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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Analytical model for the power-yaw sensitivity of wind turbines operating in full wake" *by* Jaime Liew et al.

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The authors present their manuscript on a novel analytical model for the power-yaw sensitivity of turbines operating in full wake. In this model, they consider the trajectory of each turbine blade element as it passes through the incoming wake, with the aim of analytically determining a power-yaw loss coefficient. The model is validated against HAWC2, with velocity input from both a medium and high fidelity wake model.

The paper is of good quality and I enjoyed reading it. It clearly shows the need of a power-yaw sensitivity model through proper citations to available literature. I believe this work is relevant to the community, as the model can be very useful in increasing the fidelity of engineering models for wind-farm optimization and control.

I do have some comments, which could improve the overall quality of the paper prior to publication. They are listed in the points below. Furthermore, the paper should be thoroughly examined on typos, I've listed some for the first few pages below as well.

Major comments

1. p1, l19: *'Part of the discrepancy and uncertainty **might** stem from unintentional yaw misalignment'*. This formulation is quite vague, and should be made more precise if possible. Could the authors make more clear how big they expect / know the effect of yaw misalignment to be? The subsequent citations to literature clearly indicate that yaw misalignments are common, but do not really measure their contribution to the aforementioned discrepancies and uncertainties.

2. It is not completely clear to me why r_m is a random variable, I suppose this is due to uncertainty on γ. The probabilistic framework introduced in 2.1 hence came a bit as a surprise when reading the text. The source of uncertainty should be stressed more.

3. The yaw misalignment γ is introduced on p2, l5 as the yaw misalignment with the free wind direction. Given that the local wind direction can change throughout a wind farm (e.g. due to Coriolis effects), downstream turbines can have a non-zero γ whilst still being aligned with the local wind (as the authors also point out on p2. However, does this definition of γ then still uphold in the remainder of the text (e.g. Figure 1, and the analytical model), or should γ be interpreted as the misalignment to the local wind direction?

4. The main novelty of the current work is being able to account for non-uniform flow conditions in the wake. In a uniform wake, $\bar{U}(r_R) = U(r_R)$, and I suppose from section 2.2 that α would simply equal α_0. Is this true? If yes, please mention this. If not, please explain.

5. p 7, l4: Please don't use D both as symbol for the downstream distance. In literature, D virtually always is the turbine diameter. Even in this manuscript, p7 l16 (*ranges of 2D to 14D*), I suspect D indicates the turbine diameter. Use a small d instead to represent the variable downstream distance. A similar thing can be said about the subscript R, in the rotor coordinate system r_R,ψ_R. R is almost always used to indicate the rotor radius (like you also do in line 29, p8). However, I guess finding another meaningful symbol to represent this is not as simple (since r is already taken for the radial position).
6. Section 3.2.2: The LES wake is post-processed: it is time-averaged, the shear is removed, and azimuthal variations are removed by averaging over the azimuthal direction to obtain a radial wind speed function, which the authors claim to be comparable to that generated by the DWM model. In this sense, I think the added value of including LES in this study should be justified more clearly and perhaps earlier in the manuscript. For instance in Section 5, the authors indicate that wake break down occurs earlier in LES than in DWM. This could probably also be seen from the data in Figure 4, if some cuts at different streamwise locations are taken. I think it would be useful to discuss the relevant observed differences between LES and DWM wakes in Section 3.
7. Added value of LES: Fig2 (why not LES), why even use LES if you make it so close to a DWM? Can the model account for a truly turbulent wake?
8. Figure 5. This is an interesting Figure. Some comments.
   - Would it be insightful to include panel(s) with both the analytical and HAWC2 results on top of each other to highlight the differences?
   - The lines have X markers. I'm assuming this is where the yaw angles have been sampled for the simulations. Please indicate this.
9. Figure 6.

   - Perhaps add markers where you sampled these lines (i.e. which simulations you actually ran)
   - The differences between your model and HAWC2 seem to increase at lower turbine spacings. However, in practice, such low turbine spacings are rare. Mentioning this in the text would further justify the utility of your model.
10. In the context of wake steering with yaw misalignment, literature has shown that wakes tend to take curled shapes, hence axisymmetric wakes would be rare in farms with active wake steering. Could such wakes also be incorporated using the azimuthal-time averaging? I believe so, and explicitly mentioning this would further strengthen your case.
11. The Lemma's in Appendix A would be better readable if they were self-contained (i.e. defining symbols etc.). Also, in both Lemma's you use captial symbol R again, for a different meaning than simply a subscript indicating the rotor reference frame. Please consider revising this, as this comes off confusing.
12. You propose an analytical method which allows (p 13, l25) *a quick and reliable method to calulate α*. Can you compare the computational complexity of your model with HAWC2?

Minor comments

1. p2, eq (1): P_0 is not defined explicitly, I assume this is simply P_γ with $\gamma = 0$ (so a similarly waked turbine with misalignment 0), but in literature P_0 is sometimes referring to an unwaked turbine. Better to make this explicit.
2. p4, l10: Mention that r is radial position and ψ is azimuthal angle.
3. p4, Figure 1. This is a nice figure which clearly presents the trajectory of a blade segment. However, in this general theory section, it would be more appropriate to

normalize the length scales in the figure by the rotor radius or diameter, instead of visualizing the concept for a specific turbine with rotor radius 45m. Furthermore, the windspeed deficit could also be normalized with respect to freestream velocity.

4. p5, l9: Indicate clearly that the Lemma is in the appendix. Also, consider changing the order of Lemma A.2 and A.1 (A.2 is referred to earlier in the text than A.1)
5. p6, l4. ρ and a are not defined.
6. Figure 4. The yellow color in the LES flow field is not present in the color scale. Are all figures plotted using the same color scale as shown on the right?

Typographical

1. p1, l17: includes include
2. p1, l24: show shown, misalignment misalignments
3. p1, l25: I think it's better to say either 'The probability ... was more than 25%', or 'The waked turbines were yaw misaligned more than 25% of the time', not both.
4. p2, l8: overestimate overestimates
5. p2, l20 includes include
6. p2, l5: wind wind wind
7. p2, l30: increase increased
8. p2, l31: its their

9. p3, l18: benefit by benefit from
10. p3, l19: focus focuses
11. p3, l24: need of need for
12. p3, l26: optimization optimisation (be consistent in American vs British English)

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