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Aerodynamic Measurements on AD8-180

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Motivation & Background

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HighRe

Validating low- and high-fidelity tool chains against field measurements of an 8 MW wind turbine

- Low fidelity models based on smaller wind turbines
 - No data available on large multi-MW rotors
 - Adwen 8MW (AD8) (offshore) wind turbine as research infrastructure by Fraunhofer IWES in Bremerhaven (2018-2022)
 - Large turbine measurement campaign conducted within the **HighRe** project:
 - Inflow and wake measurements using a met mast, ground lidars, nacelle lidars
 - Turbine data available for BEM and CFD purposes within project (electric power, root bending moments, pitch, azimuth, blade data ...)
 - Development of an aerodynamic measurement device (aerodynamic glove) that was attached on one blade
 - Aiming at validation of in-house toolchains and investigate measurements for high Reynolds number effects (HighRe)
 - Approach: getting setup as close as possible to real conditions, while targeting the scopes of the different tools (BEM, CFD)
- Unique measurement campaign with this turbine size

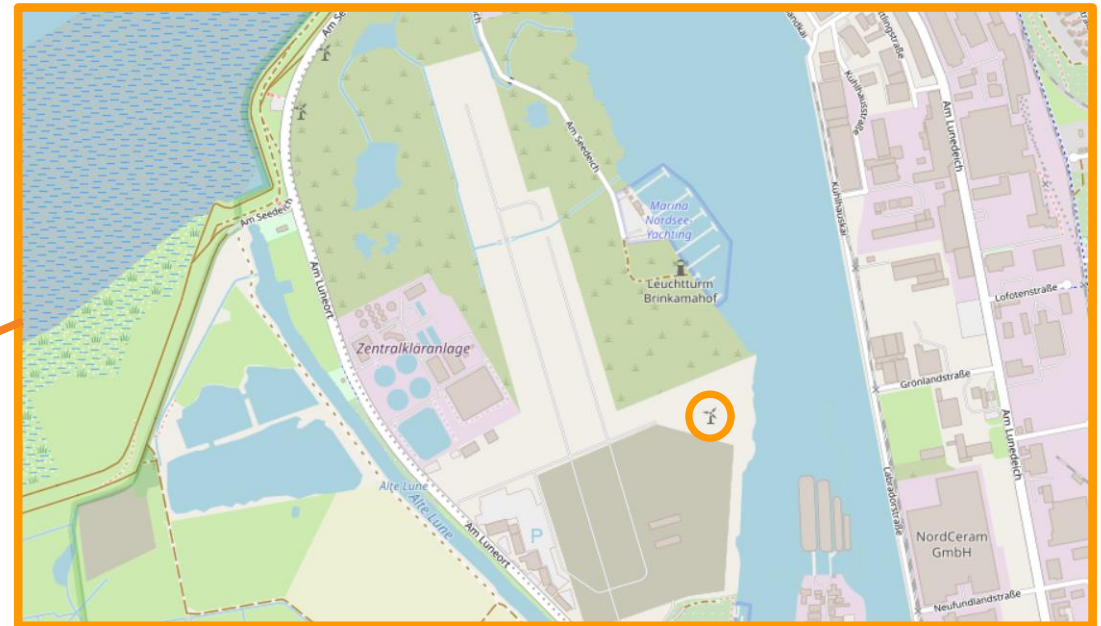
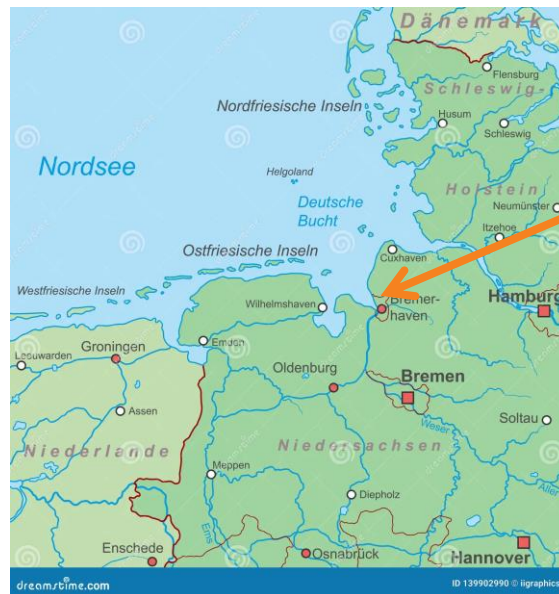
Measurements

Measurements

Testsite

Turbine specifications

- Former airport in the harbor of Bremerhaven, Germany
- Surrounded by field, water and a few buildings
- Main wind direction South/Southwest
- Adwen 8MW turbine:
 - 8 MW rated power
 - 180m rotor diameter
 - 115m hub height
 - Prototype turbine

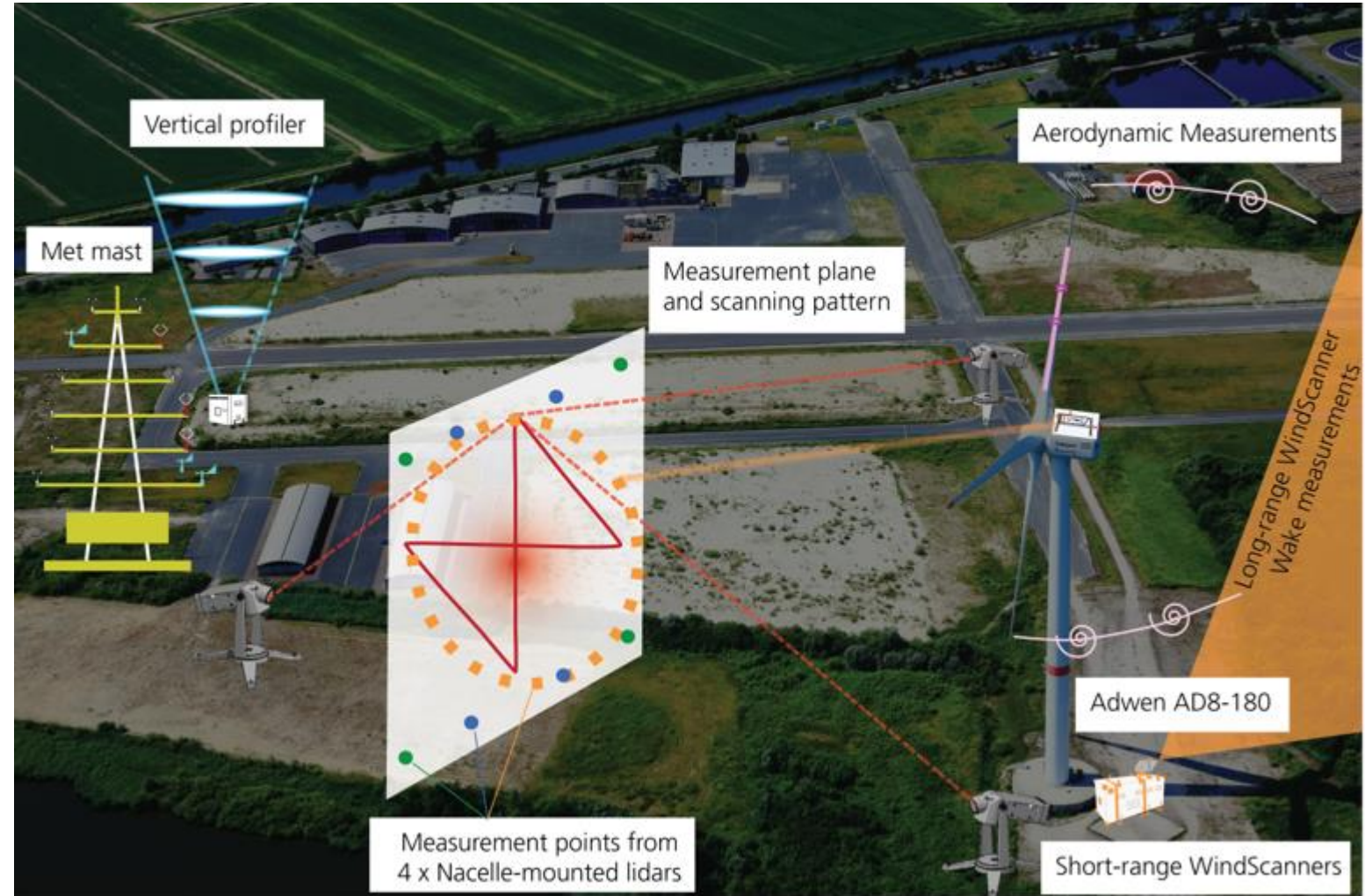


Wind Measurements

Measurements on the AD8 turbine in Bremerhaven

Setup for wind field measurements

- Met mast located southwest of the turbine (main wind direction)
- Vertical profiler, short range wind scanner and nacelle mounted lidars for inflow measurements
- Long-range wind scanners for wake measurements



Turbine Measurements

Blade acceleration

17 sensors (1 blade)
6 sensors (2 blades)

Nacelle vibration

4 sensors

Blade loads

Torsional moment at 50 m (all blades)
Acceleration at 4 radii (1 blade)
Torsional acceleration at 2 radii (1 blade)

Tower loads

Acceleration at 4 levels
Bending moment at 4 levels

Angular rate and acceleration
3 Inertial measurement unit sensors (1 blade)

Drive train acceleration
27 3D sensors

Aerodynamics

Blade surface pressure distribution
at 60m und 73m (1 blade)

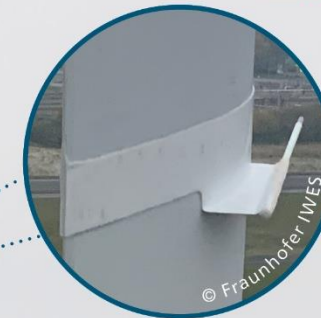


Photo: © Hauke Müller

Turbine Measurements

Aerodynamic Measurements

Blade inaccessible from inside

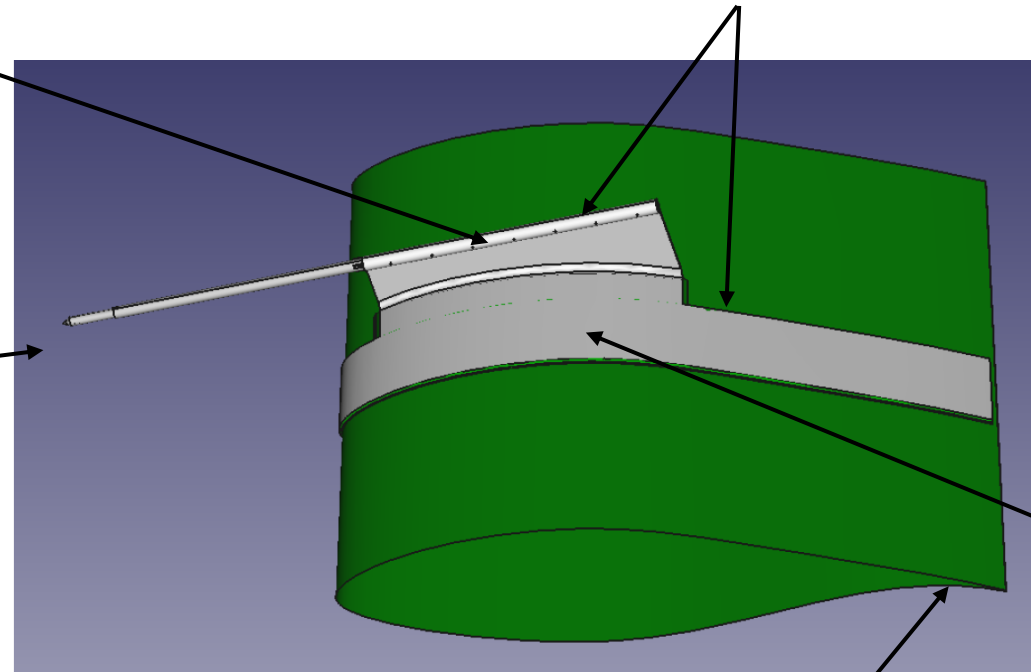
- 5-hole probe attachment on the outside

Probe tip outside induction zone of the blade



No influence of the sensors by the construction

- edge of construction with enough distance from sensors (model result)
- probe holder at outer radius



No influence of the sensors by each other

- staggered positioning
- surface roughness of shell similar to blade

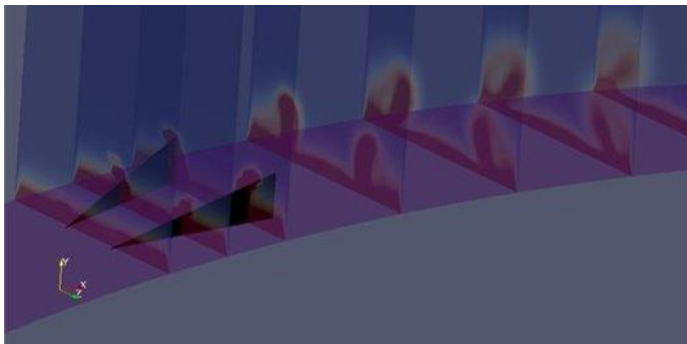
No feedthrough of cables possible at outer radii

- cable guiding close to trailing edge to avoid an influence on aerodynamics

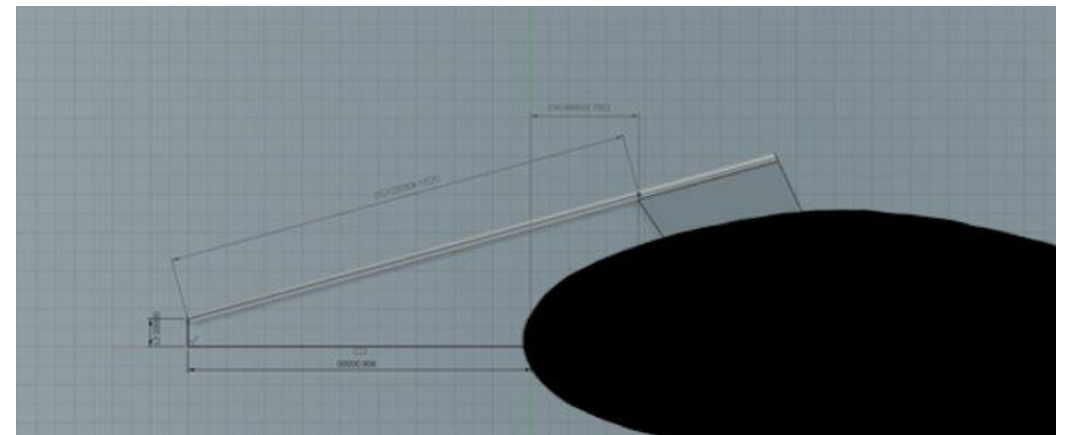
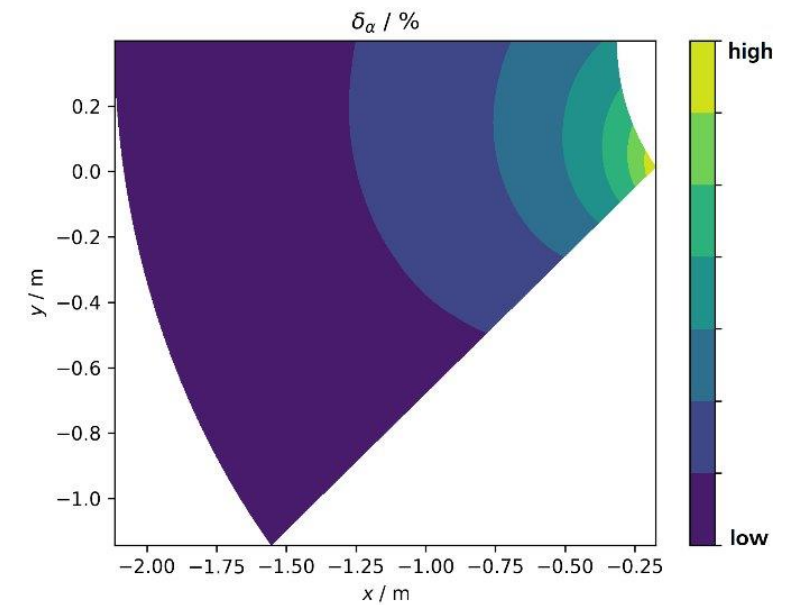
Design of the Measurement System

Simulations

- CFD support on aerodynamic glove design (positioning of sensors)
- Analysis of blade add-ons
 - Overset methodology (CFL3D) for probes
 - Bay model for Vortex Generators (non-resolved grids)



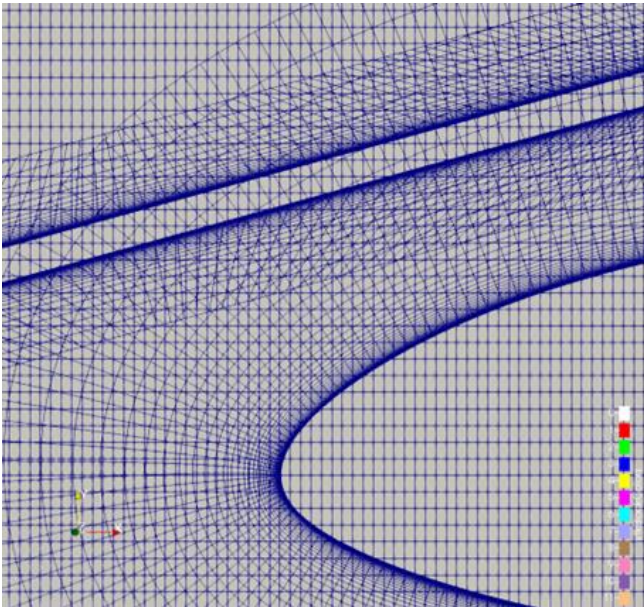
Example of simulation results from Vortex Generators



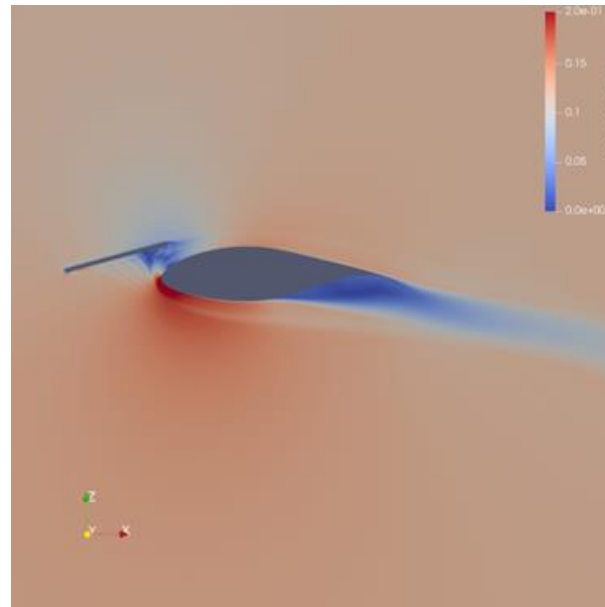
Design of the Measurement System

Simulations

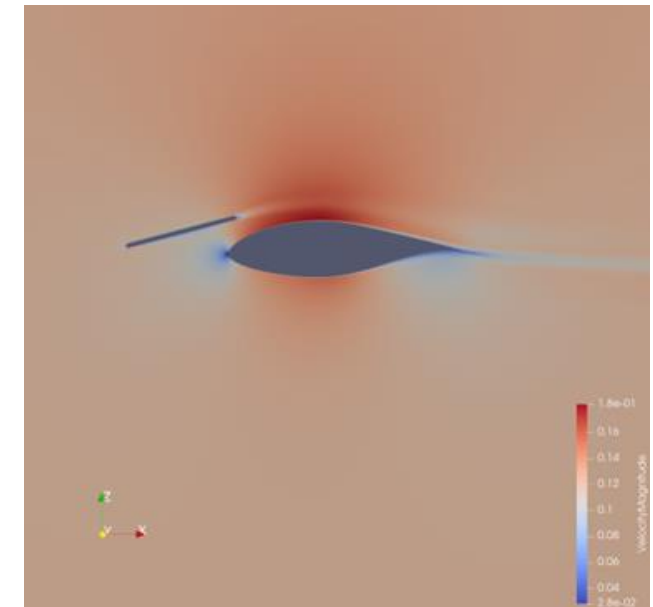
- Fully-resolved aerodynamic probe to estimate its effect on polars



Mesh resolution around rotor blade and probe



CFD simulation results: Speed of flow



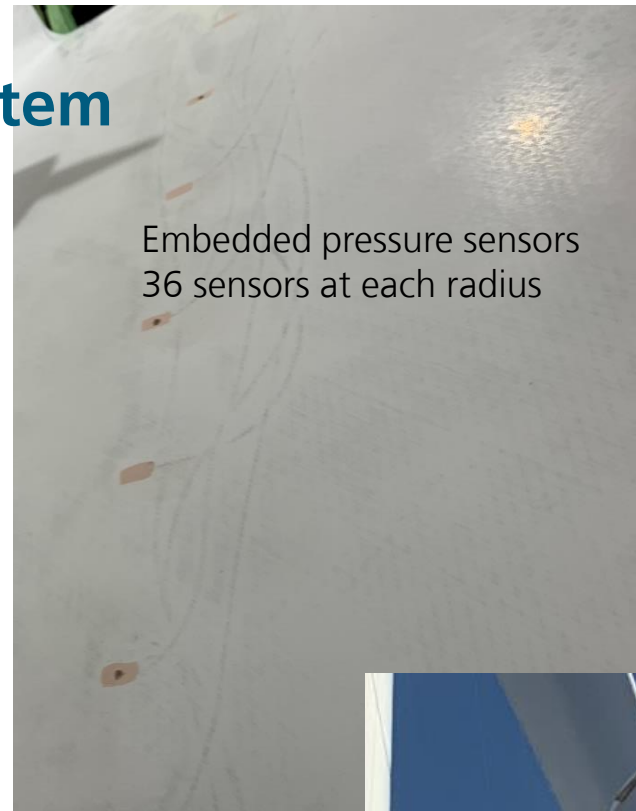
CFD simulation results: Pressure distribution

Design of the Measurement system

Construction and Installation



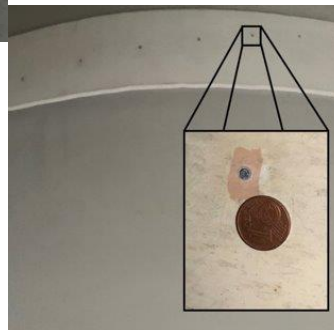
Molds for pressure shells in the Fraunhofer IWES demo center, milled from foam blocks with epoxy coating.



Embedded pressure sensors
36 sensors at each radius



Installation process



Installation completed
November 2021: shell/probe @73 m
March 2022: shell/probe @ 60 m
De-Installation July 2022

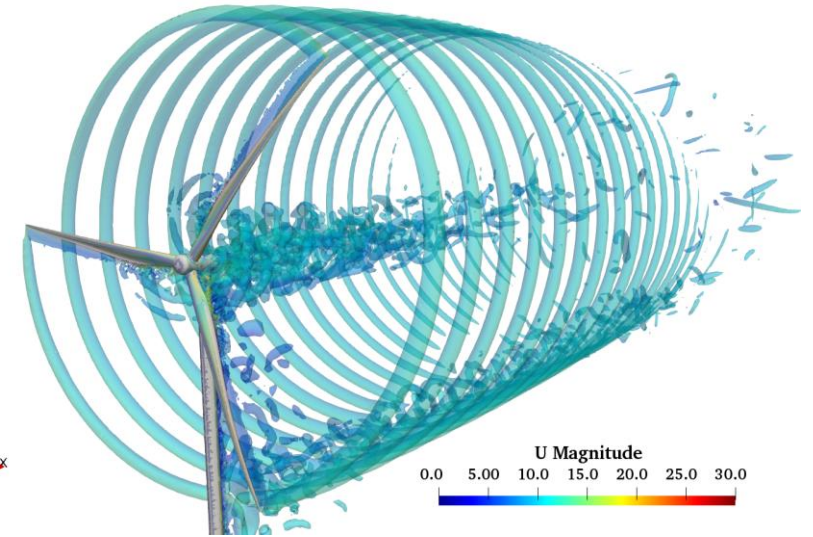
Results

Comparison of BEM and CFD

Blind test for unsteady conditions

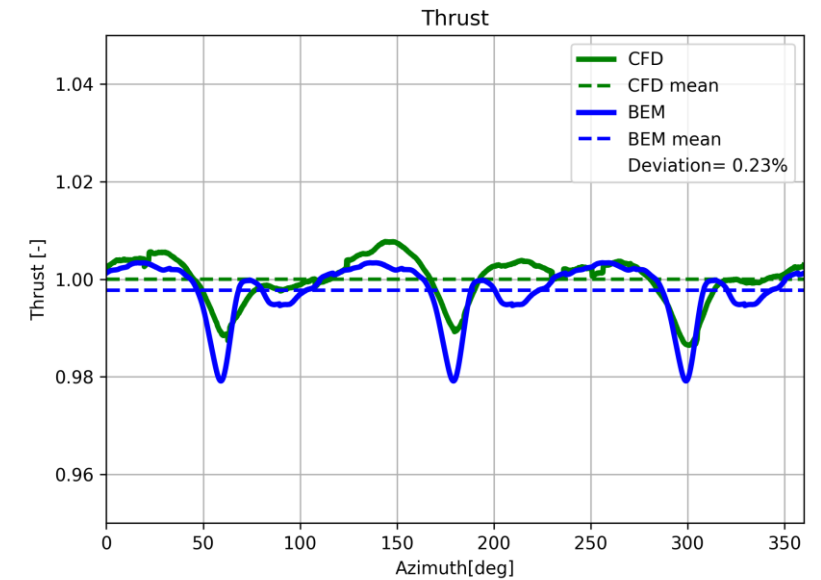
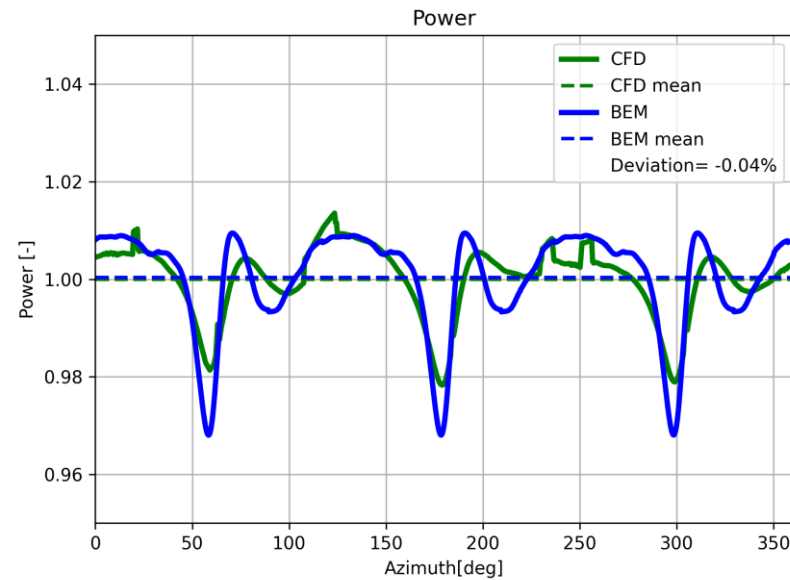
Unsteady turbine conditions

- Full turbine simulation comparable
- Mean quantities aligning well
- Small offsets for example in 3P tower effects



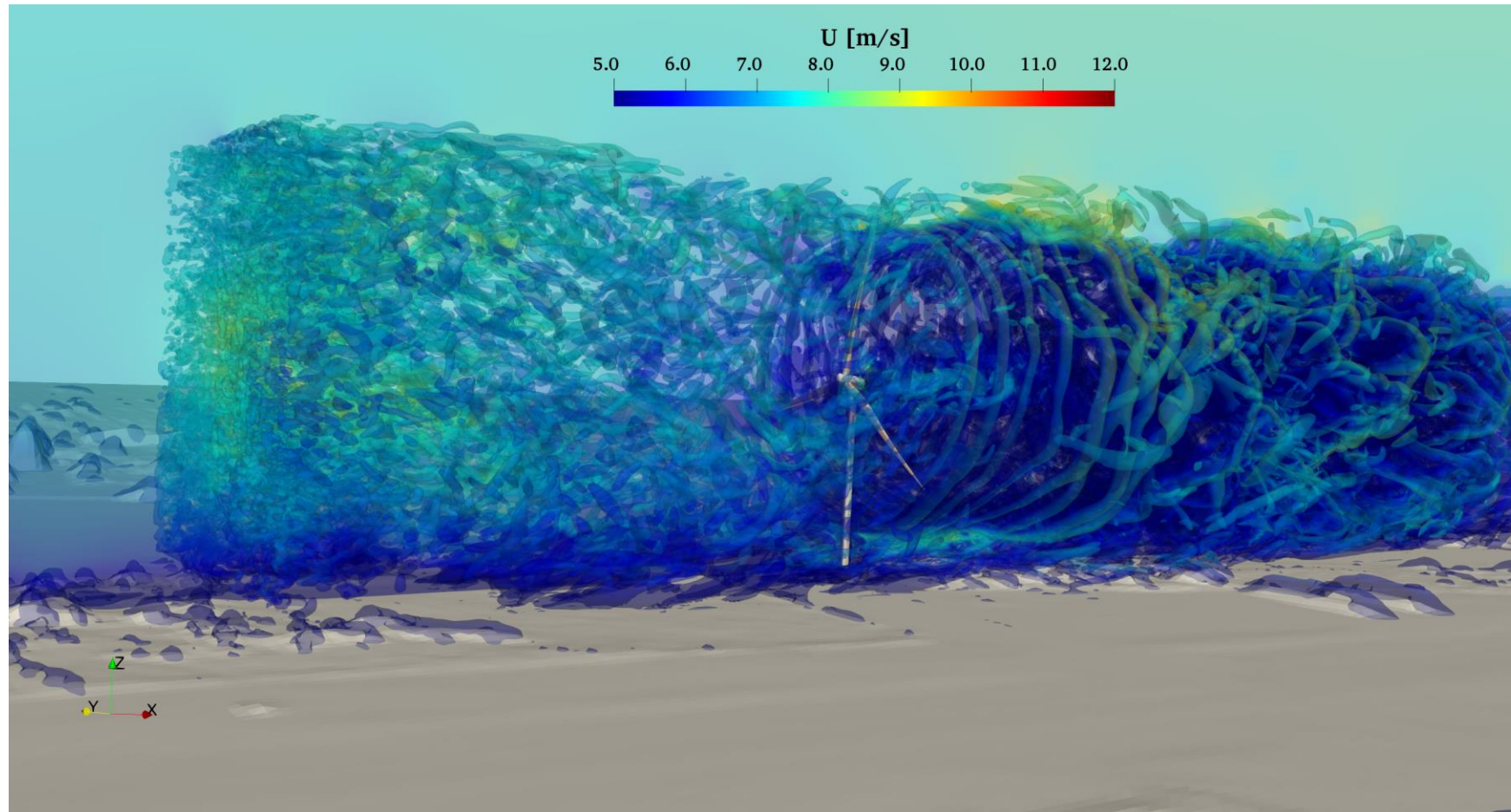
Conclusion unsteady verification

- Dynamic setup aligning well
- Differences in ground modelling could explain offset in 3P power jumps
- Inclusion of surrounding terrain
- Validation towards field measurements necessary



Comparison of Experiments, BEM and CFD

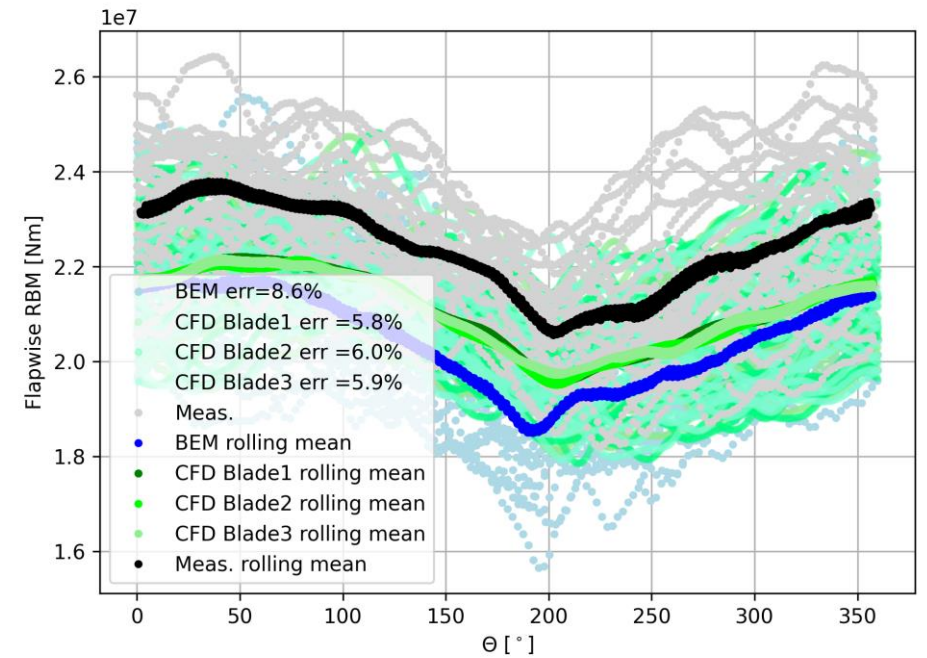
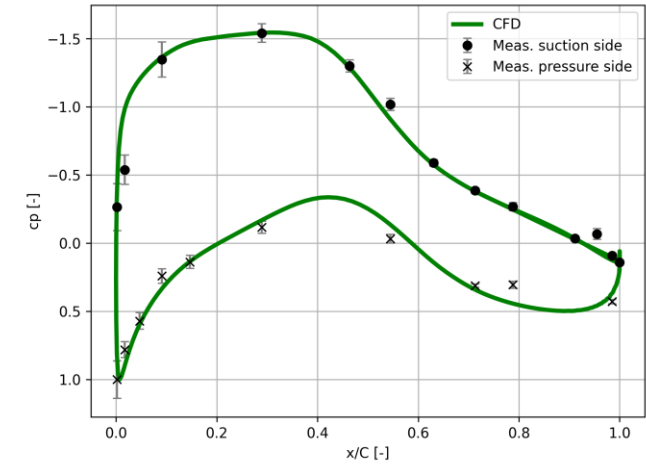
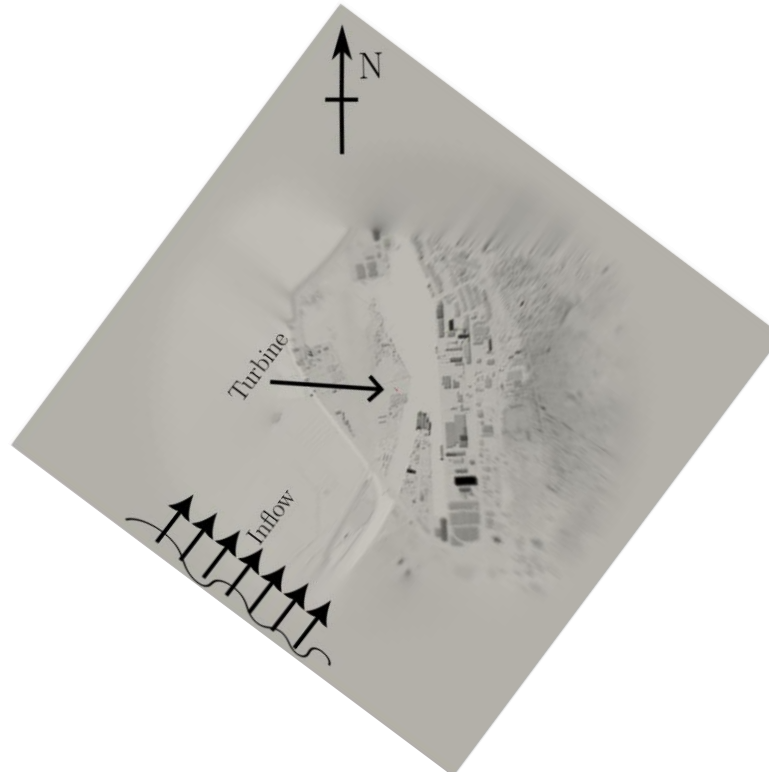
CFD simulation including relief and turbulent inflow



Comparison of Measurements, BEM and CFD

Simulations in comparison towards glove measurements

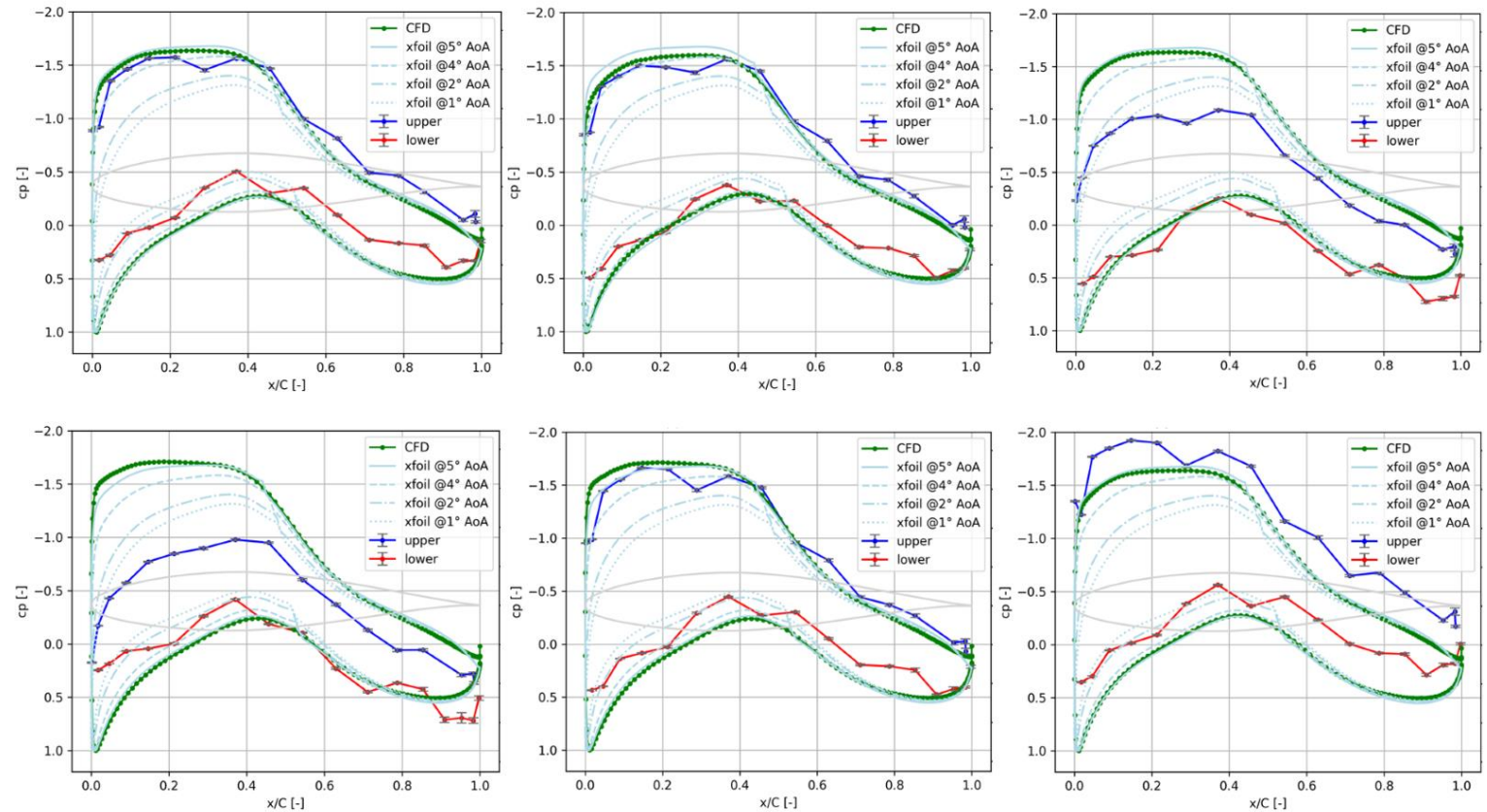
Turbulent wind field constrained by measured data
Injected by source terms upstream of turbine
15° yaw misalignment



Comparison of Measurements and CFD

Simulations in comparison towards glove measurements

- CFD simulations performed with clean blades
- Measurements corrected for:
 - Height differences
 - Drifting effects
 - Temporal offset
- Fluctuations in measurements larger than in simulations
- Overall good agreement
- Huge amount of data available in BEM, CFD and field measurements → comparisons to be done to understand deviations in aerodynamic

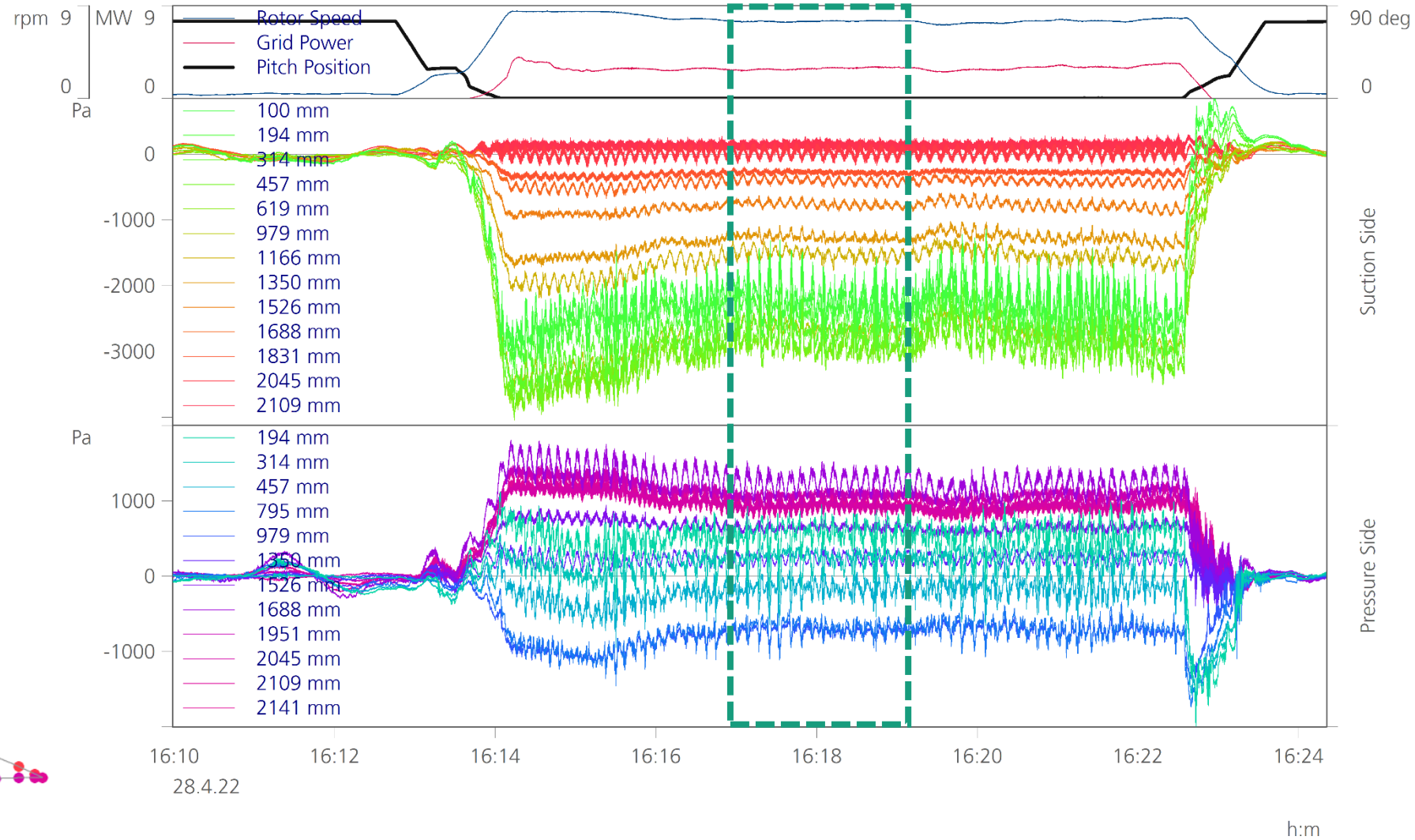
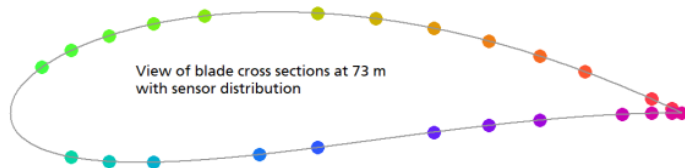


Tower passage

Results

Time series

- 15 min
- 73 m rotor radius
- Measurements corrected for:
 - Height differences
 - Drifting effects
 - Temporal offset
- Turbine conditions:
 - Below rated conditions
 - 7.7m/s inflow
 - El. Power 2.9 MW
 - Pitch 0°

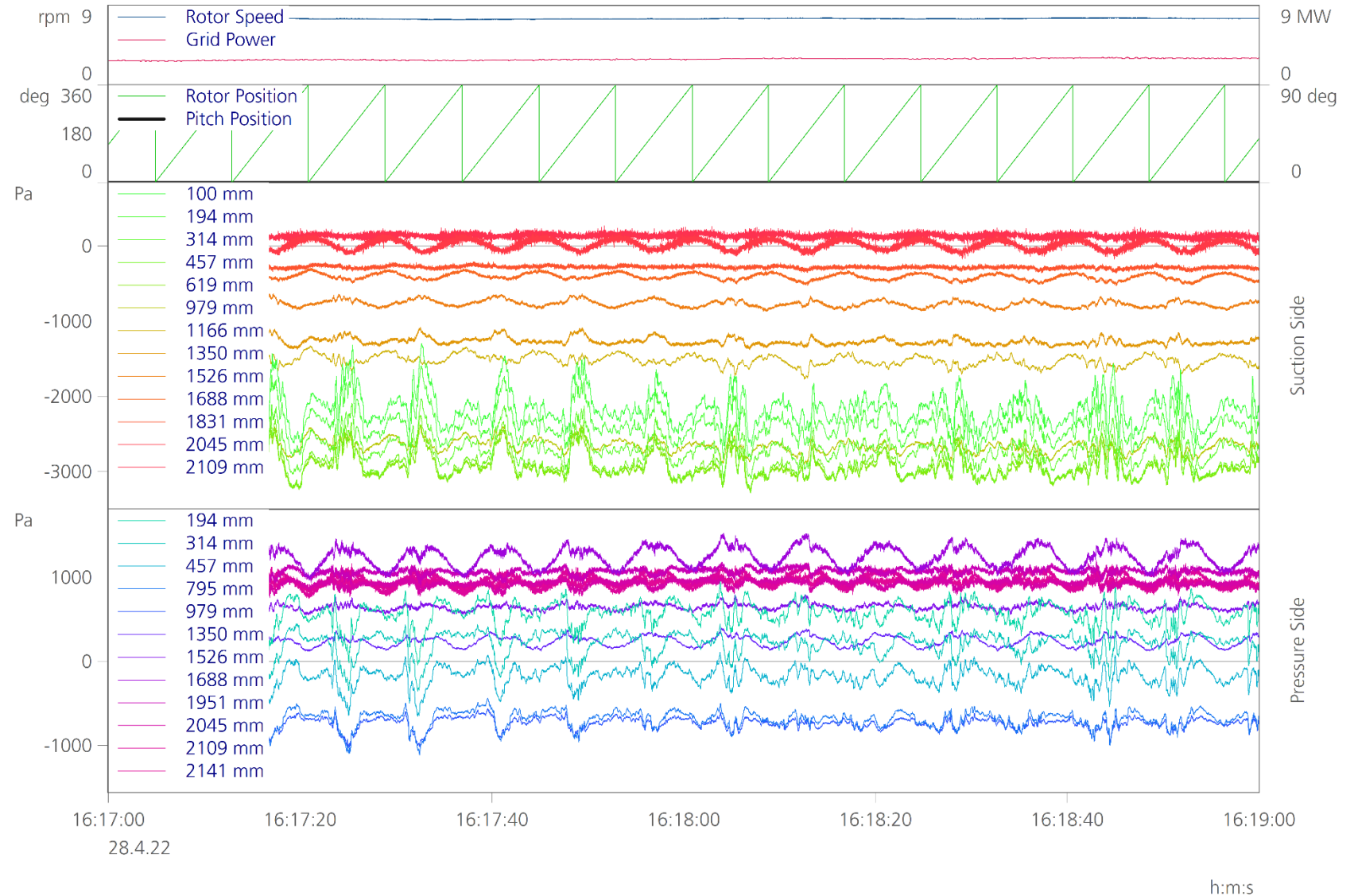
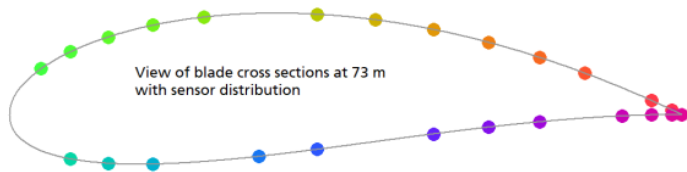


Results

Time series

Rotor rotation

- 73 m rotor radius
- Measurements corrected for:
 - Height differences
 - Drifting effects
 - Temporal offset
- Turbine conditions:
 - Below rated conditions
 - 7.7m/s inflow
 - El. Power 2.9 MW
 - Pitch 0°

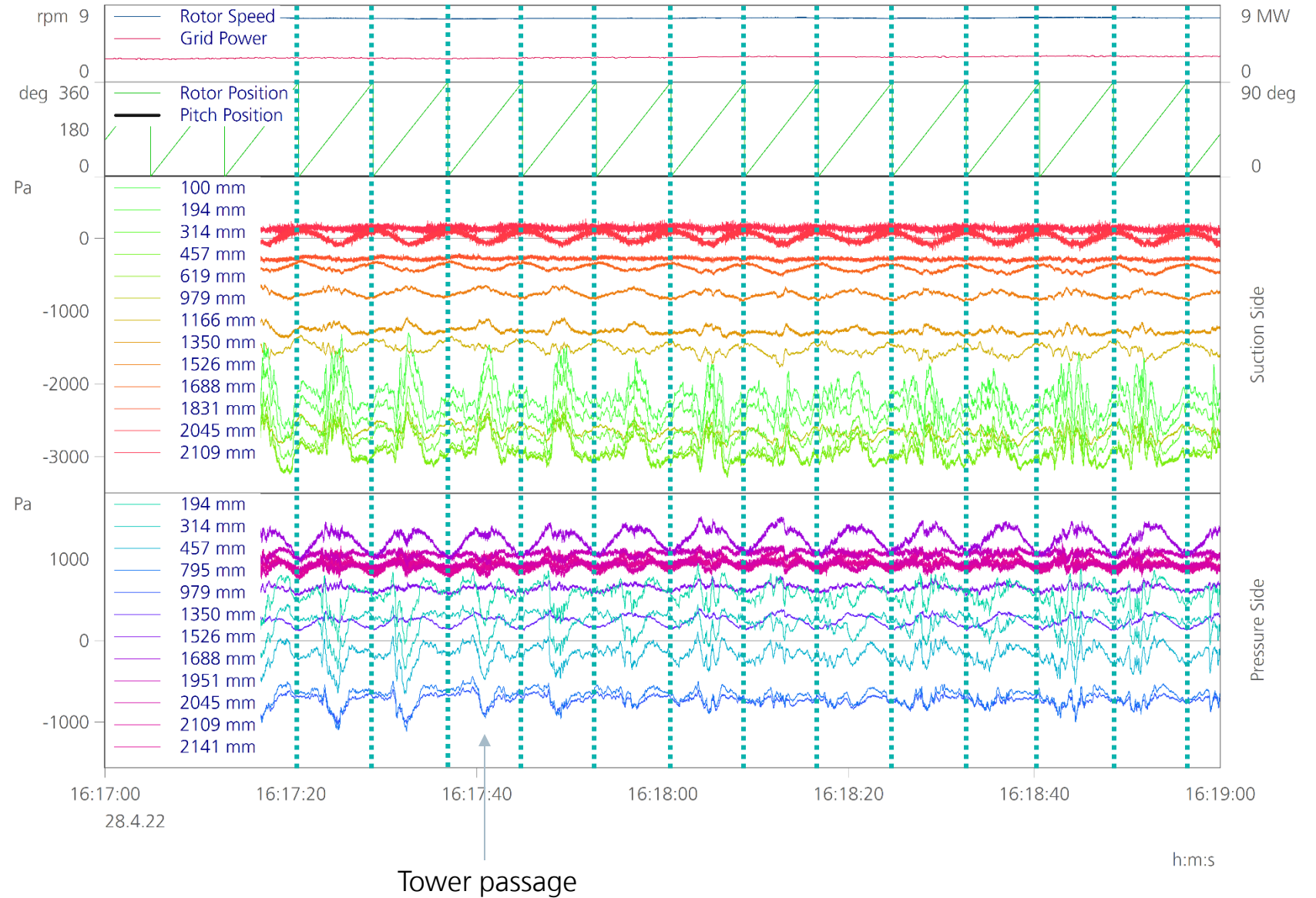
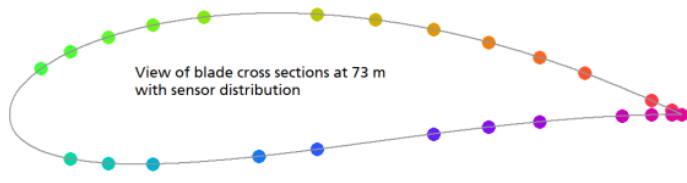


Results

Time series

Rotor rotation

- 73 m rotor radius
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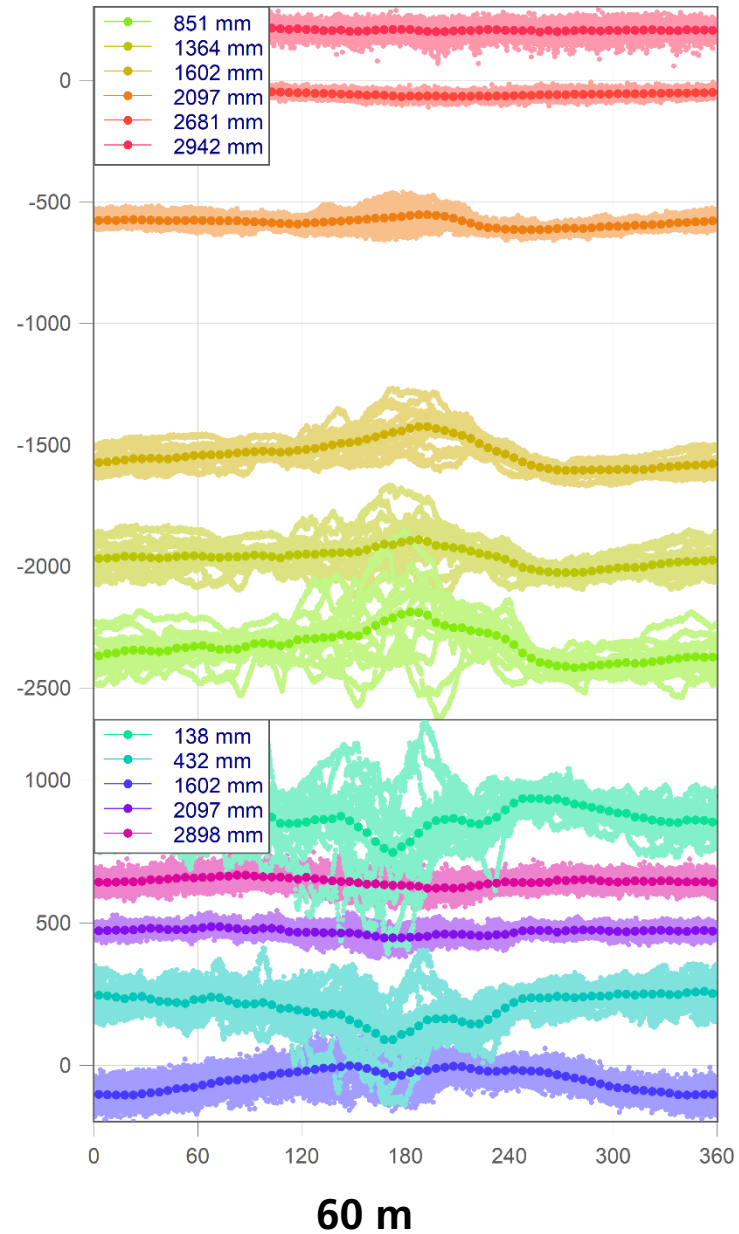
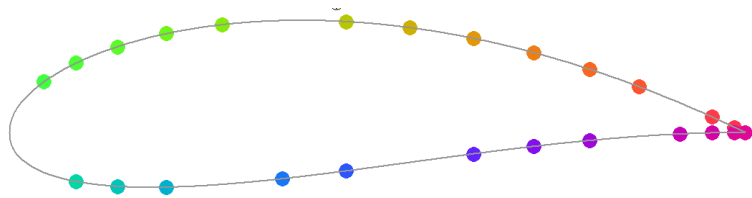


Results

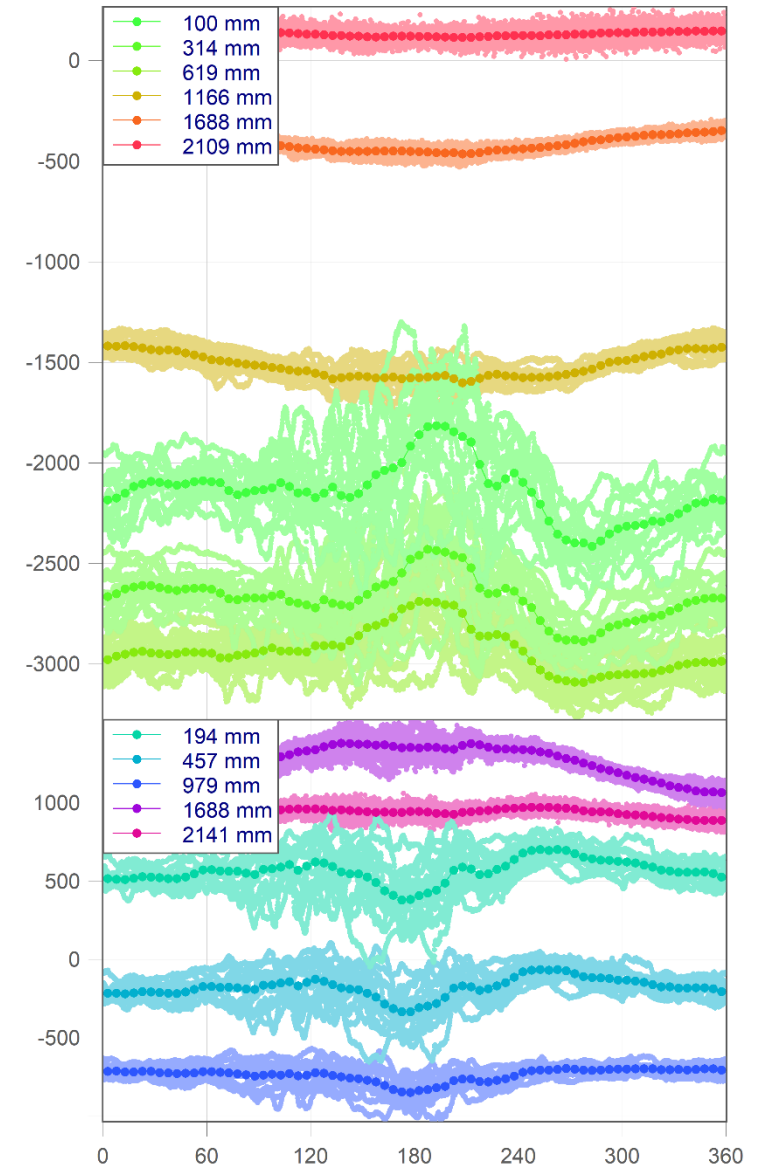
Time series

Rotor rotation

- Measurements corrected for:
 - Height differences
 - Drifting effects
 - Temporal offset
- Turbine conditions:
 - 2 minutes
 - Below rated conditions
 - 7.7m/s inflow
 - El. Power 2.9 MW
 - Pitch 0°



60 m



73 m

Outlook

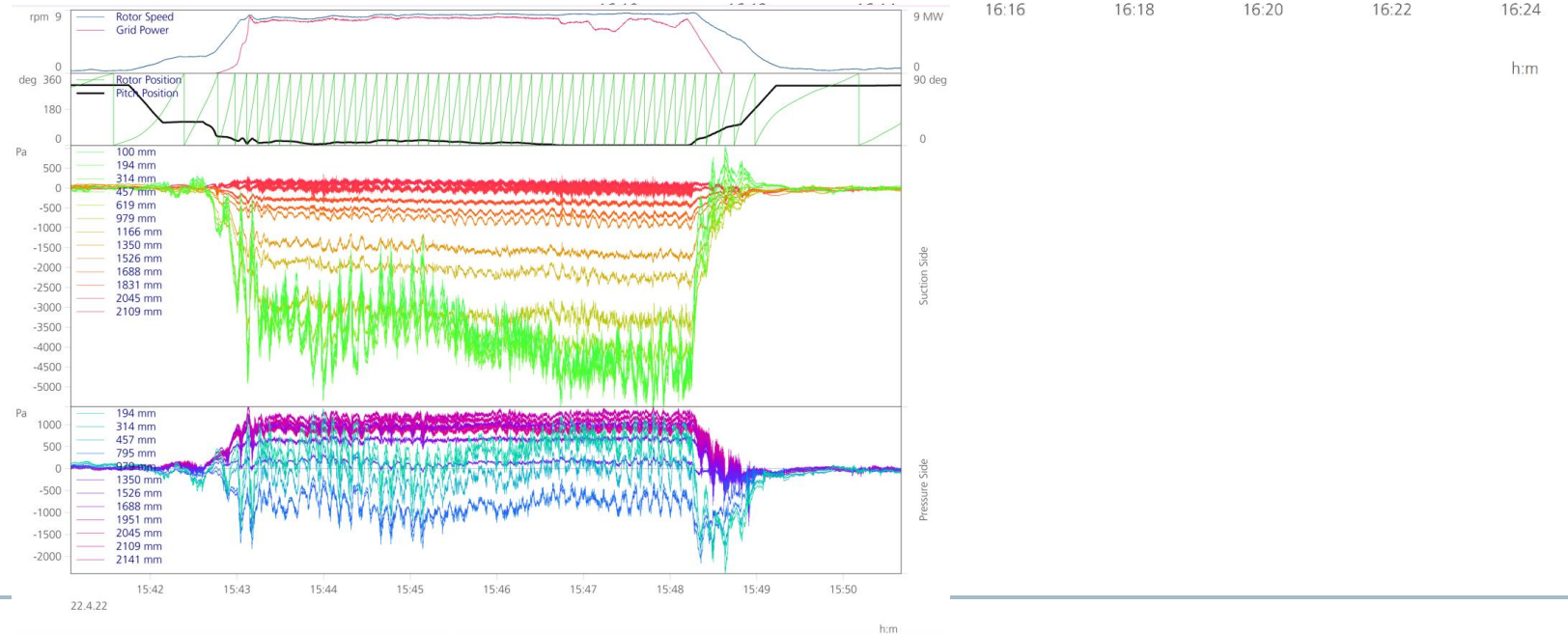
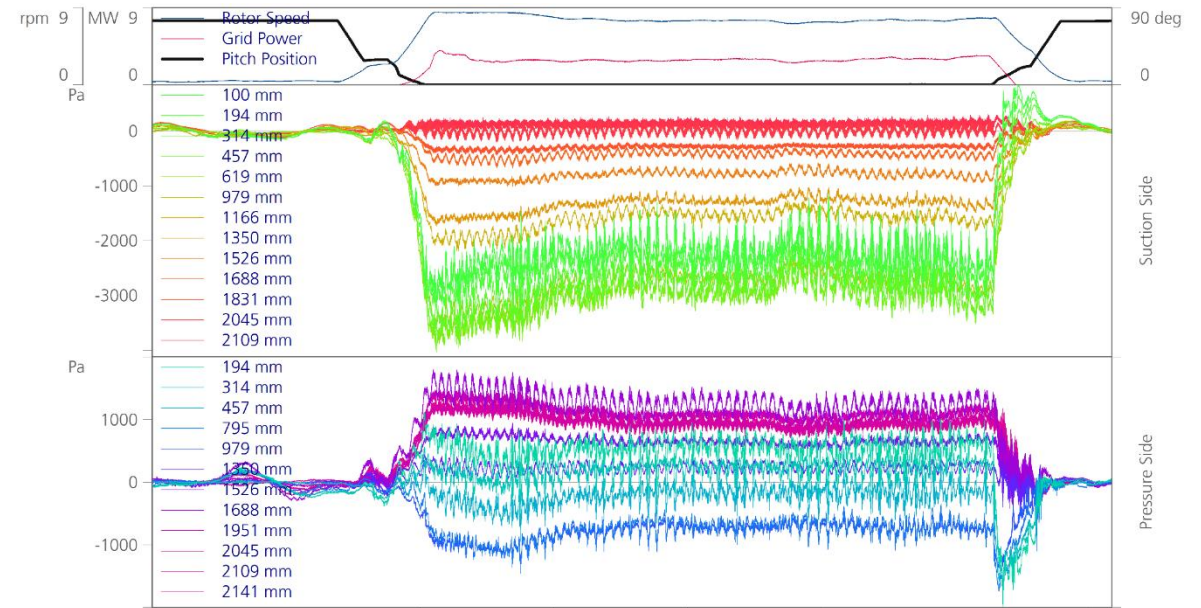
Current state: Large data set for various sensors available (multiple months); further usage of data planned

Data evaluation

- Transition during start-up and slow-down
- More time intervals
- Angle of attack from probe measurements

Simulation

- Evaluate different load cases



Acknowledgements/References

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Thank you
for your attention!

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