wes-2025-63: Reductions in wind farm main bearing rating lives resulting from wake impingement

**Response to Reviewer 2**

We thank the reviewer for their comments, which we feel have helped improved the quality and clarity of this manuscript. Reviewer comments are listed below, followed by our responses in blue.

Introduction

• Lines 35-43: Two questions are stated – one related to validity of ISO-based main bearing rating life, and one related to what constitutes a realistic system model. I assume that this research is an attempt to answer the latter, but this is not very clearly stated. Am I correct? If not, the second question seems redundant. Please rephrase.

The current study is essentially seeking to (at least partially) address both questions, with the outcome shedding light on both whether wake effects are required for a sufficient system representation, and to what extent this might allow for ISO bearing life equations account for reported rates of field failures. We agree, however, that this could be better explained at this point of the manuscript, and so we will improve this discussion when undertaking revisions.

• Line 37: Duplicate reference to Kenworthy et al.

Thanks, we'll sort that.

• Lines 44-46: Inconsistent use of "Sect." and "Section" – please check the guidelines of WES.

We'll confirm the correct style and update the manuscript accordingly.

Background

• The paper "Main bearing response in a waked 15-MW floating wind turbine in below-rated conditions" by Krathe et al looked at partial wake impingement effects on main bearing rating lives and should be referenced here.
https://link.springer.com/article/10.1007/s10010-025-00808-z

Thank you for flagging this paper to us. We agree it is a relevant reference to discuss here, and we'll add this in when revising the paper.

Section 2.1

• Line 59: Radial and axial bearing loads are referred to here but not defined until p. 7. Please check give a brief description of them here.

Will do.

Section 2.2

• Lines 109-110: The fatigue damage of the bearings depend highly on CD, and it is not useful to compare the damage of the upwind and downwind main bearing without commenting on the difference in CD.

Valid point, we'll add that context to this discussion.

Section 2.3

• Line 131: The reference applied for the Dynamiks Python package looks strange. Please check that it is presented as intended.

Will do.

• Line 144: For someone not familiar with the model proposed by Hart, it is not trivial to understand what the elliptical and folding parameters describe. Please provide a brief explanation indicating what physical properties these parameters describe. In general, a more detailed description of this method would be useful to understand the results of this work.

Fair point, we'll expand on the description of this model and seek to provide a more complete and intuitive explanation.

Section 3.1

• Please provide more details related to the turbine. A table summarizing rated wind speed, hub-height, shaft tilt and rotor diameter would be useful. Is this a geared drivetrain?

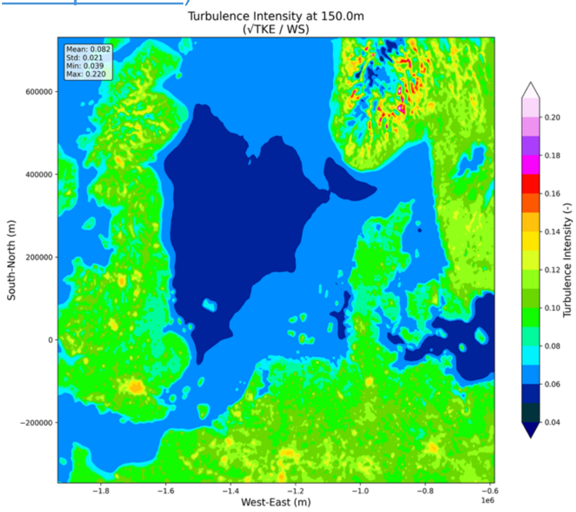
Thank you for this suggestion. We will include a new table with relevant turbine info for the 10MW DTU turbine. Yes, it is a medium speed geared drivetrain (we'll highlight that also).

• I assume that the wind farm is landbased (not offshore), but this is not stated anywhere. Please clarify.

The TotalControl reference wind farm is offshore, hence we did not simulate any terrain effects and used a 5% TI, we'll add a clarification to the paper.

• What is the rationale behind the choice of 5 % turbulence intensity? Turbulence intensity will significantly influence the wake recovery, which could alter the conclusions of this work. For a landbased turbine, 5 % is quite low compared to values recommended in the standards. It is important to discuss the validity of this assumption. The paper seeks to explain premature failure in main bearings, mainly reported for landbased turbines. If turbulence intensity is generally higher than what applied in this work, so that the wake recovers more quickly, it might not be valid to conclude that farm effects contribute that much to reduced main bearing lives.

We used 5% TI as a representative value for some offshore sites. For example, the following figure shows TI values from a mesoscale simulation of the North sea (based on data from https://orbit.dtu.dk/en/publications/environmental-mapping-and-screening-of-the-offshore-wind-potential):



Similarly, the following analysis of offshore sites shows that 5% TI is around the mode of TI distributions for various offshore sites, and again a reasonable representative value. https://windeurope.org/summit2016/conference/allposters/PO293.pdf

It is a valid point, however, that for sites with higher TI the wakes may recover faster, possibly lessening the impacts we report here. We'll therefore highlight this when revising the manuscript.

• How is shear modeled in this work? If the power-law is applied, what shear exponent is used? Wind shear is highly important for main bearing rating lives. Combined with the wake deficit, the shear profile will determine what the "final" shear that the downstream turbine experiences. I.e. low shear could result in a "reversed" shear profile in which the wake velocity deficit (which is typically deflected vertically due to shaft tilt) leads to reduced mean wind velocity with height. Please clarify and discuss.

We used a power law shear profile using a shear coefficient of 0.2. We'll make sure this is clearly indicated in the paper, and will add some discussion about the impacts of this assumption and suggest possible future work looking into these interactions in detail.

• It is common in industry to use a generator-side locating (carrying axial loads) bearing. To be relevant for industry, I would recommend reversing the setup (I assume this does not require running Dynamiks simulations over again but is related to post-processing).

We cannot make this change without needing to re-run all simulations, as a result of the manner in which results were obtained. In addition, there are a variety of drivetrain setups which exist that include both configurations. Either way, we feel that our analysis is valuable and instructive to both cases. The setup we utilised here was based on a benchmarking drivetrain designed by ORE Catapult in a commercial project.

• Please state what X and Y (load factors) are applied for each bearing. This is useful to understand the importance of thrust versus radial loads in the fatigue calculations.

This can change based on the ratio of axial radial bearing load, we'll add some more info to clarify what the values and change point are.

• What is the rationale behind the choices of CD? Are these values representative of 10 MW turbines? The authors later (Section 4) comment on the high rating lives, but these results highly depend on CD.

Bearing data for large wind turbines are not easily obtained, and aren't available in the literature. For instance in https://doi.org/10.1002/we.2476 main bearings are specified which don't meet the design life for that turbine, and apart from this there are little to no alternatives. The main bearing specs used in this study were obtained via ORE Catapult, from a drivetrain they designed for a 10MW wind turbine within a commercial benchmarking project. We'll add some clarification of this to the manuscript. It is also possible to show that results scale directly with CD (due to linear properties of the resultant rating life equations), which generalises the results beyond any single bearing design. We'll include that discussion when updating the manuscript.

• The authors investigate a 10 MW turbine, while main bearing failure reports mainly exist for smaller turbines. Could the authors comment on whether wake effects can be generalized across turbine sizes? Could wake effects be less important for smaller turbines, and therefore not have result in the same reduction in main bearing rating lives?

We'll happily include some discussion of these questions. Generally speaking we'd expect wake effects in the context of main bearings to be fairly general across turbine scales, given that turbine spacing tends to scale with the size of the turbines. While wake effects could conceivably be less important for smaller turbines, there remains a gap between predicted and observed main bearing lives across all scales for which, from the current work, wake impacts appear to be at least a credible candidate contributing cause.

Section 3.2

• Why is 5D applied in the two-turbine parametric analysis?

We undertook the same analysis at 3D and 4D and all results were qualitatively the same, hence we avoided overburdening the reader with lots of matching results. We'll clarify this in the paper and include a reference for why 5D is a sensible separation to choose as the nominal separation distance.

Section 3.3

• It could be useful to put the parameters presented here (e.g. k, annual mean wind speed, mean wind speeds, inflow directions etc.) into a table for better overview.

Good idea, we'll do that!

• What is the spatial grid resolution in the wind farm simulations and turbulent wind fields?

We will clarify in the paper that our turbulent wind field has a resolution of 3 meters in x, y, and z dimensions. Additionally, each turbine wake has a turbulence box with (3.8, 1.5, 1.5) m resolution in x, y, and z, which is the default setup in Dynamiks.

• Line 214: Suggest rephrasing to: "For each main bearing and each direction ":

Agreed.

• The distances between turbines along x and y should be stated more clearly

We'll clarify that the TotalControl wind farm has east-west spacing of 10 D and north-south spacing of 5 D.

• Figure 2a: Axes missing.

This subfigure is indicating the setup for the parametric analysis, rather than seeking to provide full positional data, and all pertinent info is stated in the caption and/or manuscript in non-dimensional nD form.

• Line 221: The reference to Hart should not be in parenthesis.

Good spot!

• Line 221: "Based on model fitting to data" – what kind of data? For what location are these ranges of wind roses realistic? What are the criteria for realistic? Is this data site-specific?

Will add some additional context here, thanks for highlighting this.

• Figure 3: Do all the wind roses evaluated have the prevailing direction of 180 degrees?

The simulated TotalControl wind farm is designed for a site with prevailing wind direction along the East-West direction (see Figure 2b), and we therefore maintained that prevailing wind direction throughout our analysis. More generally, the modelled wind roses can be readily rotated in order to shift to a different prevailing wind direction, but this didn't seem appropriate for the current analysis.

Section 4
• It could be useful to split this section into subsections to have a better overview of the different results.

We'll gladly consider whether this approach might improve readability.

• Line 228: The authors assume that the locating main bearing fails most commonly. What is this assumption based on? Why not present results of the rear bearing too (e.g. in the appendix)?

The locating bearing failing most commonly is established based on failure data, and discussions with industry. We'll add a citation. Given the weak link is the locating bearing, it seemed to be distracting to overly focus on the rear bearing results as well. We'll revisit this decision when revising the manuscript to see if there could be merit in including these additional results.

• Line 230 and 240: "…bearing rating lives can be seen to far exceed the minimum design life…" Again, the rating lives are dependent on the value of CD. A more detailed description of the choice of CD should be given if these findings should be considered important.

We'll include that improved context here, but it's also worth highlighting that these findings are consistent with our previous paper (https://doi.org/10.1002/we.2883) in which these same findings held for bearings where we had full bearing data for commercially available main bearings. Certainly we can reference this earlier work to shore-up this discussion.

• Figure 4: Asymmetries are more pronounced for higher wind speeds. Could the authors comment on the differences in results between wind speeds?

This is a good point, and could be resulting from a variety of interacting effects. Perhaps the most obvious candidate would be that aerodynamic loads are more sensitive to wind perturbation at higher wind speeds (due to the v^2 term in lift and drag loads). Similar changes in local wind speeds due to wake presence could therefore be expected to elicit a greater magnitude of response in higher wind-speed cases.

• Lines 245-255: I think this explanation of the asymmetry is a bit too simple. Gravity mainly acts in the in-plane-bending moment in the blades and less so in the out-of-plane bending moment, depending on the shaft tilt and curvature of the blades. Out-of-plane blade root bending moments are predominantly important for main bearing loads (relative to in-plane BM). Is gravity in the blades driving hub pitch and yaw moments? When removing gravity, as presented in Fig. A1, the shaft moment due to rotor weight vanishes, and the radial loads are significantly reduced. With regards to the locating main bearing, bearing rating lives are now likely governed by axial loads, so that any asymmetry trend would disappear among the axial loads. It would be interesting to see a closer investigation of this effect.

We respectfully disagree on this point. The fact that turning gravity off removes this asymmetry in results provides strong evidence for the position that the effect relates to rotor in-plane forcing effects, which can interact with the gravity force vector. Importantly, all in-plane moments along the blade are generated by in-plane forces acting at a distance from the centre of rotation. It is those forces which can then act to perturb the mean vertical force being applied at the hub centre. Even if these changes are relatively small at the force level, recall that bearing rating life scales as 1/(applied load)^10/3, hence any change in applied vertical forcing will be magnified by this effect.

Note, we agree with your argument that the loading situation is very much changed once gravity is turned off, but gravity (as you point out) doesn't impact out-of-plane rotor forces and moments very much at all. If the asymmetry in results was principally driven by changes in out-of-plane moments, then we'd expect that asymmetry to persist in the absence of gravity. As that's not what we see, we conclude that it must be an effect of the type outlined above driving these interactions.

• Line 257-258: "Within a wind farm, the standard grid spacing between turbines will commonly be on the order of 3D-5D". Is this referring to spacing in the predominant cross-wind direction? I believe that larger distances are seen in the predominant wind direction. A reference would be useful.

You are of course correct on this point, and this is also the case for the wind farm we simulate in our study. We will correct this and provide a relevant reference as you suggest.

• Lines 275-285: Again, it would be useful to explain the physical meaning of a and f before discussing their impact on main bearing rating lives.

Fair point, will do!

Conclusion

• The impact of turbulence intensity and shear on the results should be discussed.

We will add in discussion of these important points, and highlight that more detailed investigations into their impacts in this context will be important future work.