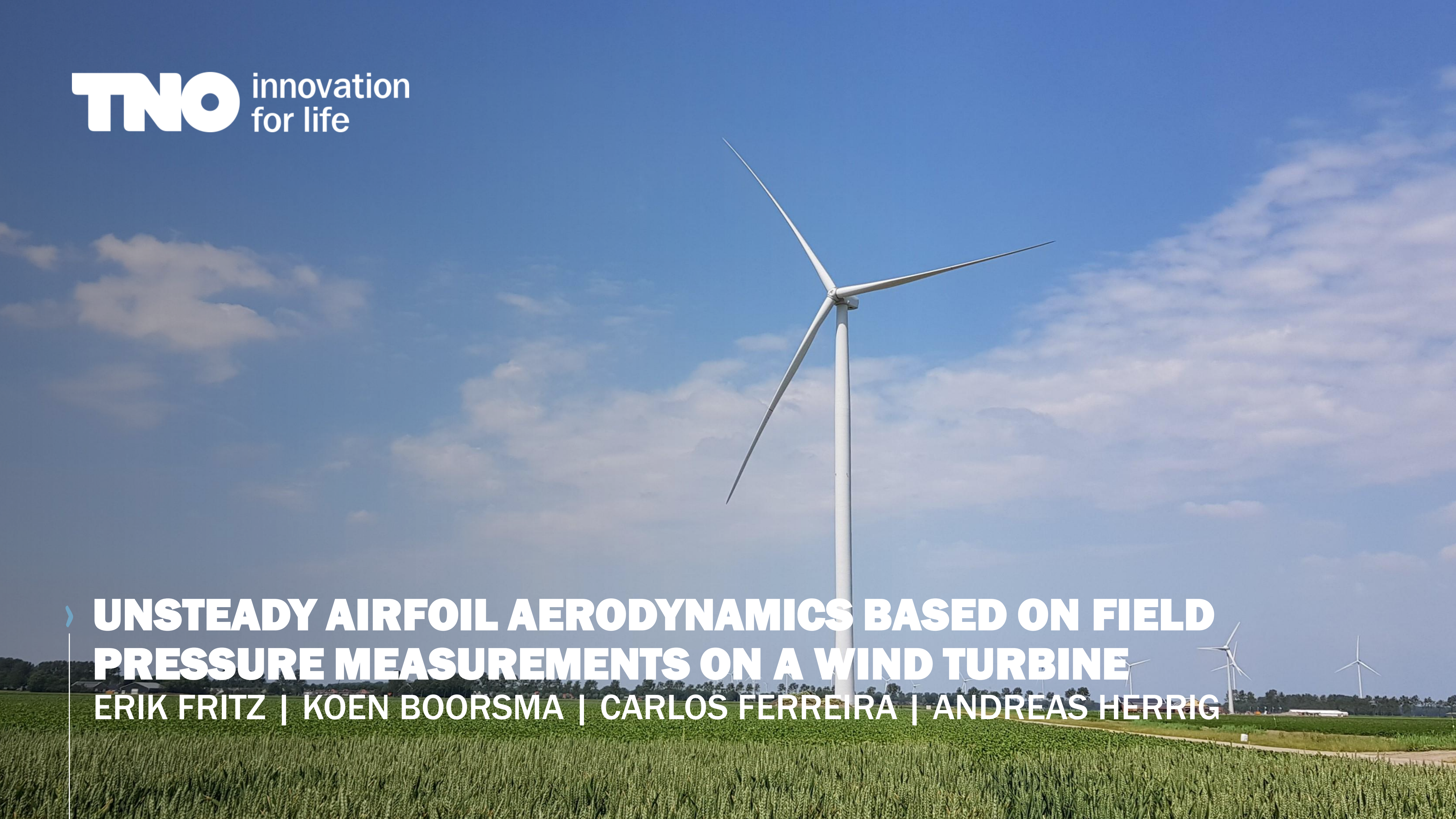
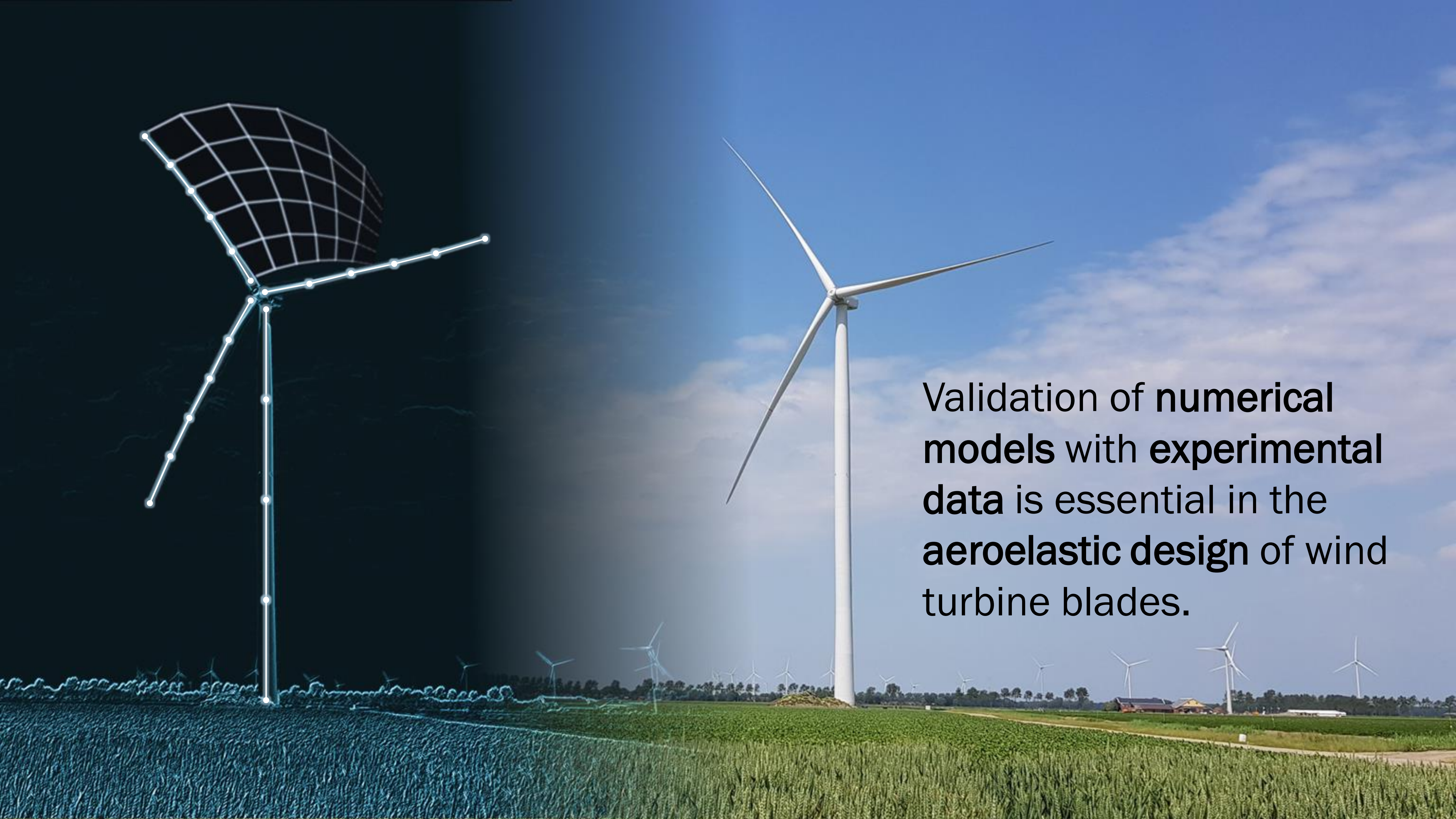


TNO innovation for life

UNSTEADY AIRFOIL AERODYNAMICS BASED ON FIELD PRESSURE MEASUREMENTS ON A WIND TURBINE

ERIK FRITZ | KOEN BOORSMA | CARLOS FERREIRA | ANDREAS HERRIG


Validation of numerical models with experimental data is essential in the aeroelastic design of wind turbine blades.

OVERVIEW

Experimental setup

Numerical simulations

Results

Takeaways

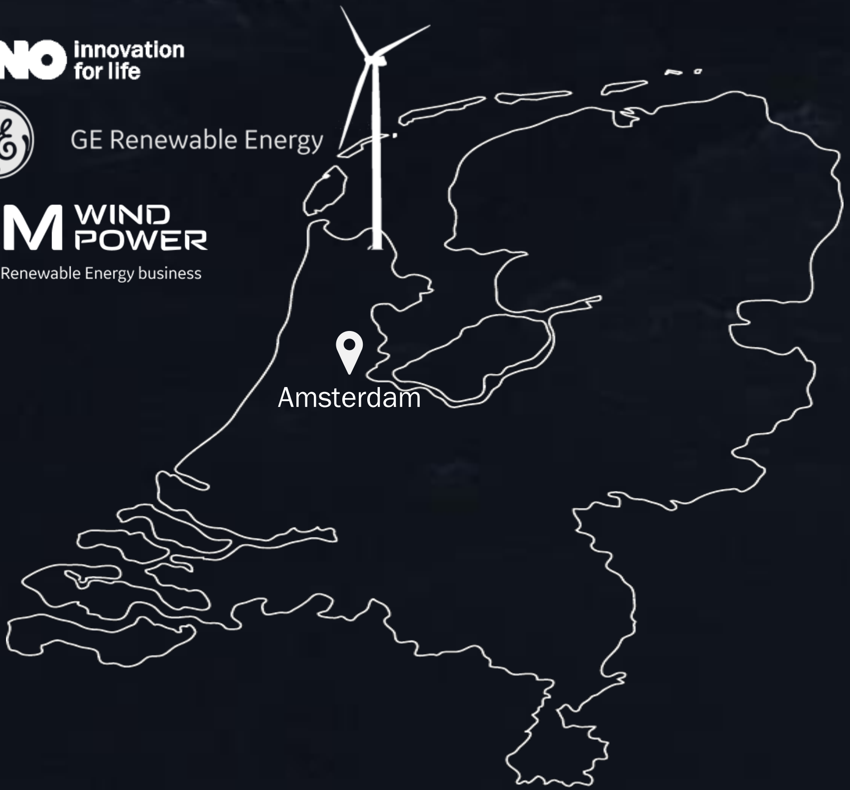
EXPERIMENTAL SETUP
PROJECT OVERVIEW

TIADE (Turbine Improvements for Additional Energy)

TNO innovation for life

GE Renewable Energy

LM WIND POWER
a GE Renewable Energy business



Scope of TIADE project:

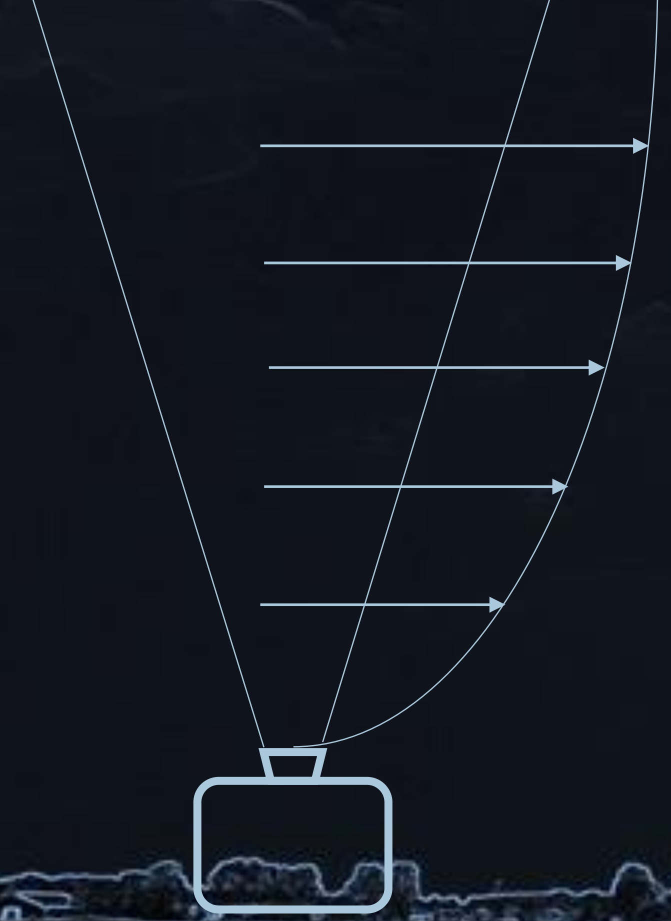
- Blade improvement (innovative tip shapes, VGs, turbulator)
- Validation (erosion, yawed inflow, stall and/or vortex induced vibrations)
- Measurement innovations (aerodynamic pressure, torsion deformation, fibre optics)

Scope of PhD:

- Development of an aeroelastically tailored tip
- Numerical aeroelastic simulations & comparison to field data

EXPERIMENTAL SETUP
DATA ACQUISITION

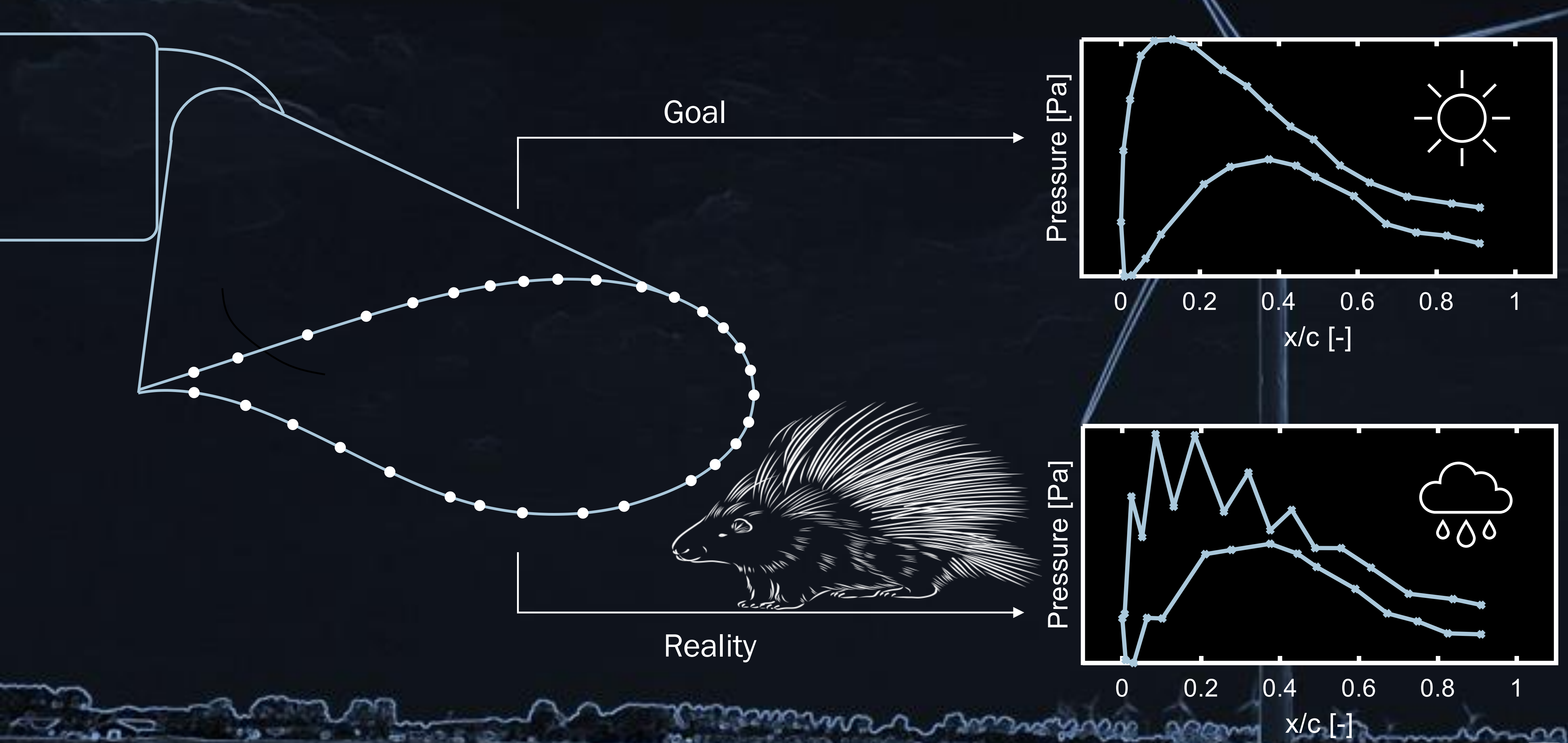
- A LiDAR system is used to measure the wind field



- The blade is equipped with pressure sensors at about 25% of the blade radius

- Operational conditions are monitored
  - Power
  - Rotational speed
  - Rotor azimuth
  - Blade pitch
  - ...

EXPERIMENTAL SETUP
CHALLENGES



NUMERICAL SIMULATIONS
SIMULATION TOOLS (1/2)

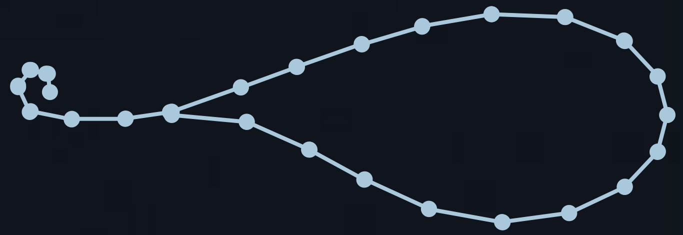
Input:
- Aerodynamic and structural turbine model
- Operating conditions

Output:
- Power, thrust
- Blade aerodynamics, moments and deformations

- **Phatas**
  - BEM
  - Structural solver

Input:
- Airfoil geometry
- Reynolds number, Angle of attack, c/r value

Output:
- Airfoil polars: c_d, c_l, c_m
- Pressure coefficient distribution



- **RFOIL**
  - 2D panel method
  - Based on XFOIL
  - Modified for rotating airfoils

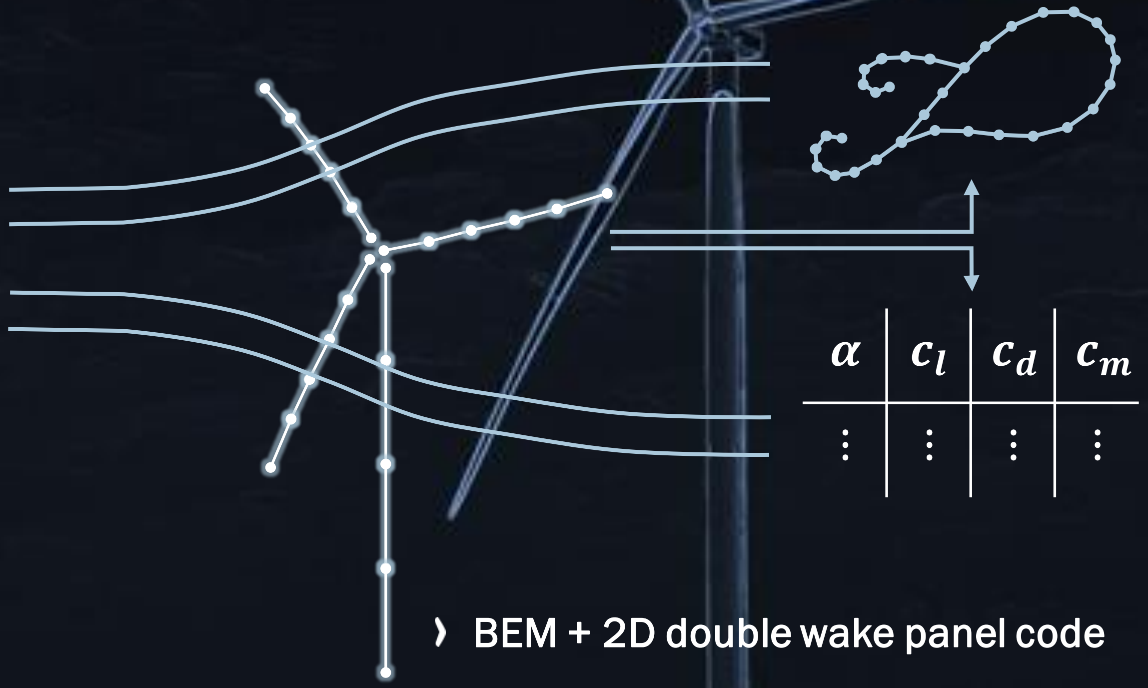
NUMERICAL SIMULATIONS
SIMULATION TOOLS (2/2)

Input:

- Aerodynamic and structural turbine model
- Airfoil geometry
- Operating conditions

Output:

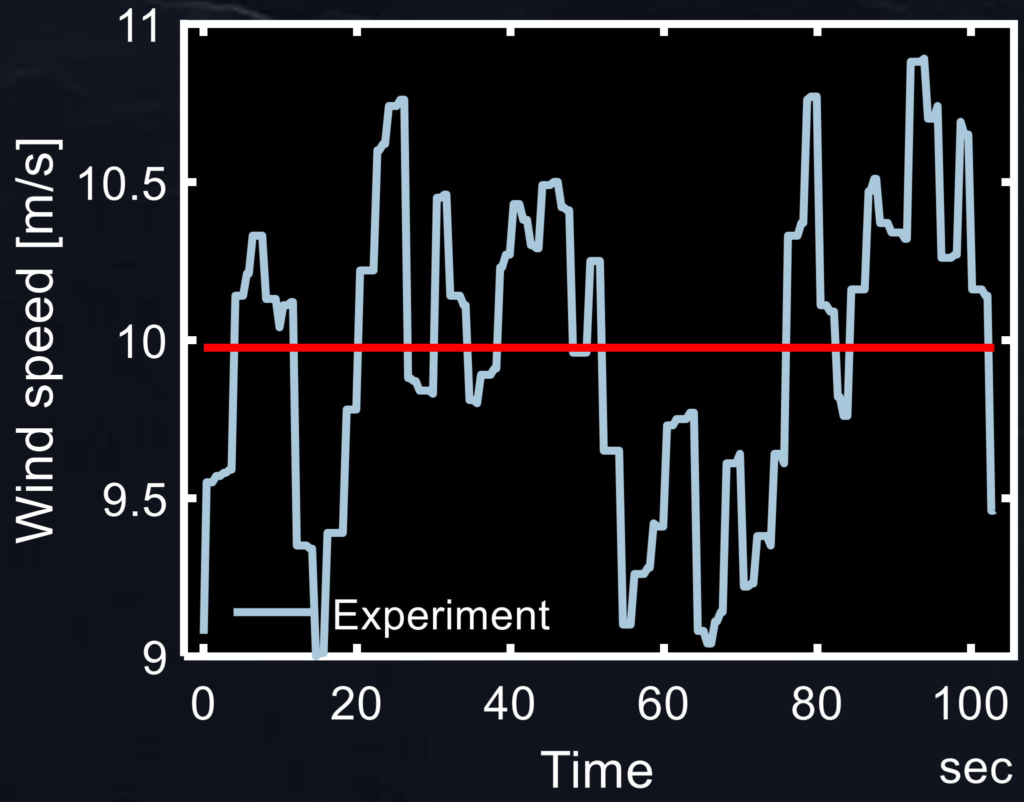
- Power, thrust
- Blade aerodynamics, moments and deformations
- Unsteady pressure distributions

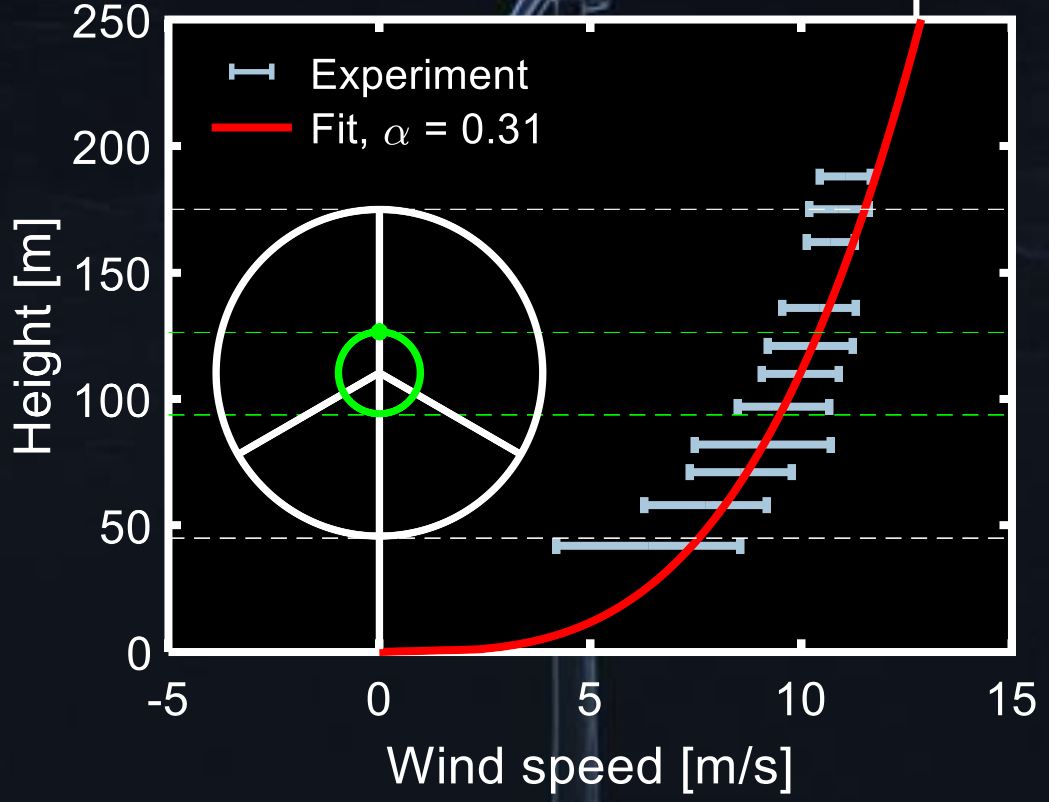


- **BEM + 2D double wake panel code**
  - Regular BEM algorithm
  - Locally, lookup table can be replaced by 2d double wake panel method

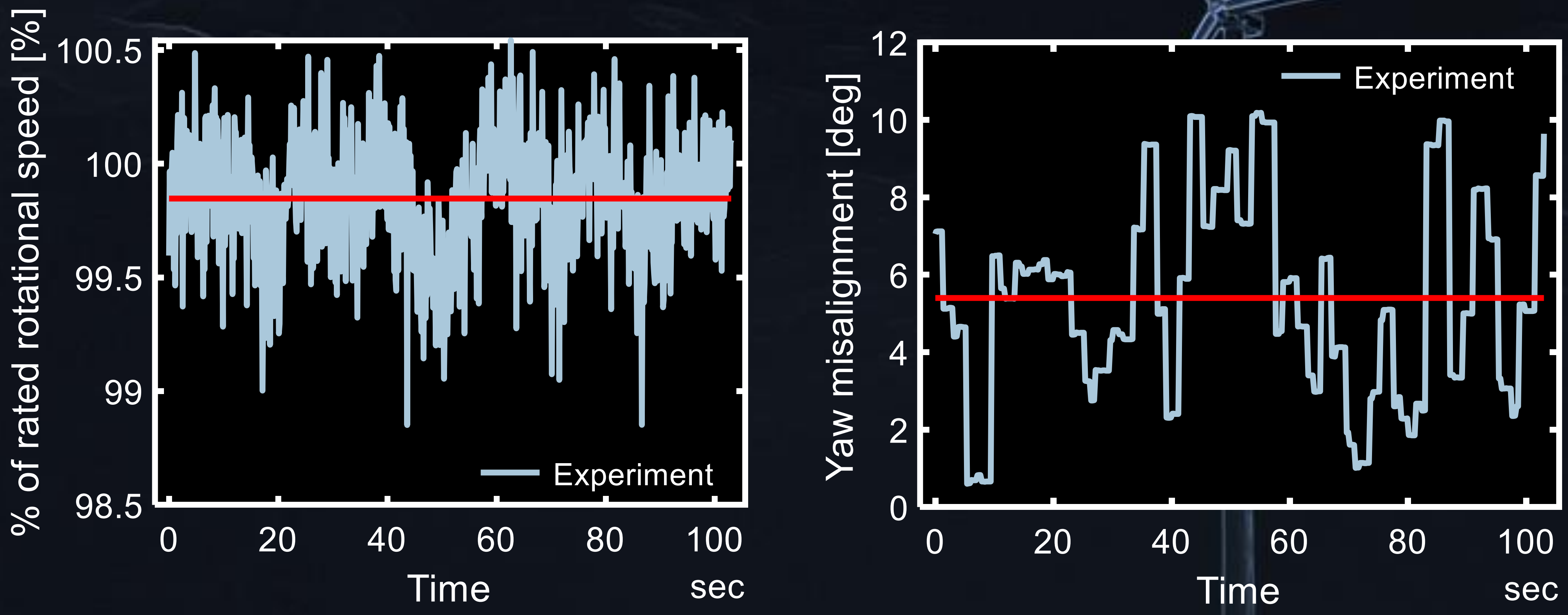
RESULTS
OPERATING CONDITIONS (1/2)

$$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha}$$



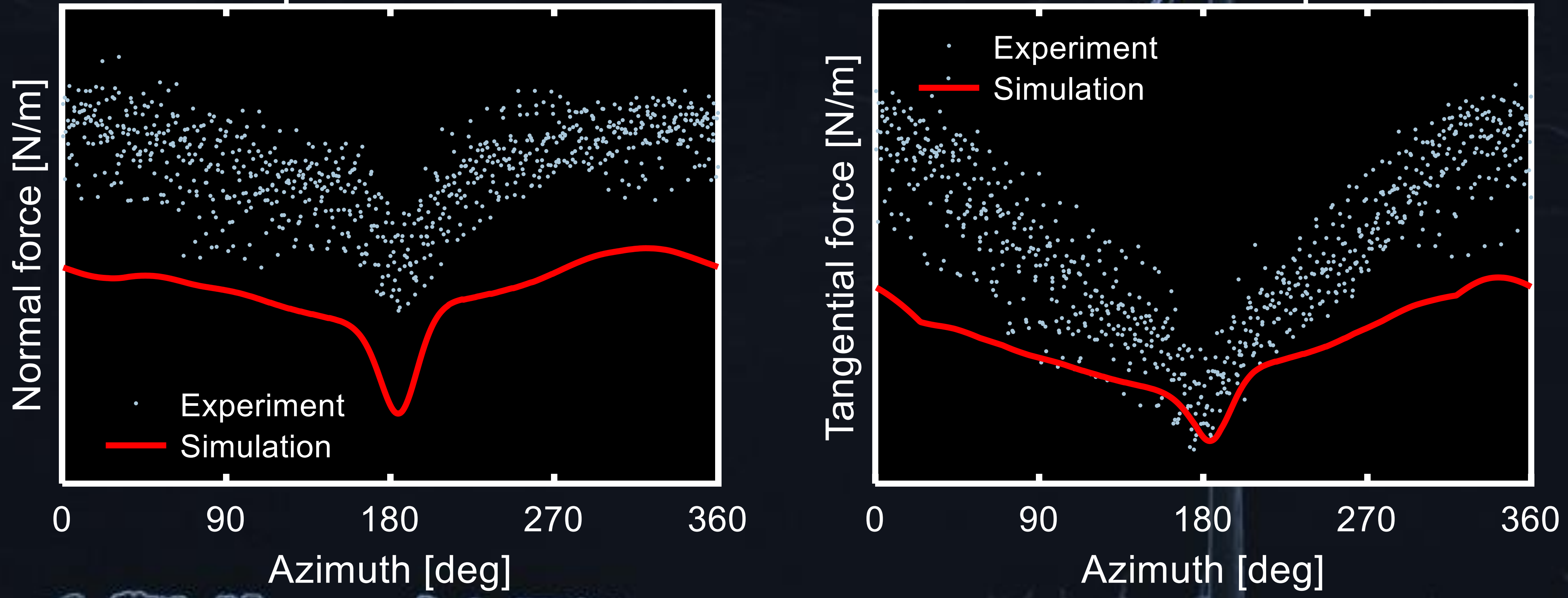


RESULTS
OPERATING CONDITIONS (2/2)

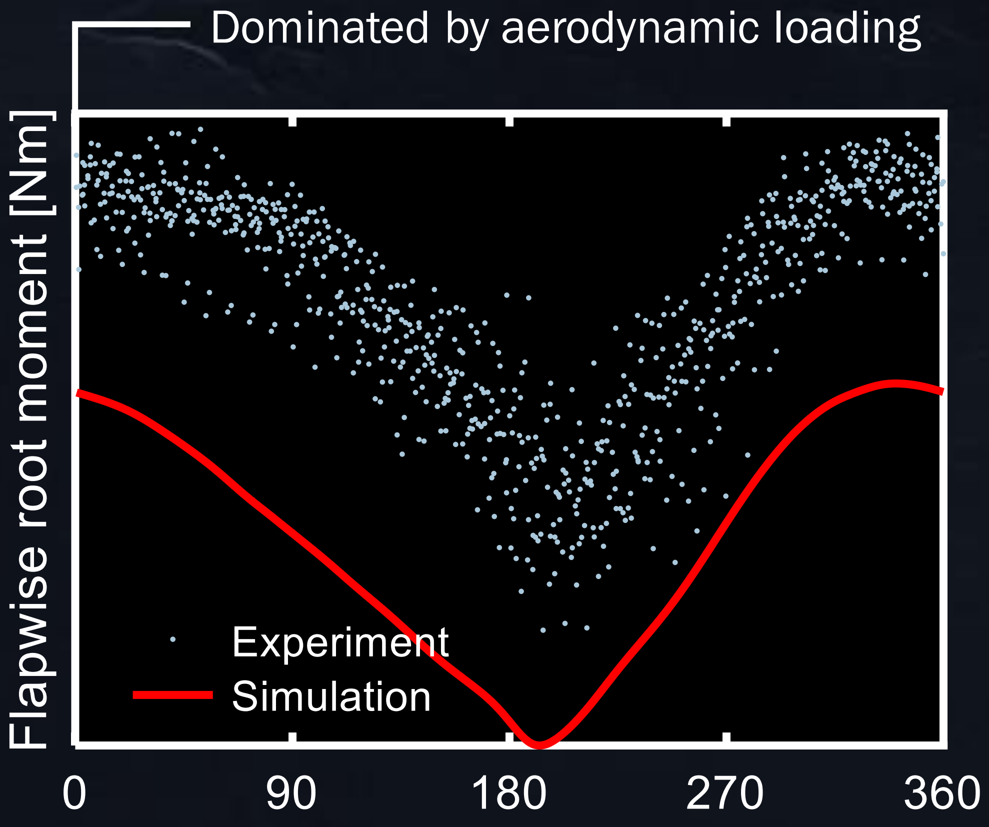


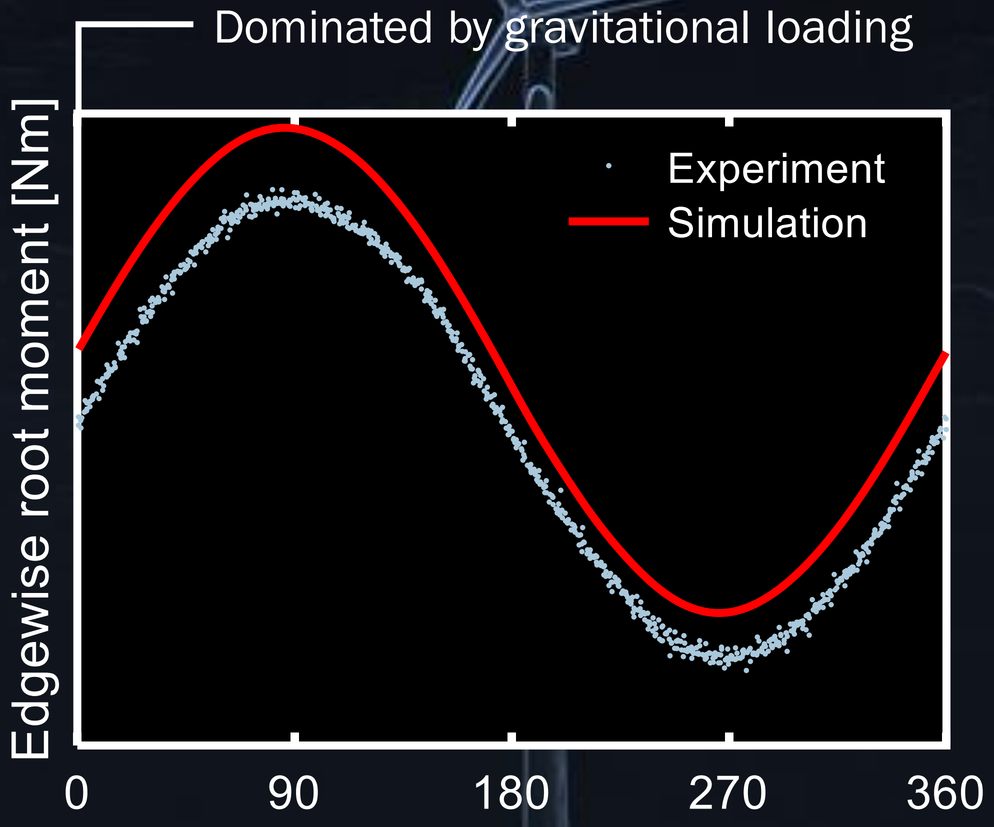
RESULTS
SECTIONAL FORCES

Effect of wind shear and of the tower passage visible

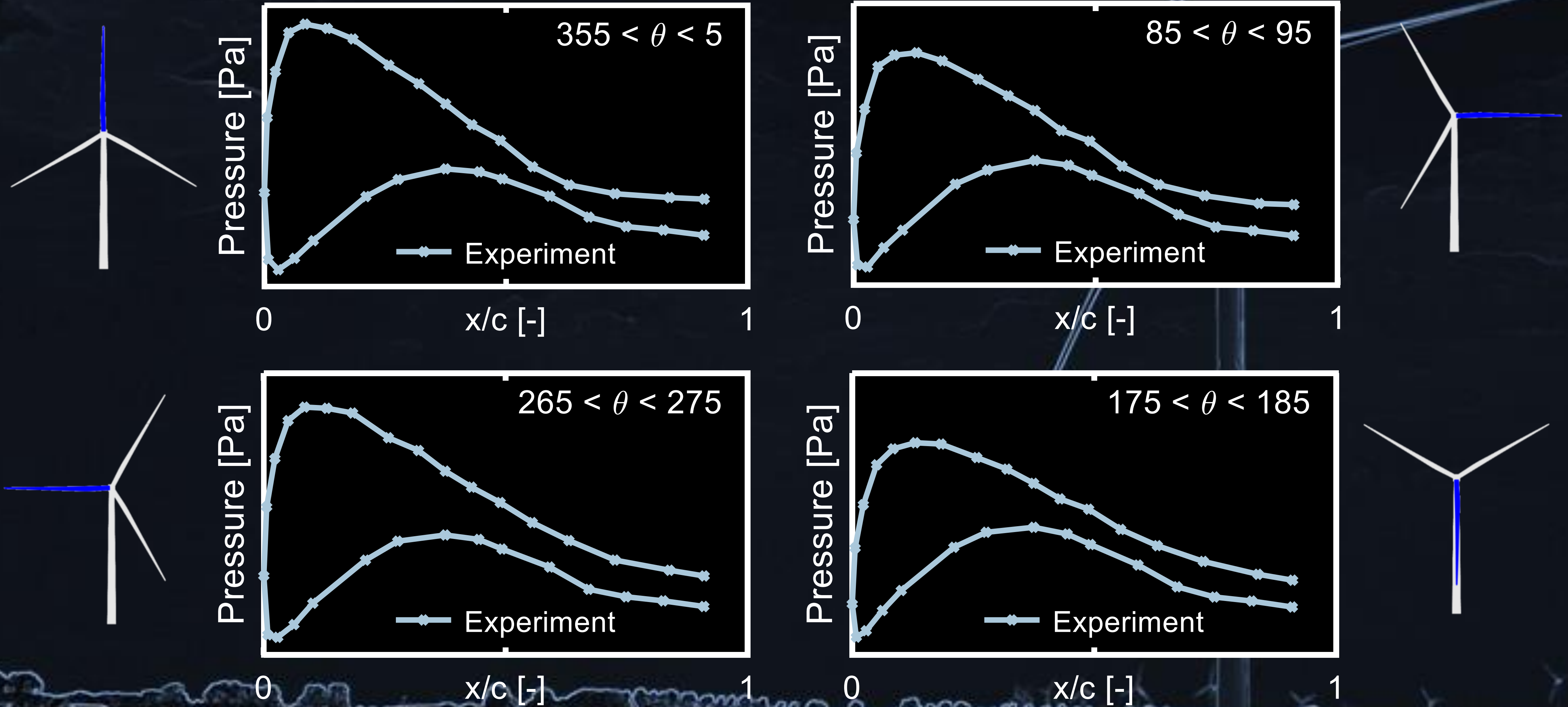


RESULTS
BLADE ROOT BENDING MOMENTS





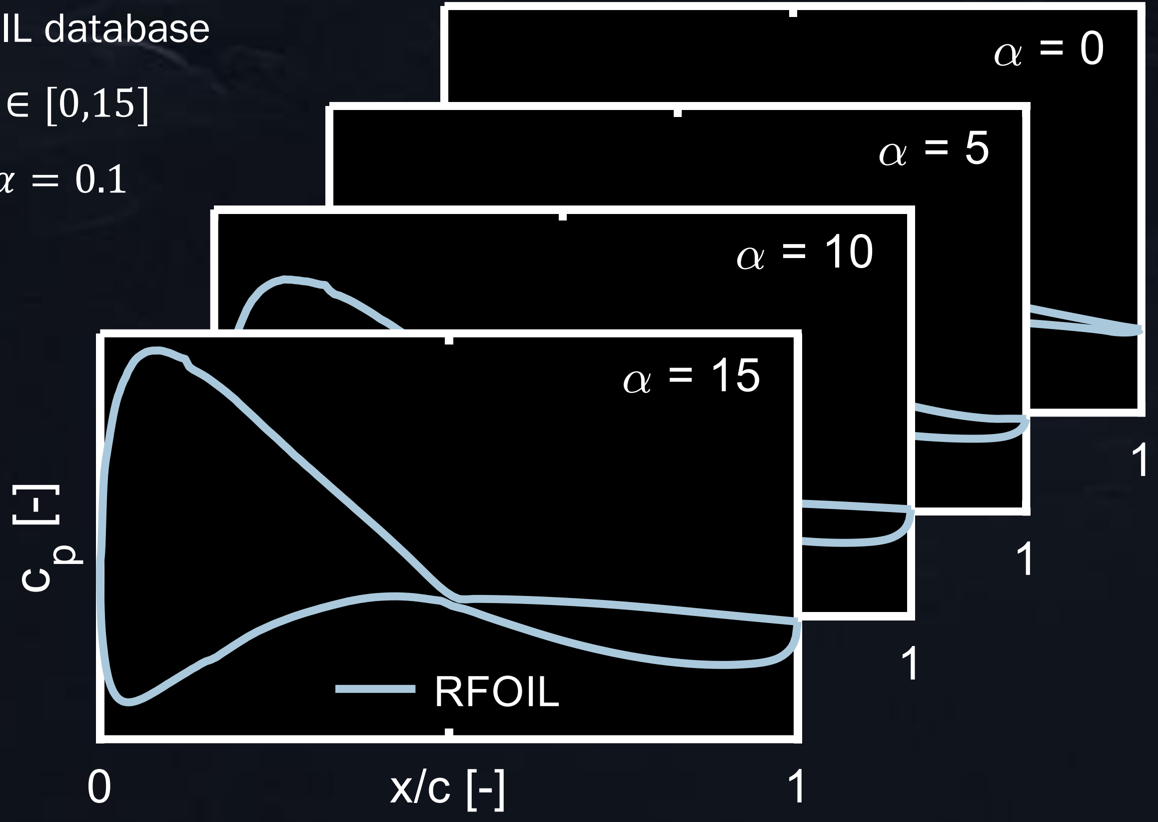
RESULTS
PRESSURE VARIATION DURING ONE ROTATION

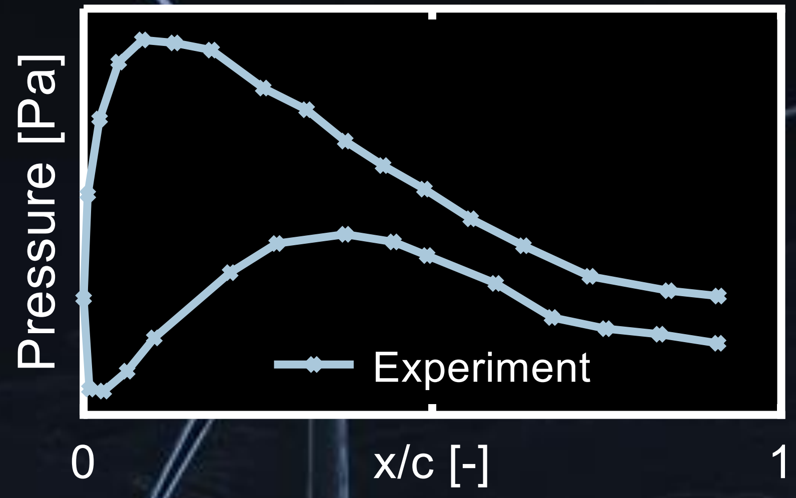


RESULTS

ANGLE OF ATTACK ESTIMATION

- RFOIL database
  - $\alpha \in [0,15]$
  - $\Delta\alpha = 0.1$

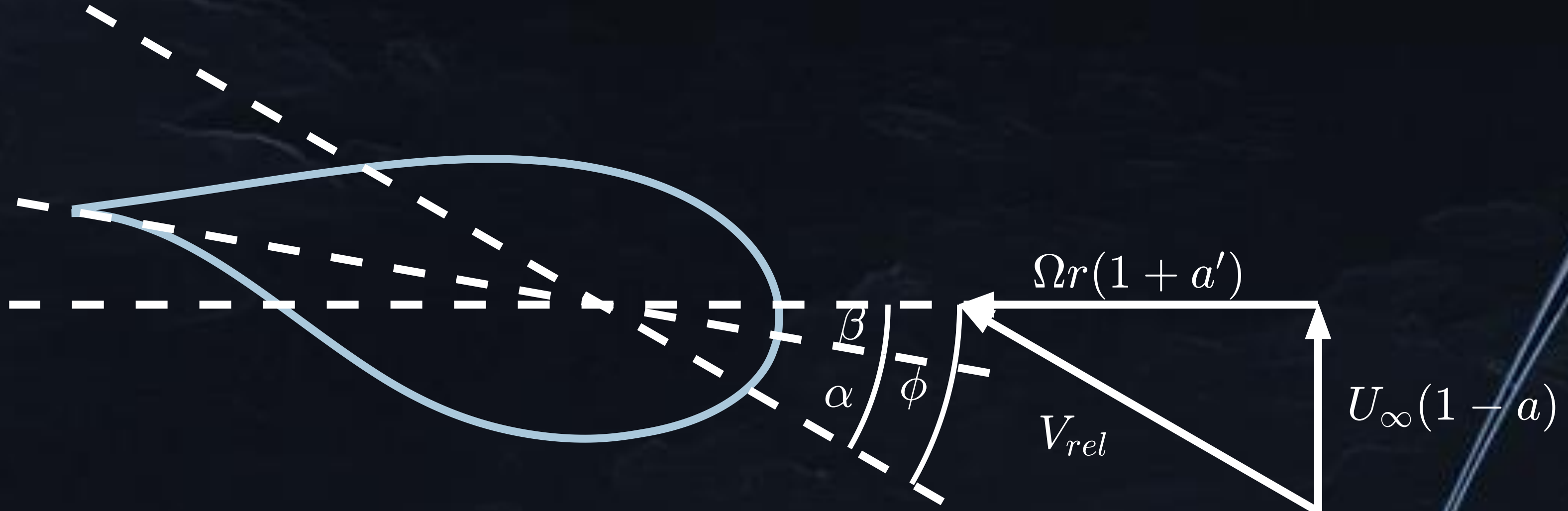




Pattern matching

Angle of attack estimation

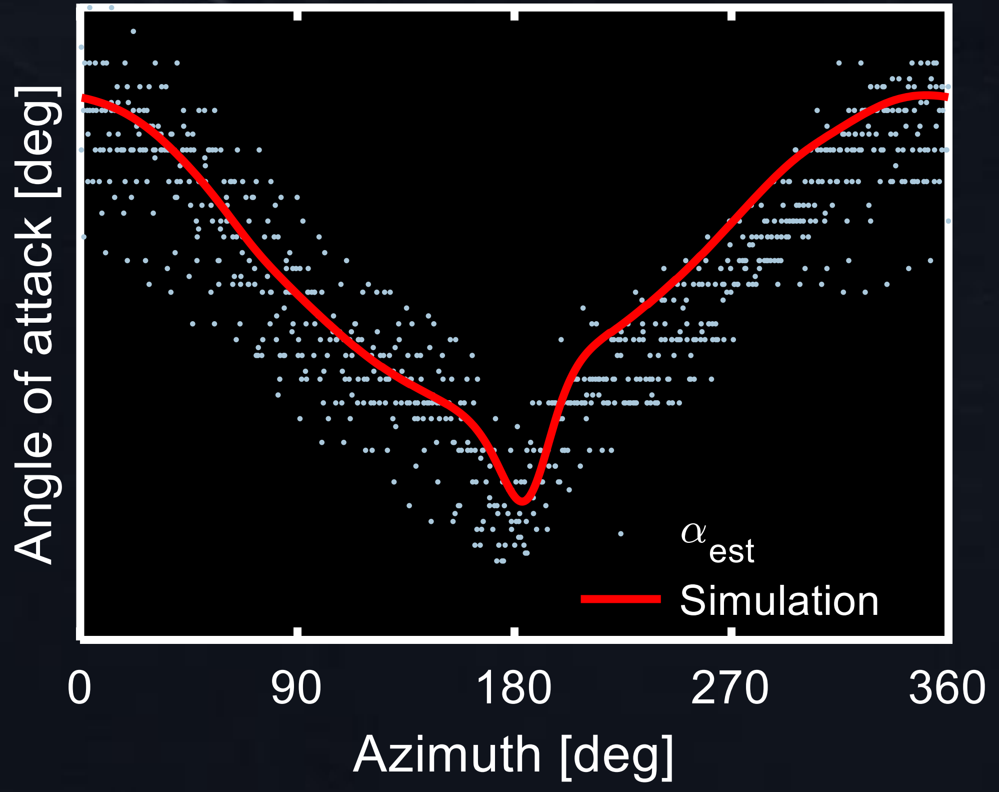
RESULTS
RELATIVE VELOCITY ESTIMATION

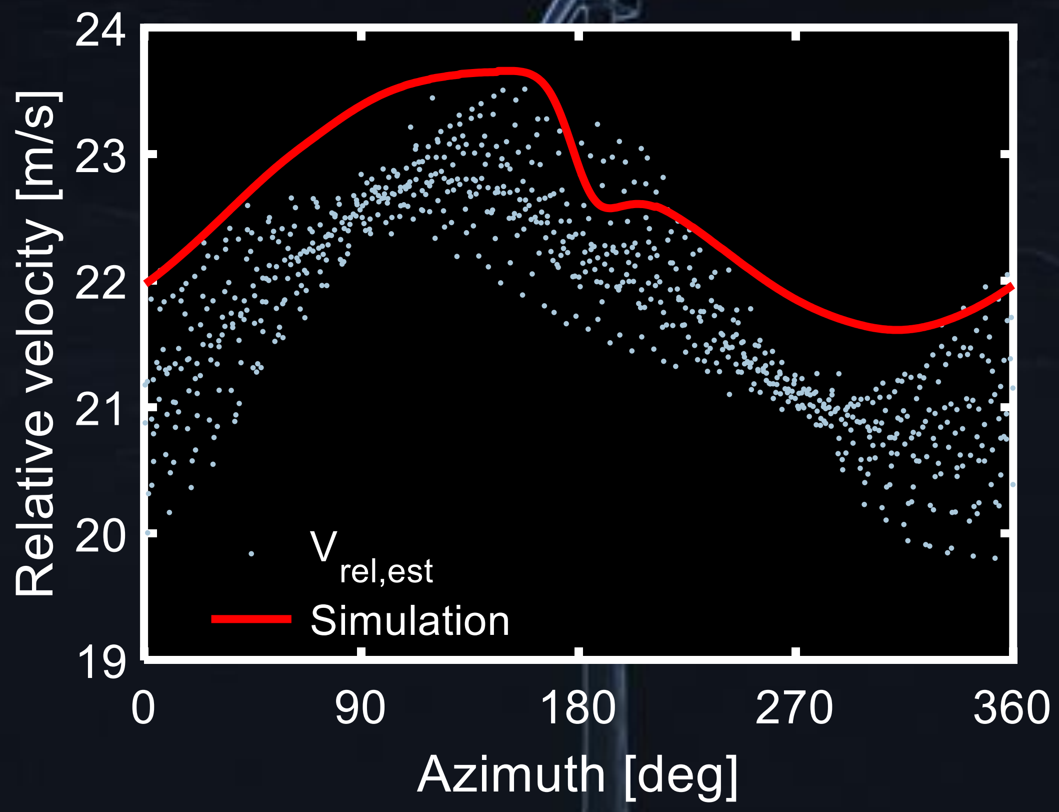


Angle of attack	α	✓
Pitch and twist angle	β	✓
Inflow angle	ϕ	✓
Rotational velocity	Ωr	✓
Free stream velocity	U_∞	✓
Axial induction factor	a	✓
Tangential induction factor	a'	
Relative velocity	V_{rel}	✓

- $\phi = \alpha + \beta$
- $U_\infty(1-a) = \Omega r(1+a')\tan\phi \approx \Omega r \tan\phi$
- $V_{rel} = \sqrt{\left(U_\infty(1-a)\right)^2 + (\Omega r)^2}$

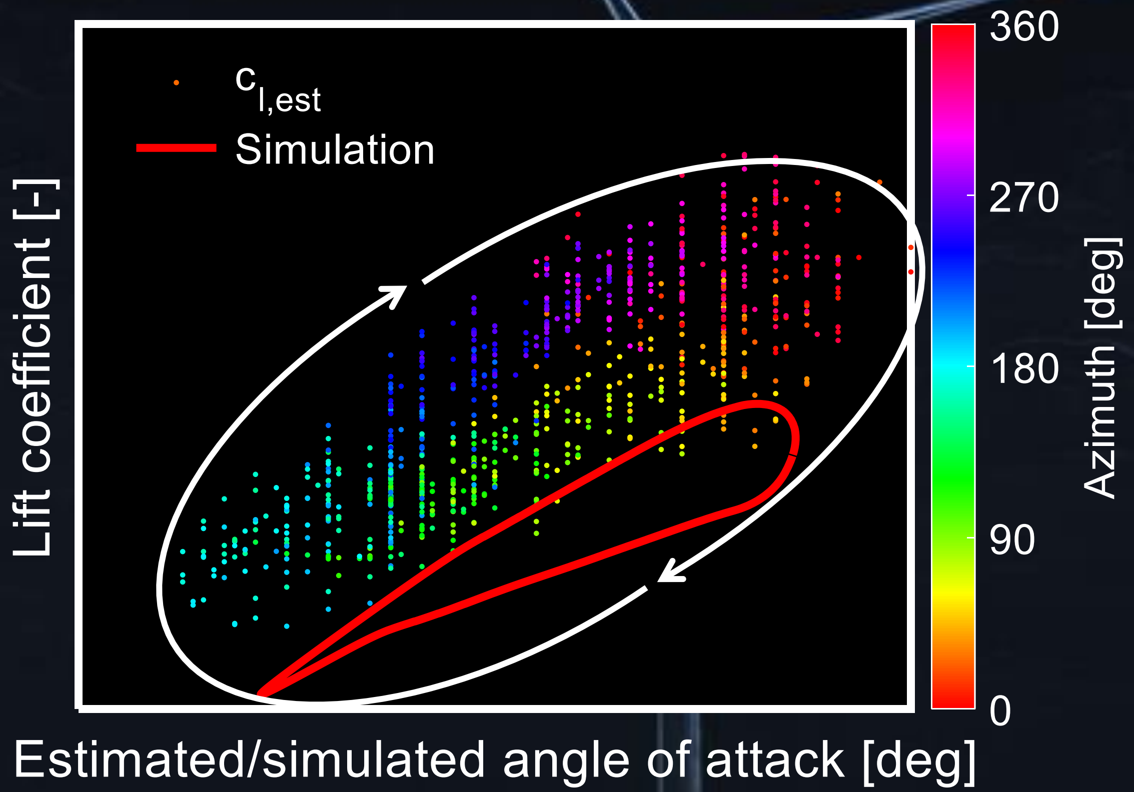
RESULTS
ANGLE OF ATTACK AND RELATIVE VELOCITY



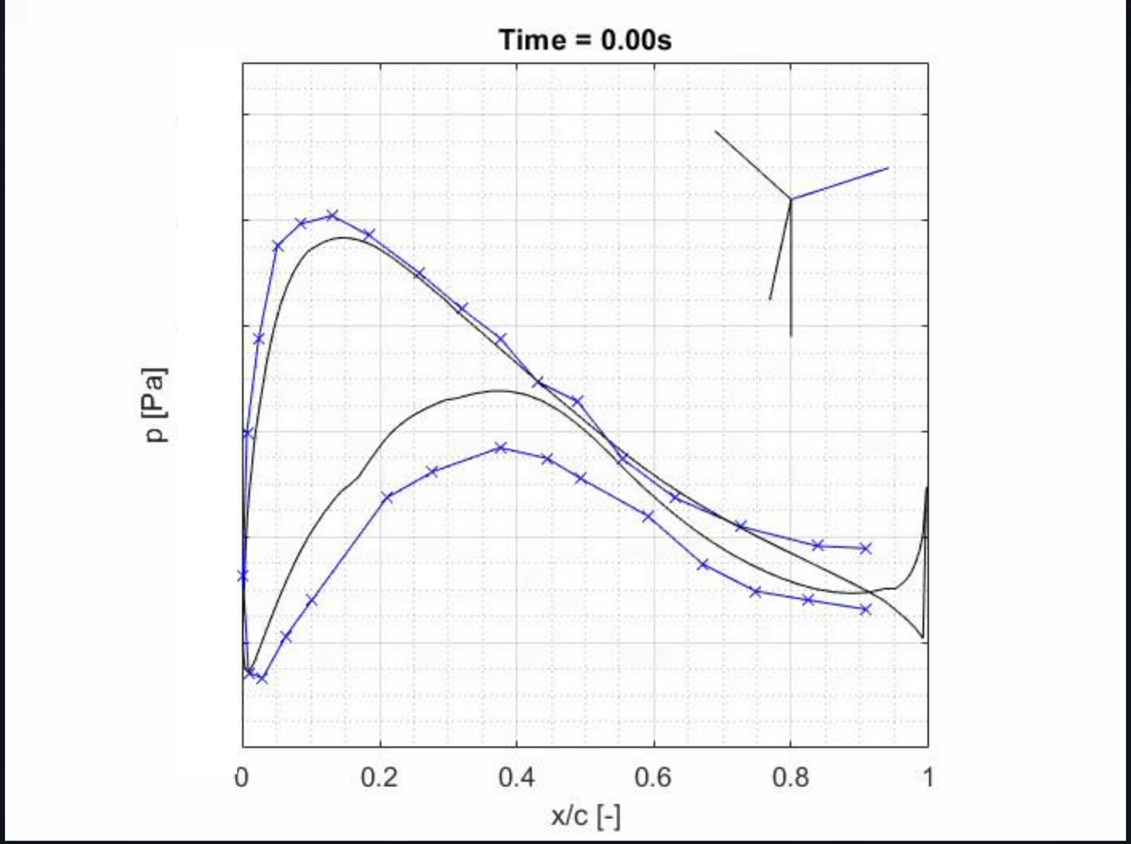


RESULTS
UNSTEADY LIFT COEFFICIENT CURVE

- Simulations use Snel's dynamic stall model of 1st order
- Hysteresis effect clearly visible in simulation and experiment
- Magnitude of $c_l = \frac{L}{\frac{\rho}{2}V_{rel}^2 c}$ influenced by
  - Lift force (simulations underpredict experiment)
  - Relative velocity (simulations overpredict experiment)



RESULTS
DOUBLE WAKE CODE VS MEASURED PRESSURE



- Animation shows:
  - Turbine rotation, blade equipped with sensors in blue
  - Measured pressure distribution (blue)
  - Simulated pressure distribution (black)
- Findings:
  - Detailed insight into sectional aerodynamics
  - Partly already good agreement between experiment and simulation
  - Overprediction of the suction peak due to inviscid formulation of double wake code

AEROELASTIC WIND TURBINE BLADE BEHAVIOUR
TAKEAWAYS

- Field experiments bring a lot of challenges in data acquisition
- Experimental data is very valuable for the validation of numeric models
- Good agreement between simulations and experiment regarding shape and range but not in magnitude
- Combined BEM + double wake panel code offers detailed insight into airfoil aerodynamics
- More engineering work required to make up for missing physics and improve code accuracy


THANK YOU FOR
YOUR TIME
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