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WIND AND WATER POWER PROGRAM

2011 Marine Hydrokinetic Device Modeling Workshop: Final Report

March 1, 2011

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2011 Marine and Hydrokinetic Device Modeling Workshop

Summary Report

Workshop Date: March 1, 2011

Location: National Wind Technology Center, Boulder, CO

Funded by DOE Project # 20689, Agreement # 20067

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Executive Summary

This report summarizes the proceedings of the 2011 DOE Marine and Hydrokinetic (MHK) Device Modeling Workshop, held on March 1, 2011, at the National Wind Technology Center, National Renewable Energy Laboratory, south of Boulder, CO. Numerical modeling is a critical step in the MHK device design process as it is the main part in the initial design stage. Accordingly, robust, reliable, and efficient modeling tools are needed to advance MHK technology. Unfortunately, existing numerical design and analysis tools do not meet all the needs of the MHK industry because these tools only simulate the characteristics of the MHK devices partially. As a result, there is an opportunity to accelerate the development of new and innovative MHK technologies by providing an improved set of numerical modeling tools.

The purpose of the workshop was to provide a forum for numerical modeling experts, from industry, national laboratories, DOE, and academia, to identify areas where improvements in numerical modeling technologies are possible and, which improvements can provide maximum benefit to the MHK industry. The workshop was comprised of several invited presentations on MHK modeling techniques and two discussion sessions in which all attendees of the workshop were encouraged to participate.

During the workshop, three priority action items for improving the present set of numerical modeling tools were identified:

1) Provide benchmark experimental results that can be used to validate numerical models;

2) Develop a computationally efficient numerical method that can accurately simulate non-linear interactions between MHK devices and the wave and current environments, in which the devices operate; and

3) Develop systems-level engineering modeling approaches that integrate different disciplines, such as power systems, hydrodynamics, and structures into a single numerical modeling package.

Purpose and Objectives

The energy within earth's oceans, estuaries, straights and rivers is a relatively untapped source of renewable energy. Ocean energy is contained in salinity, density, and temperature gradients, and also in the hydrokinetic energy of ocean waves and currents. Over the past decade, increasing fossil fuel prices and renewable energy policies have spurred commercial interest in developing technologies capable of extracting energy from the earth's oceans.

Reliable analytical and numerical modeling tools are needed to design efficient and cost effective MHK devices. For this reason, these tools need to be both accurate and robust in order for the MKH industry to be successful. Unfortunately, existing MHK modeling tools are limited in their capabilities and only a few of them have been thoroughly validated. The purpose of the *2011 DOE Marine and Hydrokinetic Device Modeling Workshop,* held on March 1, 2011, was to provide a forum for modeling experts from industry, the national laboratories, DOE, and academia to review state-of-the-art modeling techniques and identify areas in which the present numerical and analytical models could be improved. More specifically, the objectives for the modeling workshop were to:

- Review the designs of existing MHK device prototypes and discuss design and optimization procedures
- Assess the utilization and limitations of modeling techniques and methods presently used for modeling MHK devices
- Assess the utilization and limitations of modeling methods used in relevant areas, such as wind technology, naval architecture, oil and gas, and ocean engineering
- Identify the necessary steps to link modeling with other important steps (e.g., tank testing, power take-off (PTO) design, mechanical design) in the design process
- Identify the next steps to advance the MHK modeling methods for the modeling tasks in the national laboratories under DOE support
- Assist the technology developers to advance the technology readiness levels (TRLs) of their technologies and assist governmental agencies to identify the TRL status of the various technologies.

A further important objective of the workshop was to bring together scientists and engineers, who have developed models of MHK device models, with those who are now using these models, and with others who are building on prior work and developing advanced models. This interchange was important so that model users fully understand the limitations of the models they are using, so that model developers do not reinvent models that already exist, and so model users could articulate desired capabilities. If the MHK modeling community becomes more familiar with the work of their peers, it will foster a healthier and more productive technical exchange and collaboration among modelers and users.

The morning agenda for the workshop was planned so that researchers with significant prior experience and expertise in modeling ocean wave and energy systems provided presentations on the methods and tools they felt could be successfully applied to solve current problems. There

were separate sessions focused on wave device models and on current device models. These sessions established a benchmarking of existing modeling approaches and techniques. In the afternoon, the meeting was open for discussion around two key questions:

1. Which analysis methods can be used in the near term for analysis of energy capture, operational loads, extreme loads, mooring loads, or other design situations?
2. What aspects of the analysis methods need to be improved and/or validated, and what advanced methods should be explored?

Presentations

This section lists the presentations that were given during the workshop and provides brief descriptions of the topics that were covered. The posted pdfs were supplied by the presenters and may not meet NREL web standards.

Overview of Device Modeling Challenges:

Overview of Device Modeling Status (PDF 1.6 MB)

Presenter: Ye Li – NREL

Description: High-level overview of state-of-the-art numerical and analytical MHK modeling.

Wave Devices:

Buoy Arrays & Coastal OWC's for Wave Energy Extraction (PDF 2.5 MB)

Presenter: Chang Mei – MIT

Description: Analytical techniques for modeling buoy arrays for wave energy extraction.

Design, Analysis, and Validation of UC-Berkeley Wave Energy Extractor (PDF 3.7 MB)

Presenter: Ronald Yeung – Berkeley

Description: A systematic design and evaluation process of a heave-only floating point absorber type wave energy conversion system.

Physical Modeling: Studies of Diffraction Focusing Wave Energy Conversion Devices (PDF 449 KB)

Presenter: Michael E. McCormick – U.S. Naval Academy

Description: The practicalities involved with large-scale studies of diffraction focusing by point absorbers and attenuators.

Current Devices:

A Systematic Investigation of the vertical axis tidal current turbine system with twin-rotors (PDF 1.3 MB)

Presenter: Ye Li – NREL

Description: Experimental measurements and numerical predictions of a vertical-axis tidal current turbine performance.

Preliminary Work in Tidal Turbine Farm Computational Fluid Dynamics Simulations (PDF 648 KB)

Presenter: Matthew Churchfield – NREL

Description: The development of a large-eddy simulation (LES) computational fluid dynamics (CFD) model for simulating arrays of horizontal-axis tidal current turbines.

Prediction of performance and design of tidal/ocean current turbines (PDF 41 MB)

Presenter: Spyros Kinnas

Description: Potential flow methods (e.g. vortex lattice method and boundary element method) for modeling MHK devices.

Simulating turbulence in natural waterways with MHK devices (PDF 8.0 MB)

Presenter: Fotis Sotiropoulos – University of Minnesota

Description: Recent advances and future challenges in computational and experimental techniques used to model various aspects of MHK devices.

The VIVACE Converter (PDF 27 MB)

Presenter: Michael Bernitsas – University of Michigan

Description: The design and CFD modeling of a novel MHK device that uses vortex-induced vibration of a cylinder to generate power.

Structural Design of the Tidal Current Turbine Composite Blade (PDF 518 KB)

Presenter: Gunjit Bir – NREL

Description: A structural mechanics code that optimizes the internal layout of MHK turbine blades.

Discussions

Many useful technical discussions took place during and after the presentations listed in the previous section. To help guide in the development of advanced MHK models and their effective application two facilitated discussion sessions were held to further explore the questions raised during the presentations:

What are the key limitations of the existing set of MHK numerical modeling tools?

How can relevant numerical modeling experience gained and/or tools created in other fields (e.g. wind, oil, and gas and naval architecture) be effectively leveraged?

How can numerical modeling tools be best developed and improved in the future so that they are more user-friendly?

How can the burden of environmental monitoring and modeling on industry be reduced?

How can collaboration among DOE, National Laboratories and universities be improved?

The following sections present the topics covered during the facilitated discussion session in an outline list format for simplicity. The notes below are a summary of open workshop discussions, rather than the views of the workshop organizers.

Please note that some topics have a comprehensive background description because the discussion started with a topic review, which was then followed by the core discussion that included recommendations or suggestions. Not all topics include the background section.

1 Device modeling issues and limitations

1.1 How should MHK models be improved?

- **Discussion Background:** Linearized models are widely used to study wave energy devices at the present time. These models are restricted by device size and operating constraints, such as small motions well away from resonance. However, these are exactly the conditions under which wave energy converters need to operate to perform best. Computational fluid dynamics (CFD) simulations can capture non-linear effects to model both wave and current devices. For example, CFD codes such as CCM+, Fluent, OpenFOAM, CFX, along with a wide variety of other "in-house" developed codes are widely used. However, these codes are too computationally expensive to be used in design optimization. In most cases, they require massively parallel computers and require at least a day to solve a single design case. Research projects could involve looking at fluid structural interaction in detailed scenarios, while industrial design projects could require the analysis of the device's overall performance.
- **Discussion:** Non-linear wave analysis models are needed. They should be time domain, and be less computationally costly than those using CFD codes.
- **Discussion Background:** At this point, development of new simplified design models is needed, as has been done for wind turbines. Much can be borrowed from wind research to study MHK turbines.

  Discussion: Design models for water turbines and their capability to capture non-linear hydrodynamics effects need to be improved and dynamic effects such as turbulence and flexible body motions need to be included in the modeling. Improved CFD models, which include both turbulence and flexible body effects, should be explored.
- **Discussion Background:** Control strategies are very critical for device performance and reliability:

  Discussion: Approaches that can link non-linear hydrodynamics effects together with control strategies are needed to design control systems that maximize energy capture, both for rotor current devices and for wave machines.
- **Discussion Background:** Turbulence effects need to be included in existing potential flow models to assess the impact on dynamic loads.

  Discussion: Experimental measurements of turbulence are urgently needed. Without turbulence inflow data, it is impossible to develop accurate numerical rotor models and more robust and reliable rotor designs.

1.2 How can we facilitate better, more consistent modeling of MHK devices?

- **Discussion:** Guidance documents, best practice procedures, and design methods are needed to assist designers and assure that all of the relevant design situations are addressed.
- **Discussion:** Design application guidance, in the form of best design practices, also is needed to cover such issues as bio-fouling, noise, and survivability

requirements. Following verification, these can be included in the design standards, such as IEC TC114.

1.3 How should our analysis and design codes be benchmarked and validated?

- **Discussion Background:** The wind industry is mature when compared to the MHK industry, and because of the similarities between wind turbines and water turbines, wind design tools are being adapted for rotor modeling applications for both horizontal axis and cross-flow machines.
- **Discussion:** Wind turbine experience should speed up model development and increase credibility and reliability. Furthermore, the wind turbine design process can be adapted to design MHK water current turbines.
- **Discussion:** Experiments should be performed to provide experimental data that can be used for code validation. Numerical simulations should be performed without *a priori* knowledge of the experimental results to insure that the models are not "tuned" to match the experiments. A good example of this approach is the NREL Unsteady Aerodynamics Experiment that was performed in conjunction with a set of numerical simulations, with the goal of validating wind turbine design and analysis codes.[1] In this case, the experimental data was released into the public domain only after the numerical simulations were completed.
- **Discussion:** The experimental methods must be agreed upon, by both the numerical modelers and those conducting the experiment, to ensure valid data inputs for the numerical models that result in fair comparisons.
- **Discussion:** The DOE Reference Models may be able to provide some experimental data for code validation purposes.

1.4 Can we leverage ocean engineering capabilities and experience to advance MHK device design and analysis?

- **Discussion Background:** MHK analysis and design includes many of the same technical areas as ocean engineering, coastal engineering, and offshore engineering, as well as naval architecture.
- **Discussion:** Many ocean engineering design methods and computer-aided design tools should be directly applicable, which provides the opportunity to leverage decades of work and experience to provide a foundation for MHK tools. However, these models should be validated for application to MHK modeling to ensure validity under the differing conditions.
- **Discussion Background:** In an oceanographic engineering world, buoys that measure wave climate and other metocean details have been successfully designed for many years.
- **Discussion:** Existing buoy design tools should be directly applicable to the design of floating point absorber devices.

[1] Simms, D.; Schreck, S.; Hand, M.; Fingersh, L. J. (2001). NREL Unsteady Aerodynamics Experiment in the NASA-Ames Wind Tunnel: A Comparison of Predictions to Measurements.

1.5 How can we best leverage the European MHK development experience?

- **Discussion:** The United States Global Marine Renewable Energy Conference, which is similar to the International Ocean Energy Conference in Europe, has generated some international collaboration and cross pollination with European entities.
- **Discussion:** Europe has established the European Wave and Tidal Energy Conference, which focuses on modeling and experimental research. Perhaps, the United States should establish a similar research-focused conference. This would open much more of the DOE-sponsored research to a wider audience of U.S. industry members and universities to accelerate domestic learning.
- **Discussion:** The United States should foster better collaboration with the European Union to accelerate learning based on their experience. This could take the form of conference attendance grants for students, industry members, and state agencies, as well as sponsored study fellowships and personnel exchanges.

2 MHK model user issues and questions:

2.1 How can MHK model users access the available DOE supported models

- NREL's website[2] will post the NREL tools that were presented in the workshop, and will in the future provide additional models as they are developed by MHK partners, and universities. Links to other modeling tools will be provided, where possible. In addition, all of the MHK laboratories will publically release any modeling tools developed under DOE funding.

2.2 Are there guidelines for modeling methods?

- Two review articles outlining present MHK modeling methods are being developed presently and will be published as a technical report in FY12.

2.3 How user-friendly can, or should, these models be?

- It may be possible to develop user-friendly front ends (or GUIs) for research codes, so that they can be used in the design process more easily.
- It may useful to develop example problems and benchmarks that describe how the computer models should be used to accelerate learning and application to prototype devices designs.

[2] Until the in-process water power website is created. NREL wind website will be used for posting water power information

3 How can the burden of environmental monitoring and modeling on industry be reduced?

- Perhaps DOE, through the national laboratories, could lead efforts to conduct environmental modeling and monitoring of early deployments, which may reduce industry efforts and improve credibility.
- Methods for efficiently coupling near-field device models, with far-field flow modeling, need to be investigated in more detail.

4 How can collaboration DOE, National Laboratories, and universities be improved?

- Improve communications among MHK modeling groups and individuals at academia, industry, national laboratories, and the DOE through more frequent workshops, where modeling and experimental research can be discussed in significant detail.
- The MHK community, including DOE, the national laboratories, universities, and industry, could benefit by encouraging more cross-discipline collaboration, such as mechanical, electronics, transmission, hydrodynamics, and environmental science, to develop holistic teams to develop more robust inclusive models for MHK technologies.
- DOE or the national laboratories should sponsor a workshop in which all MHK stakeholders provide input into strategic planning for the MHK program.

Recommended Priority Work Areas

The 2011 DOE Marine and Hydrokinetic Device Modeling Workshop provided a forum for MHK experts from industry, the national laboratories, and academia to discuss state-of-the art analytical and numerical modeling techniques and to identify presently unmet modeling needs. The presentations and facilitated discussions during the workshop revealed several priority areas, in which current MHK modeling capabilities need improvement. The key recommended actions from the workshop presentations and discussions are summarized in the three recommendations below:

1. High quality benchmarking experiments should be performed to provide data that can be used to validate the accuracy of existing modeling tools. These experiments would require that all of the validation data and test article design details be made public for accurate modeling and comparison.

2. Cost-effective and time efficient numerical methods that can capture non-linear and turbulent effects should be developed. A number of inexpensive, simplified methods are available that can provide rough predictions of device performance, but they have considerable limitations. High fidelity methods that can predict device performance, without limitations, also are available, but they are computationally expensive and time consuming to use.

3. Integrated systems engineering and design approaches should be developed for MHK device modeling tools. The approaches should include mechanical, electrical, materials engineering, and environmental science. An MHK device, like a ship, is a product that necessitates advanced systems engineering and requires expertise from many disciplines.

Appendix A: List of Attendees

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Appendix B: Workshop Agenda

Time	Topic	Speaker	Moderator
8:45 - 9:00	Arrive at NREL and coffee/tea		
9:00 - 9:15	Welcome and Introductions	Y. Li/R. Thresher (NREL)	
9:15 - 9:45	Overview of Device Modeling Challenges	Y. Li (NREL)	
9:45 - 11:15	Wave Devices	C.C. Mei (MIT) R.W. Yeung (UC-Berkeley) M. McCormick (USNA)	Y. Li
11:15 - 11:30	Break		
11:30 - 13:00	Current Devices I	Y. Li (NREL) M. Churchfield (NREL) S. Kinnas (UT Austin)	R. Thresher
13:00 - 13:45	Lunch		
13:45 - 15:15	Current Devices II	F. Sotiropoulos (UMN) M. Bernitsas (U Mich) G. Bir (NREL)	Y. Li
15:15 - 16:00	National Wind Technology Center Site Tour		
16:00 - 16:15	Break/Briefing of UNH testing facility	K. Baldwin(UNH)	
16:15 - 17:30	Facilitated Discussion 1. Which analysis methods can be used in the near term for analysis of energy capture, operational loads, extreme loads, mooring loads, or other? Facilitated Discussion 2. What aspects of the analysis methods need to be improved or validated, and what advanced methods need to be explored?		R. Thresher/ Y. Li
17:30 - 17:45	Closing Remarks	R. Thresher (NREL) R. Bagbey (Cardinal Engineering/DOE)	
18:30	No-Host Dinner, Location TBD		

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