Response to Reviewer Comments

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Thank you for supplying us with a thorough review of WES-2023-101. The comments were valuable and we tried to address them all appropriately. In addition to addressing the comments, the document has been reviewed by a professional editor to improve grammar, etc., which resulted in minor editorial changes throughout the paper.

Here are our responses to the specific comments, with the referee comment in green, our response in black, and changes made to the paper indented black.

Referee #1

The manuscript discusses a novel comparison FAST.Farm and SOWFA-OpenFAST against measurement data. The work is crucial for the community and very relevant to the readers of Wind Energy Science. I find that the description of the results, their presentation in the figures, and the main findings (what are the main benefits of the different approaches) can be improved; see my list of recommendations below. I hope these suggestions can help to enhance the presentation of the findings.

* Line 154: missing citations;

Author response: Citations have been added for (Jonkman et al. (2018); Doubrawa et al. (2020)).

* Line 162-165: without discussion of the actual parameters, this paragraph is rather vague.

Author response: The paragraph in question has been updated and combined with the previous paragraph:

> In addition to experimental turbine load comparisons, the wake evolution between FAST.Farm and SOWFA-OpenFAST-ALM results are compared. For each turbine, the wake center position was computed using the Simulated and Measured Wake tracking algorithms. There are several wake-tracking algorithms available in the SAMWICH ToolBox. The one chosen for this work is the two-dimensional Gaussian fit model, which solves an optimization problem to determine the wake position, two-dimensional shape, and rotation parameters of a Gaussian wake-deficit function. This method is able to estimate the wake center, size, and shape. This and other wake-tracking methods available in SAMWICH Box are discussed in more detail in Quon et al. (2019). Because the wake-tracking algorithm may be sensitive to instantaneous mean wind conditions and the presence of background turbulence structures, the resulting wake center time series can include non-physical discontinuities. To minimize this, filtering is applied to remove spurious results as was done previously by Doubrawa et al. (2020). For each wake center time series, a median filter was first applied to remove the majority of non-physical spikes in the data. Any remaining spikes were removed by eliminating high gradients in the data, and then a final median filter was applied.

* Figure 3: These results are very interesting. It would be great if you could find a way to better demonstrate the differences between the various models, which, in the current representation, is difficult to judge.

Author response: Quantitative comparisons between the models are made later in the paper.

* Figure 4: It is stated that this figure demonstrates that the algorithm captures the wake center location accurately. This is not so clear from the figure; I would guess the wake centers should be a bit lower. Can you comment on this and how it may impact the final results?

Author response: The following parenthetical comment has been added after this statement in the text to clarify the statement:

> (this might not be fully obvious from Figure 4, but is clearer when the wakes are shown with the ambient inflow subtracted out, which is how SAMWICH processes the wake centers)

* Figure 5: It is unclear why the results for Tr01 are not normalized.

Author response: The rationale for showing the non-dimensional results (normalized by the freestream turbines Tr01 and Tr05, as described in the accompanying text) was to highlight the waked turbine response. As such, we have removed the non-dimensional subfigures for Tr01, Tr02, and Tr05.

* Section 3.1: The description of figures 5, 6, and 7 is unclear as their explanation is merged, and the reference to the different figures is unclear.

Author response: The results of each figure are discussed in their own paragraphs within this section.

* Figure 6: "Vertical dashed lines indicate the 3P and 6P frequencies based on the average SOWFA-OpenFAST_AD rotor speed." --> This seems to be a typo.

Author response: Changed to:

> Vertical shaded regions are used to show when wake steering of more than ±10° is present (red) and when there was prominent waking of Tr03 and Tr04 (purple).

* Figure 6: Are the lower panels normalized? This is not indicated on the vertical axis

Author response: Yes, as indicated in the associated text.

* Figure 6: Define the meaning of the rad bands.

Author response: The description has been fixed as indicated above.

* Figure 6: Please define TS. Does this refer to time series?

Author response: Yes, TS = Time series. This was previously defined in the caption of Figure 5.

* Figure 7: Make sure text and graphs are not overlapping

* Figure 7: The vertical dashed lines mentioned in the caption are (nearly) invisible. Please make these clearly visible.

Author response: We have cleaned up this figure for clarity.

* Figure 7: Define clearer what is defined by good and poorer agreement between model and observations. Looking at the spectra, the location of the peaks is captured better than in the top panels.

Author response: A discussion of this comparison is provided in the text, which explains where the better/worse agreement is seen.

* Figure 8: Indicate vertical dashed lines.

Author response: These are 3P and 6P frequencies as stated in the figure caption.

* Figure 9: Improve alignment of the different panels.

Author response: This figure has been cleaned up.

* Line 260: "Though SOWFA-ALM results show more wake deflection that [typo: should be than] FAST.Farm results at 2D of Tr03, agreement 260 between the computational methods is very good at 5D downstream." --> Can this be discussed in more detail? [See left middle column]: This result suggests wake development in the different models is different.

Author response: Possible reasons for these results have been added to the text.

> SOWFA-ALM results show more wake deflection than FAST.Farm results at 2D downstream of Tr03; FAST.Farm is not expected to accurately model wakes in the near region, but rather, the near-wake model of FAST.Farm exists so as to more accurately model the far wake. Further downstream of Tr03, agreement between the computational methods is very good at 5D downstream, as well as 3D downstream of Tr04.

* Conclusion: What is meant by terms like "good" or "strong" agreement should be more clearly defined.

Author response: Clarification was made in terms of what showed the agreement. However, a more quantified result (e.g., percent difference) is not included due to the nature of the comparisons made in the text.

* Conclusion: I missed a discussion summarizing the benefits and limitations of each approach.

Author response: A discussion of SOWFA and FAST.Farm are provided in sections 2.2 and 2.3, respectively. To address this comment, the following text was added in sections 2.2, 2.3, and 4 respectively:

> In general, the AL model requires a finer discretization and is considered higher fidelity than the AD model.

> Compared to SOWFA, which resolves the inflow and wakes of the flow field (through the scales resolved by LES), the flow field in FAST.Farm is solved via engineering models for wave evolution, meandering, and merging atop the inflow field. The main disadvantage relative to SOWFA is the potentially lower accuracy (hence the need for validation) and the main advantage being a drastic reduction in computational expense.

> Considering that FAST.Farm is much less computationally expensive than SOWFA-OpenFAST, this three-way validation effort provides further confidence to apply FAST.Farm to the calculation of wind turbine power production and structural loading in wind farm settings, including wake interactions between turbines.

Typos

Line 201: "and and"

Author response: Fixed.

Referee #2

Comments on the manuscript entitled "Wind Farm Structural Response and Wake Dynamics for an Evolving Stable Boundary Layer: Computational and Experimental Comparisons" by Shaler et al. submitted to Wind Energy Science.

In this study, the authors assessed the capability of FAST.Farm in predicting wind turbine loads and wake evolution under realistic atmospheric conditions by comparing its results with LES and measurements. Evaluating a wind energy model for real-life conditions is challenging due to the multitude of factors involved. Comments are as follows:

The paper contains vague statements like "good agreement", "excellent agreement", and etc., which require quantifiable assessments. Moreover, it is not accurate as there are discrepancies as shown in the comparison results. This should be checked throughout the paper including the abstract the conclusion section.

Author response: See our response to a similar comment from Referee # 1.

Regarding Figure 2: If the authors aim to compare the inflows used in FAST.Farm and LES with the measurements, these should be taken at the same position as the measurements, rather than at the turbine location.

Author response: The comparison between measured and LES inflow is included in the companion paper, which focuses on matching conditions at a single location where the profiling lidar and meteorological mast are co-located. Figure 2 shows the inflow conditions extracted from that LES that are directly used in the aero-servo-elastic turbine simulations here.

Accurate inflow is crucial, as emphasized by the authors. Suggestions include adding a brief description of how realistic inflow is generated in FAST.Farm and LES cases, and comparing the time series of inflow wind direction. One more question is raised: Is there a quantitative measure on the accuracy of the employed inflow?

Author response: The accuracy of the simulated inflow is discussed at length in the companion paper. An important result that is relevant to this work has been included:

> As discussed in Quon (2023), the mean absolute errors in inflow wind speed, wind direction, and turbulence intensity are 0.19 m/s, 1.5°, and 0.031 (non-dimensional), respectively, during the study period.

Clarify "relative to the wind turbine" on Line 250, Page 14: Is it relative to the averaged wake center or the centerline passing the rotor center in the mean wind direction?

Author response: This has been clarified in the text:

> Shown in Figure 9 are probability density function (PDF) distributions for the lateral and vertical wake center location for each wind turbine at various downstream distances, relative to the wind turbine location (e.g., the results for Tr02 are relative to the location of Tr02).

The statement “A bimodal wake center position is captured for both methods at 9D downstream of Tr01, but this could be due to deficiencies in the wake tracking algorithm when wake breakdown occurs.” on line 255 page 14: the authors need to clarify whether it is caused by the wake tracking algorithm before drawing conclusions from the figure.

Author response: Upon closer inspection, this bimodal response is due to the changing wind direction and resulting change in yaw, which is supported by the yaw misalignment values in Figure 2. The text has been updated to reflect this:

> A bimodal wake center position is captured for both methods at 9D downstream of Tr01. This is due to the changing wind direction and resulting change in turbine yaw misalignment (ranging between +5 and -10 degrees), which has a more pronounced impact on the wake location further downstream of the turbine and is seen developing by 5D downstream of Tr01.

Following from the last comment: does the employed 2D Gaussian fit model work when there are superpositions of wakes?

Author response: When the wakes from multiple rotors overlap, SAMWICH does not track the wake of each rotor separately. Rather, the wake center of the “superimposed” wakes is tracked by SAMWICH. While superimposed wakes are most likely not 2D Gaussian in shape, the post-processing with SAMWICH is done consistently across the various results that are compared in this work, and so, the comparison is considered valid.

Typo on Line 160 page 7: “Guassian”.

Author response: Fixed.