



# The Biggest Mistakes We Made with the LUPA WEC, and How We Tackled Them

Courtney Beringer, Bret Bosma, Bryson Robertson



# Outline

- What is LUPA?
- How has LUPA been used?
- Lessons learned from
  - Design
  - Build
  - Test
  - Modeling
- Future directions

# What is LUPA?

- Laboratory Upgrade Point Absorber
- Motivations
  - Open-source
  - Modular
  - Share lessons learned!
- Funding
  - DOE
  - Business Oregon
  - TEAMER
- Project start: 2020

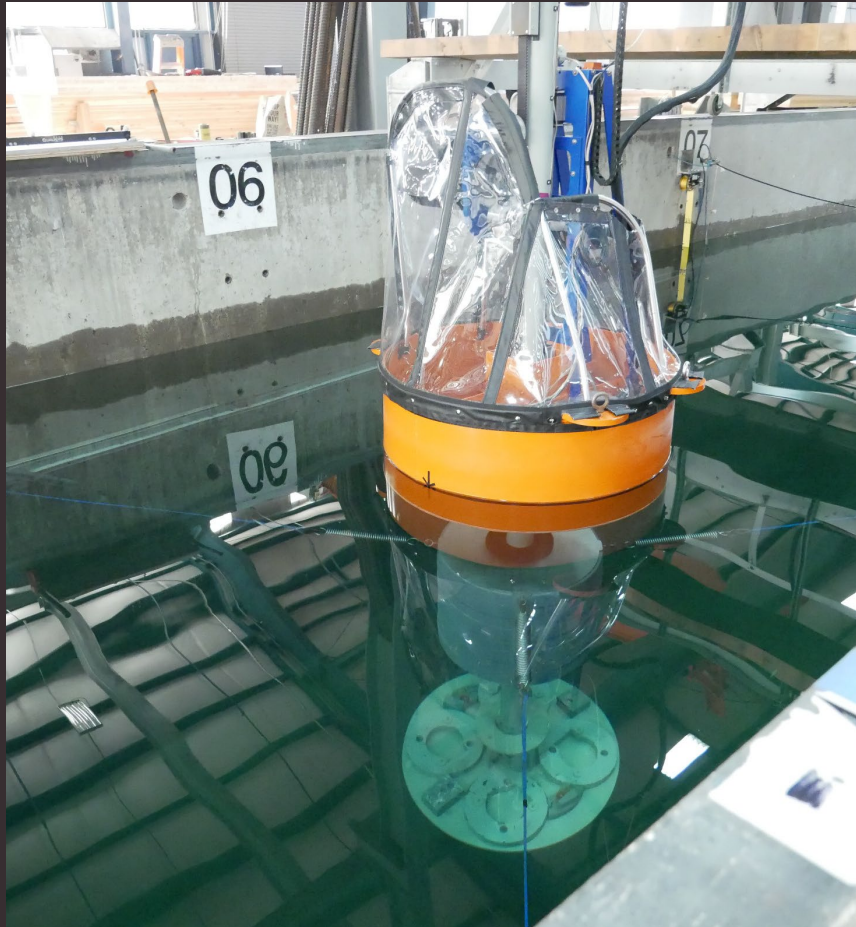
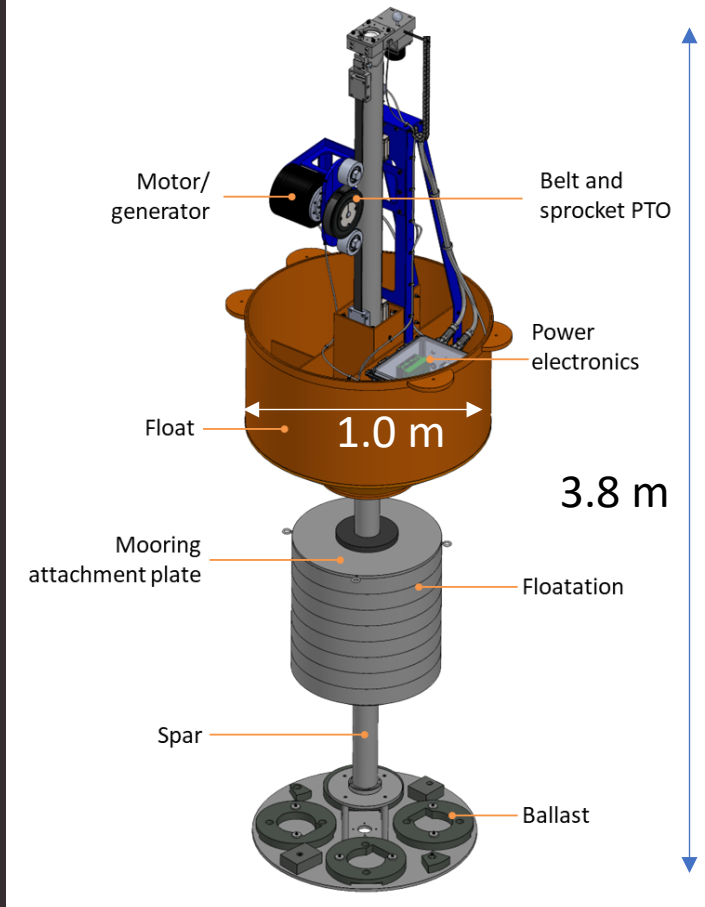
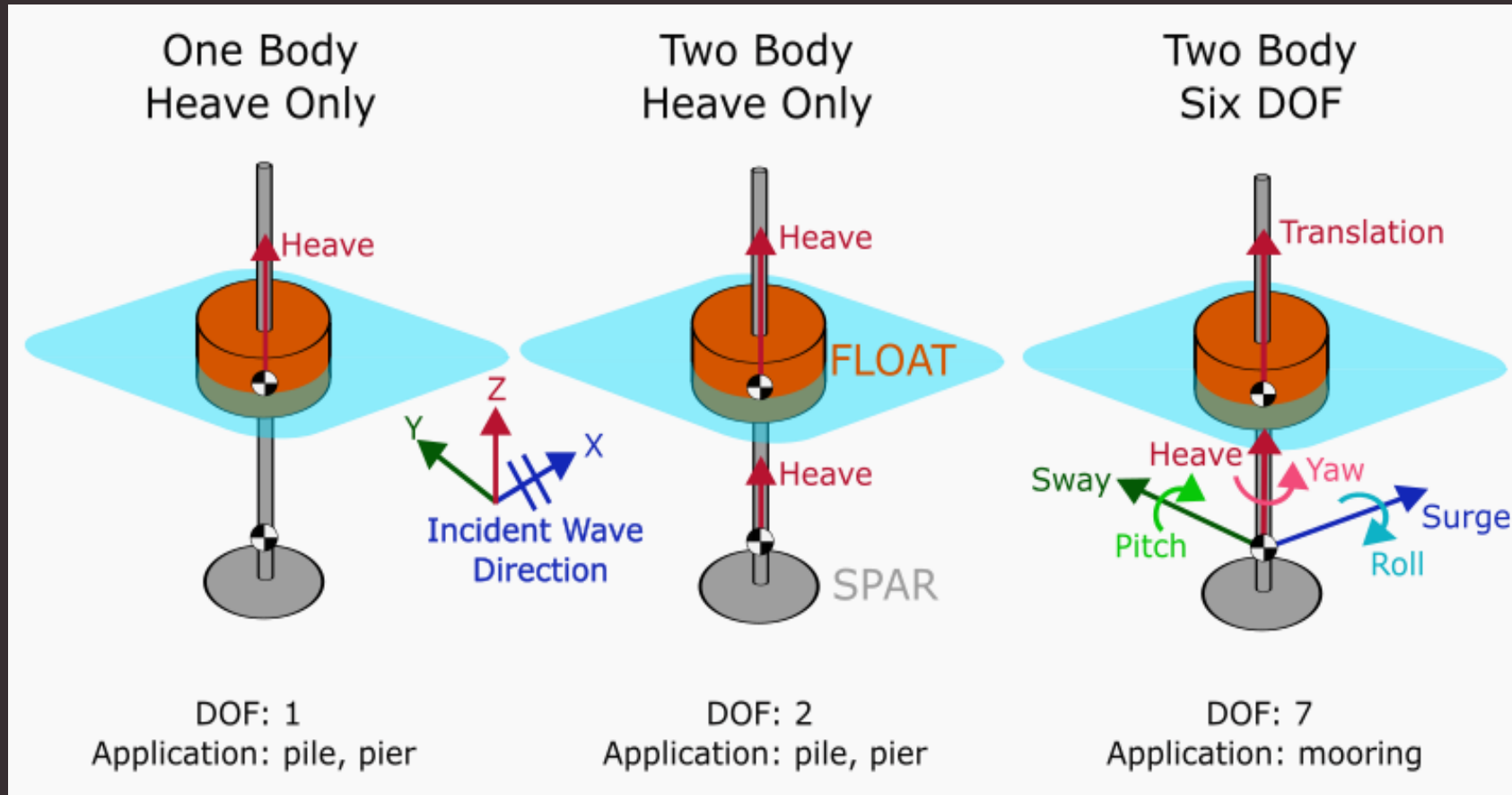


Photo by Samantha Quinn



O.H. Hinsdale Wave Research  
Laboratory  
Large Wave Flume  
Oregon State University  
Corvallis, OR, USA

# Modes of Operation: simple to complex





- Actively controlled PTO with damping and stiffness control through MATLAB real-time interface
- WEC-Sim, WAMIT, ProteusDS, WecOptTool models
- TEAMER facility w/ Hinsdale
- Fully detailed CAD models
- Photos, videos
- Papers, presentations

## Capabilities



# DOE WPTO: Signature Project

## LUPA

### Project Information

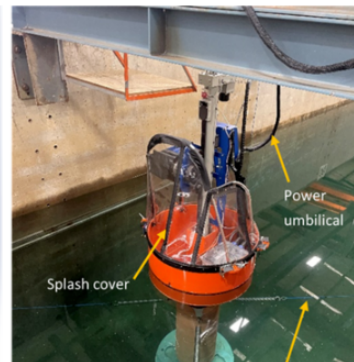
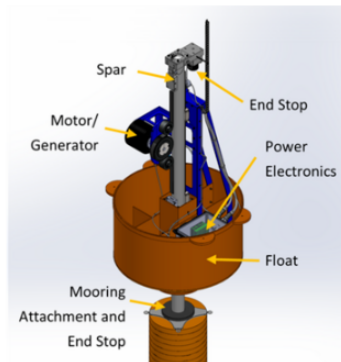
#### Project Purpose

The Laboratory Upgrade Point Absorber (LUPA) Project was designed to create an open-source, modular numerical and physical WEC system to create a common benchmark for WEC hydrodynamics, controls, mooring systems, and student learning.

#### Project Description

The Lab Upgrade Point Absorber (LUPA) project, sponsored by the U.S. Department of Energy (DOE), has developed open-source modular point absorber for WEC hydrodynamics, controls, mooring systems, and student learning. A visual of the experimental and numerical LUPA WEC are shown in Figure 1. The LUPA development team collaborated with the DOE National Marine Energy Centers (NMECs), Sandia National Laboratory (SNL), National Renewable Energy Laboratory (NREL), and private industry in the development of the LUPA WEC physical specimen and experimental device.

Status:	Ongoing
Start Date:	2020/04/01
Source:	<a href="#">LUPA Website</a>
Organization:	<a href="#">Pacific Marine Energy Center (PMEC)</a> , <a href="#">Oregon State University (OSU)</a>
Contact:	<a href="#">Bryson Robertson</a>



[https://openei.org/wiki/PRIMRE/Signature\\_Projects/LUPA](https://openei.org/wiki/PRIMRE/Signature_Projects/LUPA)

# Campaigns + Research

- Initial deployment Fall 2022
- TEAMER testing internal Fall 2023
- WEC modeling and controls workshop Spring 2024
- TEAMER testing external Spring 2025
- Over 100 deployment days
- Through all this... we have successes and failures to share

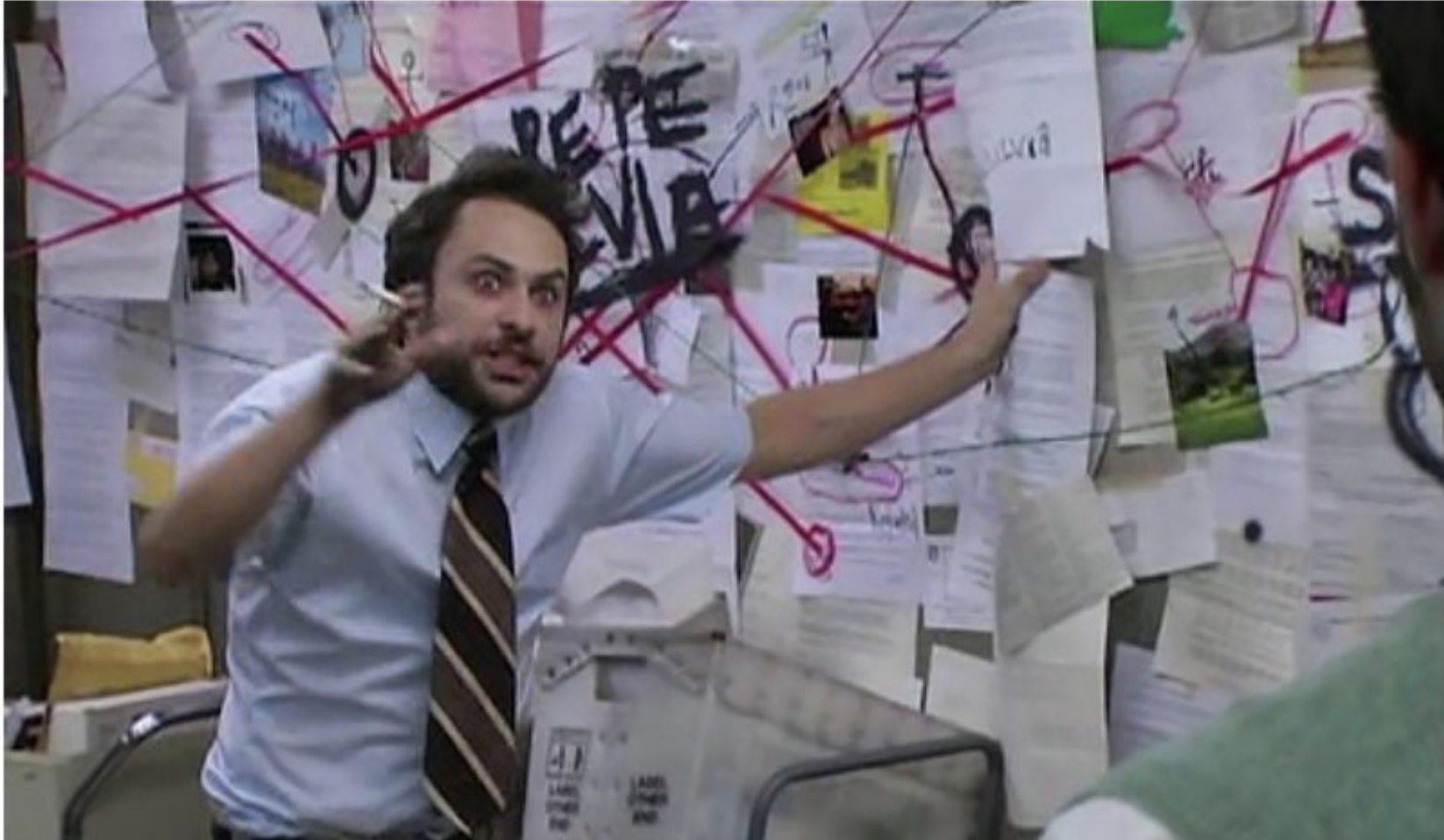


# Stability Off the shelf Safety Configuration functionality

- Spar tube is hollow
- Spar positively buoyant
- Heavy generator high up
- Off the shelf steel pulleys
- **Problem: very unstable when deploying and recovering, high center of gravity**



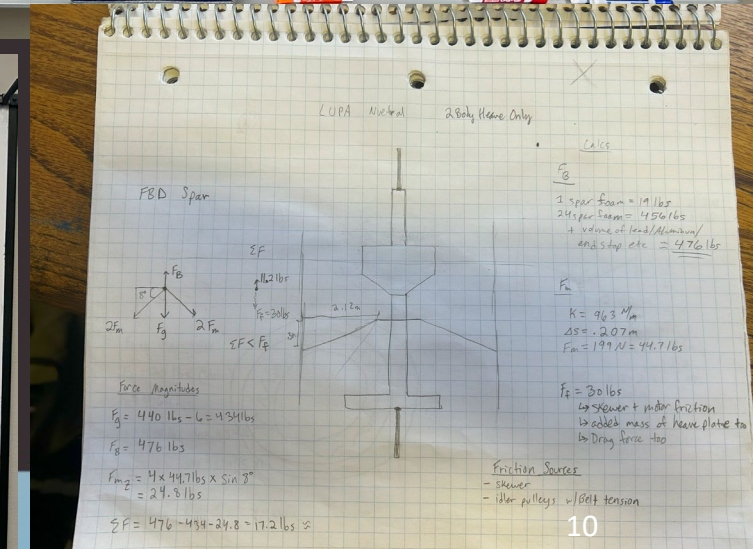
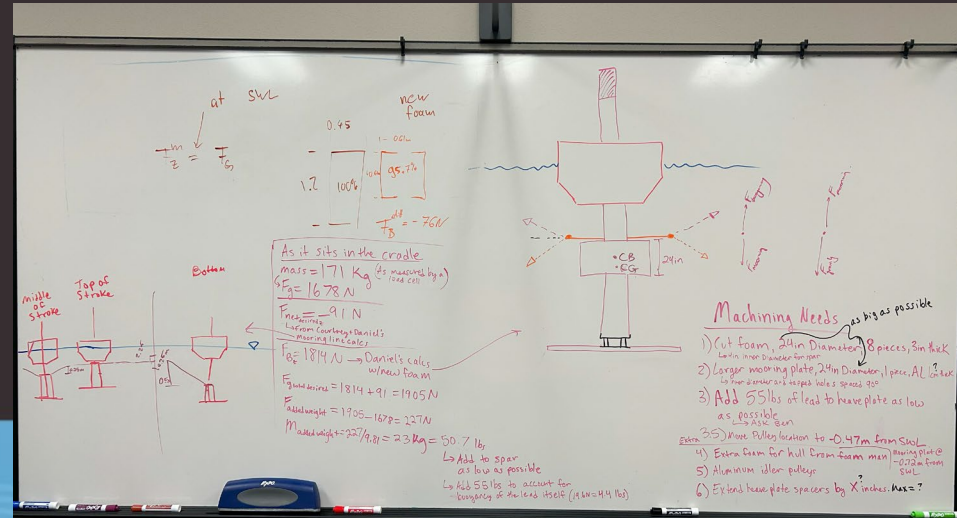
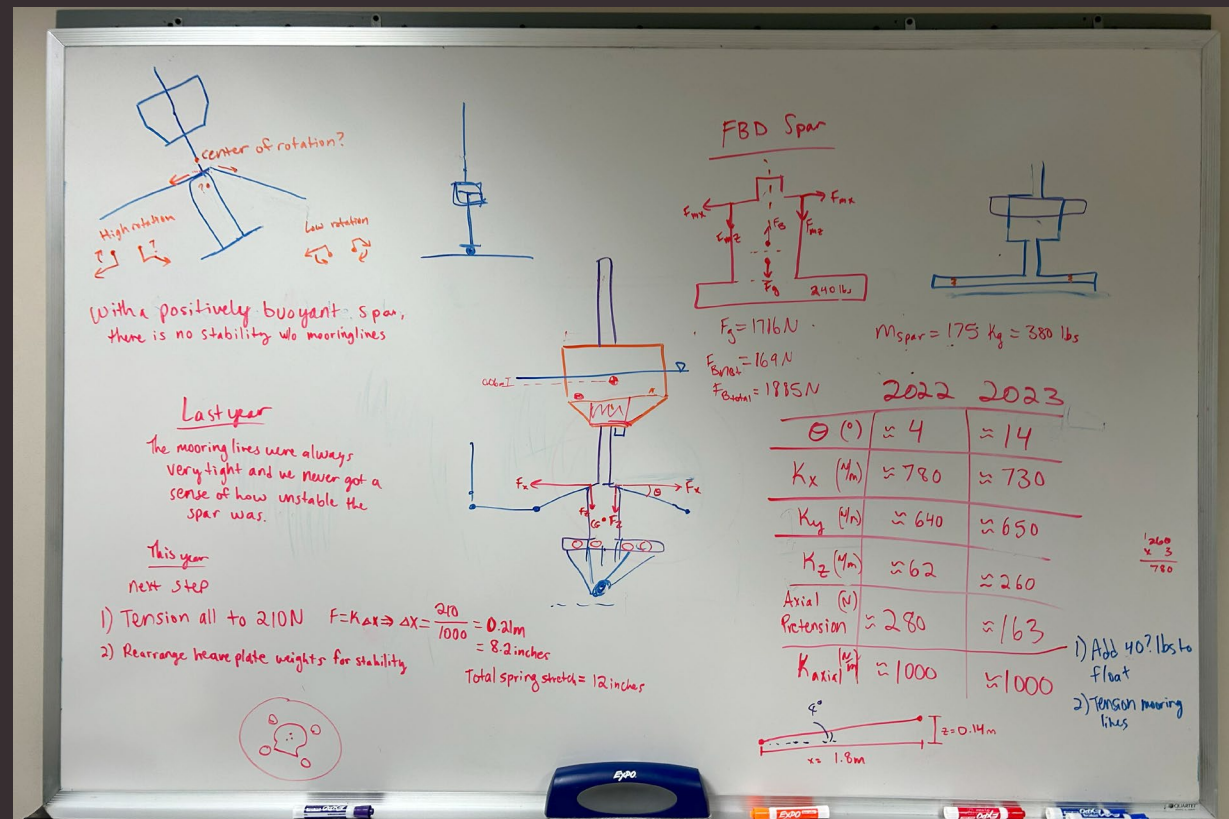




Us for the first hour of realizing this is a problem and we can't go on

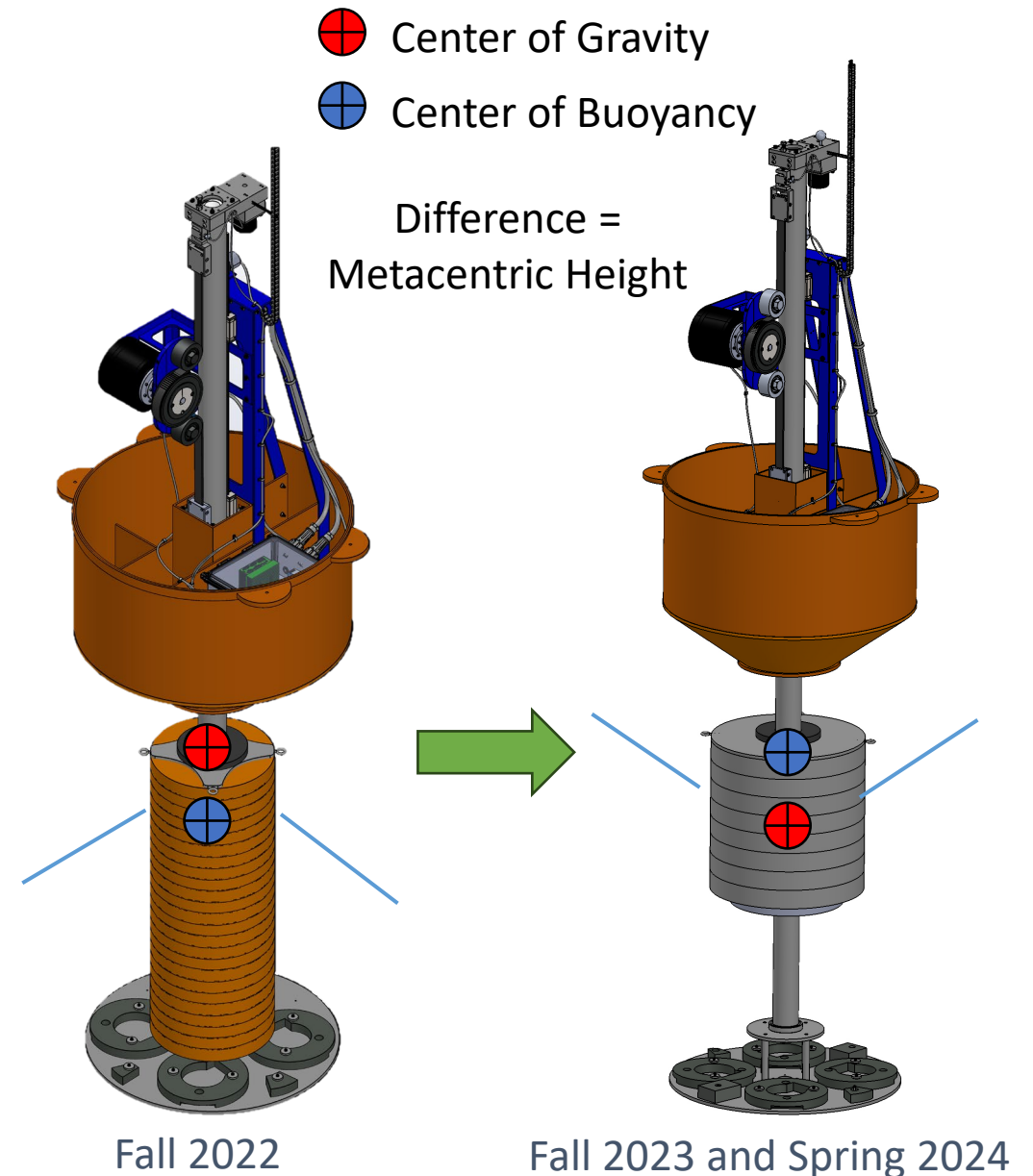
# Us for the next week

- Calling naval engineering friends
- Geometry, trigonometry, free body diagrams
- Brownies and good vibes to machinists
- Run wave calibrations so we don't waste precious tank time
- McMaster fast shipping
- Calling foam man
- CAD drafting
- MATLAB coding
- Undergrad errands



# Improved LUPA

- Spar is now negatively buoyant
- Spar higher floatation, lower ballast = new CG
- Mooring pretension and angle changed
- Float lost a few pounds replacing steel pulley with aluminum
- Extended heave plate by 10 inches
- **Result: night and day stability**
- **Lessons learned**
  - Out of the water and to the white board
  - Build good relationships with suppliers and machinists





# Build Lessons learned

- Mock up humans next to device in CAD
- First build: test fit and modify
- Disassemble everything
- Powder coating paint
- Second build: final assembly
- Cranes, forklifts, pallet jacks..
- LUPA weight?
- Cradle weight?





# Assembly instructions

## Step 18

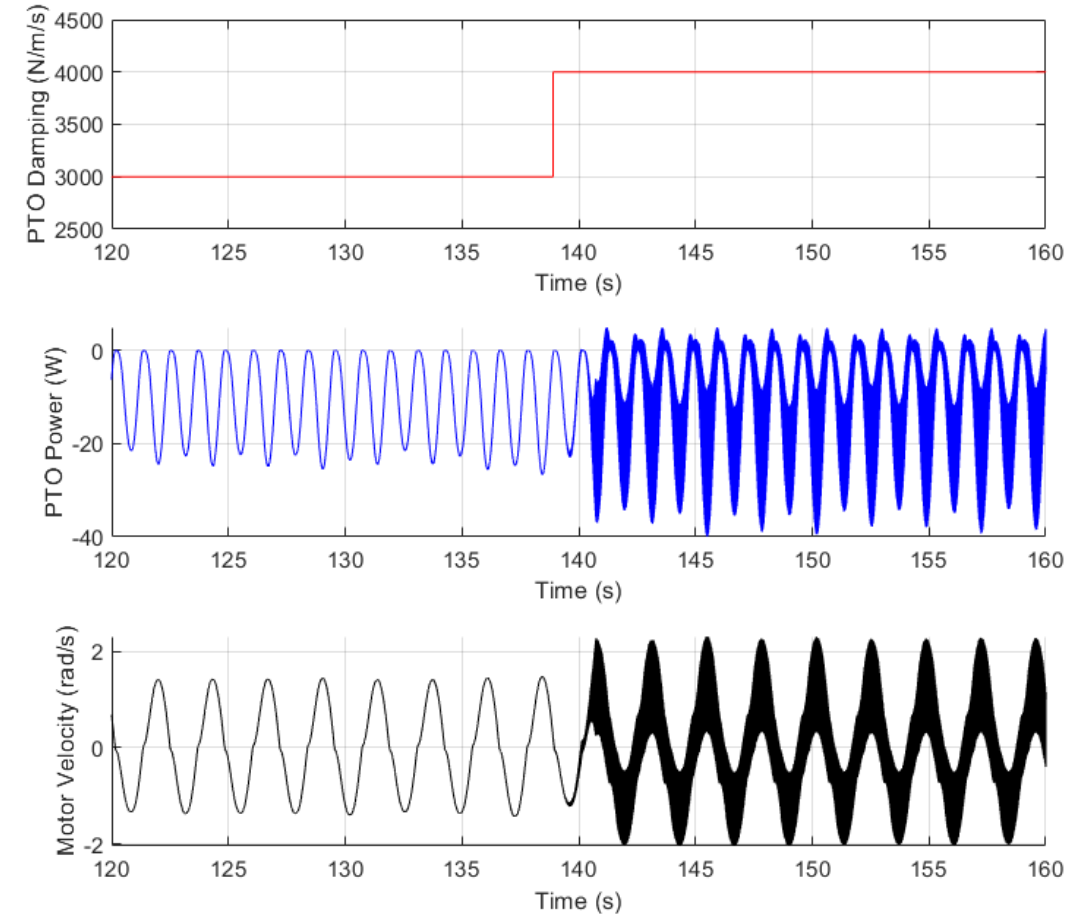
### Pulley and Sprocket Install

<b>Parts</b>	<ul style="list-style-type: none"><li>Box 1: pulleys (2) , 3 sprockets (large, med, small), key (1)</li></ul>
<b>Tools</b>	<ul style="list-style-type: none"><li>5/16 Allen wrench</li></ul>
<b>Instructions</b>	<ul style="list-style-type: none"><li>First decide what size sprocket you want</li><li>Insert sprocket onto drive shaft with shaft key inserted. Tighten the short, threaded, headless bolts into the holes across from each other.</li><li>Thread on pulleys into correct tapped hole depending on the size sprocket chosen</li><li>The exact location of the pulleys and sprocket needs to align with the belt.</li></ul>
<b>Helpful Hints</b>	<ul style="list-style-type: none"><li>The sprockets have 3 threaded holes. The two across from each other are used to tighten the bushing. The one hole offset is used to loosen the bushing.</li></ul>



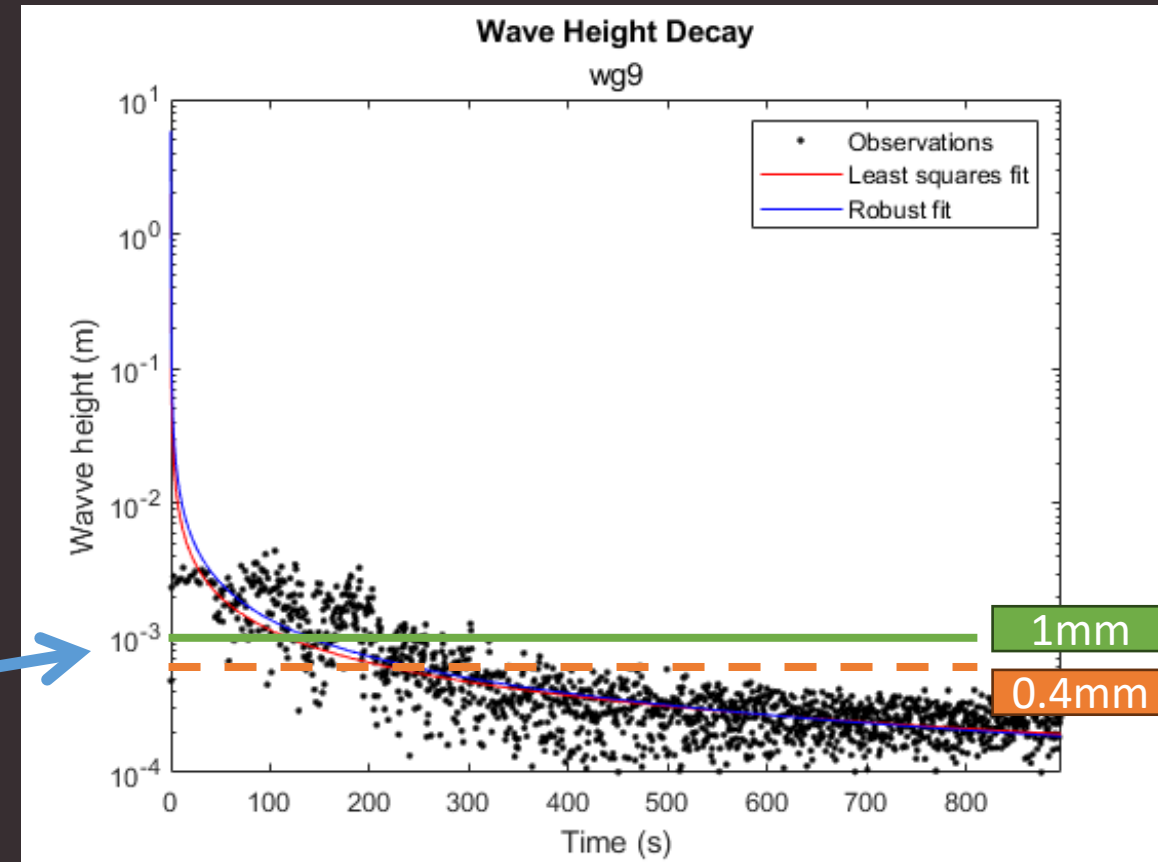
# Test

- Issues with PTO control feedback loops
- High frequency PTO belt vibrations
- Violent! Broke load cell hardware
- First and only emergency stop use
- Solve: notch + low pass filter



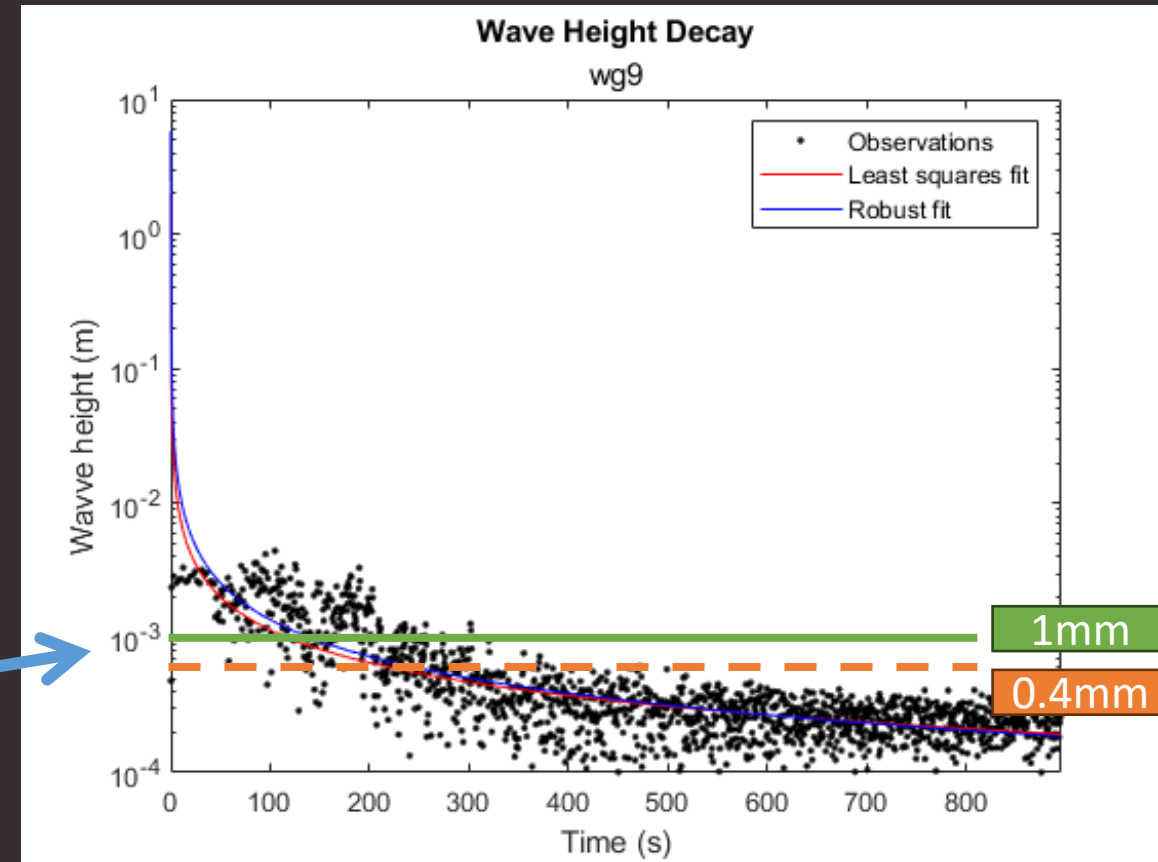
# Test: Tank settling analysis

- Measure quiescent wave height (0.4mm)
- Run each condition of interest 1x
- Continue wave gauge data collection for ~20 min
- Analyze the wave height decay over time
  - 2 min to  $H=1\text{mm}$
  - 4 min to  $H=0.4\text{mm}$



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Lesson learned: saved 8 hours  
of test time ~\$6K



# We have all been here...

Shameless use of WEC-Sim issues page!!

<https://github.com/WEC-Sim/WEC-Sim/issues>



# Future directions

- New motor drive to measure electrical power capture
- Adding battery charging capabilities and small load conditioning
- Lockout tagout on LUPA electrical box side
- Filters to prevent high PTO damping noise feedback loop

# Future testing

- LUPA x Marine Carbon Dioxide Removal with NOAA / University of Minnesota
- LUPA x Autonomous Underwater Vehicle with WPTO / UW-APL + UH
- Codesign with WPTO / Sandia
- Reinforcement learning control with TEAMER/MTU

# Many thanks and contributors!

- Bret Bosma
- Bryson Robertson
- Pedro Lomonaco
- Rebekah Miller
- Tim Maddux
- Brian Johnson
- Darin Kempton
- Wave lab undergrads
- Belen Barcamontes
- Cedric LaPeyre
- Hannah Mankle
- Daniel Gaebele





# Thank you!

## Questions?

Courtney Beringer

PhD Candidate Oregon State University

[www.linkedin.com/in/cberinger/](https://www.linkedin.com/in/cberinger/)  
beringec@oregonstate.edu



**Oregon State**  
University



# Extra slides

# Mooring lines: Turnbuckle vs Winch

## Turnbuckle

- Slow
- Heavy
- Limited stroke
- Operate from kayak in water

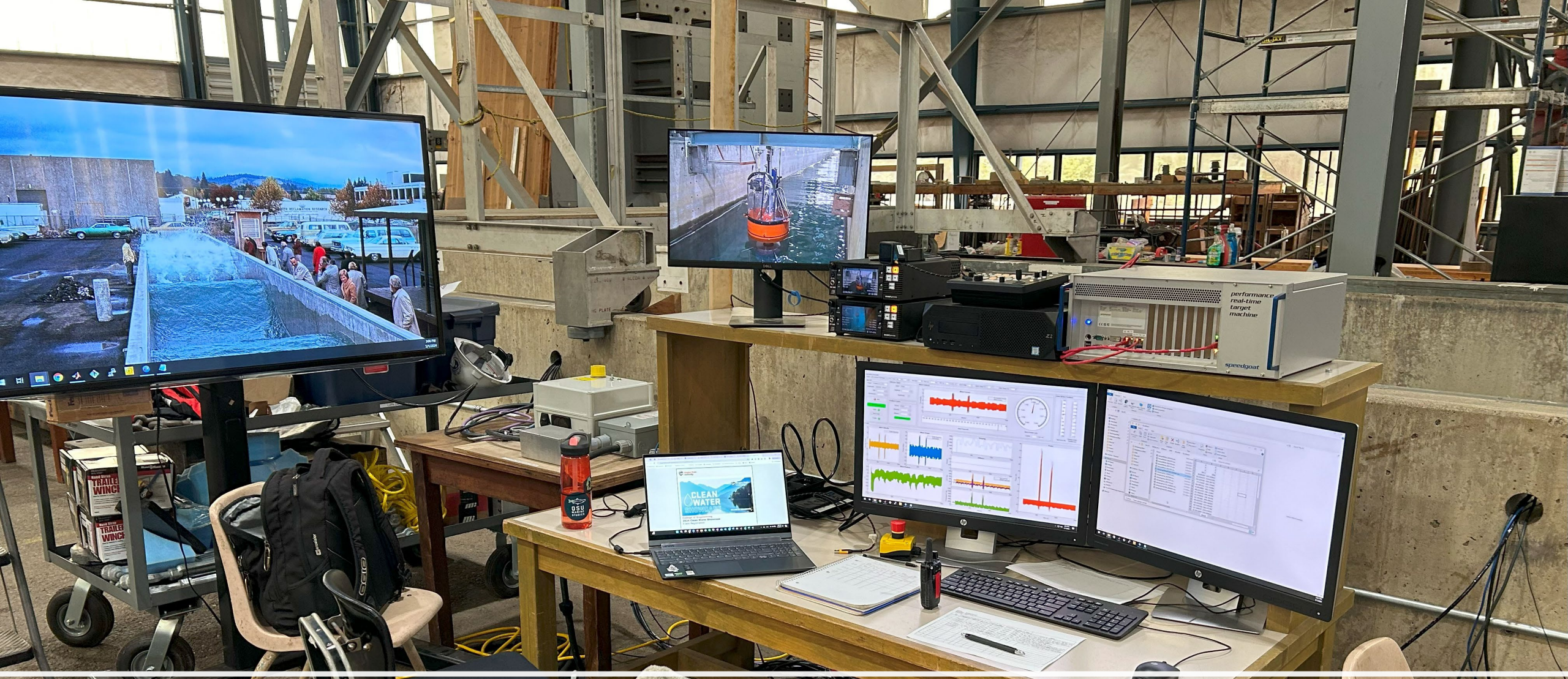


## Winch

- Fast
- Solid mount
- Nearly unlimited stroke
- Operate from dry above flume



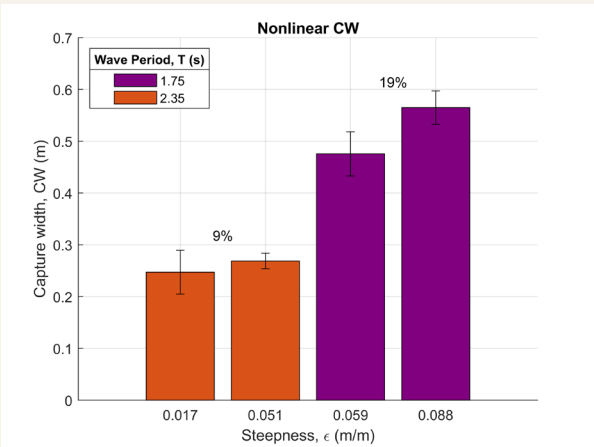
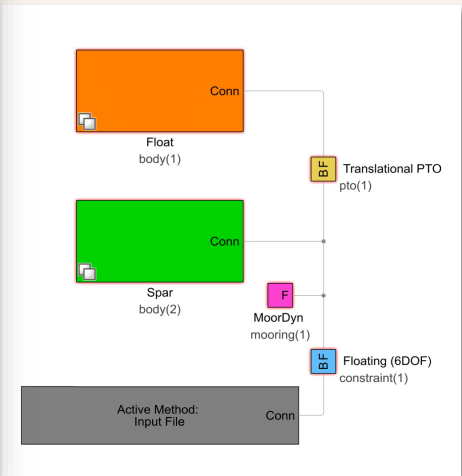
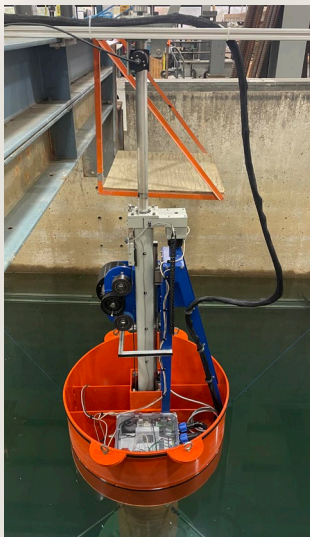
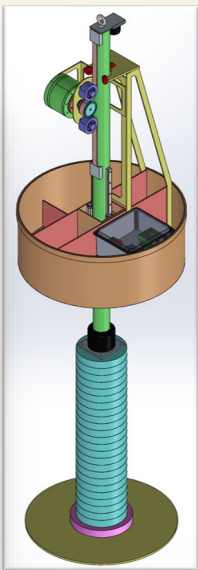
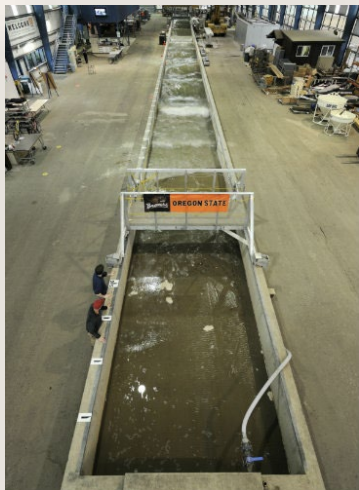




Human errors on motor current limit



# Timeline



Concept development

Design iterations

Field expert feedback

Build device

Experimental testing

Numerical modeling & uncertainty

Publishing on controls, uncertainty, system ID, and DOF

2020

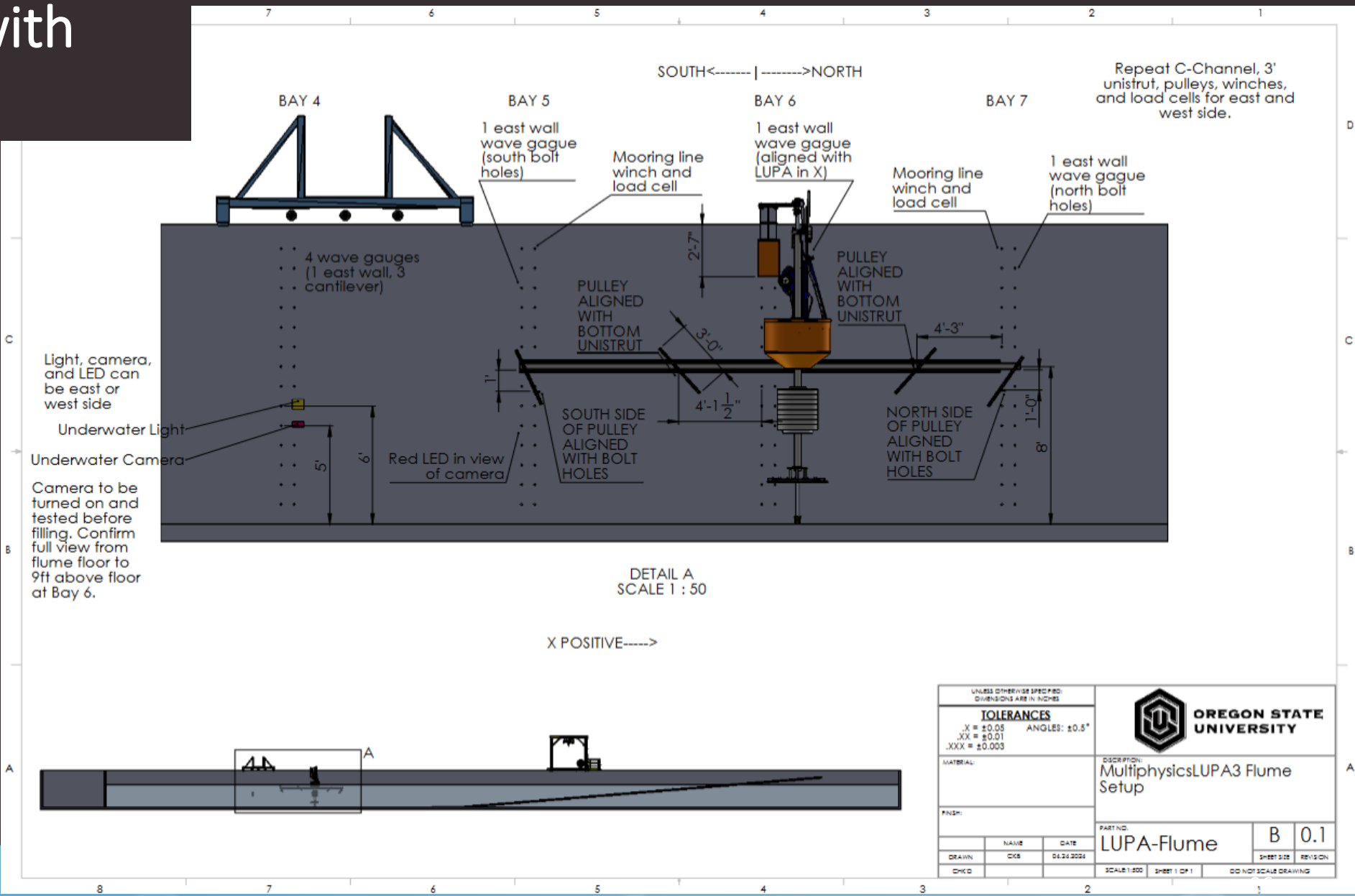
2021

2022

2023


2024-25





# Flume drawings to communicate with wave lab team




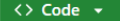





# Control Code Management on GitHub

<https://github.com/PMEC-OSU/LUPA>



 **LUPA** Public

 Edit Pins  Watch 1  Fork 3  Starred 8

 main  2 Branches  6 Tags   Code

 **Wave User** and **Wave User** End of LUPA7 project  ac44a61 · 5 months ago  175 Commits

ELMO	end of TEAMERAOELUPA6	5 months ago
Homing	first day of TEAMERMTULUPA5 testing	6 months ago
Simulink	End of LUPA7 project	5 months ago
TwinCAT	Swapped in EL3751 units for the load cells	11 months ago
docs	Update faqs.md	last year
.gitignore	End of TEAMERMTULUPA5	5 months ago
LICENSE	Initial commit	3 years ago
README.md	Update README.md	last year

 **README**  Apache-2.0 license

## LUPA

Laboratory Upgrade Point Absorber small scale research Wave Energy Converter This repository contains the control codes for experimental testing of LUPA.

CAD files here: <https://zenodo.org/record/8156350>

### About

Laboratory Upgrade Point Absorber small scale research Wave Energy Converter

[www.pmec.us/LUPA](http://www.pmec.us/LUPA)

Readme

Apache-2.0 license

Activity

Custom properties


8 stars

1 watching

3 forks

Report repository

### Releases 6

 **LUPA7** Latest  
on Apr 2

+ 5 releases


### Packages


No packages published

[Publish your first package](#)

### Contributors 4

Mar 10

 bretbosma

 TEAMERMTULUPA5

a97f95e


Compare


## TEAMERMTULUPA5

TEAMERMTULUPA5 test campaign final code. Reinforcement learning test campaign. Piston wavemaker and 2.74 m water depth.

**Assets 3**

May 20, 2024

 bretbosma

 Spring\_2024\_LUPA3

ce8f475


Compare

## MultiphysicsLUPA3\_WorkshopLUPA4 - Spring 2024


Back to back MultiphysicsLUPA3 in two body heave only mode and WorkshopLUPA4 in one body heave only mode. Flap wavemaker and 2.781 m water depth.


**Assets 2**

rgcoe reacted with hooray emoji

 1 person reacted

May 20, 2024

 bretbosma

 Fall\_2023\_TEAMERLUPA2

cc53a6d

Compare


## TEAMERLUPA2 - Fall 2023

Second deployment of LUPA. 6DOF mode with 3.695 m of water. Focus on uncertainty and system identification.

**Assets 2**

# GitHub for WEC-Sim model control

LUPA\_WEC-Sim / LUPA Fall 2022 /

 **ckberinger** Update wecSimInputFile.m

Name	Last commit message
..	
OneBodyHeaveOnly	Initial commit of LUPA Fall 2022 WEC-Sim
TwoBodyHeaveOnly	Update wecSimInputFile.m
TwoBodySixDOF	Update wecSimInputFile.m
WAMIT	Update README
geometry	Initial commit of LUPA Fall 2022 WEC-Sim
hydroData	Add files via upload
ReadMe.txt	Update ReadMe.txt