Numerical Wave Tank testing for Marine Renewable Energy Devices Part 1

Dr Josh Davidson

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Objective

To teach students about the development and optimisation of marine renewable energy (MRE) devices at low to mid Technology Readiness Levels (TRL) using computational models. Demonstrating the advantages of:

- Early-stage numerical wave tank (NWT) experimentation to increase the Technology Performance Level (TPL) of devices before investing in expensive physical prototyping, tank and ocean testing, and
- Later-stage NWT simulations to supplement the physical testing campaigns.

Outline

Part 1 - The role of NWTs in MRE device development

- Techno-economic optimisation
- Strengths and weakness of NWTs

Part 2 - NWT Implementation and Experiments

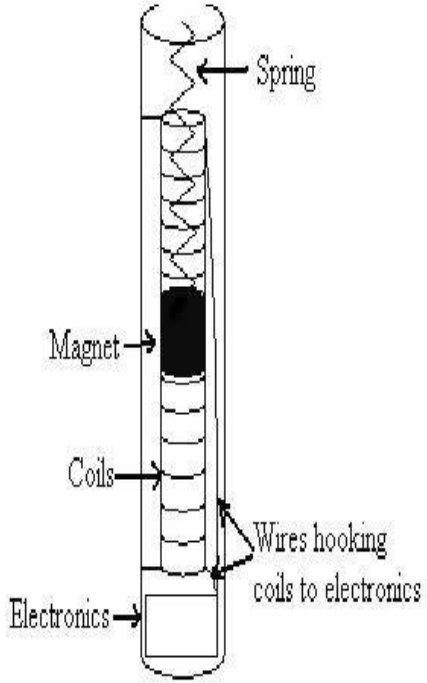
- Implementing the NWT and subsystems
- Example use cases

But first....

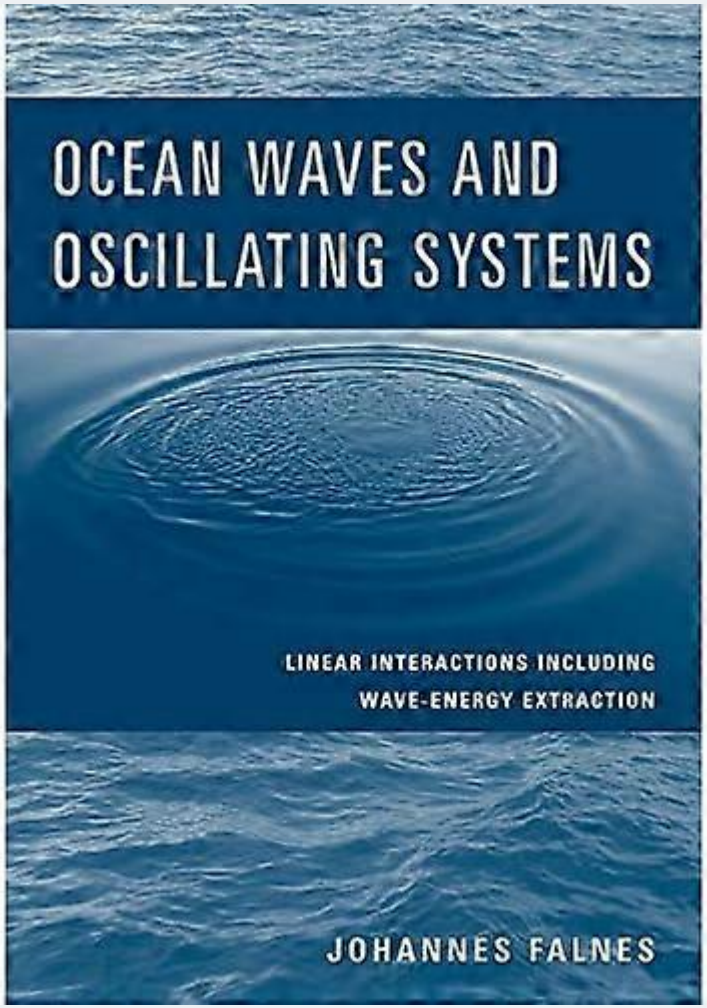
JCU

The Problem

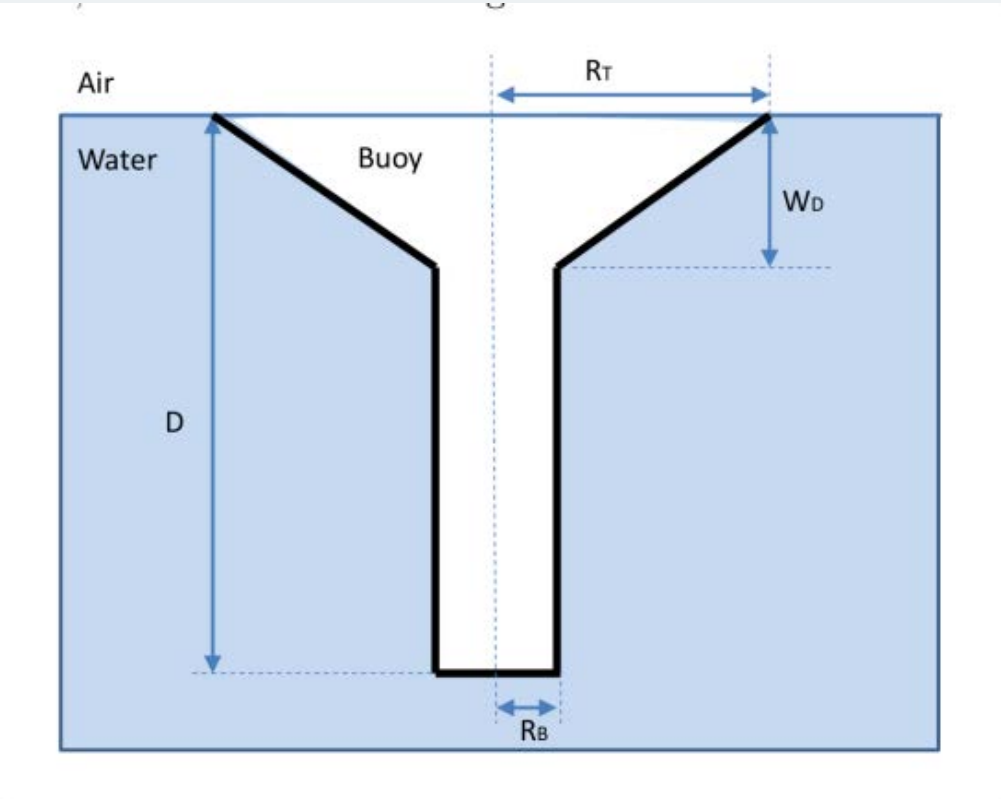
Final Year Project



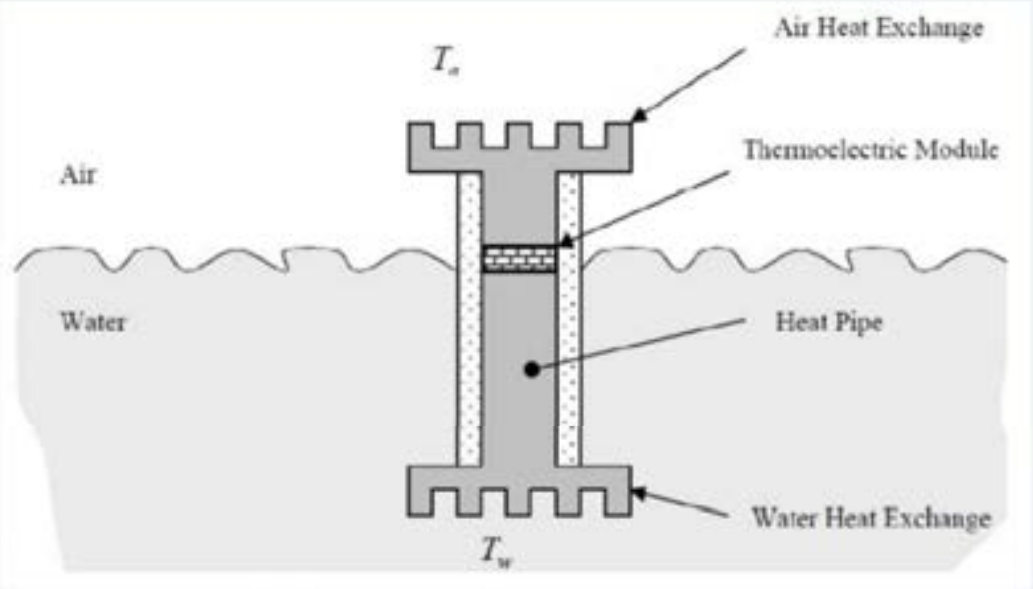
Hydrodynamic Modelling

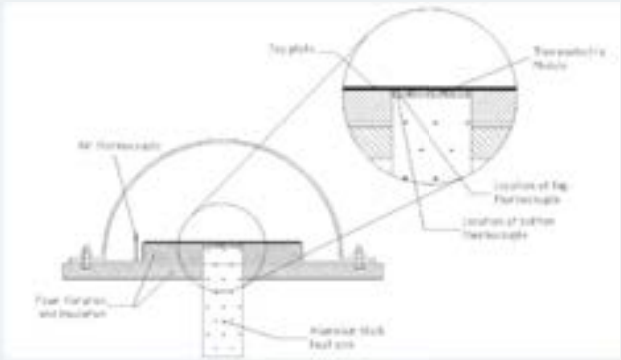


Wave energy harvesting



Thermal energy harvesting





COER

Centre for Ocean Energy Research

Maynooth University
National University of Ireland Maynooth

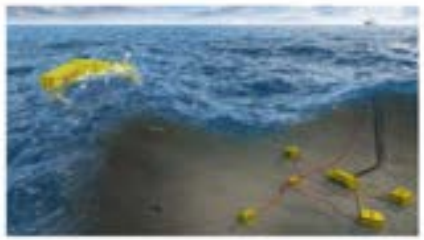
Projects

- Nonlinear parametric modelling and control for wave energy devices using numerical tank testing
- Development of the next generation of controllers for wave energy devices

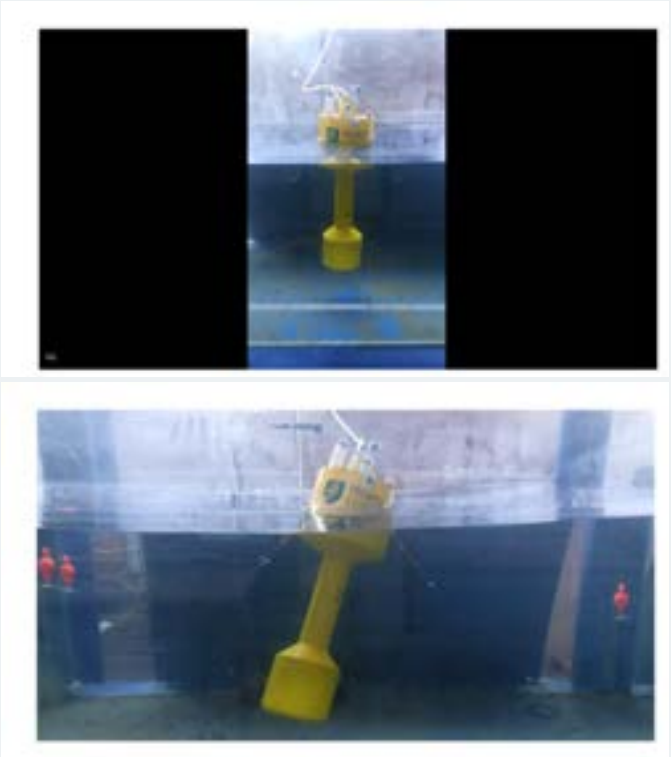
BME

Dept of Fluid Mechanics

Wave Energy in Hungary?



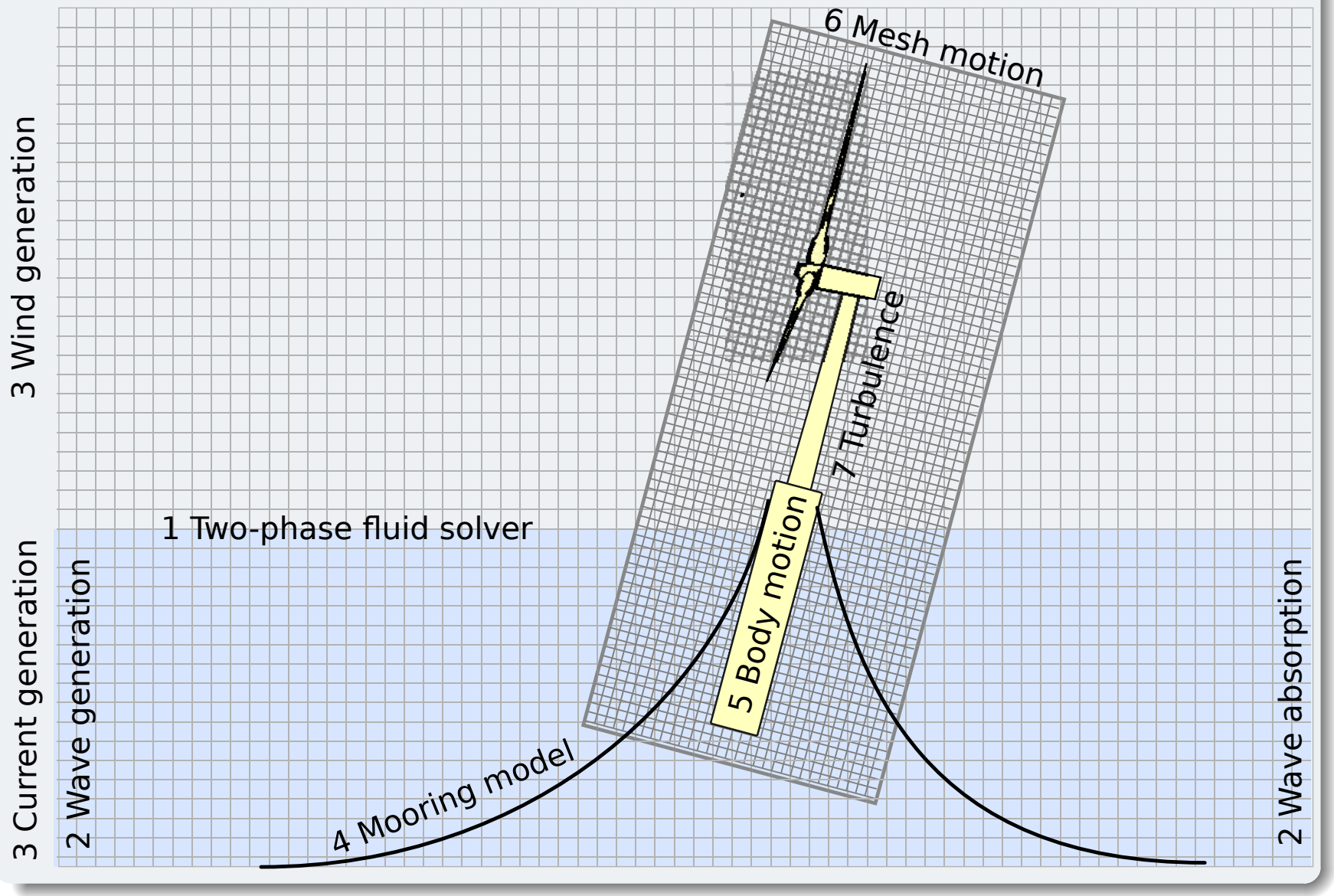
Nonlinear Rock and Roll - Modelling and Control of Parametric Resonance in WECs



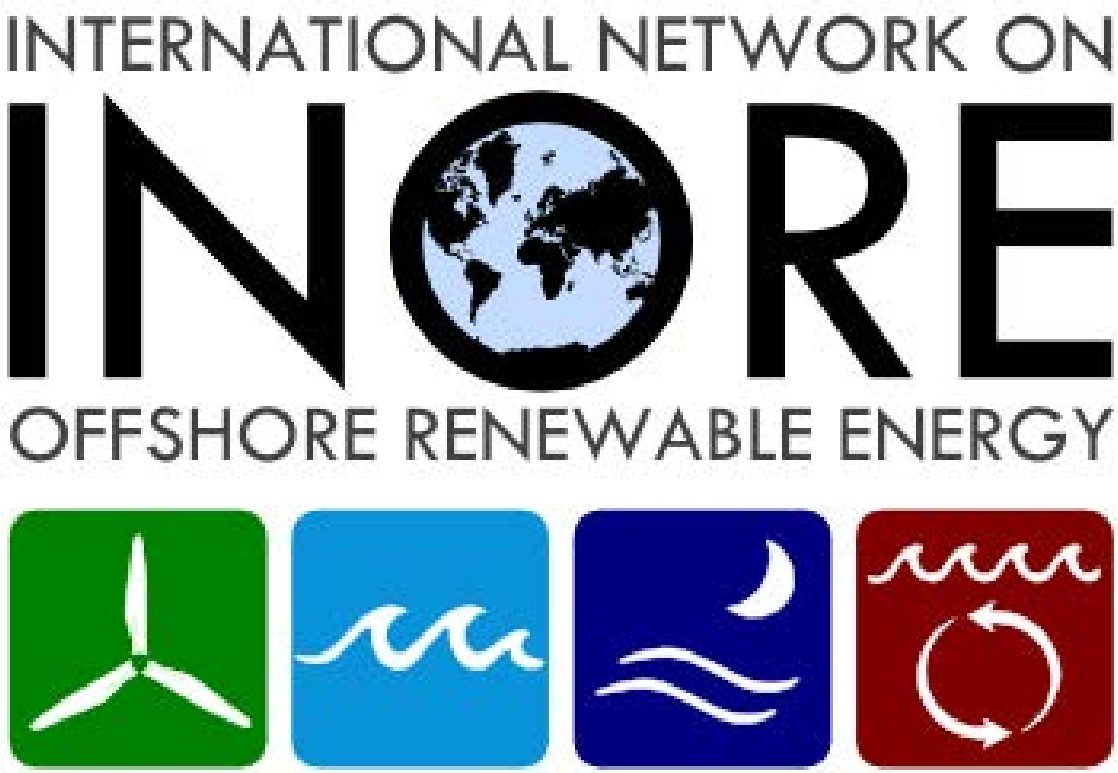
Dept of Fluid Mechanics

- Lecturing
  - Open-source CFD
  - Fluid Mechanics
- Research
  - The next generation of numerical wave tanks
  - Nonlinear dynamics in WECs
  - Wave powered desalination

High Fidelity Simulations and Deep Learning for Offshore Wind



For you young/early-stage researchers....



For you young/early-stage researchers....

The role of NWTs in MRE device development

Outline

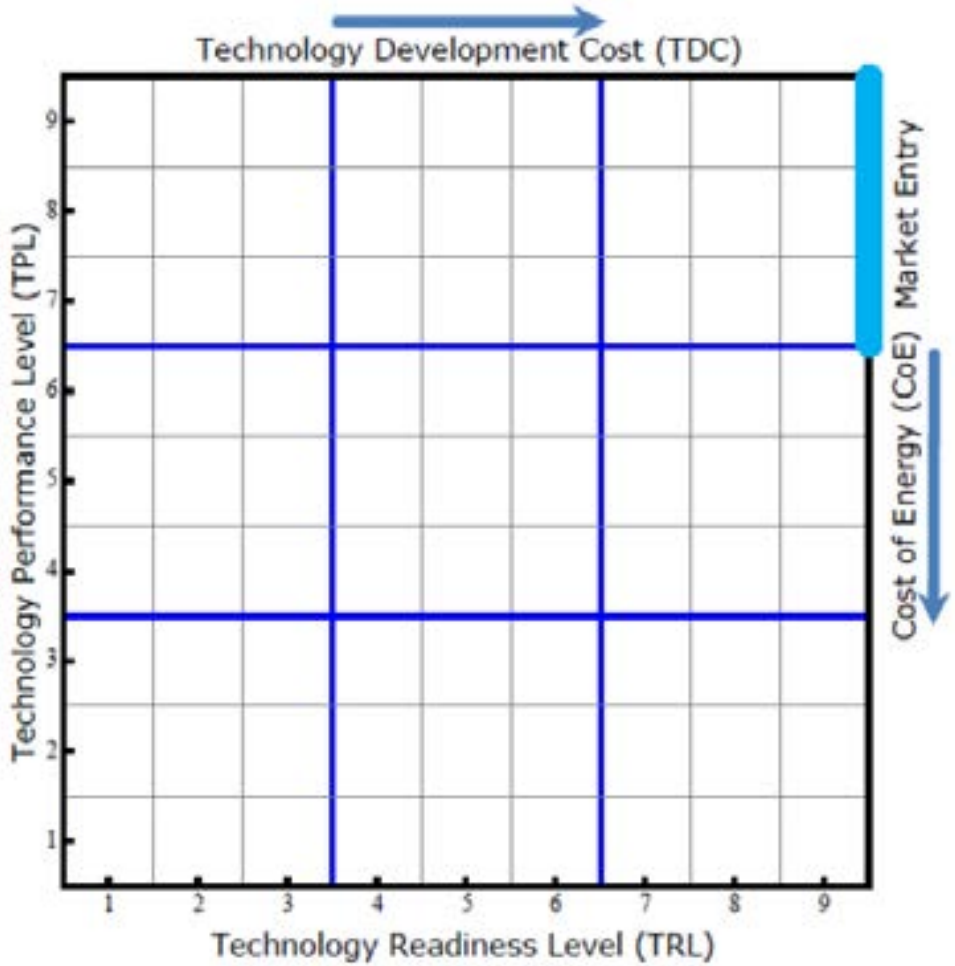
- The TRL-TPL matrix and the optimal development trajectory of MRE devices
- Numerical Wave Tanks

Techo-economic optimisation

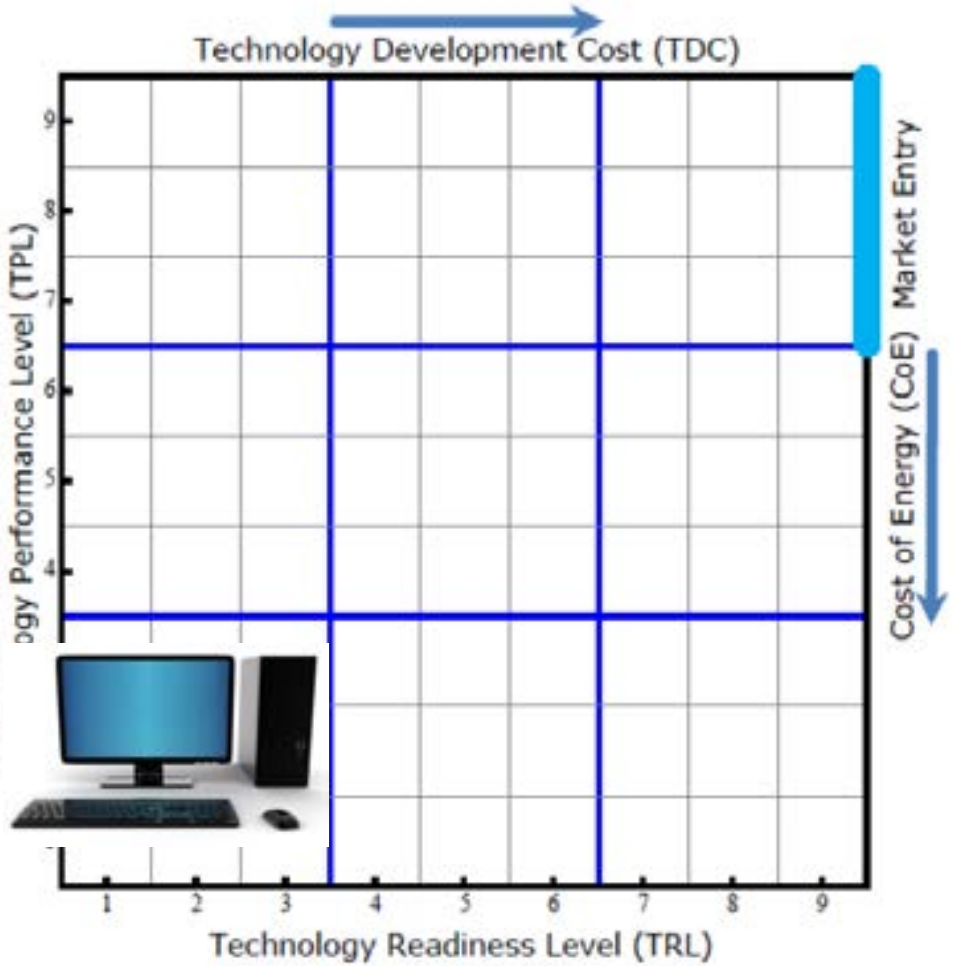
Techo-economic optimisation

Techno-economic system optimisation is referred to as the process of defining a WEC system technology that is best suited to satisfy the economic requirements, and thereby implied technical requirements, with respect to a defined application scenario

[1] Weber, Costello, Mouwen, Ringwood and Thomas, *Techno-economic WEC system optimisation - Methodology applied to Wavebob system definition*, 3rd International Conference on Ocean Energy, Bilbao, 2010



[1]Weber, Costello and Ringwood, *WEC Technology Performance Levels (TPLs) - Metric for Successful Development of Economic WEC Technology*, Proc. 10th EWTEC, Aalborg, 2013



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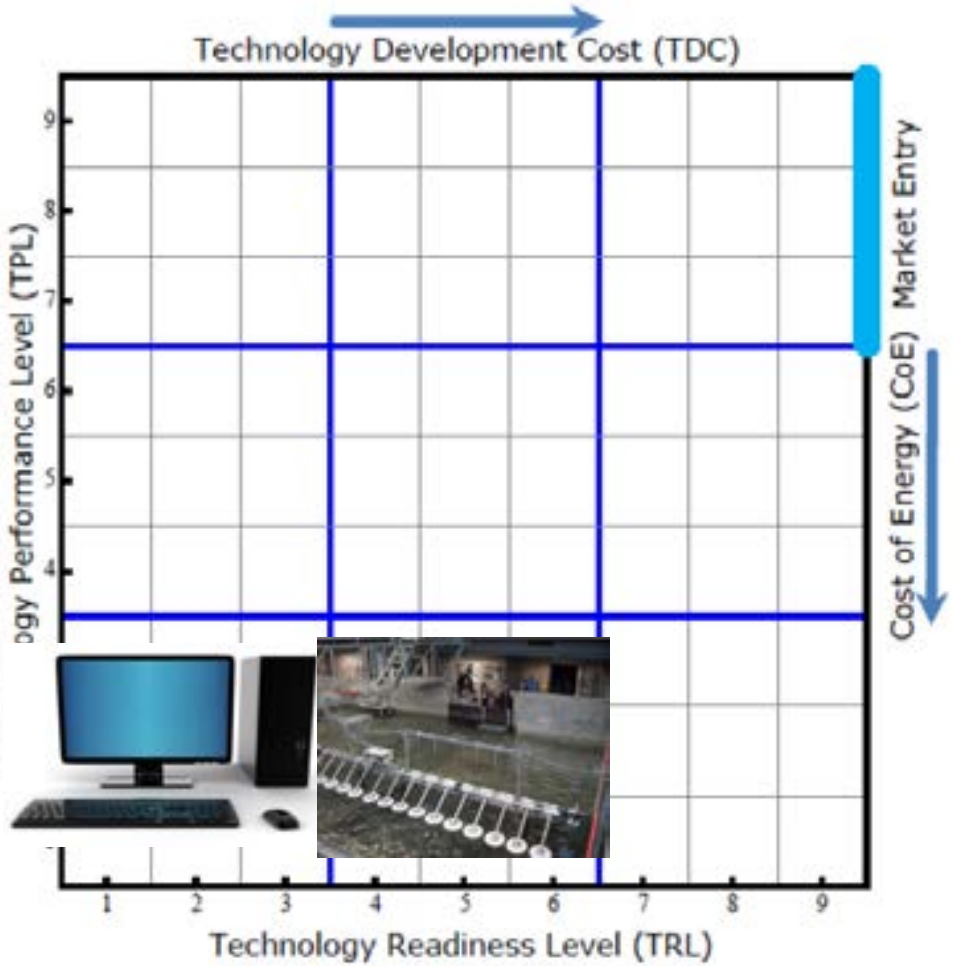

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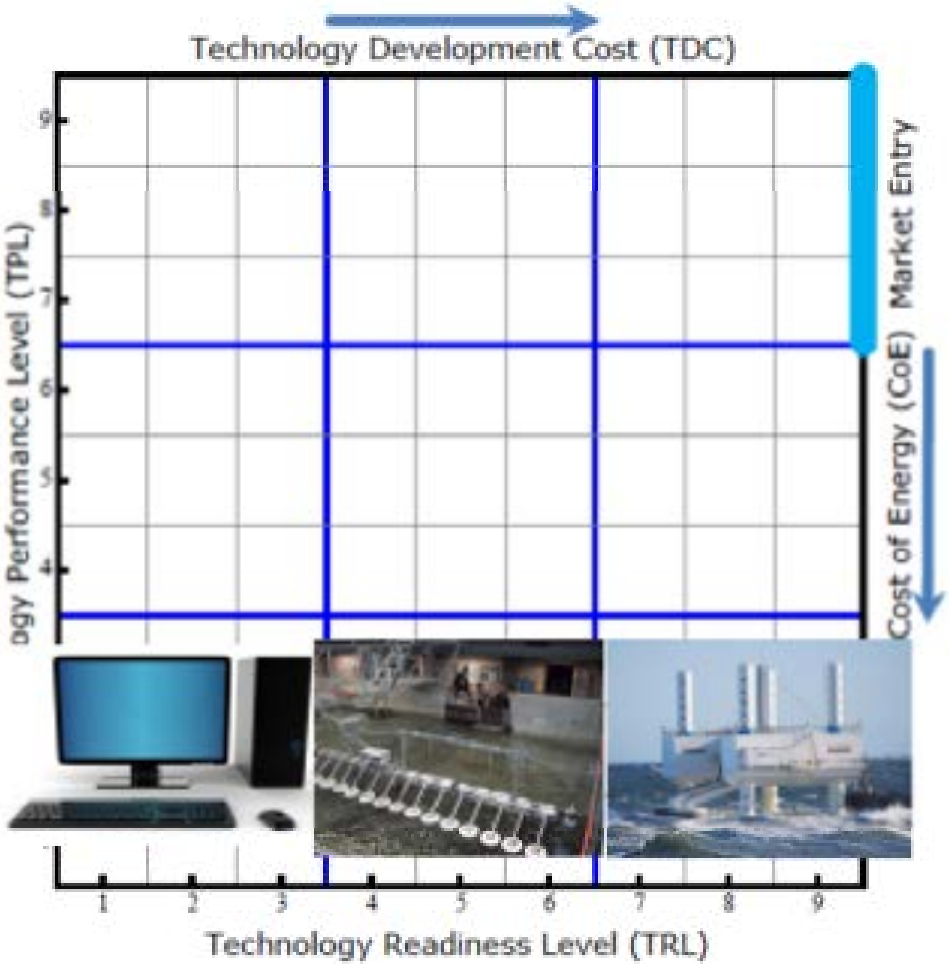

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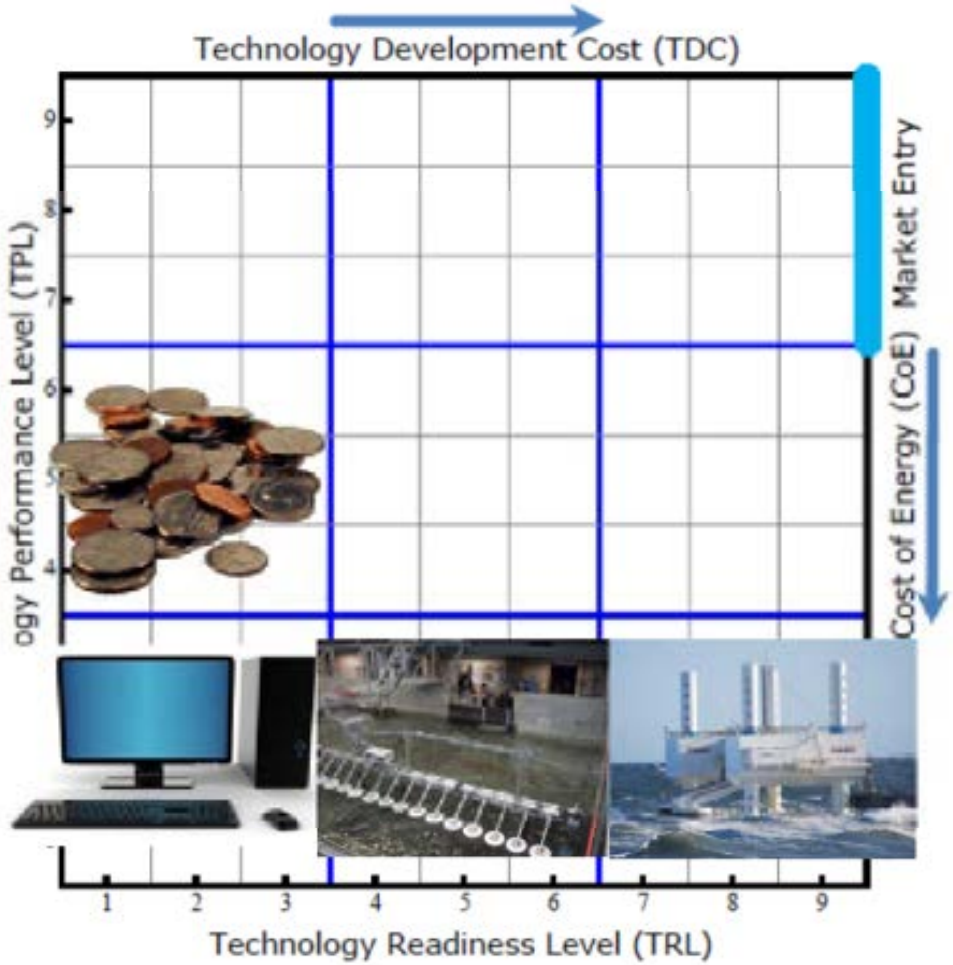

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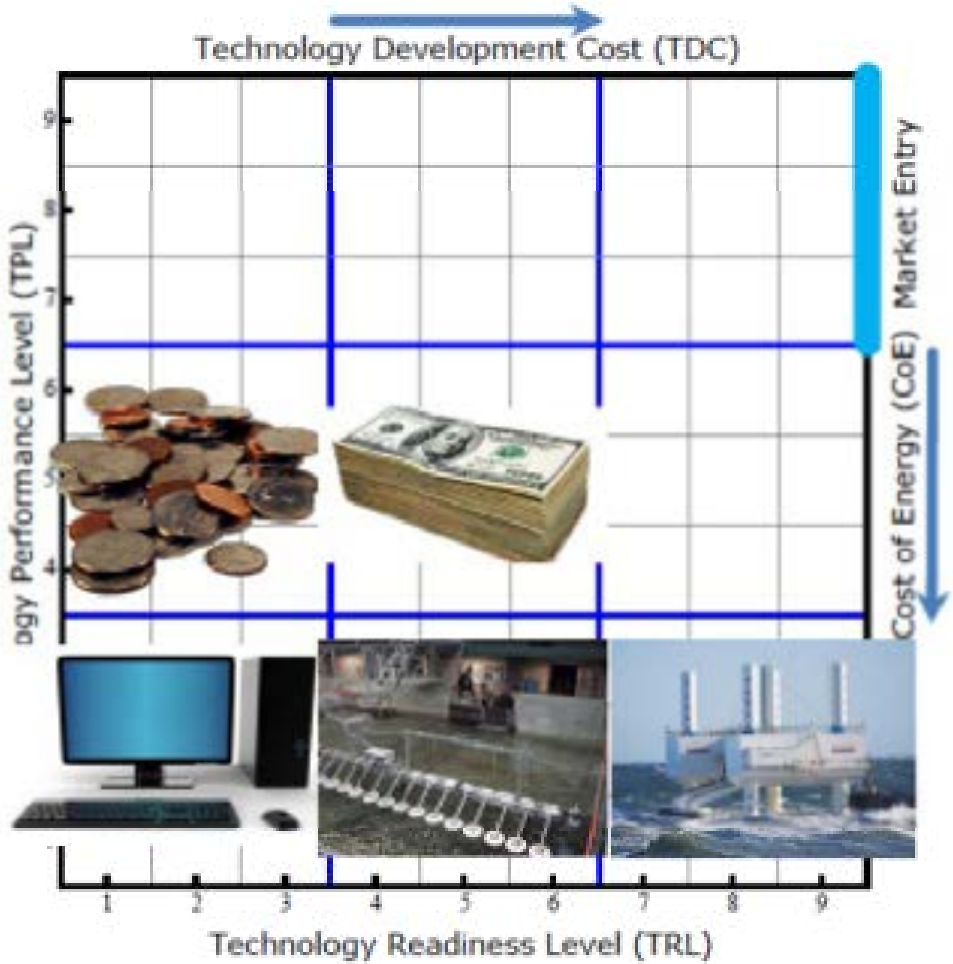

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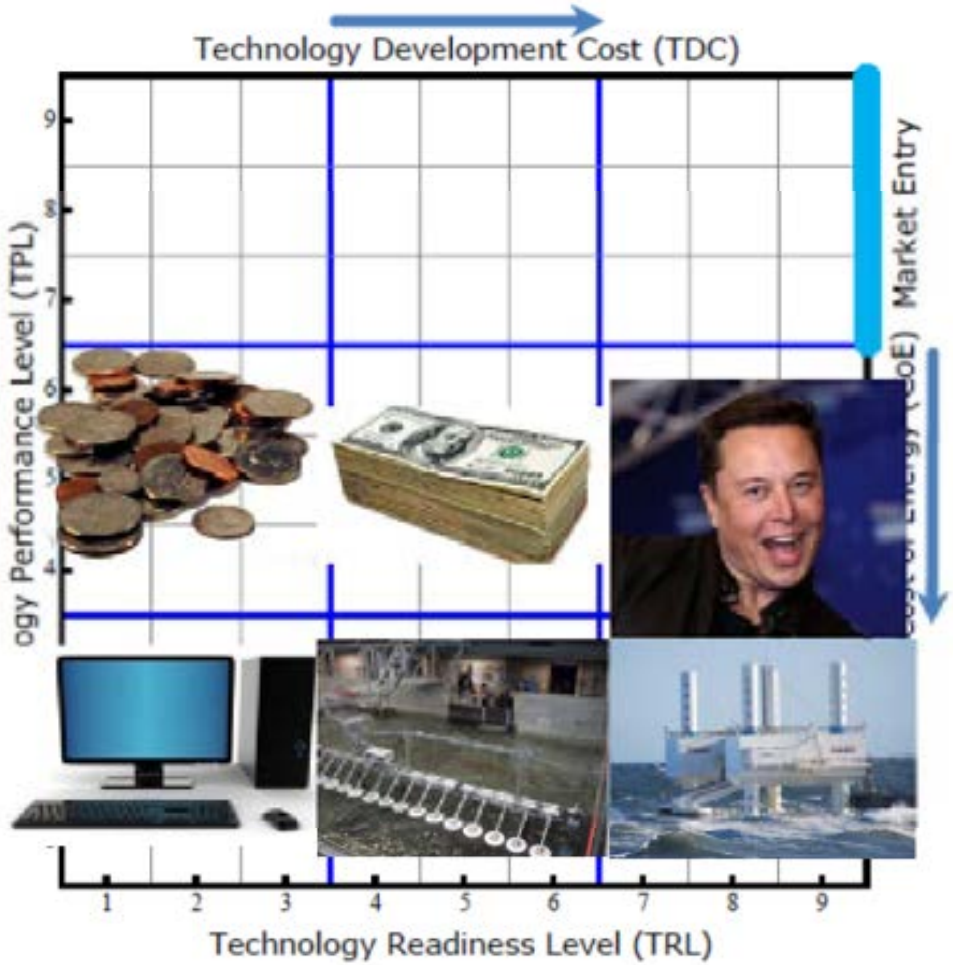
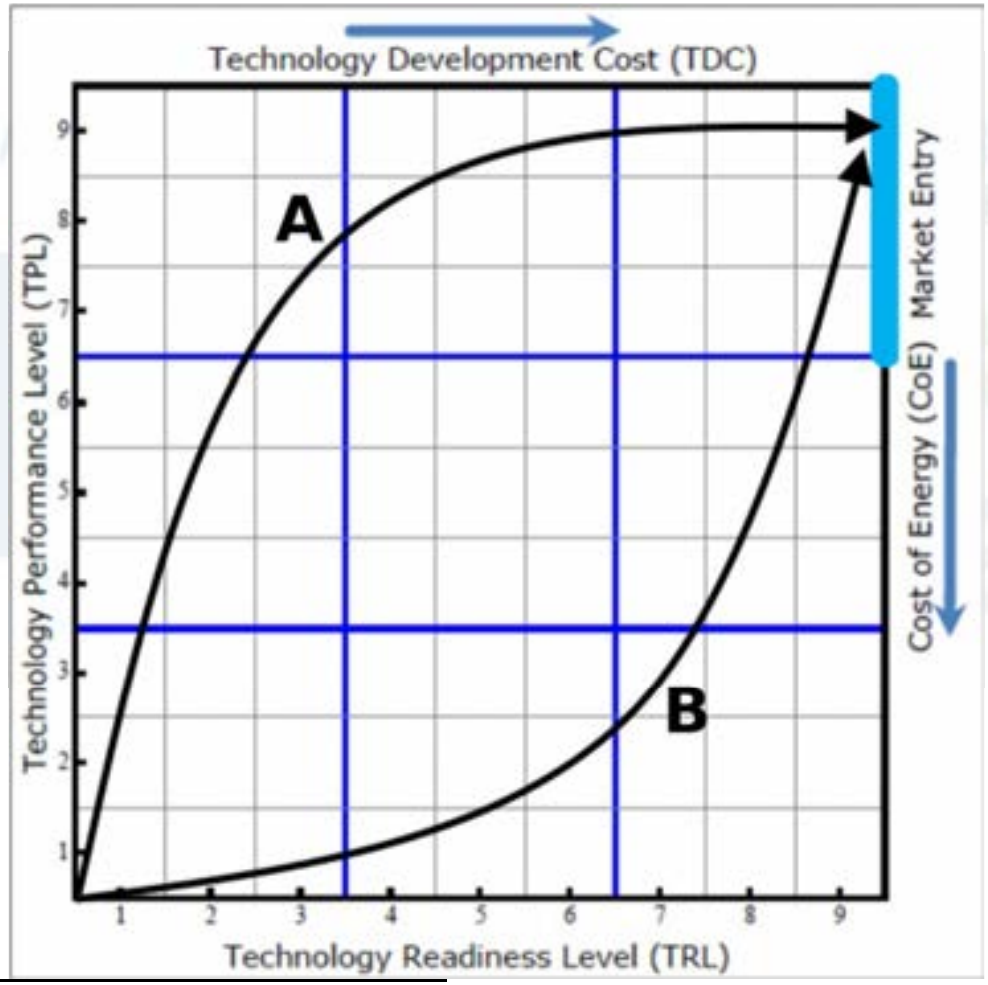


[1] Adapted from : Weber, Costello and Ringwood, *WEC Technology Performance Levels (TPLs) - Metric for Successful Development of Economic WEC Technology*, Proc. 10th EWTEC, Aalborg, 2013

Question

Which development trajectory is better: **A** or **B**?



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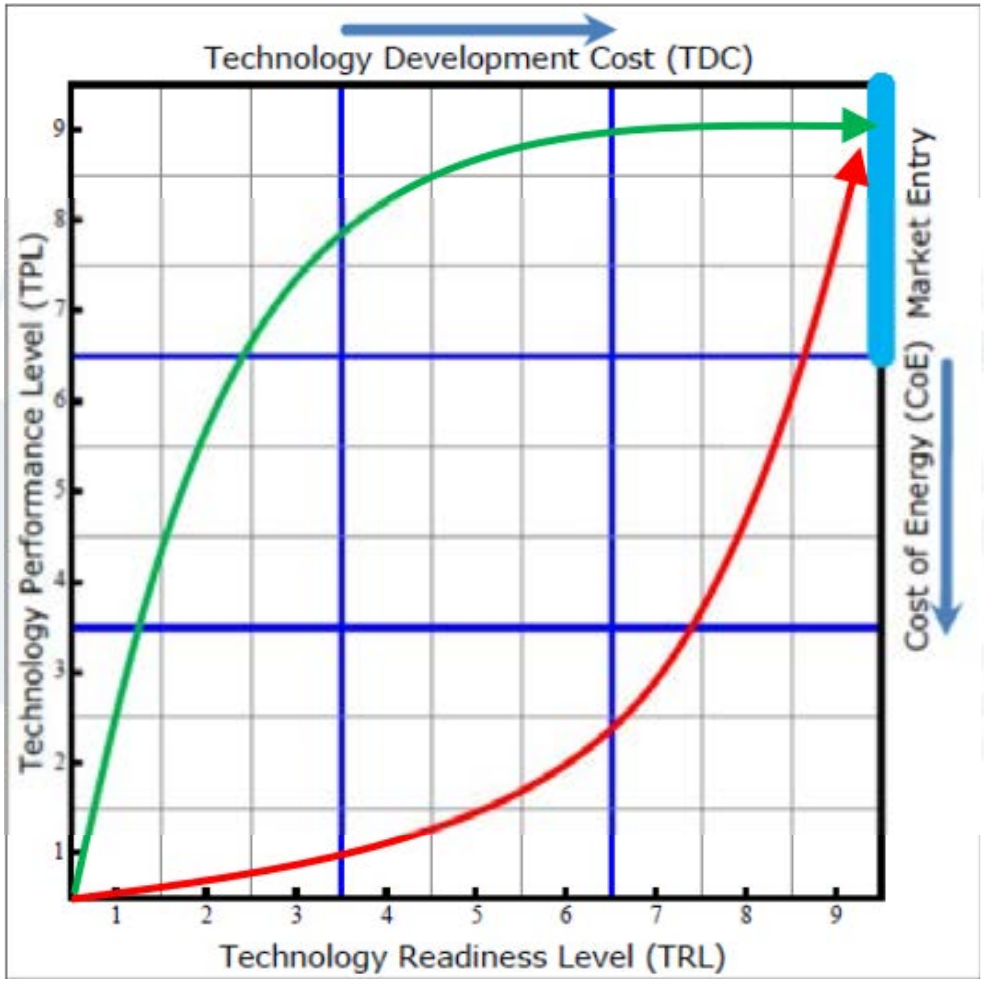


[1] Adapted from : Weber, Costello and Ringwood, *WEC Technology Performance Levels (TPLs) - Metric for Successful Development of Economic WEC Technology*, Proc. 10th EWTEC, Aalborg, 2013

The role of simulation in product development for other industries

"CFD is now a ubiquitous part of the engineering design process. In their desire to reduce cost and project time, or time-to-market, industries ranging from automotive to rotating machinery have steadily increased their reliance on CFD simulations. For example, in a modern car, everything from the aerodynamic and engine performance to rain management is designed using CFD. For example, in an effort that is not atypical in the industry, Jaguar Land Rover (JLR) is working to fulfil their 2020 vision: complete a vehicle design sign-off based only on virtual design."[1]

[1] Kim et al, *Technical and economical readiness review of CFD-based numerical wave basin for offshore floater design*, Offshore Technology Conference, 2016

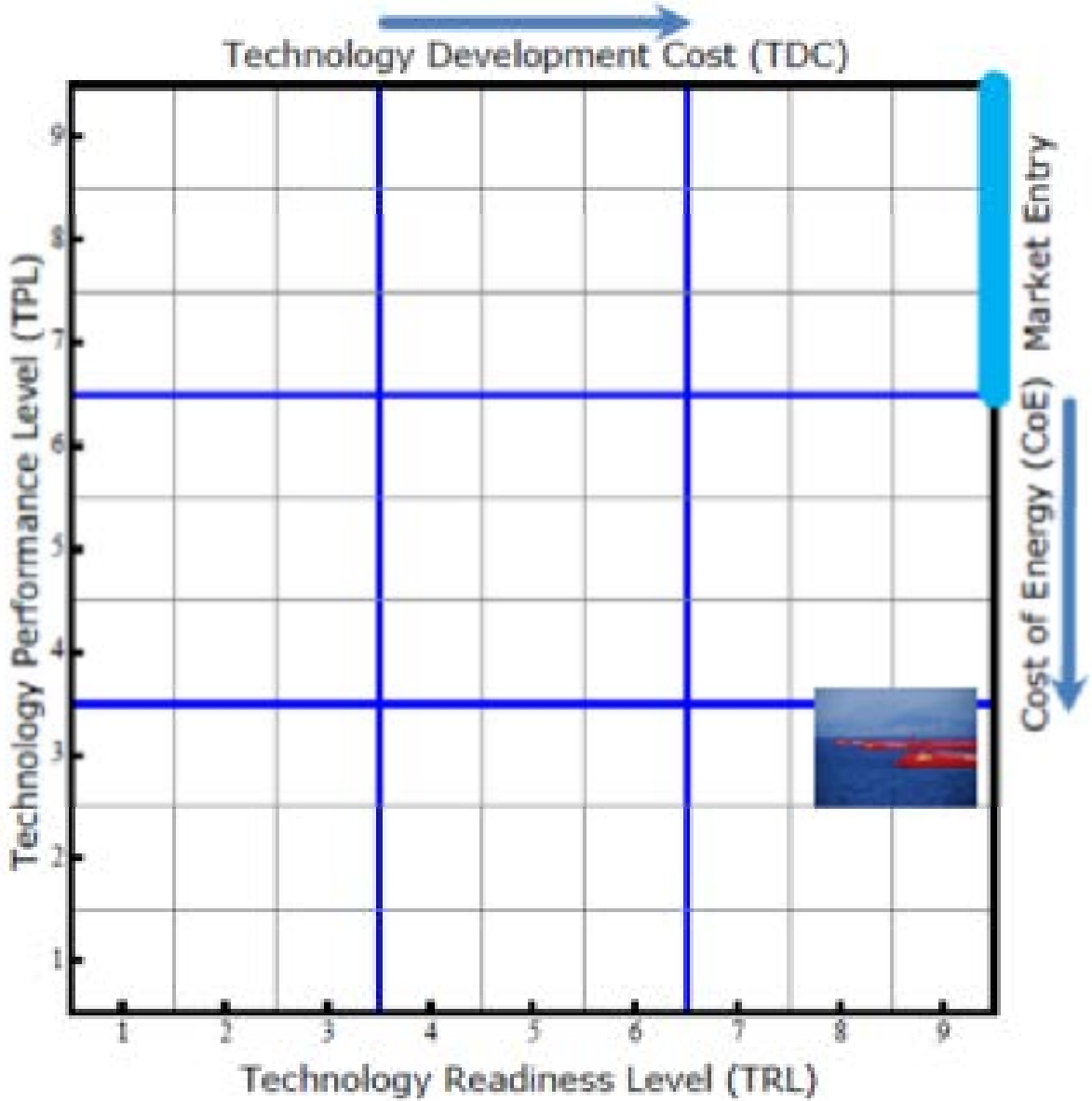

mocean
energy

The role of NWTs in MRE device development

Mocean - Recall the Pelamis

The role of NWTs in MRE device development

Mocean - Recall the Pelamis



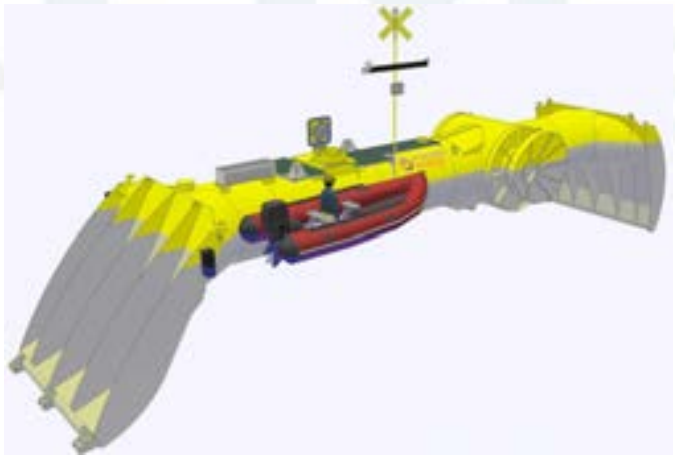
The Mocean WEC

The Mocean WEC is a hinged raft device. The dynamic response of the raft's two bodies to wave forcing leads to a flexing motion about the hinge, which drives a power take-off mechanism that converts the kinetic energy into electricity.

[1] https://www.waveenergyscotland.co.uk/programmes/details/novel-wave-energy-converter/mocean-wave-energy-converter/

The Mocean WEC

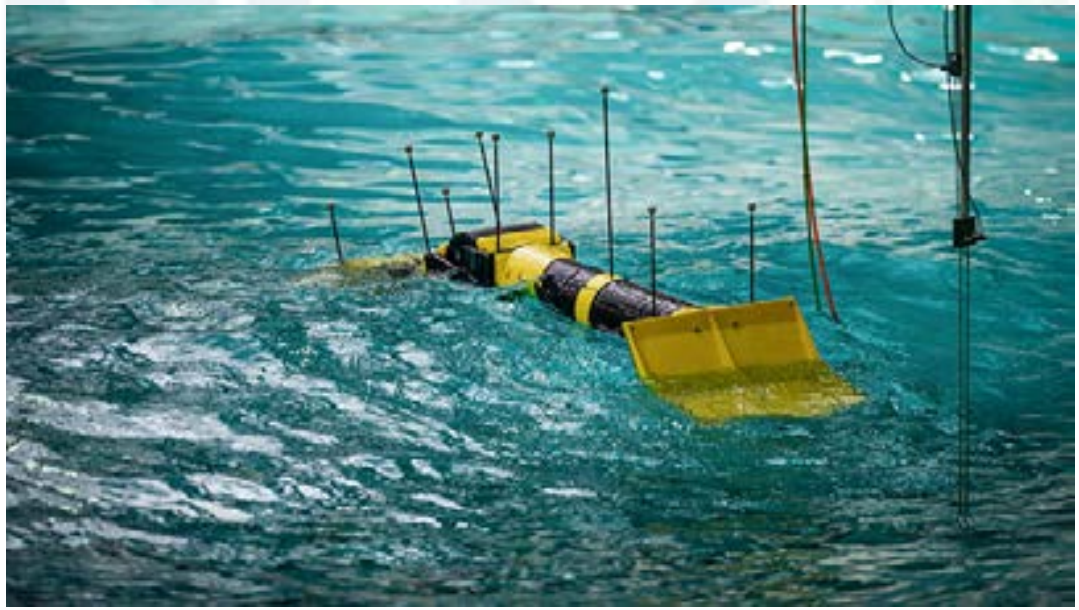
The innovation of the Mocean WEC is in the design of the shapes of the bodies, which dramatically improves its dynamics and thus power absorption. The configurations are based around varying the ratio and position of the water-plane area to the submerged volume, where the water-plane area affects the hydrostatic restoring force and the volume affects the mass and added mass. By changing these values one can induce coupling between the modes of motion and so tune the resonant response to improve performance in wavelengths that are significantly longer than the overall length of the machine.



[1] https://www.waveenergyscotland.co.uk/programmes/details/novel-wave-energy-converter/mocean-wave-energy-converter/

The Mocean WEC

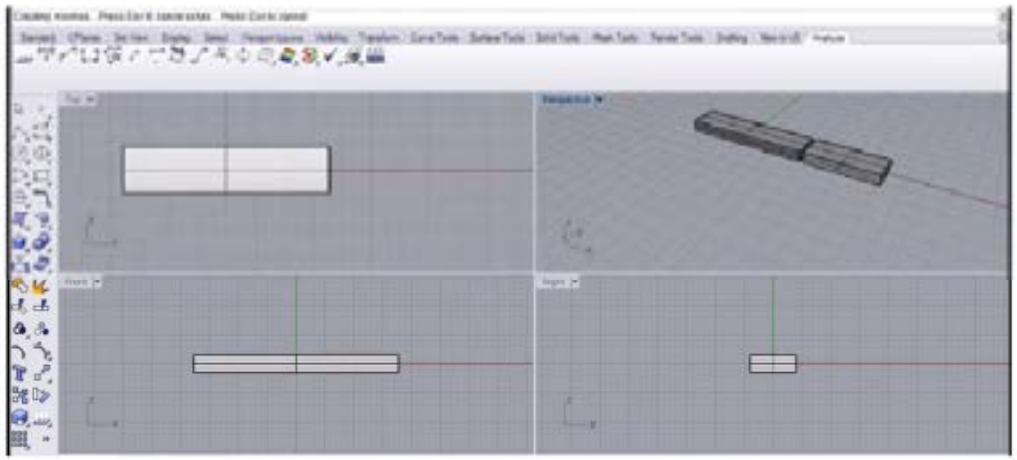
The component bodies are designed to be hydrodynamically quite dissimilar. Consequently, although the power take-off is solely in flex around the hinge, there is extensive cross-coupling with other degrees of freedom, and when excited by wave action the device responds not only in flex but substantially in heave and also pitch and surge. This results in greater cancellation of the incoming wave and a broader bandwidth response than a standard hinged raft.



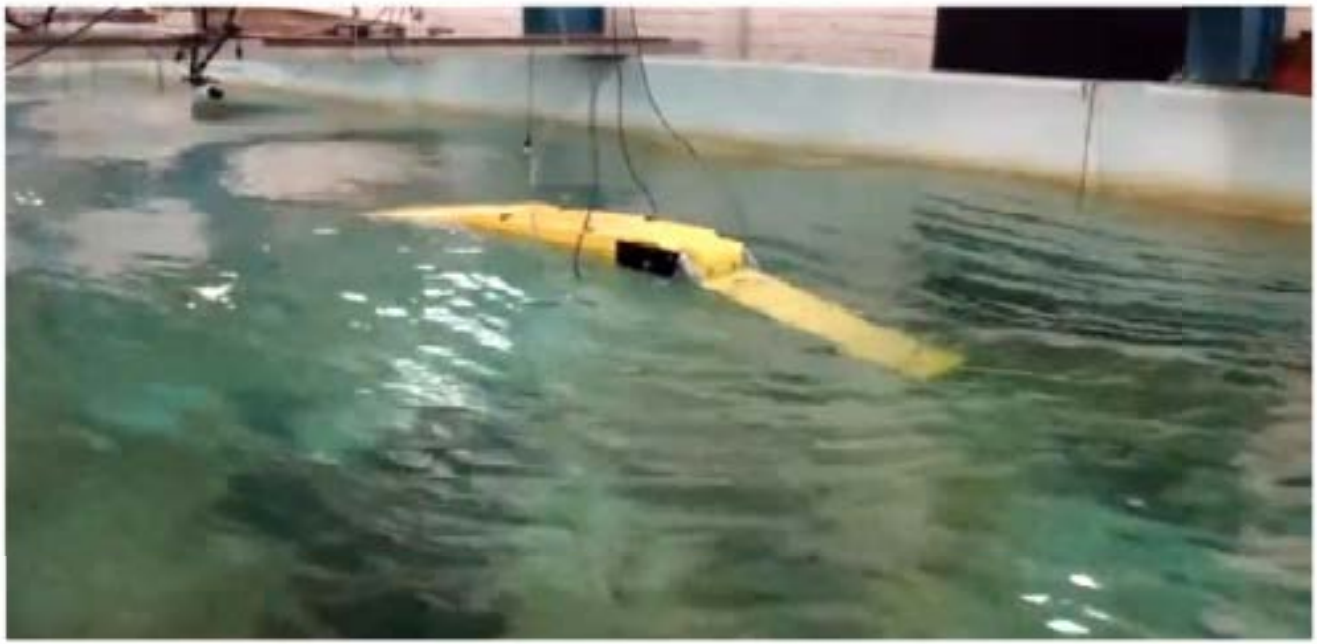
[1] https://www.waveenergyscotland.co.uk/programmes/details/novel-wave-energy-converter/mocean-wave-energy-converter/

Development

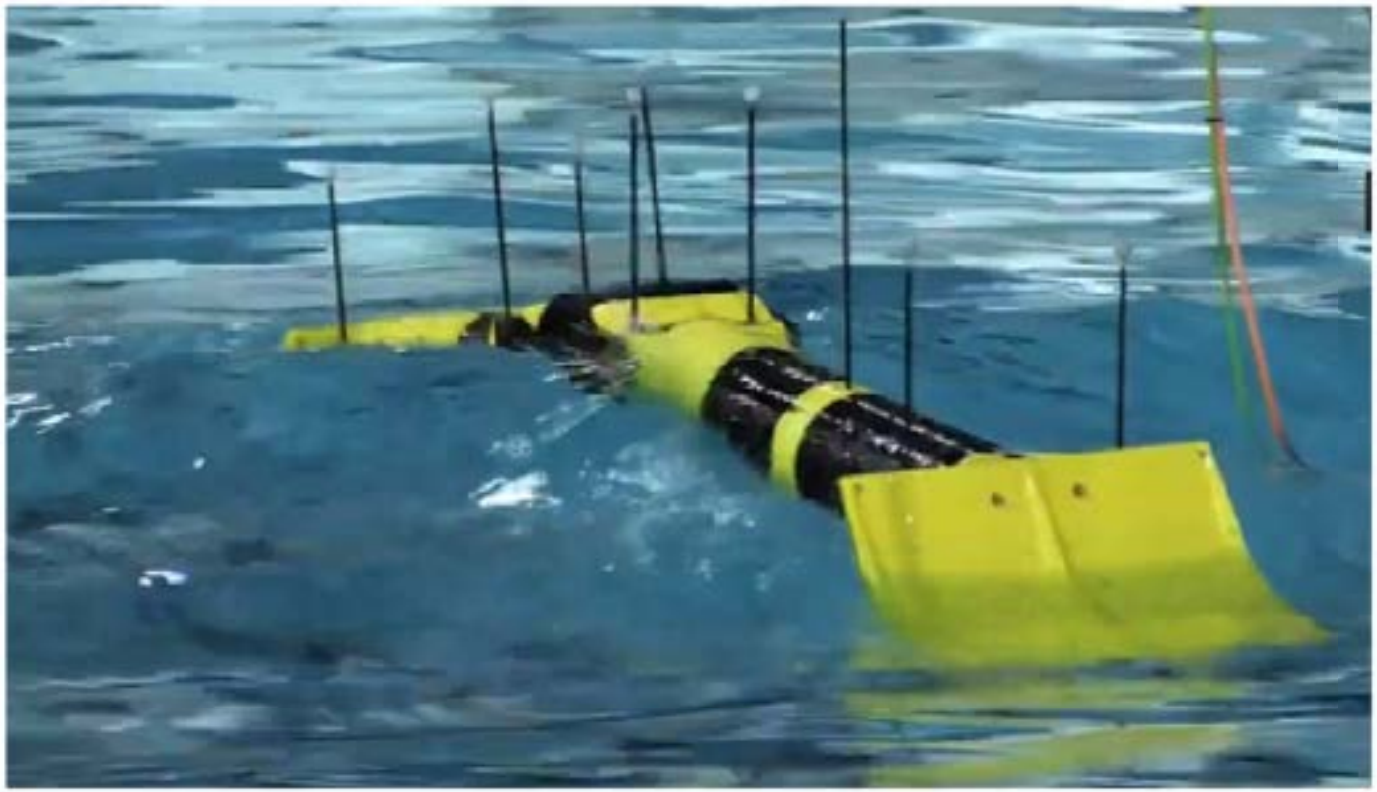
The underlying principle of the Pelamis was taken all the way back to TRL-1, where the concept of introducing hydrodynmaic coupling between DoFs was introduced to change to the TPL of the device. The design of the device was then fundamentally changed through countless iterations of optimisation via numercal simulation.



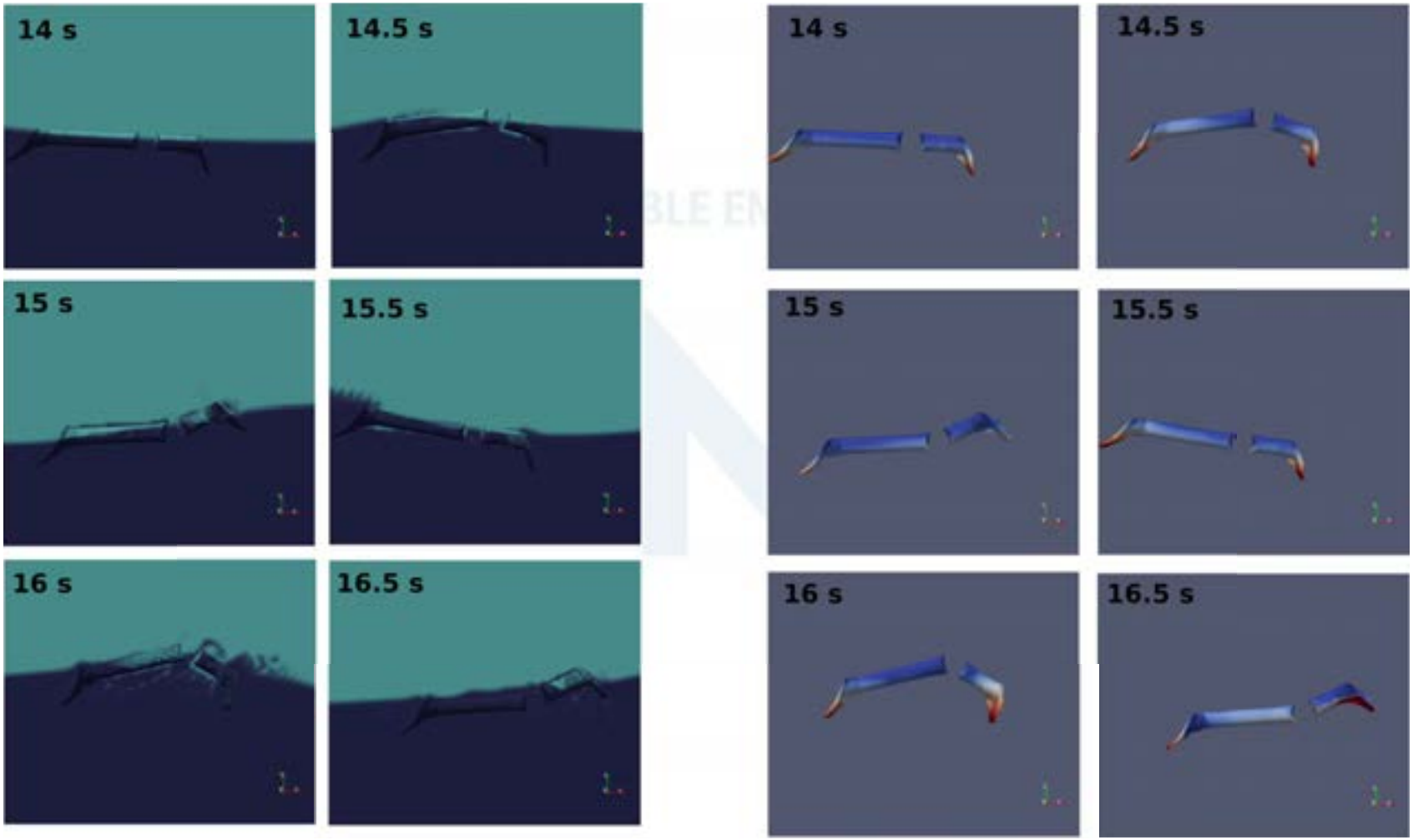
[1] https://www.youtube.com/watch?v=BxtZNh5OSQw



[1] https://www.youtube.com/watch?v=oVeDlnAy_V0



[1] https://www.youtube.com/watch?v=lmaH6-WvkbI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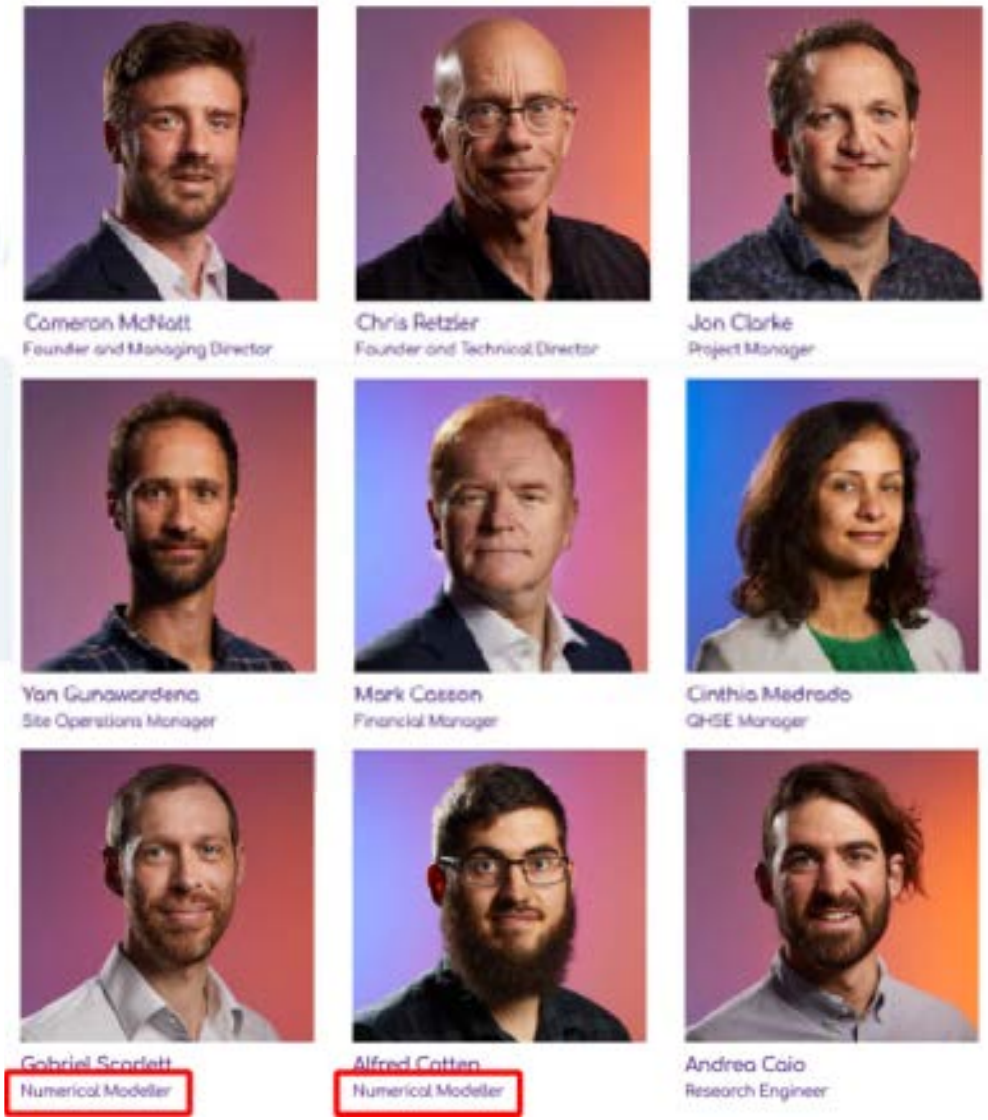
2 out of 9 employees are numerical modellers



Definition

"A NWT is a generic name of numerical simulators for nonlinear free surface waves, hydrodynamic forces and floating body motions" [2]

[1] Tanizawa, K, *The state of the art on numerical wave tank*, In Proceeding of 4th Osaka Colloquium on Seakeeping Performace of Ships, 2000

History

NWTs for MRE piggybacks on work from other well established ocean engineering fields

- Shipping
- Offshore Oil and Gas

[1] Tanizawa, K, *The state of the art on numerical wave tank*, In Proceeding of 4th Osaka Colloquium on Seakeeping Performace of Ships, 2000

Historical Perspective

Therefore NWTs were based on **linear hydrodynamics**

Assumptions

- Incompressible fluid
- Inviscid fluid
- Irrotational fluid
- Small amplitude waves
- Small amplitude body motions

Linear hydrodynamics

- Forced mass-spring-damper system:
  $m\ddot{x}(t) + d\dot{x}(t) + kx(t) = F(t)$

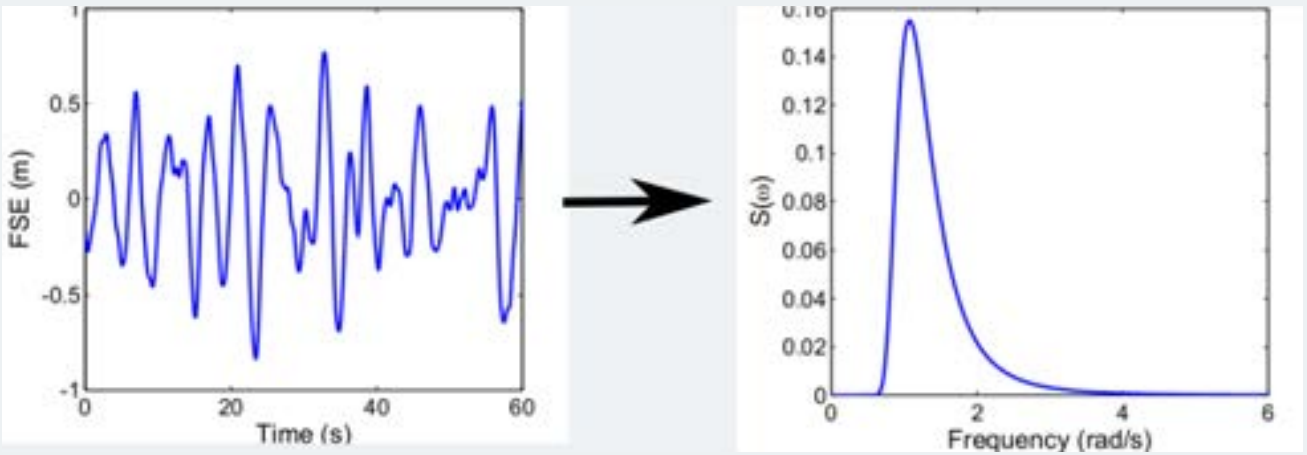
Linear hydrodynamics

- Forced mass-spring-damper system:
  $m\ddot{x}(t) + d\dot{x}(t) + kx(t) = F(t)$
- Terms
  - Mass:
  - Spring:
  - Damper:
  - Forcing:

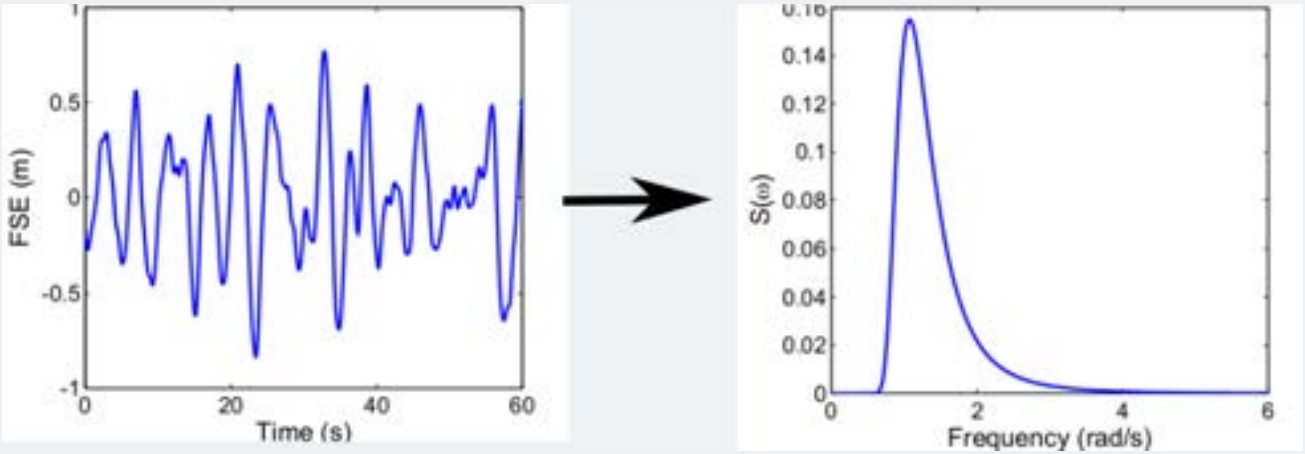
Linear hydrodynamics

- Mass-spring-damper system
  $m\ddot{x}(t) + d\dot{x}(t) + kx(t) = F(t)$
- Terms
  - Mass: Dry mass plus hydrodynamic added mass
  - Spring: Hydrodynamic restoring force
  - Damper: Hydrodynamic radiation force
  - Forcing: Wave excitation force

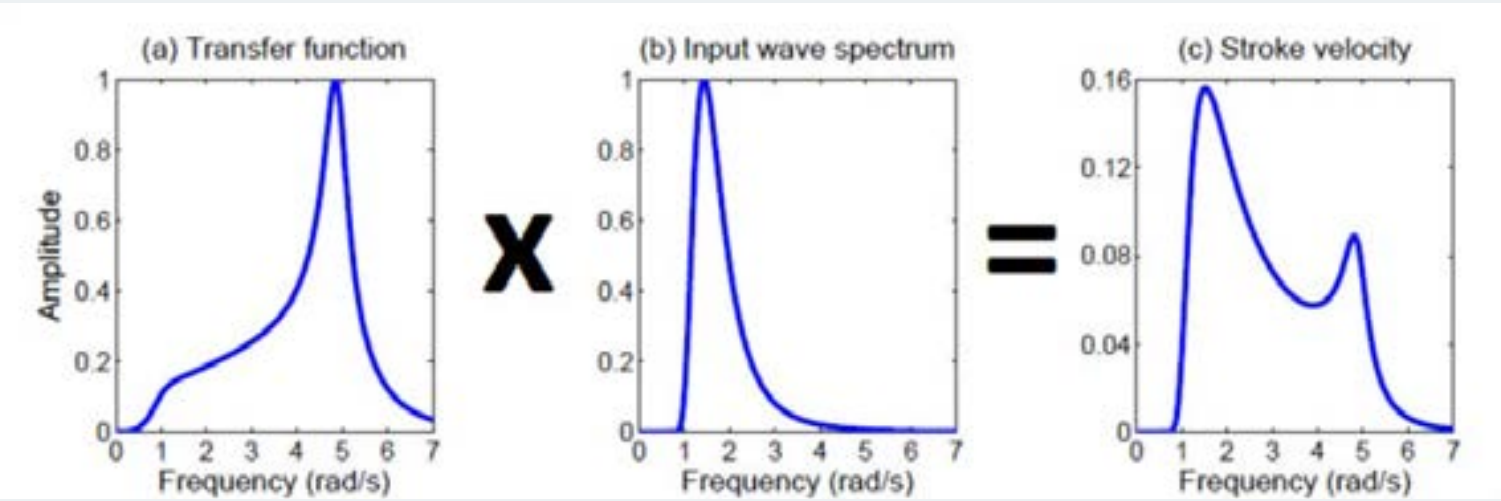
Frequency Domain

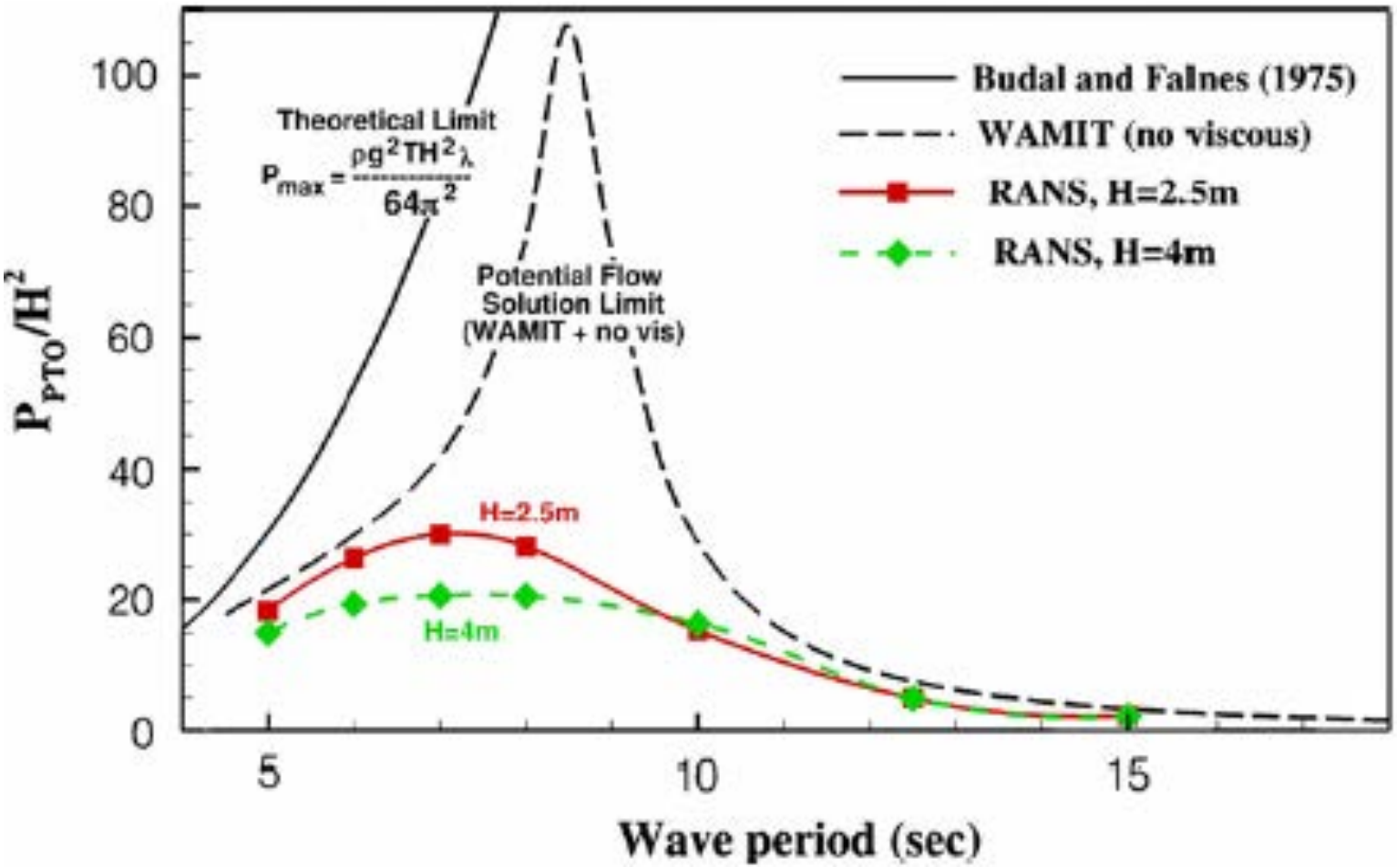


Frequency Domain

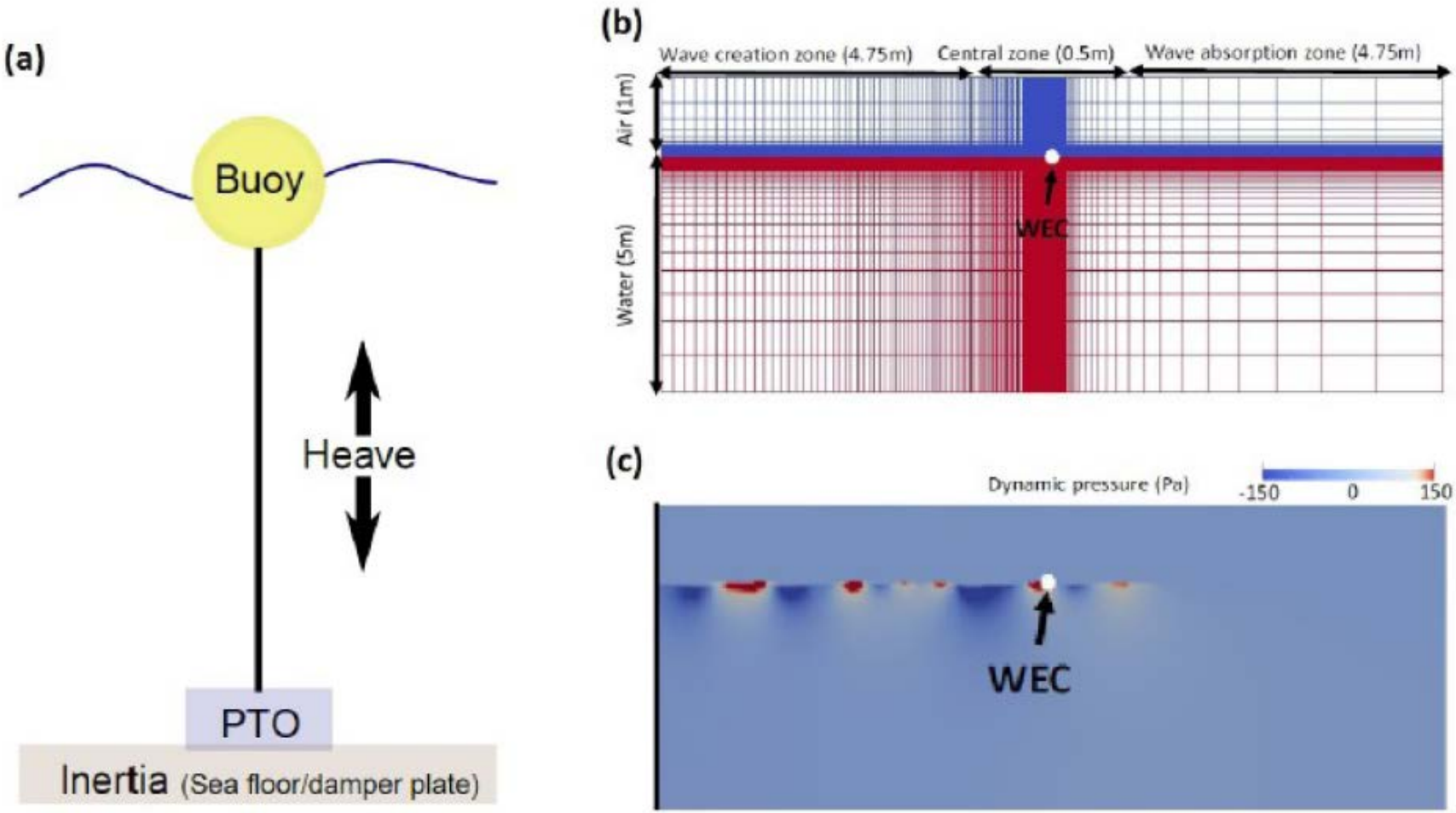


Transfer Functions

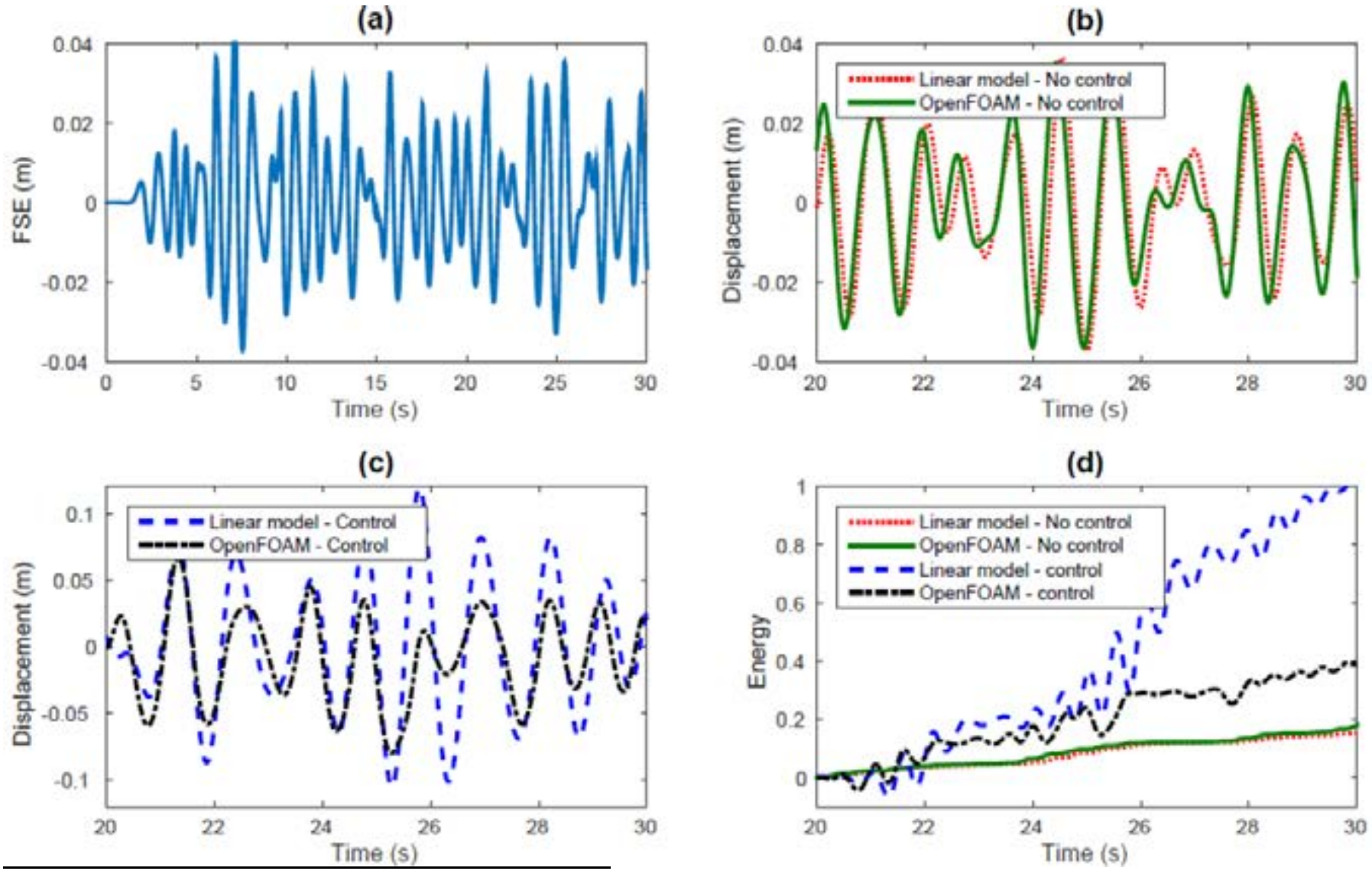




[1] Yu and Li, *Reynolds-Averaged Navier-Stokes simulation of the heave performance of a two-body floating point-absorber wave energy system*, Computers and Fluids, 2013



[1] Davidson et al, *Evaluation of Energy Maximising Control Systems for WECs using OpenFOAM*, OpenFOAM - Selected papers from the 11th Workshop, 2019



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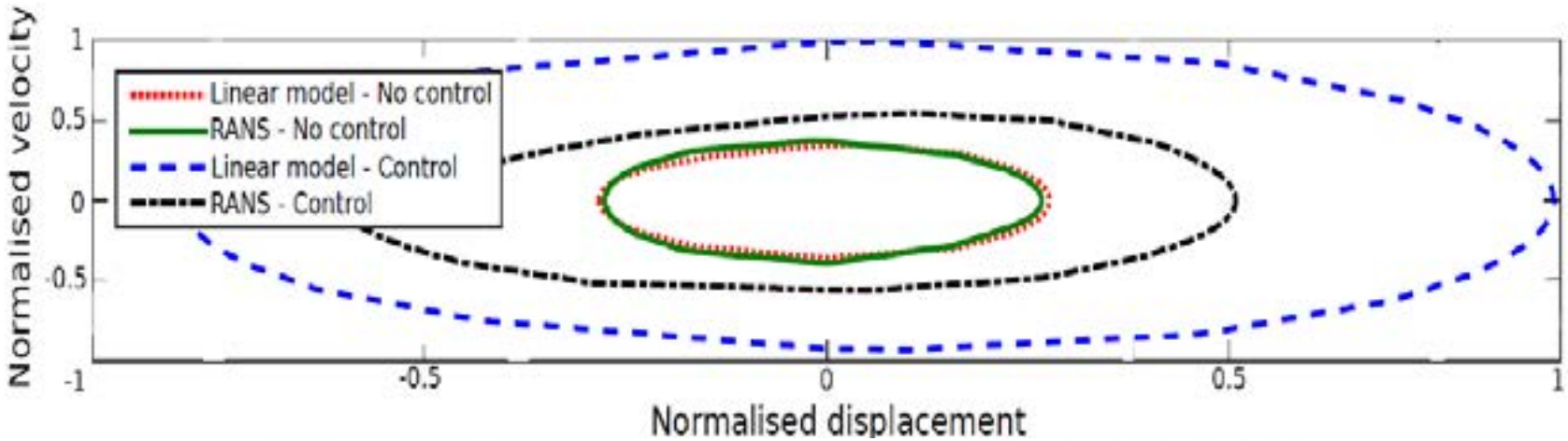
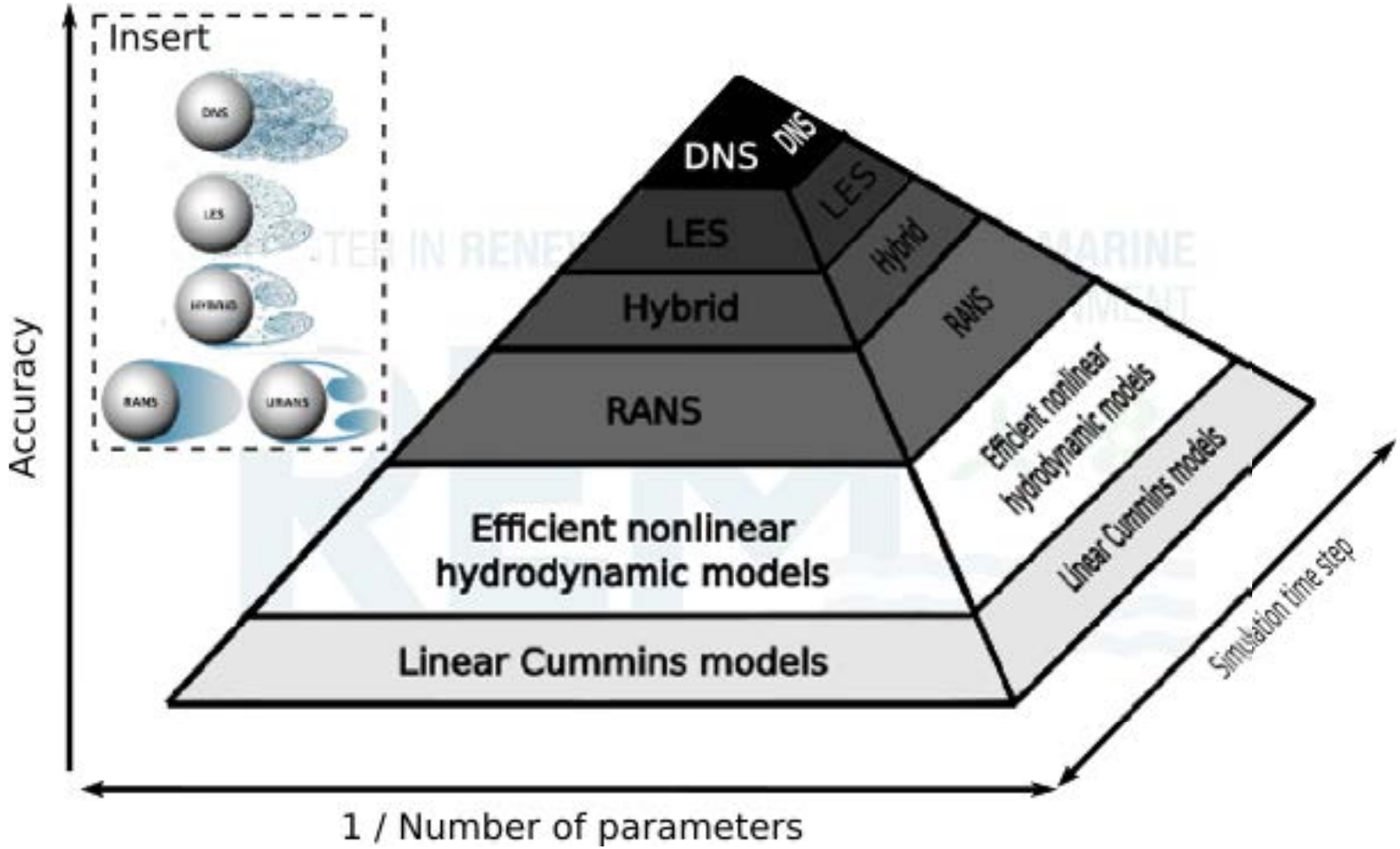
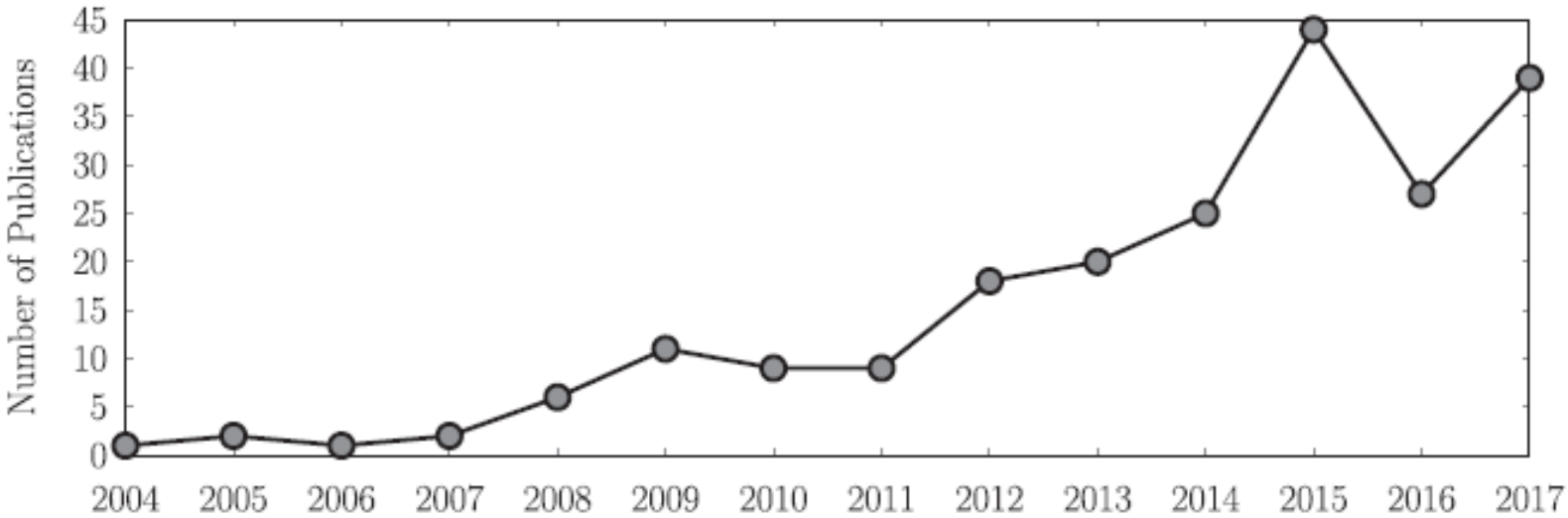


[1]Davidson, Windt, Giorgi, Genest and Ringwood, *Evaluation of Energy Maximising Control Systems for WECs using OpenFOAM*, OpenFOAM - Selected papers from the 11th Workshop, 2019



[1] Davidson and Costello, *Efficient nonlinear hydrodynamic models for wave energy converter design - A scoping study*, Journal of Marine Science and Engineering (Special Issue "Nonlinear Numerical Modelling of Wave Energy Converters"), 2019

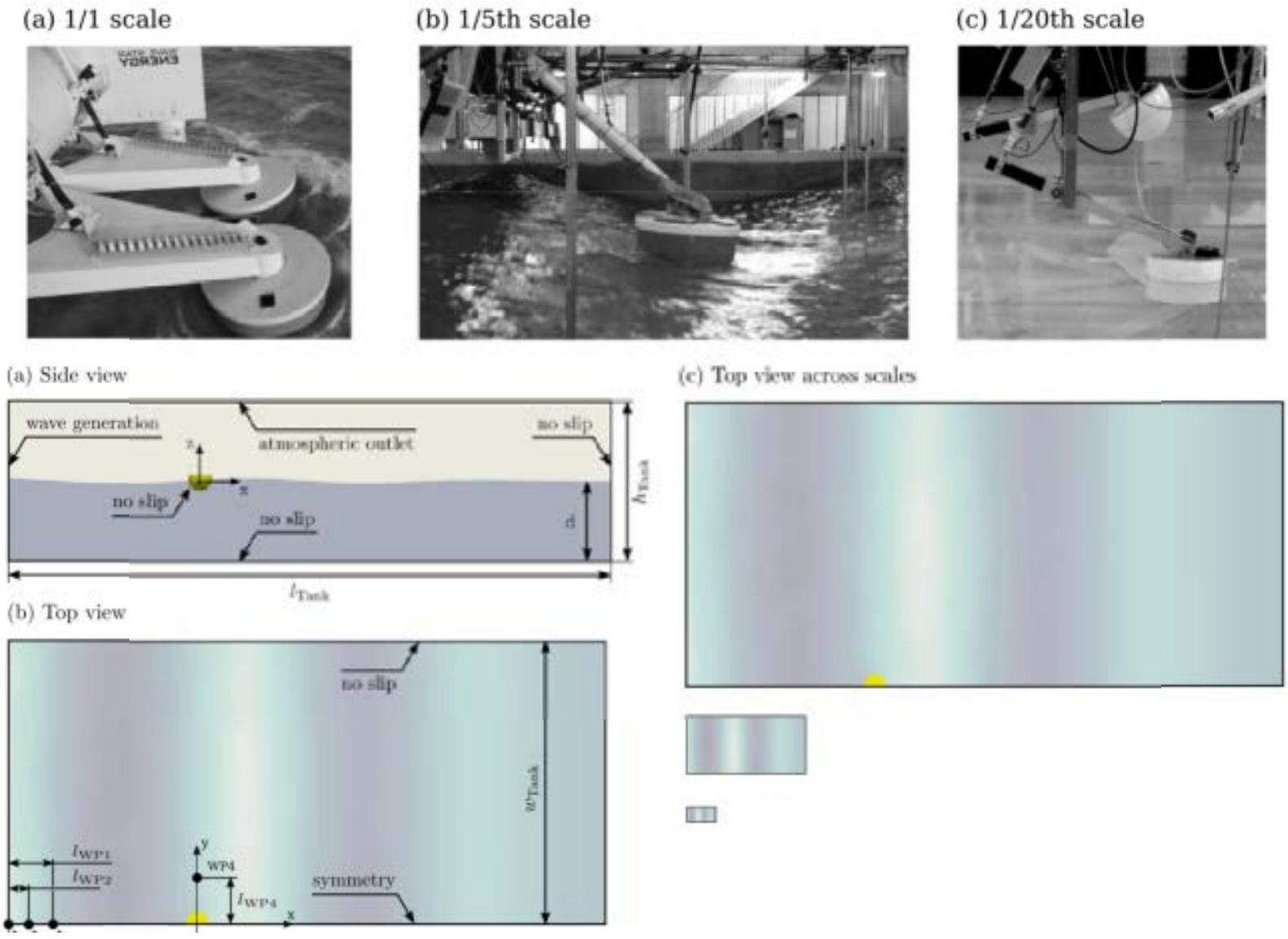


[1]Windt, Davidson and Ringwood, *High-fidelity numerical modelling of ocean wave energy systems: A review of CFD-based NWTs*, Renewable and Sustainable Energy Reviews, 2018

NWT - Strengths and weaknesses

Advantages

- **Scale:** NWTs offer significant advantage of being able to test at full scale. The scaling issue is a drawback of using PWTs, since nonlinear effects may not upscale correctly from PWT to full scale.



[1]Windt, Davidson and Ringwood, *Numerical analysis of the hydrodynamic scaling effects for the Wavestar wave energy converter*, Journal of Fluids and Structures, 2021

Advantages

- **Reflections:** NWTs are superior in eliminating undesired reflections from the tank walls contaminating the experiments, with NWTs capable of limiting reflections below 1% [3], whereas world class PWTs can incur reflection coefficients of around around 10% in the wave propagation direction, and often have no absorption from the side walls.

[3] Windt, Davidson, Schmitt and Ringwood, *On the Assessment of Numerical Wave Makers in CFD Simulations*, Journal of Marine Science and Engineering, 2019

Advantages

- **Constraints and restraints:** NWTs allow the MRE device to be easily constrained to single DoFs if desired, whereas PWTs require complex mechanical restraints to achieve this task, which introudce friction and alter device dynamics. The same is true for external forces, which can be applied exactly to the MRE device in a NWT, but require physical actuators in a PWT which introduce some level of inaccuracy.

Advantages

- **Measurements:** NWTs allow non-intrusive measurement of as many variables as desired, with zero measurement noise, without requiring physical measuring devices to be added to the system. NWTs also allow easy measurement of some useful vairables which are extremely difficult/impossible to measure in a PWT, such as the exact pressure everywhere on the MRE device surface, or the fluid velocity and vorticity around the MRE device.

Advantages

- **Cost:** In the design phase of a MRE device development, varying the MRE device geometry may be necessary for optimisation studies, which can easily implemented in a NWT through a few lines of code, whereas a physical prototype needs to be manufactured for each geometry tested in a PWT.

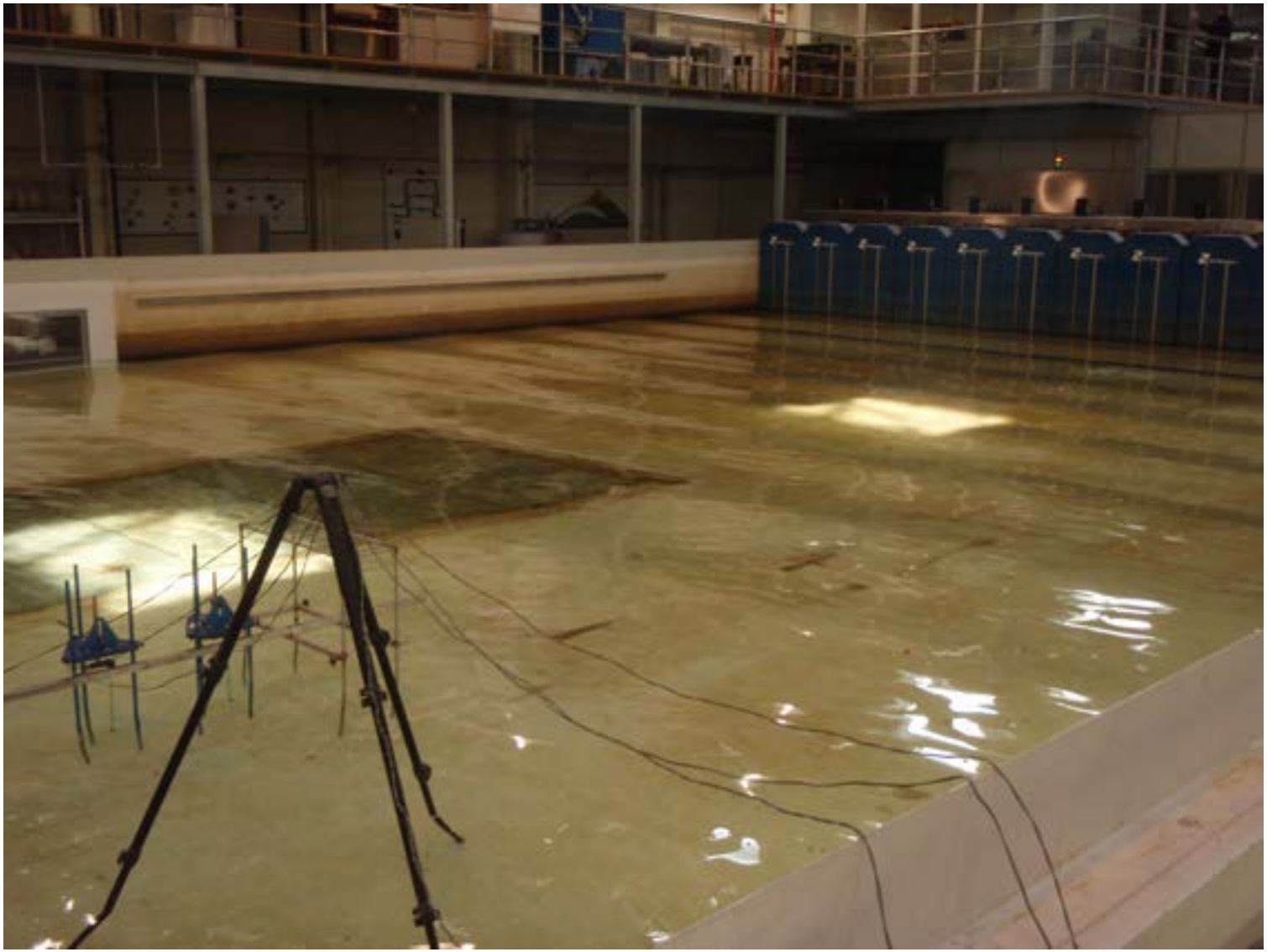
Advantages

- **Availability:** Testing time in PWT facilities must be organised months in advance and is kept to a tight schedule, whereas with the rise of cloud computing, NWT resrouces are always available, multiple experiments can be run in parallel and testing time can be increased on the fly.

A few examples from my tank testing experiences

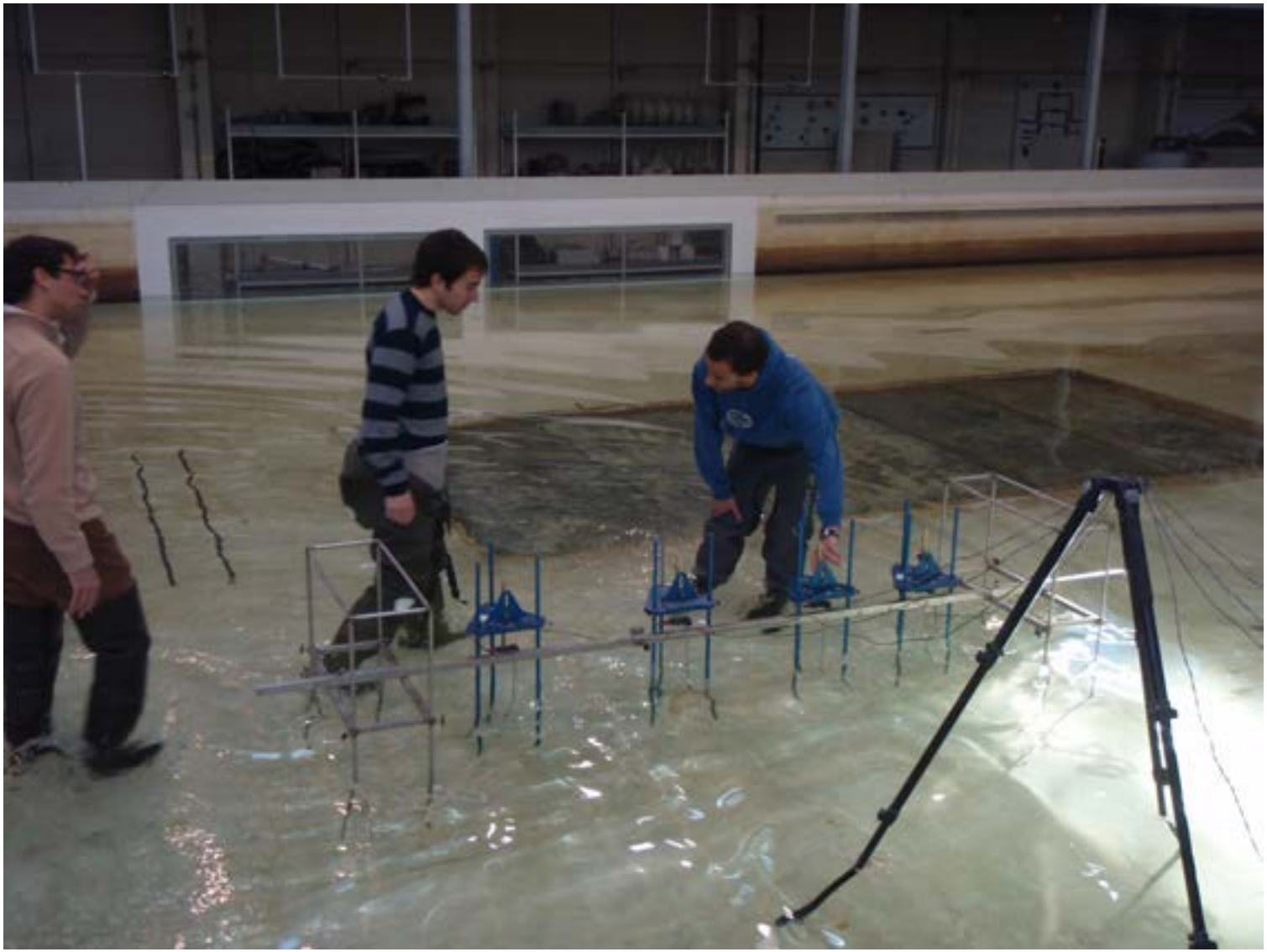
The role of NWTs in MRE device development

Physical Wave Tanks - University of Porto



The role of NWTs in MRE device development

Physical Wave Tanks - University of Porto



The role of NWTs in MRE device development

Physical Wave Tanks - Aalborg University

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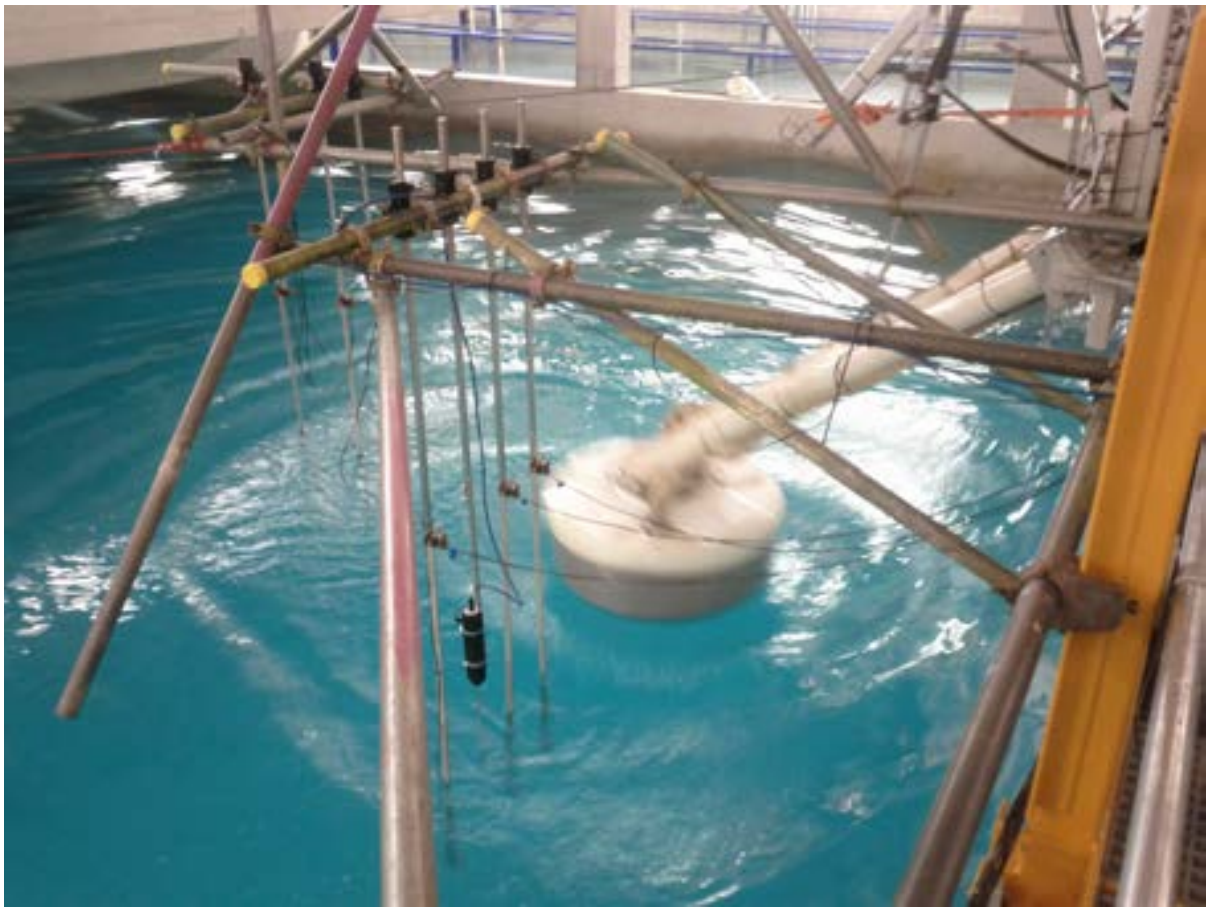
Physical Wave Tanks - Aalborg University

The role of NWTs in MRE device development

Physical Wave Tanks - Plymouth University Ocean Basin



The role of NWTs in MRE device development

Physical Wave Tanks - Plymouth University Ocean Basin

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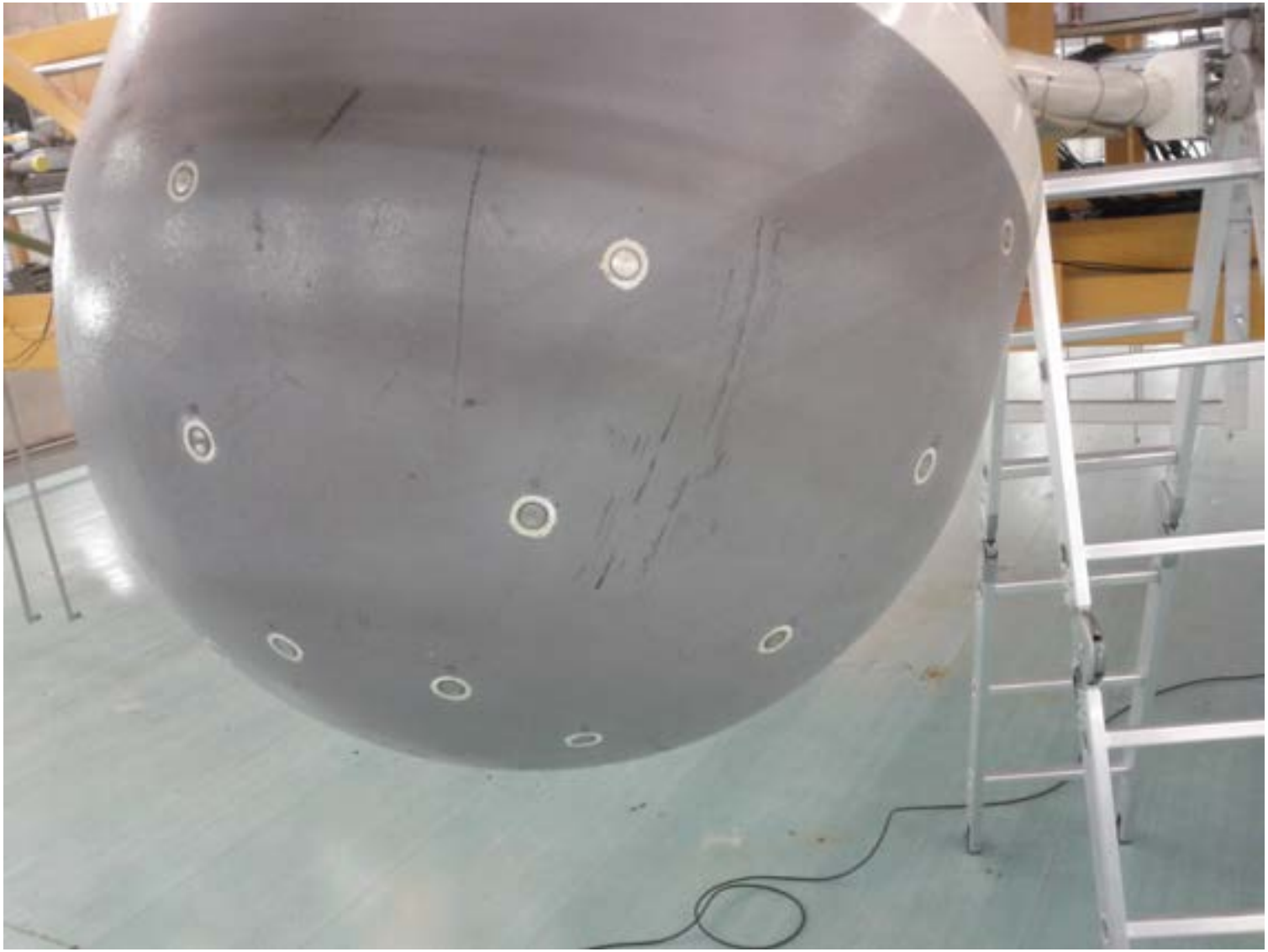
Physical Wave Tanks - Plymouth University Ocean Basin



The role of NWTs in MRE device development

Physical Wave Tanks - Plymouth University Ocean Basin

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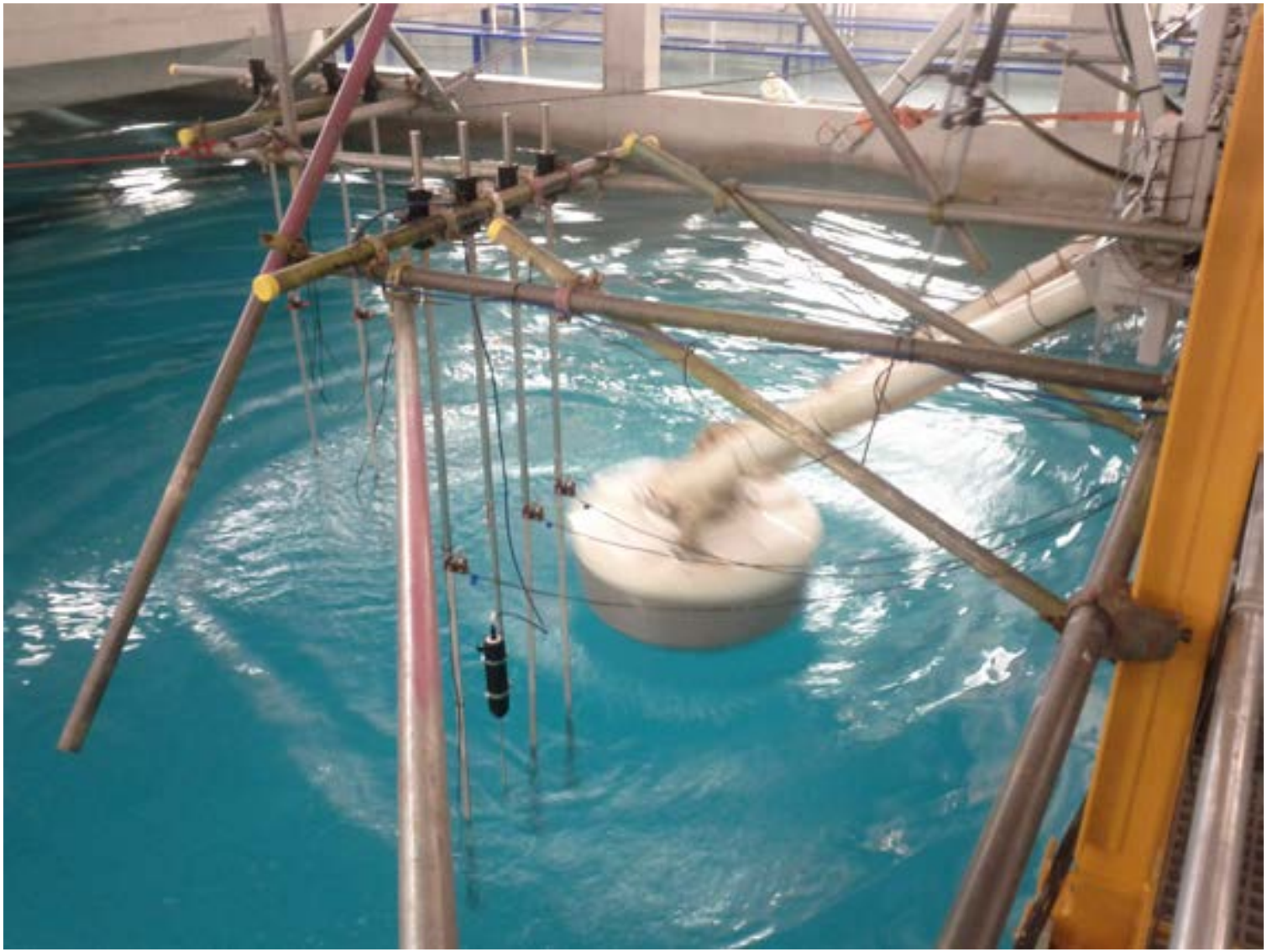
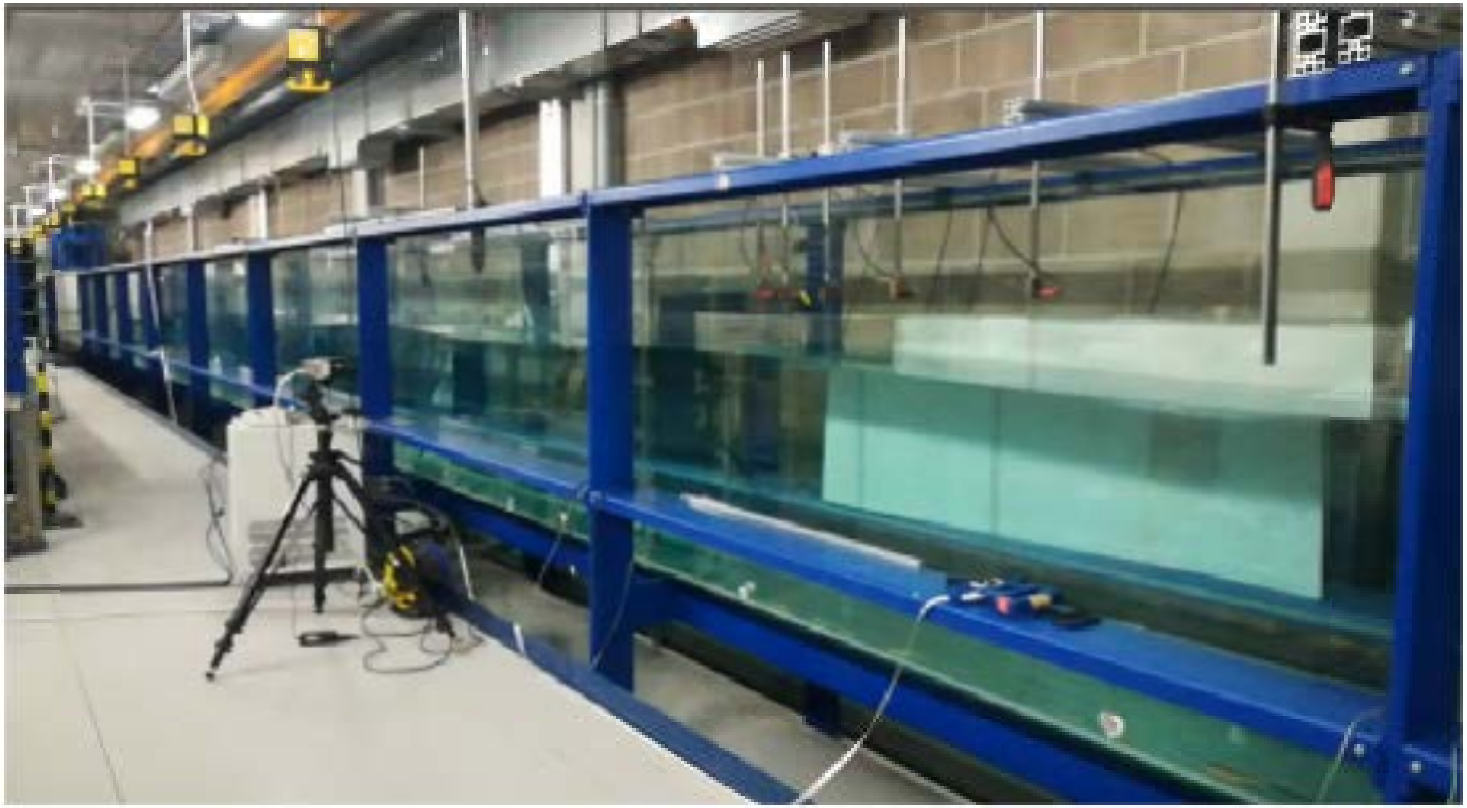


The role of NWTs in MRE device development

Physical Wave Tanks - Wavestar Prototype

The role of NWTs in MRE device development

Physical Wave Tanks - Plymouth University Wave Flume

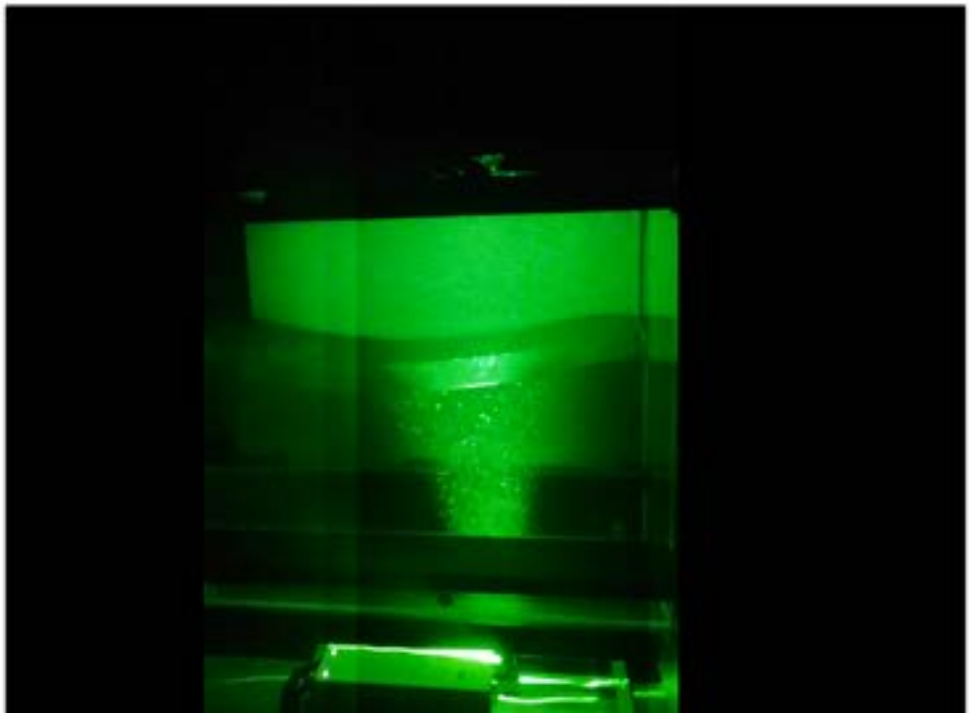


The role of NWTs in MRE device development

Physical Wave Tanks - Plymouth University Wave Flume

The role of NWTs in MRE device development

Physical Wave Tanks - Plymouth University Wave Flume



The role of NWTs in MRE device development

Physical Wave Tanks - IST Lisbon

Disadvantages

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- **Computational expense:** There is a trade-off between the fidelity of a NWT simulation and the computational expense. More accurate simulations require more computational expense.

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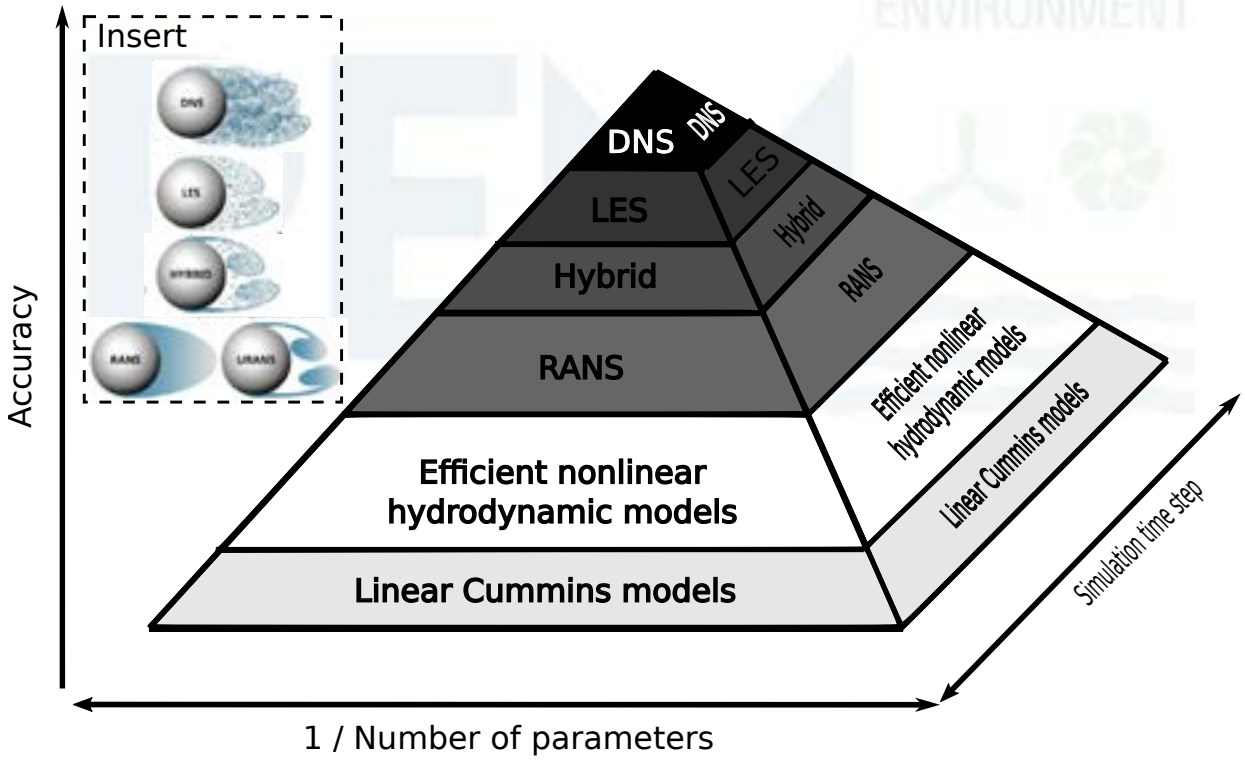

Disadvantages

- **Expertise requirement:** Setting up and post-processing a 'good' NWT simulation requires a degree of expertise.

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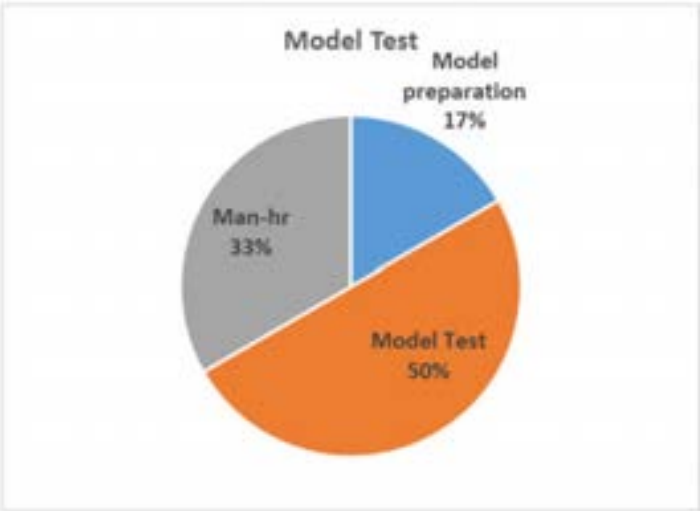
Disadvantages

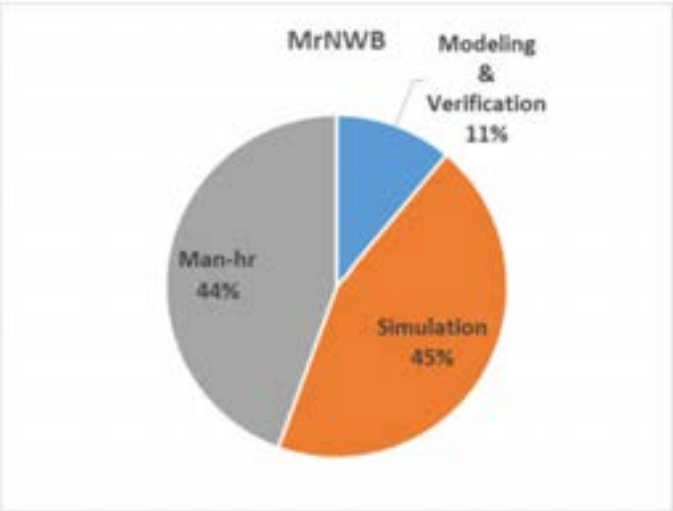
- **Validation:** Results from NWT experiments need to be validated against physical experiment before they are deemed trustworthy.

Costs and Benefits of CFD-Based Numerical Basin

Based on the cost and time estimation exercise, the most expected benefits of using CFD-based Numerical Wave Basin are:

- Predictable and reliable time schedule and cost estimation
- Quick turn-around time for changes in design and metocean data during the project
- Lower cost and time for the second campaign of NWB simulation in case additional simulation is required





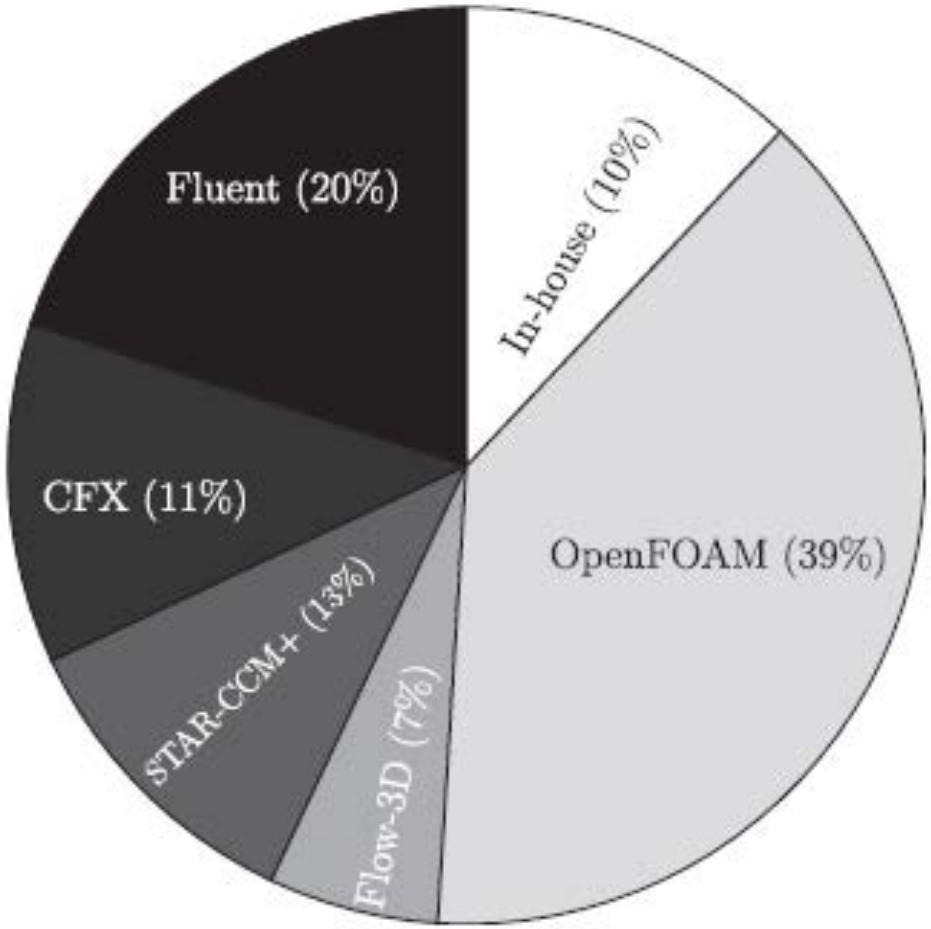
[2] Kim et al, *Technical and economical readiness review of CFD-based numerical wave basin for offshore floater design*, Offshore Technology Conference, 2016

Opensource software

- Eliminates costs/license fees for software
- Can reduce required manhours by sharing/using pre-developed NWTs/toolboxes (see for example [1])
- Many useful Opensource software and projects:
  - Software
    - OpenFOAM (see for example [2])
    - SPHysics
  - Projects
    - OpenORE (www.openore.org)
    - CCP-WSI (www.ccp-wsi.au.uk)

[1] Schmitt, Windt, Davidson, Ringwood and Whittaker, *The efficient application of an impulse source wavemaker to CFD simulations*, Journal of Marine Science and Engineering, 2019

[2] Davidson et al, *Implementation of an OpenFOAM Numerical Wave Tank for Wave Energy Experiments*, Proc. 11th European Wave and Tidal Energy Conference (EWTEC), Nantes, 2015



[1]Windt, Davidson and Ringwood, *High-fidelity numerical modelling of ocean wave energy systems: A review of CFD-based NWTs*, Renewable and Sustainable Energy Reviews, 2018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