REVIEW OF WES-2021-65

Development of a Curled Wake of a Yawed Wind Turbine under Turbulent and Sheared Inflow

authors:
Paul Hulsman
Martin Wosnik
Vlaho Petrović
Michael Hölling
Martin Kühn

Summary:

The manuscript entitled "Development of a Curled Wake of a Yawed Wind Turbine under Turbulent and Sheared Inflow" presents data collected with a continuous wave lidar during a wind tunnel experiment, characterizing the evolution of a yawed wind turbine's wake. The authors state that "the objective is to determine the effect of the boundary layer and turbulence intensity at different yaw angles on the wake deficit, wake deflection and wake dissipation," and is investigated by repeating the experiment in three slightly different inflow cases. The main finding appears to be that "The curled wake develops sooner and stronger in the case of the boundary layer inflow compared to the uniform inflow, suggesting that boundary layer inflow enhances the counter-rotating vortex pair (CVP)," although the connection between the inflow (shear, turbulence, etc.) and the development of the CVP is fairly descriptive. The paper would be greatly strengthened by improving the discussion of the causes of the observed changes, rather than simply describing difference in the flow cases. Additionally, the language in the paper is often convoluted and complex. Simplifying the text will help readers understand the content of the article much more easily.

Major points:

- page 1 — The experiment uses a single lidar. How then are dual-Doppler measurements achieved?
- page 2 — What does 'steady and reliable' mean? Steady state? Low uncertainty?
- page 4 — The assumption that $v = w = 0$ must not be true in yawed conditions. Can you quantify with Eq. 2 (to at least the first order) how realistic this assumption is?
- page 4 — What is meant by 'structural resolution'?
- page 5 — Lissajous trajectories for the horizontal and vertical planes appear to have a greater measurement density near the borders of the scan area. Does this lead to a difference in measurement uncertainty? Is error greatest in the center of the scan simply due to the measurements?

- page 8 — What are the min and max wavenumbers considered in equation 8? How are they determined? This description does not provide sufficient detail to understand the methods applied.
- page 8 — "...which remains well below the rotor area (highlighted as a shaded green area)." The boundary layer appears to be nearly up to the rotor area by $13D$ or $16D$, not well clear of it. Is this expected to impact measurements?
- page 9 — It looks like there is some acceleration near $z/D = 0.5$ for $x/D > 0$. Is this from the passive grid?
- page 9 — "air from the outside was sucked into the wind tunnel segment near the bottom leading to the visible speed-up region." This explanation is not clear to me. How would still air from the outside lead to an acceleration near the wind tunnel floor? It seems like air sucked into the tunnel would be slower than the flow in the tunnel.
- page 9, Figure 3 — Does the decay of TI in the uniform passive grid case impact the consistency of results? Is it accounted for in the analysis?
- page 10 — The paragraph discussing turbulence characteristics in the inflows is not clear. For example, in the sentence "This indicates that turbulence is maintained at a near constant level due to the mean shear, which causes production of turbulent kinetic energy." Are the authors saying that that turbulence 'decay' (energy transfer from large scales to small scales, I suppose?) is balanced by production?
- page 11, Figure 4— Interesting that the uniform inflow - no grid has a lower wind speed at the wall than the passive grid case. This seems inconsistent with the description of the inflow cases.
- page 13 — I believe that Martínez et al state that the opposite is true. "We assume that the wake rotation vortex does not decay or deform as it moves downstream. This is not necessarily true, as turbulence mixing will decrease the wake rotation."
- page 14, Figure 6 — I find this figure difficult to follow. Would the evolution of the location of the maximum deficit be more clearly shown with a line plot as a function of downstream distance?
- page 14 — "The turbulent kinetic energy dissipation rate (ε) gives an indication how the flow behaves within the wake: a high dissipation rate indicates a faster mixing of the wake whereas a small dissipation rate suggests that the wake will persist further down stream." I'm not sure that the argument made in this sentence is true. The dissipation rate ε represents the rate at which turbulent kinetic energy is dissipated into heat, not wake recovery. The key difference here is that wake recovery is typically associated with turbulent mixing and turbulent flux of kinetic energy, not with turbulent dissipation.
- page 13 — "In addition, the difference between the wind speed in the upper part and the lower part reduces for the case with a uniform passive grid shown in Figures 4d to 4f." This sentence is difficult to understand. It seems like the authors are stating that the distribution of momentum deficit in the wake is different than for the no-grid case. Please rephrase.
- page 14 — It is not clear what is meant by "enhanced" dissipation or turbulence. "Enhance" typically means "to make better". Do the authors mean to say "increased"?
- page 14 — The authors frequently refer to the wake of a yawed turbine as being "elliptical," although it does not appear to be. It may be safer to simply state that the wake is no longer axisymmetric due to the CVP or that the curled shape becomes more pronounced moving downstream, as the CVP has had more time/space to deform the $0.9u_\infty$ boundary.
- page 17 —"This also caused that the increment of the energy dissipation rate at hub height is not visible at a downstream distance of $5D$." This sentence is not clear. Are you saying that the turbulent mixing has decreased the dissipation rate following the nacelle?
- page 17 — "...a low dissipation rate is also visible at the region with the highest wake deficit" Turbulent dissipation is related to the gradient of Reynolds stresses. In the center of the wake, those gradients are quite small, so not surprising.

- page 18, Figure 9 — I find the markers on each of the contour lines difficult to distinguish. Would the contours be clearer without the markers? I think the color gradient would be sufficient to distinguish between the lines. Also the caption may be clearer by stating that each line shows the boundary of 0.9 u_infty at each downstream location.
- page 19, Figure 11 — Dotted lines are difficult to see. Please update line styles. Also, the use of color here does not help to distinguish between the different yaw angles or between the spread of wake center locations. Coloring each inflow case does not help interpret the results.
- page 20, Table 2 — Are these values spatially averaged as well? It is not clear why the data in the table are included in the paper, or what they are intended to communicate.
- page 22 — How is the dissipation rate calculated for the hotwire measurements? It might be nice to see how this was calculated to help understand the comparison.

Minor points:

- Forward references are used throughout the text. Please try to keep figures near their discussion in the manuscript, and the definition of variables near their appearance in the equations.
- page 8 — The sentence including, "avoiding that the turbulence and wind shear characteristics break down within the measurement domain." is not clear. Please rephrase.
- page 8 — In some cases, descriptions of lengths or distances are in units of meters, while figures describe the domain in terms of rotor diameters. Please be consistent throughout the manuscript.
- page 9 — "turbulence characteristics is crucial" should be "turbulence characteristics are crucial"
- page 10 — As a consideration for the writing style, phrases like "Here it can be detected that, ..." and "Furthermore, ..." do not contribute to the readers understanding of the content of the article and can be safely removed—everywhere.
- page 13 — "transferred to a certain direction" do the authors mean "advected" or "deflected"?
- page 13 — "The transfer of the wake deficit is visualized..." This is not clear. See above.
- page 13 — "detecetion" is repeated on line 29.
- page 22 — "...area which increases at 5D in width." This phrasing makes it sound like the high-dissipation ring is $5D$ wide. Please rephrase.
- page 22 — "can be related due" would be clearer as "attributed"