Tidal Turbine Benchmarking Project:
Stage I – Steady Flow Experiments

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Bath: Anna Young, Ian Benson

6th September 2023

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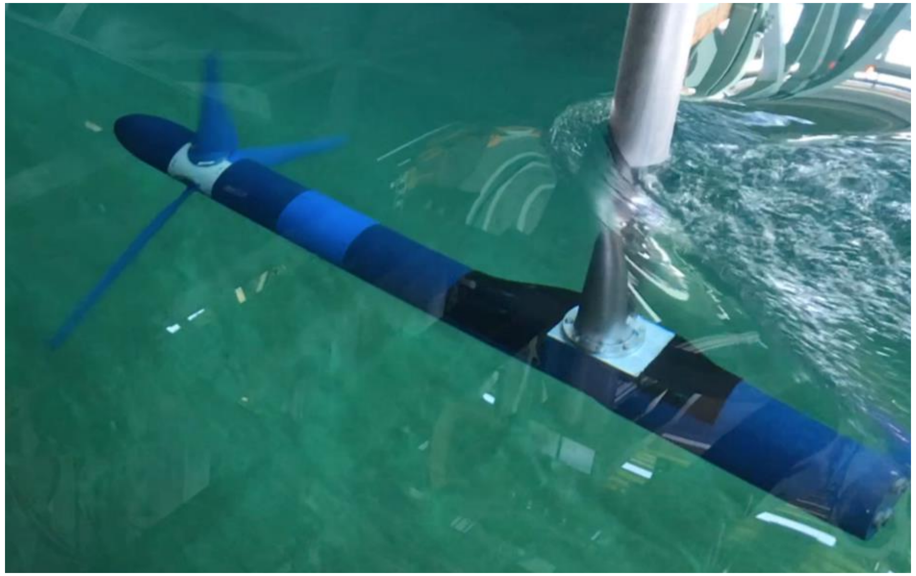
Benchmarking Project: Overview and Objectives

- ***Unsteady loading and the inability to confidently predict unsteady loading and / or quantify errors drives unnecessary redundancy and design conservatism.***
- **Objectives**:
  - i. improve accuracy of modelling techniques,
  - ii. improve confidence in the use of modelling techniques,
  - iii. quantify modelling errors for different techniques under different loading scenarios,
  - iv. development of novel measurement techniques.
- **Approach**:
  - i. Conduct a large laboratory test of a highly instrumented tidal turbine in waves and turbulent current to provide underlying data,
  - ii. Conduct a series of community wide (academia and industry) blind prediction exercises with staged data release, leading to an open access dataset.



Requirements, Tests & Facility

Test requirements:

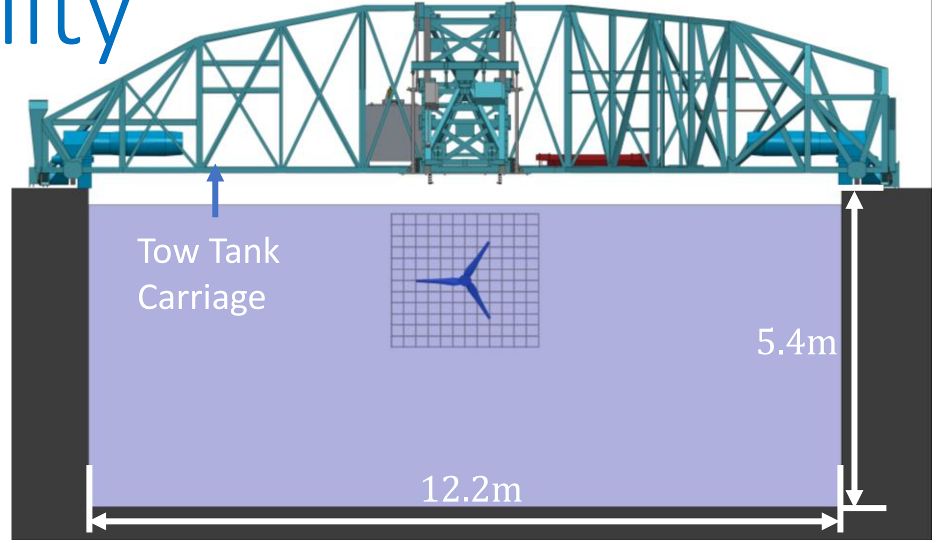
- Require **low blockage** experiments with a **large diameter** rotor for **in-blade sensing** and **Reynolds independence**.
- Flume options – blockage too high
- Tow tank – low blockage but turbulence low.
- Solution: **tow tank with an upstream turbulence grid**

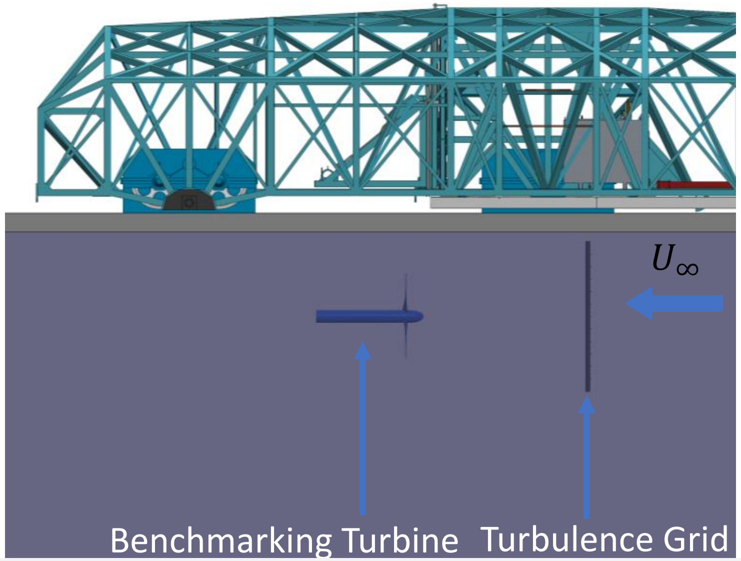
Test conditions:

- Uniform flow
- Uniform flow + Waves
- Uniform flow + Grid generated turbulence

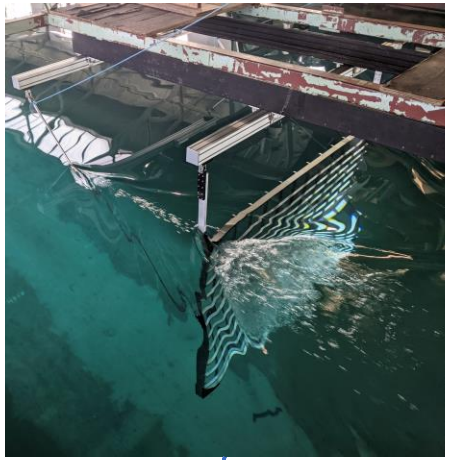
QinetiQ towing tank facility, Haslar, Portsmouth UK

- 270m (L) x 12.2m (W) x 5.4m (D)
- Tow speed 1m/s
- Tow length approx. 150m
- Settling time ~15mins





Timeline



15th EWTEC 2023
European Wave and Tidal Energy Conference Series
BILBAO
3rd -7th SEPTEMBER 2023

Turbulence Grid and wave characterisation Experiment

July 2021

April 2022

Benchmarking Turbine Experiment

Workshop I: Modelling Kick-off

June 2022

Stage 1 Analysis Submission Deadline

5th September 2022

2nd November 2022

Workshop II: Stage 1 Data Presentation (TBC)

Workshop III: Stage 1 Round Up

17th January 2023

EWTEC September 2023

Workshop IV: Stage 2 – Release of first set of Wave Conditions

Follow on Wave Experiments

TBC

TBC

Workshop V: Stage 2 Data Presentation

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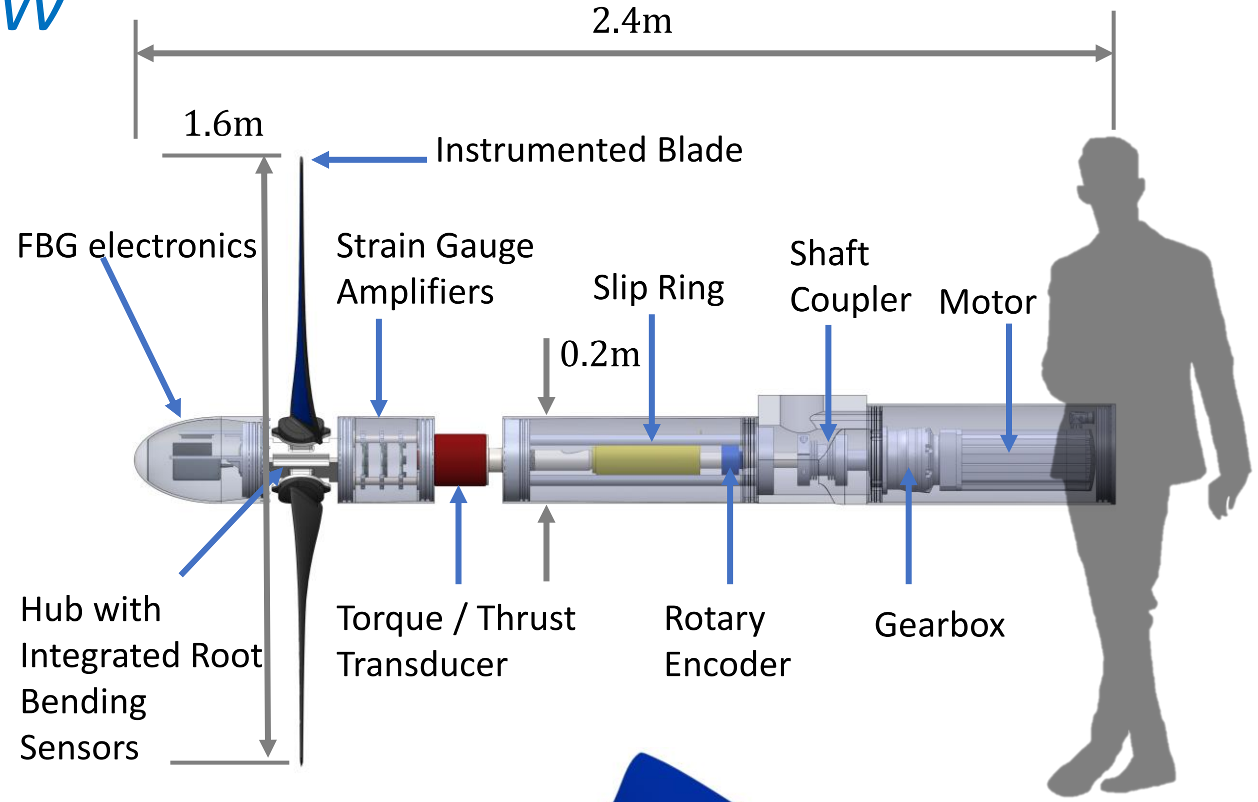
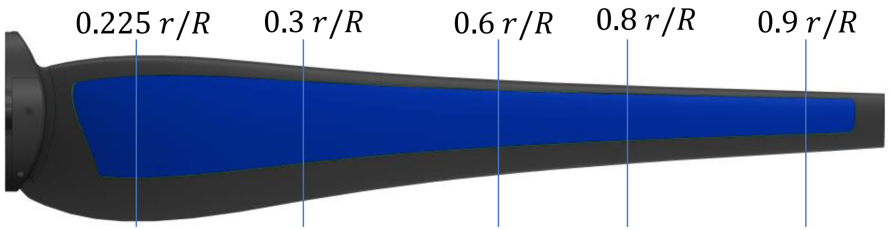
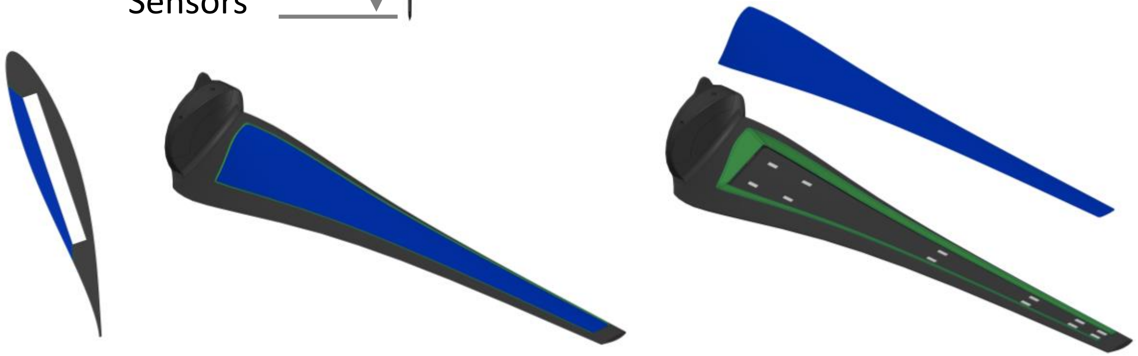
Turbine Design - *Overview*

- 1.6m diameter rotor / 0.2m diameter nacelle
- Two blades instrumented with strain gauges at six radial locations in both edgewise and flapwise directions.
- Remaining blade instrumented with fibre Bragg sensors with similar resolution.
- Individual blade loads measured with hub – integrated root bending sensors (flap and edge). 100 strain gauges, 4 optic fibers
- Torque and Thrust measured by shaft mounted transducer upstream of front bearing.
- Shaft rotary encoder for speed and position.

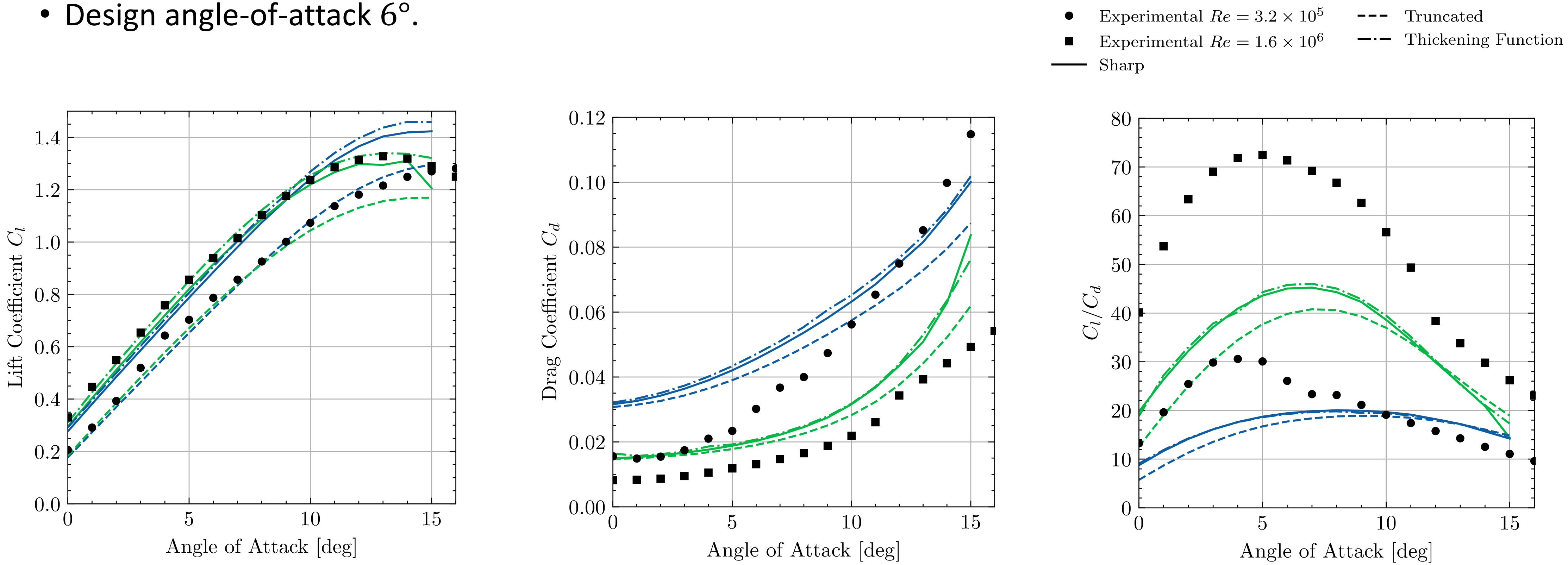






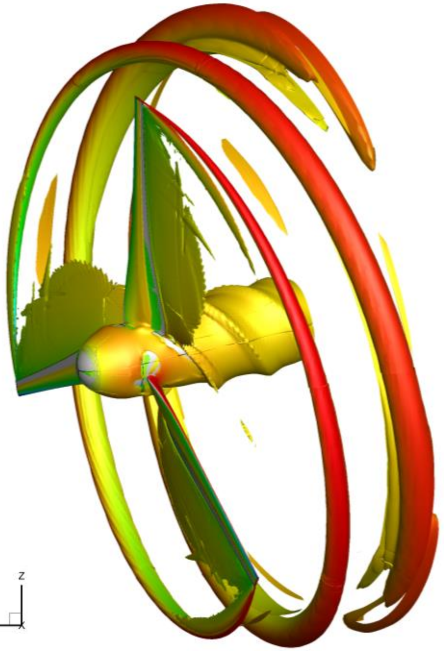
Blade Performance and Trailing Edge treatment

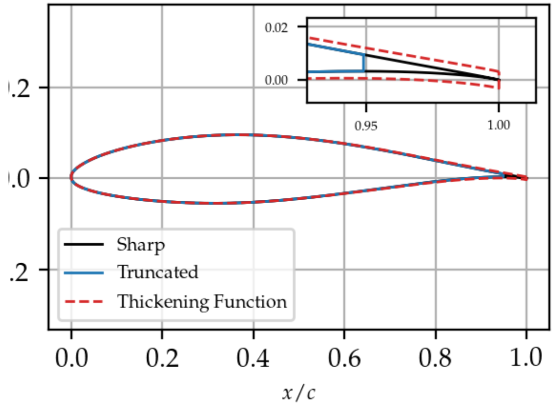
- Blade section performance of the NACA 63-415 hydrofoil,
- Sharp, truncated and thickened trailing edges considered for turbulence level; Tu = 8% (blue), 1.3% (green),
- Sharp and thickened trailing edges perform very similar – advantageous for benchmark simulations.
- Design angle-of-attack 6°.



Rotor Design Process

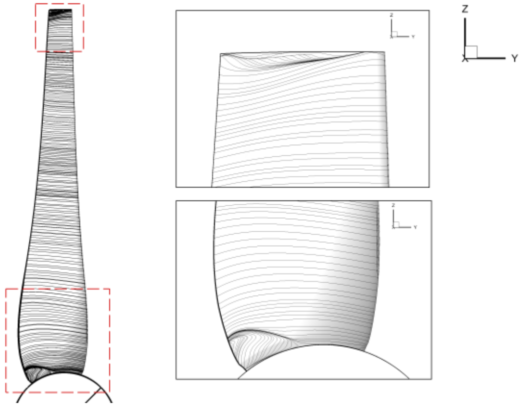
- Rotor designed for facility and operating conditions
- Considerations: $U = 1\, m/s, Tu = 5\%$
- Post-critical blade **Re > 280k**
- Uniform hydrodynamic profile along span to simplify modelling
- Low blockage (3.05%)
- Design method**: RANS embedded BE solver**



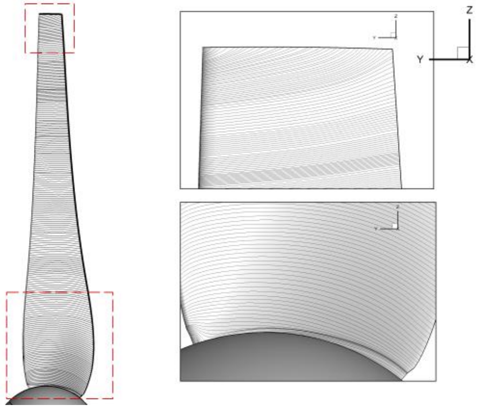


Blade profile

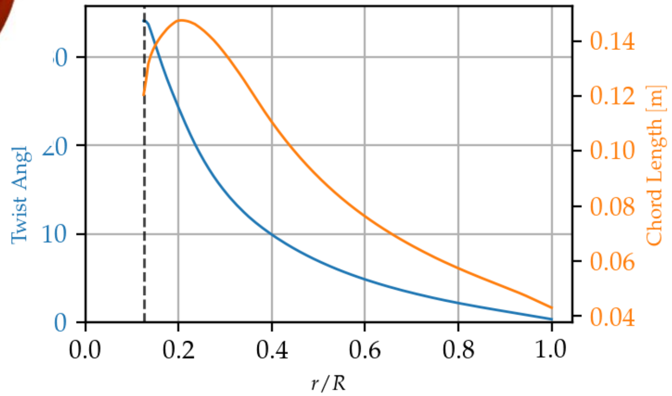
Pressure Surface



Suction Surface

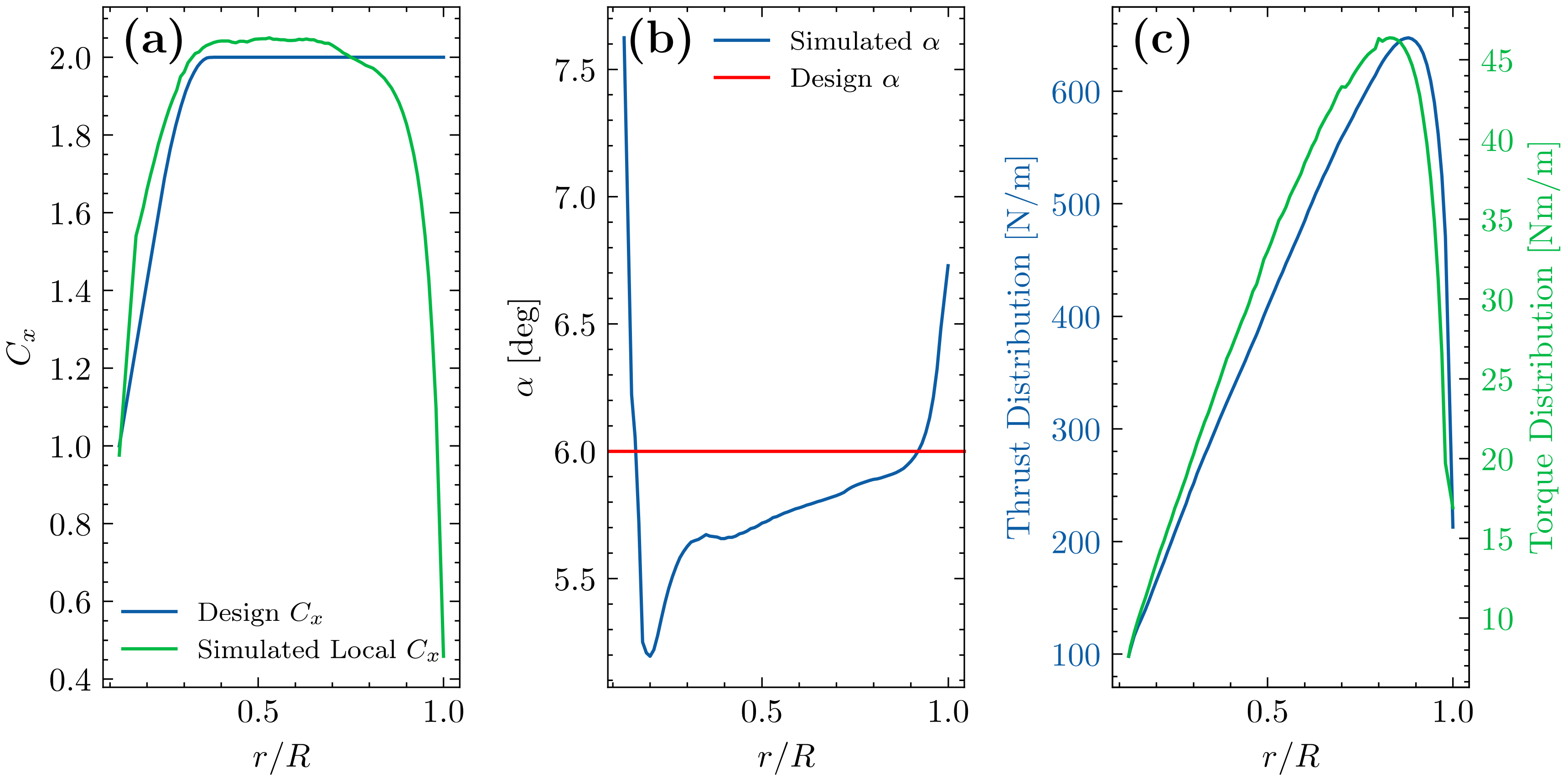


Chord & Twist



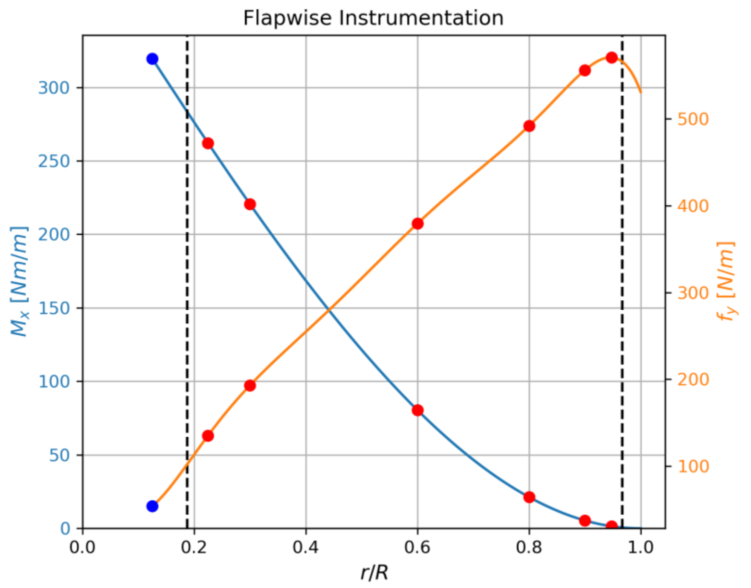
Blade Design

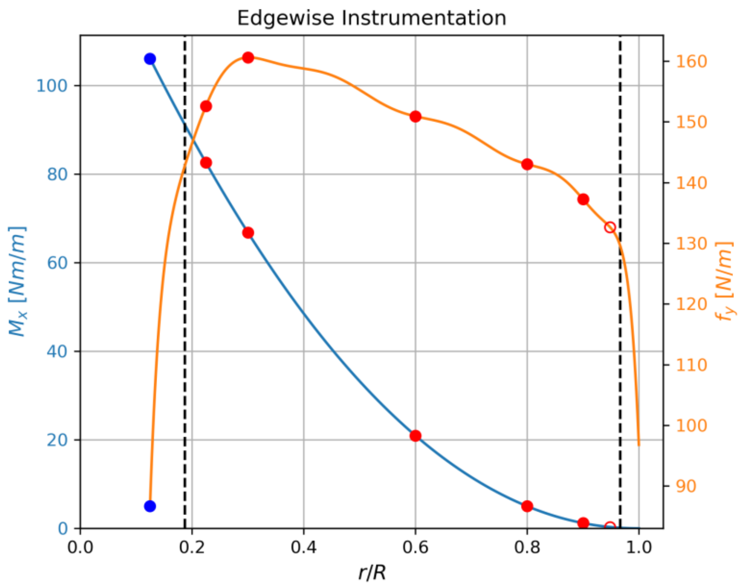
- Targeted angle-of-attack, α, and local force coefficient, C_x,
- CFD MRF simulation of single blade confirms blade performance and loading distribution.

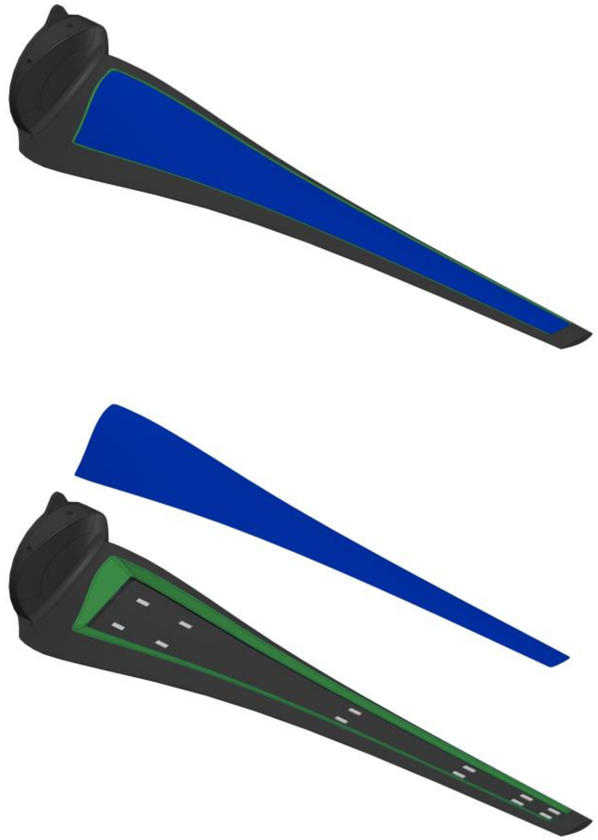


Turbine Design - *Instrumented blades*

- Two part construction of blade to provide instrumentation channel,
- Instrumentation channel twists and tapers with blade with faces aligned with local neutral axes,
- Two blades instrumented with strain gauges at six radial locations,
- Flapwise bending moment at locations 1-6, edgewise bending moments at locations 1-5.

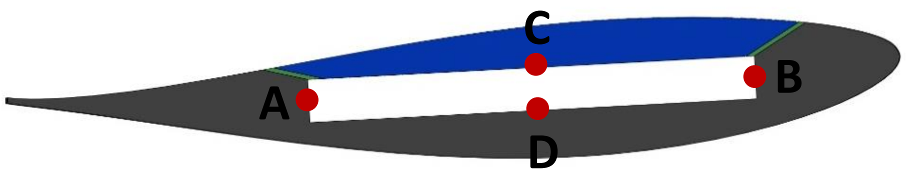


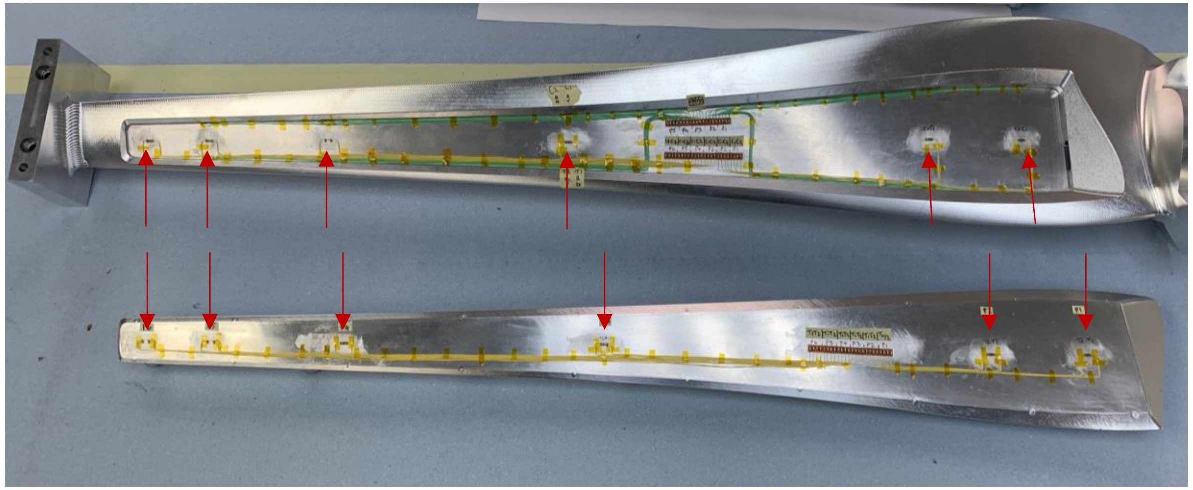




Turbine Design - *Instrumented blades: Strain gauged*

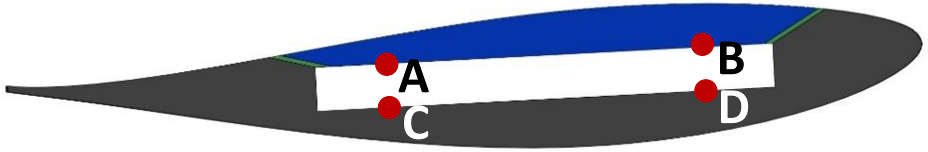
- Positions chosen to minimise cross-talk between measurement directions,
- Full bridge configurations for both edgewise and flapwise measurements.

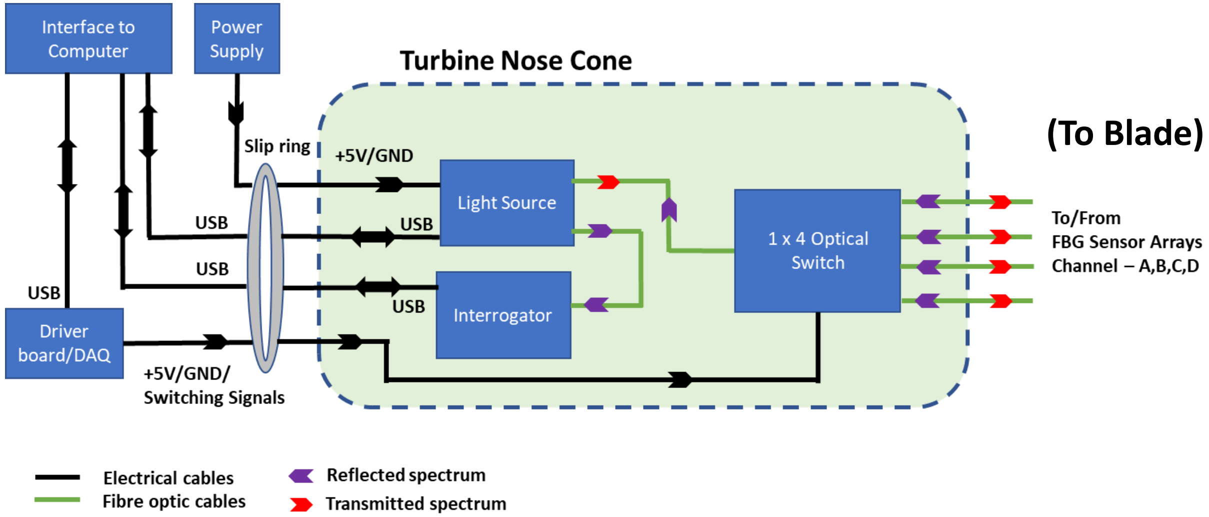


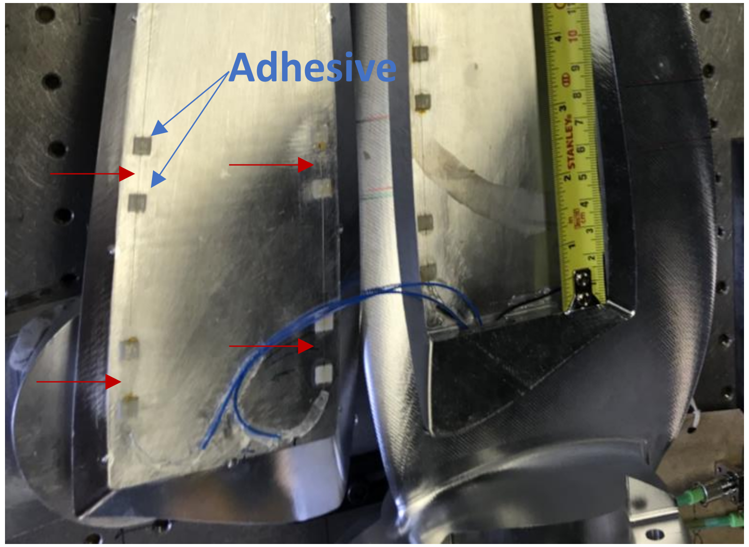


Turbine Design - *Instrumented blades: Fiber Bragg*

- Sensors located only on pressure and suction sides of internal slot due to size constraints,
- To minimise the influence of shear strain the fibre either side of the FBG sensor is adhered with a 12.5mm gap around the sensor.







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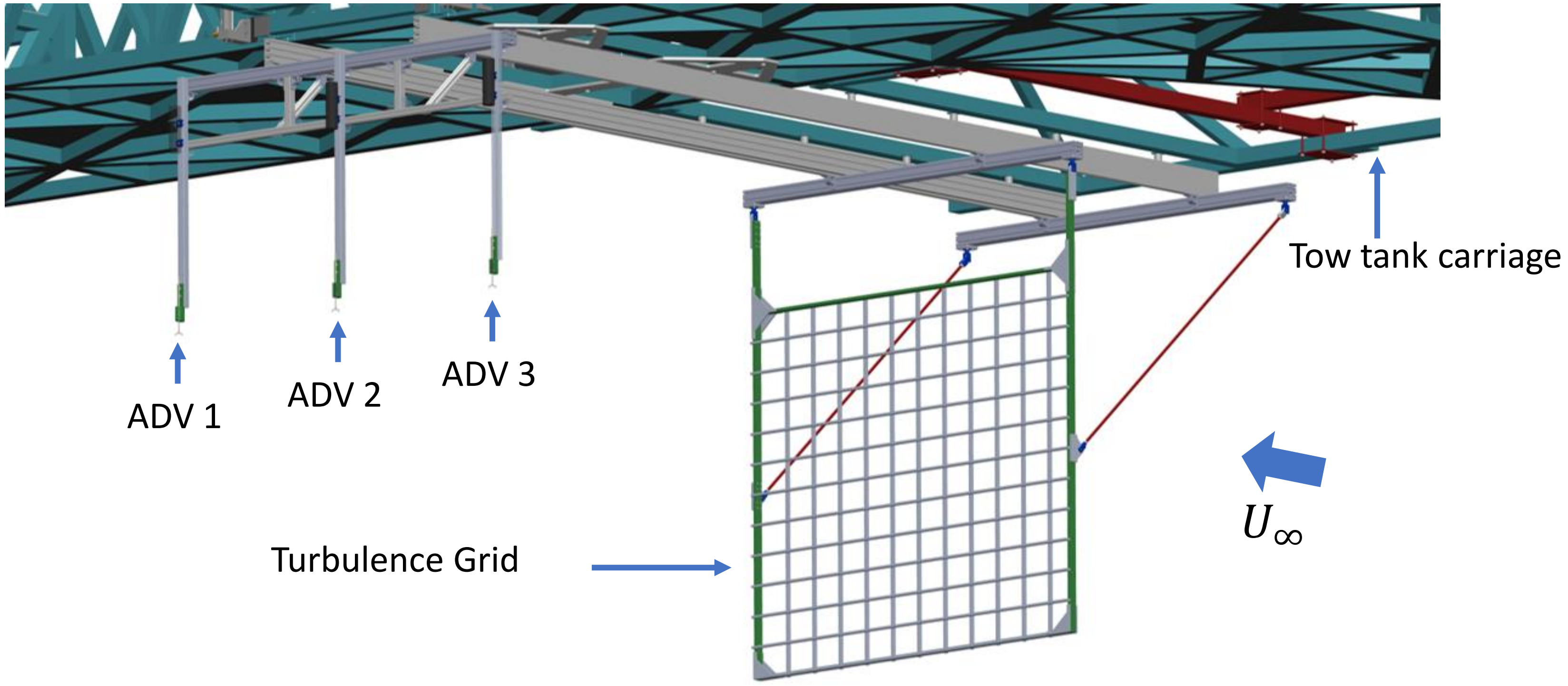
Turbulence Grid: Flow Characterisation (ADV)

- Size: $1.5D \times 1.5D = 2.4 \times 2.4\text{m}$
- Flow velocity measured with 3 Acoustic Doppler Velocimeter (ADV) probes
- ADV positions varied to obtain a horizontal, vertical and diagonal profiles

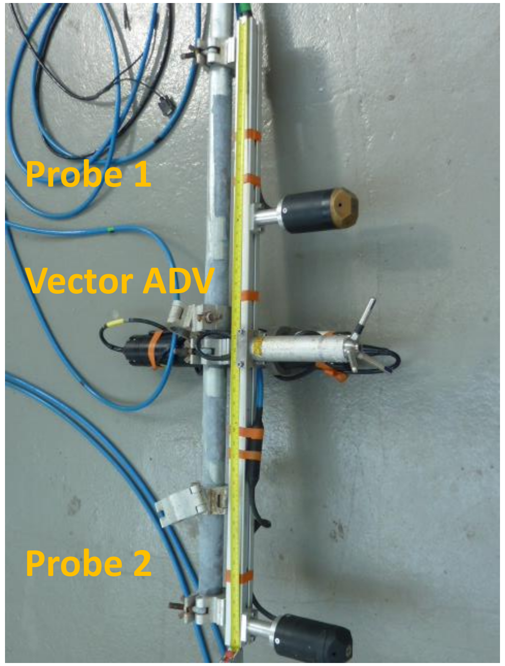


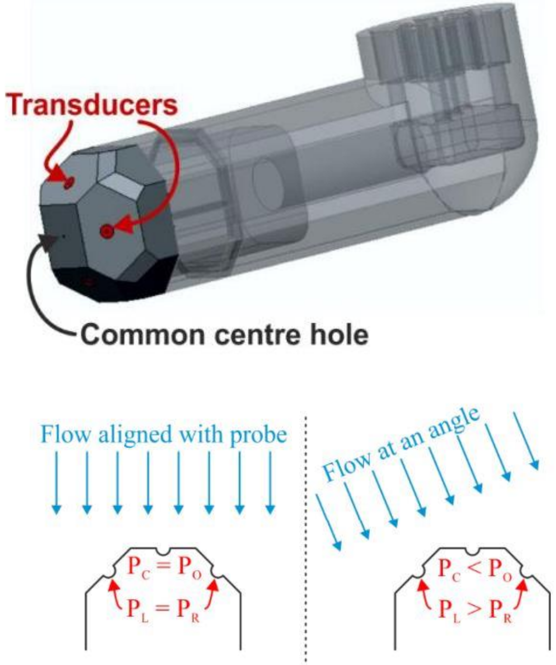
Turbulence Grid: Flow Characterisation (ADV)

- ADVs require seeding particles to calculate flow velocities,
- The large volume of towing tanks prohibits uniform seeding of the entire tank (17.8 million litres),
- Targeted seeding injected with a pump at the measurement location along the tank prior to test run,
- 10 tonnes of seeded water pumped into tank during campaign.

Turbulence Grid: Flow Characterisation (Barnacle)

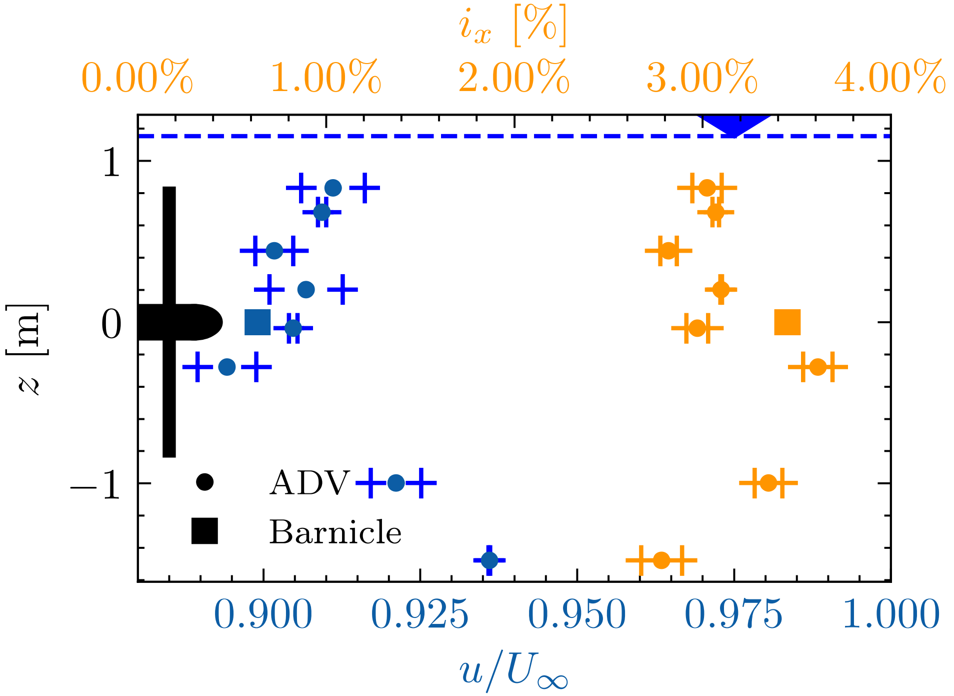
- 5-hole unsteady Barnacle probe developed by Anna Young and Ian Benson, University of Bath,
- Combines pressure measurements at five face centres, yielding **yaw, pitch and velocity magnitude,**
- Two barnacle probes mounted at different depths with lowest positioned at the hub depth,
- Integrated IMU in Nortek Vector ADV used to evaluate carriage vibration.

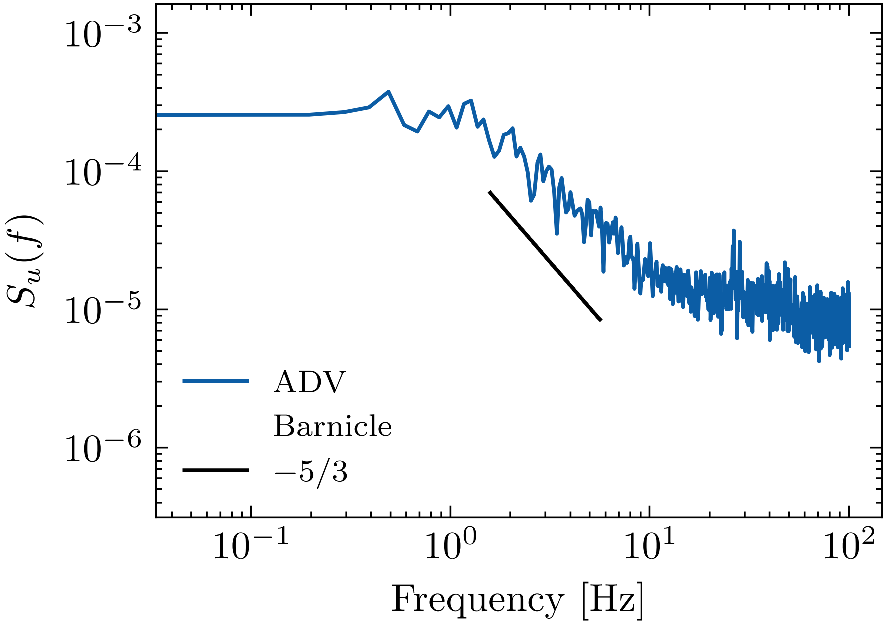




Turbulence Grid: Velocity Profile

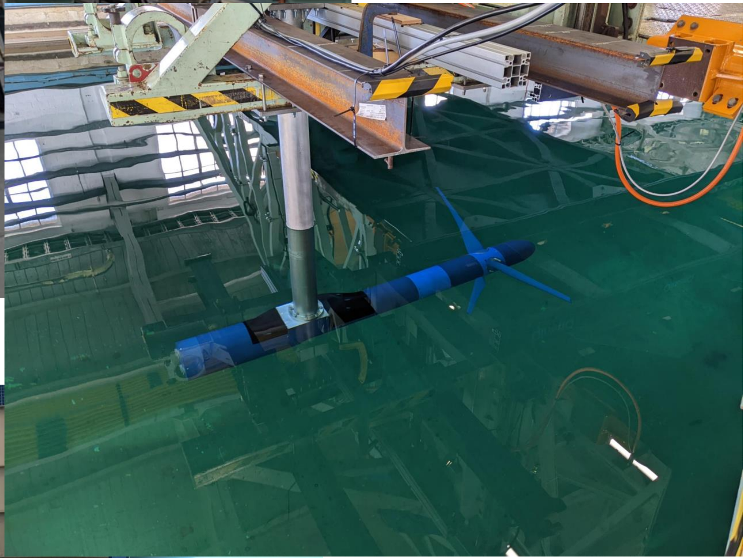
- Minimum streamwise velocity of $0.913\ U_\infty$ at centre of turbulence grid,
- Area weighted mean of $0.9207\ U_\infty$ across turbine with $\pm 0.5\%$ variation.
- Streamwise TI across turbine between 2.8% and 3.5% with an area weighted mean of 3.1%
- Lower TI than in field but a well defined condition for testing simulations & engineering models.

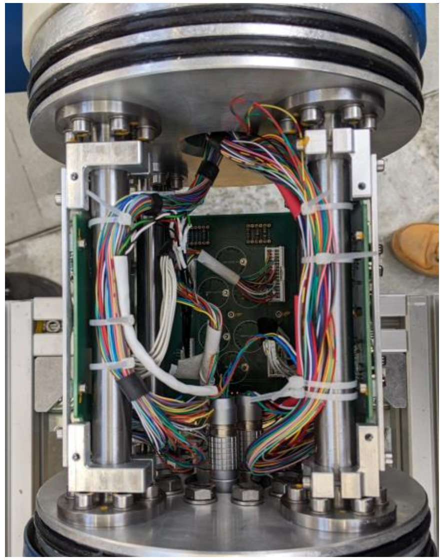


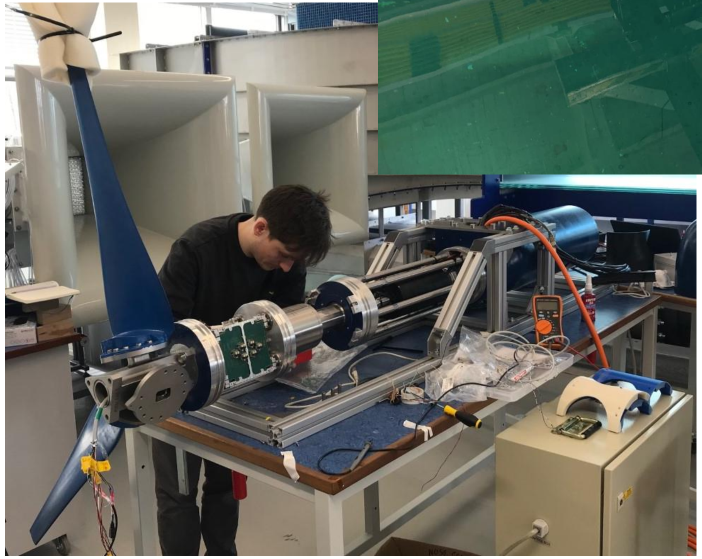


April 2022 Experiments

- Successfully tested in **April 2022 campaign** with data obtained for all steady and turbulent flow conditions,
- A selection of wave cases were also completed, with further wave testing scheduled for **Later Tests.**







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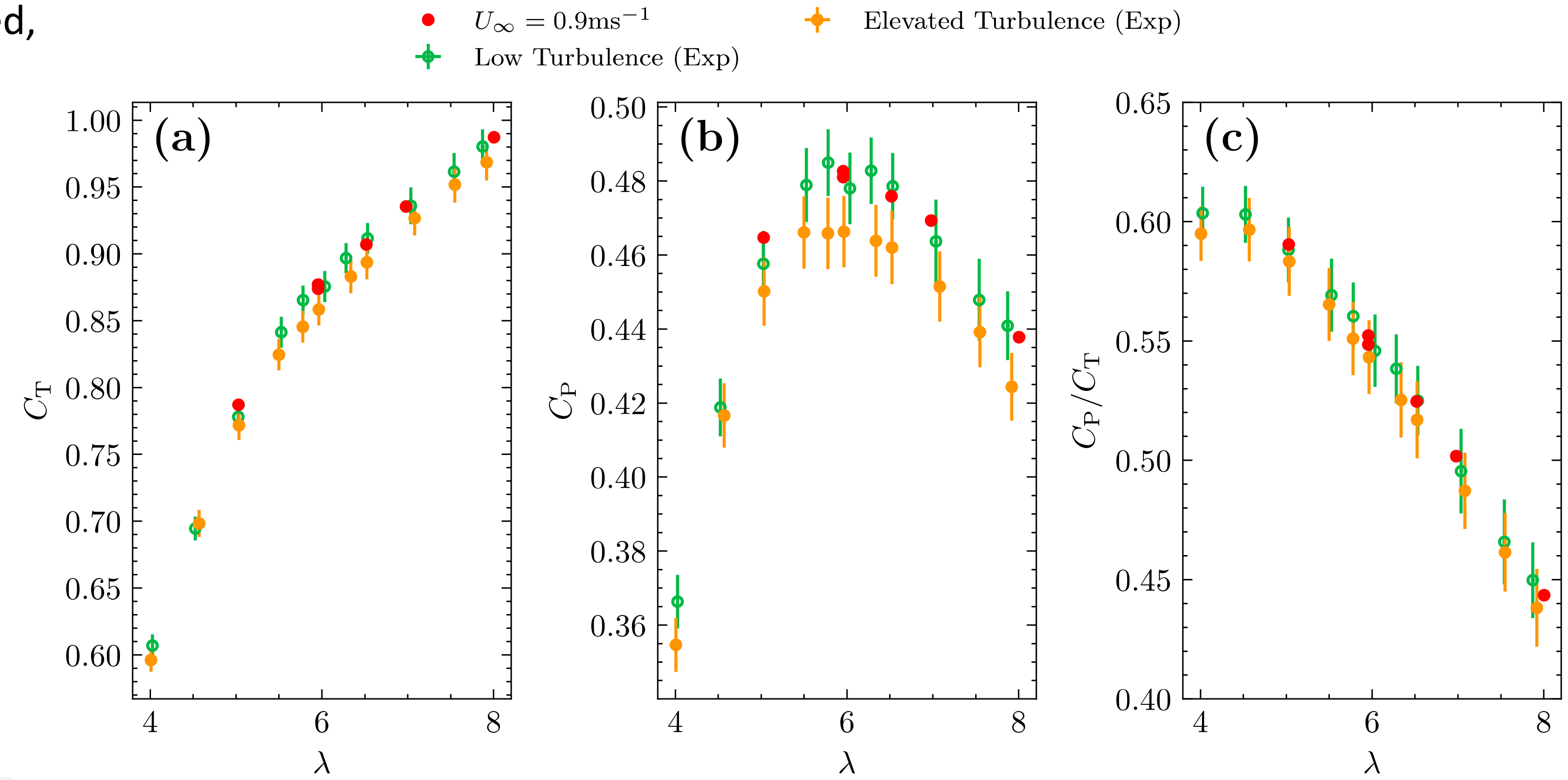
Experimental Results: Re independence

- Two flow speeds tested 0.9m/s and 1.0 m/s without turbulence grid,
- 3 repeats of each TSR providing uncertainty interval,
- Re independence achieved,
- Relevant post-
  -transitional Re data set.



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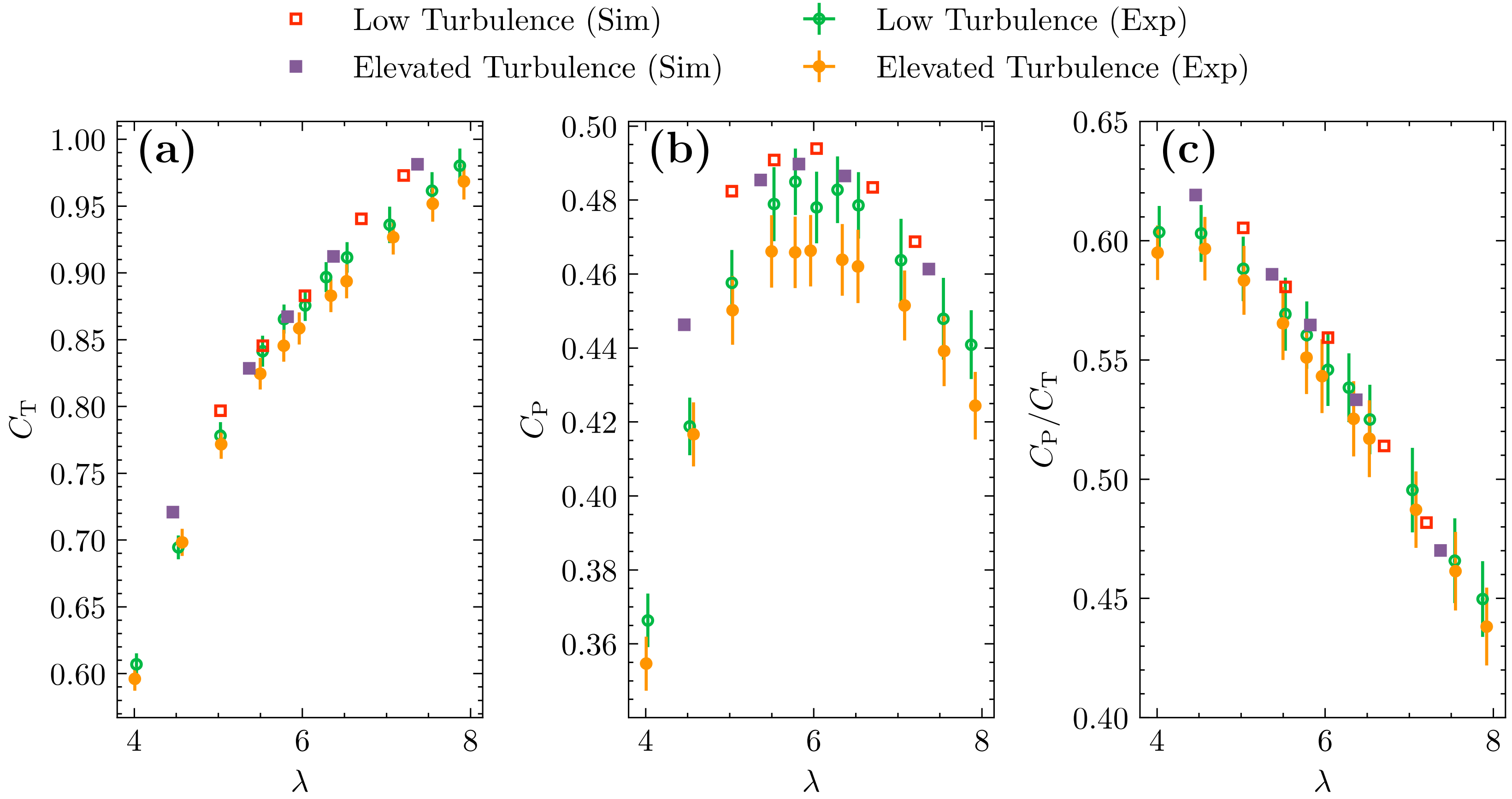
Experimental Results: Integrated Variables

- Peak C_p of **0.485** at a TSR of **5.78**,
- Elevated turbulence has **little influence on thrust coefficient** with a **small decrease on power coefficient**,

- Well controlled to low TSR.
- Blade resolved simulations (single blade MRF, RANS) show good agreement with Low TI but are largely insensitive to TI.

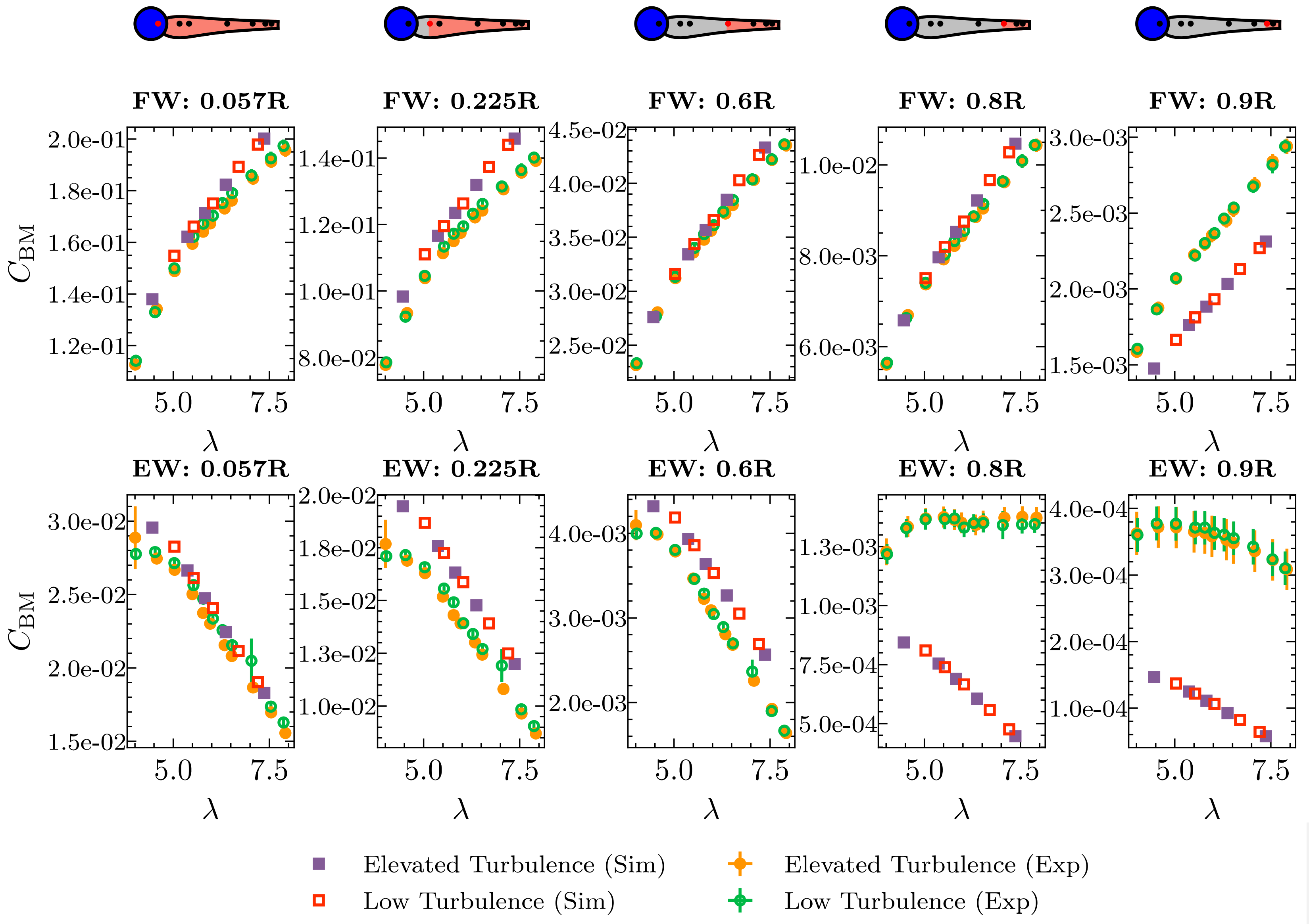


Experimental Results: In-blade & Root Bending Moments

- Flapwise (FW) and Edgewise (EW) bending moment coefficients

$$C_{BM} = M_{BM} \frac{16}{\rho \pi D^3 U_\infty^2}$$

- Minor changes between Low and Elevated TI levels,
- CFD simulations over-predict EW in mid-span locations & under-predict FW & EW at tip,
- Root BM well predicted
- Blade tips thought to have twisted during experiments.



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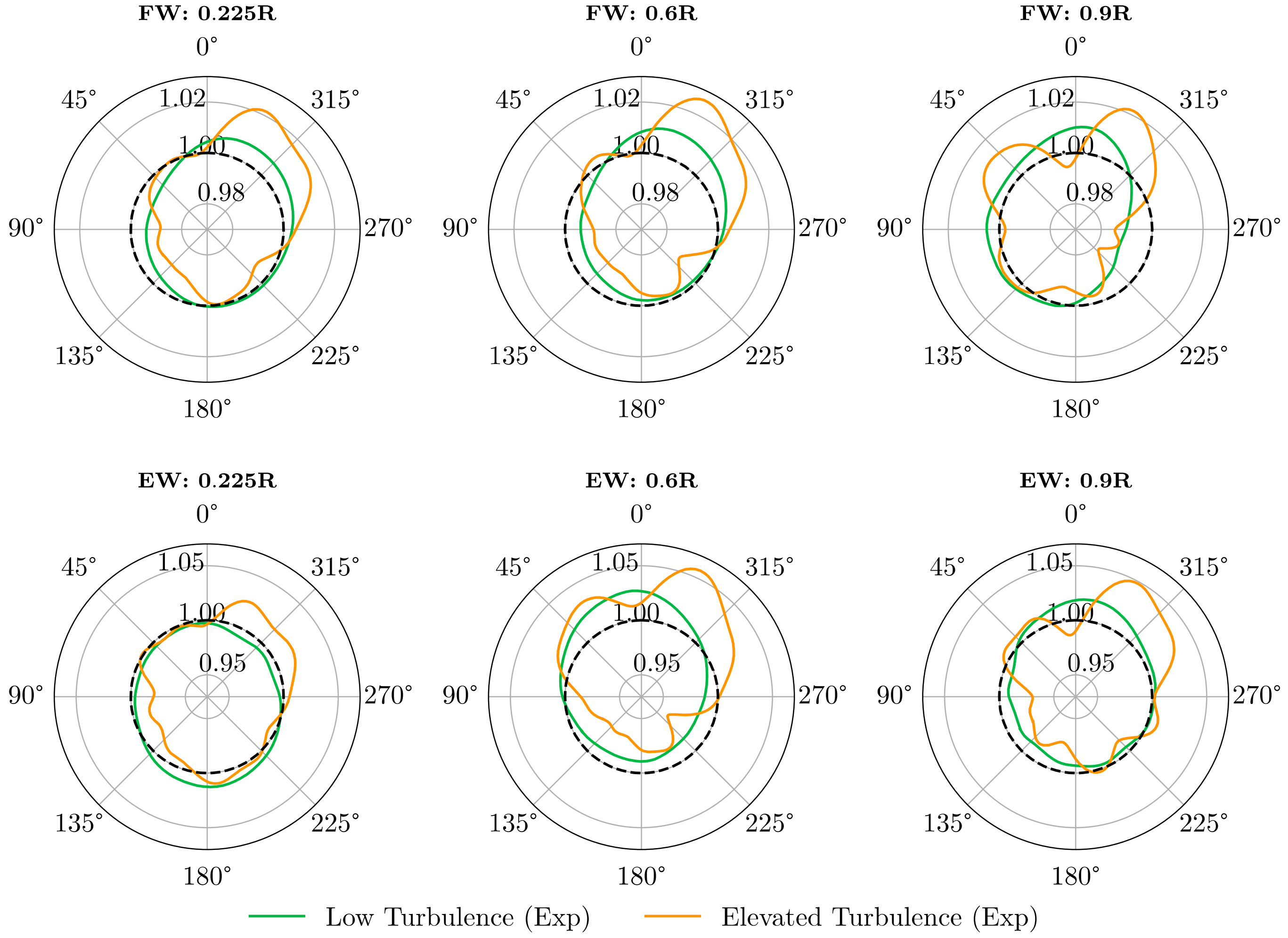
Experimental Results: In-blade & Root Bending Moments

- Normalised bending moment coefficients

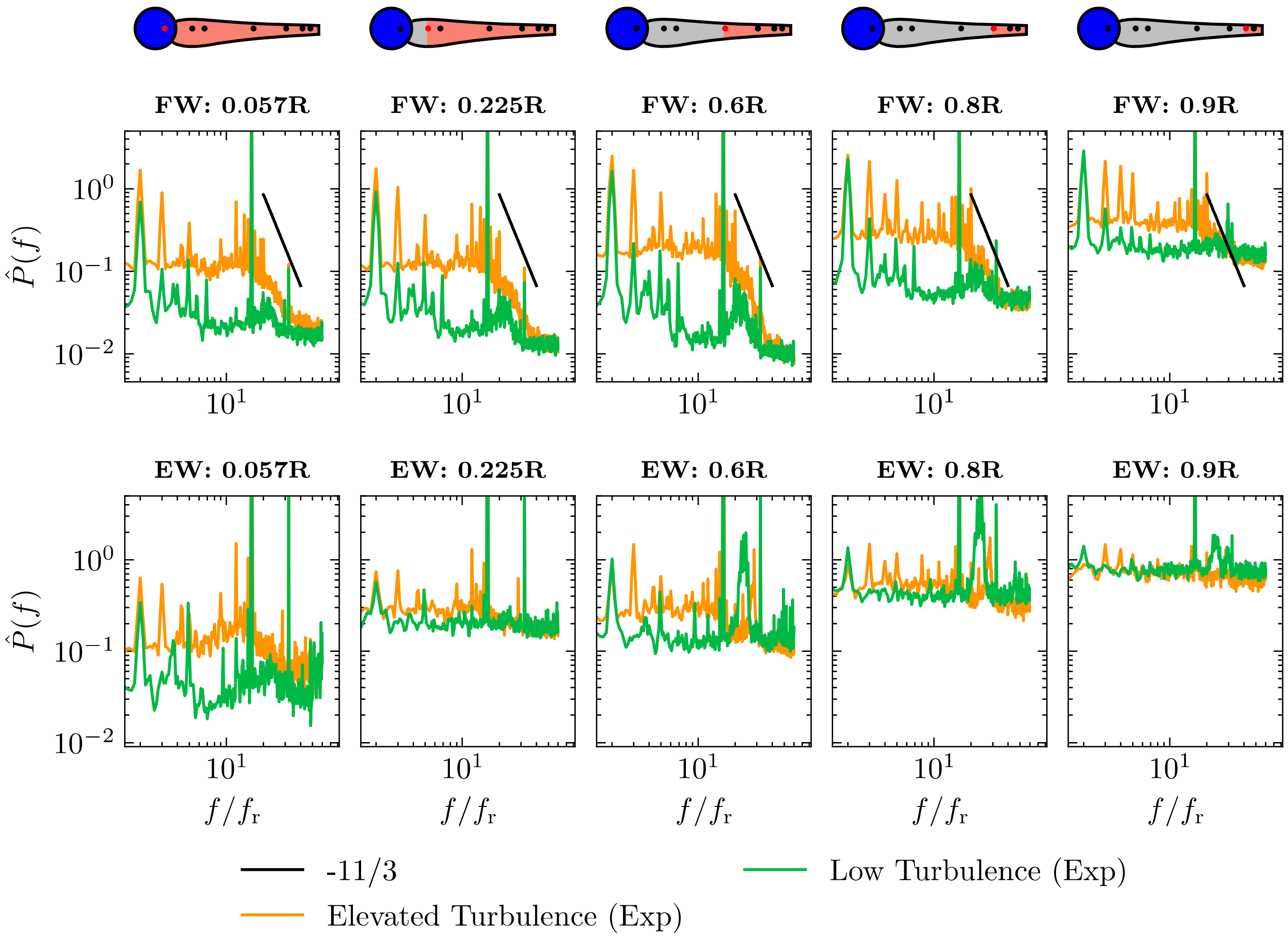
$$C_{BM} = M_{BM}\frac{16}{\rho\pi D^3 U_\infty^2}$$

- Shade indicates data fluctuation,
- Azimuthal variations at Low TI shows once per revolution content - FW and EW BM peak before and after top-dead-centre, due to surface passing,
- At Elevated TI, azimuthal variation shows higher frequency components.



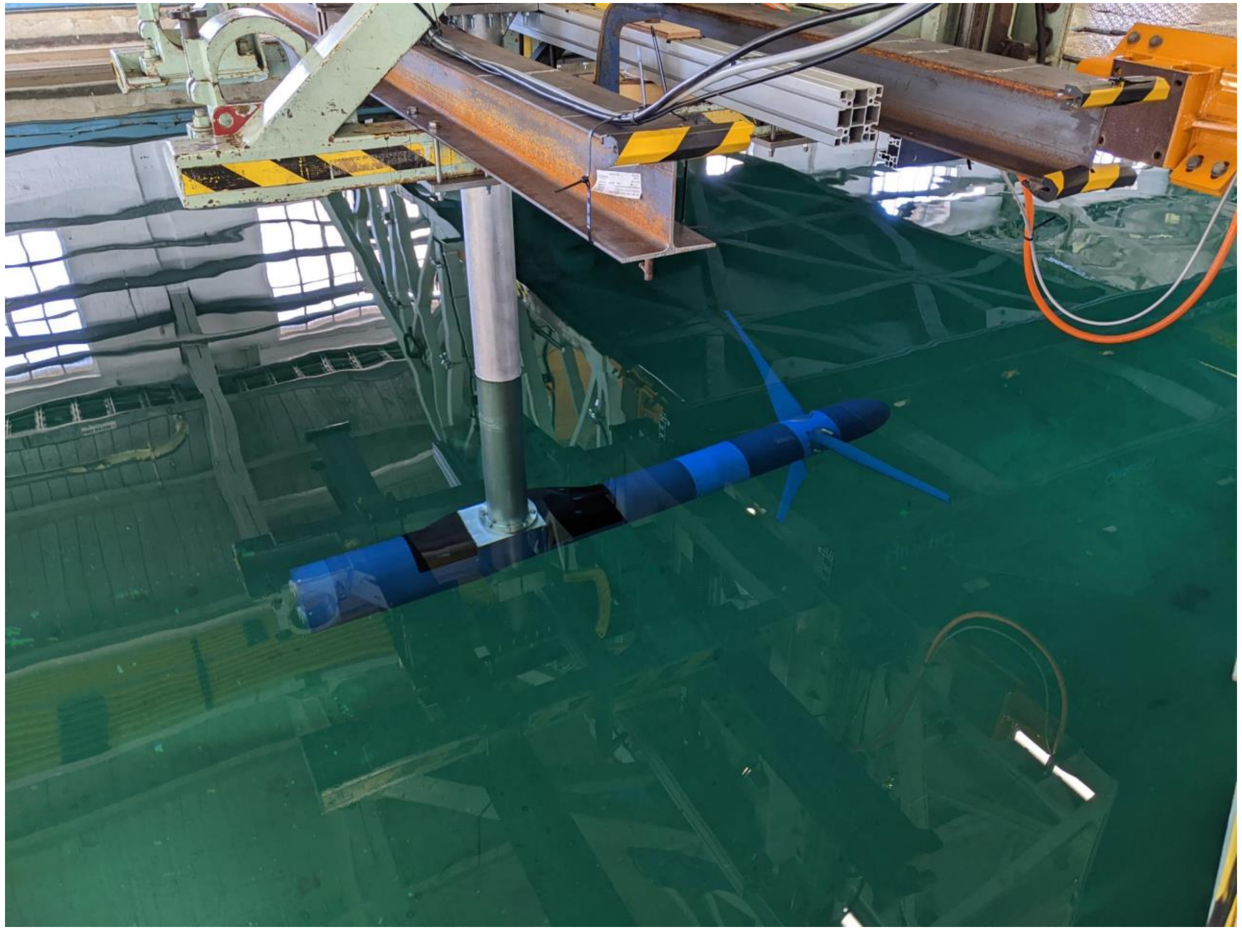
Experimental Results: In-blade & Root Bending Moments

- Uplift in spectral content between Low and Elevated TI levels,
- FW BM appears more sensitive to TI level than EW BM,
- High freq. decay following -11/3.

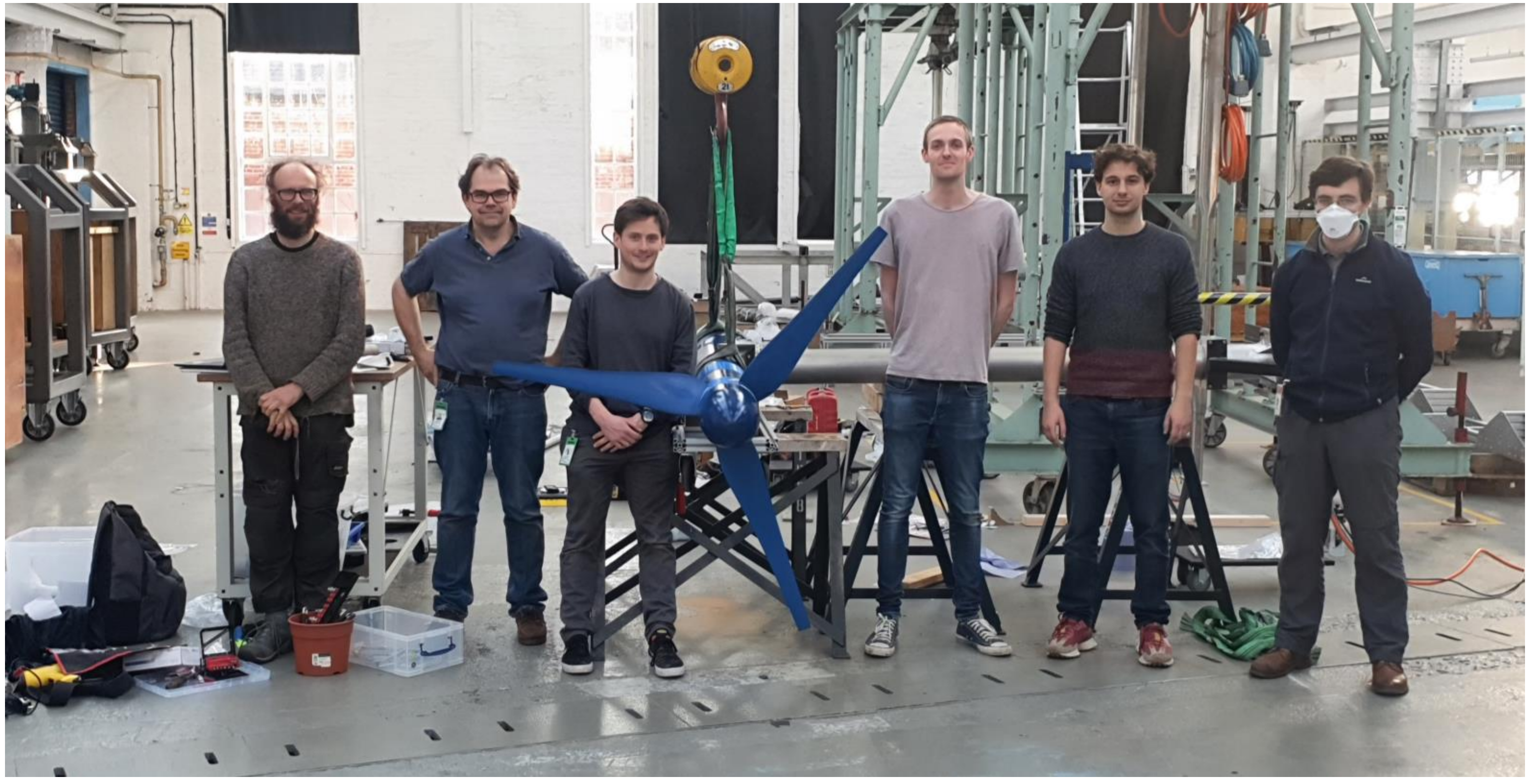


Conclusions

- Successfully designed and tested a 1.6m diameter tidal turbine in Low and grid generated Elevated (3.1%) turbulence conditions,
- In-blade strain gauging and optic fiber bragg gratings systems developed,
- Recorded spanwise bending moment distributions and their variation around azimuth,
- Mean BM between Low and Elevated TI not significantly different,
- But even this low level of TI leads to more energetic BM across frequency range,
- In-house blade resolved CFD simulations agree relatively well with departures in tip region due to blade twisting in the experiments.



Questions?



EWTEC Workshop: Supergen ORE Hub Research and Tidal Turbine Benchmarking Project
Side Event 9 at 4-5:30pm, room Oteiza, 1st floor