SAND2013-5441C

Wave Energy Converter Design Tool for Point Absorbers with Arbitrary Device Geometry

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Overview

- Sandia National Laboratories
- Modeling Methodology
- Single-Body Application
- Two-Body Application
- Conclusions and Future Work

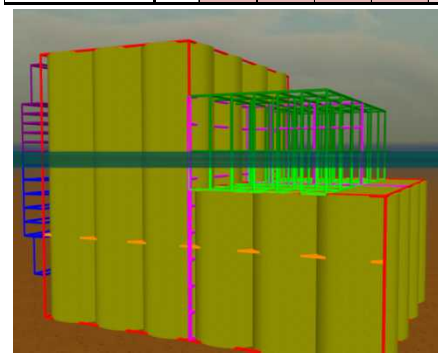
SANDIA NATIONAL LABORATORIES

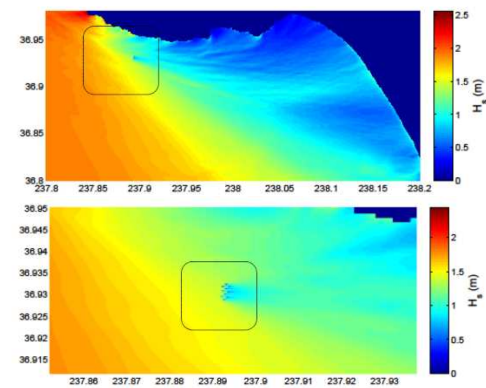
Wind and Water Research Program

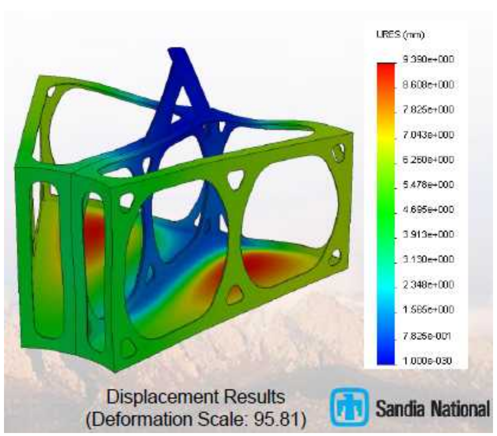
Marine Hydrokinetic Research Projects

- WEC Device & Farm Modeling
- Wave Resource Assessments
- Anchoring and Mooring
- Power Performance and Controls
- Environmental Impact
- Sediment Measurements
- Materials and Coatings

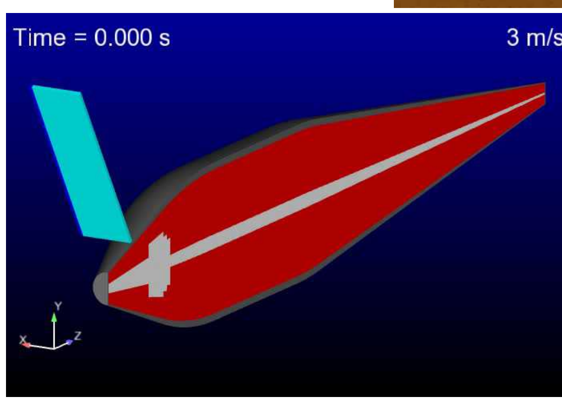
	WAVE HEIGHT [m]												
WAVE PERIOD [s]	0-0.4	0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-5.4	5.5-6.4	6.5-7.4	7.5-8.4	8.5-9.4	9.5-10.4	>10.5	TOT %	TOT N
< 3.0	*	*	-	-	-	-	-	-	-	-	-	-	0	3
3.0 - 3.9	-	0.1	-	-	-	-	-	-	-	-	-	-	0.1	212
4.0 - 4.9	-	0.5	0.1	-	-	-	-	-	-	-	-	-	0.6	836
5.0 - 5.9	*	1.5	0.6	0.1	*	-	-	-	-	-	-	-	2.1	2989
6.0 - 7.9	*	8.6	4.5	0.9	0.2	*	-	-	-	-	-	-	14.2	20420
8.0 - 9.9	*	8.1	8.5	2.3	0.7	0.2	*	*	-	-	-	-	19.9	28683
10.0 - 12.9	*	8.1	18.2	10.6	4.4	1.5	0.5	0.1	*	*	-	-	43.5	62642
13.0 - 15.9	*	2.6	3.2	3	2	1	0.4	0.1	*	*	*	*	12.4	17890
16.0 - 20.0	*	2	1.4	1.1	0.7	0.4	0.2	0.1	*	*	*	*	6	8703
>= 20.0	-	0.3	0.4	0.3	0.1	*	*	*	*	*	-	-	1.2	1697

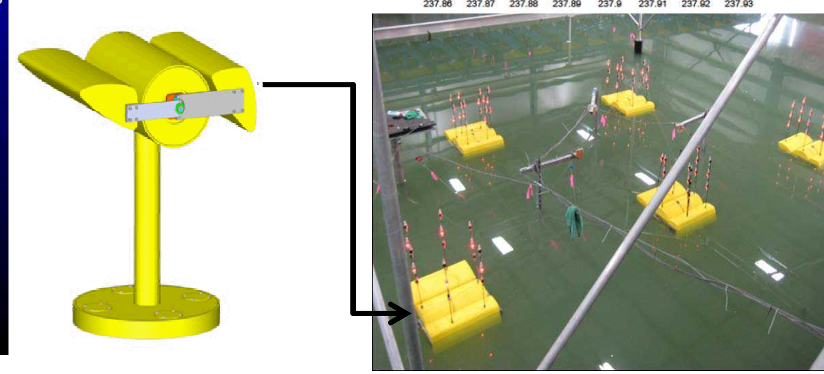






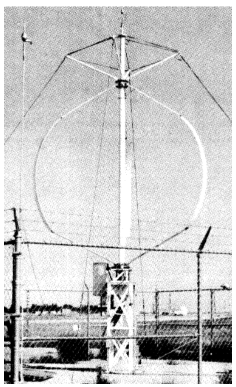
Displacement Results (Deformation Scale: 95.81)



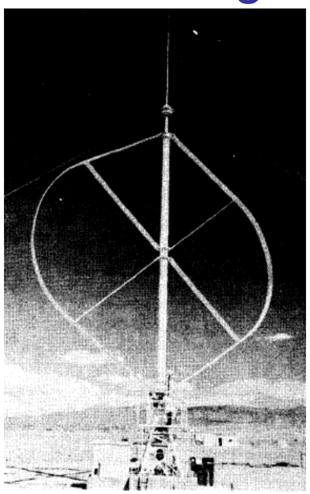


Offshore Wind Research Projects

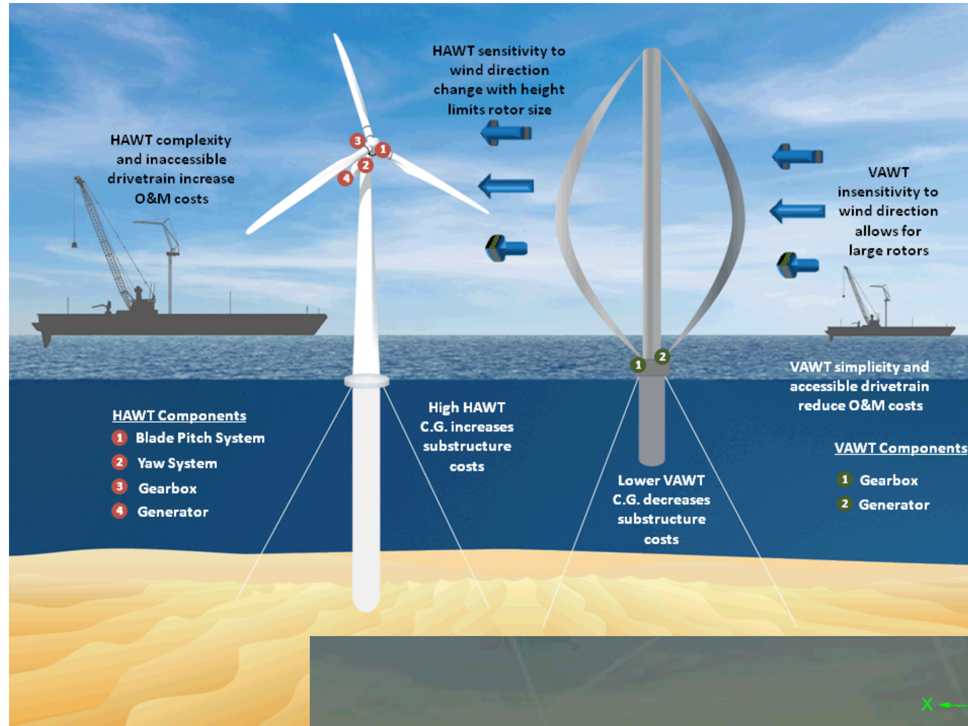
- Vertical & Horizontal Axis
- Large Scale Rotor Design
- Code Development & Controls
- Aero-Hydro Modeling

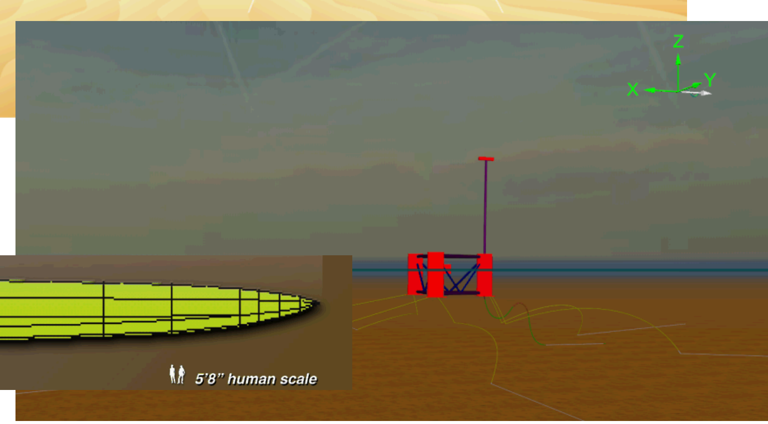


5m VAWT



65kW 17m VAWT





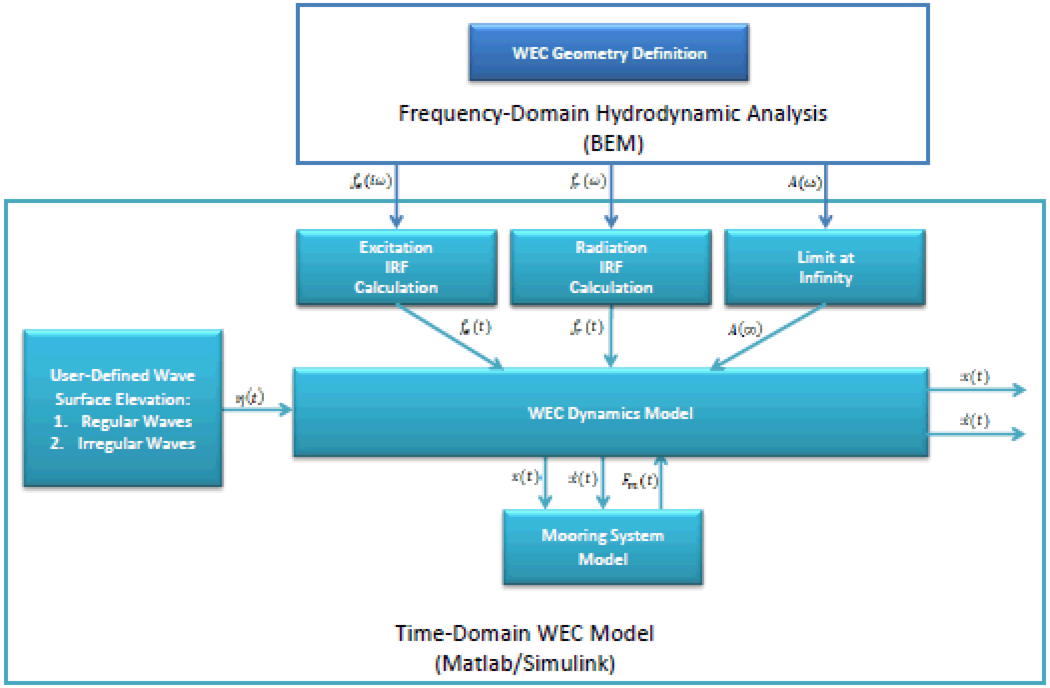
POINT ABSORBER MODELING METHODOLOGY

WEC Dynamic Models

- Frequency-Domain
  - Fastest solving, commercial codes available (BEM, WAMIT), linear (hydrodynamics, PTO, mooring, etc)
- Time-Domain
  - Fast solving, some commercial codes available ($$$), some non-linearities (mooring, hydrostatics, PTO, control)
- High Fidelity (CFD, SPH, etc)
  - Computationally intensive, some commercial codes available (SSS), fully non-linear, limited control

Proposed Modeling Methodology

- Import hydrodynamics from linear BEM code and convert to time-domain equivalent
- Input time-series wave surface elevation
- Solve governing EOM in Matlab/Simulink framework



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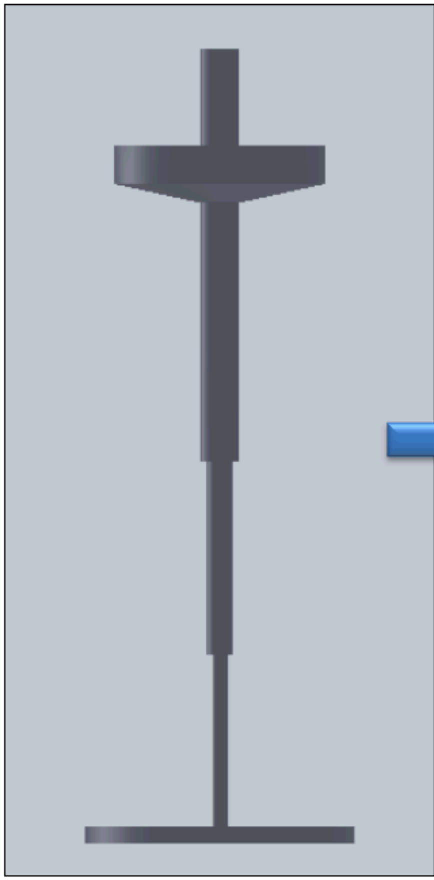
Sandia National Laboratories

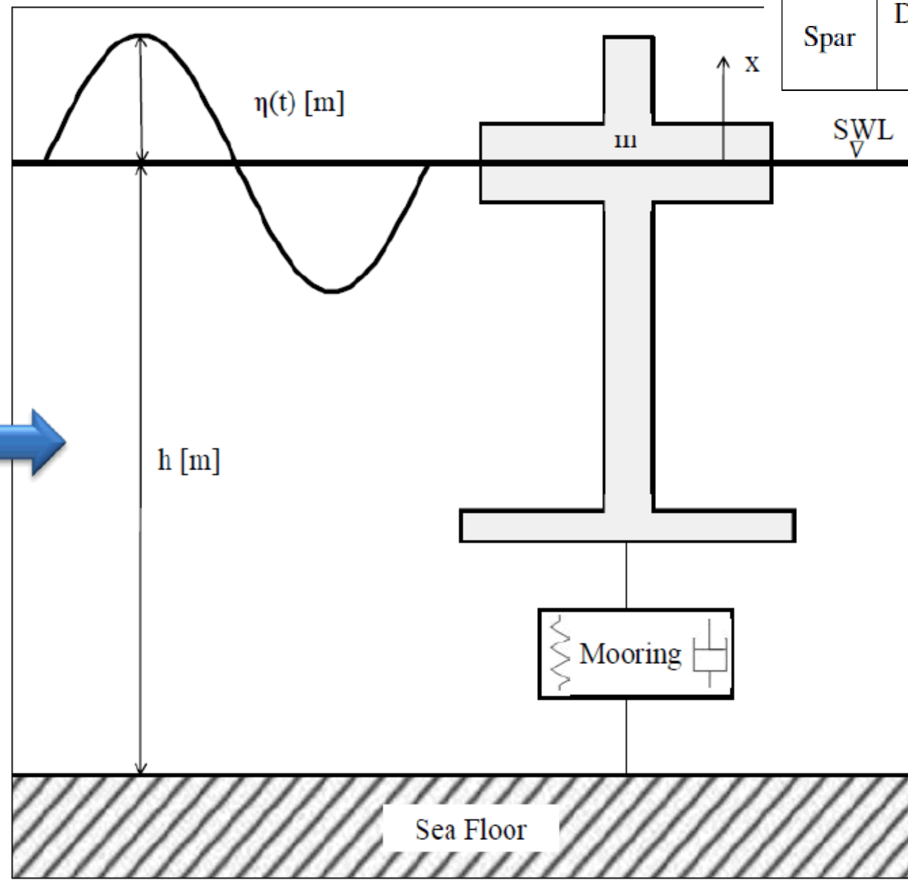
ISOPE-2013 Anchorage

SINGLE-BODY APPLICATION

Single-Body Point Absorber

Buoy	Diameter	11 [m]
	Height	2 [m]
Plate	Diameter	14 [m]
	Height	0.84 [m]
Spar	Diameter	2 [m]
	Height	41.34 [m]





$$m = 250,000\ [kg]$$

$$h = 70\ [m]$$

Single-Body Point Absorber EOM

$$F_e(t) - F_r(t) - F_m(x,\dot{x}) = K_{hs}x + b_v\dot{x} + (m + A(\infty))\ddot{x}$$

– Excitation Force

$$F_e(t) = \int_{-\infty}^{\infty} \eta(\tau) f_e(t-\tau) d\tau$$

– Radiation Force

$$F_r(t) = \int_{-\infty}^{t} f_r(t-\tau)\dot{x}(\tau) d\tau$$

– Hydrostatic Force

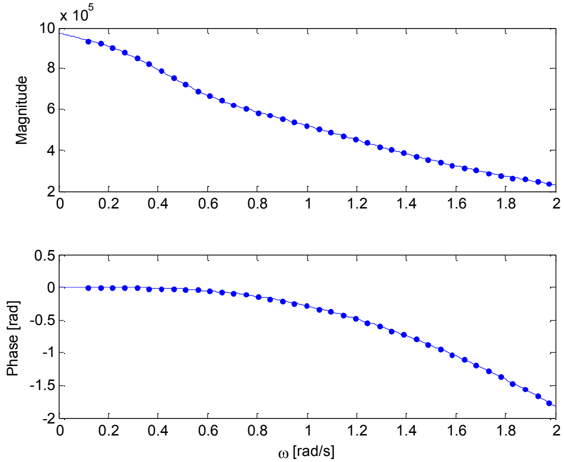
$$F_{hs}(t) = K_{hs}x = \rho_{sw} g A x$$

– Mooring Force

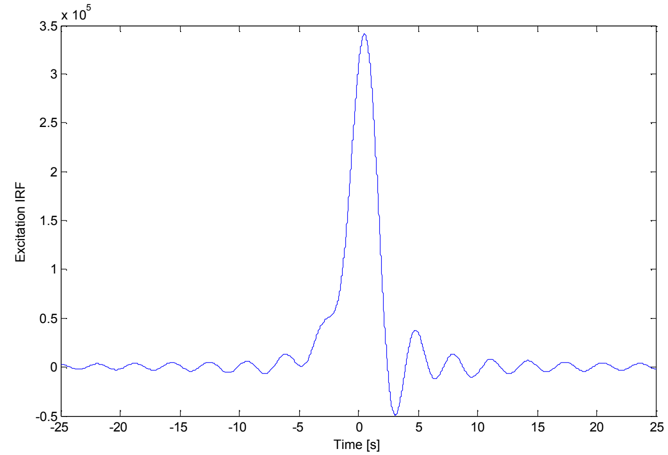
$$\begin{aligned} F_m(x,\dot{x}) &= k_m x + b_m \dot{x} \\ &= 8k_m \left(1 - \frac{l_m}{\sqrt{{l_m}^2 + x^2}}\right) x \end{aligned}$$

Frequency-Domain → Time-Domain

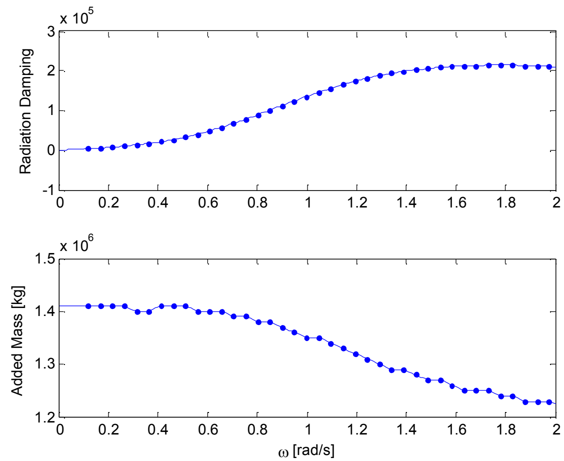
Excitation



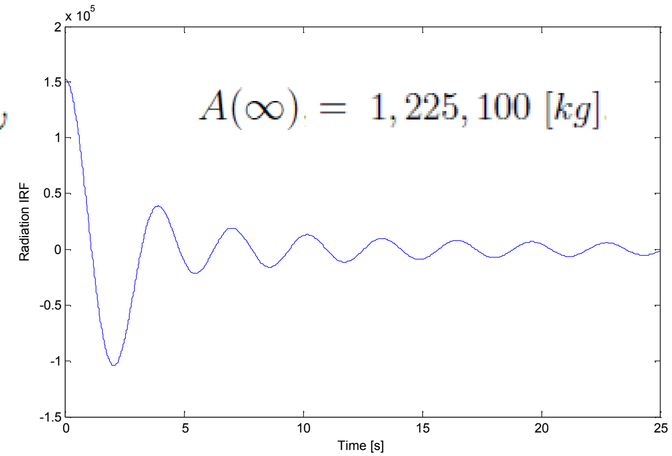
$$f_e(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} f_e(i\omega) e^{i\omega t} d\omega$$



Radiation

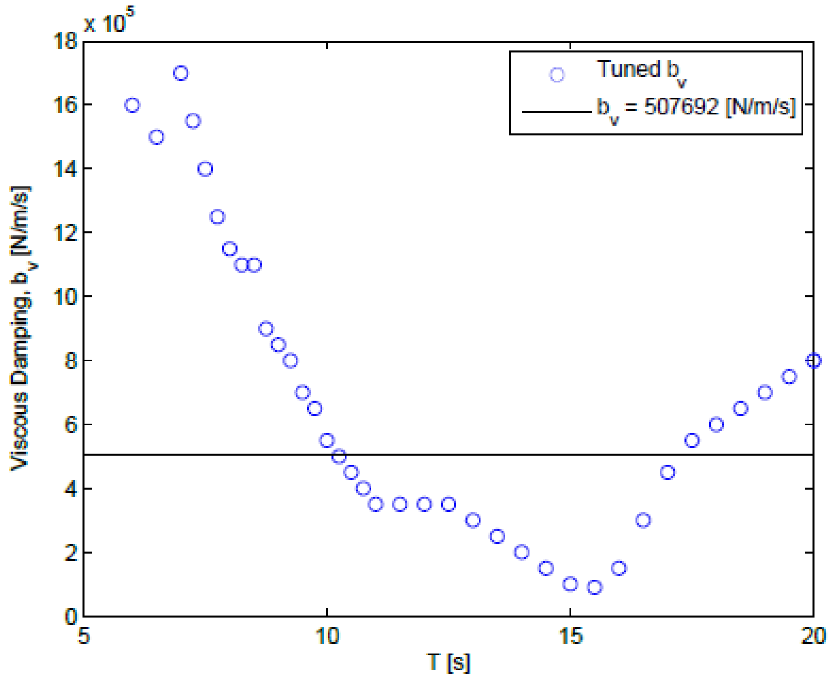


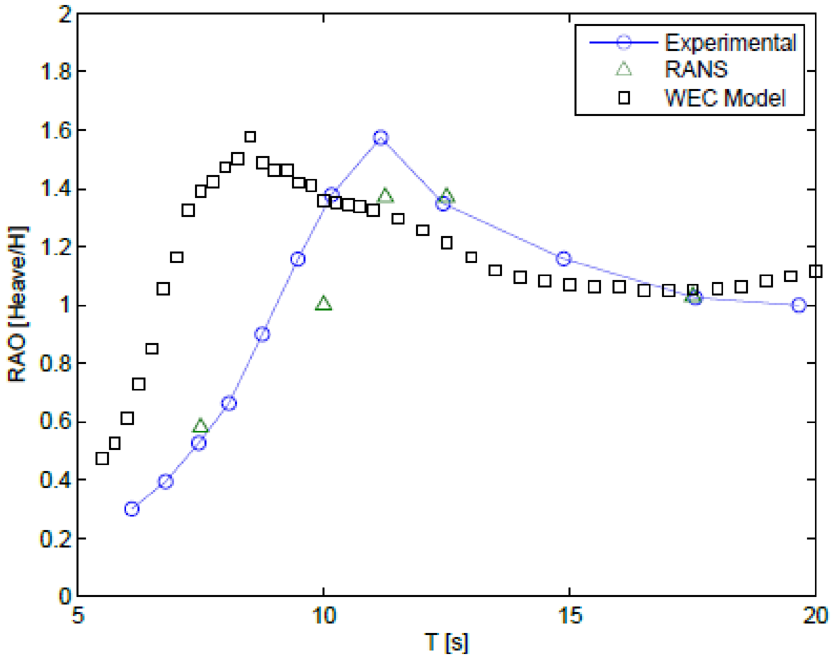
$$f_r(t) = \frac{2}{\pi} \int_{0}^{\infty} f_r(\omega) cos(\omega t) d\omega$$



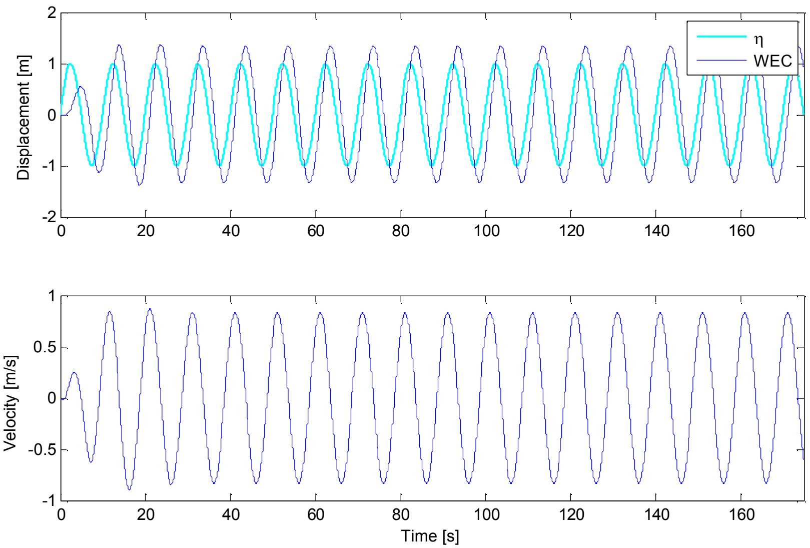
Numerical/Experimental Comparison

– Viscous damping based on Oregon wave climate, T = 9-13 [s]
– b_v = 507,692 [N/m/s]





Single-Body Simulation

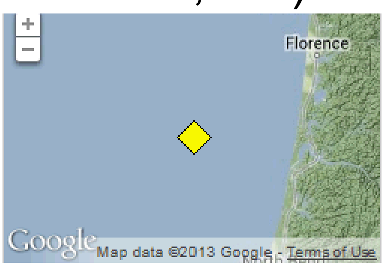


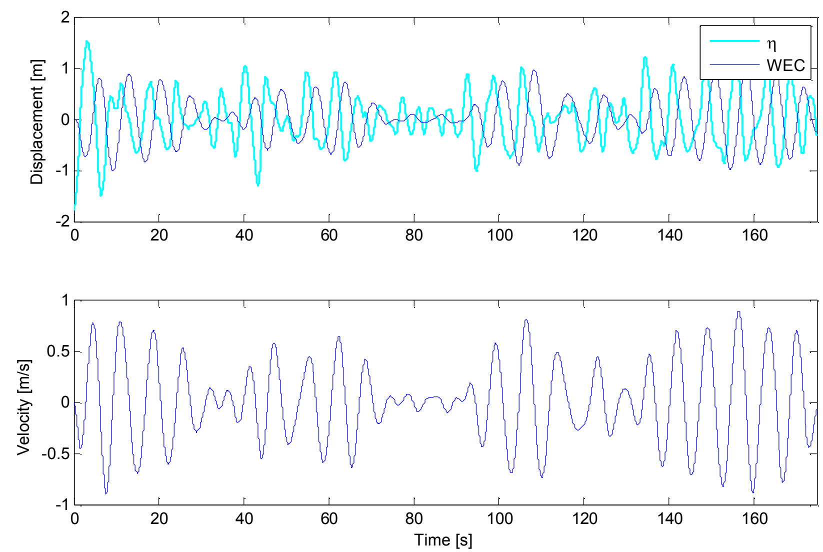
Regular Wave with T = 10 [s], and H = 2 [m]

Undamped RAO = 3.2054

Damped RAO = 1.3618

Irregular Wave from NDBC Buoy 46229 (Umpqua Offshore, OR) in June 2008

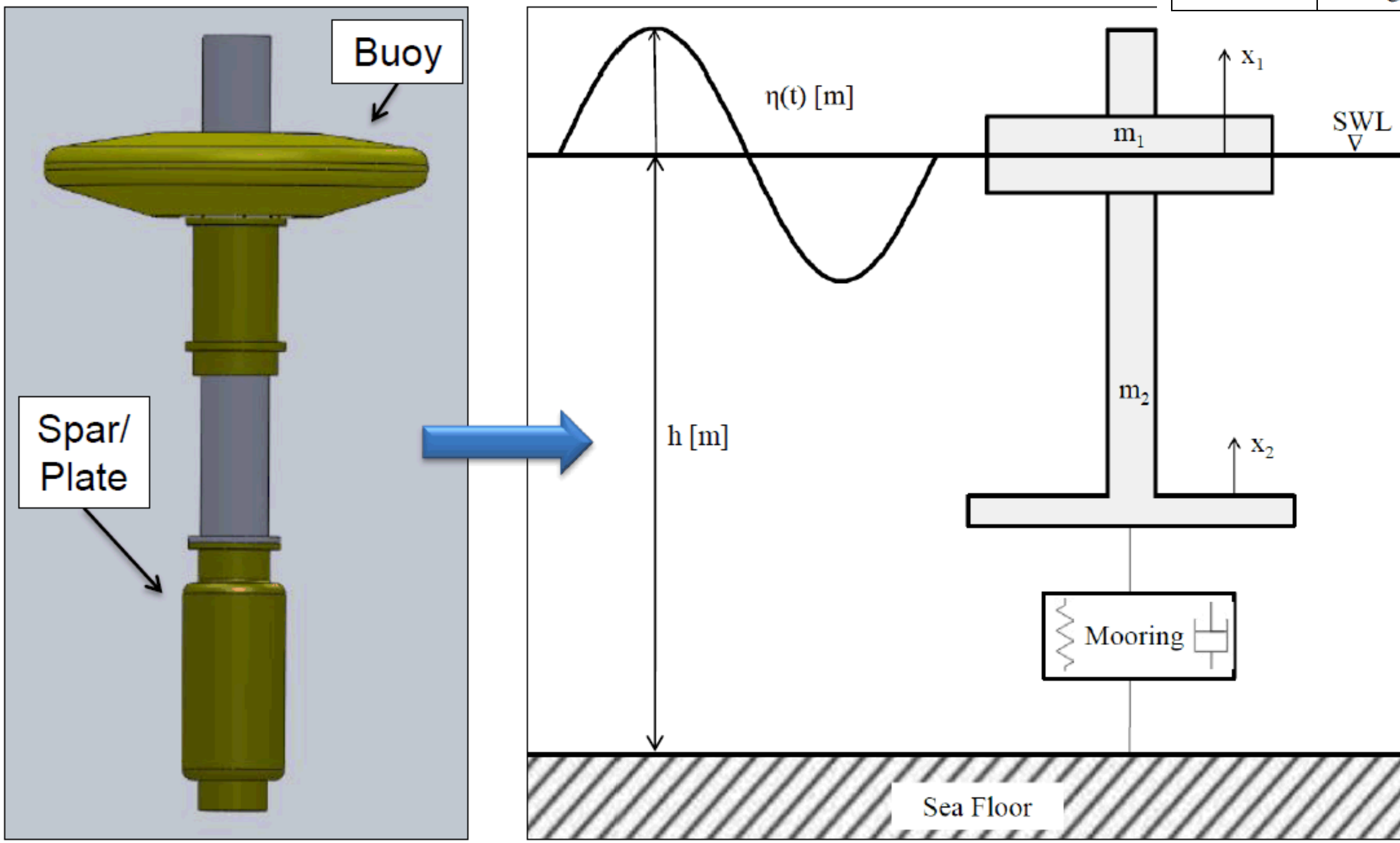




TWO-BODY APPLICATION

Two-Body Point Absorber

Buoy	Diameter	3.5 [m]
	Height	0.76 [m]
Spar/Plate	Diameter	1.1 [m]
	Height	7.03 [m]



$$h = 100 \; [m]$$

$$m_1 = 2,625.3 \; [kg] \qquad m_2 = 2,650.4 \; [kg]$$

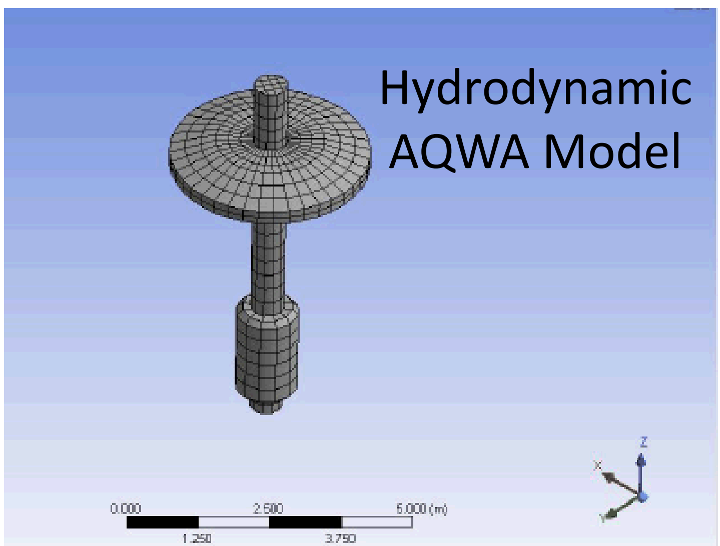
Two-Body Point Absorber EOM

Buoy EOM

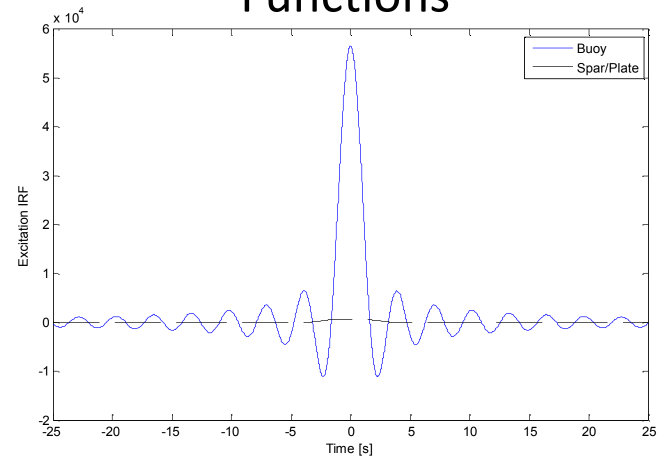
$$F_{e_1}(t) - F_{r_{11}}(t) - F_{r_{12}}(t) = K_{hs}x_1 + b_{v_1}\dot{x}_1 + (m_1 + A_{11}(\infty))\ddot{x}_1$$

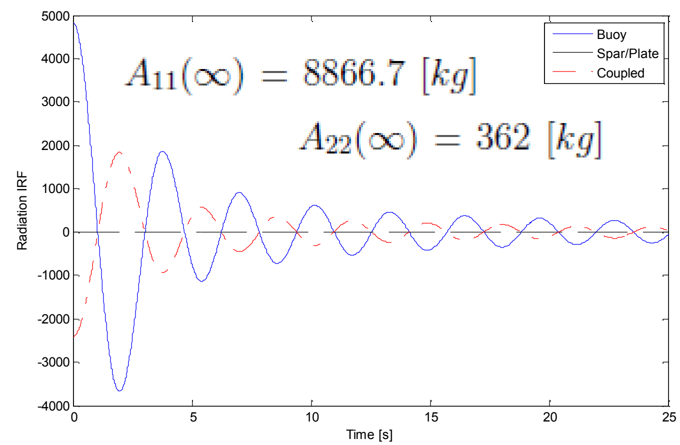
Spar/Plate EOM

$$F_{e_2}(t) - F_{r_{22}}(t) - F_{r_{21}}(t) - F_m(x_2, \dot{x}_2) = b_{v_2}\dot{x}_2 + (m_2 + A_{22}(\infty))\ddot{x}_2$$



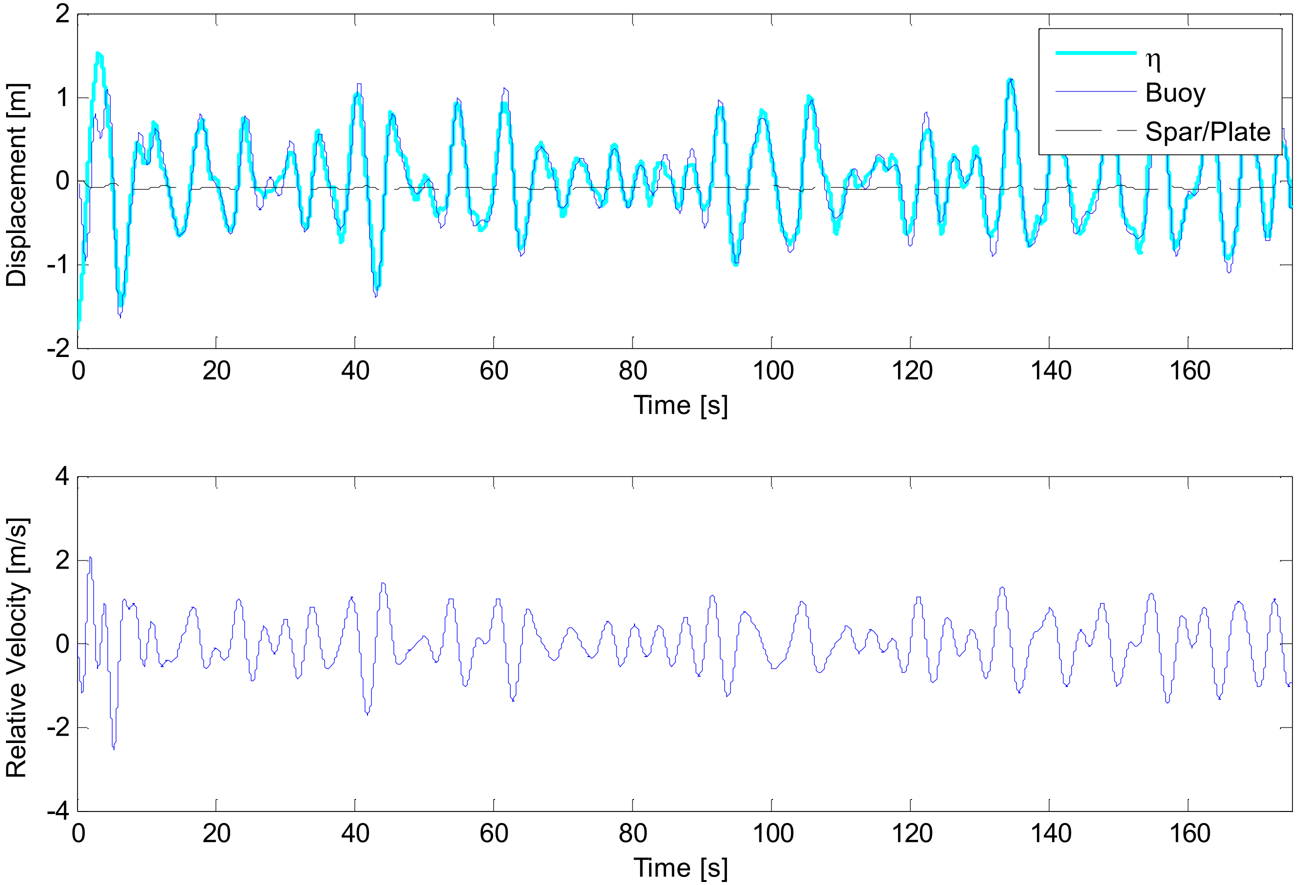
Impulse Response Functions

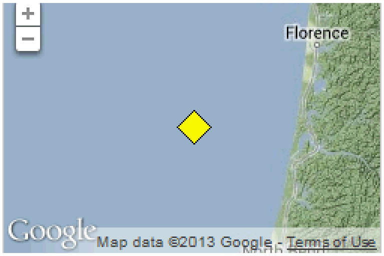




Two-Body Simulation

Irregular Wave from NDBC Buoy 46229
(Umpqua Offshore, OR) in June 2008





CONCLUSIONS AND FUTURE WORK

- Conclusions
  - 1DOF hydrodynamic model verified in comparison to experimental data and CFD
  - Extended single-body model to two-body model
- Future Work
  - Couple hydrodynamic model with power performance model, improve mooring system model, apply advanced control algorithms
  - WEC-Sim, a DOE funded 3 year collaborative project between Sandia and NREL to develop an open source WEC Model

U.S. DEPARTMENT OF ENERGY

NREL

Thank you

- Kelley Ruehl
  - Sandia National Laboratories
  - Water Power Department
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