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A Review and Comparison of Floating Offshore Wind Turbine Model Experiments

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Abstract

Floating offshore wind turbines provide more access to deeper water than conventional fixed-bottom wind turbines, which expands the viable area for wind energy development, reduces visibility from shore, and can potentially be located in areas with a higher and steadier wind characteristic. However, since floating turbines are in the early prototype stage of development, there are very limited data to use for validating computer models of these machines. This lack of validation increases uncertainty and risk for future installations. In lieu of large scale test turbines, which are expensive to build and operate, a few institutions have conducted small scale experiments in wave basins. This paper will present a review of the past and planned model-scale floating offshore wind turbine experiments, with a focus on types of data collected and challenges encountered by these tests.

The objective of this review is to provide a background for the Integrated Research Program on Wind Energy (IRPWind), specifically for Work Packages 6.1 and 6.2. The goal of these work packages is to create a database of both fixed-bottom and floating offshore wind turbine test cases that can be accessed by researchers to verify and validate computer-aided engineering codes. The database will consist of a number of benchmarks that will validate different parts of a given design code. This review will discuss two model experiments that are likely to be included in the IRPWind database.
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1. Introduction

The offshore wind energy resource worldwide is one of the largest renewable energy sources. Much of this resource is located over deep water, and current fixed-bottom turbine technology may not be an economical solution for developing this deep water resource. Floating offshore wind turbines (FOWT) are being developed that have the potential to economically capture energy over deep water. Floating wind turbines have added benefits, as the ability of being towed out to the energy production site allows for assembly in port, and the potential to be located farther from shore reduces visibility impacts. However, for useful design work to be possible, accurate computer modeling tools are essential. Validation of computer models with full-scale prototype data would be optimal, but there have

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been very few full-scale floating tests, and most of them are proprietary and the data is not available to the research community. Therefore, there have been a number of scaled experiments in wave tanks around the world. This paper will review the literature discussing these experiments and provide comparisons.

2. Description of Floating Experiments

In this section the details of the seven FOWT experiments will be discussed. See Table 1 for a summary of the experimental tests discussed here.

Table 1: FOWT experiment comparisons.

Experiment Name	Scale	Testing Location	Platform Type	Aerodynamic Setup
Spar at NRMI (2009)	1/22.5	NMRI	Spar Buoy	Steady Force
WindFloat (2010)	1/105	UC Berkeley	Semi-submersible	Actuator Disk + Rotating Mass
DeepCWind (2011)	1/50	MARIN	Semi-submersible, Spar Buoy, and Tension-Leg Platform	Full Rotor (Froude-Scaled)
DeepCWind, continued (2013)	1/50	MARIN	Semi-submersible	Full Rotor (Performance Scaled)
Tension-Leg Bouy (2011)	1/100	MARINTEK	Tension-Leg Buoy and Spar Buoy	None
Tension-Leg Bouy (2014)	1/40	IFREMER	Tension-Leg Buoy	None
Concrete Star (2014)	1/40	ECN	Braceless Semi-Submersible	Ducted Fan
MARINTEK Braceless (2015)	1/30	MARINTEK	Braceless Semi-Submersible	Novel Actuator
INNWIND.eu Model Test (2015)	1/60	ECN	10MW Semi-Submersible	Ducted Fan and Froude-scaled Rotor

In 2009, researchers from Kyoto University in Japan performed a 1/22.5 scale experiment using a spar buoy platform (see Fig. 1a) at the National Maritime Research Institute (NMRI) in Tokyo, Japan [1]. Free decay, regular wave, irregular wave tests were conducted. Additionally, tests combining regular waves and the application of a constant force on the top of the tower to replicate a steady thrust force were performed. No other aerodynamic forces or interactions were considered.

The Oregon-based company Principal Power has installed a full-scale prototype of their WindFloat platform off the coast of Portugal. A small-scale (1/105) experiment using this platform (see Fig. 1b) was conducted in 2010 [2]. This experiment utilized an actuator disk to replicate wind thrust, as well as a scaled spinning mass to generate gyroscopic forces as if there was a true rotor. This experiment was mainly used to test platform performance the 100-year wave case, but some regular wave cases were also conducted to get a baseline platform response.

The DeepCWind Consortium, led by the University of Maine, conducted a series of experiments in a wave pool at MARIN in the Netherlands in 2011, and again in 2013 [3,4]. In the 2011 test, a UMaine designed semi-submersible and tension-leg platform as well as a spar buoy based on the OC3 Spar Buoy (see Fig. 1c) [5] were tested at 1/50th scale in a variety of conditions including free decay, regular waves, irregular waves, and wind. This first experiment used a Froude-scaled rotor based on the NREL 5MW blade design. Due to the Reynolds mismatch when Froude scaling, a higher wind speed was used to replicate the full-scale aerodynamic/hydrodynamic force balance. Since the blades for this first test were direct geometric scales of the NREL 5MW blades, the aerodynamic performance did not match expectation at the lower Reynolds numbers of the test, so a second round of testing was performed in 2013 using the semi-submersible platform and a new rotor designed to be equal in performance as the full-scale NREL 5MW rotor.

Researchers from the Norwegian University of Life Sciences (UMB) and the Institute for Energy Technology (IFE) developed and tested a tension-leg buoy platform (see Fig. 1d) [6–8]. A 1/100 scale platform was tested in 2011 and compared to a spar-buoy with more conventional catenary mooring lines in a MARINTEK wave tank, and a 1/40th scale tension-leg buoy was developed and tested in 2014 at IFREMER. These tests were purely hydrodynamic, and as such, did not include a rotor or other actuator to simulate aerodynamics. Free decay, regular wave, and irregular wave tests were conducted for both testing campaigns.

In 2013, a braceless semi-submersible (see Fig. 1e) was tested in Ècole Centrale de Nantes (ECN) wave tank which used a feedback-controlled ducted fan to simulate aerodynamic forces [9]. The braceless semi-submersible, called the Concrete Star Wind Floater, was designed by Dr.techn.Olav Olsen AS, and is designed to use concrete at

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