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This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 727689

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Loads and forces experienced by model tidal turbines

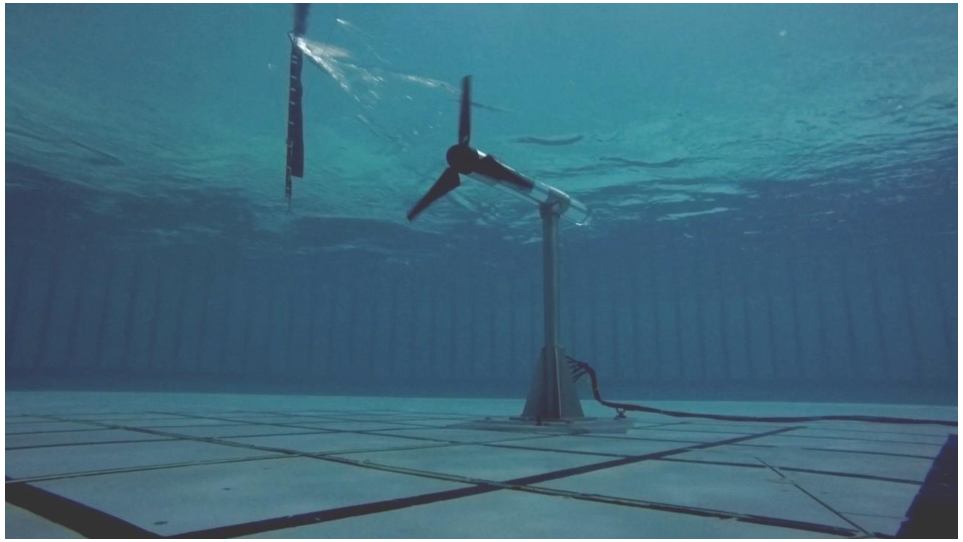
Prof David Ingram

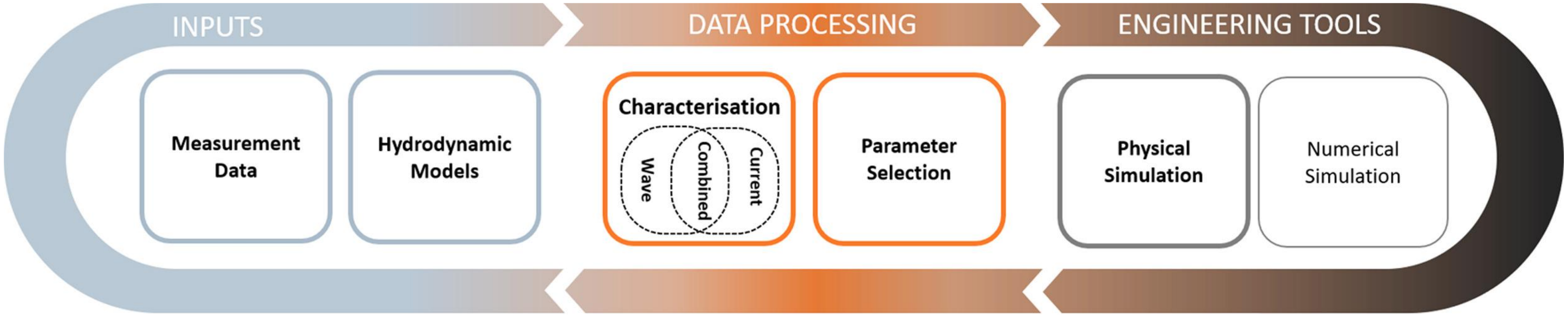
The University of Edinburgh

Impact of Model Testing

We need to:

- Understand the loads, forces and moments acting on turbines in the *real environment*
- Validate numerical models and design tools





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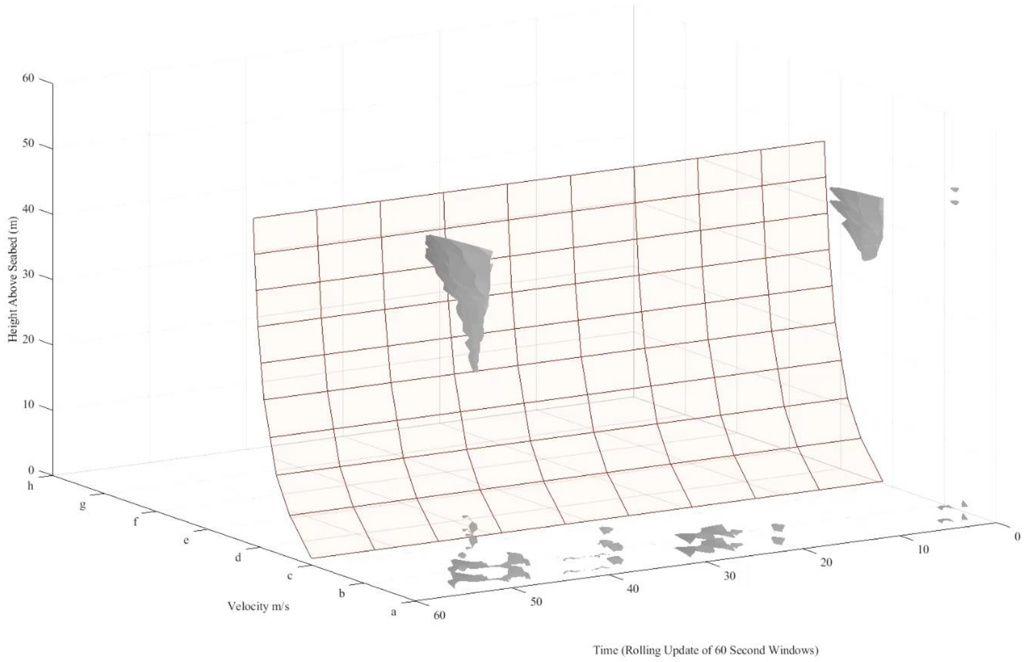
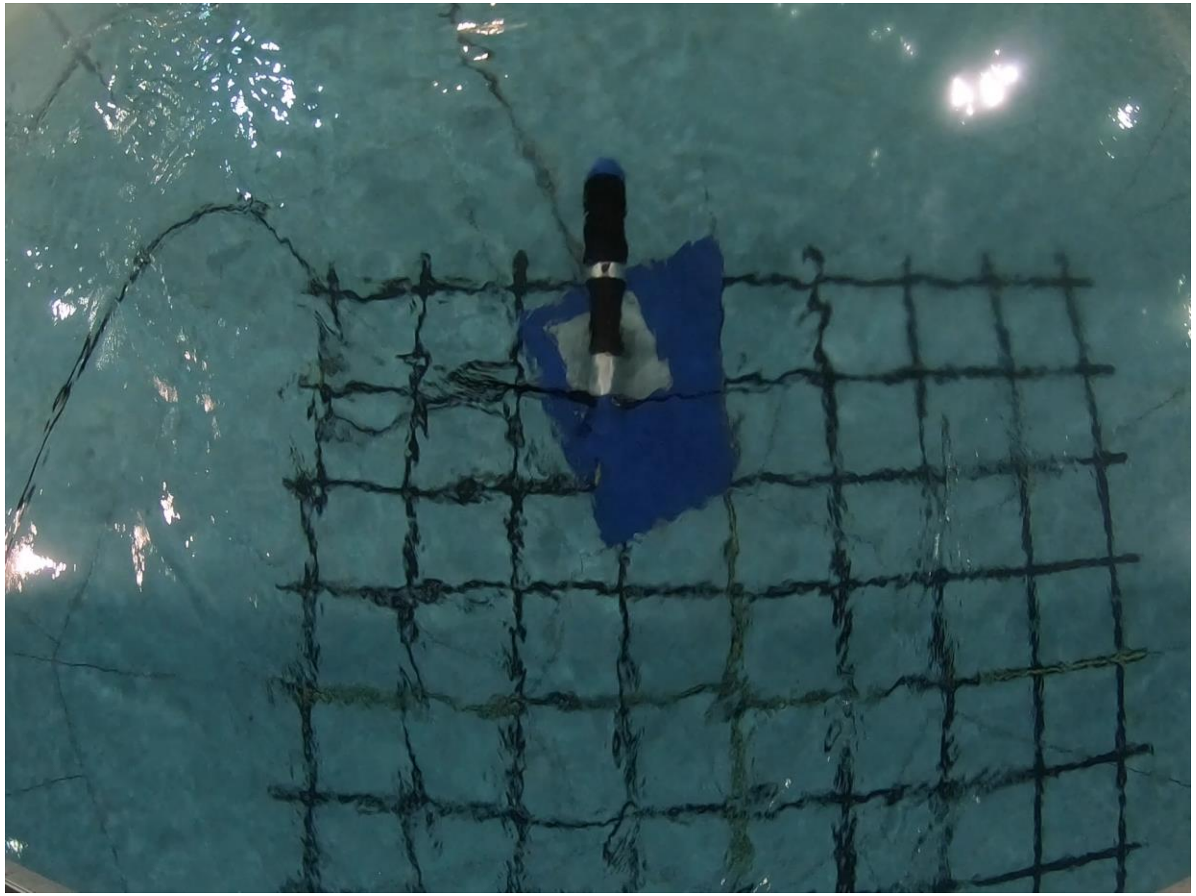
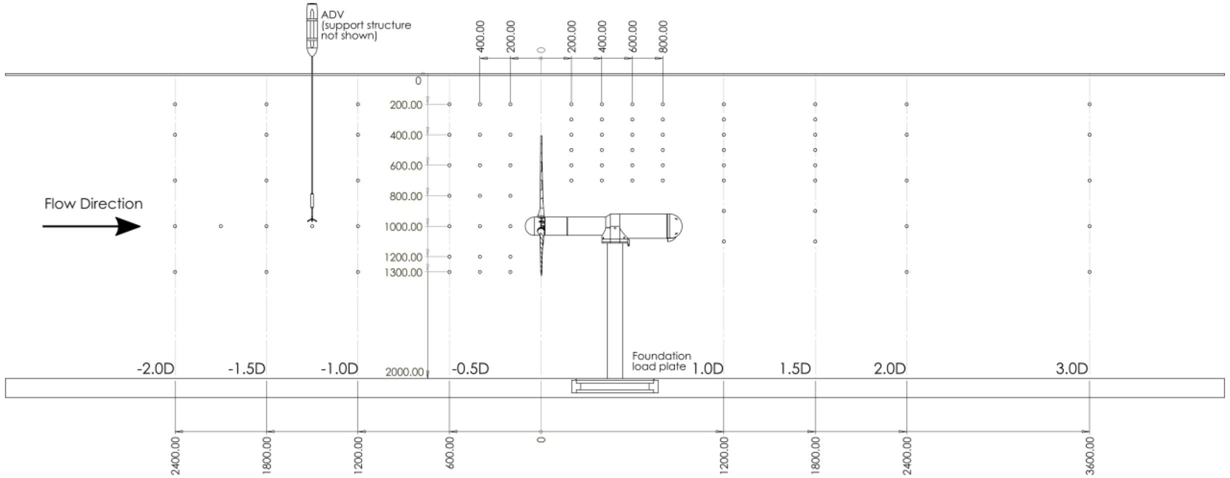
Waves and Currents



- Turbines near the seabed in 50m deep water are subjected to significant velocity changes due to wave action.
- Wave and current directions may not be co-incident
- Unsteady loading accelerates fatigue and may lead to ultimate limit states in some cases.

Model testing





Turbine measures thrust, torque, speed, root bending moments and forces and moments at the tower base.

Extensive matrix of flow measurement points between 2D upstream and 3D downstream of the rotor plane

Design information

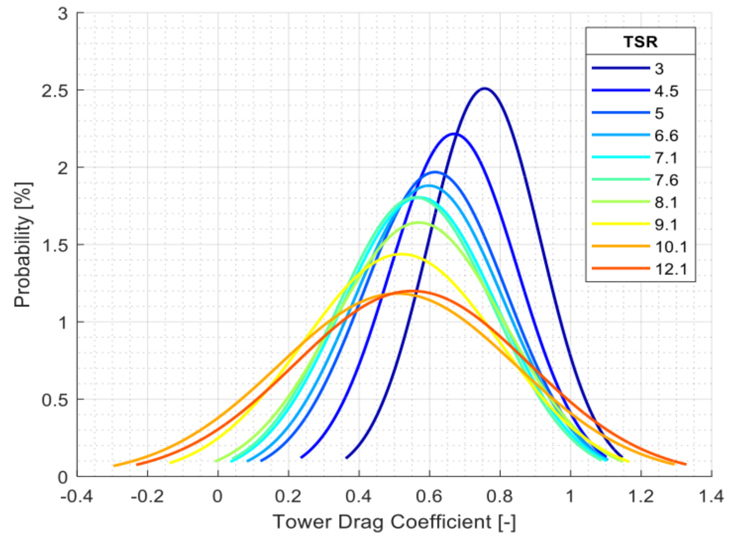
An extensive database of:

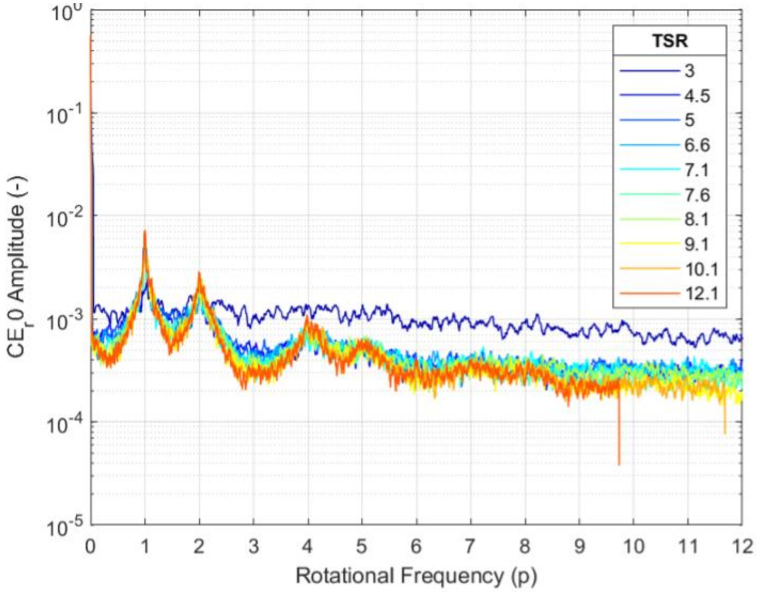
- tank test data,
- load probabilities, and
- load spectra

Will shortly be available on the RealTide website.

This provides:

- A basis for design for OEMs
- Model calibration data for numerical models
- Load time history data for materials scientists and designers of novel blade geometries.





Finding out more

Public deliverables including the loading dataset are on www.realtide.eu

A detailed report on the model tests and the database of experimental results will be available shortly.

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Laboratory Testing (MONITOR WP6)

Gregory PINON & many collaborators
University Le Havre Normandy

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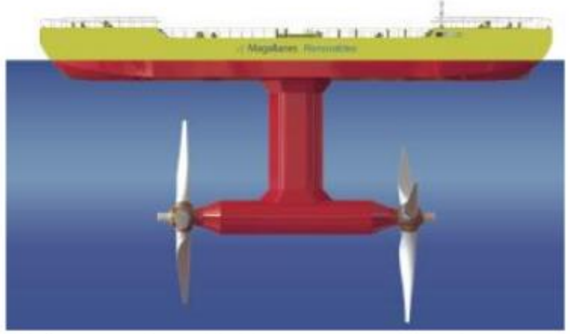
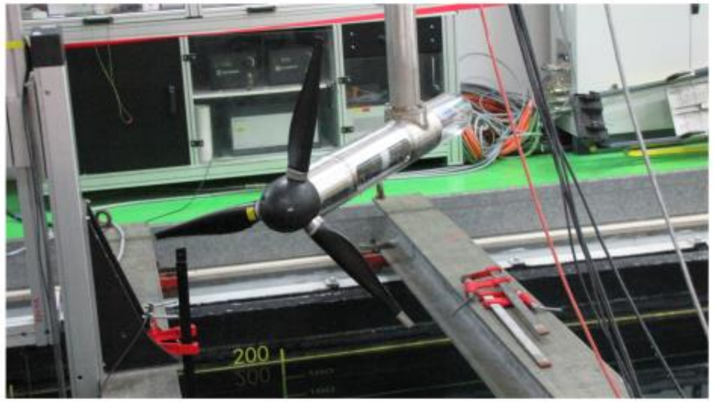
Laboratory testing.

Magallanes Renovables' ATIR: floating 3-bladed bi-rotor turbine

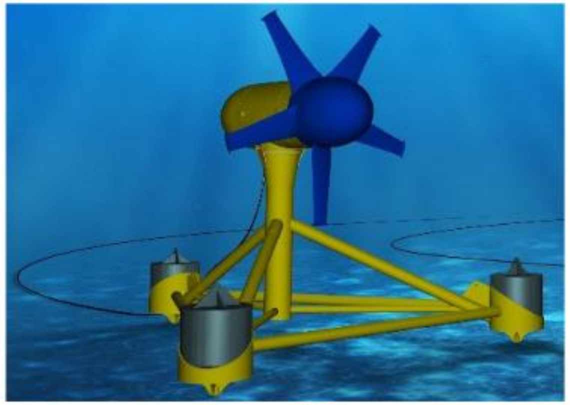


Schematic CAD representation of the prototype.

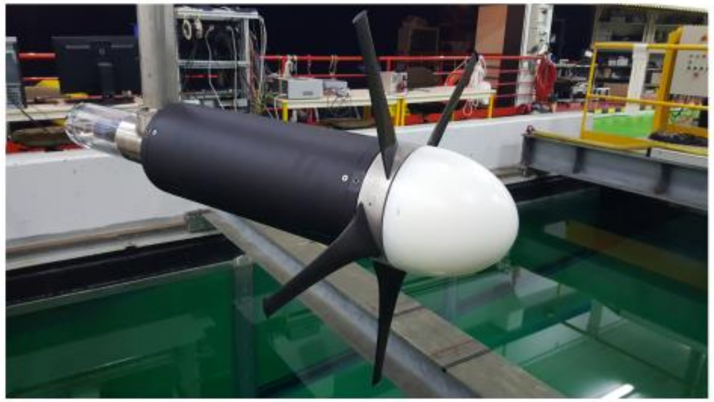


Picture of the 1:28 scaled turbine.

Sabella's D12: bottom mounted 5-bladed turbine



Representation of the prototype.



Picture of the 1:20 scaled turbine.

- Different blade profile, blade number, solidity
- Bottom-mounted or floating
- Influence of turbulence
- 3rd generic turbine

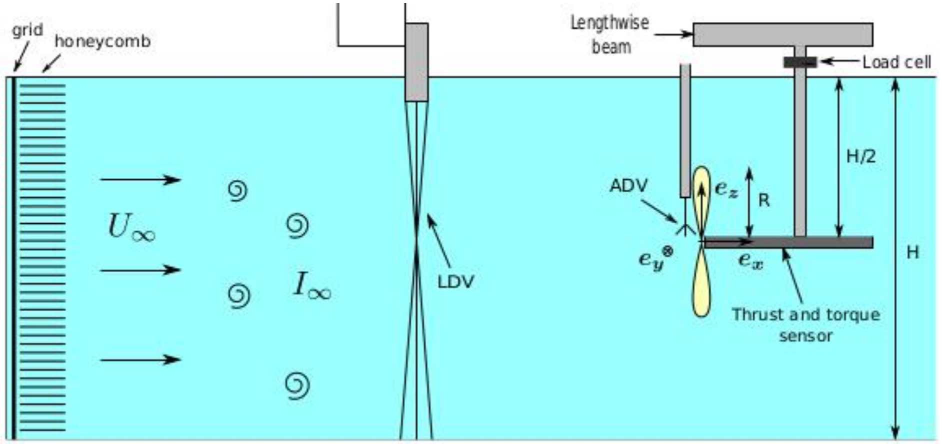
IFREMER turbine

Flume tank & experiment configuration

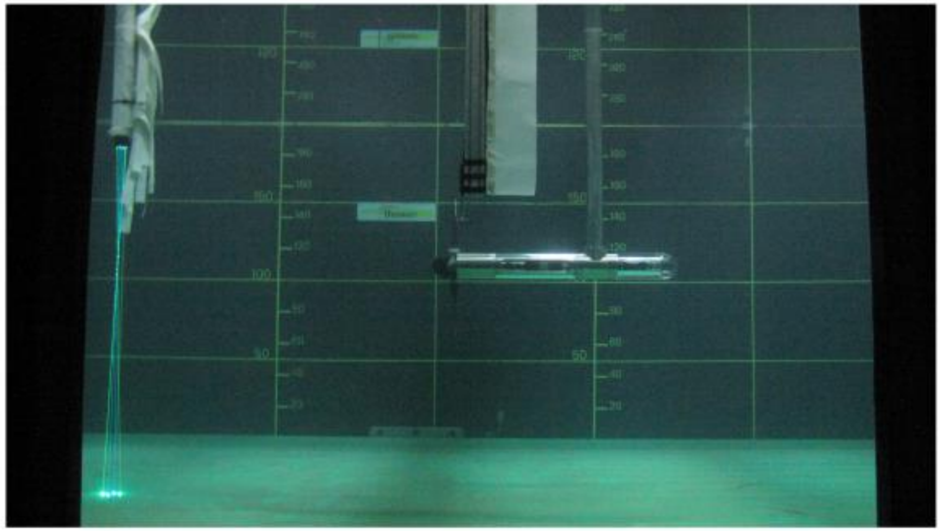
IFREMER wave and current flume tank in Boulogne-sur-Mer

Experimental set-up

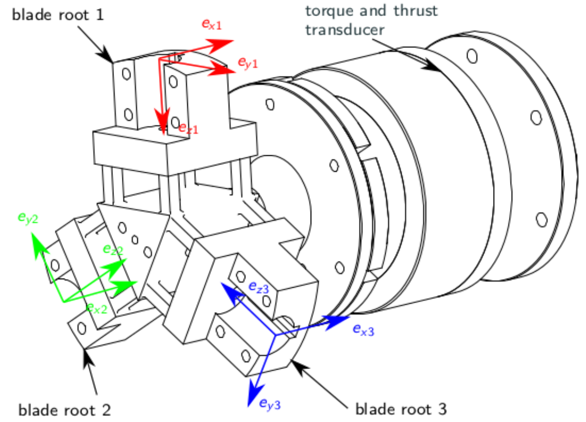
- In the flume tank:
  - 2D Laser Doppler Velocimeter (LDV)
  - Acoustic Doppler Velocimeter (ADV)
  - Flow straighteners
  - 3 wave probes
  - Piston-type wave generator
- On the scaled turbine:
  - Torque and thrust sensor
  - 5-components load-cells at blade roots



Schematic side-view of the experiment configuration.


Side view of the turbine in the flume tank.

Blade root load-cells



The blade root load-cells with the three coordinate systems and the torque and thrust transducer.

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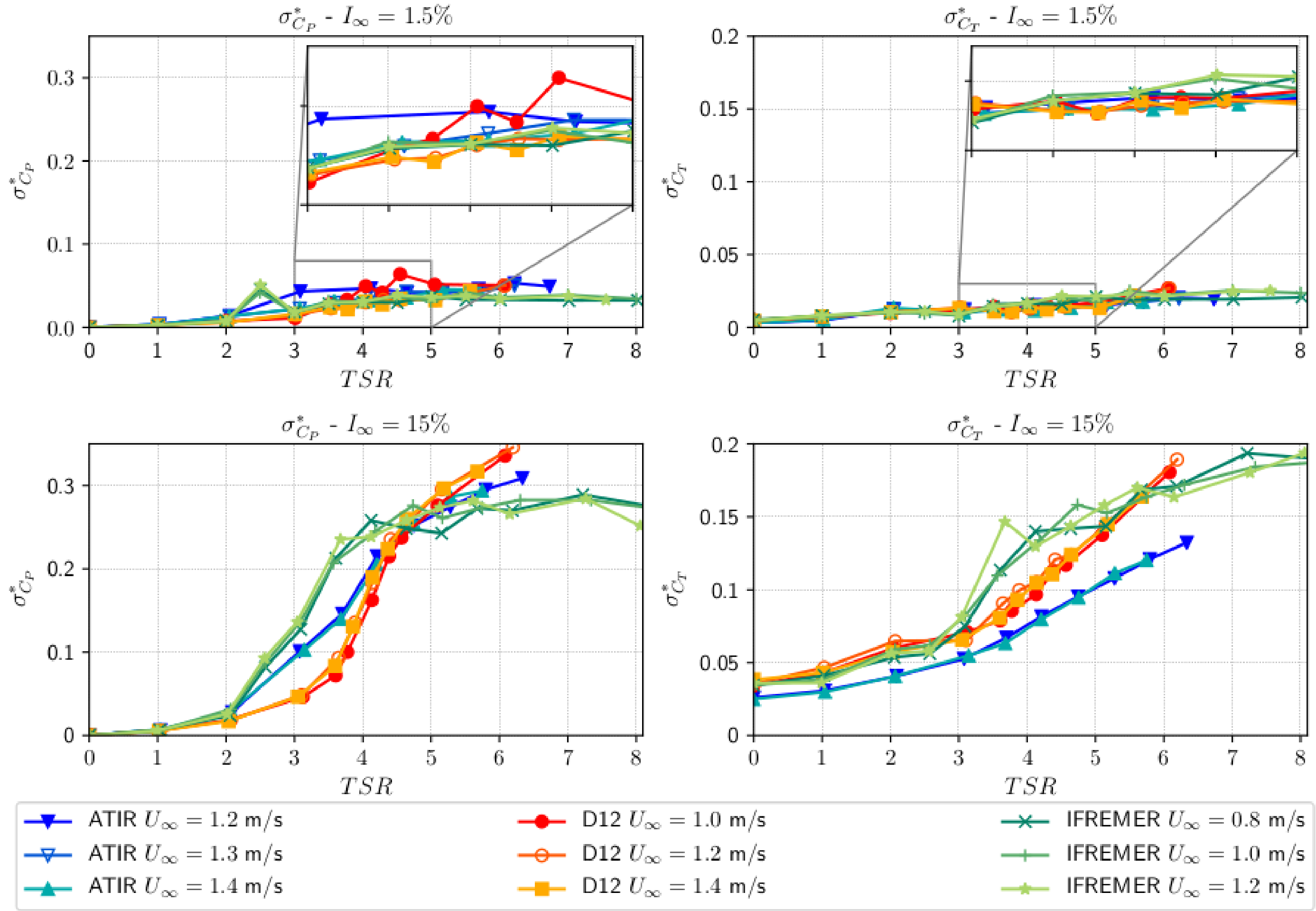
Research highlight #1:
Effect of turbulence intensity on performances

Standard deviations of the power and thrust coefficients



Comparison of the normalised standard deviation of the ATIR, D12 and IFREMER turbines power and thrust coefficients for two ambient turbulence intensities.

- Pinon, G., El Hadi, C., Slama, M., Nuño, J., Mansilla, P., Nicolas, E., Marcille, J., Facq, J.-V., Belarbi, I., Gaurier, B., Germain, G., Pacheco, A. & Togneri, M.

Influence of turbulence and wave flow conditions on different scaled tidal turbines. In Proceedings of the 13th European Wave and Tidal Energy Conference (EWTEC 2019)

- Slama, M., Pinon, G., El Hadi, C., Togneri, M., Gaurier, B., Germain, G., Facq, J.-V., Nuño, J., Mansilla, P., Nicolas, E., Marcille, J. & Pacheco, A.

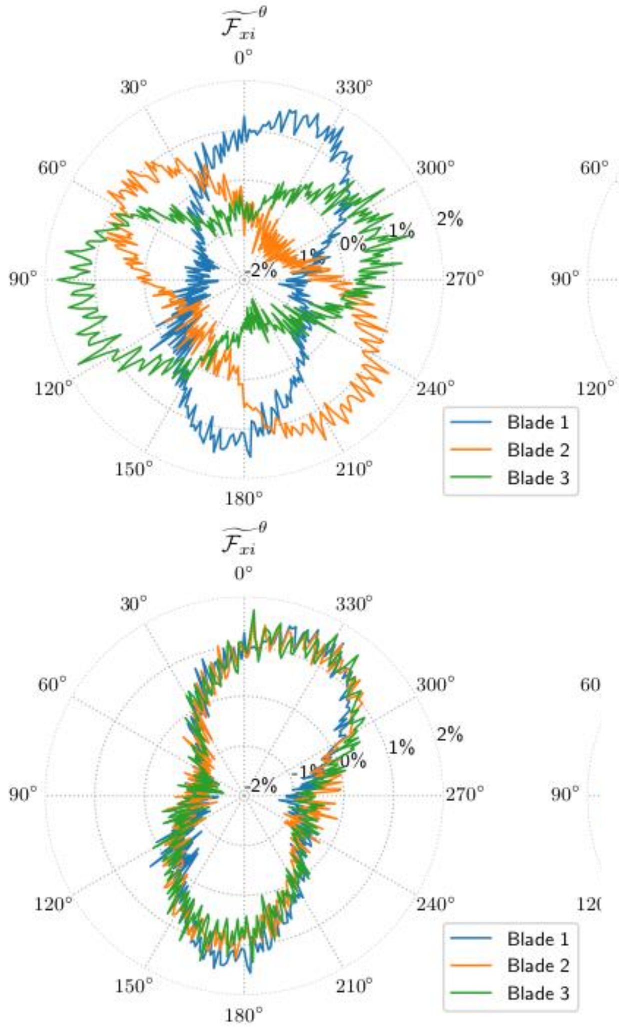
Turbine design dependency to turbulence: an experimental study of three scaled tidal turbines.

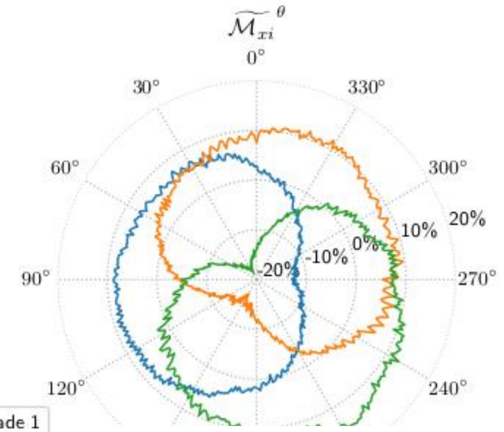
Ocean Engineering 2021

Research highlight #2:
Effect of turbulence on blade root loads

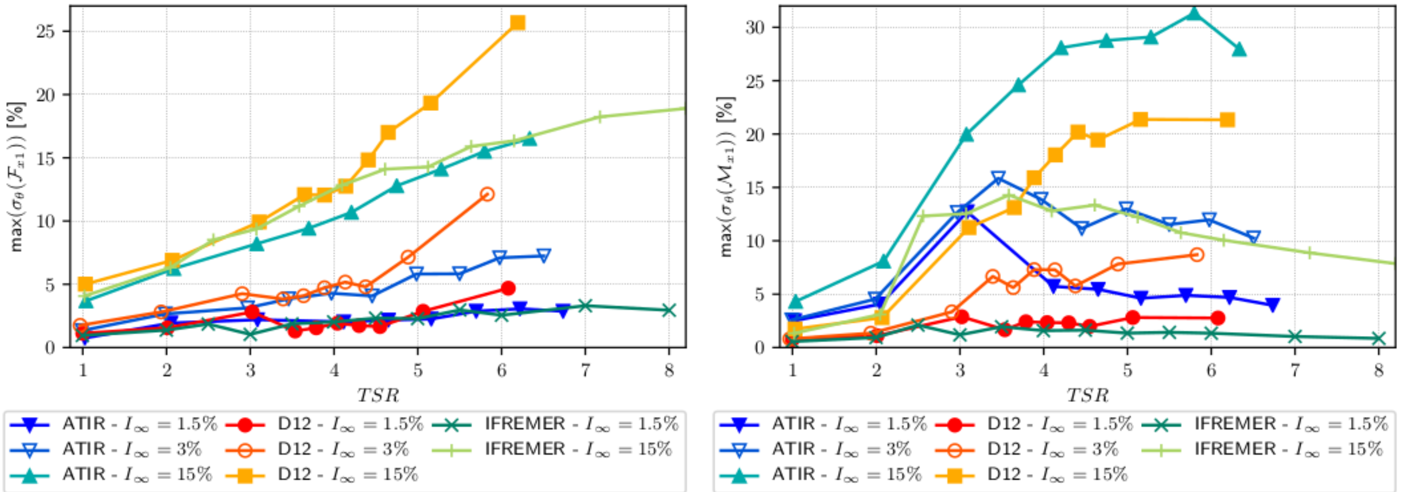
- Slama, M., Pinon, G., Togneri, M., Jump, E., Gaurier, B., Germain, G., Represas, F., Grande, J., Nicolas, E., & Marcille, J.

Blade root load variations on two scaled industrial tidal turbines. In Developments in Renewable Energies Offshore: Proceedings of the 4th International Conference on Renewable Energies Offshore (pp.624-632). CRC Press. 2020





Comparison of the phase-standard deviations for 3 turbines



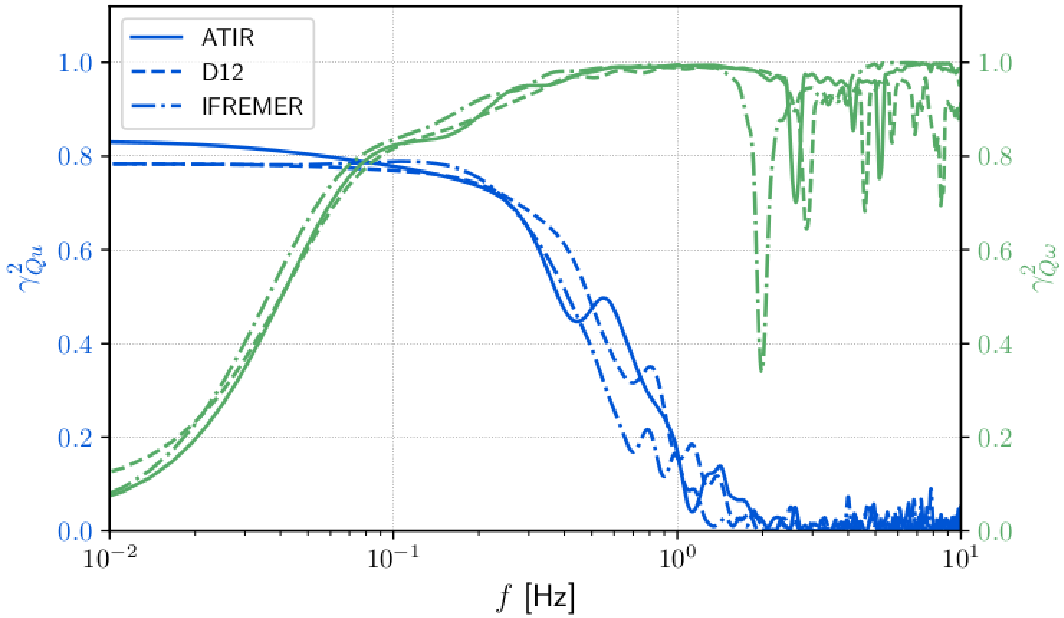
Phase-averaged blade root loads for the ATIR model (
Left panels: axial forces, right panels: edgewise bendin

Maxima of the phase-standard deviations of the axial force (right) / edgewise bending moment (left) on blade 1 with respect to the TSR.

Research highlight #3:
Influence of the drive train control vs. turbulence

The magnitude squared coherence (MSC) of two signals $X(t)$ and $Y(t)$ is defined as:

$$\gamma^2_{XY} = \frac{|S_{XY}(f)|^2}{S_{XX}(f)S_{YY}(f)}$$



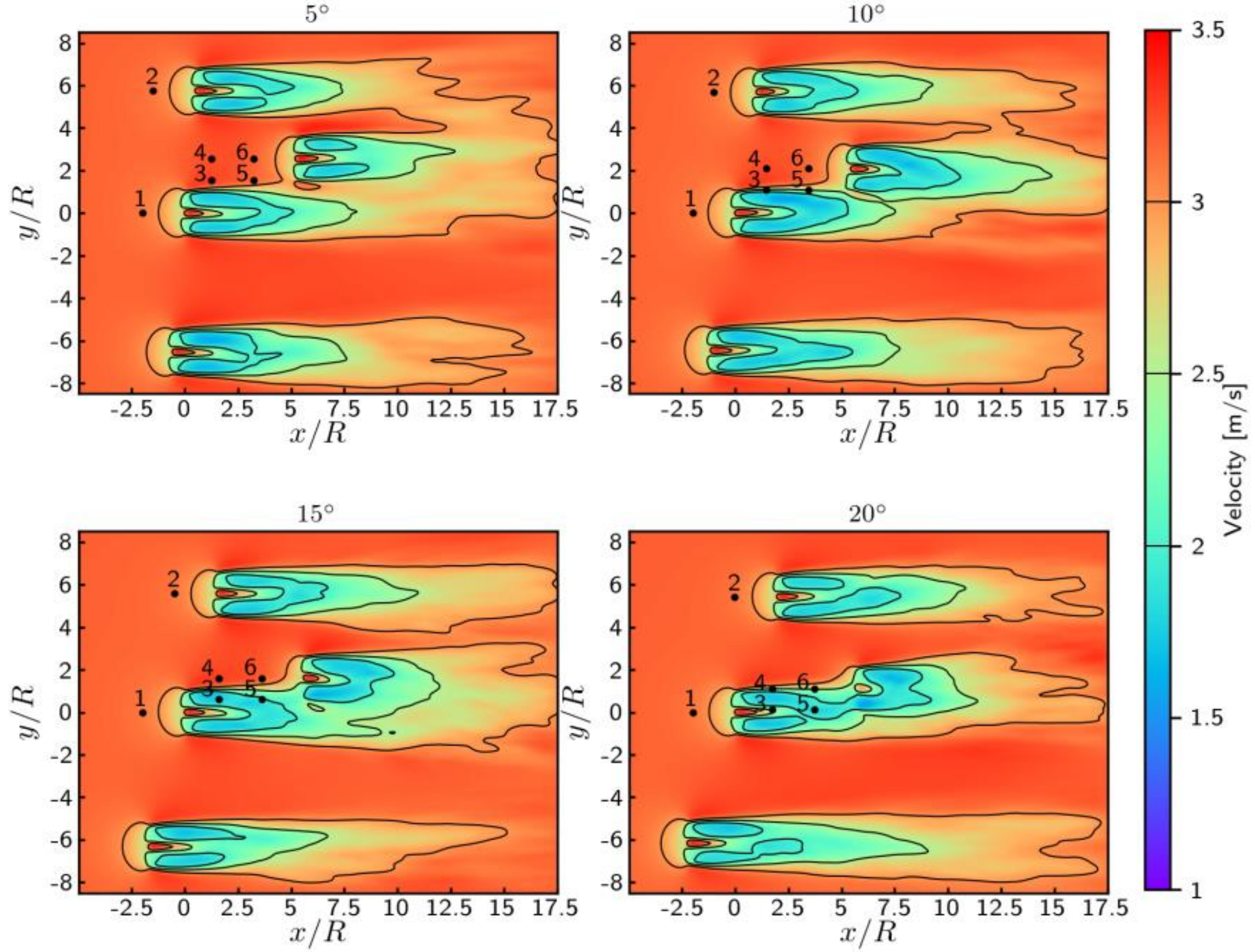
Comparison of the magnitude squared coherences between the torque, the axial flow velocity and the rotational speed, obtained for the three turbines at TSR $\approx$ 4.5 and $U_\infty = 1.2$ m/s (ATIR/D12) or $U_\infty = 1.0$ m/s (IFREMER), $I_\infty = 15\%$.

- Slama, M., Pinon, G., El Hadi, C., Togneri, M., Gaurier, B., Germain, G., Facq, J.-V., Nuño, J., Mansilla, P., Nicolas, E., Marcille, J. & Pacheco, A.

Turbine design dependency to turbulence: an experimental study of three scaled tidal turbines.

Ocean Engineering 2021

Links with numerical work



Time-averaged wakes

Slama, M., Choma Bex, C., Pinon, G. Togneri, M. & Evans I.

agrangian Vortex Computations of a
our Tidal Turbine Array: An Example
ased on the NEPTHYD Layout in the
lderney Race.

nergies 2021

- Slama, M., Pinon, G., Ben Belkacem, Y., Choma Bex, C., Togneri, M. & Evans I.

Fluctuating loads perceived by the downstream turbine in a farm (EWTEC 2021)

Presentation on XXX

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Blade resolved CFD modelling of RealTide tidal turbines

S. Loubeyre

Bureau Veritas Solutions Marine & Offshore

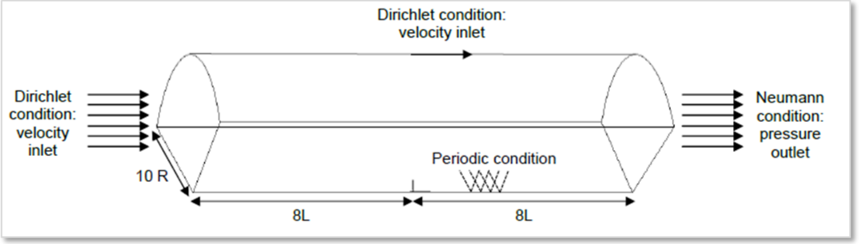
Research highlight

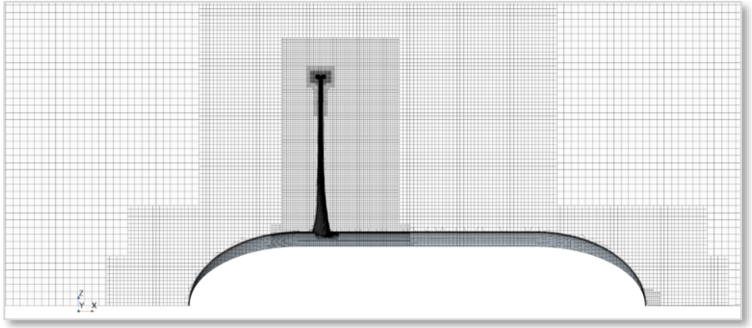
Performance assessment in open-water

Key objective – Develop a Blade resolved CFD model enabling the analysis of blade performance in "ideal" flow

CFD model

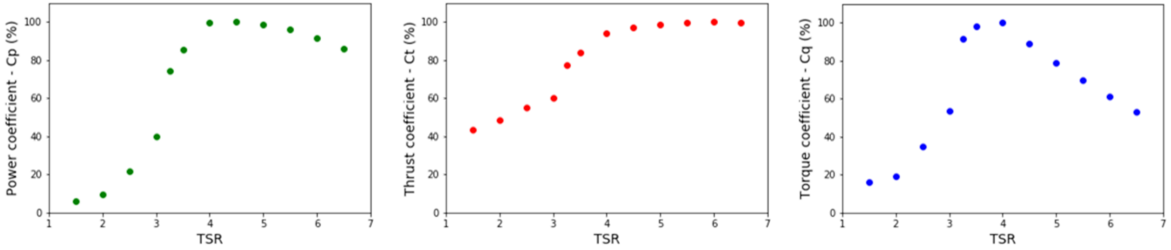
Simplified approach simulating the rotor operation in ideal condition (uniform current, no support structure considered, RANSE k-ω SST, Moving reference frame)



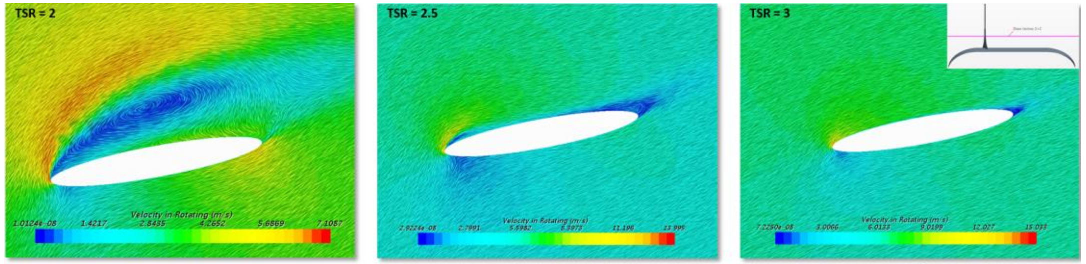


Results

Open-water performance curves for tidal turbines of interest (for comparison with BEM and experiments – with satisfying agreement)

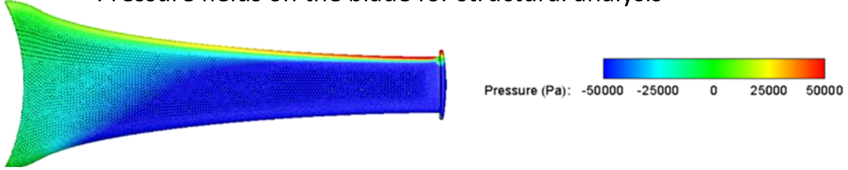


Analysis of the flow around the blade profile for various TSRs



Velocity profile around the blade at TSR = 2, TSR = 2.5 and TSR = 3 for a uniform unidirectional inflow velocity $U_{current} = 2.75\ m.s^{-1}$

Pressure fields on the blade for structural analysis



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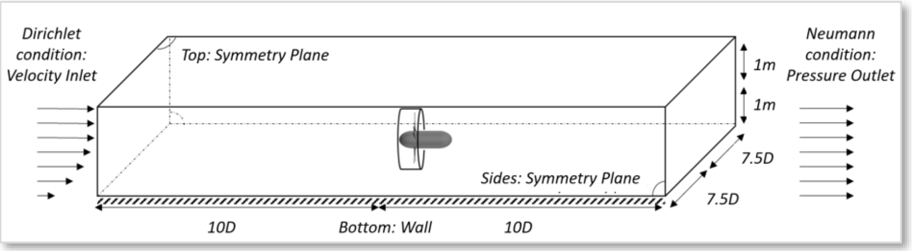
Research highlight

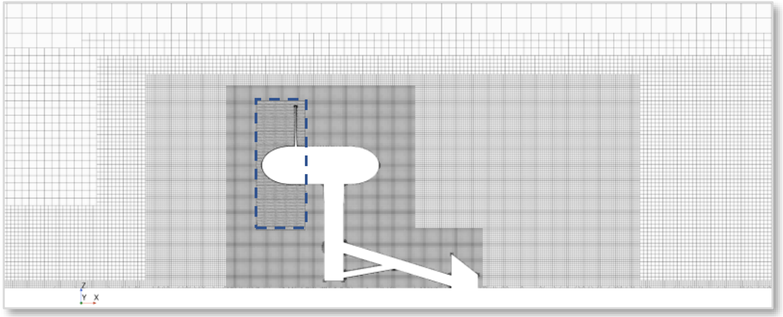
Performance in realistic env. conditions

Key objective – Simulation of the turbine loads and performance on operating conditions as per deployment site

CFD model

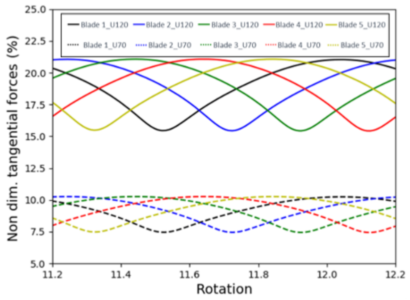
Integration of support structure, seabed/free surface & realistic environmental conditions (turbulence, velocity profile, wave influence, RANSE k-ω SST, Rigid body motion)

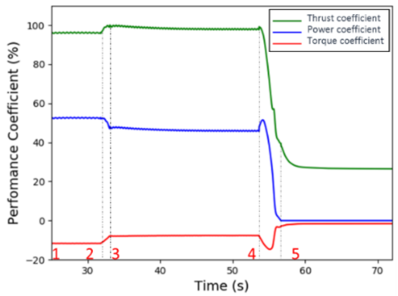




Results

Quantification of the influence of the structure & environmental factors on the turbine operations (flow profile or incidence, wave horizontal velocity…)





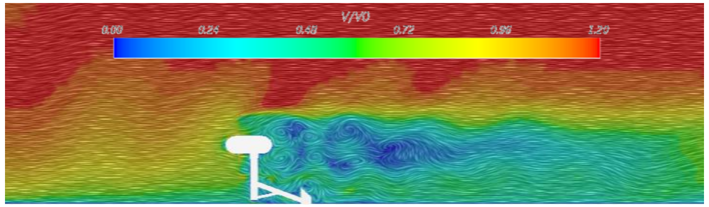


Illustration of the wake field behind the D12 turbine subjected to the Fromveur vertical velocity profile

Discussion on the blade resolved CFD model

Well defined methodology which can be re-used on other tidal turbines

Turbulence influence not visible in the loads due to RANSE method – DES would be required

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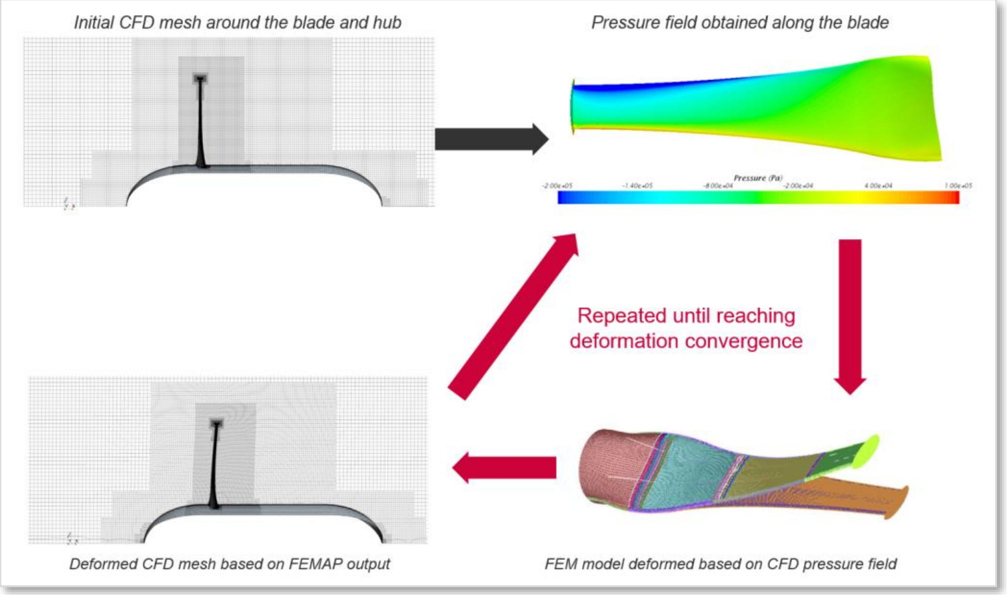
Research highlight

Blade deformation analysis

Key objective – Use blade resolved open-water CFD model to study the turbine blade deformation through coupling with FEM model

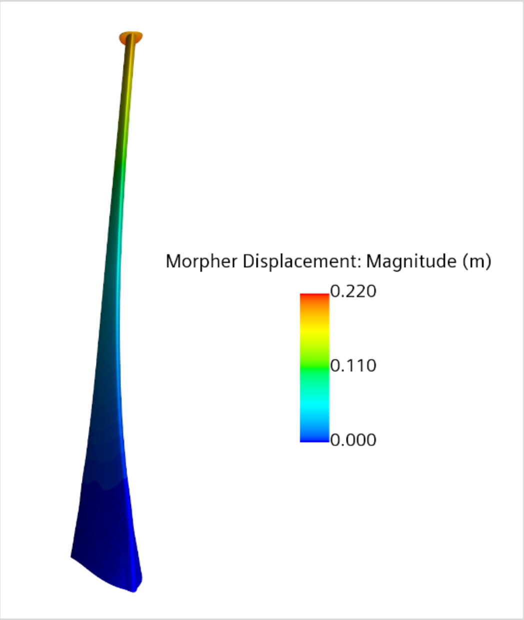
Description of the methodology

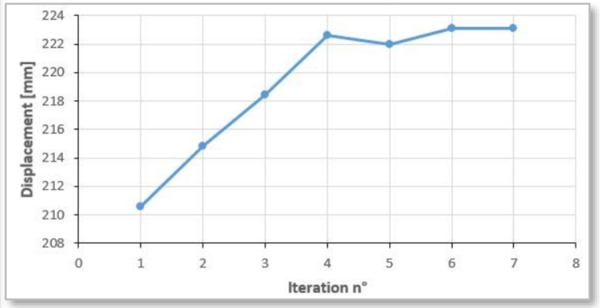
Coupling of blade resolved CFD model (pressure loads) with FEM model (deformation) of the composite blade – Iterations until convergence is reached



Results

Converged deformation of the blade profile based on the structural properties of the composite blade after 7 iterations





Discussion on the CFD/FEM coupling

Development of a successful coupling strategy between the CFD and structural models to study blade deformation

Weak coupling as manual iterations are necessary – Could be developed even further for automated process

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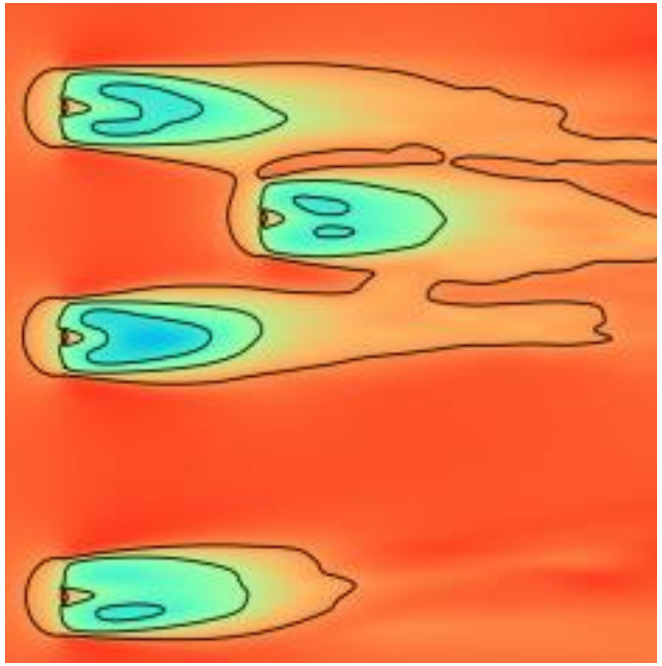
MONITOR WP5 – Numerical Modelling

Iestyn Evans

Swansea University

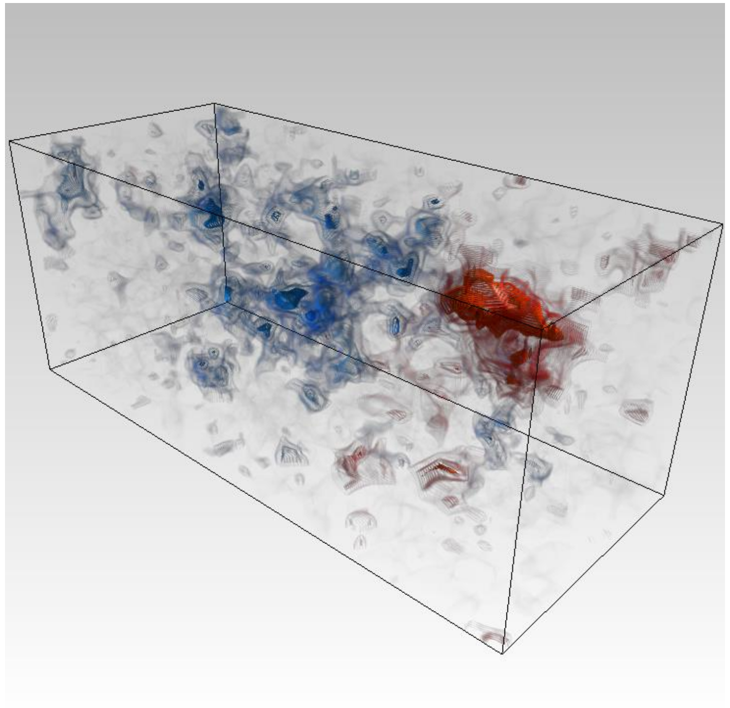
Impact of numerical modelling

- Predicts performance and loads
- Family of tools employed and refined throughout design process
- Validation by comparison to laboratory and full scale testing
  - But allows cases that cannot be realised otherwise
- Vital for a full picture of reliability



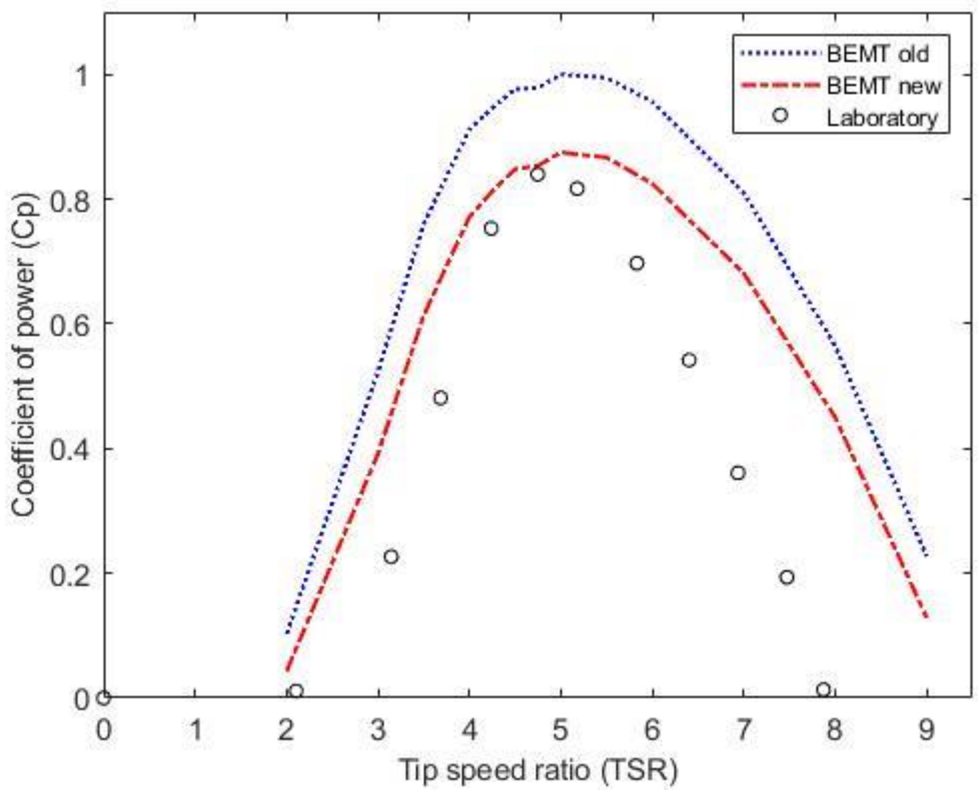
Outputs & lessons learned

- Blade element momentum theory (BEMT)
  - Loads and performance of a single TST.
  - Accuracy improved by 8% to 94.4%.
- Vortex particle method (VPM)
  - Greater detail than BEMT and applied to arrays of TSTs.
  - Induced blade and drivetrain fluctuating loads significantly affected by downstream wakes.
- Synthetic turbulence approaches
  - Synthetic eddy and Spectral Sandia methods.
  - Effects peak loads and fatigue life of TSTs.
  - Variability of turbine loads has a straightforward linear relationship to the turbulence intensity of the inflow.



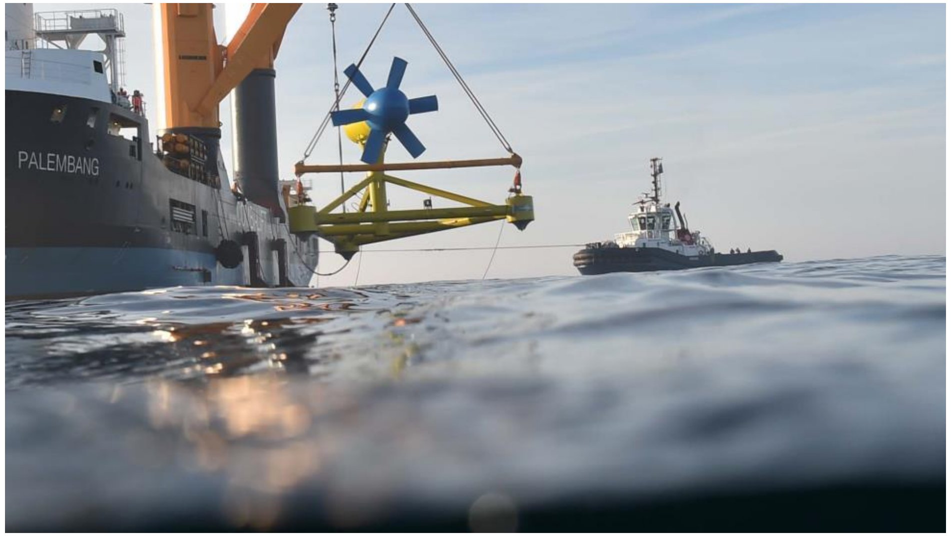
Research highlight

- Improvements to BEMT
  - Geometry of rotor blade more accurately represented.
- Increased accuracy of loads and performance predictions from numerical model.
  - Comparison to laboratory testing.
- Evaluation of rotor design
  - Enhance reliability.



Further information

- Comparison of synthetic turbulence approaches for blade element momentum theory prediction of tidal turbine performance and loads
  - DOI: 10.1016/j.renene.2019.05.110
- Lagrangian Vortex Computations of a Four Tidal Turbine Array: An Example Based on the NEPTHYD Layout in the Alderney Race
  - DOI: 10.3390/en14133826
- Implementing varying blade profile and Reynolds Number in BEMT code
  - Evans I, Togneri M, Lake T, Gwenter R, Masters I, Pinon G, et al. Implementing varying blade profile and Reynolds Number in BEMT code. In: 4th International Conference on Renewable Energies Offshore (RENEW 2020). 2020.



- Any questions? Please get in touch.
- iestyn.evans@swansea.ac.uk