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Lancaster University Renewable Energy Group

EPSRC NHP-WEC
TALOS WEC Research Project

Lancaster University

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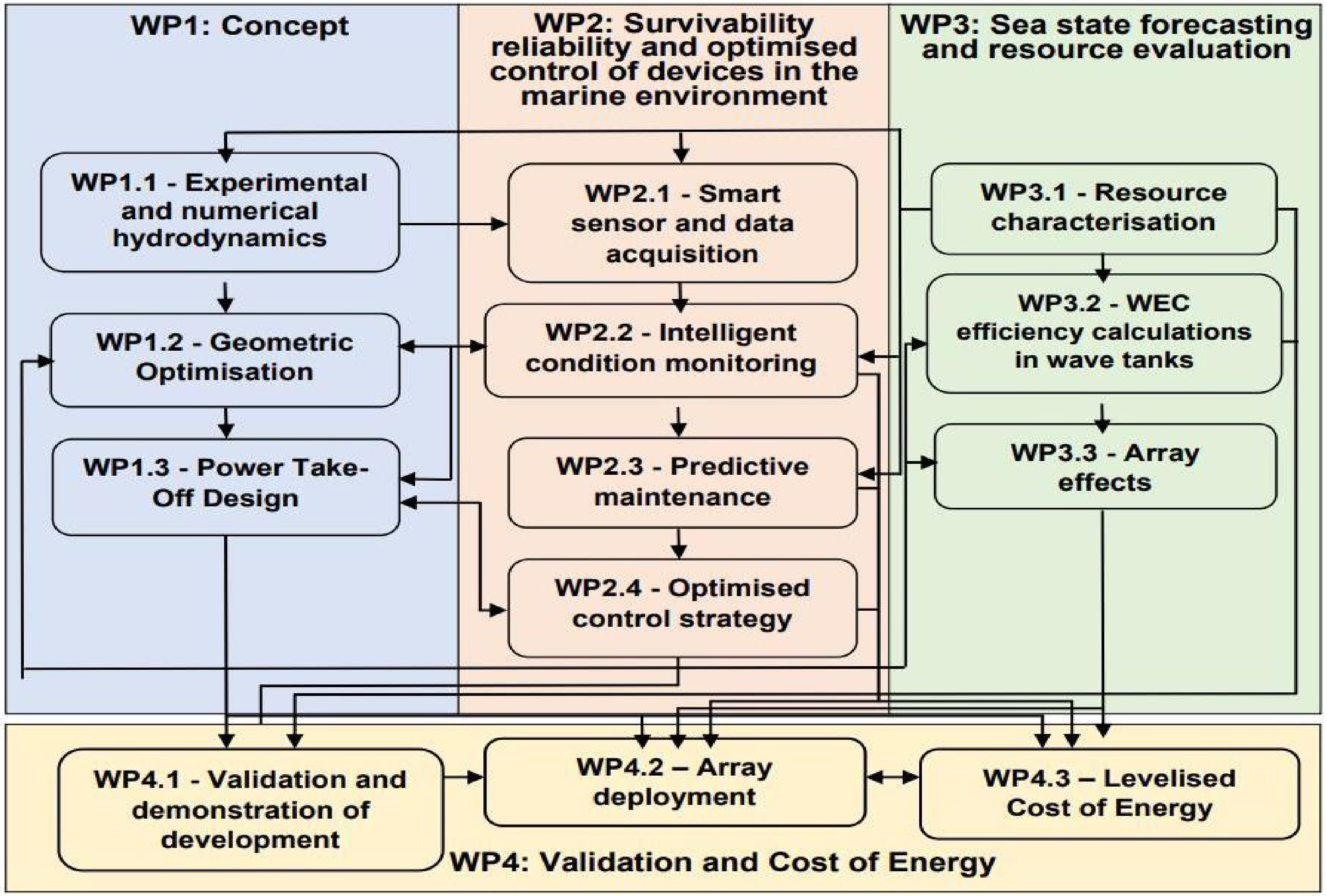
Project Team & WP Structure

Lancaster University

- P-I - Professor George AGGIDIS
- Co-I - Dr Xiandong MA
- Co-I - Professor C. James TAYLOR
- PDRA1 - SRA - Dr Wanan SHENG
- PDRA2 – RA – Dr Yueqi WU

University of Hull

- Co-I - Dr Robert DORRELL
- Co-I - Professor Daniel PARSONS
- PDRA3–SRA – Dr Igor RIZAEV



WP1 - Publications: paper 1 & paper 2

Paper 1 (open access):

'Hydrodynamic studies of floating structures: Comparison of wave-structure interaction modelling', *Ocean Engineering*, Vol. 249, 110878

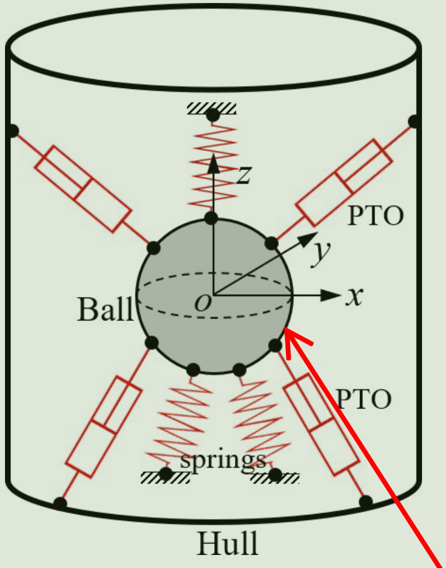
Paper 2 (open access):

- **'Time-Domain Implementation and Analyses of Multi-Motion Modes of Floating Structures'**, Journal of ***Marine Science and Engineering***, Vol. 10, 662. https://doi.org/10.3390/jmse10050662

WP1 - Implementation & Comparison of TALOS WEC

Equations for hull motion

$$
\begin{cases}
(m_s + A_{11})\ddot{x}_{s1}(t) + \sum_{j=1}^{6}\int_0^t K_{1j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s1}x_{s1}(t) = F_1^{exc}(t) - F_{pto1}(t) - F_{spr1}(t) \\
(m_s + A_{22})\ddot{x}_{s2}(t) + \sum_{j=1}^{6}\int_0^t K_{2j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s2}x_{s2}(t) = F_2^{exc}(t) - F_{pto2}(t) - F_{spr2}(t) \\
(m_s + A_{33})\ddot{x}_{s3}(t) + \sum_{j=1}^{6}\int_0^t K_{3j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s3}x_{s3}(t) = F_3^{exc}(t) - F_{pto3}(t) - F_{spr3}(t) \\
(I_{s44} + A_{44})\ddot{x}_{s4}(t) + \sum_{j=1}^{6}\int_0^t K_{4j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s4}x_{s4}(t) = F_4^{exc}(t) - M_{pto1}(t) - M_{spr1}(t) \\
(I_{s55} + A_{55})\ddot{x}_{s5}(t) + \sum_{j=1}^{6}\int_0^t K_{5j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s5}x_{s5}(t) = F_5^{exc}(t) - M_{pto2}(t) - M_{spr2}(t) \\
(I_{s66} + A_{66})\ddot{x}_{s6}(t) + \sum_{j=1}^{6}\int_0^t K_{6j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s6}x_{s6}(t) = F_6^{exc}(t) - M_{pto3}(t) - M_{spr3}(t)
\end{cases}
$$

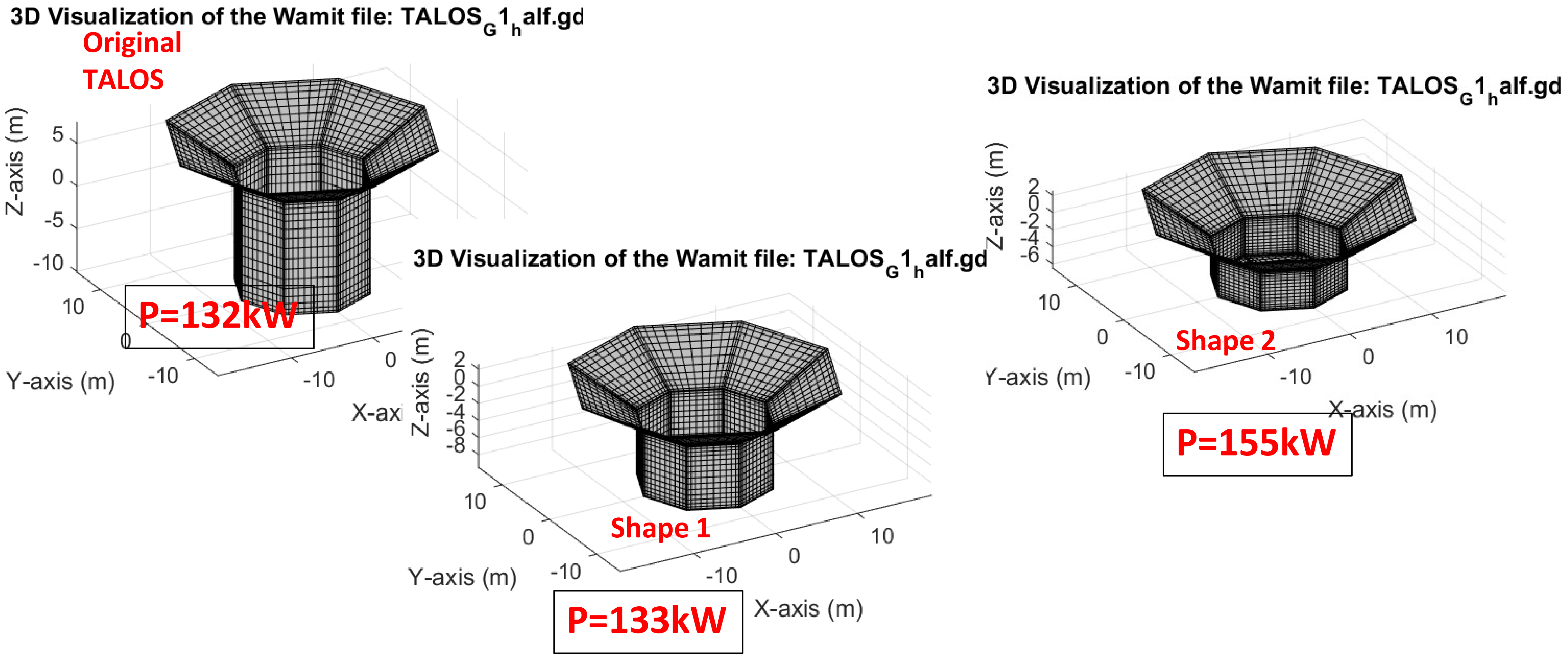


2-body system:
Hull + Ball

$$
\begin{cases}
m_b\ddot{x}_{b1}(t) = F_{pto1}(t) + F_{spr1}(t) \\
m_b\ddot{x}_{b2}(t) = F_{pto2}(t) + F_{spr2}(t) \\
m_b\ddot{x}_{b3}(t) = F_{pto3}(t) + F_{spr3}(t) \\
I_{bxx}\ddot{x}_{b4}(t) = M_{pto1}(t) + M_{spr1}(t) \\
I_{byy}\ddot{x}_{b5}(t) = M_{pto2}(t) + M_{spr2}(t) \\
I_{bzz}\ddot{x}_{b6}(t) = M_{pto3}(t) + M_{spr3}(t)
\end{cases}
$$

Equations for ball motion

WP1 - Initial Optimisation of TALOS WEC



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WP1 - International collaborations

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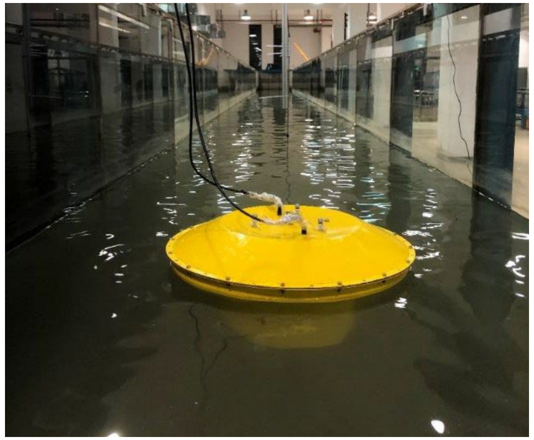
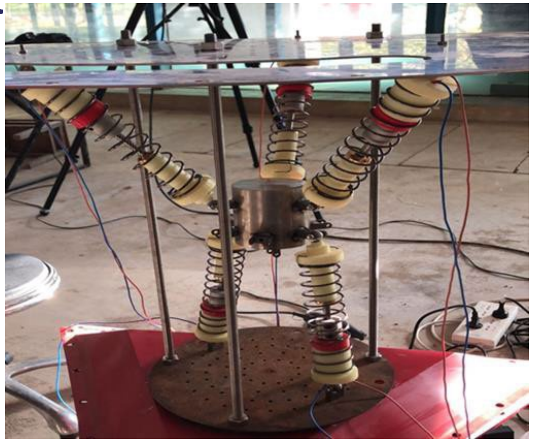
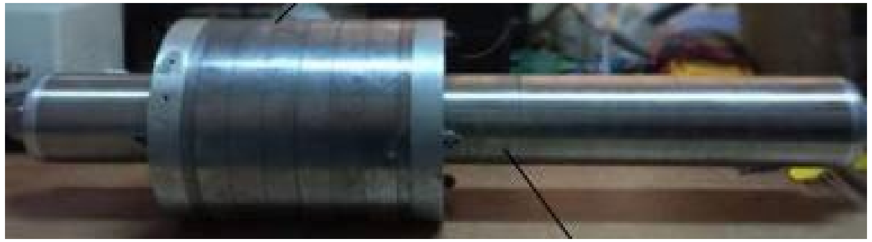
- **NREL & Sandia NL (USA),** a TEAMER funding support ($150,000) approved to build time-domain modelling for TALOS WEC using WEC-SIM facility
- **AUTH & IHU Universities (Greece)** are building time-domain model using DNV SESAM code (for comparisons with in-house time-domain model)
- **Zhejiang University (China),** experimental testing & computational time-domain model of TALOS WEC







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WP2 - Survivability Reliability & Optimised Control of Devices in the marine environment

Tasks	Quarter	1	2	3	4	5	6	7	8	9	10	11	12
WP2: Survivability, Reliability and Optimised Control of Devices in the Marine Environment													
Smart sensor and data acquisition system					■	■	■						
Intelligent condition monitoring							■	■	■				
Predictive maintenance									■	■	■		
Optimised control strategy											■	■	■

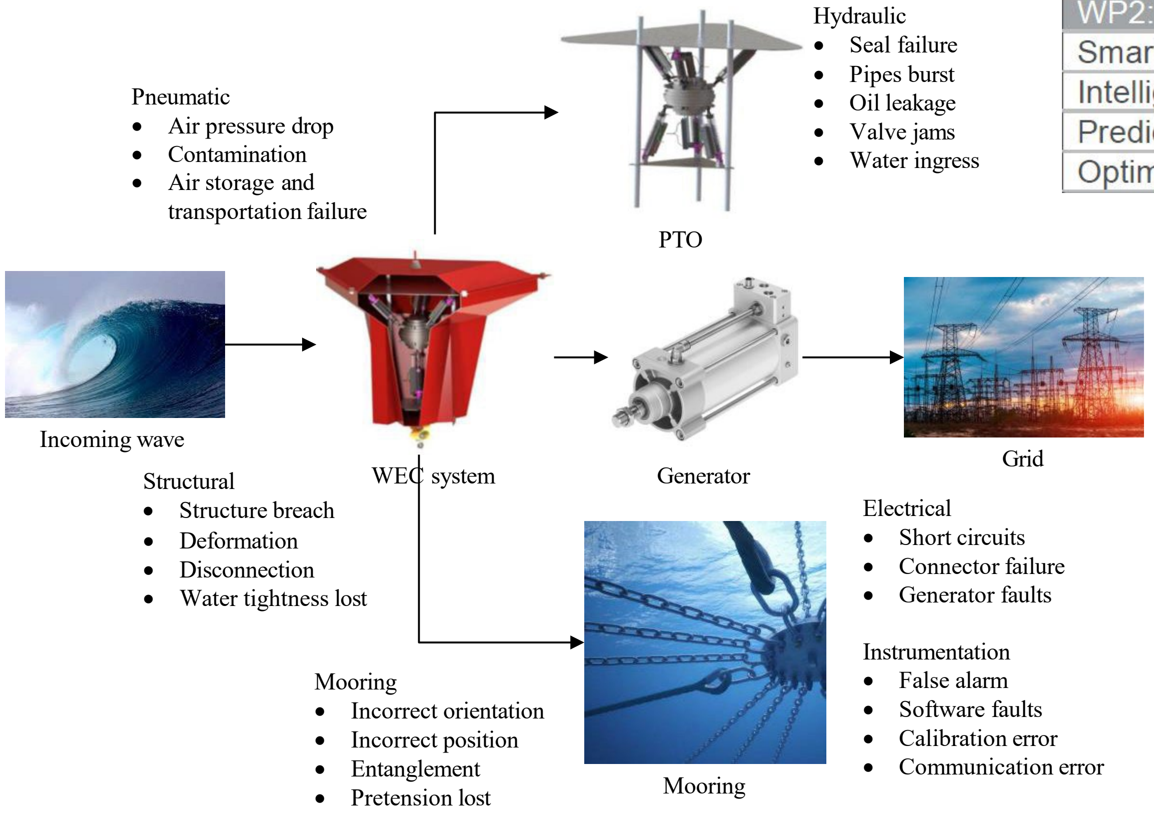

Figure. 1 Common failure modes of WEC

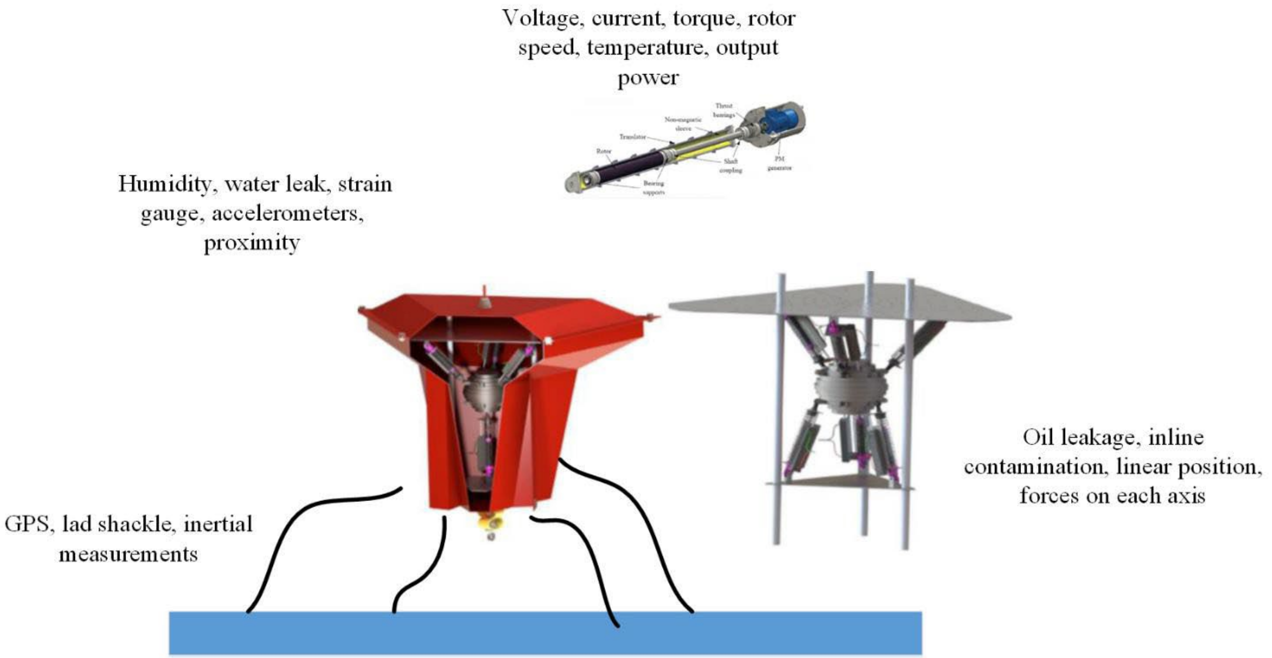

Figure. 2 Sensing system of the TALOS WEC

WP2 - Survivability Reliability & Optimised Control of Devices in the marine environment

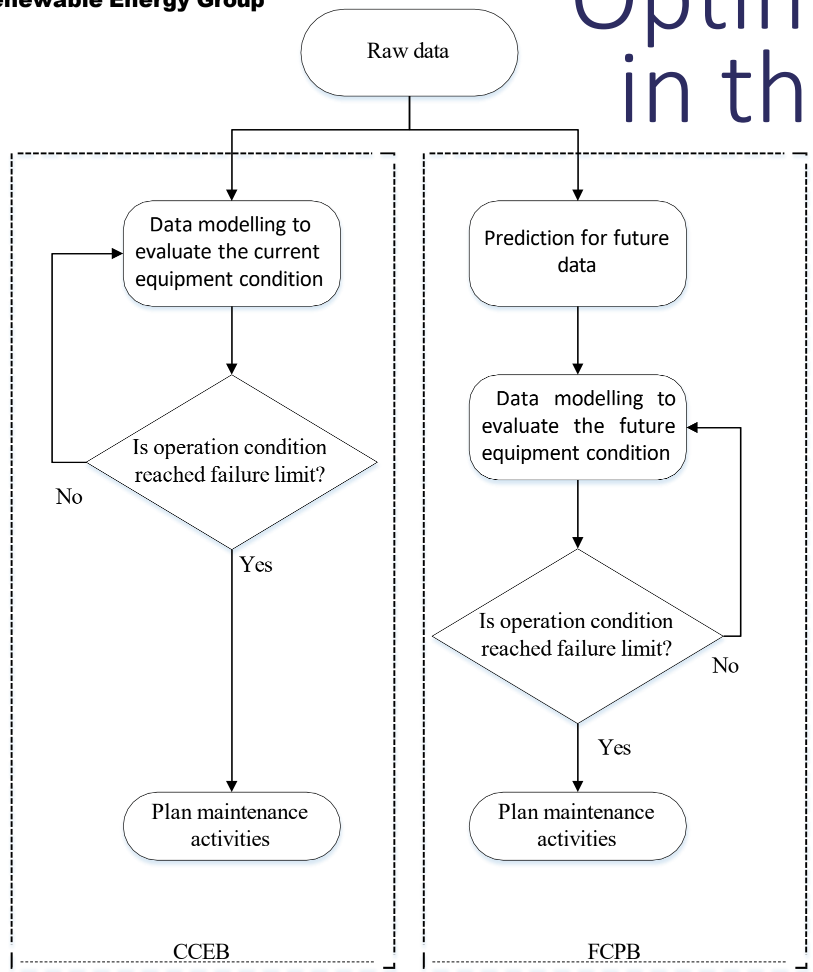

Figure. 3 Frameworks of current condition evaluation-based (CCEB) and future condition prediction-based (FCEB) maintenance strategies

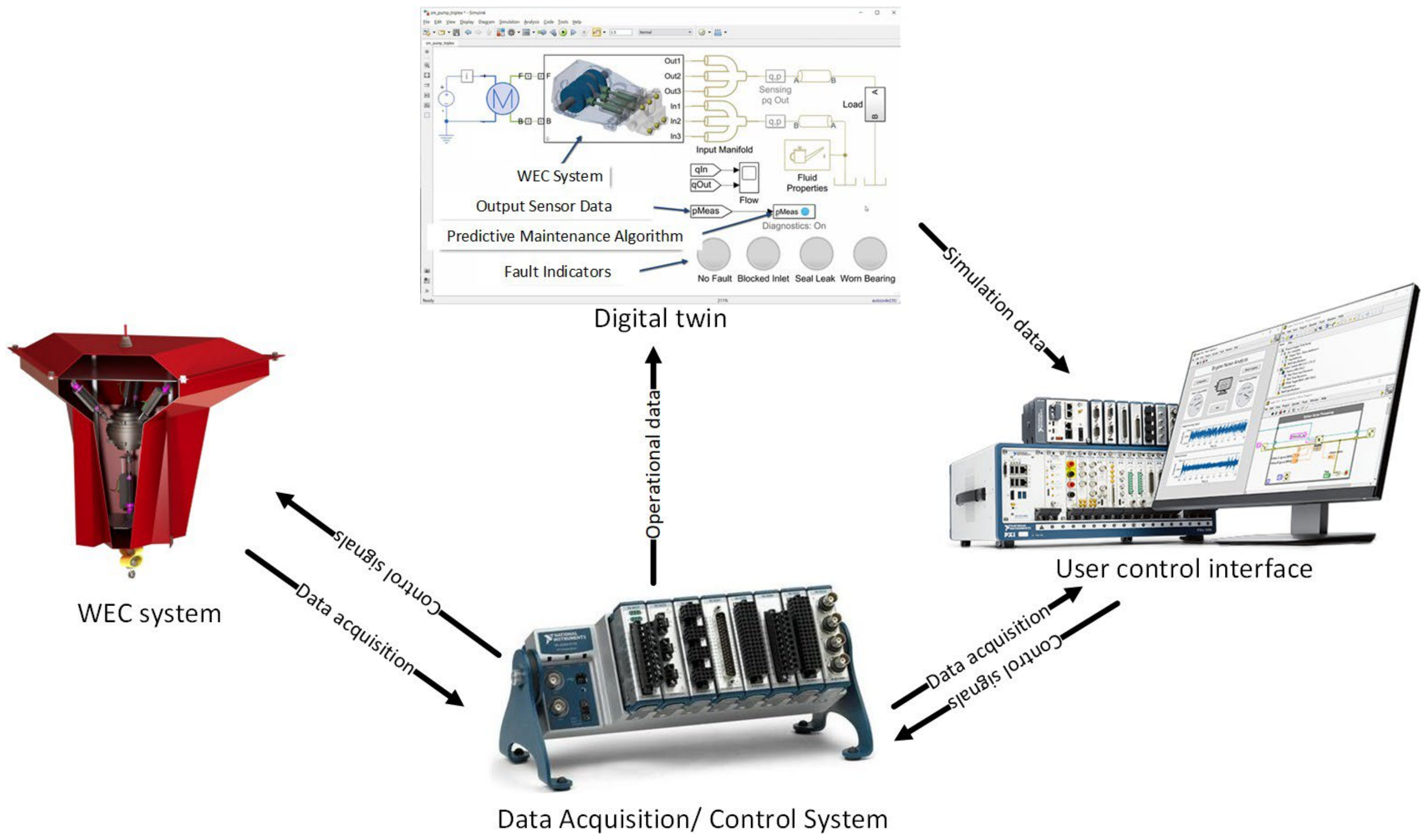

Figure. 4 Optimised control strategies

WP3 - **SmartWave** - High Accuracy & High Spatial Fidelity Wave Prediction

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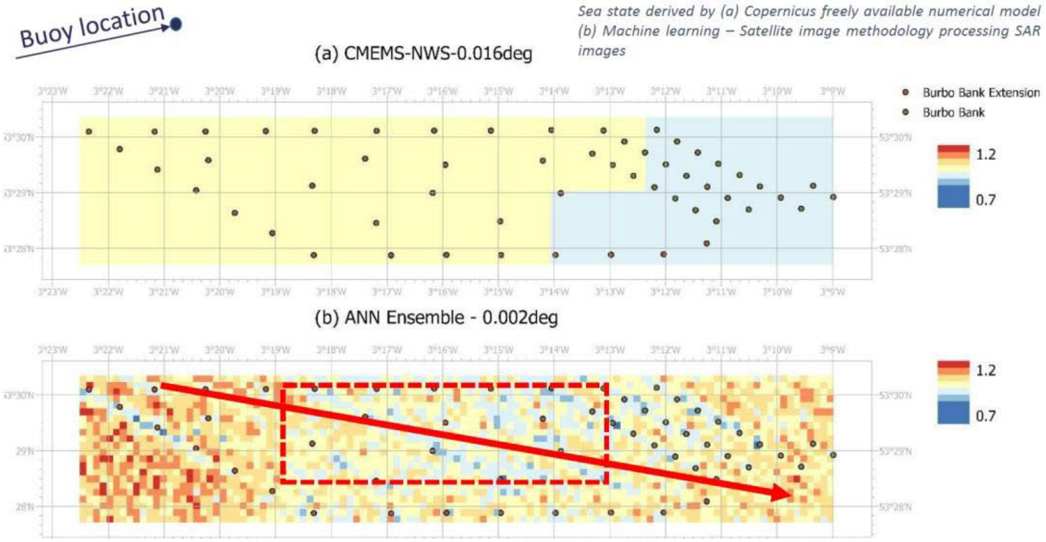
Artificial Intelligence (Artificial Neural Network – ANN and Convolutional Neural Network – CNN) will be advanced to estimate key oceanographic parameters i.e. wave height, direction, frequency, and speed. State-of-the-art remote sensing monitoring and in situ data from European Space Agency satellite Sentinel 1 (Synthetic Aperture Radar – SAR) will be utilised, whilst access to high-fidelity data from the Cefas WaveNet buoys will provide ground truth data for validation.

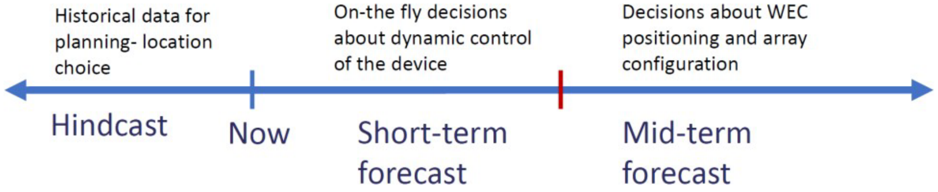
Example results – Burbo Bank

Comparison of Sea state conditions at 2/4/2019 06:32:16am

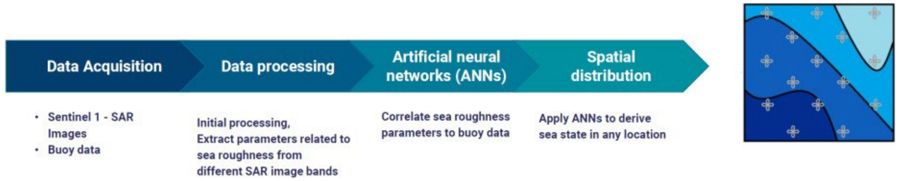
Buoy data: 0.89m (6:30am) – 1.07m (7:00am)	Numerical model at the buoy: 0.92m	ANN Ensemble: 0.95m

- Same trend of significant wave height for both hindcasts
- Higher resolution for machine learning-satellite image methodology
- Possible to identify pattens like sheltering in the inner wind turbines compared to the ones that are at the edge of the wind farm.





ANN based system



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WP3 - CNN based system

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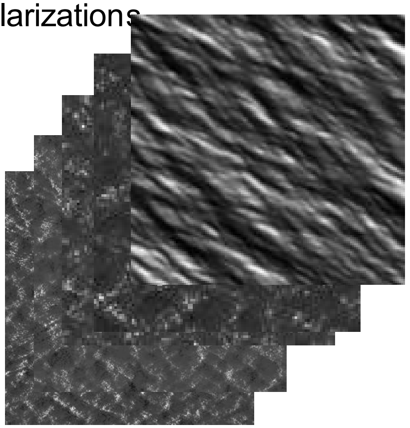
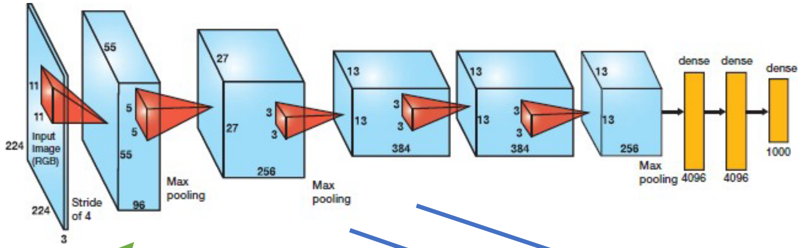
Deep learning

SAR imagery synthetic database creation

Different parameters:
wind directions
wind speeds
fetch size
incidence angles
polarizations

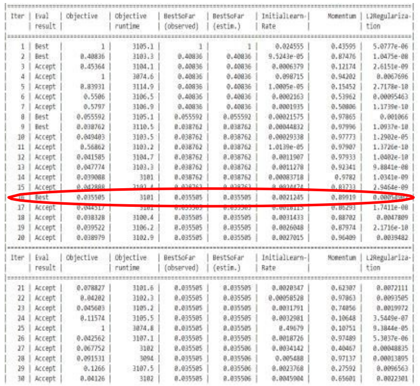


Training CNN (AlexNet)



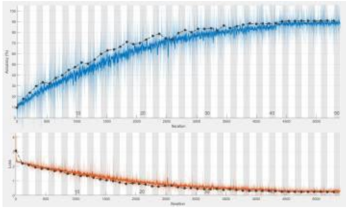
Strategies:
Training from scratch
Transfer learning with real data

Automated classification and estimation of sea state parameters:
wave height
direction
frequency
speed



Iter	Eval result	Objective	Objective runtime	BestSoFar (observed)	BestSoFar (estim.)	InitialLearn-Rate	Momentum	L2Regulariza-tion
1	Best	1	3105.1	1	1	0.024555	0.43595	5.0777e-06
2	Best	0.40836	3103.3	0.40836	0.40836	9.5243e-05	0.87476	1.0475e-08
3	Accept	0.45364	3104.1	0.40836	0.40836	0.0006379	0.12174	2.6151e-09
4	Accept	1	3074.6	0.40836	0.40836	0.098715	0.94202	0.0067696
5	Accept	0.83931	3114.9	0.40836	0.40836	1.0005e-05	0.15452	2.7178e-10
6	Accept	0.5506	3106.5	0.40836	0.40836	0.0002163	0.53962	0.00095463
7	Accept	0.5797	3106.9	0.40836	0.40836	0.0001935	0.50806	1.1739e-10
8	Best	0.055592	3105.1	0.055592	0.055592	0.00021575	0.97865	0.001066
9	Best	0.038762	3110.5	0.038762	0.038762	0.00044832	0.97996	1.0937e-10
10	Accept	0.049403	3103.5	0.038762	0.038762	0.00029338	0.97773	1.2902e-05
11	Accept	0.56862	3103.2	0.038762	0.038762	1.0139e-05	0.97907	1.3726e-10
12	Accept	0.041585	3104.7	0.038762	0.038762	0.0011907	0.97933	1.0402e-10
13	Accept	0.047774	3103.3	0.038762	0.038762	0.0011278	0.92341	9.8841e-08
14	Accept	0.039088	3101	0.038762	0.038762	0.00083718	0.9782	1.0341e-09
15	Accept	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.83733	2.9464e-09
[illegible]	Best	0.035505	3101	0.035505	0.035505	0.0021245	0.89919	[illegible]
17	Accept	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.7411e-08
18	Accept	0.038328	3100.4	0.035505	0.035505	0.0031433	0.88702	0.0047809
19	Accept	0.039522	3106.2	0.035505	0.035505	0.0026048	0.87974	2.1716e-10
20	Accept	0.038979	3102.9	0.035505	0.035505	0.0027015	0.96409	0.0039482

Iter	Eval result	Objective	Objective runtime	BestSoFar (observed)	BestSoFar (estim.)	InitialLearn-Rate	Momentum	L2Regulariza-tion
21	Accept	0.078827	3101.6	0.035505	0.035505	0.0020347	0.62307	0.0072111
22	Accept	0.04202	3102.3	0.035505	0.035505	0.00058528	0.97063	0.0093505
23	Accept	0.045603	3105.2	0.035505	0.035505	0.0031791	0.74056	0.0019972
24	Accept	0.11574	3105.5	0.035505	0.035505	0.0032981	0.10648	3.5449e-07
25	Accept	1	3074.8	0.035505	0.035505	0.49679	0.10751	9.3844e-05
26	Accept	0.042562	3107.1	0.035505	0.035505	0.0018726	0.97489	5.3037e-06
27	Accept	0.067752	3102	0.035505	0.035506	0.0034142	0.40467	0.00048835
28	Accept	0.091531	3094	0.035505	0.035506	0.005488	0.97137	0.00013895
29	Accept	0.1266	3107.5	0.035505	0.035506	0.0023768	0.27592	0.0096563
30	Accept	0.04126	3102	0.035505	0.035506	0.0045904	0.65601	0.0022301



Bayesian optimization to find optimal network hyperparameters

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WP3 - Mapping of wave power for shallow, intermediate, and deep-water areas

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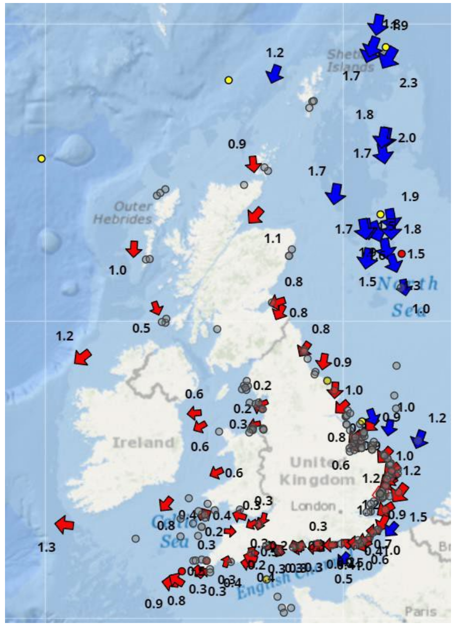
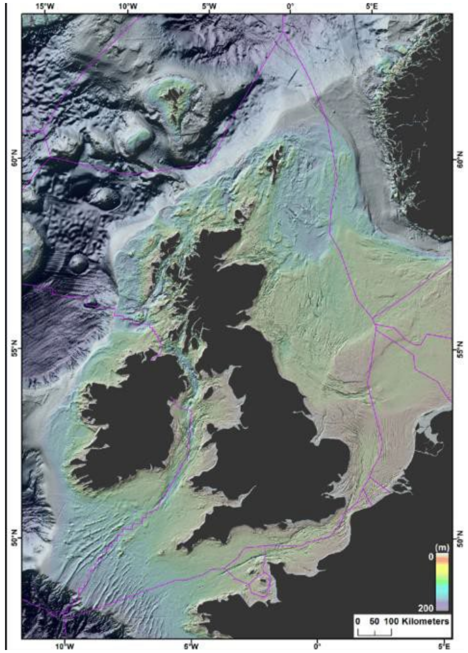
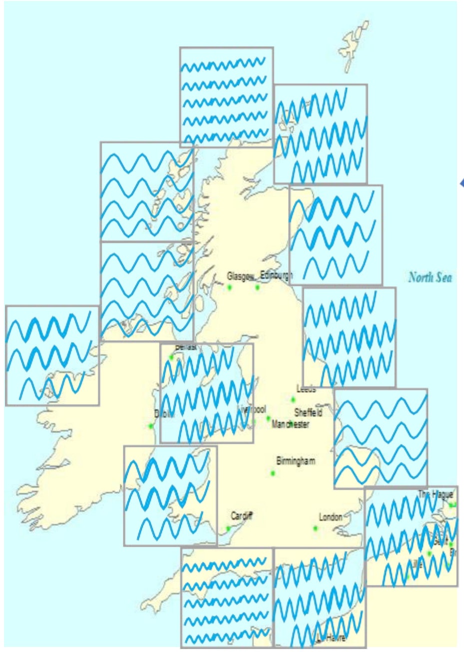
Cefas WaveNet buoys



Bathymetry offshore model of the UK (EMODnet and GEBCO)



Determination of wave type dominance



Mapping of waves based on simulation

TMA for shallow

JONSWAP for deep

Wave power

Model of the mean wavelength

Hindcast wave parameters (1980-2022)
Total: Hs, Tp, Tz, Dp
Components: Tm_w, Tm_s1, T_ms2, Dw, Ds1, Ds2

WP4 - Collaborations

- Ass Prof Chenglong Guo (China) & Professor Dakshina De Silva (UK)
  - Review of the levelized cost of wave energy based on techno-economic model
- Dr David Howard (UK)
  - Environmental aspects
- Ass Prof James DiLellio (USA)
  - Bridge the gap between TALOS WEC small-scale modelling and the higher TRL required to provide cost evidence and demonstrate its commercial potential

TALOS International Collaboration

Lancaster University Renewable Energy Group

Lancaster University

Professor Spyros Mavrakos
Professor John Anagnostopoulos

Dr Jochem Weber
Dr Robert Thresher
Dr Aidan Bharath
Dr David Ogden
Dr Matthieu Ancellin

NREL Transforming ENERGY

Dr Sal Husain
Dr Stein Housner
Dr Matthew Hall

Sandia National Laboratories

Dr Jorge AndresLeon Quiroga

Renewable Energy Technologies

Dr Budi Gunawan

International Hellenic University

Ass Professor Constantine Michaelides

Copernicus Europe's eyes on Earth

Copernicus Marine Service

POSEIDON SYSTEM

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國立陽明交通大學 NATIONAL YANG MING CHIAO TUNG UNIVERSITY

Ass Professor Yi-Hsiang Yu

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Professor Brad Buckham
Professor Curran Crawford

南京林業大學 NANJING FORESTRY UNIVERSITY

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Professor Dakshina De Silva

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Professor John Ringwood

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Professor Pierre Ferrant
Professor Alain Clément
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Ass Professor Guillaume Ducrozet
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Dr Ruddy Kurnia

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Zhejiang University 1897

Professor Dahai Zhang
Dr Tan Ming

Ass Professor Hui Zhang

Pepperdine Graziadio Business School

Ass Professor James DiLellio

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Ass Professor Carrie Hall

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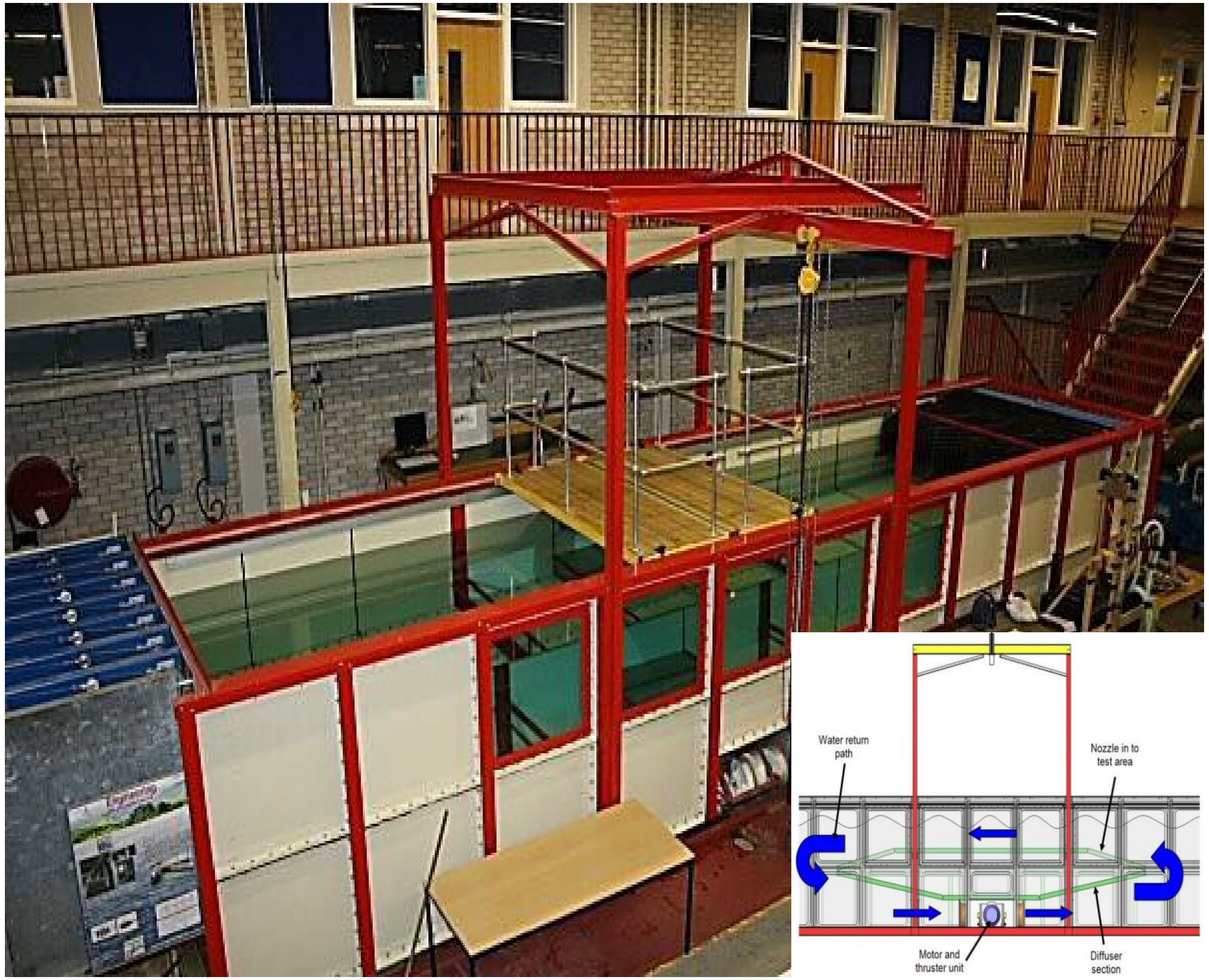

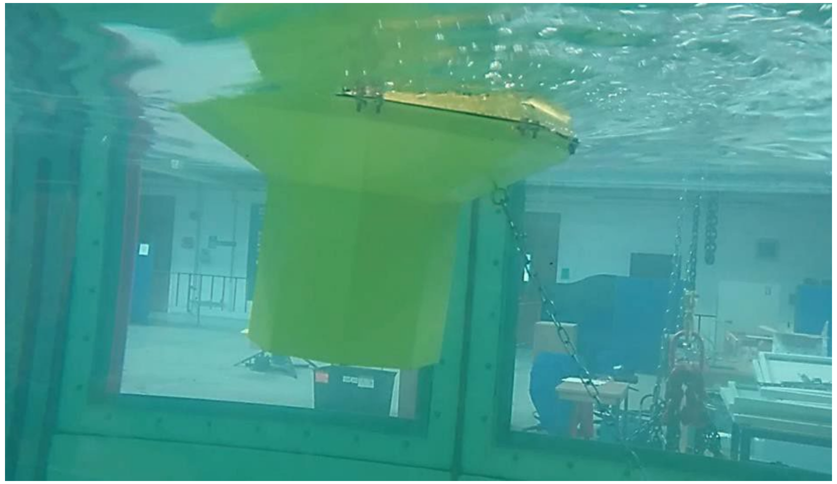

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