Supergen Offshore Renewable Energy

Flexible Fund Award Showcase

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UKRI Engineering and Physical Sciences Research Council

Cost Effective Methods of Installing Offshore Wind Infrastructure

Dr Marcin Kapitaniak
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Engineering and Physical Sciences Research Council
Supergen Offshore Renewable Energy
CATAPULT Offshore Renewable Energy
aubin

Research motivation

The National Decommissioning Centre
Innovation through Partnership

UNIVERSITY OF ABERDEEN

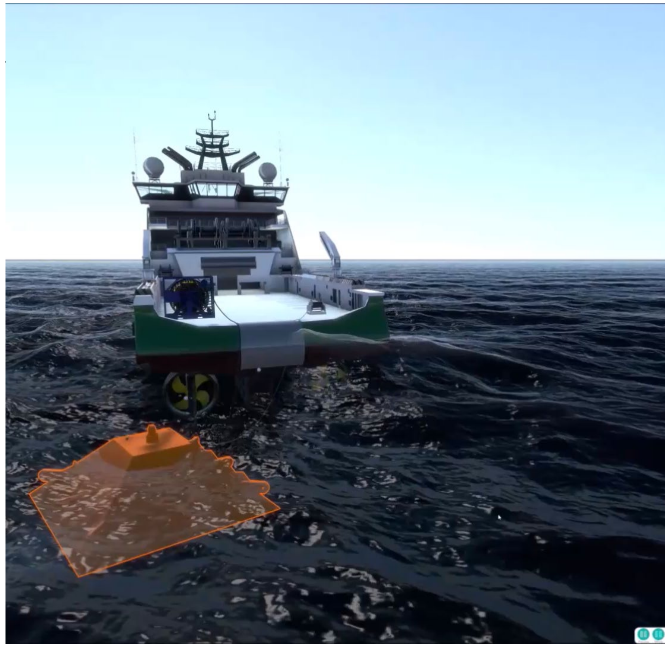
Net Zero Technology Centre
Technology Driving Transition

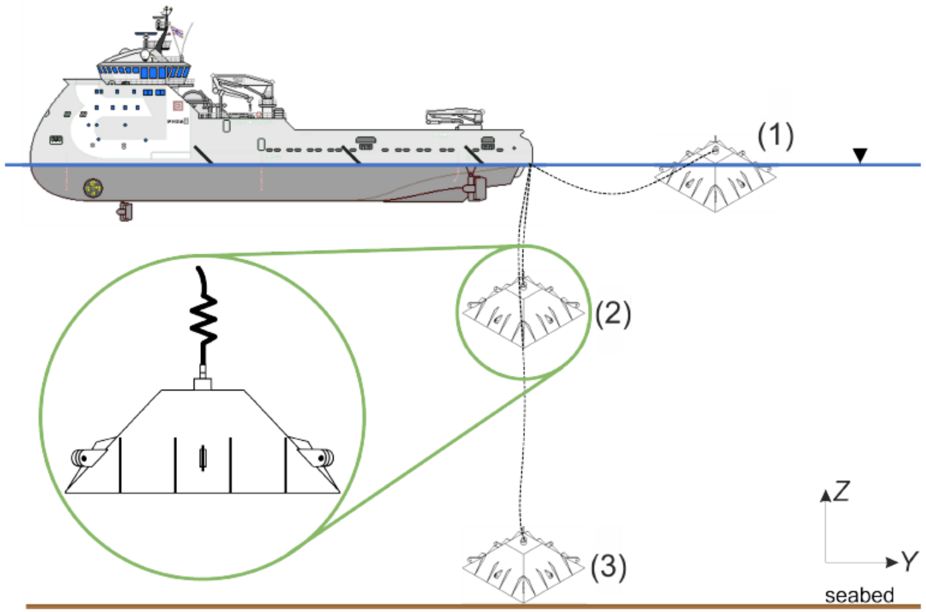
Motivation:

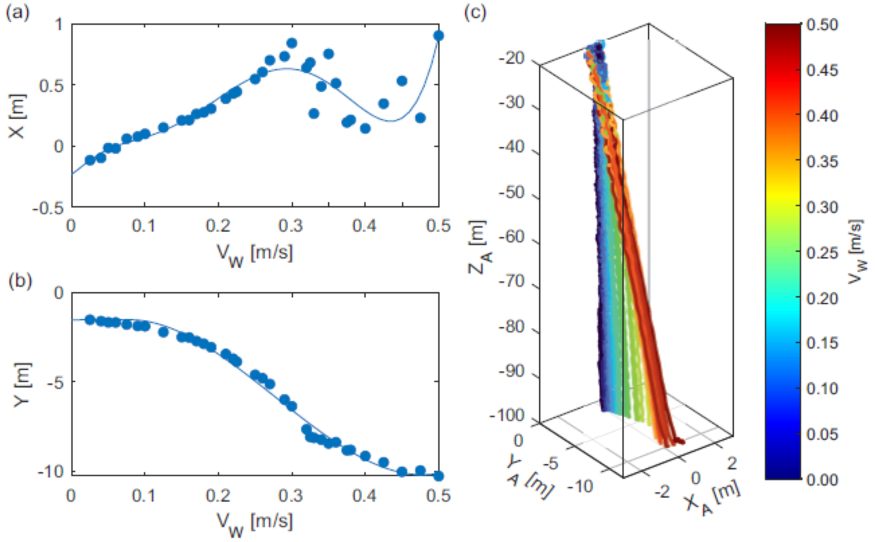
- To simplify the installation and reduce costs of floating offshore wind turbines.

Proposed solution:

- Liquid Anchor technology, that delivers improved anchor holding capacity and thereby reduced installation costs.
- A variable buoyancy anchor towed and installed from smaller vessel without the need of heavy lift equipment.
- Virtual field trials with a Marine Simulator through multi-physics simulations under controlled multi-variables conditions: waves, currents, wind, drag & lift forces and more.

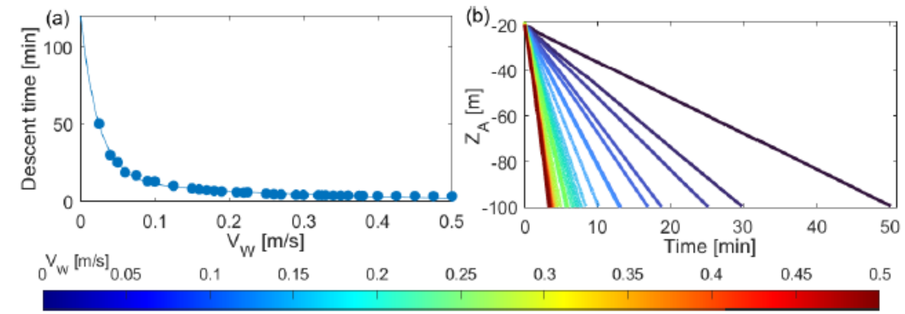




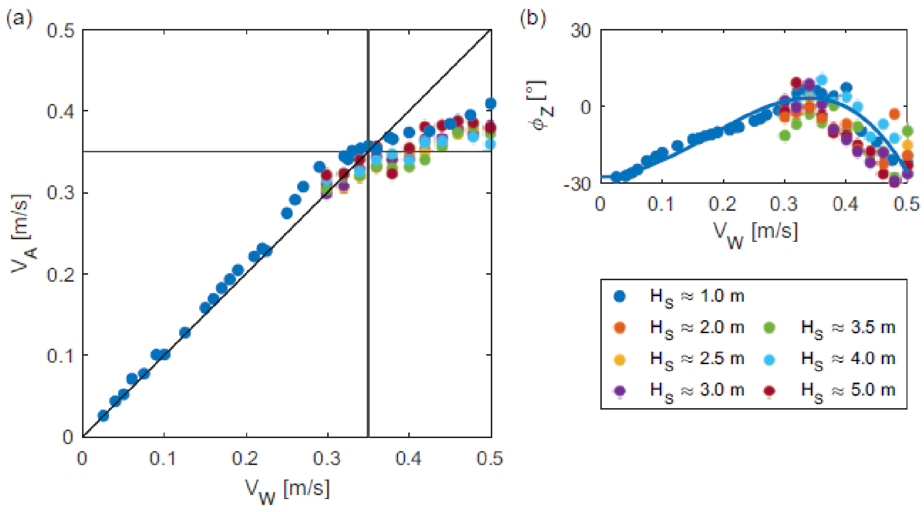


aubin OCEANETICS℠

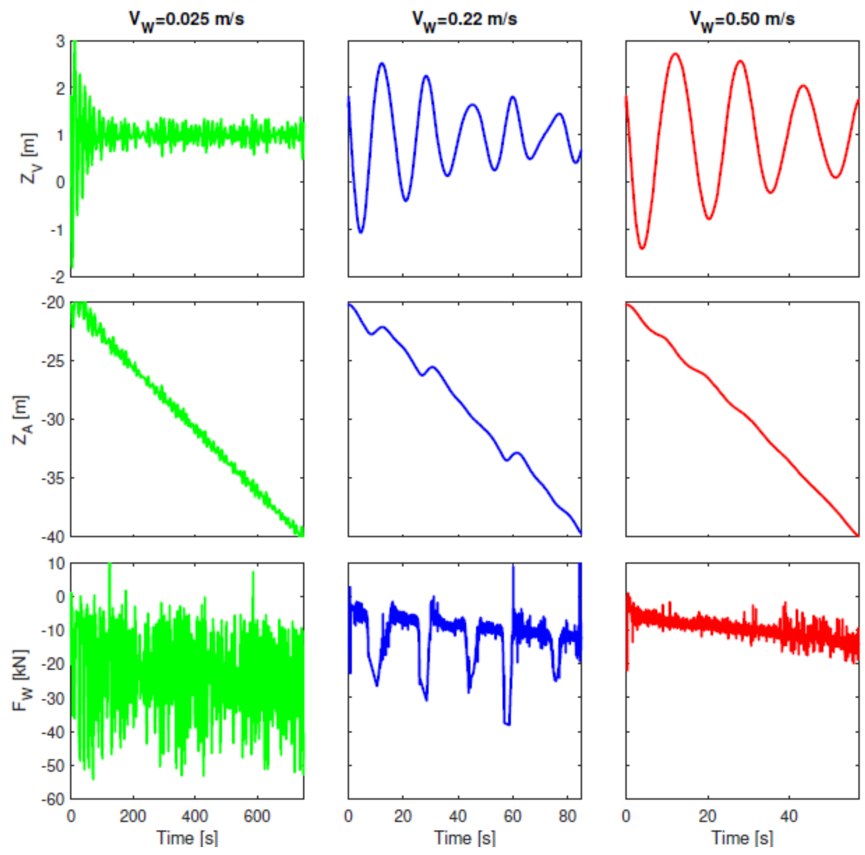
Descent to seabed

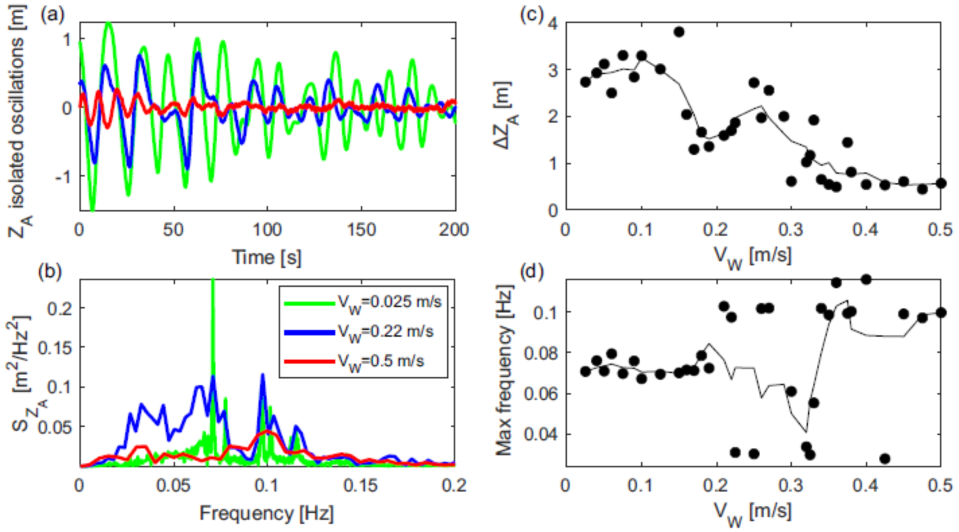


- Observe coupling between vessel's heave and anchor's vertical position
- The coupling diminishes as winch velocity increases

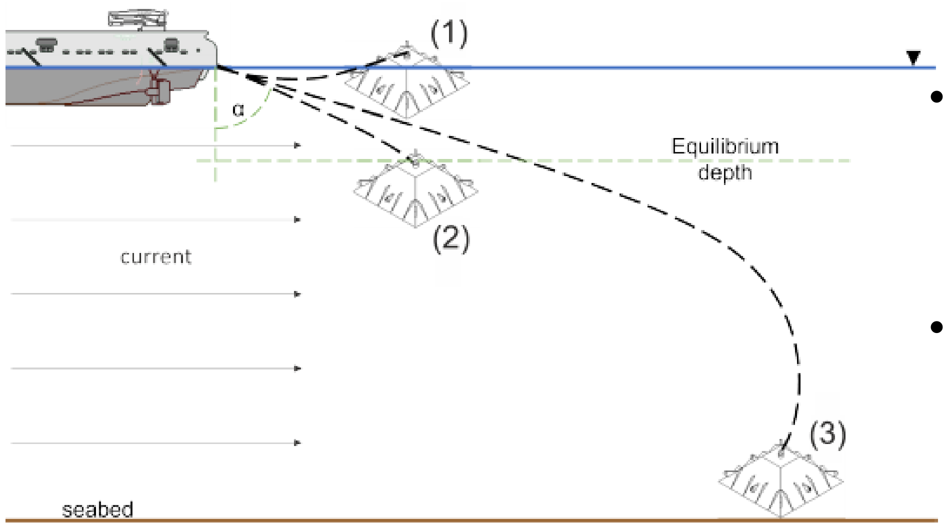


- At winch speed V_W=0.35 m/s the anchor velocity (V_A) stops increasing at the same rate (1:1) as V_W.
- Induced yaw minimum around V_W=0.35 m/s
- Similar behaviour for all wave cases.

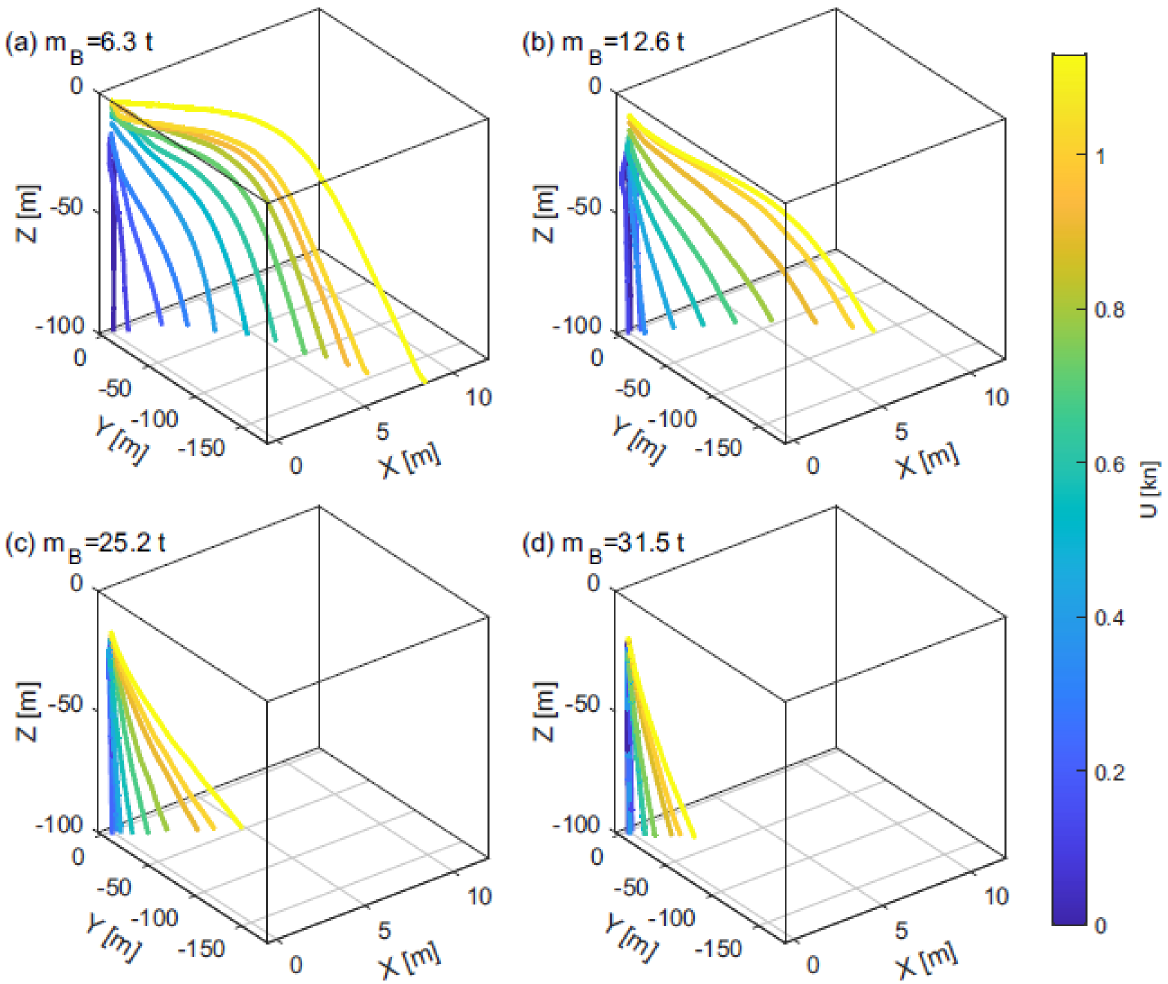


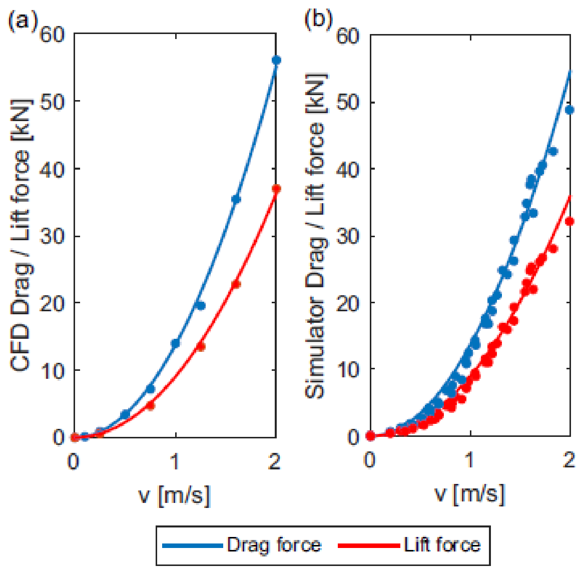


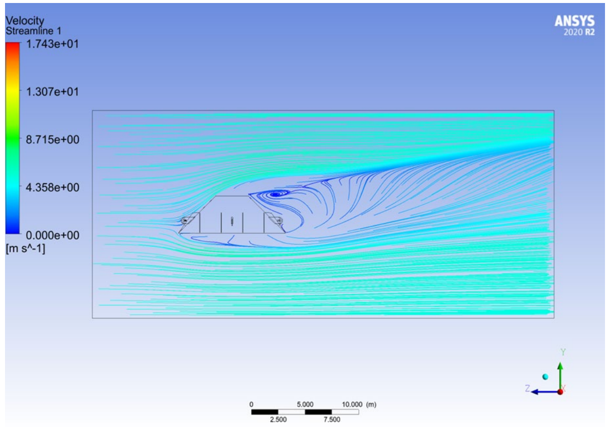
Current effect

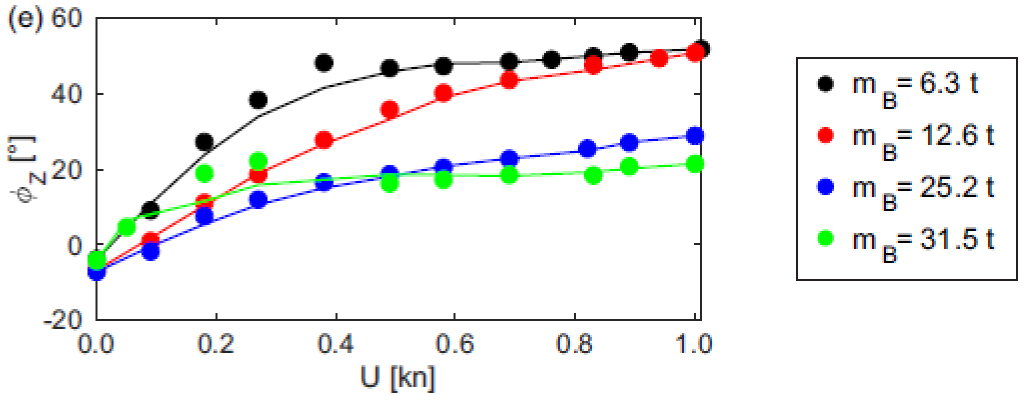


- Ballast weight limits the impact currents have on the anchor's drift
- High currents can be dealt with by increasing amount of ballast









THE PLACE OF USEFUL LEARNING

THE FACULTY OF ENGINEERING

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THE AWARDS 2019

WINNER
UK UNIVERSITY OF THE YEAR
FOR A SECOND TIME

THE TIMES THE SUNDAY TIMES
GOOD UNIVERSITY GUIDE 2020
SCOTTISH UNIVERSITY OF THE YEAR

The Queen's Anniversary Prizes
For Higher and Further Education
2019

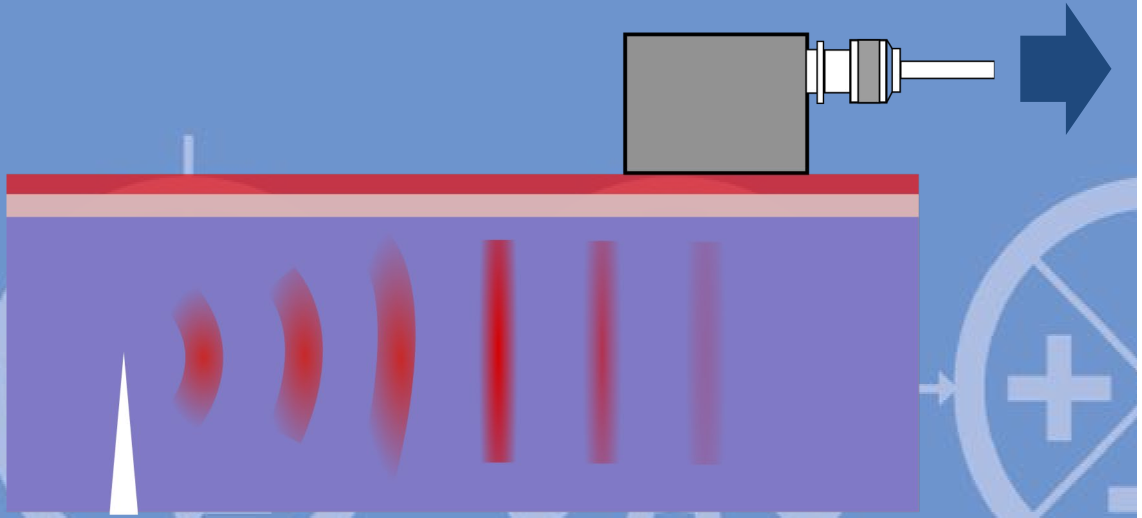
Times Higher Education University of the Year 2012 & 2019
Times Higher Education Widening Participation Initiative of the Year 2019
The University of Strathclyde is rated a QS 5-star institution

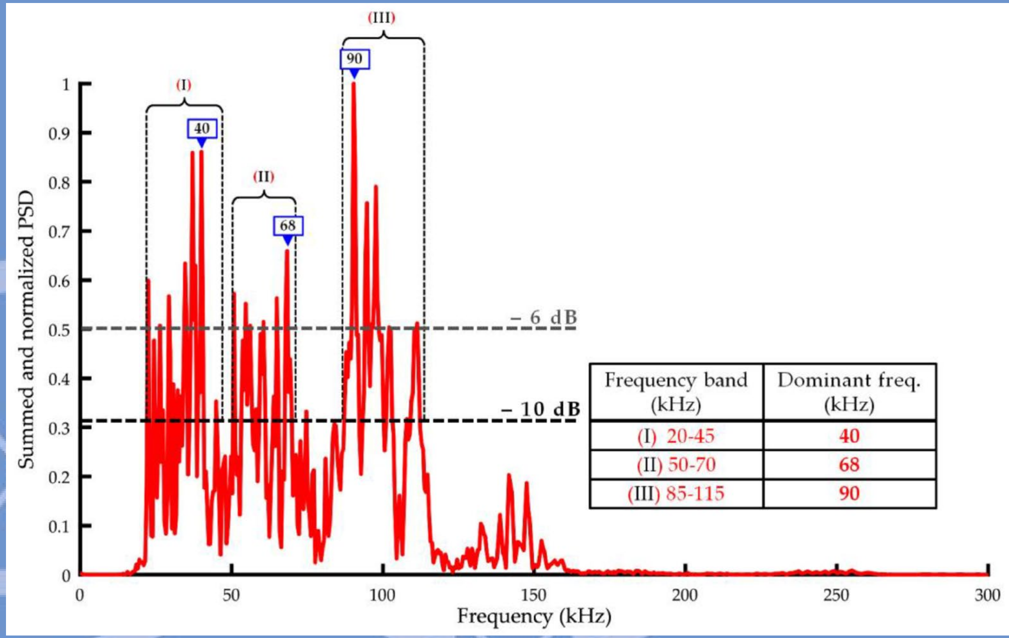
NOVEL PIEZOELECTRIC COMPOSITES FOR PARTIAL DISCHARGE MONITORING

- Dr Rolan Mansour, Dr Andrew Reid, Prof Brian Stewart, Prof James Windmill

ACOUSTIC EMISSIONS DETECTION

- Partial discharges can occur across the voids, causing voltage stress and an acoustic impulse
- For a partial discharge, typical frequency range is low ultrasound up to 200 kHz

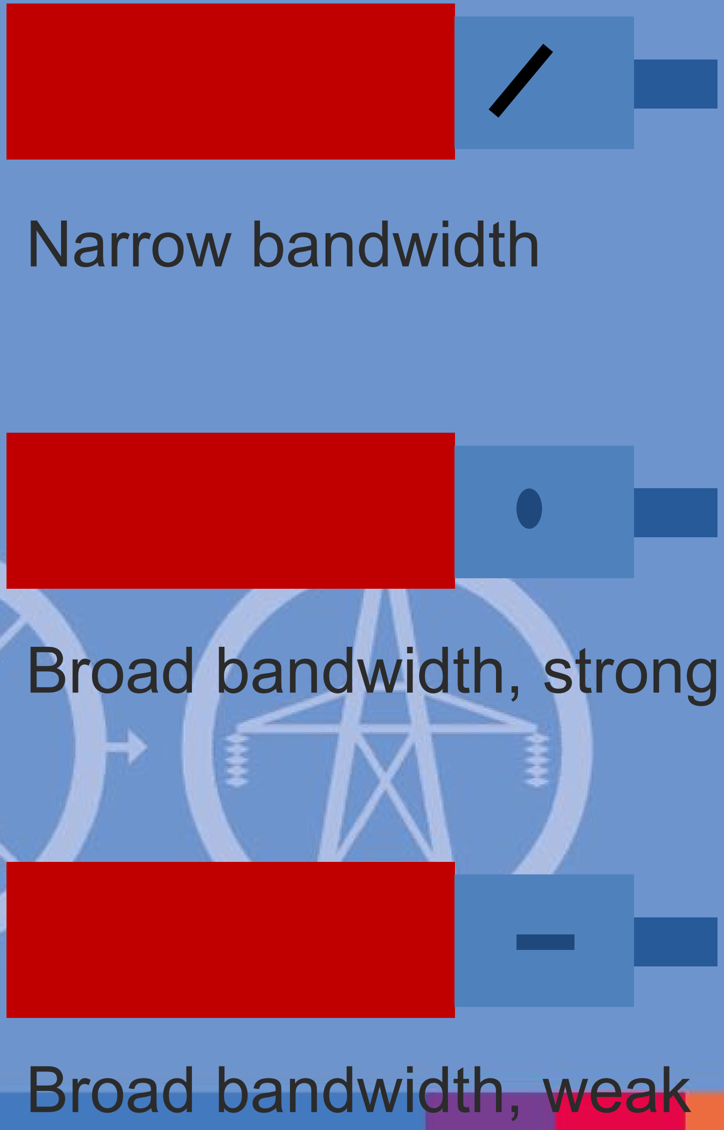




[1] Sikorski, Sensors (2019), 19(8) 1865

ACOUSTIC EMISSION ANALYSIS

- We can gain some information about the fault from the frequency spectrum
- But the medium is dispersive and highly attenuating
- Signal quality degrades rapidly



PARTIAL DISCHARGE DETECTION

Newcastle University

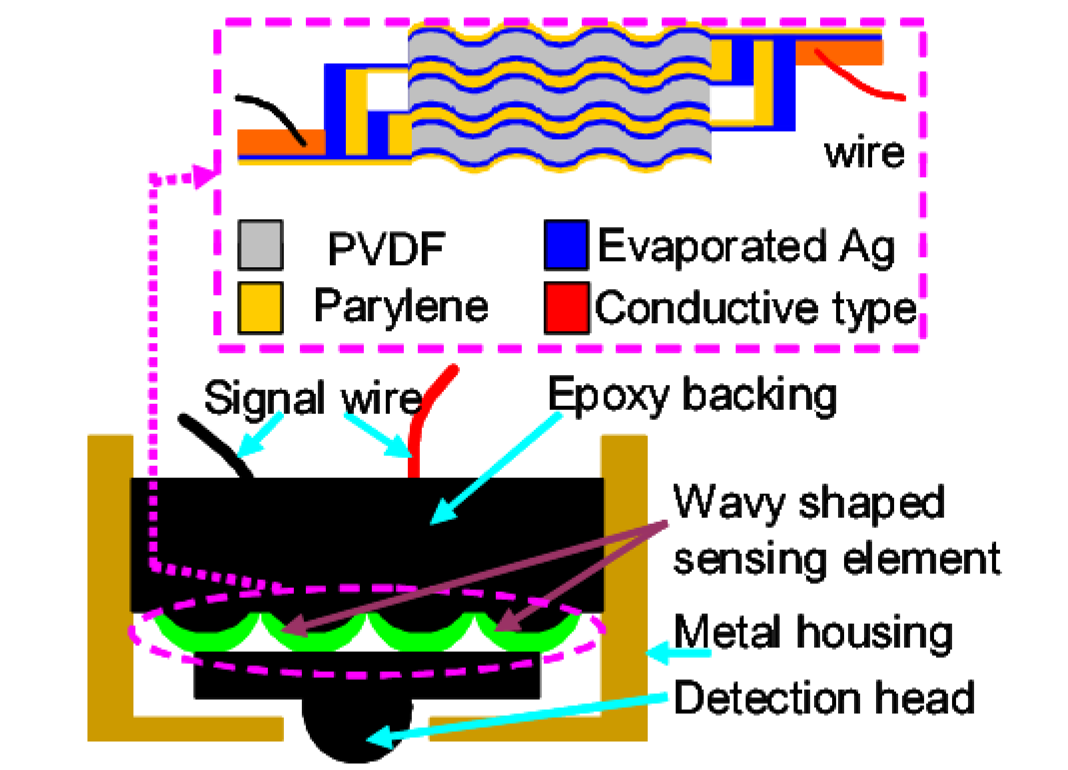
- Partial discharge detection already well developed using pulse detection – why use acoustic?
- Significant disadvantages – poor sensitivity, limited range, hard to determine level of partial discharge and requires some calibration to make sense
- Existing acoustic emission detectors are not made for high voltage cables.
- Why?
    - Low cost
    - Non-destructive
    - No EM interference

Olympus Range

Physical Acoustics

ON-LINE STRUCTURAL HEALTH MONITORING

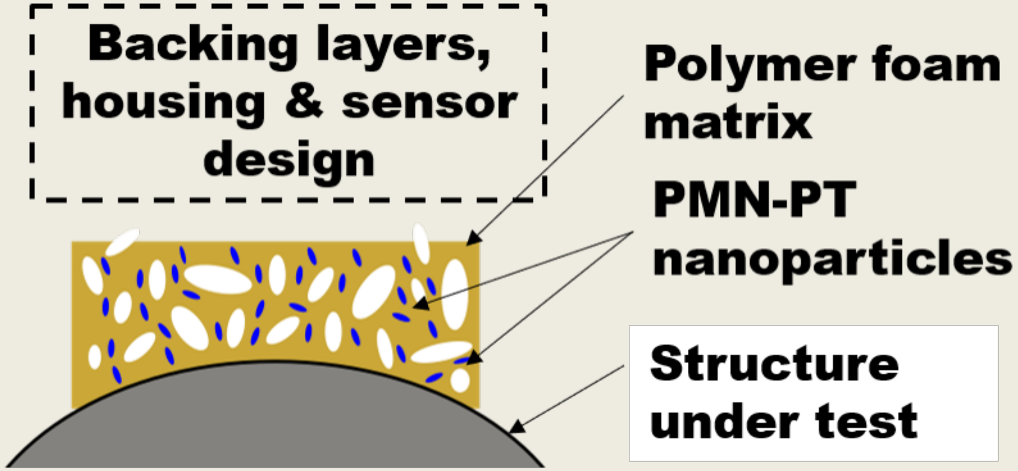
- ‘Soft’ sensors becoming popular for composite inspection.
- Sensors can be embedded or confirm to the surface under test.
- ‘Fit and forget’ system – low cost, passive monitoring of equipment health.



Feng (2009), InSENSORS IEEE Oct 25.

NOVEL COMPOSITE SOFT SENSOR

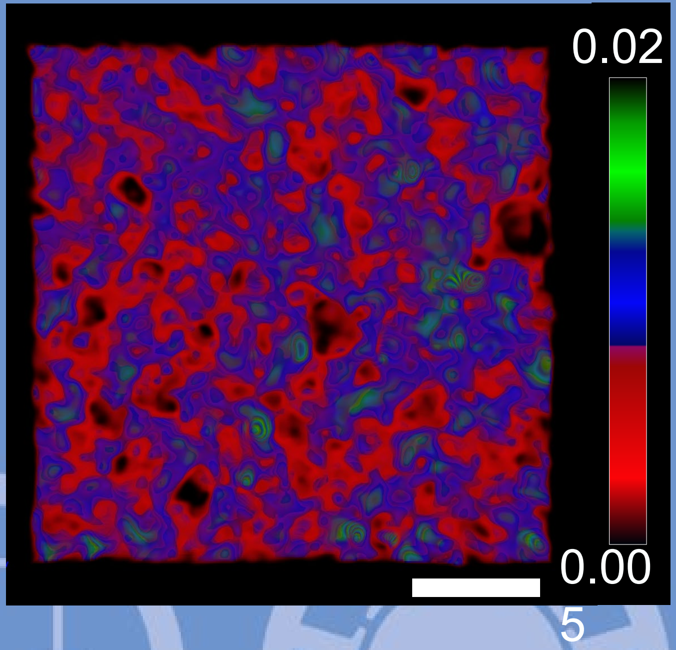
- Polymer composite of PMMA and PMN-PT remains highly flexible
- Photopolymerizable, can be made to fit any cable / pipe
- Significantly higher coupling co-efficient than PVDF.



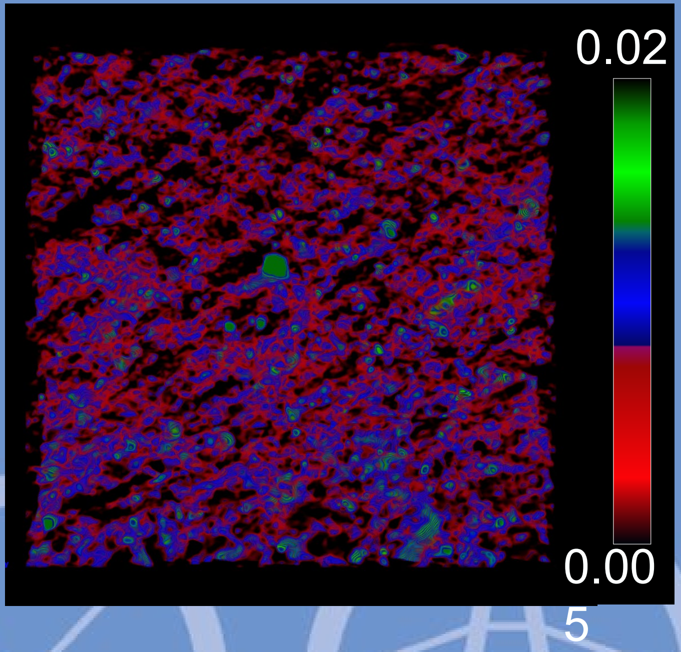
SIMPLE FABRICATION METHODS

Single-layer curing of 0-3 composite (without voids)

SUGAR CASTING



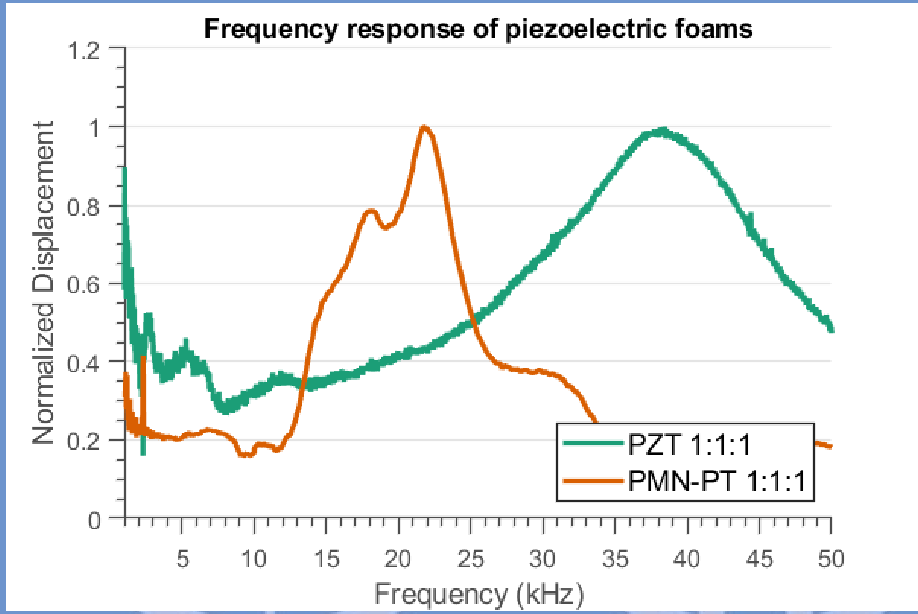
Icing sugar / PMN-PT / PMMA



Boiled PMN-PT / PMMA

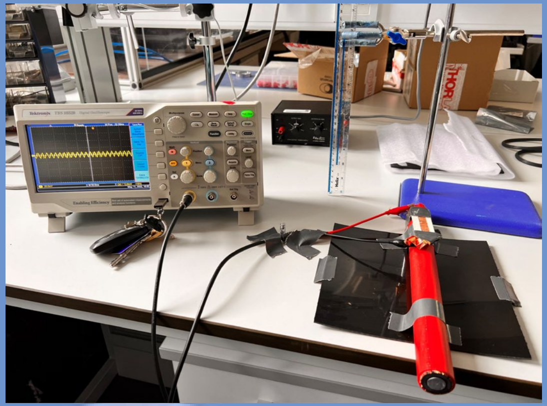
- Sugar casting provided a simple entry point compatible with photopolymerization.

GAIN IN COUPLING COEFFICIENTS



Polymer/ Piezo composite	d33 measurement	
	No voids	Sugar cast
PZT / FormLabs Grey	33 pm/V	33 pm/V
PMN-PT / FormLabs Grey	35 pm/V	69 pm/V

RESPONSE TO BUMP TESTS

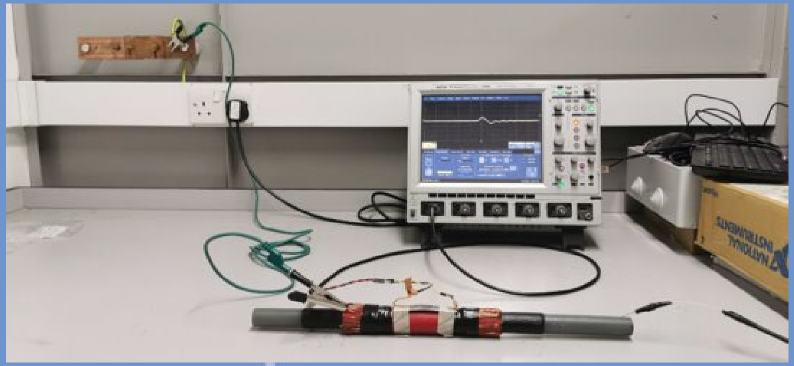


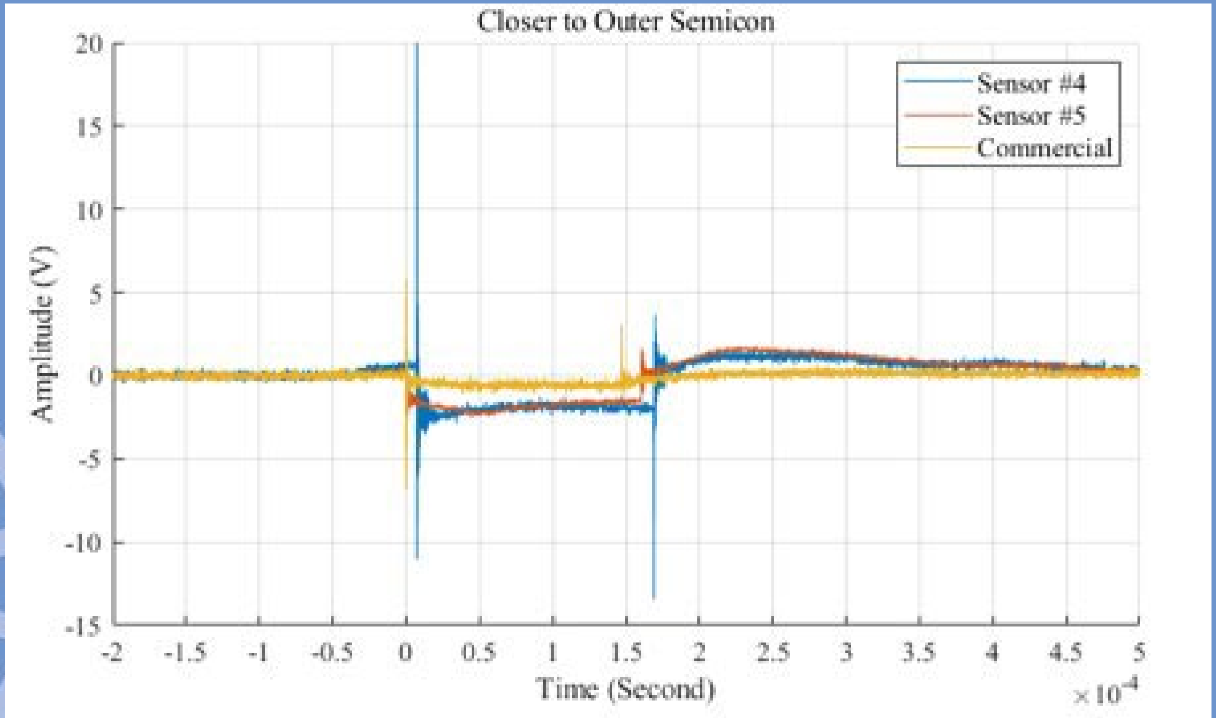
100 mm

200 mm

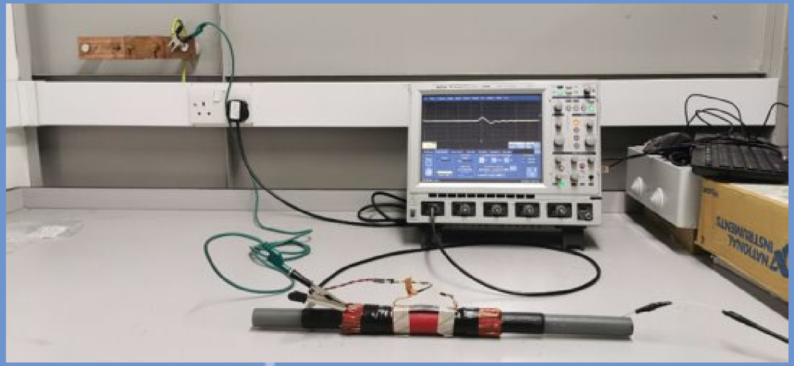
300 mm

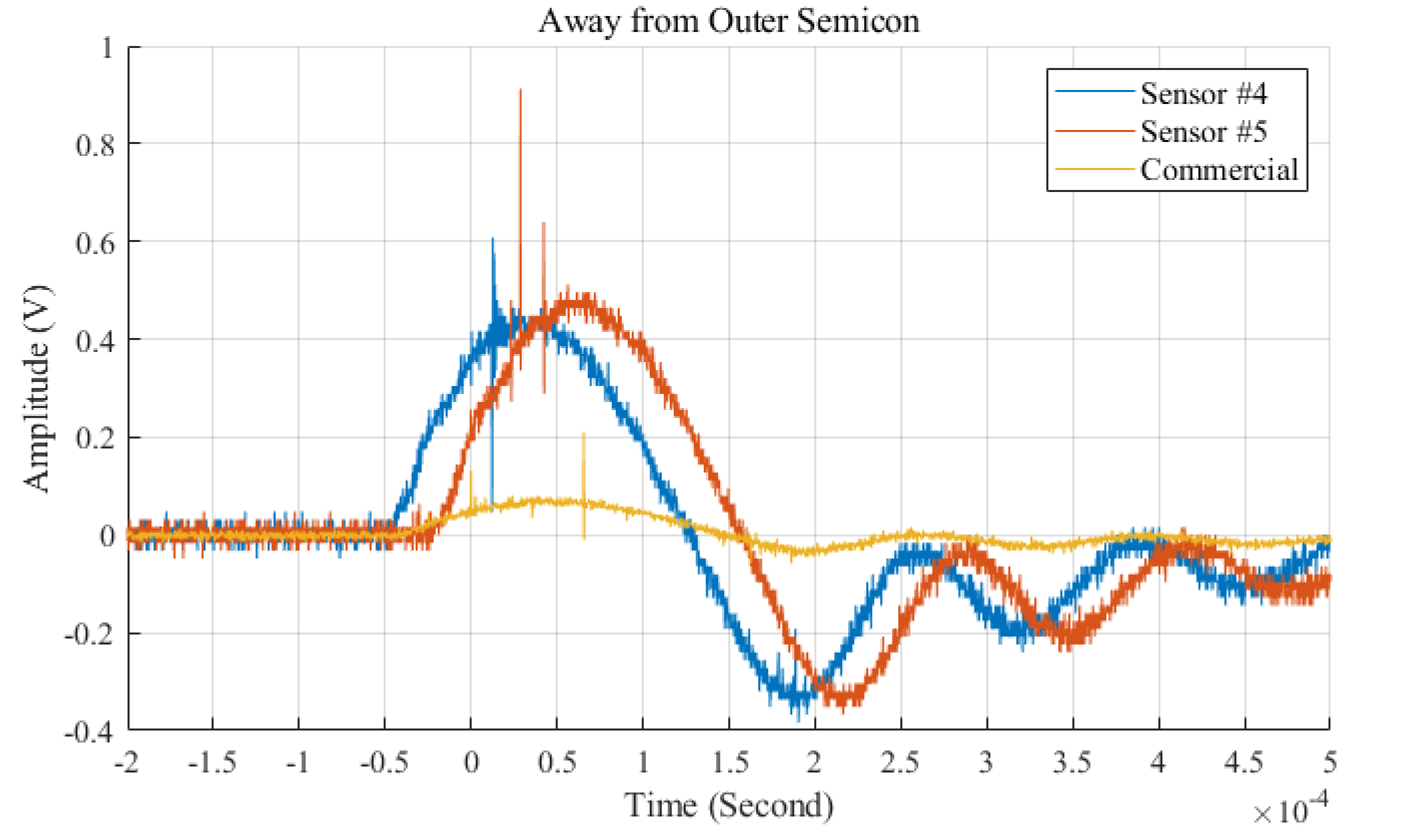
RESPONSE TO PARTIAL DISCHARGE





RESPONSE TO PARTIAL DISCHARGE





WHAT IS NEXT?

- Novel, promising material – needs to be integrated into a sensor package
- Room for improvement of the material? Sandwich structured PVDF with voids has shown to increase dielectric constant and breakdown strength
- Structured polymer composite design is possible with 3D printing steps.

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Supergen ORE Hub Annual Assembly
12th July 2023, Southampton, UK

Newcastle University

University of Strathclyde Engineering

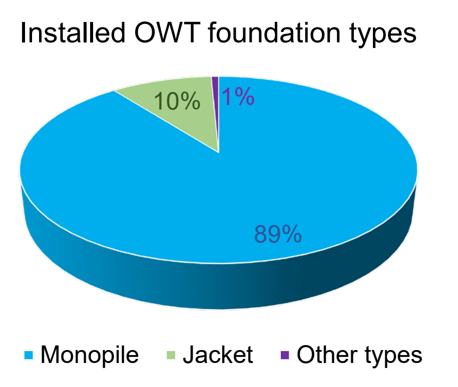
Corrosion and fatigue protection of offshore wind turbine structures using additive manufacturing technology (COATing)

Prof. Ali Mehmanparast (PhD, MBA, CEng, CMgr)
Professor of Structural Integrity
University of Strathclyde

Offshore Wind Turbine Support Structures

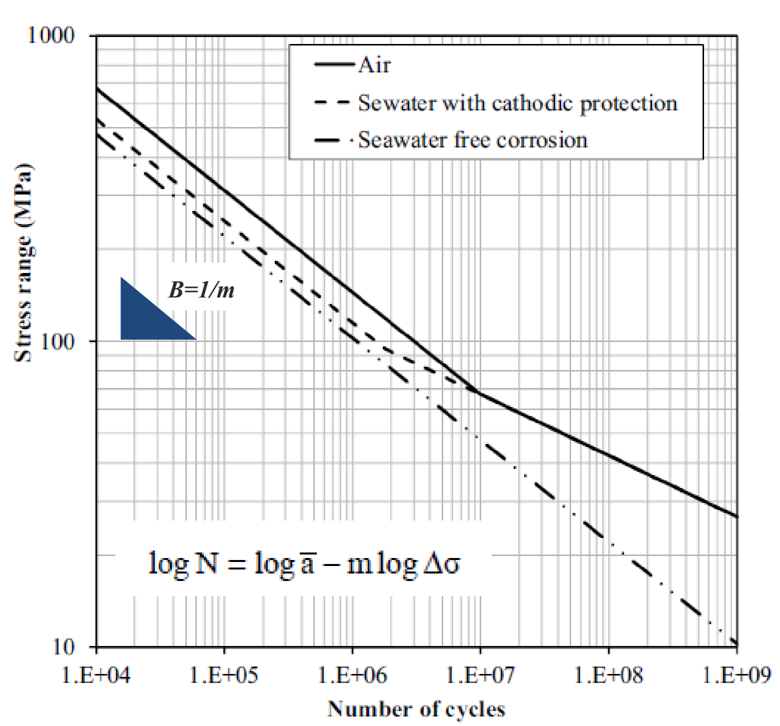
- Offshore wind turbines (OWTs) consist of three main parts; foundation, transition piece and tower
- Common types of offshore wind turbine foundations are
  - Monopile
  - Jacket
  - Floating
- Corrosion and fatigue are the dominant material degradation mechanisms in OWT structures, particularly in the foundations which are in direct contact with seawater and subjected to cyclic fatigue loading condition
- The overall aim of this project was to enhance corrosion-fatigue life in OWT foundations … actur

London Array

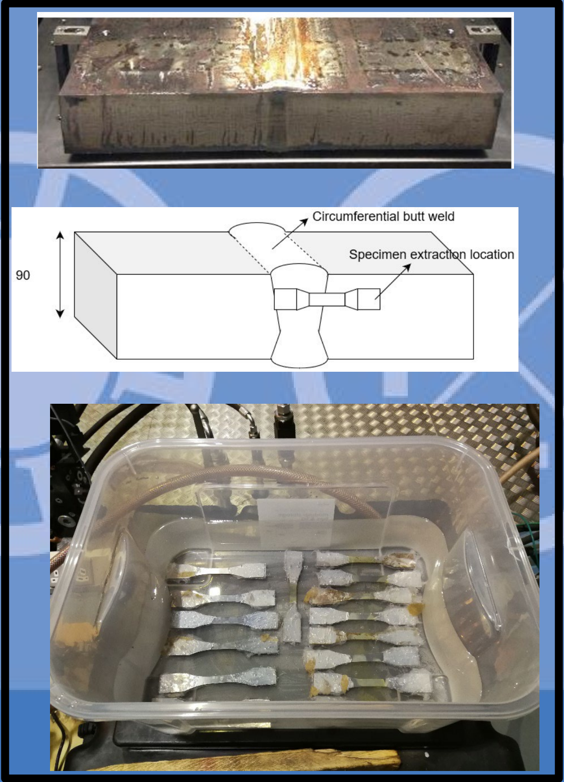


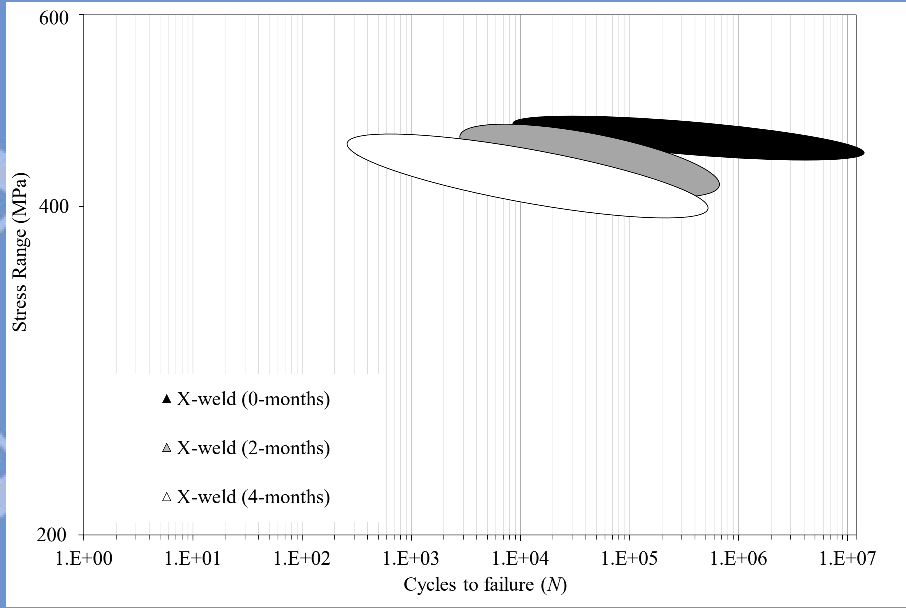
Corrosion effects on fatigue life of welds

- OWT foundations are designed against fatigue, by employing appropriate S-N design curves specified in international standards (e.g. DNV, BS) for different classes of weld (e.g. D, C1)
- Design curves heavily depend on operational environment; air/cathodic protection/free corrosion
- In COATing project, the pitting corrosion effect on fatigue life of conventional welds (flush ground condition) was investigated by performing tests on S355 cross-weld specimens with 0, 2 and 4 months exposure to seawater, and **a time-dependent fatigue life reduction model was developed**.



S-N curves in air taken from DNV C203

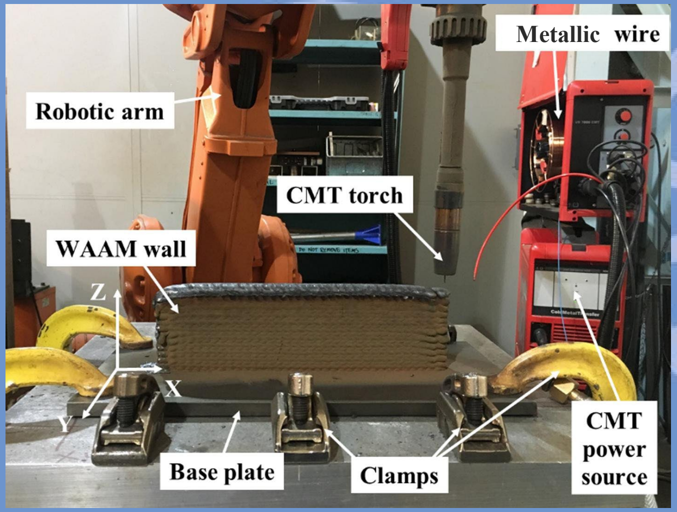




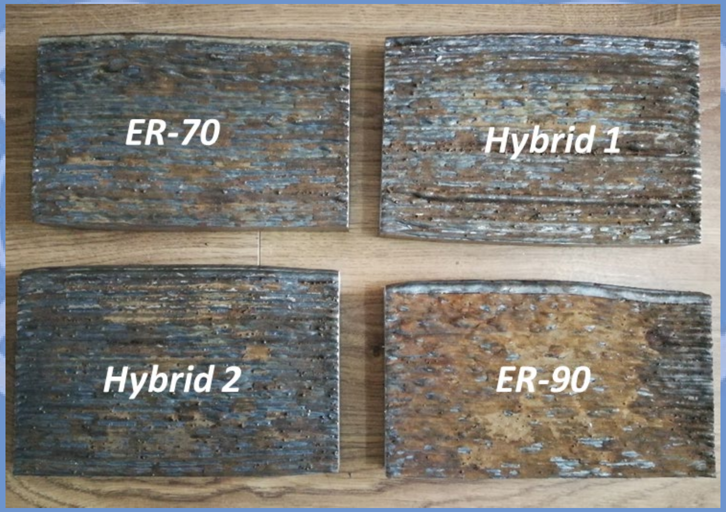
$t_{seawater}\Uparrow \rightarrow B\Uparrow \rightarrow N\Downarrow$ (>>×3)

Corrosion-fatigue life enhancement with WAAM

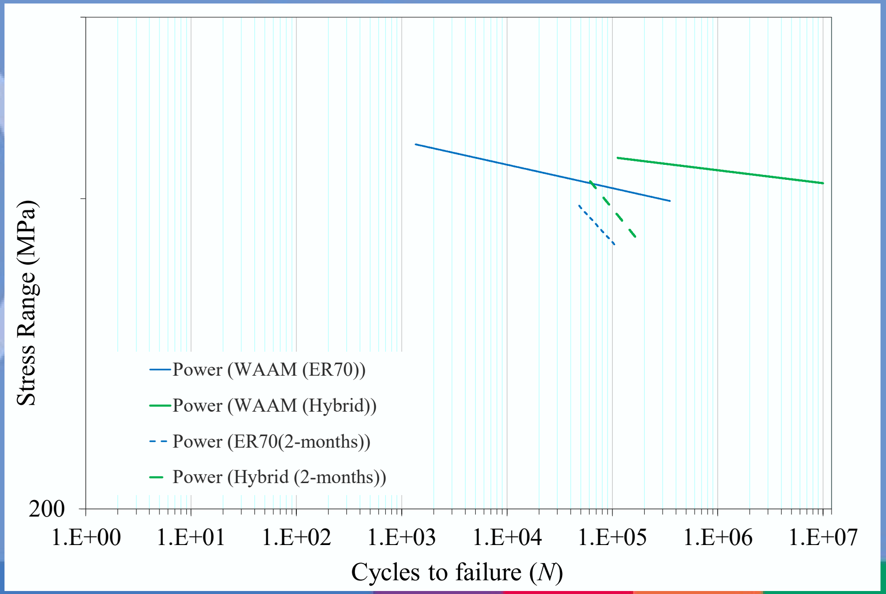
- Wire Arc Additive Manufacturing (WAAM) technology is suitable for rapid and large-scale fabrication
- Hybrid WAAM deposition was conducted by mixing two alloys, ER70 and ER90, with complementary properties (fatigue and corrosion resistance) in the melt pool
- **Hybrid WAAM has been found to enhance fatigue (≈ ×100) and corrosion-fatigue (≈ ×2) life**.
- This technology can be used as a **permanent coating technology** to protect critical parts of OWT monopile foundations such as circumferential welds.



WAAM set-up



WAAM produced samples



Conclusions

- ❑ Seawater (i.e. pitting corrosion) significantly reduces the fatigue life of OWT weldments.
- ❑ A time-dependent model has been developed to estimate the life reduction factor in seawater environment.
- ❑ The WAAM technology was examined for application in offshore environment.
- ❑ The indicative S-N curves show that hybrid (ER70+ER90) WAAM samples exhibit enhanced fatigue and corrosion-fatigue life, compared to ER70.
- ❑ The obtained results prove the suitability of the research hypothesis in COATing that hybrid additive manufacturing can be used as an effective technique to enhance fatigue and corrosion-fatigue behaviour in the critical parts of OWT support structures.

Publications

- Shamir, M., Igwemezie, V., Lotfian, S., Jones, R., Asif, H., Ganguly, S. and Mehmanparast, A., 2022. Assessment of mechanical and fatigue crack growth properties of wire+ arc additively manufactured mild steel components. *Fatigue & Fracture of Engineering Materials & Structures*, 45(10), pp.2978-2989.
- Shamir, M. and Mehmanparast, A., 2023. Fatigue life assessment of offshore wind support structures in the presence of corrosion pits. *Marine Structures*, Under Publication.
- Shamir, M., Lotfian, S., Ganguly, S. and Mehmanparast, A., 2024. Corrosion-fatigue life enhancement of offshore steel structures using hybrid wire arc additive manufacturing technology. *Additive Manufacturing*, Under Preparation.

Improved Models for Multivariate Metocean Extremes (IMEX)

Supergen Offshore Renewable Energy

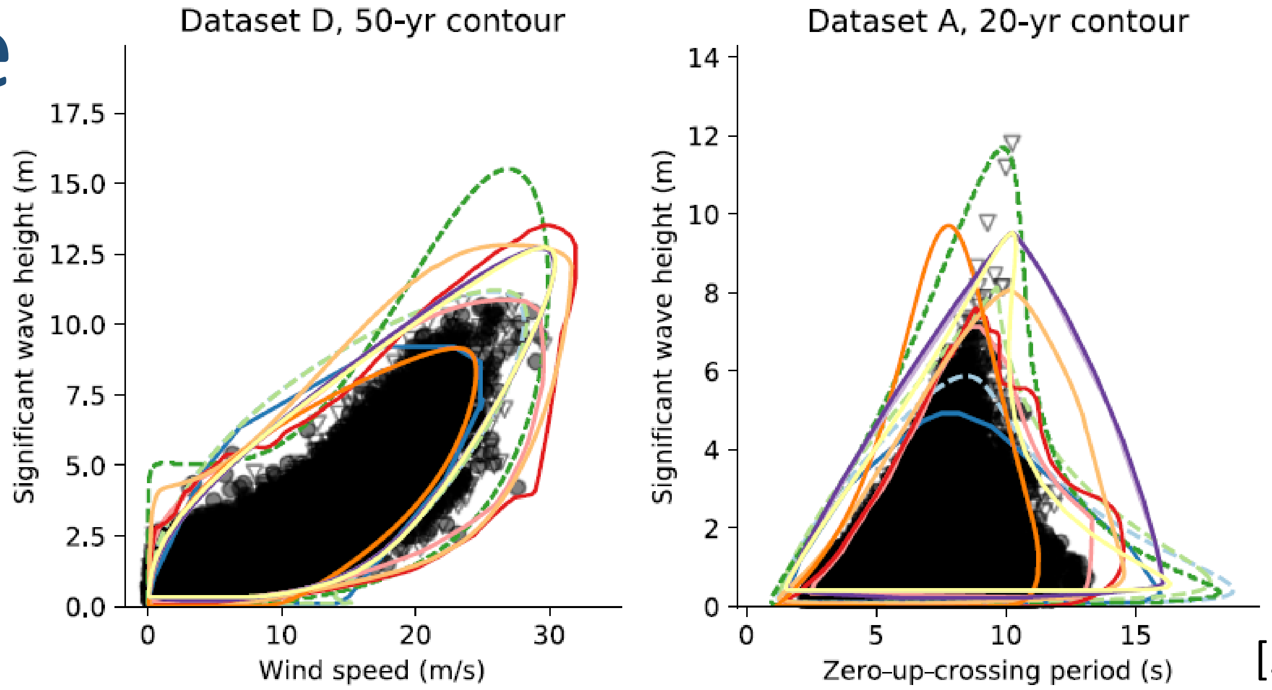
Flexible Fund Call 2

Dr Ed Mackay (PI),
University of Exeter
Prof. Philip Jonathan (Co-I),
Dr Emma Eastoe (Co-I),
Dr Anna Barlow (RA),
Lancaster University

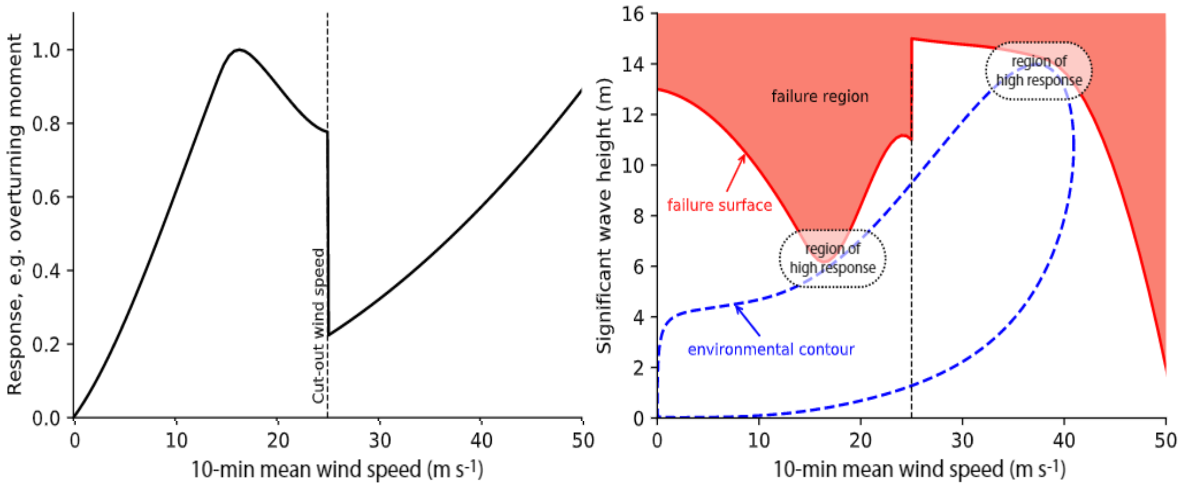
University of Exeter Lancaster University DNV·GL bombora MARINE POWER SYSTEMS

IMEX: research challenge

- Design of ORE structures requires estimates of **joint extremes** of winds, waves and tides
- Current design standards recommend models that make strong assumptions about form of joint distribution
- Statistical models can lead to errors in extreme response of the order of ±50% [1]
- **Reduced uncertainty** in environmental conditions leads to **more efficient and reliable designs**



[2]



[3]

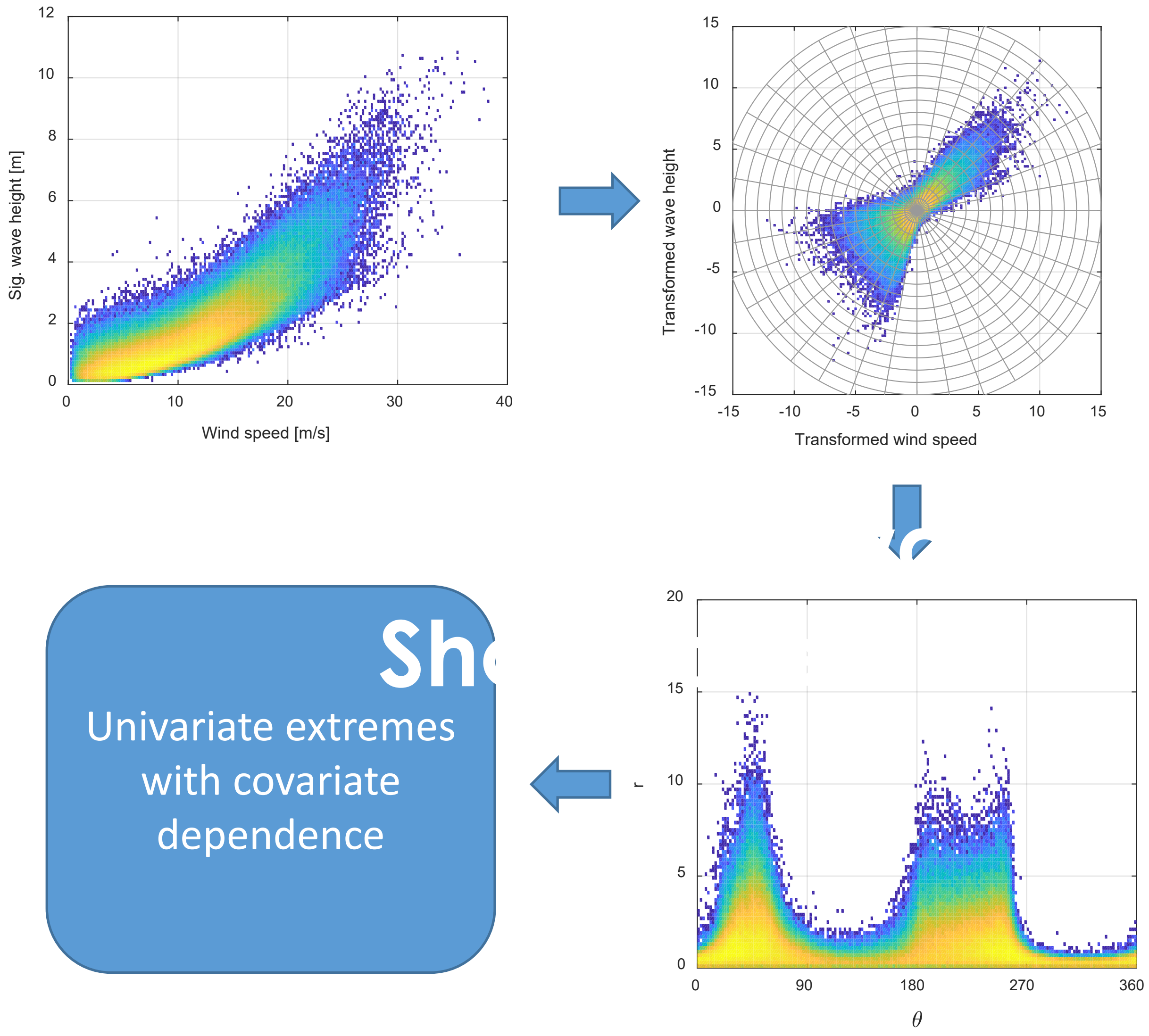
[1] de Hauteclocque et al. "Quantitative assessment of environmental contour approaches". Ocean Eng. 245 (2022)
[2] Haselsteiner et al. "A benchmarking exercise for environmental contours" Ocean Eng. 236 . (2021)
[3] Haselsteiner et al. "Long-term extreme response of an offshore turbine: How accurate are contour-based estimates?". Renew. Energy. 181 (2022)

IMEX objectives

- Develop new models for multivariate extremes
  - Based on **justifiable mathematical principles**
  - **Flexible** enough to represent observed datasets
  - **Simple** enough for routine engineering use
- Integrate models into open-source software:
  - https://github.com/edmackay/PPL-model
  - https://github.com/edmackay/Direct-IFORM

The SPAR model

- Semi-Parametric Angular-Radial (SPAR) model
- Reframes multivariate extremes as an intuitive extension of univariate theory, with angular dependence
- Inference is standard univariate problem with covariate dependence [5]
- More flexible than existing methods for multivariate extremes:
  - Existing methods are special cases of SPAR
- Extends to higher dimensions
- Method is applicable for wide range of multivariate extremes problems



[5] Barlow et al. (2023). “A penalised piecewise-linear model for non-stationary extreme value analysis of peaks over threshold”. Ocean Engineering

Supergen Offshore Renewable Energy

EPSRC Wave Energy Projects Showcase

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Engineering and Physical Sciences Research Council

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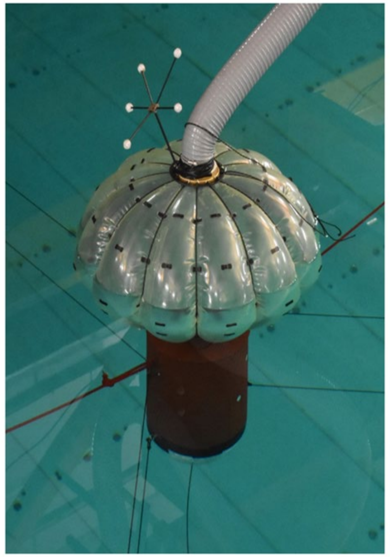
Offshore Renewable Energy

Flexible Responsive Systems in Wave Energy: FlexWave



Supergen ORE Hub Annual Assembly 2023, 12th July 2023

Jingyi Yang, Krishnendu Puzhukkil, Xinyu Wang, Alistair Borthwick, Edward Ransley, John Chaplin, Martyn Hann, Maozhou Meng, Robert Rawlinson-Smith, Shanshan Cheng, Siming Zheng, Zhong You, Deborah Greaves*

University of Southampton
University of Oxford
University of Plymouth
UKRI Engineering and Physical Sciences Research Council

Outer shell design of the flexible Origami WEC

- The origami WEC model design
  - Two origami WEC sections are attached on each side of the central frame;
  - Each origami WEC section has a range of motion 0 < θ < 60°.
- Minimal strain design of the origami WEC section
  - Concentrate strain on the red facets;
  - Optimise the geometry of the origami WEC section to obtain minimal strain on the red facets.

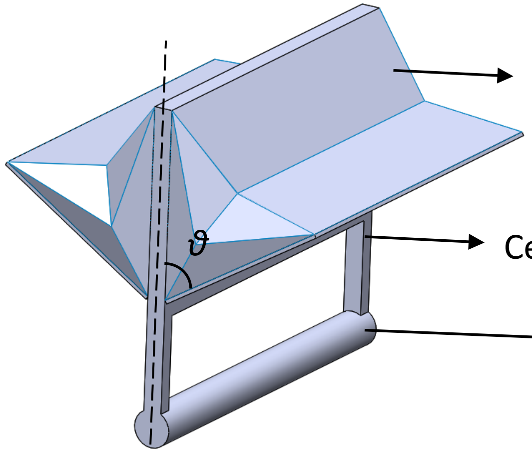


Figure 1. The origami WEC model design

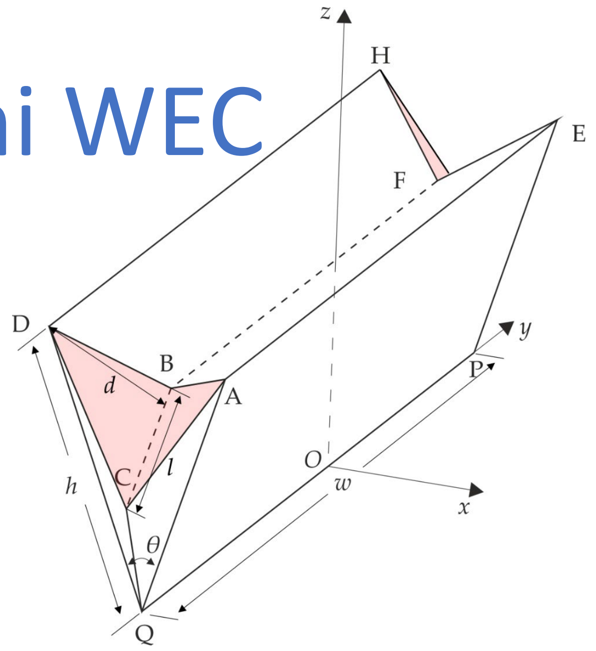
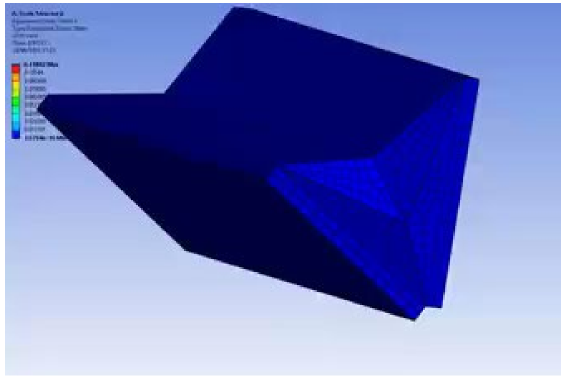
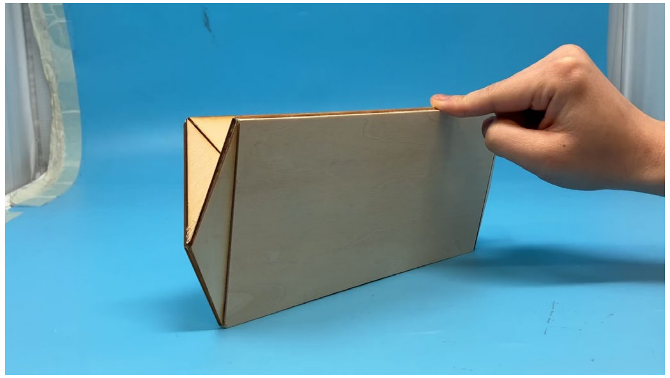


Figure 2. Minimal strain design of one origami WEC section.



Video 1. FEA of the flexible origami WEC .



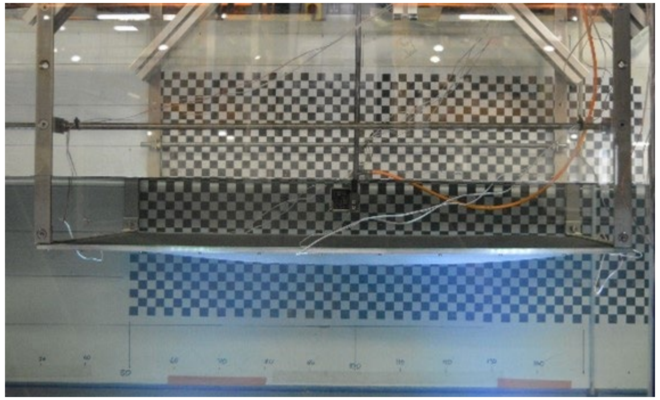
Video 2. A physical prototype of an origami WEC section.

Hydro-elastic response of flexible membranes

CCP-WSI
a Collaborative Computational Project in Wave Structure Interaction

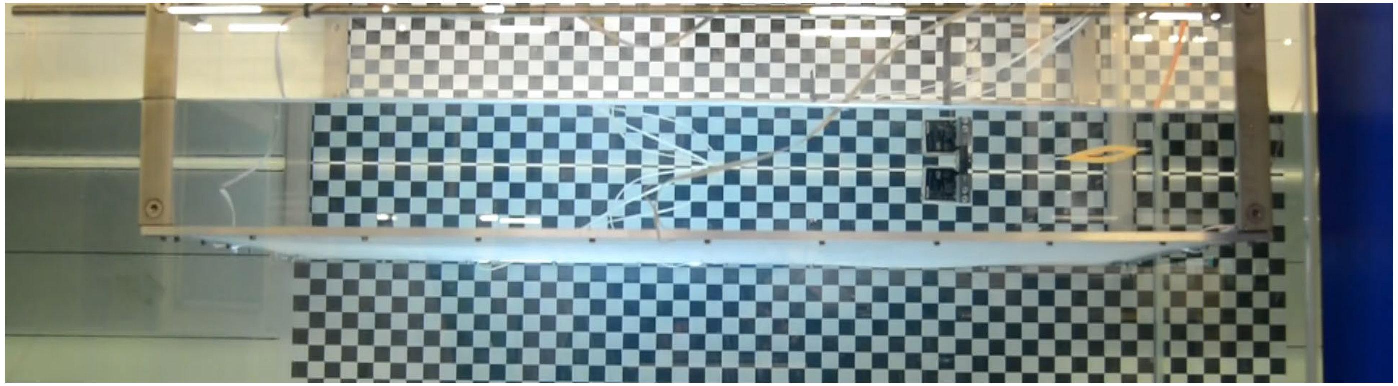
Neoprene Rubber data shared in the CCP-WSI Blind Test Series 4

- Presented at ISOPE 2023 and ISOPE24
- 8 groups and 9 nations participating so far
- Special Issue planned for IMEJ



https://www.ccp-wsi.ac.uk/data_repository/test_cases

- Hydro-elastic experiments conducted in 35 m x 0.6 m wave flume at the COAST Laboratory, UoP
- Materials tested: Neoprene Rubber, Reinforced Neoprene Rubber, Silicone and Polyurethane
- Membrane samples submerged and tested in regular & focused waves
- Laser distance sensor used to measure membrane response

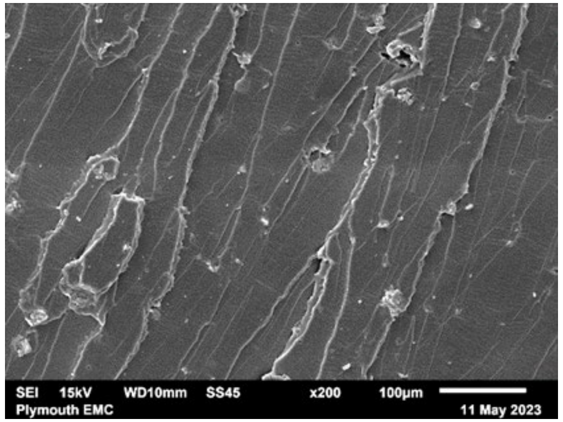


Interaction of Silicone membrane with regular wave

University of Southampton · University of Oxford · University of Plymouth · UKRI Engineering and Physical Sciences Research Council

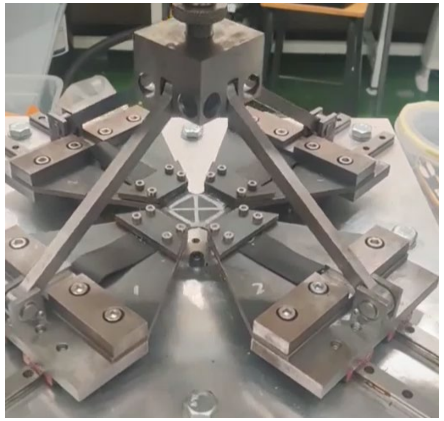
Assessment of materials manufacture & performance in flexible WECs

- Material manufacturing
  - This project explores **room-temperature curing (RTC)** elastomers to avoid using the costly rubber vulcanising method.
  - Graphene oxide (GO) with **hydrophobic treatment** is proven to have great potential as rubber reinforcement in marine environments.



The fracture surface of GO-filled PU rubber (109 % of the increase in tensile strength is achieved with 1 wt. % of treated GO)

- Material testing
  - A **database** of the **dynamic** performance of six different types of elastomers has been established based on testing results.
- Future work
  - A **visco-elastic model** describing the **dynamic** performance of the tested materials is to be developed, then verified with flume testing.



Biaxial dynamic testing setup, where materials' visco-elastic properties are investigated

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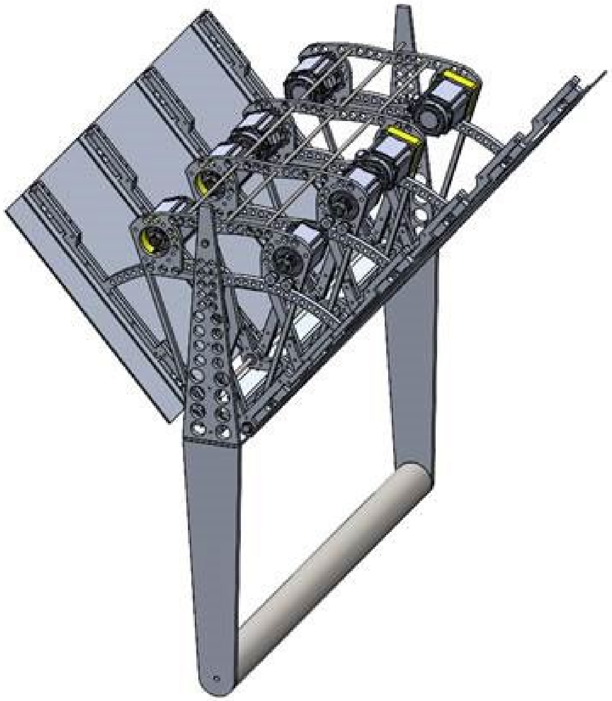
Project Progress

- An optimised outer shell design of the origami WEC has been finalised;
- Hydro-elastic responses of different flexible membranes tested in the wave flume facility;
- A database of the dynamic performance of a selection of elastomers has been established;
- A patent and three conference papers have been submitted.



Future work

- Finite element analysis to validate the optimum structural design;
- 1:50 scale prototype of the origami WEC is to be tested in the Ocean Basin;
- A visco-elastic model describing the dynamic performance of the elastomer materials is to be developed

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EPSRC Marine Wave Energy Programme

New Generation Modelling Suite for the Survivability of Wave Energy Convertors in Marine Environments (WavE-Suite)

Outline of Recent Progresses

Qingwei Ma
email: q.ma@city.ac.uk

Research Team

Research teams			
Investogators			
Title	Name	Role in the project	Organisation
Prof.	Qingwei Ma (QM)	PI, overall management of project	City, University of London
Dr.	Shiqiang Yan	Co-I, leading WP1 and 5	City, University of London
Prof.	Vengatesan Venugopal	Co-I, leading WP4	University of Edinburgh
Prof.	Christopher Pain	Co-I, co-leading WP2 and WP1	Imperial College London
Dr.	Rossella Arcucci	Co-I, leading WP2	Imperial College London
Dr	Jun Zang	Co-I, leading WP3	University of Bath
Dr.	Zhihua Xie	Co-I, co-leading WP3 and WP5	University of Cardiff
Dr.	David Pizer	Project Advisor	Consultant Scientist
Researchers			
Dr.	César Quilodrán Casas	Named researcher	Imperial College London
Dr.	Haoyu Ding	Researcher	University of Bath
Dr.	John Samuel	Researcher	University of Edinburgh
Dr.	Qian Li	Researcher	City, University of London
Dr.	Aristos Christou	Researcher	University of Cardiff

Advisory Board

Advisory Board for WavE-Suite				
Title	**Name**	**Role in the board**	**Expertise**	**Organisation**
Dr. and FREng	RV Ahilan	Chair and partner member	hydrodynamics and, offs	AqualisBraemar LOC
Dr.	Chris Retzler	Partner member	Wave energy;	Mocean Energy Ltd
Dr.	Jørgen Hals Todalshaug	Partner member	Wave energy;	CorPower Ocean
Dr.	Yago Torre-Enciso	Partner member	Wave energy;	BiMEP
Dr.	Jon Lekube Garagarza	Partner member	Wave energy;	BiMEP
Prof.	Decheng Wan	Partner member	Numerical modelling	Shanghai Jiaotong Univ
Dr.	Songwei Sheng	Partner member	Wave energy;	Guangzhou Institute of Energy Conversion
Dr.	V Sriram	Partner member	Hydrodynamics and num	IIT Madras
Dr.	Hakim Mouslim	Partner member	Offshore renewable ener	INNOSEA with ABL LOC
Prof. and FREng	Alistair BORTHWICK	invited member	Hydrodynamics and num	University of Edinburgh
Prof.	Andrew Moore	invited member	Data Assimilation and c	University of California Santa Cruz
Prof.	Paul Taylor	invited member	Wave dynamics and appl	University of West Australia
Prof.	Nigel Barltrop	invited member	Offshore engineering	university of Strathclyde

Objectives - What do we plan to achieve

Main Objectives:

- Develop a new numerical modelling suite (WavE-Suite) equipped with advanced machine leaning algorithms by coupling five individual numerical models that are suitable for physics of different scales and nature, supported by dedicated databases, which is efficient and accurate enough.
- Realise that WavE-Suite has the ability to deal with irregular waves together with current and to simultaneously capture both large and small-scale physics.
- Validate the WavE-Suite by bespoke experiments and sea trial data.
- Demonstrate WavE-Suite to be able to identify the survival conditions and quantify extreme loads and motions of WECs

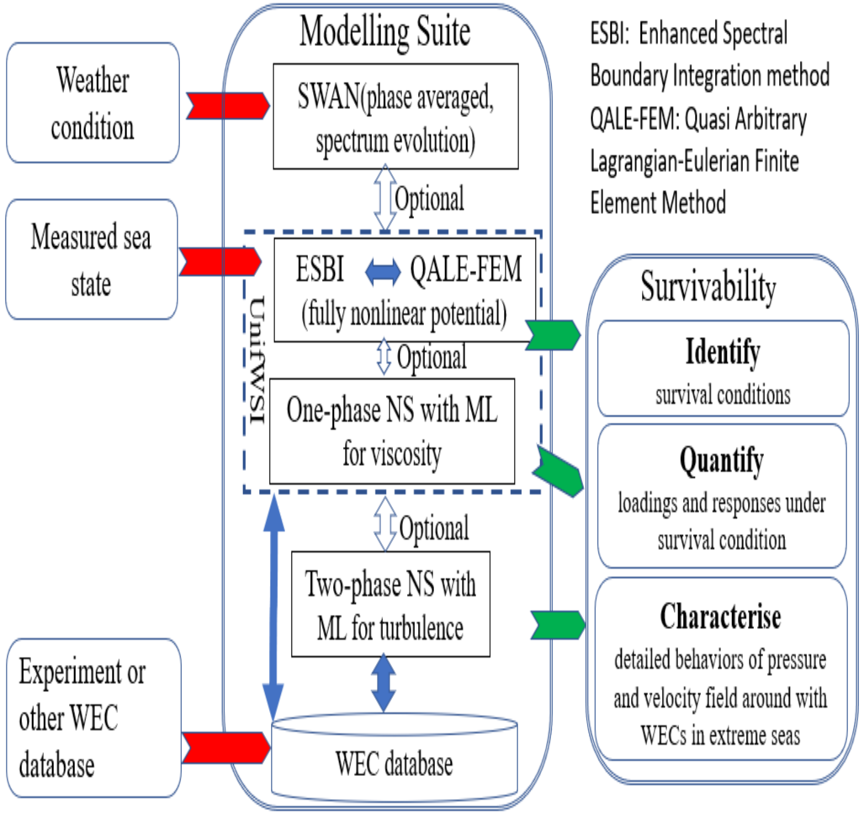
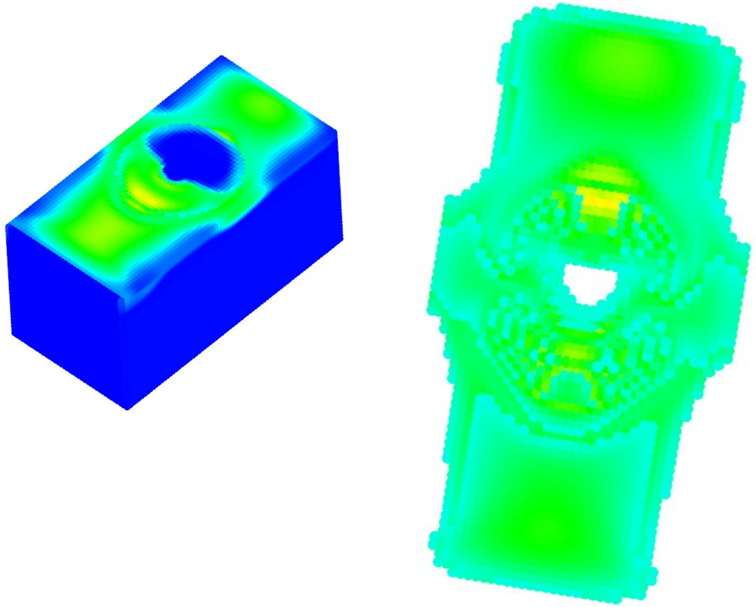


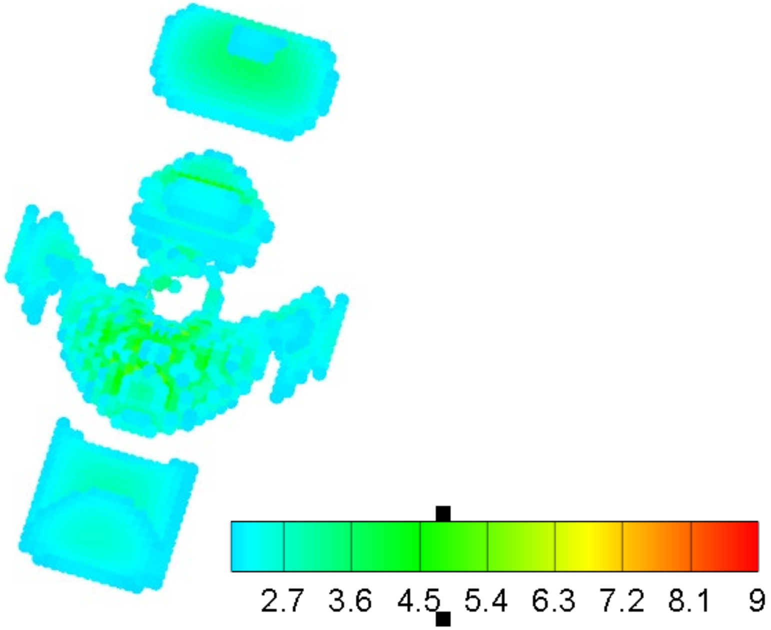
Fig. 3 Coupling mechanism of MMS modelling suite

Progress – 1: ML algorithm for predicting turbulent Viscousity

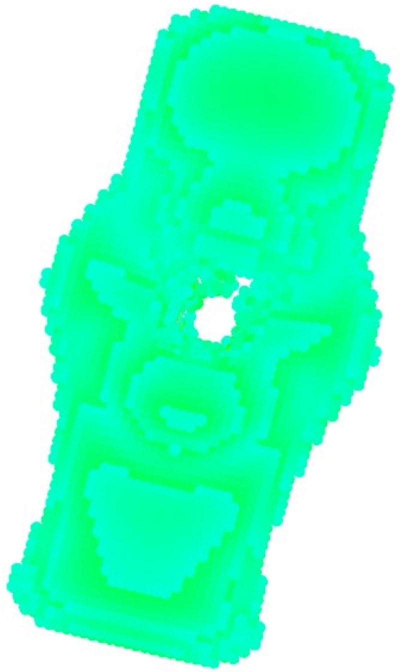
Graph Neural Network (GNN) developed and trained to predict the turbulent viscosity (WEC in focusing waves)



Distribution of turbulent viscounty near free surface around a WEC **computed by CFD**



Difference between the turbulent viscosities obtained by CFD and GNN

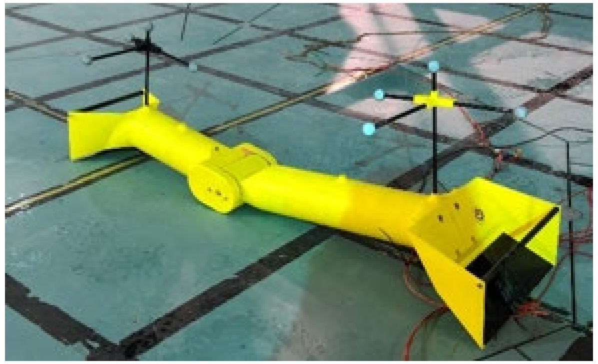


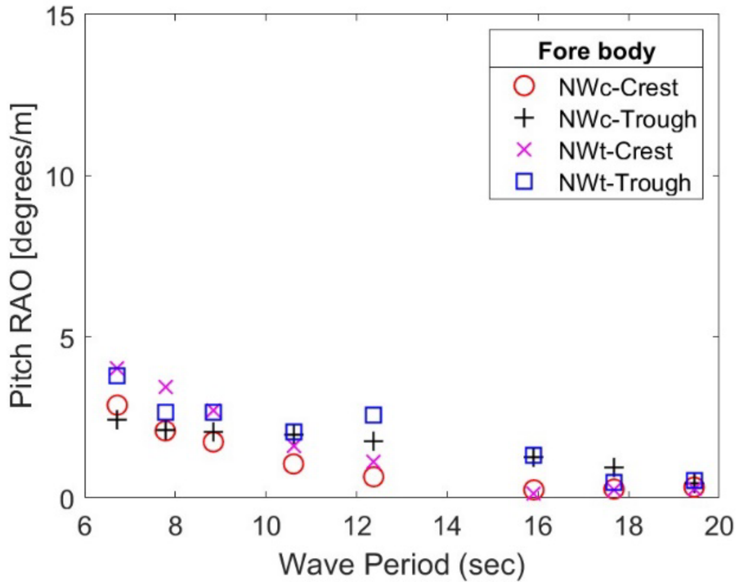
Distribution of turbulent viscounty near free surface around WEC **Predicted by GNN**

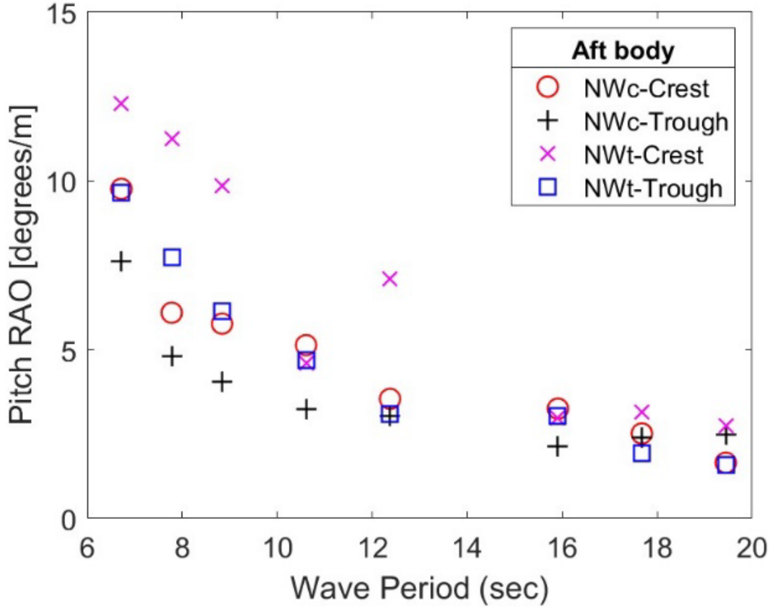
Progress – 2: Experiments on Mocean

Mocean WEC in extreme waves focusing on the crest and trough

Motion responses of the trough-focusing waves (NWt) generally surpass those of the crest-focusing waves (NWc)



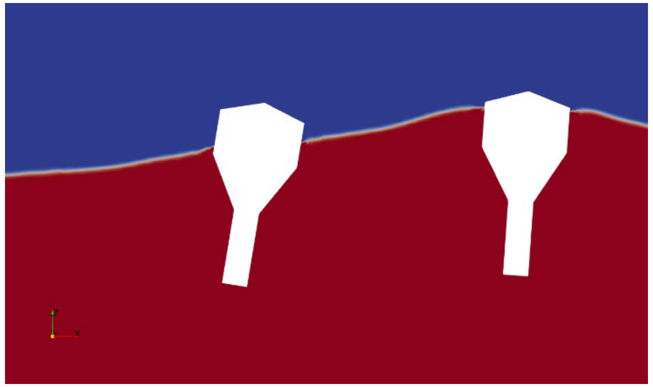




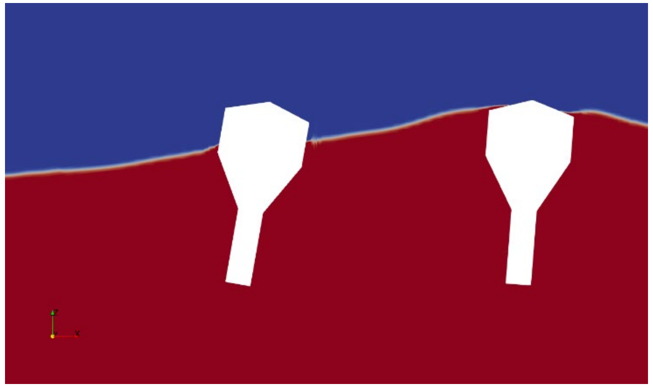
Pitch motion of Mocean hinged raft WEC subjected to NewWaves

Progress – 3: Study on wave loads and responses of two WECs

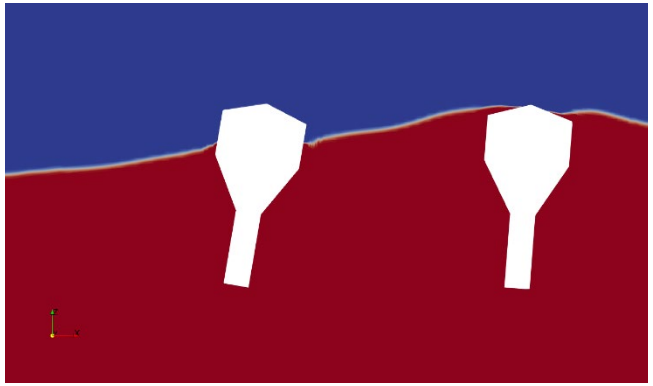
Effects of PTO on wave overtopping *in the waves of* <u>*H* = 0.42 m</u>; *T* = 2.25 s



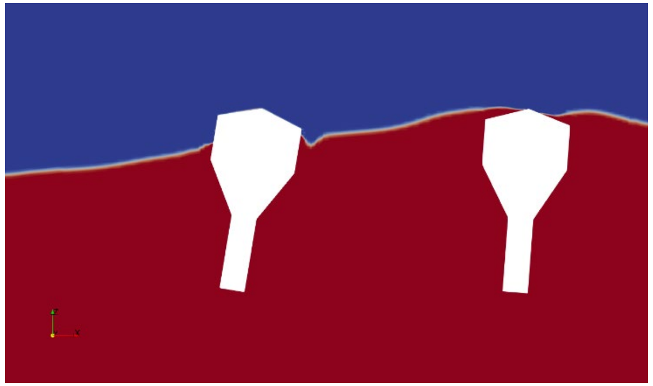
(a) B_{PTO} = 238 kg/s



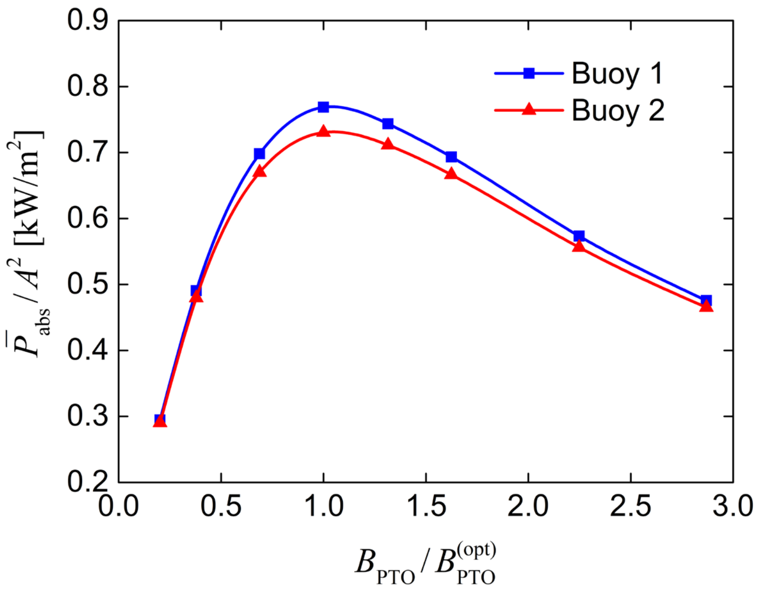
(b) B_{PTO} = 628 kg/s



(c) B_{PTO} = 1020 kg/s



(d) B_{PTO} = 1802 kg/s



Mean absorbed power ($B^{(opt)}_{PTO}$ =628 kg/s)

EPSRC Marine Wave Energy Programme

MoorWEC

Mooring analysis and design for offshore WEC survivability and fatigue

Peter Stansby (PI), Samuel Draycott, Georgios Fourtakas, Steven Lind, **Gangqiang Li**, Long Zhang, **Xuefei Wang** (University of Manchester),

Lars Johanning, Philipp Thies, **Chenyu Zhao** (University of Exeter),

Qingwei Ma, Shiqiang Yan, **Yi Zhang** (City University of London)

Qing Xiao, **Xiang Li** (University of Strathclyde)

PDRAs in bold

M4WavePower

Moored MultiMode Multibody

MANCHESTER 1824
The University of Manchester

Hybrid nonlinear – linear modelling

- Time domain Cummins method –> OREGEN platform
- Nonlinear Froude Krylov and restoring forces,

linear excitation, added mass, radiation damping

- Single float experiments on elastic mooring to :

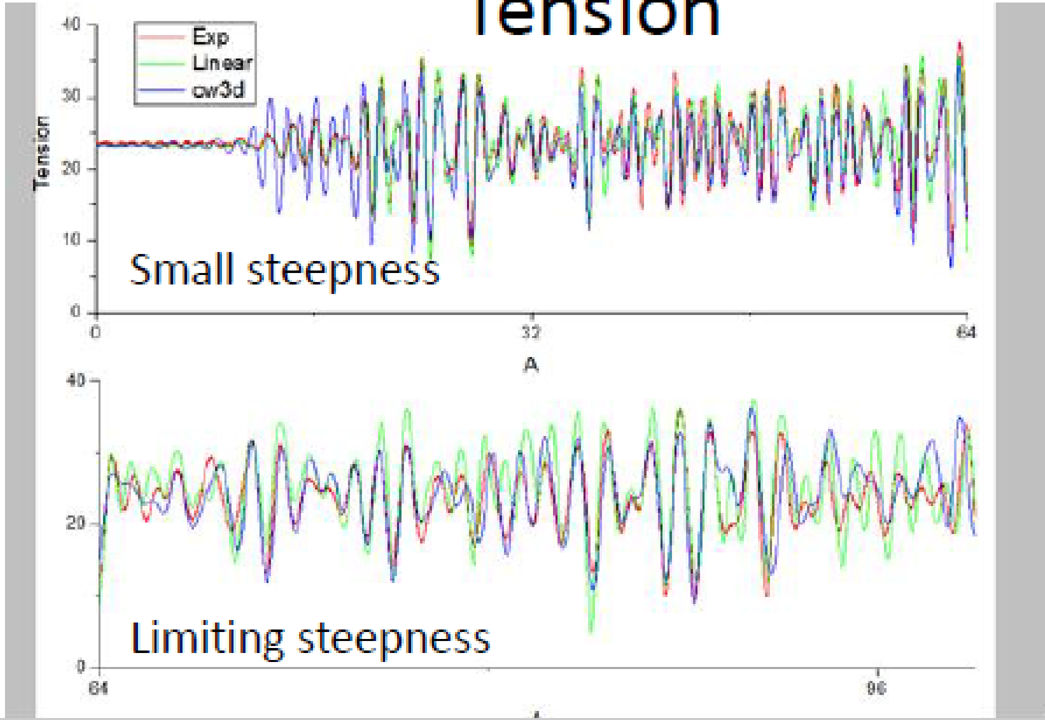
1. characterise latex mooring line
2. validate hydrodynamic modelling

- OceanWave3D and linear waves input

1. Linear input good for small/moderate waves with exact matching of surface elevation
2. OceanWave3D much better for steep waves

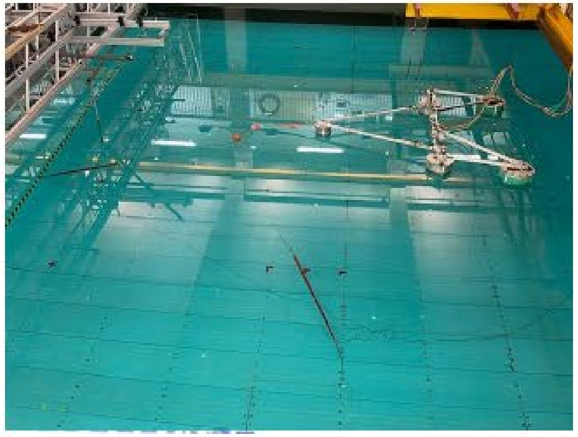
- Near completion

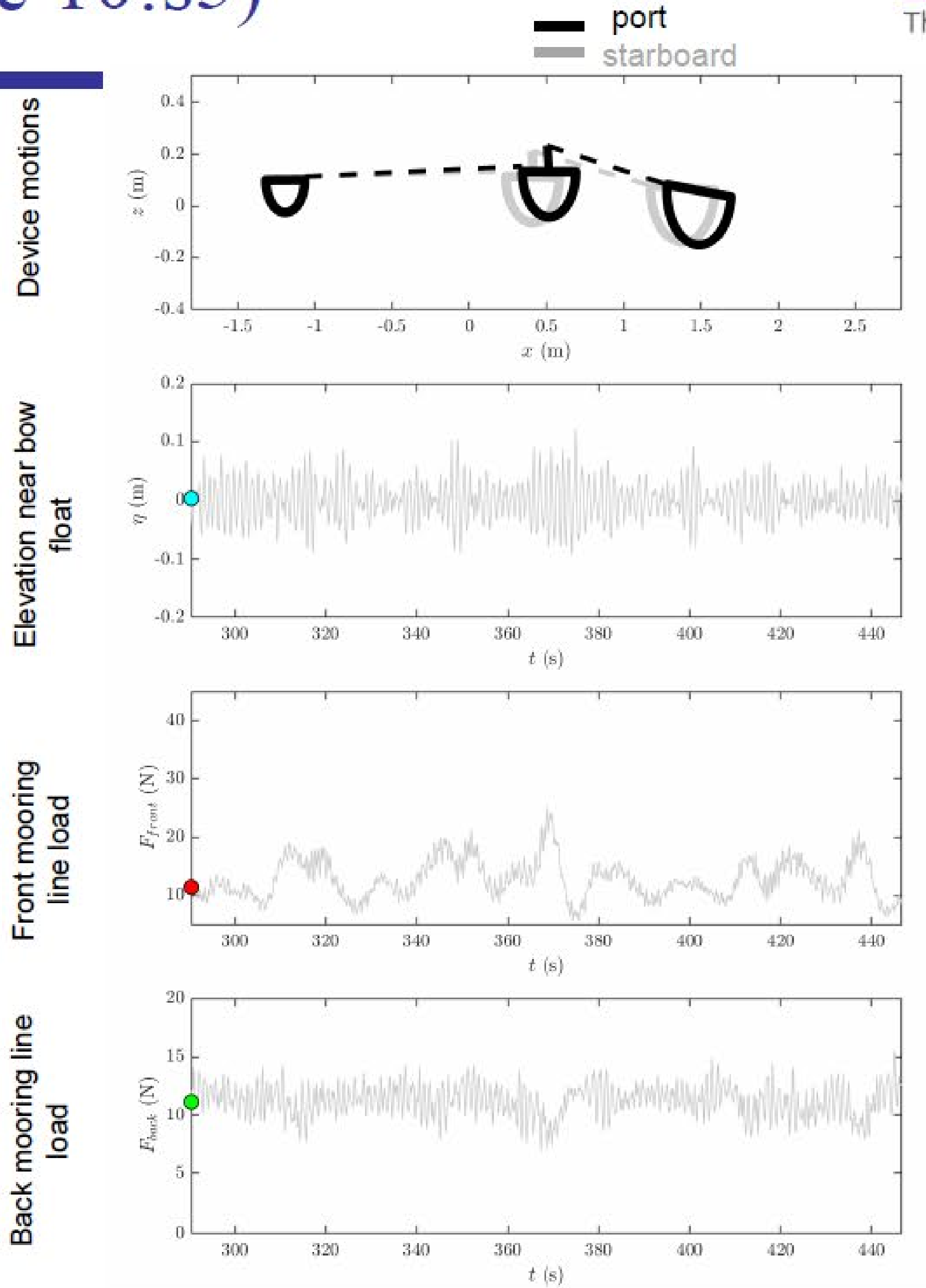
Tension



Results: Directionally Spread (case 10:s5)

Movie director:
Sam Draycott





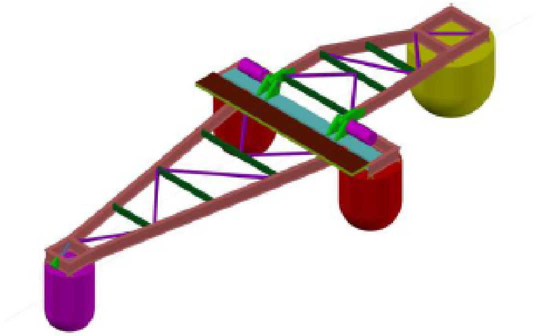
System identification of mooring forces

(led by Long Zhang)

- Models trained on experimental measurements
- Input surface elevation time series
- NARX models to output angular rotation and force time series
- Angular rotation quite linear
- Mooring force highly nonlinear
- Models fit given wave condition, some generalisation between conditions
- Statistics, spectral and rainflow, well predicted
- Same models with linearised waves and OW3D input waves give similar predictions
- Potential for in situ monitoring to give updated fatigue life

General points

- Wave modelling (OceanWave3D, QALE_FEM, OpenFOAM), DualSPHysics) ongoing for input to OREGEN
- Orcaflex modelling has shown some but limited success
- OREGEN platform plan : make BEM, OW3D FK force, and mooring modules open source in 2024, but not overall package
- Australian UWA ocean tests on track for December

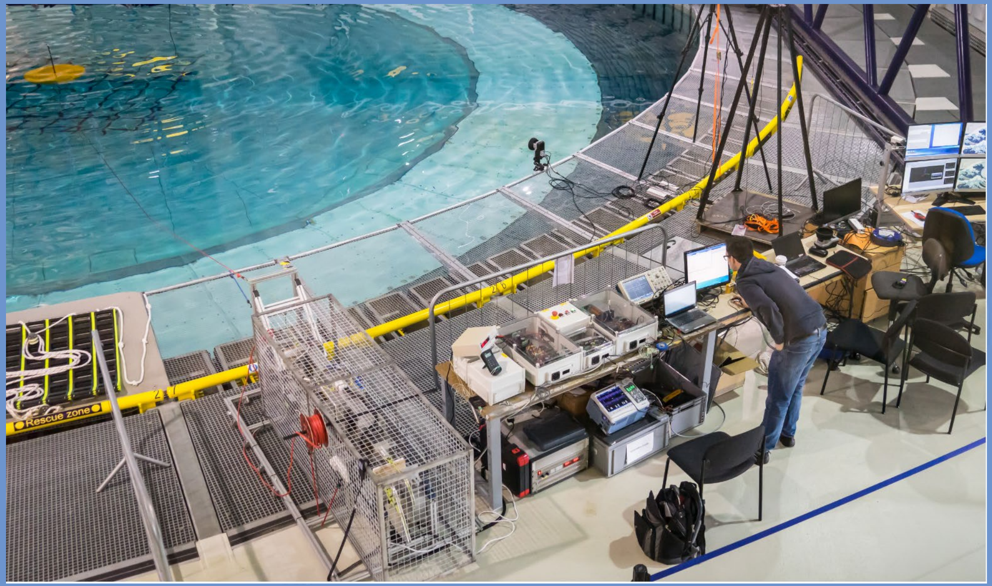


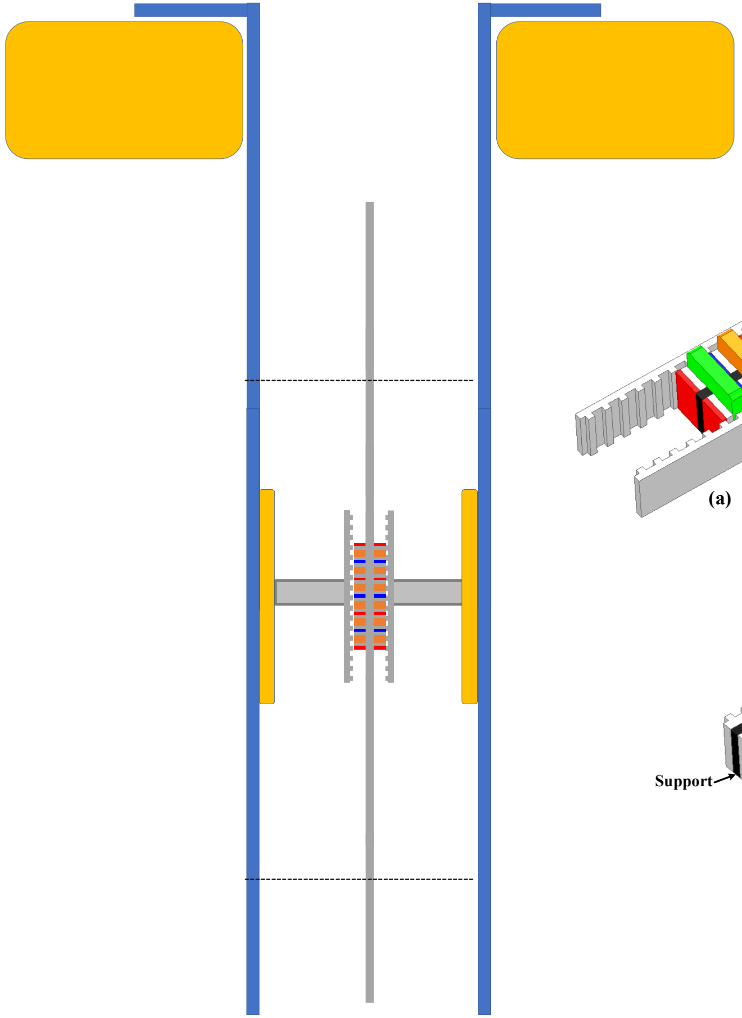
- Thanks and questions

Newcastle University
School of Engineering
Electrical Power Research Group

Marinisation and upscaling of All Electric Drive Train

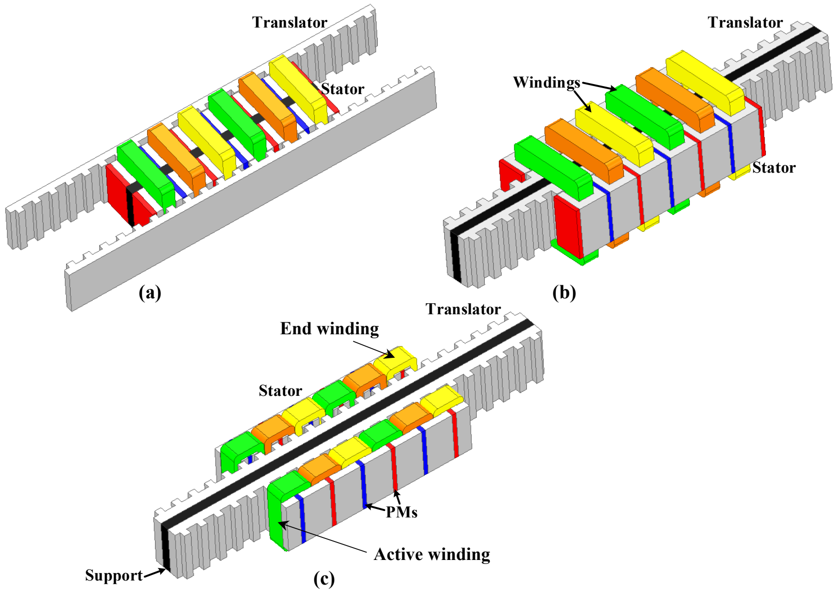
Nick J Baker, Serkan Turkman, Jeff Neasham (Newcastle University)
Markus Mueller, (University of Edinburgh)

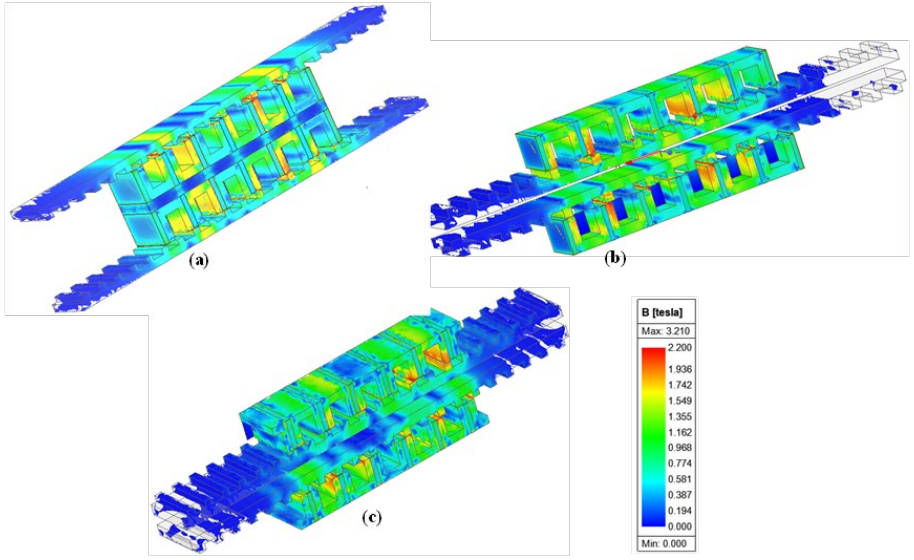


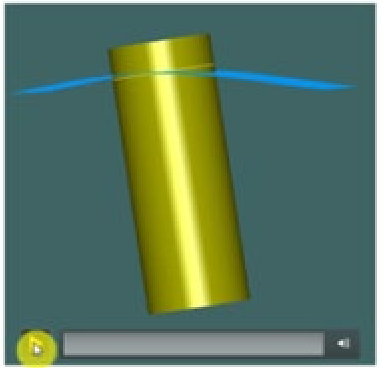


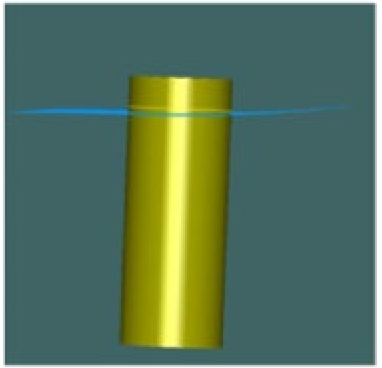
- Hydrostatics
- Hydrodynamics
- Electrical optimisation
- biofouling

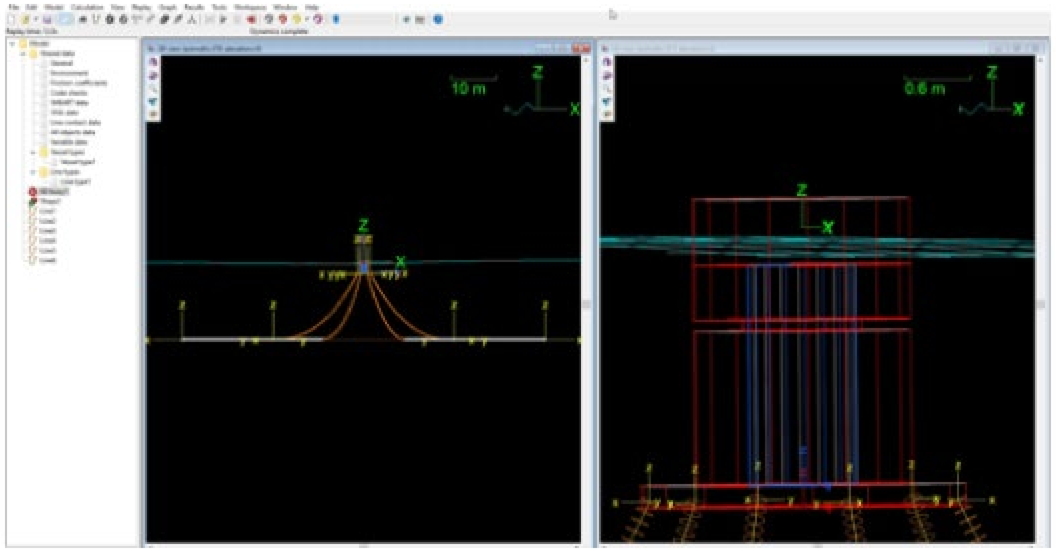
- 4 academics
- 3 RAs
- 4 PhD



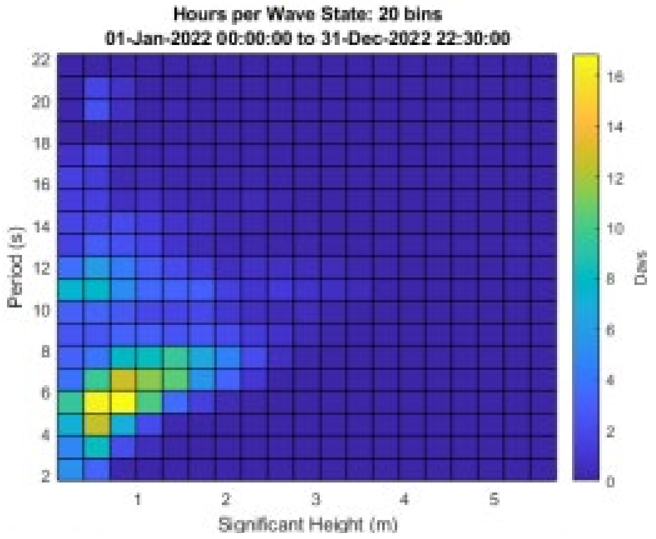


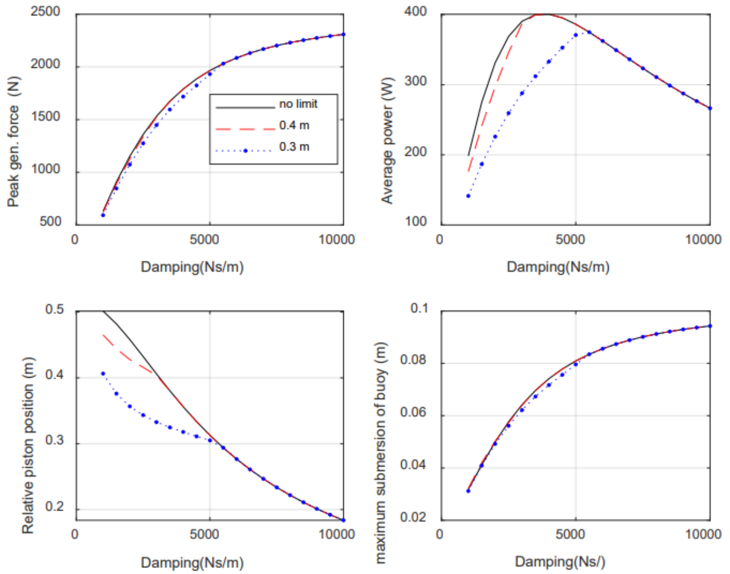


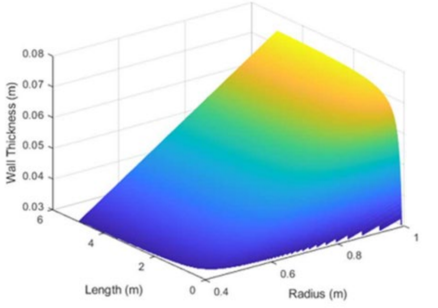




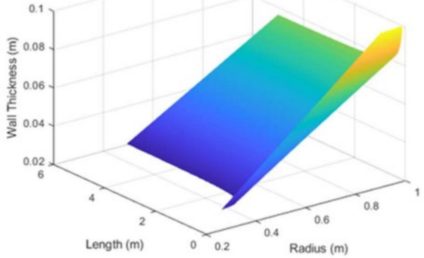
V. WAVE RESOURCE

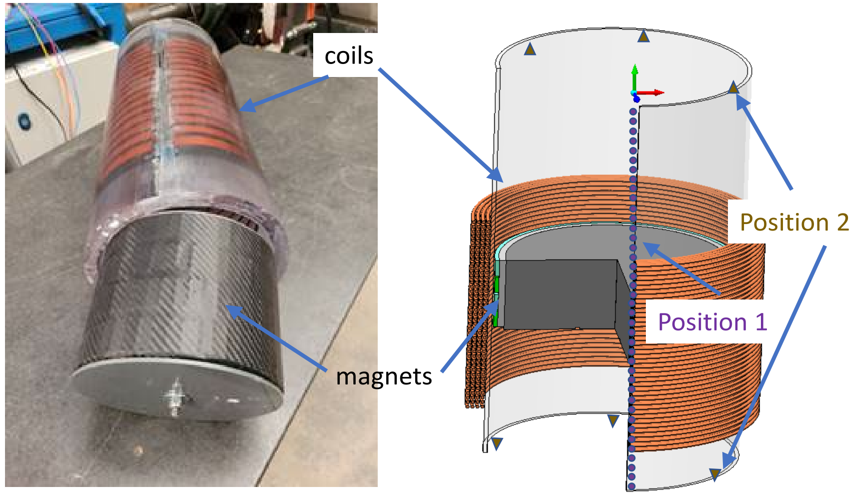


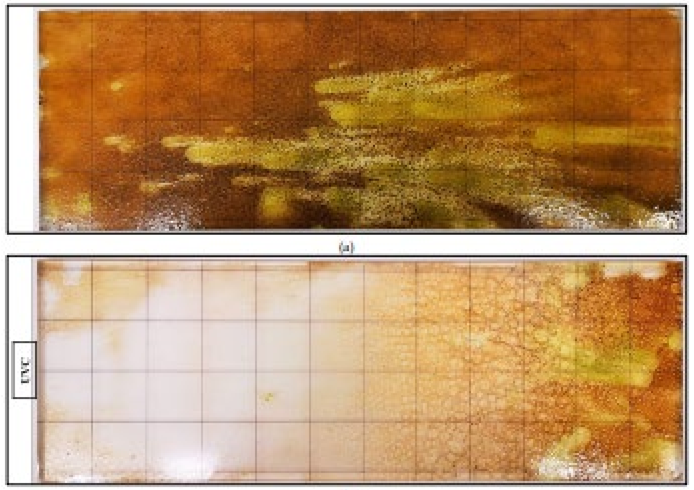


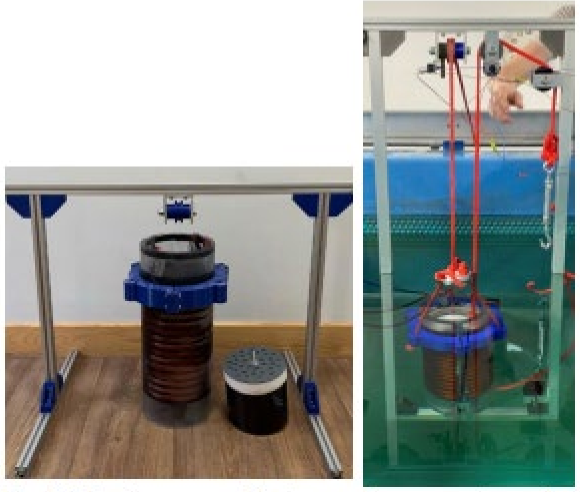


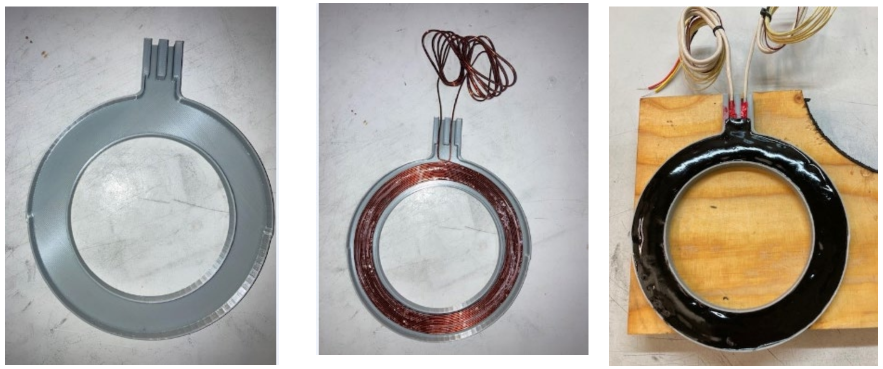
(a) No foam used

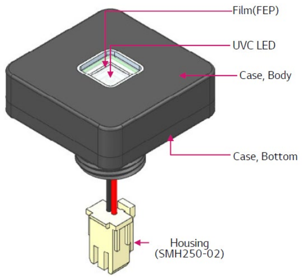












- System is sized and ‘concept’ designed
- Final design dictated by £

UK EPSRC NHP-WEC Research Project

Research progress on TALOS multi axis WEC

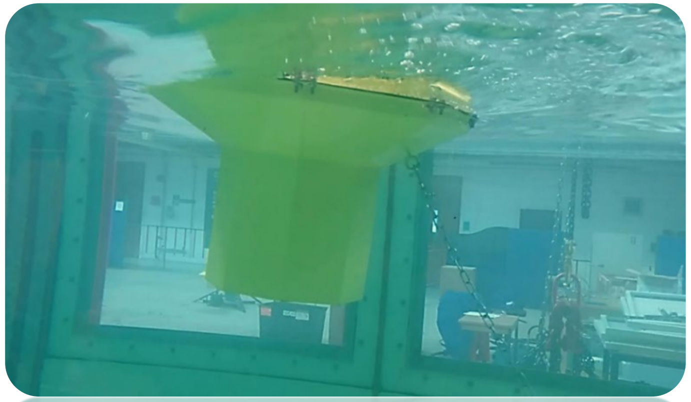
Lancaster University

UNIVERSITY OF HULL

Prof George Aggidis, Dr Wanan Sheng, Dr Xiandong Ma, Prof James Taylor, Dr Yueqi Wu

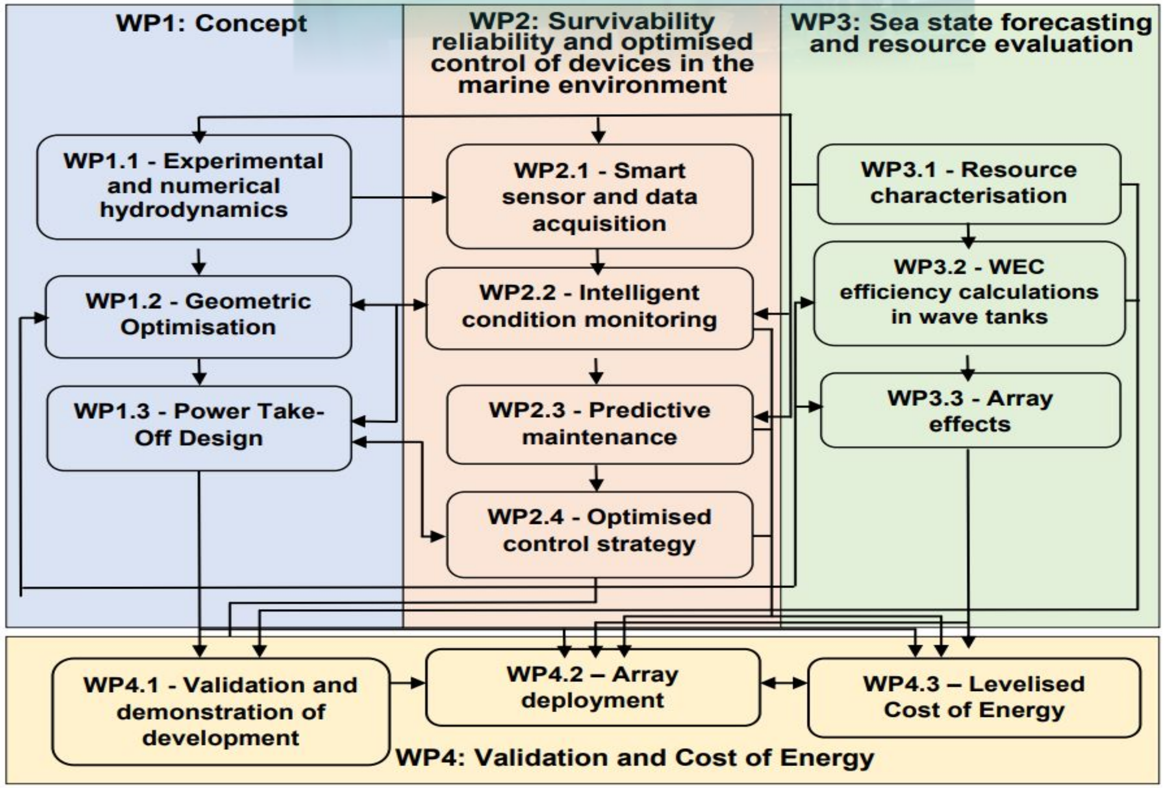
Prof Robert Dorrell, Prof Dan Parsons, Dr Igor Rizaev

TALOS Project Aim & Objectives



- The project aim: *Advance WEC technology by developing essential device control and monitoring systems that are integrated with high-fidelity sea state forecasting.*
- Objectives:

1. *Concept optimisation – Parameterize hydrodynamic behaviour due to the WEC geometry and PTO design to refine, optimise and maximise performance.*
2. *Operational systems – Investigate and implement sensors and actuators required to develop a condition monitoring system that will improve reliability and survivability, and control methods for the multi-axis PTO system advancing overall conversion efficiency.*
3. *Resource forecasting – Develop machine-learning based forecasting tools to provide both short-term accurate predictions for the operational systems and long-term energy yield predictions for the device across various deployment sites.*
4. *Device deployment potential – Develop a wave-to-wire model to determine the Levelised Cost of Energy (LCOE) at given sites, for both standalone devices and arrays, quantifying the TRL financial baseline performance essential to stimulate commercialisation.*
5. *Marine wave energy development – Develop industrial input and research impact objective, including dissemination and showcasing of all the outputs, to ensure that not only one technology develops but that the solutions proposed will benefit the wider energy community.*

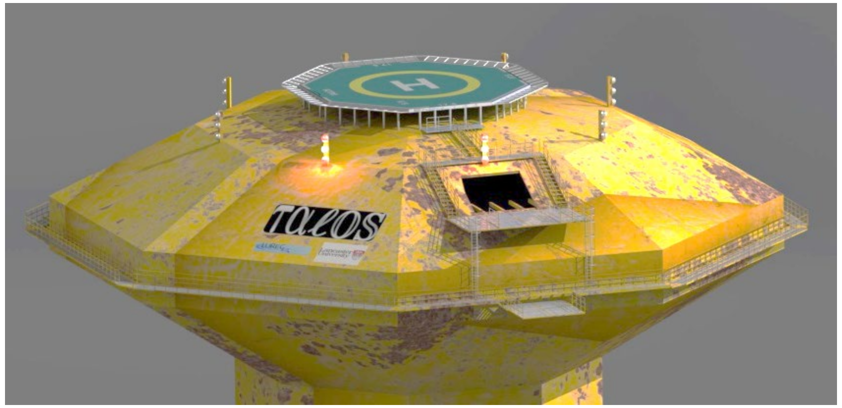


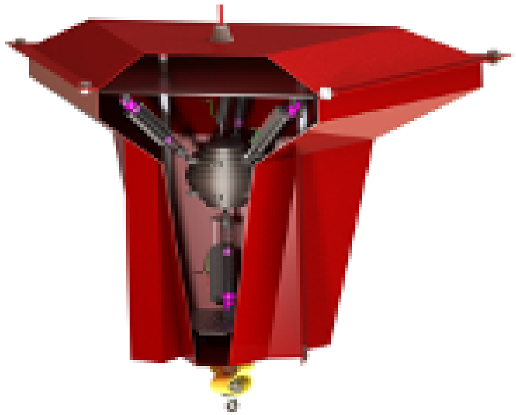
Lancaster University | University of Hull | SmartWave

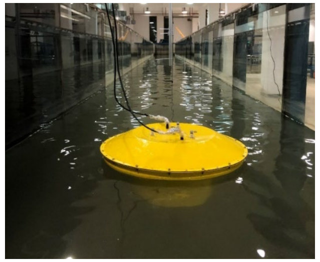
Chair of Advisory Board

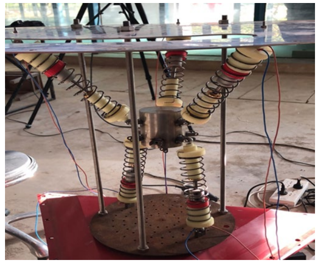
TALOS WEC

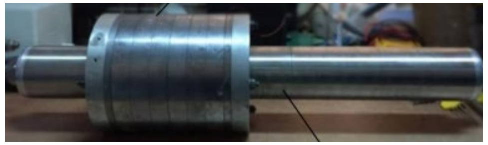
TALOS WEC – Multi Axis Point Absorber Style WEC completely enclosed with internal inertial mass using Hydraulic Cylinders or Linear Generators PTO











References

- Aggidis, G.A. and Taylor, C.J., 2017. Overview of wave energy converter devices and the development of a new multi-axis laboratory prototype. IFAC-PapersOnLine, 50(1), pp.15651-15656.
- Ayub, M.W., Hamza, A., Aggidis, G.A. and Ma, X., 2023. A Review of Power Co-Generation Technologies from Hybrid Offshore Wind and Wave Energy. Energies, 16(1), p.550.
- Darwish, A. and Aggidis, G.A., 2022. A Review on Power Electronic Topologies and Control for Wave Energy Converters. Energies, 15(23), p.9174.
- Sheng, W., Tapoglou, E., Ma, X., Taylor, C.J., Dorrell, R.M., Parsons, D.R. and Aggidis, G., 2022. Hydrodynamic studies of floating structures: Comparison of wave-structure interaction modelling. Ocean Engineering, 249, p.110878.
- Sheng, W. and Aggidis, G., 2022.Environmental Fundamentals of Wave Energy Conversions: The Dynamics of the Wave-Structure Interactions and Wave Energy Optimisation, Eliva Press.
- Sheng, W., Tapoglou, E., Ma, X., Taylor, C.J., Dorrell, R., Parsons, D.R. and Aggidis, G., 2022. Time-Domain Implementation and Analyses of Multi-Motion Modes of Floating Structures. Journal of Marine Science and Engineering, 10(5), p.662.
- Zhang, H., Sheng, W., Zha, Z. and Aggidis, G., 2022. A Preliminary Study on Identifying Biomimetic Entities for Generating Novel Wave Energy Converters. Energies, 15(7), p.2485.
- Guo, C., Sheng, W., De Silva, D.G. and Aggidis, G., 2023. A review of the levelized cost of wave energy based on a techno-economic model. Energies, 16(5), p.2144.

ISOPE 2023 - Canada

- Renewable Energy and Environment Symposium of ISOPE 2023 Ottawa, Canada, June 19–23, 2023, included:
    - **1** invited Speech: “Research progress on TALOS multi axis WEC”
    - **2** specific focus sessions with the title: TALOS 1 and TALOS 2
    - **12** TALOS related papers: From USA, China, Greece Turkey and UK
    - **1** TALOS Workshop

EWTEC 2023 - Spain

- The 15th European Wave and Tidal Energy Conference, EWTEC2023, 3rd – 7th September 2023, Bilbao, Spain

3 TALOS related paper submissions:

1) 1 from USA & UK Collaboration on Computational Modelling WEC Sim - (WP1)

2) 1 from UK & Greece Collaboration on Computational Modelling DNV SESAM - (WP1)

3) 1 from USA & UK Collaboration on TALOS Control - (WP2)

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

THANK YOU

Professor George AGGIDIS – g.aggidis@lancaster.ac.uk

HAPiWEC

Holistic Advanced Prototyping and Interfacing for Wave Energy Control

HAPiWEC MULTI-USER REMOTELY ACCESSIBLE PROOF OF CONCEPT DEMONSTRATOR

Holistic Advanced Prototyping and Interfacing for Wave Energy Control

UKRI Engineering and Physical Sciences Research Council

University of Strathclyde Engineering

THE UNIVERSITY of EDINBURGH

RENEWABLE DYNAMICS

NREL Transforming ENERGY

wave energy SCOTLAND

WEAMEC MARINE ENERGY

UK Research and Innovation

HAPiWEC

THE UNIVERSITY of EDINBURGH

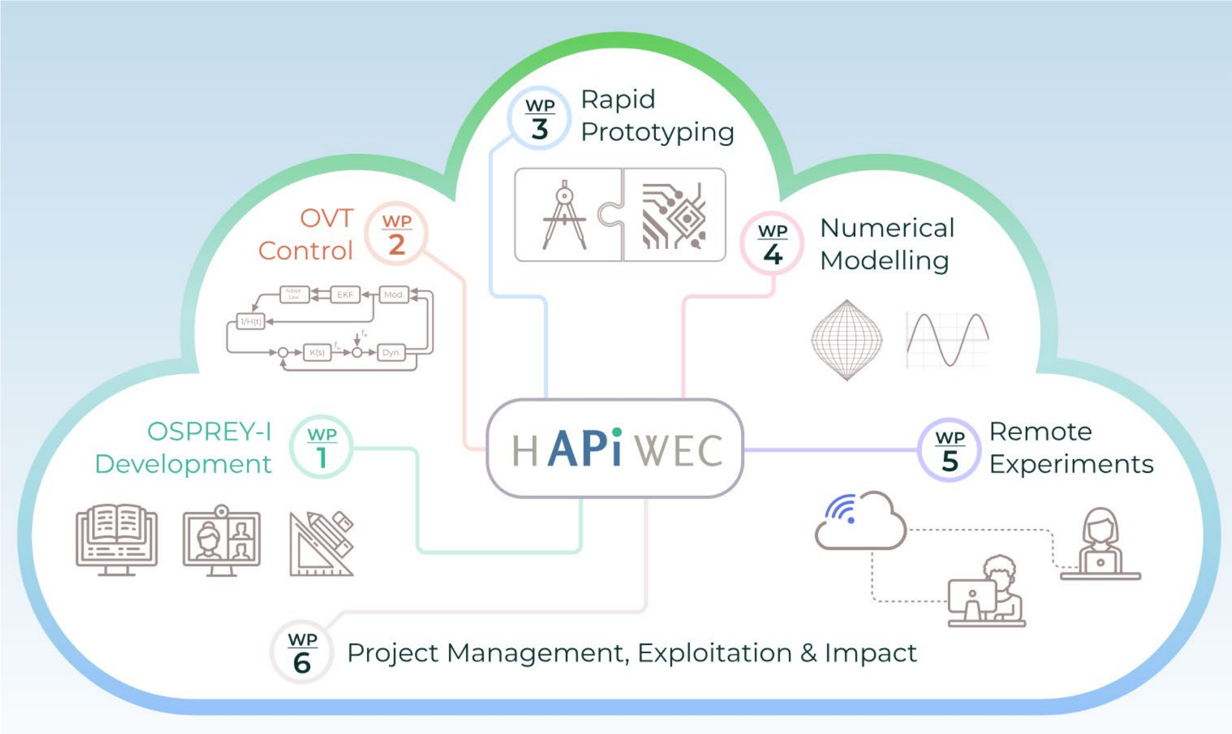
University of Strathclyde Engineering

Holistic Advanced Prototyping and Interfacing for Wave Energy Control

HAPiWEC MULTI-USER REMOTELY ACCESSIBLE PROOF OF CONCEPT DEMONSTRATOR

Holistic Advanced Prototyping and Interfacing for Wave Energy Control

"This project proposes that through the implementation of **rapid prototyping hardware** and **remotely accessible user control**, novel control algorithms can be demonstrated and validated at unprecedented levels of efficiency"



WP1	WP2	WP3	WP4	WP5	WP6
A WEC Test-Rig	OVT Control for WECs	Rapid Prototyping for WEC control	Numerical Modelling	Physical Testing	Management, and Outreach

UK Research and Innovation

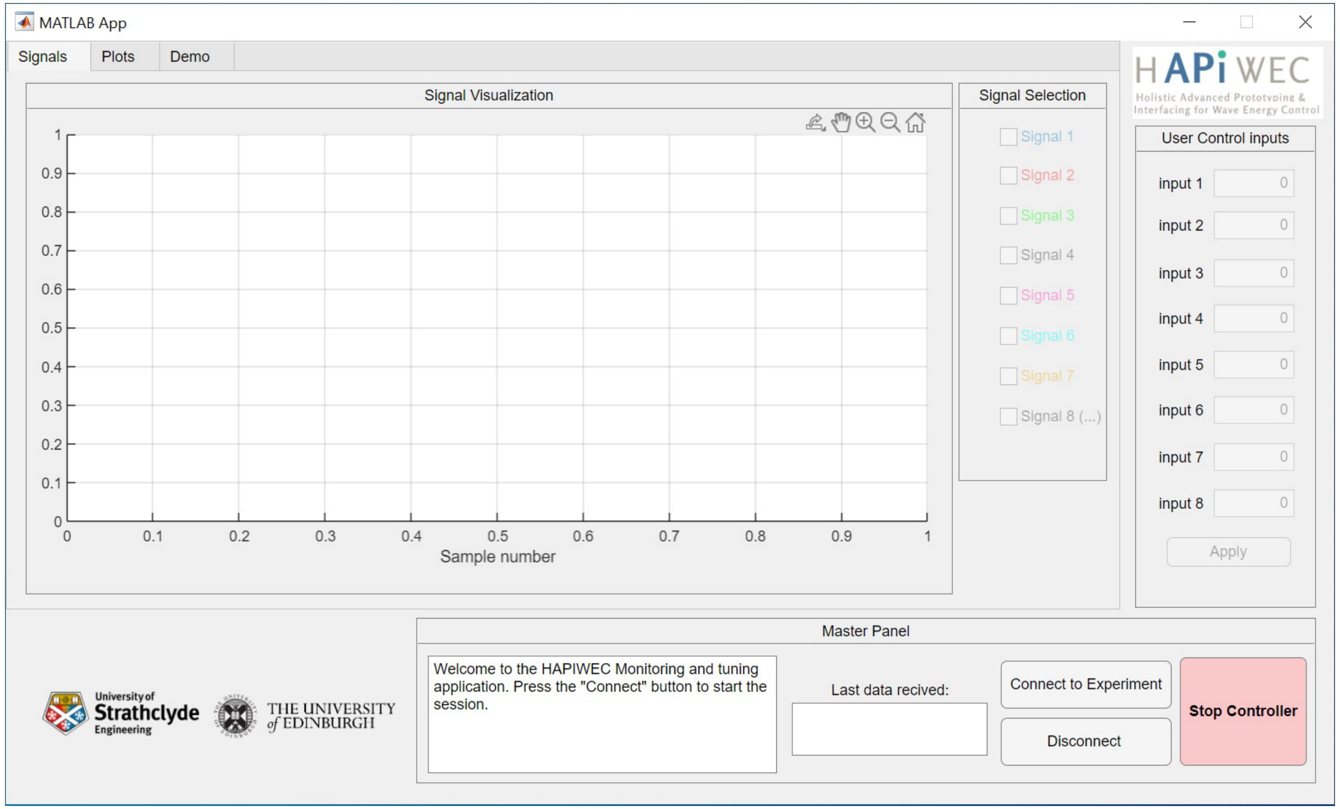
HAPiWEC

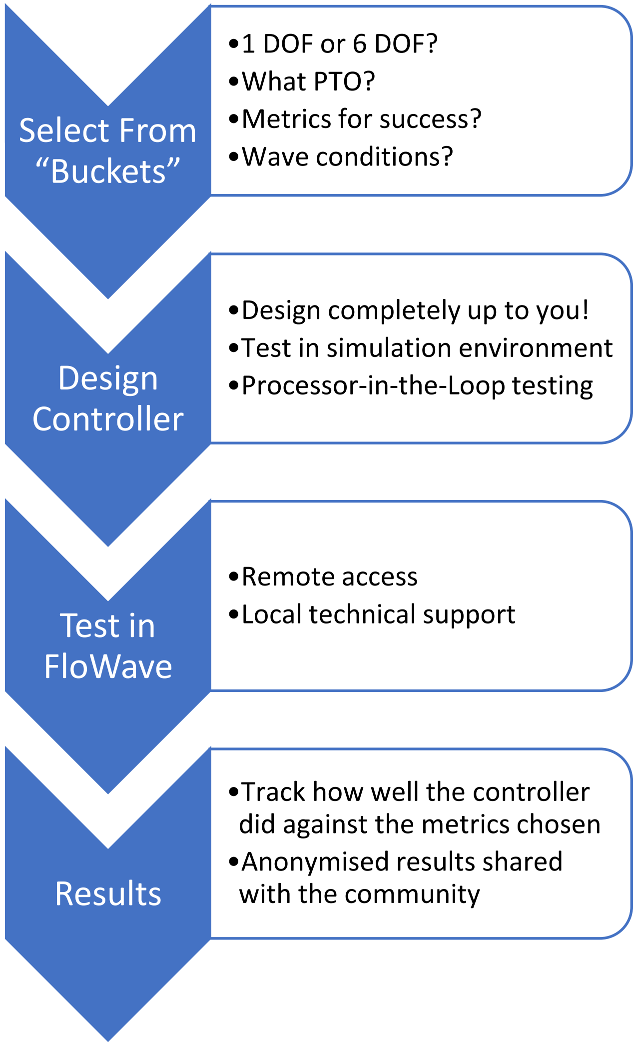
THE UNIVERSITY of EDINBURGH

University of Strathclyde Engineering

Environment for rapid testing of control: HAPiGYM

- Not a competition
- Variable and customisable complexity
- Remotely accessible





UK Research and Innovation

HAPiWEC

THE UNIVERSITY of EDINBURGH

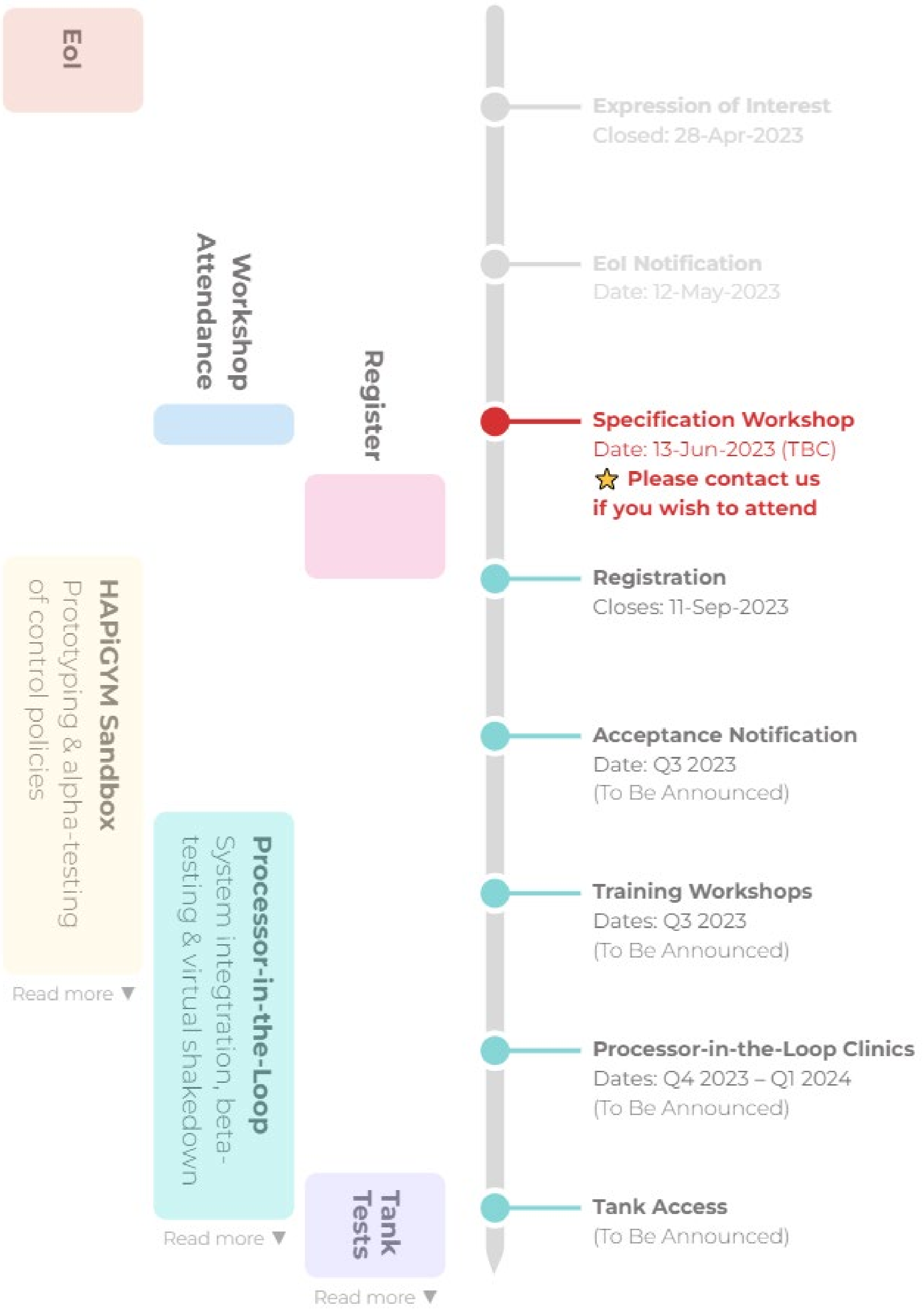
University of Strathclyde Engineering

HAPiWEC MULTI-USER REMOTELY ACCESSIBLE PROOF OF CONCEPT DEMONSTRATOR

Holistic Advanced Prototyping & Interfacing for Wave Energy Control

HAPiWEC Homepage

www.hapiwec.net



System-level Co-design and Control of Large Capacity Wave Energy Converters with Multiple PTOs

Guang Li

The University of Manchester

12/July/2023

To be presented at Supergen ORE Hub Autumn Assembly

Outline of the project

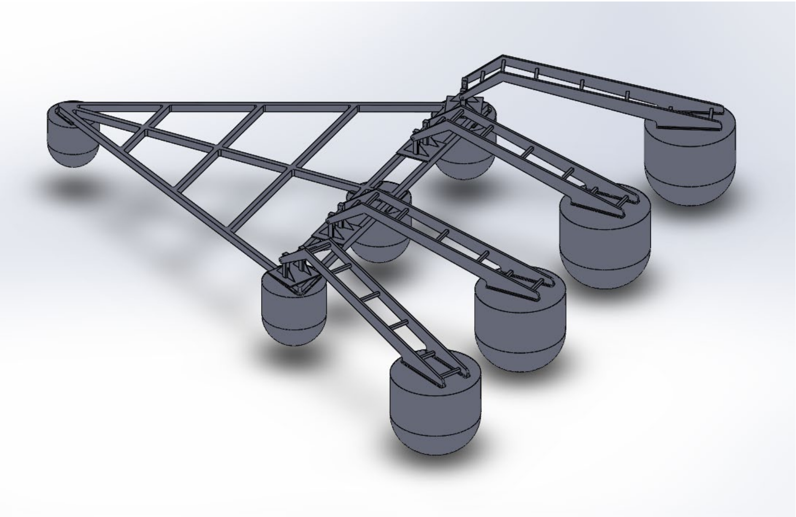


Fig. 1: M4 with 3 PTOs

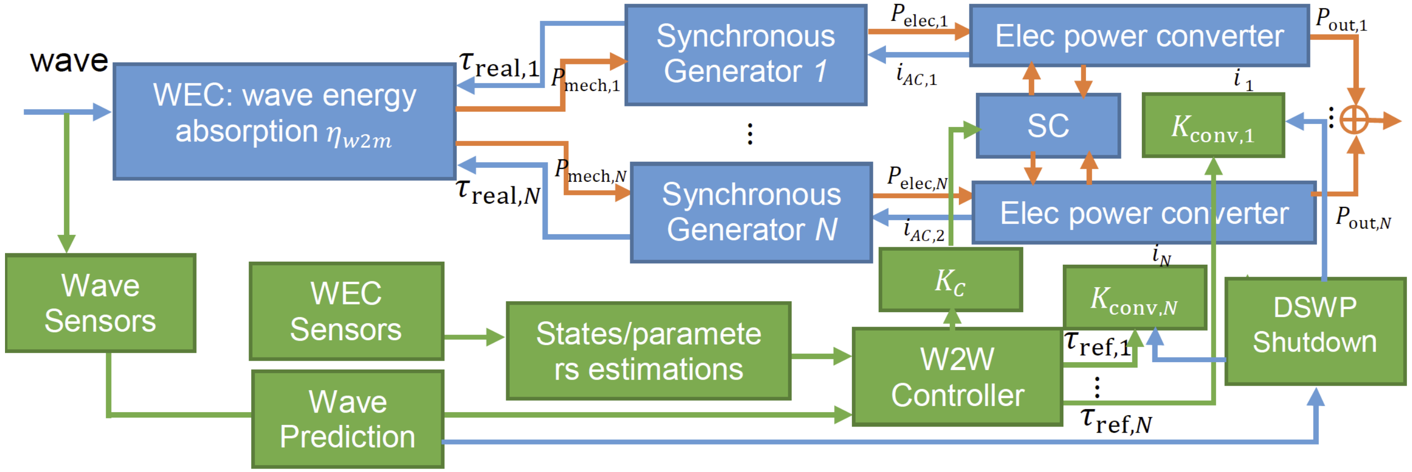


Fig. 2: Control system block diagram

- WP1: Modelling for all the subsystems: wave-to-wire model.
- WP2: Multi-directional wave prediction and shutdown.
- WP3: Control framework based on the wave-to-wire model.
- WP4: Co-design of the whole system.
- WP5: HIL for validation of control and co-design.

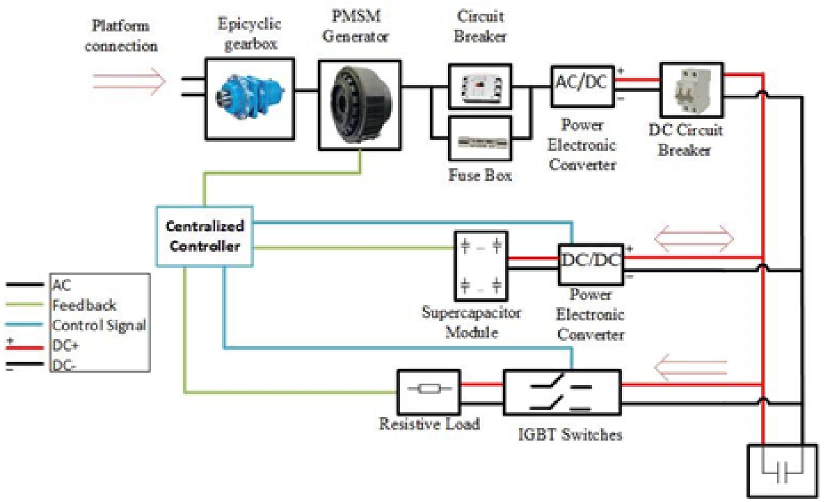


Fig. 3: Electric system overview of one channel of the M4 PTO: Gear box, generator, supercapacitor, electronic converters.

Progress

- Modelling of all sub-systems (hydrodynamic, electrical) are finished.
- Control-oriented wave-to-wire model of the multi-PTO WEC is built and validated.
- Fast Wave Profile Estimation created for Multi-directional Deterministic Sea Wave Prediction (DSWP).
- A hierarchical switching control framework is developed for the M4 W2W system:
  - High level: Model predictive control for power maximisation and peak power limiting
  - Local level: Field oriented PI control for constraints handling
- The HIL test rig has been constructed and used for control validations.
- Our next steps: 1) co-design of the W2W system; 2) power conditioning.

Workpackages		Year 1				Year 2				Year 3			
	Lead	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
WP1.1 Wave-to-wire modelling and virtual tank	UoM												
WP1.2. Control-oriented W2W model	QMUL												
WP2.1. Multi-DSWP integration into control.	UoE												
WP2.2. Multi-DSWP shutdown and integration into control	UoE												
WP3. W2W control framework development	QMUL												
WP4. Co-design of the WEC system.	QMUL												
WP5.1. W2W test rig design and construction	UoM												
WP5.2. Dry testing on W2W test rig	UoM												
WP6. Evaluation and exploration of the proposed techniques	QMUL												

Wave-to-wire modelling

- Dynamics in different domains and coupling:
  - Hydrodynamic
  - Mechanical
  - Electric
- Different operation stages
  - normal (no saturation)
  - torque/current limiting (gearbox protection)
  - speed/voltage limiting (inverter protection)
  - power shedding (extreme wave conditions)
- Main challenge for control
  - Effectively handle peak power

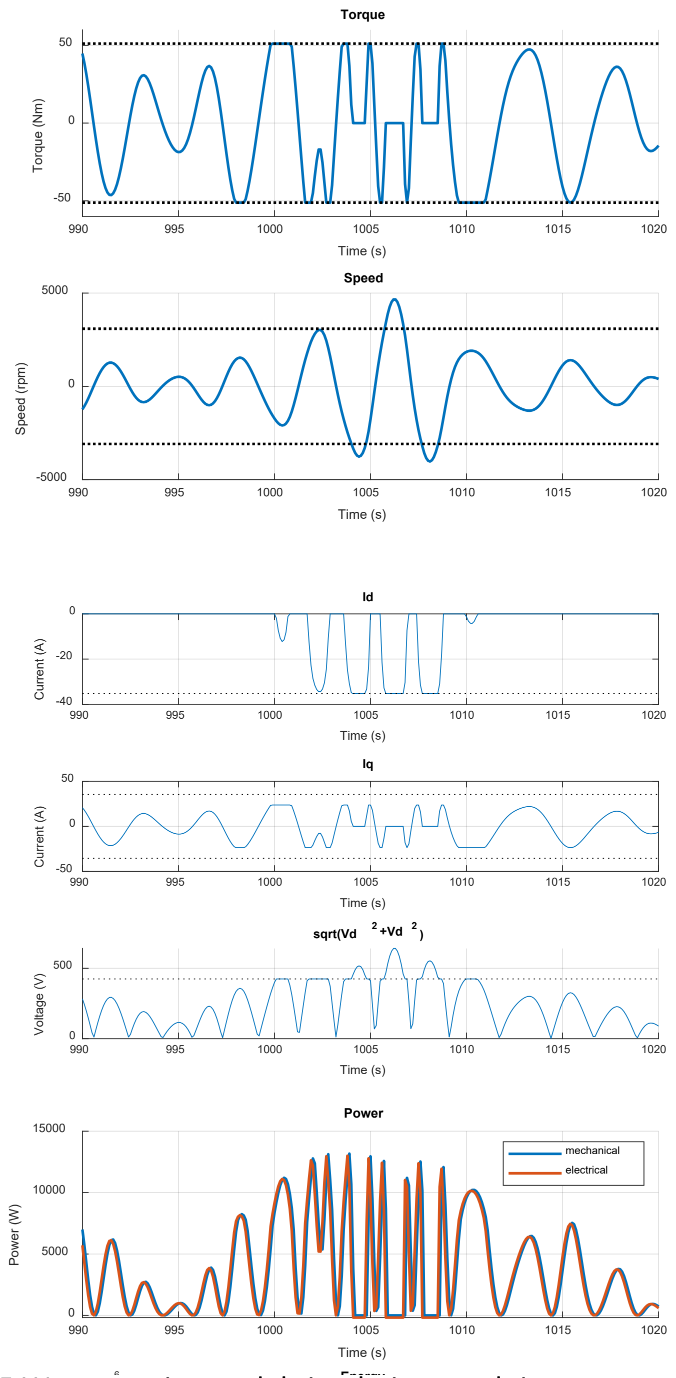


Fig. 5 Wave-to-wire model simulation result in extreme sea condition.

System Level Control Design

- Multi-layer control scheme
  - Local level: (field-oriented, PI)
    - Torque reference tracking & Constraints handling
  - High level: (Model predictive control & switching)
    - Energy maximising / Speed limiting

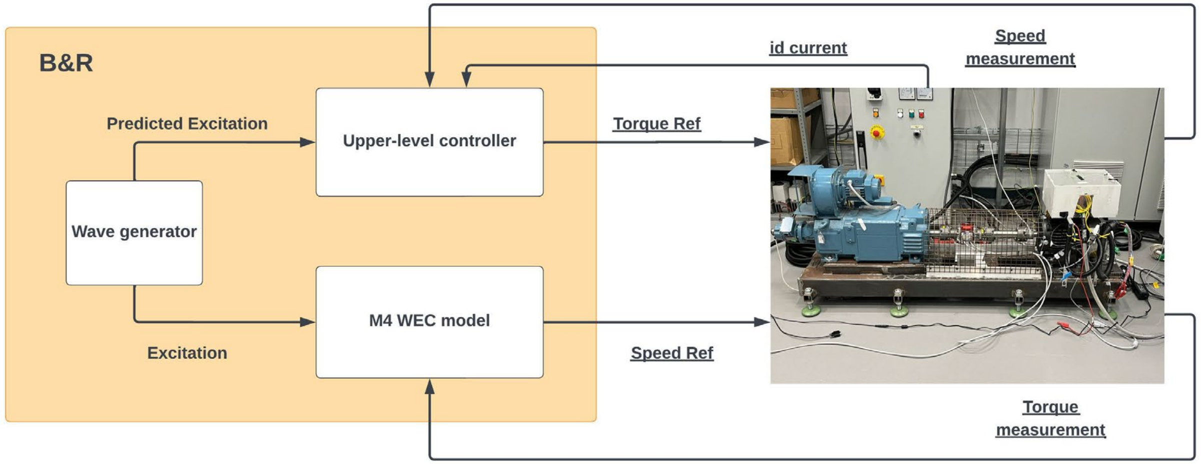


Fig. 6 Hardware-in-the-Loop test rig for control validation.

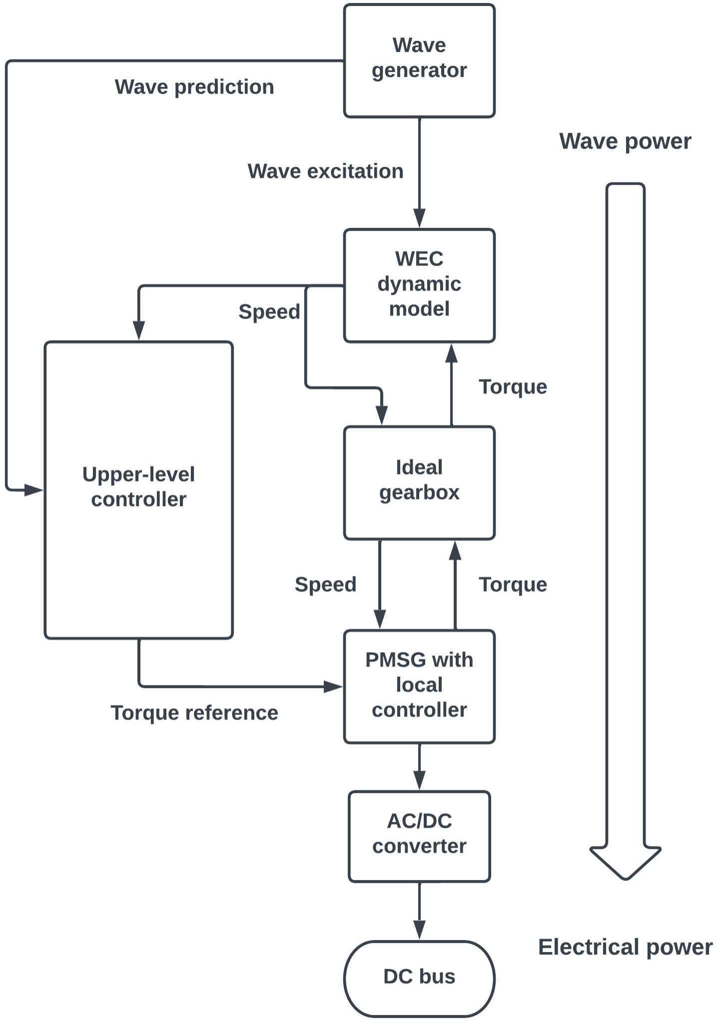


Fig. 7 System level control block diagram.

Experimental results

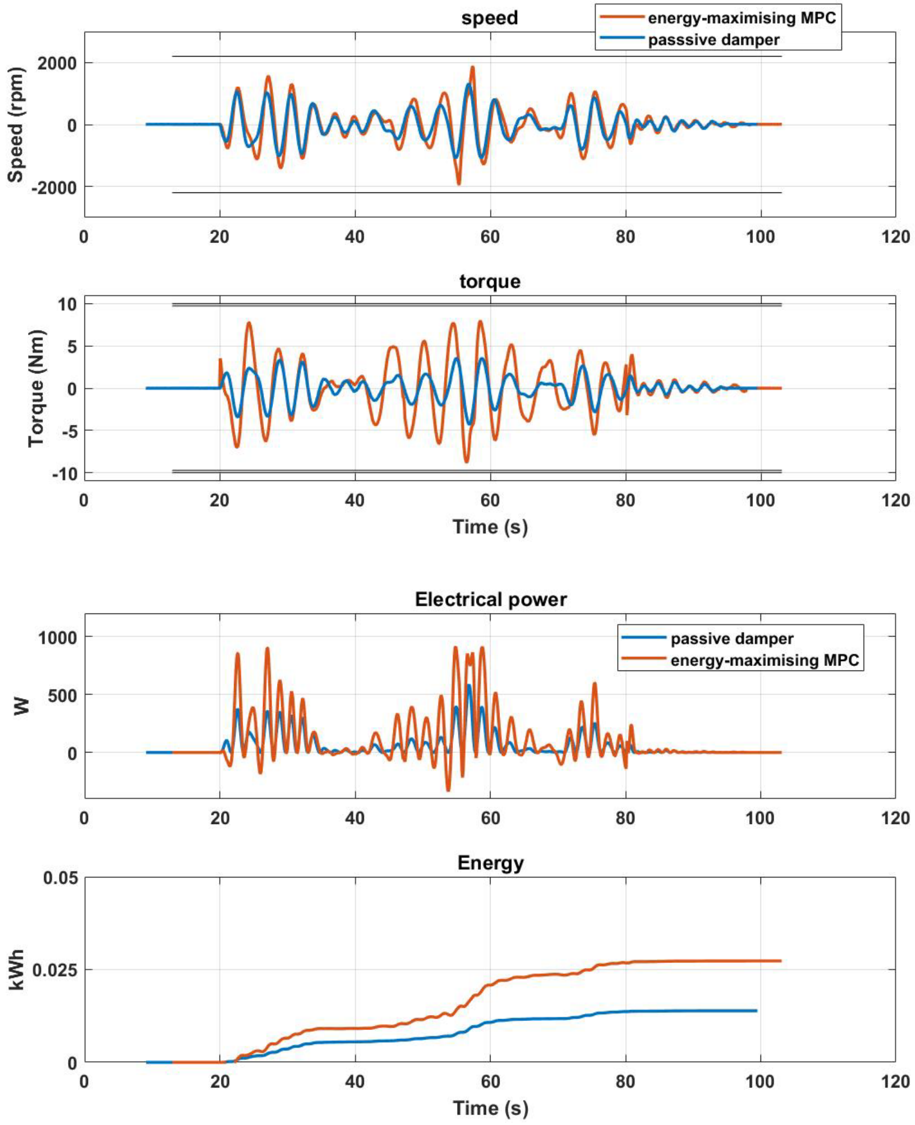


Fig. 8 MPC maximizes energy generation in **moderate sea state**.

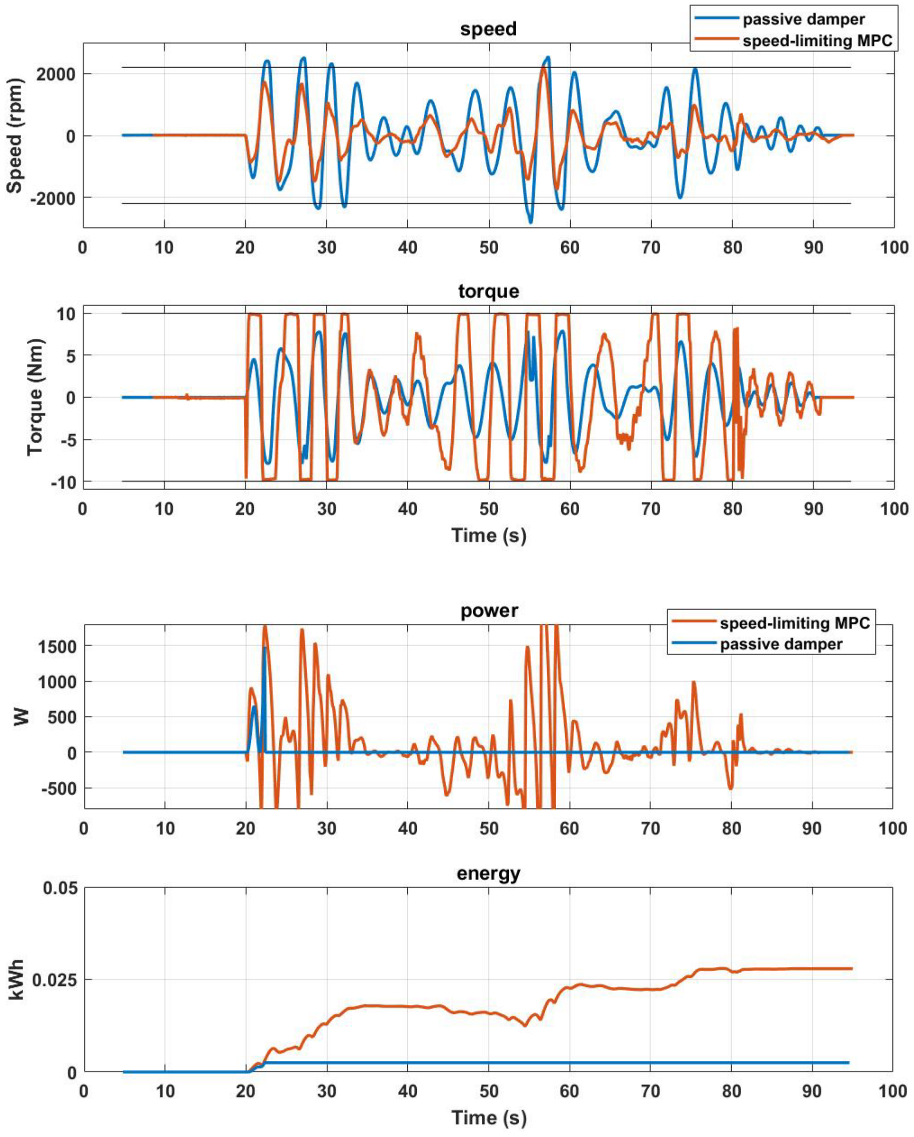


Fig. 9 MPC limits speed of generator for longer generation time in **extreme sea state**.

Planned sea trial in Albany, Australia

- 20 m long (1/4 scale), kW, datasets will be available in public domain

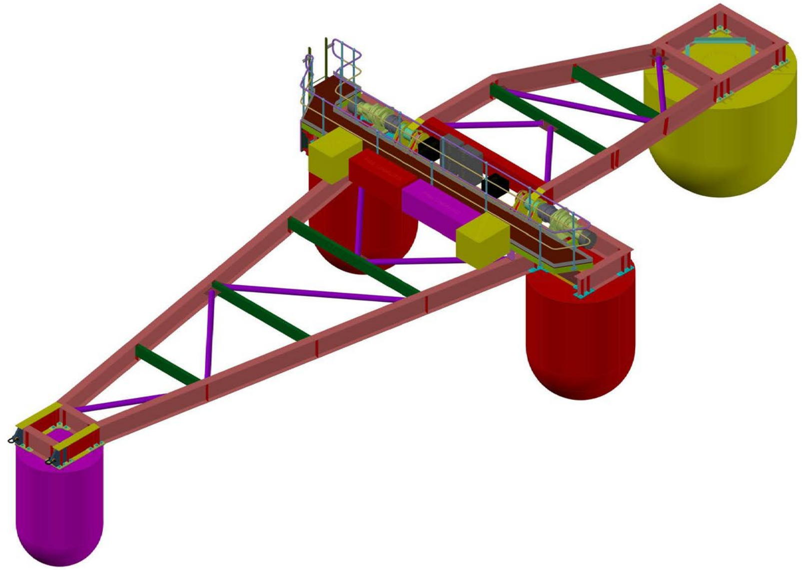


Fig. 10 CAD image of the 121 M4 wave energy platform from BMT Ltd.

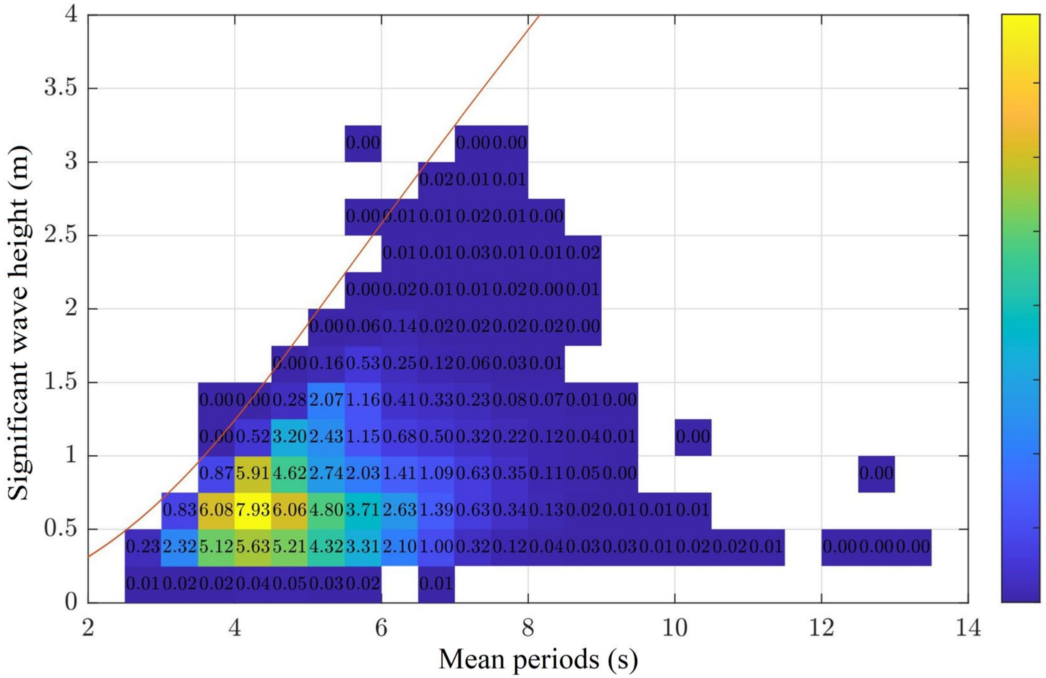


Fig. 11 Scatter diagram showing occurrence of significant wave height and mean period combinations for summer wave conditions at the test site.

Thank you!

EPSRC Engineering and Physical Sciences Research Council

University of Strathclyde Glasgow

EPSRC Marine Wave Energy Programme

Bionic Adaptive Stretchable Materials for WEC (BASM-WEC), EP/V040553/1

Qing Xiao, Sandy Day, Feargal Brennan, Saeid Lotfian, Saishuai Dai

Department of Naval Architecture, Ocean and Marine Engineering

Liu Yang

Department of Mechanical and Aerospace Engineering

Iain Bomphray

Lightweight Manufacturing Centre

Researchers: Guillermo Idarraga Alarcon, Farhad Abad & Yang Huang

University of Strathclyde, UK

NSRI National Subsea Research Initiative

WaveVenture

CATAPULT Offshore Renewable Energy

SBM OFFSHORE

国家海洋技术中心 NATIONAL OCEAN TECHNOLOGY CENTER

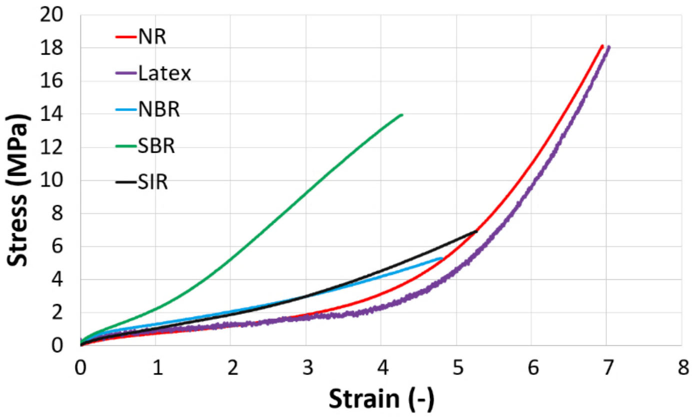
UKRI Engineering and Physical Sciences Research Council

BASM-WEC project update (1-10 months)

- The main ***aim*** of the project: to develop an analysis and laboratory testing integrity toolbox to reliably design, analyse, and process the state-of-the-art adaptive stretchable materials and structures applicable to WECs.

Material characterization

Various material tests

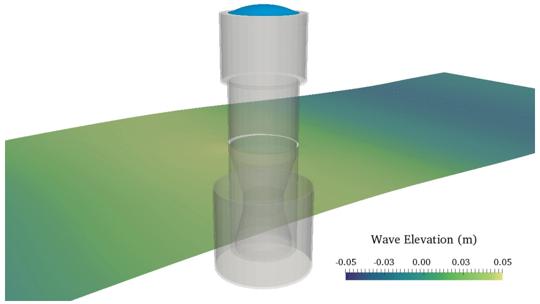


Stress-strain curves of different materials

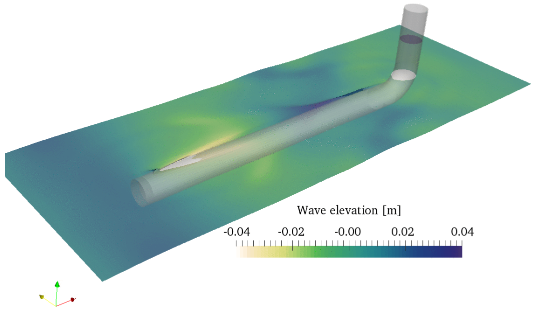
Wave tank tests

Flexible OWC test

CFD-FEA numerical analysis



Poly-A-OWC WEC modelling



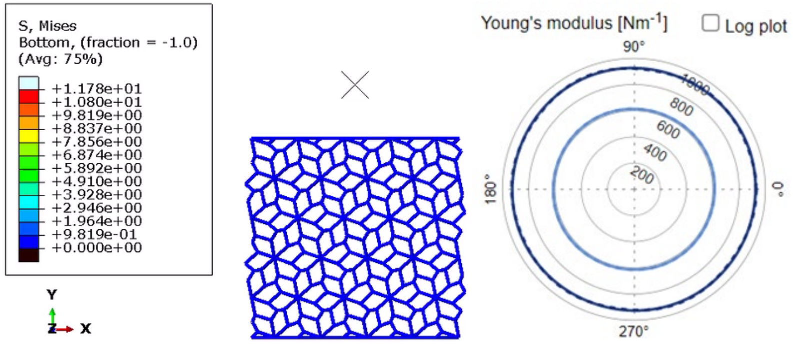
Anaconda WEC modelling

BASM-WEC project update (10-18 months)

University of Strathclyde Glasgow

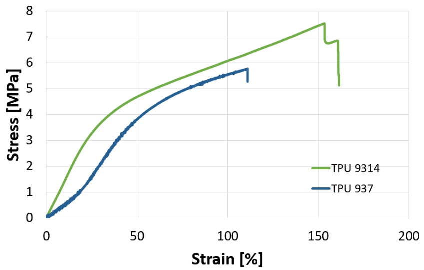
❖ Material development

- ✓ Structured membrane
- ✓ Isotropic pattern
- ✓ Material characterization



Isotropic pattern and planar test

Structured membrane sample



Stress-strain curve

❖ Dry test

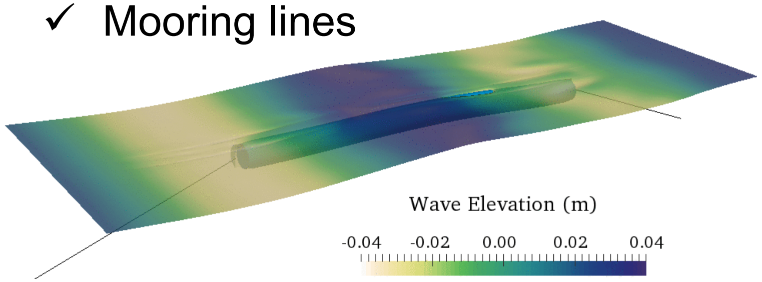
- ✓ Dry test rig provides harmonic pressure
- ✓ Bulge test - to conduct inverse material characterisation for flexible materials, provide more accurate hyperelastic model parameters for the numerical simulation

Dry test rig

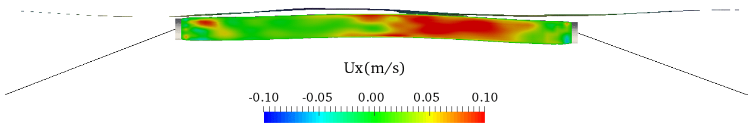
Bulge test for new material

❖ CFD-FEA numerical analysis

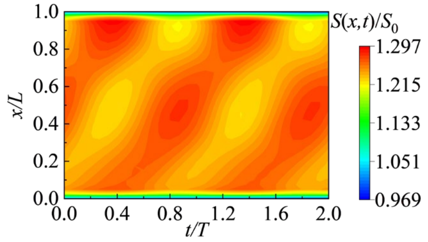
- ✓ CFD-FEA analysis tool
- ✓ 6DoF motions
- ✓ Mooring lines



Wave structure interaction: outer flow



Velocity field inside tube indicates highly non-uniform characteristics



Time and spatial distribution of cross-sectional area demonstrates the existence of standing wave

Conference and Journal Publications

➢ Published or under review

- ✓ Abad Farhad, Lotfian Saeid, Dai Saishuai, Zhao Guangwei, Idarraga Guillermo, Yang Liu, Huang Yang, Xiao Qing, Brennan Feargal, 'Experimental study on inflatable circular diaphragms used in the oscillating water column wave energy converter', Proceedings of the 9th International Conference on Marine Structures (MARSTRUCT 2023), Gothenburg, Sweden, April 3-5, 2023 (Published).
- ✓ Idarraga Guillermo, Yang Liu, Abad Farhad, Huang Yang, Dai Saishuai, Xiao Qing, Lotfian Saeid, Brennan Feargal, 'Hyperelastic Modelling of Elastomers for Wave Energy Convertors', In proceedings of the 42nd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2023-100523, Melbourne, Australia, June 11-16, 2023 (Published).
- ✓ Huang Yang, Xiao Qing, Idarraga Guillermo, Yang Liu, Dai Saishuai, Abad Farhad, Brennan Feargal, Lotfian Saeid, 'Numerical analysis of flexible tube wave energy convertor using CFD-FEA method', In proceedings of the 42nd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2023-101302, Melbourne, Australia, June 11-16, 2023 (Published).
- ✓ Huang Yang, Xiao Qing, Idarraga Guillermo, Yang Liu, Dai Saishuai, Abad Farhad, Brennan Feargal, Lotfian Saeid, 'A CFD-FEM analysis for Anaconda WEC with mooring lines', Proceedings of the 15th European Wave and Tidal Energy Energy Conference (EWETC 2023), Bilbao, Spain, September 3-7, 2023. (Accept, paper ID: 163).
- ✓ Huang Yang, Xiao Qing, Idarraga Guillermo, Yang Liu, Dai Saishuai, Abad Farhad, Brennan Feargal, Lotfian Saeid, 'Novel CFD-FEA solution for the study of flexible material wave energy converters', Physics of Fluids, (Second review, paper ID: POF23-AR-MRNE2023-03769).

➢ Coming journal papers

- ✓ Abad Farhad, Inverse material characterization of elastomers using bulge test.
- ✓ Idarraga Guillermo, Selection, characterisation and modelling of elastomers for wave energy convertors.
- ✓ Idarraga Guillermo, New passive/active stiffness elastomeric structured membranes for WECs devices.
- ✓ Yang Huang, CFD study on two typical flexible tube WECs.

Near future work

- **Material development**
  - ✓ Characterization on hyper-elastic properties of structured membranes
  - ✓ Investigate the influence of structural patterns on flexible materials
- **Wave tank test**
  - ✓ Flexible tube WEC test in wave tank
  - ✓ Scaling test of flexible WEC
- **Numerical analysis**
  - ✓ Consider impact of electric field in FSI simulation
  - ✓ Add PTO module and directly output generated power

Thank You !

Website:
https://basm-wec.org/