

# Hydrodynamics Of Wave Energy Converters

April 3-7, 2017

BCAM-Basque Center for Applied Mathematics

Mazarredo 14, Bilbao, Basque Country, Spain

<http://www.bcamath.org/es/workshops/hywec2017> Contact: [mario.ricchiuto@inria.fr](mailto:mario.ricchiuto@inria.fr)

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**Yanlin SHAO**, Technical University of Denmark (Lyngby, Denmark)

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**Yi-Hsiang YU**, NREL-National Renewable Energy Laboratory (Colorado, USA)

**Iñaki ZABALA**, SENER, (Bizkaia, Basque Country, Spain)

## Aim:

### 1. Focus on numerical modelling techniques. We will have talks on advanced and recent approaches including

- Depth averaged/Boussinesq type approximation and models
- Potential and Euler models
- Full CFD simulations

### 2. Give an overview of examples of industrial techniques and applications with several European industrial actors

#### Scientific Committee:

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# Hydrodynamics of wave energy converters

## BCAM, 03 - 07 April 2017

### PROGRAM

Day	Time	
03 April 2017	14:45	Welcome and opening of the workshop
	15:00-15:30	General purpose conference (e.g. presentation of European school on wave energy by J.M. Blanco)
	15:30-16:30	PLENARY 1: <b>Jesús María Blanco</b> Development and application of innovative algorithms associated to the hydro-dynamic coastal model: validation and optimization of computational tools through laboratory tests.
	16:30	Welcome Cocktail
04 April 2017	09:30-10:30	PLENARY 2: <b>Malin Goteman</b> Modelling of wave energy parks
	10:30-11:00	Coffee Break
	11:00-12:00	PLENARY 3: <b>Raul Guanche García</b> On the importance of calibration and validation procedures: hybrid modeling
	12:00-15:00	Lunch
	15:00-16:00	PLENARY 4: <b>Peter Stansby</b> SPH for wave body interaction
	16:00-17:00	PLENARY 5: <b>Johan Jansson</b> Direct FEM modeling of turbulent multiphase flow in marine renewable energy
	17:00-17:30	Coffee Break
	20:45	Dinner (speakers & organisers)

Day	Time		
05 April 2017	09:30-10:30	<b>PLENARY 6: David Lannes</b> A compressible-incompressible approach for floating structures	
	10:30-11:30	<b>PLENARY 7: Iñaki Zabala</b> Spar Buoy oscillating-water-column wave energy converter tank calibrated 6 DOF hybrid mooring non-linear model	
	11:30-12:00	Coffee Break	
	12:00-13:00	<b>PLENARY 8: Jeffrey Harris</b> Using the boundary element method for modeling wave-structure interactions with fully nonlinear potential flow	
	13:00-15:00	Lunch	
	15:00-16:00	<b>PLENARY 9: Allan-Peter Engsig-Karup</b> On recent progress on the development of new general-purpose fully nonlinear marine hydrodynamics models for wave propagation and wave-body applications.	
	16:00-16:30	Coffee Break	
	16:30-17:30	<b>PLENARY 10: Yanlin Shao</b> Harmonic Polynomial Cell method with Immersed Boundaries	
	06 April 2017	09:30-10:30	<b>PLENARY 11: Yi-Hsiang Yu</b> WEC-Sim Development, Verification and Validation
		10:30-11:30	<b>PLENARY 12: Josh Davidson</b> Evaluation of energy maximising control systems for WECs using CFD
11:30-12:00		Coffee Break	
12:00-13:00		<b>PLENARY 13: Vincenzo Nava</b> Challenges in the hydrodynamics modelling of wave energy converters	
13:00-15:00		Lunch	
15:00-16:00		<b>PLENARY 14: Claes Eskilsson</b> Towards Reliable and Efficient CFD Simulations of Moored Wave Energy Converters	
16:00-16:30		Coffee Break	
07 April 2017	09:30-11:00	Open Session	
	11:00-11:30	Coffee break	
	11:30-12:30	Open Session	
	12:30	Closing of workshop	

**J.M. Blanco<sup>1</sup>, G.A. Esteban<sup>2</sup>, U. Izquierdo<sup>3</sup>, A. Peña<sup>4</sup>, U. Fernández<sup>5</sup>,  
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Development and application of innovative algorithms  
associated to the hydro-dynamic coastal model: validation and  
optimization of computational tools through laboratory tests

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

In the hydro-dynamic coastal field, innovative models validated through experiments are highly requested nowadays. This work is divided into two main parts:

Firstly, we present the research recently carried out in the preparation of an experimental wave flume [1] and the corresponding computational simulations by means of full CFD commercial codes (StarCCM+ and ANSYS FLUENT), whose main objective is to show the behavior and effect on floating structures such as wave energy converters (WEC), in the range of intermediate deep waters [2], aiming to provide technical support to BIMEP (Biscay Marine Energy Platform).

The numerical solution of such fluid flows usually means a relatively large computational cost, becoming sometimes even prohibitive [3], either because the size of the model itself or because of the short time available to obtain an effective solution [4]. In many of these cases the best option is to use "Reduced Order Methods" (ROM), and more specifically the "Proper Orthogonal Decomposition" (POD) method, which uses a set of numerical solutions of the whole problem (called "snapshots") to create an orthogonal base on which to project the equations, fully describing the physical phenomena [5], requesting much less computational cost. This has been successfully applied to active techniques in aerodynamic control [6] but its use in WEC's is also desirable.

## References

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# Malin Göteman

Modelling of wave energy parks at Uppsala University

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

The focus of this talk will be on the hydrodynamical modelling of wave energy parks performed by the wave energy group at Uppsala University, Sweden. Both analytical, numerical and experimental modelling will be covered, based on earlier and ongoing work.

In early works by the group, properties of wave energy arrays were studied using the linear potential flow boundary element software WAMIT. The hydrodynamical output from WAMIT was used in a time-domain model where irregular waves was used as input. The waves at the group's offshore test site at the west coast of Sweden are continuously measured and analysed using a commercial Datawell Waverider buoy. Arrays with 9–64 wave energy converters with different array geometries, spacing, wave directions etc were studied and evaluated as functions of power production and power fluctuations.

To enable modelling of large parks and many parameter configurations, an analytical model was developed based on multiple scattering between devices. In a first step, a point-absorber approximation was made, implying that the method was computationally very fast and could be used to study parks with over 1000 devices. The method was later extended to full hydrodynamical interaction and used to study parks with over 100 devices. In current work, the model has been coupled with a genetic algorithm and used for multiple parameter optimization of wave energy parks, and has also been extended to model devices with different buoy geometries and topologies. Ongoing work also includes developing the time-domain model to incorporate control methods, optimizing power take-off in a park using an active set algorithm, and using artificial neural networks in wave power control applications.

Experimental work is performed both in wave tank in collaboration with Plymouth University, UK, and offshore at the group's test site. In the talk, planned array experiments in both wave tank and offshore will be described.

Whereas the focus of the talk will be on the modelling of device arrays, I will also review briefly the numerical and experimental modelling of wave energy converters in extreme waves.

## **Raul Guanche**

### **On the importance of calibration and validation procedures: hybrid modeling**

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**BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters**

## **Abstract**

Extraction of wave energy from the oceans has been studied since the 1970s. In the last decade, energy high prices and the need of new energy sources have motivated recent Marine Renewable Energies (MRE) developments. Most of them are still focused on a wide variety of different technologies and physical principles.

The diversity of technologies need to be tested at reduced scale and proved throughout sea trials prior to become a commercial product. However, both approaches need to be supported by adequate numerical tools. Wave energy numerical modeling it is an essential tool towards design optimization. Laboratory experiments and sea trials are very expensive methodologies, because of that numerical models are a crucial engineering tool at every design phase.

Nevertheless both, advanced CFD models and the more simplified potential theory based numerical models, need to be calibrated and validated prior to become a trustable tool. All the numerical approaches used in wave energy engineering have physical assumptions and simplifications that need to be proved first. Moreover, most of the wave energy converters (WEC) technologies already under development, show physical principles that yields in design strategies different from other marine sectors like ship designing. Some wave energy converters are designed for high rates of roll or pitch, in contrast with ship designing best practices which limits the maximum roll up to safety or comfort limits (6 degrees in merchant ships, NORDFORSK, 1987).

The present talk will analyze the risks of non-validated numerical models. It will also propose a hybrid modeling strategy where physical and numerical models cooperate from the very early stages of a wave energy concept design. A hybrid modeling strategy takes the most from numerical models and physical experiments, reducing numerical model uncertainties and design risk.

**Peter Stansby**  
**SPH for wave body interaction**  
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**BCAM-Basque Center for Applied Mathematics, 3-7 April 2017**  
**Hydrodynamics of wave energy converters**

## Abstract

Survivability is fundamental to the design and success of wave energy converters whether on fixed or floating platforms. Progress has been made on improving energy capture to reduce LCOE and we have a particular development of a multi-body floating system known as M4 at Manchester. There has been extensive experimental testing and linear diffraction modelling showing that such modelling can be accurate in extreme as well as operational conditions, for non-breaking wave conditions [1,2]. Breaking occurs in shallow and intermediate depths and can occur in deep water and is likely to magnify loading and response markedly [3]. SPH is well suited to predict loading and response in breaking waves [4] however it is expensive computationally. This may be reduced through computer architecture, idealisation of physics, and novel numerics. Idealisation of physics is attractive and the Froude-Krylov assumption with linear added mass and radiation damping has proved remarkably effective [5]. There is the question of the extent of generality. The use of GPUs is expanding rapidly for both 3-D WCSPH and ISPH where the Poisson solver is the major issue. Hybrid schemes with SPH applied local to the body with an efficient far field solver are under development. A particular development here is combining Eulerian (high accuracy) SPH with Lagrangian for the free surface [6]. Finally in extreme waves the interface with breaking waves is generally two-phase as water becomes aerated affecting loads in a complex way. This has been investigated for some idealised cases [7] also using hybrid schemes [8] where it is shown how the air phase can reduce forces (cushioning) [7] or magnify due to trapped air [8]. The question is show to package for general use and progress is being made on all these fronts.

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# Johan Jansson

Direct FEM modeling of turbulent multiphase flow in  
marine renewable energy

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

For the past decade we have developed the Direct FEM Simulation (DFS) methodology [4, 3] with a and FEniCS-HPC software framework [1] for automated solution of general partial differential equations (PDE), with successful application to predicting gross quantities in turbulent flow at high Reynolds number [2].

Our methodology is based on a piecewise linear approximation in space and time and with a numerical stabilization in the form of a weighted least squares method based on the residual, which acts as a parameter-free implicit model of the unresolved subscales. Goal-oriented error estimates based on an adjoint solution automatically optimize the mesh for mean-value outputs such as drag.

We here present an extension of the methodology and software to multiphase flow with marine renewable energy applications in mind by directly solving the variable density incompressible conservation equations, with an initial condition on the density modeling the different phases. Shock-capturing is used to stabilize the sharp phase interface, and a mass-conservative phase-separation term is added to the density equation to enhance preservation of the sharp interface for long times, with results for the MARIN benchmark [5] comparable to the state of the art.

We describe applications of the DFS methodology in our collaboration with Tecnalia on simulation of floating wind turbines in the ICERMAR Basque government project. Recent developments in coupled rigid-body modeling, and a prototype for parallel-in-time computation, with the possibility of fast scalable computation of long time intervals, are also presented.

## References

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# David Lannes

A compressible-incompressible approach for floating structures

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

Using vertically averaged models for the hydrodynamic equations (full Euler equations, nonlinear shallow water or Boussinesq equations), the pressure exerted on the immersed part of a floating body can be expressed as a Lagrange multiplier associated to the constraint on the water elevation under the body. The resulting model is of mixed compressible (in the free surface region) and incompressible (under the body) structure. We will show how to handle this coupling. An analysis of the pressure term allows moreover an efficient formulation of the equations for the solid motion. This approach can also be implemented at the numerical level and several simulations will be shown.

## References

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## Spar Buoy oscillating-water-column wave energy converter tank calibrated 6 DOF hybrid mooring non-linear model

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
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### Abstract

The OWC spar buoy is possibly the simplest concept for a floating oscillating water column (OWC) wave energy converter [1]. It is an axisymmetric device consisting basically of a submerged vertical tail-tube-fixed to an axisymmetric floater that oscillates essentially in heave. The air flow displaced by the water motion inside the tube drives a self-rectifying biradial air turbine.

This work presents a new detailed wave-to-wire model based on a diffraction-radiation hydrodynamic model in a 6 degrees-of-freedom time-domain simulation of the spar-buoy OWC including a non-linear model of the self-rectifying biradial turbine and the mooring lines. The spar-buoy OWC geometry selected to be used in the current work is the result of an optimization procedure [2].

The hydrodynamic model has been calibrated based on an extensive 1:16 tank testing developed in NAREC. Turbine and generator models have been calibrated from 1:3 and 1:1 laboratory testing and include optimized feedback control [3, 4].

Numerical results are presented for device's performance in irregular waves for linear and non-linear tank calibrated device hydrodynamics. This analysis will permit to assess the influence of non-linearities in the WEC performance.

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# Jeffrey C. Harris

Using the boundary element method for modeling  
wave-structure interaction with fully nonlinear potential flow

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

Potential flow theory has been widely successful at predicting many aspects of the dynamics of water waves prior to the point of breaking. Most models based on potential flow make assumptions of small steepness or amplitude of the waves which may not agree with experiment for highly nonlinear waves near structures of practical importance, such as wave energy converters. These approximations are a result of the difficulty of solving the Laplace equation on complex geometries, whereas this can be done with the boundary element method (BEM) [1]. The use of the BEM, although in principle straightforward, has seen numerous advancements in recent years, with the widespread use of parallelization, the use of different element types, and the application of methods to accelerate calculations, like the fast multipole method [2]. Results will be presented for wave propagation and wave-body interactions, given typical structures used for offshore renewable energy.

## References

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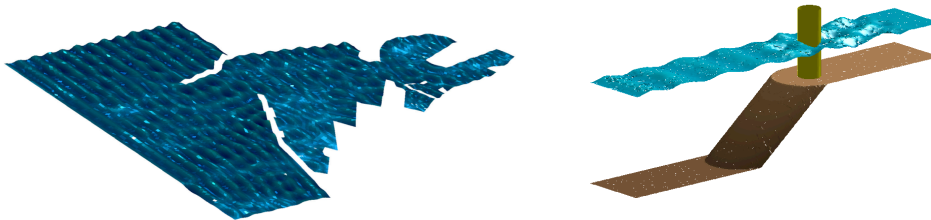
# Allan P. Engsig-Karup

## On recent progress on the development of new general-purpose fully nonlinear marine hydrodynamics models for wave propagation and wave-body applications

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Hydrodynamics of wave energy converters



### Abstract

In this talk, an overview of recent years research related to advanced computational hydrodynamics carried out at Department of Applied Mathematics and Computer Science, Technical University of Denmark. The research have emphasized fundamental scientific computing aspects to enable progress on the development of new general-purpose fully nonlinear marine hydrodynamics models for wave propagation and wave-body applications. The main research challenges have been to research robust high-order numerical methods to significantly improve cost-efficiency [3], designing fast iterative solvers with minimal memory footprints and carrying out high-performance implementations on modern - possibly heterogeneous - many-core hardware systems for fast, scalable and portable execution across the system chain from desktop-sized workstations to the largest super clusters [1,4]. Recent breakthrough in the use of the general Spectral Element Method framework for discretization [2] have made it possible to introduce geometric flexibility and expand opportunities for efficient and accurate prediction of wave propagation and wave-body interactions in geometries of engineering relevance. The research seek to address practical aspects that makes it possible to increase the range of possible applications whether it is large-scale computations for realistic marine areas, marine energy systems and improving the engineering analysis capabilities via improved turn-around-times for the simulations. Highlights of current and ongoing research will be given together with results of benchmarking. The research and development contributes to make it possible to target a broad range of practical applications in marine engineering.

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**Yanlin Shao<sup>1</sup> & Finn-Christian W. Hanssen<sup>2</sup>**

Harmonic Polynomial Cell method with Immersed Boundaries

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

Shao & Faltinsen (2012, 2014a) has initiated the development of a new FNPF model based on a novel harmonic polynomial cell (HPC) method. The computational domain is discretized by overlapping cells. Within each cell, the velocity potential is represented by the linear superposition of a complete set of harmonic polynomials, which are the elementary solutions of Laplace equation. The original HPC method of Shao & Faltinsen (2012, 2014a) works on structured grid and has been verified and validated by idealized cases. The structured grid has been found to limit the application of the HPC method in general wave-structure analysis. Recent development of the HPC method is focusing on handling complex structure geometries and deforming free surfaces. To achieve that, several strategies have been proposed. Among others, the immersed boundary (IB) approach has been proposed by Hanssen et al. (2015, 2017) looks more powerful in terms of modelling complex geometries.

The general idea of the IB approach is to utilize the continuous representation of the flow variable (the velocity potential) within each cell in the HPC method. In practice, we operate with ghost nodes and ghost cells, where the velocity potential is extended out of the physical computational domain. However, this has no implication for the solution inside the fluid domain. Another consequence of the HPC formulation is that it is easy to couple different solution domains directly, where communication points between grids can be considered as IBs in the respective solution regions. The figure below illustrates a practical example where the IB approach is combined with an overlapping-grid method to simulate the flow due to a heaving cylinder. To the left, an Earth-fixed background grid with a relatively coarse discretization is shown. The red square indicates the outer boundaries of the body-fixed grid, with details shown to the right. Here, boundary conditions at the body surface are taken into account in the grey-shaded ghost cells. The free surface, indicated with blue markers, is treated as an IB in both domains. In both grids, the red circles indicate communication nodes where the velocity potential from the other grid is given as a boundary condition.

The obvious advantages of the IB approach is that we can operate with structured grids that are easy to generate and that do not deform with time, even in the case of complex surface geometries. The overlapping-grid approach represents a further enhancement of the IB method, which enables grid refinement close to body boundaries without having to stretch the grid and independent of the surface's position.



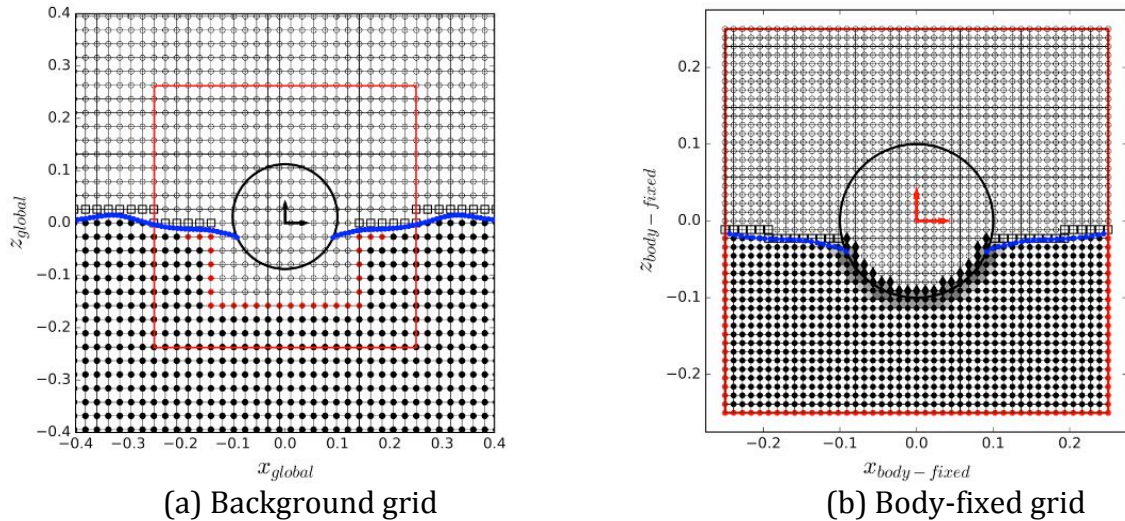


Fig. 1 The grid systems used for a semi-submerged heaving circular cylinder

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- Hanssen F.-C. W., Greco M. and Shao Y.L. (2015), The Harmonic Polynomial Cell Method for Moving Bodies Immersed in a Cartesian Background Grid, 34th International Conference on Ocean, Offshore and Arctic Engineering, May 31–June 5, St. John’s, Newfoundland, Canada.
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- Shao Y.L. and Faltinsen O.M. (2014), Fully-nonlinear wave-current-body interaction analysis by a Harmonic Polynomial Cell (HPC) method, *J. Offshore Mech. Arct. Eng.*, 136(3), 031301-031307.

# Yi-Hsiang Yu

## WEC-Sim Development, Verification and Validation

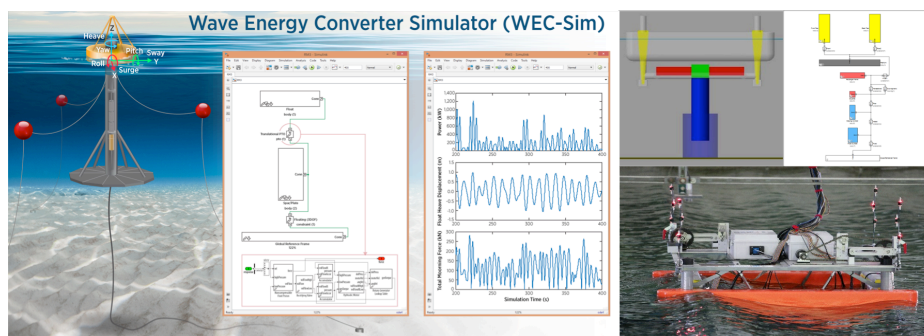
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### Abstract

WEC-Sim (Wave Energy Converter SIMulator) is a time-domain numerical model that has been jointly developed by the National Renewable Energy Laboratory and Sandia National Laboratories and funded by the US Department of Energy Water Power Technologies Office to promote and support the wave energy industry. WEC-Sim is developed to simulate wave energy converter systems that are comprised of rigid bodies, power-take-off systems, and mooring systems, with a focus on system power performance prediction and design optimization.

WEC-Sim is a radiation, diffraction based numerical model that solves the equation of motion for each body, about its center of gravity, based on Cummins' equation, using hydrodynamics coefficients typically obtained from a frequency-domain potential flow model and empirically obtained viscous damping coefficients [1]. This type of linear, or possibly weakly nonlinear, method assumes small amplitude motion and wave elevation, and relies on experimental measurements or computational fluid dynamics simulations to determine the relevant viscous damping coefficients. However, because WECs are typically made up of multiple bodies and are designed to maximize their power output at dominant sea states as resonant devices, this often leads to more complex interactions between the wave forces and the system dynamics [2]. To better understand and more accurately predict the WEC system response, WEC-Sim has been used to simulate a wide range of WEC designs, where the simulation results were compared to those obtained from other numerical models and measurements from experimental tests [1,3–5]. This presentation will cover a series of verification and validation studies including the experimental wave tank test specifically designed to validate the WEC-Sim model. The presentation will also include a discussion on the challenges and complexity of verifying and validating the numerical models, which depends on the geometry of WECs, the mooring configuration and the complexity the power take-off drivetrain, and will include lessons learned from these studies.



### References

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- [2] Li Y., and Yu Y.-H., 2012, "A Synthesis of Numerical Methods for Modeling Wave Energy Converter-Point Absorbers," *Renew. Sustain. Energy Rev.*, **16**(6), pp. 4352–4364.
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- [5] Combourieu A., Lawson M., Babarit A., Ruehl K., Roy A., Costello R., Weywada P. L., and Bailey H., 2015, "WEC3 : Wave Energy Converter Code Comparison Project," 11th European Wave and Tidal Energy Conference, EWTEC.

# Josh Davidson

Evaluation of energy maximising control systems  
for WECs using CFD

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

To increase the amount of energy absorbed by a WEC, an energy maximising control system essentially tunes the WEC dynamics to resonate with the incident waves. The resulting large amplitude resonant motions of the WEC, challenge the validity of many of the linearising assumptions which traditional hydrodynamic models are based upon. Therefore, evaluating the performance of a WEC under controlled conditions using linear hydrodynamic models would be misleading, and predictions likely biased towards unrealistically high amounts of power absorption, due to the absence of nonlinear effects such as viscous damping.

In this presentation I will discuss using computational fluid dynamics (CFD) based numerical wave tank experiments to evaluate energy maximising control systems for WECs. The high fidelity treatment of the fluid structure interaction provided by CFD, enables a realistic simulation environment for assessing the performance of a WEC under controlled conditions. Implementation details, using a coupled OpenFOAM-MATLAB environment will be discussed, and examples given showing the discrepancy between the predicted controller performance evaluated using linear hydrodynamic models versus the CFD experiments. Current research, focussed on implementing adaptive controllers using CFD experiments, will be presented, whereby an adaptive algorithm is used to estimate the control model in real-time, based on measured values of position, velocity, wave elevation or control force. The on-line estimation of the WEC model, used by the controller, will therefore estimate the best representative model of the WEC's dynamical behaviour under controlled conditions, capturing nonlinear hydrodynamic effects present in the CFD simulation.

**Vincenzo Nava**

Challenges in the hydrodynamic modelling of  
wave energy converters

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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
Hydrodynamics of wave energy converters

## Abstract

Devices for harnessing energy from ocean waves, namely Wave Energy Converters (WECs), are currently investigated by the scientific community and technology developers in order to optimise their design and make this source of renewable energy cheaper and competitive if compared to fossil-based sources as well as other renewables, such as onshore wind and solar energies. Given the environment in which they are inserted, the design of WECs must consider the interaction between fluid and structure (Fluid Structure Interaction, FSI). Error and lack of accuracy in the modeling of the FSI may lead to underestimate and/or overestimate power production, forces, displacements and tensions on the devices affecting the survivability of the system and/or the profitability of the investment.

It is evident that different models for representing the hydrodynamics of WECs should be considered by the designers, depending on the specific characteristics of the devices, the wave climate, the seabed characteristics as well as the level of accuracy required by the technology readiness level (TRL) of deployment of the project. In this presentation, therefore, most of these methods –linear and nonlinear potential flow models, semiempirical viscous loss based models, numerical solutions to full Navier Stokes equations, etc...- , will be reviewed as in [1] based on the experience of Tecnalia R&I, briefly detailing their characteristics and computational challenges as well as their impact on accuracy; moreover, as a reverse engineering process, a review of methods on how to interpret the lessons learnt in an experimental campaign in order to validate the numerical models will be presented. Finally, analytical and semi analytical models for studying the FSI in an array of WECs will be reviewed.

## References

- [1] H. A. Wolgamot and C. J. Fitzgerald, “Nonlinear hydrodynamic and real fluid effects on wave energy converters,” *Proc. Inst. Mech. Eng. Part J. Power Energy*, vol. 229, no. 7, pp. 772–794, Nov. 2015.

# Claes Eskilsson

## Towards Reliable and Efficient CFD Simulations of Moored Wave Energy Converters

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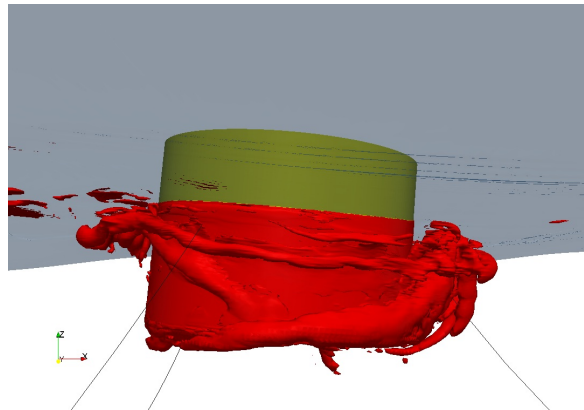
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BCAM-Basque Center for Applied Mathematics, 3-7 April 2017  
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### Abstract

While the use of linear radiation/diffraction models remain the tools of the trade for wave energy application, there is an ongoing paradigm shift towards more complete numerical models. The trend is driven by the fact that point absorbers in the resonance region have clear nonlinear motion response, and that overtopping, slamming and green water are expected to occur at extreme events. In this talk I will discuss our work on coupled mooring simulations using a in-house high-order DG mooring dynamic solver and the OpenFOAM VOF-RANS solver with focus on verification and validation techniques.



## Lunches

Date: 4<sup>th</sup> April 2017

Time: 13:00

Restaurant:  
Il Giardinno Della Nonna  
at Mazarredo 18-Bilbao



Date: 5<sup>th</sup> April 2017

Time: 13:30

Restaurant: Atea at  
Paseo Uribitarte,4 Bilbao



Date: 6<sup>th</sup> April 2017

Time: 13:30

Restaurant: Kafe Antzokia  
at San Vicente Street,2 - Bilbao

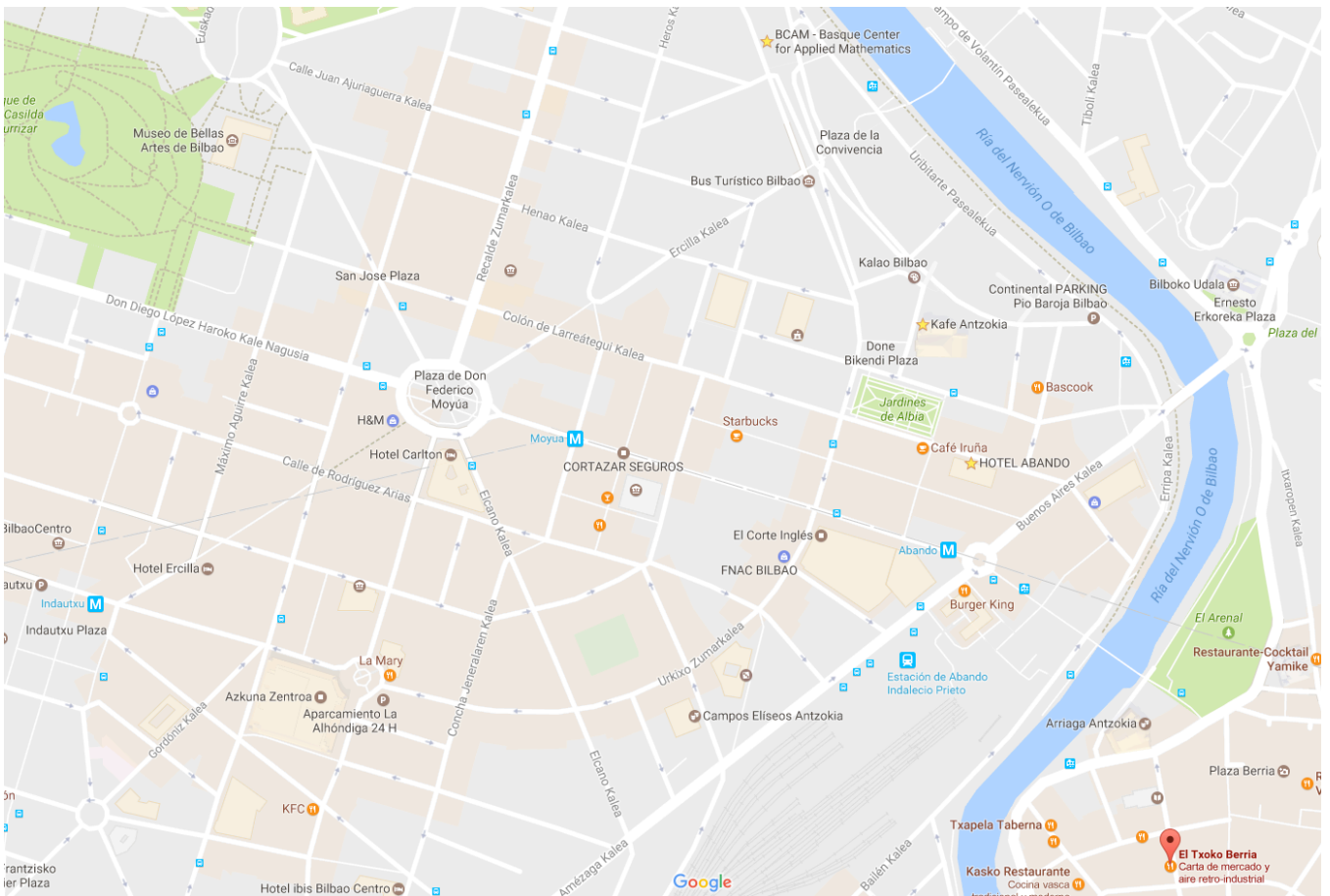


# Dinner

Date: 4<sup>th</sup> April 2017

Time: 20:45

Place: El Txoko Berria Restaurant at Bidebarrieta str. no.14 - Bilbao



## NOTES:

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