Coupled Dynamic Simulation in a Wave Environment

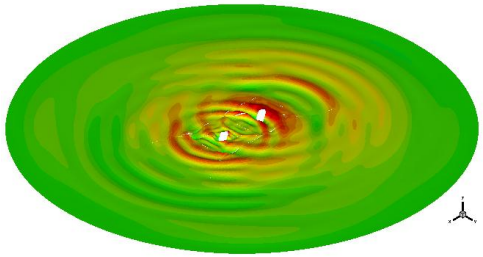
(Navatek, AEGIR, and WECs)

Marine and Hydrokinetics Instrumentation Workshop

9 July 2012

David Kring, Navatek Ltd.

Presentation Overview



- Introduction to Navatek

- AEGIR brief: resistance, seakeeping, global and local loads

  a 3D, NURBS-based, high-order, Rankine boundary element method

  … from same lab as at MIT as WAMIT and SWAN,

  with pFFT acceleration

  coupling with controls, structures, aerodynamics, power take-offs

- Some WEC applications at Navatek

Company Background

Honolulu, Hawaii, USA

A “Research Shipyard” based in Honolulu, HI

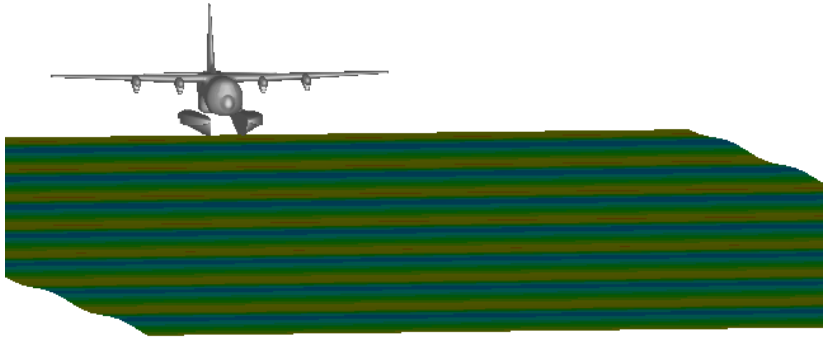
Combining simulation-based design with prototype construction and at-sea testing

<u>Main focus:</u>
Advanced Naval concepts

<u>Also have projects in:</u>
Offshore Platforms
Wave Energy Converters
Wind Power

Coupled Dynamics (AEGIR Co-simulation Capability)

- Interprocess communication using TCP/IP sockets for co-simulation with other dynamics
- AEGIR callable from Matlab, FORTRAN, C/C++ and Python
- Equations of motion solved in external codes or with AEGIR
- Permits coupling to proprietary models without getting under the hood
- Rapid integration with other dynamics models
- Previous examples
  - Control algorithms
  - Flight dynamics
  - Air Cushion Vehicles
  - Multi-body connections

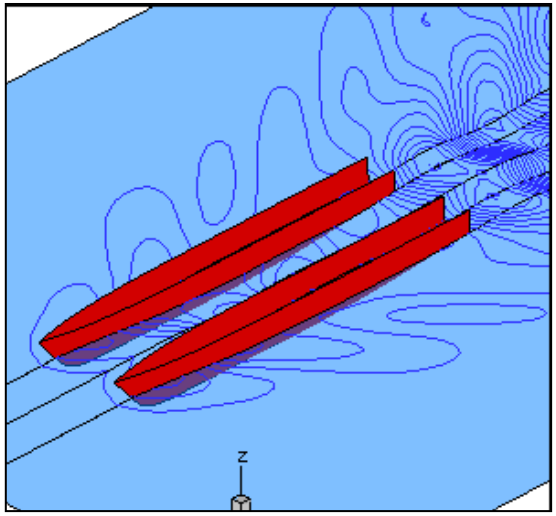


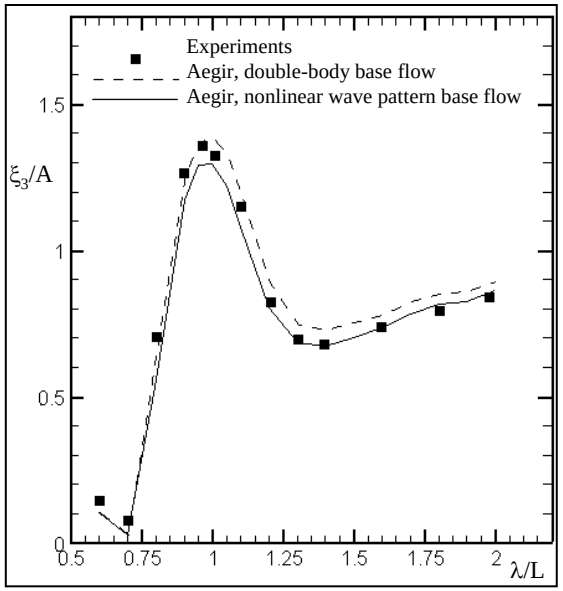
Easily coupled to proprietary dynamics models

Articulated Stable Offshore Platform

AEGIR Overview

- Initial implementation by Kring (1998); on-going development by Kring & Milewski *et al* since 2000
- Potential flow model
  - Rankine source & dipole
  - High-order B-Spline spatial discretization
  - Steady-state and time-domain solvers
- **Zero through high Froude number (exact description for current)**
- Free surface BC in Zakharov form
  - Linear or **nonlinear**
  - Numerical beach to enforce radiation condition
- 3D Lifting surfaces with iterative-pressure Kutta condition
- **Co-simulations using TCP/IP sockets for control algorithms and multi-disciplinary dynamics**
- Applications: mono-hulls, multi-hulls, air cushion vehicles, multi- ship configurations, design optimization studies
- Validation cases include: Delft Cat; LCAC; T-Craft; ASOP; T-AKR 300 & T-AK-3008 multi-ship and T-Craft & LMSR multi-ship configurations





Comparison of Wave-Body Codes

	Solution Domain	Free Surface Boundary Condition	Geometry Representation	Solution Representation	O(N) Solver
AEGIR	time	fully nonlinear	B-spline (with CAD interface)	B-spline	yes
WAMIT*	frequency	2nd-order	B-spline	B-spline	yes
SWAN2	time	weak scatterer or 2nd order	flat panels	limited B-spline	no
SWAN1	frequency	linear	flat panels	limited B-spline	no
LAMP4	time	weak scatterer	flat panels	constant**	yes
DAS BOOT	steady-state	nonlinear	flat panels	desingularized	no

* zero-speed only
** high-order method being developed

AEGIR implementation leverages lessons learned from previous code developments

Potential Flow Formulation

$\Psi(\vec{x},t) = \Phi(\vec{x}) + \phi(\vec{x},t) + \psi(\vec{x},t)$

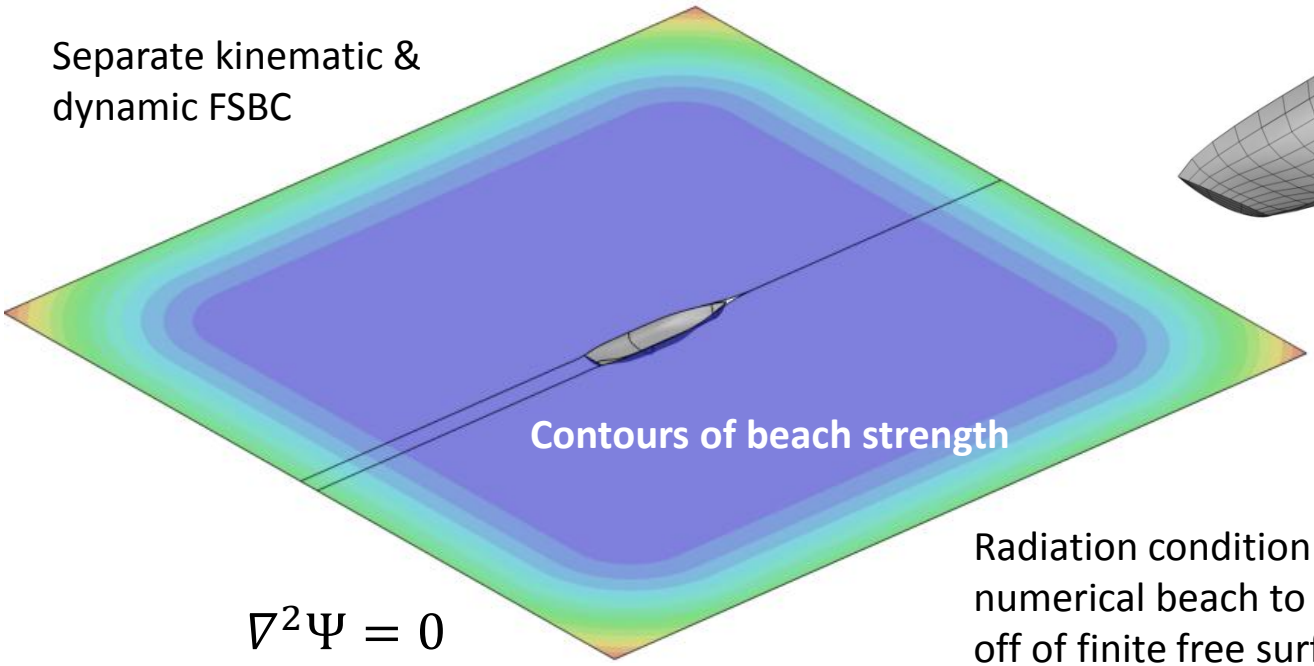
$\Psi(\vec{x},t)$ – total disturbance potential

$\Phi(\vec{x})$ – basis flow potential, either Neumann-Kelvin or double body

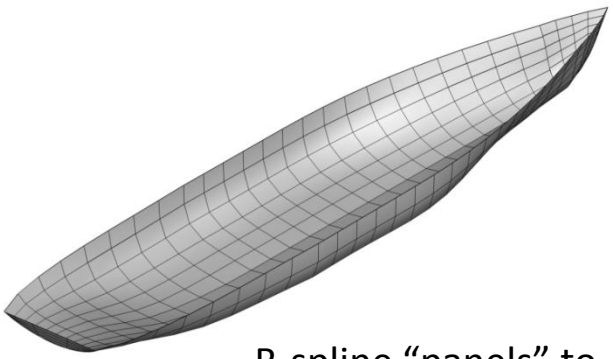
$\phi(\vec{x},t)$ – local (instantaneous fluid response) perturbation potential

$\psi(\vec{x},t)$ – memory flow (wave) potential

Separate kinematic & dynamic FSBC



$$\nabla^2\Psi = 0$$



B-spline "panels" to discretize hull and free surface patches

Radiation condition enforced via numerical beach to damp reflections off of finite free surface boundaries

Numerical solution based on perturbation potential and boundary integral equation method

Fully-Nonlinear, Time-Domain Boundary Conditions

AEGIR uses the Zakharov approach

- accurate free surface tracking
- avoids common problems of the Lagrangian approach (e.g., particle clumping, body penetration, etc)

Body:

$$\phi_n = \vec{V} \cdot \hat{n}$$

Kinematic Free Surface:

$$\zeta \equiv \text{elevation}, \varphi(u,v,t) = \phi(\vec{x}(u,v),t) \text{ for } \vec{x} \text{ on the free surface}$$

$$\left[\frac{\partial}{\partial t} - \left(\vec{U} + \frac{\partial \vec{x}}{\partial t}\right) \cdot \nabla\right] \zeta = (1 + \nabla\zeta \cdot \nabla\zeta)\phi_z - \nabla\varphi \cdot \nabla\zeta$$

forward speed (or current) and waterline variation

nonlinear terms

$$\zeta \equiv \text{elevation}, \ \varphi(u,v,t) = \phi(\vec{x}(u,v),t), \ \text{for } \vec{x} \text{ on the free surface}$$

Dynamic Free Surface:

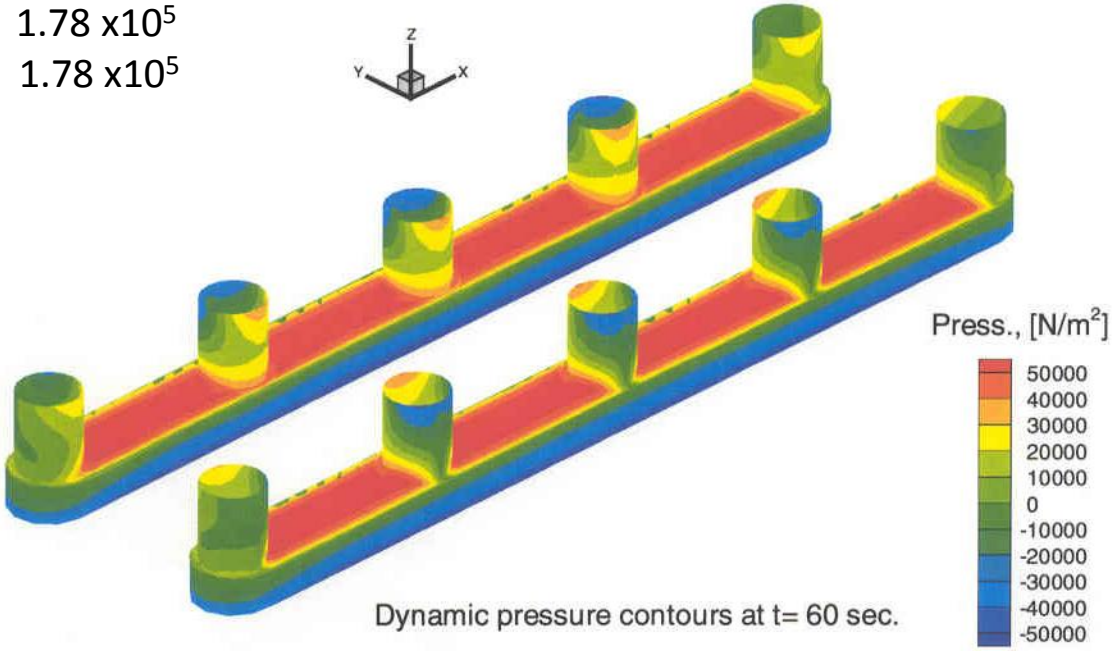
$$\left[\frac{\partial}{\partial t} - \left(\vec{U} + \frac{\partial \vec{x}}{\partial t}\right) \cdot \nabla\right] \varphi = -g\zeta - \frac{1}{2}\nabla\varphi \cdot \nabla\varphi + (1 + \nabla\zeta \cdot \nabla\zeta)\phi_z^2$$

nonlinear terms

Pressures on a Semisub in Heave (T=10 sec)

Added Mass [tons]:

WAMIT (v5.0)	1.80 x10^5
WAMIT (v6.0)	1.78 x10^5
AEGIR	1.78 x10^5



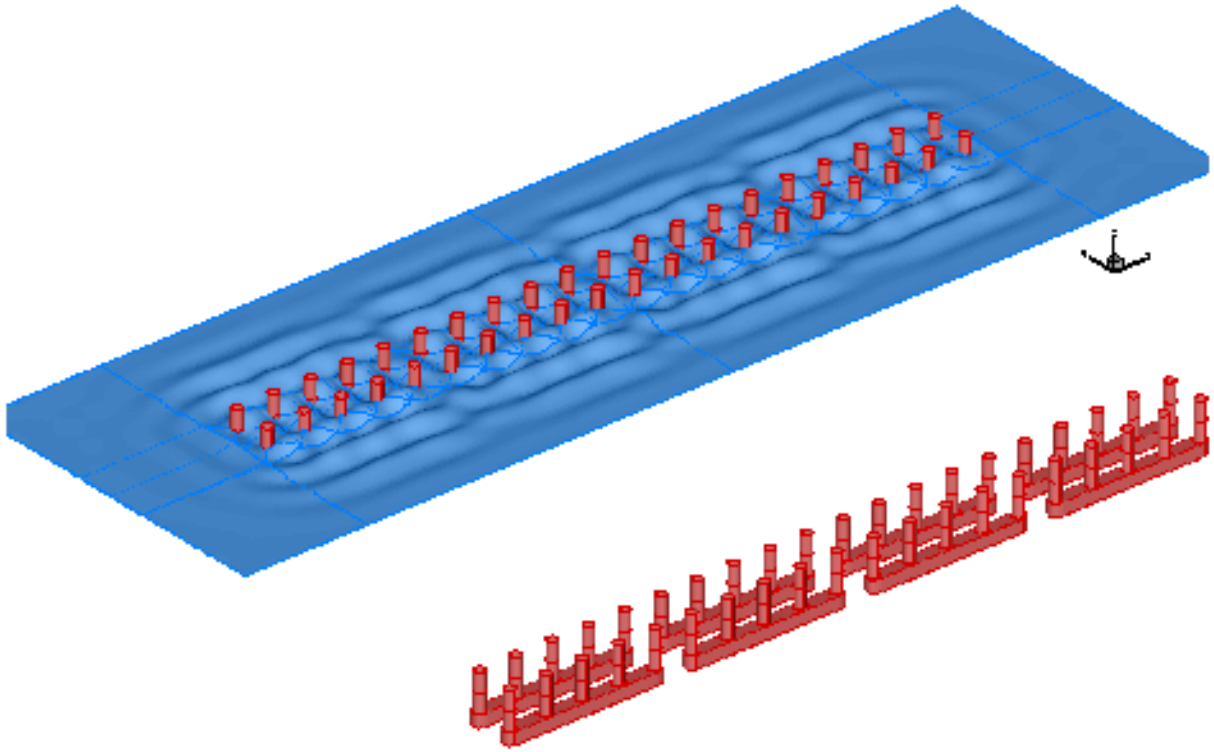
Benchmark vs WAMIT

Seakeeping for ONR/NFESC Mobile Offshore Base

Heave wave pattern for MOB

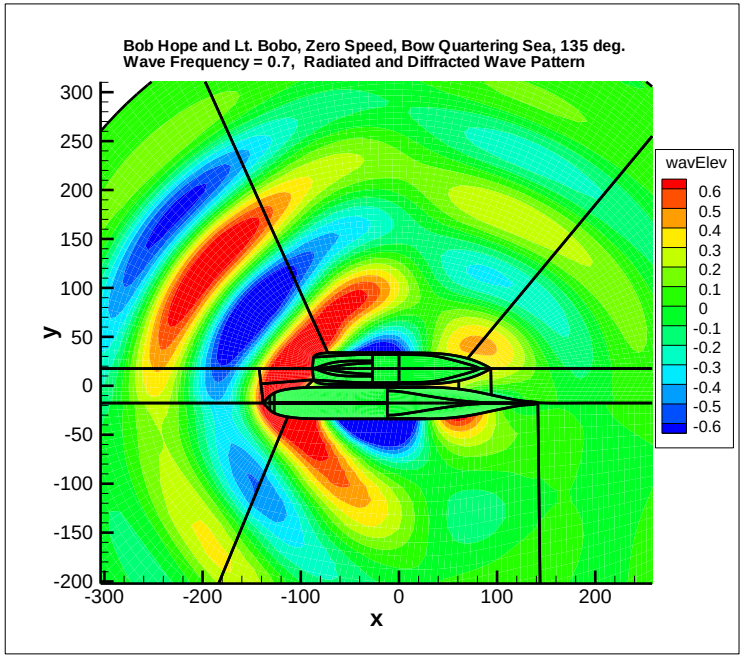
61,000 elements.

accelerated O(N) solution about 1/30th the time and 1/10th memory of traditional approach

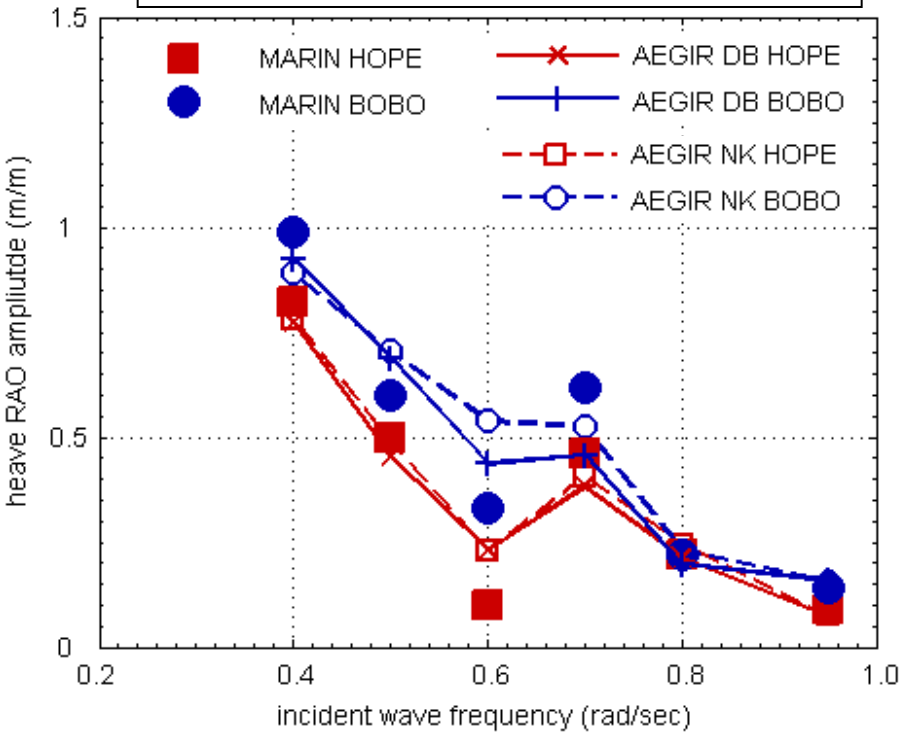


Numerical implementation designed to make challenging simulations feasible

Multi-Ship Simulation Capability



5 knot; 3m separation; 135 deg heading



AEGIR captures hydrodynamic interactions between multiple bodies in close proximity with and without forward speed

Courtesy of Dr. Mike Hughes of NSWCCD;
Sponsor: Dr. Paul Hess & Ms. Kelly Cooper of ONR

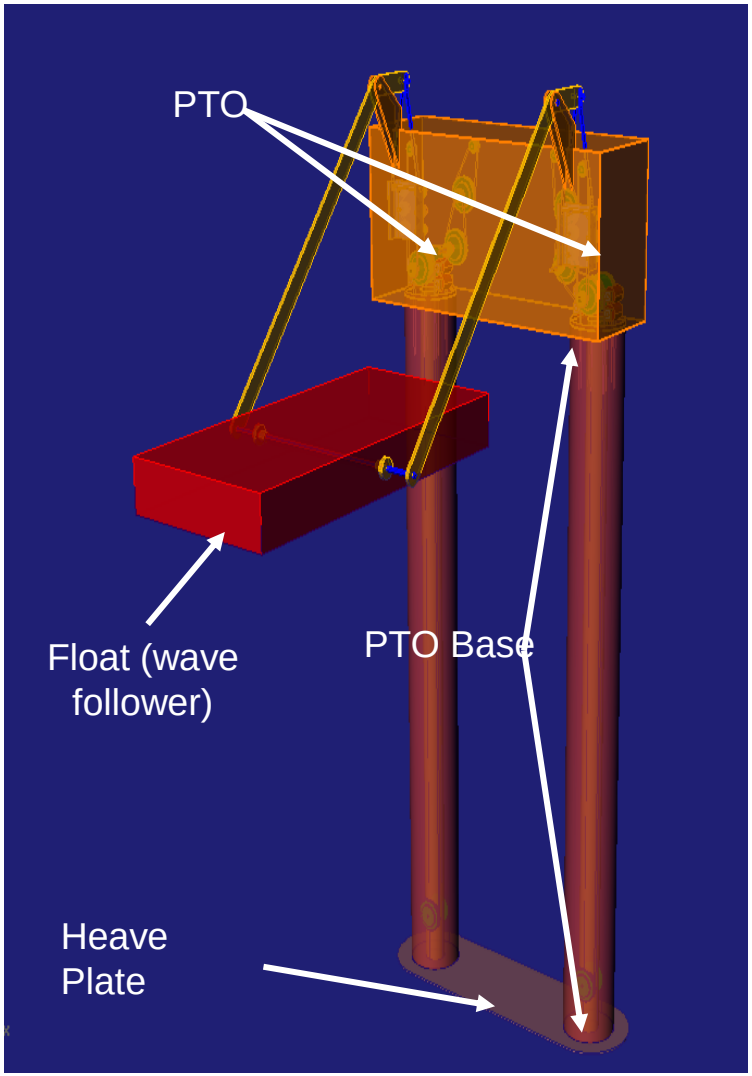
Navatek WEC Design

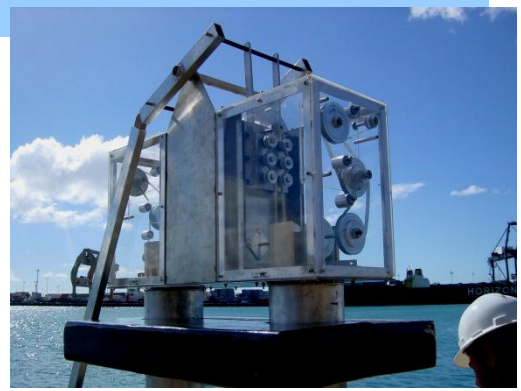
Large range of amplitudes and frequencies in ocean waves

- PTO should collect energy from small and large amplitude waves
- Mechanical stops in large waves should be avoided

Approach: Accumulate energy as potential energy over time and generate electricity over a short time more efficiently

Heave and pitch can be tuned to different wave periods





PTO for 1/16th scale demo

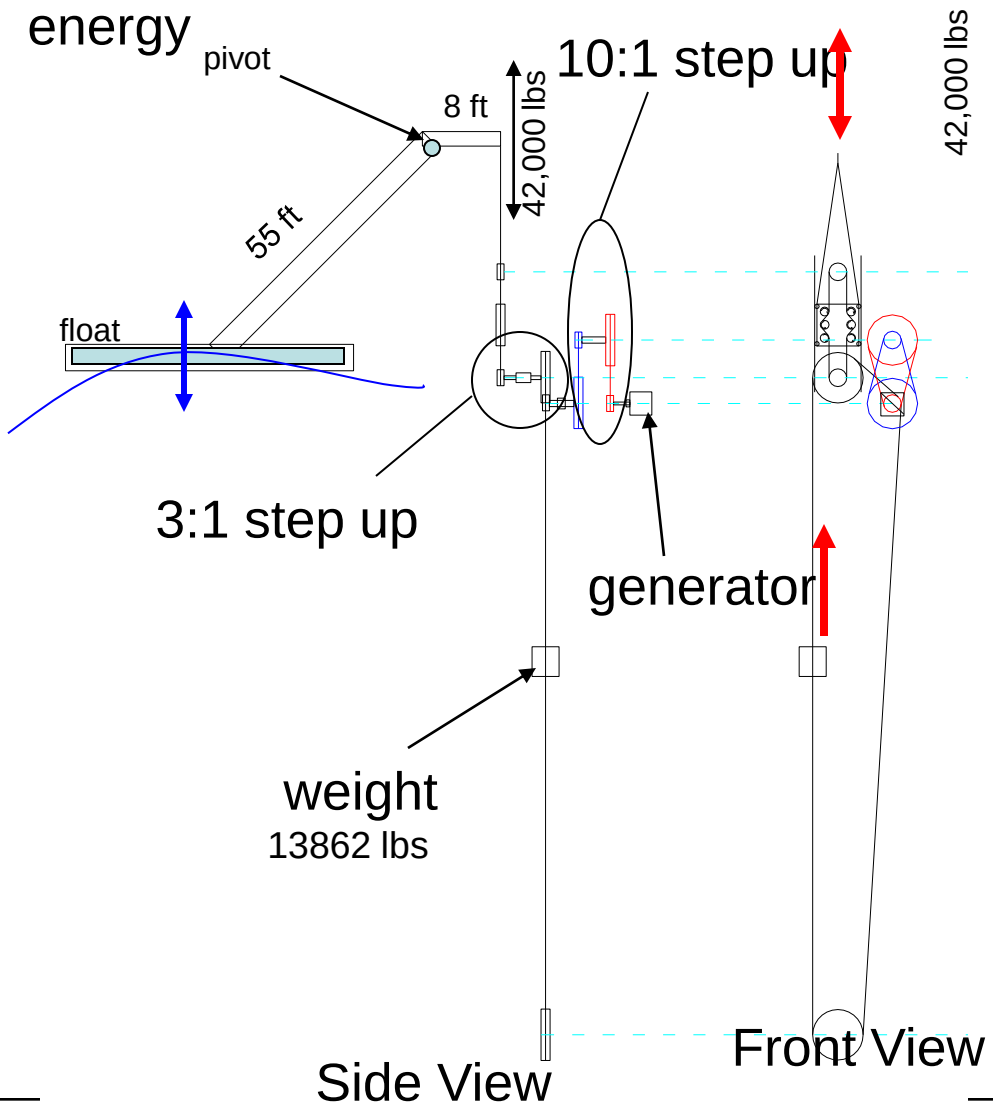
PTO Goals

- Capture energy from small and large waves
- Simple
- No high tech parts
- Robust
- COTS parts
- Low maintenance
- Standard generator

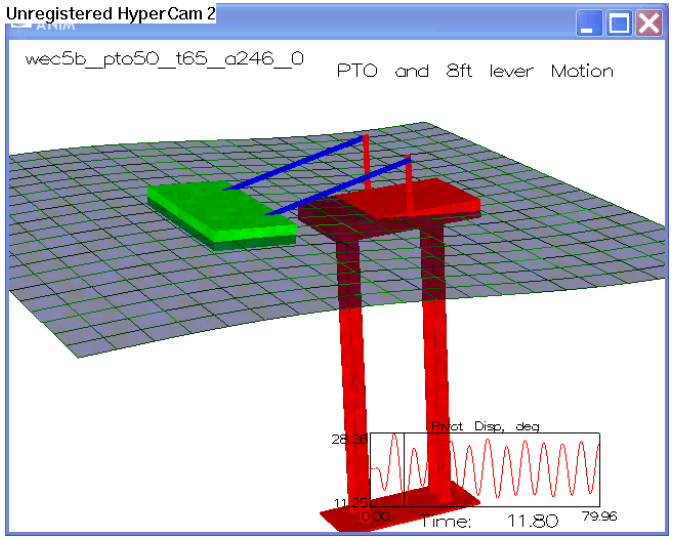
  Operate at 1800 rpm

  Avoid operating at off design conditions

Accumulate wave energy as potential energy



Tank test at Offshore Model Basin



Discussion

AEGIR

- no-cost license
- might consider extreme, overturning waves

… hybrid approach with Lattice Boltzmann

WEC applications

- Not current pursuing this, but could collaborate in design, construction, or at-sea testing
- Hawaii provides some interesting opportunities for MHK

Other alternative energy at Navatek:

- Plasma flow control for wind turbines

… currently lab testing in our wind tunnel

… field test in on wind turbines in Hawaii in the fall