Design and Evaluation of a Two-Membrane Wave Energy Converter

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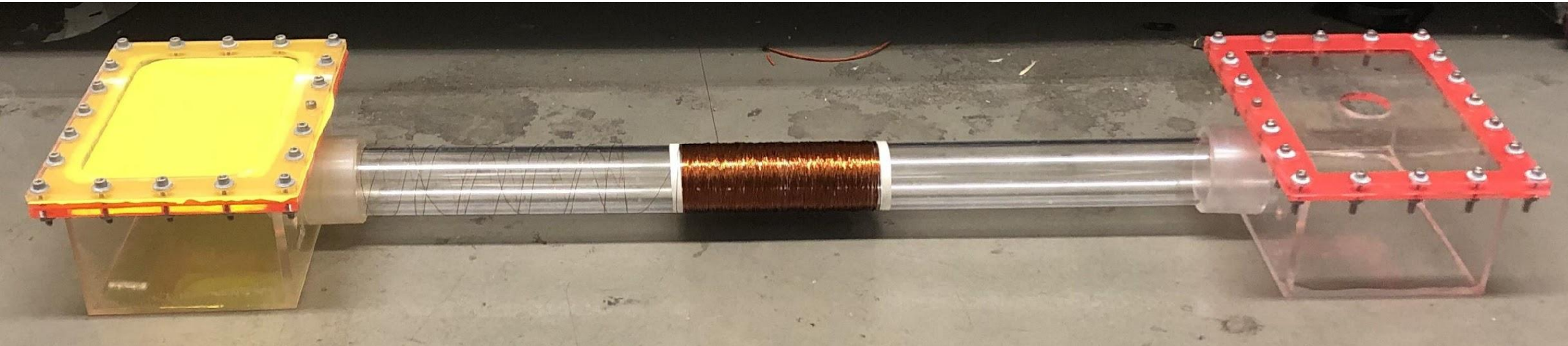
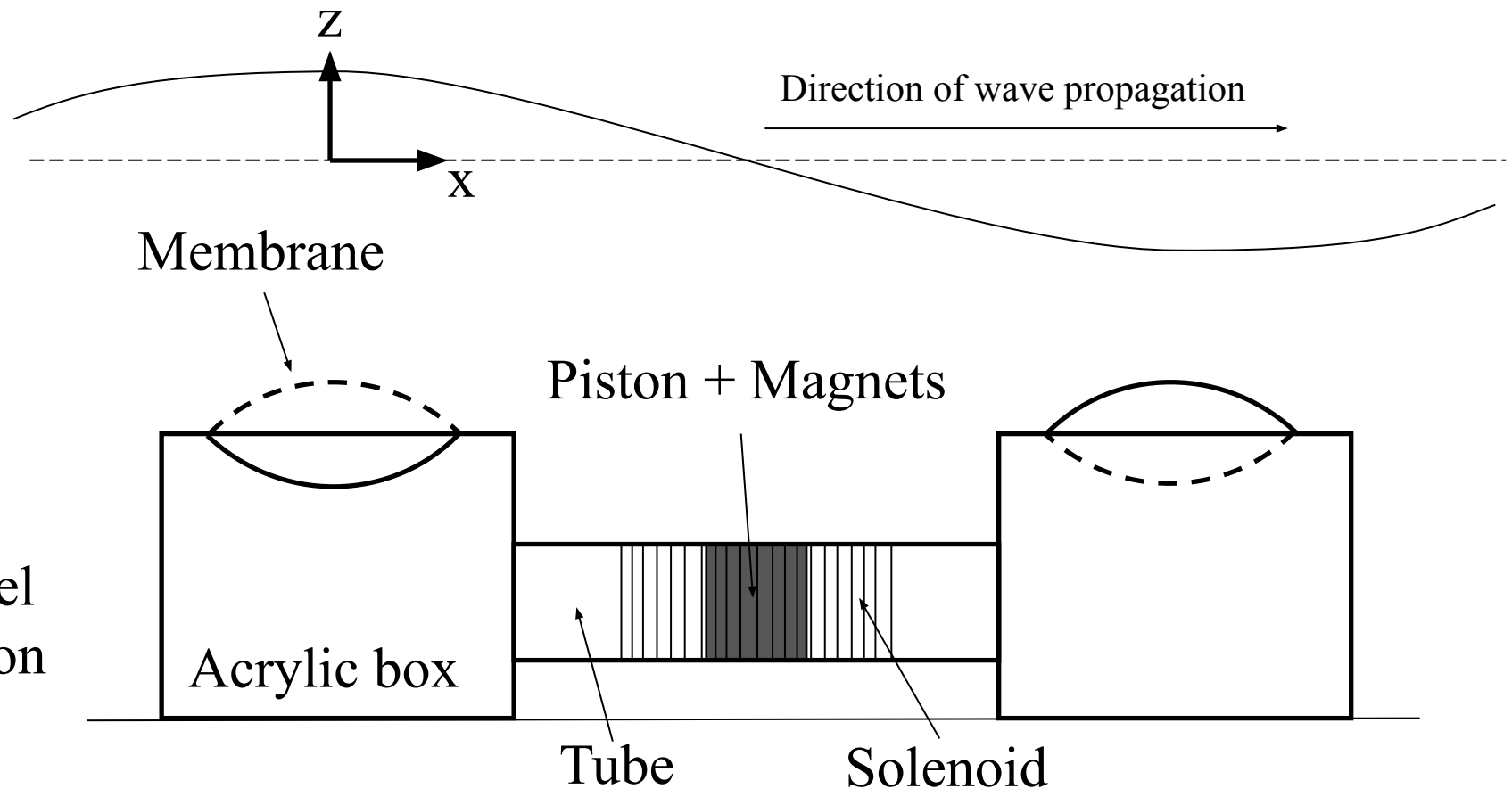
BS Mechanical Engineering



Project Overview

Task
Complete “an original project … which will take you through the entire engineering process”

Our system
Flexible wave energy converter (WEC) with novel two membrane configuration

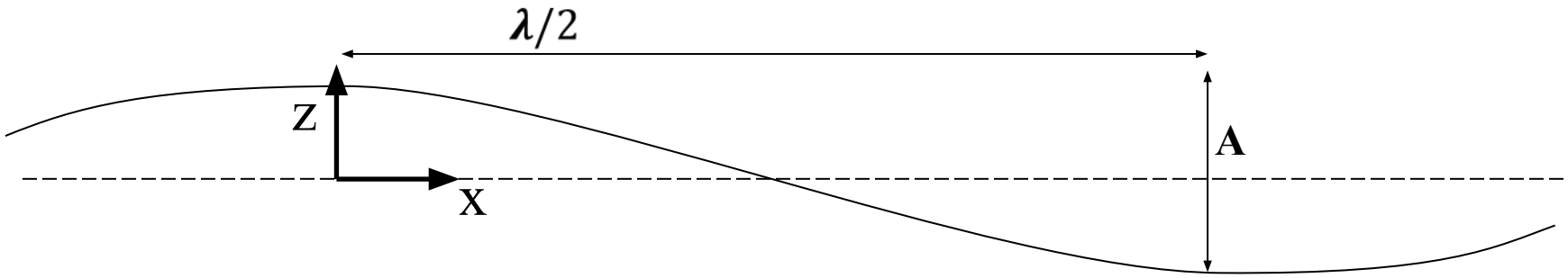


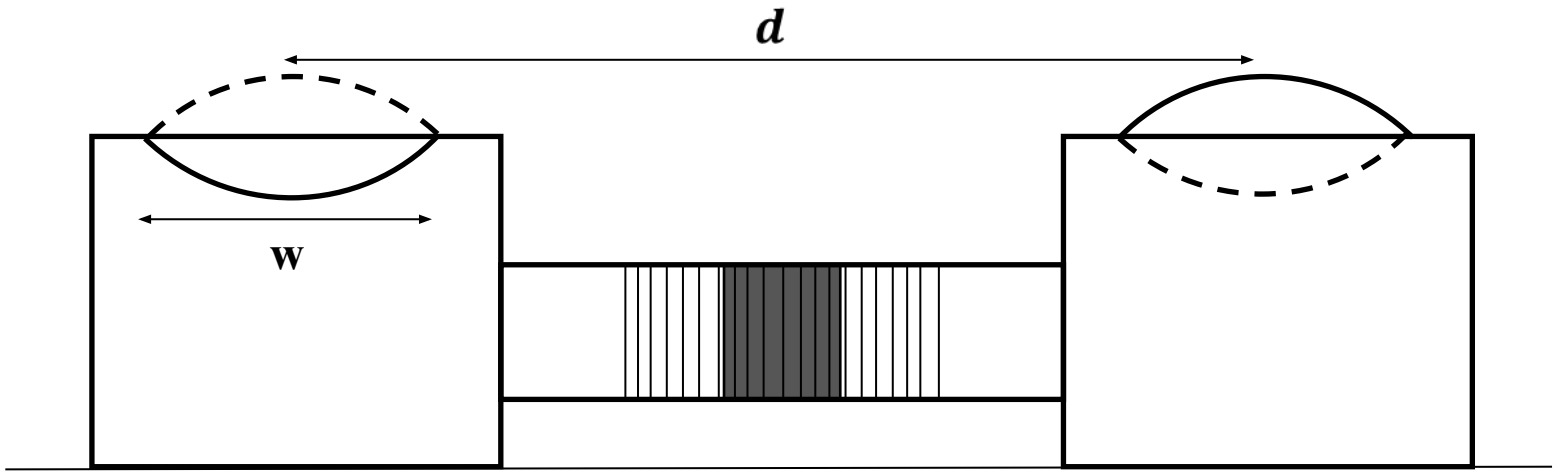
Final Design

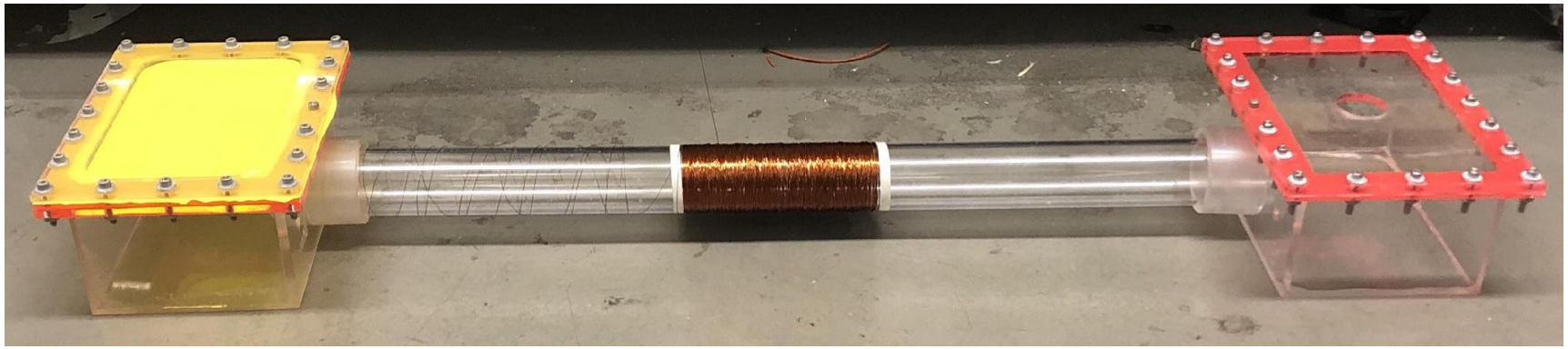
Inputs
wave frequency f
-(f determines λ)
wave amplitude A
1 or 2 membrane

Output
voltage across solenoid

Quantities of Interest
absolute power P_{out}
relative power P_{out}/P_{in}
optimal w/λ
optimal d/λ





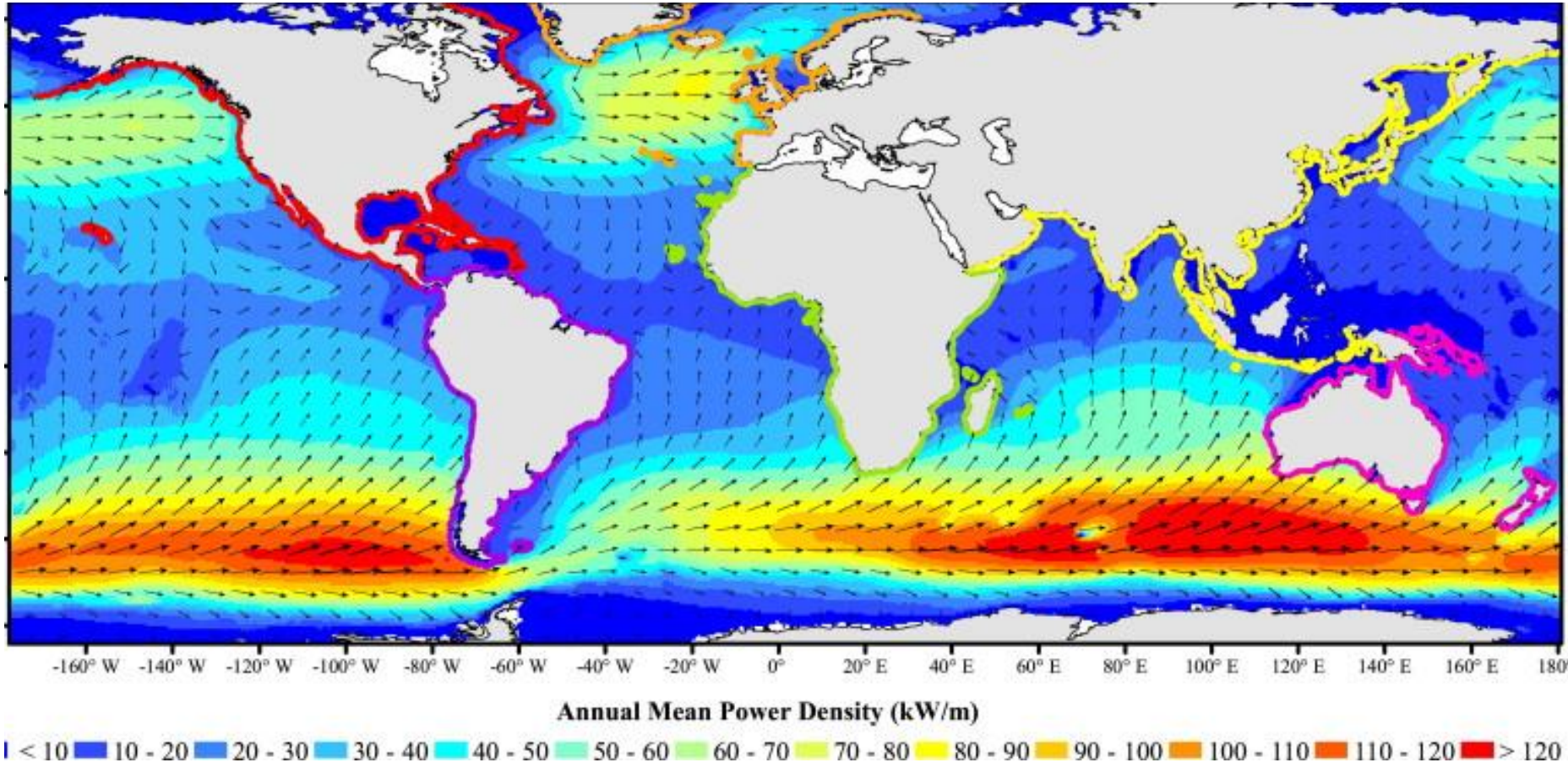


How did we get here?

Motivation

Why…

… hydropower?
Low emission;
diversify renewables
portfolio

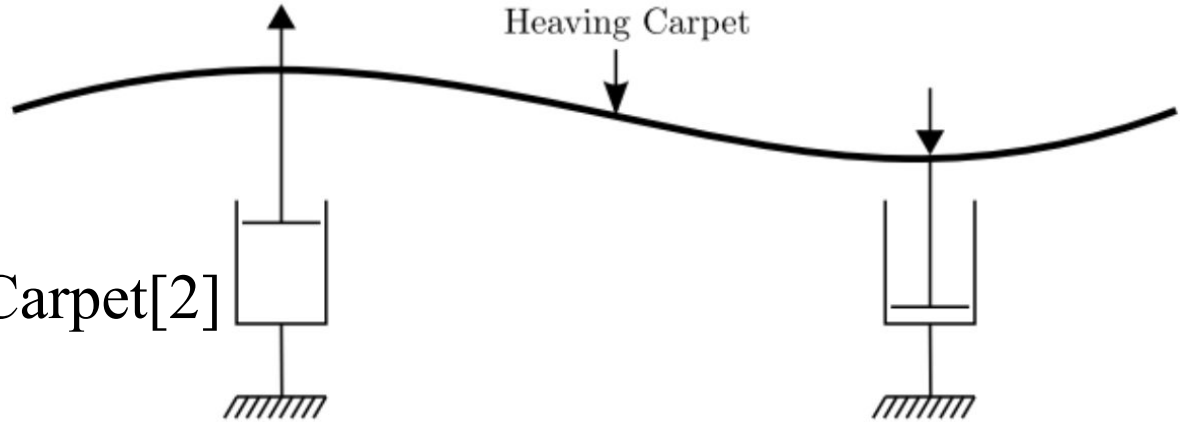


… a WEC? Untapped potential (2.11 ± 0.05 TW) [1]; less ecological disruption

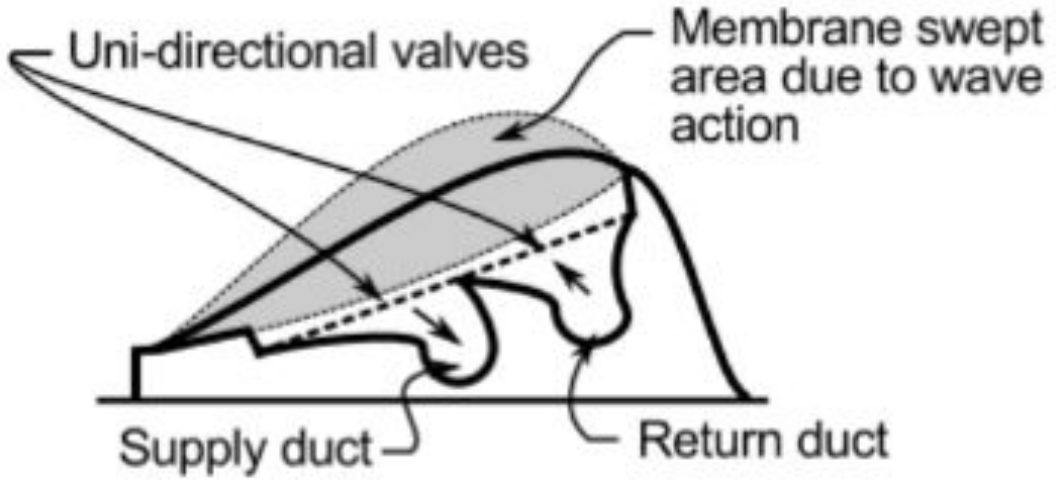
… a flexible WEC? Fewer parts; young technology

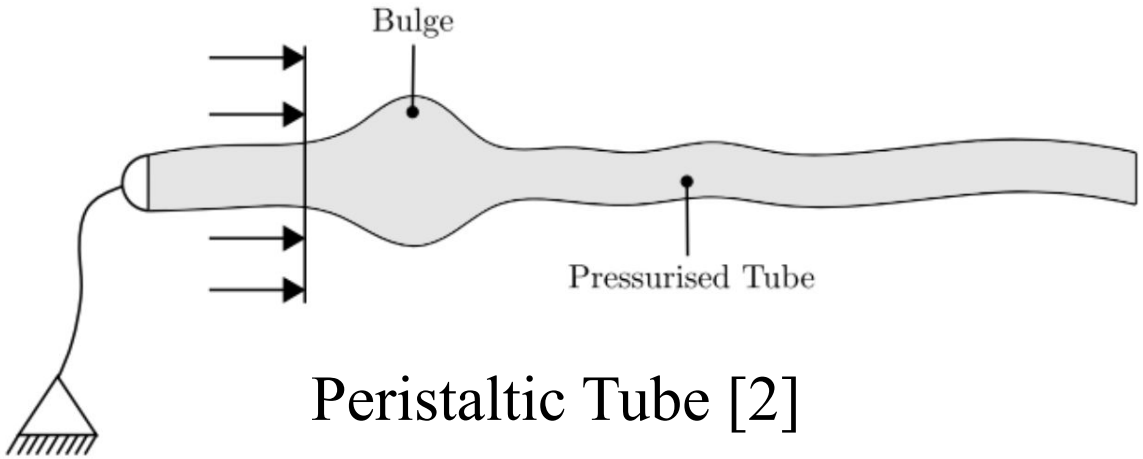
Existing flexible WEC Designs

Carpet[2]



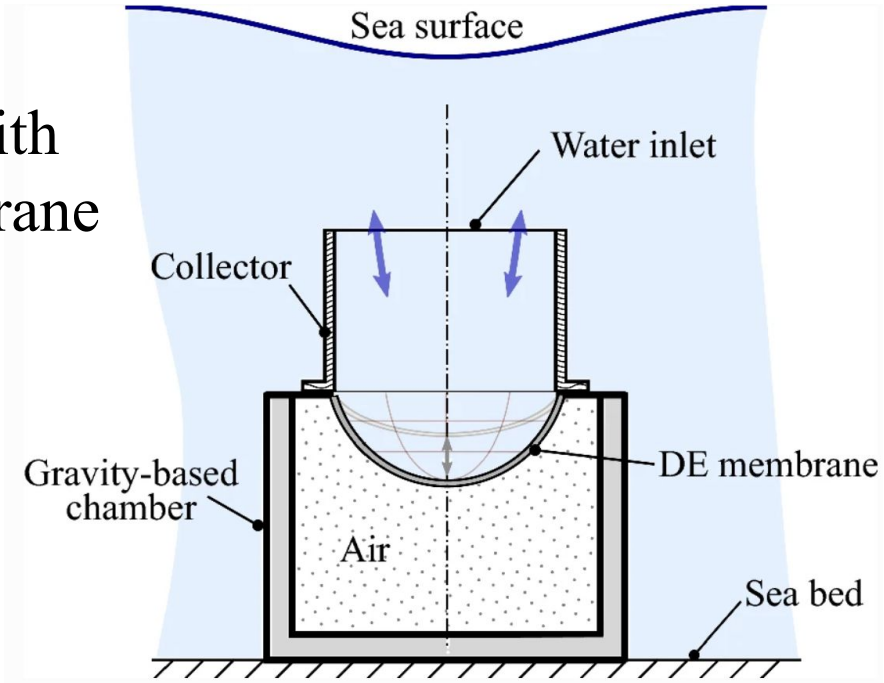
Bombora mWave™ [3]





Peristaltic Tube [2]

Column with DEG membrane [4]

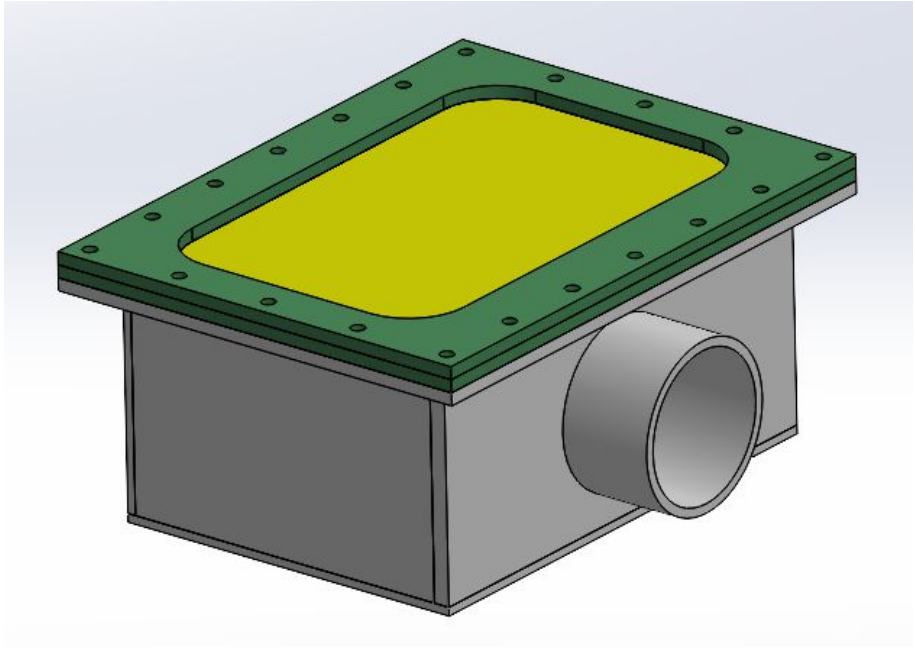


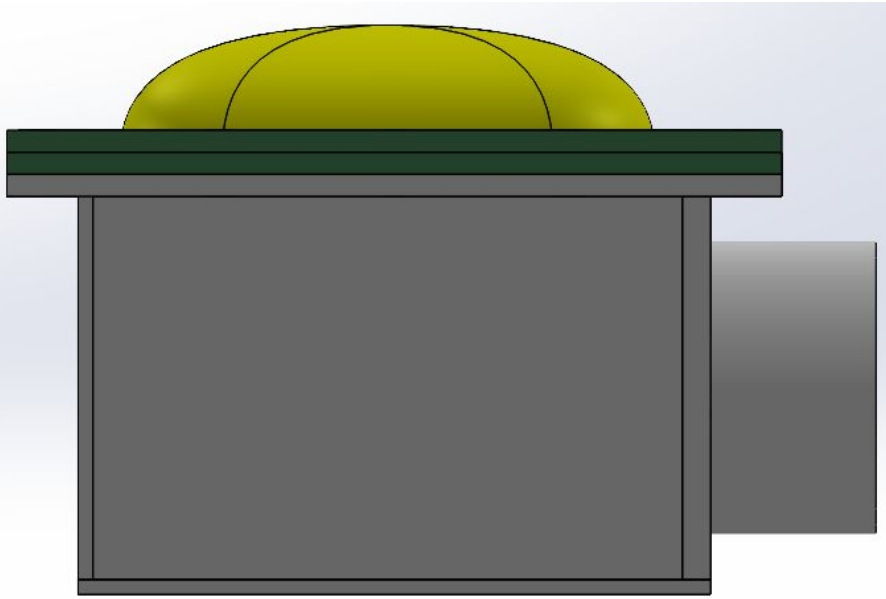
System Design

Key design considerations:

- Box dimensions
- Material selection
- Membrane fastening
- Tube length and diameter
- Box/tube interface

Why have membranes at all?

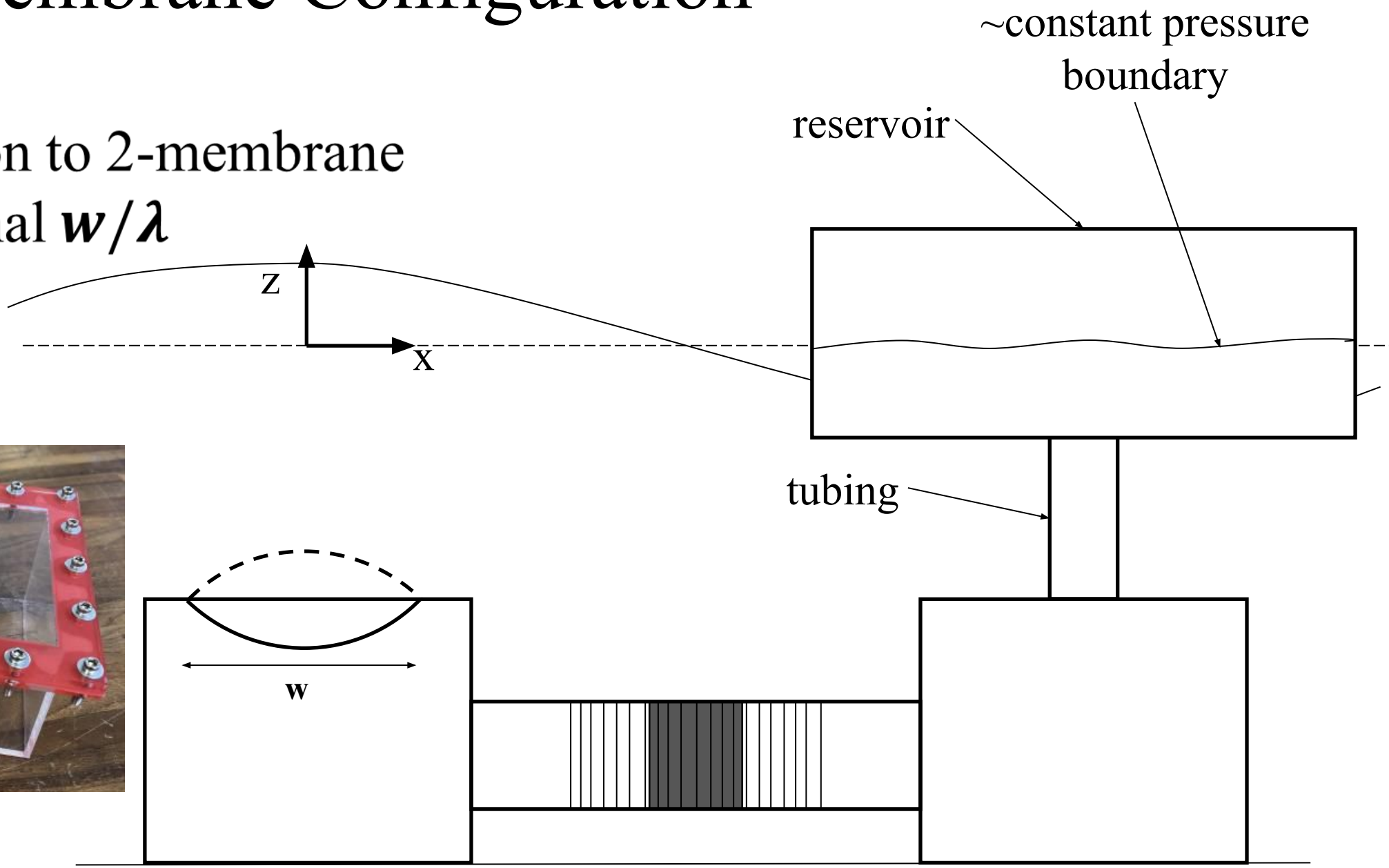




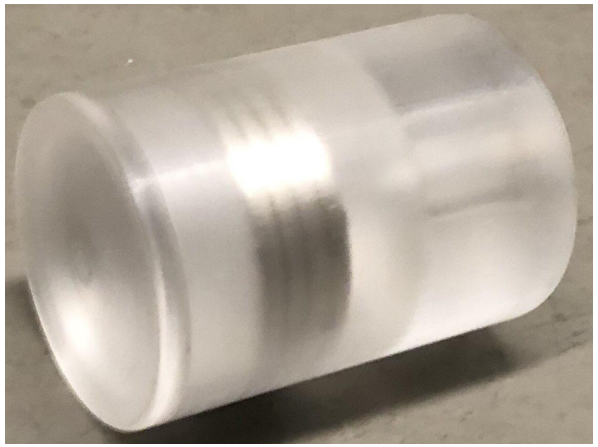
Single-Membrane Configuration

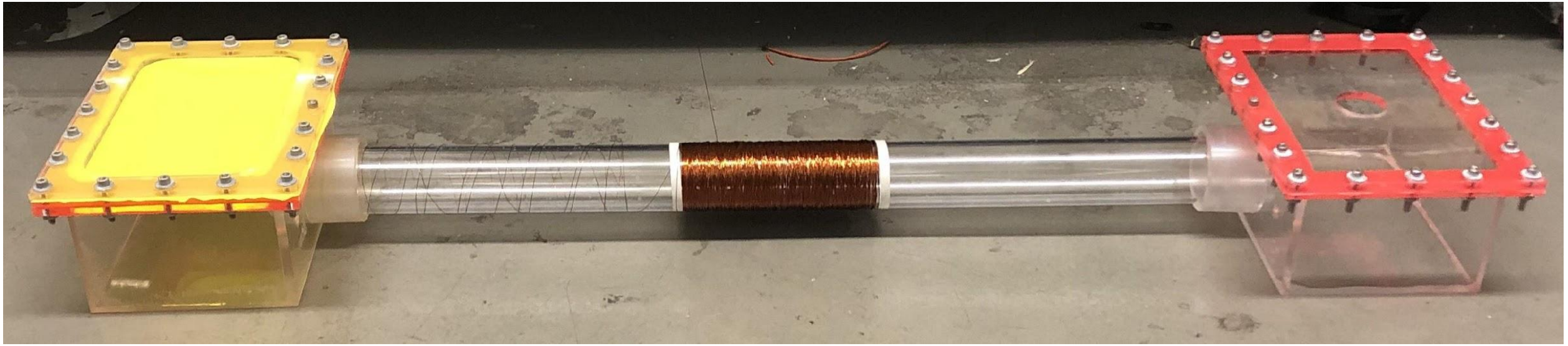
Purpose:

1. Comparison to 2-membrane
2. Find optimal $\boldsymbol{w/\lambda}$



Assembled System





Mathematical Model

Modelled as linear 2nd order system:

$$m\ddot{x} + c\dot{x} + kx = \overbrace{p_0 A_p}^{force}\sin(\omega t)$$

$\boldsymbol{x}$ – piston displacement
$\boldsymbol{m}$ – inertia of piston + displaced water
$\boldsymbol{c}$ – magnetic and viscous damping
$\boldsymbol{k}$ – membrane elasticity
$\boldsymbol{p_0}$ – amplitude of incident pressure wave
$\boldsymbol{A_p}$ – area of piston face

Assumptions

- 2D
- sinusoidal plane wave
- equal pressure on either side of membrane
- 0 fluid friction (!)

Predicted power generation [mW]

Max Efficiency: 19%
Min Efficiency: 0.02%

		f[Hz]			
		0.25	0.5	1	2
a[cm]	1	22	5.7	1.1	0.083
	3	200	52	10	0.75
	5	**550**	140	28	2.1

Experiment Design

Independent Variables:

Frequency

0.25 - 1Hz, 1/8 Hz step

Amplitude

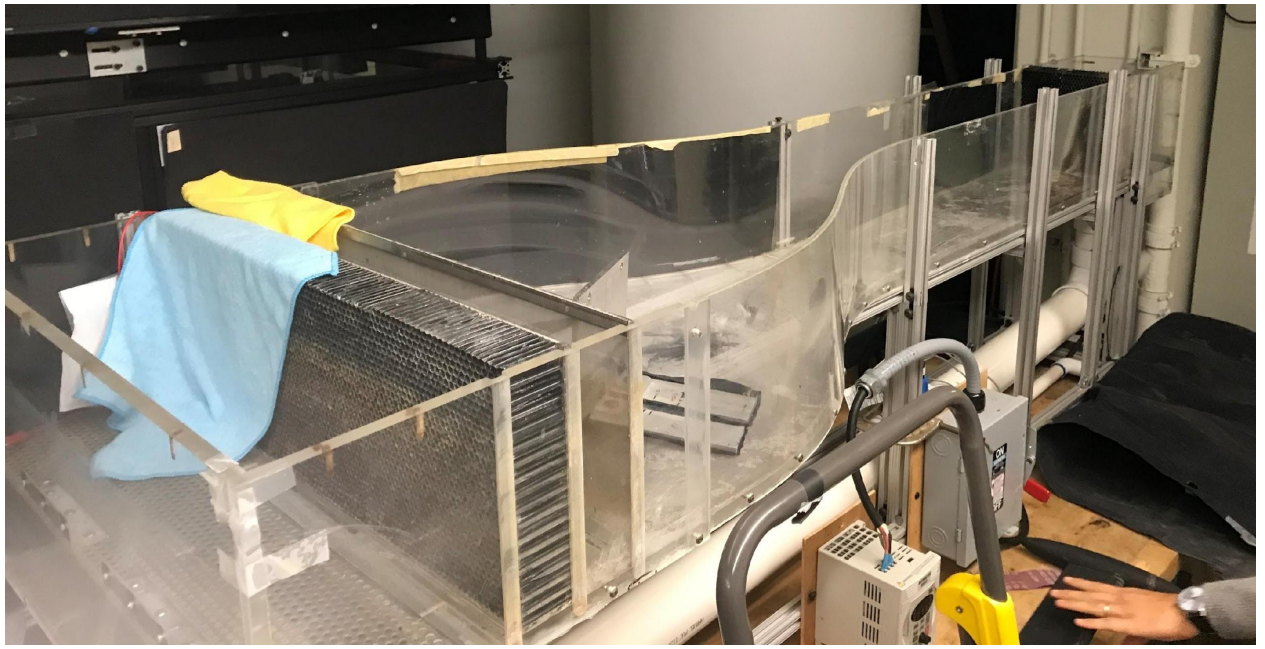
small, med, large

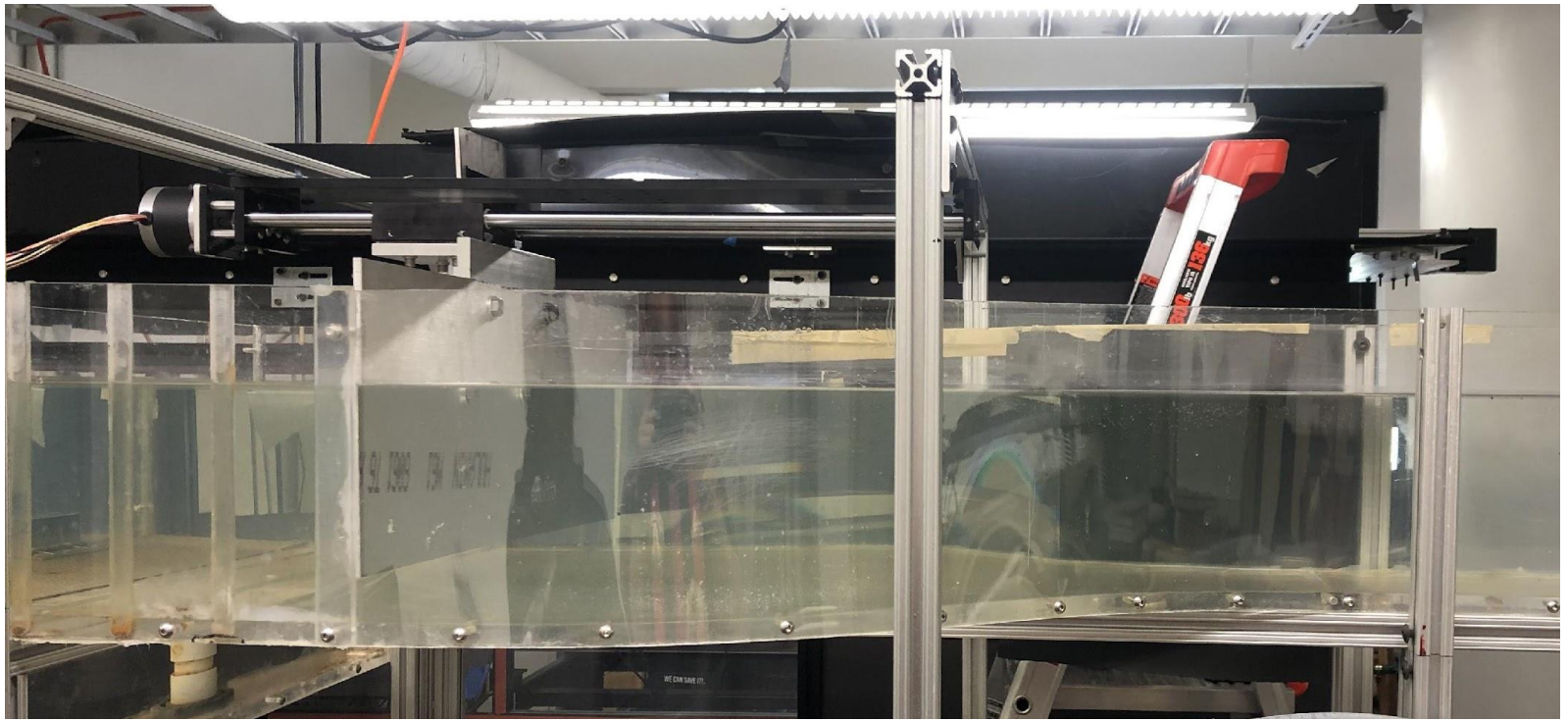
Configuration

one or two membrane

Dependent Variable

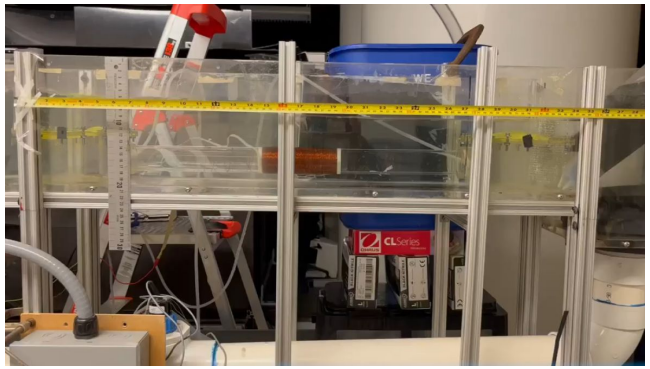
Voltage(t)



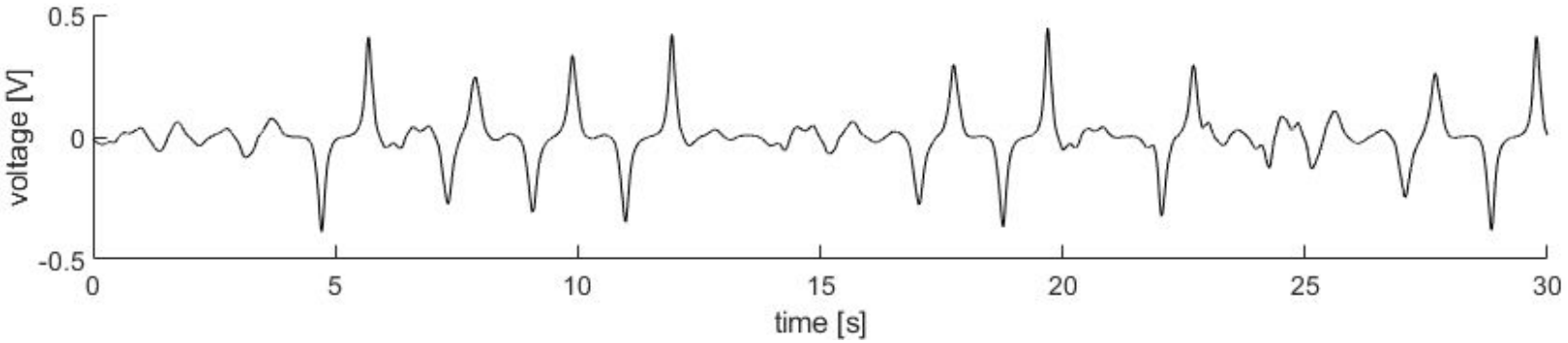


Experiment Setup – Data Collection

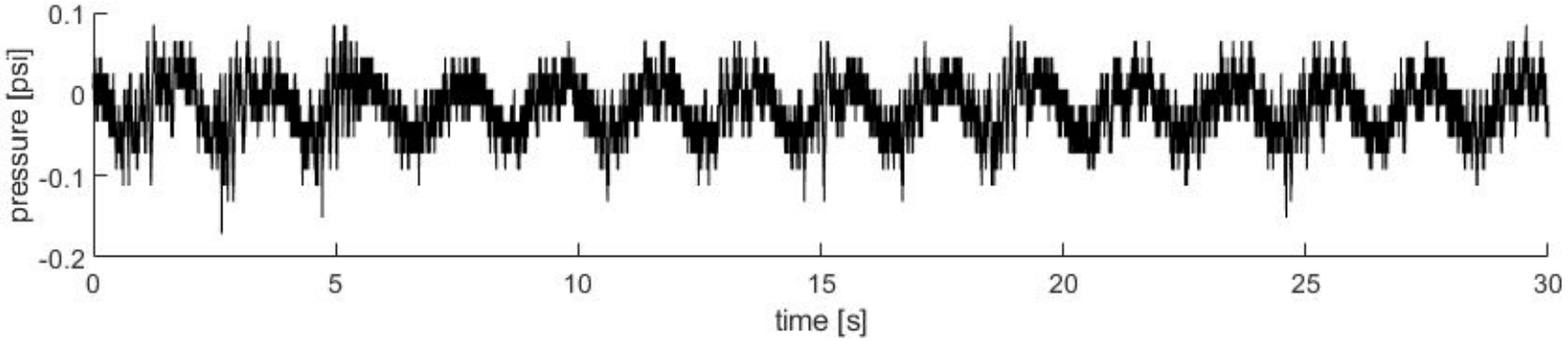
Phone camera

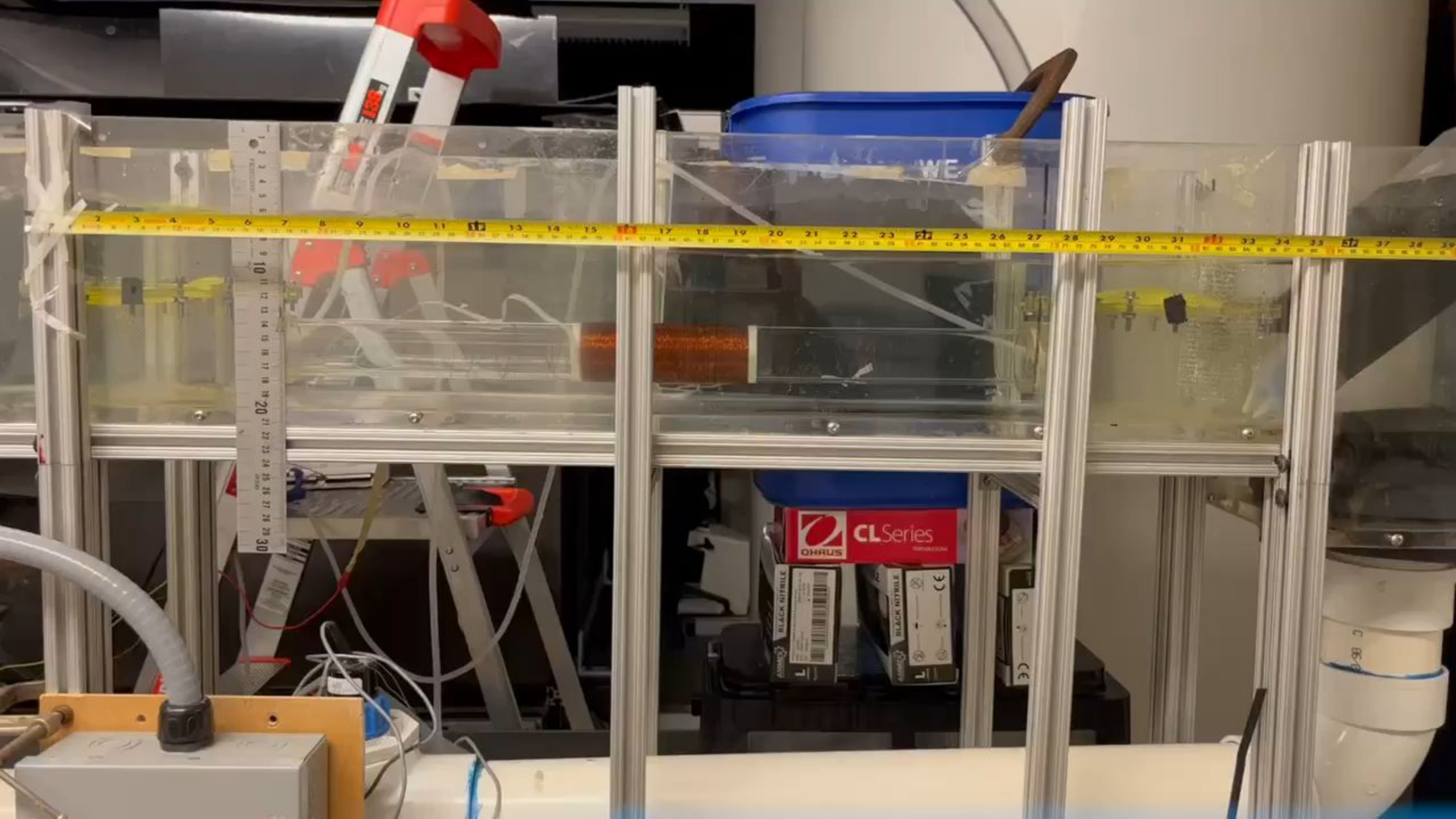


Oscilloscope



Differential pressure sensor

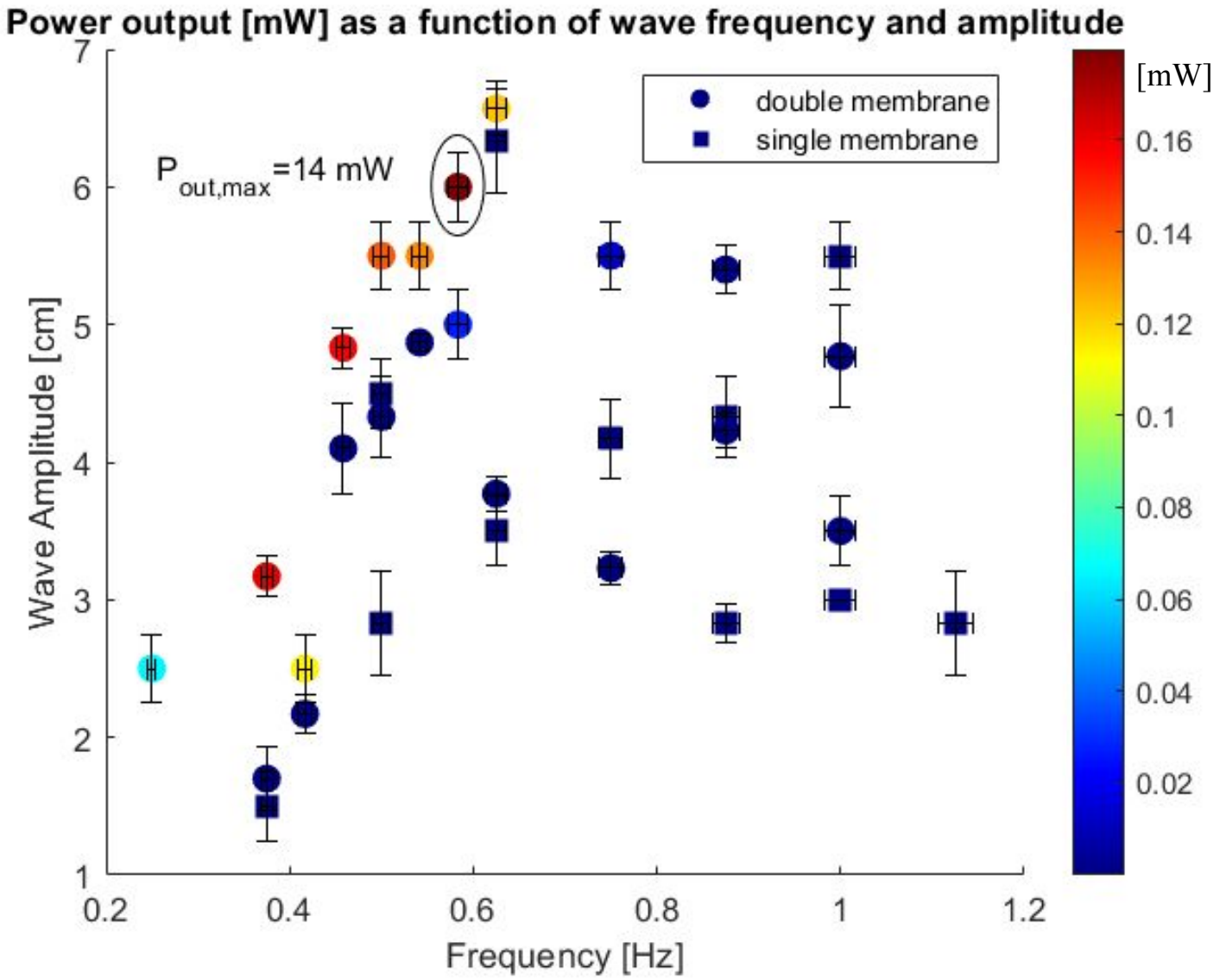


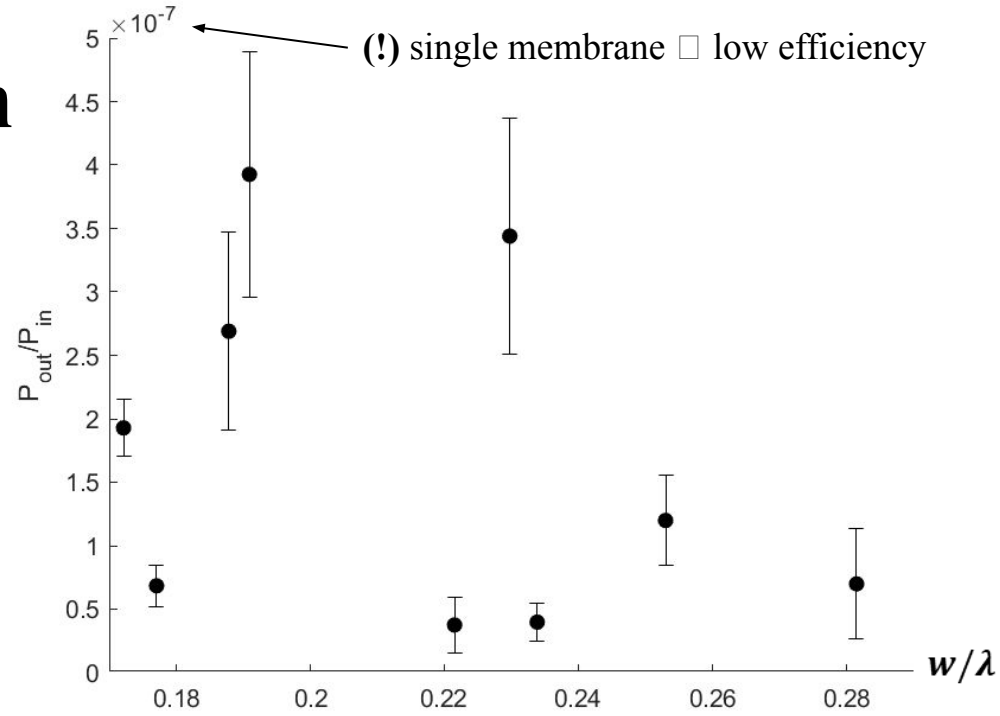

OHAUS
CL Series
BLACK NITRILE
BLACK NITRILE

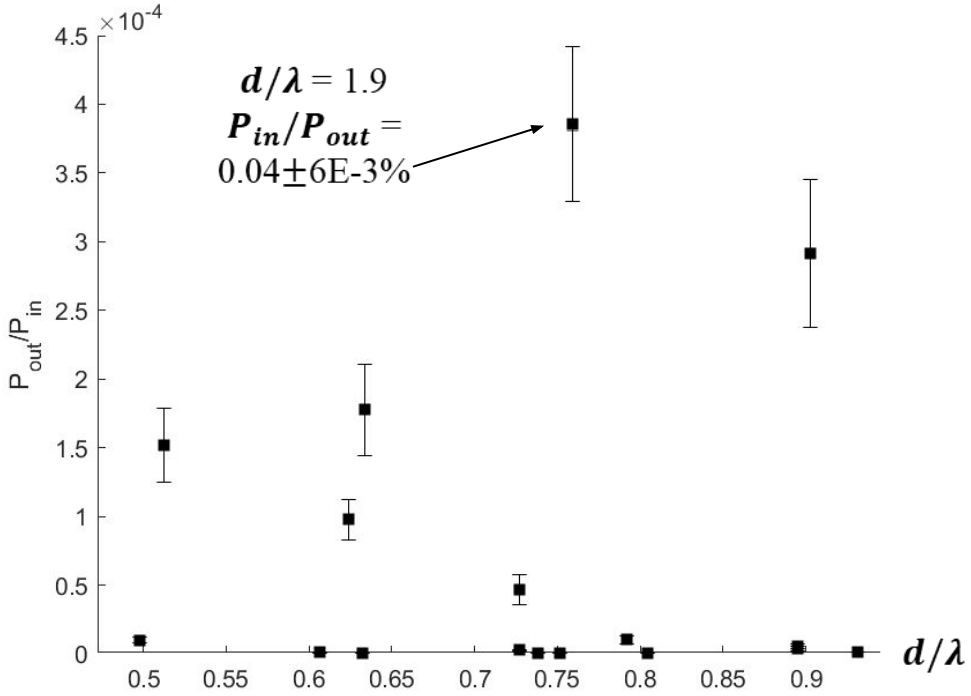
Results

1m wave, 0.04% □ 4 W/m

(<lightbulb)

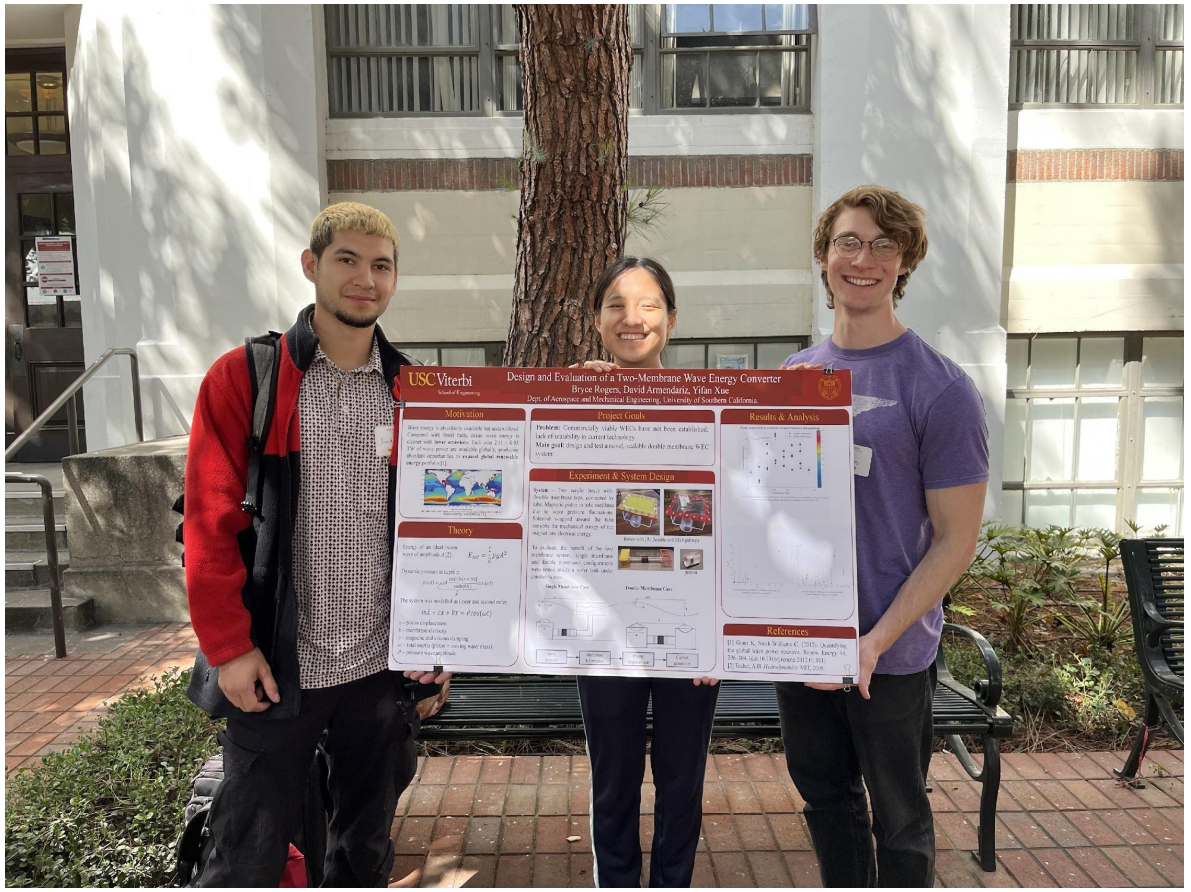






Hypothetical future steps

- Determine if efficiency can be improved at scale
- Validate power take off performance at scale
- Resonant frequency dynamically tuned to incoming waves?



Key Takeaways

Project-specific

- Power increases with ***A***, has a frequency "sweet spot"
- Two membrane configuration may be preferable over one membrane
- More work needed to determine if efficiency could be sufficiently high at scale to be cost effective

Engineering in general

- Robust theory and preparation essential to success
- No decision can be made with 100% certainty, engineering judgements must be made to progress

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Questions?

Works cited

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[2] Collins, Ieuan, et al. “Flexible Membrane Structures for Wave Energy Harvesting: A Review of the Developments, Materials and Computational Modelling Approaches.” Renewable and Sustainable Energy Reviews, vol. 151, 2021, p. 111478., https://doi.org/10.1016/j.rser.2021.111478.

[3] Ryan, S., et al. The Bombora Wave Energy Converter: A Novel Multi-Purpose Device for Electricity, Coastal Protection and Surf Breaks: Semantic Scholar. 1 Jan. 1970, https://www.semanticscholar.org/paper/The-Bombora-wave-energy-converter%3A-A-novel-device-Ryan-Algie/a8925cdc5b07e026cd1fb8916c56008d3c4f5d50.

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