Novel Approaches for Physical Model Testing of Floating Wind Turbine Platforms

1. Introduction

Accurately assessing the hydrodynamic performance of a floating wind turbine is challenging due to the complex coupling between aerodynamics and hydrodynamics.

Conventional direct testing of a floating wind turbine involves manufacturing the blades and the control system at a reduced scale. In addition to the requirement of a high-quality wind generator system, the manufacture of scaled blades capable of representing the performance of a prototype wind turbine demands extensive efforts. It needs typically ultralight materials to satisfy the requirement of correct mass and inertia properties. Besides, alternation of the blade geometry and surface roughness is required to correctly address the conflict between the Froude scaling (hydrodynamics scaling) and Reynolds scaling (aerodynamics scaling) [1].

Alternative simplified indirect hybrid methods have been proposed to compromise the challenges mentioned above [2]. A hybrid method typically involves applying the corresponding wind turbine thrust to the floating foundation instead of modelling the wind. Some research employs a mean thrust load under a typical wind condition throughout the entire test, while others developed a method called "software-in-the-loop". The idea of the “software-in-the-loop” requires a piece of software that is able to calculate the thrust load acting on the wind turbine with considering the platform motion response. This type of method is able to minimize the aerodynamics scaling issue as the simulation can be done at full scale. On the other hand, the “software-in-the-loop” has its own drawback. For example, the system may experience delays as the system can run at most the speed of the software. The software has to be customized to fit a particular wind turbine and platform design.

The aim of the current project is to identify and validate novel approaches for simulating the wind loading on floating wind turbines in hybrid model tests. In particular the project aims to identify approaches based on meta (or proxy) models of the thrust loading which are simpler and more flexible to implement and run faster than a full “software in the loop” approach, and can be built from response data rather than requiring full details of turbine and controller (which are typically highly sensitive).

2. Project outline

2.1. FAST simulation

A series of coupled aero-hydro-servo-elastic dynamics (AHSE) simulations, using the well-known open-source package *FAST*, has been carried out to provide data for the training of the novel models. The NREL 5MW, as shown in Figure 2-1, a commonly used benchmark model, was selected for further investigation as detailed design information is readily available to the public.

Error! Reference source not found. illustrates a typical simulation result obtained from the FAST simulation. The wind, surge, pitch and their corresponding velocity are chosen to be the input variables to the proxy model and the thrust at the hub is

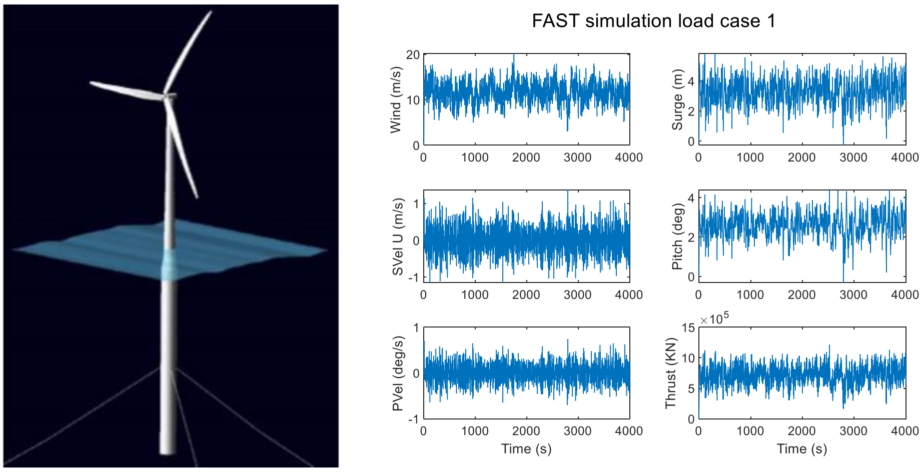


Figure 2-1 Hywind spar with NREL 5MW turbine. Example data is illustrated on the right-hand side.

2.2. Proxy model numerical simulation

UoS focus on the AutoRegressive with Extra input (ARX) model, the ARX model can be implemented as a polynomial equation in the control system and hence can run much faster than a full software simulation. UoP stuided a nero-network based model while UoE investigated a state-space model. It is decided to impelement the ARX model in physical testing because of its simple implementation in the control software.

Series of different training models has been investigated, including both linear and non-linear ARX models. Example comparison between the fast simulation and the corresponding linear ARX model output is demonstrated below. Results suggested the current ARX model is capable of reproducing the FAST simulation.

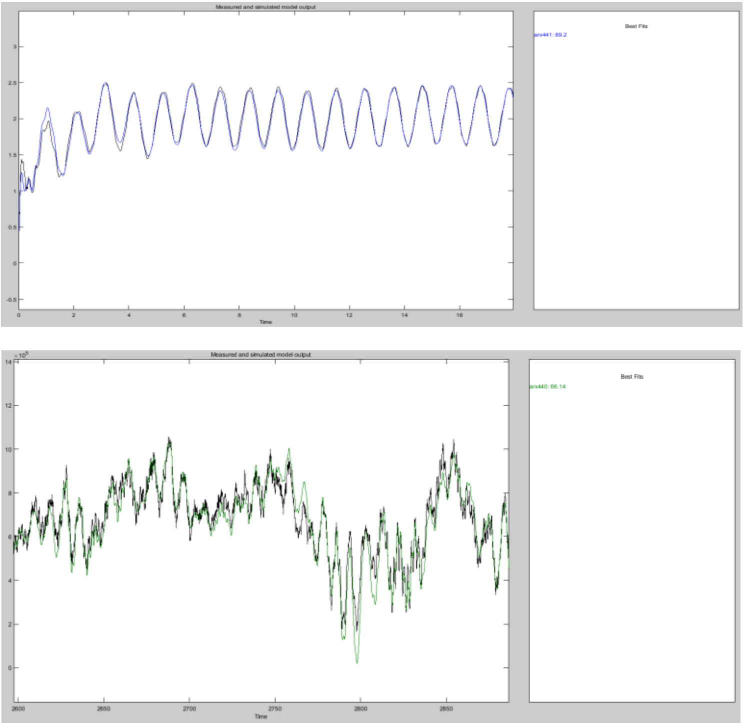
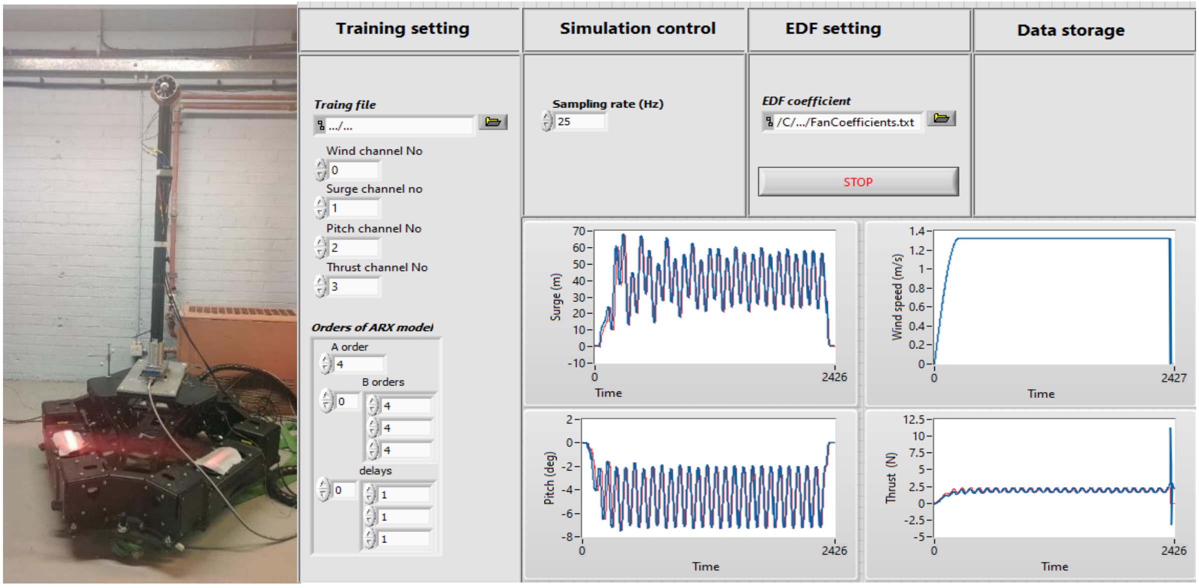


Figure 2-2 Arx model validation results. Regular wave and constant wind (above). Seastate and turbulent wind (down), where the black lines are the FAST simulation thrust. The blue and green lines are the output thrust modeled by the ARX model.

2.3. Hardware implementation and bench test.

After the trained ARX model was validated numerically, the ARX model was physically tested on a 6 degree of freedom motion platform as shown in Figure 2-3. The purpose of this set of test is trying to identify the uncertianties and delays in the hardware implementation.



Training setting

Traing file .../...

Wind channel No 0

Surge channel no 1

Pitch channel No 2

Thrust channel No 3

Orders of ARX model

A order 4

B orders 0 4 4 4

delays 0 1 1 1

Simulation control

Sampling rate (Hz) 25

EDF setting

EDF coefficient /C/.../FanCoefficients.txt

Data storage

Figure 2-3 6DOF motion platform (left), control software (right).

A 74th scaled Hywind tower was built and fitted onto the top of the motion platform. During the test, motion response pre-calculated by the FAST was feed to the platform, and the motion of the platform was measured by Qualysis optical motion measurement system. The measured motion was then fed to the custom made control software (see Figure 2-3) which generate the control signal for the Electrical-Ducted-Fan (EDF). Figure 2-4 illustrated one example comparision between the target thrust and the measured thrust. Clearly, the measured amplitude with the target well. No obvious dely was observed thanks to the simple algothm of ARX model which is not computational demanding.

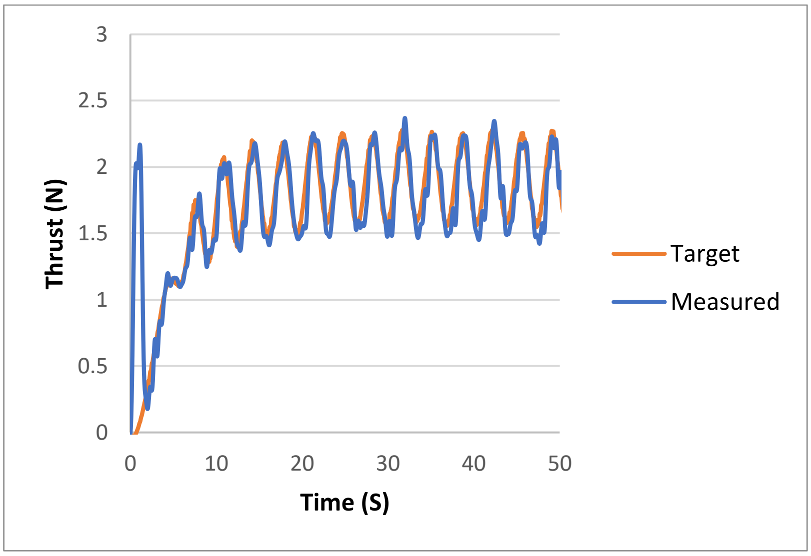


Figure 2-4 Measured EDF output thrust compared with expected target thrust.

2.4. Spar tank testing

After the one-way coupled bench test, the EDF and control system was fitted to a 74th scaled model and tested at the Kelvin Hydrodynamics laboratory. Results of the regular waves are presented from Figure 2-5 to 7. It is clear that the current-ARX model correctly reproduced the damping effect caused by the aerodynamics and hydrodynamics coupling at long wave periods. Comparison between the FAST simulation and the tank test results suggested the current method is cable of accurately reproducing the aerodynamics and hydrodynamics coupling effect accounted by the FAST package. Due to the inputs to the current ARX model is response-based, it is anticipated that the model can reproduce the performance of a full-scale device providing the full-scale measurement data.

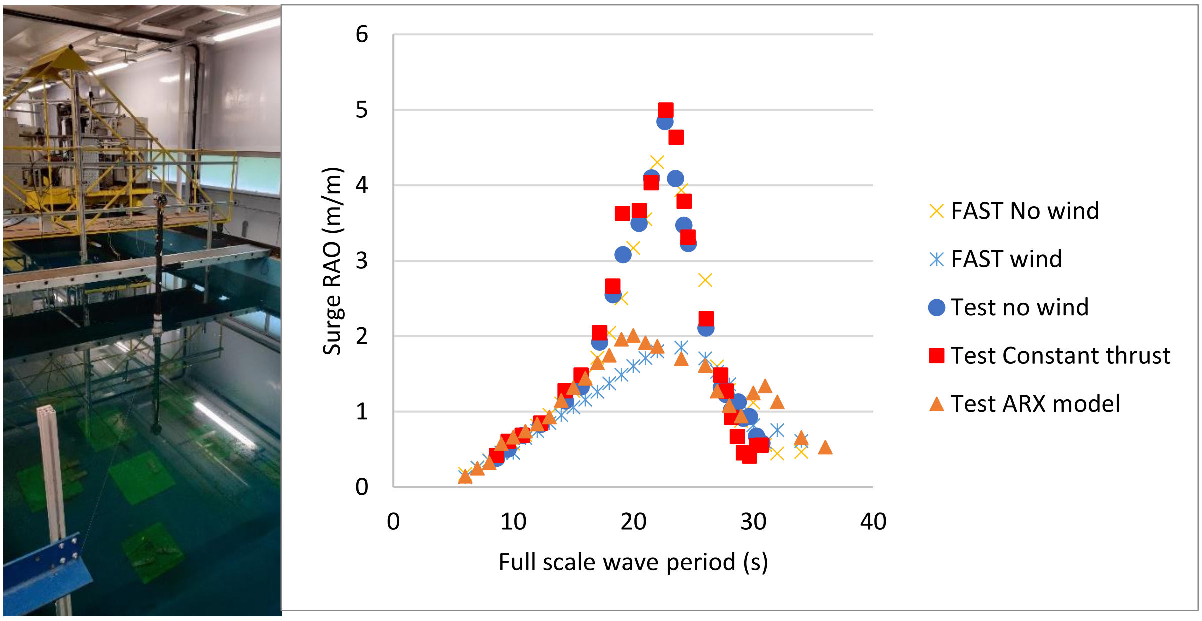


Figure 2-5 Comparision of Surge RAO obtained under different wind load strategies.

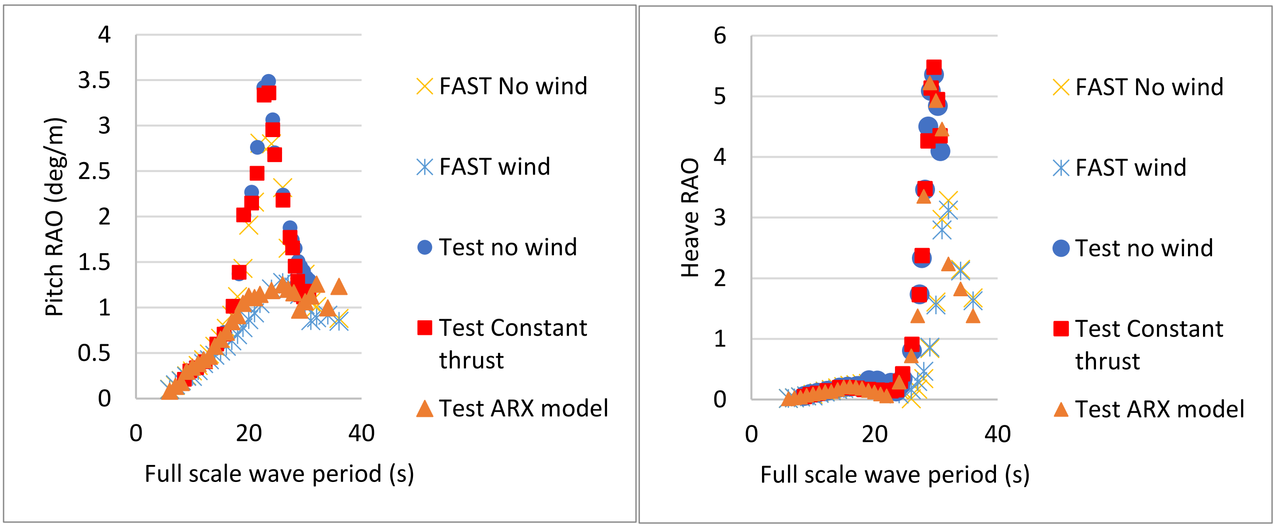


Figure 2-6 Comparision of Pitch and heave RAO obtained under different wind load strategy

Another finding from the test, as suggested by Figure 2-6, is that the constant thrust wind load modelling method does not lead to a meaningful aerodynamics and hydrodynamics coupling effect. In fact, the response operator under constant thrust is more or less identical to that obtained under no wind load condition.

3. Conclusion and future work

The current project successfully developed a simple proxy model that is able to address the coupling between the aerodynamics and hydrodynamics in testing of a floating wind turbine. The developed model does not require extensie computational resource to ensure minimum delay in the excution, and does not need detailed turbine and servo design as it is reponse based. The team is planning to draft a journal manuscript to publish the details of implenting the system in tank testing. It is anticipated that the result of the current project can help wave tanks who does not have wind generators to carry out aero and hydrodynamics coupled floating wind turbine tests.

1. Martin, H.R., et al., *Methodology for wind/wave basin testing of floating offshore wind turbines.* Journal of Offshore Mechanics and Arctic Engineering, 2014. **136**(2).
2. Gueydon, S., I. Bayati, and E. de Ridder, *Discussion of solutions for basin model tests of FOWTs in combined waves and wind.* Ocean Engineering, 2020. **209**: p. 107288.