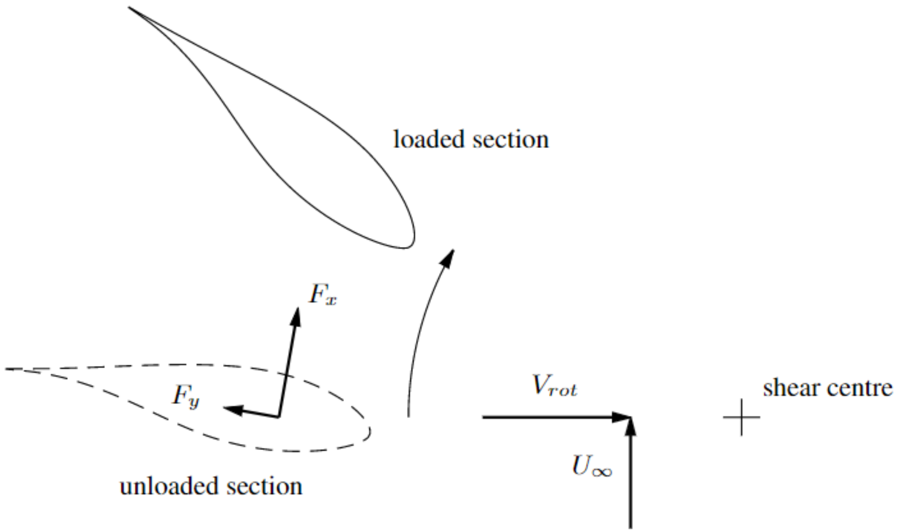
EXPERIMENTAL ANALYSIS OF THE EFFECT OF BLADE SWEEP ON A SCALED IEA 15 MW WIND TURBINE

ERIK FRITZ | ANDRÉ RIBEIRO | CARLOS FERREIRA | KOEN BOORSMA

MOTIVATION

- Motivation for blade sweep:
  - Wind turbine blades are becoming increasingly long and flexible
  - Measures for aeroelastic tailoring are becoming important
  - Blade sweep couples bending and torsional deformations
  - Distance between aerodynamic centre and shear centre
  - Example: Aft-swept blade twists to lower angles of attack when loaded → load reduction



- Motivation for this experiment:
  - Better understand the aerodynamics of swept wind turbine blades
  - Create a dataset to validate numerical models for swept blades
  - Bonus: Create an experimental dataset of a thrust-scaled IEA 15 MW RWT model

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RESEARCH ARTICLE

WILEY

An efficient blade sweep correction model for blade element momentum theory

Erik Kaspar Fritz[1,2] | Carlos Ferreira[2] | Koen Boorsma[1]

PRESENTATION OVERVIEW

Experimental setup

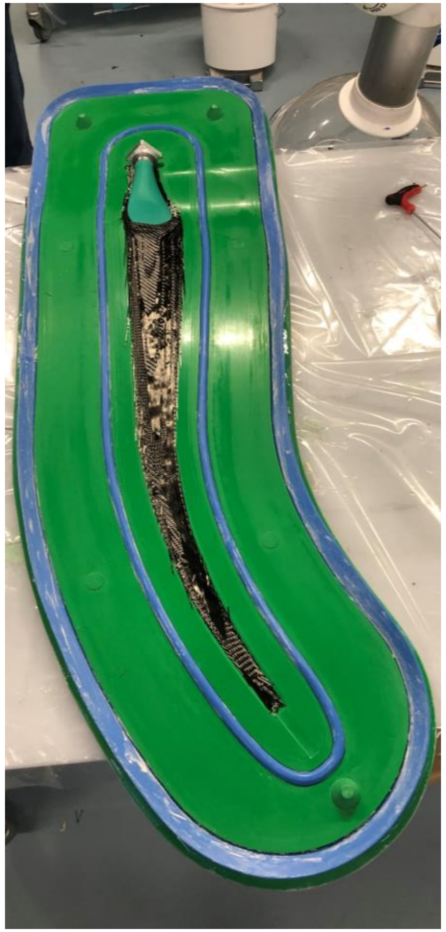
Data processing

Results

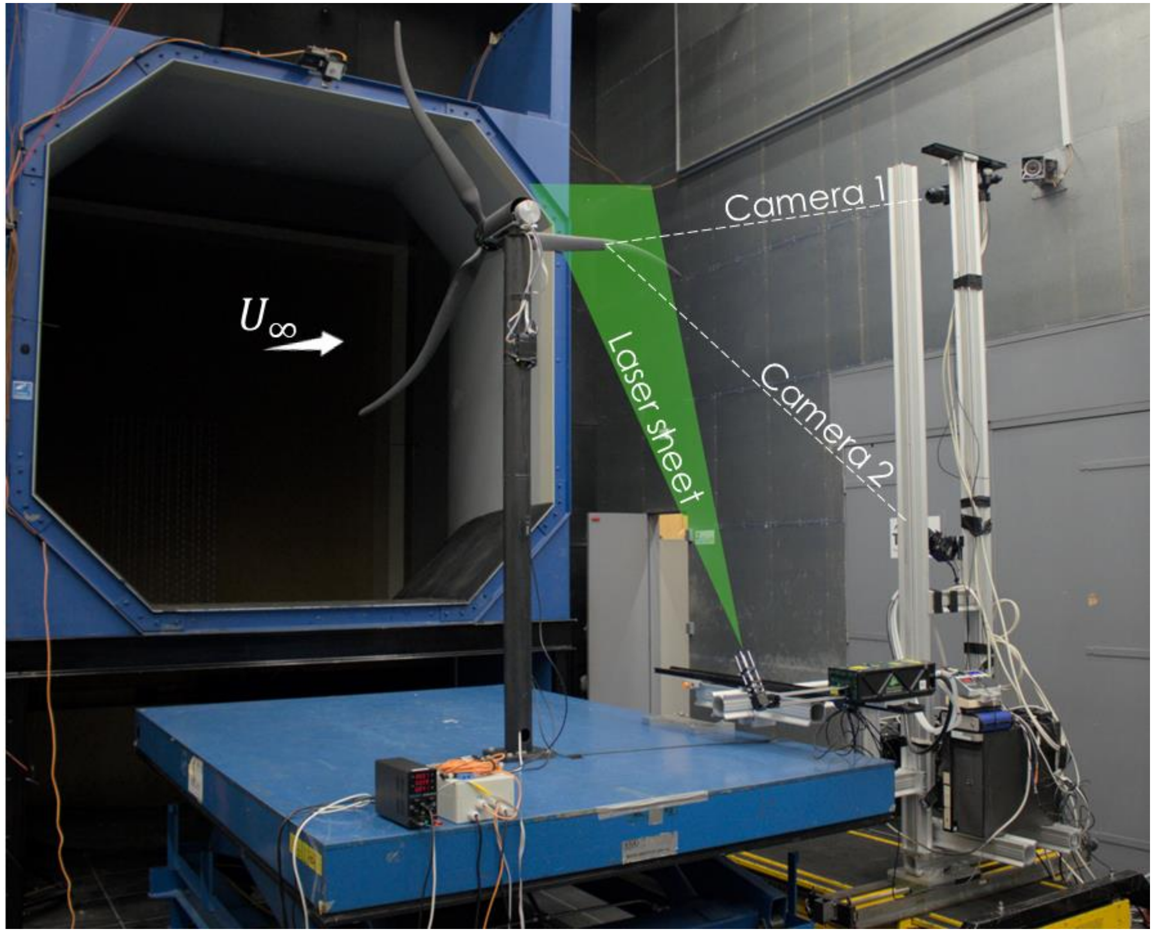
Conclusions

EXPERIMENTAL SETUP
OVERVIEW

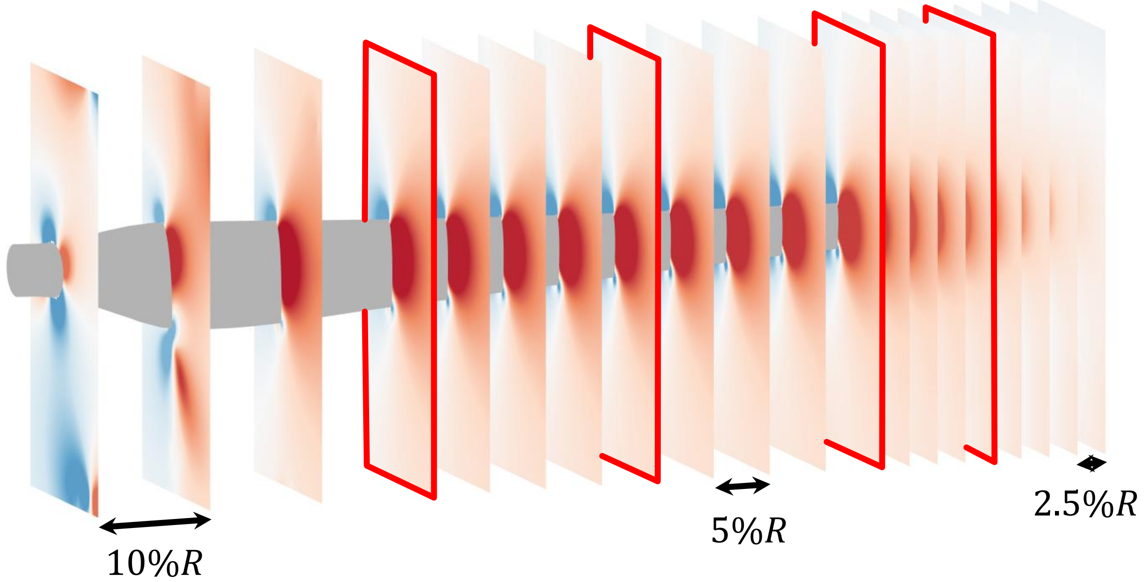
Carbon fibre-reinforced blades (vacuum-infused)

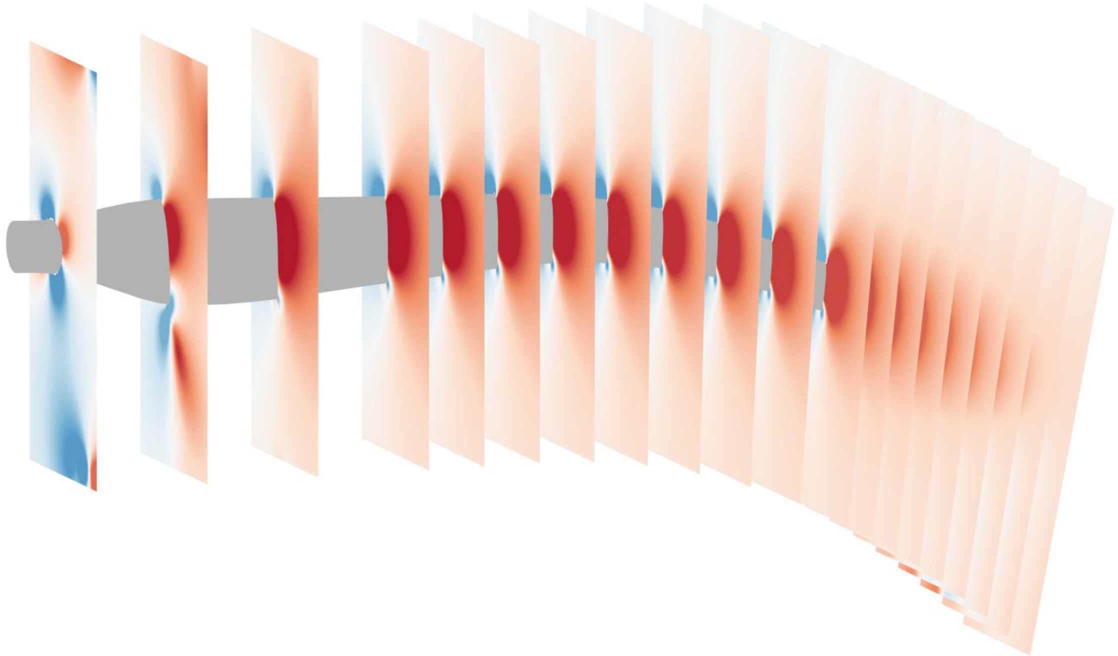


Measurement system (Particle Image Velocimetry)



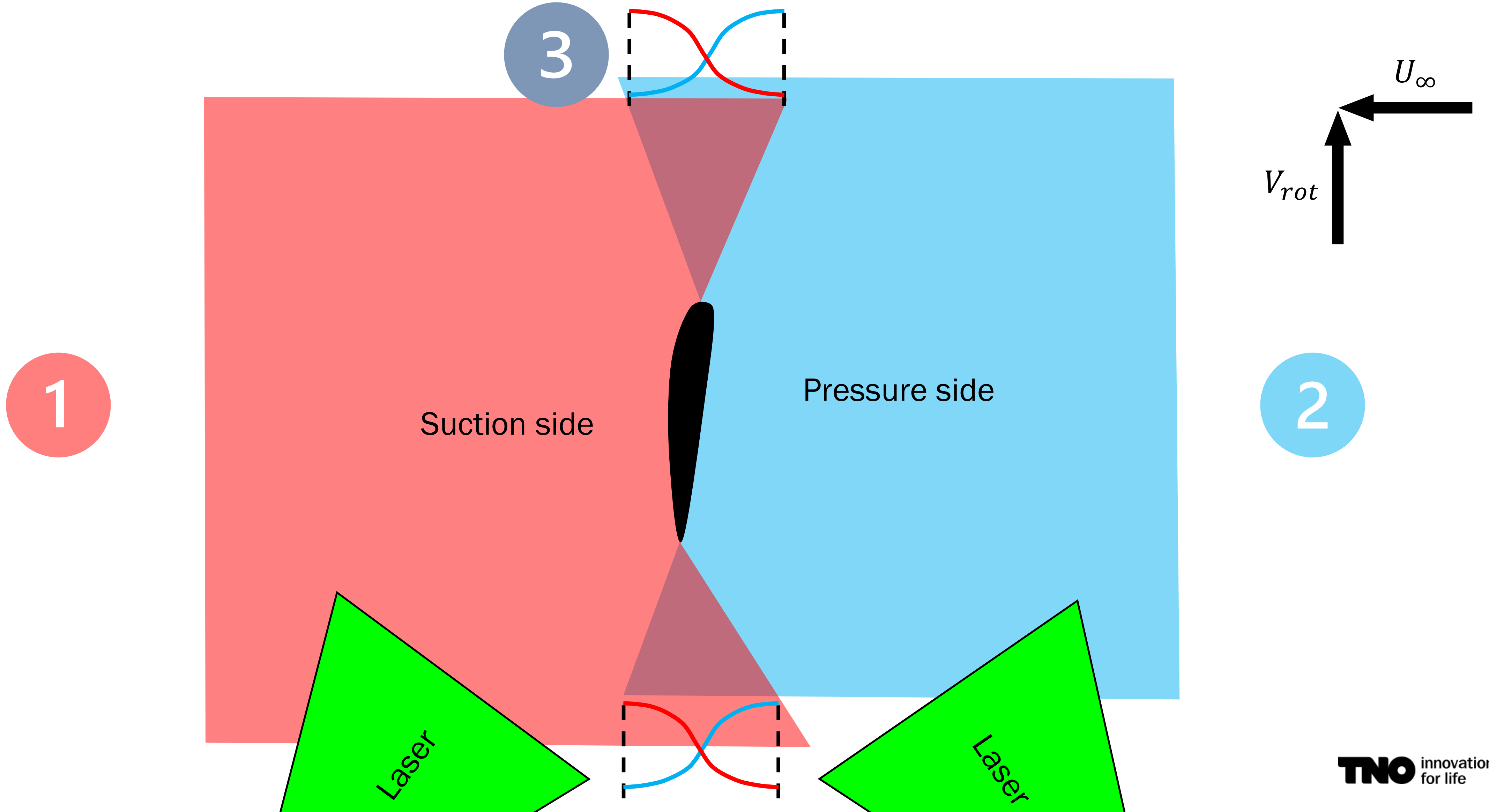
EXPERIMENTAL SETUP
MEASUREMENT PLAN





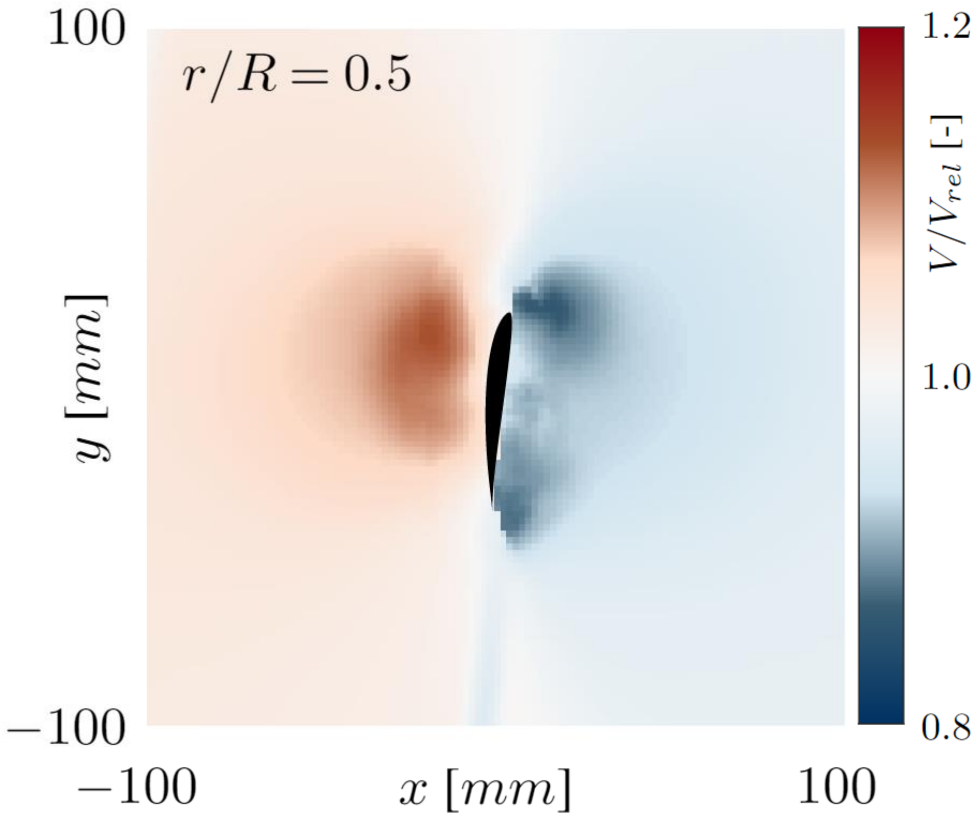
- $U_\infty = 3.75\frac{m}{s}$, $\lambda = 9$, $\beta_{pitch} = 0°$
- 20 planes per blade configuration, higher resolution towards the tip
- At 40%, 60%, 80% and 90% radius, all three blades are measured, at all other locations only one blade
- For swept blade configuration, planes are chosen at radius identical to straight blade planes

DATA PROCESSING
STITCHING THE PIV MEASUREMENTS

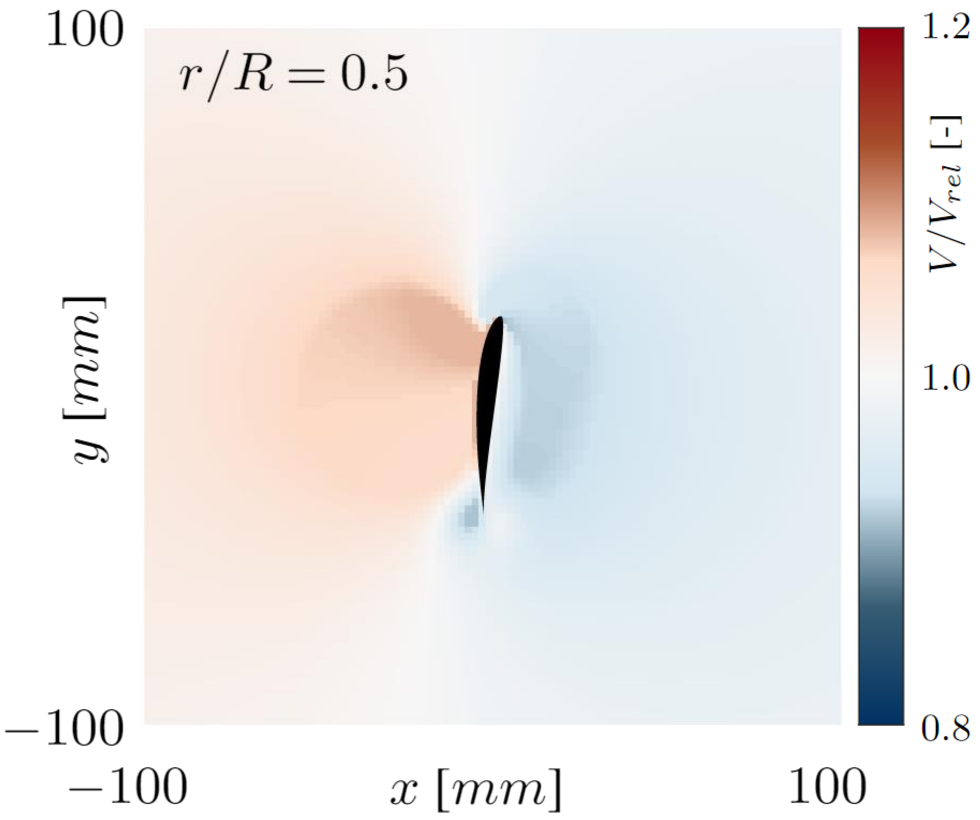


DATA PROCESSING
FLOW FIELD

- Measured flow field



- Panel code simulations for comparison



DATA PROCESSING
CIRCULATION AND FORCE DERIVATION

- **Circulation** from velocity integral:

$$\Gamma = -\oint_S \boldsymbol{u} \cdot \mathrm{d}\boldsymbol{s}$$

- **Forces** from velocity field using Noca's method [1]:

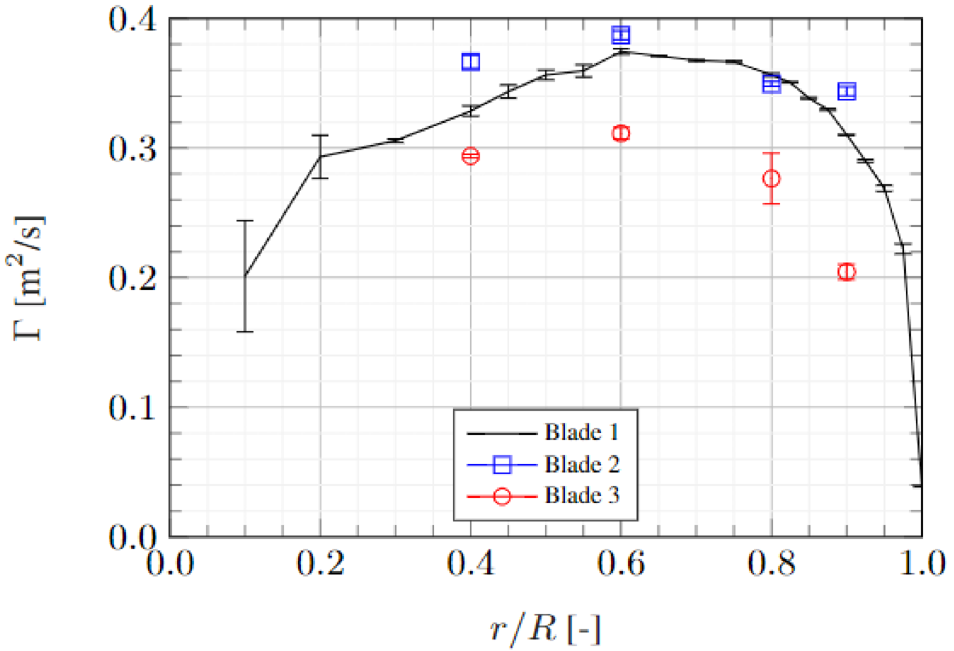
$$\frac{\boldsymbol{F}}{\rho} = \oint_S \boldsymbol{n}\gamma \,\mathrm{d}s - \oint \boldsymbol{n} (\quad)^{\mathrm{T}} \boldsymbol{u} \,\mathrm{d}s - \frac{\mathrm{d}}{\mathrm{d}t} \oint_{S_B} \boldsymbol{n} \left(\boldsymbol{u}^{\mathrm{T}} \boldsymbol{x}\right) \mathrm{d}s$$

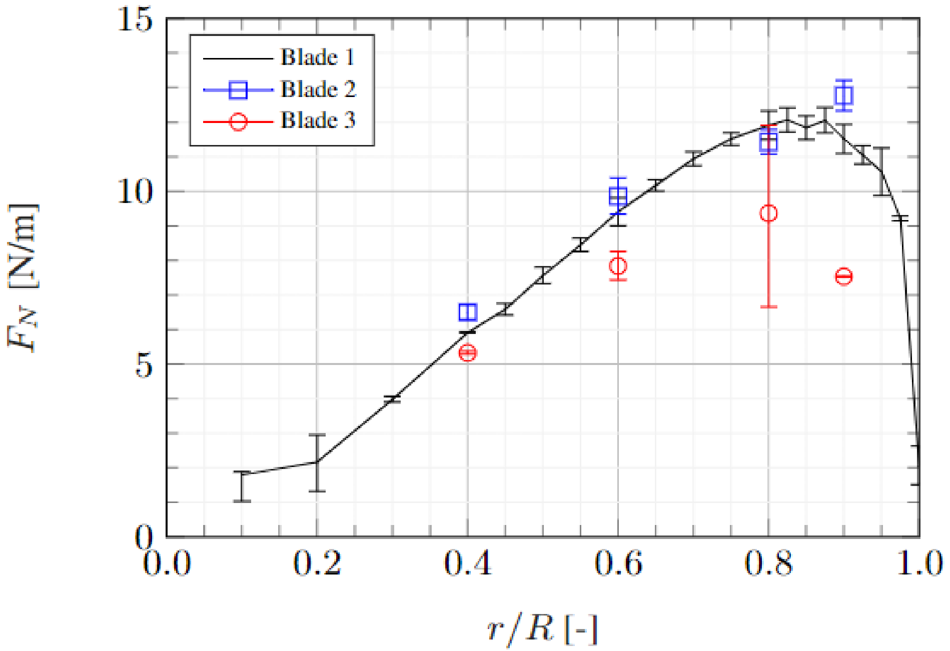
Forces can be calculated based on velocity field and its spatial and time derivatives.

[1] Noca et al. (1999): A comparison of methods for evaluating time-dependant fluid dynamic forces on bodies, using only velocity fields and their derivatives, https://doi.org/10.1006/jfls.1999.0219

DATA PROCESSING
DISCREPANCIES BETWEEN BLADES

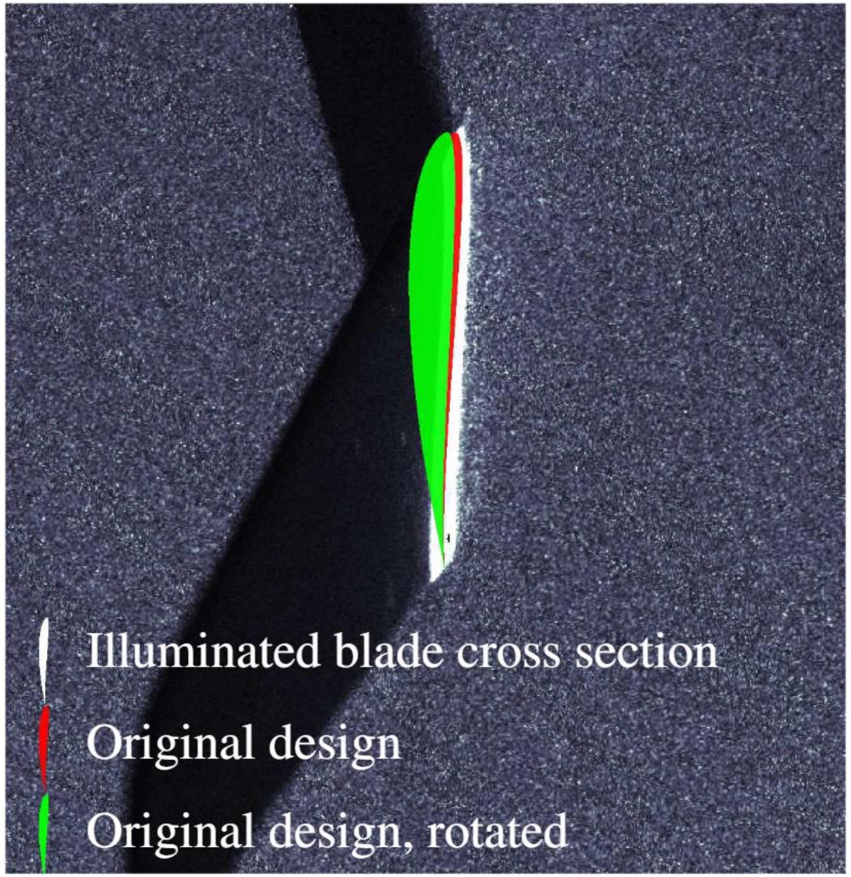
- Large differences in aerodynamic quantities between the three blades



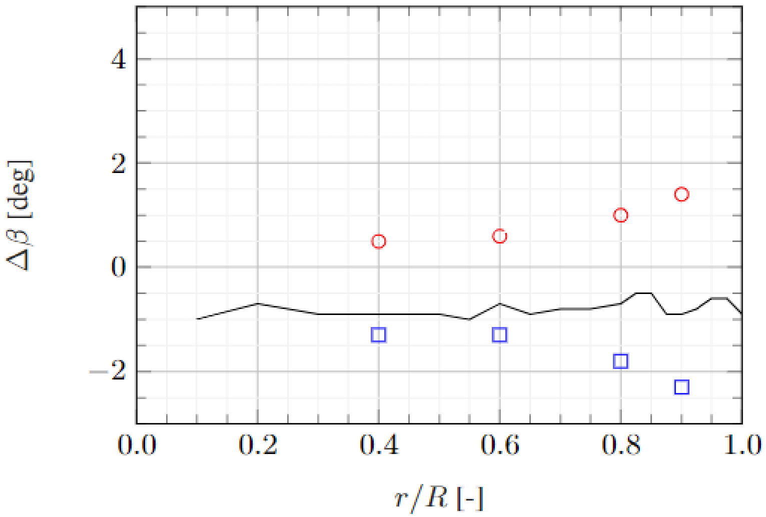


- What causes these discrepancies?
- Can we correct for this?

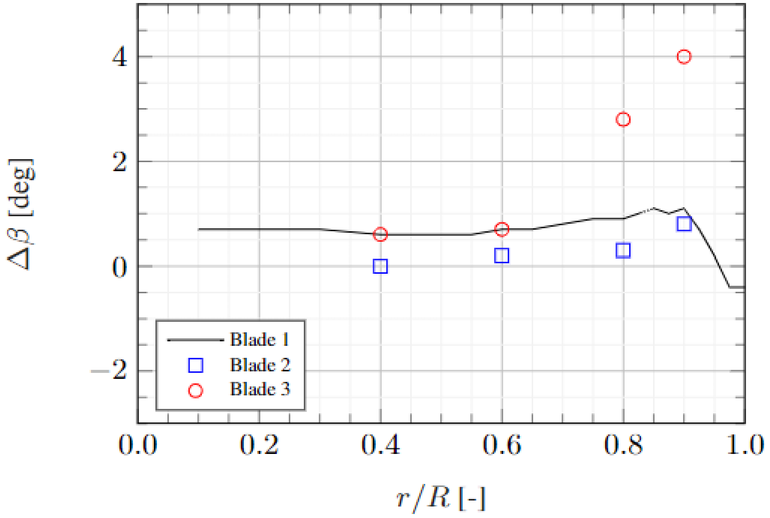
DATA PROCESSING
PITCH OFFSET / TWIST DEFORMATION



Straight blades



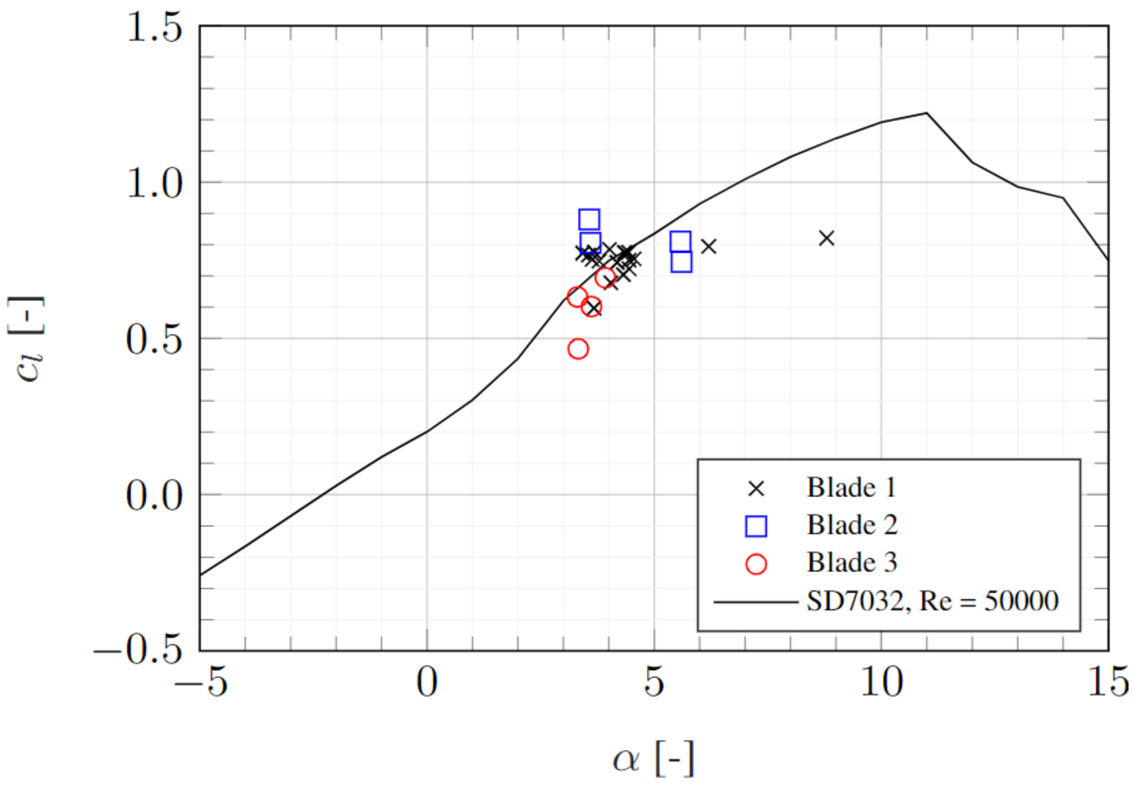
Swept blades



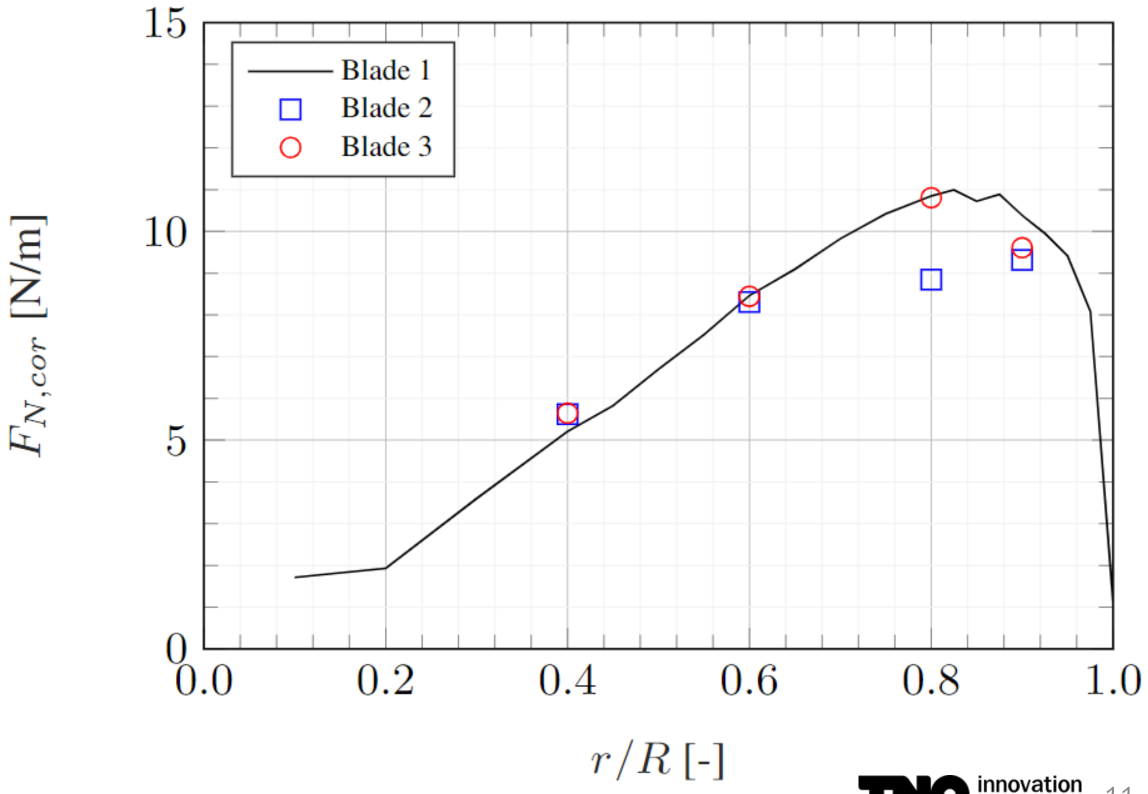
- Explanation:
  - Manual manufacturing leading to differences in final fibre layup
  - Manual mechanism to set pitch angle

DATA PROCESSING
PITCH OFFSET / TWIST DEFORMATION - CORRECTION

- **Apply inverse BEM** (including twist/pitch offset) to derive values of induction and angle of attack

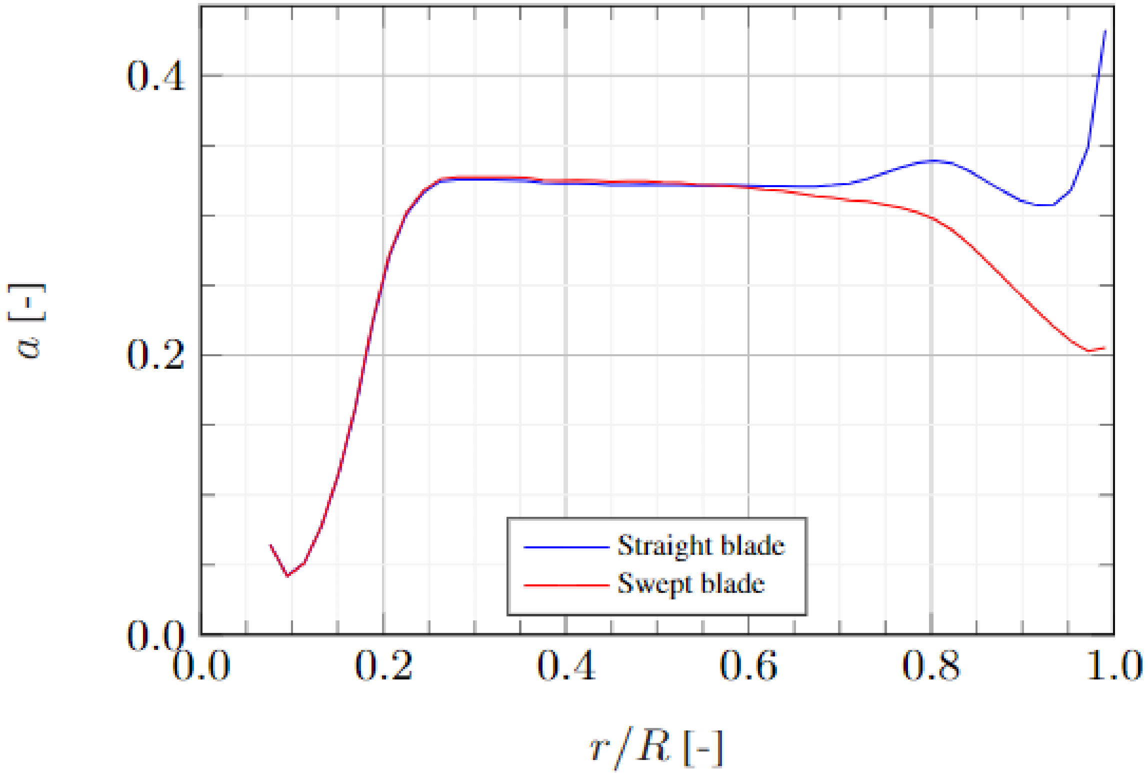


- **Correct forces** parallel to polar lift slope using BEM equations to correct for twist/pitch offset

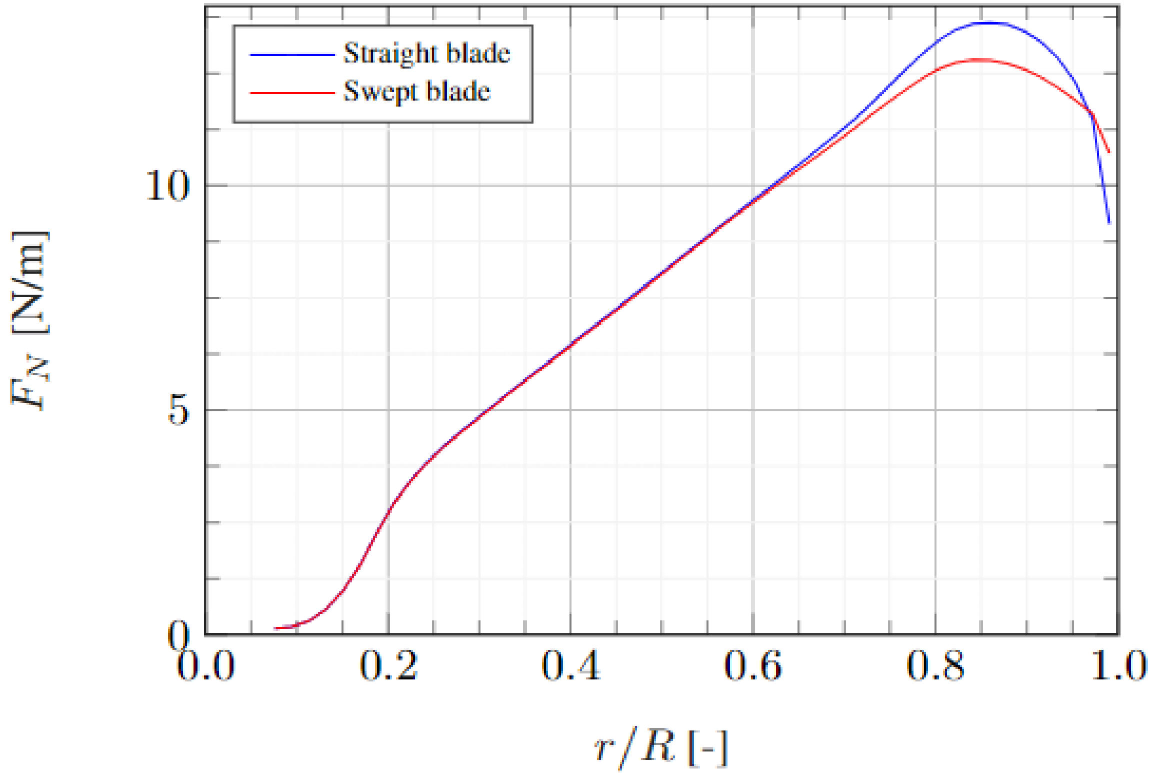


RESULTS
NUMERICAL SIMULATION

- Axial induction drop-off towards the blade tip due to crossflow principle and displacement of the tip vortex

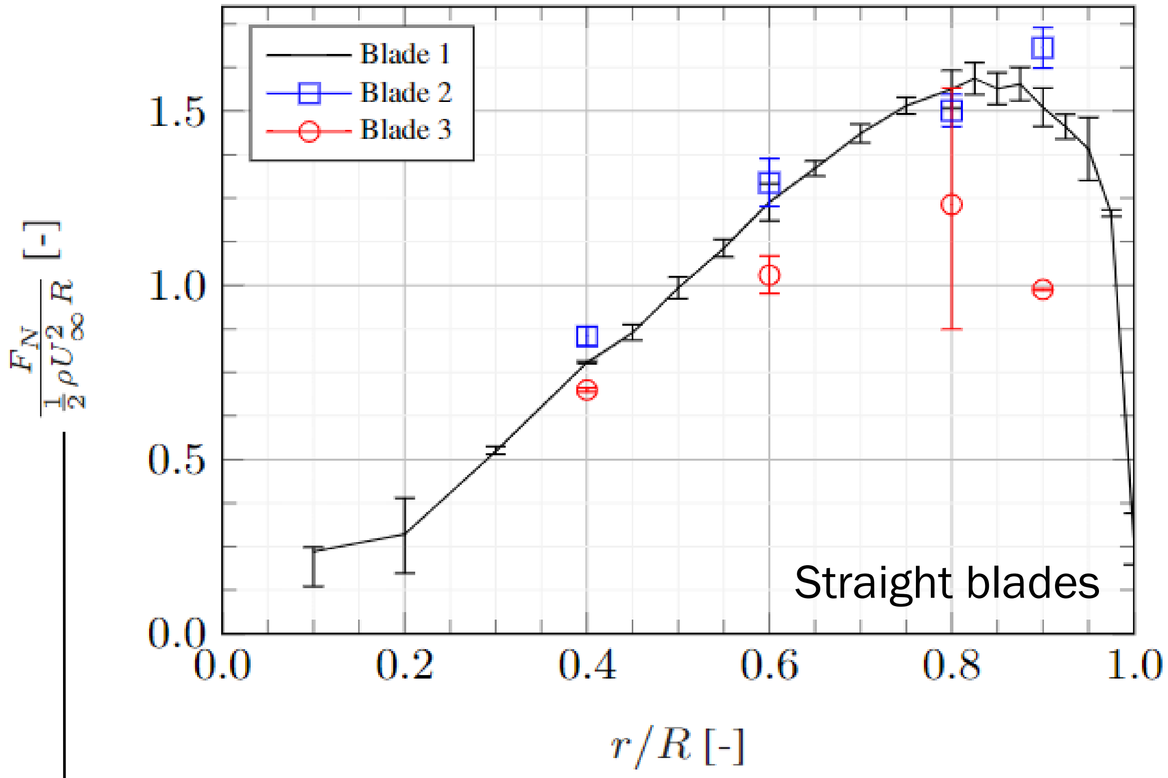


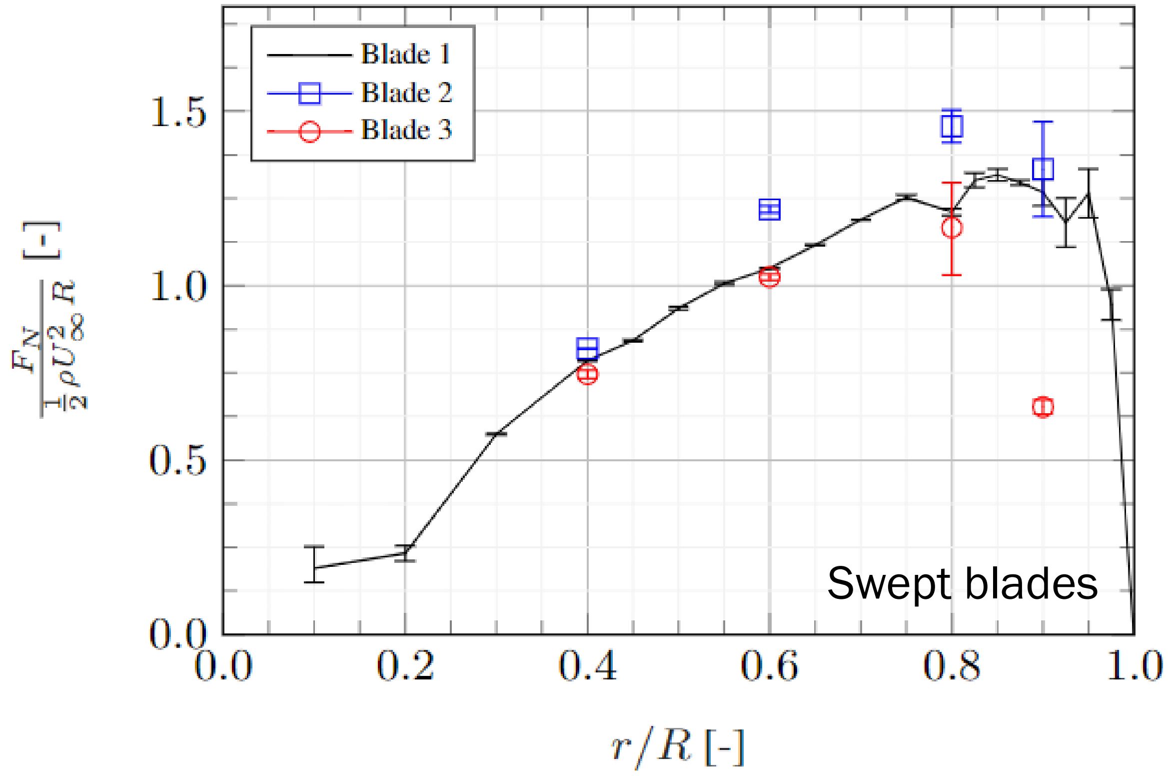
- Consequently, also an axial force drop-off at the tip



RESULTS
EXPERIMENT – AXIAL FORCE, UNCORRECTED

- Uncorrected forces represent the expected trend





Non-dimensionalisation to account for slight changes in operating conditions

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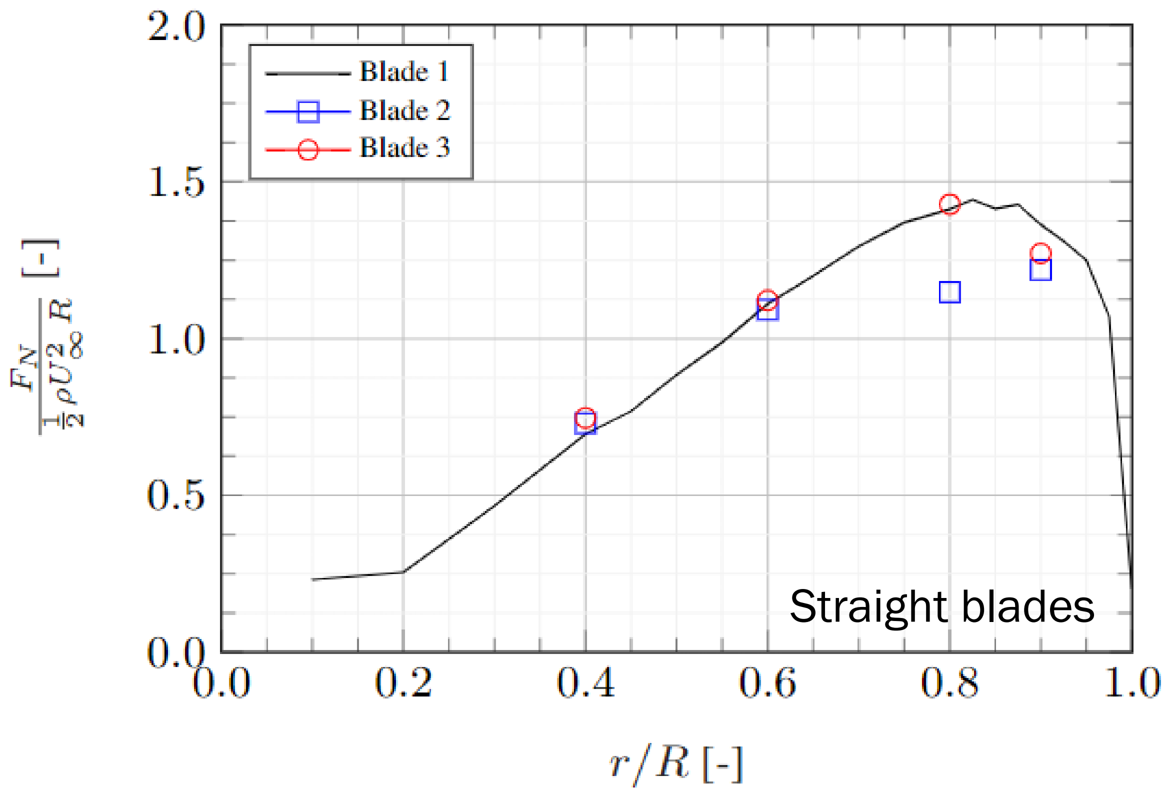
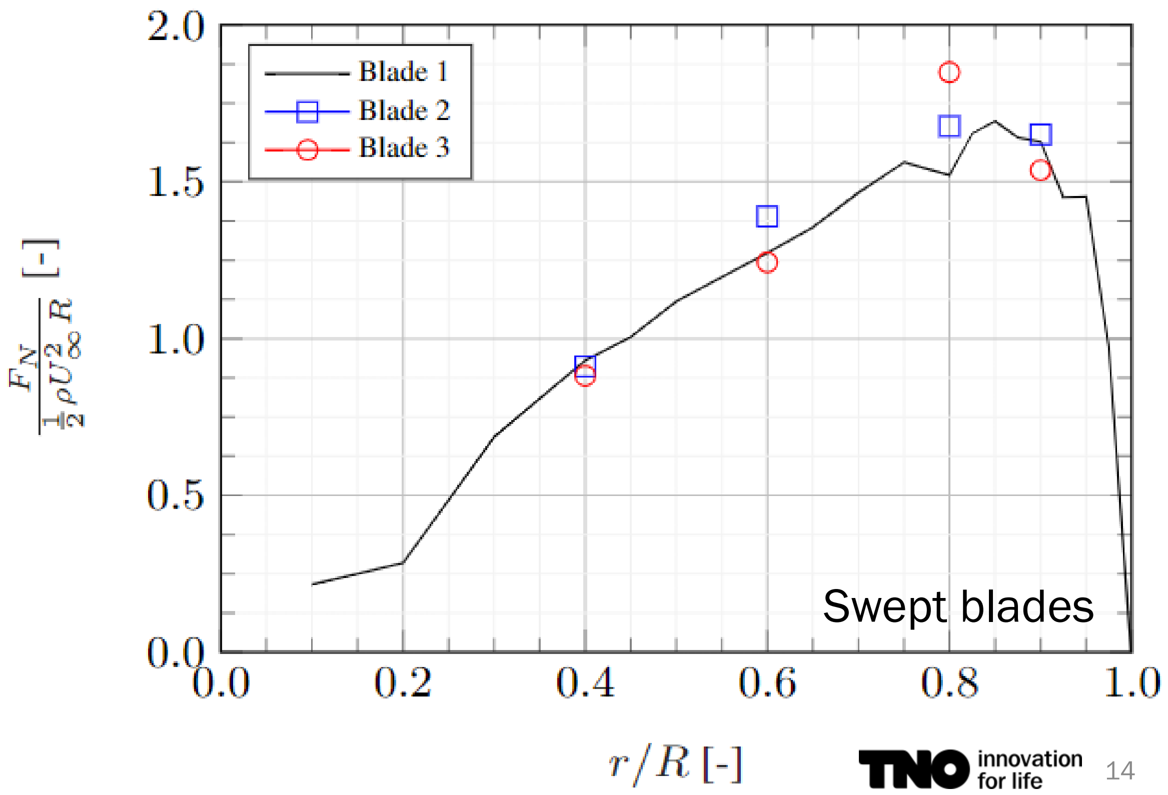
RESULTS

EXPERIMENT – AXIAL FORCE, CORRECTED

- Corrected forces are **not** aligned with expectations
  - Overall higher forces along the span, also at the geometrically identical inboard part of the blade
  - Sweep-induced force drop-off not detectable





CONCLUSIONS

- Achievements
  - Created an experimental database of a thrust-scaled IEA 15 MW model (flow fields, circulation, forces, induction values)
  - Created an experimental database of a rotating HAWT with swept blades
- Challenges
  - Manually manufactured blades exhibit varying stiffness properties
  - Manual pitch mechanism led to pitch offsets
- Future work
  - More accurately determine induction values
    → improving correction for pitch/twist offset
  - Use results for validation of numerical models

THANK YOU FOR YOUR TIME

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