Authors' final response - "Dynamics of floating wind turbine wakes in a wind tunnel setup"

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1 General remarks

The authors thank the reviewer for their valuable feedback and believe that the main concerns have been addressed in the new version of the manuscript. In the author's understanding, the main concerns with the manuscript were: (1) the insufficient number of cases to support generalized conclusions; (2) the lack of contextualization of this manuscript and its novelty within the literature; (3) the lack of literature review pertaining to more recent and relevant work; (4) the simplified nature of the setup (laminar flow, no turbulence, constant rotor speed, scaled-down turbine); (5) the statement that the prescribed motions were realistic; and (6) the use a wind tunnel setup with an asymmetric cross-section and high blockage ratio. All the comments from the reviewer are addressed in this document, and the comments pertaining to the main concerns are addressed first.

This document is structured in the following way:

- RC1 - where all the comments are addressed, starting with the ones perceived as the most critical.
- Additional Changes - the authors highlight further changes to the manuscript, beyond the comments, that they believe improve the quality and readability of the manuscript.

2 RC1

2.1 Comment from referee

The study investigates the effect of platform motions in different directions on wake behavior, considering two reduced frequencies for each motion direction. In my opinion, this limited number of motion frequencies is insufficient to support generalized conclusions. Experimental and CFD studies conducted by multiple institutions have shown that wake response to rotor motion is strongly frequency

dependent: the influence of motion typically increases with frequency up to a certain Strouhal number (often around $St \approx 0.4$, depending on the study) and then decreases as St tends toward infinity. This well-established behavior should be better acknowledged and reflected in the analysis.

2.1.1 Authors' response

The authors agree that simulating two reduced frequencies is insufficient to support generalized conclusions, either in terms of frequency dependency or in motion direction. In order to support the conclusions, the authors introduced comparisons with the references in the literature, including the ones proposed by the reviewers, and believe these will increase confidence in the results. The well-established behavior mentioned by the reviewer is now more clearly highlighted throughout the paper.

2.1.2 Authors' changes in manuscript

Acknowledging and reflecting the literature in the analysis: L48-L54, L198-L200, L284-L295, L321-L330, L335-L344, L350-L361, L370-L374, L396-L402, L404-L413, L426-L432, L441-L450, L467-L478, L486-L495, L505-L509, L579-654.

2.2 Comment from referee

The introduction does not clearly articulate how the present work differs from existing CFD studies of scaled floating wind turbines (for example [4], [5], [7], [8]). In particular, the manuscript should explicitly state what is novel in terms of the numerical approach, the motion conditions considered, and/or the wake analysis methodology.

2.2.1 Authors' response

The three key features of this study are: (1) it compares surge, sway, roll, pitch, and yaw motions; (2) it uses data sampled from radial probes that cover circular two-dimensional sections of the wake at several downstream positions, instead of the commonly used linear probes; and (3) it analyzes the wake in terms of recovery, recovery gradient, turbulence intensity, wake velocity spectral components, morphology, and tip and root vortex trail evolution and merger. The numerical approach (LES-ALM), the motion conditions considered (surge, sway, roll, pitch and yaw), and the pairs of Strouhal number and amplitude are not novel. In terms of wake analysis methodology, the methods used can be found in some form in the literature, although not exactly in the same form and level of detail. The novelty of this study is found when contextualizing the study in the broader Politecnico di Milano wind tunnel work carried out with the 1:75 scaled-down version of the DTU 10 MW. In the context of this work, to the best knowledge of the authors, the simultaneous coverage of points (1), (2),

and (3) has not been carried out prior to the current work, especially in terms of the tip and root vortex trail analysis. This is now stated in the "Introduction".

2.2.2 Authors' changes in manuscript

Overview of the performed cases, data used and analyses: L70-L80.

Novelty in the context of the broader Politecnico di Milano wind tunnel work carried out with the 1:75 scaled-down version of the DTU 10 MW: L81-L98.

2.3 Comment from referee

The literature review and discussion of wake dynamics are generally well developed. However, an important body of related work is missing. The turbine and experimental setup investigated in this study have recently been the subject of additional wind tunnel experiments and correlated CFD simulations aimed at improving the understanding of wake dynamics, including motion directions not covered in the UNAFLOW campaign ([2], [3], [4], [7], [8]). While I am not requesting the addition of citations, it would be intuitive and appropriate to acknowledge the existence of this related work in order to better position the present study.

2.3.1 Authors' response

The authors welcome the extra references provided by the reviewer and recognize that a large body of literature pertaining to experimental work directly relevant to this study, as well as to the effect of turbulence and prescribed motion direction on the wake was missing from the literature review. These references were now included in the literature review, as well as in each section when comparing the results of this study.

2.3.2 Authors' changes in manuscript

References regarding the effect of turbulence: L55-L65.

References regarding cross-stream motion prescription: L66-L69.

Acknowledgment of related work carried out in the Politecnico di Milano wind tunnel: L48-L52, L81-L85.

Acknowledging and reflecting the literature in the analysis: L48-L54, L198-L200, L284-L295, L321-L330, L335-L344, L350-L361, L370-L374, L396-L402, L404-L413, L426-L432, L441-L450, L467-L478, L486-L495, L505-L509, L579-654.

2.4 Comment from referee

L107: "This simplification ... relatively low". However, simulations have shown that this low value is sufficient to have noticeable differences with respect to purely laminar case. The authors should discuss the effects this simplification has on the results, also looking at other published work that specifically addressed this point.

2.4.1 Authors' response

The authors have reformulated the sentence, included the published work in the literature review and discussed the effect of turbulence intensity.

2.4.2 Authors' changes in manuscript

Sentence reformulated with discussion and references: L179-L183.

References regarding the effect of turbulence: L55-L65.

Discussion of the effect of turbulence in "Discussion": L638-L646.

2.5 Comment from referee

L126: "pairs for single-DOF surge and pitch were realistic". Realistic compared to what? How did you compare. the amplitude of single-DOF harmonic motion to the (broadband) response of a floating wind turbine? Do you refer to the spectral amplitude? At which frequency?

2.5.1 Authors' response

No comparison was performed in this study. The authors made this statement based on Bergua et al. [2023], who performed the same surge and pitch cases. The relevant excerpt from Bergua et al. [2023] is the following: "The platform motion amplitudes shown in Table 4 correspond to oscillations ranging from 0.6 to 9.375 m at a full scale (i.e., from 0.003 to 0.05 rotor diameter). In terms of periods at a full scale, the tests cover the range from 12.5 to 20 s (Mancini et al., 2020). Most FOWT testing is done with Froude-scaled models. However, in the two testing campaigns considered in this study, the scaling was based on the reduced frequency to try to preserve the relationship between the wind and the platform velocity. In this case, the wind velocity was scaled by a factor of 3 and the physical dimensions by 75 (Mancini et al., 2020). These amplitudes and periods are considered representative of different FOWT support structures."

The language was changed from "realistic" to "representative".

2.5.2 Authors' changes in manuscript

Sentence reformulated with reference to Bergua et al. [2023]: L201-L204.

2.6 Comment from referee

L179: "These results suggest ...". As mentioned before, I think this conclusion come from the fact that only two frequencies were analyzed. I think it is difficult to generalize it.

2.6.1 Authors' response

The authors were not affirming that higher Strouhal number and lower amplitudes would in general excite the wake more than lower Strouhal numbers and higher amplitudes, but were rather referring to the specific simulated pairs. This is more clearly stated now. Also, this statement is now compared with the literature, and to another section of the manuscript providing a physical explanation for it.

2.6.2 Authors' changes in manuscript

Sentence reformulated: L284-L292.

2.7 Comment from referee

In several instances, the manuscript adopts a colloquial tone, with phrasing that is uncommon in research articles. A thorough language revision would improve clarity and ensure a more formal scientific style.

2.7.1 Authors' response

A thorough language review was performed and the authors believe the language is now suitable for a scientific article.

2.7.2 Authors' changes in manuscript

Manuscript-wide language review.

2.8 Comment from referee

"One way of maximizing ...". I don't want to change the cut of this study but i think that at this stage is more important (and safe) to understand the impact of motions, and design choices, on the energy in a floating wind farm. Designing floating wind turbine to excite wakes seems very far away.

2.8.1 Authors' response

The authors have reformulated the sentence.

2.8.2 Authors' changes in manuscript

Sentence reformulated: L27-L28.

2.9 Comment from referee

L85: "No tower, nacelle ... DOFs". I understand the meaning but this sentence needs to be rewritten because the components actually do not appear in the figure

2.9.1 Authors' response

The authors have reformulated the sentence.

2.9.2 Authors' changes in manuscript

Sentence reformulated: L136-L137.

2.10 Comment from referee

L90: "since it was prescribed ...". Not clear, especially because you also consider motion due to platform rotations where the velocity is not the same for every point of the rotor.

2.10.1 Authors' response

The experimental setup of the IEA task OC6 Phase III was different for the translation and rotation cases, hence the different values in Table 2. The authors only give the hub height in the translation configuration because the prescribed motion velocity is the same at every point in the rotor for these cases. All the other dimensions in Fig. 1 (b) are irrelevant for this configuration. For the platform rotation cases, these dimensions are relevant, as mentioned by the reviewer, and are given in Table 2. The authors reformulated the excerpt in order to make it clearer.

2.10.2 Authors' changes in manuscript

Sentence reformulated: L138-L142.

2.11 Comment from referee

Caption of Table 3: I suggest recalling the meaning of the acronyms in the table caption so to ease the reading of the table itself.

2.11.1 Authors' response

The authors added the nomenclature in the caption of the table, which is now Table 4.

2.11.2 Authors' changes in manuscript

Added nomenclature in the caption of Table 4: L208-L210.

2.12 Comment from referee

L120: "from the corresponding values of the DTU 10 MW". Which corresponding values?

2.12.1 Authors' response

The authors meant to say that the frequency and amplitudes prescribed to the scaled-down model had been scaled down from the frequency and amplitude values that the full-scale DTU 10 MW would be subject to in conditions representative of different FOWT support structures. The sentence was reformulated to highlight this.

2.12.2 Authors' changes in manuscript

Sentence reformulated: L201-L204.

2.13 Comment from referee

L123: "summing ... surge and pitch cases". This is not clear. Is it that you applied the surge and pitch together?

2.13.1 Authors' response

The surge-pitch cases were removed from the manuscript to reduce the size of the manuscript, and because the number of cases was too few to be able to draw any generalized conclusions.

2.13.2 Authors' changes in manuscript

Removed coupled surge-pitch cases and discussions.

2.14 Comment from referee

L152: "there were difficulties on both sides". Do you mean uncertainties in the experiment and numerical simulation?

2.14.1 Authors' response

Indeed, the authors meant modeling limitations on the simulation side, as well as technical limitations and uncertainties on the experimental side. The sentence was reformulated.

2.14.2 Authors' changes in manuscript

Sentence reformulated: L229-L231.

Sentence reformulated: L782-L787.

2.15 Comment from referee

The results section uses some complex metrics about the wake (e.g., the velocity perturbation amplification factor, the normalized standard deviation of the velocity magnitude.) I think it would be useful to briefly present here the subsections that follows and explain, at high level, which analysis are conducted in each of them and to which purpose.

2.15.1 Authors' response

The authors have included such explanation at the beginning of the "Results" section.

2.15.2 Authors' changes in manuscript

Added excerpt: L248-L276.

2.16 Comment from referee

L208: "to originate wake recovery excess..." Not clear.

2.16.1 Authors' response

The surge-pitch cases were removed from the manuscript to reduce the size of the manuscript, and because the number of cases was too few to be able to draw any generalized conclusions.

2.16.2 Authors' changes in manuscript

Removed coupled surge-pitch cases and discussions.

2.17 Comment from referee

L240: replaces "excesses" with variations or "increments".

2.17.1 Authors' response

The authors thank the suggestion, which improves clarity.

2.17.2 Authors' changes in manuscript

Changed "excesses" to "increments": L302, L307, all the remaining mentions throughout the manuscript.

2.18 Comment from referee

L250: "The link makes sense ... experiment". The sentence, and the mechanism that is hypothesized for the explanation are not clear.

2.18.1 Authors' response

The sentence was removed as Messmer et al. [2025] identifies the responsible mechanism as the increase in Reynolds shear stress gradients.

2.18.2 Authors' changes in manuscript

Sentence removed.

2.19 Comment from referee

L252: "the coupling ... the wake". This part of the sentence does not have any meaning (the coupling result into some coupling).

2.19.1 Authors' response

The surge-pitch cases were removed from the manuscript to reduce the size of the manuscript, and because the number of cases was too few to be able to draw any generalized conclusions.

2.19.2 Authors' changes in manuscript

Removed coupled surge-pitch cases and discussions.

2.20 Comment from referee

L265: what are the "reminiscent peaks"?

2.20.1 Authors' response

The mention was removed from the manuscript.

2.20.2 Authors' changes in manuscript

Sentence reformulated: L430.

2.21 Comment from referee

L279: "this frequency range ... was found". Can you relate this conclusion to other studies on wake evolution of floating wind turbines (numerical or experimental)?

2.21.1 Authors' response

The authors added a comparison to an experimental study directly related to the performed cases.

2.21.2 Authors' changes in manuscript

Sentence reformulated: L445-L450.

2.22 Comment from referee

L298: "amplification potential". In terms of lateral motion of the wake but i think the metric you have studied does not assess the amplification in the streamwise direction which corresponds to pulsing of the streamwise velocity.

2.22.1 Authors' response

The authors recognize that the sentence might have led the reader to think that the amplification potential of surge was also the lowest in the streamwise amplification factors, which is not true.

2.22.2 Authors' changes in manuscript

Sentence reformulated: L479-L481.

2.23 Comment from referee

L303: "Still, did this . . . ". Avoid rhetorical questions and give answers instead.

2.23.1 Authors' response

The authors have reformulated the sentence.

2.23.2 Authors' changes in manuscript

Sentence reformulated: L482-L485.

2.24 Comment from referee

L317: "long lived" clarify that this means the vortices are found further downstream.

2.24.1 Authors' response

The authors have reformulated the sentence.

2.24.2 Authors' changes in manuscript

Sentence reformulated: L502-L503.

2.25 Comment from referee

L323: "since defining the shear layer . . . ". Can you be more explicit? the additional information is needed to understand what really your metric is.

2.25.1 Authors' response

The authors added information explaining the concept.

2.25.2 Authors' changes in manuscript

Added information explaining the concept: L510-L519.

2.26 Comment from referee

L400: "in terms of wake recovery...". this sentence is poorly written, and the second part repeats the first one.

2.26.1 Authors' response

The discussion was completely reformulated and is now organized with the following sub-discussions: low-St/high-A^* results, high-St/low-A^* results, SuHS exception, cross-stream motion preference, the effect of the wind tunnel setup and simplifications, and the effect of realistic conditions on the results.

2.26.2 Authors' changes in manuscript

Complete reformulation of the "Discussion": L579-L654.

2.27 Comment from referee

L405: "If the wake recovery ... recovery". This sentence is speculation. Reframe it or remove it.

2.27.1 Authors' response

The speculation was removed and the sentence was reformulated.

2.27.2 Authors' changes in manuscript

Speculation removed and sentence reformulated: L623-L626.

2.28 Comment from referee

L426: "At this point ...". How this conclusion relates to those of other research efforts on the same topic? Is it completely new? Does it agree or not?

2.28.1 Authors' response

The discussion was completely reformulated and is now organized with the following sub-discussions: low-St/high-A^* results, high-St/low-A^* results, SuHS exception, cross-stream motion preference, the effect of the wind tunnel setup and simplifications, and the effect of realistic conditions on the results. The

conclusions are not new, and are compared with the literature in the new "Discussion".

2.28.2 Authors' changes in manuscript

Complete reformulation of the "Discussion": L579-L654.

Specific point mentioned by the reviewer: L613-L617.

2.29 Comment from referee

L433: "The patterns ..." Rewrite this sentence.

2.29.1 Authors' response

The authors reformulated the sentence.

2.29.2 Authors' changes in manuscript

Sentence reformulated: L583-L585.

2.30 Comment from referee

L445: "The wake meandering..." This sentence is not clear.

2.30.1 Authors' response

The wake meandering analysis was removed from the manuscript to reduce the size of the manuscript, and because it did not add anything beyond what the velocity amplification factors added.

2.30.2 Authors' changes in manuscript

Wake meandering results and discussion were removed.

2.31 Comment from referee

L478: "The prescribed motion ..." Show them or remove this sentence.

2.31.1 Authors' response

The authors removed the sentence.

2.31.2 Authors' changes in manuscript

Sentence removed.

2.32 Comment from referee

L571: "Differences between the simulation setup ...". All these effects were introduced one by one in the simulations during OC6 [1], where most of the participants obtained a mean thrust close to 35N using a laminar inflow. I think the error of around 1N with respect to the results of OC6 could be related to the modelling of the boundary layer of wind tunnel walls. Assuming the boundary layer grows of 0.01m every going downstream the tunnel chamber, the boundary layer on every wall is around 0.2m at the turbine location. This affects the flow velocity that accelerate in the center of the tunnel, and this can explain the slightly lower mean thrust that was obtained here. I cannot comment on other uncertainties introduced by the simulation tools itself (like calculation of angle of attack along the actuator lines).

2.32.1 Authors' response

The authors agree that that could be the cause. Nevertheless, the authors have also demonstrated that the cell size increase due to the inclusion of a geometry-resolved nacelle in the fixed-bottom case of this study would increase the thrust by about 1N Amaral et al. [2024], highlighting another factor that might have led to better/worse match with the experiment among the CFD participants. This is better acknowledged in the manuscript.

2.32.2 Authors' changes in manuscript

Sentence reformulated: L782-L796.

2.33 Comment from referee

L1: "in a wind tunnel setup" is redundant.

2.33.1 Authors' response

The authors removed the sentence.

2.33.2 Authors' changes in manuscript

Sentence removed.

2.34 Comment from referee

L84: add "used in the CFD simulations" after "The turbine configuration".

2.34.1 Authors' response

The authors added the sentence.

2.34.2 Authors' changes in manuscript

Sentence added: L134-L135.

2.35 Comment from referee

L133: "larger" -¿ "longer (in the wind direction)".

2.35.1 Authors' response

The authors corrected the word.

2.35.2 Authors' changes in manuscript

Word corrected: L212-L213.

2.36 Comment from referee

L147: I suggest c_{CFL} in place of "CFL" otherwise it seems C*F*L.

2.36.1 Authors' response

The authors corrected the symbol.

2.36.2 Authors' changes in manuscript

Symbol corrected: L224-L225.

2.37 Comment from referee

L227: replace "TI" with "I_i" or "I_x".

2.37.1 Authors' response

The authors corrected the symbol.

2.37.2 Authors' changes in manuscript

Symbol corrected: L364-L365, Fig. 9, L367, all other mentions in the manuscript.

2.38 Comment from referee

L238: replace "side to side" with cross stream?

2.38.1 Authors' response

The authors corrected the word.

2.38.2 Authors' changes in manuscript

Word corrected: L14, all other mentions in the manuscript.

2.39 Comment from referee

L316: replace "merger" with "merging".

2.39.1 Authors' response

The authors corrected the word.

2.39.2 Authors' changes in manuscript

Word corrected: L501.

2.40 Comment from referee

L359: "are" is missing between "paper" and "well".

2.40.1 Authors' response

That sentence was reformulated.

2.40.2 Authors' changes in manuscript

Sentence reformulated: L576-L577.

2.41 Comment from referee

L485: "Appendix A: Prescribed motion validation". I think this is more a verification of the blade kinematics in the simulation.

2.41.1 Authors' response

The name of the appendix was changed.

2.41.2 Authors' changes in manuscript

Name changed: L695.

2.42 Comment from referee

L570: "Appendix C2 Discussion". It's unusual to have sections in appendix.

2.42.1 Authors' response

The section was removed but all the content was kept .

2.42.2 Authors' changes in manuscript

Removed section but kept all the content.

3 Additional Changes

In addition to replying to reviewers' comments , the authors took advantage of the opportunity provided by the review of this manuscript to make further changes that they believe improved the quality and readability of the manuscript. These include:

- Due to the manuscript size increase as a result of the review, content related to wake meandering (sections "Wake meandering" and "Appendix D: Instantaneous wake center") was removed because it added little information beyond what the cross-stream velocity amplification factors were already showing. Likewise, content related to the coupled surge-pitch cases was removed because these cases were too few to be able to draw any conclusions.

- The abstract, "Discussion" and "Conclusions" sections underwent significant revisions.

- Ω is now used for the rotor speed expressed in rpm, whereas ω is used for the rotor speed expressed in rad/s.
- Removed mentions of "normalized" but indicated in L170 that "All the quantities used in the study are normalized, i.e., made non-dimensional, unless otherwise indicated. Hence, the adjective "normalized" will be dropped after the quantity is defined, to avoid unnecessary repetitions."

- The high-St_p/low-A^*_p pitch case was added to Fig. 5, to further highlight the effect of cross-stream perturbations.

- Figure 6 (a) was changed to include the wake recovery of all cases, and the plot was zoomed in to show the different recovery onset positions. In Fig. 6 (c), the wake recovery gradient increments of the low-St_p/high-A^*_p cases are much lower and steadier compared to those of the high-St_p/low-A^*_p cases. Since this can be assessed from Fig. 6 (b), the low-St_p/high-A^*_p cases were removed from Fig. 6 (c) to highlight the high-St_p/low-A^*_p cases.

- In the legend of Figs. 6, 9, 11 and 15, the high-St_p/low-A^*_p cases are now shown as solid lines, while the low-St_p/high-A^*_p cases are shown as dashed lines. No markers were used.

- The cases shown in Figs. 8 and 12 were changed to match those of Fig. 5, to allow for a more direct comparison between all the figures.

- Added an intermediate step in Equation 12.

- Added the Q-criterion surface for the YaHS case in Fig. 13 and discussed it in L507-L509.

- In "Tip and root vortex trails", the tip vortex trail mergers (L560-L577) are now discussed after the comparison between the tip vortex trail thickness and the average cross-stream velocity spectrum (L546-L559).

- While the conclusions throughout the whole manuscript did not change, a thorough language review was performed in order to better frame the findings, and to include more comparisons with some of the references proposed by the reviewers.

- In "Appendix A: Prescribed motion validation", the relative error symbol was changed from ϵ to RE (L713-L714), not to overlap with the smearing length scale. In Table A2, A_{pb} was changed to A_{pp}, where "pp" stands for "prescribed point".

- In "Appendix B: Flow field convergence", the streamwise flow field convergence study of the SwHS case was added (Fig. B2).

- In "Appendix C: Experimental comparison", the symbol of the difference relative to the experimental value was changed from ϵ to RE (L773), not to overlap with the smearing length scale.

References

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