

Field experiments of wind turbine vibrations in stand still conditions

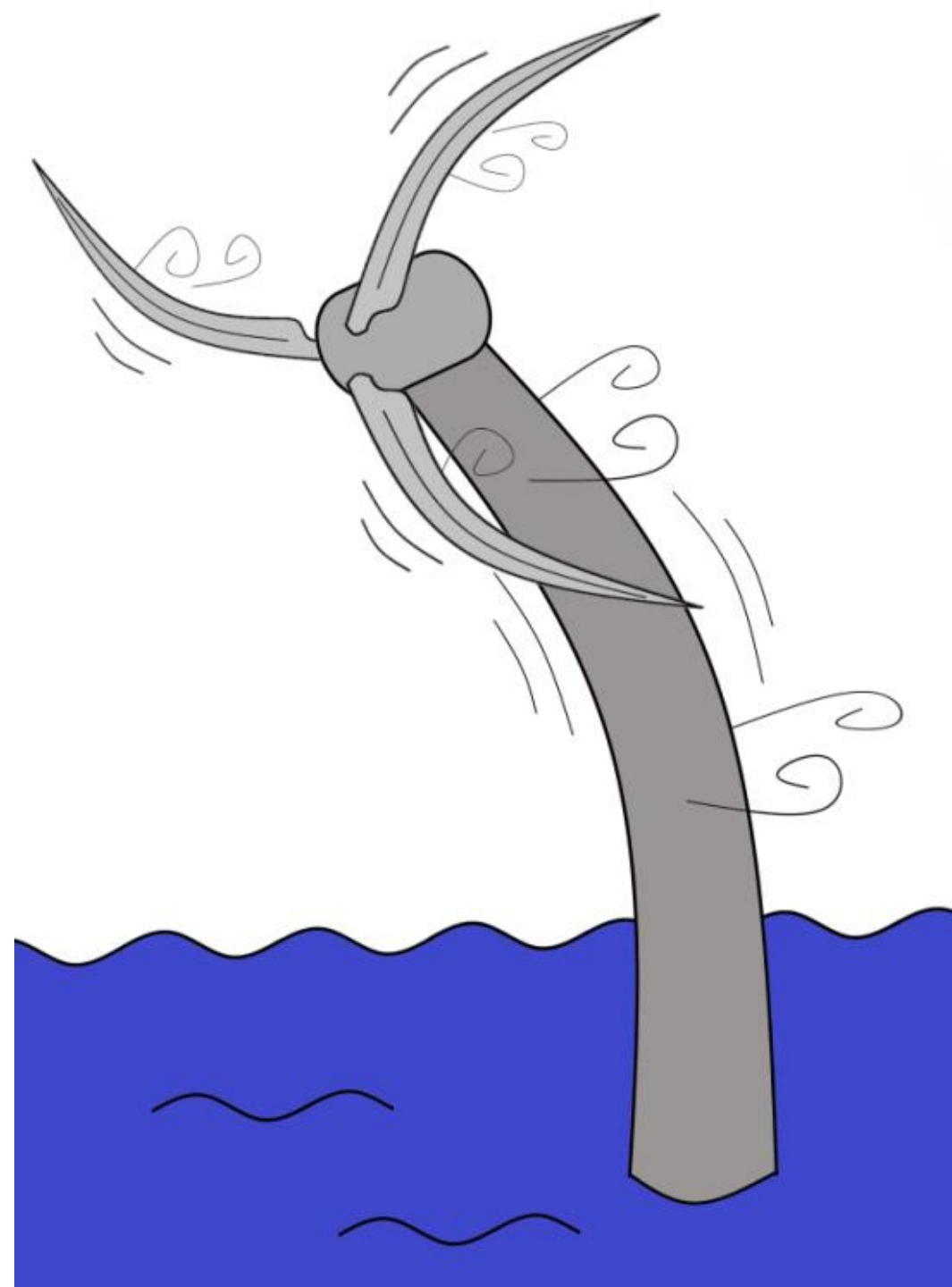
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Koen Boorsma, Andreas Herrig (LM Windpower),
Max Bouwmeesters

Deepwind 2025, Trondheim, 15 January 2025



Motivation

- Severe Vibrations are observed in the field at high wind speeds.
- Source of excitation and exact setting like blade pitch, yaw angle and azimuth are unknown.
- Industry is currently struggling with:
 - Instability predicted in design, which does not occur in reality;
 - Occurrence of Stall and Vortex induced vibrations but not predicted during design.



Content



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2. Vortex and stall induced vibrations
3. Test set-up and measurements
4. Measured power spectral response
5. Pressure measurements
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Project overview

TIADE (Turbine Improvements for Additional Energy)

2020 - 2024



Scope of TIADE project:

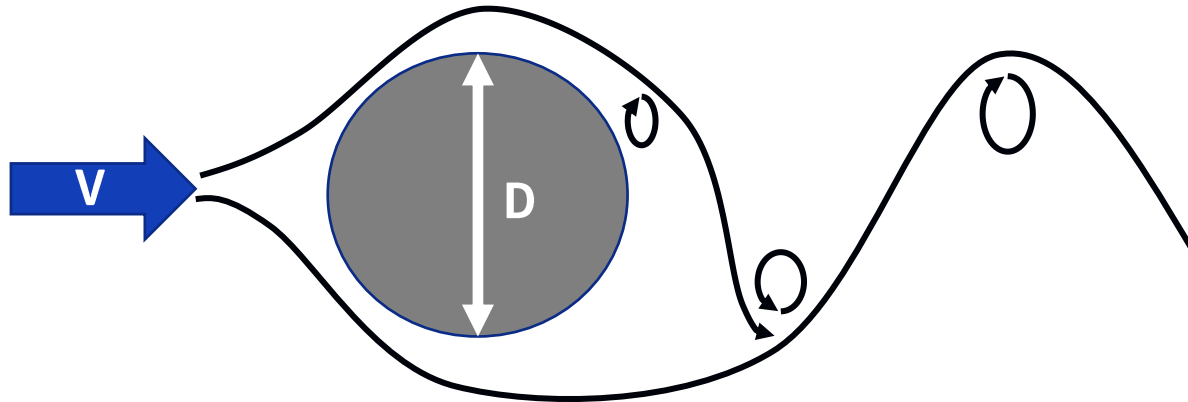
- Blade improvement (innovative tip shapes, VGs, turbulator tips)
- Validation (erosion, yawed inflow, stall and/or vortex induced vibrations)
- Measurement innovations (aerodynamic pressure, torsion deformation, fibre optics)
- Digital twin development

K. Boorsma et al, *TIADE final report*, TNO-2024-R12112, December 2024,
<https://publications.tno.nl/publication/34643564/vPzmF6yO/TNO-2024-R12112.pdf>

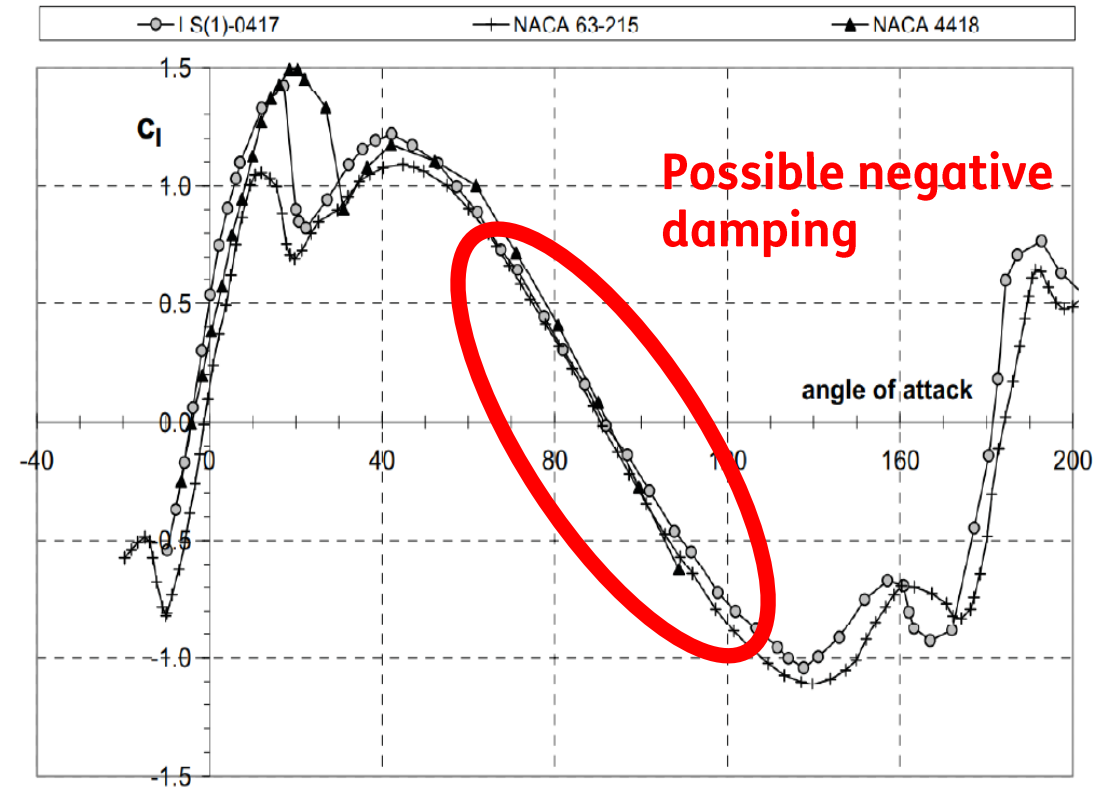
TIADE has been co-financed with Topsector Energiesubsidie from the Dutch Ministry of Economic Affairs under grant no.TEHE119018.

Vortex and Stall induced vibration

Vortex induced

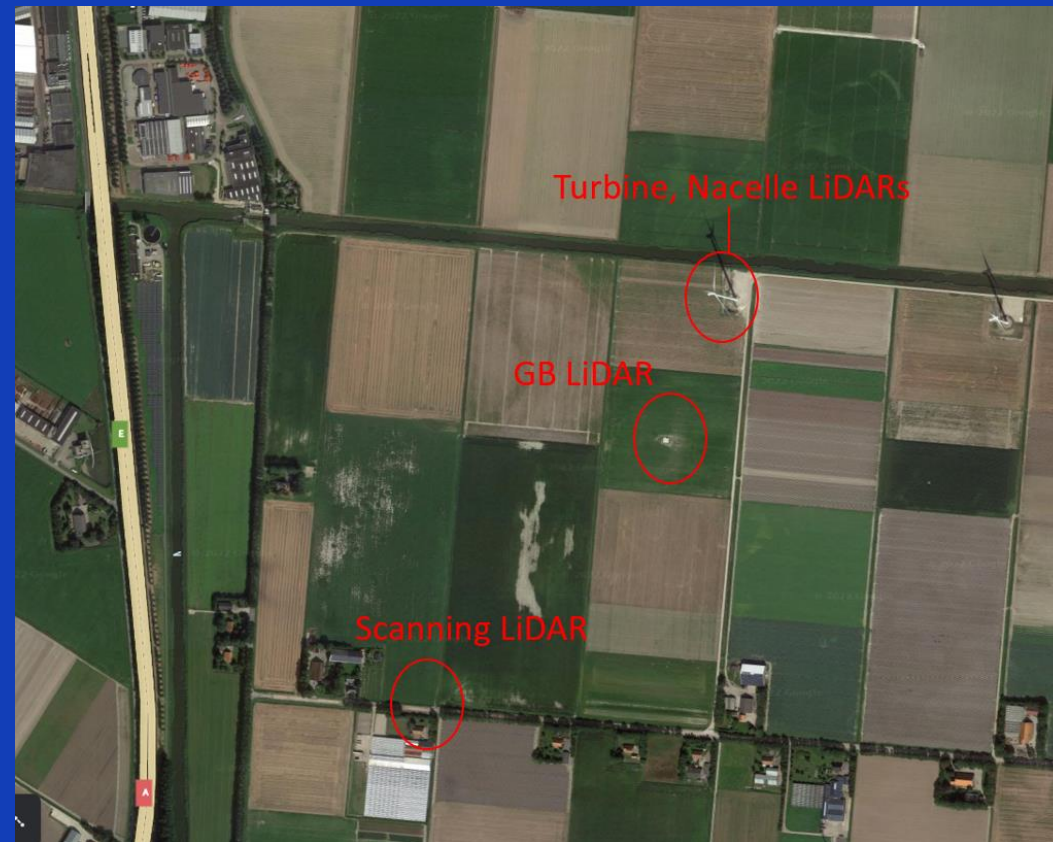


Stall induced



Source: W. A. Timmer. "Aerodynamic characteristics of wind turbine blade airfoils at high angles of attack." In: TORQUE (2010).

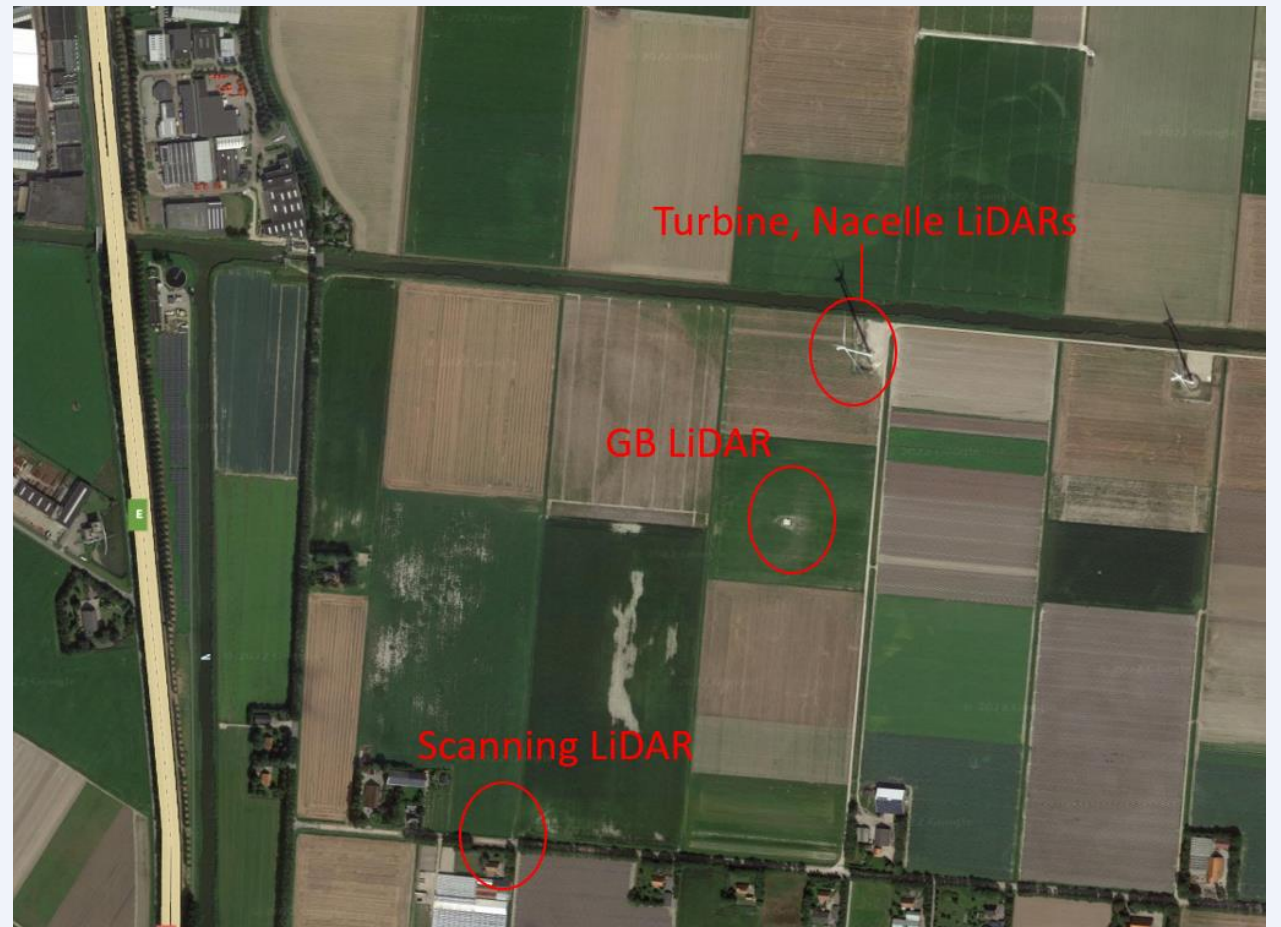
Test set-up and measurements



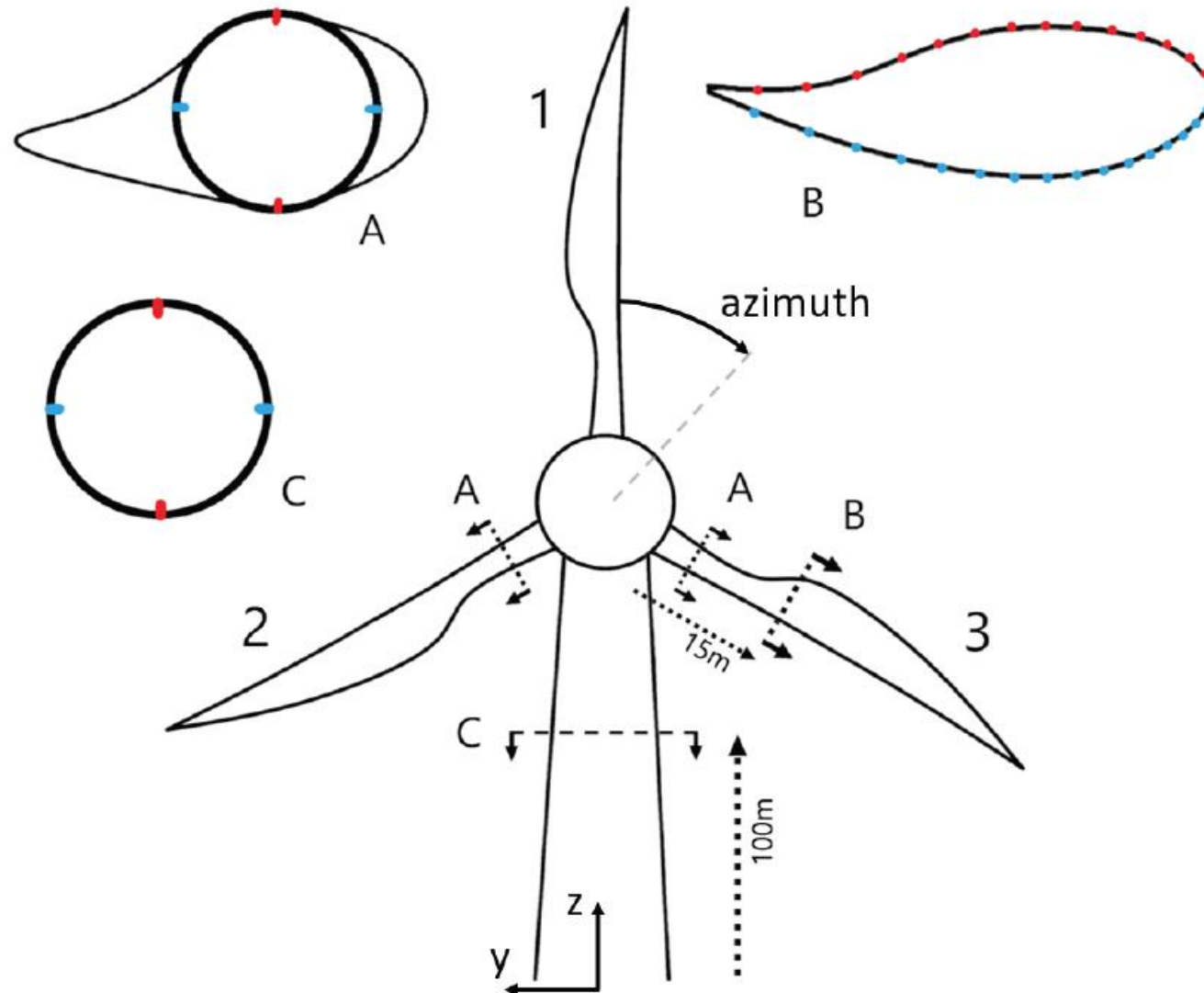
Test set-up

Test site overview

- Turbine type: 3.8MW, 110 m hub height, 130 m rotor diameter
- Ground based Windcube LiDAR @ 11 heights (42 - 188 m)
- 2 Nacelle based fwd looking LiDARs (~0.25D - 5D)
- Meteo mast at 2.0 km from turbine (wind, press, temp, disdro)
- Scanning LiDAR to measure wake at hub height (1D - 5D)



3.8 MW testing turbine

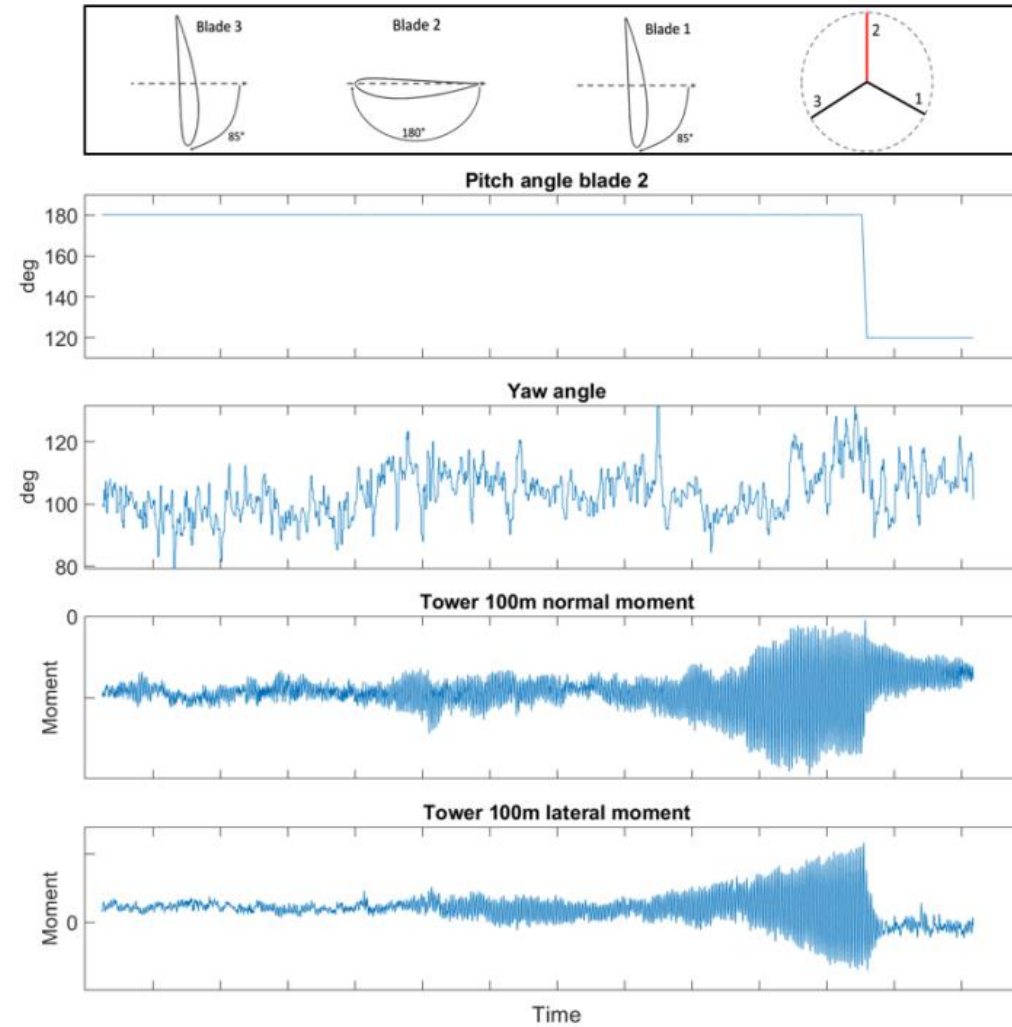


- A: Strain gauges
- B: Pressure sensor
- C: Strain gauges

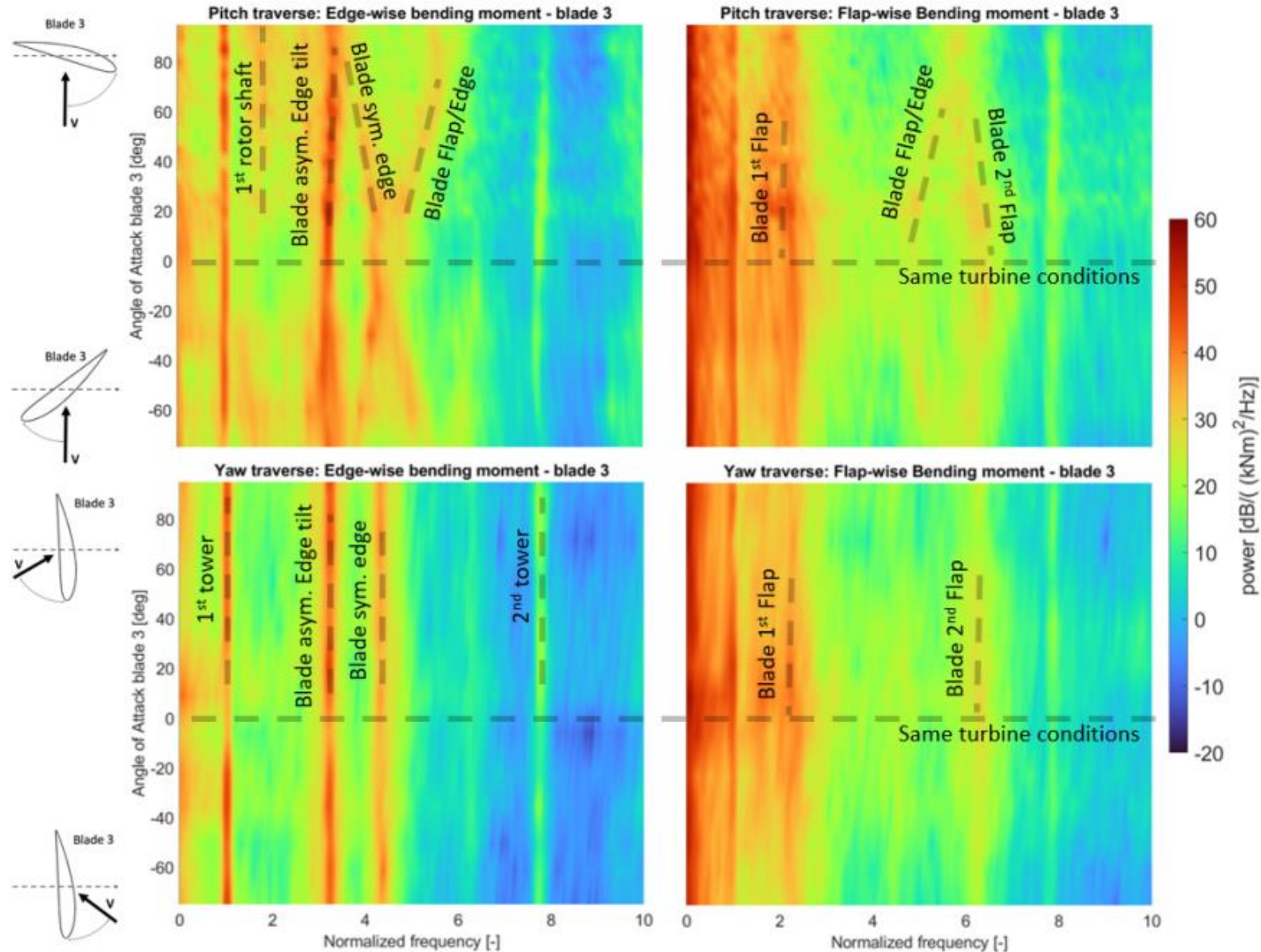
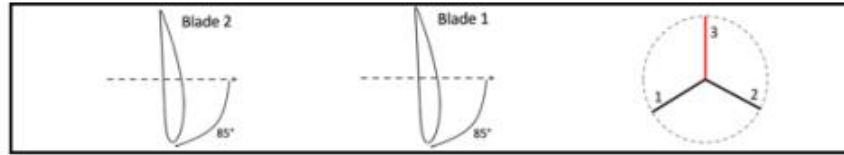
Experiments

#	Pitch angle			Yaw misalignment	Rotor azimuth	Wind (std) [m/s]	Ti [%]	Wind dir. Lidar : 210°
	Blade 1	Blade 2	Blade 3					
1	85°	-15° till 85°	85°	0°	120°	15.9 (2.0)	13%	290°
2	85°	85°	-15° till 165°	0°	240°	14.3 (1.6)	11%	150°
3	85°	85° till 180°	85°	90°	120°	18.8 (2.6)	14%	265°
4	85°	85°	85°	0° till 60°	120°	15.9 (2.0)	13%	290°
5	85°	85°	85°	-130° till 95°	240°	14.3 (1.6)	11%	150°
6	85°	85°	85°	-5° till 200°	240°	19.1 (2.6)	14%	242°
7	85°	85°	85°	-110° till 90°	330°	17.4 (3.4)	19%	270°
8	85°	180°	85°	94° till 113°	120°	19.5 (2.8)	14%	270°
9	85°	85°	180°	117° till 94°	240°	16.6 (1.8)	11%	268°
10	89°	89°	89°	90°	240° till 360°	19.2 (2.6)	14%	256°

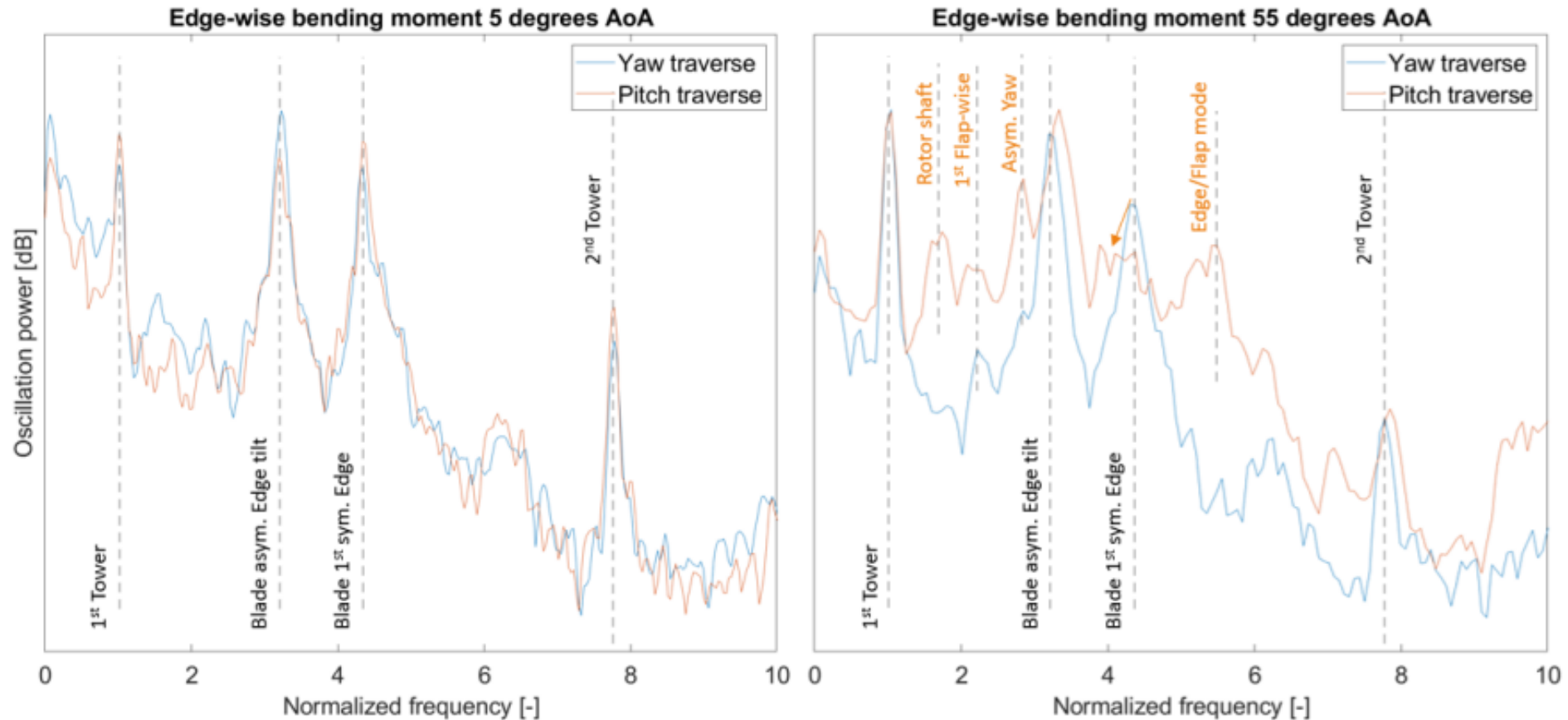
Case 8 Extreme vibration observed



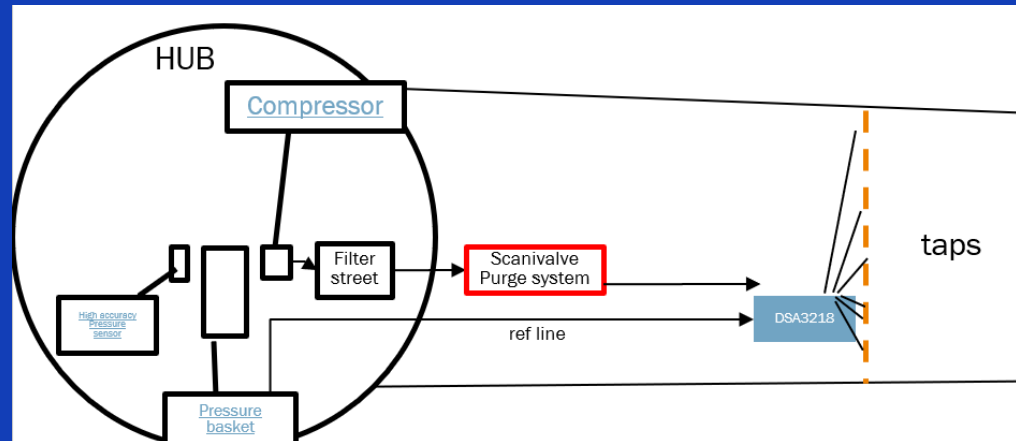
Measured power spectral response



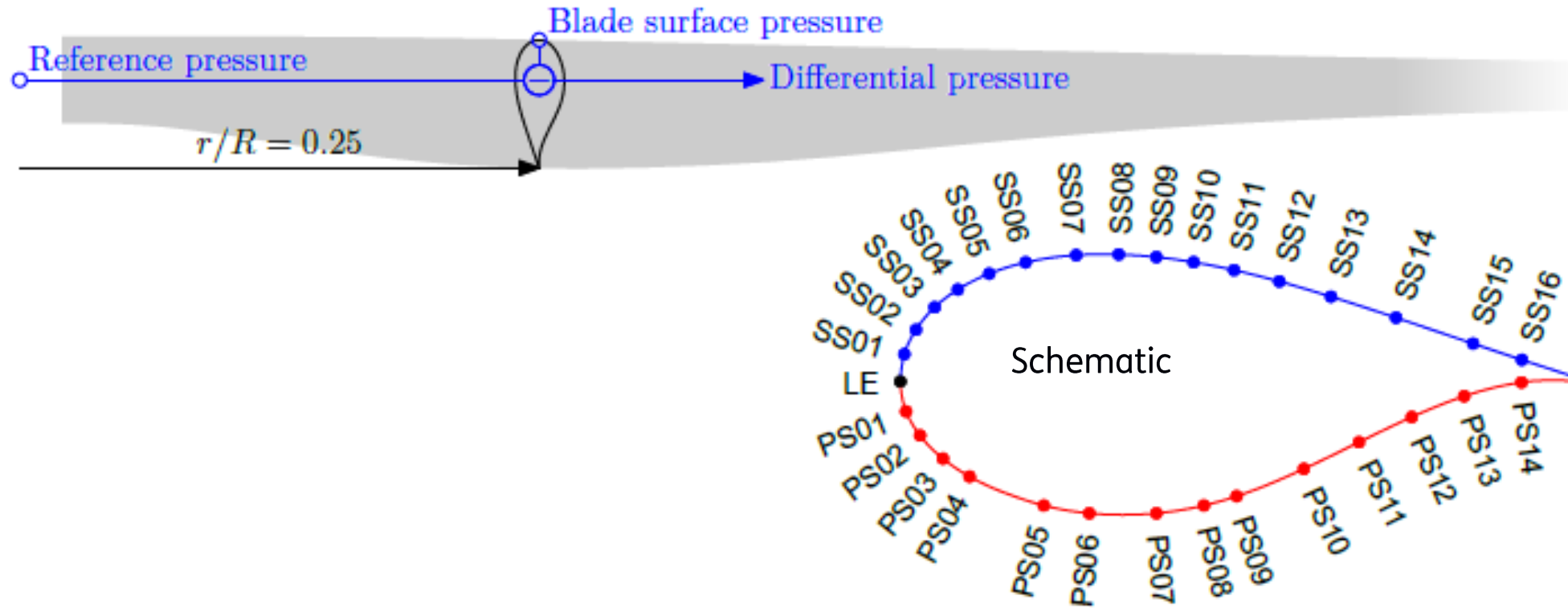
Response spectra at 5 and 55 degree angle of attack



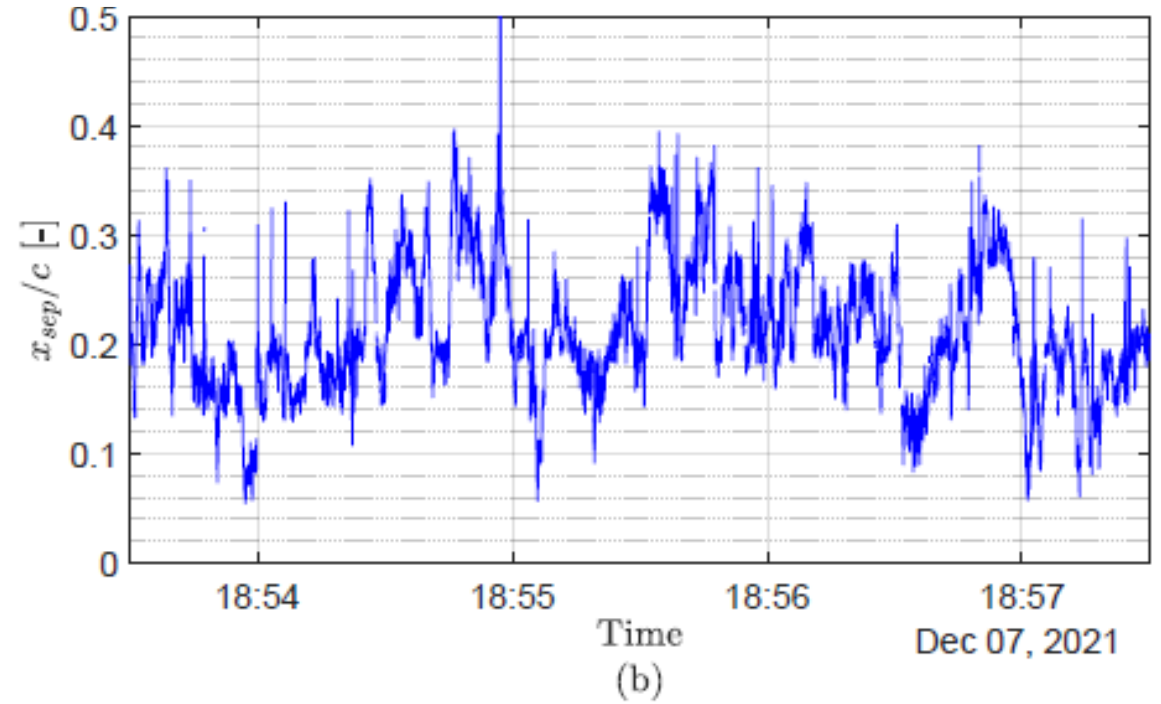
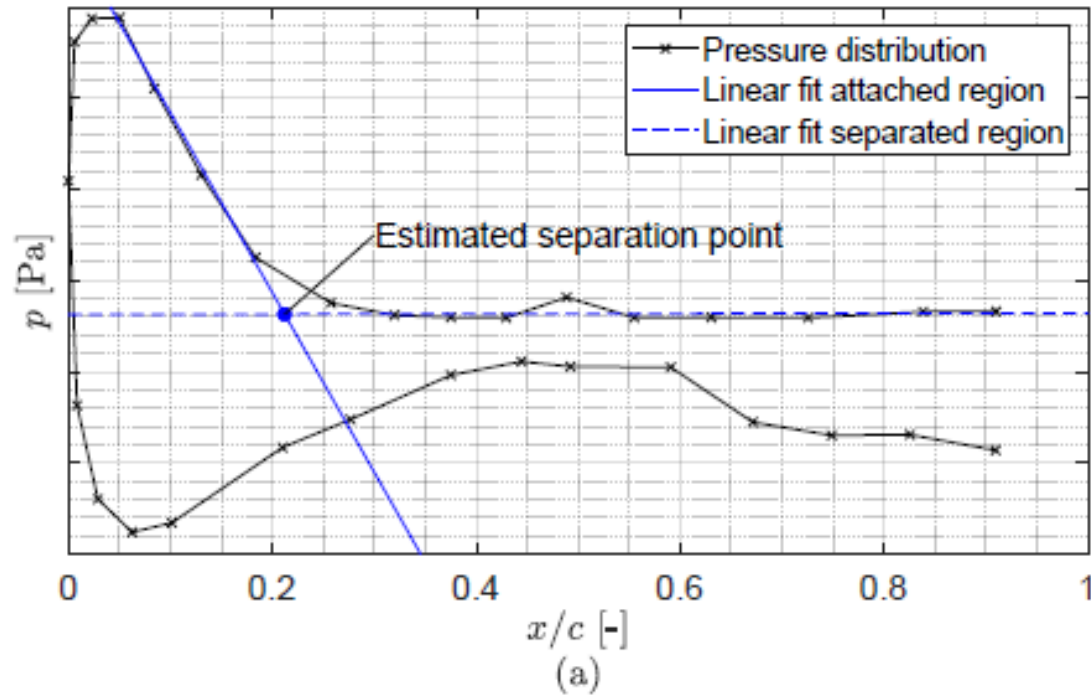
Excitation and pressure measurement



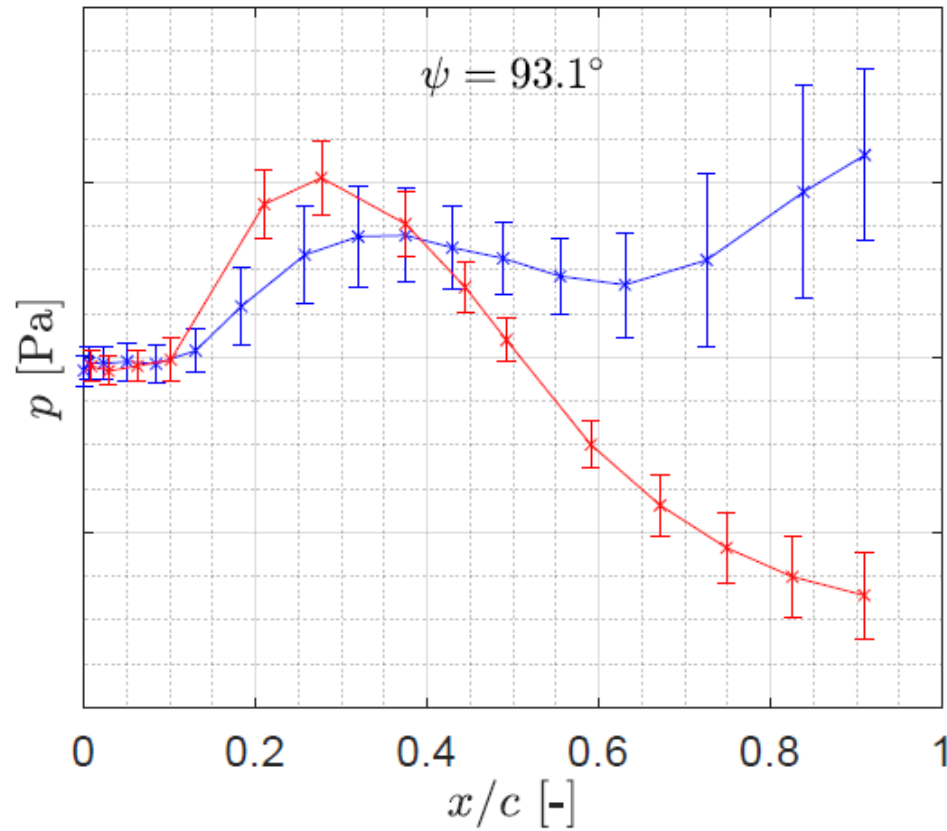
Test set-up



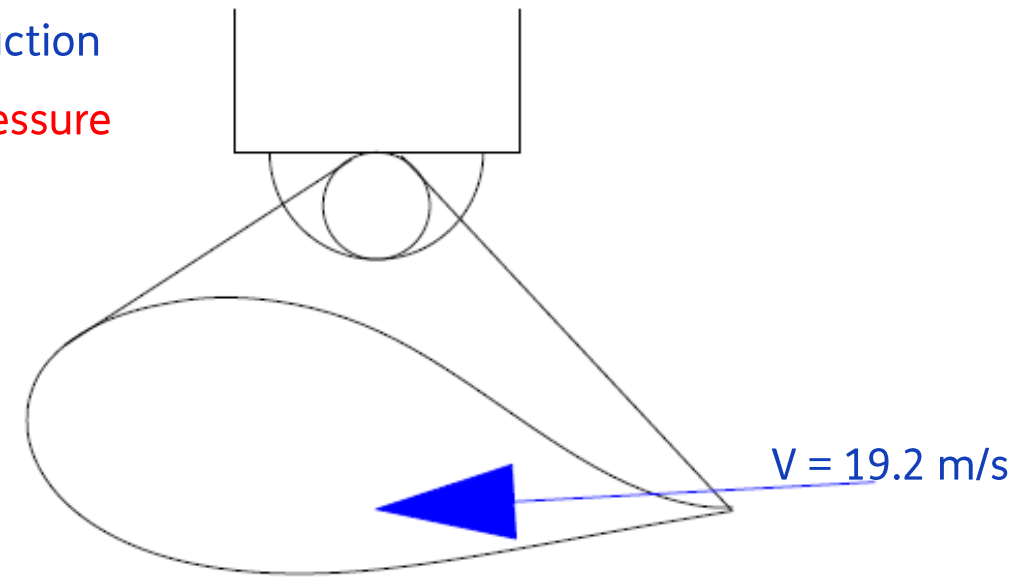
Separation point determination



Mean pressure distributions case 9

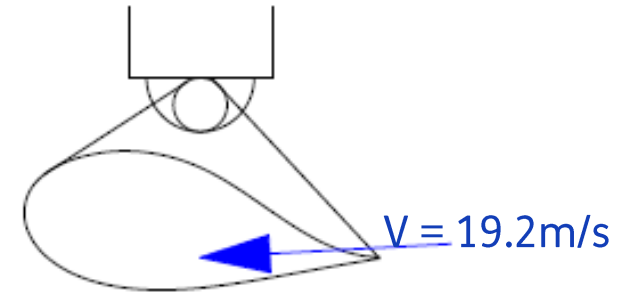
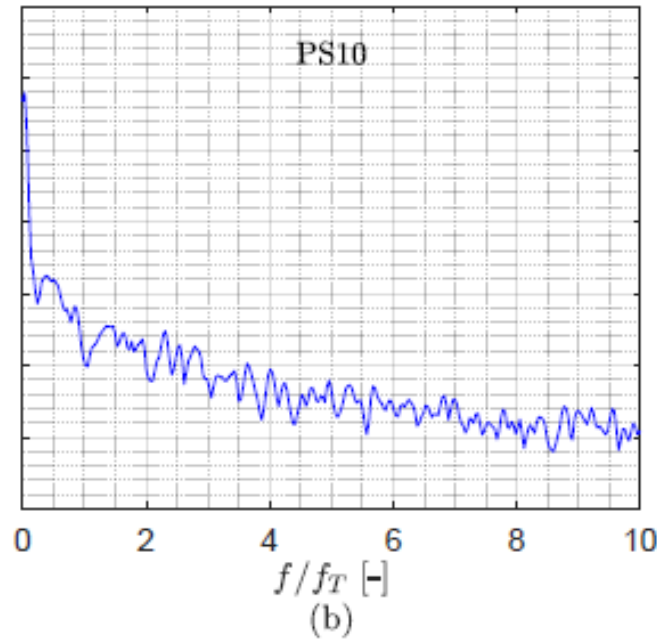
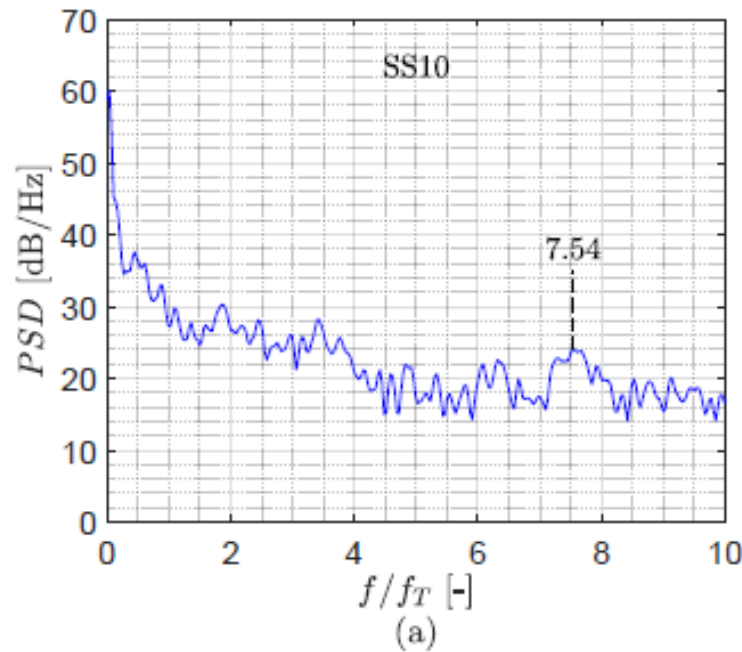


Blue: suction
Red: pressure



Incoming wind at “trailing edge”.

Power spectral density of pressure sensors SS10 (a) and PS10 (b) case 9



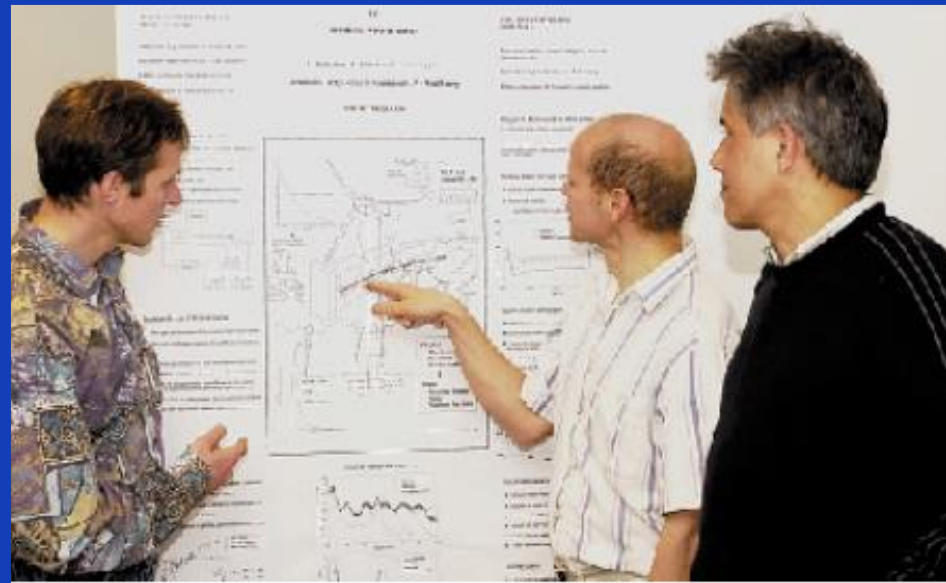
$$St = 0.16 \rightarrow f_{exp}/f_T = 7.63$$

$$St = 0.20 \rightarrow f_{exp}/f_T = 9.54$$

(c)

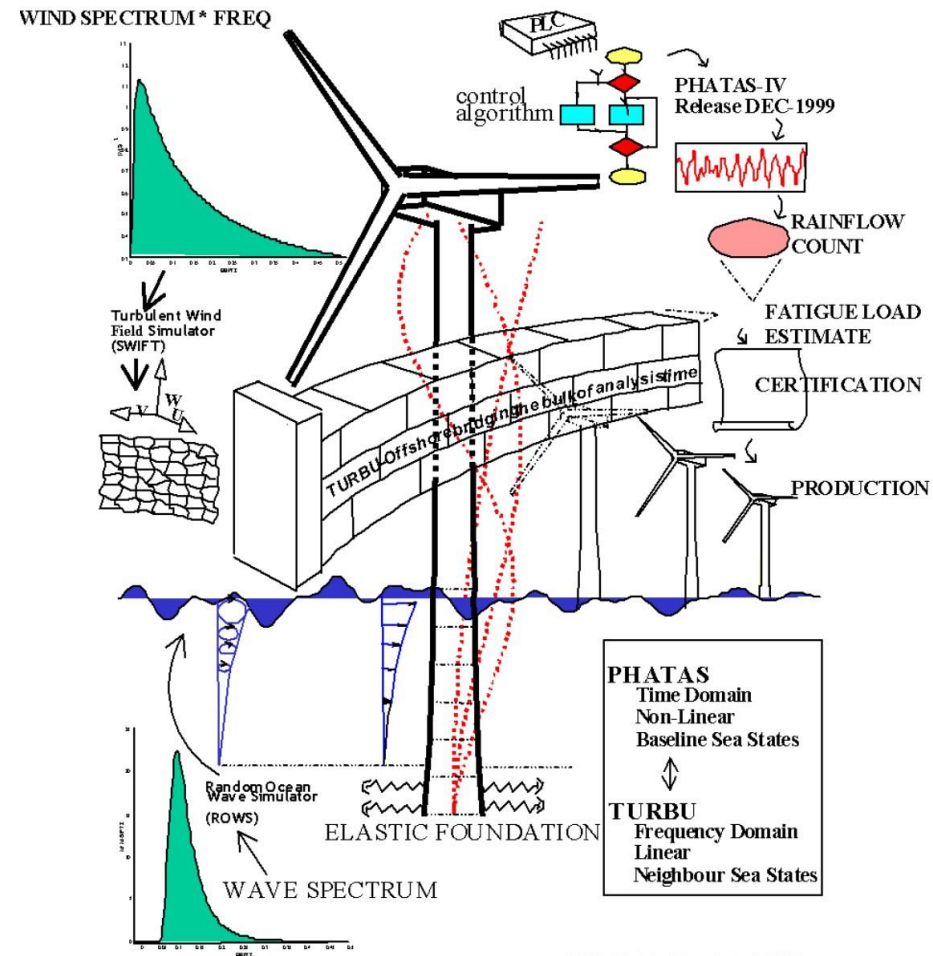
2nd tower mode visible. No vortex induced vibrations observed.

Simulations



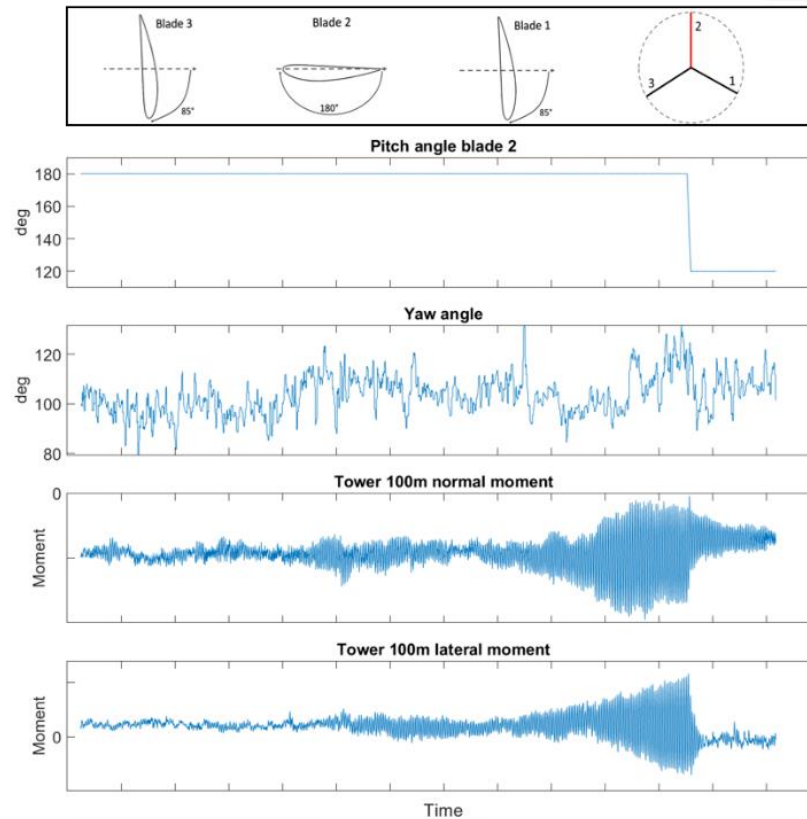
Design codes Turbu and Phatas

- Wind & waves
- Elastic foundation
- Tower
- Nacelle
- Rotor
- Control
- Fatigue and ultimate loads

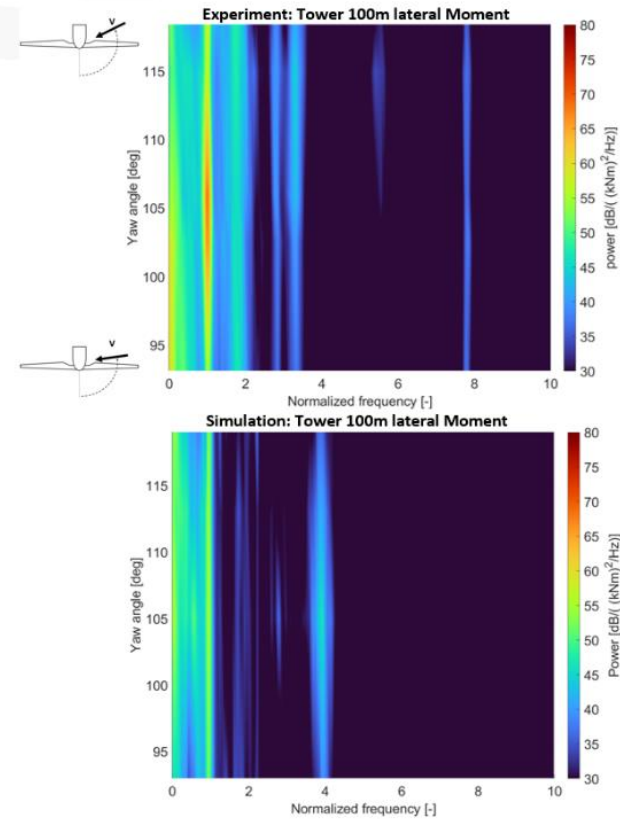


Source: Koert Lindenburg and Tim van Engelen

Validation of models



(a) Time series of standstill vibrations



(b) Visualization of measured (above) and simulated (below) spectra for the yaw traverse

Turbu model

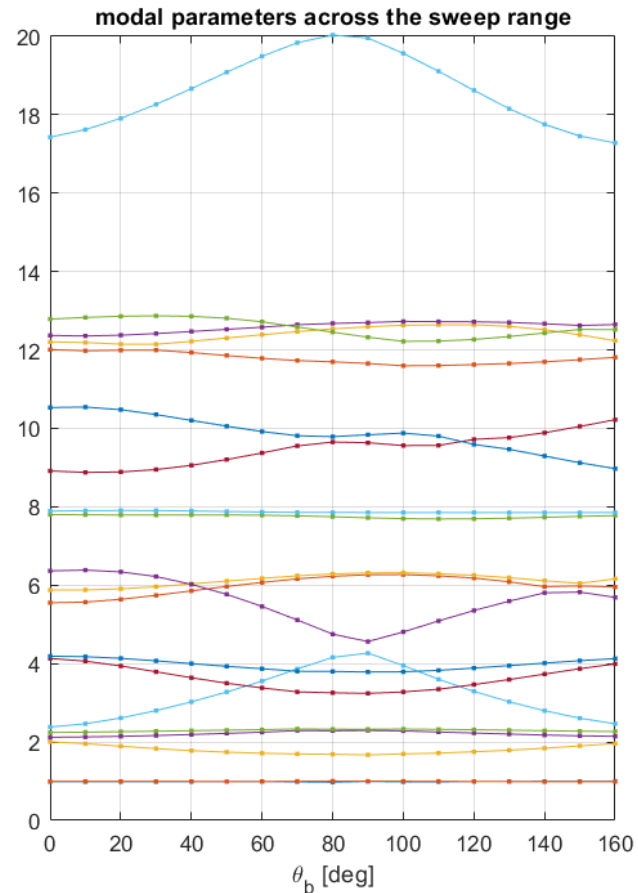
- Linear frequency and time domain analysis of 3-bladed Horizontal Axis WTs
- Full non-linear steady state model (multi-body average deformation)
- Time-invariant linear dynamic model (multi-body, Newton, Coleman)
- Dynamic wake, unsteady aerodynamics
- Reduced order blade and tower models (Hurty [Craig-Bampton])

Turbu analyses

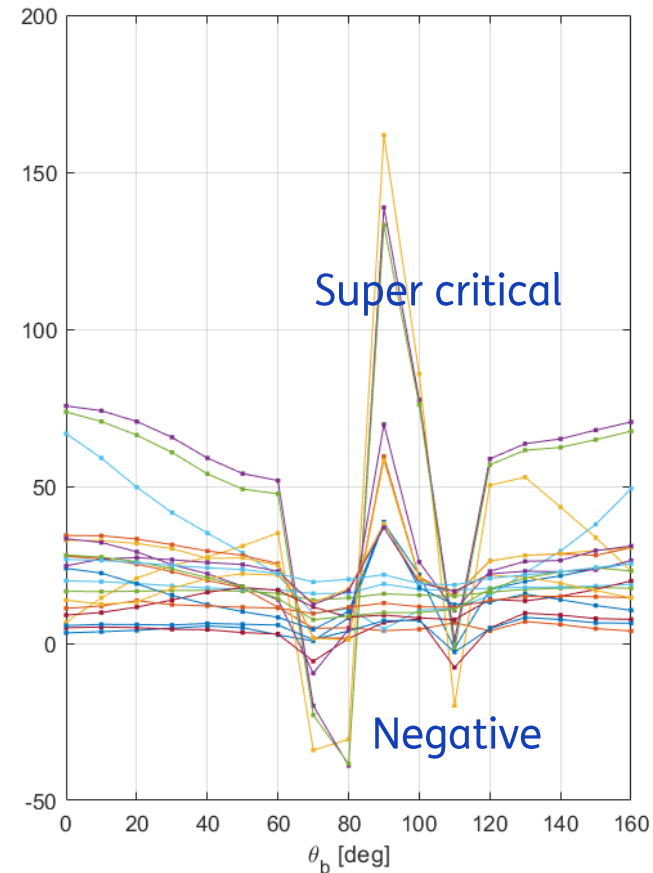
- Aeroelastic stability analysis
- Control design
- Frequency domain load calculations

Pitch sweep modal parameters

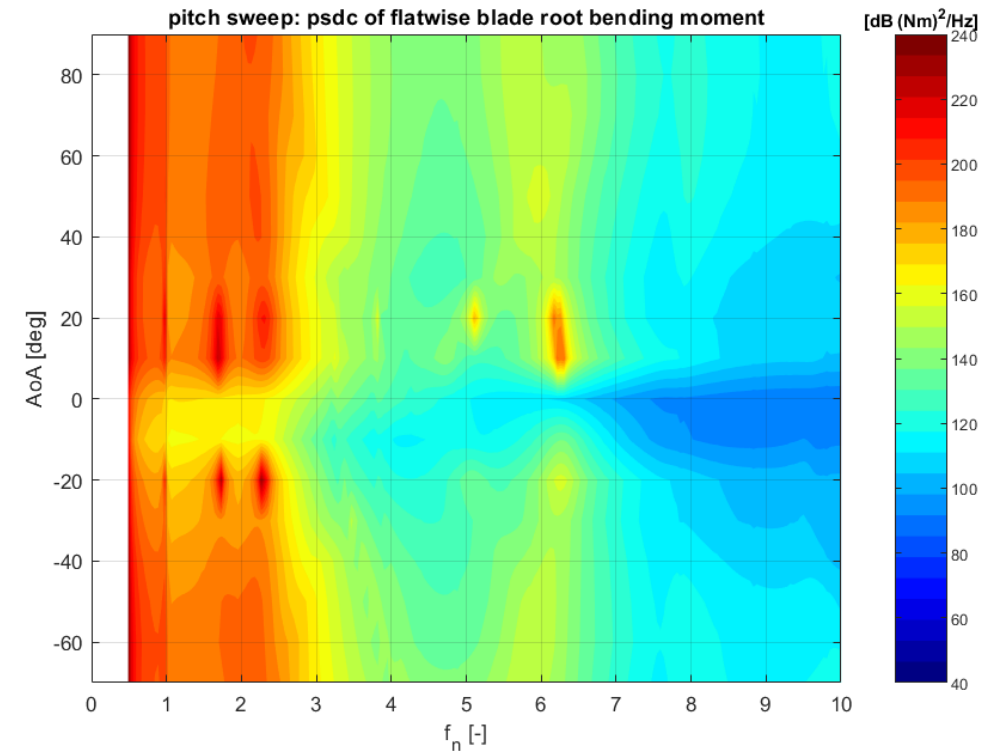
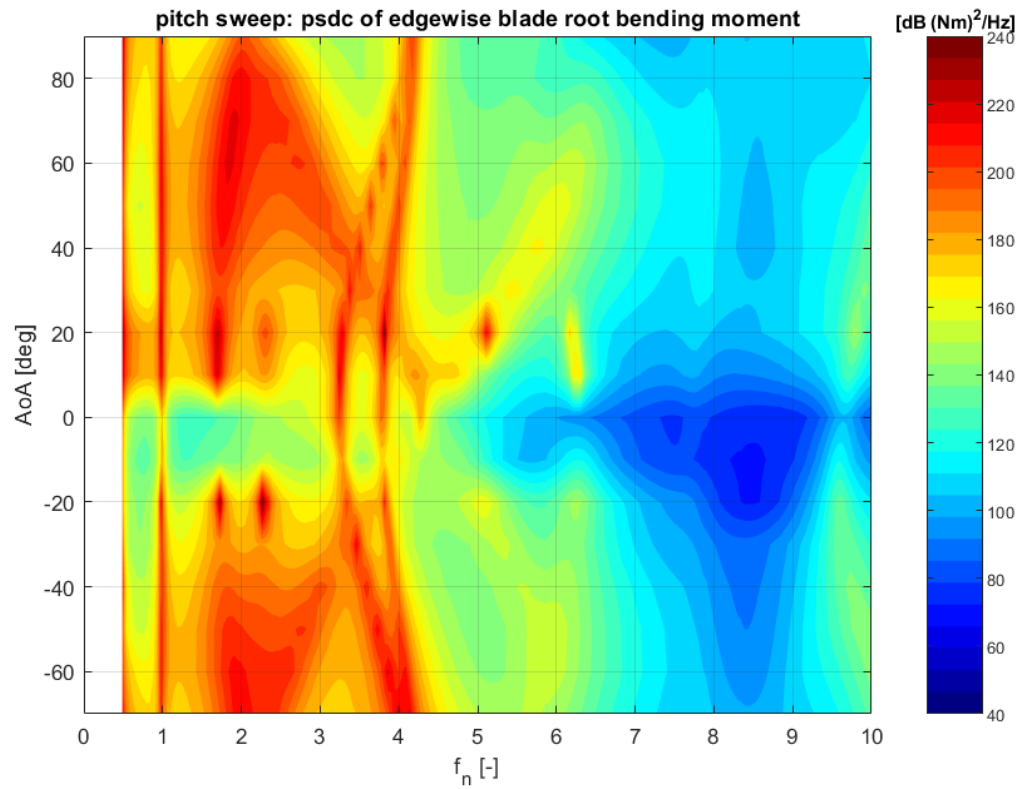
Non dimensional frequency



Damping



Power spectral density contour all blades pitched in Turbu!



Conclusions and future research

Conclusions

- The experimental data from the TIADE field campaign, including unique pressure measurements, are a valuable source.
- **Measurements:**
 - The pitch and yaw traverse are well suited to extract many relevant vibration frequencies of the turbine.
 - Severe vibrations are observed.
 - Analyzing the spectra of the pressure sensors and that of the derived separation point do not indicate the presence of a dominant vortex shedding frequency.
- **Simulations:**
 - The predicted response under realistic conditions shows similar trends as observed from the measurements.



Future research

- The industry needs more robust, validated design methods and engineering models to take these vibrations into account.
- More pressure sensor in different locations along the blade.
- Pitch multiple blades.
- We need to better understand these vibrations at stand still and idling and their potential causes.
- A dedicated wind tunnel test in controlled environment is proposed to accelerate on these topics.