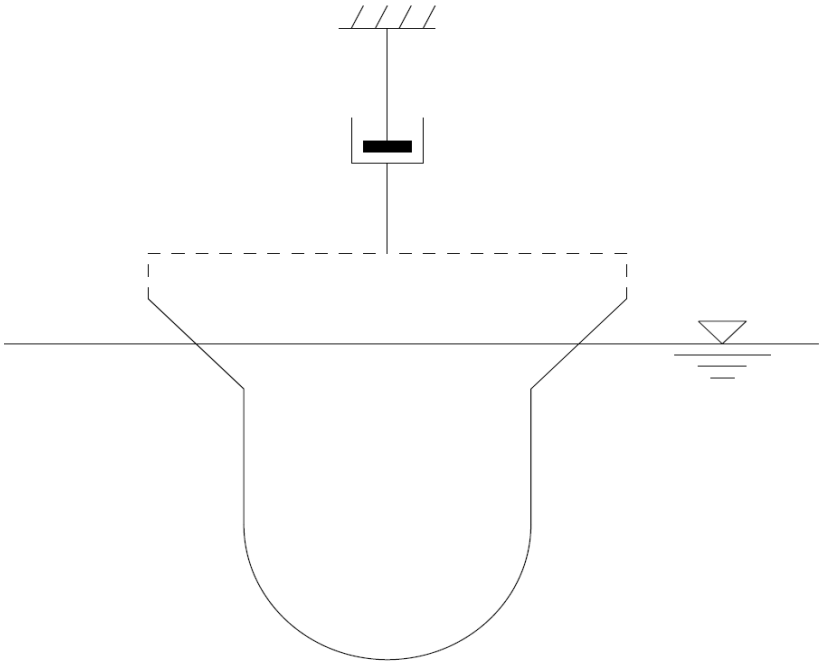
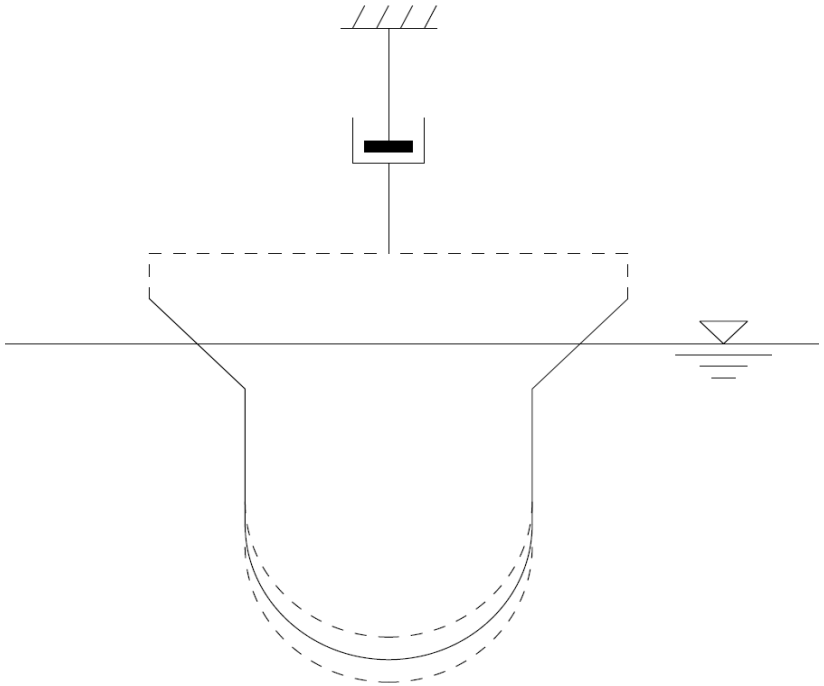


Rigid point absorber



Compressible point absorber

Passive Control for WECs (NASA CDOF)

Giorgio Bacelli
Sandia National Laboratories
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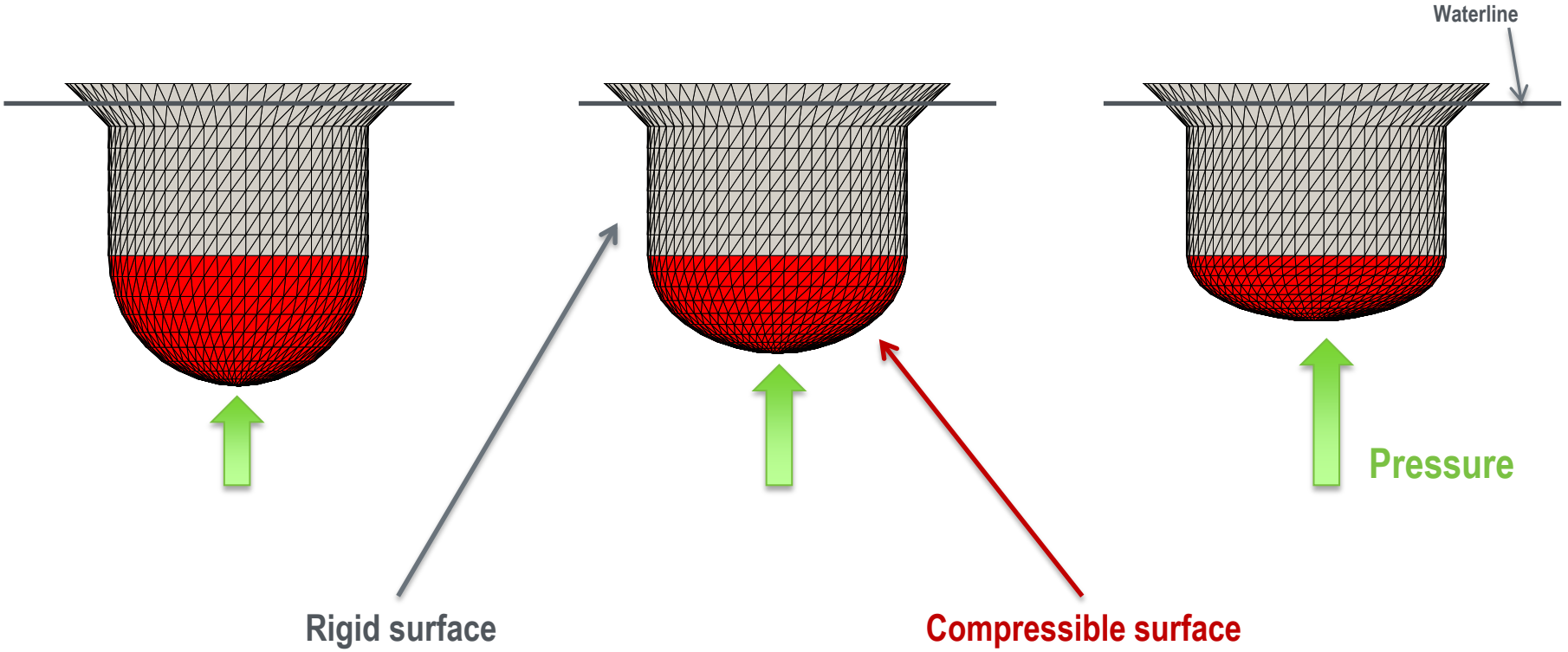
February 2017

Point absorber with compressible surface



Project Overview

Passive Control for WECs: Demonstrated that a compressible point absorber, with optimized damping using passive power-take-off (PTO), can increase energy capture by broadening the bandwidth response, similar to an optimally controlled rigid-point absorber requiring a PTO generating reactive power. Eliminating the need for a reactive PTO would significantly reduce complexity and cost, and increase efficiency.

The Challenge: Wave energy converters (WEC) must be tuned to resonate with incident waves in order to capture energy over broad range of incident wave periods.

Partners: National Aeronautics and Space Administration (NASA) (Dr. Robert Haberman, Raytheon Integrated Defense Systems, review and QA/QC)

Program Strategic Priorities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Technology Maturity

- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- **Conduct R&D for Innovative MHK systems & components**
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

Deployment Barriers

- Identify potential improvements to regulatory processes and requirements
- Support research focused on retiring or mitigating environmental risks and reducing costs
- Build awareness of MHK technologies
- Ensure MHK interests are considered in coastal and marine planning processes
- Evaluate deployment infrastructure needs and possible approaches to bridge gaps

Market Development

- Support project demonstrations to reduce risk and build investor confidence
- Assess and communicate potential MHK market opportunities, including off-grid and non-electric
- Inform incentives and policy measures
- Develop, maintain and communicate our national strategy
- Support development of standards
- Expand MHK technical and research community

Crosscutting Approaches

- Enable access to testing facilities that help accelerate the pace of technology development
- Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets
- Exchange of data information and expertise

Project Strategic Alignment

Technology Maturity

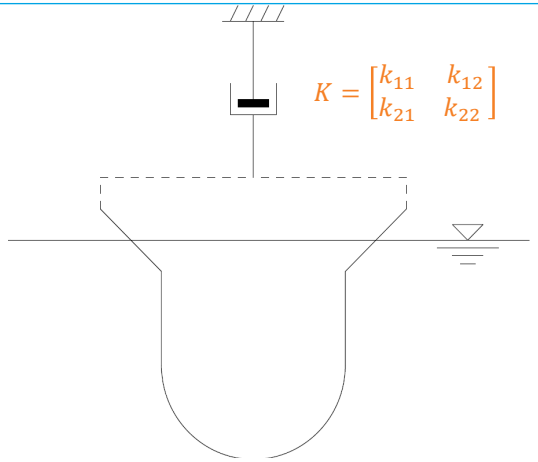
- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- **Conduct R&D for Innovative MHK systems & components**
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

Target/Performance Metric: Achieve maximum theoretical limit of absorbed power over full range of incident wave periods

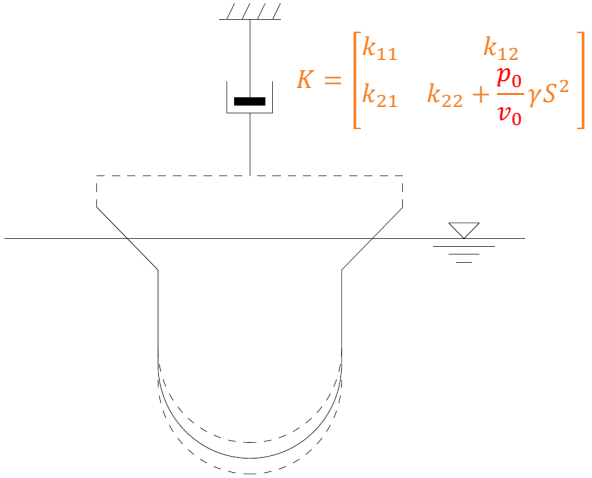
Impact: Identified and demonstrated strategy for WEC technology developers to reduce design complexity and cost

Endpoint & Final Products: (1) Demonstrated proof of concept; (2) SAND report with study details; (3) Paper submitted to peer-reviewed journal, *Renewable Energy*

Technical Approach



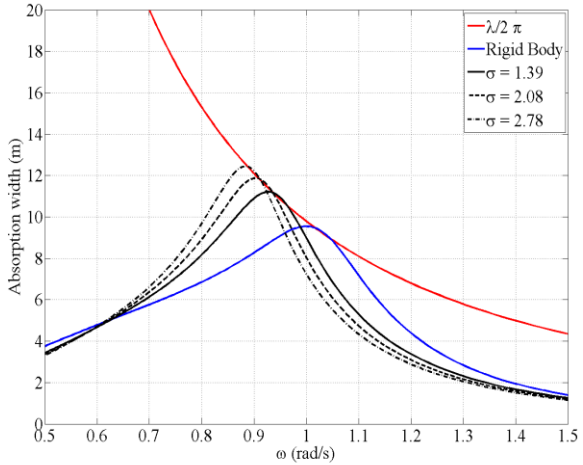
Rigid point absorber



Compressible point absorber

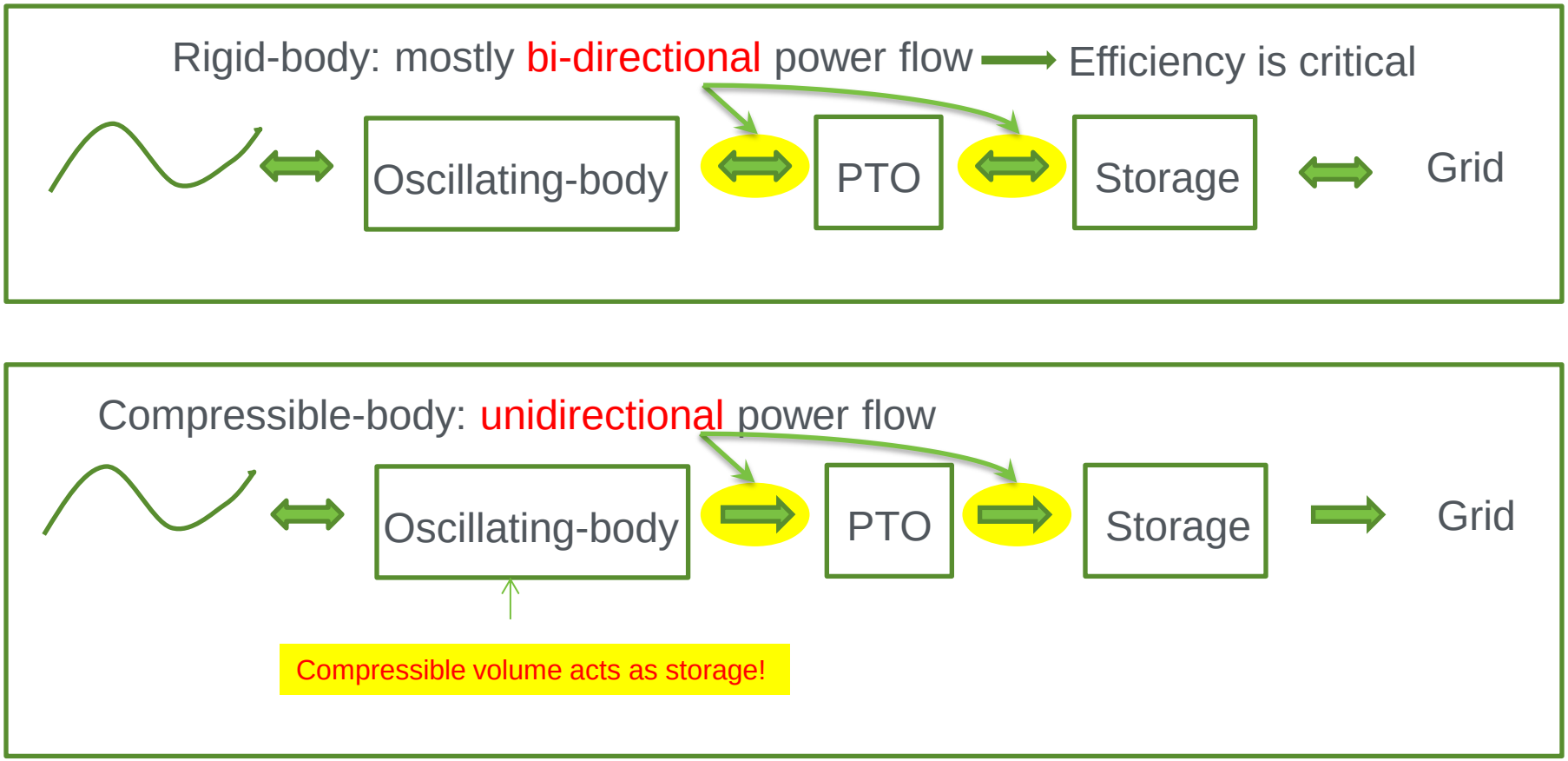
$$\left(-\omega^2\left(M + m(\omega)\right) + i\omega R(\omega) + K\right)\begin{bmatrix}\xi_3 \\ \xi_r\end{bmatrix} = \begin{bmatrix}F_3 \\ F_7\end{bmatrix}$$

ξ_3 : heave position of the WEC
ξ_r : relative position of the compressible surface
F_3 : excitation force on the WEC
F_7 : excitation force on the compressible surface



WEC power absorption width as a function of angular frequency. the value for σ denotes the ratio of the compressible air volume relative to the submerged volume of the point absorber.

Effects on conversion efficiency



Conversion efficiency of the PTO is less critical
Implement reactive control with passive PTO

Accomplishments and Progress

- Demonstrated value of compressible degree of freedom for reducing complexity and cost of tunable point absorbers, and for increasing energy absorption
- Successful transfer of NASA technology
- Poster presented at conference: Bacelli, G., V.S. Neary and A.W. Murphy (2016). Compressible degree of freedom (CDOF): A potential strategy for improving wave energy capture. Proceedings of the 4rd Marine Energy Technology Symposium (METS2016), Washington, D.C., April 25-27, 2016
- Technical report published: Bacelli, G. V.S. Neary, and A.W. Murphy (2015) Compressible degree of freedom (CDOF): A potential strategy for improving wave energy capture. SAND2015-11134, December 2015. 50 pages.
- Manuscript submitted to peer-reviewed journal: Bacelli, G. and V.S. Neary and A.W. Murphy. Compressible degree of freedom (CDOF): A potential strategy for improving wave energy capture. *Renewable Energy.*

Project Plan & Schedule

- Project original initiation date: October 1, 2014 (FY15 start)
- Project planned completion date: September 30, 2015
- Actual completion date: September 30, 2015 (on time and on budget)

Project Budget

Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	N/A	$200k	N/A	$0	N/A

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators: Dr. Bob Haberman, Raytheon IDS (NASA Contractor), provided QA/QC of model formulation and peer review of SAND report.

Communications and Technology Transfer:

- One SAND report
- One conference presentation: METS 2015
- One peer-reviewed journal manuscript submitted, *Renewable Energy*

Next Steps and Future Research

FY17/Current research: N/A

Proposed future research: Validate numerical modeling approach with experimental measurements. May physically model CDOF at Navy's Manuvering And Sea Keeping (MASK) basin in FY18 as part of Advanced WEC Dynamics and Control project to verify the dynamics of a compressible point absorber.