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PFI: Commercialization of Advanced Composites in Offshore Wind Energy

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Preview of Award 0917974 - Final Project Report

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Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	0917974
Project Title:	PFI: Commercialization of Advanced Composites in Offshore Wind Energy
PD/PI Name:	James S Ward, Principal Investigator Habib Dagher, Co-Principal Investigator Robert Lindyberg, Co-Principal Investigator
Recipient Organization:	University of Maine
Project/Grant Period:	08/01/2009 - 12/31/2012
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Submitting Official (if other than PD\PI):	James S Ward Principal Investigator
Submission Date:	06/19/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	James S Ward

Accomplishments

*** What are the major goals of the project?**

The specific program goals as defined in the proposal with percentages complete are listed below:

1. Identify knowledge centers that will stimulate the development of floating offshore wind turbine platforms, and establish new partnerships between the University of Maine and these key technology stakeholders - including federal labs, maritime colleges, the offshore construction industry, and state government agencies.

The University of Maine-led DeepCwind Consortium, a consortium of 36 member organizations, including universities, national laboratories, and industrial partners, was founded with funding from the National Science Foundation-Partnerships for Innovation, theU.S. Department of Energy, the Rockefeller Brothers Foundation, and the Maine Technology Institute, among others. 100% complete.

2. Develop an innovation strategy for commercializing floating offshore wind turbine platforms.

Working with the national laboratorties, the need for validated design tools for floating offshore wind turbine platforms was identified as the major barrier to commercialization. In order to pursue commercial development of floating wind turbine technology a validated aero-hydro-servo-elastic numerical model is needed to accurately predict the dynamic system behavior during the design and optimization process. Currently, there are very few publicly available coupled numerical models for simulating the performance of floating wind turbines. These codes, such as the NREL's FAST (Jonkman and Buhl, 2005; Jonkman, 2007), had yet to be fully validated against real data as little published information of this type currently exists. 100% complete.

3. Develop the basic design for a full-scale floating offshore wind turbine demonstration platform.

The primary goal of the basin model test program discussed herein is to properly scale and accurately capture physical data of the rigid body motions, accelerations and loads for different floating wind turbine platform technologies. The intended use for this data is for performing comparisons with predictions from various aero-hydro-servo-elastic floating wind turbine simulators for calibration and validation. Of particular interest is validating the floating offshore wind turbine simulation capabilities of NREL's FAST open-source simulation tool. Once the validation process is complete, coupled simulators such as FAST can be used with a much greater degree of confidence in design processes for commercial development of floating offshore wind turbines. The model basin testing program became the basis for this funding, in order to remove the major commercialization barrier. Other funding was received to pursue larger partial-scale and full-scale design. 100% complete.

4. Identify funding sources for the construction of a full-scale demonstration platform.

The University of Maine received funding from the U.S. Department of Energy, among others, to develop and test a 1:8-scale floating offshore wind turbine and platform at the University of Maine Deepwater Offshore Wind Test Site and other sites in the Gulf of Maine. This model was deployed on June 2, 2013 and is currently undergoing testing in a 1:8-scale wind/wave environmental off the coast of Castine, Maine, and is the first offshore wind turbine in the Americas. This is a patent-pending design.

The University of Maine was selected out of 70 competing proposals for Advanced Technology Demonstration Project funding, the first $4 million of a potential $47 million award from the U.S. Department of Energy to design, manufacture, and deploy two full-scale (6 MW) floating offshore wind turbines. UMaine's industrial partners have pledged another $30 million so far in the pursuit of these objectives. The first turbine is planned for installation in 2016 in the Gulf of Maine.

* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

Major Activities: The test program subsequently described in this report was performed at MARIN (Maritime Research Institute Netherlands) in Wageningen, the Netherlands. The models considered consisted of the horizontal axis, NREL 5 MW Reference Wind Turbine (Jonkman *et al.*, 2009) with a flexible tower affixed atop three distinct platforms: a tension leg platform (TLP), a spar-buoy modeled after the OC3 Hywind (Jonkman, 2010) and a semi-submersible. The three generic platform designs were intended to cover the spectrum of currently investigated concepts, each based on

proven floating offshore structure technology. The models were tested under Froude scale wind and wave loads. The high-quality wind environments, unique to these tests, were realized in the offshore basin via a novel wind machine which exhibits negligible swirl and low turbulence intensity in the flow field. Recorded data from the floating wind turbine models included rotor torque and position, tower top and base forces and moments, mooring line tensions, six-axis platform motions and accelerations at key locations on the nacelle, tower, and platform. A large number of tests were performed ranging from simple free-decay tests to complex operating conditions with irregular sea states and dynamic winds.

Specific Objectives:

Significant Results:

With the data in hand, analysis of the floating wind turbine responses revealed several of the unique dynamic behaviors of the various floating wind turbine concepts. In particular, the tests highlighted the interplay of the combined wind and wave forcing on floating wind turbine motions and structural load behavior. After analyzing the response of the floating wind turbine concepts, the data was used to validate the floating wind turbine simulator FAST through correlation of the numerical simulation output and test data for the three floating wind turbine types. In addition, validation of coupled simulators other than FAST was also undertaken. A much greater understanding of the strengths and weaknesses of the FAST tool was established through these efforts. In addition to the validation of FAST, several other simulators were investigated many of which utilized more sophisticated hydrodynamics and mooring modules than the standard FAST tools. These efforts were quite helpful in providing suggested improvements for addressing the shortcomings of FAST's fluid-structure interaction calculations. An additional benefit of the validation exercises was the identification of several possibilities for improving model testing procedures for future floating wind turbine wind/wave basin model tests.

Key outcomes or
Other achievements:

*** What opportunities for training and professional development has the project provided?**

The faculty, research staff, graduate students, and undergraduate students involved in this program have become the only researchers worldwide to have conducted side-be-side comparisons of the three basic floating platform types in a wind/wave date.

The research, testing, and offshore engineering skills and experience provided by Technip, MMA, and National Renewable Energy Laboratory/National Wind Technology Center have expanded the capacity of UMaine considerably. Dr. Andrew Goupee of UMaine has continued working with researchers in these organizations to improve on the numerical models provided by National Wind Technology Center.

*** How have the results been disseminated to communities of interest?**

The scale model test program conclusions have been disseminated through conferences and scientific journals, a selection of which are below:

A.J. Coulling, A.J. Goupee, A.N. Robertson, J.M. Jonkman and H.J. Dagher, 2013, Validation of a FAST semi-submersible floating wind turbine model with DeepCwind test data, Journal of Renewable and Sustainable Energy 5, 023116.

A.J. Goupee, B.J. Koo, K. Lambrakos and R.W. Kimball, "Model tests for three floating wind turbine concepts," Proceedings of the 2012 Offshore Technology Conference, Houston, Texas, USA, 30 April-3 May 2012.

Goupee, A.J., Koo, B, Kimball, R.W., Lambrakos, K.F. and Dagher, H.J., " Experimental Comparison of Three Floating Wind Turbine Concepts," Proc. 31st ASME International Conference on Offshore Mechanics and Arctic

Engineering, Rio de Janeiro, Brazil.

A. Jain, A.N. Robertson, J.M. Jonkman, A.J. Goupee and R.W. Swift, “FAST code verification of scaling laws for DeepCwind floating wind system tests,” Proceedings of the 22nd International Offshore and Polar Engineering Conference, Rhodes, Greece, 17-22 June 2012, pp. 355-365

B. Koo, A.J. Goupee, K. Lambrakos and R.W. Kimball, “Model tests for a floating wind turbine on three different floaters,” Proceedings of the 31st ASME International Conference on Offshore Mechanics and Arctic Engineering, Rio de Janeiro, Brazil, 1-6 July, 2012.

B. Koo, A.J. Goupee, K. Lambrakos and H.-J. Lim, 2013, Model test correlation study for a floating wind turbine on a tension leg platform, Proceedings of OMAE 2013, ASME 32nd International Conference on Offshore Mechanics and Arctic Engineering, Nantes, France, June 9-14, 2013, accepted for publication.

Martin H., 2011, Development of a Scale model Wind Turbine for Testing of Offshore Floating Wind Turbine Systems, M.S. Thesis, University of Maine.

H.R. Martin, R.W. Kimball, A.M. Viselli and A.J. Goupee, “Methodology for wind/wave basin testing of floating offshore wind turbines,” Proceedings of the 31st ASME International Conference on Offshore Mechanics and Arctic Engineering, Rio de Janeiro, Brazil, 1-6 July, 2012.

University of Maine and James W. Sewall Company, “Maine deepwater offshore wind report,” February 2011.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
20130614_NSFPFI_final_Part1.pdf	Part 1 of final report	James Ward	06/19/2013
20130614_NSFPFI_final_Part2.pdf	Part 2 of final report	James Ward	06/19/2013
20130614_NSFPFI_final_Part3.pdf	Part 3 of final report	James Ward	06/19/2013
20130614_NSFPFI_final_Part4.pdf	Part 4 of final report	James Ward	06/19/2013

Products

Books

Book Chapters

Conference Papers and Presentations

B. Koo, A.J. Goupee, K. Lambrakos and R. Kimball, (2012). *, Model tests for a floating wind turbine on three different floaters*. OMAE 2012, ASME 31stInternational Conference on Offshore Mechanics and Arctic Engineering. Rio de Janeiro, Brazil. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

M. Masciola, A. Robertson, J. Jonkman, A. Coulling and A. Goupee (2013). *Assessment of the importance of mooring dynamics on the global response of the DeepCwind floating semi-submersible offshore wind turbine*. ISOPE 2013, The 23rd International Ocean and Polar Engineering Conference. Alaska. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

A. Jain, A.N. Robertson, J.M. Jonkman, A.J. Goupee, A.H.P. Swift (2013). *A comparison of*

calibration and validation of FAST code numerical models of the DeepCwind floating wind turbine systems with 1:50-scale tank data. ISOPE 2013, The 23rd International Ocean and Polar Engineering Conference. Alaska. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

M.J. Fowler, R.W. Kimball, D.A. Thomas III and A.J. Goupee (2013). *Design and testing of scale model wind turbines for use in wind/wave basin model tests of floating offshore wind turbines*. OMAE 2013, ASME 32nd International Conference on Offshore Mechanics and Arctic Engineering. Nantes, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

A.J. Coulling, A.J. Goupee, A.N. Robertson and J.M. Jonkman (2013). *Importance of secondorder difference-frequency wavediffraction forces in the validation of a FAST semisubmersible floating wind turbine model,*. OMAE 2013, ASME 32ndInternational Conference on Offshore Mechanics and Arctic Engineering. Nantes, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

A.J. Goupee, B. Koo, K. Lambrakos and R. Kimball, (2012). *Model tests for three floating wind turbine concepts*. Offshore Technology Conference 2012. Houston, texas. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

R.W. Kimball, A.J. Goupee, A.J. Coulling and H.J. Dagher (2012). *Model test comparisons of TLP, spar-buoy and semisubmersible floating offshore wind turbine systems*. SNAME,. Rhode Island. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

B. Koo, A.J. Goupee, K. Lambrakos and H.J. Lim, (2013). *Model test correlation study for a floating wind turbine on a tension leg platform,*. OMAE 2013, ASME 32nd International Conference on Offshore Mechanics and Arctic Engineering. Nantes, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

I. Prowell, A. Robertson, J. Jonkman, G.M. Stewart and A.J. Goupee (2013). *Numerical prediction of experimentally observed scalemodel behavior of an offshore wind turbine supported by a tension-leg platform*. Offshore Technology Conference (OTC 2013. Houston, texas. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

A.N. Robertson, J.M. Jonkman, A.J. Goupee, A.J. Coulling, I. Prowell, J. Browning, M. Masciola and P. Molta (2013). *Summary of conclusions and recommendations drawn from the DeepCwind scaled floating offshore wind system test campaign*. OMAE 2013, ASME 32nd International Conference on Offshore Mechanics and Arctic Engineering. Nantes, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions
Nothing to report.

Journals
A.J. Coulling, A.J. Goupee, A.N. Robertson, J.M. Jonkman and H.J. Dagher (2013). ,Validation of a FAST semi-submersible floating wind turbine model with DeepCwind test data. *Journal of Renewable and Sustainable Energy*. 5 023116. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses
Nothing to report.

Other Products
Nothing to report.

Other Publications

Patents
Nothing to report.

Technologies or Techniques
Nothing to report.

Thesis/Dissertations

Websites
Nothing to report.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Ward, James	PD/PI	1
Dagher, Habib	Co PD/PI	2
Lindyberg, Robert	Co PD/PI	0

Full details of individuals who have worked on the project:

James S Ward
Email: jsward@maine.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Leadership, project strategy

Funding Support: NSF-PFI, U.S. Department of Energy, University of Maine

International Collaboration: Yes, Netherlands
International Travel: No

Habib Dagher
Email: hd@umit.maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Technical leadership, integration into larger offshore wind program at UMaine

Funding Support: NSF-PFI, US Department of Energy

International Collaboration: Yes, Netherlands
International Travel: Yes, Netherlands - 0 years, 0 months, 4 days

Robert Lindyberg
Email: robert.lindyberg@umit.maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 0

Contribution to the Project: Previously helped manage program. No longer works at UMaine.

Funding Support: NSF-PFI, U.S. Department of Energy, industrial testing contracts

International Collaboration: Yes, Netherlands
International Travel: Yes, Netherlands - 0 years, 0 months, 4 days

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
MARIN	Other Nonprofits	The Netherlands
Maine Maritime Academy	Academic Institution	Castine, Maine
NREL/NWTC	Other Nonprofits	Golden, CO
technip	Industrial or Commercial Firms	Houston, texas

Full details of organizations that have been involved as partners:

MARIN

Organization Type: Other Nonprofits
Organization Location: The Netherlands

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: MARIN, an independent research institute specializing in hydrodynamics and nautical research, was contracted by UMaine after an extensive RFP as the official test basin for the spring 2011 tank testing.

Maine Maritime Academy

Organization Type: Academic Institution
Organization Location: Castine, Maine

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Professors Richard Kimball and Barbara Fleck have worked with University of Maine (UMaine) graduate students to develop and test 1/50 scale model wind turbine modeling methods for coupled aeroelastic and hydrodynamic testing. Professor Kimball attended the tank testing in the Netherlands in spring 2011.

NREL/NWTC

Organization Type: Other Nonprofits
Organization Location: Golden, CO

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: NWTC has supplied analytical software for coupled aeroelastic-hydrodynamic testing of floating offshore wind turbines, and has supplied technical personnel and expertise in the development of platform and test specifications. Dr. Amy Robertson, a senior engineer at NWTC specializing in structural dynamics, attended a portion of the tank testing in the Netherlands in spring 2011.

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technip

Organization Type: Industrial or Commercial Firms
Organization Location: Houston, texas

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Technip is a world-leading offshore oil and gas engineering company that has worked closely with the project team to develop functional specification for floating offshore wind platforms, develop a tank testing matrix and specification, and develop a Request for Proposals (RFP) for designers to compete for an intermediate-scale floating turbine deployment in the Gulf of Maine in July 2012. Additionally, Technip has served as an overall project advisor and sent the Senior Technical Advisor for Offshore Technology Services, Dr. Bonjun Koo, to accompany UMaine and MMA to the tank testing in the Netherlands in spring 2011.

What other collaborators or contacts have been involved?

YES

Impacts

What is the impact on the development of the principal discipline(s) of the project?

In order to pursue commercial development of floating wind turbine technology a validated aero-hydro-servo-elastic numerical model is needed to accurately predict the dynamic system behavior for use in efficient design and optimization. Currently, there are very few coupled numerical models for simulating the performance of floating wind turbines. These codes, such as NREL's FAST (Jonkman and Buhl 2005, Jonkman 2007), had yet to be fully validated against real data as little published information of this type currently exists.

The work conducted under this funding significantly improved the understanding of floating platform behavior. Never before had three platform types been compared side-by-side in a wind/wave basin.

What is the impact on other disciplines?
Nothing to report.

What is the impact on the development of human resources?

The research, testing, and offshore engineering skills and experience provided by Technip, MMA, and NREL/NWTC have expanded the capacity of UMaine considerably. Dr. Andrew Goupee of UMaine has continued working with researchers in these organizations to improve on the numerical models provided by NWTC.

Staff and students from UMaine have continued to teach the "Inventing a Floating Platform" activity at schools, workshops, and conferences across the state. Over 2,000 students have been reached in three years.

Each May, middle and high school students participated in the first annual DeepCwind's Windstorm Challenge at UMaine in May. This program, the sister program to the successful Maine Wind Blade Challenge, ask middle and high

school student teams to design, construct, and test a scale model floating platform, and then deliver a sales pitch to a panel of judges. Over 500 Maine students and 30 companies participated in the programs each year.

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?

The numericals tools have been used to help develop a full-scale 6MW floating offshore wind turbine for deployment in 2016.

What is the impact on society beyond science and technology?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Special Requirements

Responses to any special reporting requirements specified in the award terms and conditions, as well as any award specific reporting requirements.
Nothing to report.