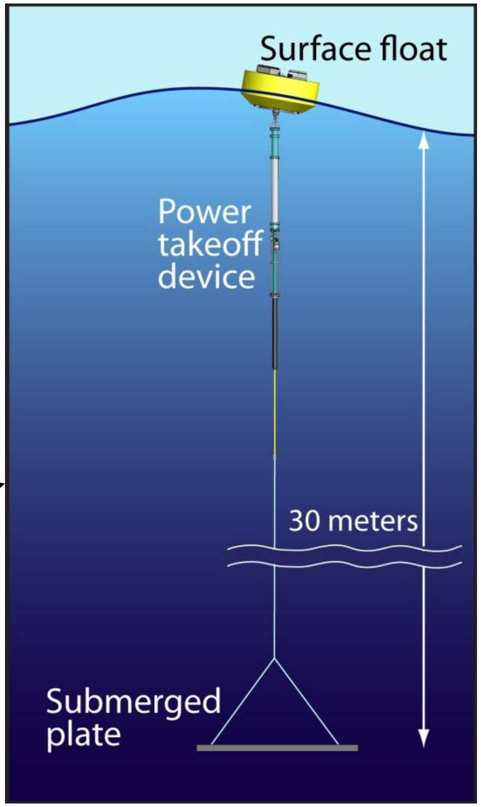
Wave-Energy Powered Oceanographic Systems

MBARI Mooring with
Wind and Solar Collection:

Weight	Avg. Power
5000lbs	60W

Wave Power Buoy Prototype

Weight	Avg. Power
5000lbs	300W-600W



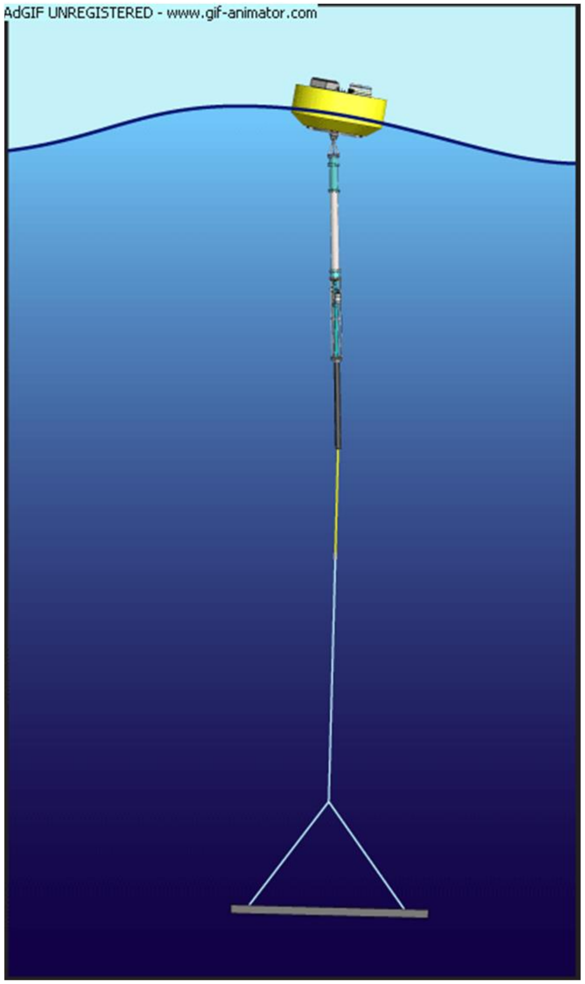
Potential for significant increase in the amount of power available on autonomous platforms. (AUV’s, Buoy Based Instrumentation, etc)

Project Activities

- Development of a numerical modeling tool specific to this task

- Build and test a proof-of-concept system

- AUV homing and docking



<u>Engineering Challenges</u>
- System Dynamics
- Power Take-Off System
- Station Keeping
- Survivability
- AUV Docking
    - Vehicle Maneuverability
    - Homing
    - Capture and Connect

Buoy and Power-Take

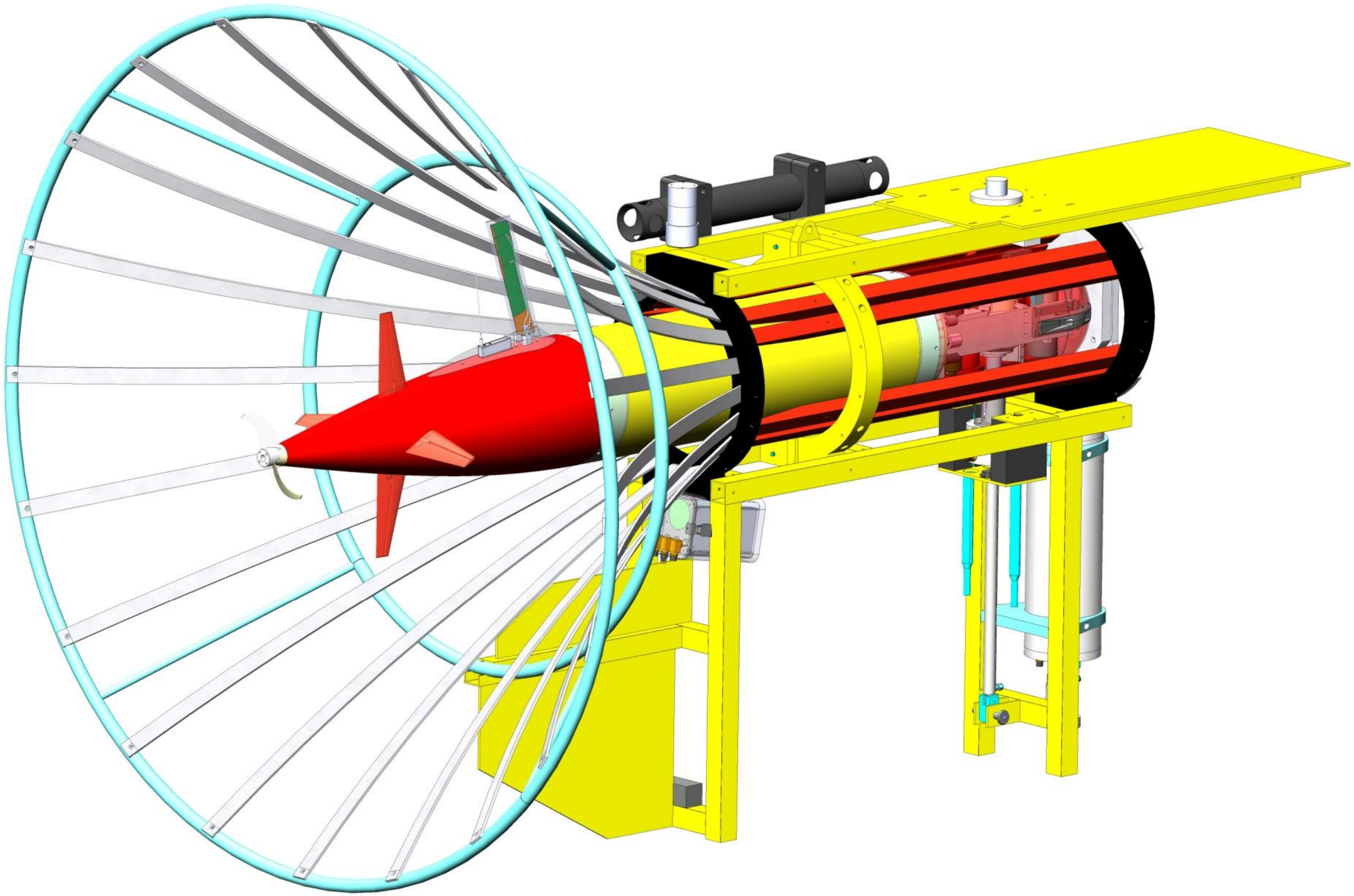
Submerged Plate

Wet Tow Deployment

Deployed with Wave-Rider

Rough Conditions

LRAUV in Dock



Four Technology Elements

- Numerical modeling tool specific to wave-energy harvesting applications

- Energy Producing Buoy System

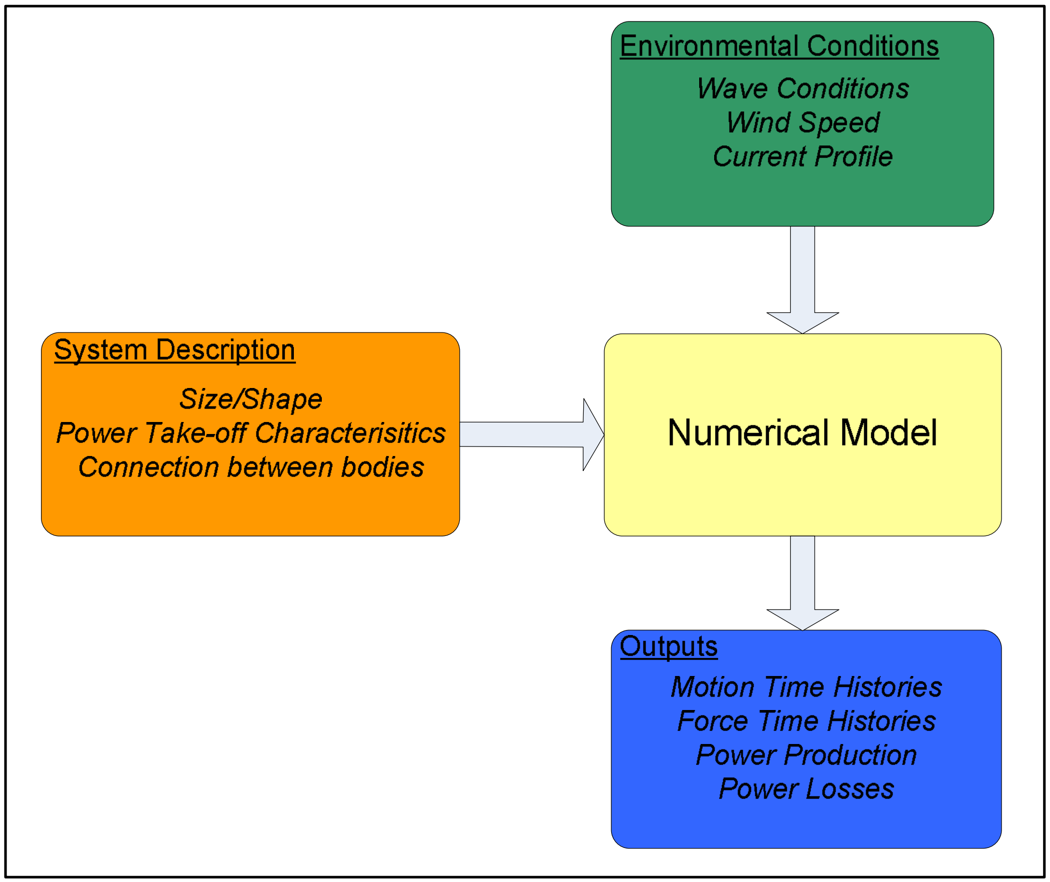
- Electro-Hydraulic Power Take-Off Device

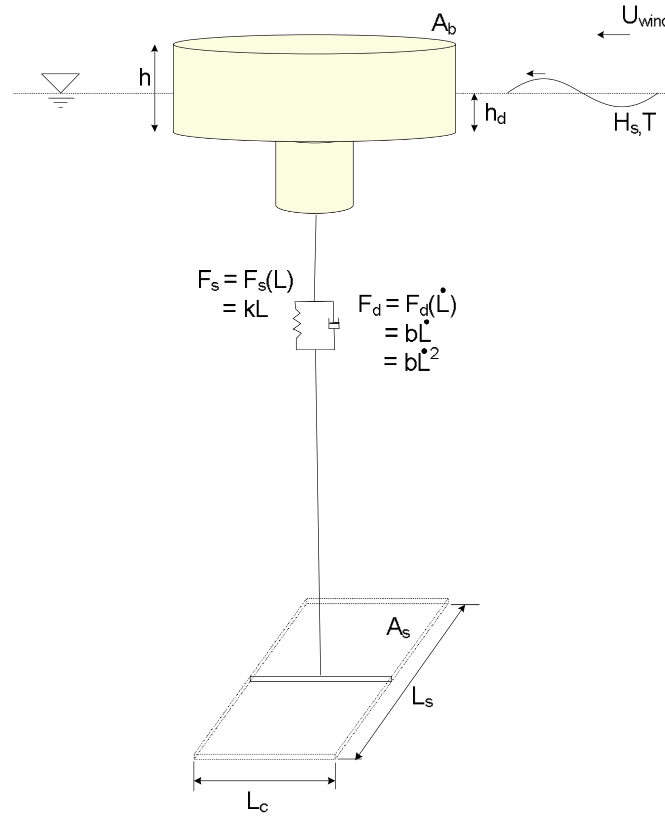
- AUV Docking Development

Numerical Modeling Tools and Parametric Design Study

Numerical Modeling Tools

Goal: Develop a tool to analyze floating wave energy extraction devices.





Simulation Example

Environment

- Waves: PM Spectrum H_s = 1m
- Wind: 20kts, from right

System Characteristics

- Buoy WaterPlane Area = 20 m^2
- PTO Damping: 10000 N/m/s
- Spring Force 2000lbs/m
- Foil area = 20 m^2

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Simulation Outputs

- System Motion Histories
- Force Histories
- Power Generation
- Loss Mechanisms
- Propulsion forces

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Model Use

The numerical tool developed enables the following capabilities:

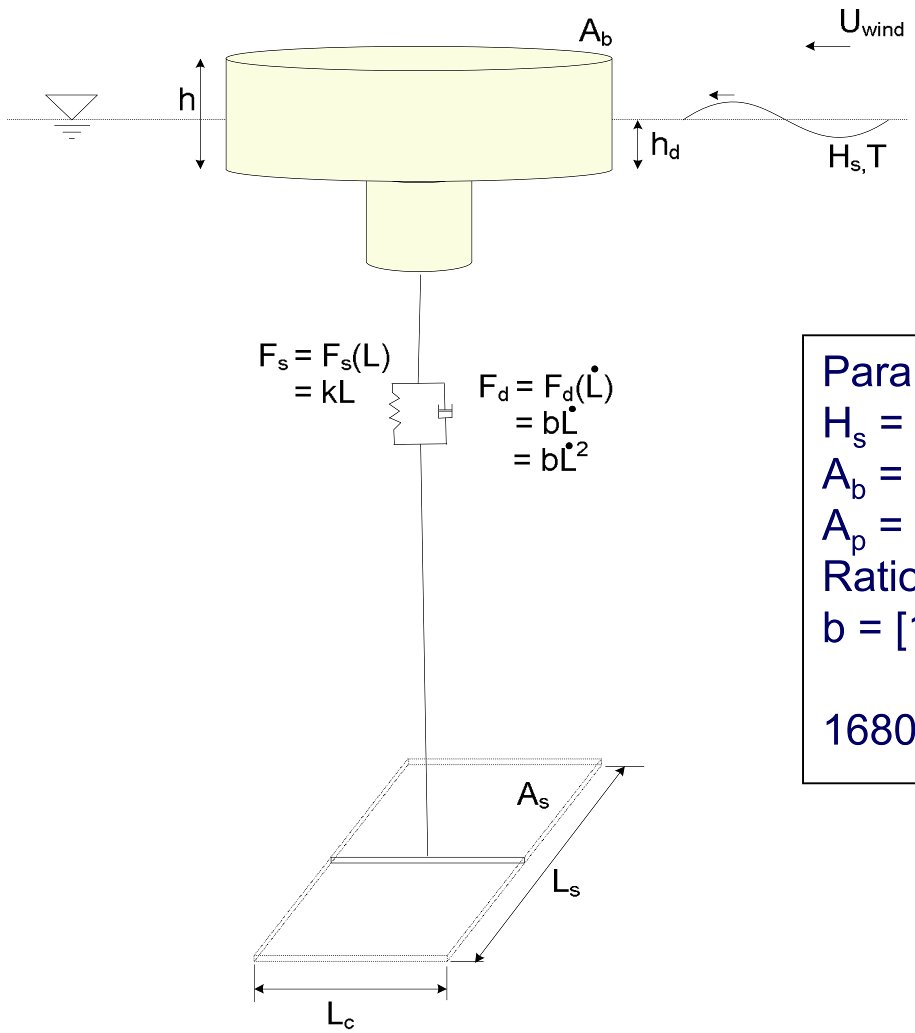
- Predict the power generating capabilities of a particular device in a range of sea conditions.

- Understand the power take-off device force versus speed requirements that optimize power generation.

- Understand the forces the system must be designed to withstand.

These capabilities have been applied to the design of the wave-energy buoy system in this program.

Submerged Plate Parametric Study



Parameters:

H_s = [1 2 3 4 5] m (PM Spectrum)

A_b = [2 5 10 20] m^2

A_p = [.25 .5 1 2 4 6 8] X Ab (Plate to Buoy Area Ratio)

b = [1000 2000 3000 … 12000] N/m/s

1680 Combinations!

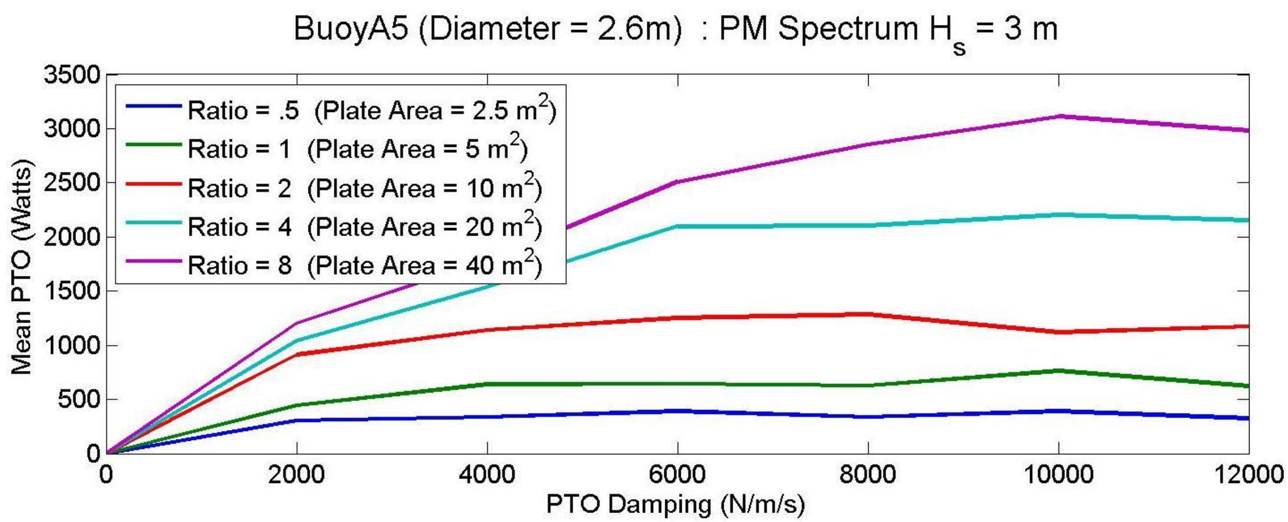
Parametric Study

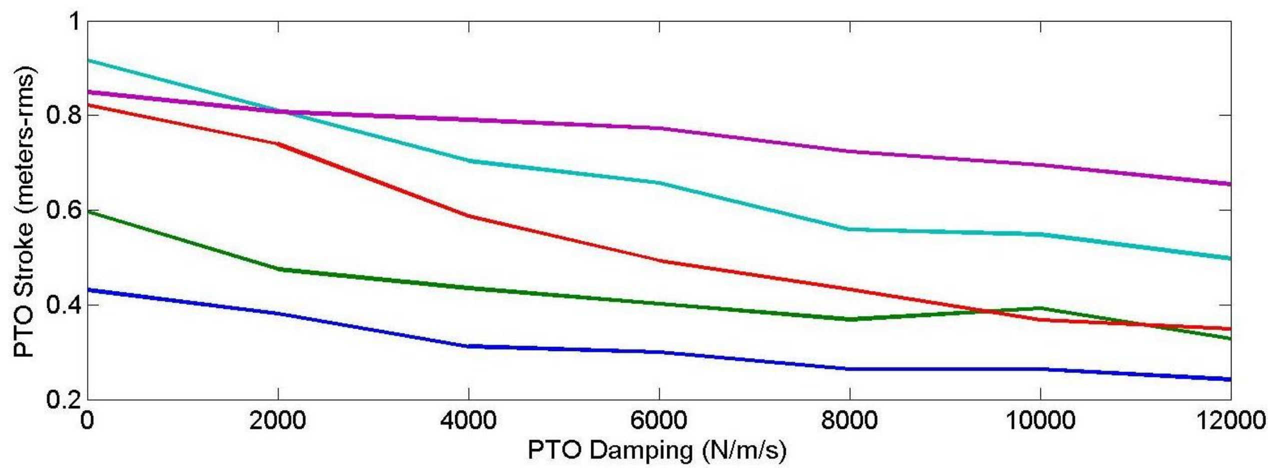
Parameters:

H_s = [1 2 **3** 4 5] m (PM Spectrum)
A_b = [2 **5** 10 20] m^2
A_p = [.5 1 2 4 8] X Ab (Ratio)
b = [0 2000 … 12000] N/m/s

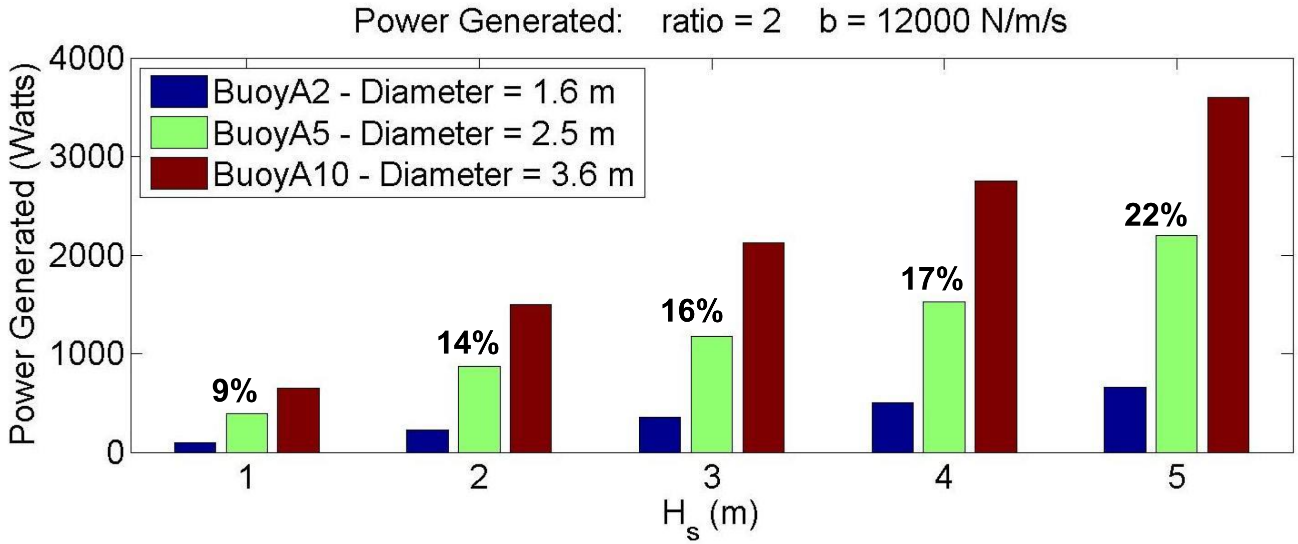
Model Output Shown:

Power take-off (Watts)
PTO Stroke (meters)

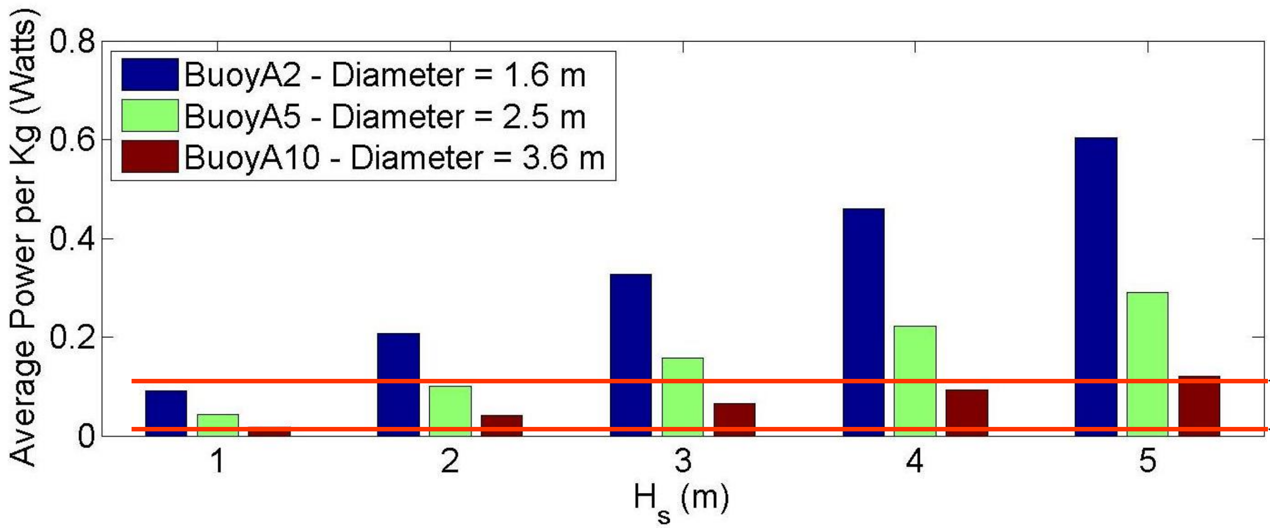




Average Power Levels for Various System Sizes



Percentages represent how much of the theoretical maximum is being captured for the 2.5m diameter buoy.

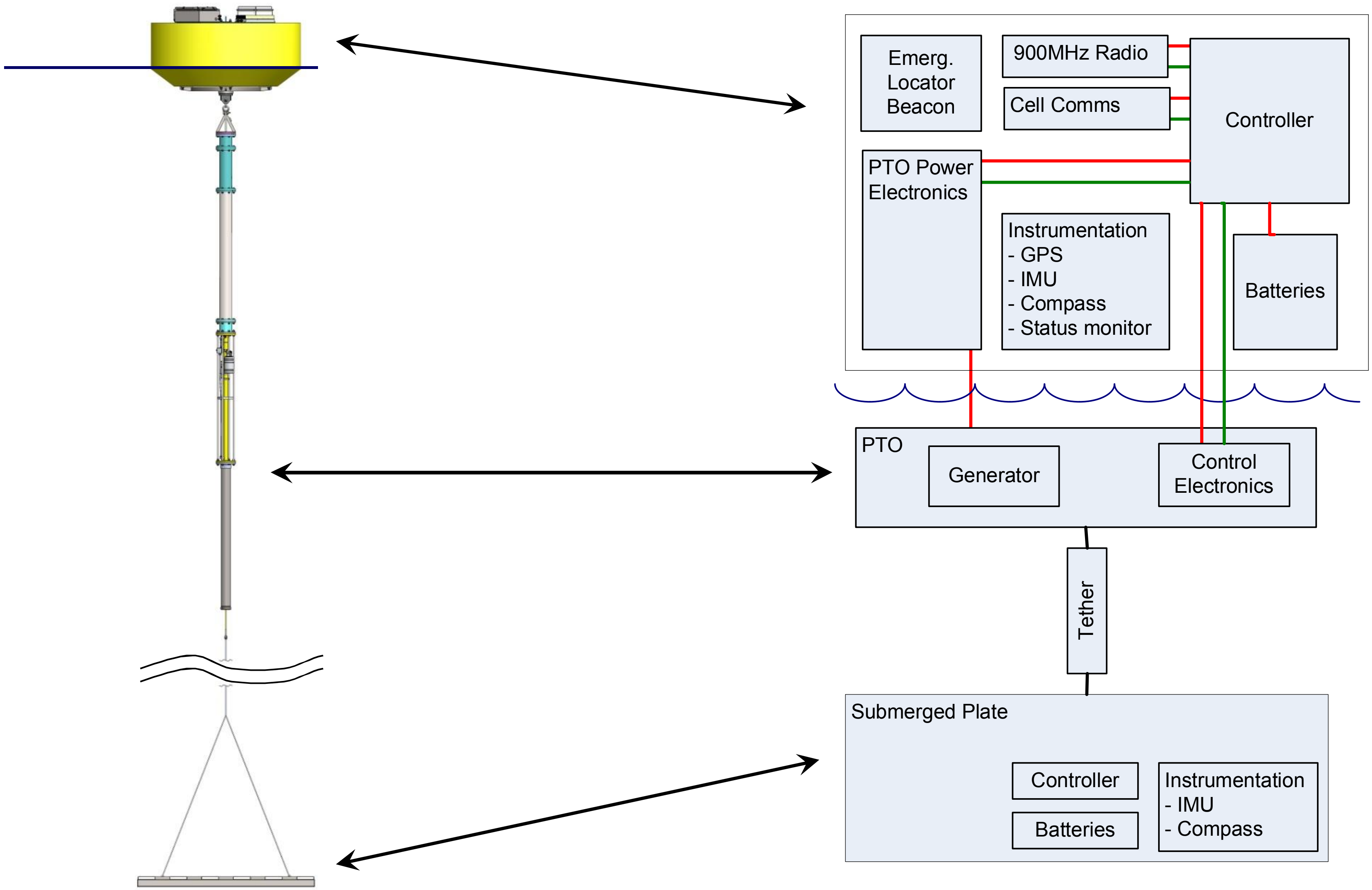


LeadAcid Batteries for **5 days** (.1 W/kg)

2.5m Solar/Wind Buoy (.03 W/kg)

Energy Producing Buoy System

Wave-Buoy Components



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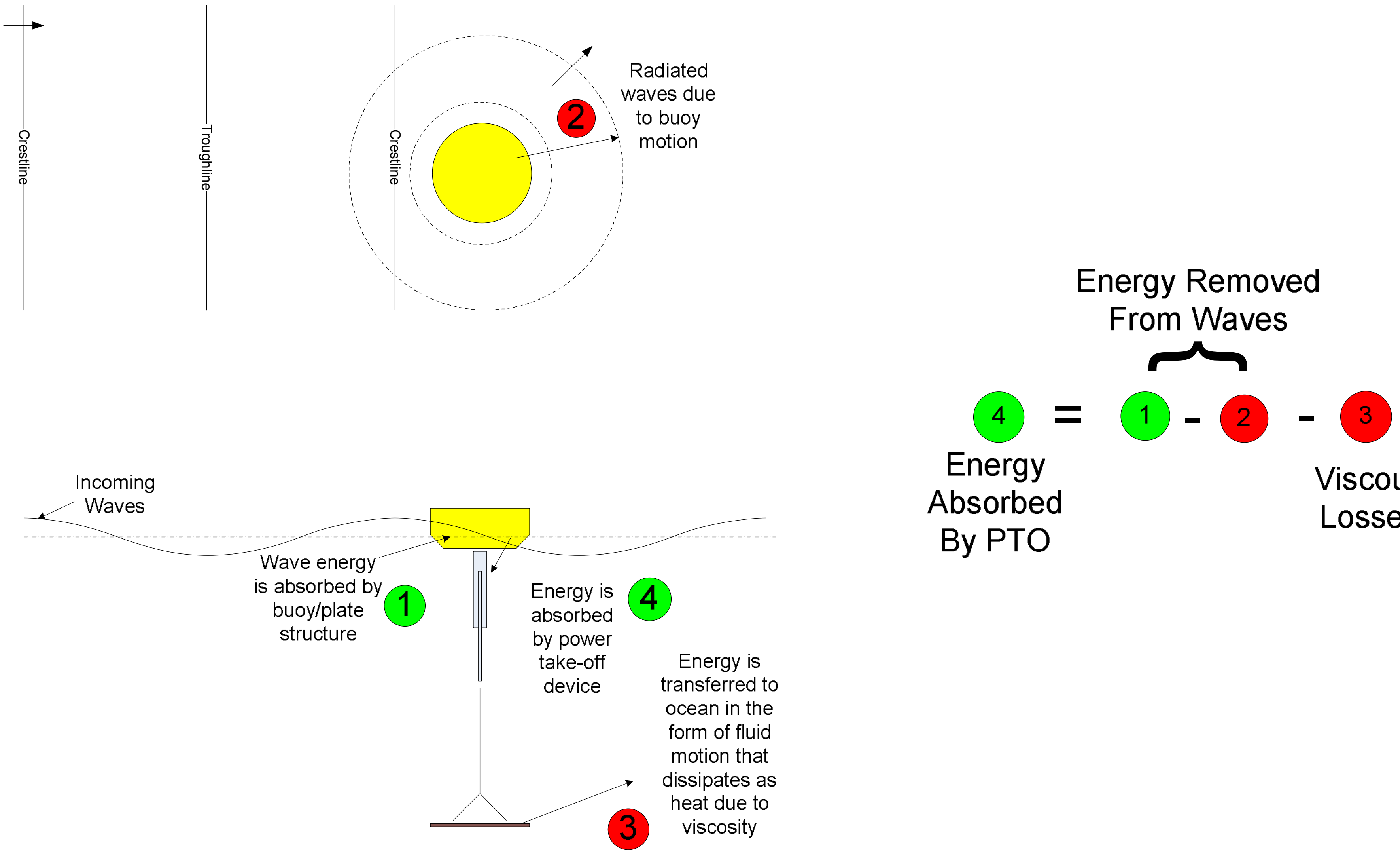
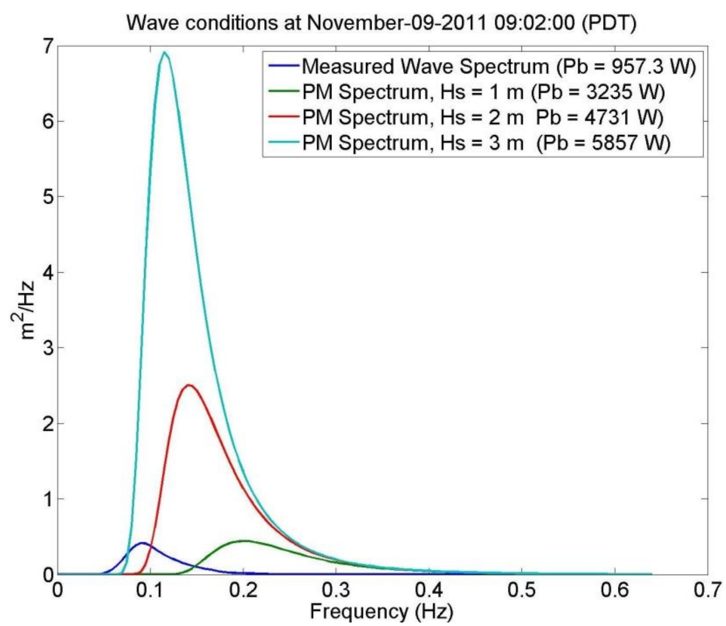
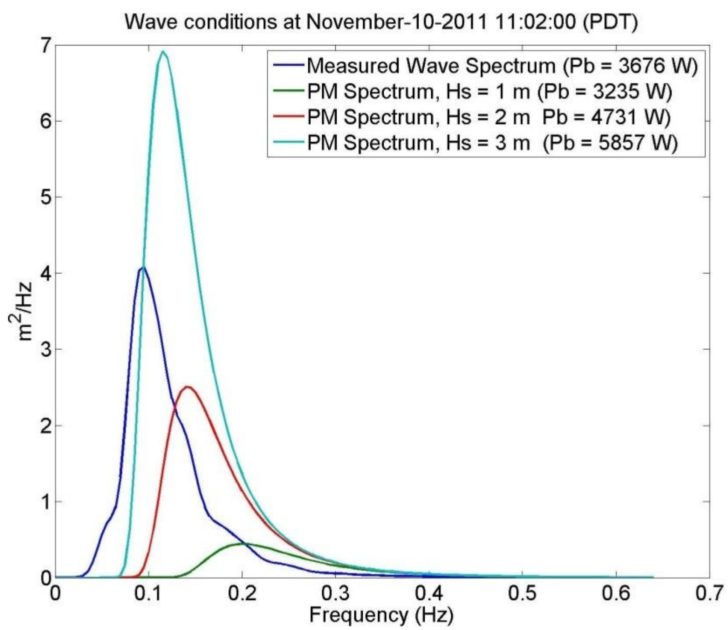
Energy Balance



Measured Performance

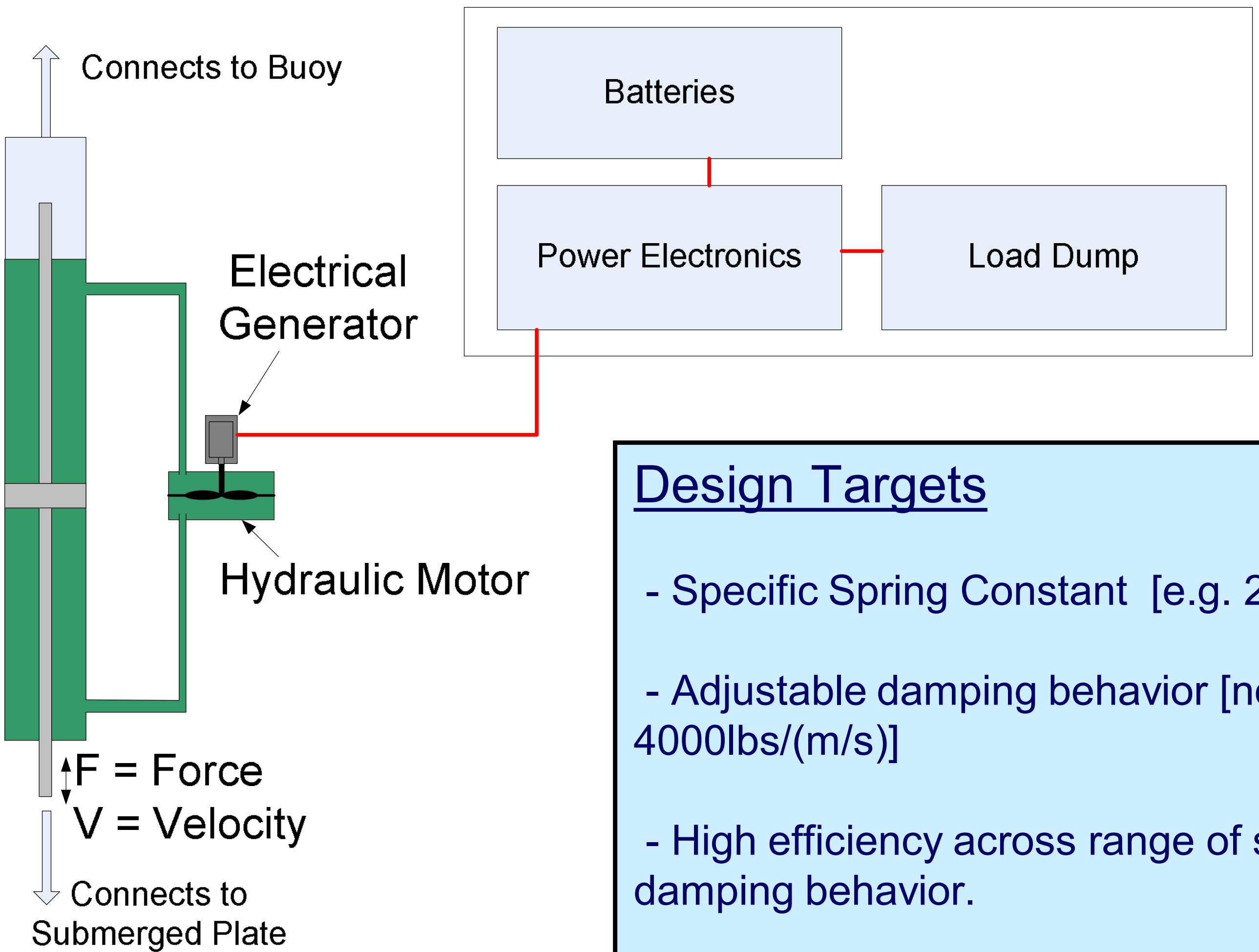
		Numerical Model Predictions		Sea-Test Results
Sea State	Absorbable Power	Power Coupled to PTO	Power Converted to Electricity	Measured Electrical Power
	(W)	*(Watts)*	*(Watts)*	*(Watts)*
Nov 9, 2011 9-10 PDT	957 Watts	25 W (2.6%)	14 W (1.4%)	10W (1.0%)
Nov 10, 2011 11-12 PDT	3676 Watts	386 W (10.5%)	238 W (6.4%)	357 W (9.7%)
Jan 5, 2012 18-19 PDT	4350 Watts	602 W (13.8%)	360 W (8.3%)	405 W (9.3%)
Jan 5, 2012 20-21 PDT	4010 Watts	498 W (12.4%)	299 W (7.4%)	369 W (9.2%)





Electro-Hydraulic Power Take-off Unit

Power Take-Off Device



Design Targets

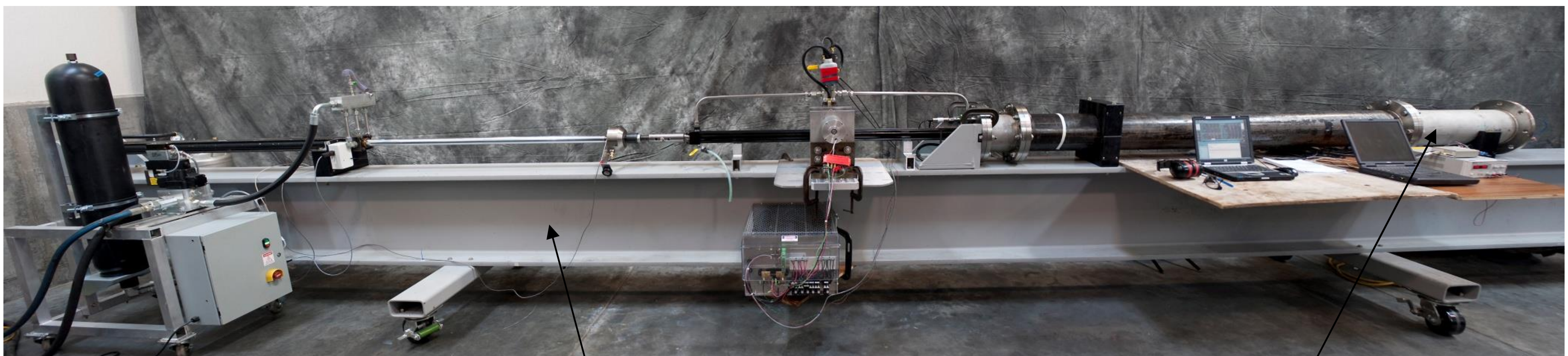
- Specific Spring Constant [e.g. 2000lbs/m]

- Adjustable damping behavior [nominally 4000lbs/(m/s)]

- High efficiency across range of speeds and damping behavior.

Test Facility

Test facility allows exercising of PTO system across entire range of at-sea conditions

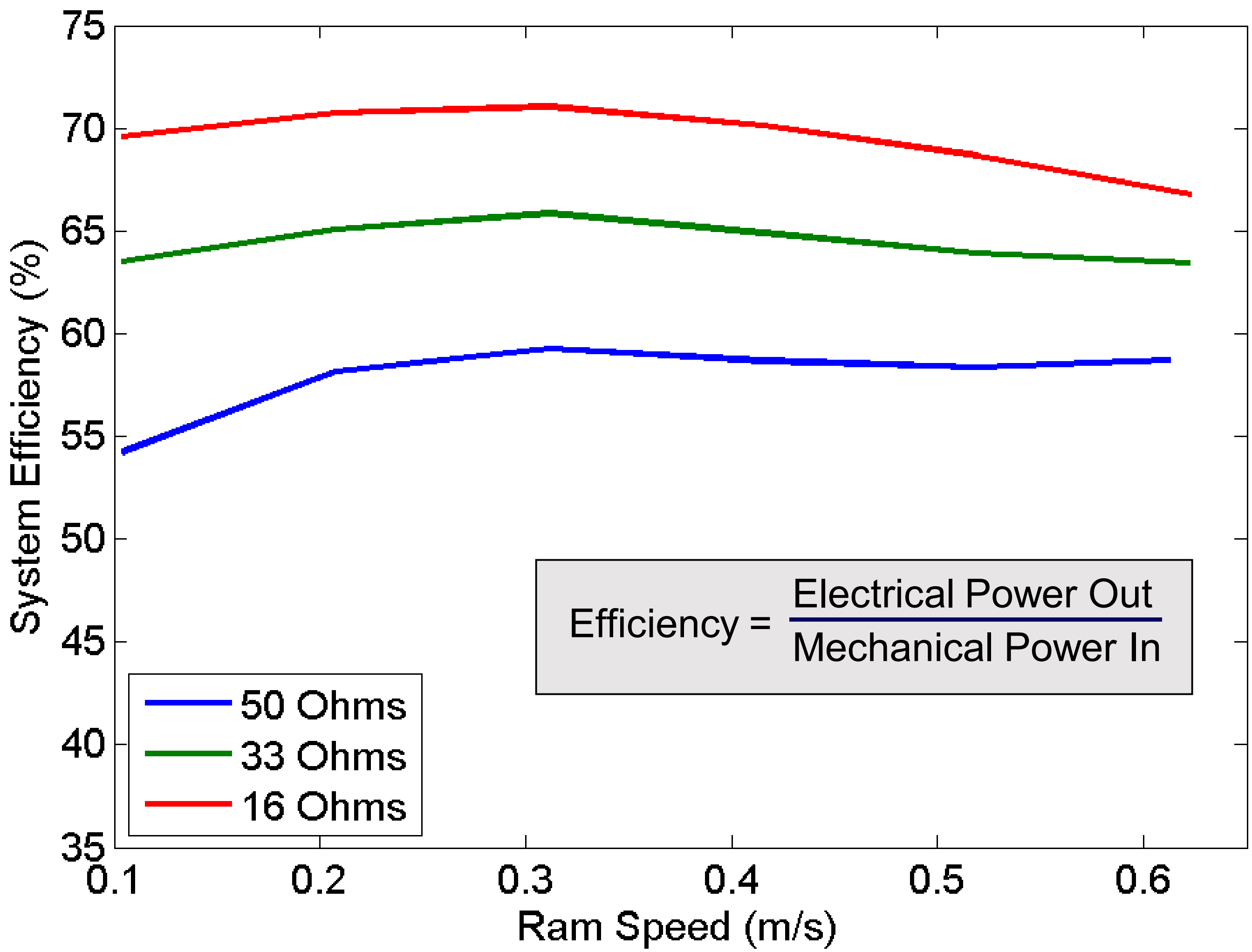


Driving Hydraulics And Control

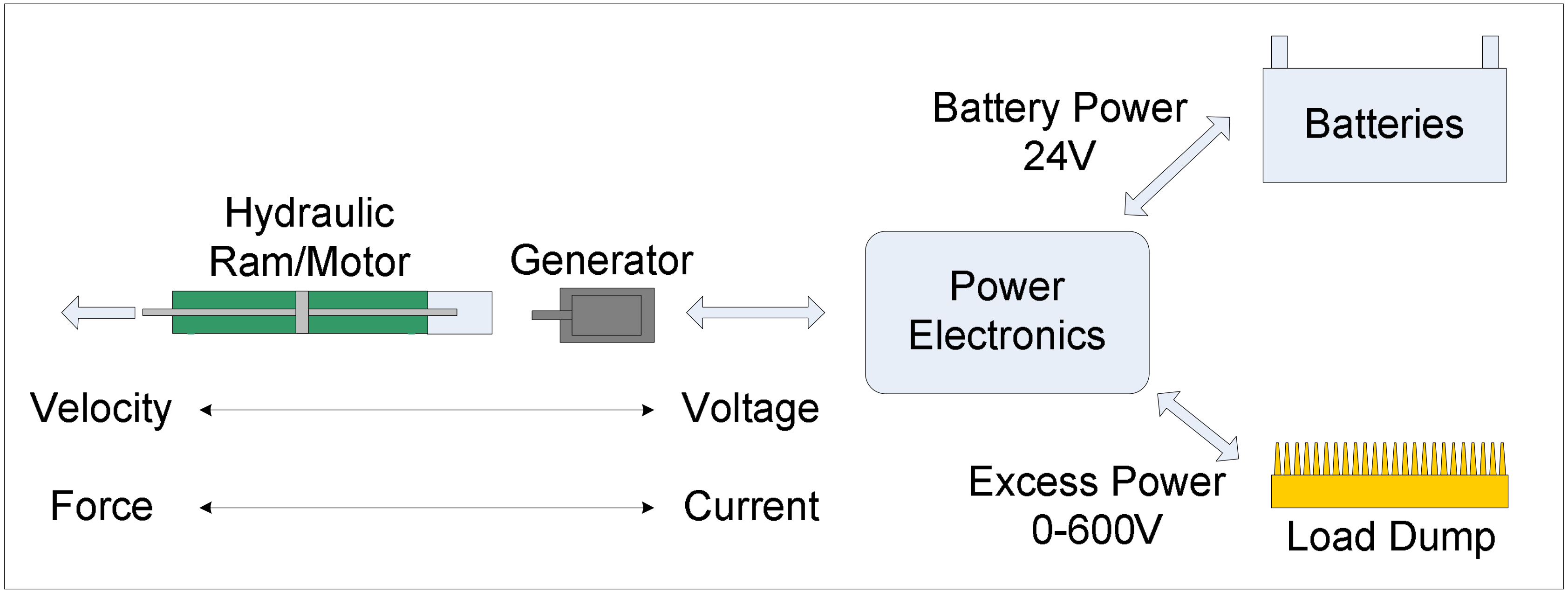
StrongBack

PTO System

Measured Efficiency



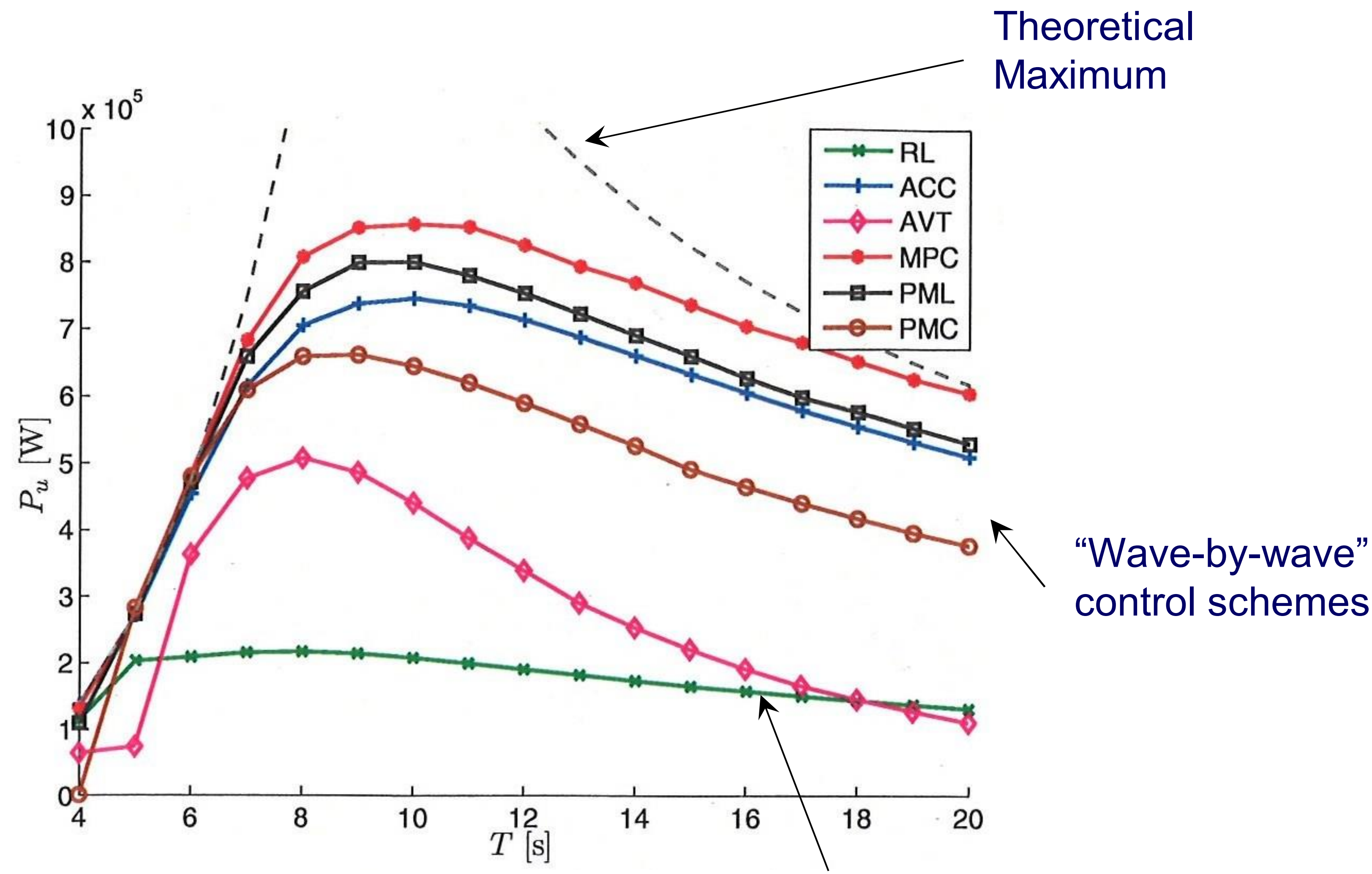
Power Control Electronics



Power Electronics

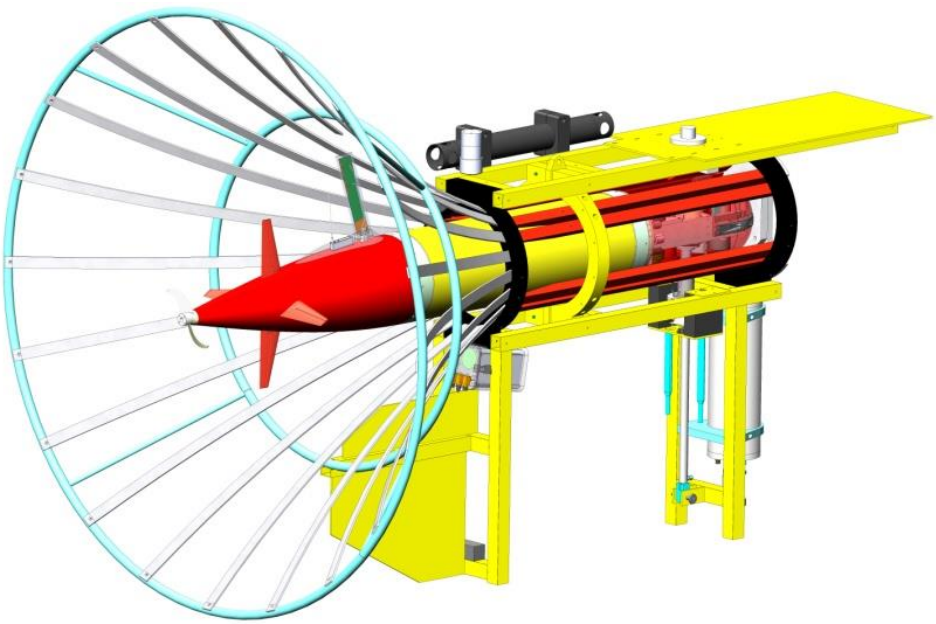
- Convert raw voltage to battery voltages
- Maintain appropriate load on the system for survivability, and to maximize power generation.

Control Optimization



Hals (JOMAE 2011)

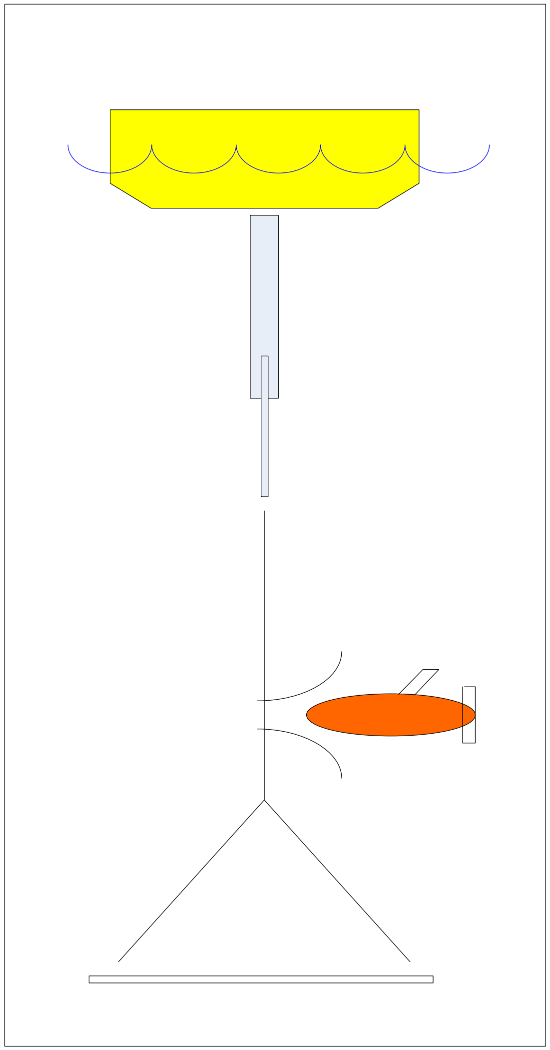
AUV Docking



Docking to Wave-Energy Buoy

• Remote deployments are limited to floats and gliders - low speed and low power payloads

• AUV Docking from an Wave-Energy buoy can support higher power payloads at higher speeds



Applications

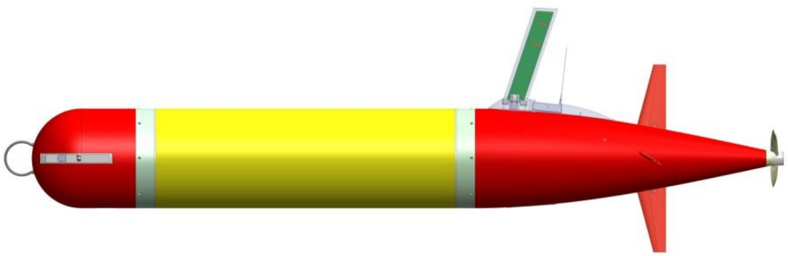
- AUV can be power or data "Mule" from fixed or slow platforms
- Reduces station keeping requirements on buoy
    - Coverage area a function of AUV range
- Enables persistent AUV presence

Engineering Challenges

- Homing to moving target
  (may require active dock stabilization)
- Capture and connect
- Reliability and Bio-fouling

Implementation Details

Vehicle

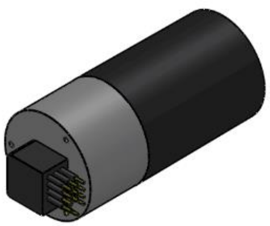


- MBARI LRAUV
    - Operate 6 days, charge for one
    - 600+ km range/charge

Dock Type

- Cone Dock
- Previously implemented at MBARI.

Homing Sensor



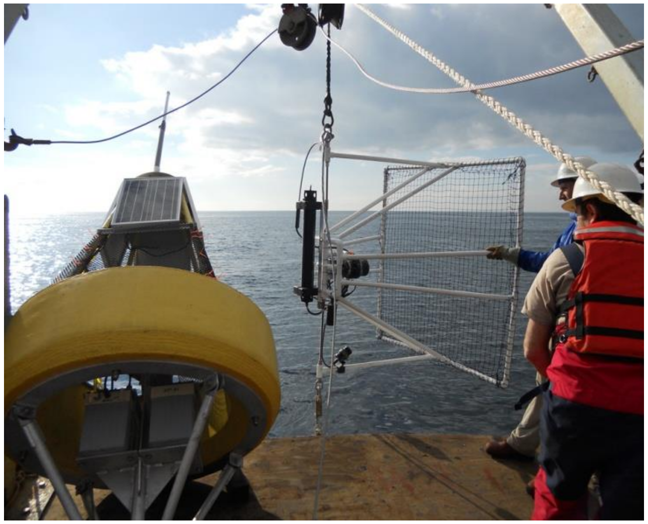
- Inverted USBL with acoustic modem: Benthos DAT
- Provides Range, Bearing, and Low Bandwidth Comms

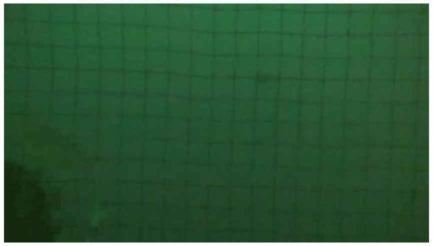
Power and Data Transer

- Direct plug-in connection: ODI Nautilus
- Needs to be isolated from seawater when vehicle is away.

AUV Docking Project Status

- AUV Fitted with Homing Sensor
- Algorithms to locate and home to dock working
- AUV Dock 90% built, but electrical system not ready
- Test Deployment “Mock Dock” operational
  - Develop AUV Homing System
  - Simple Target in place of dock
  - Mock Dock contains acoustic modem w/compass, camera, batteries and telemetry to shore
  - Vehicle passed within 1m of dock 8/10 times last deployment
- Docking AUV damaged at sea and has yet to be recovered – though we know where it is





Homing Hit Video