WEC-SIM FY13 STATUS REPORT

FY13 Q4

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BACKGROUND AND MOTIVATION

Over the past few decades, numerical modeling tools have helped the wind turbine and offshore oil and gas industries achieve commercial viability by enabling the rapid development, analysis, and certification of system designs. The recent emergence of the Wave Energy Converter (WEC) industry in the U.S. and across the globe has created a need for WEC design and analysis tools that enable the advancement of WEC technologies. Currently wave energy developers are dependent on commercial codes to model WECs. These codes are expensive, and are not easily customizable because the source code is proprietary. Additionally, because WECs are very diverse in design, operating principles and energy conversion mechanisms, commercial codes are often limited in their ability to model the breadth of WEC designs. Providing an open-source tool will enable developers to easily modify the code to meet their specific modeling needs, and will reduce the cost burden that commercial codes place on developers. To meet this need, DOE has directed the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL) to initiate a code development and validation effort to produce a publicly available and open source WEC simulation capability to meet the needs of the marine hydrokinetic (MHK) community, including device manufacturers, project developers, government agencies, educational institutions, and non-government organizations. The overall objectives of this modeling effort are to:

- Develop WEC-Sim, an open-source time-domain computer aided engineering tool for the analysis and optimization of WECs at TRL 3-4. The code will be capable of running on a standard personal computer.
- Perform a rigorous verification and validation of the WEC-Sim capability. This will be done via code-to-code and experimental data comparisons.
- Leverage stand-alone numerical parametric models (e.g. frequency-domain) created as part of the Reference Model Project for preliminary WEC-Sim verification. This will provide physical insight and first-cut design capabilities to industry and the national labs for TRL 1-3.
- Utilize coding competitions and crowd sourcing to increase the pace of code development while simultaneously reducing costs. Preliminary plans are to develop an open-source boundary element code through a code competition using the TopCoder platform.

PROJECT STATUS

Year 1 of the WEC-Sim effort is on track; the SNL/NREL team has successfully completed its FY13 milestones and deliverables, an outline of which can be seen in Table 1. For a more detailed overview of the WEC-Sim project status, please refer to the Gantt chart uploaded to the WEC-Sim SharePoint site under the DOE Deliverables folder. The WEC-Sim team will continue to update this chart each quarter to track the project’s status.

The beginning of Year 1 consisted of SNL/NREL planning meetings and the labs’ submission of a comprehensive WEC-Sim Modeling Plan document to DOE HQ that outlined the Year 1 milestones as well as a path forward for future years on 1/15/13. This plan was reviewed by DOE HQ, revised by the labs and re-submitted on 3/15/13. As a result of questions regarding the initial modeling plan, DOE HQ requested more information on both WEC-Sim Verification and Validation, and an Extreme Events Modeling, resulting in jointly written SNL/NREL reports submitted to DOE HQ 1/15/13 and 5/15/13 respectively. Both of these documents resulted in new work scope for FY14, as the original WEC-Sim effort was only for an operational wave code with verification only.

The second half of Year 1 was primarily focused on WEC-Sim code development. SNL and NREL held two code development meetings, one at NREL and one at SNL, focused entirely on linking the WEC-Sim modules into one comprehensive code. Individual module development was initially tasked to specific labs; however there has been significant contribution on the part of both labs to modules not initially assigned to them. For example, Wave-Sim was initially developed by SNL, but was coupled with WAFO by NREL. Similarly, the 6DOF (Degree of Freedom) solver was initially developed by NREL, but SNL contributed significantly to its restructuring and interface. This kind of collaboration can be attributed to both the success of the code development meetings, and to the use of GitHub for WEC-Sim's development. The combination has allowed for transparency between the labs on the code development side, and time to regroup, determine project priorities and assign tasks on the project management side. During Q3 and Q4, the SNL/NREL team made significant headway on the development of WEC-Sim, resulting in one comprehensive code that has been used to model a point absorber WEC. Additionally, SNL submitted a report to DOE HQ on PTO-Sim, describing power conversion chains of interest, and the development of WEC-Sim was described during two 2013 GMREC conference presentations given by the WEC-Sim development team. The code competition to develop an open-source BEM solver was delayed to allow DOE and NASA COECI to initiate a contract. The contract was recently finalized and a kickoff meeting is being held with TopCoder, DOE, and NREL the week of September 22nd. The culmination of the Year 1 efforts will be presented to DOE HQ during a video conference, demonstrating WEC-Sim's current status and its application to modeling the RM3 point absorber WEC.

Table 1. WEC-Sim Year 1 Milestones and Deliverables

Q1 FY13	
COMPLETE: NREL and SNL meet to plan the WEC-Sim code development effort. Several meetings were held in Q1 to plan the development effort, the last of which was held at Sandia on December 20, 2012.	Tue 12/20/12
Q2 FY13	
COMPLETE: Deliver the modeling plan to DOE HQ	Tue 1/15/13
COMPLETE: Deliver the verification and validation plan to DOE HQ	Tue 1/15/13
COMPLETE: Deliver the extreme event modeling plan to DOE HQ	Sun 3/31/13
Q3 FY13	
COMPLETE: GMREC presentation describing the WEC-Sim development effort	Sun 3/10/13
COMPLETE: Deliver a report to DOE HQ describing relevant PTO technologies that PTO-Sim will model	Sun 6/30/13
COMPLETE: Post Wave-Sim code on GitHub	Sun 6/30/13
COMPLETE: Post HydroForce code on GitHub	Sun 6/30/13
Q4 FY13	
COMPLETE: Upload alpha version of WEC-Sim to SharePoint and hold a video conference to demonstrate the code's capabilities to DOE. This meeting will also be used to review WEC-Sim progress and plan the FY14 development effort	Mon 9/30/13
In Progress: Stage Gate: Evaluate the success of Competition 1 and determine if further competitions will be held	Delayed until FY14 due to difficulty setting up a contract between DOE and NASA/Harvard/COECI
FY14+ Milestones in AOP and Gantt Chart	

WEC-SIM MODULE DEVELOPMENT

As outlined in the modeling plan document, the WEC-Sim code is developed in a modular structure, allowing multiple developers to independently create physics or device component models, which combine to create a complete device simulation capability. As Figure 1 illustrates, WEC-Sim consists of pre-processing, time-domain simulation, and post-processing environments. Pre-processing modules are executed only once at the beginning of the simulation based on user inputs, and provide information needed by the simulation modules (e.g. hydrodynamic coefficients). Simulation modules model specific device components and are executed each time-step in the simulation to update forces and motions of the various components. Post-processing modules perform analysis and visualization of simulation results and are only executed after the simulation is complete. Details on the function of the different modules and coupling of the data inputs and outputs (I/O) between modules are shown in Figure 1 and Table 1. Additional physics and device component modules can be developed or modified, as necessary, to model complex or atypical WEC devices. The modules currently under development correspond to the ones contained within the orange box, including both the pre-processing modules and the time-domain simulation, but excluding the user inputs and post-processing modules. In the following subsections, the development of each of the WEC-Sim modules will be described.

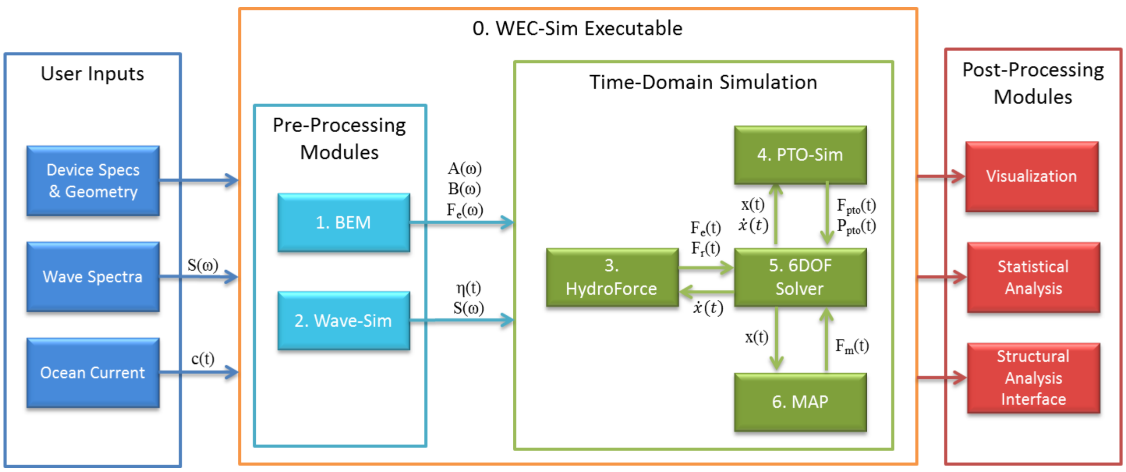


Figure 1. Schematic of the WEC-Sim code structure

Table 2. WEC-Sim module I/Os

Variable	Description	[units]
η(t)	Time-series wave surface elevation	[m]
c(t)	Time-series ocean current speed	[m/s]
S(ω)	Frequency-dependent wave spectra	[m^2/Hz]
A(ω)	Frequency-domain added mass	[kg]
B(ω)	Frequency-domain radiation damping	[Ns/m]
$F_e(\omega)$	Frequency-domain wave excitation (per η)	[N/m]
$F_e(t)$	Time-domain wave excitation force	[N]
$F_r(t)$	Time-domain wave radiation force	[N]
$x(t)$	WEC displacement	[m]
$\dot{x}(t)$	WEC velocity	[m/s]
$F_m(t)$	Time-domain mooring force	[N]
$F_{pto}(t)$	Time-domain PTO force	[N]
$P_{pto}(t)$	Time-domain PTO Power	[Nm/s]

0. WEC-SIM EXECUTABLE

In order to run the current version of the WEC-Sim executable, the user must have the following programs installed on their PC: MATLAB 2013a (v8.1), SIMULINK (v8.1), SimMechanics (v.4.2), and SimScape (v3.9). The version of MathWorks is important for the correct hydrodynamic forcing calculations; this is due to updates MathWorks made between 2012 and 2013. In order for the SimMechanics visualizations to load properly, the user install Windows SDK 7.1 compiler. A tutorial on how to install Windows SDK 7.1 is available on the MathWorks website at http://www.mathworks.com/support/solutions/en/data/1-FPLDGV/.

The WEC-Sim executable has been developed as a MATLAB script that runs all of the individual WEC-Sim modules, linking them to one another at every time step. The executable file is located on the top level of the WEC-Sim GitHub repository, titled 'WEC_Sim.m'. The executable file specifies all of the file paths, imports the hydrodynamic coefficients, initializes the model by specifying time-step and simulation length, and runs the simulation by calling on the different modules and running the Simulink model, 'WEC_Sim_Driver.slx', as shown in Figure 2.

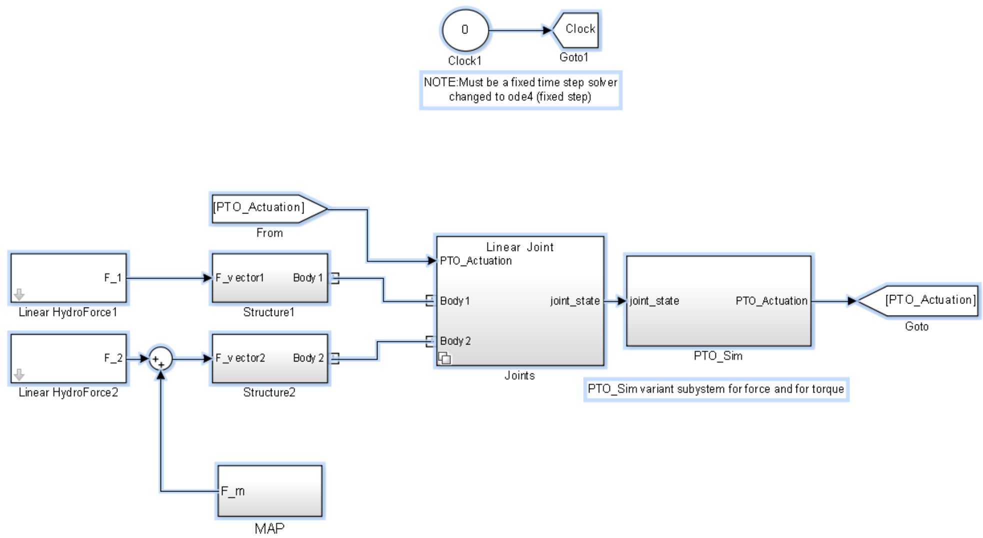


Figure 2. Top level of WEC_Sim_Driver.slx showing module coupling

1. BEM

Currently WEC-Sim uses the BEM code WAMIT, a commercial Boundary Element Method solver that is available for monthly, yearly and permanent user licensing, http://www.wamit.com/index.htm. In its current state, WEC-Sim is imports and processes WAMIT output files to extract the necessary hydrodynamic coefficients, A(ω), B(ω) and F_e(ω), to its run simulations. In the future, WAMIT will be replaced by OpenBEM, an open source BEM code that will be developed via a code competition run by TopCoder.

2. WAVE-SIM

Wave-Sim is the module that generates the wave input for WEC-Sim. Depending on how WEC-Sim is run, Wave-Sim either feeds the Time-Domain Simulation, outlined by a green box in Figure 1, a wave surface elevation time series, η(t), or frequency-dependent wave spectra, S(ω). The module was jointly developed by SNL and NREL. SNL developed a series of MATLAB scripts that generate and imports wave spectra, and both regular and irregular wave time-series based on NDBC/CDIP buoy data, or user defined wave fields, characterized by H_s and T_p. These scripts process wave data and interpolate between data points to format the wave data appropriately for the Time-Domain Simulation. NREL then linked the scripts developed by SNL with the open source code WAFO. By linking with WAFO, Wave-Sim now has the ability to generate many different spectral shapes commonly used to characterize wave climates, such as: JONSWAP, Pierson-Moskowitz, and Bretschneider. This allows the user the flexibility to run WEC-Sim with whatever operational wave cases they are interested in, and can even import their own time-series from wave tank data for validation. An example of the kind of wave information passed from Wave-Sim to the Time-Domain Simulation is shown in Figure 3.

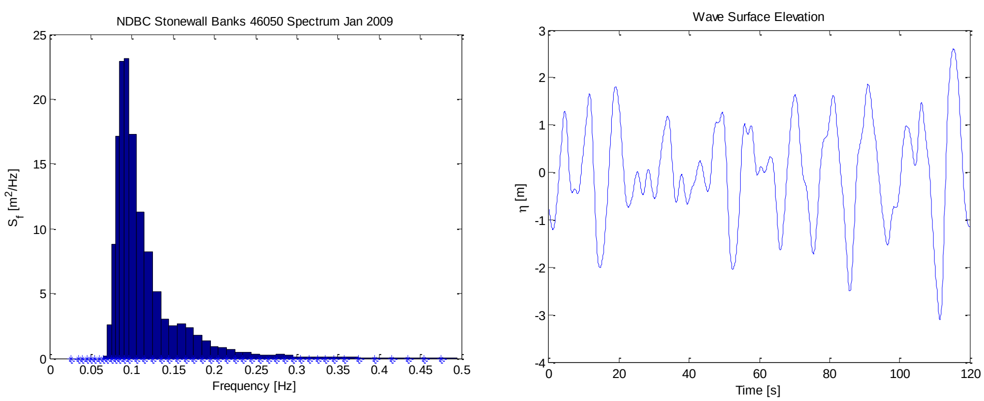


Figure 3. Wave-Sim data fed to the Time-Domain Simulation

3. HYDROFORCE

Hydroforce is the module for calculating the hydrodynamic wave forces based on results from WAMIT. The module is being developed by NREL and includes two parts. The first part contains a set of MATLAB subroutines that are used for gathering all the hydrodynamic coefficients and wave diffraction and excitation forces from WAMIT and generating the necessary force history for the time-domain system dynamics simulations. These subroutines are called in the “WEC-Sim.m” file, prior to the time-domain simulations. The second part (as shown in Figure 4) is a module that takes all the pre-calculated hydrodynamic coefficients and force histories and imports these values into the time-domain module. The current version of the HYDROFORCE module calculates the hydrodynamic restoring forces and wave excitation forces based on linear theory. A more advanced feature will be included in FY14, which calculates these two forces based on the instantaneous water surface. This feature will be important for modeling more complex wave energy designs such as Columbia Power Technology’s SeaRay and StingRay, which have multiple bodies and convert wave energy based on multiple modes of motion.

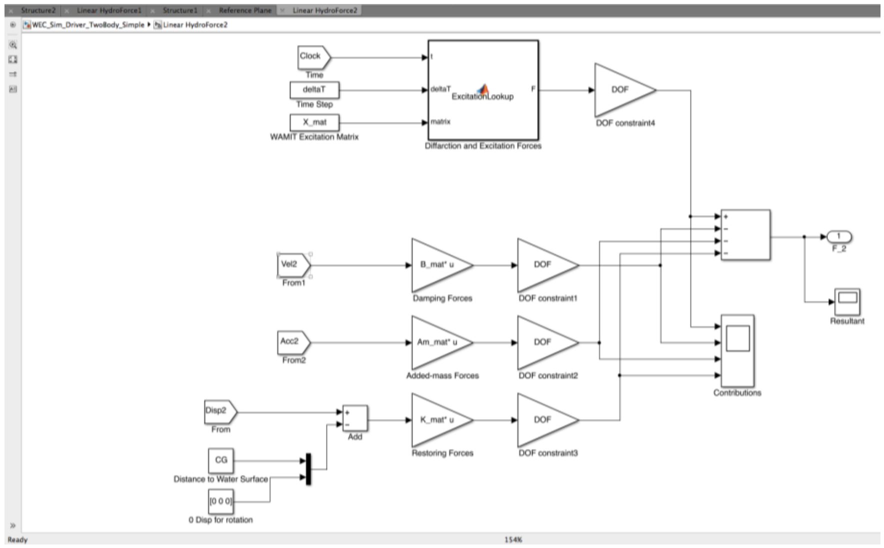


Figure 4. HYDROFORCE module for feeding data into the time-domain simulation

4. PTO-SIM

PTO-Sim is the module that takes the mechanical motion of the WEC and converts that motion into usable power. This is accomplished by modeling the power take-off (PTO) system, also referred to as the power conversion chain (PCC). Before determining the different PCCs to model, SNL evaluated different PCCs currently implemented by industry to determine which topologies would be most beneficial to both the WEC-Sim project and industry. Based on this assessment, SNL determined that nearly all WECs use one of the following energy conversion mechanisms: relative linear motion, relative rotary motion, or fluid capture. Once the WECs are categorized according to their energy conversion mechanism, there are many different paths developers can take to convert wave motion into electrical power, as shown in Figure 5. While most developers are pursuing a hydraulic drivetrain, more recently there is a trend of developers switching to mechanical drivetrains due to their relative simplicity and typically higher efficiency. Hence, it was determined that PTO-Sim should be able to model relative linear motion and relative rotary motion, each with both hydraulic and mechanical drivetrains. Fluid capture PTOs were omitted from the scope of PTO-Sim because of the large disparity between these devices and the rest of the WECs. For more detailed information on the results of this study, please refer to the FY13 Q3 PTO-Sim Report that is uploaded to the WEC-Sim SharePoint site.

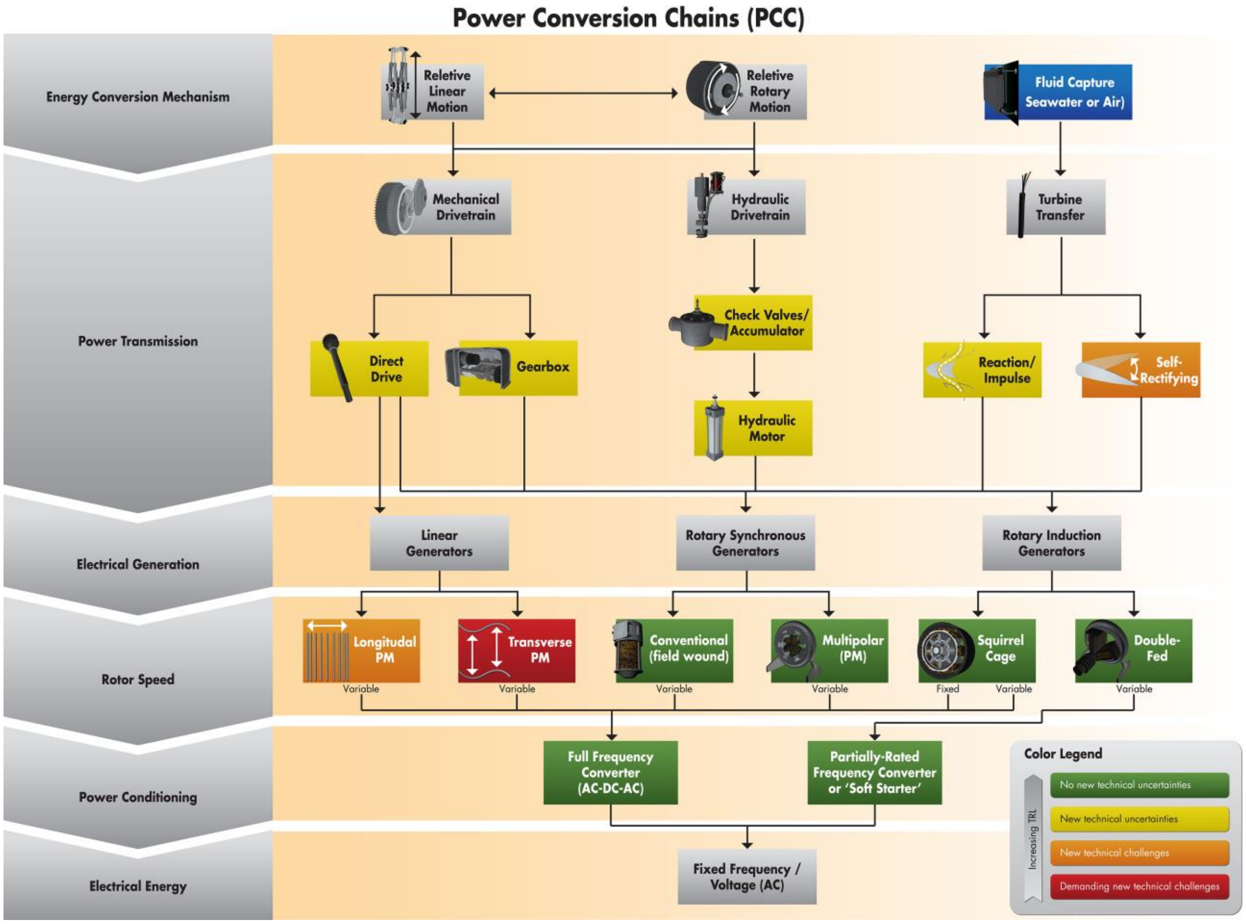


Figure 5. Power conversion chains from mechanical energy to electrical grid connection.

PTO-Sim currently models different PCCs by utilizing variant subsystems in SIMULINK, which allow for multiple implementations of a subsystem where only one implementation is active during the simulation. The PTO-Sim subsystem used in the simulation is specified in the WEC-Sim executable file, 'WEC_Sim.m'. This allows the user to change which subsystem is active in the executable file without having to change the Simulink model file, 'WEC_Sim_Driver.slx'. PTO-Sim's implementation of variant subsystems is shown on the top level of the PTO-Sim module, as shown on the left side of Figure 6, where both the Drivetrain and the Electricity_Generation blocks are variant subsystems with different possible configurations. The right side of Figure 6 shows what the Drivetrain variant subsystem looks like with the Direct-Drive system turned on and the Hydraulics model turned off. Similarly, the Electricity_Generation variant subsystem has 3 possible configurations, corresponding to Spring_Damper, Damper, and Thev_equiv electric generator models. By utilizing variant subsystems in PTO-Sim, the user has the ability to model many different PCCs without having to change the Simulink model file. This structure gives PTO-Sim flexibility, and provides the user the ability to develop and customize their own variant subsystems, and add them to PTO-Sim without negatively impacting existing subsystems. For the current version of WEC-Sim, only the simplest form of PTO-Sim is implemented, a simple spring-damper system. However due to the complexity of developing a PCC model, PTO-Sim development is ongoing and preliminary models of both direct drive and hydraulic systems have been developed. The models can be used for both relative linear and relative rotatory motion, depending on what joint type is specified on the top level of WEC-Sim, as shown in Figure 2.

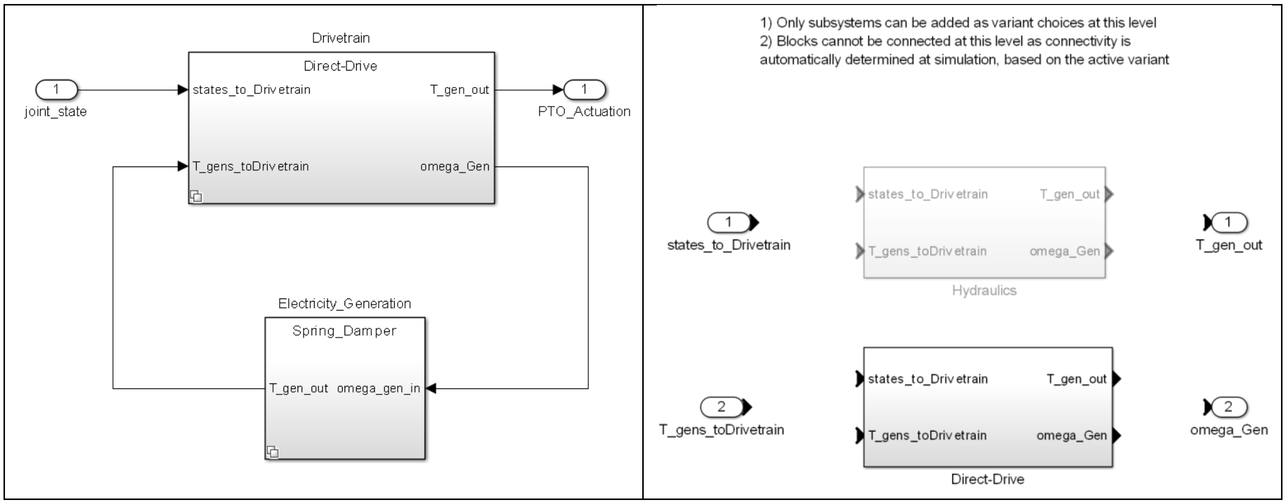


Figure 6. Left: PTO-Sim top level with Drivetrain and Electrivy_Generation variaent subsystems Right: Drivetrain varient subsystem with Direct-Drive subsystem turned on

5. 6DOF SOLVER

The 6DOF Solver simulates the WEC motion by solving the governing time-domain equations of motion at each time-step, and applying external forcing due to the waves, mooring system and PTO system. WEC-Sim's 6DOF solver is SimMechanics, a set of rigid bodies, joints, and connections defined within SIMULINK that define and constrain the device motion. SimMechanics allows the user to import a 3D CAD geometry file, specify its mass and moment of inertia properties, and solves for the resulting device motion. An added benefit of SimMechanics, is its visual interface, which allows the user to see the simulated device motion in the Mechanics Explorer, as shown in Figure 7.

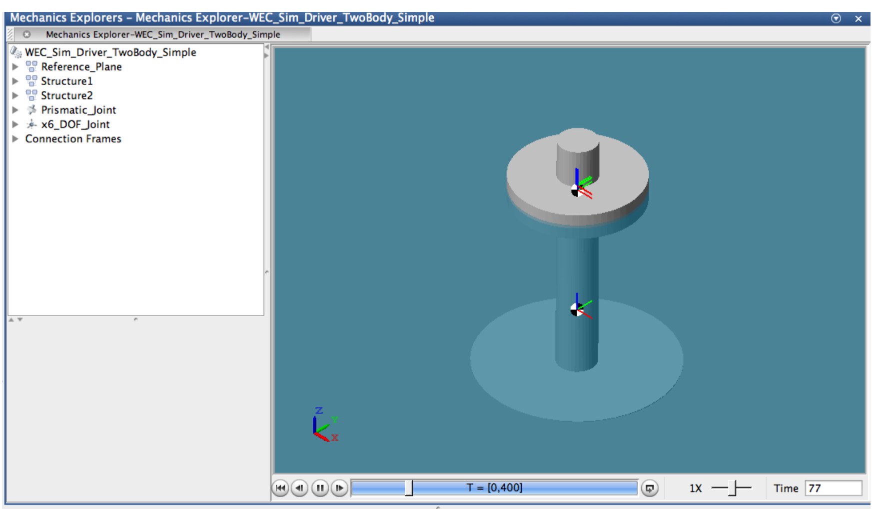


Figure 7. SimMechanics simulation with imported the RM3 3D CAD geometry

6. MAP

MAP, the Mooring Analysis Program, is the WEC-Sim module that takes the mechanical motion of the WEC, calculates the mooring loads, and applies them to the WEC. MAP is coupled to FAST v8, has been verified against FAST v7.2, and is interoperable with the Python language as a standalone design/simulation tool (Figure 8). A C/C++ and Fortran binding library has been integrated into the MAP source code to give users the option to call MAP from codes written in Fortran. This feature is supported by multiple compilers and works on different operating systems. Though the primary intention for MAP is for it to be used as a simulation tool, MAP can also output a linearized stiffness matrix about an operating equilibrium point. This feature was implemented based on the initial development needs of WEC-Sim. As more advanced features are added into WEC-Sim, the linearized stiffness matrix mooring line representation will be replaced with direct calls to MAP at each time-step to generate the nonlinear restoring force coefficients. A paper summarizing the work was given at the ISOPE 2013 conference in July. The MAP source code and user manual will be made public with the release of FAST on October 3, 2013. Efforts will continue into FY2014 to improve the accuracy and refinement of the solution strategy in MAP with offshore wind funds.

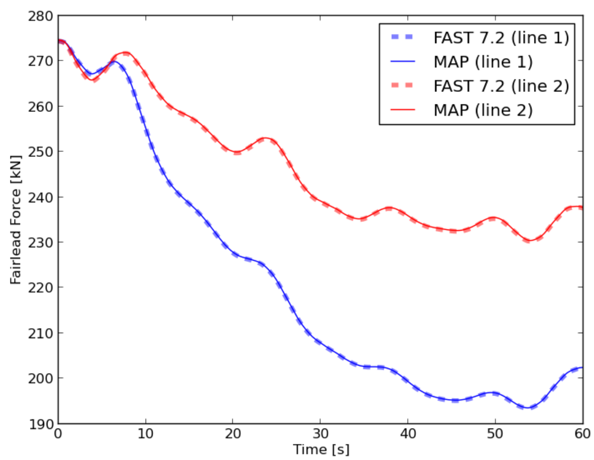


Figure 8: Results comparing FAST v7.2 with MAP driven by a Python script.

WEC-SIM DEMO

GEOMETRY DEFINITION

The Reference Model 3 (RM3) device, a two-body heaving point absorber design, was chosen as the first application of WEC-Sim. While the WEC is free to move in all 6DOF in response to wave motion, power is only captured in the heave direction. The RM3 device was chosen to leverage a prior DOE funded project, and because the design has already been well characterized both numerically and experimentally as a result of the reference model project, it has relatively simple operating principles, and is representative of WECs currently pursued by the wave energy industry. It is a simple heaving two-body point absorber, consisting of a float and a spar-plate, the full-scale dimensions and mass properties of which are shown in Figure 9 and Table 3. It should be noted that there are several different versions of the RM3 geometry, due to its iterative design process. This RM3 geometry was chosen because it is the full-scale version of the 1:33 Froude scale device tested at Scripps Institute of

Oceanography in San Diego from November 30th – December 2nd 2011. Accordingly, simulations of the RM3 geometry defined below performed by WEC-Sim and other WEC modeling codes (WaveDyn and AQWA) can be directly compared to experimental data obtained through the reference model project.

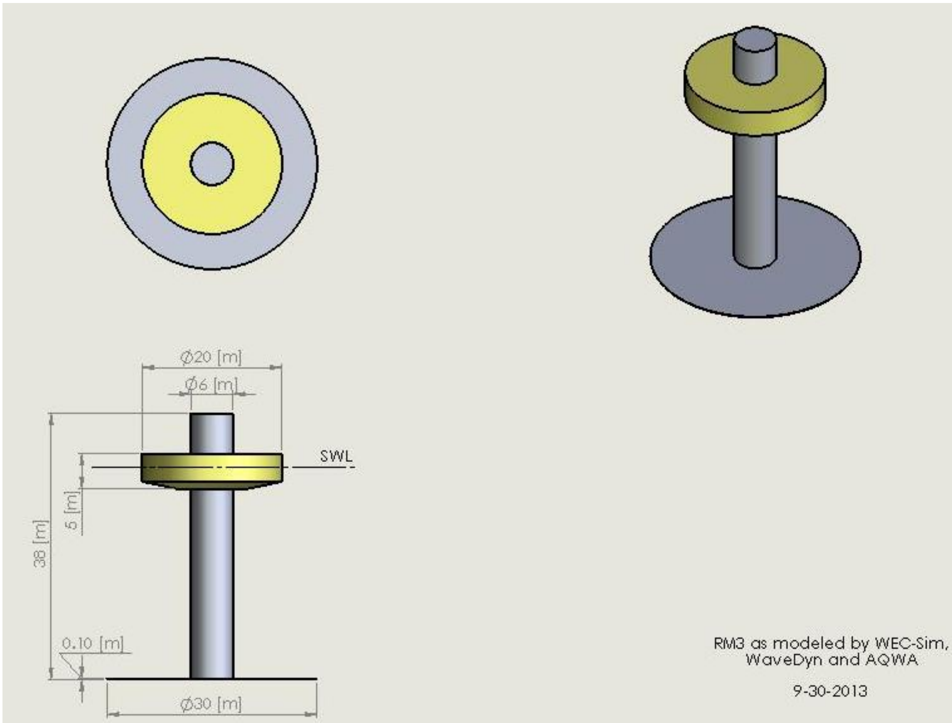


Figure 9. RM3 Heaving Two-Body Point Absorber Full-Scale Dimensions

Table 3. RM3 Heaving Two-Body Point Absorber Full-Scale Mass Properties

Float Full Scale Properties				
CG [m]	Mass [tonne]	Moment of Inertia [kg-m^2]		
0	727.01	20907301	0	0
0		0	21306090.7	4304.89323
-0.72105		0	4304.89323	37085481.1
Spar-Plate Full Scale Properties				
CG [m]	Mass [tonne]	Moment of Inertia [kg-m^2]		
0	878.30	94419614.6	0	0
0		0	94407091.2	217592.785
-21.285		0	217592.785	28542224.8

SIMULATION PARAMETERS

In addition to the device geometry, it is important to define the simulation parameters. These should be representative of the RM3 1:33 experimental setup, shown in Figure 10, and must be the same for all simulations. The full-scale water depth, h = 1.5 [m]*33 = 49.5 [m], and the fluid density is that of water, ρ = 1000 [kg/m^3] (not that of salt water).

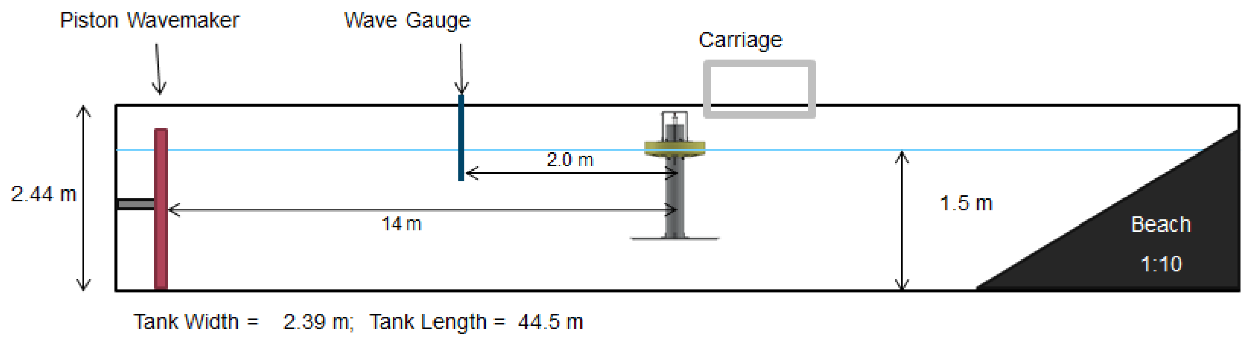


Figure 10. RM3 1:33 Scale Wave Tank Setup

Initial RM3 simulations were run for a representative regular operational wave, of a constant wave height, H = 2.5 [m], and for wave periods, T = 8 [s] and 12 [s]. Future RM3 simulations will include a wave period sweep and irregular operational waves, based on wave time-series directly from NDBC/CDIP data buoys, or generated from wave spectra.

PRELIMINARY WEC-SIM VERIFICATION

In order to verify the alpha version of WEC-Sim's functionality, a preliminary code-to-code comparison was performed, where the RM3 point absorber described above was simulated in WEC-Sim, and compared to simulation of the same device using the commercial codes WaveDyn (Garrad Hassan) , AQWA (ANSYS) and OrcaFlex (Orcina). The RM3 point absorber was first modeled with 1DOF (heave only) in WEC-Sim, WaveDyn and AQWA. Then, the RM3 point absorber was model with 3DOF (heave, pitch and surge) in WEC-Sim and OrcaFlex. In the following subsections, results from the code-to-code comparison for both the 1DOF and 3DOF simulations are shown. While WEC-Sim verification of a point absorber is not due until FY14 Q1, the results shown in this report demonstrate initial efforts towards meeting this milestone. It should be noted that since this is a preliminary comparison, there are some discrepancies between the results (which have been noted).

1DOF CODE-TO-CODE COMPARISON

The first verification effort for WEC-Sim was performed by modeling the RM3 point absorber in 1DOF (heave only) using the alpha version of SNL/NREL developed code WEC-Sim, and comparing its results to the commercial codes WaveDyn and AQWA. All three codes were run for regular waves with T = 8 [s] and H = 2.5 [m], where the WEC motion was restricted to heave motion only, and did not include any motion due to coupled DOFs. Results from the 1DOF code-to-code comparison with no PTO damping are shown in Figure 11, and for PTO damping = 1200 [kN-s/m] in Figure 12. The left side of both figures shows the full 400 [s] time-series, and the right side shows the same figure zoomed in for the last 100 [s]. The full time-series shows the overall trends in the WEC heave response, and shows the different ramping functions for each of the models. WaveDyn uses a simple linear ramping function, whereas WEC-Sim uses a hyperbolic tangent function, and AQWA uses a $\sin^2$ function.

Results from the regular wave simulation without PTO damping for the float response, shown in Figure 11 have very good agreement in terms of both the amplitude and phase, especially between WaveDyn and WEC-Sim where the results are almost indistinguishable. However, while the AQWA solution also has good amplitude and phase agreement, there is an offset in its steady state equilibrium position of about 0.2 [m] from the still water line (SWL). This discrepancy is possibly due to a difference in the float's defined mass or its SWL which requires further investigation. Although not shown, the spar/plate AQWA response is also a source of error, with significant differences in both the response magnitude and phase. These issues will be addressed in the FY14 Q1 milestone.

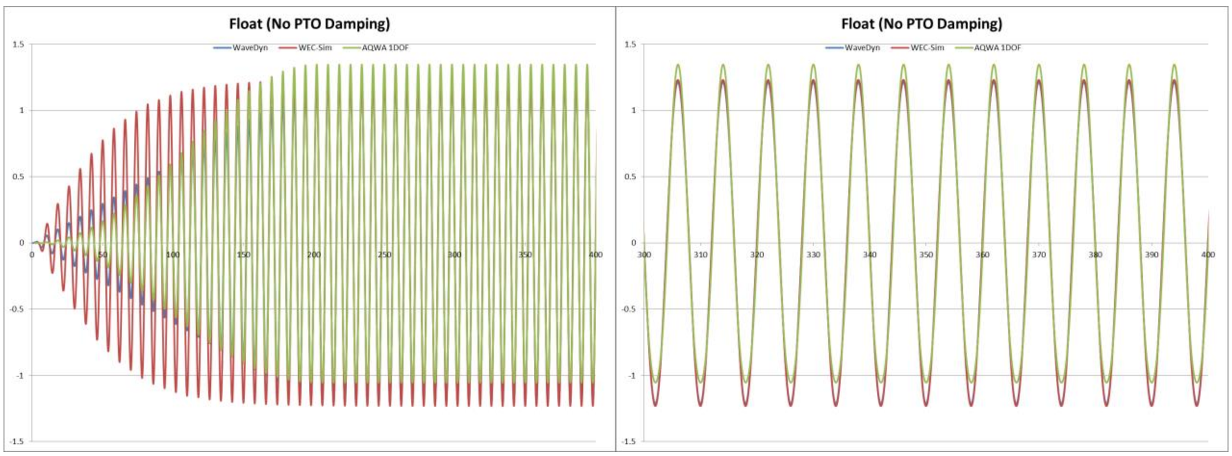


Figure 11. RM3 float heave response from WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 0 [kN-s/m] for the full time series (left) and zoomed in for the last 100 [s] (right)

Results from the regular wave simulation with PTO damping = 1200 [kN-s/m] for the float response, shown in Figure 12 have good agreement in terms of both the amplitude and phase. For this case, the WEC-Sim and WaveDyn solutions are still very similar, with a very slight difference in magnitude, on the order of 0.04 [m]. However, the AQWA solution's magnitude differs more substantially, on the order of 0.2 [m], and has the same offset in its steady state equilibrium position from the SWL and issue with the spar/plate solution. These discrepancies will be addressed in the FY14 Q1 milestone. Overall the WEC-Sim team is very pleased with the preliminary results from the code-to-code comparison for the 1DOF RM3 device, and views this effort as significant progress in the overall code development effort.

The very slight discrepancy between the WaveDyn and WEC-Sim results may be explained by the fact that WaveDyn includes additional hydrodynamic terms in the equation of motion that represent the interaction between multiple bodies (e.g., added mass term from other body). The effect of these terms was small for the two-body point absorber, as expected, since the plate was deep in the water and far away from the float. Nevertheless, these additional terms could be important when modeling multiple-body WEC designs (e.g., CPT's SeaRay and StingRay designs), where different bodies are placed close to each other.

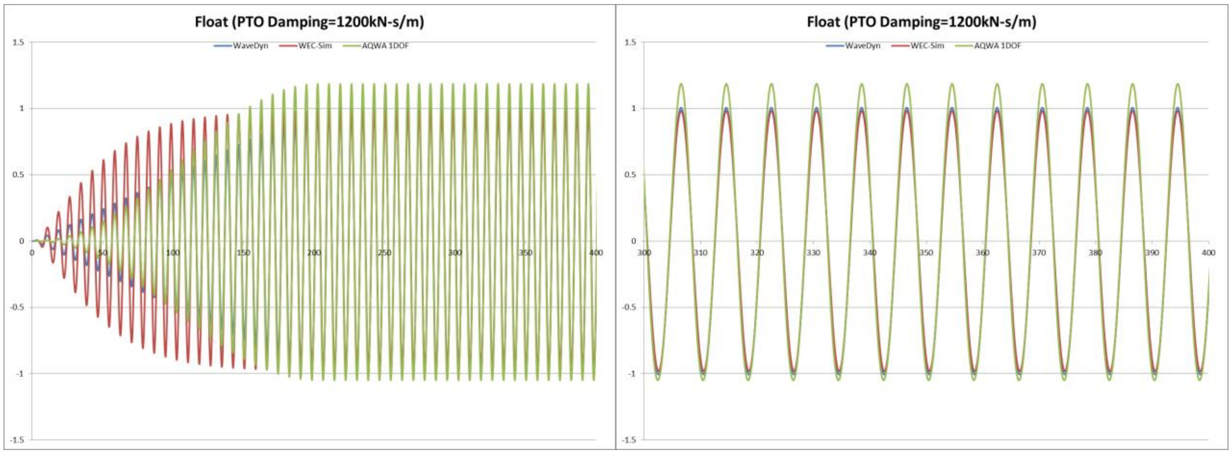


Figure 12. RM3 float heave response from WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 1200 [kN-s/m] PTO damping for the full time series (left) and zoomed in for the last 100 [s] (right)

3DOF CODE-TO-CODE COMPARISON

To further verify WEC-Sim, the WEC-Sim team also performed simulations in 3DOF, where the device was allowed to move freely in heave, surge and pitch. The simulation from the alpha version of WEC-Sim was compared to results from OrcaFlex. In the OrcaFlex simulation, the float and the spar/plate were modeled as two separate vessels connected with a spring-damper link, which contained infinite bending stiffness so that the float was only allowed to move along the spar. Because OrcaFlex only accepts single body WAMIT hydrodynamic coefficients for each body, the WEC-Sim code was modified so that the two codes used exactly the same WAMIT hydrodynamic coefficients and simulate the problem in exactly the same way.

The analysis was conducted with regular waves, for wave height, H = 2.5 [m], and for wave periods, T = 8 [s] and 12 [s]. The time history of the device pitch response and the relative motion between the float and the spar/plate obtained from WEC-Sim and OrcaFlex were compared, results of which are plotted in Figure 13 and Figure 14. A half cosine ramp function, which was similar to the one used in OrcaFlex was applied in WEC-Sim to slowly start the simulations in order to minimize the transient response. Results from WEC-Sim 3DOF simulation agreed very well with those obtained from OrcaFlex.

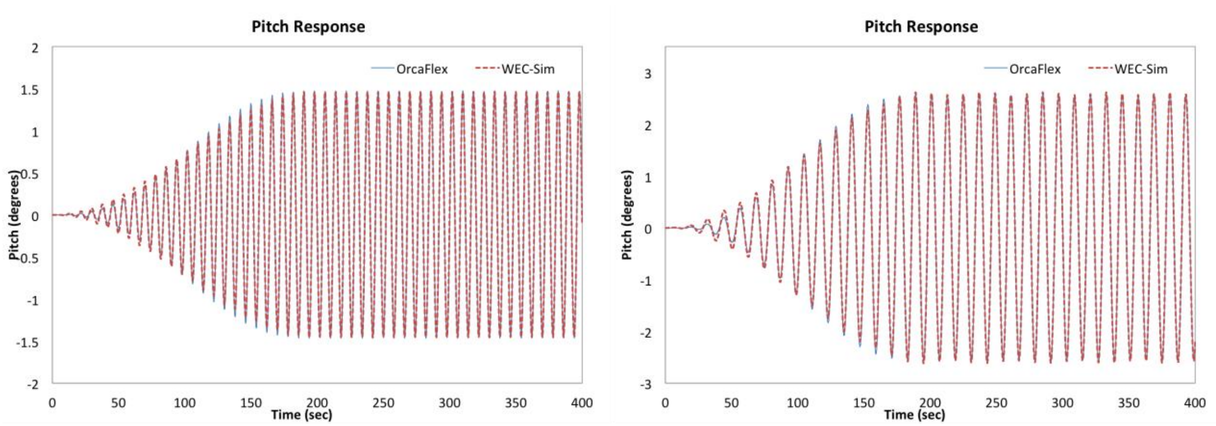
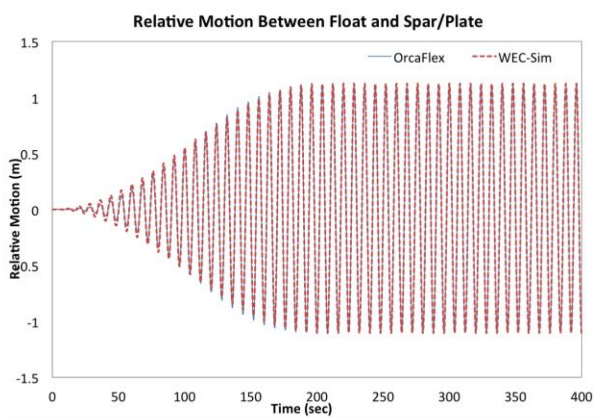


Figure 13. RM3 float pitch response from WEC-Sim and OrcaFlex with incoming wave period, T = 8 [s] (left) and 12 [s] (right)



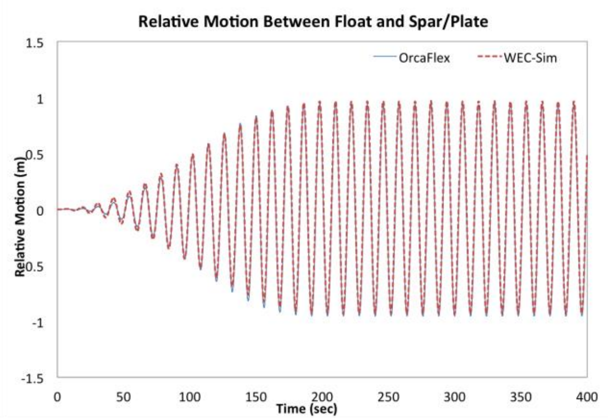


Figure 14. Device relative heave motion between the float and the spar/plate from WEC-Sim and OrcaFlex with incoming wave period, T = 8 [s] (left) and 12 [s] (right)

In the simulation, mooring connections were not incorporated to constrain the device surge motion. No restoring stiffness or additional damping term was implemented in the surge equation of motion, except surge radiation damping, which was insignificant. Therefore, the device can drift in surge even if the system is subject to monochromatic forces. Generally, the drift is induced by the numerical algorithm and depends on what ramp function and numerical integration schemes are applied. OrcaFlex and WEC-Sim use different time integration schemes, have different methods for handling radiation terms in transition and probably use different matrix solvers. As a result, the device was predicted to drift 2 [m] in WEC-Sim and only 0.03 [m] in OrcaFlex when forced by T=8 [s] waves. Overall the WEC-Sim team is very pleased with the 3DOF code-to-code comparison results for the RM3 device. Further code-to code verification study will be continued in FY14.

LIMITATIONS OF COMMERCIAL WEC MODLEING CODES

As discussed above, the WEC-Sim team has tested the commercial modeling codes WaveDyn, AQWA, and OrcaFlex. While all of these codes provide basic modeling capability needed to simulate WEC's, each code has limitations that preclude turn-key modeling of WEC devices. The remainder of this section reviews WaveDyn, AQWA, and OrcaFlex and discusses their limitations and nuances.

AQWA

AQWA was not originally developed to model WECs, its intended application was naval architecture and offshore oil and gas, thus AQWA has issues generating a sufficient mesh for complex geometries due to its limited number of diffracting and non-diffracting elements. Additionally, there are also several flags specified in the AQWA input file that can keep the program from converging to a solution, and with AQWA's limited help files and user group, it can be difficult to determine what is causing the error. An AQWA limitation, relevant for the RM3 design, is that it only allows for definition of rotational joints (hinge, ball and socket, universal and rigid), and does not allow definition of translational joints. This makes applying a PTO force between two bodies with relative linear motion difficult, and requires the user to write an external function applying PTO forcing.

WAVEDYN

WaveDyn was developed specifically to model WEC devices and is therefore relatively straight forward to set up and run. The bottom line is that WaveDyn is developed for modeling WECs, but is still in the development process. The currently released version still uses the linear hydrodynamic restoring and excitation model and the robustness of the code, such as the time integration scheme and the use of ramp function, need to be improved so that the simulation will be more stable, particularly when rotational motion is considered.

Moreover, WaveDyn is at a very early stage of development. In fact, it appears that NREL is one of the first commercial users of the code and has found several bugs in the code (e.g. a broken mooring line module) and features that were not sufficiently documented. NREL has worked with the WaveDyn code developer (GL-GH) to address these issues and the result has been an improved WaveDyn code. Nevertheless, a significant amount of improvement to WaveDyn is needed before it is a turn-key commercial product. Specifically, non-linear buoyancy and excitation capabilities are needed, a viscous damping model must be developed, and better documentation and tutorials are needed. GH-GH is working hard to make these improvements and some of these issues will be addressed in the next release of WaveDyn, which is scheduled for early 2014.

ORCAFLEX

OrcaFlex is code developed for modeling the fluid/wave and structure interaction. It has widely been used for modeling the dynamics of offshore systems, such as offshore supply vessels and offshore platforms. OrcaFlex has a strong mooring capability and robust numerical integration algorithm. However, the code was not developed for modeling WECs, particularly multi-body designs. OrcaFlex only accepts single body WAMIT hydrodynamic coefficients for each body. As a result, users have to run a WAMIT run for each body, and the effect of the interaction between different bodies on the hydrodynamic coefficients is neglected. Technically, this can be avoided if users write their own functions to import correct hydrodynamic coefficients for each body from a single multiple-body WAMIT run or manually insert the correct values. However, this makes using OrcaFlex to model WECs more difficult.

CONCLUSIONS AND FUTURE WORK

The WEC-Sim effort is currently on track. The SNL/NREL WEC-Sim team has met all of their Year 1 milestones, as shown in the Gantt chart uploaded to the WEC-Sim SharePoint site under the DOE Deliverables folder. During year one, the WEC-Sim team has clearly defined the project objectives and timeline, developed an alpha version of WEC-Sim, applied it to model a two-body point absorber WEC, and performed preliminary comparison to both experimental and numerical models. In the past year, WEC-Sim has been presented at three technical conferences with a wave energy focus: GMREC 2013, ISOPE 2013, and EWTEC 2013; resulting in 2 oral presentations, 1 poster presentation and 2 publications. As a result, the WEC-Sim effort has gained attention from both industry and academia, allowing the WEC-Sim team to develop key partnerships for WEC-Sim's future development and application. The WEC-Sim team has been contacted by wave energy developers who would like to use WEC-Sim to model their device, including Columbia Power Technologies, Northwest Energy Innovations, and Ecomerit. While the two devices modeled by WEC-Sim in FY14 are still to be determined, the decision will be made based on the technical complexity of the device, access to numerical and experimental data, and fundamental operating principles of the device. It is important that the devices modeled by WEC-Sim span the WEC design space, in order to demonstrate the code's ability to model a wide range of devices.

The main objective of the WEC-Sim project is to develop an open-source time-domain computer aided engineering tool for the analysis and optimization of WECs at TRL 3-4 capable of running on a standard personal computer. While WEC-Sim is an open-source code, currently it relies on commercial codes to run, some of which have associated license fees, outlined in Table 4. The current cost of WEC-Sim is approximately $32k, including $12k yearly fees for the Matlab, Simulink and SimMechanics interface and a one-time fee of $20k for the BEM code WAMIT. The WEC-Sim team plans to develop an open-source boundary element code, OpenBEM, through a code competition using the TopCoder platform. This will reduce WEC-Sim's cost burden on users by approximately $20k in FY14. For comparison, commercial codes with similar modeling capabilities have the following costs: AQWA is $40k/year and WaveDyn which was released Oct 2012 is approximately $40k/year.

Table 4. WEC-Sim Present and Estimated Future Cost

FY 13 Cost		**Estimated FY14 Cost**	
Matlab/Simulink	$8k/year	Matlab/Simulink	$8k/year
SimScape/SimMechanics	$4k/year	SimScape/SimMechanics	$4k/year
WAMIT	$20k/site	OpenBEM	free
Total	$12k/year + $20k	**Total**	$12k/year

During FY14, the WEC-Sim team will continue development of WEC-Sim, model two more WECs, perform verification of the code by code-to-code comparison, and draft a validation test plan. Whenever possible, the WEC-Sim team will leverage existing data sets and other DOE funded wave tank experiments for the WEC-Sim validation effort. The details of the FY14 and future tasks are outlined in the Gantt Chart, and each lab's FY14 quarterly milestones are defined in the lab's AOP.