# Unsteady Loading Tidal Turbine Benchmarking Project

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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.
- **Objective**:
  - improve accuracy of modelling techniques,
  - improve confidence in the use of modelling techniques,
  - quantify modelling errors for different techniques under different loading scenarios.
  - development of novel measurement techniques
- **Approach**:
  - Conduct a large laboratory test of a well instrumented tidal turbine in waves and current to provide underlying data,
  - Conduct a series of community wide (academia and industry) blind prediction exercises with staged data release.

Inspection of Sustainable Marine Energy Plat-I turbine blades [1]

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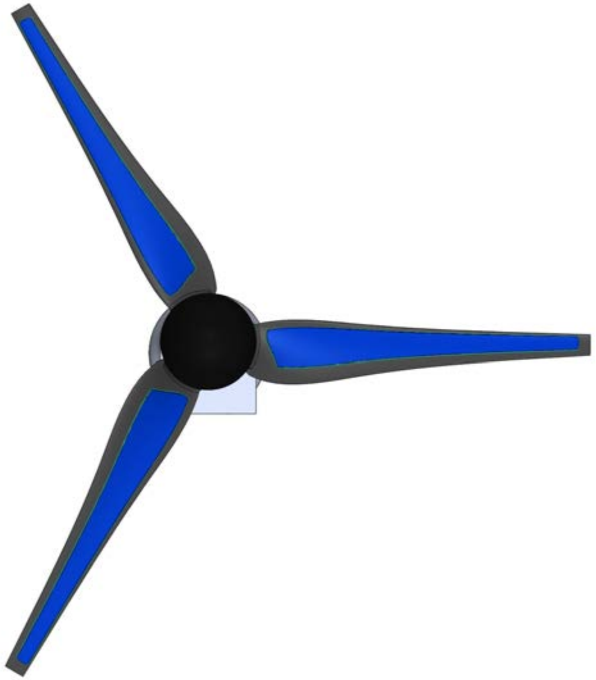
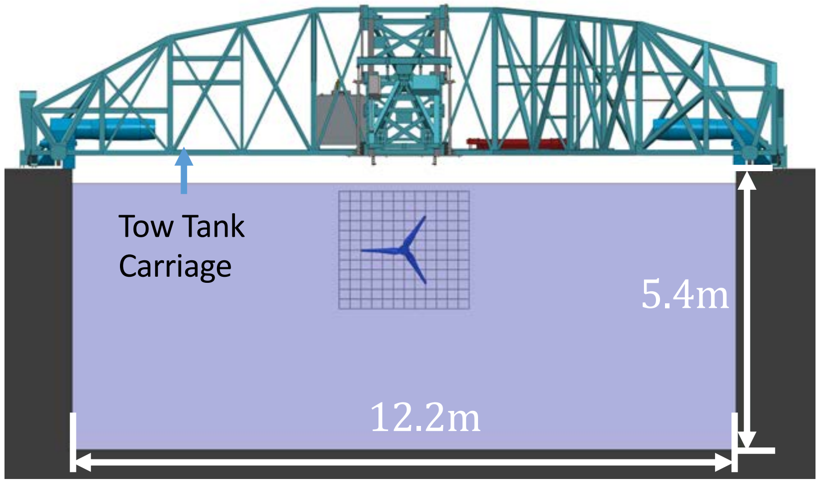
# Benchmarking Project: Turbine requirement

- Validation data sets (MEXICO, NREL IV etc) exist for wind.
- Whole rotor and whole blade data sets (Bahaj, Ifremer etc) exist for tidal, i.e. rotor torque/thrust and blade root bending.
- To understand and be able to predict the impact of waves and turbulence on blade loads we need a higher data resolution in the form of **spanwise loading distributions**.
- Require **in-blade sensing** (strain gauges, optic fibres).
- Critically important to achieve **Reynolds number independence**.
- **1.6m diameter 3 bladed rotor** with in-blade sensing.



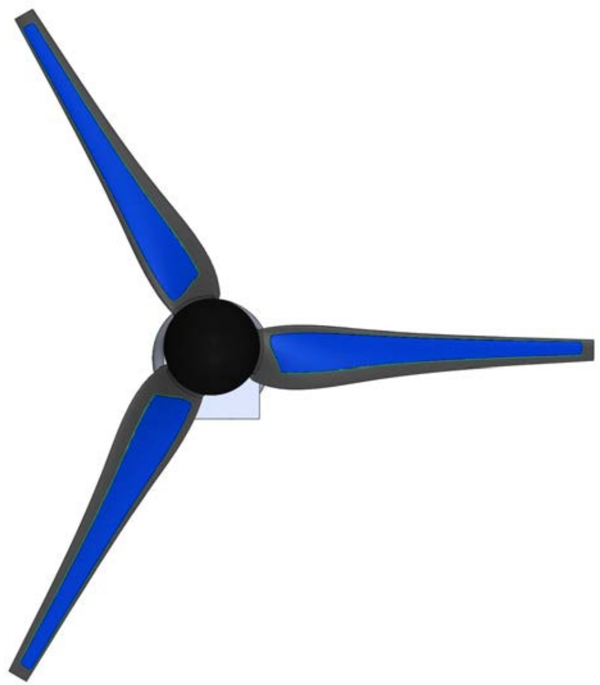
# Benchmarking Project: Facility and Tests

- Require **low blockage** experiments with a **large diameter** rotor for sensing and **Reynolds independence**.
- Flume options – blockage too high
- Tow tank – low blockage but turbulence too low
- Solution: **tow tank with an upstream turbulence grid**
- Test conditions:
  a) Uniform flow
  b) Uniform flow + Waves
  c) Uniform flow + Grid generated turbulence



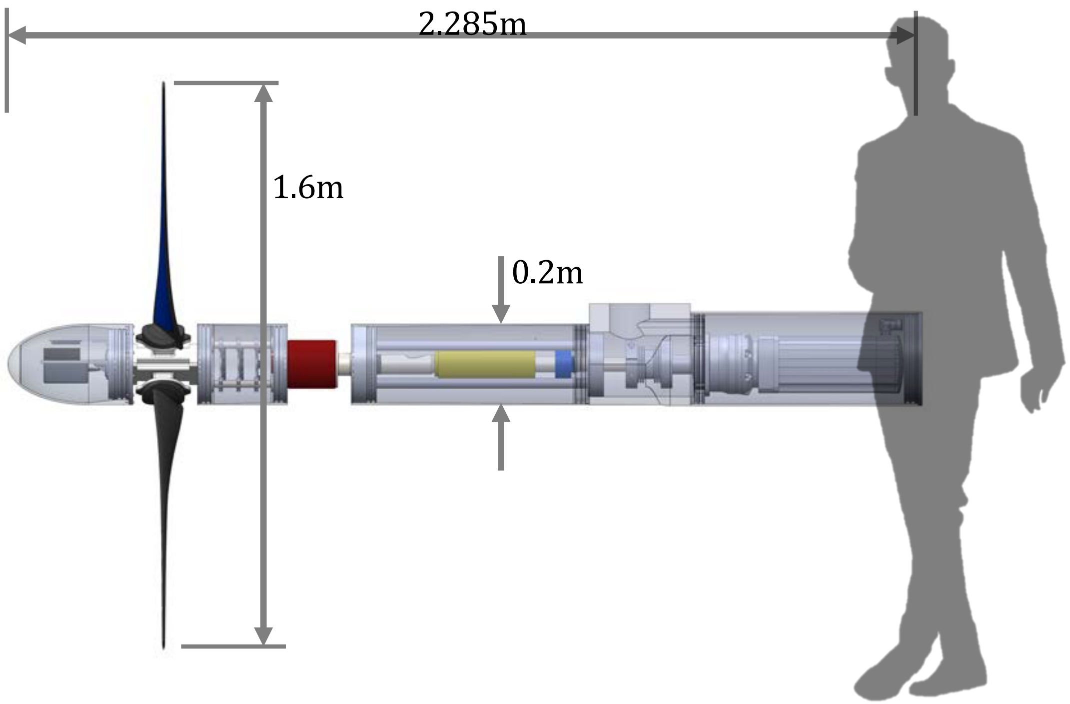
# Agenda

1. Turbine design / blade hydrodynamics
2. Blade instrumentation
3. Test facility
4. Turbulence grid and flow characterisation
5. Details of benchmarking exercise
6. Timeline
7. Open Discussion



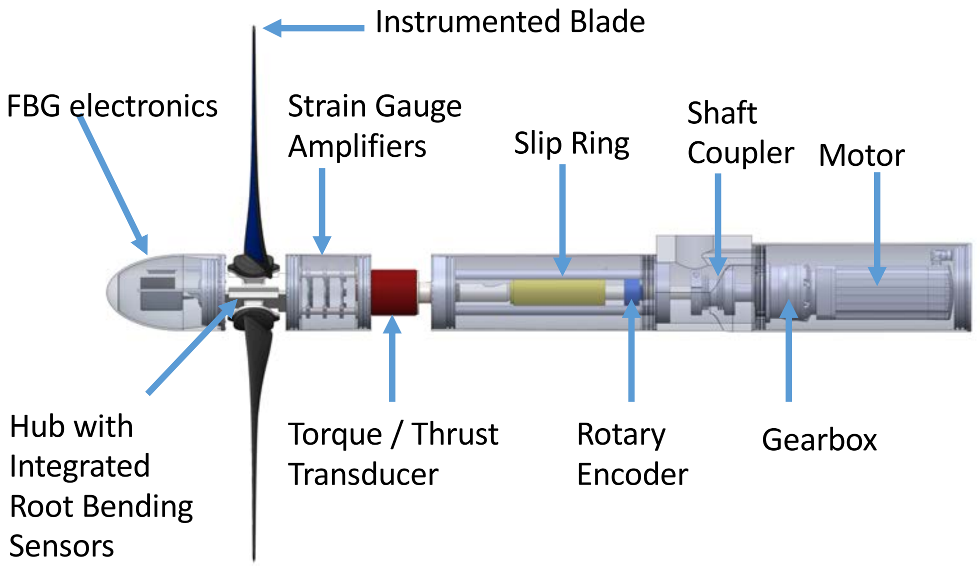
# Turbine Design: Overview

- 3 bladed tidal rotor
- Top mounted (carriage-mounted for towing tank experiment)
- $0.2\text{m}$ nacelle diameter provides $d_n/D$ of $0.125$.
- Nacelle diameter increased to $0.248\text{m}$ to accommodate large Moog servo motor



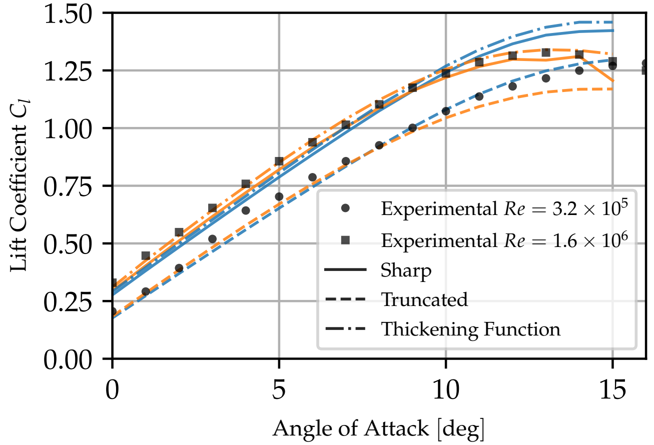
# Turbine Design: Overview

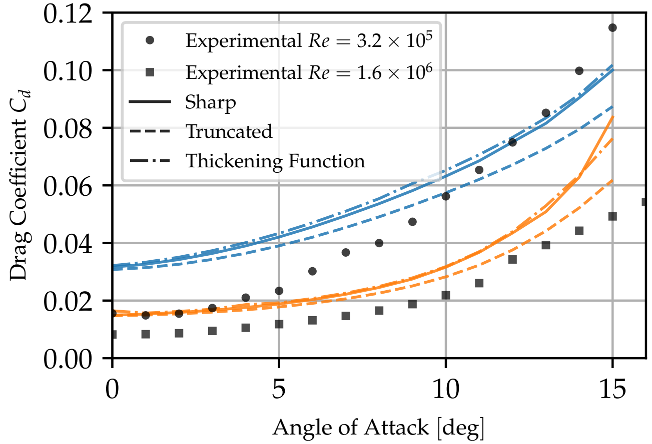
- Two blades instrumented with strain gauges at six radial locations in both edgewise and flapwise directions.
- Remaining blade instrumented with fibre Bragg sensors with similar resolution.
- Individual blade loads measured with hub – integrated root bending sensors (flap and edge).
- Torque and Thrust measured by shaft mounted transducer upstream of front bearing.
- Shaft rotary encoder for speed and position on low speed side.
- Motor and encoder on high speed side.

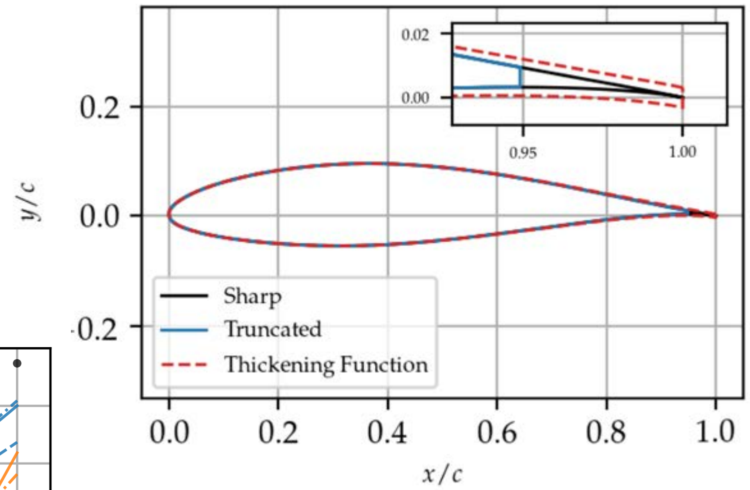


# Blade Hydrodynamics: Profile Selection

- Single foil selected for entire blade span.
- NACA 63-415 and 63-815 investigated as candidate foils
- Investigation of the use of a trailing edge thickening and truncating functions.



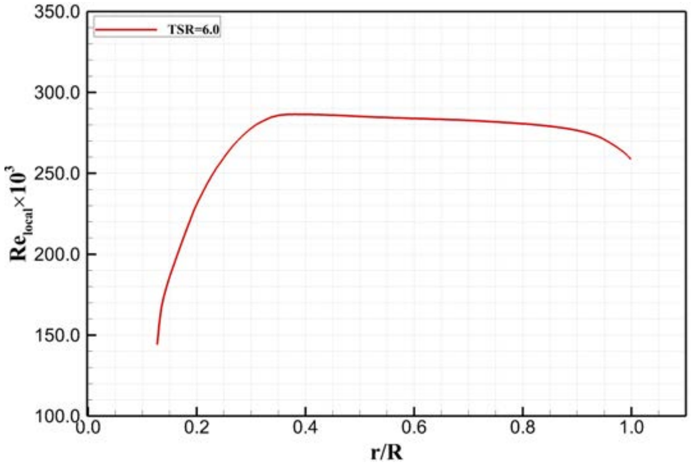



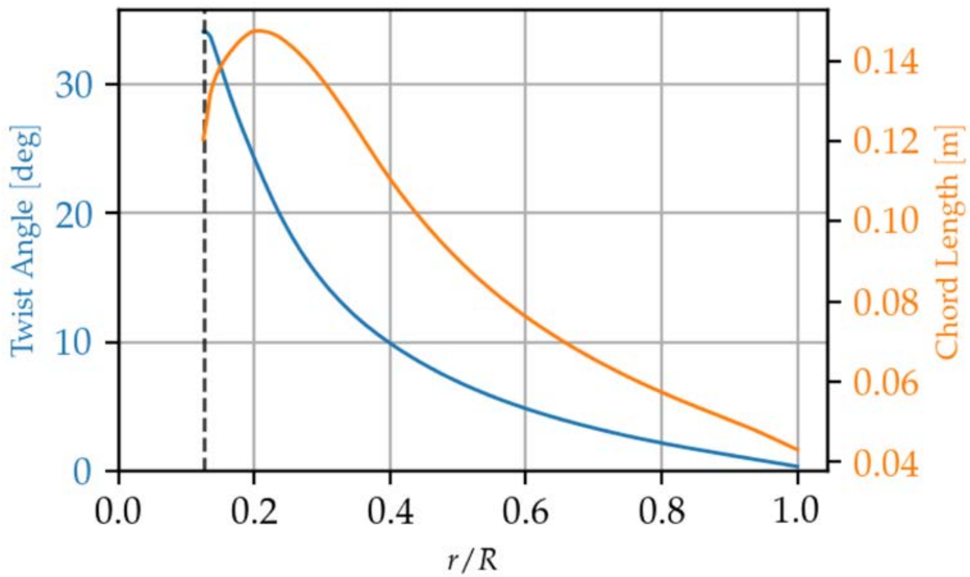




- 2D RANS simulations with SST turbulence model
- Thickening function provides coefficients much closer to the sharp trailing edge result
- NACA 63-415 profile selected with constant thickening function, i.e. single foil section along blade span.

# Blade Hydrodynamics: Design Simulation

- RANS – BE design simulation with target local loading of $C_x = 2$ and $\alpha$ to achieve max foil $C_L/C_D$
- Cylindrical domain – blockage matched to QinetiQ facility, $B = 3.05\%$
- Inlet conditions:
  - $U_\infty = 1\ m/s$
  - $Tu = 8\%, Lt = 1.12\ m$
- Tip correction neglected in design simulation

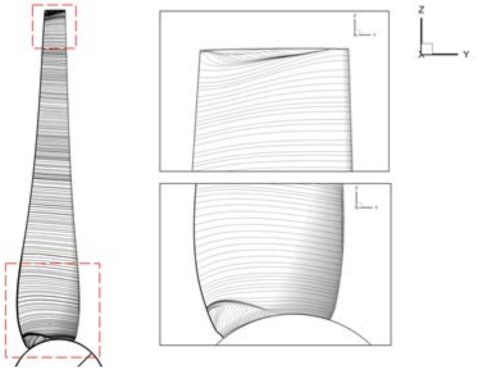


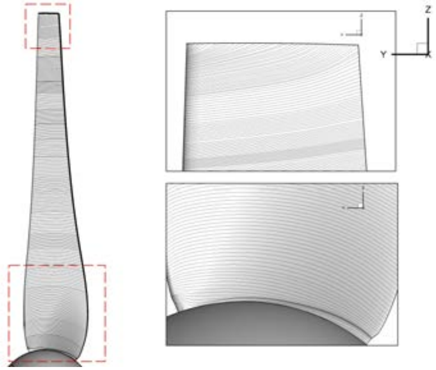
# Blade Hydrodynamics: Rotor Simulation

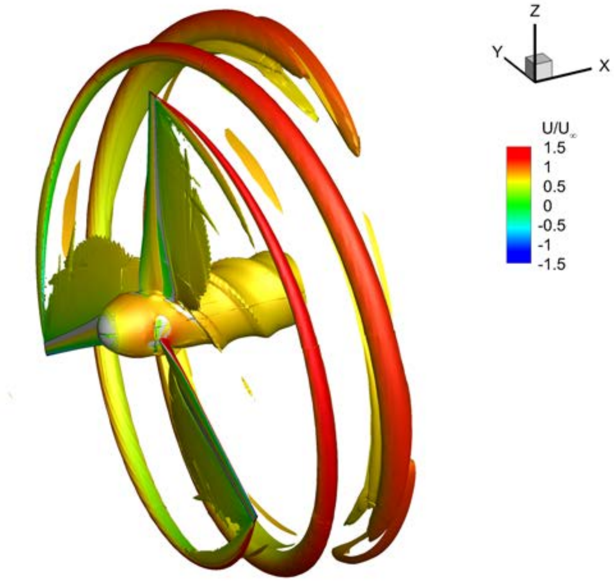
- Detailed 3D flows in hub and tip regions analysed and local modifications to twist and chord made to improve flow quality.
- RANS simulation with rotating frame of reference.
- 1/3rd mesh, 38M elements, kω-SST turbulence model.

**Pressure Surface**



**Suction Surface**

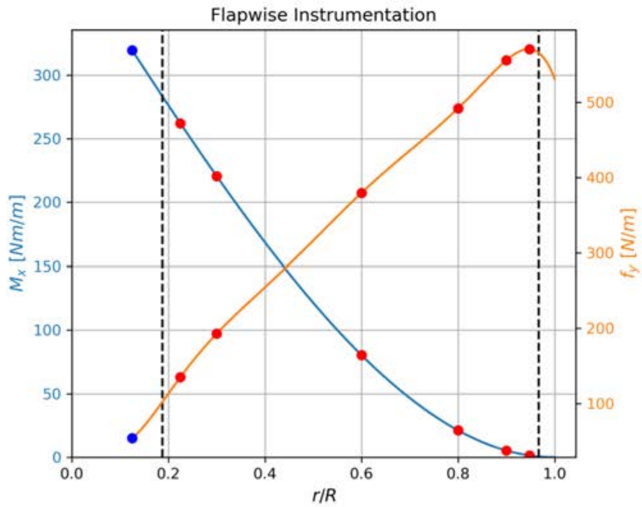


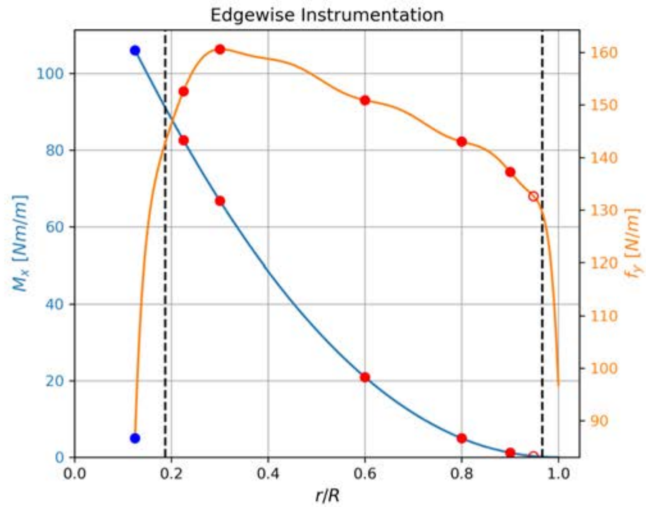



Isosurfaces of $\lambda_2$ vortex criterion

# Turbine Design: Instrumented Blades

- Two blades instrumented with strain gauges at six radial locations
- Flapwise bending moment at locations 1-6, edgewise bending moments at locations 1-5
- Locations chosen to capture BM variation.
- Instrumentation to $r/R$ of 0.94 flapwise and $r/R$ of 0.88 edgewise.

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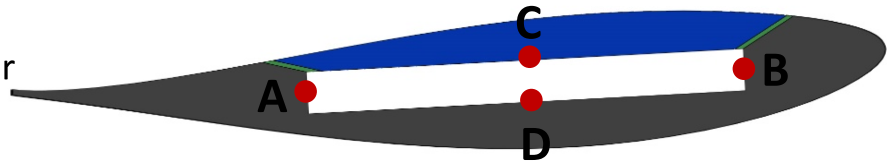
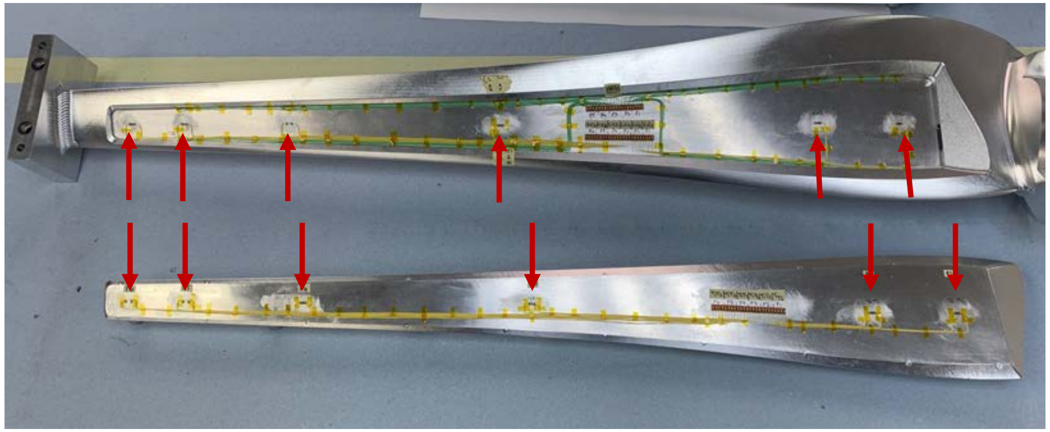
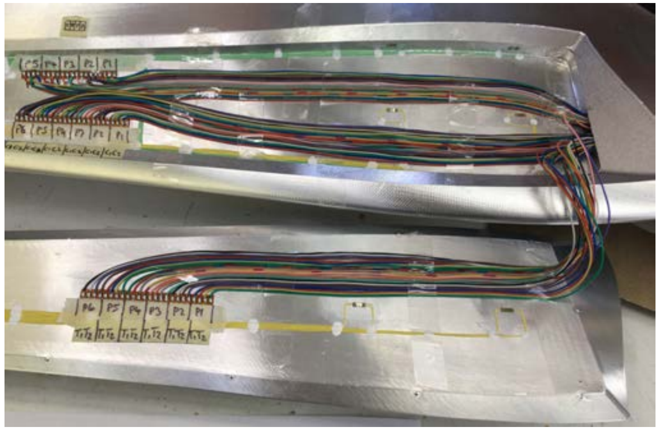
# Turbine Design: Instrumented Blades

- Instrumentation slot tapered and twisted around and along blade Neutral Axis.
- Sloped interface to maximise contact surface for slot cover adhesion.
- Post instrumentation final blade CNC once slot cover adhered followed by anodizing.

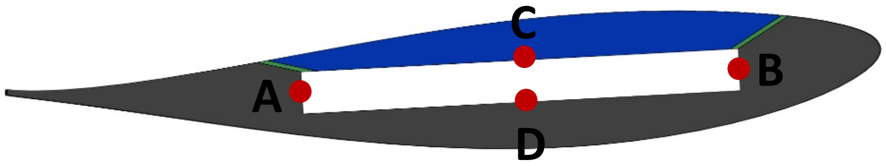


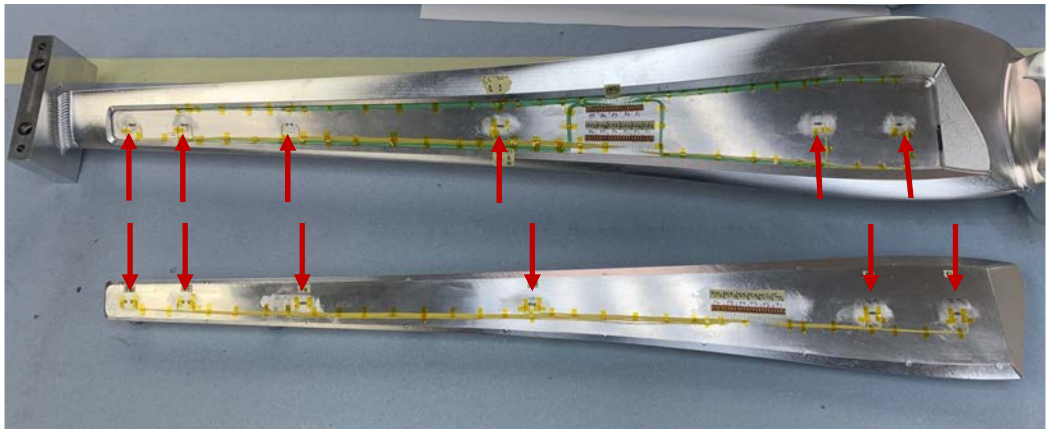



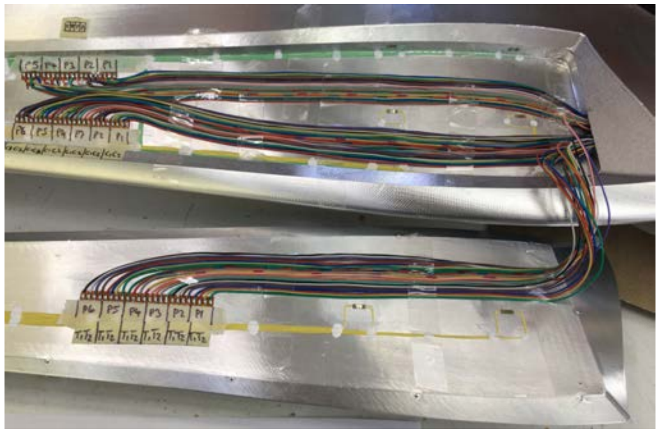


# Turbine Design: Strain Gauging

- Strain gauge positions chosen to minimise cross – talk between measurement directions.
- Full bridge configurations for both edgewise and flapwise measurements.
- Total 100 strain gauges; 44 in each blade, 4 in each blade root.

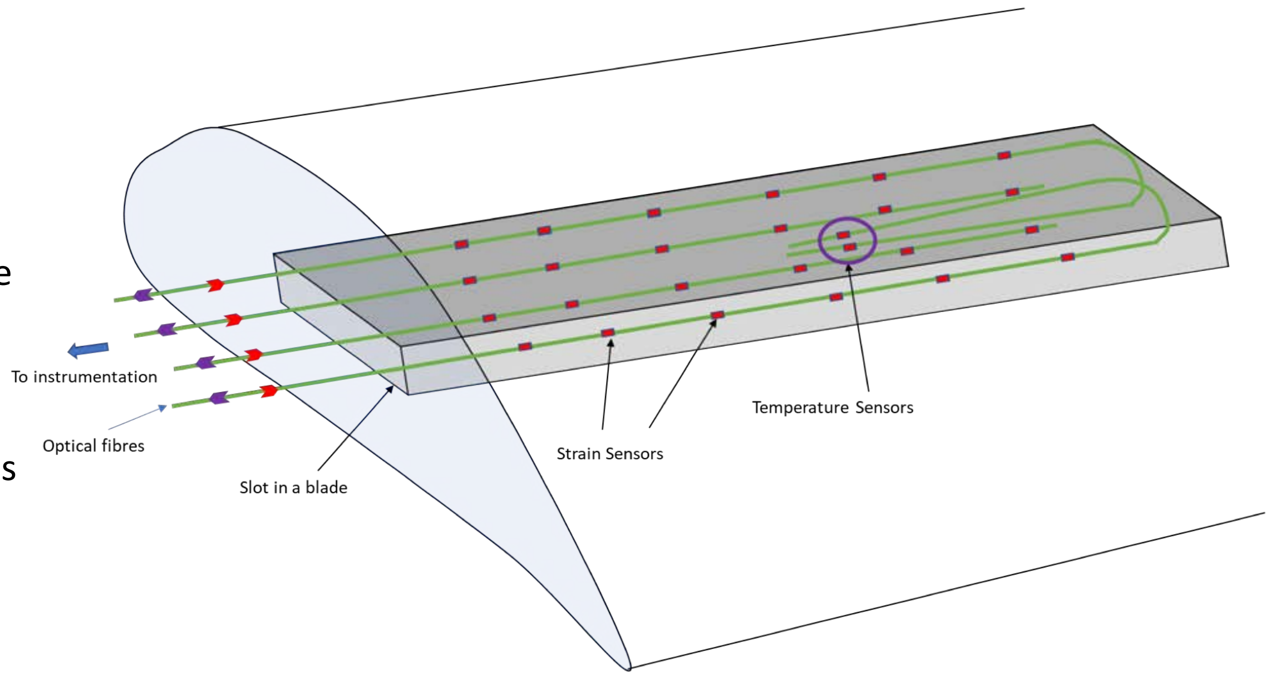




# Turbine Design: Fibre Bragg System

- Four independent fibres mounted into blades with FBG sensors positioned at measurement locations
- Fibre either side of sensor is adhered to the internal surface of the slot with epoxy
- Two additional fibres provide temperature sensing to compensate for thermal effects

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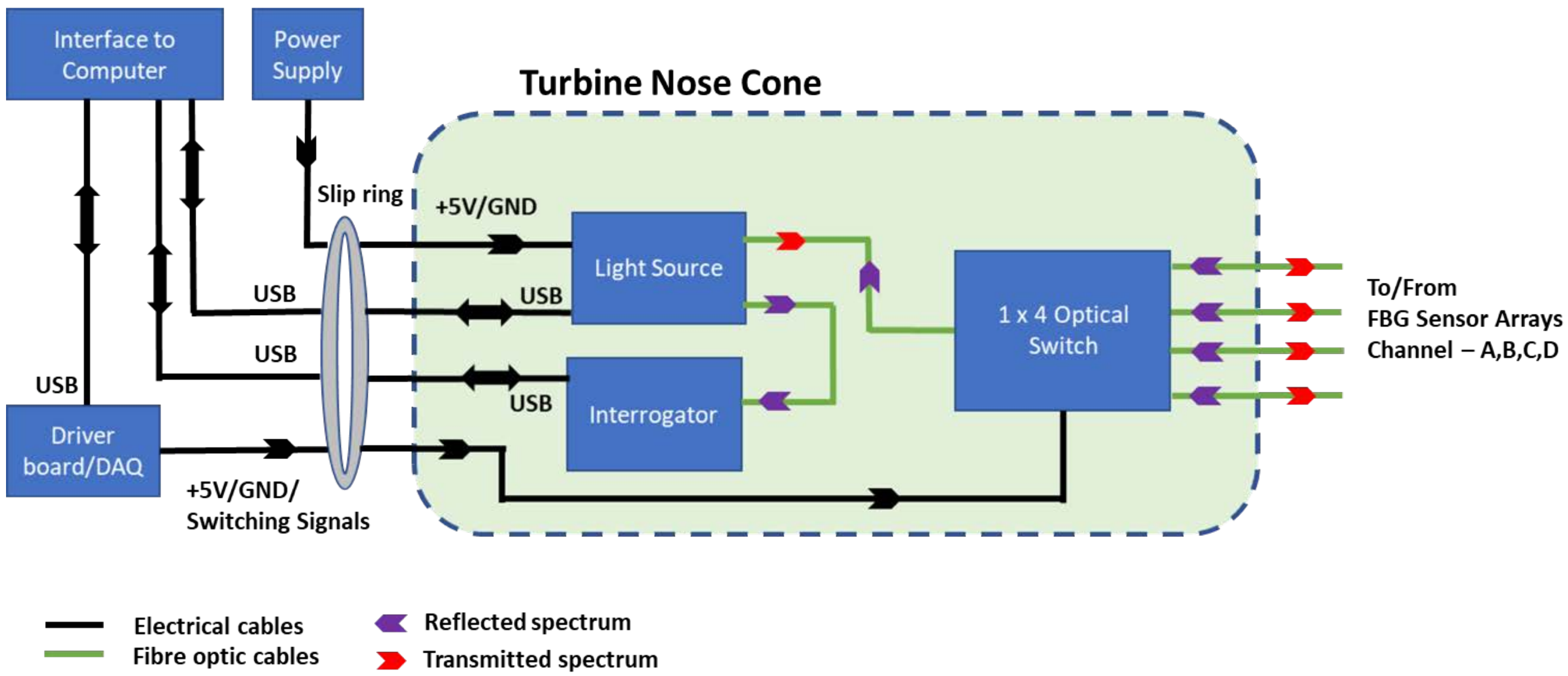
# Turbine Design: Fibre Bragg System

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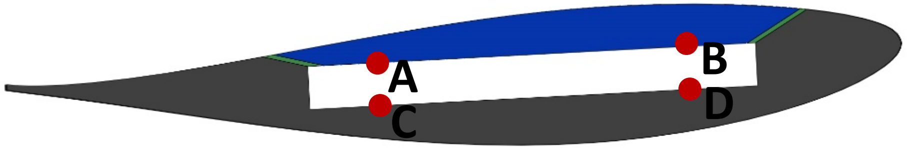
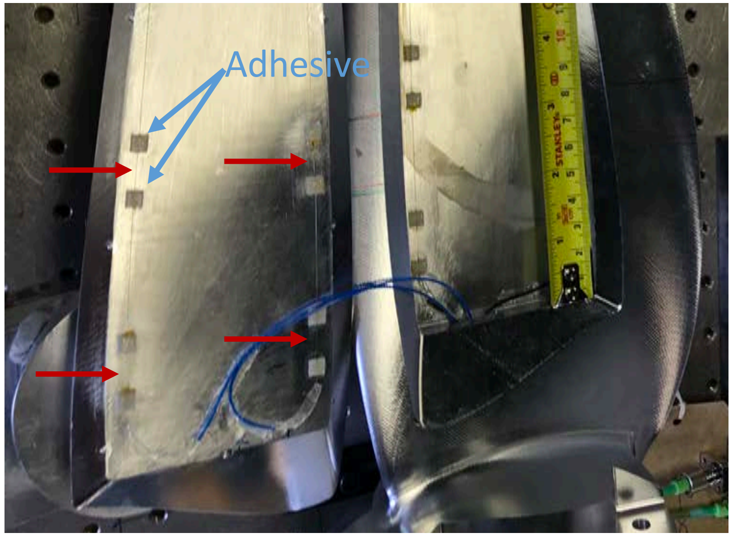
# Turbine Design: Fibre Bragg System

- 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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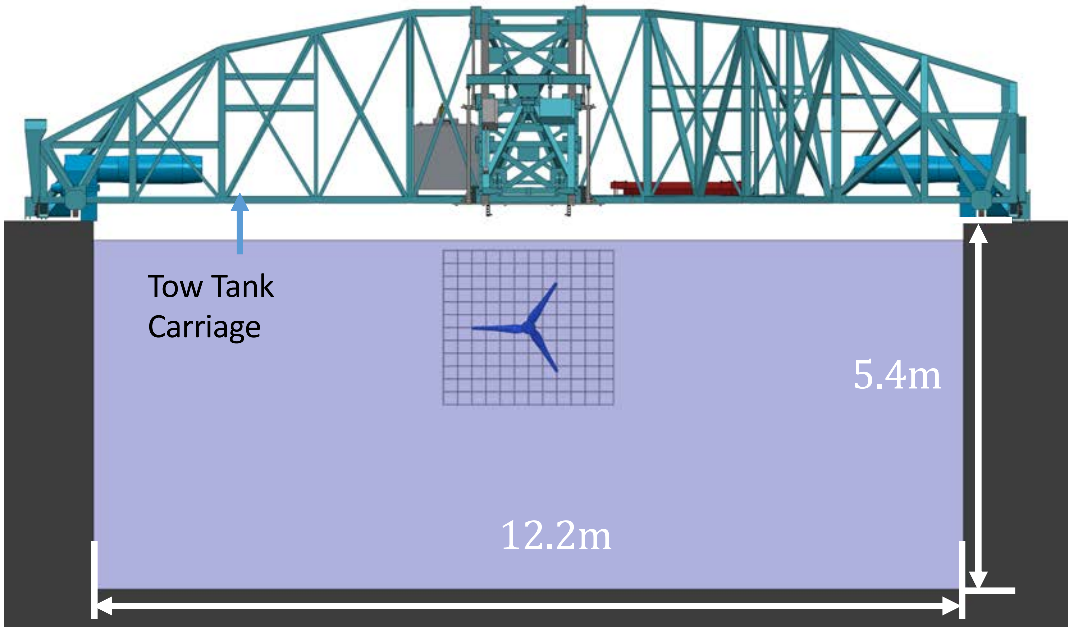
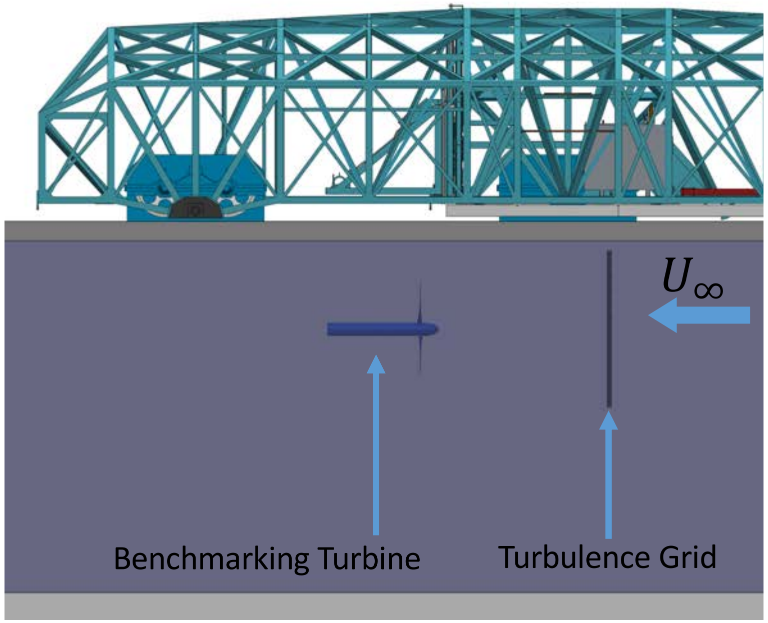
# Tow Tank Facility

- QinetiQ towing tank facility, Haslar, Portsmouth UK
- 270m (L) x 12.2m (W) x 5.4m (D)
- Speeds of up to 12.25m/s and drag loads up to 5kN
- Target tow speed 1m/s
- Tow length approx. 150m
- Settling time ~15mins

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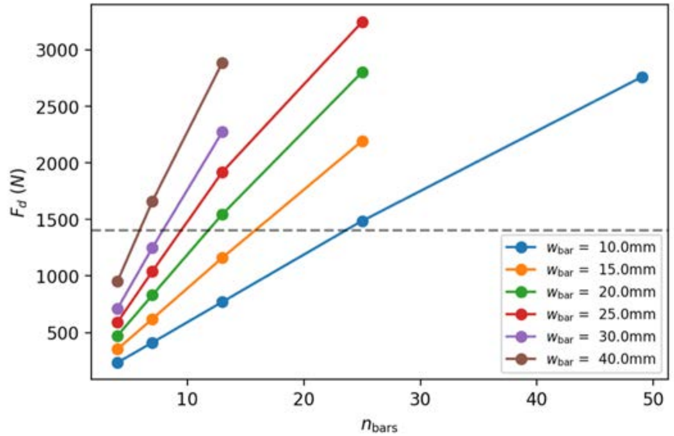
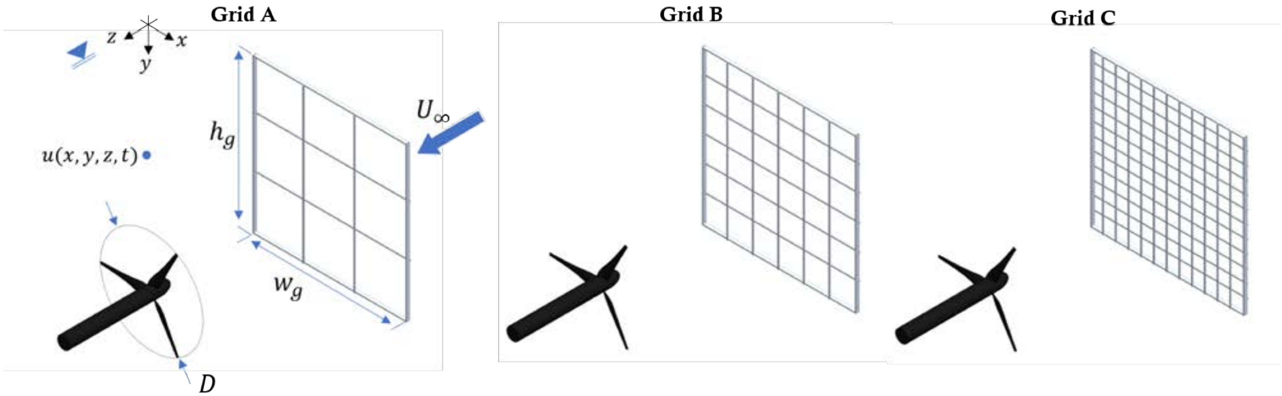
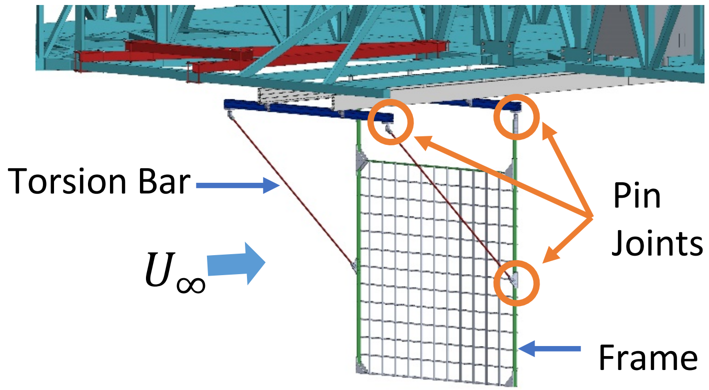
# Turbulence Grid Design

- Size: $1.5D \times 1.5D = 2.4 \times 2.4\text{m}$
- Variable porosity (adjust number of bars)
- Torsion bars used to resist drag force
- Use of pin joints allows the turbulence grid to rotate between a horizontal and vertical configuration

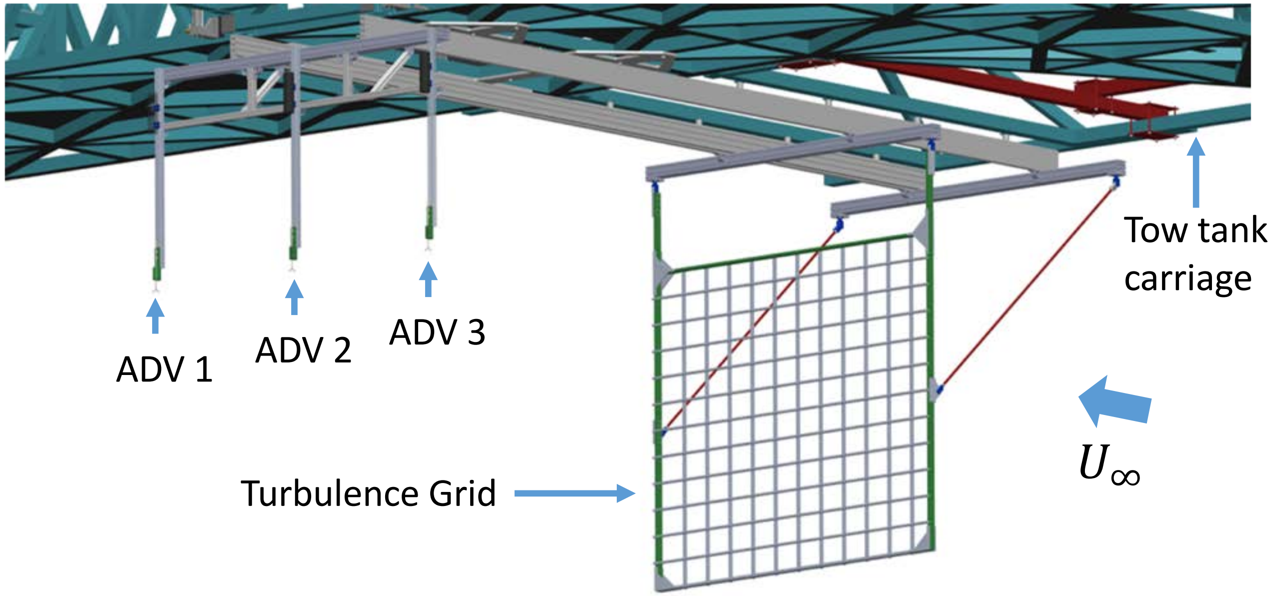


# Turbulence Grid: Flow Characterisation

- Flow velocity measured with 3 Acoustic Doppler Velocimeter (ADV) probes
- ADV positions to be adjusted to obtain a horizontal, vertical and diagonal profile each with 6 points



# Turbulence Grid: Flow Characterisation

- Acoustic Doppler Velocimeters require seeding particles to calculate flow velocities
- The large volume of towing tanks prohibits uniform seeding of the entire tank (17.8 million Litres - £130,000 in seeding material!)
- Targeted seeding injected with a pump at the measurement location along the tank prior to test run.
- Approx. $0.8\ m^3$ seeded fluid pumped per seeding cycle. Total of around $10\ m^3$ of seeded fluid injected.

# Turbulence Grid: Flow Characterisation

- Minimum streamwise velocity of $0.913\ U_\infty$ at centre of turbulence grid
- Average value of $0.917\ U_\infty$ across turbine with $\pm 0.5\%$ variation
- Turbulence intensity can be defined as,

$$I_i = \frac{u'_{i\ \mathrm{rms}}}{\sqrt{\bar{u}_x^2 + \bar{u}_y^2 + \bar{u}_z^2}}$$

- Streamwise turbulence intensity across turbine between $2.9\%$ and $4.3\%$ with $3.5\%$ mean

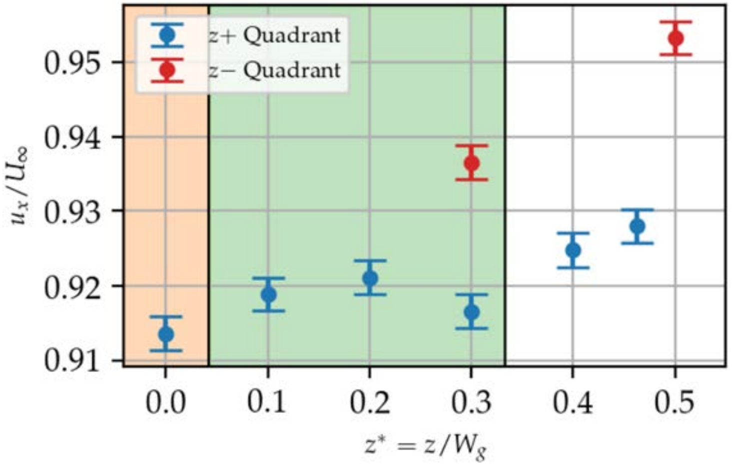
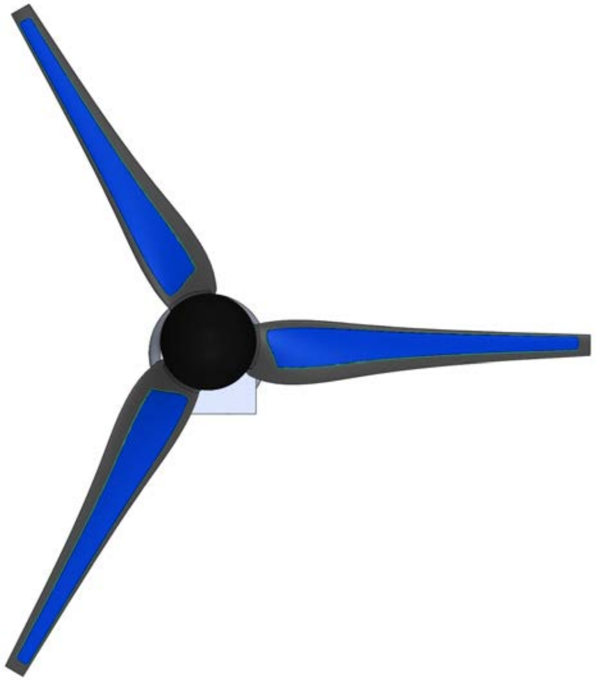



Figure: vertical profile of streamwise velocity measured close to the location of the turbine plane.

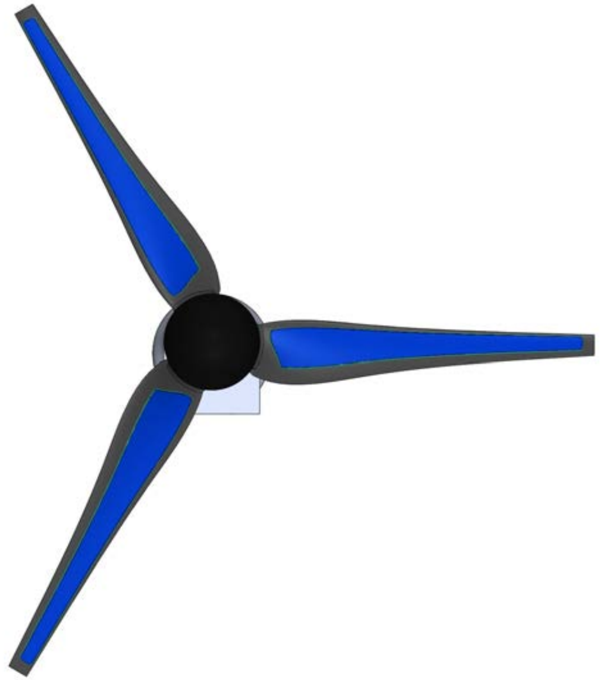
# Benchmarking: Provided Data / Test Conditions

- **Turbine geometry:**
  - 3D CAD data of nacelle and tower
  - 2D aerofoil sections / chord and twist distributions
  - 2D aerofoil data
  - Blade 3D CAD data
- **Turbulence grid geometry:**
  - 3D CAD data
- **Test conditions:**
  - TSR range / turbine speed and carriage velocities
  - Wave conditions
  - Flow data from turbulence grid characterisation



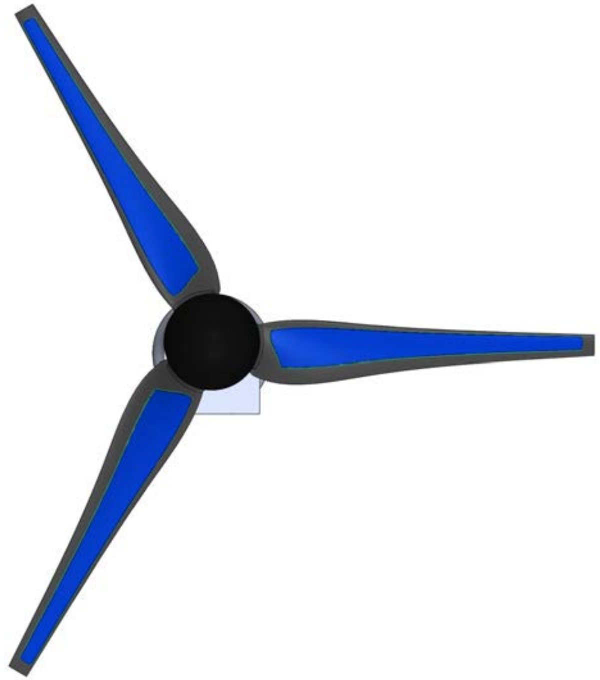
# Benchmarking: What will be compared?

- **Integrated variables:** ($C_p$ and $C_t$) over the full TSR range
- **Blade loads:**
  - Edgewise and flapwise root bending moments
  - Edgewise and flapwise bending moment distributions
- **Turbine wake flow measurements:** TBC
- **Wave measurements:**
  - Surface elevation above turbine plane
  - Additional measurement locations TBC



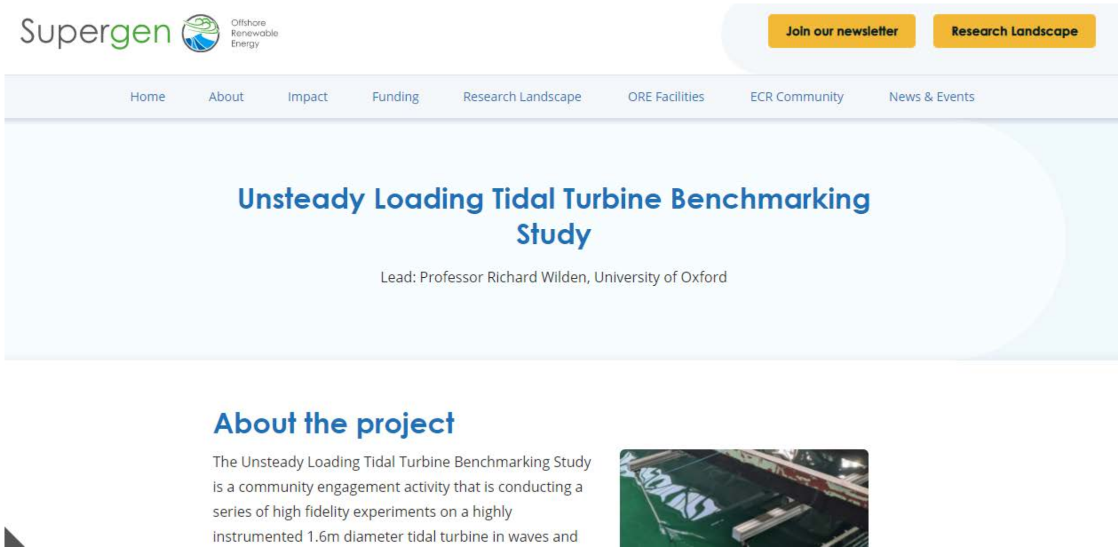
# Benchmarking: Participation

- **Community Project**: all academic and industry modellers are welcome to take part in the benchmarking exercises.
- We are looking for participation across the whole suite of modelling techniques:
- BEM, Blade resolved CFD, RANS-BE, Actuator Line, Vortex methods and others.
- This is not a competition! The objective is to **quantify errors** and limits of applicability of different modelling techniques and application of those techniques, **to build confidence**.
- Two workshops with staged release of data:
  - Workshop 1 – Uniform flow at low and higher turbulence levels
  - Workshop 2 – Turbine in waves
- Final open access release of all data.
- **How to participate?** Email Richard.willden@eng.ox.ac.uk to register your interest in participating in the benchmarking exercise including what modelling techniques you intend to use



# Benchmarking project webpage

- A webpage on the Supergen website will host all information / links to repository for the benchmarking project
- URL: https://supergen-ore.net/projects/tidal-turbine-benchmarking

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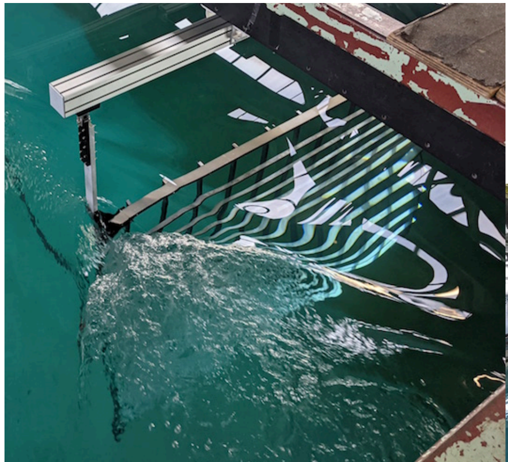
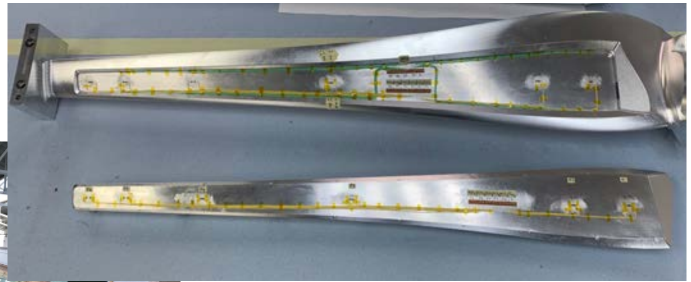
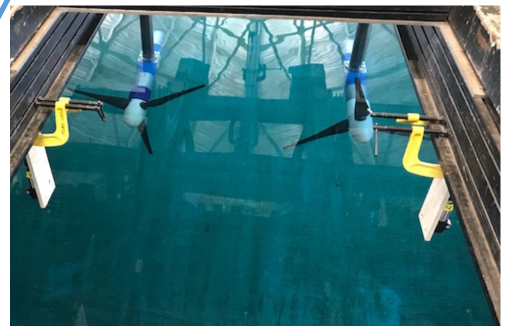
# Timeline





Benchmarking briefing at EWTEC conference to kick-start the modelling work



Turbulence Grid Characterisation Experiment I

Turbulence Grid and wave characterisation Experiment II

EWTEC Conference

Blade Manufacture Complete

Benchmarking Turbine Experiment

First Benchmarking Workshop (TBC)

April 2021

July 2021

September 2021

December 2021

April 2022

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