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D2.1: Database of Wind Tunnel Experiments

STEP4WIND

Training network in floating wind energy

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Document History

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1	First draft	Felipe Novais		20 Oct 2022
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1. Introduction

Due to the complex dynamics involved in Floating Offshore Wind Turbines (FOWTs), whose motions are a compound interaction of turbine, wind, current and waves, there is a necessity for a comprehensive understanding of the servo-aero-hydro-elastic codes utilized during the design and certification processes, demanding the validation and calibration of such tools through high-fidelity simulation or representative data.

Model test of FOWTs is a valuable tool at this early stage of the industry as means to understand the overall dynamics of the system, identify the presence of any unforeseen phenomena, evaluate the system's response under extreme environmental conditions as well as provide a baseline for validating numerical models.

At Politecnico di Milano, several test campaigns were already conducted to better understand the unsteady aerodynamic behavior of turbines when undergoing motions caused by the floating platform. Examples of joint efforts can be seen in UNAFLOW [1] and OC6 [2], where experimental data is utilized as a benchmark for the validation of numerical simulation tools.

Previous experimental test campaigns had as the main objective to investigate the effects of the unsteady aerodynamics of a turbine under pitch and surge motions. However, these previous experiments were conducted utilizing a fixed rotor speed as well as at a constant pitch angle. Nevertheless, operational modern wind turbines utilize controllers that constantly adjust these parameters according to the inflow conditions.

The present work brings the description of an experiment conducted in July of 2022 as part of the STEP4WIND project. The data provided consists of a series of tests investigating the effects of the pitch motion both with the turbine under fixed rotational speed and with a controller implemented.

2. Experimental Setup

The test campaign was conducted at the boundary layer test section of the GVPM wind tunnel at Politecnico di Milano. The utilized section is 13.84 meters wide, 3.84 meters high and 35 meters long. A sketch of the wind tunnel is shown in Figure 1.

1. Turbine Model Characteristics

Rotor Diameter	2.400 m
Blade length	1.110 m
Hub diameter	0.180 m
Rotor overhang	0.139 m
Tilt angle	5.000 °
Tower to shaft	0.064 m
Tower diameter	0.075 m
Tower length	1.400 m
Nacelle mass	1.975 kg
Blade mass	0.240 kg
Rotor mass	2.041 kg
Tower mass	2.190 kg

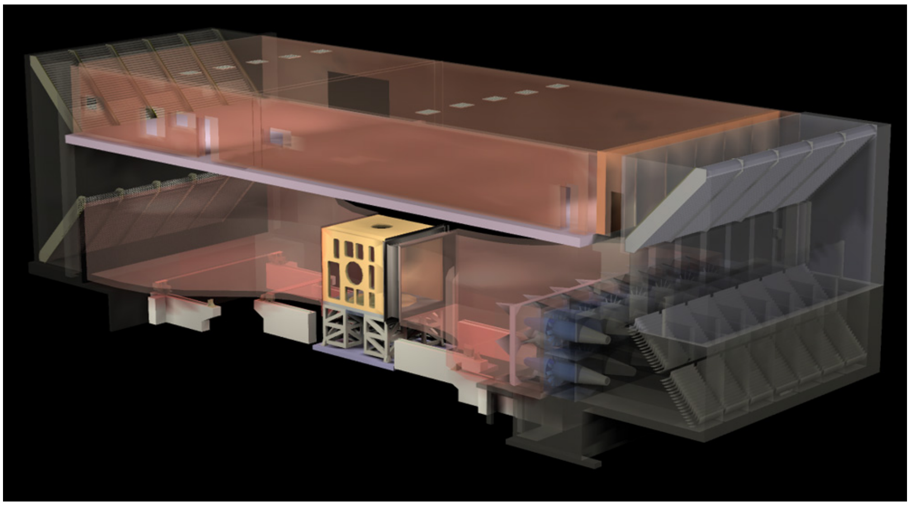

Figure 1. Render of the GPVM Wind Tunnel at Politecnico di Milano.

The experiment utilized a turbine that is a 1:100 scale model of the open-source IEA 15-MW model [3] following a scaling procedure to match the thrust $C_t$and power coefficients C_p of the full-scale system. The rotor has previously been tested in [4]. Table 1 shows an overview of the main parameters of the turbine model and Figure 2 presents a picture of the full setup mounted during the test campaign.

Figure 2. Experimental setup.

3. ROSCO Controller

The wind turbine had active generator torque control and collective blade pitch control. The controller is the Reference Open-Source Controller (ROSCO) [5], and the controller functionalities used in the experiment are:

- Generator torque controller: tip-speed ratio tracking below rated and constant torque above rated.
- Set point smoother.
- Wind speed from filtered hub-height wind speed measured with the pitot tube upwind the turbine model.

The other functionalities of ROSCO were excluded.

The ROSCO was implemented in Simulink and compiled as a DLL to run on a NI PXIe-8133. A NI PXI-7841R FPGA board provided the I/O interface with the turbine model. The controller was run at model scale, at a frequency of 1kHz. Accordingly, all the controller parameters were defined at model scale and are provided as an input file in the standard Bladed-style DISCON interface format (compatible with ROSCO version 2.5.0). The DISCON file utilized is provided with the dataset.

4. Measurement and Post-Processing

The main measurements were derived as depicted bellow:

- Tower top loads: Tower-top loads are measured with an ATI Mini45 6-components force transducer connected at the interface between the tower-top and RNA connection flange.
- Platform motions: a laser transducer is utilized to measure the displacement of the turbine.
- Generator speed and torque: The effective generator speed is obtained from a magnetic encoder connected to the wind turbine scale model torque unit. The effective generator torque is computed from the actual current reading of the torque actuator.

The aerodynamic forces are derived from the measured loads by the 6-component load cell. For each test, prior to conducting the experiment with a spinning rotor, the forces are also measured without wind and with a standstill rotor for the same amplitudes and frequency conditions. The time series of the force measured with wind is then subtracted by the force measurement without wind. An example of the inertia subtraction procedure and synchronization of the measurements is shown in Figure 3, where NOW stands for the test without wind and with zero rotor speed whilst SIW is the test with wind and active rotor for a given frequency and amplitude. The synchronization of the measured pitch position is done by performing a cross-correlation between the time series with and without wind. This process of utilizing the subtraction procedure with the tests in motion is needed to circumvent the difficulties in evaluating the inertia properties of the rotor, resulting in higher accuracy of the measured shear forces, since the inertia forces are quite significant and therefore, its contribution must be deducted from the transducer measurements.

The measured signal by the force transducer had a sampling frequency of 2 kHz and subsequently in the post-processing was averaged for every 10 sets of samples, therefore, the data provided has a sampling rate of 0.0005 seconds for each channel. The data has not been previously filtered, so it is up to the user to define its methodology for removing the noise accordingly to which goal wants to be achieved with the utilization of the data, and that way, avoid removing relevant frequencies that should be included. A generic example of how to perform the data filtering is provided in Figure 4, where a band-pass filter is applied by extracting only the information related to the frequency component of the imposed motion.

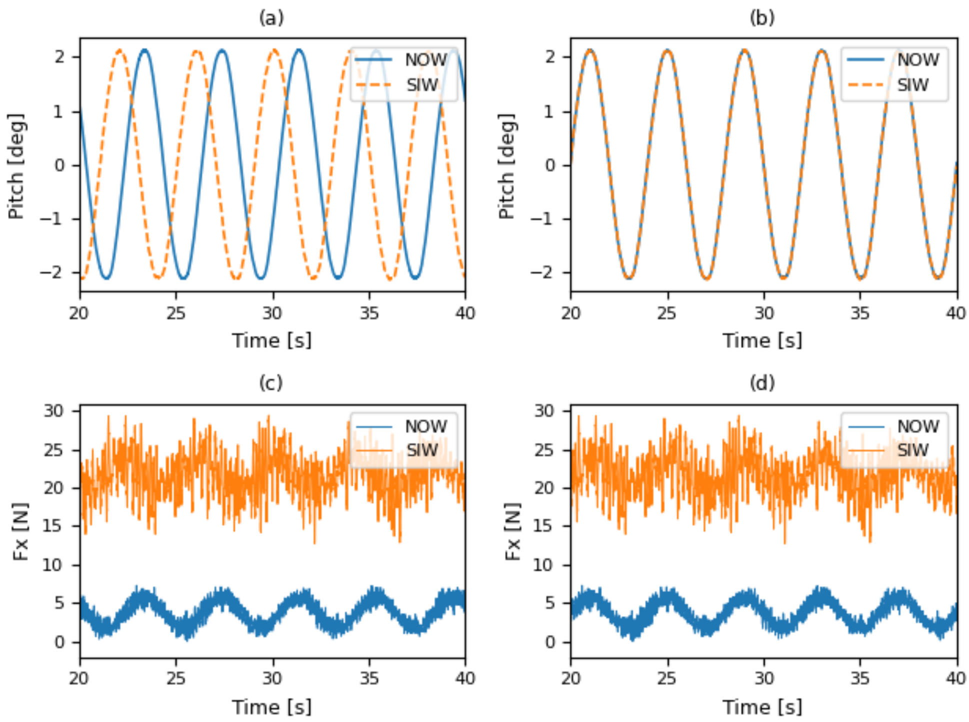

Figure 3. (a) and (b) illustrate the process of signal synchronization. (c) and (d) show the measure force signal before and after, respectively, the time-shift adjustment.

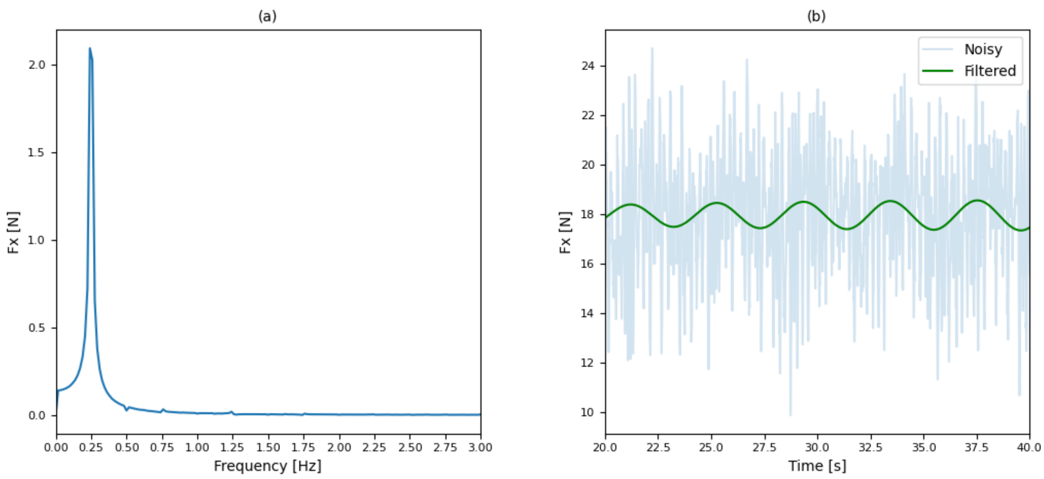

Figure 4. (a) shows the detection of the imposed motion frequency. (b) shows the filtered signal force signal after all the frequencies not related to the imposed motion were filtered.

5. Test Matrix

The tests performed consisted of progressively increasing the motion frequency of the hexapod. The frequency values displayed in Table 2 are in model scale and range from 0.25 Hz to 2 Hz, with the upper boundary being set by the limitations of the experimental setup and to avoid the 1P rotor passing frequency. The sampling time for each test is of around 60 seconds, with slices of the data deducted due to the synchronization procedure done for the inertia subtraction. For each frequency, three different amplitudes were selected, as the pitch period decreased, the idea behind this is to understand, for each frequency, the effect that the different amplitudes have over the aerodynamic quantities and behaviour of the controller. However, it was also necessary to decrease the range of the pitch motion due to the acceleration limits of the hexapod, so as progressively as the frequency of the pitch motion increases, the more restrictive are the boundary conditions of the ranges of the hexapod displacement. Each test was repeated for two sets of wind conditions, below rated, 2.87 m/s, and above rated, 5 m/s.

The two inflow conditions were chosen due to the fact that each represents a different region of operation of modern wind turbine controllers. For the above-rated condition, at 5 m/s, the blade pitch control regulates the rotor speed, maintaining fixed power output. On the other hand, for the bellow-rated wind condition, 2.87 m/s, the objective of the turbine is to maximize the power production by adjusting the torque to achieve the optimal tip speed ratio, and in this case, the blade pitch angle is set constant. Figure 5 illustrates the differences between the two operating conditions for a test with the same amplitude and frequency but different wind conditions.

Table 2. Test Matrix

Frequency [Hz]	Amplitude [deg]
0.25	3
0.25	2
0.25	1
0.75	3
0.75	2
0.75	1
1.25	2
1.25	1.5
1.25	1
1.5	1.75
1.5	1.5
1.5	1
1.75	1
1.75	0.75
1.75	0.5
2	0.75
2	0.5
2	0.25

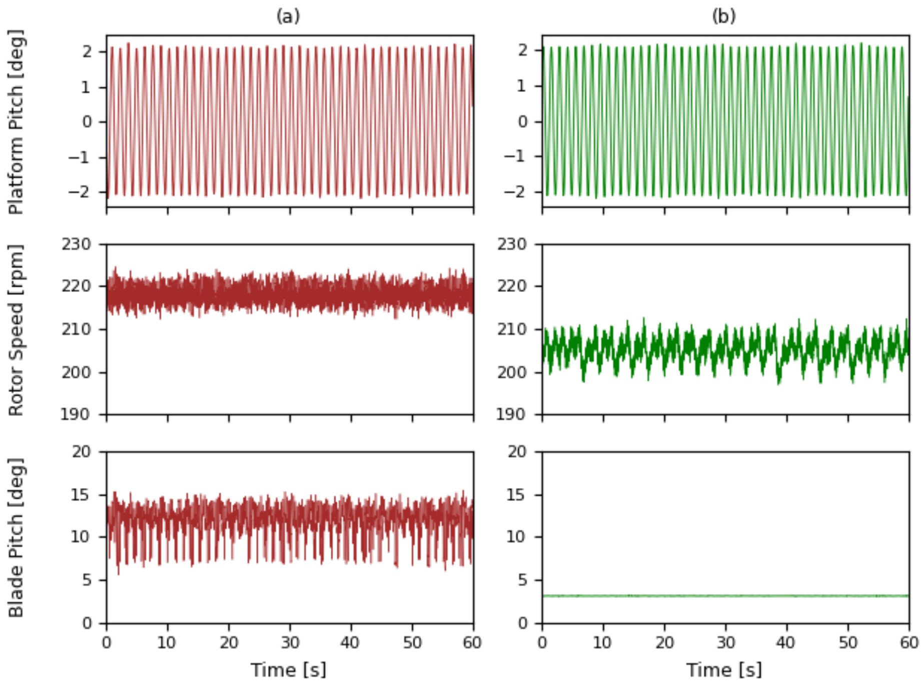

Figure 5. (a) represents a case with the turbine operating in region III whereas (b) shows a test applying the same frequency and amplitude of the pitch motion but in this case with the turbine operating in region II.

6. Dataset

The data files are given in tab-delimited file format. Each file contains the sampling time, pitch displacement, rotor speed, blade pitch, aerodynamic thrust, and mechanical torque. A description of each column and its respective units is presented in Table 3. A time series could be visualized in Figure 6, displaying the acquired signals for a test with a pitch amplitude of 2 degrees and a frequency of 0.5 Hz. The naming convention utilized for each data file is the following:

WindCondition_MotionFrequency_MotionAmplitude_Controller_SF.dat

- WindConditions: Consists in the wind tunnel speed. BR stands for bellow rated, 2.87 m/s at model scale, and AR, which is the above rated condition, 5 m/s at model scale.
- MotionFrequency: Imposed pitch frequency ranging from 0.25 to 2 Hz on model scale.
- MotionAmplitude: Imposed pitch amplitude ranging from 0.25 to 3 degrees on model scale.
- Controller: Indicates whether the ROSCO controller was activated or not. SIW stands for tests with fixed rotor speed whereas SIWC means that the tests were conducted with an active controller.
- SF: Wind speed scale factor utilized. Either 3 or 3.5.

Table 3. Headers of each file.

Column Name	Units	Description
Time	s	Sampling Time
Pos	deg	Platform Pitch Displacement
RotSpd	rpm	Rotor Speed
BldPitch	deg	Blade Pitch Angle.
Fx	N	Tower-Top X Shear Force.
Mx	Nm	Tower-Top X Moment

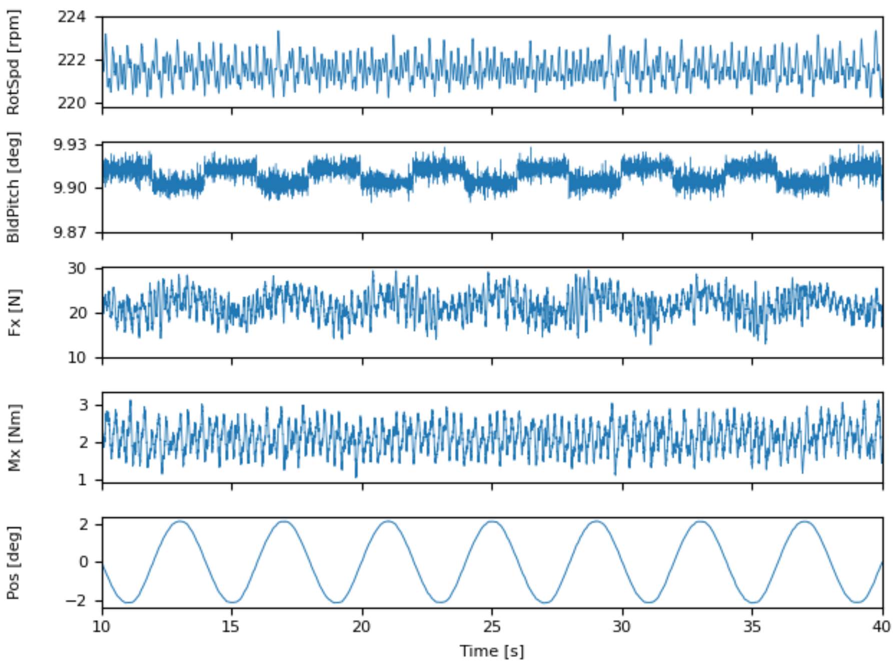

Figure 6. Time series of a test sample with fixed rotor speed and fixed blade pitch.

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