Renewable energy consultants

GL Garrad Hassan

Experience with Validating MHK Tools

National Renewable Energy Laboratory – Broomfield, CO - July 9th 2012

Contents

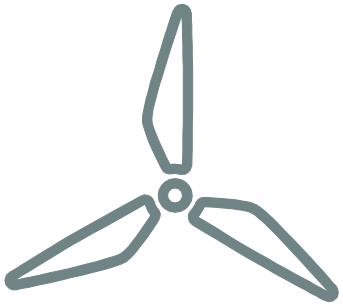
- Overview of GL Garrad Hassan

- List of Tools/Core Expertise: Dedicated Software
    - Waves: Resource assessment and site data analysis
    - WaveDyn: WEC performance and loads calculation (time-domain)
    - WaveFarmer: Planning and optimization of a WEC array
    - Tides: Resource assessment and site data analysis
    - Tidal Bladed: Tidal Turbine performance and loads calculation (time-domain)
    - TidalFarmer: Planning and optimization of a tidal turbine array

- Validation Experience
    - Tidal Bladed
    - ReDAPT
    - PerAWaT
    - WaveDyn

Who are GL Garrad Hassan?

- Industry-leading independent renewable energy consultancy
- Established in 1984
- Over 950 full time staff, in 42 locations, across 24 countries worldwide
- Working in 5 continents
- No equity stake in any technology / project developers
- Part of the Germanischer Lloyd Group



Onshore & Offshore Wind

Wave & Tidal

Solar PV & CSP

GL Garrad Hassan Wave & Tidal Tools

WaveDyn

Tidal Bladed

WaveFarmer

TidalFarmer

Waves

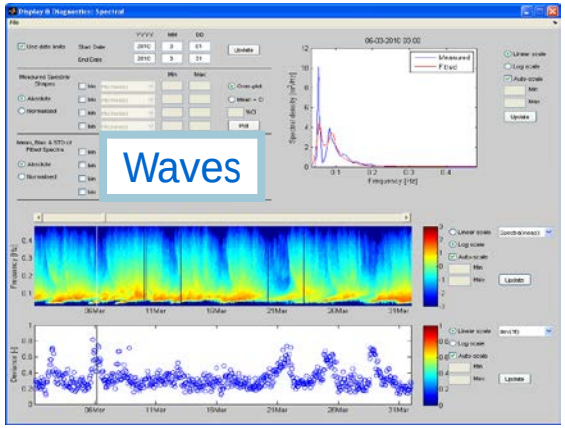
Tides

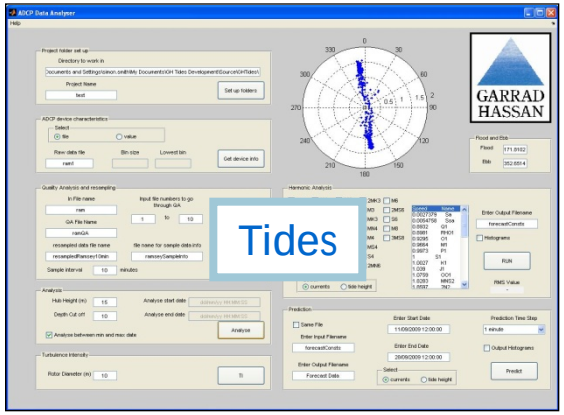
O2M

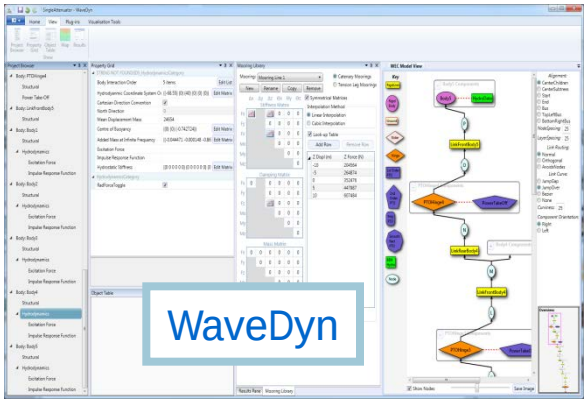
O2C

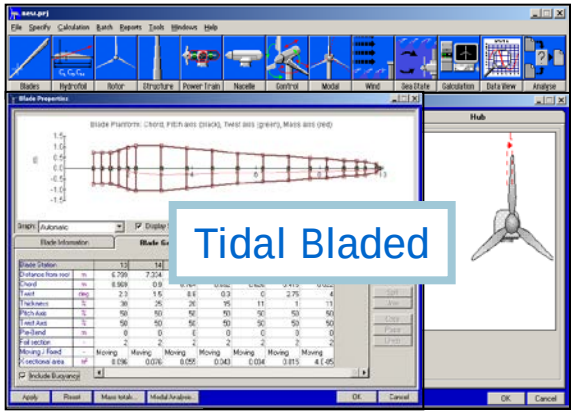
GH SCADA

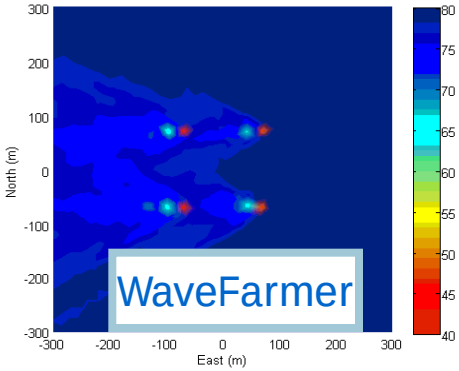
Developer's Database

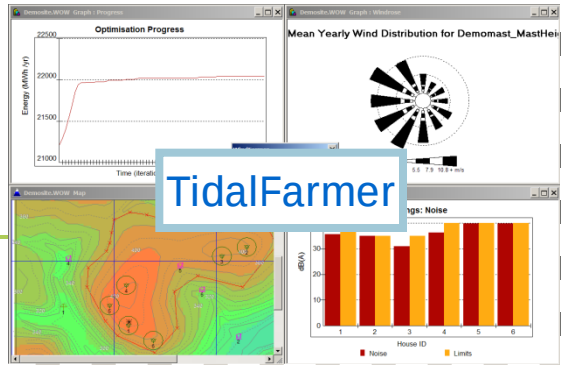










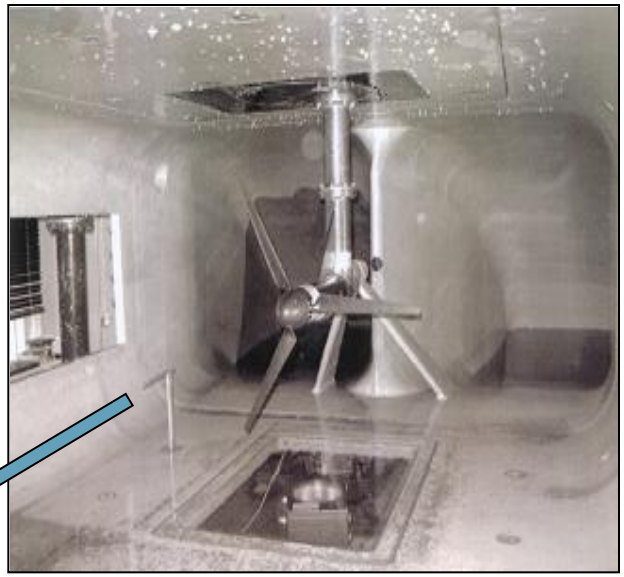


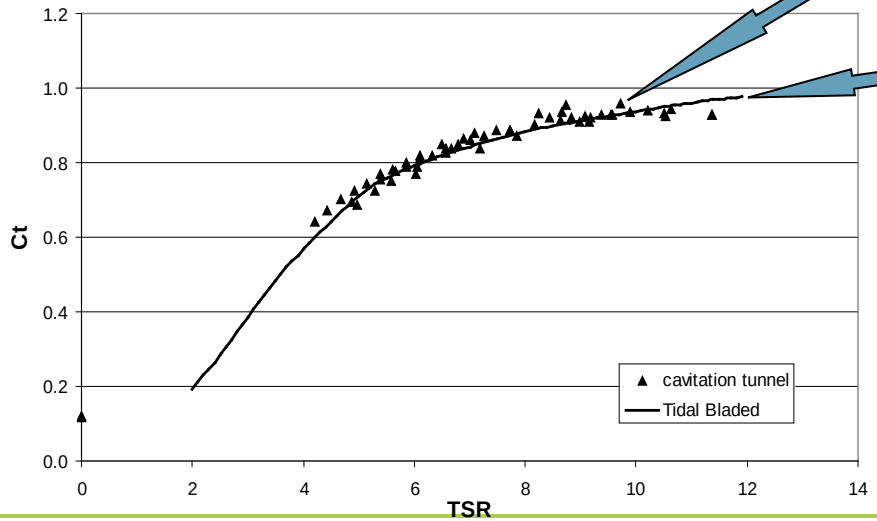
Tidal Bladed Validation

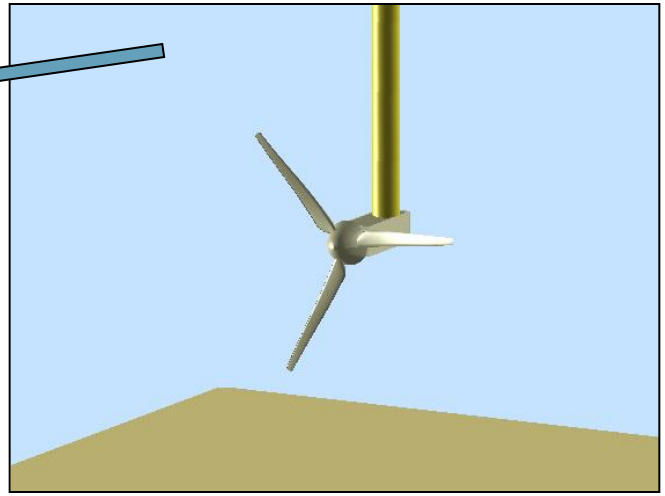
- Scale model validation (measurements provided by the University of Southampton)

- Several full scale validation studies undertaken (but confidential)

- ReDAPT – Validation and tool development

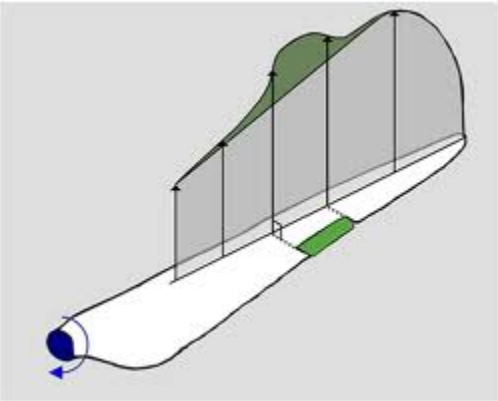






Tidal Bladed – Initial Validation Results

Tidal Generation Limited (TGL) – 500kW



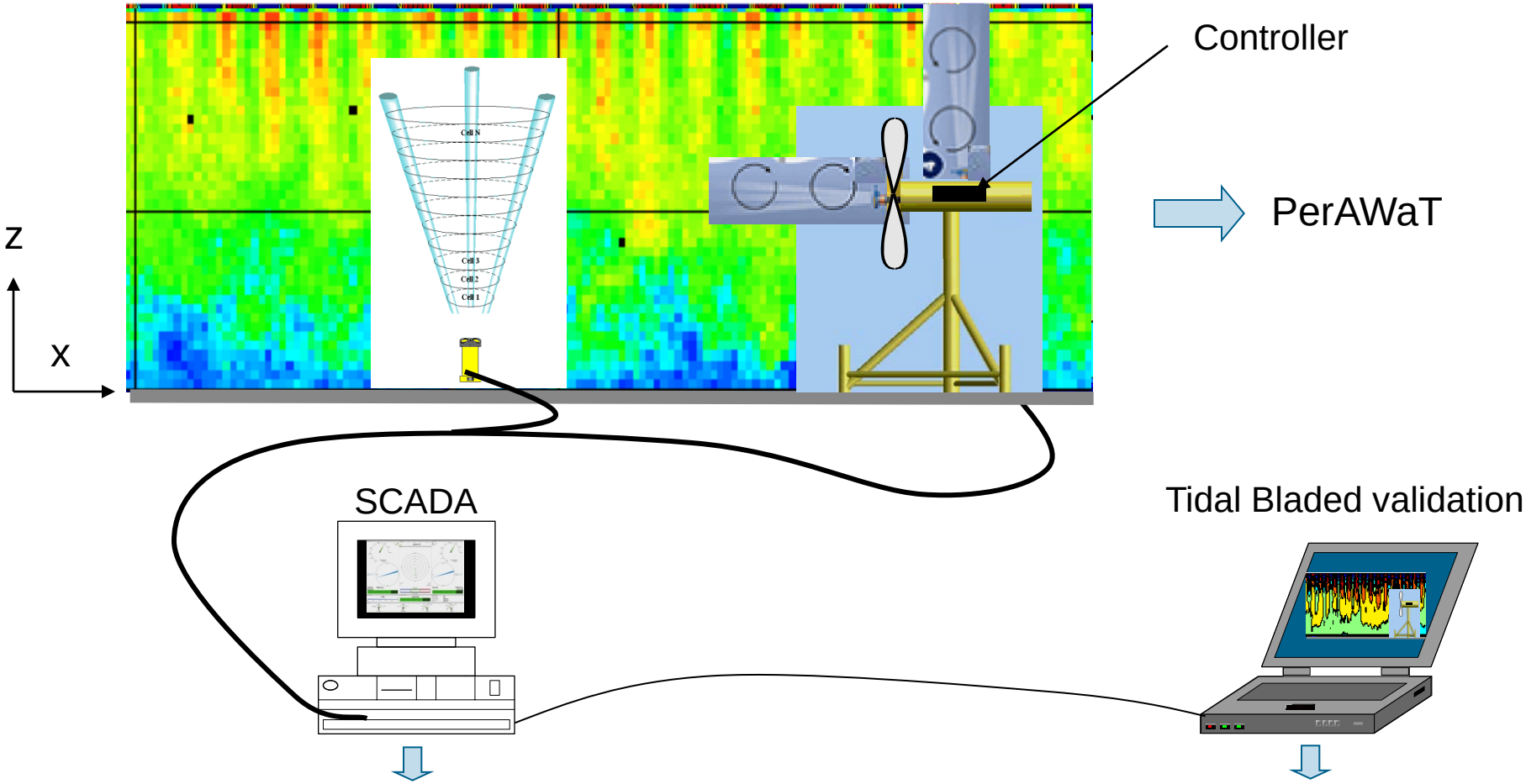
ReDAPT- Reliable Data Acquisition Platform for Tidal

- Project will enable data collection, insights and lessons to be learned specifically regarding device performance and the environmental impact of a device. Key outcomes will be industry tools/methods/ standards/protocols

- 3 year project bringing together key consortium of universities, utilities and an engineering consultancy

- ETI Investment: £12.4 million
- Project Completion: Summer 2014

ReDAPT: GH involvement



Standards & other working groups

Measurements to be taken from ReDAPT

Measurements which can be used in numerical model validation:

- Ambient inflow conditions (device scale)
  - Turbulence kinematics
  - Waves kinematics
  - Shear profile

- Ambient inflow conditions (array/basin scale)
- Device performance
  - General behaviour (Cp,Ct)
  - Dynamic behaviour
  - Near wake
  - Far wake

Performance Assessment of Wave and Tidal Array Systems (PerAWaT)

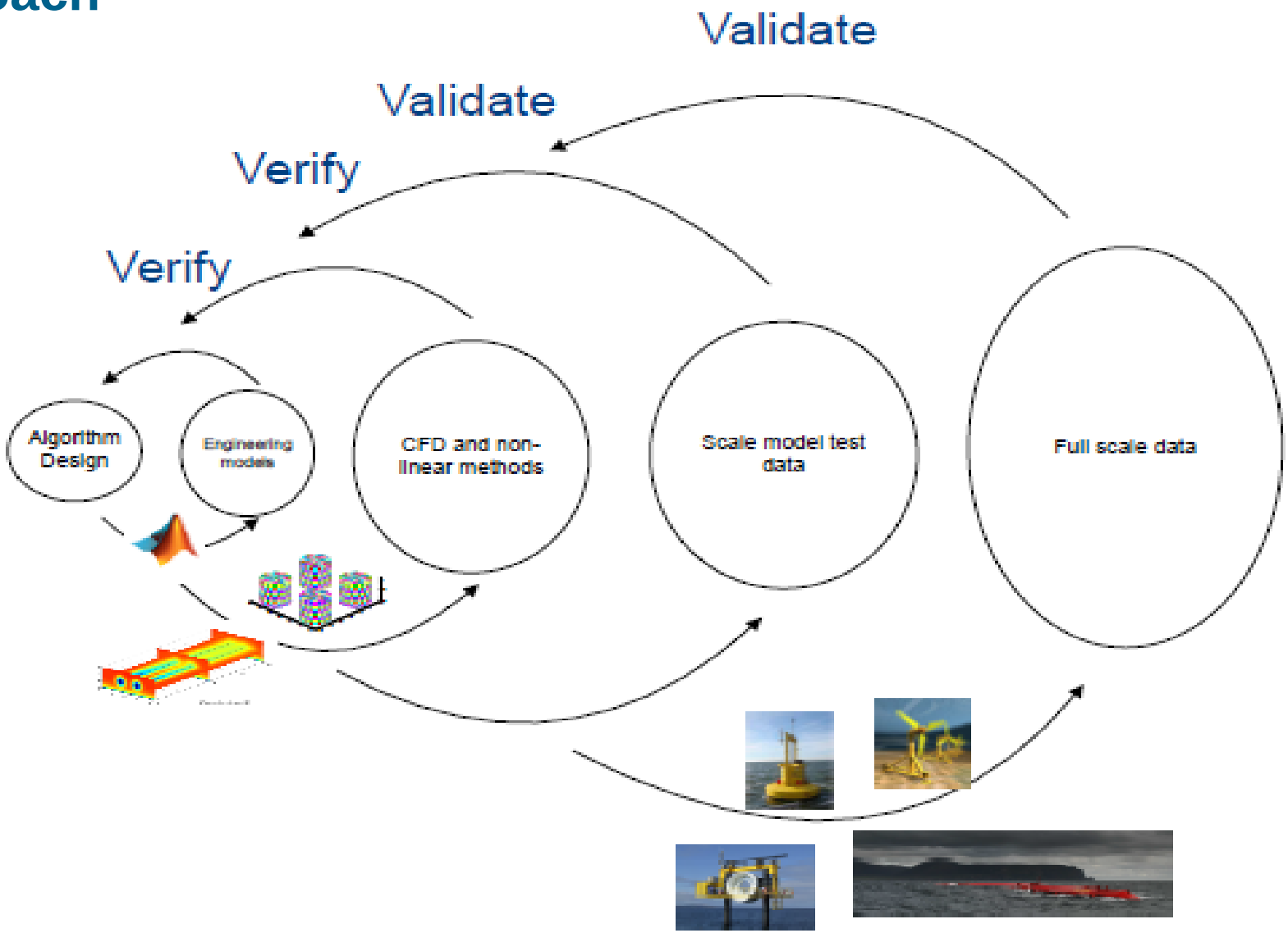
Primary Goal:

*To **establish** and **validate** numerical models to predict the performance of wave & tidal energy converters (WECs and TECs) operating in arrays*

- ETI Investment: £8 million
- Project led by GL Garrad Hassan
- Project Announced October 2009
- Project Completion: End 2013

Four year £8m project bringing together key consortium of universities, utilities and an engineering consultancy.

Approach


Validate
Validate
Verify
Verify
Algorithm Design
Engineering models
CFD and non-linear methods
Scale model test data
Full scale data

Key Outcomes of PerAWaT Project

- Establish and validate a suite of engineering models which when integrated can be used to analyze the performance of wave and tidal array systems.
- Verify the engineering models by cross comparison with more complex methods which will provide detailed insight into the physics.
- Validate all numerical models against physical testing.
- Integration of all numerical and physical testing outputs within engineering tools for use by project developers for the design and assessment of the performance of wave and tidal arrays.

PerAWaT Wave Testing Update

- Recently completed large scale tank tests in leading European facilities utilizing two different fundamental device concepts from two leading European developers subcontracted to the project
- Multiple models and tests were done for each machine
- Single devices as were tested as well as small arrays
- Data used in further validation of WaveDyn
- More details to be published soon

WaveDyn Validation with Columbia Power Technologies*

Motivation and Key Objectives

Key objectives

- Build a Columbia Power WEC in WaveDyn
- Analyse the WEC performance in a variety of conditions (regular and irregular waves)
- Post-process experimental data from tests done at multiple scales (1:33 and 1:15)
- Compare numerical estimates with experimental results
- Preliminary assessment of the uncertainty

Key outputs

- Detailed load and performance indicators for the Columbia Power WEC
- Validated estimates for a wide range of input conditions
- Contribution to the understanding of uncertainty in WEC R&D

***These slides on WaveDyn Validation with CPT are based on OMAE 2011 proceedings**

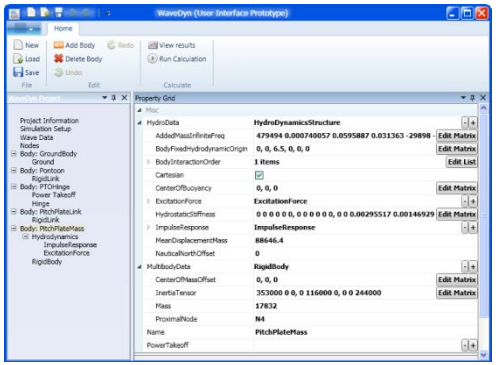
Role of WaveDyn

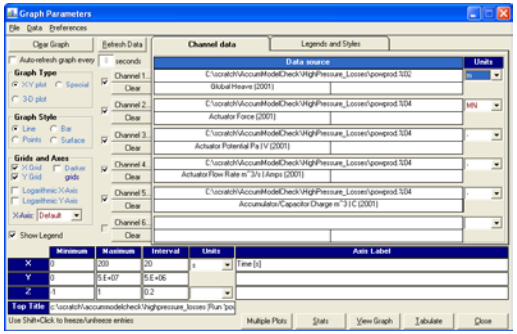
Multi-body formulation

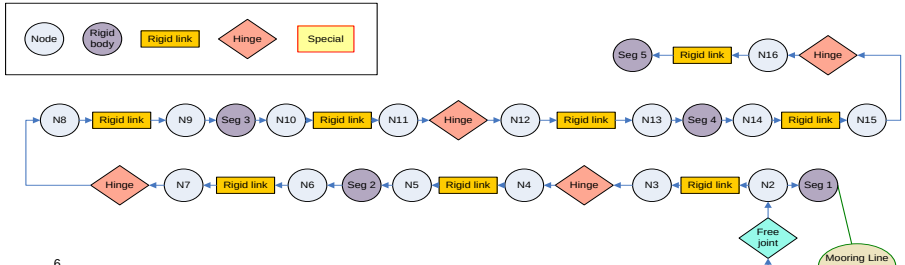
Time-domain core solver

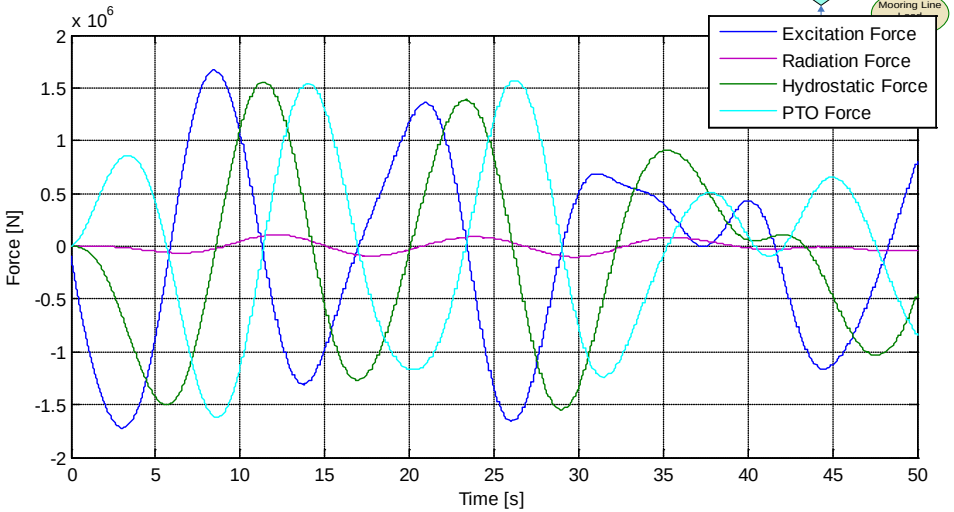
Modular structure

- Wave
- Hydrodynamic
- Power-take-off
- Control
- Moorings
- Post-processing









Numerical Setup

First-order hydrodynamics

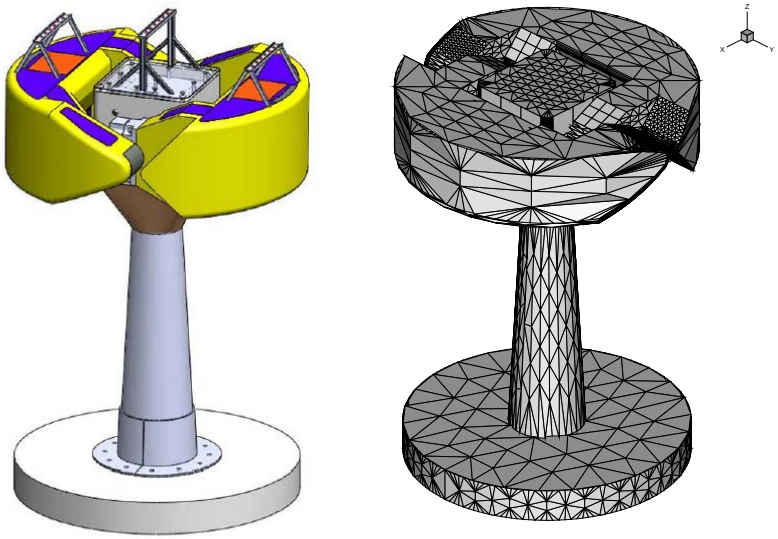
- Wave exciting force & hydro coefficients
- WAMIT (high-order panel method)

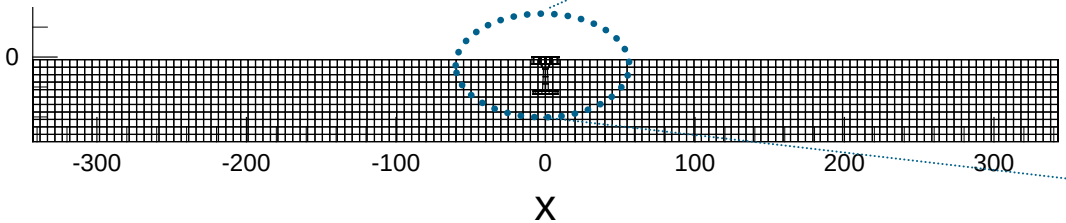
Catenary mooring (3 lines)

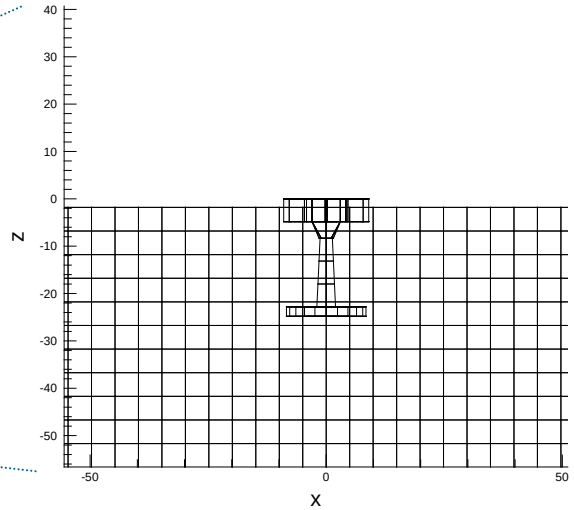
Linear PTO (torque vs angular velocity)

Full potential of WaveDyn not explored

- Frequency and time-domain formulation possible in linear model







Experimental Setup

Hinsdale Wave Research Lab (HWRL), Oregon State University (OSU) / NNMREC

1:33 scale tests

Tsunami Wave Basin (TWB) - 48.8x26.5x2.1m

29 piston wavemakers

Max H = 0.8m | 0.5<T<10s

1:15 scale tests

Large Wave Flume (LWF) – 104x3.66x4.57m

1 piston wavemaker

Max H = 1.6m | 0.5<T<10s

In both cases the GH involvement comprised:

a) Development of the tank testing plan

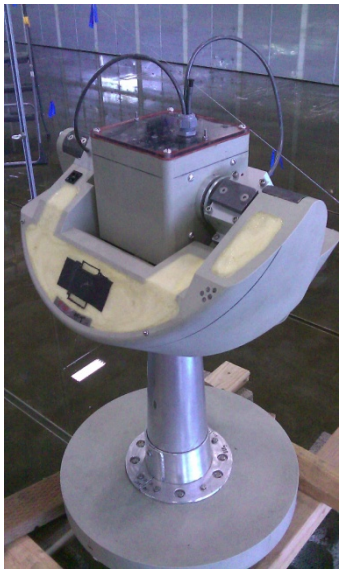
b) Onsite support during testing

Validation of Key Performance Indicators

Scale models: two different scales (Froude), same functionalities (see OMAE2010)

Regular wave testing: amplitude and frequency scans

Irregular wave testing: one shape (Bretschneider), multiple Hm0, T-10 pairs



Variable Monitored	Instruments Used
Body motions $$RAO_i = \frac{rms(\xi_i)}{rms(\eta)}$$	PhaseSpace Accelerometer (spar) Encoders (relative pitch between floats and spar)
PTO Torque	Torque sensor (one per PTO mode)
Mooring force	Strain gauges (one per mooring line)
Free-surface elevation	Conductivity wave gauges (eight positions)

Validation of Key Performance Indicators

Inputs

Regular waves

- Amplitude scan (3 H for 7 T)
- Frequency scan (1 H for 14 T)

Irregular waves

- Bretschneider
- Oregon (NBDC / NOAA)
- Orkney / Lewis (UK Marine Energy Atlas)

Dominant wave direction

- 0deg (i.e. head-on)
- 45deg

PTO damping settings

- Equivalent [17MNms @ full-scale]
- Optimal [fwd: 25.6MNms; aft: 6.12MNms]

Outputs

Calibration data

- Wave gauge and WEC sensors
- Reflection coefficient (TWB)

PTO torque

- Correlation between target and measured

Response Amplitude Operators (RAOs)

- Amplitude scan
- Frequency scan

Power absorption

- Relative capture width (RCW)
- $\overline{P}_{abs}$ under irregular waves

Validation of Key Performance Indicators

Outputs

Calibration data

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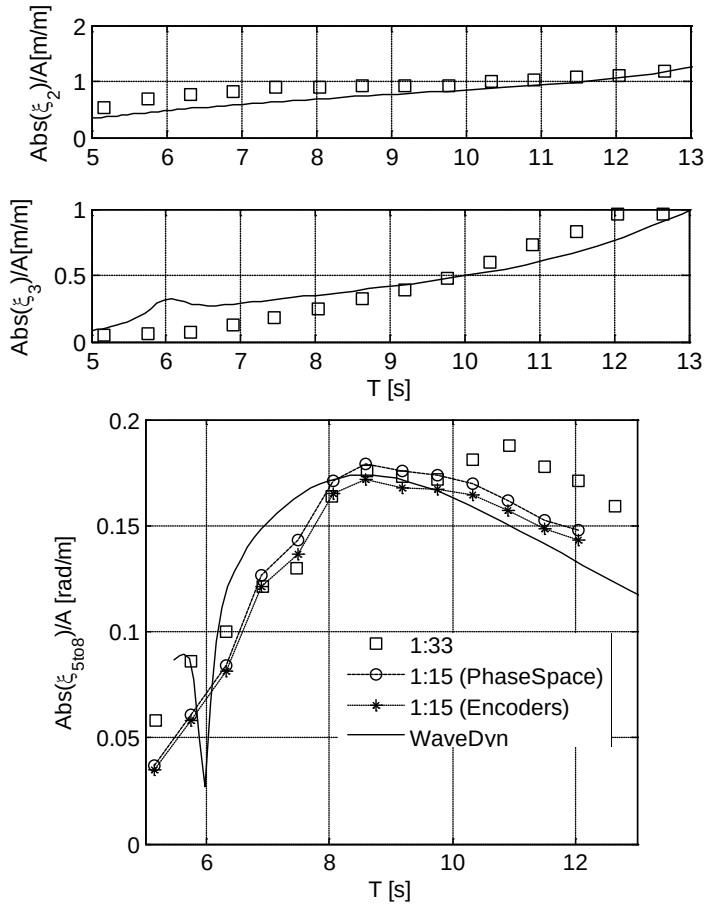


Comparison between numerical and experimental RAOs:
Top: 1:33 sway and heave (OP – Heading 45deg)
Bottom: fwd float relative pitch (EQ – Heading 0 deg)

Validation of Key Performance Indicators

Outputs

Calibration data

- Wave gauge and WEC sensors
- Reflection coefficient (TWB)

PTO torque

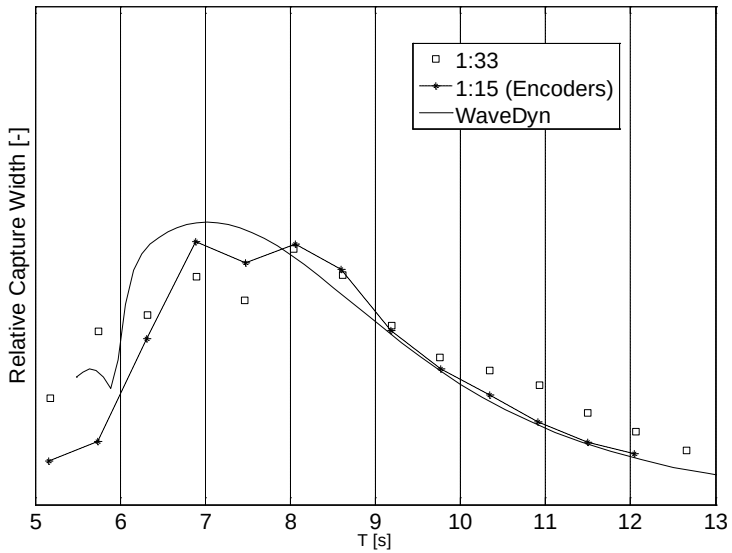
- Correlation between target and measured

Response Amplitude Operators (RAOs)

- Amplitude scan
- Frequency scan

Power absorption

- Relative capture width (RCW)
- $\overline{P}_{abs}$ under irregular waves



Comparison between numerical and experimental RCW
(Equivalent damping – Heading 0deg)
[RCW values removed for proprietary reasons]

Key Findings and Next Steps

A new multi-body, nonlinear equation of motion solver suitable for loads calculations exercises in WEC is introduced (WaveDyn)

Numerical simulations are compared with 1:33 and 1:15 scale model experiments conducted at OSU in 2009 and 2010

There is a strong correlation between WaveDyn estimates and experimental results

e.g. Irregular wave results show an average difference of 4.5% in Pabs

Relevant lessons regarding experimental uncertainty: scale effects and input data uncertainty

Use of 1:33 or 1:15 scale data can introduce significant differences (up to 12.7% in Pabs)

Use of measured S(f) is key – up to 28% difference in Pabs if target S(f) is used

Further work will address comparisons with a 1:7 scale mode deployed in Puget Sound (WA)

Thanks to Columbia Power Technologies for their input*

***The previous slides related to modeling of the CPT WEC were based on OMAE 2011 proceedings**

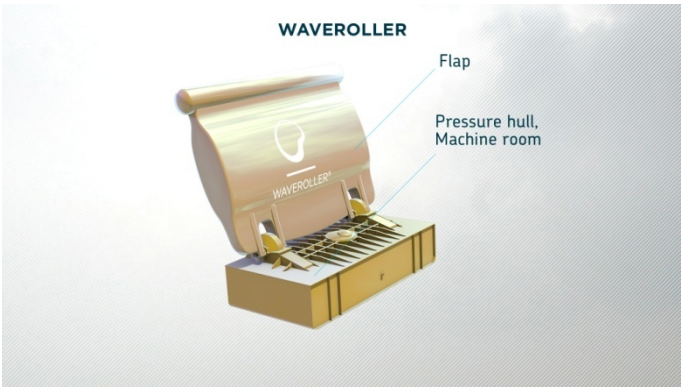
Design of AW-Energy's WaveRoller WEC

WAVEROLLER

Commercial scale design

Loads and performance model (WaveDyn)
- First and second-order hydrodynamics
- Linear and nonlinear PTO profiles
- PTO constraints: Max PTO torque
- Wave induced forces and power matrices

Pre-Commercial arrays (WaveFarmer)
- 5 WECs
- Layout and PTO optimisation
- Links to ongoing activities



WAVEROLLER

GL Garrad Hassan

GL

Some Closing Thoughts

- Designers need to be able to depend on design tools to inform decisions, without the need to continuously conduct new tests.
- “Learn-by-doing” has value, but an approach entirely dependent on it is especially costly when approaching commercial scale and dealing with difficult environments.
- Verification and validation need to be incorporated into the tool development process from the beginning, so reliable design tools are created.
- Think about ways to take measurements, and install instrumentation which can provide useful data for validation efforts.
- Developers should strive to collect data to validate whichever design tool they are using at an early stage, and continuously conduct checks throughout the development process.
- More complex and/or computationally intensive tools DO NOT necessarily mean more accurate or realistic results.

Further Information

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