OC6 semisubmersible response to waves in offset positions caused by constant thrust loads

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Abstract. In 2019, a semisubmersible floating wind foundation was tested in the Concept Basin of MARIN in waves and under several levels of constant thrust. This paper compares the motion of the floater and the tensions in its mooring lines in waves under different levels of thrust. The end goal of this work is to present experimental results of the response of a floating wind turbine semisubmersible under the combined effects of waves and constant thrust. As these new experiments were focused on the hydrodynamic response of the floater in its offset position, their results represent reference data for the validation of numerical tools that account for this offset in the calculation of the hydrodynamic loading and response.

1. Introduction

In 2018, a semisubmersible floating wind foundation was tested in the Concept Basin of MARIN in wave only conditions. These test results have been used as reference data for the validation of a variety of engineering and high fidelity simulation tools during the phase I of the OC6 project led by NREL ([1]). As a complement to these model tests, MARIN proceeded with a new series of tests of the moored floater under waves and constant thrust. The rigid tower of the OC6 model used in 2018 was replaced by a wind turbine equivalent to the one of the OC5-DeepCwind semisubmersible ([2]) with increased rigidity. The wind turbine loads were emulated by a ducted fan (Fig. 1), which has been run with fixed rotation speeds to produce multiple levels of steady thrust. The test matrix included the same waves as for the OC6 campaign but this time with the addition of tests with constant thrust of several levels. The semisubmersible drifted and tilted as a consequence of the constant thrust. The tilted configurations of the floater are a novelty that brings this set of experimental data closer to real operational conditions of a floating foundation for wind turbines than the OC6 experiments. This will represent an additional challenge for future comparison with numerical tools. First, this paper explains how the test set-up of the OC6 was adapted to include the thrust. Then it compares the motion of the
floater and the tensions in its mooring lines under different levels of thrust. The waves of the OC6 campaign have been repeated for several RPM settings of the fan to allow for the investigation of the response of the semisubmersible under tilted conditions. This comparison brings to light what the main effects of the thrust on the motions and the mooring line tensions are.

2. Adaptation of the OC6 experimental set-up to account for the wind turbine thrust
The set-up of the OC6 campaign has been used as a starting point for this new series of model-tests. The floater and the mooring system of the OC6 model-tests were used again for these tests. The basin and the position of the set-up in the basin were kept identical as they were for the configuration 1 of the OC6 model-tests. Figures 3 and 4 show the experimental set-up of the OC6 campaign and a sketch of its mooring system. Only the tower was replaced by a new tower that had the same length as the tower of the DeepCwind experiments of 2013 used for the OC5 project [3]. On the other hand, the new tower was made as stiff as possible by using a very stout tube and tensioning 3 guy wires from its top to the columns of the semisubmersible. The wind turbine steady thrust loads were emulated by a ducted fan mounted on top of this tower. A force balance designed and engineered by MARIN was placed underneath the fan. This force balance was used to monitor the thrust exerted by the fan in real time during every experiment. Details of the new experimental set-up including the new tower, the fan and the load frame are visible on Fig 1.

3. Main characteristics of the tested system and resemblance with previous systems
This semisubmersible platform has been tested numerous times in many different facilities. MARIN alone has used this floater in 6 different testing campaigns earlier than this new series of model-tests. As previously mentioned, the present system borrows elements from systems tested in 2013 and 2018 (i.e. some characteristics of the tower used in 2013, the mooring system and the waves of the campaign of 2018). It is interesting to give the main characteristics of these systems in a single table to grasp their similarities and differences. For brevity’s sake, the new system is called OCF, whereas the system tested in 2018 is given the name of OC6 and the one tested by the DeepCwind consortium in 2013 is named OC5.

The OC6 campaign was motivated by the need for simplification of the OC5 test set-up with the objective to study the response of the floater to waves only [4]. Considering the resemblance of the OCF and OC5 systems’ mass distribution, it can be claimed that the OCF system is a simplification of
the OC5 system that is now aiming at studying the effects of constant thrust on the response of the semisubmersible to waves.

Table 1 Main characteristics of the semisubmersible systems for 3 distinct testing campaigns given at full scale

|                  | OC5         | OC6         | OCF         |
|------------------|-------------|-------------|-------------|
| Mass             | 13958 ton   | 14196 ton   | 14158 ton   |
| Draft            | 20 m        | 20 m        | 20 m        |
| Water depth      | 200 m       | 180 m       | 180 m       |
| Vertical position of CoG w.r.t. keel | 11.93 m | 12.47 m | 12.50 m |
| Pitch radius of gyration | 33.38 m | 30.1 m | 31.05 m |
| Hub height       | 90.0 m      | -           | 90.0 m      |
| Tower fore-aft 1st bending frequency | 0.32 Hz | Considered rigid | Considered rigid |
| Surge natural period | 106.7 s | 104.1 s | 102.6 s |
| Heave natural period | 17.5 s | 17.2 s | 17.2 s |
| Pitch natural period | 32.5 s | 30.7 s | 31.5 s |

4. Metrics used for the comparison of results of model-tests

The responses of the system in different offset positions are compared by looking at the mean value and standard deviation of every measured signal. For the tests in irregular waves, the power spectral densities (PSD) and the response amplitude operators (RAO) are also determined and compared. The wave elevation measurement during the calibration test (i.e. with no model in the basin) is used as reference signal for the RAOs. In addition, two response metrics of a previous study on the same floater [1] are presented in this paper. These are:

M2. **PSD Sum, Low Frequencies**: the integral of the power spectral density (PSD) of surge and pitch motions over the low-frequency range;

M3. **PSD Sum, Wave Frequencies**: the integral of the PSD of surge and pitch motions over the wave-frequency range.

The frequency ranges considered in the determination of M2 and M3 for the two irregular waves are given in Table 2.

Table 2: Frequency limits for summation of power spectral density function for response metrics M1 and M2

| Wave                  | Low-frequency window (M2) | Wave-frequency window (M3) |
|-----------------------|----------------------------|----------------------------|
| White noise           | 0.031 rad/s – 0.234 rad/s | 0.234 rad/s – 0.88 rad/s   |
| Irregular wave        | 0.031 rad/s – 0.314 rad/s | 0.314 rad/s – 0.88 rad/s   |

5. Resemblance with the OC6 experimental results (with no wind)

As the OCF and OC6 are based on the same floater, same mooring system and same basin, there are many of similarities between the response of these two systems when tested in waves only.
5.1. Surge restoring characteristics
For both systems, static load tests were done during which the floater is pulled in the surge positive and negative directions by a system of pulleys and weights. For both OC6 and OCF systems, the mooring arrangement is very linear and the stiffness values obtained from these curves are very close to each other (about 3% difference).

5.2. Response in wave only
Results of the moored semisubmersible in waves are presented for the OC6 and OCF systems to establish their level of similitude. Identical wave realizations were used for the OC6 and OCF model tests. Table 2 contains the 2 regular waves and 2 irregular waves that were generated during these tests. The irregular sea state follows a Joint North Sea Wave Project (JONSWAP) spectrum representative of a yearly storm event in the Gulf of Maine [6].

Table 3 Wave conditions for OC6 and OCF campaigns

| Test Name         | Waves            |
|-------------------|------------------|
| Regular wave 1    | H=7.1 m, T=12.1 s |
| Regular wave 2    | H=4 m, T=9 s     |
| White noise       | Hs=7.1 m, T=6-26 s |
| Irregular wave    | Hs=7.1 m, Tp=12.1 s |

The motions of the floater are given by looking at the displacements of a point located at mid-ship, centre-line, water line. As all tests are done in head waves, only the surge, the heave and the pitch motions are reported here. The other motions were measured and analyzed but they are not reported here for conciseness. However, they were similarly small. The tensions in the mooring lines are measured at the fairleads (i.e. the connection with the floater).

5.2.1. Regular wave 1. For the first regular wave the mean values and the standard deviation (STD) of the quantities of interest are shown in bar plots (Fig. 4-7). Each bar plot displays the results for the 6 repeats of this wave during the OC6 tests in addition to the results of the new test labelled OCF. The wave statistics of OCF are within the variations observed between the repeats of the OC6 tests. As the OC6 and OCF systems present some differences in their mass distribution (e.g. position of the CoG and radius of gyration) and mooring line pre-tensions, the initial position and orientation of the model in these two campaigns were slightly different. Also, the point around which the floater rotates isn’t precisely the same for these two systems. From the observation of the pitch mean values of Fig. 6, a trim angle of -0.12 deg was present in the OCF tests whereas the trim angle during the OC6 tests was closer to zero (even slightly positive for the first repeat with 0.04 deg). This difference in the vertical orientation of the semisubmersible at rest results in a surge offset that is observed in the mean value of surge (Fig. 5). This trim angle is also shifting the fairlead position of the front line upwards and the fairleads of the side lines downwards which impacts the pre-tensions in all mooring lines. Figure 7 contains the statistics of the line in front of the semisubmersible (moored to the front column). The standard deviations of the tensions in the mooring lines are influenced by the level of pre-tension and the surge and pitch motion of the floater as these will lead to different local motions at the fairleads for the two different systems. Despite these differences, there is a great level of similarity between the results of OC6 and OCF in regular wave 1.

5.2.2. Regular wave 2. For this wave, they were only two repeats done during the OC6 campaign. The most striking differences were again found in the mean values of surge and pitch (not shown here). These can also be explained by the difference in the mass distribution and related initial pitch angle difference between the OC6 system and the OCF system. Interestingly enough, the two repeats of OC6 had also different surge and pitch mean values, which shows the great sensitivity of the OC6 system to
any change in the experimental set-up that may happen in the duration of the campaign (like a small modification of the pre-tension for instance). Nevertheless, the test results are overall similar between the two systems OC6 and OCF.

5.2.3. White-noise wave. Except for the surge and pitch mean values and in lesser extend their standard deviations, the other statistics were similar between the OC6 and OCF systems (not shown). For this irregular waves, the power density spectra (PSD) of the most interesting signals are presented: wave (Fig. 8), surge, heave and pitch on the same plot (Fig. 9). Globally, there is a good resemblance between the responses of the OC6 and OCF system. The PSDs highlight the great similarities in low frequencies while the RAOs show the resemblance in the wave frequency range (not shown). The three vertical dash-lines of Fig. 9 correspond to the frequencies of Table 2. They delimit the windows used for the calculations of the low-frequency PSD sum (LF PSD sum) and wave-frequency PSD sum (WF PSD sum), which results are shown on Fig. 10 for the motions and Fig. 11 for the mooring line tensions. While the PSD sums over the wave frequency range are almost equal for the heave motion for both OC6 and OCF systems, small differences can be seen for the surge and pitch motions. Differences in surge were already pointed out in the mean values and standard deviation values (Fig. 5). The differences in the pitch rotations of the OCF and the OC6 responses are consistently present in the statistic data (Fig. 6) and low frequency and wave frequency PSD sum results. These small differences can be explained by the small variations of the CoG’s position, the equilibrium trim angle, the surge and pitch natural periods between the OCF and OC6 systems. The PSD sums of the tensions in the 3 mooring lines (Fig. 11) are globally similar for the low frequencies and the wave frequencies for the two systems.

5.2.4. JONSWAP wave. The comparison of the results of OC6 and OCF for this wave is not reported to save space. The observations were perfectly in line with those of the White-noise wave.
The results of the OCF campaign are very close to the results of the OC6 campaign. Moreover, the differences are understood and small in comparison with differences reported between others experiments of the same systems [7].

![Image of white-noise wave PSD](image1)

Figure 8 White-noise wave PSD (3 vertical dashed lines delimiting the frequency windows for the calculation of the PSD sums M2 and M3)

![Image of surge, heave and pitch PSDs](image2)

Figure 9 Surge, heave and pitch PSDs for the white-noise wave (3 vertical dashed lines delimiting the frequency windows for M2 and M3)

![Image of surge, heave and pitch PSD sums](image3)

Figure 10 Surge, heave and pitch PSD sums M2 (left) and M3 (right)

![Image of front and side mooring line tension PSD sums](image4)

Figure 11 Front and side mooring line tension PSD sums M2 (Left) and M3 (right)

6. Tests with constant thrust
The added value of OCF with respect to OC6 resides in the possibility to generate a constant thrust at the top of the wind turbine tower. This new series of tests provides data where the floater has drifted away and tilted under the effect of constant thrust. The thrust is delivered by a ducted fan. The ducted fan is commanded by setting the rotation speed of the fan to a fixed value of rotation per minute (rpm) for each test. By setting the rpm to a fixed value, no variation of the thrust with the motion of the hub are accounted for and the aerodynamic damping of the wind turbine are thus omitted in these
experiments. The rpm settings were chosen to cover a range of thrust values for which floating wind turbines may be tested in this basin (4N to 12N in the basin). For scaling factors varying from 50 to 65, a wide range of wind turbines (4MW to 20 MW) would deliver a thrust at rated wind speed that falls in this range. First, the relation between the fan’s rotation velocity and the thrust is discussed. Then the influence of the thrust on the responses of the semisubmersible to waves is examined.

6.1. Relation between fixed rpm settings and thrust

This section presents results of the tests in which the moored semisubmersible is submitted to constant thrust while laying in still water. First of all, the relation between levels of rpm and monitored thrust is shown (Fig. 12). This relation is quasi-linear. It is noted that for a requested level of rpm the measured thrust is not precisely constant but exhibits small variations around its mean value. However these variations represent less than a few percentages of the mean thrust for each rpm setting. It was also seen that the semisubmersible got to a stable pitch angle under the effect of the constant thrust.

6.2. Responses under the combined effects of waves and constant thrust

Results of the moored semisubmersible in waves and steady wind are presented and discussed in this sub-section. First, tests in regular waves for different fixed rpm settings of the fan are analyzed. Then, tests in irregular waves with a succession of fixed rpm settings are looked at. The wave realization was kept the same when the rpm setting changed with the goal of having identical wave time series. The combinations that were tested are reported in Table 4. The main objective of this chapter is to discuss the evolutions of the motion responses and mooring line tensions for various levels of rpm settings, each corresponding to a constant level of thrust.

| Test Name          | Waves       | Rpm settings |
|--------------------|-------------|--------------|
| Regular wave 1     | H=7.1 m, T=12.1 s | 0, 3600, 4650 |
| Regular wave 2     | H=4 m, T=9 s    | 0, 4650      |
| White-noise        | Hs=7.1 m, T=6-26 s | 0, 3960, 4650, 4710, 5400 |
| Irregular wave     | Hs=7.1 m, Tp=12.1 s | 0, 3960, 4650, 5400 |
reflecting the trim angle caused by the thrust (Fig. 15). The pitch standard deviation is just slightly affected by the rpm setting as figure 15 seems to indicate a small increase with growing rpm settings. The tensions in the mooring lines vary much with the change of rpm. The mean tension in the front line increases with higher rpm settings while its standard deviation decreases (Fig. 16). The tensions in the two side lines have identical evolution with regards to the rpm settings. The mean value drops with increasing rpm, and so does the standard deviation too (not shown).

6.2.2. Regular wave 2 with 2 levels of thrust. Two tests with regular wave 2 were carried out: one test with an inactive fan and the other test with the fan requested to run respectively at 4650 rpm. The observations reported for regular wave 1 were also made for regular wave 2.

6.2.3. White-noise wave with 5 levels of thrust. Tests with 4 different rpm settings and one with an inactive fan were run with this wave. The effects of the different levels of thrust on the response of the floating wind turbine are analyzed thanks to these tests. The repeatability of this wave condition for the different tests was verified (Fig. 21). The effects of the steady thrust on the floater’s motion are mostly noticed in the surge and pitch motions. The surge offset gets larger with greater rpm settings. The absolute standard deviation of the surge grows with the thrust (Fig. 17). The heave does not vary much between the tests with different rpm settings. Their standard deviation slightly decreases for higher rpm settings (Fig. 18). The variations of the mean value and the standard deviation of the pitch rotation (Fig. 19) follow the same trend as for the surge motion. The effect of the thrust on the mooring line tension is large (Fig. 20). The side lines behave in the same way due to the symmetry in the system. The mean tension increases in the front line while it decreases in the side lines which are located backwards. The standard deviations of the tensions also have opposite evolutions with respect to the rpm setting: it grows with the thrust in the front line while it gets smaller for higher thrust levels in the side lines (not shown).
The surge RAO is mainly unaffected by the different level of thrust (Fig. 22). The heave response is slightly modified under the effect of steady thrust. Figure 23 shows that the resonance peak in heave gets lower for larger rpm settings. Around 0.43 rad/s, the response has a local minimum. This minimum can be identified as a cancellation frequency for which the heave forces on the columns of the semisubmersible are partly cancelling each other (Fig. 25). At this frequency, this local minimum gets even smaller for higher rpm settings. The pitch RAO is the most impacted by different levels of rpm settings. Overall, the amplitude of the response is bigger for higher rpm settings (Fig. 24). The larger the level of thrust is, the broader the pitch RAO becomes. This broadening effect is mostly visible for frequencies bigger than 0.7 rad/s. At last but not least, a local peak coinciding with the heave eigen frequency neatly appears in the RAO of the tests with the operating fan. The amplitude of this peak gets larger for greater rpm settings. This heave contribution to pitch can be interpreted as the heave force resulting into a pitch moment on the trimmed floater. As the rotation centre is not located on the same vertical line as the centre of gravity for the trimmed floater, the heave force acting at the centre of gravity times the arm due to this misalignment results in a moment around the y axis.

The study of the PSD plots of the motions (Fig. 26) highlights different evolutions for surge, heave and pitch around their respective eigen frequencies. The surge response peak increases with larger rpm settings whereas the wave response peak stays the same. This is confirmed by the evolution of the surge PSD sums (Fig. 28) where only the LF PSD sums grows with the RPM level. The heave response peak decreases with higher rpm settings. As the heave resonance frequency is in the wave frequency range, this decreasing trend is visible in the WF PSD sum of the heave motions and not in the LF PSD sum which is very small for heave. While the evolution of the pitch response is hard to read on the PSD plot (Fig. 26), it is very clear on the graphic of the PSD sum (Fig. 28). Both the resonance response (captured by the LF PSD sum) and the wave response (captured by the WF PSD sum) are growing with higher RPM. As for the tension in the mooring lines, the impact of the thrust on the surge resonance peak is mainly converted in an increase of the peak at this frequency in the front line (Fig. 27) and a decrease for the side lines. It can be observed that the wave excitation peaks of the
PSDs of the tensions are decreasing as rpm settings get bigger. These trends are well illustrated in the evolution of the LF PSD sums and WF PSD sums of the tensions (Fig. 29).

Figure 21 White-noise wave PSD
Figure 22 Surge RAO
Figure 23 Heave RAO
Figure 24 Pitch RAO
Figure 25 Visualisation of a wave corresponding to a cancellation frequency in heave
Figure 26 Surge, heave and pitch PSDs for the white-noise wave (3 vertical dashed lines delimiting the frequency windows for M2 and M3)

Figure 27 Mooring line tension PSDs for the white-noise wave (3 vertical dashed lines delimiting the frequency windows for M2 and M3)

Figure 28 Surge, heave and pitch PSD sums M2 (left) and M3 (right)

Figure 29 Mooring line tension PSD sums M2 (left) and M3 (right)

6.2.4. Irregular JONSWAP wave with 4 levels of thrust. A JONSWAP spectrum was generated. Tests with 3 different rpm settings and one with an inactive fan were run with this wave. All results are briefly discussed but no figures are presented.

The effects of the steady thrust on the floater’s equilibrium position are similar to what has been observed for the white-noise condition with different rpm settings. The surge offset and the pitch inclination get larger with greater rpm settings as seen for the white-noise wave. However, the absolute standard deviations of the surge and pitch are more stable in the test with the operational wave than they were for the tests with the white-noise wave. Also, the heave standard variation is more or less unaffected by the different rpm settings. The effect of the thrust on the mooring line tension is large. The mean tension increases in the front line while it decreases in the side lines. The standard deviation in the front line is more stable over different rpm settings than it was for the white-noise wave.
The PSD plots do not fully corroborate the observations done with the white-noise test. This time, the growth of the surge resonance peak for higher rpm settings is less obvious. The decrease of the heave resonance is present but less pronounced than for the previous wave condition. The pitch resonance peak is now clearly decreasing. The amplitudes of the peaks in the tension PSD plots that coincide with the surge eigen frequency are impacted by the effect of the steady thrust. The peak is increased in the front line while it is reduced in the side lines.

As for the white-noise wave, the surge RAO is unaffected by the different levels of fan’s rotation speed. Some differences between heave RAOs for different levels of thrust are visible around the peak of the wave spectrum. The deepening of the local trough around cancellation frequency is accentuated for the tests with active fan. The pitch RAO is getting bigger and broader with higher rpm settings. The range of the RAO does not fully cover the heave eigen period and therefore the heave contribution to pitch is not fully visible in the results of the JONSWAP wave tests but the sign of a local increased of the amplitude can be found.

7. Summary of the effects of constant thrust on the response of the semisubmersible
The lessons learnt from the analysis of the tests in regular waves and different settings of rpm are that the effects of the steady thrust on the response of the floater are mainly limited to the equilibrium state of the moored semisubmersible. Indeed the impacts of the different levels of constant thrust on the standard deviations of the motions and mooring line tensions were small for the two regular waves examined in this study. Their impacts were important on the static equilibrium and mostly visible thanks to:
- A large contribution to the mean surge motion that increases with the thrust,
- A large contribution to the mean pitch angle that increases with the thrust,
- A large contribution to the mean tension in the spring mooring lines which is positive for the front line and negative for the side lines located at the back.

The effects of the different levels of constant thrust on the static equilibrium of the semisubmersible were all confirmed in the tests in irregular waves. In addition, the standard deviations of the surge motion and the pitch rotation appeared to grow with increasing thrust levels. For surge, this increase comes from the growth of the low frequency response. As a consequence, the variations in the front line also increased while those of the side lines (located backwards) decreased. It was also noted that the growths of the variations in surge, pitch and their consequences on the variations of the mooring line tensions were much more pronounced for the broad wave spectrum (white-noise spectrum) than for the operational wave (JONSWAP spectrum). This denotes a frequency dependency of the impact of the constant thrust on the increase of the variations of the motions. The level of energy of the wave excitation in the range of the heave eigen frequency seems to be the factor that triggers the increases of the variations of the motions. Further examination of motion responses shows that the heave resonance response peak is much greater for the broad wave spectrum than for the JONSWAP wave spectrum (while this is the other way around for the surge and pitch responses). Moreover, the pitch RAO clearly shows the arising of a peak localized at the heave eigen frequency while the thrust increases for the white-noise wave. This peak on the pitch response at the heave frequency gets bigger for larger thrust levels. The presence of this peak is less obvious for the JONSWAP wave because there isn’t as much energy in this frequency range as for the white-noise wave. This local peak on the pitch response at the heave frequency is attributed to the contribution of the heave force on the pitch moment of a trimmed floater. It is therefore the expression of a coupling of the heave motion on the pitch motion resulting from the inclination of the floater under the effect of the thrust. It can thus be said that the variations of the motions are due to increase for sea states with significant energy in the waves of similar periods than the heave period when the floater experienced a trim angle. As this experimental set-up does not account for the aerodynamic damping of the wind turbine, the dynamic effects of the thrust on the response of the semisubmersible may be overestimated.
8. Conclusions
Tests with constant thrust have been realized with the same semisubmersible as used for the OC6 study. This new set of experimental data enables the study of the effects of the constant thrust on the response of this floater and more specifically the effects of the position and pitch offsets on the hydrodynamic response. This study shows that the response of a semisubmersible varies with its pitch offset angle. The results published in this paper are of particular interest to all participants of the OC6 comparison study as they can easily update their numerical model with the inclusion of a constant thrust and verify that the experimental observations reported in this paper are correctly reproduced by their numerical model. It is worth noting that the hydrodynamic database supporting the simulation of the wave loads and radiation damping of a floating wind turbine is commonly determined for one unique trim angle, which is often taken as the trim angle in the absence of thrust. Moreover, the hydrostatics of the floater is often represented by a matrix representing the situation with no trim angle (e.g. [8]). One can expect these simplifications to be insurmountable obstacles for the proper account of the pitch offset on the hydrodynamic response. Among the effects of the constant thrust on the hydrodynamic response of the floater, the appearance of a coupling of heave on pitch is the most spectacular effect. It has been explained that this coupling is directly linked to the trim angle of the floater. It is the cause of an increase of the floater’s pitch motion in waves which have periods similar to the heave natural period of the floater. This observation can be of importance for the design of floating wind turbines. For floaters that are likely to experience frequently significant heave motions, it can be necessary to account for this heave/pitch coupling in their design if there is no active ballasting to prevent or limit the static inclination of the floater under the effect of the mean component of the wind turbine thrust.

References
[1] A N Robertson et al 2020 J. Phys.: Conf. Ser. 1618 032033
[2] A J Goupee et al 2014, “Additional wind/wave basin testing of the DeepCwind semisubmersible with a performance-matched wind turbine,” Proc 33rd ASME Int Conf Ocean, Off and Arctic Eng, San Francisco, California, 10 pp.
[3] A N Robertson et al 2017, “OC5 Project Phase II: Validation of global loads of the DeepCwind floating semisubmersible wind turbine,” Energy Procedia, 137, pp. 38-57.
[4] A N Robertson et al 2020, “Total experimental uncertainty in hydrodynamic testing of a semisubmersible wind turbine, considering numerical propagation of systematic uncertainty,” Ocean Engineering, 195, pp. 106605.
[5] A M Viselli et al 2015, “Estimation of extreme wave and wind design parameters for offshore wind turbines in the Gulf of Maine using a POT method,” Ocean Eng, 104, 649-658.
[6] A J Goupee et al 2014, “Additional wind/wave basin testing of the DeepCwind semisubmersible with a performance-matched wind turbine,” Proc 33rd ASME Int Conf Ocean, Off and Arctic Eng, San Francisco, California, 10 pp.
[7] S Gueydon 2019, “Effects of Variations on the Experimental Set-up on the Motion Response of a Floating wind Semisubmersible (OC4 Type),” Proc. of the ASME 2nd International Offshore Wind Technical Conference, Saint Julian, Malta, 10pp.
[8] A N Robertson et al 2014, “Definition of the Semisubmersible Floating System for Phase II of OC4,” NREL/TP-5000-60601, National Renewable Energy Laboratory, Golden, Colorado.