Far-field maximal power absorption of a bulging cylindrical wave energy converter

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with

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HyWEC 2, 18th June 2019

Context

A. Babarit, J. Singh, et al. "A numerical model for analysing the hydroelastic response of a flexible Electro Active Wave Energy Converter". In: *Journal of Fluid and Structures* 74 (2017), pp. 356–384

- Goal: open lightweight tool for the hydrodynamical design of WEC with non-trivial degrees of freedom.

Summary

Theory of far-field maximal absorption width

Implementation

Applications

- Floating buoy
- Bulging cylindrical WEC

Conclusion and perspectives

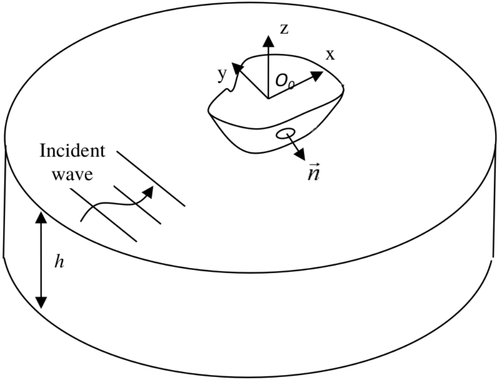
1 Theory of far-field maximal absorption width

Strategy

- Linear potential flow in frequency domain.
- Energy balance:

  captured $= \oint$ incoming and leaving waves

- For a given geometry, find the motion giving the best captured width.



Scheme adapted from (Babarit and Delhommeau 2015)

Preliminary definitions

Kochin function H

$$\Phi(R, \theta, z) = 4\pi \sqrt{\frac{1}{\lambda R}} H(\theta) f_0(z) e^{i\left(2\pi \frac{R}{\lambda} + \frac{\pi}{4}\right)} + O\left(\frac{1}{R^{\frac{3}{2}}}\right)$$

Complex-valued amplitudes of motions $\hat{a}_j$

Linear potential flow $\Rightarrow$ linear combination of dofs

$$H = \sum_{j=1}^{n} \hat{a}_j H_j$$

Absorption width W

$$W = \frac{\text{mean absorbed power [W]}}{\text{mean wave power flux [W/m]}}$$

Absorption width

For a given motion $\hat{a} = (\hat{a}_j)_{j \in \{1,\dots,n\}}$:

$$\frac{W(\hat{a})}{8\pi k} = \Im\left(\sum_{j=1}^{n} \hat{a}_j H_j^*(\pi + \beta)\right) - k^2 \int_0^{2\pi} \left|\sum_{j=1}^{n} \hat{a}_j H_j(\theta)\right|^2 d\theta$$

Maximal absorption width

$$W^{\text{optimal}} = \max_{\hat{a} \in \mathbb{C}^n} \left[W(\hat{a})\right]$$

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Constraints on motion

Actually, $\hat{a}^{\text{optimal}}$ might be unphysical.

Maximal absorption width under constraint

$$W^{\text{optimal}} = \max_{\hat{a} \in \{\text{adimissible motions}\}} [W(\hat{a})]$$

Example of constraints for a single degree of freedom:

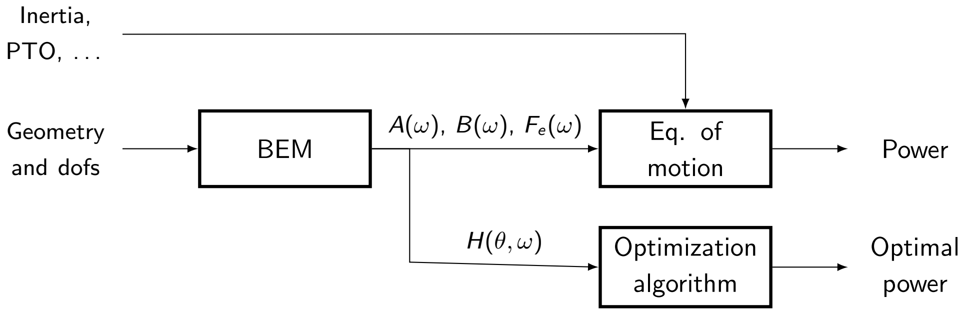
$$|\hat{x}| = \max(|x(t)|)_{t \in [0,T]} < cst.$$

Some previous works

- J.N. Newman. "Absorption of wave energy by elongated bodies". In: *Applied Ocean Research* 1.4 (1979), pp. 189–196
- FJM. Farley. "Wave energy conversion by flexible resonant rafts". In: *Applied Ocean Research* 4.1 (1982), pp. 57–63
- FJM. Farley. "Far-field theory of wave power capture by oscillating systems". In: *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 370 (2012), pp. 278–287
- J. Falnes and A. Kurniawan. "Fundamental formulae for wave-energy conversion". In: *Royal Society open science* 2.3 (2015), p. 140305
- A. Babarit. *L'énergie des vagues: Ressource, technologies et performance*. ISTE éditions, 2018

2 Implementation

Structure of the code



Capytaine: a Python-based distribution of Nemoh

- Full rewrite of Nemoh in Fortran 90 + Python.
- Improving user interface, documentation and testing.
- Integration with Python ecosystem (here Scipy optimization algorithm).
- Experimental optimizations.

- Openly available under GPL license:
  - `conda install -c conda-forge capytaine`
  - Documentation: `https://ancell.in/capytaine/`
  - Source code: `https://github.com/mancellin/capytaine/`

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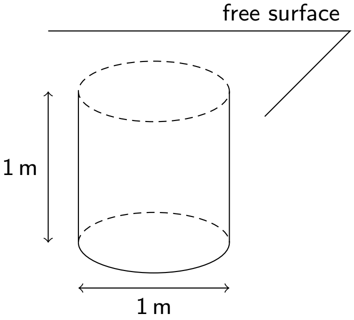
3 Applications

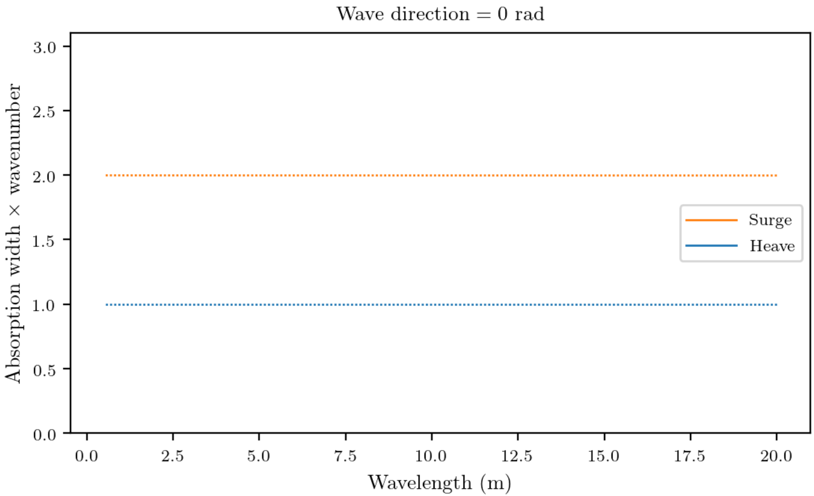
Application to a floating buoy

Vertical cylinder.

Dof: surge or heave or both.



Absorption width as a function of wavelength



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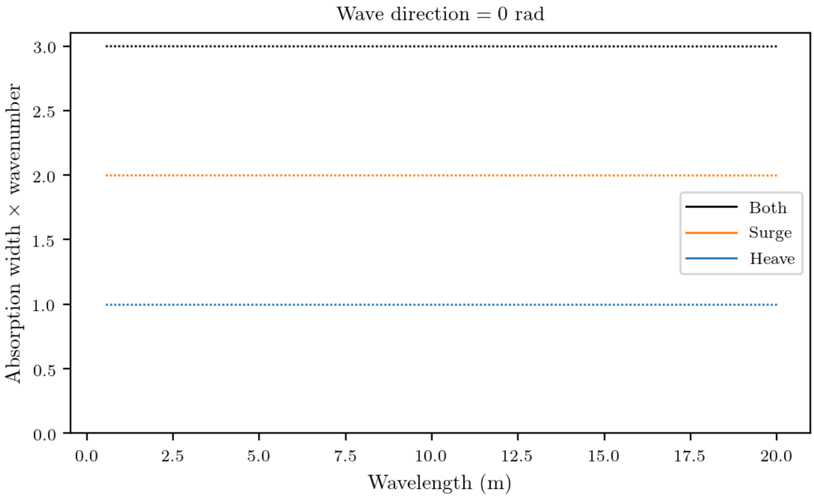

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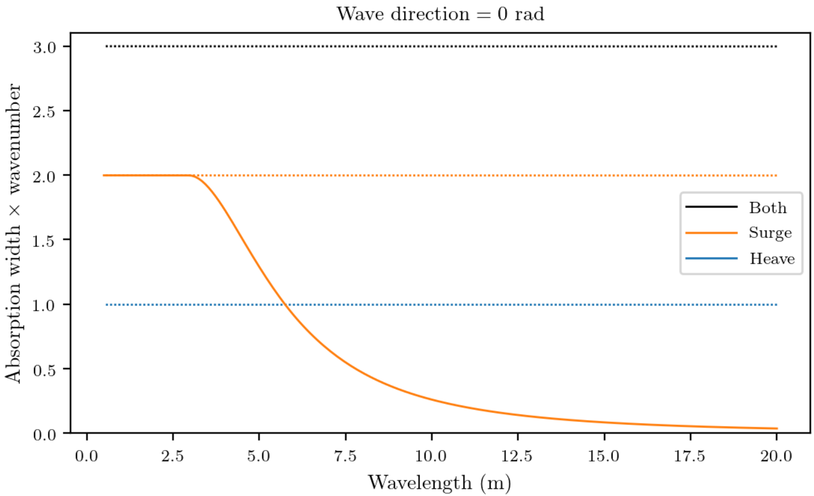

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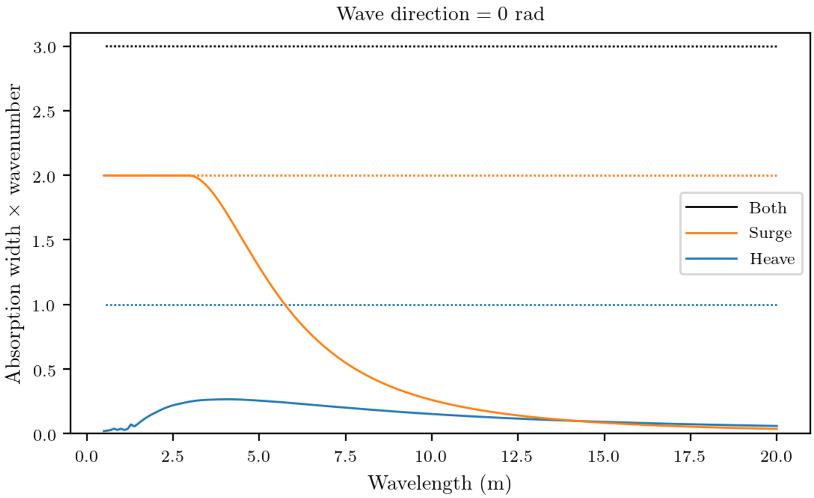

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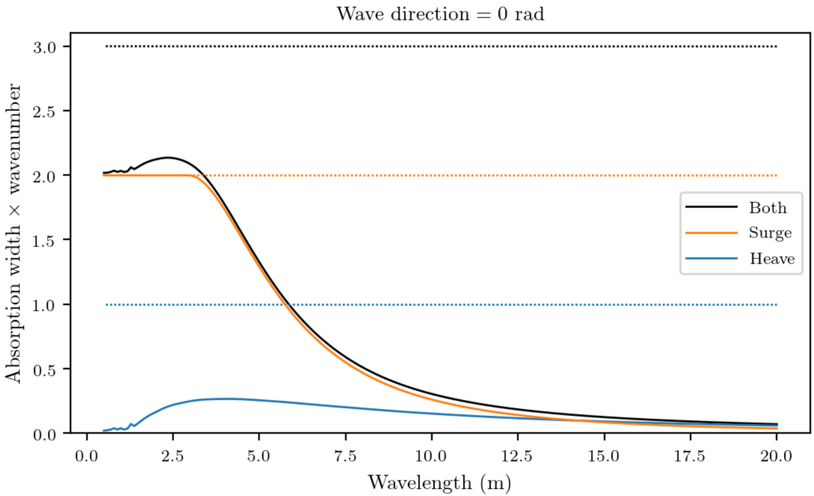

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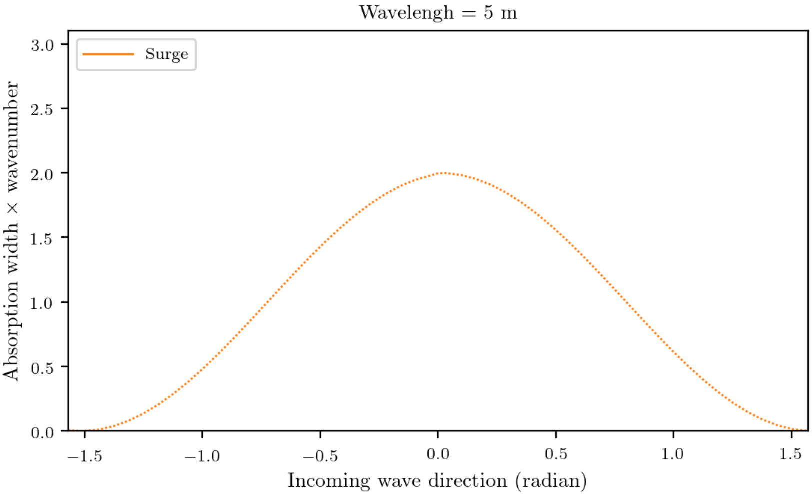
Absorption width as a function of wave direction



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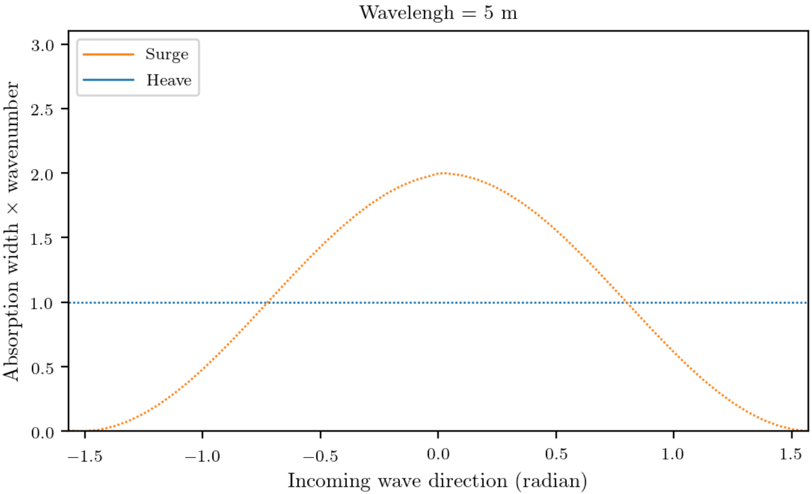

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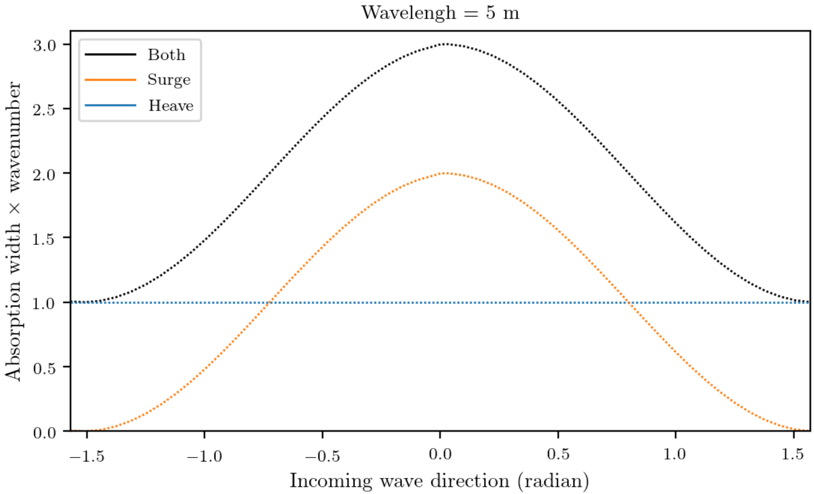

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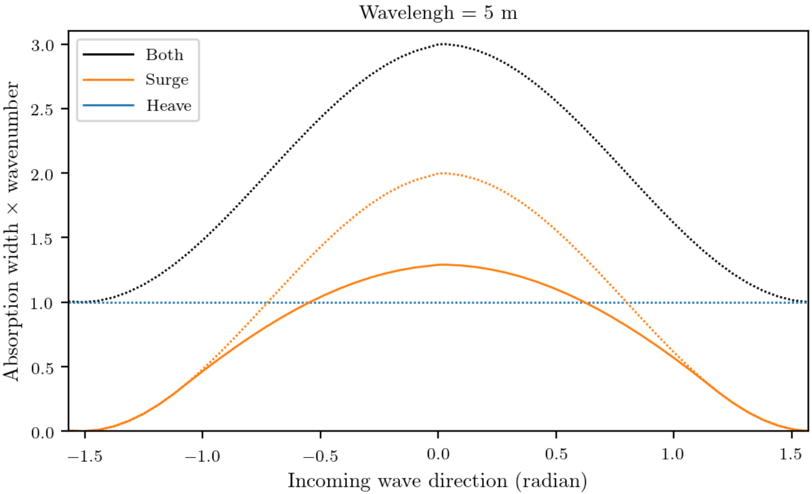

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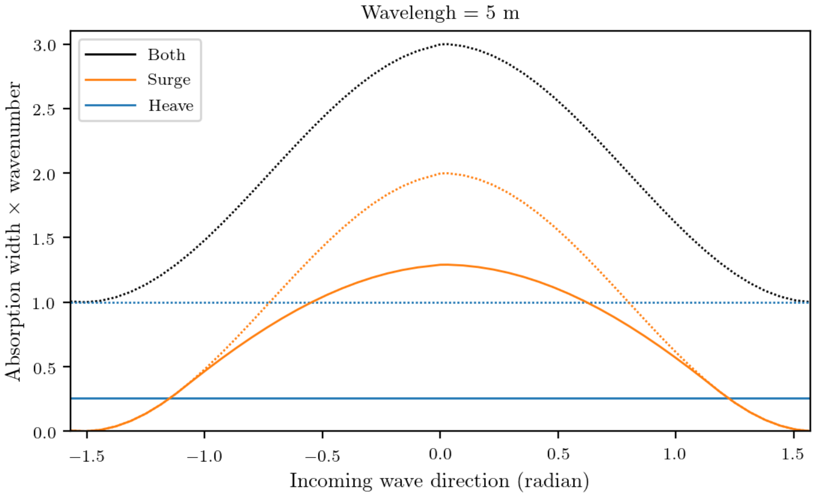

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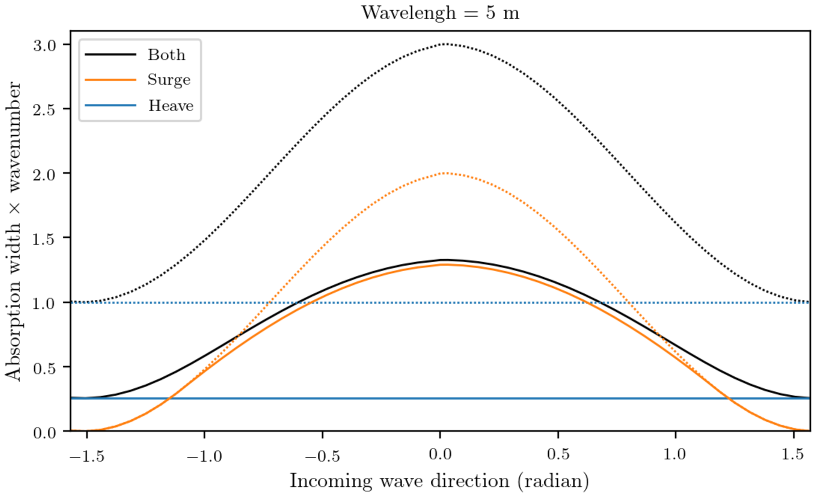

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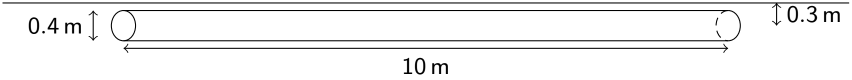
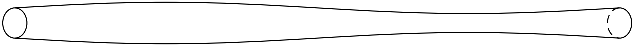
Application to a simplified S3

Small scale model of bulging WEC:



with only 4 simplified degrees of freedom:

$\sin(1 \times 2\pi x/L)$ 

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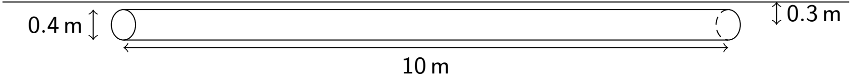

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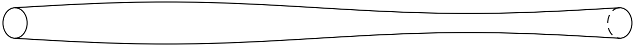
$\sin(1 \times 2\pi x/L)$ 

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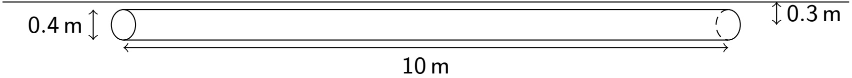
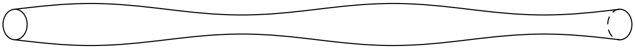


with only 4 simplified degrees of freedom:

$\sin(2 \times 2\pi x/L)$



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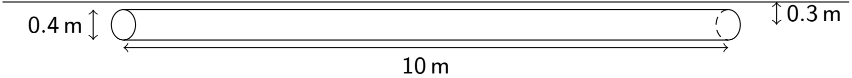
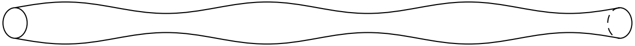


with only 4 simplified degrees of freedom:

$\sin(3 \times 2\pi x / L)$



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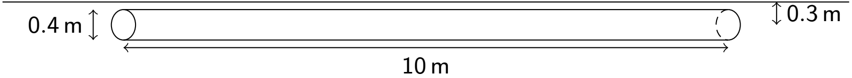
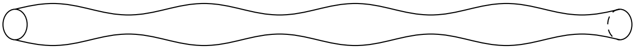


with only 4 simplified degrees of freedom:

$\sin(4 \times 2\pi x / L)$



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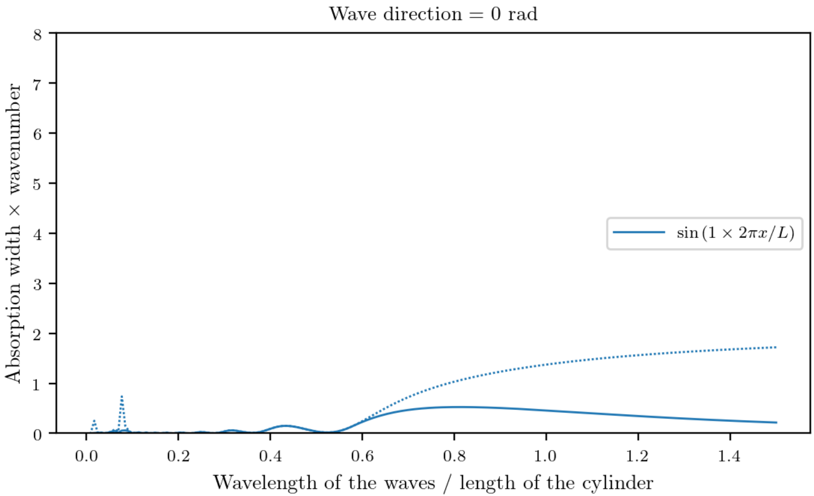

Dotted line: unlimited motion. Plain line: $\sqrt{\sum_j |\widehat{\delta r_j}|^2} < r_0/2$.

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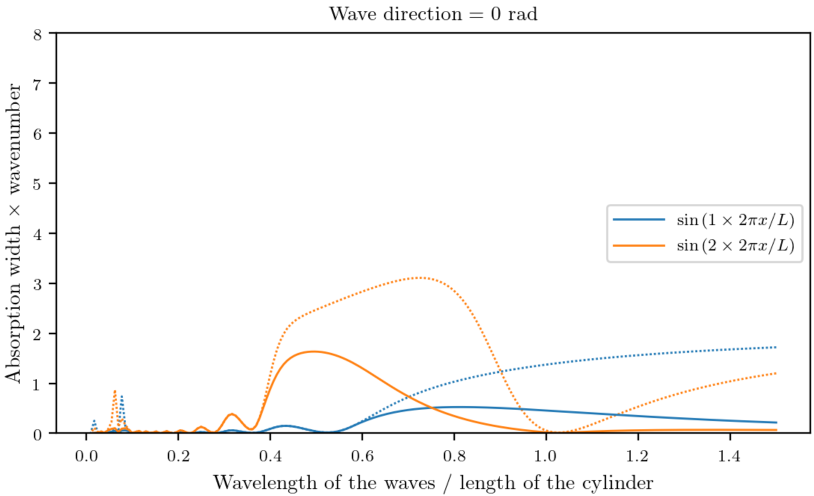

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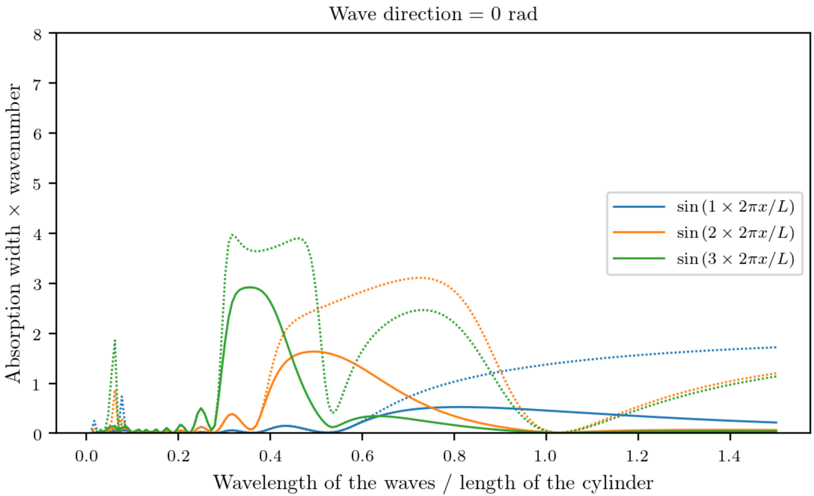

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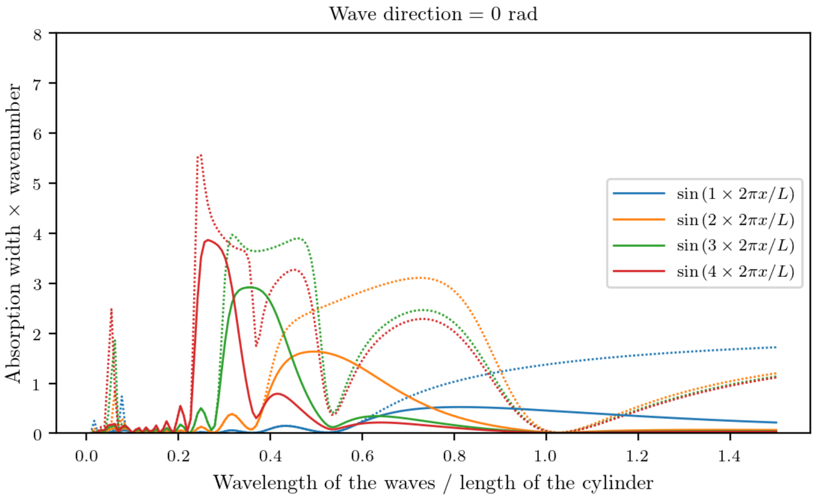

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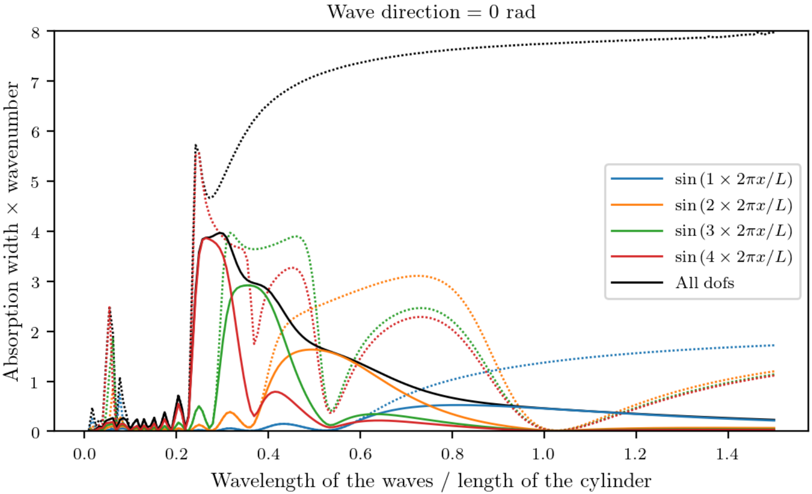

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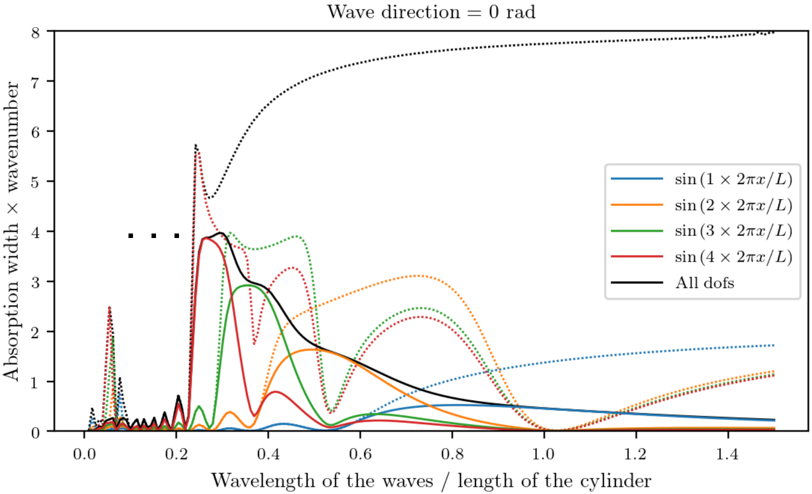

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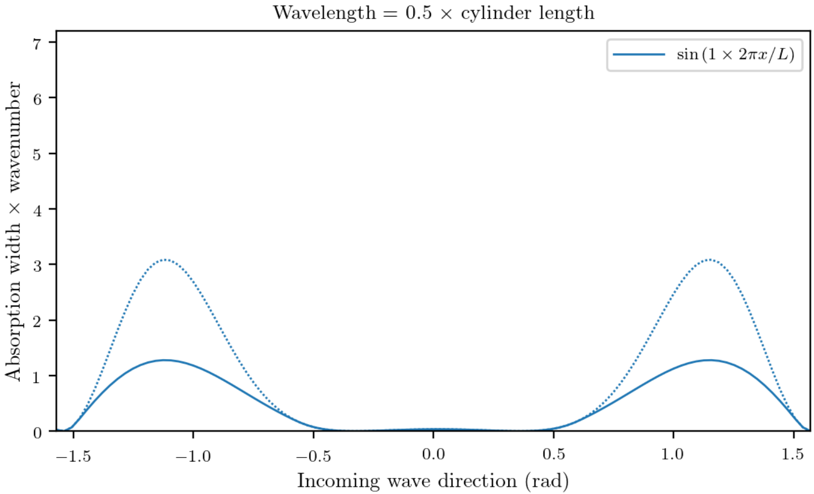

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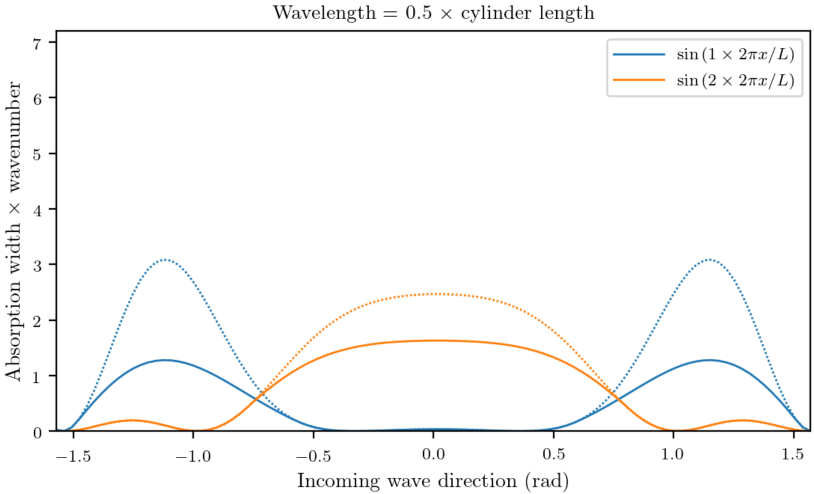

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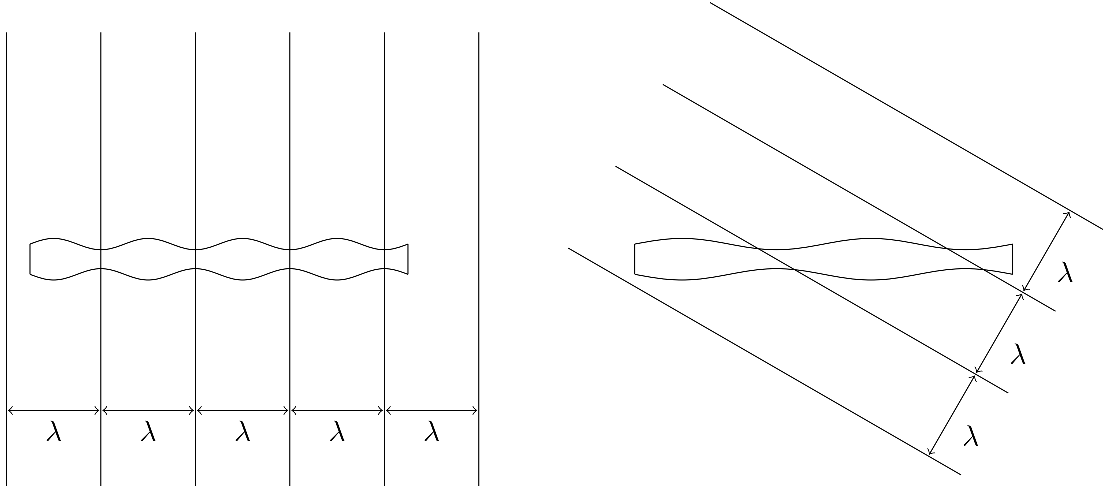
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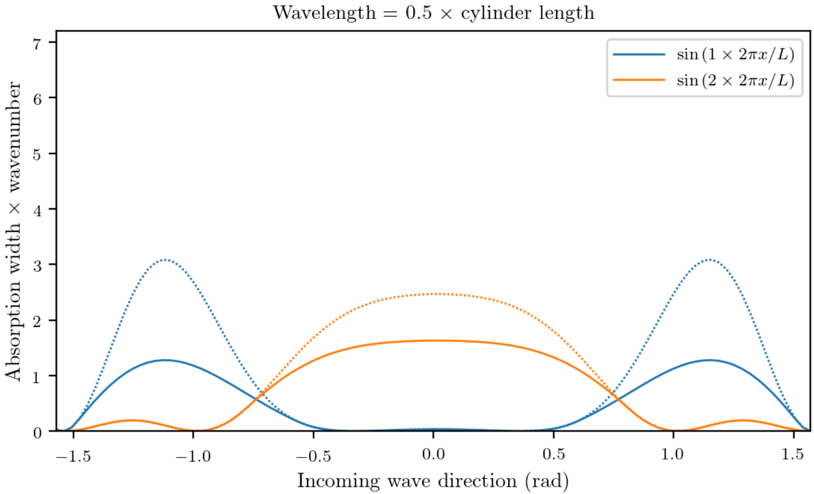

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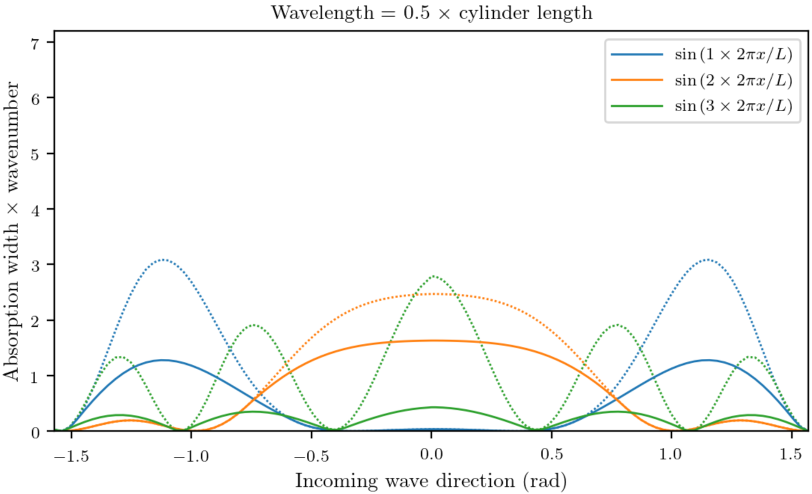

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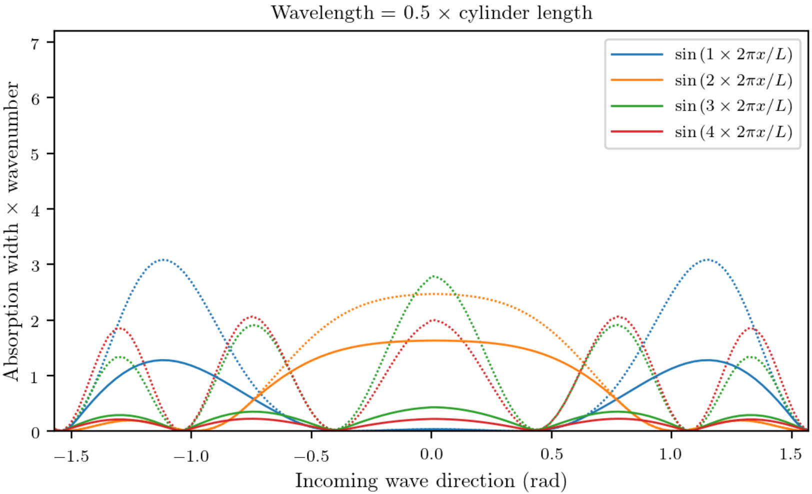

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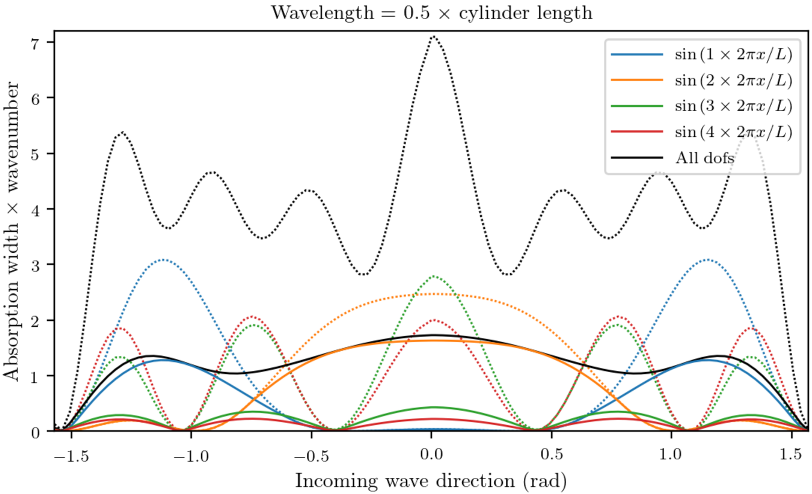

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4

Conclusion and perspectives

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Perspectives

- Continuing work at UCD:
  - Comparison with equations of motion from (Babarit et al., 2017).
  - Use of the actual modes of deformation of the S3 and parametric studies;
- To-do:
  - More physical constraints, including incoming wave height;
  - Dedicated optimization algorithm?
  - Analytical resolution of the optimization problem?

Conclusion

- Proof-of-concept of a lightweight model for WECs design:
  - Based on far-field radiated waves;
  - Purely hydrodynamical;
  - Few inputs: the geometry, the active dofs and their maximal amplitude;
  - Including any non-trivial dofs.

Thank you for your attention!

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