infty \tag{3}$$

Induction as a function of U_∞

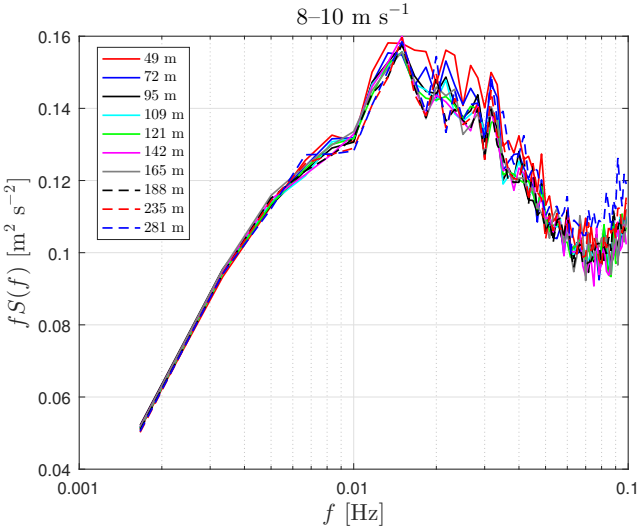
from 10-minute beam-0 measurements



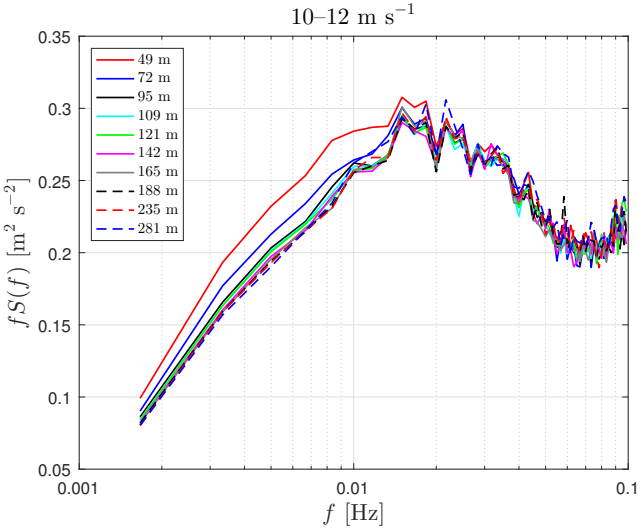
u-spectra measured by lidar



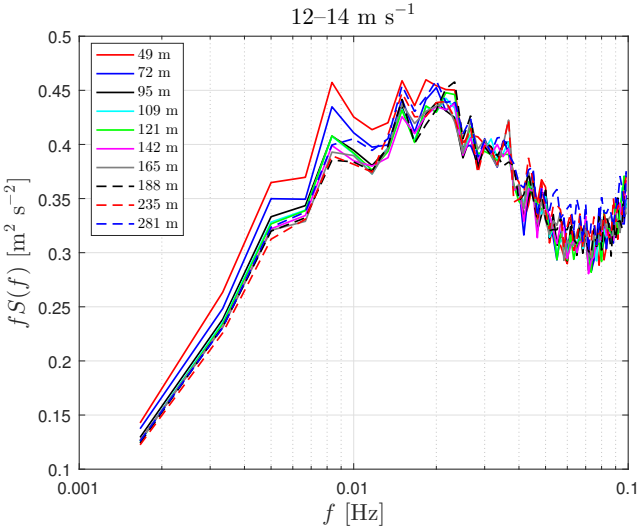
u-spectra measured by lidar



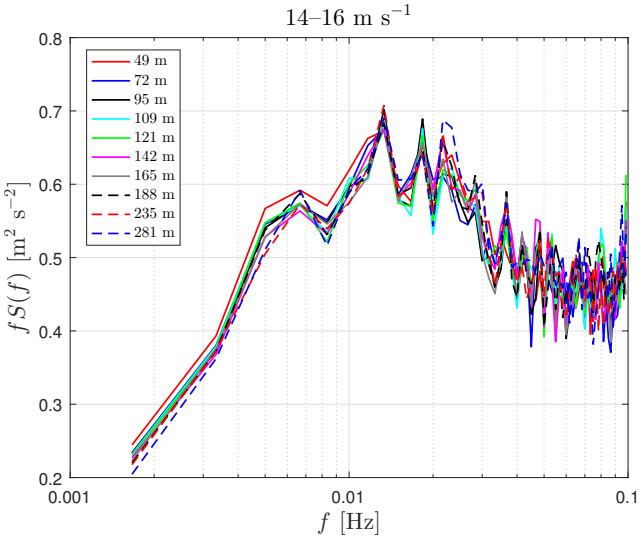
u-spectra measured by lidar



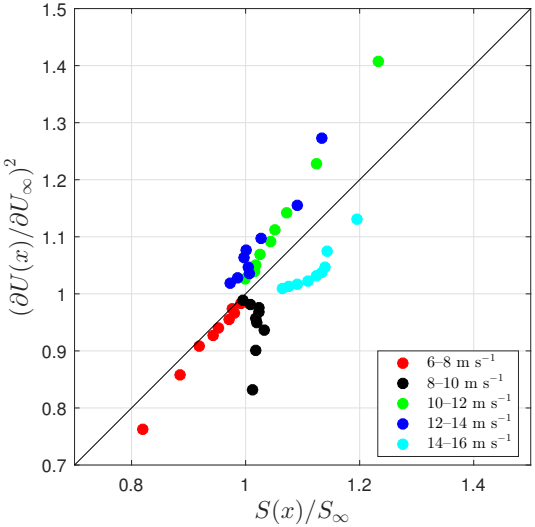
u-spectra measured by lidar



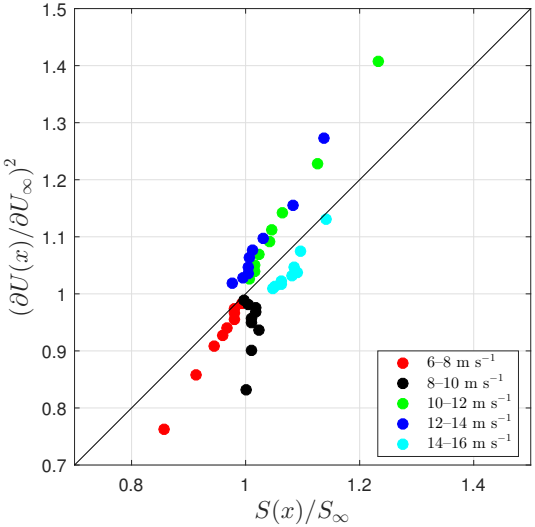
u-spectra measured by lidar



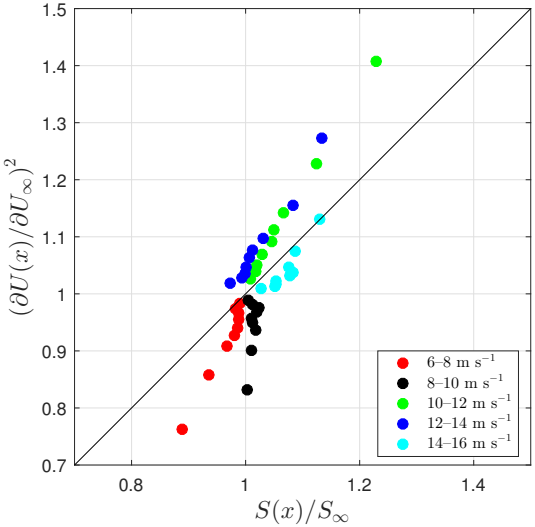
Comparison with theory for low frequencies



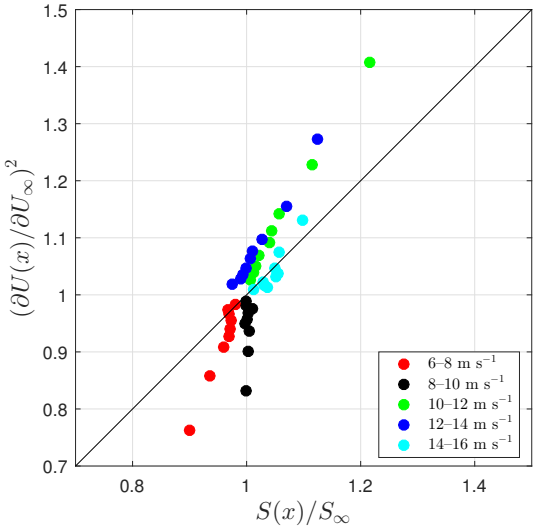
Comparison with theory for low frequencies



Comparison with theory for low frequencies

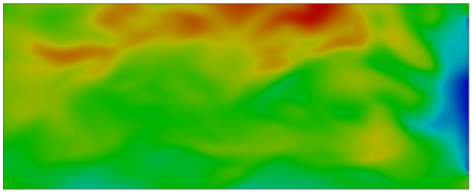


Comparison with theory for low frequencies

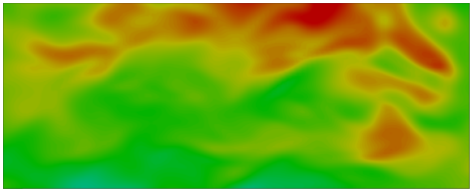


LES approach

- Simulations with and without a SQT93-2.3 turbine with identical ambient flow
- Turbine simulated as an actuator disk
- Turbulence generated by Mann model at 8, 11 and 13 m/s (shear free)



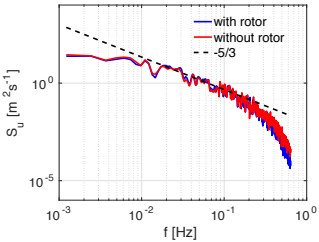
Snapshot of streamwise velocity **with rotor**



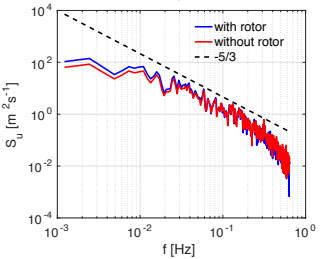
without rotor

Spectra at rotor center

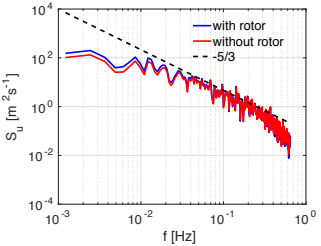
8 m/s



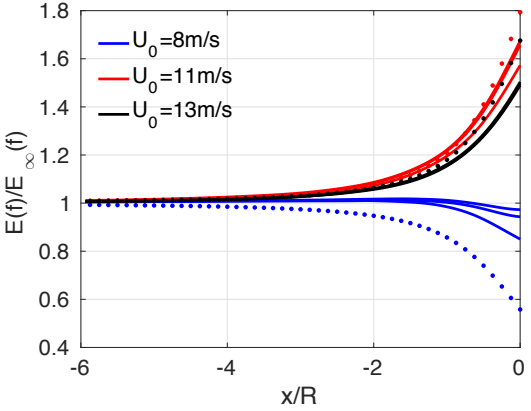
11 m/s



13 m/s



Energy of lowest three frequencies (full lines) compared to quasi-steady model (dots)



- Above rated the change of energy approaching the rotor is well predicted by model
- Below rated LES shows less reduction then model

Conclusion

- A simple, quasi-steady model for changes of inflow turbulence is developed

Conclusion

- A simple, quasi-steady model for changes of inflow turbulence is developed
- The slope of the thrust coefficient curve is the crucial parameter

Conclusion

- A simple, quasi-steady model for changes of inflow turbulence is developed
- The slope of the thrust coefficient curve is the crucial parameter
- It reproduces the low-frequency changes observed from a forward looking lidar

Conclusion

- A simple, quasi-steady model for changes of inflow turbulence is developed
- The slope of the thrust coefficient curve is the crucial parameter
- It reproduces the low-frequency changes observed from a forward looking lidar
- LES supports (partially) the findings

Conclusion

- A simple, quasi-steady model for changes of inflow turbulence is developed
- The slope of the thrust coefficient curve is the crucial parameter
- It reproduces the low-frequency changes observed from a forward looking lidar
- LES supports (partially) the findings
- Higher frequencies remains to be investigated and measured