March 6, 2025

We wish to thank the reviewer for their helpful and constructive comments. The reviewer's comments and questions are addressed below. Changes to the manuscript are made in bold red font.

Reviewer 1

In this work, the authors proposed an engineering wake model to consider the effects of active wake mixing strategies. The proposed model is based on the triple decomposition of instantaneous velocity into time-averaged components, wave components, and turbulent fluctuations. The time-averaged component is computed by solving the parabolic RANS equations with the turbulent fluctuations modelled using the k-epsilon model. The wave component is modelled using a simplified spatial linear stability formulation. The model predictions are compared with the large-eddy simulation results. An overall good agreement was demonstrated. It is a nice work, allowing fast estimations of different AWM strategies on accelerating the wake flow recovery. Specific comments are as follows:

1. Double check eq. (2), and equations on lines 97 and 99.

   In the revised document, we have fixed typographical errors in the equations, including the definition of the pitch actuation, equation (2), and a few other mistakes in the original manuscript.

2. It is suggested to plot in figure 1: instantaneous, time-average, wave component and turbulent fluctuations.

   As suggested by the reviewer, we have added some additional contour plots to figure 1 (also replicated below) so that it now shows an example of the instantaneous $u(x,t)$, time-average $\overline{U}$, phase average $\langle u \rangle$, wave component $\tilde{u}$, fluctuating component u', and turbulent kinetic energy decomposition of the flow field.

3. Line 261: "he wave".

   This typo has been corrected in the text.

4. The proposed model assumes axisymmetry. In LES the ground is included, making the comparison between the two unfair. It is suggested to run ideal LES cases under uniform inflow and with symmetry BCs on the four sides to verify the model first.

   We agree with the reviewer that, as the LES is currently performed, the comparison could be deemed unfair. A comparison to an axisymmetric LES of just the turbine rotor would have yielded a direct comparison. However, the objective of this work is to provide a usable, proof-of-concept framework that illustrates how a RANS model with a linear stability model can capture most of the phenomena of interest in the LES data. This was adequately demonstrated in the manuscript. The long-term goal, as

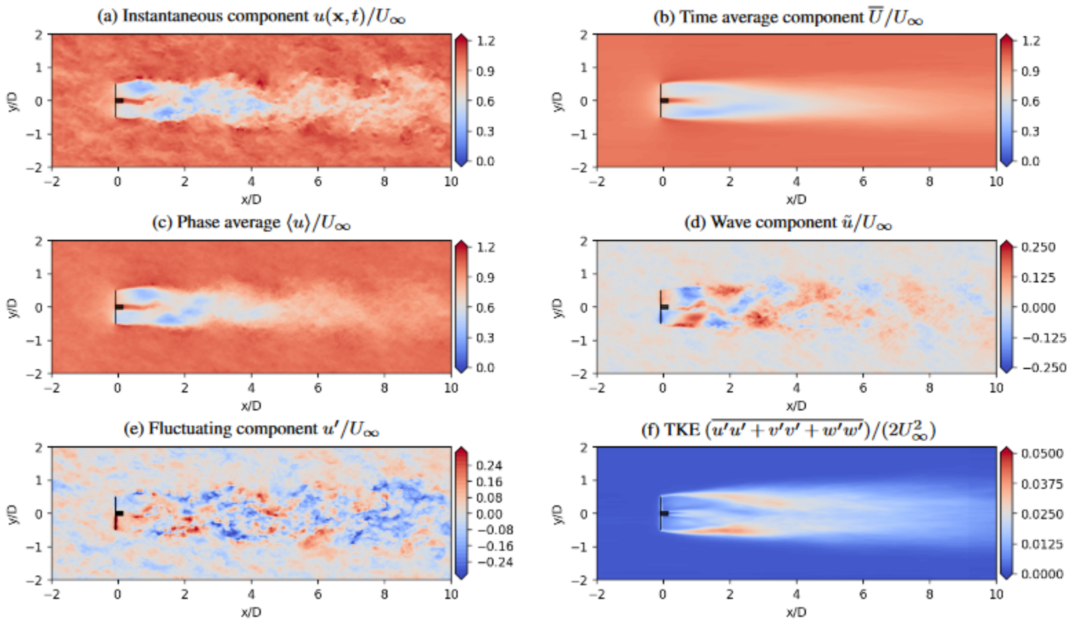

Figure 1. An example of a triply decomposed flow field for a wind turbine wake. This case is from the HelixA4 case under stable Low WS ABL conditions with 4° amplitude forcing. In each contour, the normalized streamwise velocity, U/U_∞, is plotted.

stated in the conclusions discussing future work, of such a framework is to build it up from common principles towards being able to capture increasing physics complexity, such as shear effects, veer, and asymmetry. As such, it does not serve the current manuscript to remove physical phenomena and perform an ideal LES with uniform inflow and symmetry boundary conditions. This would be discarding the important physics of wind farm LES without informing the potential failure modes of the proposed framework to point to future improvements. Given the simplicity of the resulting flow of an axisymmetric LES without boundary conditions, it can be fully expected that a calibrated axisymmetric RANS model as proposed in the manuscript would fully be able to capture the physical quantities of interest. The current work has the merit of highlighting that the current approach performs well in comparison with complex LES data while also highlighting future improvements.

Though noted in the conclusions, other parts of the manuscript do not clearly lay out these goals and, therefore, additional discussion along these lines was added to Section 3.1.

5. Discrepancies shown in figure 9 are large. Discussions are necessary.

   Additional discussion regarding the observed discrepancies for the High WS case are now included in section 3.1 and 3.2 of the revised manuscript. In section 3.1, we show that mean flow calculated using the RANS model overestimates the potential core region of the wake when compared to the equivalent AMR-Wind case, leading to lower centerline and rotor averaged velocity. These differences then impact the behavior of the large-scale coherent structures as predicted by the RANS and linear stability model. The larger potential core region in the RANS profiles limits the modifications from the coherent structures to the wake shear regions until farther downstream in the wake. This leads to relatively minor changes to the centerline velocity for the High WS case compared to the Med or Low WS cases. These results suggest that accurately capturing the mean flow is critical to modeling the impact of large scale structures on wake behavior. We hope that future work in this area will improve the baseline RANS models and calibrations, and increase the accuracy of the overall model.

6. There are models in the literature developed to predict coherent flow structures in wind turbine wakes (e.g., J. Fluid Mech. (2024), vol. 980, A48, doi:10.1017/jfm.2023.1097). It is suggested to review them in the introduction section.

   A paragraph has been added to the introduction that discusses dynamic wake models, in addition to the steady-state models that are commonly used for wind farm optimization. The primary focus is on data-driven representations of coherent flow structures. Three recent developments using Spectral Proper Orthogonal Decomposition, Resolvant Analysis, and Dynamic Mode Decomposition are discussed in the context of Active Wake Mixing. The Dynamic Wake Meandering model is also briefly mentioned as another reduced-order modeling approach aimed at representing unsteady dynamics.