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WEC-SIM PHASE 1 VALIDATION TESTING - NUMERICAL MODELING OF EXPERIMENTS

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FOSWEC – Hydrodynamic Design

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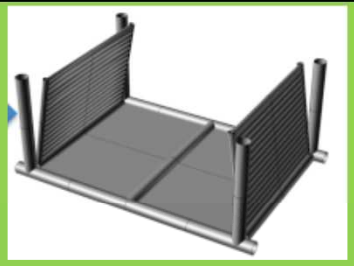
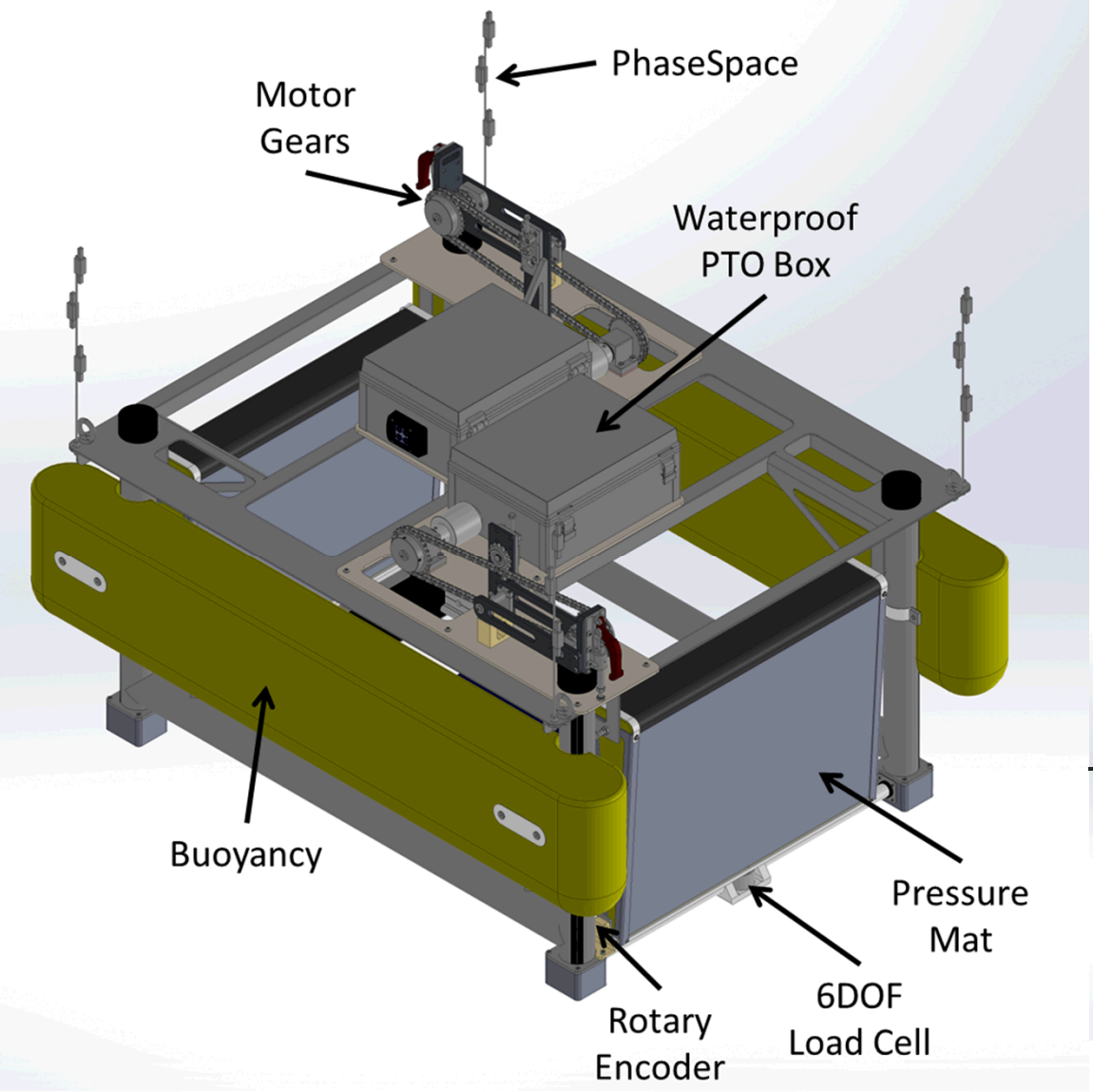
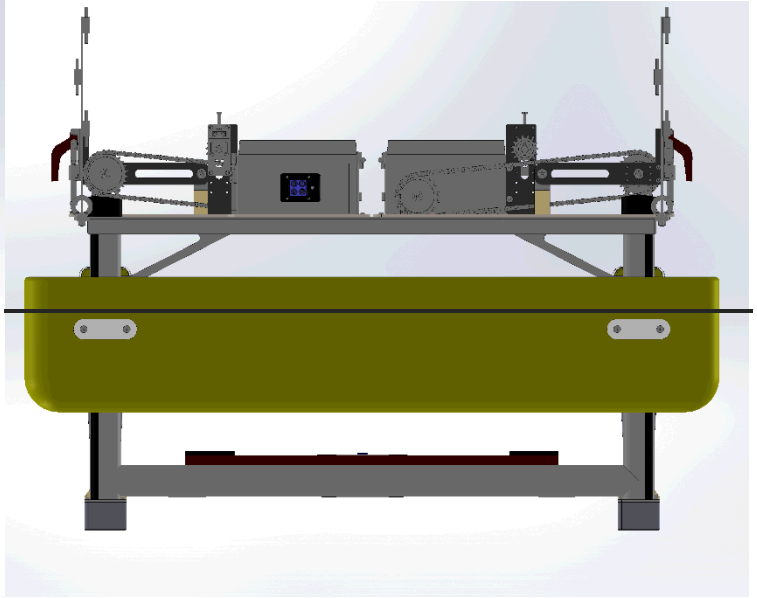
Wave Energy Converter					
Example Image		Archetype	Industry Example	Operating DOF	PTO Type
		Floating oscillating surge device	Langlee 	3: Surge, heave, pitch	Rotational
Validation Ability					
WEC-Sim Modeling	*DOF Testing*	*Wave Directionality*	*Body-to-Body Interaction*	*Nonlinear hydrostatics & hydrodynamics*	***Validation Ability Total***
2	2	2	2	2	**2**
Testability					
Modularity of Testing	*Performance Instrumentation*	*Ease of Deployment*	*Ease of Construction*	*Loads Instrumentation*	***Testability Total***
2	2	1	1	2	**1.63**
Weighted Total					**1.88**

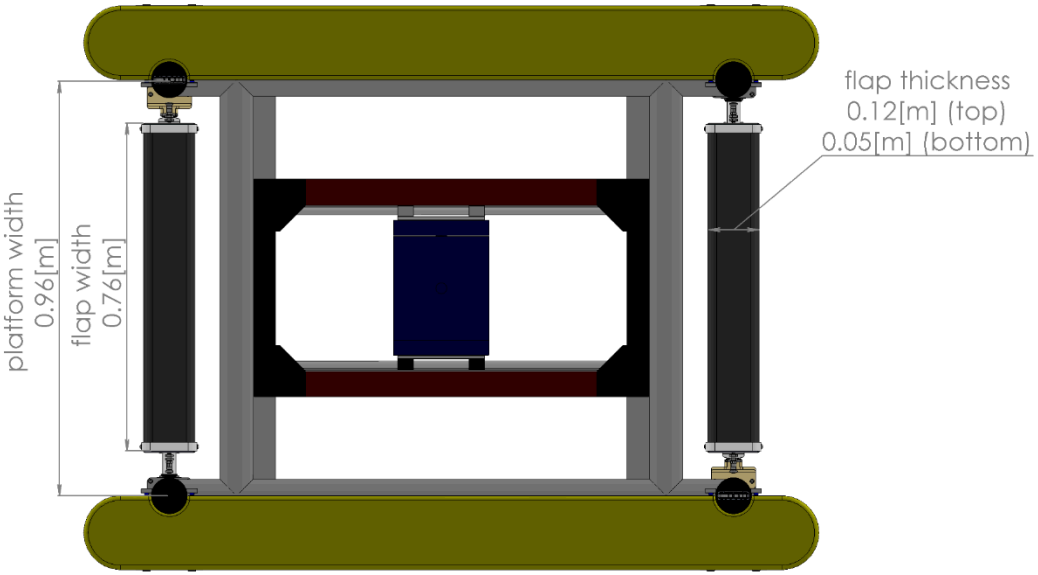
FOSWEC Design/Fabrication

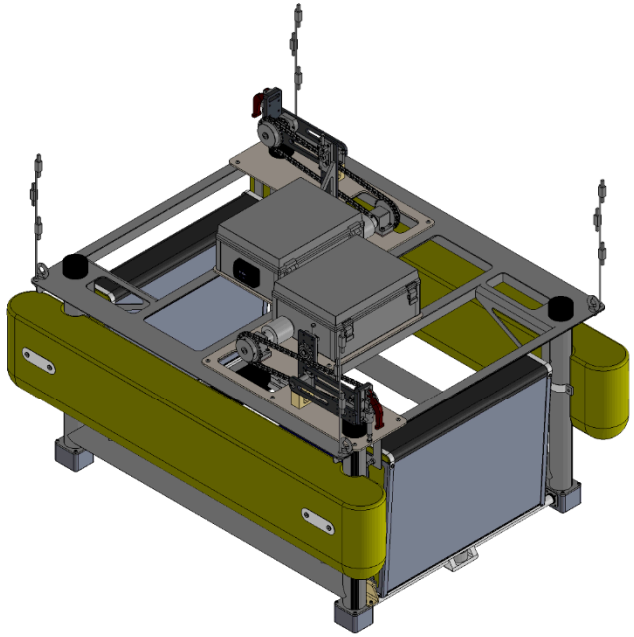


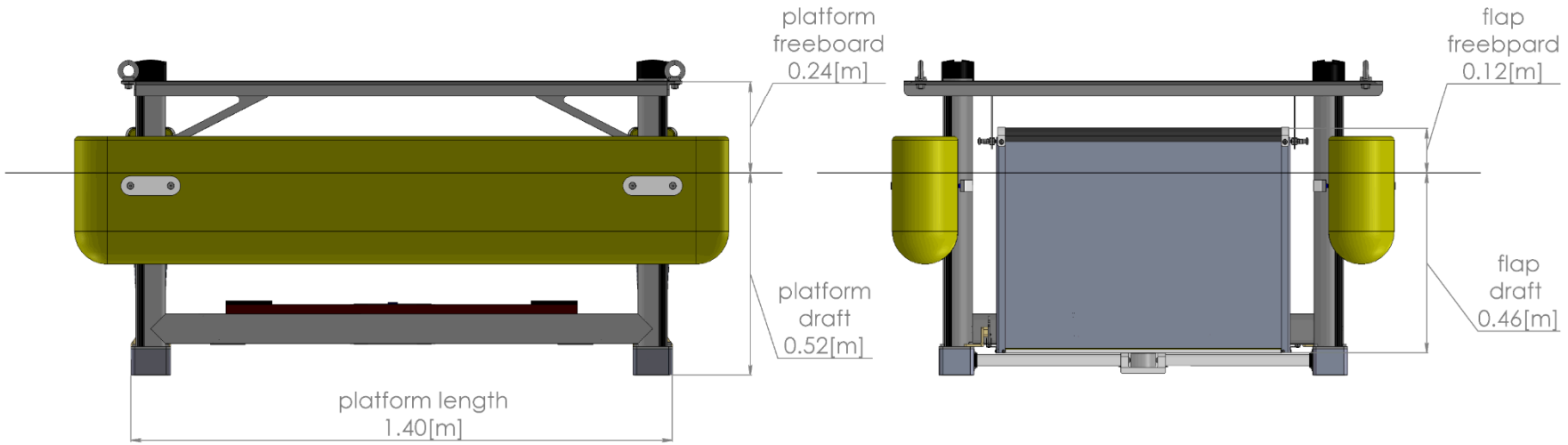
Side View



FOSWEC Design/Fabrication







Arm Design/Fabrication

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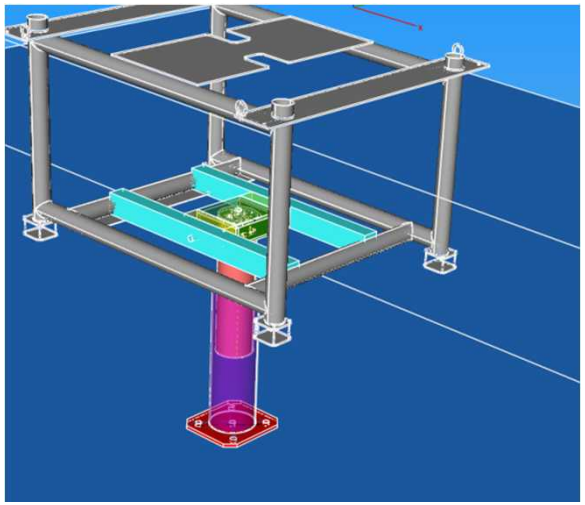
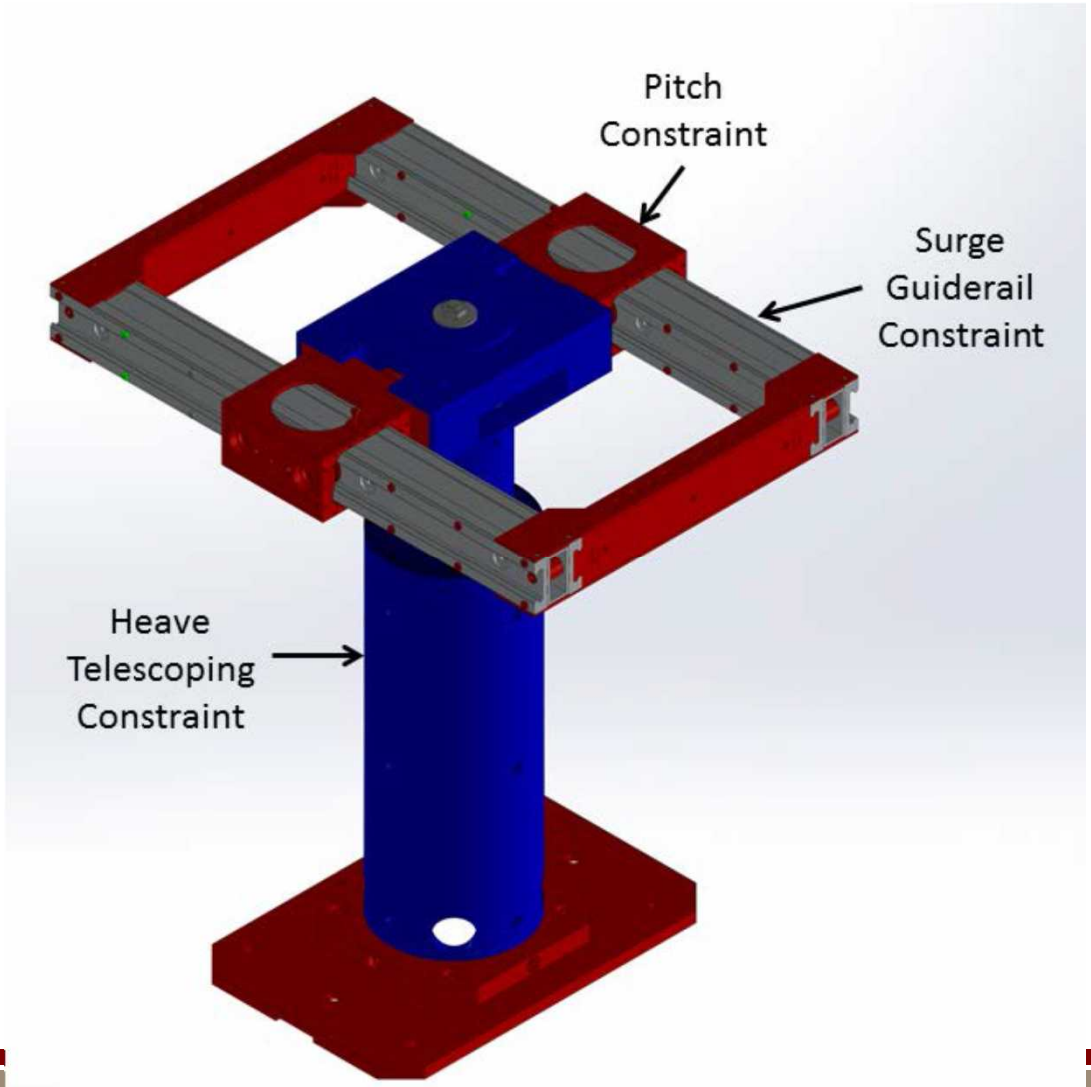




FOSWEC Phase 1 Experiments

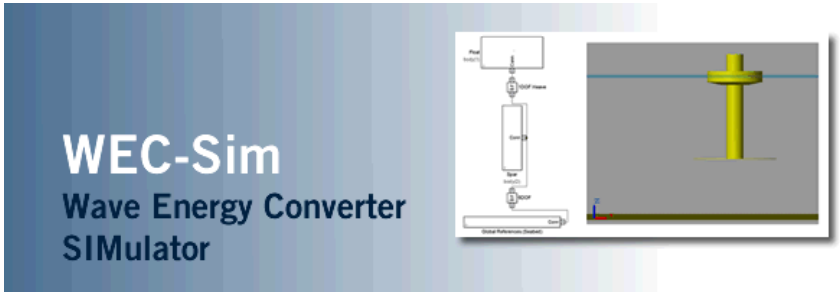
- Dry Tests

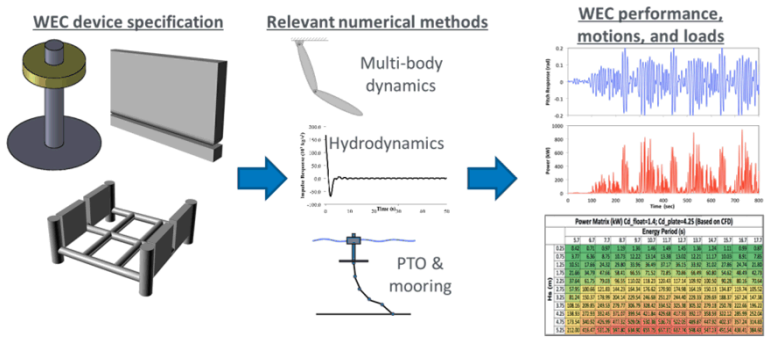
1. Heave Decay
2. Pitch Decay
3. Surge Decay
4. Flap 1 Decay

WEC-Sim Overview

WEC-Sim is an open source multi-body code that solves WEC dynamics and performance when subject to operational waves

- Funded by the US DOE
- Jointly developed by SNL and NREL





- Publicly available on GitHub
  https://github.com/WEC-Sim/WEC-Sim
- WEC-Sim Website and Documentation
  http://wec-sim.github.io/WEC-Sim/index.html

Hydrodynamic Properties

- Flap and Platform hydrodynamic coefficients determined from ANSYS-AQWA
- Excitation Force
- Added Mass
- Radiation damping
- Will be compared to experiments from Phase 2

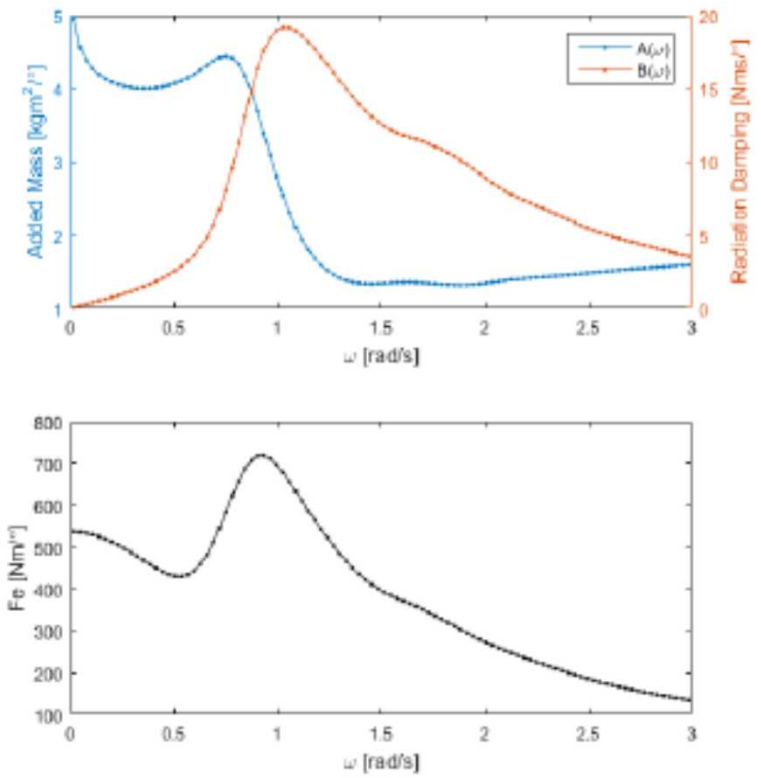


FIGURE 6. FLAP PITCH HYDRODYNAMIC COEFFICIENTS: ADDED MASS, RADIATION DAMPING AND EXCITATION

Mass Properties

- Flap and Platform mass properties determines from Swing Tests, used in WEC-Sim simulations

TABLE 1. FOSWEC 1:33-SCALE MASS PROPERTIES.

	$Flap_1$	$Flap_2$	Platform
Mass (kg)	23.14	23.19	153.8
X_{cg} (m)	-0.65	0.65	-0.0009
Y_{cg} (m)	0.0108	0.0017	-0.0044
Z_{cg} (m)	-0.29	-0.29	-0.063
I_{xx} (kg m^2)	1.42	1.58	37.88
I_{yy} (kg m^2)	1.19	1.62	29.63
I_{zz} (kg m^2)	1.99	1.25	53.61

TABLE 2. MOTION CONSTRAINT MASS PROPERTIES

	Heave	Pitch	Surge
Mass (kg)	27.35	4.47	23.66
X_{cg} (m)	0	0	0
Y_{cg} (m)	0	0	0
Z_{cg} (m)	-0.782	-0.366	-0.366
I_{xx} (kg m^2)	2.2	0.29	1.44
I_{yy} (kg m^2)	2.15	0.02	2.21
I_{zz} (kg m^2)	0.28	0.30	3.58

WEC-Sim Simulations

- Ran Phase 1 experiments in WEC-Sim for numerical comparison

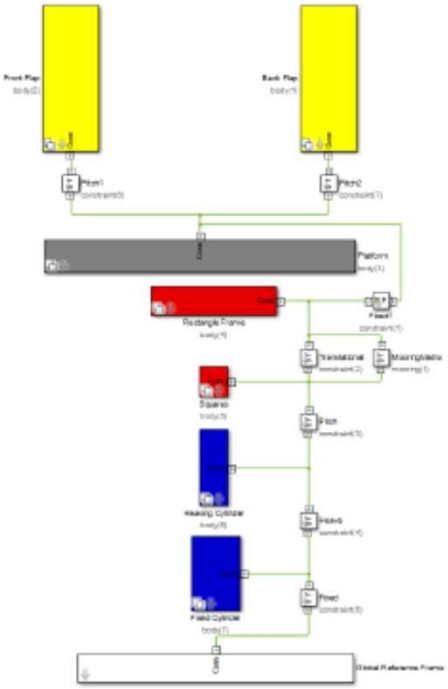


FIGURE 8. MODEL OF THE FOSWEC USING WEC-SIM LIBRARY

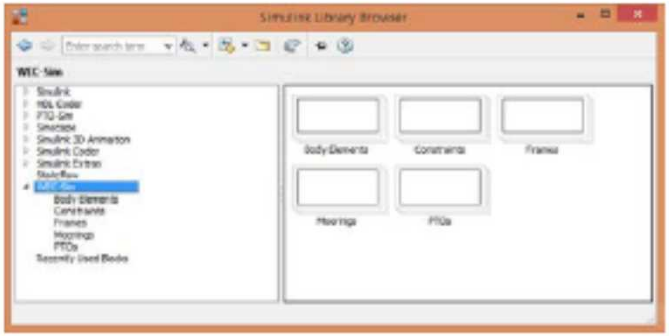


FIGURE 7. WEC-SIM LIBRARY IN SIMULINK

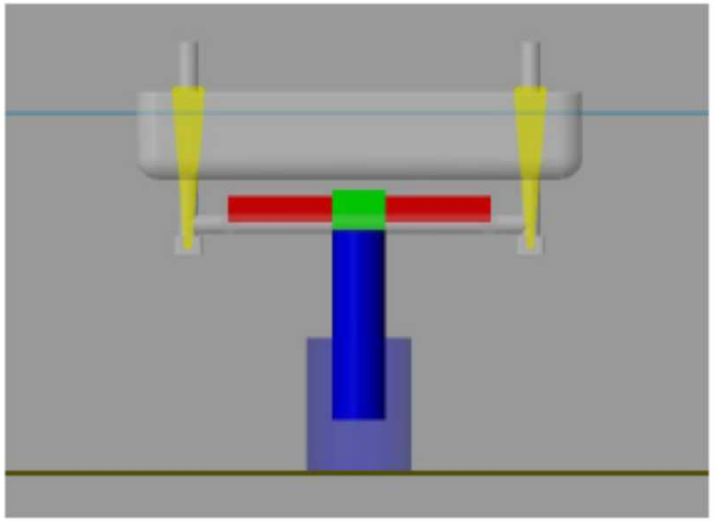
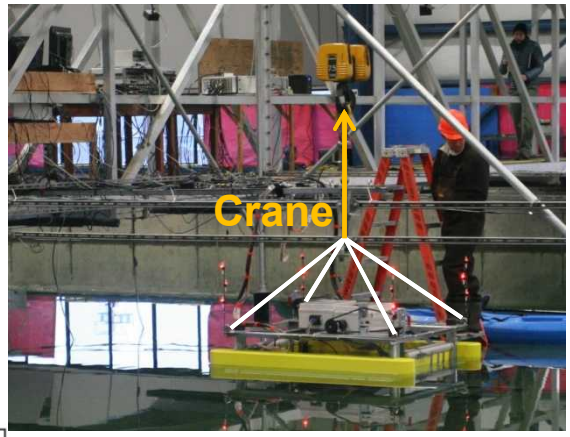


FIGURE 9. FOSWEC MODEL VISUALIZATION IN WEC-SIM

Heave Decay and Static Offset

For natural frequency (ω_n), damping (@ω_d), and restoring stiffness

- ***Heave Δz = 3, 5, 7, 10, 15 cm***
- Repeated 3 times
- Platform pitch/surge locked
- Flaps locked



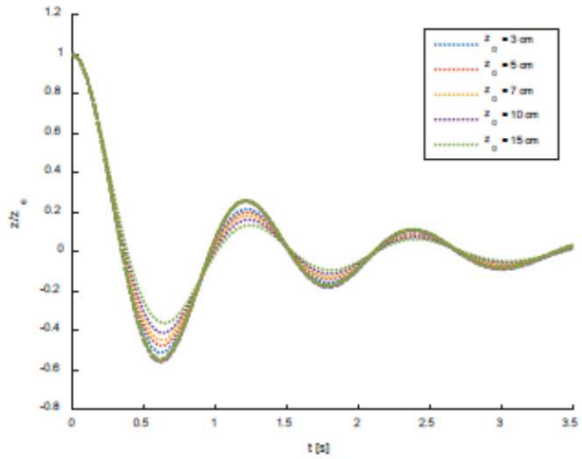


FIGURE 10. NORMALIZED WEC-SIM HEAVE DECAY SIMULATIONS FOR DAMPING OF 450, AND C_D OF 1.28 (DOTTED), AND DAMPING OF 450, AND C_D OF 0 (DASHED)

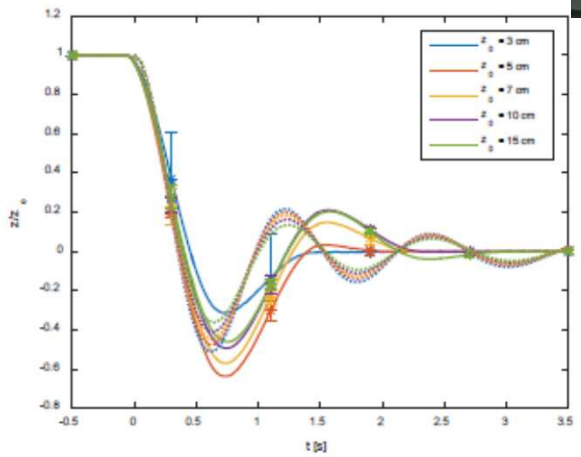


FIGURE 11. NORMALIZED FOSWEC HEAVE DECAY EXPERIMENTAL RESULTS WITH 90% CONFIDENCE INTERVAL (SOLID), AND WEC-SIM HEAVE DECAY SIMULATIONS WITH DAMPING OF 450, AND C_D OF 1.28 (DOTTED)

Pitch Decay and Static Offset

For natural frequency (ω_n), damping (@ω_d), and restoring stiffness

- ***Pitch ΔRY_0 = 2, 3, 5, 7, 8.4 deg***
- Platform heave/surge locked
- Repeated 3 times
- Flaps locked

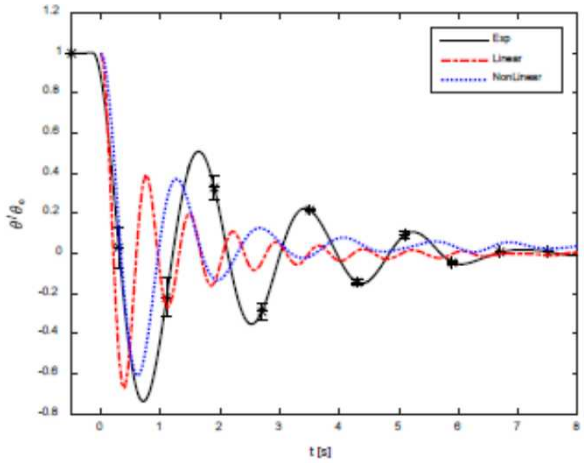


FIGURE 12. NORMALIZED PITCH DECAY FOR 5° INITIAL DISPLACEMENT, EXPERIMENTAL RESULTS (SOLID), LINEAR WEC-SIM (DASHED), NONLINEAR WEC-SIM (DOTTED)

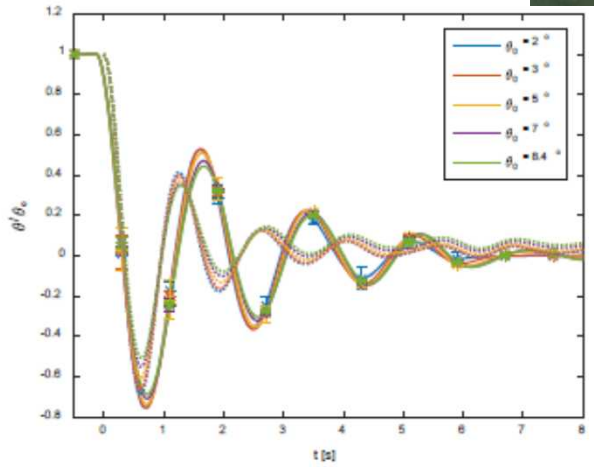
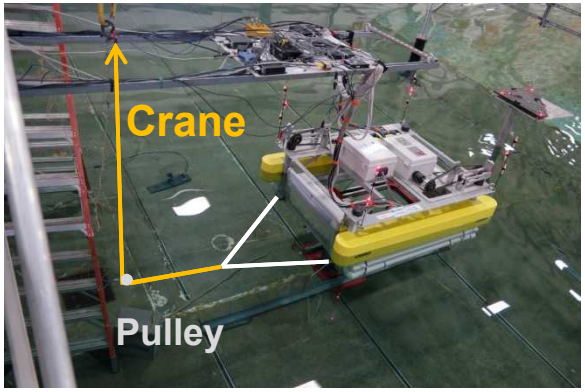


FIGURE 13. NORMALIZED FOSWEC PITCH DECAY EXPERIMENTAL RESULTS WITH 90% CONFIDENCE INTERVAL (SOLID), AND WEC-SIM PITCH DECAY SIMULATIONS WITH NONLINEAR HYDROSTATICS, DAMPING OF 40, AND C_D OF 8 (DOTTED)

Surge Decay and Static Offset

For natural frequency (ω_n), damping (@ω_d), and restoring stiffness

- ***Surge Δx = 7, 10, 15, 20 cm***
- Repeated 3 times
- **Platform Free in all DOF, Flaps locked**
  - *NOTE: had issues with setup, see notes*
- Surge restoring: **4 Blue Bungees**



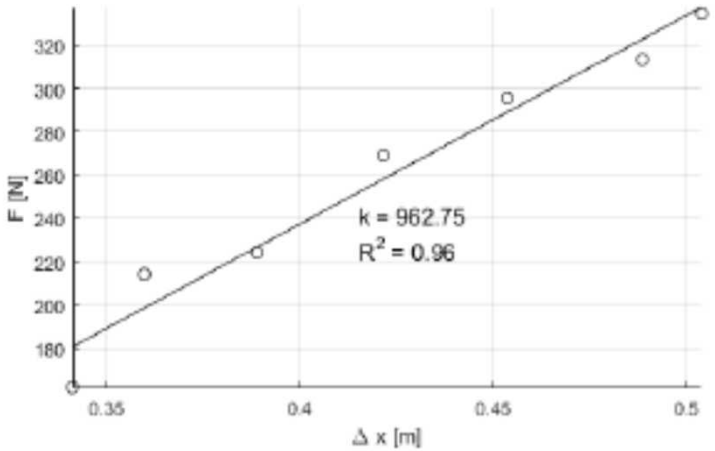


FIGURE 14. FOSWEC SURGE STATIC OFFSET TEST, FORCE VERSUS DISPLACEMENT SLOPE, K = 962 WITH R^2 = 0.96

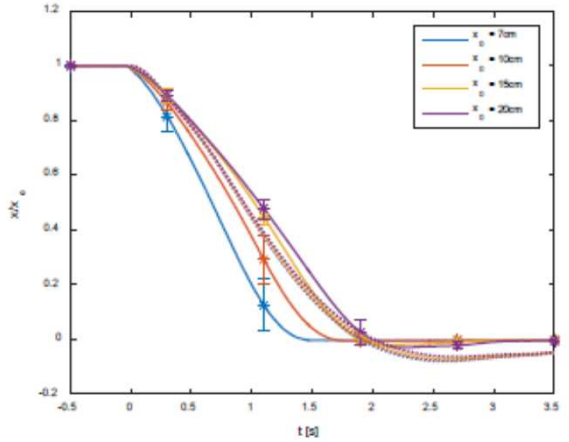
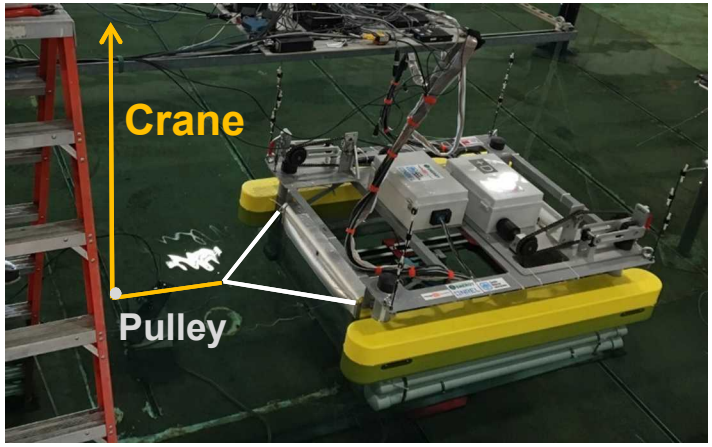


FIGURE 15. NORMALIZED FOSWEC SURGE DECAY EXPERIMENTAL RESULTS WITH 90% CONFIDENCE INTERVAL (SOLID), AND WEC-SIM SURGE DECAY SIMULATIONS WITH STIFFNESS OF 962, DAMPING OF 770, AND C_D OF 1.28 (DOTTED)

Flap1 Decay and Static Offset (wPTO connected)

For natural frequency (ω_n), damping ($@\omega_d$), and restoring stiffness

- ***Pitch ΔRY = 5, 7, 10, 15, 20 deg***
- Repeated 3 times
- Platform locked, Back flap free
- w/PTO connected, no damping



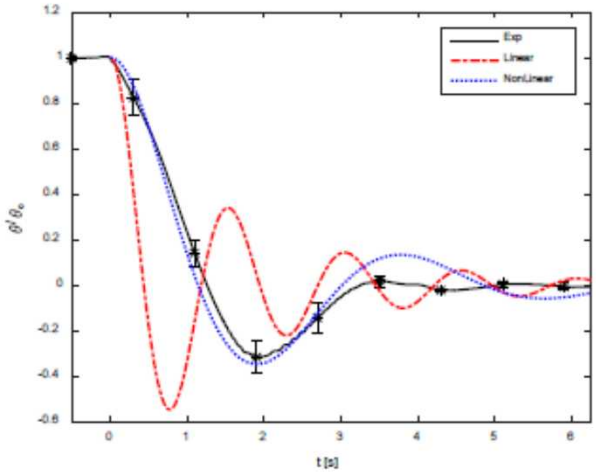


FIGURE 16. NORMALIZED FLAP PITCH DECAY FOR 10° INITIAL DISPLACEMENT, EXPERIMENTAL RESULTS (SOLID), LINEAR WEC-SIM (DASHED), NONLINEAR WEC-SIM (DOTTED)

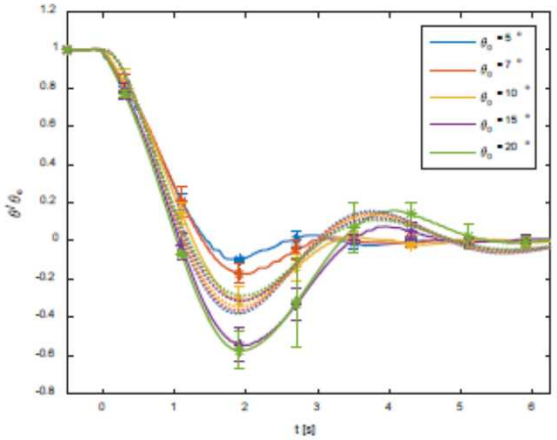


FIGURE 17. NORMALIZED FLAP PITCH DECAY EXPERIMENTAL RESULTS WITH 90% CONFIDENCE INTERVAL (SOLID), AND WEC-SIM FLAP PITCH DECAY SIMULATIONS WITH NONLINEAR HYDROSTATICS, DAMPING OF 0 , AND C_D OF 8 (DOTTED)

Phase 1 - Lessons Learned

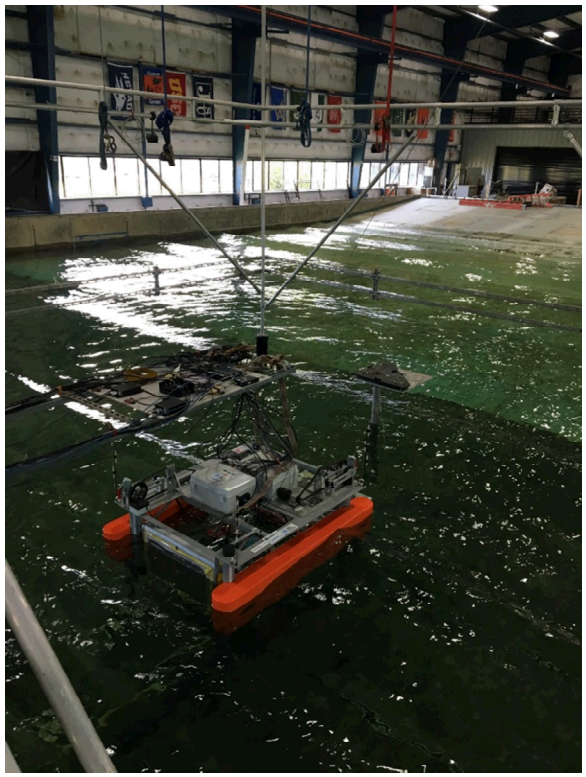
- FOSWEC inclinometer
  - not accurately measure above certain accelerations (ie: pitch decay)
- Pressure mats ***complete***
  - front pressure mat never worked in water
- Flap rotary encoder ***complete***
  - Cannot be used to control PTO and does not measure +/-45deg
- Arm design ***complete***
  - Pitch constraint has a lot of play
  - DOF not easy to lock/unlock when tank is full
- FOSWEC design ***complete***
  - Larger buoyancy floats to compensate for arm weight
  - PTO drivetrain has a lot of play in the system
  - Mechanical lock on flap shaft for wave excitation tests
- Motor issue ***complete***
  - Gears moving in gear housing, manufacturer tightened mounting

Phase 2 - Lessons Learned

- Flap rotary displacement measurement
  - This was the most challenging measurement, went through 3+ iterations and is *most* critical measurement
- Pressure mats
  - Nothing but issues with pressure mats, manufacturer not helpful
- BSpace
  - Lots of BSOD and matlab crashes

Future Work

- Phase 2 testing, experimental/numerical comparison, and data release



Thank You!

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