Reviewer 2

The paper investigates the applicability of equilibrium and non-equilibrium turbulence models from classical wake theories for wind turbine wake flows. Single hot-wire anemometry is used to characterise turbine wakes in three different scenarios: (i) a turbine subject to laminar inflow, (ii) one subject to full wake conditions, and finally (iii) a case in which the turbine is partially located in the wake of another turbine. The focus of the paper is given to verification of requirements for the validity of Townsend-George theory. The paper also studies in detail the evolution of wake centre velocity with streamwise distance and compare results of classical wake theories with the experimental data and common engineering wake models used in the wind energy community. Indeed, the subject of this work is interesting and relevant to the wind energy community. I appreciate the efforts of the authors to bridge the gap between turbulence research on wake flows in fluid mechanic community and the research on turbine wakes in the wind energy community. There are however major issues with suitability of experimental data and presentation of results. I will elaborate my comments in the following in the hope that it helps authors improve the quality of their manuscript:

We would like to thank the reviewer for evaluating our paper and for giving feedback that helped to improve the quality and readability of the manuscript. In the following, we will address every comment given below:

- Unsuitability of experimental dataset: I think the streamwise measurement range is too short which makes it very difficult to distinguish which model works better. For instance, in figure 12, all different relationships (x, x^1/3, x^1/2) seem to capture the variation of wake width with streamwise distance. At least, the authors could use log plots instead of linear plots for both velocity deficit and wake width plots. That way it would be much easier to find more systematically the exponent of a power function, for instance, whether the wake centre velocity deficit decreases with x^-2/3 based on Eq. 1 or with x^-1 based on Eq. 3.
    - While we agree that for a study of a classical bluff body wake, the range studied here would not be sufficient, we would like to point out that the range relevant for most wind energy applications is covered as the spacing of wind turbines rarely exceeds 8D.
    - We agree with the use of a logarithmic scale to improve the visualization of the deviation of different fits. Therefore, figures 9, 11,12,13 and 14 were changed and have now logarithmic axes.

- Comparison of model predictions: I think the way that the comparison with previous models has been made is not fair. First, EQ or NEQ models have two coefficients that can be tuned, whereas the other two models only have one empirical input. More importantly, it is not clear over which range of streamwise distance, fitting has been done. It is problematic if the whole range of [2D, 8D] is used to fit the model. The purpose of existing turbine wake models is to predict the far wake region, and these models are not expected to work well in the near wake region. For instance, in figure 9b, if you try to fit the BP and Jensen model only for [4D, 8D], their predictions should be improved.

- While we see the point of the reviewer that having two fit parameters that can be adapted is in advantage, we disagree with the statement that a comparison was "not fair": All engineering wake models are designed to describe the evolution of the wake of a wind turbine with increasing distance using only parameters that can be estimated from available information such as the current thrust coefficient and the inflow velocity. Therefore, while they have fewer free fit parameters, the used parameters are adapted to the flow and the turbine operation. They have been validated and calibrated to fit the wake of a wind turbine.

  In contrast, the EQ and NEQ model have been derived analytically from the perspective of flow physics and no calibration is applied to include the inflow or the turbine operation indirectly. Indeed, they are supposed to be valid for any generator, as far as an axisymmetric turbulent wake is produced.

- We agree that the models are *all* derived for the far wake – both the EQ and the NEQ wake models and the engineering wake models. We are aware that directly after the peak of the turbulence intensity, the turbulence may not be fully developed yet (for that reason, Neunaber (2020) uses the classification "decay region" for the transition to the far wake). However, from a practical standpoint, the description of as much of the wake as possible is of interest, especially the region starting from 2D downstream (in the case of turbulent inflow). In a wind farm, the spacing is often narrow (~3D-6D) and the ability of a wake model to also capture the wake of an upstream turbine in this situation is thus important. We therefore apply *all* wake models for the whole region in which the turbulence intensity decreases and the turbulence is already sufficiently evolved and compare the results in a similar manner. Our results, such as better performing power-law fits and the constancy of $C\varepsilon$, tend to point out that using far-wake mathematical tools in our flow remains approximately valid. There remain indeed some open questions and limitations that should be addressed in future works.

- Misleading title: there are two key words in the title: "dissipation" and "wind turbine array". None of them are really the main focus of this work. While C_epsilon is discussed in the paper, there is minimal discussion on dissipation in the turbine wake. Moreover, there is no more than two turbines used in this work. I therefore think it is a bit of stretch to use "wind turbine array" in the title.

  - We agree with the comment and changed the title to

    "*Application of the Townsend-George theory for free shear flows to single and double wind turbine wakes - a wind tunnel study*"

- Abstract should be more specific. The first half is more like an introduction talking about the importance of turbine wake studies. Also experimental setup and the data used to study these different models are not discussed in the abstract.

  - We thank the reviewer for this remark. We re-wrote the abstract following his/her recommendation. The quite long introduction part was removed in favor of a description of the methodology and the main results.

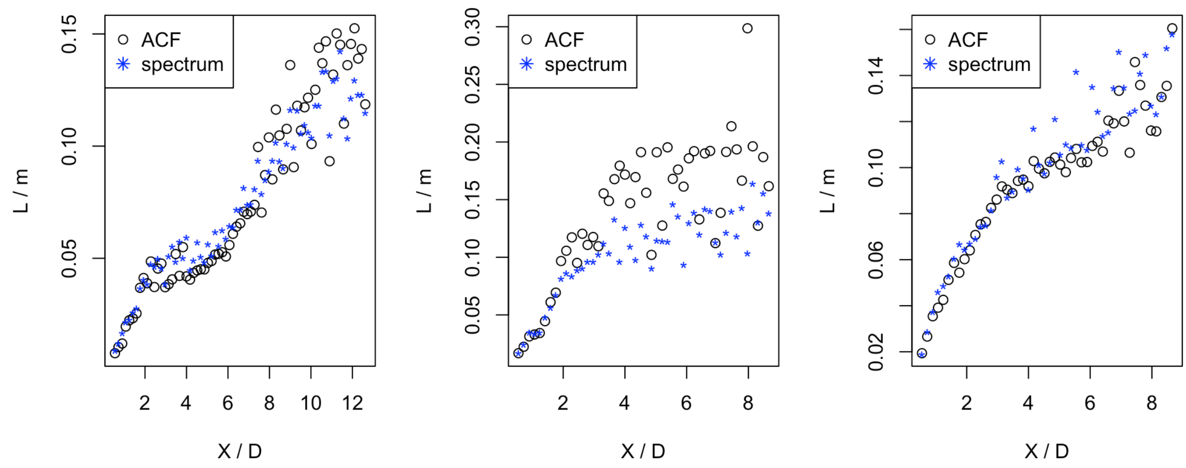
- Line 80: By placing a turbine in the wake of another turbine, the behaviour of a turbine within a turbulent background is studied. However, the turbulence generated by an upwind turbine consisting of wake rotation and shedding vorticity is not expected to be identical to the one generated in the atmospheric boundary layer flow. Please clarify this either in line 80 or somewhere else in the manuscript.

- We added a comment at ll. 94:
  "As this work serves as a proof of the applicability of the Townsend-George theory, we do not include an investigation of the influence of an atmospheric boundary layer (ABL) profile where inflow characteristics may differ. However, it is generally assumed that the wake of a wind turbine in an ABL can be seen as a superposition between the ABL profile and the mean velocity deficit (cf. Bastankhah and Porté-Agel (2014)). This is in agreement with Neunaber et al. (2021) where the Townsend-George theory also gives good results in the case of field measurements obtained in the wake of a full-scale turbine using a LiDAR."

- Section 3.2.2: For completeness, it would be useful to define the Taylor Reynolds number here.
  - We decided not to define the Taylor Reynolds number here but to refer to the appendix where the definition is given and all relevant calculations are detailed on. The relevant formulas are now linked in 3.2.2.

- Figure 6: Self-similarity of velocity deficit profiles is examined here, but the self-similarity of shear-stress profiles should be also checked. I am conscious that with single hotwire anemometry, it is not possible to look into this. Ideally repeat some of your measurements with x-wire, or at least mention this as a limitation of the experimental setup.
  - This is a valid point, and while a repetition of the measurements using an x-wire is out of the scope of this study, we now discuss this limitation of the setup in 3.2.4 but also reference the paper of Stein and Kaltenbach (2019) who investigate the self-similarity of added Reynolds stress tensor components and the added turbulent kinetic energy of a wake evolving downstream of a model turbine exposed to an ABL inflow. The passage now reads (ll. 275):
    "*As we present results obtained from 1d hot-wire anemometry, the test for self-similarity is restricted here to the mean velocity profile. However, Stein and Kaltenbach (2019) did investigate the self-similarity of the added Reynolds stress tensor components and the added turbulent kinetic energy in the wake of a model wind turbine exposed to an ABL profile. We assume therefore that this requirement also holds here.*"

- Integral length scale: Final results seem to be quite sensitive to the value of the integral length scale. Did you try estimating its value via other methods, eg autocorrelation function? It is of interest to add a brief discussion on the impact of integral length scale evaluation on final results.



- As shown in the figure above, we did calculate the integral length scale both using the autocorrelation (criterion: integration up to the first zero 0 crossing) and the energy spectrum. The results are similar so that we can conclude that a dependence of the results on the way of calculating L is not given.
- In the paper, we do not explicitly discuss the sensitivity of the results to the value of the integral length scale as it is solely used in figure 6 for the purpose of checking the requirement $L \sim \delta$ (note that the local Reynolds number ReL is defined in the Introduction using the wake width and not the integral length scale). In figure 6, we include the error bars for this reason, and details on the error estimation for L and δ are now given in the appendix.

- Line 261: wake axisymmetry: Please add a brief discussion on how the presence of ground and boundary layer may affect the axisymmetry of the turbine wake in real situations.

  - We separated the sub-section on the axisymmetry in the revised manuscript and also added a discussion of the influence of the ground and an ABL, it now reads (ll. 279):
    "3.2.5 Axisymmetry
    In addition to self-similarity, also axisymmetry of the wake is required, as explained in requirement 4. As the measurements
    that we present have been carried out in one half of the wake, we are not able to directly verify the axisymmetry. However, based on the symmetric setups for turbine 1 and turbine 2 mid and other studies with similar conditions, see e.g. Stevens and Meneveau (2017), we conclude that the requirement of axisymmetry can be taken as valid for these inflow conditions. It should be noted that the axisymmetry may be influenced by the presence of the ground and an ABL profile when investigating the wake of a wind turbine in the field. However, as the mean far wake evolving downstream a turbine exposed to an ABL inflowis often described as the superposition of an ABL profile with an axisymmetric wake, it can be assumed that the requirement also holds for these cases (Bastankhah and Porté-Agel (2014); Stein and Kaltenbach (2019))."

- Line 275: Please consider using a different title for this section. By the first look, "summary" may imply that this section is the summary of the whole manuscript.

  - We changed the title of this section to '*Summary of chapter 3.2*'

- Line 299: Please rephrase this sentence. It does not read well.
  - We rephrased the sentence, it now reads (ll.337):
    "*When the wind direction changes, the wake of an upstream turbine may pass over a downstream turbine with the consequence that Cε in the inflow changes e.g. from the wake to the ABL inflow. In such a scenario Cε changes with time.*"
- Line 29: "extend" should be replaced with "extent".
  - We corrected this
- Line 181: "be" in "This is achieved by measuring" should be replaced with "by".
  - We corrected this
- Line 136: "a axisymmetric" should be replaced with "an …".
  - We corrected this (l. 153 "…*have to be axisymmetric*")