Supergen Offshore Renewable Energy

Annual Assembly 2023

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Early Career Researcher Posters & Abstracts

UKRI Engineering and Physical Sciences Research Council

List of posters and abstracts

01	Abel Arredondo-Galeana (Research Associate, University of Strathclyde) - Hydrodynamic modelling and testing of very large hinged floating structures for offshore renewable
02	Anna Holcombe (PhD Student, University of Plymouth) - Comparison of a scaled physical model and numerical model of a dynamic power cable for a floating offshore wind turbine
03	Emma Edwards (Postdoctoral Research Fellow, University of Plymouth) - Key trends in the evolution of floating offshore wind platform designs
04	Farhad Abad (Research Associate, University of Strathclyde) - Bulge Test and Material Characterisation of Elastomers Used in the OWC Wave Energy Converter
05	Jingru Xing (PhD researcher, Cranfield University) - Application of Wave Devouring Propulsion (WDP) for floating wind platform stabilisation
06	Juliane Wihsgott (Physical Oceanographer, Plymouth Marine Laboratory) - Understanding the changes to ocean mixing and primary production in UK shelf seas by expanding offshore windfarms
07	Saeid Lotfian (Lecturer, University of Strathclyde) - A Novel Procedure for the Ultrasonic Inspection of Wind Turbine Bolted Connection
08	Shen Li (Research associate, University of Strathclyde) - Autonomous Underwater Inspection for Offshore Wind Structures
09	Huaqing Jin (Visiting Researcher, University of Plymouth) - A hybrid Wave Energy Converter-Floating breakwater with nonlinear stiffness
10	Siming Zheng (Lecturer in Ocean Engineering, University of Plymouth) - Floating hydroelastic circular plate in regular and irregular waves
11	Scott Brown (Supergen ORE Hub Research Fellow, University of Plymouth) - Short design waves for predicting extreme responses of floating ORE devices
12	Aananthy Sarmaa (PhD Researcher, University of Hull) - Multi-Point Sensing & Defect Detection of Wind Turbine Blades: An Approach Using Fibre Bragg Gratings
13	Daniel Coles (Research Fellow, University of Plymouth) - Enhancing energy security with tidal stream energy
14	Rameeza Moideen (Associate Research Fellow) - Vortex-Induced Vibrations of Dynamic Power Cable
15	Jon Hardwick (Research Fellow, University of Exeter) - Data centric numerical simulation for Tidal Stream Energy (D-TIDE)
16	Xiaosheng Chen (Research Assistant, University of Oxford) - Tidal Turbine Benchmarking Project: Stage I – Steady Flow Blind Predictions
17	Tom Tosdevin (COAST Researcher, University of Plymouth) - Short design wave and wind events for a semi-sub FOWT in operating conditions
18	Donald Noble - Research Associate in Marine Energy, The University of Edinburgh, Policy & Innovation Group

Hydrodynamic testing and modelling of very large hinged floating structures for offshore renewables

Abel Arredondo-Galeana[1], Saishuai Dai[1], Yongqiang Chen[2], Xiantao Zhang[2], Feargal Brennan[1]

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Motivation

The installation of floating offshore wind turbines requires a single and dedicated floating platform. This increases the installation costs of floating arrays with multiple turbines [1]. An alternative to the single-platform single-turbine approach could be found in **very large floating structures (VLFS)**. This type of structures offer the possibility of hosting multiple wind turbines in a single platform, and therefore, reduce installation costs. Nonetheless, very large floating structures experience high internal loading due to their large water plane areas. A solution to alleviate the internal loading of very large floating structures is found through the inclusion of **hinges** along the platform [2] , as depicted in Figure 1.

Figure 1– Artist impression of multiple wind turbines in very large hinged floating platform.

Experimental test

A prototype of a hinged VLFS was manufactured and tested at the Kelvin Hydrodynamics Laboratory at the University of Strathclyde (Figure 2). The hinged platform was built with three floaters joined by two hinges. A rigid version of the platform was also tested by replacing the hinges with rigid steel bars. The VLFS was instrumented with motion detection spheres and strain gauges at the hinge locations. Tests were carried out for a set of regular waves with an incidence angle of 0°.

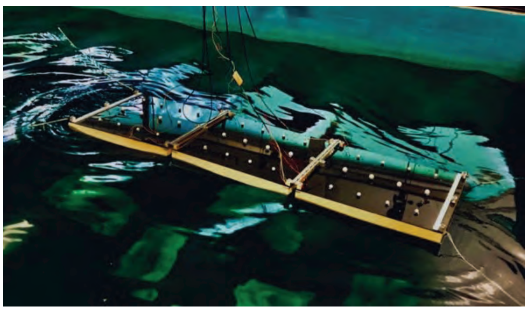

Figure 2– Very large hinged floating platform subject to regular waves.

Hydrodynamic model

The VLFS is divided into modules, as shown in Figure 3. Each module is represented by a lump mass and each lump mass is connected to each other by beam elements. The stiffness matrix (**K**) of the full structure is assembled by concatenating the individual stiffness matrices of each beam element. In the case of a hinge, no beam element is considered, since the hinge motion transfer is modelled independently through a motion transformation matrix.

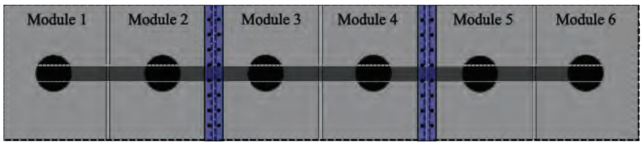

Figure 3– Very large hinge floating structure segmented in modules. Each module is represented by a lump mass and connected to each other by elastic beams.

For the case of a structure with a single hinge, the motion of each of the modules of the structure (ξ) and the forces on the hinge ($\boldsymbol{F_J}$) are obtained through a system of two equations (Eq. (1)). The first equation considers the forces acting on the platform, which include: the wave excitation [$\boldsymbol{F_E}$], the radiation damping [$i\omega\mathbf{B}(\omega)\xi$], added mass [$\omega^2\,\mathbf{A}(\omega)\xi$], inertia [$\omega^2\,\mathbf{M}\xi$], hydrostatic [-$\mathbf{C}\xi$], and elastic [-$\mathbf{K}\xi$] forces, and the force on the hinge translated to the adjacent lump masses [$\boldsymbol{\Xi}_J^T\boldsymbol{F_J}$]. The second equation accounts for the motion transfer between the lump masses and the hinge $\boldsymbol{\Xi}_j\xi$ = 0, where $\boldsymbol{\Xi}_j$ is a motion constraint matrix between the hinges and the lump masses of the VLFS. The system of equations is stated in Equation (1) as follows:

$$\begin{bmatrix} -\omega^2\big(\mathbf{M}+\mathbf{A}(\omega)\big) - i\omega\mathbf{B}(\omega) + \mathbf{C} + \mathbf{K} & \boldsymbol{\Xi}_J^T \\ \boldsymbol{\Xi}_j & \mathbf{0} \end{bmatrix} \begin{bmatrix} \xi \\ \boldsymbol{F_J} \end{bmatrix} = \begin{bmatrix} \boldsymbol{F_E} \\ \mathbf{0} \end{bmatrix} \quad \text{Eq. (1)}$$

Results

The numerical model is assessed versus experimental motion displacement measurements for both rigid and hinged floating platforms. Results are shown for the hinged structure in Figure 4(a) for a wave frequency of 0.8 Hz. Figure 4(a) shows a satisfactory agreement between the hydrodynamic model (solid black line) and the measurements (scatter points with error bars). Figure 4(b) shows the vertical load amplitude measured with 4 different strain gauges at the hinge locations (SG1, SG2, SG3 and SG4) over a wave frequency range of 0.4 to 1.6 Hz for the rigid (red markers) and the hinged (black markers) structures. Results show that the internal loading of the structure is alleviated through the use of hinges.

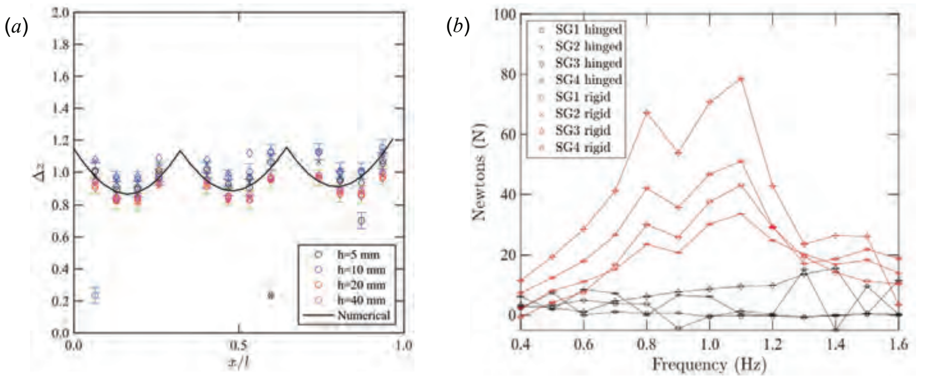

Figure 4 – (*a*) Measured motion response (scattered markers) of a two-hinged structure at f=0.8 Hz compared to numerical results (solid line) and (*b*) forces on hinges measured with strain gauges for different wave frequencies for a rigid structure (red markers) and a hinged structure (black markers).

[1] Arredondo-Galeana, A., & Brennan, F. (2021). Floating offshore vertical axis wind turbines: opportunities, challenges and way forward. Energies, 14(23), [8000].

[2] Arredondo-Galeana, A., Dai, S., Chen, Y., Zhang, X., Brennan F. (2023). "Understanding the force motion trade off of rigid and hinged floating platforms for marine renewables." In the Proceedings of the 15th European Wave and Tidal Energy Conference, Bilbao, Spain.

University of Strathclyde Glasgow

Supergen Offshore Renewable Energy

Hydrodynamic modelling and testing of very large hinged floating structures for offshore renewables

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The installation of floating offshore wind turbines requires a single and dedicated floating platform. This requirement increases installation costs of floating wind farms [1]. An alternative to the single platform single turbine approach could be found in very large floating structures. This type of structures offers the possibility to host multiple wind turbines in a single platform, and therefore, to reduce installation costs.

Nonetheless, very large floating structures experience high internal loading, which puts at risk their survivability offshore. A viable solution to alleviate the internal loading of very large floating structures is found through the inclusion of hinges in the platform. However, because very large hinged floating platforms are a novel concept, accurate hydrodynamic modelling is crucial to understand their feasibility towards deploying multiple wind turbines.

In this work, we present a numerical model to predict the motion response of very large hinged floating structures. The model accounts for the hydrodynamic loading on the floating structure, coupled to hydroelasticity effects and hinge mechanical motion. The numerical model is assessed versus experimental measurements of both rigid and hinged floating structures. The internal loading in the structures is measured and the difference in performance between both rigid and hinged platforms is demonstrated. The tested laboratory scale hinged platform is shown in Figure 1. Further details of the experimental test and hydrodynamic model have been submitted to the 15th European Wave and Tidal Energy Conference [2]. Future work includes internal loading modelling of the hinged floating structure and coupling of wind turbine loads to the motion of the structure.

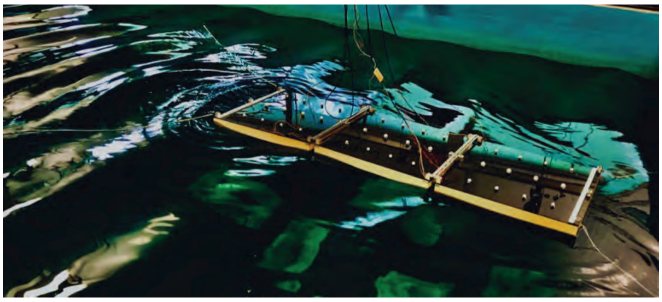

Figure 1. Laboratory scale very large hinged floating structure tested in the Kelvin Hydrodynamics Laboratory at the University of Strathclyde under regular waves

References:

[1] **Arredondo-Galeana, A.**, & Brennan, F. (2021). Floating offshore vertical axis wind turbines: opportunities, challenges and way forward. Energies, 14(23), [8000].

[2] **Arredondo-Galeana, A.**, Dai, S., Chen, Y., Zhang, X., Brennan F. (2023). “Understanding the force motion trade off of rigid and hinged floating platforms for marine renewables.” In the Proceedings of the 15th European Wave and Tidal Energy Conference, Bilbao, Spain.

Global motions and loads of **dynamic power cables** for floating ORE

Dynamic power cables are an essential component of floating ORE devices, providing the electrical connection between the device and the subsea export cables on the seabed, so that generated electricity can be exported. Research and development into dynamic power cables for ORE is an industry priority, particularly to reduce cable failure rate in ORE projects [1]. This PhD investigates global motions and loads of dynamic power cables for ORE, using both scale model experiments and numerical methods.

Abstract

Unlike static subsea cables, dynamic cables are designed to float freely in the water column, and are therefore subjected to hydrodynamic loading from waves and currents, along with motion induced by the floating device itself at the top of the cable, i.e., the hang-off. These motions and loads include highly cyclic loading and survival events, which puts emphasis on accurate design and analysis to avoid mechanical failure of the dynamic power cable.

Numerical global modelling studies analysing the motions and loads of dynamic power cables for ORE applications have been carried out previously; several with a focus on specific mechanical failures such as fatigue damage issues. However, very few scaled model experimental studies exist, and therefore these models have not been validated for specific ORE applications. An experimental scaled model study has been carried out, and the results of global motions of the power cable were compared to a numerical model.

1:70 Scale physical experiments

Testing was performed in the Ocean basin of the COAST laboratory, as seen in Figure 1, at 1:70 scale. The test subject was a Froude-scaled model of the IEA 15MW reference wind turbine [2] and the Umaine VolturnUS-S platform [3] with a 66kV dynamic power cable, in a water depth representing 210m.

Qualisys optical tracking system was used to capture the motion of the FOWT and 7 markers along the power cable. The power cable model, with buoyancy modules and Qualisys markers can be seen in Figure 3. Properties of the power cable can be seen in Table 1. The axial and bending stiffness was measured experimentally.

Table 1 Properties of dynamic power cable

Property	Unit	Full scale value
Dry mass per unit length	[kg/m]	62.2
Submerged mass per unit length	[kg/m]	41.9
Outer diameter	[m]	0.2
Axial stiffness	[MN]	19600
Bending stiffness	[kNm²]	840

Fig. 1 1:70 scale model of FOWT and dynamic cable

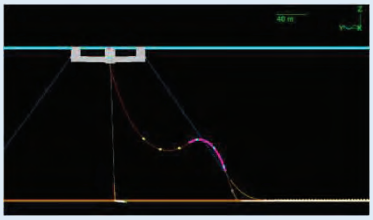

Fig. 2 Orcaflex model of FOWT and dynamic cable

Numerical model comparison

The power cable and FOWT were also modelled numerically, using Orcaflex in full scale, as seen in Figure 2. First, the static shape of the cable was compared, which can be seen in Figure 4, with a plot of the static position of each marker on the cable, in both the experiment and Orcaflex. There is a slight difference in results, which is considered most likely to be be due to inaccuracy in material property measurements.

One dynamic case has been considered so far, for a benign irregular sea state. The RMS difference for each marker during the test between the numerical model and experiment can be seen in Table 2. Lower RMS difference is seen for markers further near the touchdown.

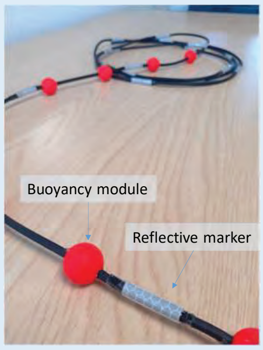

Fig. 3 1:70 scale model of dynamic power cable

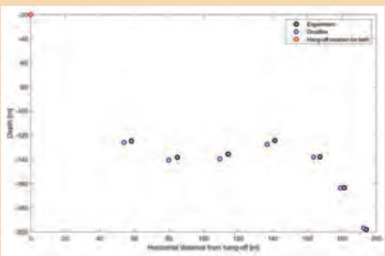

Fig. 4 Plot of power cable marker static positions

Table 2 RMS difference of motion of power cable markers along cable from hang-off to touch down

RMS difference of marker motions			
Marker	X	Y	Z
1	0.129	0.062	0.093
2	0.138	0.057	0.083
3	0.100	0.072	0.079
4	0.098	0.067	0.088
5	0.063	0.054	0.033
6	0.071	0.104	0.045
7	0.045	0.050	0.025

Further work

The presented work is part of a PhD project and will be continued. Further work items include:

- Improving the scale model of a power cable by investigating the influence of cable properties on global motion and loads, to determine whether a more suitable material could be used.
- Improving material property testing methodology
- Further analysis of the experimental-numerical comparison and further scale testing

UNIVERSITY OF PLYMOUTH

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[1] Spearman, D., et al. (2020). "Phase II Summary Report: Floating Wind Joint Industry Project". Carbon Trust, UK.

[2] Gaertner, E., et al. (2020). "Definition of the IEA 15-Megawatt Offshore Reference Wind". *Golden, CO: National Renewable Energy Laboratory.* NREL/TP-5000-75698.

[3] Allen, C., et al. (2020). Definition of the UMaine VolturnUS-S reference platform developed for the IEA Wind 15-megawatt offshore reference wind turbine, National Renewable Energy Lab.(NREL), Golden, CO (United States); Univ. of Maine, Orono, ME (United States).

Comparison of a scaled physical model and numerical model of a dynamic power cable for a floating offshore wind turbine

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Dynamic power cables are a critical component of floating offshore renewable enery systems, providing the electrical connection from the floating device to the subsea cable connection at the seabed. Research and development into dynamic power cables for offshore renewable energy (ORE) is an industry priority, particularly to reduce cable failure rate in ORE projects [1]. The cables must withstand hydrodynamic loading from waves and currents, along with motions at the hang-off from the floating device itself. These motions and loads include highly cyclic loading and survival events, which puts emphasis on accurate design and analysis to avoid mechanical failure of the dynamic power cable, such as fatigue failure.

Numerical modelling studies analysing the global motions and loads of dynamic power cables for ORE applications have been carried out previously; several with a focus on specific mechanical failures such as fatigue damage issues [2-4]. However, very few scaled model experimental studies exist, and therefore these numerical models have not been validated for specific ORE applications.

An experimental study of a 1:70 scale dynamic power cable was carried out, in the Ocean Basin of the COAST laboratory at Plymouth University. The dynamic power cable was modelled in a lazy wave configuration, connected to a model of the VolturnUS-S platform [5] in 210m water depth. Irregular wave tests were run, and the dynamic motions of the cable and floating wind platform were captured using an optical motion tracking system. An Orcaflex model was created to represent the full-scale model, using the wave elevation and FOWT motion recorded during experiments as inputs for the numerical model. The cable shape and motion during wave tests are compared between the experiments and Orcaflex model, to investigate differences.

This comparison work will be developed to further improve the methodology for scale modelling a power cable, and to understand differences present in the comparison results. Validation work will be carried out with further Ocean basin testing.

References:

[1] Spearman, D., et al. (2020). Phase II Summary Report: Floating Wind Joint Industry Project. Carbon Trust, UK
[2] Kuznecovs, A., et al. (2019). A methodology for design and fatigue analysis of power cables for wave energy converters. International Journal of Fatigue 122, 61–71.
[3] Rentschler, M., et al. (2019) Design optimization of dynamic inter-array cable systems for floating offshore wind turbines. Renewable and SustainableEnergy Reviews 111, 622–635.
[4] Nicholls-Lee, R., et al. (2021). Coupled modelling for dynamic submarine power cables: interface sensitivity analysis of global response and local structural engineering models, EWTEC.
[5] Allen, C., et al. (2020). Definition of the UMaine VolturnUS-S reference platform developed for the IEA Wind 15-megawatt offshore reference wind turbine, National Renewable Energy Lab.(NREL), Golden, CO (United States); Univ. of Maine, Orono, ME (United States).

Key trends in the evolution of floating offshore wind platform designs

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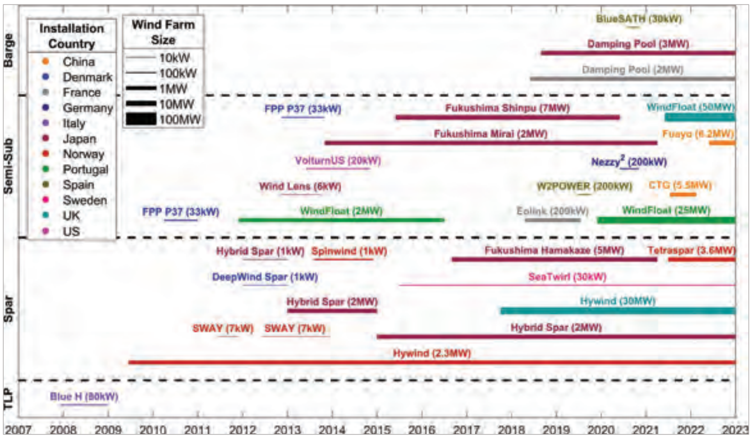


Current status of FOW

- UK leaders in global FOW capacity
- Massive expansion expected in next 10 years and beyond
- FOWT platform designs
  - **2** in operation at farm-scale
  - **21** demonstrator/prototype at sea
  - **85** earlier stages of development
    - **19** lab tests for extreme conditions
    - **21** some lab tests
    - **48** limited information about testing/ early concept

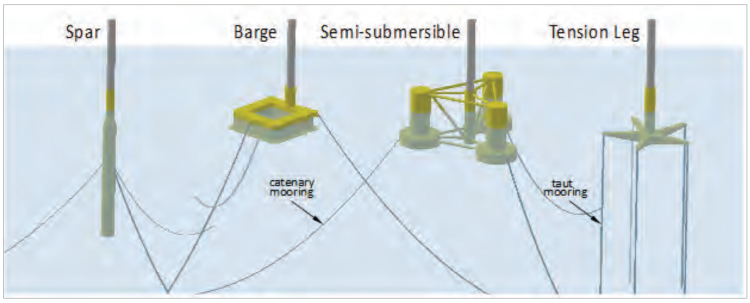
Trends in the evolution of platform designs

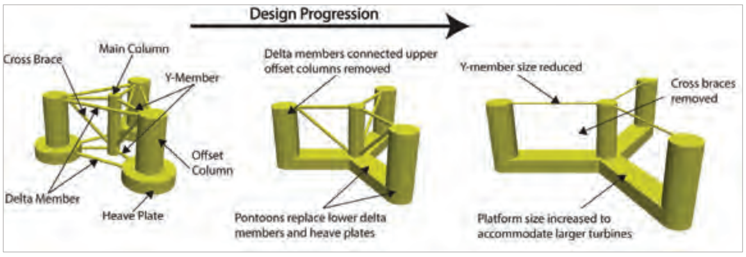
1. Phase I: Exploratory FOWT platform studies (1990-2010)
   - Proof-of-concept
   - 'Conventional' platforms vs. 'unconventional' ones

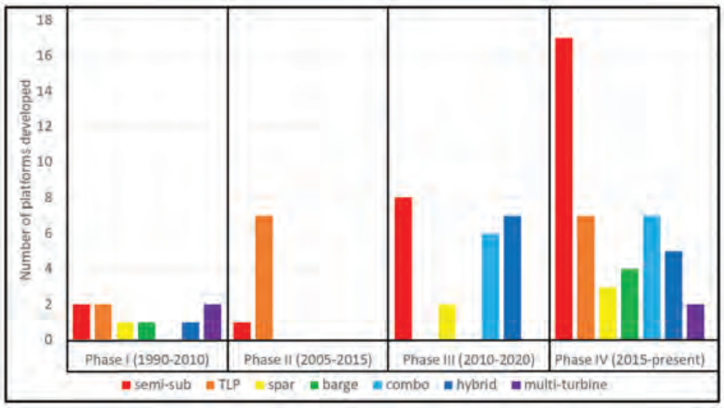
2. Phase II: Oil & Gas (O&G) influence (2005-2015)
   - Common goal of reducing platform motions

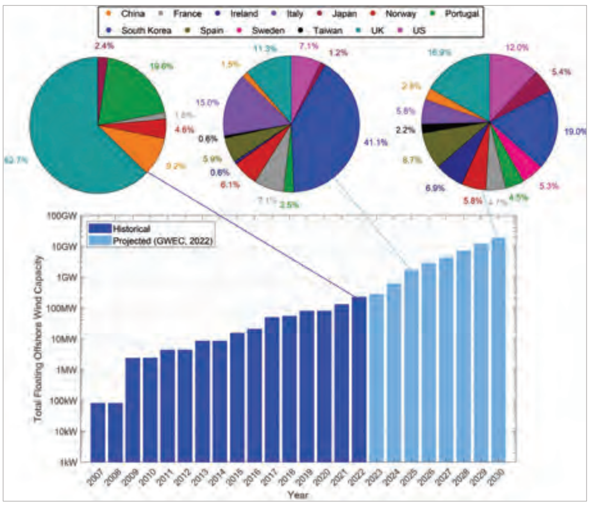
3. Phase III: Specialization to floating wind (2010-2020)
   - Co-evolution of platforms, tower and turbines
   - Reduction in the complexity of semi-sub structures
   - Combination-type platforms
   - Hybrid (multi-energy) platforms

4. Phase IV: Cost reduction strategies (2015-present)
   - Specialization to a particular location or environment
     - Creative tow-out/ways to fit at a standard port
     - Material
     - Specialization to a particular location at sea
   - Increasing manufacturability/ modularity
   - Innovative platform designs
     - Hybrid
     - Combination-type
     - Multi-turbine
     - Hydrodynamically innovative platforms









Potential future trends

- Likely to be interplay between **standardization** and **specialization**
- Larger turbines likely to be a major driver
- Promising types of platforms
  - 3 column semi-subs
  - Combination-type
  - Hybrid
  - Multi-turbine
  - Multi-mast

Edwards, EC, Holcombe, A, Brown, S, Ransley, R, Hann, M, Greaves, D (2023). Evolution of floating offshore wind platforms: A review of at-sea devices. *Renewable and Sustainable Energy Reviews.*
(Under review) Edwards, EC, Holcombe, A, Brown, S, Ransley, R, Hann, M, Greaves, D. Past and future trends in floating wind platforms: A review of early-stage devices.

Cornwall FLOW Accelerator
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Supergen ORE ECR Forum, abstract 2023 (poster presentation):

Key trends in the evolution of floating offshore wind platform designs

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Using floating platforms to support offshore wind turbines will be necessary for many countries to reach their Net-Zero targets, since much of the wind resource is located at water depths at which fixed offshore wind turbines are unfeasible. Floating platforms for wind turbines are still at a relatively early stage of development, and there has been a recent rapid development of technology. A recent review has been completed of Floating Offshore Wind Turbine (FOWT) platform design, providing a much-needed update to the state-of-the-art of the rapidly developing technology. Common design goals and resulting design features are reviewed. Levelized Cost of Energy (LCOE) for FOWTs is discussed, including a discussion on how LCOE is projected to drop considerably in the near future.

In this presentation, key trends in the evolution of FOWT platform designs, identified during this review, are discussed. Four phases have been identified, which show the chronological shifts in design thinking. The first phase, lasting from approximately 1990 to 2010, is characterized by exploratory proof-of-concept FOWT platform studies and comparing 'conventional' floating platforms to 'unconventional' ones. The second phase, lasting from approximately 2005 to 2015, is characterized by influence from the Oil & Gas (O&G) industry, a natural starting point for the technology due to the common goal of reducing platform motions. The third phase, lasting from approximately 2010 to 2020, is characterized by specializing the technology to the specific needs of floating offshore wind. The fourth phase, in which the technology current is, is characterized by cost reduction strategies. These strategies include (i) specializing the platform to a particular location or environment, (ii) increasing manufacturability, and (iii) designing an innovative platform which diverges further from conventional designs. For the latter strategy, there has been an emergence of multi-turbine platforms, hybrid platforms, platforms which use a combination of stability mechanisms, and hydrodynamically specialized platforms.

Finally, potential future trends are discussed. In particular, the sometimes-competing objectives of further standardization (e.g., to ease towing and O&M requirements, ensure safety considerations are met, and standardize supply chains) and further specialization (e.g., to optimize a solution to a particular environment and best match local supply chain) are likely to continue to be influential. Promising types of platforms are identified, including classic three-column semi-submersibles, platforms that do not fit into one of the four traditional types of floating platform, multi-turbine platforms, hybrid (multi-use) platforms, and platform which accommodate multi-mast turbines.

Bulge Test and Material Characterisation of Elastomers Used in the OWC Wave Energy Converter

Bionic Adaptive Stretchable Materials for Wave Energy Converters (BASM-WEC)

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Abstract

This study presents a novel methodology for characterising elastomer materials in oscillating water column (OWC) wave energy converters. Hyperelastic models for silicon and natural rubber (NR) were created based on the results of the bulge test experiment. A bulge test setup was designed and assembled for this aim, and various hyperelastic models were fitted to the experimental results. The most suitable models were selected based on criteria such as stability conditions, error analysis, and numerical validation.

Methodology

Figure 1 illustrates the steps outlined in this process:

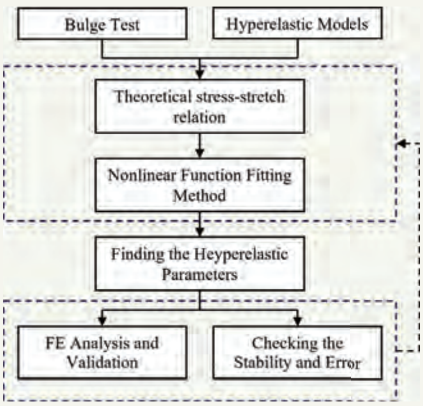

FIGURE 1: Overview of the methodology in this work.

- After conducting the bulge test for different elastomers, the collected pressure and deformation data will be transformed into the stress and stretch results.
- The results will be fitted to different hyperelastic models, and the unknown parameters will be computed.
- The hyperelastic models will be used in the numerical simulation to simulate the bulge test numerically, and the experimental results will justify the accuracy of the hyperelastic models.
- The most suitable models were selected based on stability conditions, error analysis, and Abaqus validation.

Advantages of the presented method:

- This method characterised the elastomers with the same deformation mode as the membranes in the OWC wave energy converter.
- Compared to other standard tests like tensile, compression, biaxial, and planner tests, the bulge test is less expensive and involves a more straightforward data processing method.
- This method avoids the effects of friction and edge damage that may occur when the sample is clamped on the tensile machine.
- This method can be used for characterising very thin elastomers without the concern of samples sliding on clamps.

Hyperelastic Models:

We analyse and characterise the samples using five commonly used hyperelastic models: first-order Moony-Rivlin (FOMR), second-order Moony-Rivlin (SOMR), Yeoh, Ogden with *N*=3, and Arruda-Boyce (AB). In the conducted bulge test, the axisymmetric nature of the geometry, loading, and boundary conditions allow for considering equibiaxial conditions in the equations.

Experimental setup and results

Figure 2 shows the setup prepared for the bulge test.

FIGURE 2: The experimental setup of the bulge test

- In this setup, an acrylic cylinder is fixed between a supporting structure and on one side, the elastomer will be fixed properly to avoid leakage; on the other side, an air pump is connected to apply uniform pressure inside the cylinder.
- Qualisys system and pressure transducer are used to measure the deformation and pressure during the experiment.

Experimental results and model fitting:

In this study, we tested elastomers at reasonable strain levels for the OWC wave energy converter.

- A preprocessing step was carried out to remove the noisy pressure transducer data.
- The stress stretch data were fitted to different hyperelastic models using MATLAB's lsqcurvefit function (Figure 3).

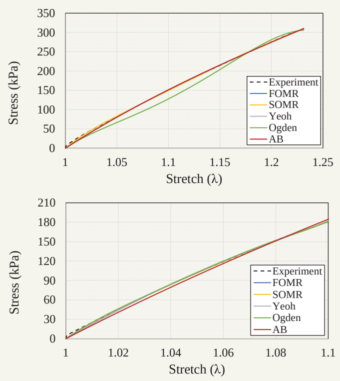

FIGURE 3: Comparison of stress-stretch curve between experimental results and fitted models for Top) NR and Bottom) Silicon

Table 1 shows the stability of models (using the Drucker stability condition) and the root mean square error (RMSE) between the stress stretch of experimental results and fitted curves.

Table 1: The stability of models and RMSE of experimental results and fitted curves.

Model	Parameters	Material	
		NR	Silicon
FOMR	Stability	< 7.7	< 0.32
	RMSE (MPa)	0.0021	0.0011
SOMR	Stability	< 0.68	< 0.25
	RMSE (MPa)	0.0010	0.00069
Ogden (*N*=3)	Stability	< 0.24	< 1.03
	RMSE (MPa)	0.0117	0.00083
Yeoh	Stability	Stable	Stable
	RMSE (MPa)	0.0021	0.0011
AB	Stability	Stable	Stable
	RMSE (MPa)	0.0021	0.0032

Numerical Results and Discussions

Numerical Simulation and Validation:

Abaqus verifies experimental results and the generated hyperelastic models. To simulate the behaviour of the elastomer, pressure transducer data, which is the resultant of fluid-solid interaction in the actual condition, is used as a loading state on its surface.

FIGURE 4: Abaqus simulation and swept view of the result

Figures 5 compare pressure against the tip displacement between the numerical simulation and experimental results. It can be seen from Fig. 5 that all the generated hyperelastic models can adequately predict the behaviour of the NR and silicon.

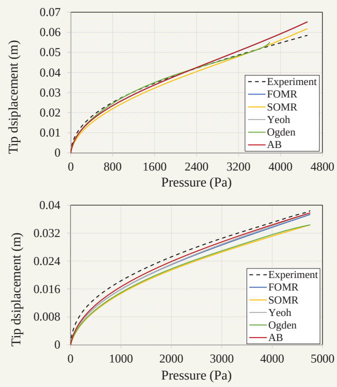

FIGURE 5: . A comparison between displacement and pressure for experimental and Abaqus results for Top) NR and Bottom) Silicon

Conclusions:

In the following, the discussion for each material is provided:

NR:

- The SOMR is stable for nominal strain less than 0.68 and has a lower RMSE than other models.
- FOMR, Yeoh and AB also have good stability and low RMSE for extensive deformation analysis.

Silicon:

- All the hyperelastic models have a relatively low RMSE, ranging from 0.00069 MPa to 0.0032 MPa.
- The AB and Yeoh models are suitable for analysing large deformations, while the Ogden model is best for nominal strains below 1.03.

Opportunity for Collaboration:

- Fatigue and hysteresis analysis of elastomers under cyclic loadings considering different environmental factors, such as temperature and humidity.
- Studying different structural solutions to increase the durability and efficiency of OWC.

Bulge Test and Material Characterisation of Elastomers Used in the OWC Wave Energy Converter

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Abstract

This study presents a novel methodology for characterising elastomer materials in oscillating water column (OWC) wave energy converters. Hyperelastic models for silicon and natural rubber (NR) were created based on the results of the bulge test experiment. A bulge test setup was designed and assembled for this aim, and various hyperelastic models were fitted to the experimental results. In this study, Abaqus verifies experimental results and the generated hyperelastic models. To simulate the behaviour of the elastomer, pressure transducer data, which is the resultant of fluid-solid interaction in the actual condition, is used as a loading state on its surface. The most suitable models were selected based on criteria such as stability conditions, error analysis, and numerical validation.

Keywords: Bulge Test; Experimental setup; Hyperelastic materials; Material Characterisation.

Application of Wave Devouring Propulsion (WDP) for floating wind platform stabilisation

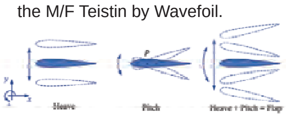
https://doi.org/10.48550/arXiv.2209.05551

Offshore Renewable Energy

Introduction

Thrust generation from a foil flapping in a fluid is often studied topic with various applications.

- Knoller [1] and Betz [2] first explained the mechanism of thrust production. The so-called `Knoller-Betz' effect was verified experimentally by Katzmayr [3].
- Isshiki [4] theoretically proved the possibility of wave devouring propulsion (WDP) by a submerged, passive flapping hydrofoil subject to the action of waves.
- Later, Isshiki et al. [5,6] conducted a series of the experiments and further theoretical discussions considering the WDP of a hydrofoil placed in waves with shallow draft.
- The first successful voyage of the WDPS ship Mermaid II was reported in 2008 and since then
- a few wave-propelled concepts have become commercially available,e.g. the Wave Glider from Liquid Robotics, the Autonomous Surface Vehicles (ASV) from AutoNaut, and the M/F Teistin by Wavefoil.



Numerical solver

An 'in-house' developed code -'one-fluid' formulation was recently proposed by Yang et al. [7] as an addition to the family of immersed methods. The incompressible Navier–Stokes equation following the exclusion of surface tension and the inclusion of the viscous stress force $\boldsymbol{f}$ at the right of the equation.

$$\rho\left[\frac{\partial \boldsymbol{u}}{\partial t} + (\nabla \boldsymbol{u})\boldsymbol{u}\right] = -\nabla p + \boldsymbol{f} + \rho \boldsymbol{g}$$

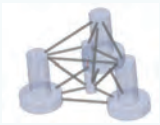
$$\nabla \cdot \boldsymbol{u} = 0$$

$$\boldsymbol{f} = \begin{cases} \nabla \cdot 2\mu_a \mathbf{D}(\boldsymbol{u}) & \text{in } \Omega_a \\ \nabla \cdot 2\mu_w \mathbf{D}(\boldsymbol{u}) & \text{in } \Omega_w \\ \rho\left[\left(\frac{\partial \mathrm{P}(\boldsymbol{u})}{\partial t}\right) + (\nabla \mathrm{P}(\boldsymbol{u}))\mathrm{P}(\boldsymbol{u})\right] + \nabla p - \rho \boldsymbol{g} & \text{in } \Omega_r \end{cases}$$

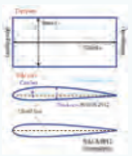
where $\rho = \rho_a H_a + \rho_w H_w + \rho_r H_r$. $\boldsymbol{u}$ is the velocity vector field, p is the pressure, $\boldsymbol{f}$ is the force on each phase Ω, $\boldsymbol{g}$ is the gravitational acceleration, μ is the dynamic viscosity and $\mathbf{D}(\boldsymbol{u}) = \frac{1}{2}\left(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T\right)$ is the strain rate tensor. The subscripts indicate the different phases, i.e., a for air, w for water, and r for rigid body.

Workflow

FOWT platform model



Flapping foil



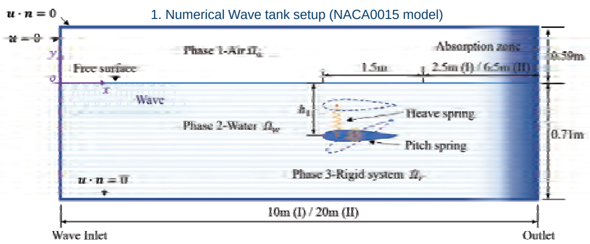
Wave Tank

The effect of Sub-structure model

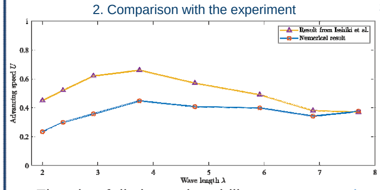
Application 1 – Passive foil in waves

Fig. 1 | 2 | 3

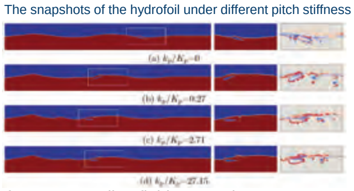
1. Numerical Wave tank setup (NACA0015 model)



2. Comparison with the experiment



3. The snapshots of the hydrofoil under different pitch stiffness

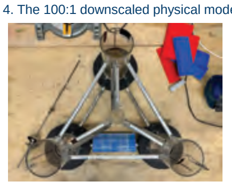


- Flapping foils have the ability to generate thrust from surrounding fluids, WDP is an environment-friendly propulsion technology.

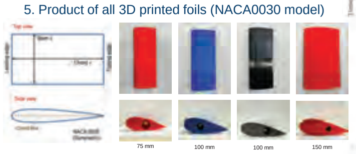
Application 2 – Rigid foil attached to platform

Fig. 4 | 5 | 6

4. The 100:1 downscaled physical model



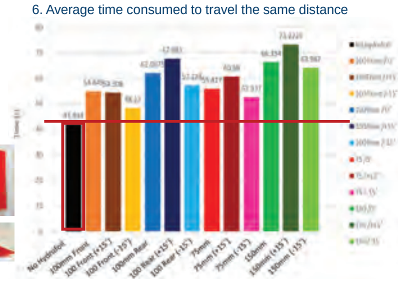
5. Product of all 3D printed foils (NACA0030 model)



Free floating tests

Wave amplitude = 0.075m Wave frequency = 0.65Hz

6. Average time consumed to travel the same distance



- Significant difference when foils are applied to the floating platform.
- The application of submerged flapping foils on marine structures has huge market potential.

Experiment setup

The model used in the experiments is an existing OC5 Semisubmersible Floating Platform with a scaled factor of 100. The scaled model platform complies with the scaling rule and is made of three offset polyethylene foam bases with 5 mm thick acrylic columns each, aluminum frames, and a central cylinder of the same thickness with a steel rod inside.

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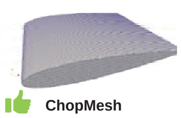
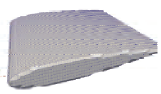
ChopMesh: Automatic OpenFOAM preprocessor



ChopMesh



SnappyHexMesh

- Better Element, Better Alignment, Better Covergence
- Cartesian hexahedral dominant
- Adaptive and robust
- Lower total elements/faces
- Less memory and time

Internal testing: send enquiry/geometry to liang.yang@cranfield.ac.uk for more information

Release in August. 2023

Application of Wave Devouring Propulsion (WDP) for floating wind platform stabilisation

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KEYWORDS: Wave Devouring Propulsion (WDP), Flapping foil, Floating structure stabilisation, Fluid-Structure Interaction

Wave Devouring Propulsion (WDP) is an eco-friendly propulsion technique that converts wave energy into thrust using submerged flapping foils [1,2,3]. Extensive studies have demonstrated the substantial benefits of WDP in improving the efficiency of both human-crewed and uncrewed vessels. By reducing ship wave resistance, as well as heave and pitch responses, WDP provides additional propulsion support and effectively reduces fuel consumption. Moreover, the potential applications of WDP extend to offshore energy production, where it shows promise in reducing wave drift and stabilizing floating structures like semi-submersible platforms. To evaluate the feasibility of utilizing WDP for floating wind platforms, this study conducted laboratory testing. The performance of various sizes of foils was evaluated through scaled-down model tests on a semi-submersible floating platform subjected to regular waves. Interestingly, the presence of the foils was found to significantly enhance the stability of the platform in certain cases.

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[1] Yang, L., Koutras, A., Topal, F., Kolios, A., & Stagonas, D. Working with nature: retrofitting solutions for reducing mooring line loads.
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Understanding the changes to ocean mixing and primary production in UK shelf seas by expanding offshore windfarms

Juliane Wihsgott[1], Tim Smyth[1], Matthew Palmer[1], Rory O'Hara Murray[2], Benjamin Williamson[3] & Beth Scott[4]
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ECOWind

Introduction

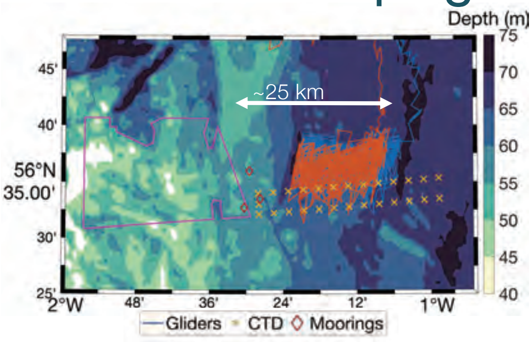
The significant expansion of offshore wind farms (OWFs) is pushing new developments into thermally stratifying shelf seas. Here, the seasonal thermocline separates the warm, lit surface layer from cool, dark and deeper water during spring and summer and thus acts as a key control on the growth of phytoplankton. What's currently unknown is how any change in ocean mixing due to the addition of infrastructure or the extraction of wind energy may impact biogeochemical cycling with knock-on-effects to higher trophic levels such as pelagic fish and seabirds. The ECOWind funded PELAgIO (Physics to Ecosystem Level Assessment of Impacts of Offshore Windfarms) project aims to address these evidence gaps. Here, we present preliminary findings from an ongoing field campaign using multi-instrumented ocean gliders complemented by acoustic platforms in the Firth of Forth.

Research questions

1. Will the increased drag and removal of wind energy by OWFs impact currents, tidal elevations, sea state and mixing and impact mixed layer depths and seasonal stratification which underpin seasonal and bi-weekly primary production cycles?
2. Will increased turbulence suspend sediment and alter changes to light penetration impacting primary production and predator-prey interaction?
3. Will mixed layer depth changes alter the rates and depths at which nutrients and dissolved gases such as O_2 are exchanged?

Observational campaign May-August 2023

Location of SSE Seagreen windfarm
Image credit: https://www.seagreenwindenergy.com



Instrument setup:

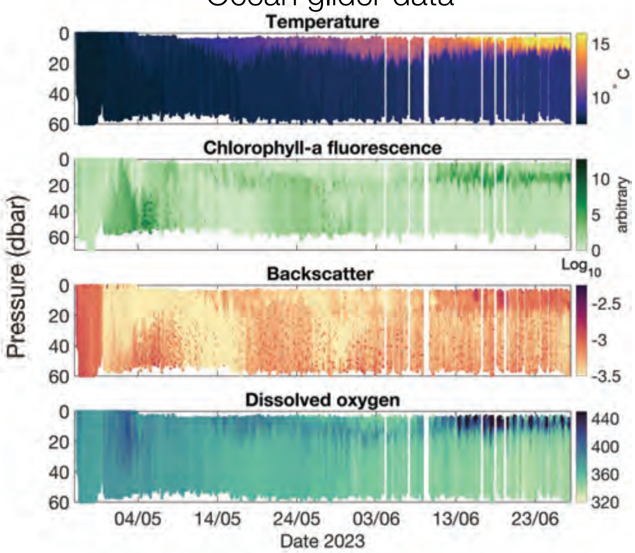
- 3 moorings measuring ocean currents and temperature structure.
- Shipborne observations of physical variables, birds and prey distribution (using acoustics).
- 2 ocean gliders measuring temperature & salinity, turbulence, chlorophyll-a fluorescence, backscatter and dissolved oxygen.

Live glider positions

SCAN ME

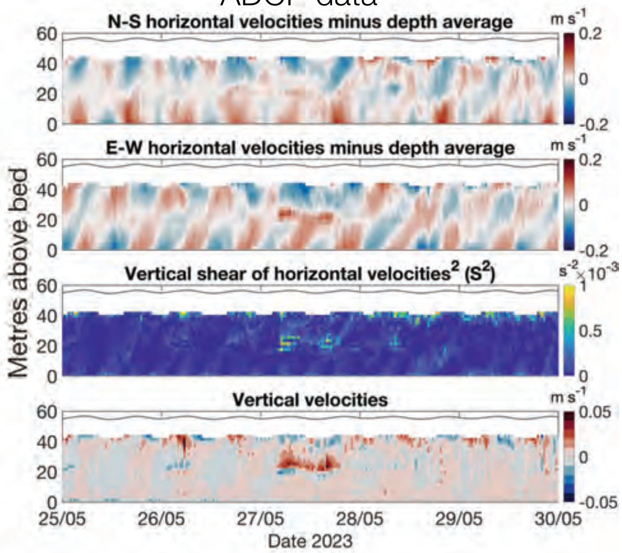
Preliminary results

Ocean glider data



New in-situ observations collected by an ocean glider show that the onset of seasonal thermal stratification in early May fuelled a phytoplankton bloom, which is indicated by elevated levels of chlorophyll-a fluorescence and dissolved oxygen. As stratification is further strengthening a subsurface chlorophyll maxima forms at the thermocline. Regular increases in bottom mixed layer backscatter are indicative of tidally modulated resuspension events.

ADCP data



Varying levels of baroclinicity are clearly evident in the horizontal velocities. These drive high levels of midwater shear, which is suggestive of strong midwater stratification and linked to bursts of elevated vertical velocities that could fuel primary production in the light lit surface layer. Further work will investigate potential impacts of turbine generated wake and wind wake effects on the physical structure of the water column and ultimately on primary production and higher trophic levels.

Understanding the changes to ocean mixing and primary production in UK shelf seas by expanding offshore windfarms

Juliane Wihsgott[1], Tim Smyth[1], Matthew Palmer[1], Rory O'Hara Murray[2], Benjamin Williamson[3] & Beth Scott[4]

[1]Plymouth Marine Laboratory [2]Marine Scotland Directorate of the Scottish Government [3]Univeristy of the Highlands and Islands [4]University of Aberdeen

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The UK's target of achieving up to 50 GW of energy produced by offshore wind by 2030 requires a significant expansion of offshore wind farms (OWFs) into deeper, seasonally stratified parts of our shelf seas.
The addition of new underwater infrastructure will increase turbulence locally around the turbine structures and lead to seabed scouring near fixed foundations. Conversely, large wind energy extraction will reduce the amount of energy that would normally go into local ocean currents via surface stress, altering sea state and mixing. In well-mixed water the physical effects of OWF are typically short-lived and constrained to local scales. In stratified water, the effects of OWF are unknown and could be more prolonged and affect larger areas of the marine environment than in well-mixed regions. Biogeochemical responses to the seasonal cycle of stratification underpins productivity and carbon cycling within northwest European shelf seas, but these are regulated by relatively subtle mixing processes and so are potentially affected by changes that might be expected from OWF expansion. This could have knock-on-effects on the diversity, health and locations of pelagic fish that are critical prey species of commercial fish, seabirds and marine mammals.
To address these evidence gaps the ECOWind funded PELAgIO (Physics to Ecosystem Level Assessment of Impacts of Offshore Windfarms) project will employ a combination of novel multi-scale (0 to >100 km), multi-trophic, coupled modelling with low-carbon observing methodologies including marine autonomous platforms. These new data will be used to investigate changes to the physical environment and impacts of these on all levels of the food chain: from plankton productivity to the availability of prey for top predators, as well as broader consequences at the ecosystem level.
A current field campaign is underway collecting fine-scale, coincident data from physics to fish and birds, over multiple scales and seasons using multi-instrumented marine autonomous vehicles complemented by acoustic platforms set beside and away from SSE Seagreen OWF in the Firth of Forth. These new data will test the effects on the higher trophic levels to build an OWF ecosystem parameterization that accounts for changes to mixing and wind deficit impacts and is scalable to next-generation OWFs. Here, we present new observations and preliminary findings from the current field campaign.

A Novel Procedure for the Ultrasonic Inspection of Wind Turbine Bolted connection

Brandon Mills[a], Saeid Lotfian[b], Yashar Javadi[a,c], Farhad Abad[b], Charles MacLeod[a], David Lines[a], Ali Mehmanparast[b], Gareth Pierce[a], Feargal Brennan[b], and Anthony Gachagan[a]

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Abstract

In this study, a new methodology is developed to detect and monitor preload in wind turbine bolts. The study is part of a larger research project to use the Phased Array Ultrasonic Testing (PAUT) system to robotically test bolt preload. The stress measurement using the ultrasonic method is explained by the acoustoelastic effect, which is based on the sound velocity change in an elastic material subjected to the static stress field.

Introduction

Industry standard practice involves using a single-element transducer and assuming that any Time of Flight (ToF) change is due to strain induced by stress [1,2].

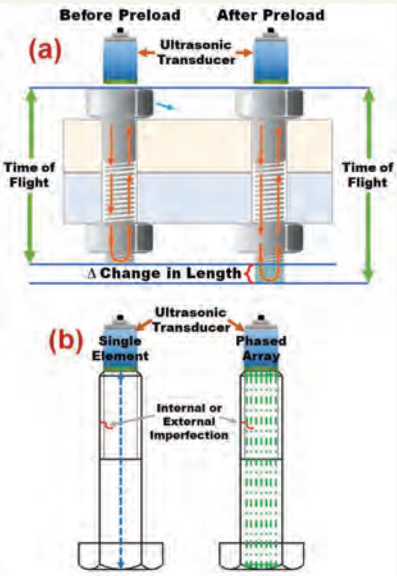

Figure 1: (a) SCHEMATIC OF BOLTS UNDER INSPECTION BY ULTRASONIC TRANSDUCER; (b) BOLTS UNDER INSPECTION BY SINGLE ELEMENT (LEFT) AND PHASED ARRAY (RIGHT) PROBES

Any imperfection that occurs in the manufacturing process or service life can also affect ToF. The above shows that while a single-element transducer may not interact with a defect during an inspection, a phased array has multiple acoustic paths, so paths can be selected so that a fault is not missed.

To demonstrate this experimentally, a viscous gel was introduced into a bolt stamp, and the bolt was inspected before and after. As a PAUT probe was used, multiple acoustic paths were generated, and both states were compared.

A difference in the ToF was noted, with it increasing in the case of the gel imperfection. This ranged from 0ns to 35ns, with an average of 10ns. This is equivalent to a stress error of 40MPa [2,3].

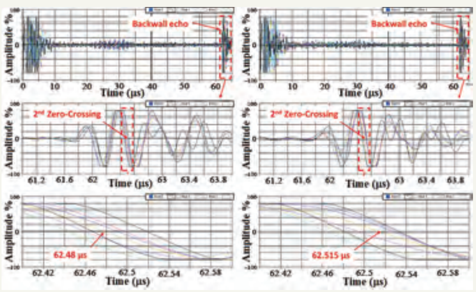

Figure 2: TIME OF FLIGHT DATA FROM A CLEAN (DEFECT-FREE) BOLT (LEFT) AND A BOLT WITH AN IMPERFECTION ANALOGOUS TO CORROSION (RIGHT)

Experimental

The methodology was followed as per the flowchart in Figure 3.

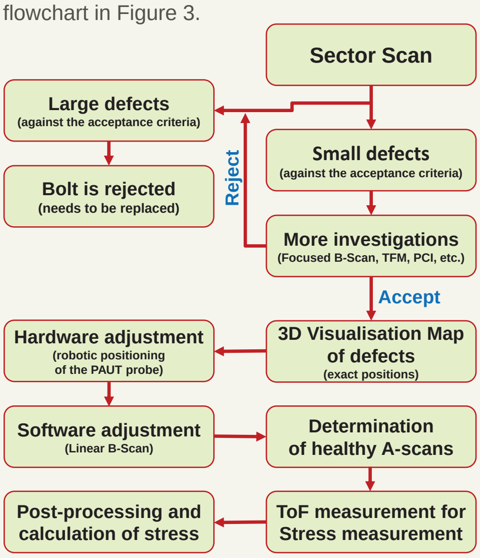

Figure 3: FLOWCHART DESCRIBING THE TESTING PROCEDURE

- This was verified using the setup in Figure 4, with an M36 bolt with a single side drilled hole with a 3mm diameter (Figure 4 left).
- Additionally, a blind test was performed on an M42 bolt (Figure 4 right).
- The preload was monitored using a washer-shaped strain gauge, and the force increased using a pneumatic tensioner.
- A 20 element, 1.2 mm pitch, 2.25 MHz ultrasonic probe was used for stress detection, connected to a PEAK-NDT micro-pulse controller.
- As the Full Matrix Capturing (FMC) technique was used, 400 acoustic paths were generated per scan, allowing for a liberal attitude to be taken with disregarding the unhealthy paths.
- At the data analysis stage, the ToF of the healthy paths were extracted, averaged and then processed into the stress data seen in Figure 5. The acoustoelastic constant here was related to 316 stainless steel: 2.28 [4].

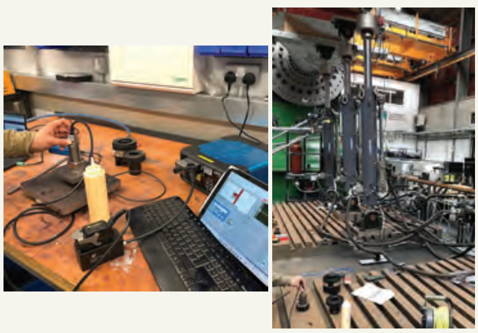

Figure 4: EXPERIMENTAL SETUP FOR PAUT (M36 LEFT, M42 RIGHT)

Results

- ➢ This technique was successfully implemented on a defective bolt.
- ➢ It was demonstrated that although 8 of the 20 elements were obscured by a defect, the average of the remaining acoustic paths gave a clear stress graph.

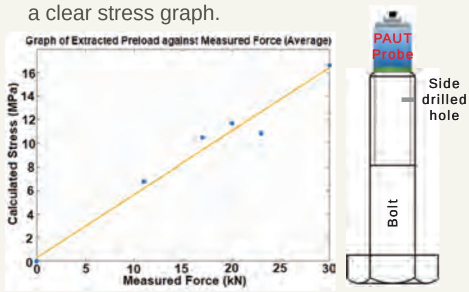

Figure 5: GRAPH OF STRESS IN BOLT AS FORCE INCREASES (LEFT) AND DIAGRAM OF BOLT UNDER TEST (RIGHT)

Conclusions and next steps:

- ❖ The procedure developed here is straightforward and can easily be taught to current operators.
- ❖ The ultimate goal of this project is constant, in–situ monitoring.
- ❖ To that end, future work of this project will focus on the automation of this measurement process using the collaborative robot and machine learning algorithms

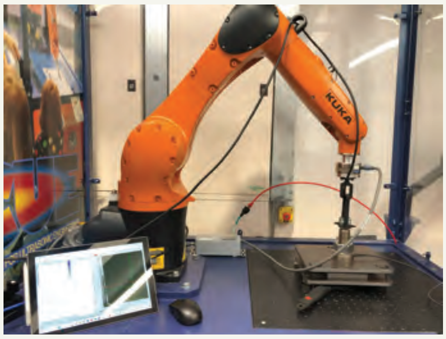

Figure 6: ROBOTIC TESTING OF THE WIND TURBINE BOLTS USING ULTRASONIC STRESS MEASUREMENT SYSTEM

References:

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A Novel Procedure for the Ultrasonic Inspection of Wind Turbine Bolted Connection

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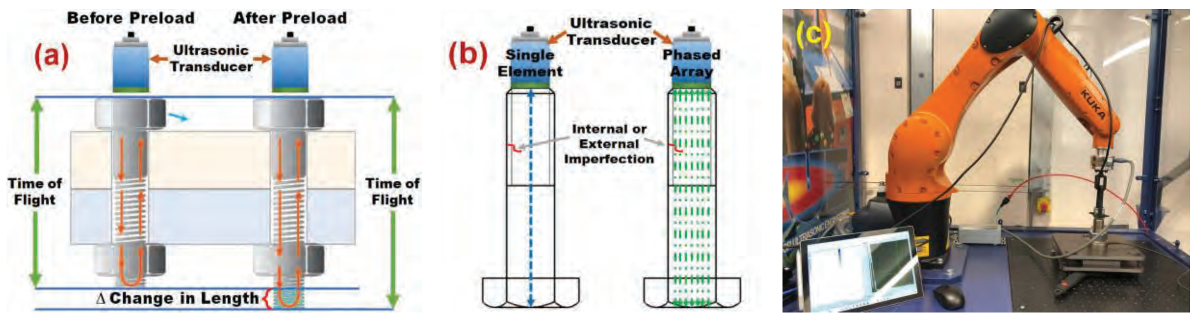
[c] *Department of Design, Manufacturing & Engineering Management (DMEM)*

In this study, a new methodology is developed to detect and monitor preload in wind turbine bolts. The study is part of a larger research project to use the Phased Array Ultrasonic Testing (PAUT) system to test bolt preload robotically. The stress measurement using the ultrasonic method is explained by the acoustoelastic effect, which is based on the sound velocity change in an elastic material subjected to the static stress field. Acceptable defects below a pre-defined size are shown to have an impact on preload measurement, and therefore, conducting simultaneous defect detection and preload measurement is investigated. The study demonstrates that even slight changes in the orientation of the ultrasonic transducer, the non-automated approach, can introduce a significant error of up to 140 MPa in bolt stress measurement and therefore, a robotic approach is employed to achieve consistent and accurate measurements. Additionally, the study emphasises the significance of considering average preload for comparison with ultrasonic data. The advantages of the proposed robotic PAUT method over single-element approaches are discussed, including the incorporation of nonlinearity, simultaneous defect detection and stress measurement, hardware and software adaptability, and, notably, a substantial improvement in measurement accuracy. Based on the findings, the conclusion strongly recommends adopting the robotic PAUT approach for preload measurement whilst acknowledging the required investment in hardware, software, and skilled personnel.



(a) Schematic of Bolts under inspection by ultrasonic Transducer; (b) Bolts under inspection by single element and phased array probes; (c) Robotic Testing of the Wind Turbine Bolts using Ultrasonic Stress Measurement System.

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AUTONOMOUS UNDERWATER INSPECTION FOR OFFSHORE WIND STRUCTURES

Shen Li, Feargal Brennan

Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde

Introduction

Maintaining the integrity of underwater sub-systems and structural components is crucial for the fitness-for-service of offshore wind assets. An international consortium including the University of Strathclyde has been awarded a prestigious Enterprise Singapore - Innovate UK grant to develop a next generation autonomous structural integrity inspection capability.

Figure 1: Consortium and funding agency

Project Vision

The vision of the project with autonomous robotics specialist BeeX, offshore energy survey and inspection provider Sulmara, and structural integrity specialists at Strathclyde, is to deliver a new Robotics-as-a-Service (RaaS) solution to reduce the resources required to conduct essential underwater inspections and asset integrity assessment of offshore wind turbines. Large vessels are currently required to transport personnel offshore to inspect the assets, incurring substantial costs throughout the entire life cycle. In this context, the costs are largely driven by the use of specialised Dynamically Positioned vessels to deploy work-class remotely operated vehicles (ROV).

Specification	ROV	AUV
Overall length	240 ft	120 ft
System deck footprint	1,000 ft²	500 ft²
System weight	80 tons	10 tons
Vessel crew size	20-40	6-8
Vessel day rate	£30k	£10k

Figure 2: Specification of support vessels for deploying ROV and AUV

Risk-Based Inspection (RBI)

Risk-based inspection, which prioritises high-risk components for inspection, offers a more focused and targeted approach to inspection planning than the traditional time-based periodic method.

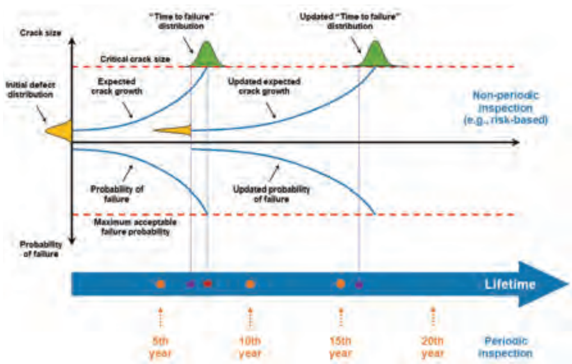


Figure 3: Periodic versus non-periodic inspection

The application of RBI provides a multitude of benefits, notably:

1. Inspection cost saving and reduction of downtime.
2. Known operational risks and thus timely remedial action prior to significant business impact occurring.

Digital Twin-Assisted RBI

Conducting a comprehensive risk analysis requires gaining a thorough knowledge of the actual operational profile and current state of the structure (e.g., consumed fatigue life) whereby accurately predicting its future performance (e.g., remaining fatigue life). Although design specifications and assumptions can serve as guidelines, a high degree of uncertainty may arise due to the discrepancy between the actual operational profile and the design assumptions. In view of this, leveraging the comprehensive information provided by digital twin technology has the potential to enhance the prediction of the degradation process and RBI.

Figure 4: Application of digital twin in RBI

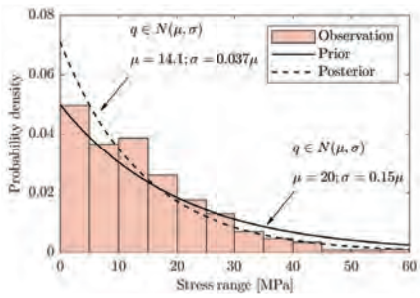


Figure 5: Prior and posterior stress range distribution

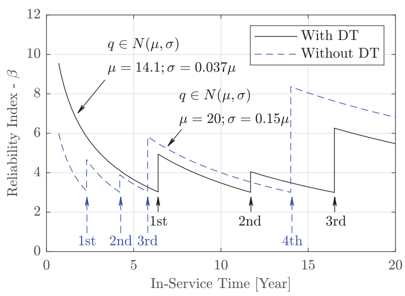


Figure 6: Time-variant structural reliability. *Note: the arrow indicates inspection time*

Conclusions and Future Outlook

A practical scheme to apply digital twin for risk-based inspection planning is suggested, paving the way for the integration of autonomy and digitalisation. Future works will be focused on: 1) Development of an optimal inspection and digital twin-based monitoring scheme; 2) Nondestructive testing (NDT) techniques deployed by HAUV and their performance; 3) Engineering critical assessment for inspected damage/defect.

Autonomous Underwater Inspection for Offshore Wind Structures

Shen Li and Feargal Brennan

Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow

Abstract: Maintaining the integrity of underwater sub-systems and structural components is crucial for the fitness-for-service of offshore wind assets. An international consortium including the University of Strathclyde has been awarded a prestigious Enterprise Singapore - Innovate UK grant to develop a next generation autonomous structural integrity inspection capability. The vision of the project with autonomous robotics specialist BeeX, offshore energy survey and inspection provider Sulmara, and structural integrity specialists at Strathclyde, is to deliver a new Robotics-as-a-Service (RaaS) solution to reduce the resources required to conduct essential underwater inspections and asset integrity assessment of offshore wind turbines. Large vessels are currently required to transport personnel offshore to inspect the assets, incurring substantial costs throughout the entire life cycle. In this context, the costs are largely driven by the use of specialised Dynamically Positioned vessels to deploy work-class remotely operated vehicles (ROV). This poster highlights the recent progress made by Strathclyde on the development of a risk-based inspection (RBI) methodology. This prioritises high-risk components for inspection and offers a more focused and targeted approach to inspection planning than the traditional time-based periodic method. However, conducting a comprehensive risk analysis requires gaining a thorough knowledge of the actual operational profile and current state of the structure (e.g., consumed fatigue life) whereby accurately predicting its future performance (e.g., remaining fatigue life). Although design specifications and assumptions can serve as guidelines, a high degree of uncertainty may arise due to the discrepancy between the actual operational profile and the design assumptions. In view of this, leveraging the comprehensive information provided by digital twin technology has the potential to enhance the prediction of the degradation process and RBI. A practical scheme to apply digital twin for risk-based inspection planning is suggested, paving the way for the integration of autonomy and digitalisation. Future works will be focused on: 1) Development of an optimal inspection and digital twin-based monitoring scheme; 2) Non-destructive testing (NDT) techniques deployed by HAUV and their performance; 3) Engineering critical assessment for inspected damage/defect.

A hybrid Wave Energy Converter-Floating breakwater with nonlinear stiffness

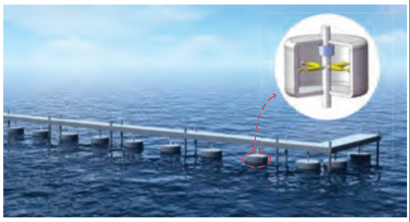
Huaqing Jin, Haicheng Zhang, Daolin Xu

Hunan University, CN

Huaqing. Jin, et.al., *Renewable Energy* 196 (2022) 1029-1047.

Highlights

- The novel hybrid WEC-breakwater system with nonlinear stiffness mechanism is initially proposed and studied.
- The nonlinear frequency domain approach is used for solving the nonlinear wave-structure coupling problem.



- The nonlinear stiffness mechanism has a "phase control" feature.
- The wave attenuation performance and low-frequency capture efficiency is enhanced by the nonlinear stiffness mechanism.

Theoretical model

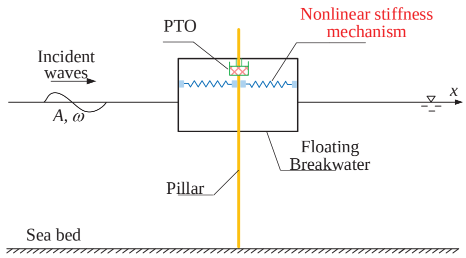


Fig.1 Model diagram of nonlinear WEC-FB

A WEC-FB with nonlinear stiffness mechanism is proposed to improve its wave attenuation and power capture performance. The semi-analytical nonlinear frequency-domain approach including the eigenfunction expansion matching method and multi-harmonic balance method is proposed to solve the nonlinear waves-structures interaction problem.

Results & discussion

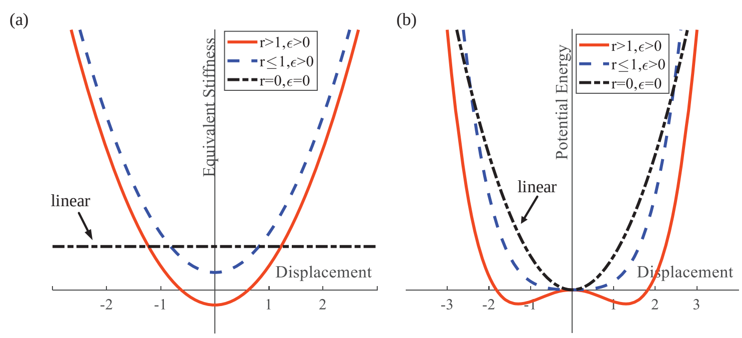


Fig.2 (a) Equivalent stiffness and (b) potential energy

From **Fig.2** it can be observed that the stiffness of the WEC-FB equipped with nonlinear stiffness mechanism can be reduced within a certain range, which decrease the equivalent stiffness of the hybrid WEC-FB and improve its performance in low frequency range.

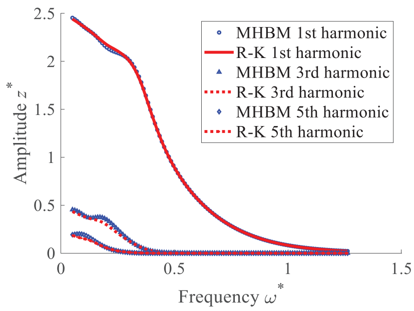


Fig.3 Motion response in frequency domain obtained by R-K and MHBM

From **Fig. 3**, it can be seen that motion of the nonlinear WEC-FB has multiple harmonics, and the amplitude of each order harmonic decreases with increasing frequency.

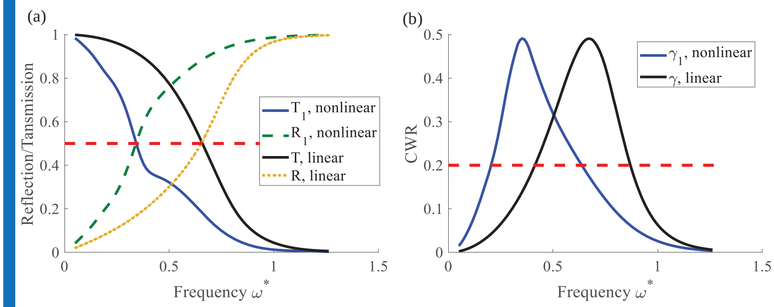


Fig.4 Performance evaluation for the linear and nonlinear WEC-FB. (a) Reflection /transmission coefficients; (b) Capture width ratio.

In **Fig. 4**(a), the nonlinear WEC-FB shows a smaller transmission than the linear WEC-FB in the whole range of frequency. In **Fig. 4**(b), we can see that the energy capturing bandwidth visibly moves to the low frequency region.

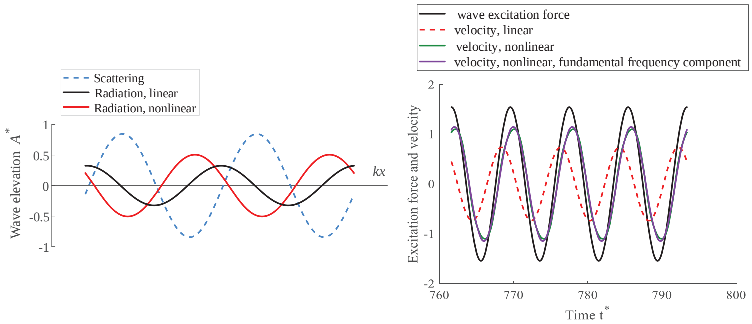


Fig.5 (a)Wave surfaces of scattering wave, radiation wave in linear WEC-FB and radiation wave in nonlinear WEC-FB. (b) The time series of wave excitation force and velocity of the floater for both the linear and nonlinear WEC-FBs.

In **Fig. 5**(a), the phase difference between radiation wave induced by nonlinear WEC-FB more anti-phase with the linear one. In **Fig. 5**(b), the velocity of the nonlinear WEC-FB more in-phase with the wave excitation force.

Conclusions

- The proposed nonlinear WEC-FB has a better effect than linear one in wave attenuation and energy extraction.
- The nonlinear stiffness mechanism has a "phase control" feature that can improve the performance of WEC-FB

A hybrid Wave Energy Converter-Floating breakwater with nonlinear stiffness

Abstract

Huaqing Jin

Wave energy is attractive for its generous, sustainable and clean, the combination of floating breakwater (FB) and wave energy converter (WEC) is an economical approach to capture wave energy and attenuate waves. The conventional hybrid WEC-FB system is ineffective for low-frequency waves. To overcome this shortcoming, this paper proposed a novel WEC-FB with nonlinear stiffness mechanism to improve its wave attenuation and power capture performance. A hybrid semi-analytical nonlinear frequency-domain approach including the eigenfunction expansion matching method (EEMM) and multi-harmonic balance method (MHBM) is proposed to solve the nonlinear waves-structures interaction problem. The performance of the nonlinear WEC-FB is demonstrated by comparing with conventional linear counterpart, and the underlying reason for the effect of nonlinear mechanism is explored. The phase control mechanism for improving low frequency performance of wave elimination and energy capture is revealed by using the analytical method. This study shows that the introduction of the nonlinear mechanism can both improve the wave attenuation and energy absorption performance, especially in the low-frequency wave region.

Floating hydroelastic circular plate in regular & irregular waves

Simone Michele, Siming Zheng, Federica Buriani, Alistair G.L. Borthwick, Deborah M. Greaves

UNIVERSITY OF PLYMOUTH

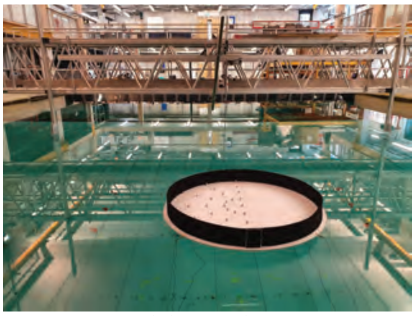
University of Plymouth, UK

Supergen Offshore Renewable Energy

Michele, S., et al., 2023. *European Journal of Mechanics - B/Fluids*, 99, 148-162.

Highlights

- Experimental data on the hydroelastic response of a flexible circular floating plate in regular and irregular waves were obtained from physical tests conducted in the COAST Lab at the University of Plymouth.
- The plate motion was recorded using a QUALISYS® motion tracking system.
- We present synchronous and subharmonic nonlinear responses for regular waves, and displacement spectra for irregular waves.
- The measured wave hydrodynamics and disk hydroelastic responses match theoretical predictions based on linear potential flow theory.



Theoretical model

A linear potential flow theory-based model is developed to study wave interaction with a floating elastic circular plate. A ***dry-mode expansion*** method is adopted, with which the motion of the plate is decomposed into heave and pitching, and a series of elastic bending modes.

Results & discussion

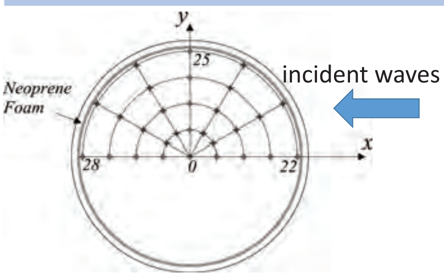


Fig. 1 Plan view of the disk, neoprene foam barrier, and marker locations. Results from markers 0, 22, 25 and 28 are used to determine the plate dynamic behaviour.

Hydroelastic response in regular waves

Tests were carried out separately on two elastic disks of different thicknesses h_p=[3;10] mm in regular waves of constant amplitude A=[2;3] cm and frequency $f \in [0.4,1.9]$ Hz. Two basin depths were considered, h=[1.5;3] m. For h_p = 3 mm we found ρ_p = 489.64 kg m^{-3} and E = 854 MPa, whereas for h_p = 10 mm we obtained ρ_p = 463.87 kg m^{-3} and E = 508 MPa.

Fig. 2 shows a comparison of the RAO response at four selected markers between the experimental results and the theoretical ones, demonstrating very close agreement.

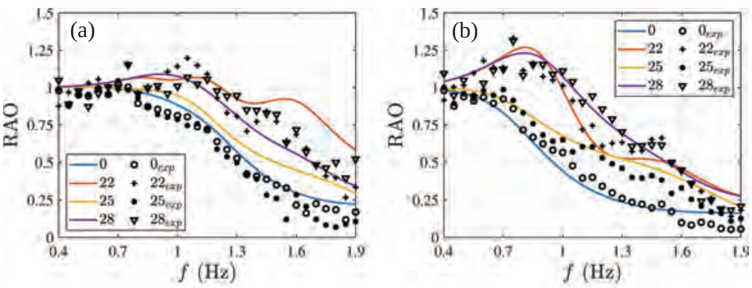


Fig. 2 Frequency response of RAO at marker locations 0, 22, 25 and 28 for water depth h = 1.5 m and wave amplitude A = 0.02 m: (a) plate thickness h_p = 3 mm, and (b) plate thickness h_p = 10 mm. Solid lines: analytical solution; symbols: experimental results.

Fig. 3 presents the 2nd & 3rd harmonic responses identified from the experimental data. The subharmonic response is smaller than the linear response, this is because subharmonics are at most O(ϵ) order effects. Even so, the second harmonic component can be important

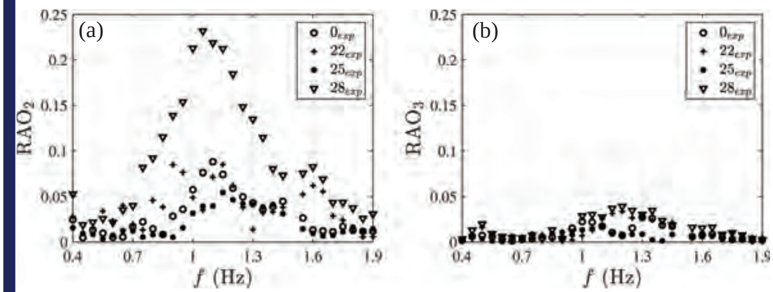


Fig. 3 Normalised higher harmonic response contributions versus wave frequency at markers 0, 22, 25 and 28 for plate thickness h_p = 3 mm, water depth h = 1.5 m and wave amplitude A =0.03 m: (a) 2nd harmonic response 2f; and (b) 3rd harmonic response 3f.

Hydroelastic response in irregular waves (JONSWAP spectra)

A close agreement between the experimental response spectra and the corresponding ones predicted by using the linear potential flow-based theoretical model is obtained (see **Fig. 4**).

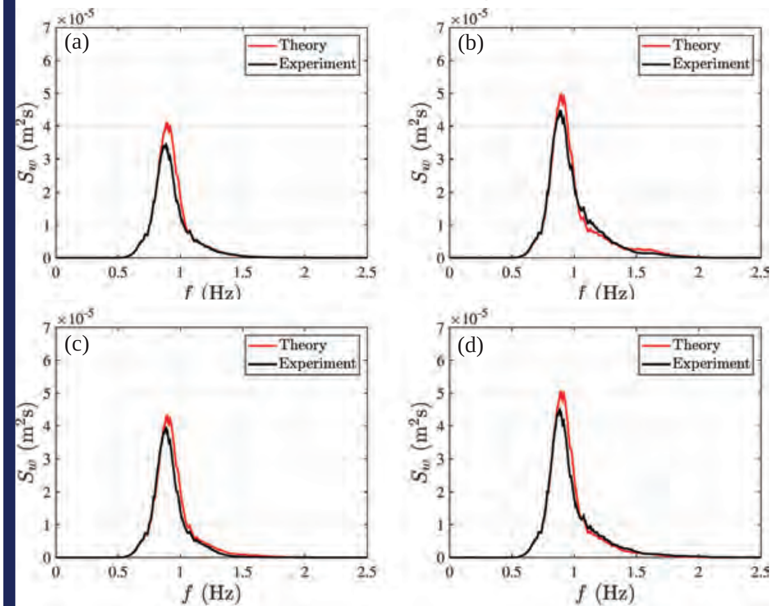


Fig. 4 Vertical displacement spectra for H_s = 0.04 m, T_p = 1.2 s and plate thickness h_p = 10 mm at (a) Marker 0, (b) Marker 22, (c) Marker 25, and (d) Marker 28. The red line corresponds to theory, and the black line is obtained from the measured displacement time series

Conclusions:

- Experimental data on the hydroelastic response of a flexible circular floating plate in regular and irregular waves were obtained from physical tests.
- The effect of rigid and flexible bending modes on overall disk motion was elucidated. Very close agreement was obtained between experimental response spectra and their counterparts predicted using linear potential flow theory.
- Using Fourier analysis, second and third sub-harmonics of the disk response were determined from the measured displacement time series. The results revealed second-order sub-harmonic resonant peaks of significant amplitude.

Floating hydroelastic circular plate in regular and irregular waves

Siming Zheng

Abstract

An understanding of the hydroelastic response of a flexible circular plate to water waves is relevant to many problems in ocean engineering ranging from offshore wave energy converters and solar wind devices to very large floating structures such as floating airports and ice sheets. This paper describes results from physical model tests undertaken in the COAST laboratory at the University of Plymouth. Response amplitude operators (RAOs) of a floating flexible circular disk are determined for incident monochromatic and irregular wave trains, the latter defined by JONSWAP spectra. Free-surface displacements are measured using wave gauges, and the plate motion recorded using a QUALISYS® motion tracking system. Different basin depths and plate thicknesses are considered in order to quantify the effects of water depth and flexural plate rigidity on the overall dynamic behaviour of the circular disk. We present synchronous and subharmonic nonlinear responses for monochromatic waves, and displacement spectra for irregular waves. The measured wave hydrodynamics and disk hydroelastic responses match theoretical predictions based on linear potential flow theory.

• A brief description of the activities you are currently engaged in.

Dr Siming Zheng is interested in problems relating to marine renewable energy and the interaction of waves with structures in a variety of settings including hydrodynamics, hydroelastics, etc. The main application areas are: theoretical/numerical modelling of ocean wave energy converters; the interaction between ice sheets and ocean waves; metamaterials in water waves; and multifunctional marine structures. He is currently engaged in wave scattering problem of a metamaterial cylinder; wave power absorption of an array of oscillating water column devices; and hydrodynamic performance of flexible wave energy converters.

- PDF poster which will be uploaded to the website

See the attached PDF.

Short design waves for predicting extreme responses of floating ORE devices

Scott Brown[*1], Tom Tosdevin[1], Siya Jin[1], Martyn Hann[1], Dave Simmonds[1] and Deborah Greaves[1]
[*]scott.brown@plymouth.ac.uk, [1]School of Engineering, Computing and Mathematics, University of Plymouth, Plymouth, UK

Supergen Offshore Renewable Energy

Introduction

In ORE design procedures, accurate predictions of extreme responses are required in order to design for survivability whilst minimising associated costs. At present, established practices involve simulation of a large number of long-duration sea states. This is only practical in scenarios where computationally efficient linear approach can be used, and can be infeasible if high-fidelity approaches are applicable. Laboratory testing can be utilised to address this to some extent, but this is still time-consuming and expensive from a financial perspective. Consequently, there has been considerable interest in the use of short design waves (SDWs) as an alternative method for speeding up the design process.

Aims and Objectives

- This work aims to determine whether short design waves can provide predictions of extreme loading on floating ORE devices that are in-line with present industry guidelines.
- This is achieved through physical modelling campaigns using a range of floating ORE devices, which are subjected to both long-duration irregular sea states and SDWs.

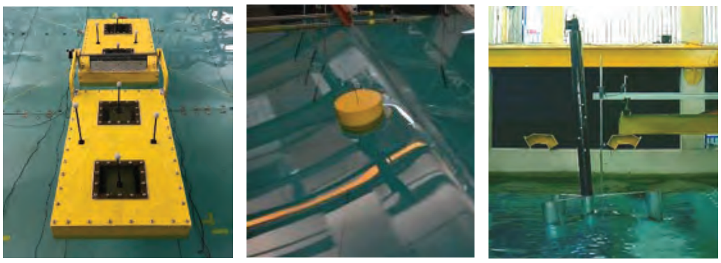


Figure 1: Examples of the ORE models that have been tested: a) a 1/50 scale generic hinged-raft WEC; b) a single-point moored point-absorber WEC; c) 1/70 scale of the VolturnUS-S FOWT.

Short Design Waves (SDWs)

- SDWs aim to bypass modelling a long-duration irregular sea state by only simulating a short wave profile that produces an extreme response.
- SDWs can either be a 'single' wave profile or a wave profile 'constrained' within a short background wave.
- Two single SDW types are considered: 'NewWave'[1], derived based on the wave spectrum; and 'MLER' [2], derived using the linear RAO of the response.
- Two constrained SDW types are also evaluated: 'Constrained NewWave'[3] and 'CRRW'[2], where the NewWave and MLER waves are embedded within a short random irregular background wave, respectively.

Physical Modelling Campaigns

- Experiments conducted in at the COAST Laboratory, University of Plymouth, UK.
- A 1:50 scale model of a generic hinged-raft wave energy converter (WEC) with a 4-point linear-mooring system[4] (Fig. 1a), assuming deployment at the EMEC test site in Scotland, UK.
- A single-point moored point-absorber WEC (Fig. 1b).
- A 1:70 scale model of a floating offshore wind turbine (FOWT) with a 3-point catenary mooring system[5] and a software in the loop system for the aerodynamic modelling based on the NREL 15MW reference turbine[6] (Fig. 1c). The environmental conditions are derived from a potential deployment site off the coast of Maine, USA.
- Sea states are identified on a 50-year return contour, determined by fitting a joint distribution to 30 years of hindcast data.
- Additional test cases at the pitch natural frequency of the WEC, and maximum thrust on the turbine are also considered.

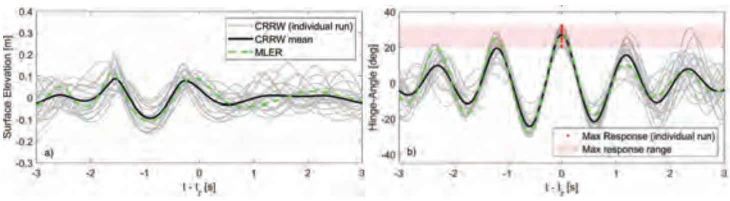


Figure 2: Example of the output of MLER/CRRW for hinge-angle of the hinged-raft WEC[4].

Key Results

- The load provided by the constrained SDWs tends to vary significantly (e.g. Fig. 2) for different background wave profiles. This indicates that history effects are an important consideration for predicting extreme loads of floating structures[4,5].
- Response conditioned focused waves show promise in predicting design loads for some types of responses (Fig. 3). The success of this method depends on how linear the response is and significant changes in system behaviour limit its applicability.
- When responses are strongly influenced by nonlinearities, such as viscous drift of semi-subs, other short design waves need investigating. We have proposed the use of constrained wave groups in this particular case.

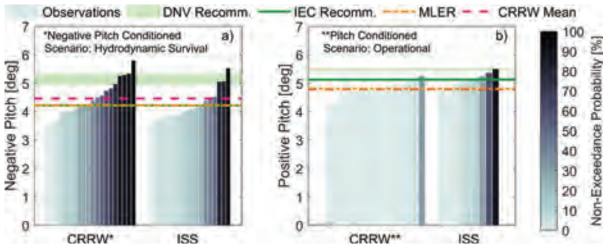


Figure 3: CRRW method compared with irregular sea states for FOWT pitch response[7]. Two scenarios are presented: (a) a 50-year sea state; (b) an operational sea state at rated wind speed.

Future Work

- Identification of trends in the data (e.g. Fig. 4) that may further improve the efficiency of the method, e.g. through refined background wave selection. This includes assessment on the transferability of these trends between similar devices.
- Optimisation on number of SDW runs required to provide characteristic extremes.
- Application of the method to additional platforms and response types.
- Extension to include additional physics; e.g. wave-wind misalignment.
- Identify whether the method can be implemented within best practice guidelines.

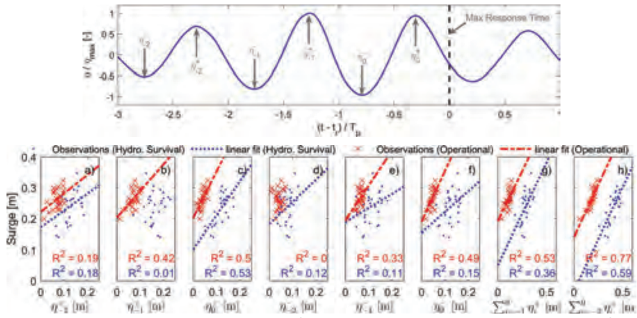


Figure 4: Trends between surge response of the FOWT and the recorded wave elevation for two different scenarios[7]. The wave parameters are defined in the top plot.

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University of Plymouth School of Engineering, Computing & Mathematics

UKRI Engineering and Physical Sciences Research Council

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Short design waves for predicting extreme responses of floating ORE devices

Scott Brown[1], Tom Tosdevin[1], Siya Jin[1], Martyn Hann[1], Dave Simmonds[1], Deborah Greaves[1]

[1]School of Engineering, Computing and Mathematics, University of Plymouth, UK

Governments around the world are increasingly focusing on the development of offshore renewable energy (ORE) as a key component of their sustainable energy strategies. As a result, there has been a surge in investment and research aimed at harnessing the vast potential of offshore resources, including wind, wave, and tidal energy. While fixed ORE structures, such as offshore wind turbines, have been successfully deployed in shallow waters, there is a growing interest in expanding ORE to deeper waters. This expansion requires the development of floating structures that can withstand the challenges posed by harsh marine environments, including extreme waves, winds, and currents. Designing these floating ORE devices to ensure their survivability and optimal performance in such conditions is a complex task. One of the major challenges in designing floating ORE devices is the limited data and understanding of their response to extreme events. Accurately predicting the ultimate loads that these structures will experience is crucial for ensuring their safety and reliability, as well as for instilling investor confidence and maintaining cost-competitiveness. Traditional design standards, however, often rely on computationally intensive methodologies that require simulating large quantities of data based on short-term irregular sea states. This makes them mostly applicable to scenarios where linear responses can be assumed, and they become impractical when high-fidelity modelling is required. While laboratory testing can provide some insights, it is a resource-intensive and expensive process.

To address these challenges, researchers have proposed the concept of "short design waves." Short design waves involve simulating specific wave profiles that are likely to generate extreme responses in order to bypass the need for modelling long-duration irregular sea states. This approach has the potential to significantly reduce computational requirements and improve the efficiency of load calculations. Different types of short design waves have been explored for floating offshore structures, but their application to floating ORE is limited. To address this knowledge gap, this study utilises physical modelling to explore the application of short design waves to a range of floating ORE devices. The study aims to determine if short design waves can produce extreme values comparable with current design practices and explore the potential for optimising short design wave procedures. The research aims to contribute to the understanding of short design wave methodologies in floating ORE design and bridge the gap between current industry practices and more efficient load calculations. The results indicate that response-conditioned focused waves show promise in predicting design loads for some types of responses. The success of this method depends on how linear the response is, and significant changes in system behaviour limit its applicability. When responses are strongly influenced by nonlinearities, such as viscous drift of semi-subs, alternative short design waves need investigating.

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Multi-Point Sensing & Defect Detection of Wind Turbine Blades: An Approach Using Fibre Bragg Gratings

Aananthy S Sarma, James M Gilbert

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Abstract

Fibre Bragg Gratings (FBG) are robust and reliable sensors which offer many advantages such as small size and weight, multiplexing capability and possibility of implementing as a distributed system which are useful in a structural health monitoring system (SHM). This poster presents the design and development of a Wavelength Division Multiplexed (WDM) FBG sensor system for measuring strain for load monitoring and defect detection of a 1.8 m scaled wind turbine blade with an artificially introduced defect present.

Introduction

Fibre Bragg Gratings is a mature technology heavily used for SHM, however there are some challenges in sensing for defect detection, especially for geometrically large structures such as wind turbine blades. Typical challenges include sensitivity to small, localised variations in strain which can indicate defects at an early stage which require high resolution, high sensitivity strain measurements with appropriate positioning and suitable spatial resolution of sensors. To investigate this, a scaled 1.8 m blade defect-free healthy blade and blade with a known defect present were tested under varying static loading conditions and different mounting orientations.

FBG Strain measurement

An optical fibre with a Fibre Bragg grating is illustrated in fig 1. When broadband light travels into the fibre, FBGs reflect part of the spectrum at a designated wavelength. When an external longitudinal force is applied to the sensor, it causes a change in the sensor's physical properties and results in a shift in the reflected wavelength. This shift in the peak position directly relates to the applied force. Strain resulting from the applied force on the sensor can be measured as illustrated in the schematic by monitoring the reflected peak position. With WDM, the optical fibre can have multiple gratings with different reflecting wavelengths which increase the number of sensing points.

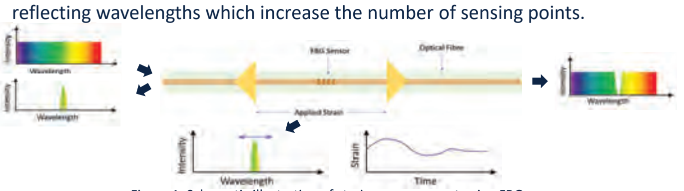

Figure 1. Schematic illustration of strain measurement using FBG sensor.

Fibre Optic Sensor System Design

The sensor system is designed with a light source, an interrogator i.e. an optical spectrum analyser and a 1x4 optical switch to switch between the different WDM arrays. All of the instrument are integrated and interfaced using National Instruments LabVIEW software.

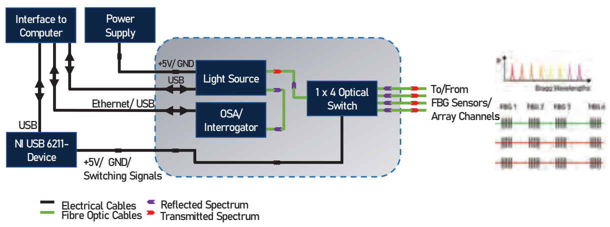

Figure 2. Schematic of the fibre optic sensor system

WDM-FBG Specification	Bonded Side	No of Arrays	No of FBGs
Healthy Blade	Pressure	1	7
	Suction	1	7
Defective Blade	Pressure	2	8
			8
	Suction	1	18

Artificially Introduced Defect In Blade

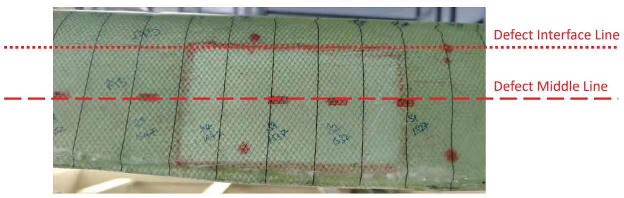

Figure 3. Defective Region Of Interest in Defective Blade

The defective region covers an area of 80 mm x 130 mm resin-rich path with 85% stiffness reduced compared to the rest of the composite material. Strain profile of both defect (middle line) as well as defect-non defect interface line are investigated.

1.8m Composite Scaled Blade and Test Rig

The 1.8m composite scaled blade was designed and manufactured using scaling laws with respect to the NREL 5MW offshore wind turbine design (Jonkman et al, 2009). A length scale factor of 1:35 was used. Three different loading positions were chosen as shown in fig 4.

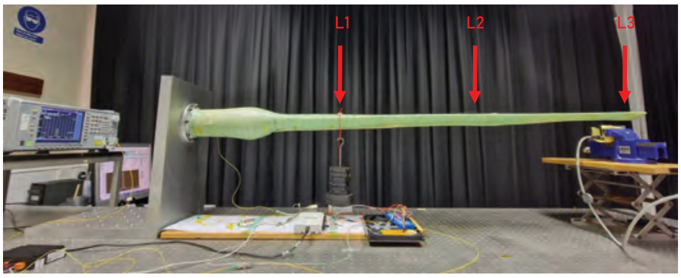

Figure 4. 1.8m Composite Scale Blade & Adaptor Plate Mounted on Test Rig with Fibre Optic Sensor System, tested under different loading conditions at various loading positions L1, L2 and L3.

The figure below shows the different blade mounting orientations with respect to the root and the leading edge positions.

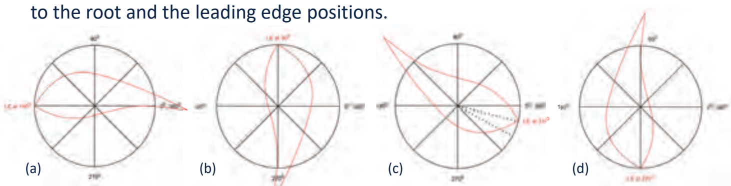

Figure 5(a). Orientation 1: LE at 180° measuring flapwise loading, (b). Orientation 2: LE at 90° measuring edgewise loading, (c). Orientation 3: LE at 315° measuring negative flapwise loading and (d). Orientation 4: LE at 270° measuring negative edgewise loading.

A sample spectrum of an array with 7 FBGs are shown in fig 6(a) with spectra of an FBG at 1546 nm shifting to the left under increasing applied loads shown in fig 6(b). The fig 7(a) and (b) below show how the strain profile changes across the blade when a tip load is applied to both the healthy and defective blade in a flapwise direction. Defective blade shows higher strain measurement due to the presence of the defect. Fig 7(c) and (d) shows the strain profile of pressure side vs suction side. All FBG sensors have shown linear responses to the applied load for a given loading scenario while experiencing different strains at respective discrete locations.

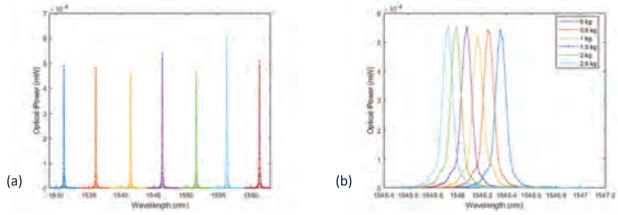

Figure 6(a). A sample spectrum of the seven FBG strain sensors and (b). corresponding peak positions of a FBG at 1546 nm monitored over different loading conditions

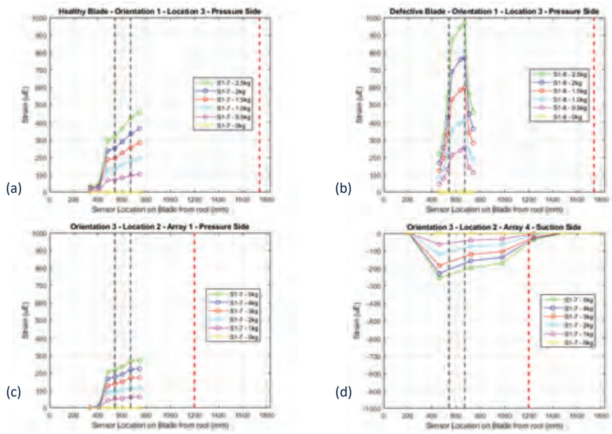

Figure 7(a). (b). Comparison between Healthy and Defective Blade arrays mounted on pressure side at orientation 1 both loaded at L3 (c). And (d). Comparison between Pressure and Suction Side arrays under same loading conditions.

Conclusion and Future Work

Using precise, pre-defined mounting and multi-point sensing, the change in strain due to the presence of defect was measured using FBGs. Comparison between results from different loading conditions, positions and mounting orientations for both healthy and defective blade will be published soon. This aids the discussion of trade-off between spatial resolution i.e. required number of sensors and sensitivity and measurement resolution.

The authors would like to thank Supergen and acknowledge that this work has been facilitated by the EPSRC Supergen ORE Hub EP S 000747-1 Grant

Multi-Point Sensing & Defect Detection of Wind Turbine Blades: An Approach Using Fibre Bragg Gratings

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Keywords: Defect Detection, Fibre Optic Sensors, Wind Turbine Blades

Structural Health Monitoring (SHM) of Wind Turbine Blades (WTB) brings significant benefits in operations and maintenance of these large complex structures in helping keep them running safely and economically. Fibre Bragg Grating (FBG) sensors for WTB-SHM is a mature and highly developed technique [1]. While a typical SHM system has its own benefits, defect or damage detection in blades come with a lot of challenges as damage is not a physical parameter which can be directly measured, rather it is a local change in the material's properties that degrades structural performance [2]. Localised defects and small variations in parameters associated with defects are much harder to detect with present SHM systems with limited spatial resolution and sensitivity. Improving the resolution of measurements and investigating the use of these sensors at different points along the blade (multi-point sensing) and using advanced sensor data processing techniques are important in getting the maximum information from the sensors.

Having already tested this on an aluminium cantilevered beam setup and a composite cantilevered beam setup, both with and without a known defect present, a composite scaled blade was designed and manufactured to test the performance of a Wavelength Division Multiplexed-FBG sensor array system for defect detection. A characterisation based on static loading tests has been completed using FBGs bonded at multiple locations of the 1.8 m composite scaled blade, with and without a defect present. The defect was pre-defined as an 80mm x 130mm resin-rich patch with 85% reduced stiffness compared to the rest of the composite material. Static weights were applied to the blades at different loading points along the blade while measurements were taken by mounting the blade at different orientation with regards to the Leading-Edge position.

Comparing the results from both the healthy and the defective blade, all FBG sensors have shown linear responses to the increasing applied load for a given loading scenario while experiencing different strains at respective discrete locations based on the mounting orientations and the loading points. At the defect location, the defective blade shows a distinguishable higher strain response compared to the healthy blade as expected due to the presence of the defect. Further investigation allows the discussion of trade-off between spatial resolution i.e. required number of sensors and sensitivity and measurement resolution.

References

[1] Glavind, L., Olesen, I. S., Skipper, B. F., and Kristensen, M. V. (2013). "Fiber-optical grating sensors for wind turbine blades: a review". In: Optical Engineering 52.3, p. 030901.

[2] G¨uemes, A., Fern´andez-L´opez, A., Dıaz-Maroto, P. F., Lozano, A., and Sierra-Perez, J. (2018). "Structural health monitoring in composite structures by fiber-optic sensors". In: Sensors 18.4, p. 1094.

Enhancing energy security with tidal stream energy

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BACKGROUND

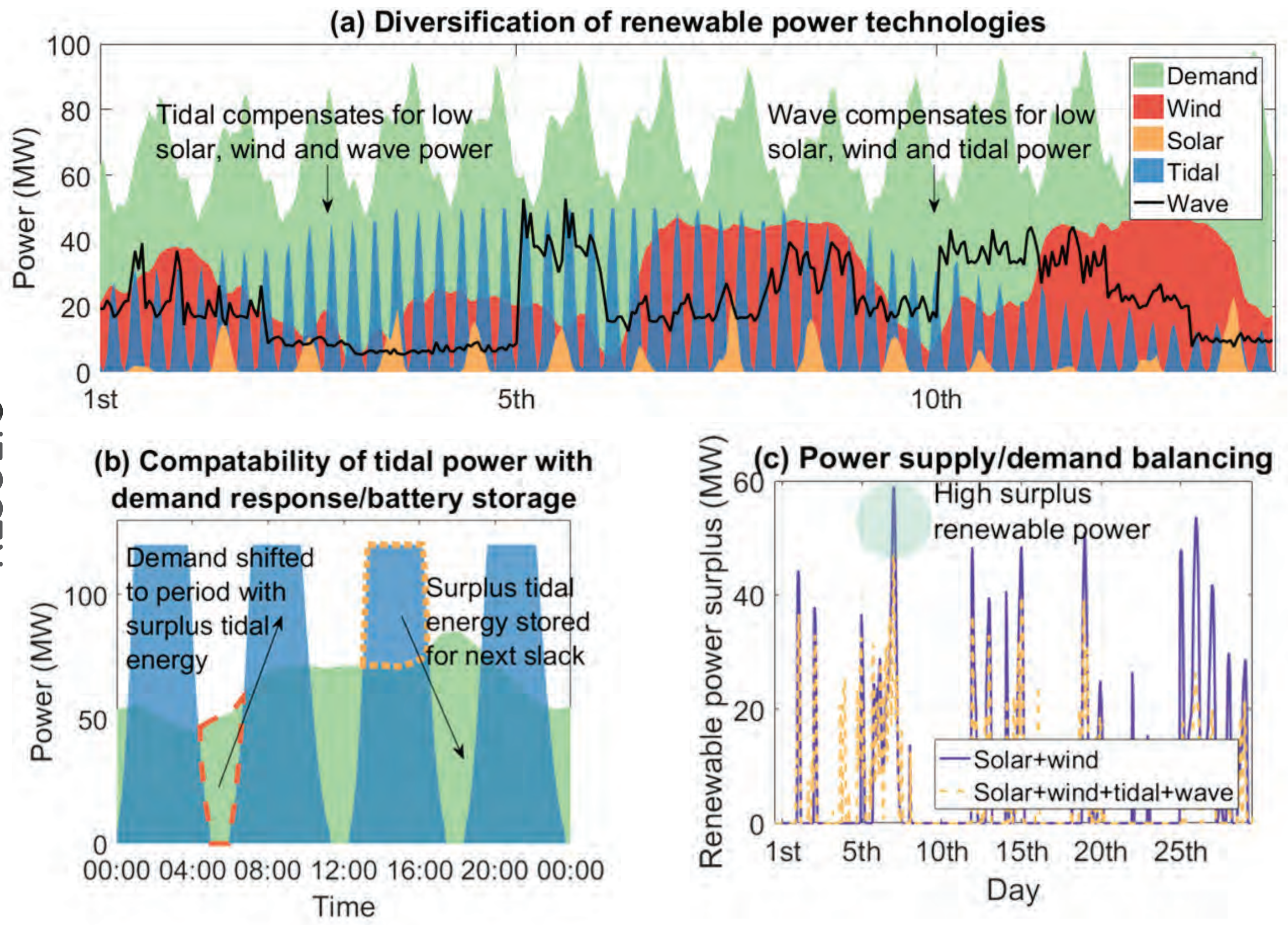
Energy security is defined as 'the uninterrupted process of securing the amount of energy that is needed to sustain people's lives and daily activities while ensuring its affordability'.

Research challenge: The UK is targeting 50 GW of offshore wind and 70 GW of solar PV by2030 and 2035 respectively [1]. This transition to variable renewables presents significant energy security challenges, such as:

- Supply-demand balancing.
- Reliance on potentially volatile/high imported power prices.

This research investigates the potential energy security benefits of installing tidal stream energy alongside wind and solar using new Energy System Modelling for Remote Communities (EnerSyM-RC) [2].

RESULTS



FINDINGS

(a) Diversification

- Tidal stream enhances supply-demand balancing during wind and/or solar droughts.
- This reduces reliance on potentially expensive/volatile imported energy.

(b) Storage/demand response

Tidal stream's relatively short power cycling period allows:

- Demand to be shifted short periods (1 hour) periods during slack water.
- Surplus tidal energy to be stored over short periods until the next slack.

(c) Power balancing

Tidal stream reduces the magnitude of power supply/demand imbalance. This reduces the capacity of grid and storage needed to prevent curtailment.

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TIGER

strategy, Technical report
[2] Coles DS et al., 2023, Impacts of tidal stream power on hybrid energy system performance: An Isle of Wight case study, Applied Energy, 334:120686

Enhancing energy security with tidal stream energy

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The UK has ambitious targets to install 50 GW of offshore wind by 2030 and 70 GW of solar PV by 2035. This level of variable power generation brings with it significant energy security related challenges, as dispatchable power generation from thermal power plants that burn fossil fuels is winded down. Energy security is defined as 'the uninterrupted process of securing the amount of energy that is needed to sustain people's lives and daily activities while ensuring its affordability' [1]. This research has developed the Energy System Model for Remote Communities (*EnerSyM-RC*) to investigate the impacts tidal stream deployment has on energy security in the future [2].

EnerSyM-RC simulates the power flows between generation and storage technologies, and demand. It optimises the mix of renewable power generation technologies, and storage, needed to enhance the system performance as a whole. This is achieved through a brute-force optimisation approach. Importantly, this method acknowledges the fact that there is no single optimal system design. Instead, systems must be designed for multiple, often conflicting objectives. For example, the system that delivers the cheapest cost of energy on an annual basis is not necessarily the system that delivers suitable resilience against high/volatile imported energy prices during wind-droughts.

This poster summarises three mechanisms by which tidal stream energy enhances energy security, based on findings from case studies of Alderney and Isle of Wight's energy systems:

1. **Energy supply-demand balancing:** Diversifying the renewable power mix by installing tidal stream alongside solar PV/wind reduces reliance on imported energy, as illustrated in Figure 1.
2. **Power supply-demand balancing:** The adoption of tidal stream alongside solar PV and wind reduces the magnitude of instantaneous power surplus. This can help to minimise the scale of grid upgrades and storage needed to prevent curtailment of renewable power.
3. **Compatibility with short duration storage:** Tidal stream exhibits relatively short power generation periods of 4-5 hours, separated by slack water which lasts for approximately 1 hour. Unlike wind, which exhibits high resource prevalence (long periods of generation/no generation), tidal stream's generation profile is highly compatible with short duration storage. Short duration storage is significantly cheaper than longer duration forms of storage, that are more necessary for supply demand balancing using wind energy.

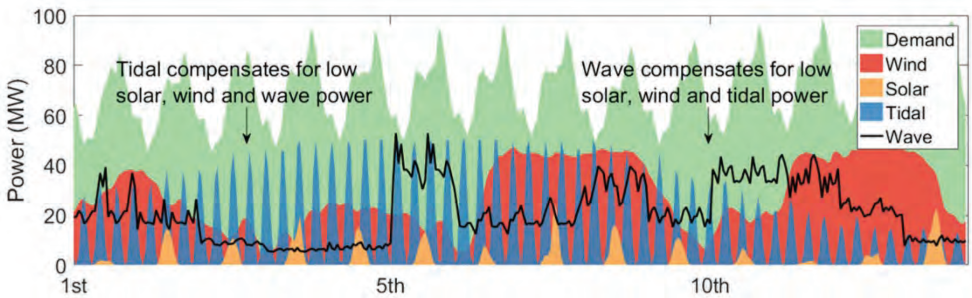

Figure 1. Illustration of how tidal stream (and wave) power complement solar PV and wind power to enhance supply-demand balancing.

[1] HM Government, 2022, British energy security strategy, Technical report

[2] Coles DS et al., 2023, Impacts of tidal stream power on hybrid energy system performance: An Isle of Wight case study, Applied Energy, 334:120686

Vortex-Induced Vibrations of Dynamic Power Cable

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Research

This EPSRC funded research will focus on the dynamic loading, motion response, Vortex-Induced Vibrations (VIV) and its suppression mechanism, and fatigue failure of subsea power cables subjected to combined 3-dimensional waves, currents, and turbulence.

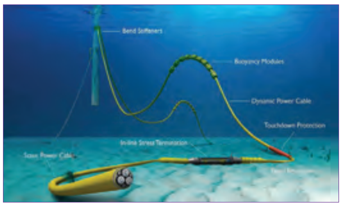

Fig 1:Floating offshore wind turbine with power cable in lazy wave configuration.

Fig 2: Power cable failures (Manuel Rentschler, WavEC Annual Seminar)

Physical modelling and instrumentation

Objective: A small-scale model of a power cable was made to reach a certain degree of possible dynamic similarity with the prototype, and the cable was tested under waves and currents

Table 1: Cable properties

Mass ratio	1.09
Dia of cable (m)	0.031
Length of cable (m)	5 m
Bending stiffness (N/m^2)	0.265
Water depth (m)	2 m
Current velocity (m/s)	0.1-0.8
Reynolds number	10^3-10^4

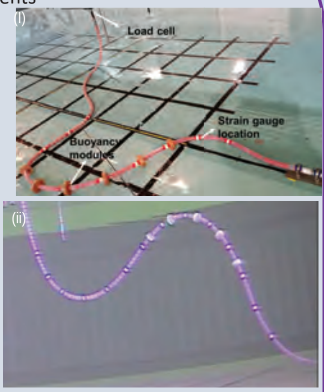

Fig 3: Cable arrangement in FloWave tank (i)out of water (ii) in water

- Strain gauges at 7 locations in the full bridge, measured bending strain
- Underwater Qualisys camera system captured 6 DoFs displacements
- Multicomponent Load cell measured Fx, Fy, Fz and Mx, My and Mz

3D printer spacers

Inner cable of diameter 9.8 mm

Arrangement of spacers with strain gauge wires

Strain gauges pasted on inner cable

Cable setup inside silicone tube of OD = 31 mm and ID = 25 mm

Fig 4: Scale model of the power cable in making

Preliminary Outcomes

Bending strains were measured at seven locations along the length of the cable (at intervals of 500 mm)

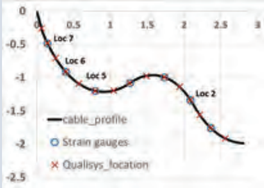

Fig 5: Cable profile showing strain gauge locations

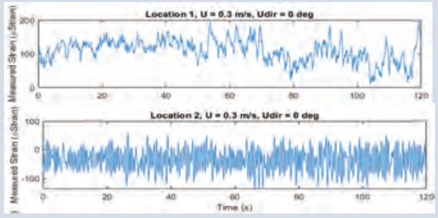

Fig 6: Variation of Strain measured at two different locations along the cable

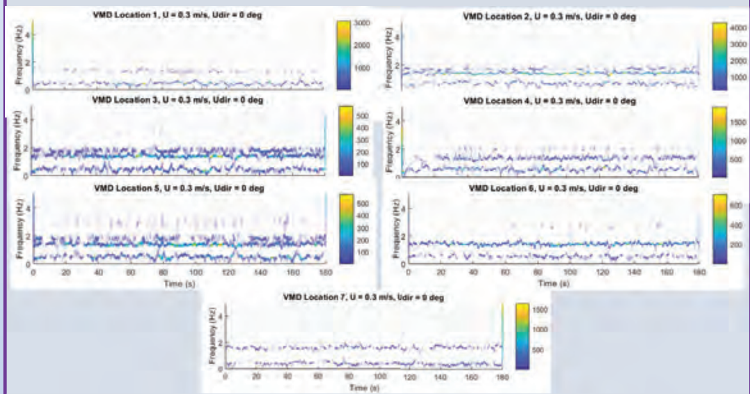

Fig 7: Time Frequency plots of measured Strain at 7 locations for current speed of 0.3 m/s. Illustration of VIV frequency contents.

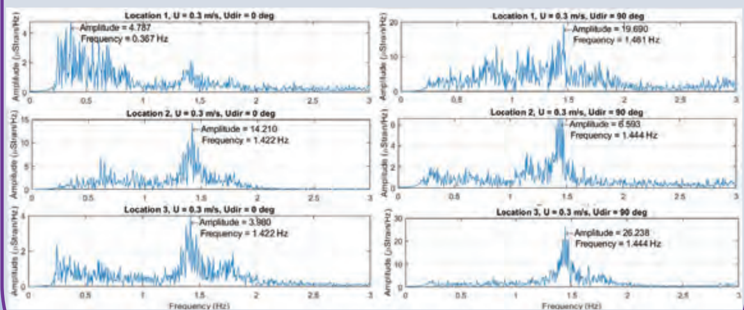

Fig 8: Strain Amplitude Spectrum illustrating VIV response for two different locations and directions

Conclusions

- Measured bending strain is higher in the touchdown zone
- The magnitude of the measured bending strains are affected by current speeds and propagation directions
- Vortex shedding frequencies vary with location of strain measurement and current velocities
- Further analysis of cable displacements and VIV response, wave-current loading, and estimation of fatigue loading is on-going.

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Vortex-Induced Vibrations of Dynamic Power Cable

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Abstract

Dynamic power cables are used to transport electricity generated by offshore wind energy platforms to substations and onshore grid. These are highly dynamic cables lengthening from the platform to the seabed. Lazy wave configuration of power cables is preferred for offshore applications as it is easier to install, requires less buoyancy, less subsea hardware and therefore making it a simpler and more economical option[3]. Dynamic power cables will interact with waves, currents and turbulence resulting in complex hydrodynamic loadings and motion responses. Vortex-induced vibrations are considered to be one of the major hydrodynamic factors causing the failure of cables under the combined action of currents, waves, and turbulence. VIV can cause large and complex deflections of the power cable altering its mechanical properties and strength, and eventually leading to fatigue-induced failure. The configuration of the lazy waves proved to be effective, but a sustained VIV on the cables necessitates further physical testing to investigate fatigue life.

As a part of the research (EP/W015102/1[4]), an experimental campaign to study the VIV response of a 1:50 scale model dynamic power cable has been undertaken at Edinburgh University's FloWave Facility. The modelling of cable is done such that to reach a similarity in dynamic behaviour with the prototype. The cables are subjected to currents from 0.1 to 0.8 m/s with propagation directions from 0 to 180 deg in steps of 30 deg. The cable is instrumented with IP68 strain gauges in full bridge connection at seven locations along the cable to measure the bending strain. Qualisys cameras installed underwater has recorded the displacements and the forces in six directions are measured by a 6 component load cell. The data analysis indicated that the point between the touchdown and the bend produced the maximum strain. The strain measurements at different locations showed the vortex shedding frequencies vary along the length of the cable with an increase in current velocity. Cable displacements and VIV response, wave-current loading, and estimation of fatigue loading are currently being analysed which can give further insight to the problem of VIV in power cables.

References

[3]Martinelli L, Lamberti A, Piero R, Pierpaolo R, Kirrane P, Fenton C, Johanning L. (2010) Power Umbilical for Ocean Renewable Energy Systems - Feasibility and Dynamic Response Analysis, *3rd Int. conference on Ocean Energy (ICOE 2010)*, Bilbao, Spain, 6th - 8th Oct 2010.

[4]https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/W015102/1

Data Centric Numerical Simulation for Tidal Stream Energy (D-TIDE)

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Overview

The D-TIDE (Data centric numerical simulation for tidal stream energy) project will involve further developing and improving an existing coupled flow-wave model (figure 1) of the English Channel. This model will be used in the design of an automated system to provide bespoke useful output to Tidal energy developers. The model was initially constructed as part of the EU Channel Interreg Tidal Energy Energiser Project (TIGER) and has already produced data that has been supplied to tidal energy developers. This project proposes to discuss with developers through engagement with the Offshore Renewable Energy Catapult, where they feel that they would benefit from further modelled output and what improvements can be made. The workload will be delivered in three work packages: developing the model, engagement with industry, and bespoke reporting.

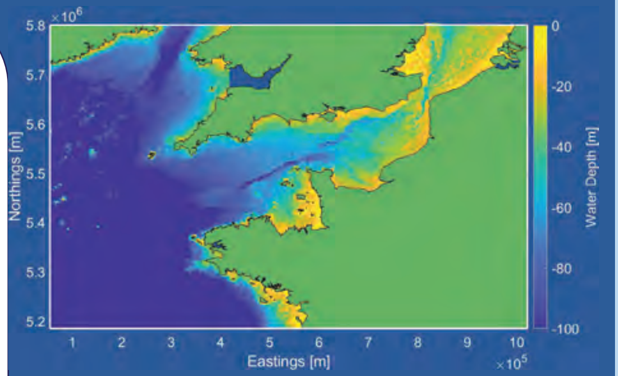

Figure 1: The extent of the coupled flow-wave model showing The English Channel. Water depth is shown on the colour scale.

£50k budget from EPSRC Innovate Launchpad Network+

10 month duration.

Outputs will include a report detailing the results of the industry engagement strategy and an end-user software tool including documentation and routines to enable easy access to high-quality bespoke model data, available to all developers and other tidal energy stakeholders. There will be a data crunch workshop to identify the industry perspective on data and modelling needs. Furthermore, the outputs will be disseminated in UK and international conference presentations and journal publications.

Workplan

WP1: Uncertainty Analysis and model improvement	• Assess data used to drive model • Identify improvements to obtain best-in-class model data. • Conduct detailed uncertainty assessment of model.
WP2: Industry Engagement	• Engage OREC and end-users to establish industry project data needs • Organise data workshop to scope requirements. • Present and discuss results with across wide range of industry, academic and other stakeholders.
WP3 Project Specific Data	• Generate data to support specific projects. • Work with OREC and industrial stakeholders to produce genuinely 'useful' output. • Develop reporting toolkit with access to model data.

Impacts

Two main impacts of improved tidal site data are targeted in this project: 1. Improved engineering design and yield predictions through better tidal site data, 2. Improved permitting and approval process.

The improved numerical modelling techniques and end-user accessibility that will be undertaken in this project have the potential to greatly increase the success of tidal energy projects and therefore enhance the development of the tidal energy sector. The in-depth models and bespoke user-friendly analytics which will be output by this work will enable developers and engineers to better understand the dynamics of the flow at tidal energy sites and to better predict the performance of their devices. This can lead to an earlier understanding of the specific conditions of a particular site and help in the development of more efficient and cost-effective systems that are better suited to the conditions.

Additionally, improved numerical modelling techniques can also play a role in the permitting and approval process for new tidal energy projects. Easy access to high quality met-ocean data will assist in all areas of the project plan and operation: engineering design, moorings and foundation design, environmental impact, logistics, maintenance, and decommissioning will all require an understanding of the site conditions and can be made easier through better access to high quality data.

Overall, the potential impacts of improved numerical modelling techniques and user-friendly data access on the tidal energy sector are significant. By providing accurate and reliable predictions of system performance and site conditions, these techniques can help to speed up the development of the industry and ensure that it is done in a sustainable and cost-effective manner. Both impacts will be realised through engagement with stakeholders and provision of data for specific uses and sites.

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Data centric numerical simulation for Tidal Stream Energy (D-TIDE)

Jon Hardwick

Tidal Stream Energy is becoming a commercial renewable energy source. The first Contracts for Difference have been awarded increasing the capacity installed in the UK to 51.2MW by 2027. Tidal Stream Energy developers are reliant on met-ocean data for many of the calculations involved in the planning and operation of their projects. From initial resource assessment studies used to identify the site, right through to the project operation and decommissioning strategies, it is essential to have a clear understanding of the conditions on site. As in-situ data is costly and time consuming to acquire, simulated data is regularly used to provide this information. There is often little consistency in the strategies used to generate and validate modelled data and there is considerable scope for improving the understanding of uncertainties in the data, ensuring that developers data needs are met as effective and efficient as possible.

The D-TIDE (Data centric numerical simulation for tidal stream energy) project will involve further developing and improving an existing coupled flow-wave model of the English Channel. This model will be used in the design of an automated system to provide bespoke useful output to Tidal energy developers. The model was initially constructed as part of the EU Channel Interreg Tidal Energy Energiser Project (TIGER) and has already produced data that has been supplied to tidal energy developers. This project proposes to discuss with developers through engagement with the Offshore Renewable Energy Catapult, where they feel that they would benefit from further modelled output and what improvements can be made. The workload will be delivered in three work packages: developing the model, engagement with industry, and bespoke reporting.

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Additionally, improved numerical modelling techniques can also play a role in the permitting and approval process for new tidal energy projects. By providing more accurate predictions of the performance of a proposed system, developers can more easily navigate the regulatory process and gain approval for their projects. Easy access to high quality met-ocean data will assist in all areas of the project plan and operation: engineering design, moorings and foundation design, environmental impact, logistics, maintenance, and decommissioning will all require an understanding of the site conditions and can be made easier through better access to high quality data.

Overall, the potential impacts of improved numerical modelling techniques and user-friendly data access on the tidal energy sector are significant. By providing accurate and reliable predictions of system performance and site conditions, these techniques can help to speed up the development of the industry and ensure that it is done in a sustainable and cost-effective manner. Both impacts will be realised through engagement with stakeholders and provision of data for specific uses and sites.

The outputs of this work will be shared at future conferences and events as well as in academic publications and press releases.

Activities

I am a research fellow in the renewable energy research group at the University of Exeter. I have worked on numerous different projects, mostly focus on developing and applying met-ocean models. I am currently finishing up work on the EU Channel Interreg Tidal Energy Energiser Project (TIGER), which ends at the end of July 2023 and will then be starting the D-TIDE project, a Researchers in Residence fellowship with the ORE Catapult on 1st August.

Tidal Turbine Benchmarking Project: Stage I – Steady Flow Blind Predictions

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and contribution from 13 other research groups (for full list see Acknowledgements)

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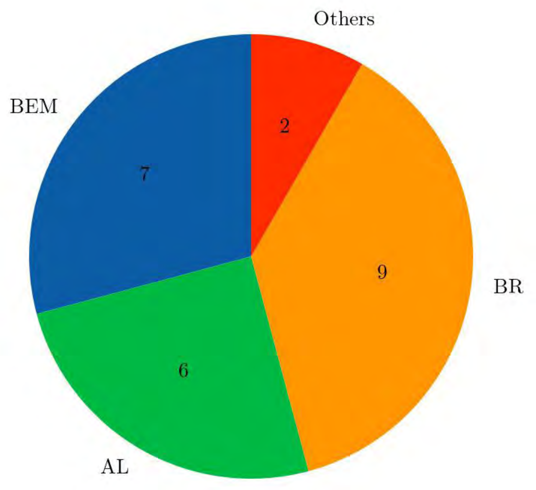
Introduction

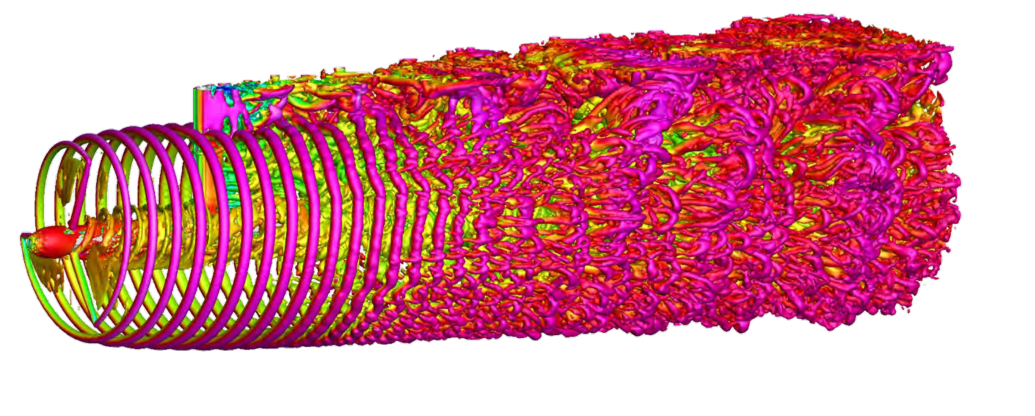
- Stage I steady flow experiments and blind prediction campaign ran in 2022 - 2023.
- Workshops held for the blind prediction campaign of Stage I measurements, in order to:
  - improve accuracy of modelling techniques
  - improve confidence in the use of modelling techniques
  - quantify modelling errors for different techniques under different loading scenarios
- **12 research groups** from across the world contributed **26 submissions** in **5 modelling approaches**:
  - Blade Element Momentum (BEM), Actuator Line (AL) (uRANS/LES), Blade Resolved (BR) (RANS/uRANS/DES), Boundary Integral Equation Model (BIEM) and Vortex Method
- Design & experimental details and results, and the blind prediction results are being published in both **EWTEC 2023 Conference and journal papers**.
- Project website: https://supergen-ore.net/projects/tidal-turbine-benchmarking
- This project is funded jointly by the EPSRC Supergen ORE HUB EP/S000747/1, and EPSRC Fellowship EP/R007322/1.

Submission Summary

- 26 submissions categorised into 5 major turbine modelling methods, covering both engineering and research models
- Quantile-style statistical analysis is applied to the submissions of each main category
- Concentration on median and 20-to-80% range predictions



Number of submission in each modelling category

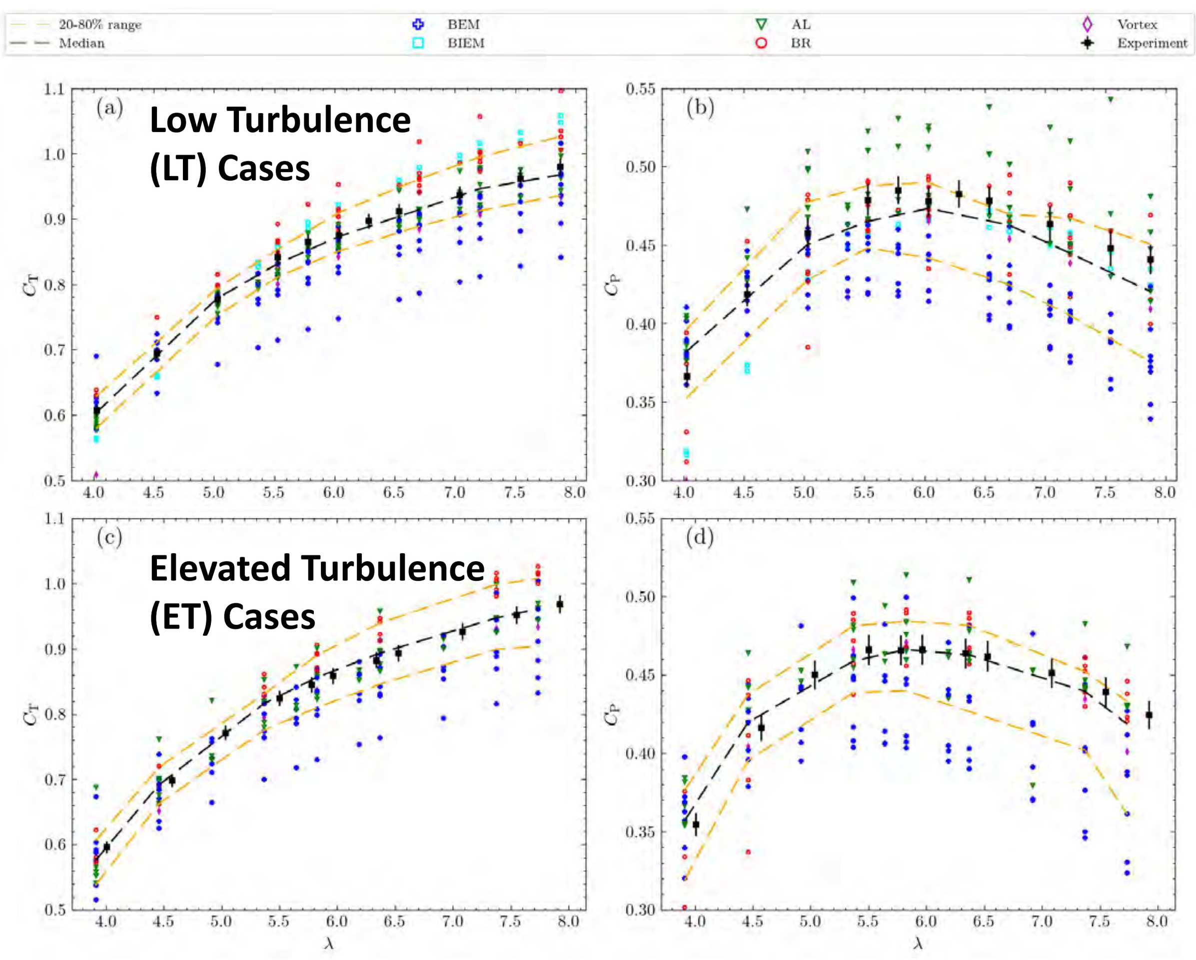


Benchmark Tidal Turbine under Operation with Flow Visualisation (from LES-AL simulation with nacelle and tower, in tow-tank submerged at experimental depth, illustrated by iso-surfaces of λ_2 coloured by velocity)

Statistical Analysis of the Benchmarking Submissions

Integrated Quantities (L2)

- Two turbulence levels studied: Low Turbulence (LT) and Elevated Turbulence (ET), 3.1%.
- Median of all blind predictions aligns well with the experimental data, with ET predictions agreeing better.
- Thrust predictions are more tightly banded than the power predictions, $\pm 5\%$ vs $+7\sim-11\%$
- BR and AL methods tend to overpredict, while BEM results generally underpredict experimental data



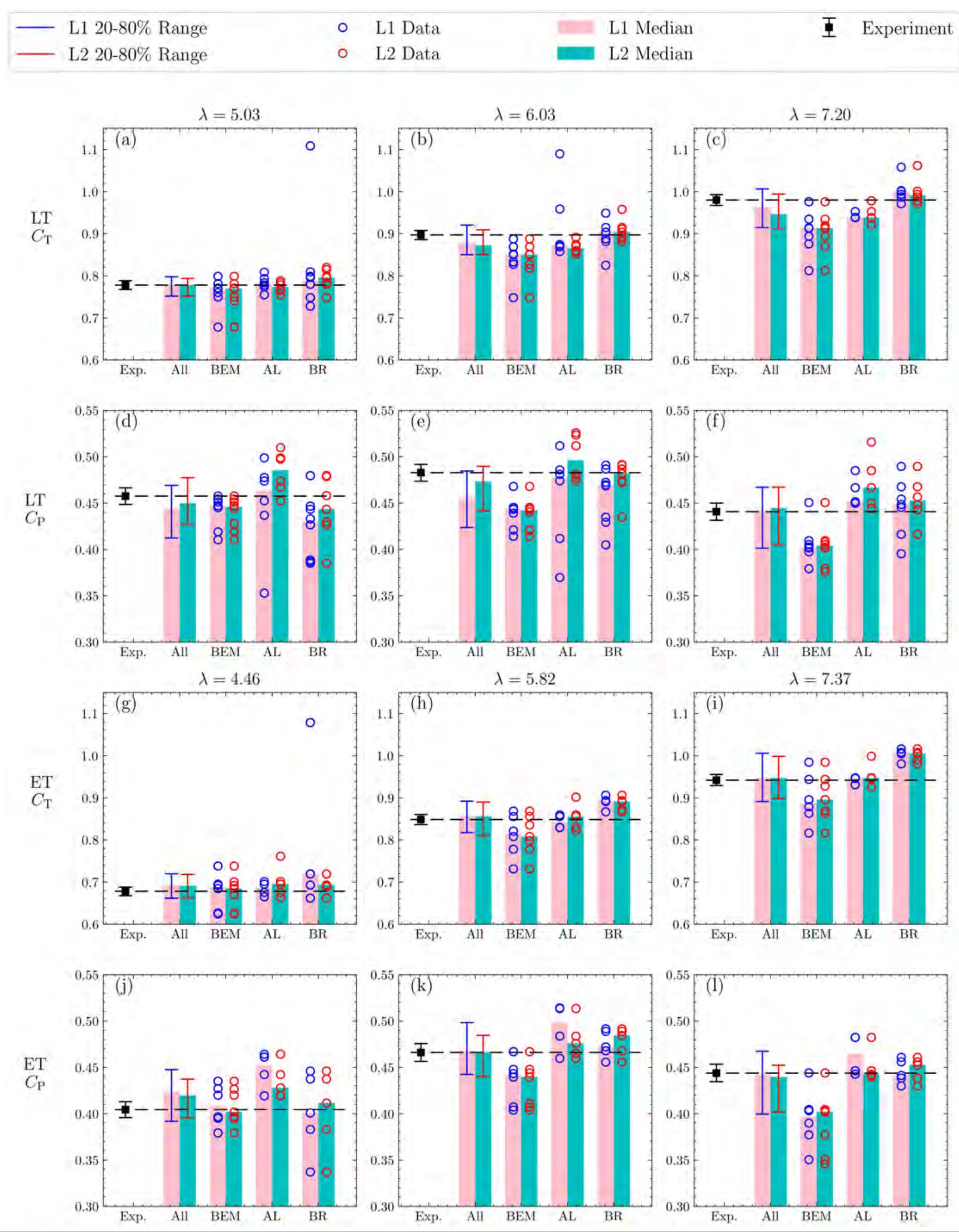
L1 and L2 Data Comparison

- Submissions are categorized into 2 levels
  - L1: the fully blind initial submissions
  - L2: re-submissions with user errors corrected
- Changes between L1 and L2 shows
  - Spread of AL and BR results significantly reduced
  - Only minor change in BEM results
- For the L2 data
  - Spread of BEM predictions is largest due to the diversity in available sub-models (tip/root/wake corrections, high-induction models etc.)
  - AL shows lowest deviations in the LT cases, while BR results are closest in the ET cases.
  - The ET conditions result in closer agreement of BR predictions, due to more turbulent boundary layer behaviour bringing different turbulence models closer

Normalised standard deviations (%) of predictions

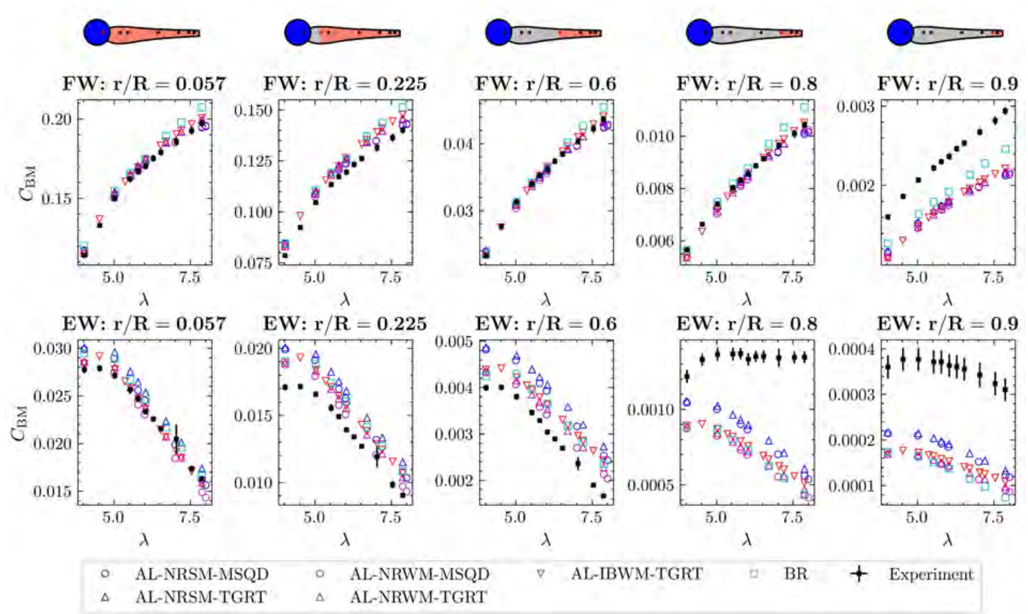
	Low Turbulence (LT) Cases							
	C_T				C_P			
	All	BEM	AL	BR	All	BEM	AL	BR
L1	11.8	6.02	17.1	17.3	15.49	5.15	10.5	15.6
L2	5.45	5.86	2.58	4.80	6.93	4.96	1.64	3.88

	Elevated Turbulence (ET) Cases							
	C_T				C_P			
	All	BEM	AL	BR	All	BEM	AL	BR
L1	14.7	7.71	2.26	22.8	16.5	6.55	1.54	22.3
L2	6.22	7.44	5.04	3.03	7.87	6.15	4.33	2.56

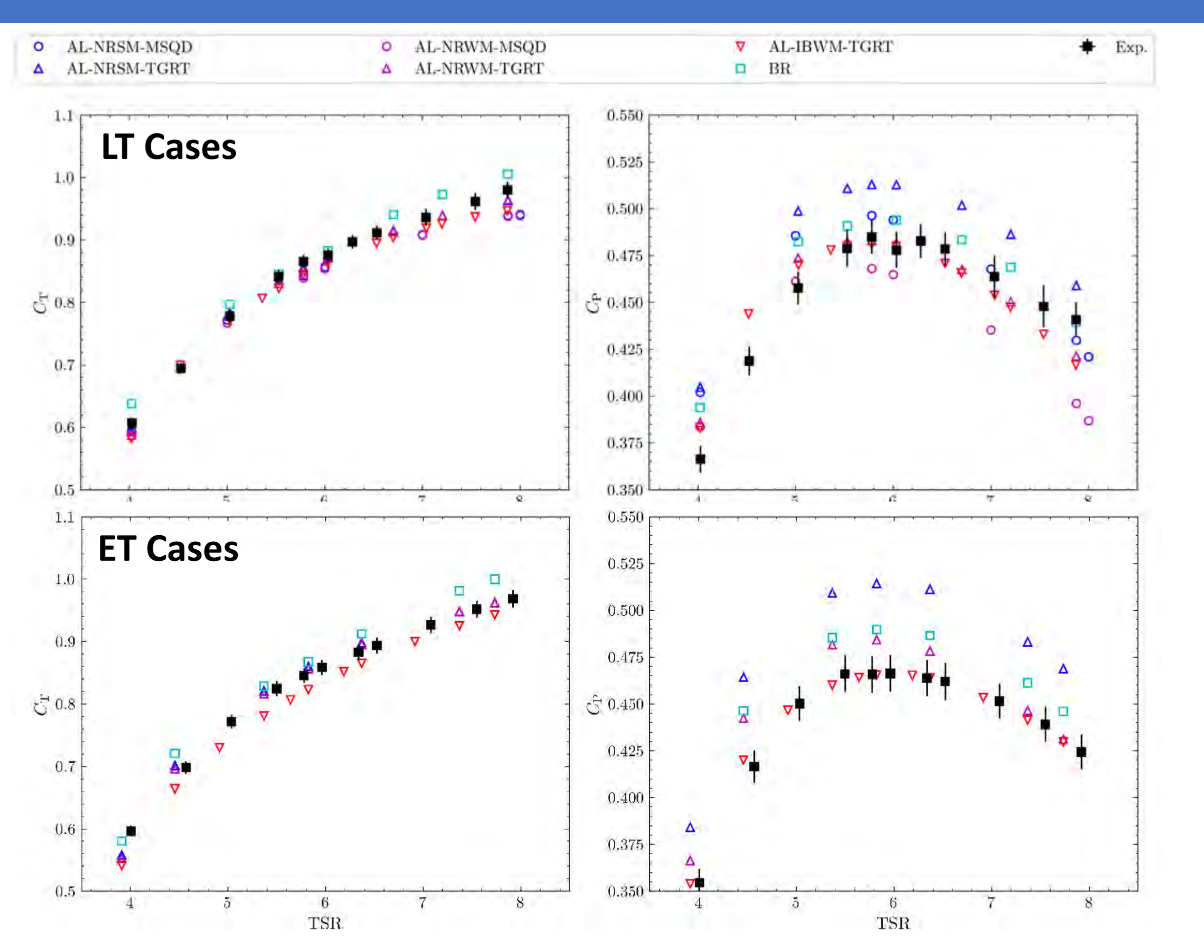


University of Oxford Predictions

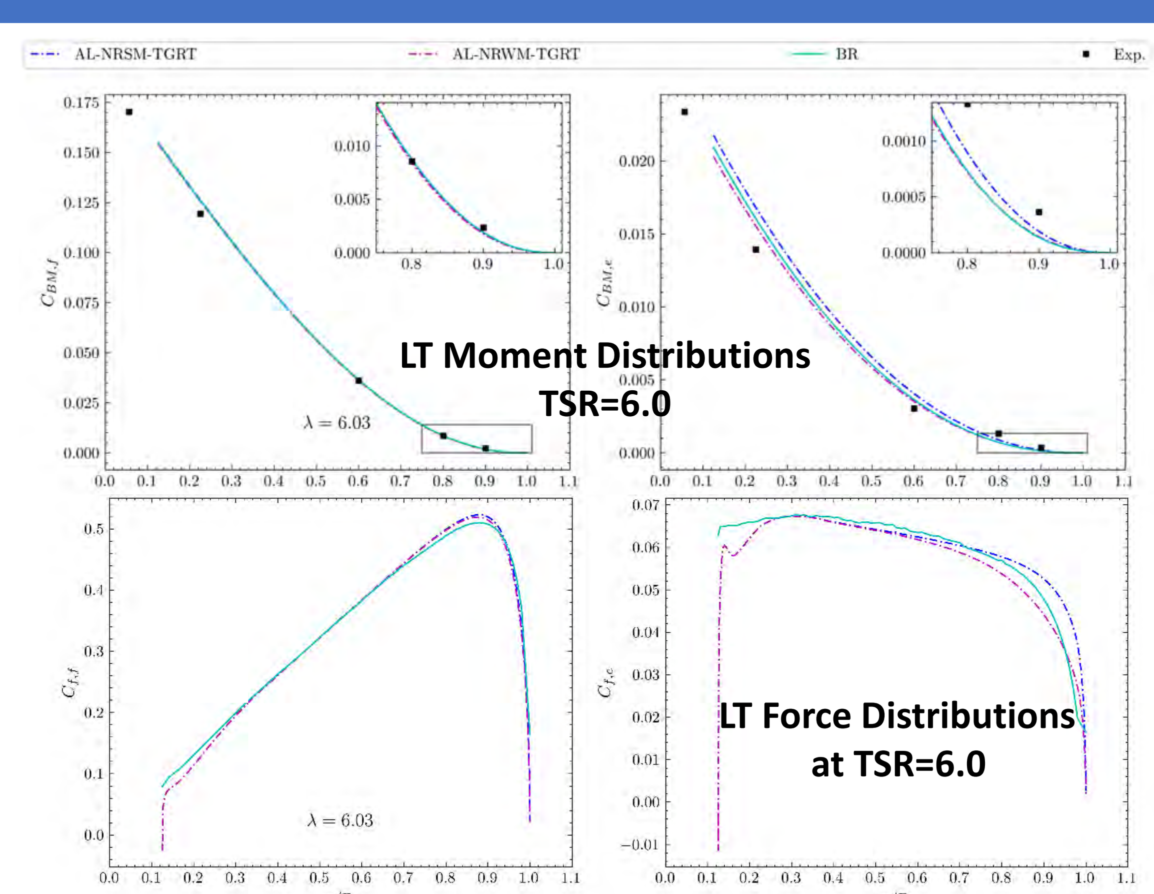
- Modelling categories:
  - Blade-resolved RANS with 120-degree wedge (BR) or uRANS Actuator Line modelling (AL).
  - Turbine in the middle of a square domain (MSQD) or at the experimental depth (TGRT).
  - Nacelle representation using an immersed boundary method (IB) or fully resolved (NR).
  - Shen (SM) or Wimshurst (WM) tip-loss correction.
- All simulations accurately predict flapwise force/moments, but wider spread in the edgewise direction due to different sub-models.



LT Bending Moment at Sensor Location



- BR predicted C_T accurately despite small overprediction at higher TSR, and small & consistent overprediction in C_P.
- MSQD vs TGRT: proximity to free surface observed to increase both thrust and power, especially in higher TSR range.



- SM vs WM: both are accurate in flapwise direction, but WM more accurate in edgewise direction.
- BR vs NR-WM: BR results show that the tip-loss effect occurs further outboard, but faster drop-off.
- More observations to follow in a journal paper.

Acknowledgements

List of contributing research groups

- Experiments: University of Hull, University of Bath
- Submissions: blueOASIS, Cape Horn Engineering, CNR-INM, LOMC University Le Havre Normandie, NREL, Queen's University Belfast, Swansea University, Federal University of Uberlandia, University of Edinburgh, University of Manchester, University of Sao Paulo

Tidal Turbine Benchmarking Project:

Stage I – Steady Flow Blind Predictions

The presented study shows the first blind prediction stage of the Tidal Turbine Benchmarking Project being conducted and funded by the UK's EPSRC and Supergen ORE Hub. In this first stage, only steady flow conditions, at low and elevated turbulence (3.1%) levels, were considered. Prior to the blind prediction stage, a large laboratory scale experiment was conducted in which a highly instrumented 1.6m diameter tidal rotor was towed through a large towing tank in well-defined flow conditions with and without an upstream turbulence grid.

Details of the test campaign and rotor design were released as part of this community blind prediction exercise. Participants were invited to use a range of engineering modelling approaches to simulate the performance and loads of the turbine. 26 submissions were received from 12 groups from across academia and industry using solution techniques ranging from blade resolved (BR) computational fluid dynamics through actuator line (AL), boundary integral equation model (BIEM), vortex methods to engineering Blade Element Momentum (BEM) methods.

The comparisons between experiments and blind predictions were extremely positive helping to provide validation and uncertainty estimates for the models, but also validating the experimental tests themselves. The exercise demonstrated that the experimental turbine data provides a robust data set against which researchers and design engineers can test their models and implementations to ensure robustness in their processes, helping to reduce uncertainty and provide increased confidence in engineering processes. Furthermore, the data set provides the basis by which modellers can evaluate and refine approaches.

This study includes further analysis based on the University of Oxford simulations to provide insight into the BR and AL modelling techniques. The choice of tip-loss model in AL simulations was found to be important: the Shen-type tip-loss correction model overpredicted the edgewise force, whereas the Wimshurst-type model was able to better predict the measured force/moments. The immersed boundary method for nacelle modelling produced a thicker shear layer at the blade hub section, which has little impact on the integrated quantities but clearly affects both the force distribution and wake flow. Furthermore, a large increase in the power and edgewise force is found when moving the turbine from the middle of the computational domain to near the water free surface, and a phase-varying load fluctuation occurs when the blade rotates towards and away from the surface.

Short design wave and wind events for a semi-sub FOWT in operating conditions

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UNIVERSITY OF PLYMOUTH

Supergen Offshore Renewable Energy

Abstract

Results from physical experiments using a 1:70 scale model of a semi-sub floating wind turbine, the VolturnUS-S, are presented. A comparison of extreme pitch and nacelle accelerations produced using irregular waves and constrained response conditioned focused wave and wind events are given. It is shown that for the responses studied that short time series efficiently produced extreme responses in line with those from extended irregular waves and turbulent wind series.

Keywords: floating wind, focused waves, constrained focused waves, response conditioned wind.

1. Device

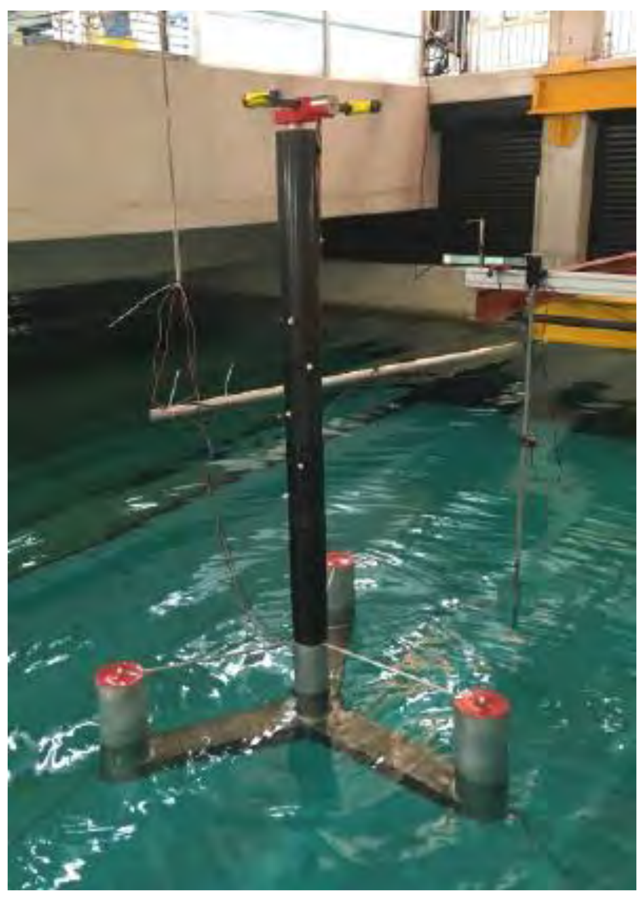
Fig.1 Photo of 1:70 scale model

The data presented in this work is for a 1:70 scale model semi-sub design; the VolturnUS-S platform and IEA 15MW reference turbine [1,2] shown in Fig.1. The physical experiments were conducted at the COAST lab at the University of Plymouth. The mooring consisted of 3 catenary chains and all waves were unidirectional. The mooring loads studied were at the fairlead on the front column. A hybrid system was used where 2 drone propellers replicate the aerodynamic thrust of the turbine using a surrogate model trained on OpenFAST simulations with the ROSCO controller. The wind is spatially homogenous in y but not in z (shear is included)

2. Long sequence irregular wave and turbulent wind approach

The extreme sea state studied had the turbine in operating conditions along the 50 year return contour for wind and wave conditions corresponding to DLC 1.6 in the design standards [3]. It was modelled on Celtic sea conditions using a JONSWAP spectrum with Hs = 5.5m, Tp = 9s and gamma = 5. 10, one hour irregular wave and turbulent wind seeds were run and the 10 largest pitch responses are plotted in Fig.2 along with the average surface elevations and responses given by the thick lines. The extreme pitch was consistently caused by an average wind and wave profile at 0s as indicated in Fig.2.

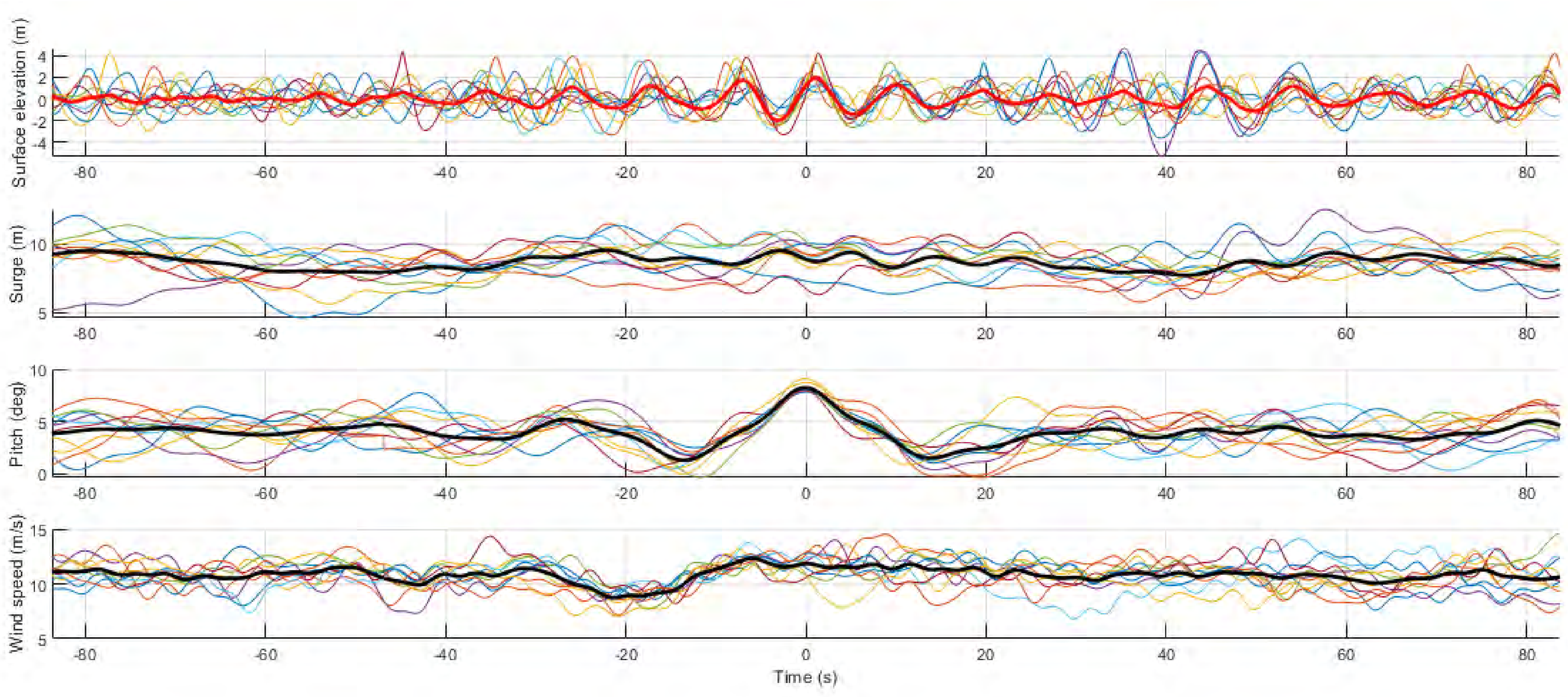

Fig.2 Empirical extremes in irregular waves and turbulent wind

3. Short sequence response conditioned approach

What are focused / constrained focused waves?
Focused waves focus wave components by linear dispersion to produce the shape of an extreme wave. These waves can be constrained into short irregular wave time series. This process has here been expanded to a turbulent wind time series.

What is meant by response conditioned?
The shape of the wave or wind time series is conditioned on the linear response amplitude operators (RAOs) to give the shape of the wave/wind profile most likely to produce the extreme of the response of interest. The single focused wave/wind is termed the most likely extreme response wave/wind (MLER) and the constrained version the conditional random response wave/wind (CRRW). More information on the method applied to the waves can be found in [4].

What are the advantages of short design waves/wind over irregular waves?
Constrained events have the potential to reduce simulation times significantly compared with the traditional one hour long time series. They are also short enough (5-10 minutes) that they may be used in computationally expensive, high fidelity numerical modelling.

Fig.3 below illustrates the response conditioned wind and wave profiles compared with the time series which lead to the extreme nacelle acceleration response in x from the 10, traditional one hour runs. The time step of the extreme response is aligned at 0s and the 10 grey lines show the profile leading to the extreme for each of the 10, one hour runs.

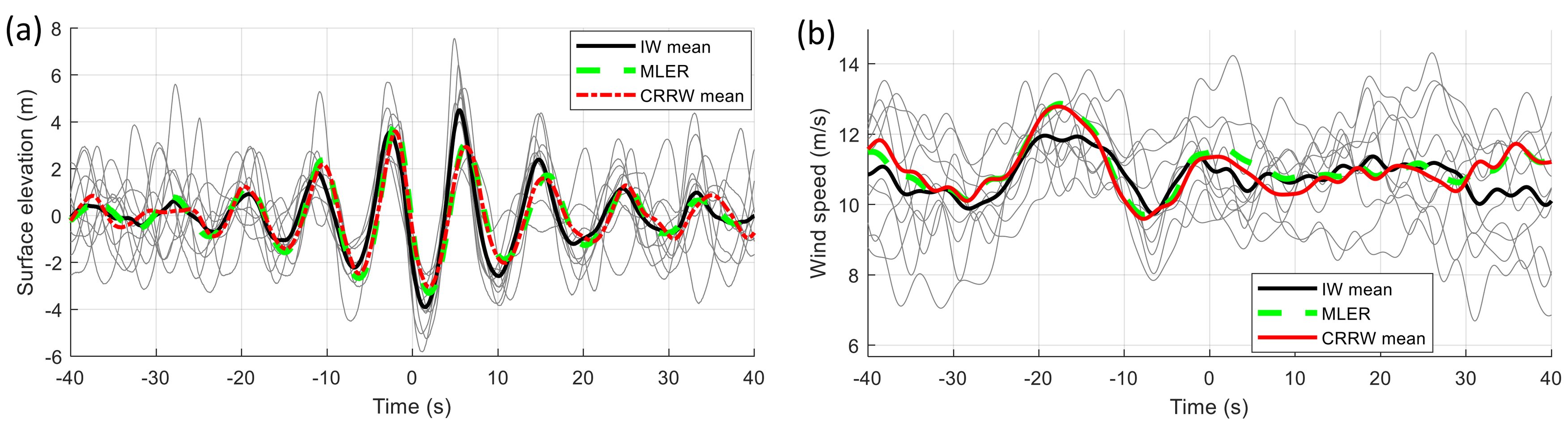

Fig.3 Empirical average wave (a) and wind (b) profile (Emp) comparison with MLER and the mean of 15 CRRWs

4. Extreme responses

The linear RAOs combined with the wind and wave spectra for the sea state are used to determine the shape of the wave and wind profiles and then to scale their amplitudes. The ratio of the response spectra are used for this purpose to determine the relative importance of the waves compared to the wind. For the Pitch response the wind was predicted to be ~4x more important than the waves, for the nacelle accelerations the wind and waves were of approximately equal importance.

Fig.4, like Fig.3, shows the response conditioned wave and wind time series are in reasonable agreement with the profiles observed to produce the extreme nacelle response from the 1hr sea states, the wave profile is overpredicted but this does not significantly translate to the response as the wind is ~4x more important.

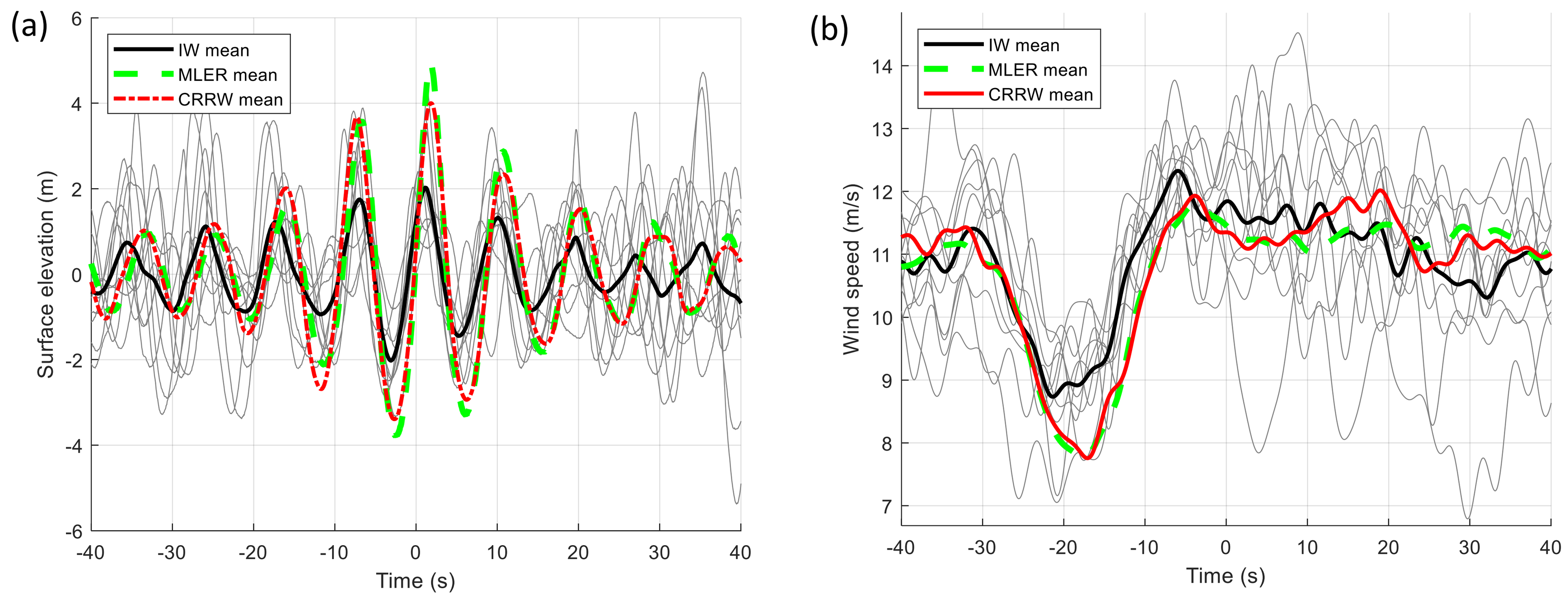

Fig.4 Empirical average wave (a) and wind (b) profile (Emp) comparison with MLER and the mean of 15 CRRWs

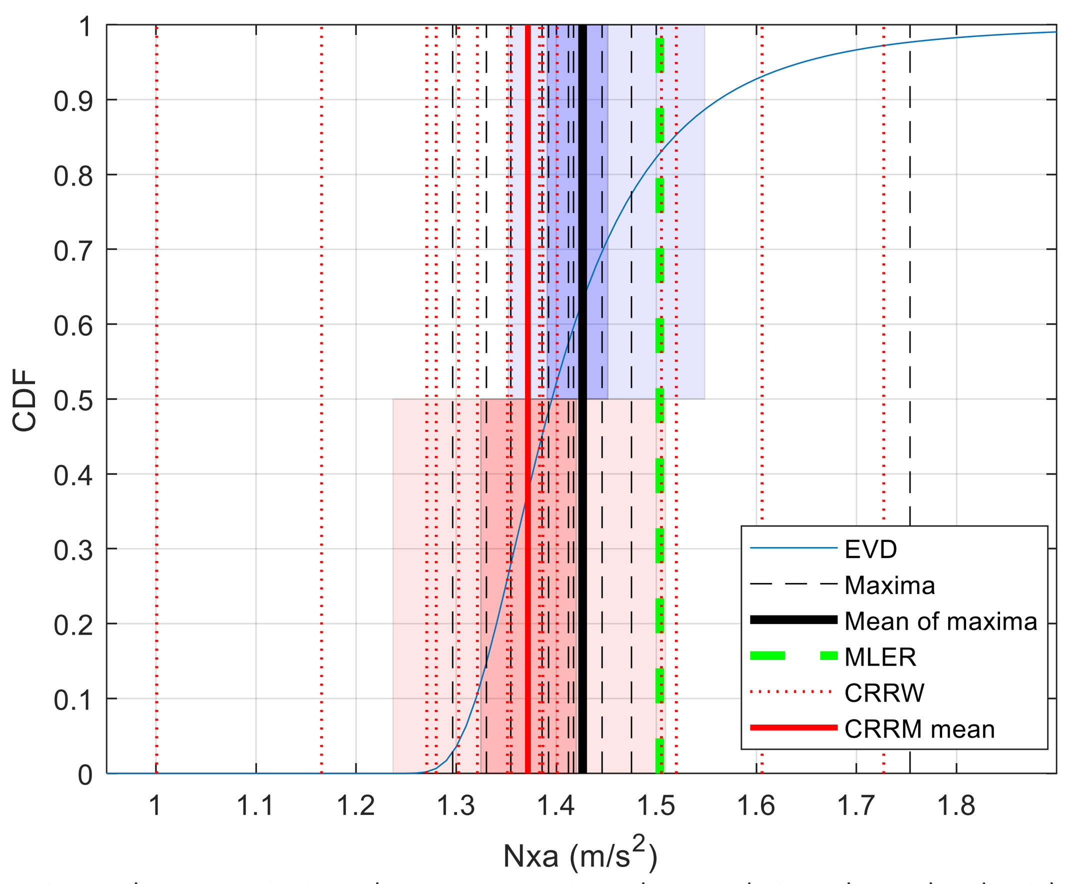

Fig.5 Characteristic values comparing the traditional method with the short response conditioned approach for nacelle acceleration

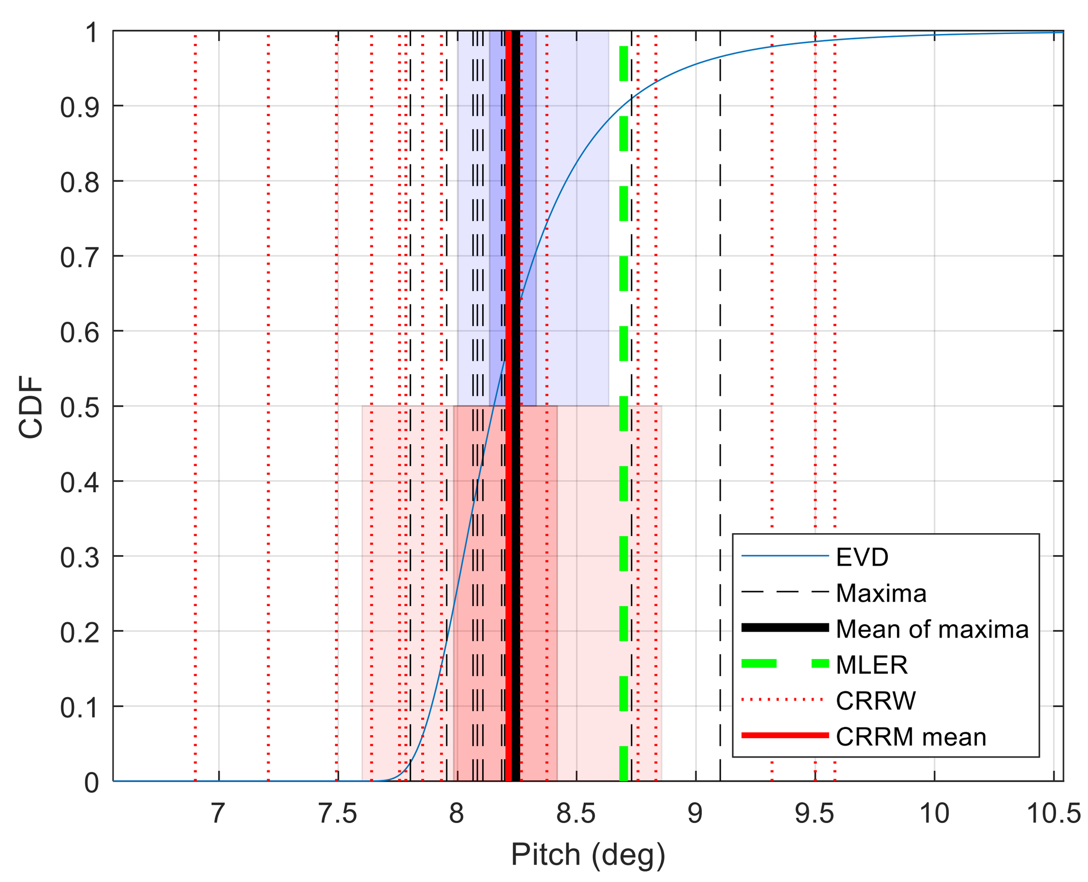

Fig.6 Characteristic values comparing the traditional method with the short response conditioned approach for pitch angle

Figs.5 and 6 compare the responses of the 15 constrained response conditioned wind and wave profiles, given by the red vertical lines, with the 10, one hour time series given in black. The single response conditioned profile response is given in green. The blue curve showing the CDF of the extreme response is calculated using a peak over threshold method and presented for comparison.

The colours in Figs 5 and 6 correspond to those of the time series in Figs 3 and 4. The background shading indicates the 50% and 95% confidence intervals for the mean of a selection of 6 cases as design standards typically say a minimum of 6 seeds should be considered. Red shading is for the short design events, blue for the traditional method. It can be seen that the confidence intervals for the short design events are wider and so an additional post processing step should be investigated to achieve a better comparison.

Conclusions

The Response conditioned wind and wave profiles produced estimates for the design response reasonably close to the traditional method and in a much shorter time. The response conditioned wind time series were similar to those observed to lead to extreme responses in the traditional method. A more comprehensive analysis will be given in an IOWTC 2023 paper and a detailed report using OpenFAST models of a range of devices and responses for DLC 6.1 (idling conditions) will be released in August.

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[1] E. Gaertner et al., "Definition of the iea wind 15-megawatt offshore reference wind turbine tech. rep," 2020.
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[3] IEC, "Iec 61400-3-2 wind energy generation systems-part 3-2: Design requirements for floating offshore wind turbines", 2019.
[4] T. Tosdevin, S. Jin, D. Simmonds, M. Hann, and D. Greaves. "On the use of constrained focused waves for characteristic load prediction", RENEW, 2022.

Tom Tosdevin

University of Plymouth

Role description

Tom is the COAST researcher at the University of Plymouth supporting the work of the COAST research group and the COAST lab through physical and numerical modelling of floating offshore renewable energy devices. Most of his research is on short design waves and extreme response modelling.

Abstract

Results from physical experiments using a 1:70 scale model of a semi-sub floating wind turbine, the VolturnUS-S, are presented. A comparison of extreme pitch and nacelle accelerations produced using irregular waves and constrained response conditioned focused wave and wind events are given. It is shown that for the responses studied that short time series efficiently produced extreme responses in line with those from extended irregular waves and turbulent wind series.

Donald Noble – Research Associate in Marine Energy, The University of Edinburgh, Policy & Innovation Group

I work on a range of UK & European projects, supporting the development of wave and tidal energy.

Within the SEETIP Ocean project, I am currently working on two tasks:

1. Contributing to identifying priority technology development areas and updating the Strategic Research & Innovation Agenda (SRIA). This work will review the priority topics for research and technology development, in consultation with a Technology Working Group consisting of ocean energy stakeholders, including device & project developers, supply chain actors, funders and researchers. Following this, a revised SRIA will be produced. It will outline the technological priority areas, objectives, and actions to encourage the commercialisation of ocean energy in Europe. The SRIA will include a development plan identifying the projects needed to deliver the EU Offshore Renewables Strategy 2030 target.
2. Leading a task to map out infrastructure and industrial production requirements for 2030s deployments. This study considers the physical infrastructure at ports/harbours to fabricate, assemble, install, operate, and maintain ocean energy arrays. The geographical scope is European waters. The temporal scope considers deployments over the next three decades to meet 2050 targets; but the focus is on the infrastructure needs for the 2030s. The projected requirements for offshore wind projects, both fixed and floating, can offer guidance towards the requirements for future ocean energy arrays. However, differences between wind and ocean energy technologies mean it is not necessarily just 'more of the same' — there may be facilities that are suitable for ocean energy projects but are suboptimal for offshore wind development.

I will be working with Orbital Marine Power within their FORWARD2030 and MAXBLADE projects. This will involve conducting a techno-economic assessment of the innovations within the FORWARD2030 project, plus lifecycle assessment (LCA) of their existing and proposed turbines and options for larger rotor blades.

Recently, I have been supporting my colleagues in the EVOLVE project to produce quantifiable outputs to illustrate the benefits associated with integrating ocean energy in low carbon energy systems. This work used a PyPSA (Python for Power System Analysis) hourly dispatch model to represent future energy scenarios in Great Britain. The impact of ocean energy deployments was quantified in terms of marginal electricity prices, curtailed volumes, balancing costs, and system security indices. The first paper from this work was recently published in Applied Energy https://doi.org/10.1016/j.apenergy.2023.121413

Prior to my current role, I completed an EngD as part of the IDCORE programme, with research into characterisation and scale model testing in the combined wave-current environment at the University of Edinburgh's FloWave Ocean Energy Research Facility.