Ocean Grazer 3.0

A hybrid, modular and scalable renewable energy capture and storage device

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Overview

- Concepts
- Project status
- Research output
- Open questions
- Conclusions

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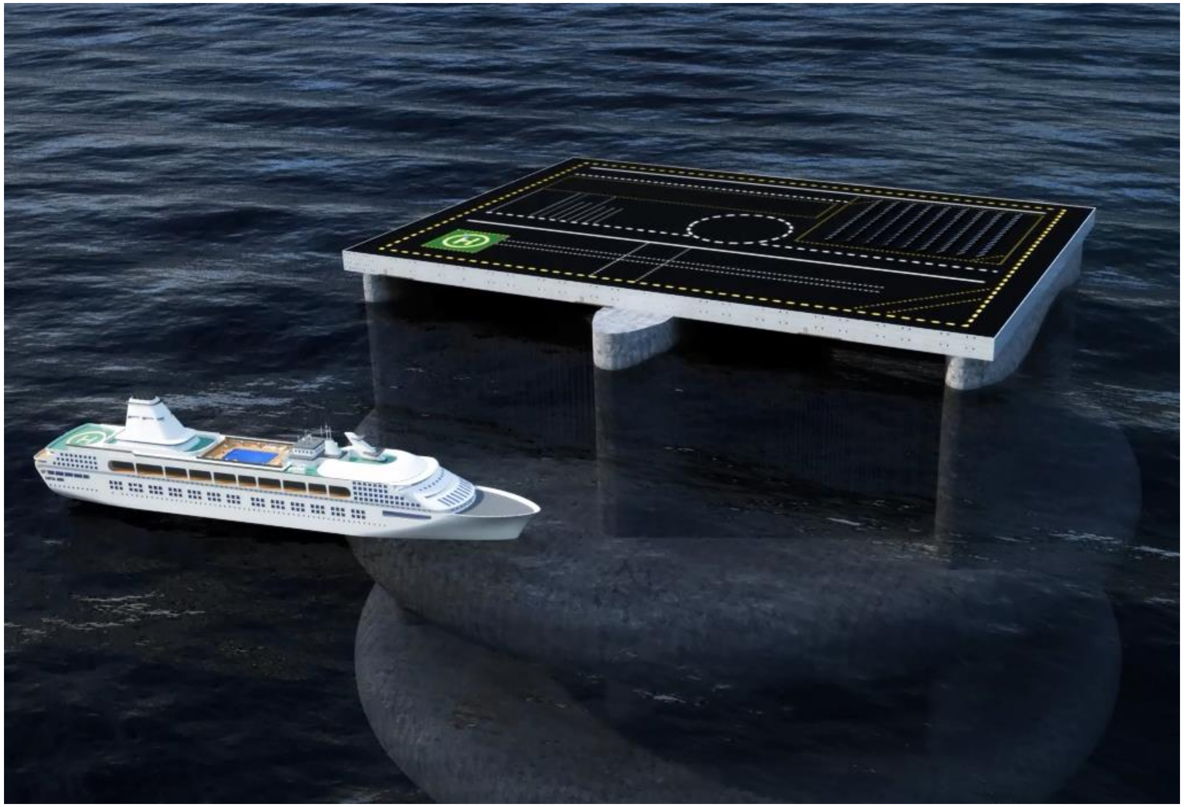
Concept 1.0 (1/3)



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Concept 1.0 (2/3)

- Integrated Wind, Wave & Storage
  - Increased resource efficiency
  - Shared network infrastructure
- Lossless Storage & Controllable Output
  - Independent of weather conditions
  - Fully isolated internal working structure
  - Market demand adaptability: energy buffer

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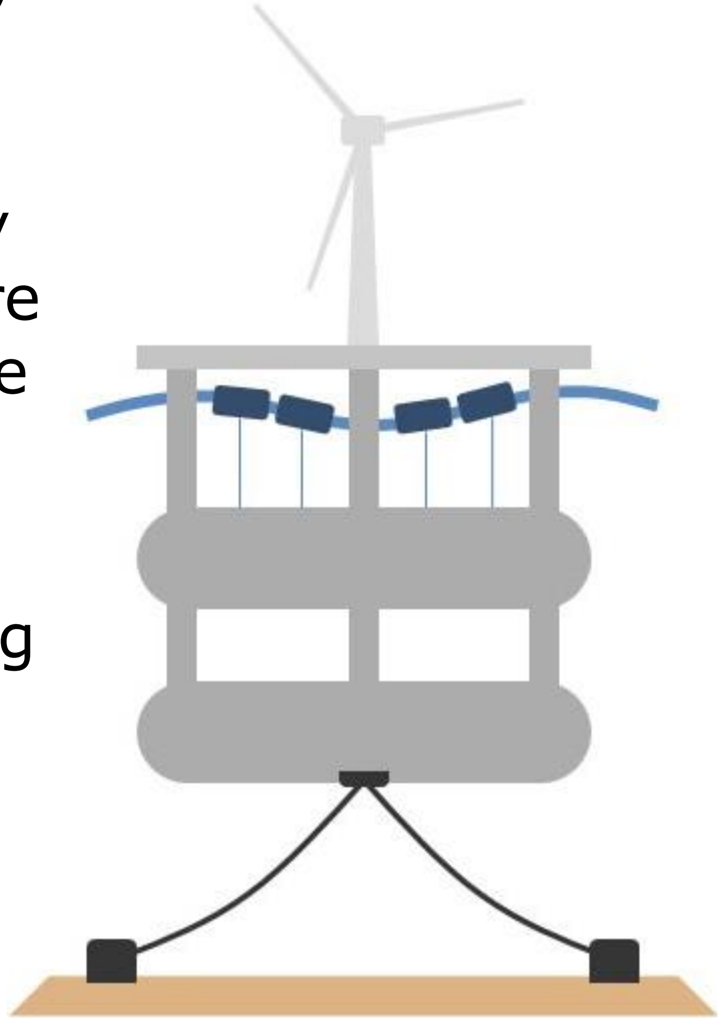

Concept 1.0 (3/3)

- Adaptability to Resource Variability
  - Energy absorbtion over full wave spectrum
  - Extraction efficiency maximization via wave prediction and sensing
- Preliminary LCOE calculations suggest non-viability; cost of superstructure alone is prohibitive

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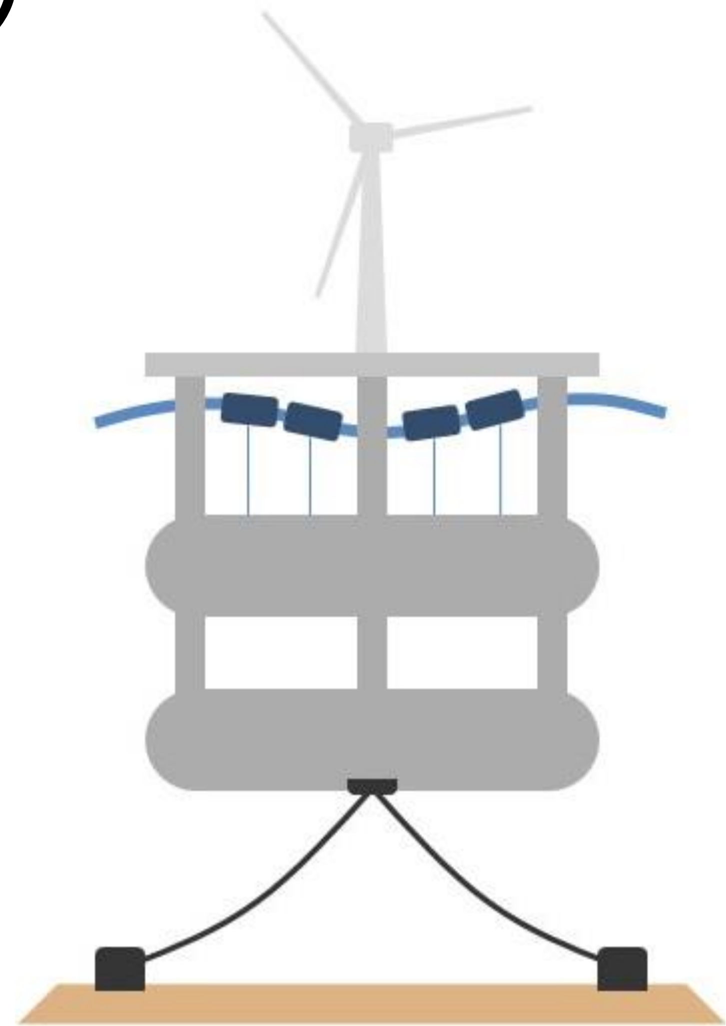
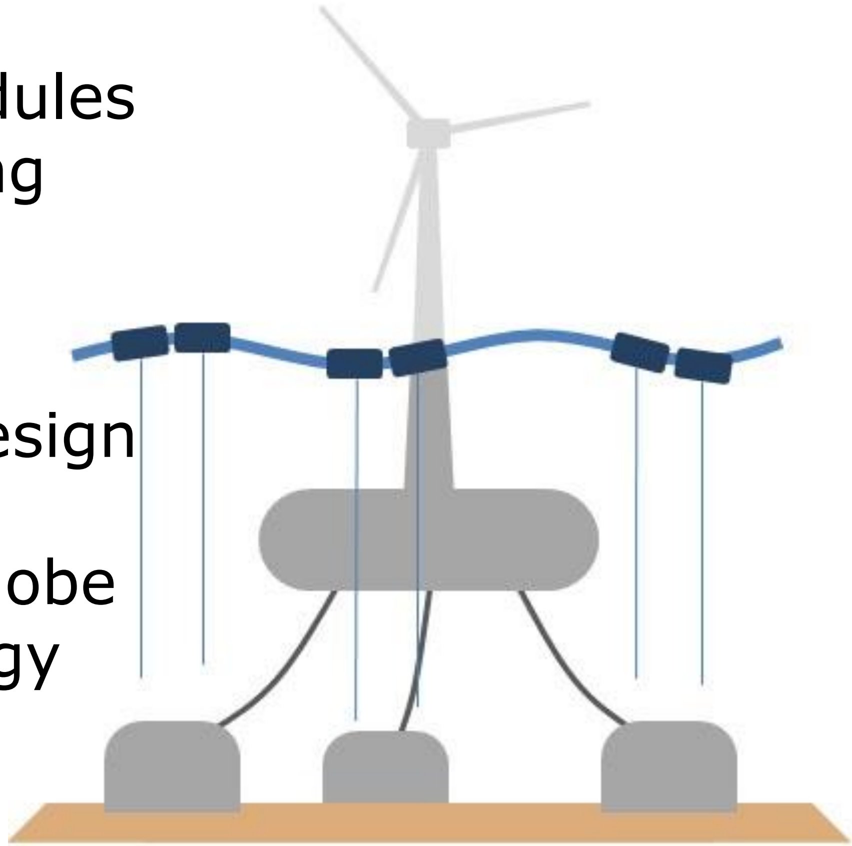


Concept 2.0

- *All features of 1.0 plus:*
- Self-contained fractal modules
  - Easy installation, mooring and maintenance
  - Increased stability with seabed-anchored pods
  - Omnidirectional array design
- Scalable Solution
  - Deployable across the globe
  - Multi-configuration energy farms



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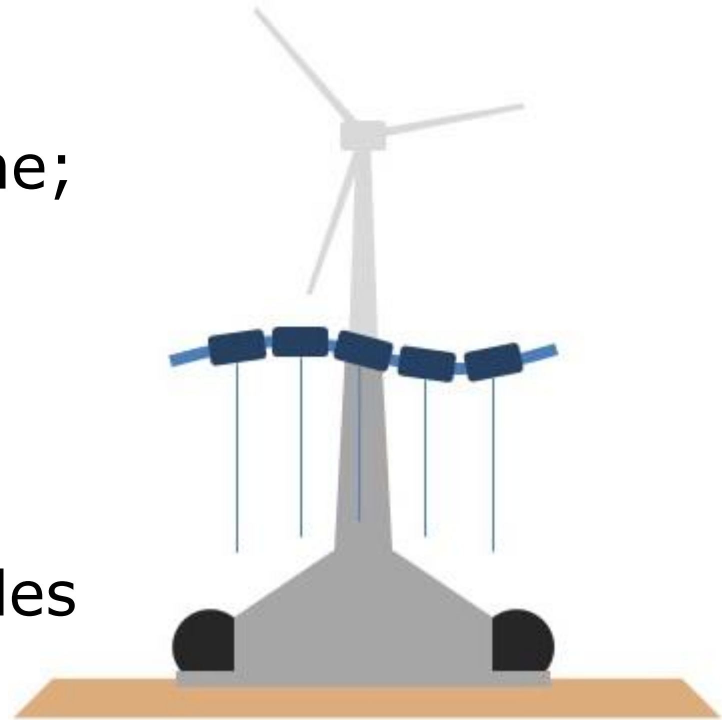
Concept 3.0 (1/2)

- *All features of 2.0 plus:*
- Gravity-based Foundation
  - Short on-site installation time; embedding within existing infrastructure
  - Limited disturbance to ecosystems
  - Reduced footprint via integration of storage modules within pods



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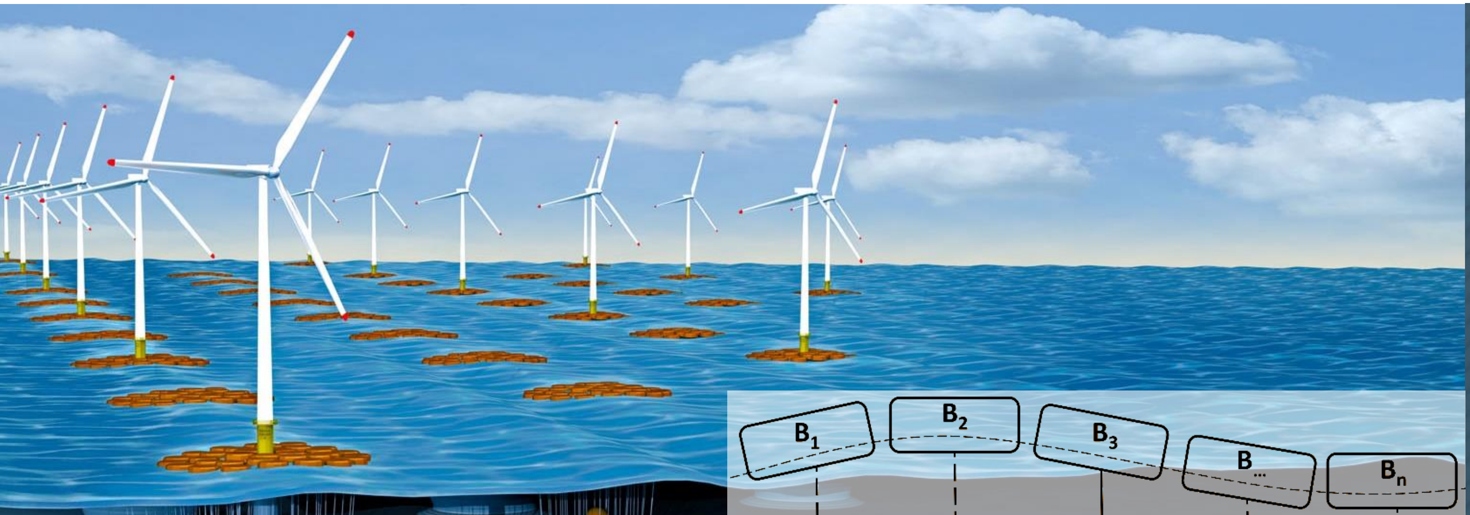
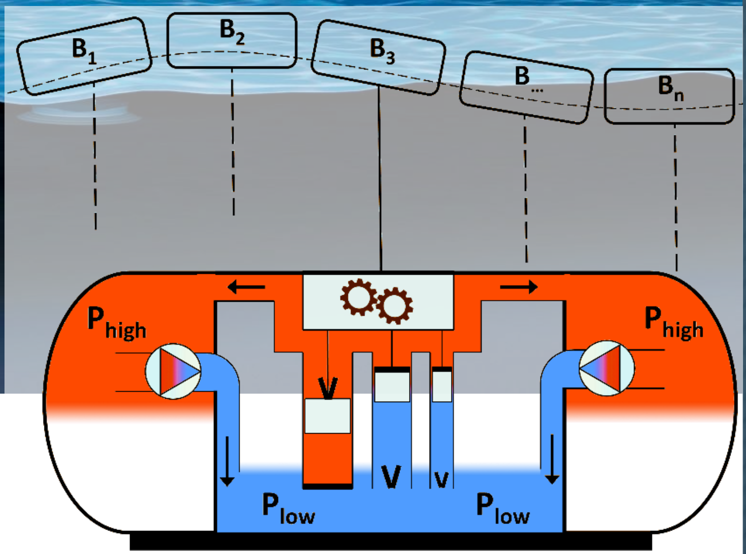
LCOE for OG3.0 calculated at 0.10 €/kWh
Assumptions: 60% total efficiency; 17 GWh/y power output; 23 M€ investment

Concept 3.0 (2/2)





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Project status (1/4)

- Research work at U Groningen started in 2013
- Internal funding received for 2 postdoctoral positions and proof-of-concept prototypes
- Scientific output
  - 2 patents: one covering OG1.0 and OG2.0 since 2014; new patent for OG3.0 filed end of 2017
  - 4 journal papers
  - 9 peer-reviewed conference papers
  - 6 other conference papers (extended abstracts)

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Project status (2/4)

› Supervision
- 1 postdoc ongoing and 1 finished
- 2 PhDs ongoing
- >15 master and >30 bachelor graduates; 6 master and 8 bachelor students ongoing

› Networking
- Province of Groningen and >5 industrial partners (Consmema, Demcon, Thales, etc.)
- More than 20 academic partners from >8 universities
- Number of dissemination activities in the press

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Project status (3/4)

- Day of the Engineer (21 March 2018)

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Project status (4/4)

- Ocean Grazer B.V. incorporated May 2018
  - F. Bliek, CEO
  - M. van Rooij, CTO
  - A.I. Vakis & B. Jayawardhana, advisory board
- Plan: secure funding from investors within next 18 months to design, build and deploy comprehensive and integrated scale prototype of the WEC in a wave tank (within 4 years)
- Long term plan: deploy at sea with wave sensing capabilities (preferably embedded in wind farms)

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Research output (1/14)

- Wind turbine technology (not our focus)
- **Wave Energy Converter (WEC) technology**: main focus of past research (discussed next)
- Preliminary results on:
  - Platform/ superstructure design & mooring
  - Modes of energy transfer to the grid
  - Levelized Cost of Electricity (LCOE) estimates
- Open questions: survivability; manufacturing; installation & maintenance; embedding in existing infrastructures; policy, etc. (discussed later)

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Research output (2/14)

› **OG-WEC’s Power take-off system modeling**:
› Single-piston pump (SPP) with single buoy
  ▪ Hydrodynamics, hydraulics, lubrication, dynamics
  ▪ Nonlinear pumping force prediction (efficiency)
› Multi-piston pump (MPP) with single buoy
  ▪ Approximation: effective pumped volume changed in discrete steps
› Multi-pump, multi-piston power take-off (MP2PTO) system with floater blanket

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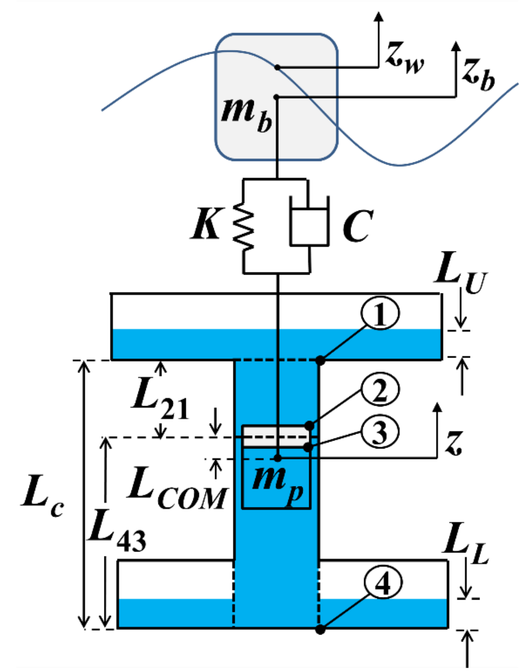
Research output (3/14)

› Single-piston pump (SPP) switching-state dynamic model with experimental validation



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Reasearch output (4/14)

- Upstroke v. downstroke dynamics: slamming
- Elastohydrodynamic lubrication (EHL) at the piston-cylinder interface
  - ISO Class HFC water-based hydraulic fluid yields best performance

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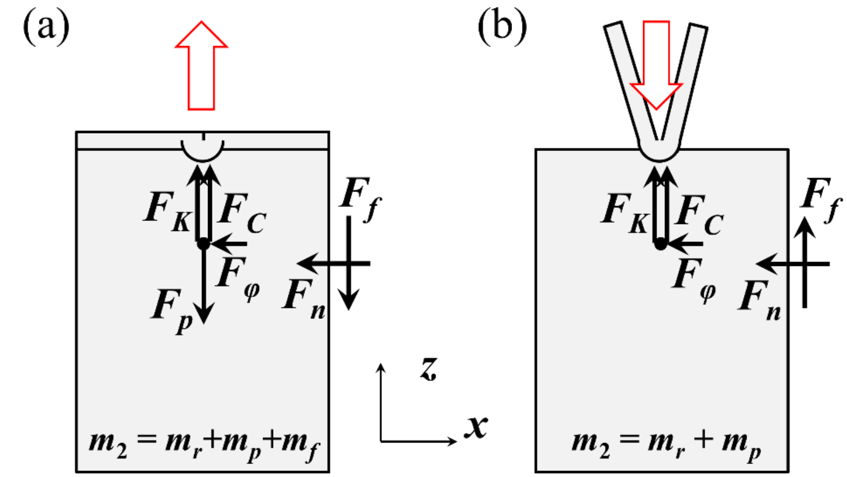
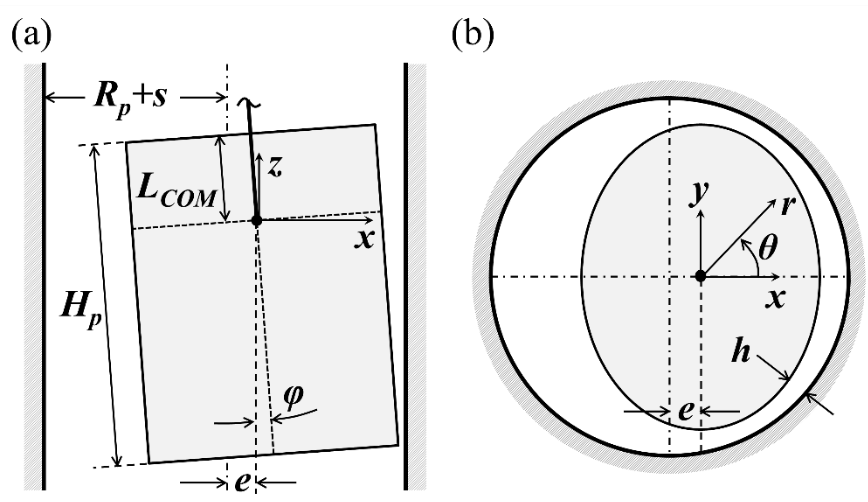
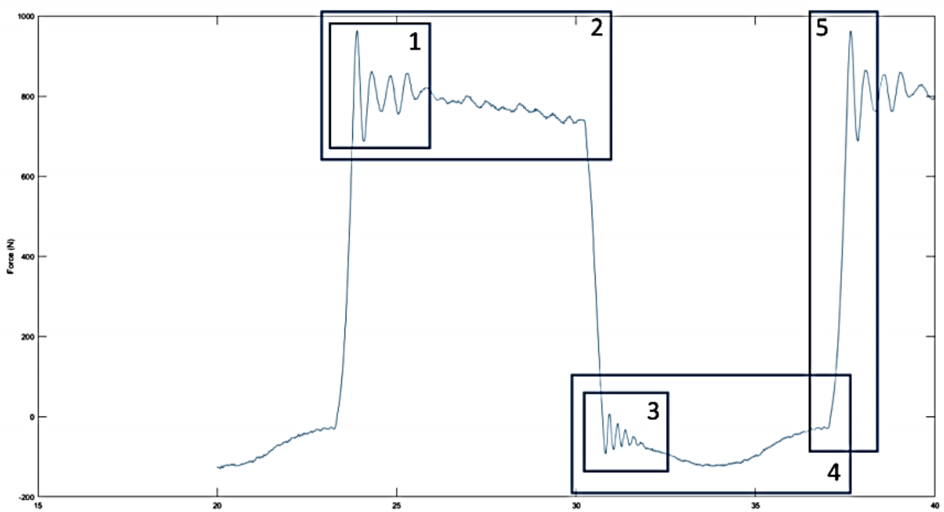




Research output (5/14)

- SPP experimental (left) and simulation results (right)



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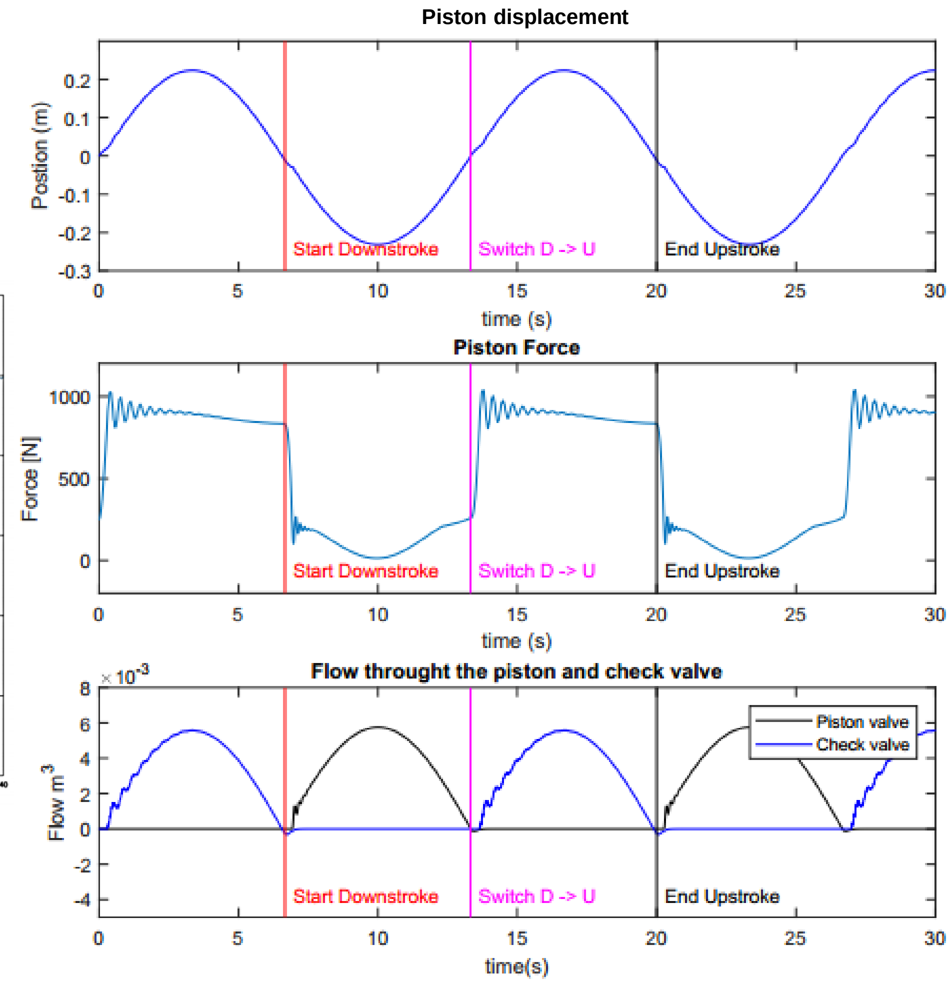
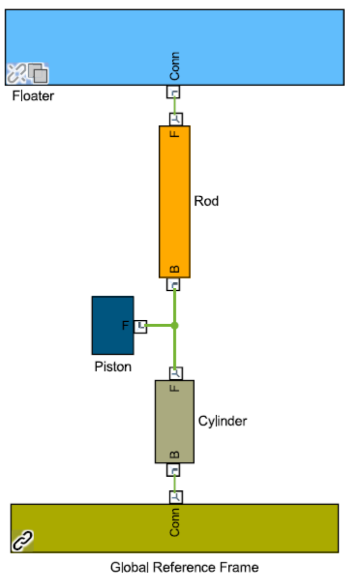
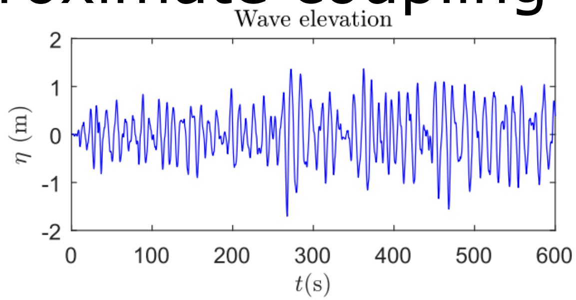
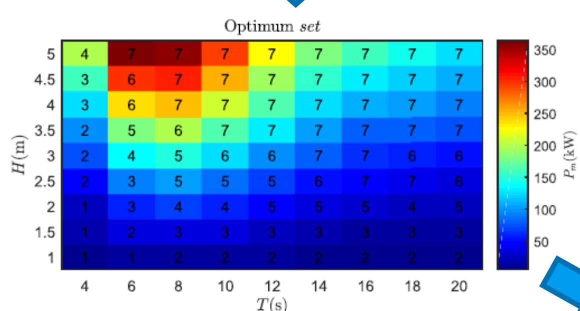


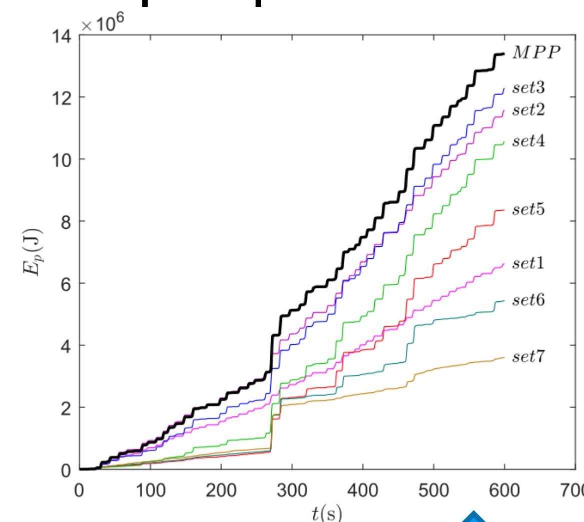
Research output (6/14)

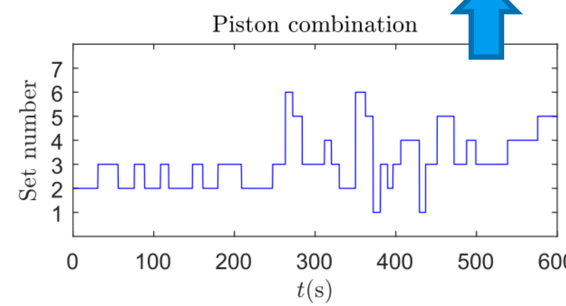
- Multi-piston pump (MPP) model: variable piston area to approximate coupling of multiple pistons











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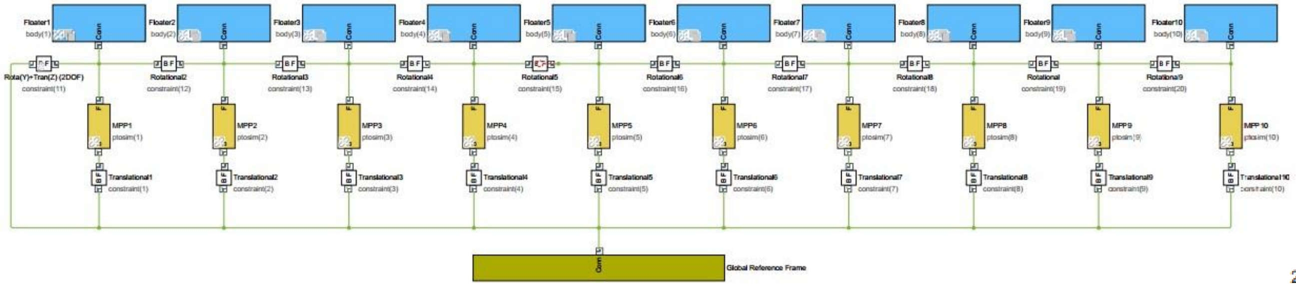
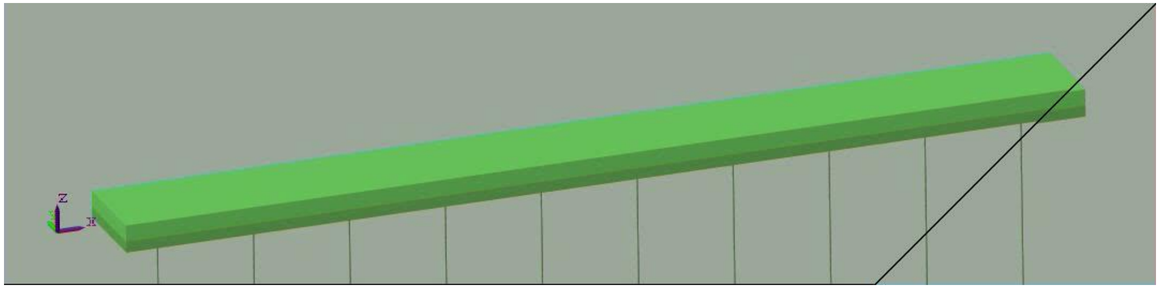
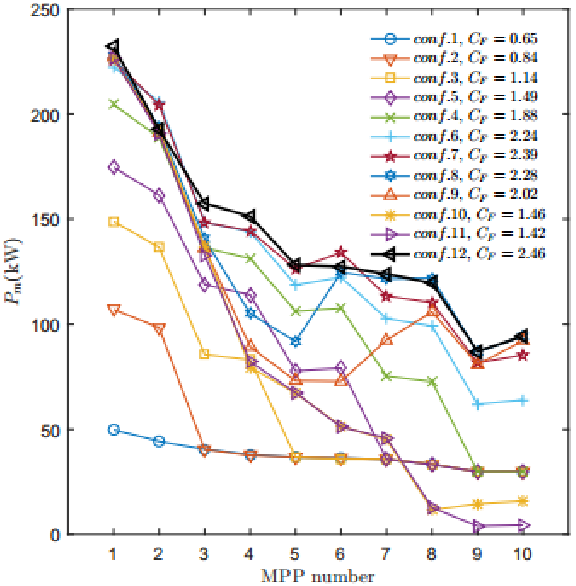
Research output (7/14)

› Floater column with MPPs







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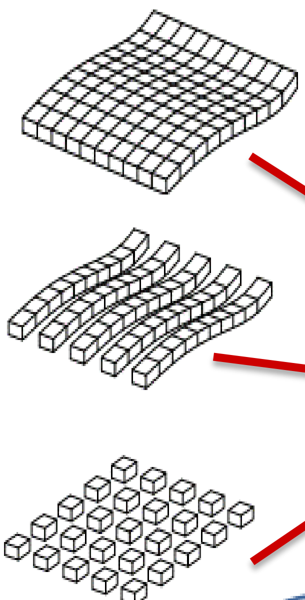
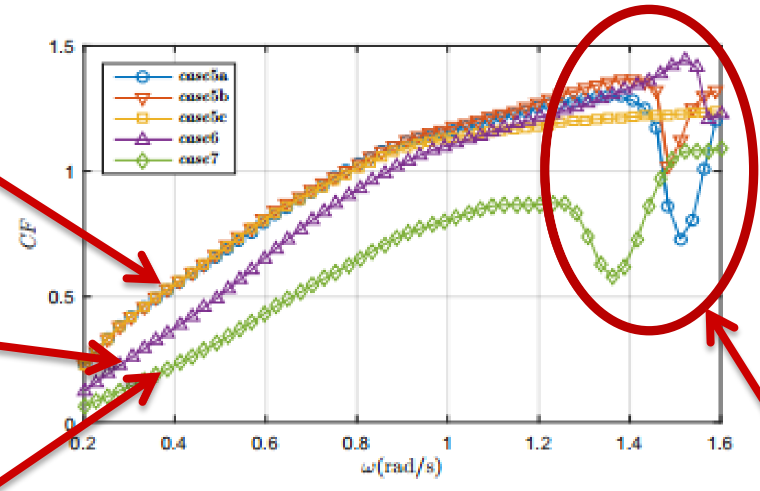
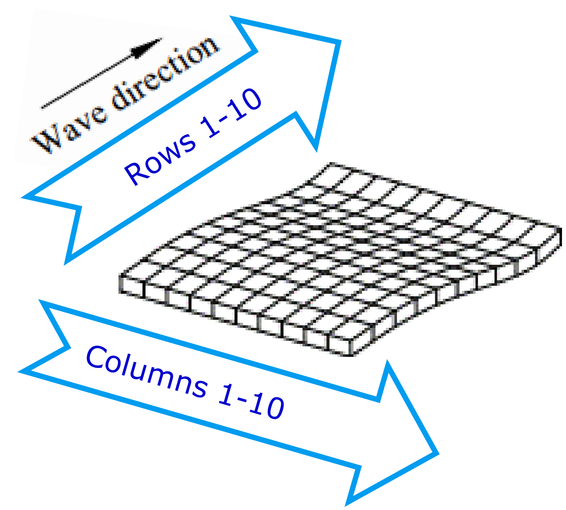
Research output (8/14)

- Frequency domain model of floater blanket with MPPs (capture factor increases past 1.0)







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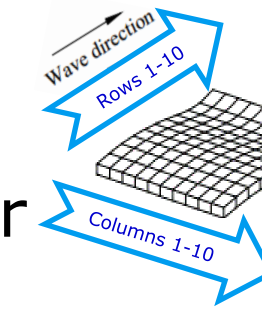
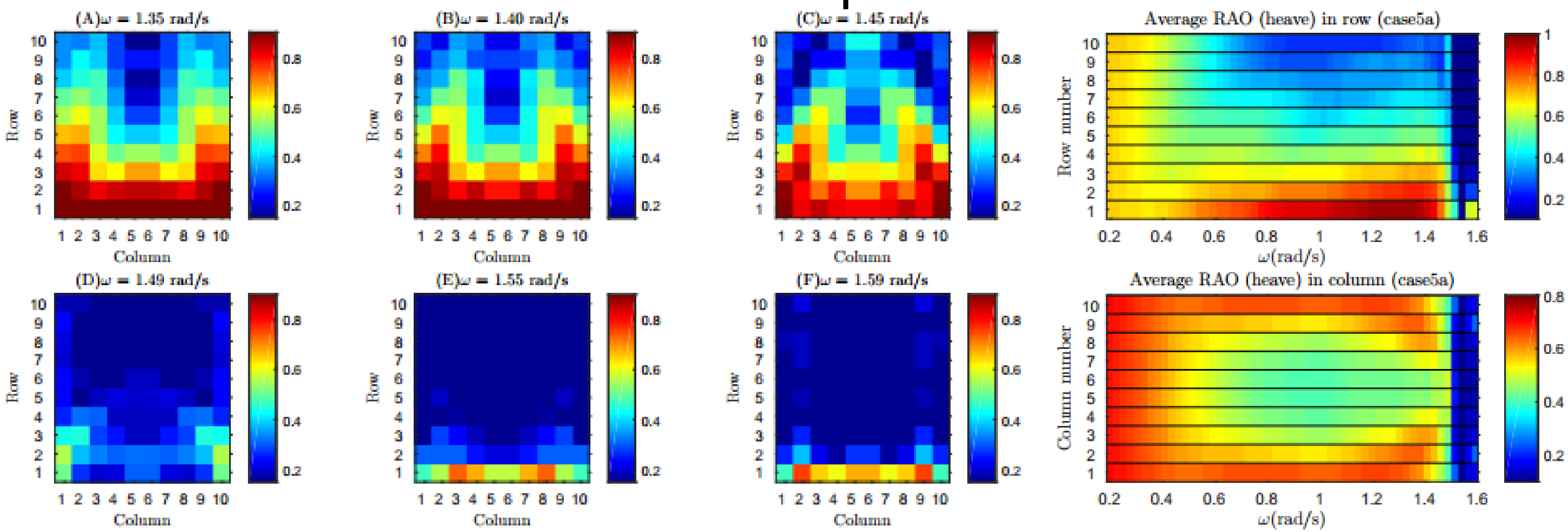
Interesting anti-resonant behavior

Research output (9/14)



› Response Amplitute Operator (RAO) for different excitation frequencies



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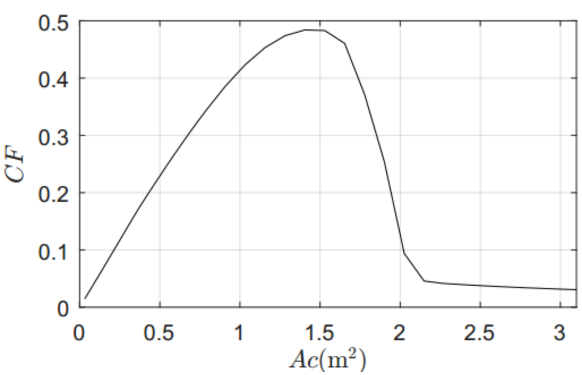
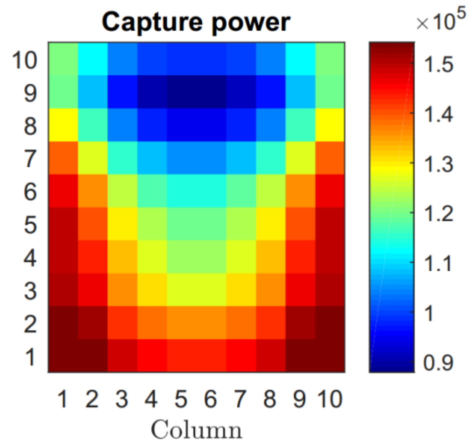
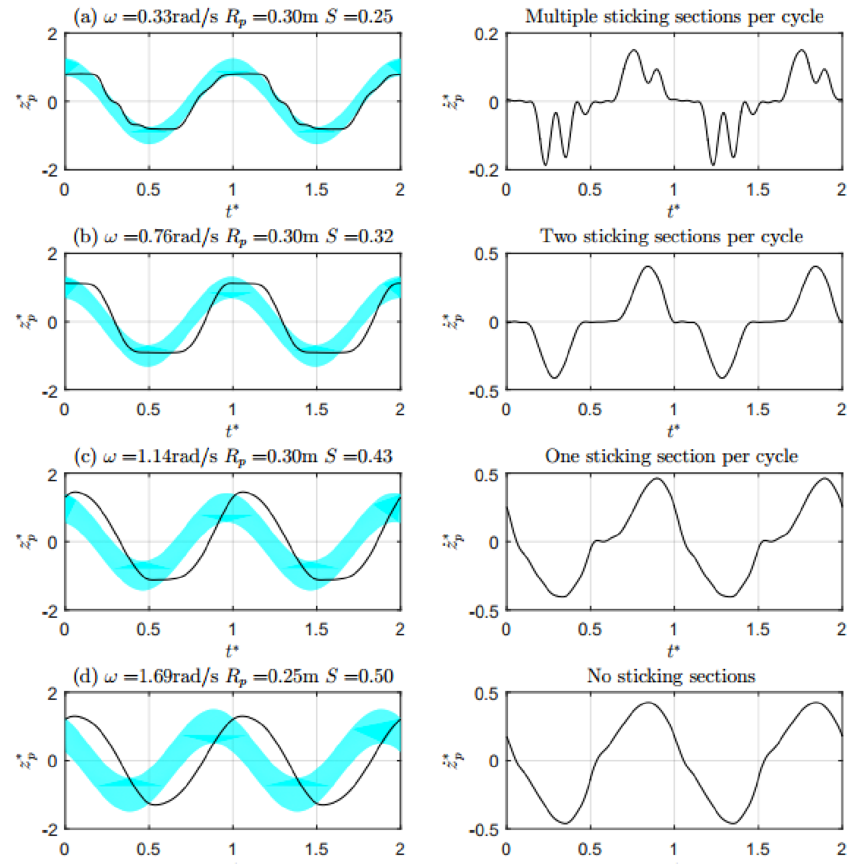
Research output (10/14)

› Fourier approximation method
› Instances of sticking
› "Tuning" of damping coefficients is necessary!







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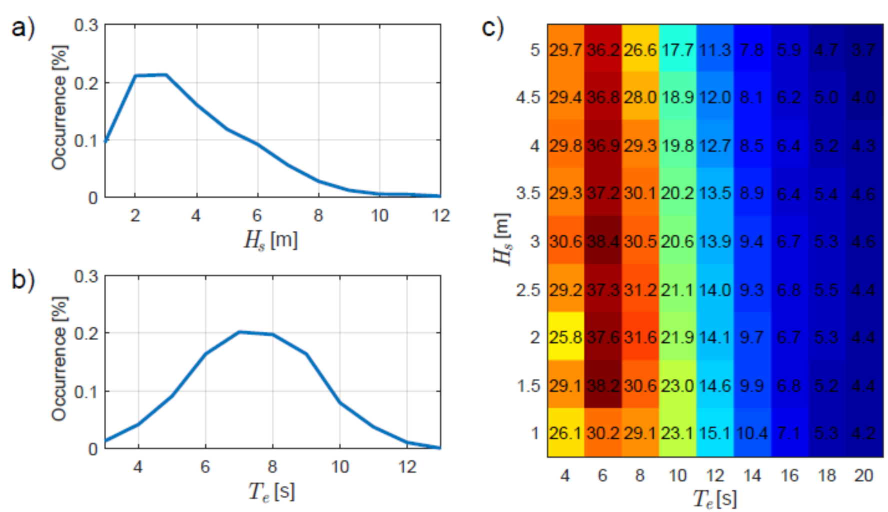
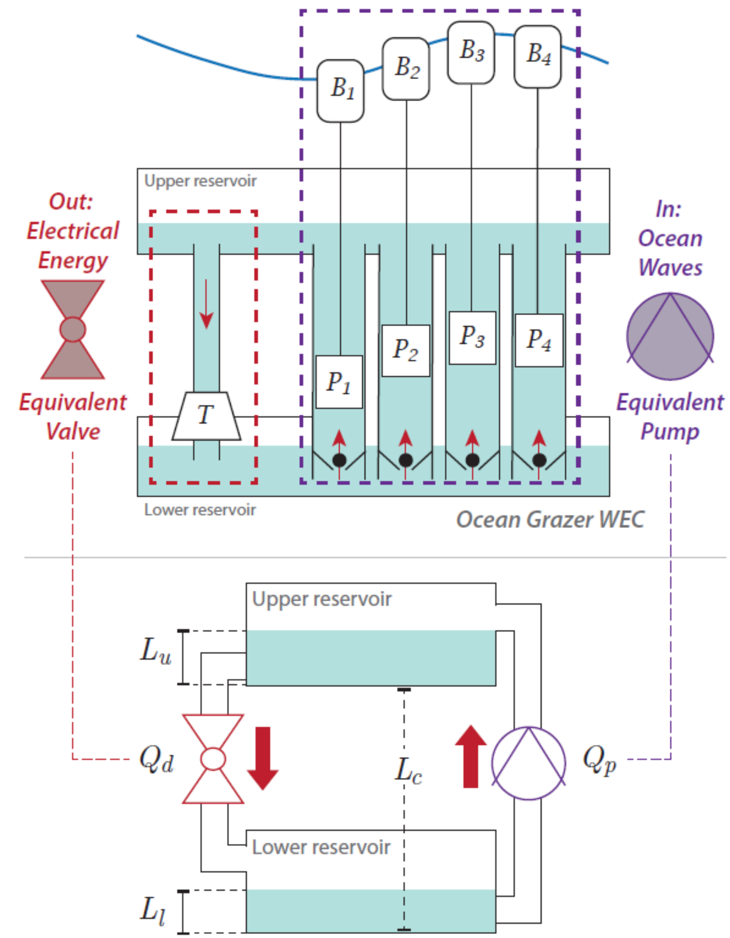
Research output (11/14)

- Equivalent net-flow lumped model validated with simulations and used with wave data to demonstrate and compare revenue maximization strategies





Ocean Grazer WEC equivalent net-flow lumped model

Research output (12/14)

- Normalized annual revenue investigated as function of turbine capacity, prediction horizon (shown right), upper reservoir capacity and differential height between reservoirs (referring to OG1.0)
- Model-predictive control (MPC) most suitable strategy

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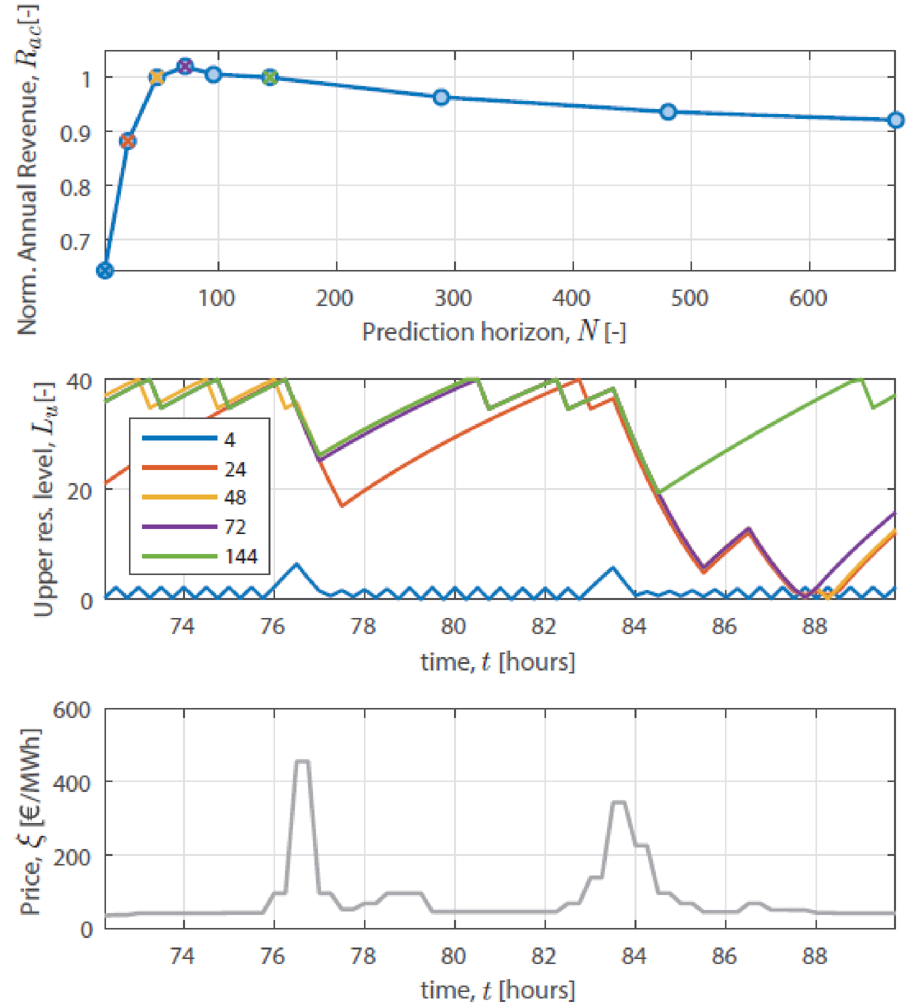
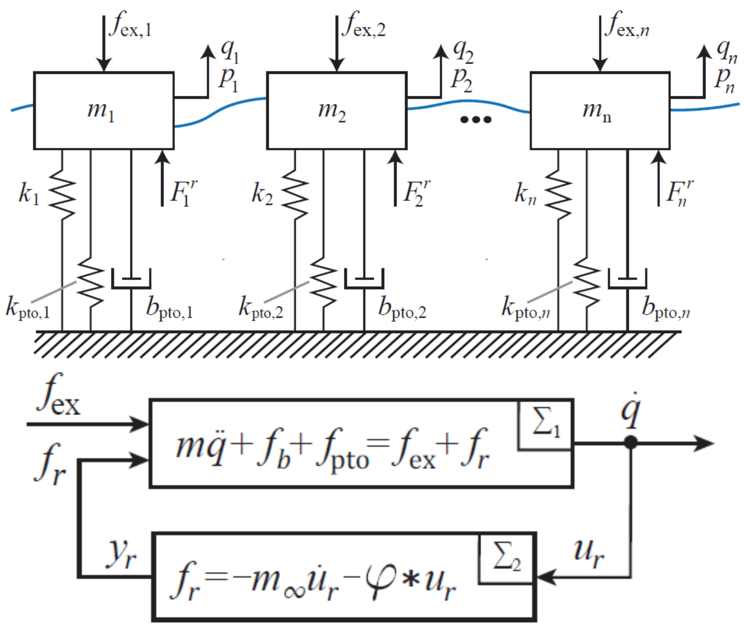
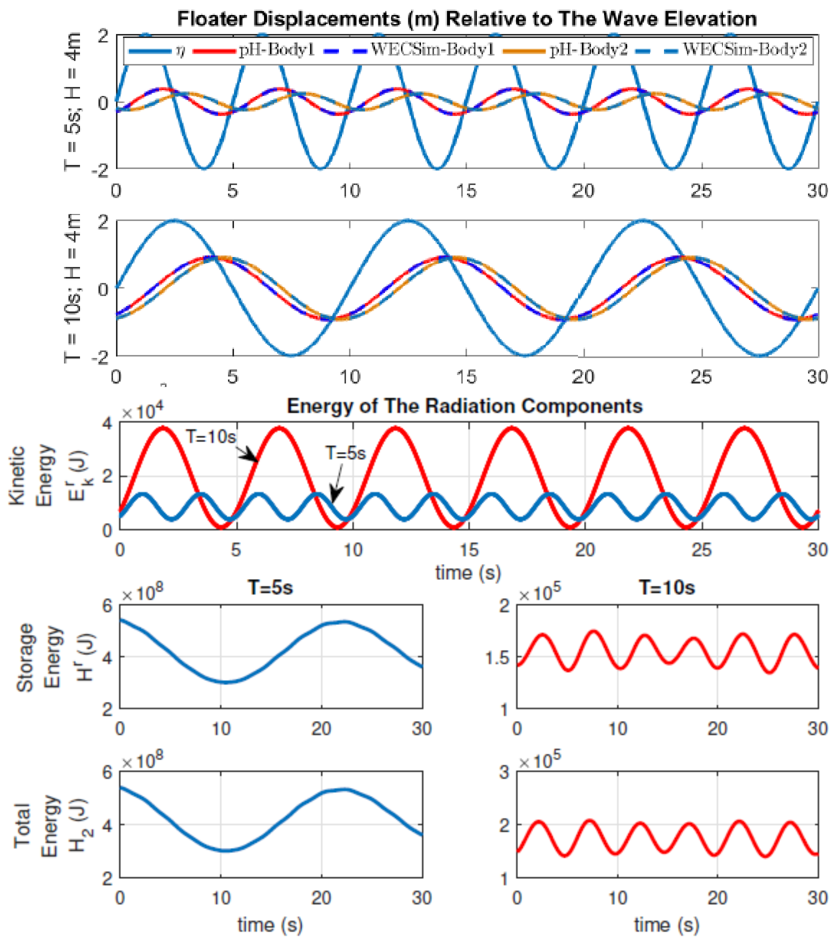


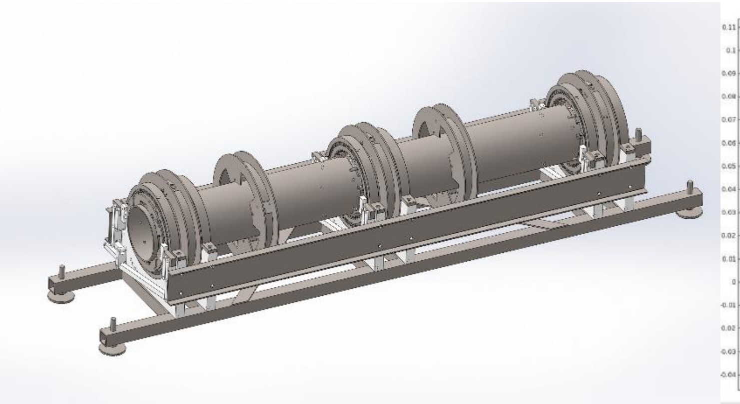
Research output (13/14)

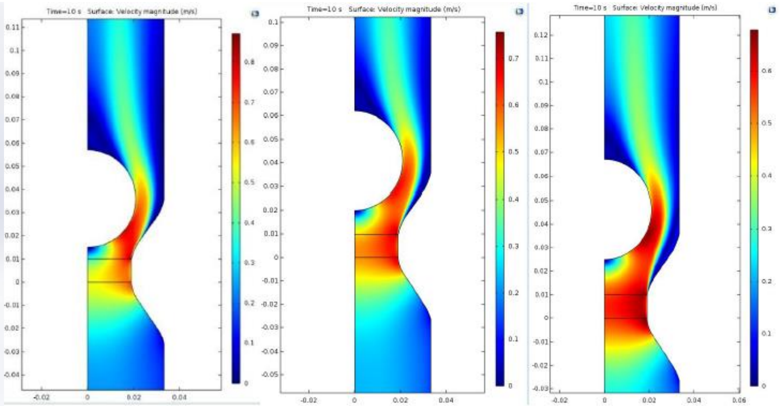
- Port-Hamiltonian approach for the Cummins' equation

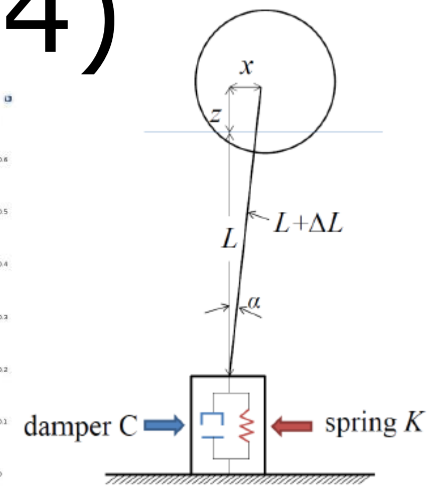


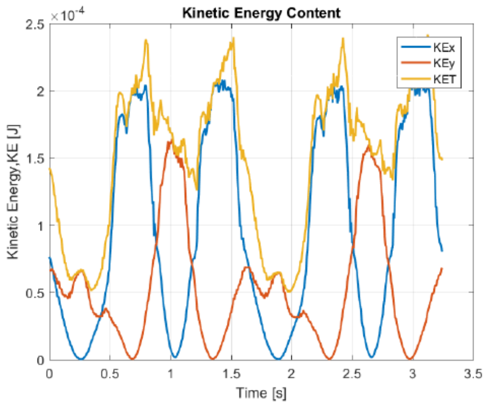


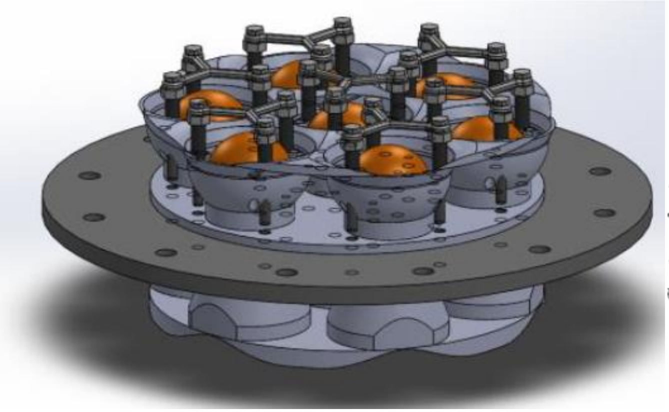
Research output (14/14)

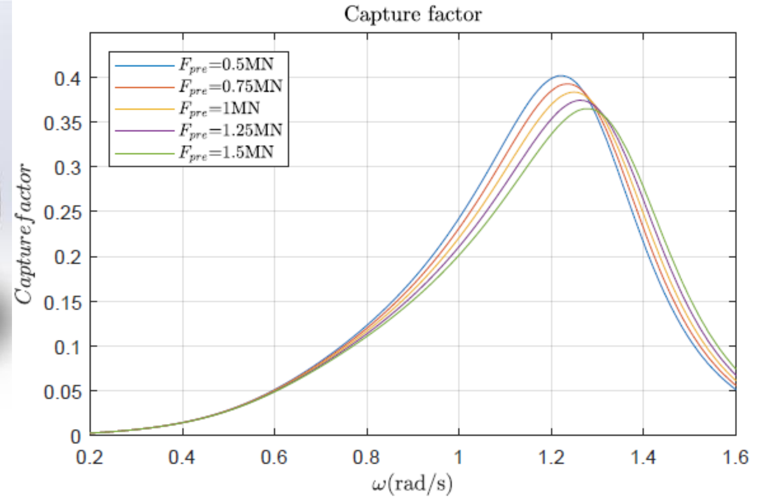












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Open questions (1/2)

1. **Optimal floater blanket design that can ensure economic viability**
2. **Optimal reservoir size that can ensure economic viability**
3. Model-based predictive control (MPC) for piston coupling mechanism
4. Control strategy for a multi-turbine system
5. **Energy extraction predictions for the MP2PTO system**
6. Wave propagation prediction models
7. Transient check valve dynamics
8. Check valve and piston valve optimization
9. Platform hydrodynamics (flow through and around the structure)
10. Design and experimental validation of the sealing system
11. Elastohydrodynamic lubrication models for the pistons and seals
12. Material and coating selection for improved tribological performance
13. Investigation of potential working fluids and their conditioning
14. Predictive models of the MP2PTO hydraulic system
15. CFD on wave-floater hydrodynamics and hydraulic system behavior
16. Experimental measurements on single floater hydrodynamics
17. Experimental measurements on the floater blanket
18. Wave radar data reconstruction
19. Distributed control algorithms for MP2PTO system adaptation
20. Experimental measurements of a multi-piston pump
21. **Flexible reservoir system design and validation**
22. **Flexible reservoir system specification analysis (including wear and fatigue)**
23. Turbine system specification analysis (including wear and fatigue)
24. Cable connection design and analysis (including wear and fatigue)
25. Floater design and analysis (including wear and fatigue)
26. Sealing system design and analysis (including wear and fatigue)
27. Check valve design and analysis (including wear and fatigue)
28. Preventive maintenance strategies
29. Maintenance and replacement in case of failure
30. Design and analysis of piston control mechanism
31. Influence of additional PTOs on OG platform design
32. Design and analysis of the concrete structure
33. **Gravity-based foundation stability, scouring, etc.**
34. Wear and fatigue analysis of the concrete structure
35. Positioning of platform to desired location / assembly techniques for construction at sea
36. Electrical energy generation, power electronics and transmission
37. Hydrogen generation and storage
38. Big data management for OG project (and platform) development
39. Dealing with big data in the control of the MP2PTO system
40. Big data in the modelling and simulations of the OG
41. Wave data reduction
42. Dynamical model reduction
43. Hydrodynamic model reduction
44. Tribological (lubrication) model reduction
45. Environmentally sustainable end-of-life OG platform demolition and/or reusability
46. **Environmental impacts of OG deployment**
47. Carbon footprint of OG construction activities
48. Damage and lifetime estimation of platform structure
49. **Optimal OG farm design and deployment/ embedding**
50. Preventive and coping strategies for biofouling of sealing system
51. **Cost estimation of development of OG**
52. Impact of OG deployment sites on marine traffic routes
53. Deployment sites review (study of potential locations)
54. Prototype deployment sites review (study of potential locations for prototype)
55. Off-grid energy transportation alternatives
56. Current EU policies: are they sufficient for OG deployment?
57. Global policies on renewable energy: how will they affect the realization of the OG?
58. Fair competition with fossil fuel producers
59. Legal framework(s) necessary for connection to existing energy grids
60. Patent management and future patenting issues
61. …

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Open questions (2/2)

1. Optimal floater blanket design that can ensure economic viability
2. Optimal reservoir size that can ensure economic viability
3. Energy extraction predictions for the MP2PTO system
4. Flexible reservoir system design and validation
5. Flexible reservoir system specification analysis (including wear and fatigue)
6. Gravity-based foundation stability, scouring, etc.
7. Environmental impacts of OG deployment
8. Optimal OG farm design and deployment/ embedding
9. Cost estimation of development of OG

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Conclusions

- We invite academic partners to help investigate fundamental and technological aspects
- Business (and device) development to proceed in parallel with research
- Criticisms, suggestions and recommendations are very welcome (and extremely useful)
- Thank you

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Mechanics and Tribology of Engineering Systems (MeTrES)