Response to the Review on the Paper wes-2022-42

On the laminar-turbulent transition mechanism on Multi-Megawatt wind turbine blades operating in atmospheric flow

B.A. Lobo, O.S. Özçakmak, H.A. Madsen, A.P. Schaffarczyk, M. Breuer, N.N. Sørensen

Review # 1

We appreciate the effort of Gerard Schepers for evaluating our manuscript in detail. In the following his remarks are answered and modifications resulting from his comments are explained. Note that in the annotated version of the manuscript all modifications (replacements, additions and deletions) regarding the remarks of reviewer # 1 are highlighted in red.

Please note that in response to both reviewers regarding a consistent writing style, the text was in general revised to achieve this by a single author. No highlights are made to such changes as the message delivered and information contained remains unaltered.

Response to specific comments:

- **Free-Stream Velocity definition throughout the text**
  We have changed for the consistency of the definition of the free-stream velocity to 'w' in the paper. That is not highlighted by red in the text. In the case of the LES simulations, however, it was necessary to retain the coordinate system used, but in this case the notations are made clear to prevent any confusion.
- **What is the red line**
  As you guessed, the red line is mainly that all the studies deal with boundary layer transition on wind turbines with some comparisons that have already been made when applicable. The focus is on the impact of the atmospheric turbulence, which makes the conditions quite different from wind tunnel investigations. The paper synthesizes information on wind turbine rotor transition from two main full scale experiments and supported by numerical simulations of rotor transition with CFD codes of different fidelity, all indicating that a mix of natural transition and bypass transition is present. This has been clarified in the last paragraph of the introduction just before discussing what to expect in the different sections of the paper.
- **Definition of turbulence intensity**
  In case of the URANS simulations of the DAN-AERO blade, the turbulence intensity is calculated from the field experiments by the relative velocity on the blade which is sampled by a Pitot tube. This information has now been added to the manuscript.

  Regarding the LES, yes, as suggested the spectrum on a rotating blade section is different than that from the free-stream. However, as is now highlighted in the text, the rotational effects are not taken into account for the LES simulations for the following reasons: Firstly, the length scales of the added inflow turbulence are far lower than those in the free atmosphere on account of computational limitations on the size of the domain. Secondly, it is of interest to study the response of the boundary layer to broad-band free-stream turbulence which includes lower frequencies not typically achieved in a wind tunnel test, but are present in the atmosphere. Thus for the purpose of the study, which is not a direct comparison to the experiment, but one to study the response of a blade section to inflow turbulence of the broad-band kind, the chosen methodology not taking into account rotation suffices.

Regarding the application of Mack's relation. This relation is the result of wind tunnel tests where rotation is not taken into account and also importantly, low-frequency disturbances are not the ones with the highest energy (in a wind tunnel) which is the case in the atmosphere (see Schaffarczyk et al., 2017 cited in the manuscript). Thus, the LES serves as a wind tunnel test including these missing lower frequency components, but does not take into account rotational effects.

- **Title says transition mechanisms on Multi MW wind turbine blades, but this can range from 2 to ∞.**
  That is true. Thus, we changed the title from Multi-Megawatt to Megawatt.

- **Addition of rated power in Table 1**
  Rated powers have been added to Table 1.

- **Table 1: Information about airfoils involved**
  Airfoil types are now included in Table 1 when applicable.

- **Inclusion of the field experiment by O. Pires et al. (2018) in Table 1.**
  This reference has been included.

- **DanAERO: More information about the experiment, specifically information about microphones and pressure taps**
  The explanation is added to the article.

- **Making Fig. 1 color-blind friendly and have extended explanation**
  Figure 1 is updated according to a color-blind friendly color palette. The T-S wave peaks and laminar and turbulent spectra are shown in the figure and further additional explanations have been added to the text according to reviewers' comments.

- **Make Fig. 3 color-blind friendly with distinguished lines**
  Figure 3 is updated according to color-blind friendly color palette and the lines and dots are made more distinct.

- **The legends of Figure 6 x/c_{tr}**
  The captions of the Figure 6 are changed according to the reviewers' comments. Thanks for noticing this.

- **Aerodynamic Glove experiment: Enhanced or replaced by thermography?**
  Results from the microphones are now also added to the text. The results from the microphones are limited in the sense that no large regions of laminar flow were seen during steady-state operation on account of the surface of the aerodynamic glove. Details have been added to the text and comparisons between transition prediction from

the microphones and thermography have been incorporated as well. This comparison also clarifies the other point made about equal accuracy between the two techniques.

- **Aerodynamic Glove experiment: Description of the measurement technique**
  A description of the measurement techniques has been added. The distance does play a role in the final resolution that is possible, details of which have been included in the text. The thermography images are instantaneous and not averaged in time. This issue has been made clear in the text. The two teams did indeed use different detector materials, but two teams were asked if they could be a part of the project and both agreed. This is the reason why results from two teams are presented.

- **The text suggests that thermography is of equal value as microphones for transition detection.**
  This was not the intended message. Transition can however be reliably detected using thermography and finds its applications in cases where a non-intrusive method is sought. The clarification of microphones being superior for the purpose of transition research has been made clear.

- **Section 3.1: Overall difficult to follow**
  This section has been heavily edited to make it easier to follow with the inclusion of this section only to show the different RANS-based techniques that are presently used for wind turbine transition calculation for the sake of completeness to this article on wind turbine transition.

  In particular, the following points have been taken into account:

  - The title "Findings from IEA Wind TCP Task 29 Subection 3.6" has been revised. The reference is also made to Task 3.6 described in Chapter 10 instead of the entire study.
  - Yes, you are right, Table 2 refers to the meshes of the DAN-AERO blade, this has been made clear.
  - Table 3: wt_{perf} is no longer referred to as an outdated BEM code.
  - It has been added that not just c_p but also c_T is underpredicted.
  - Note that the other points made regarding Section 3.1 no longer apply after the changes to the manuscript and are thus not addressed individually.

- **Line 227: URANS full rotor simulations for DAN-AERO experiments: About T.I. values calculated from experiments to apply in simulations**
  The turbulence is quantified by the turbulence intensity ($T.I.$), which is the standard deviation of the relative velocity divided by the average relative velocity over 10 minutes in this case. Ten minutes average of the velocity data obtained from the Pitot tube on the blade is used in order to obtain the $T.I.$ values.

- **Mention the relative radial position instead of the absolute y value**
  The relative radial positions are added in the manuscript

- **Figure 13: Indicate the distance of the blade section from the hub as done in Fig. 12**
  This has been done.

- **An estimate for changes in wind speed, turbulence intensity and angle of attack that the blade at section y = 36.8 undergoes**
  A text is added as follows: ¨The selected case is operating in low shear conditions. The angle of attack changes from 4 to 8 degrees, and the relative velocity on the blade changes from 62.5 to 66 m/s, showing the same trend with azimuth angle as the transition position in Figure 14. Furthermore, the inflow turbulence signals detected from a leading edge microphone show higher values (100 - 115 dB) between 0 to 150 degrees azimuth and decrease to 85 - 105 dB range between 150 to 350 degrees azimuth, showing an opposite response than other parameters with azimuth angle.¨
  In addition we are adding a supplementary plot to the response, presented below:

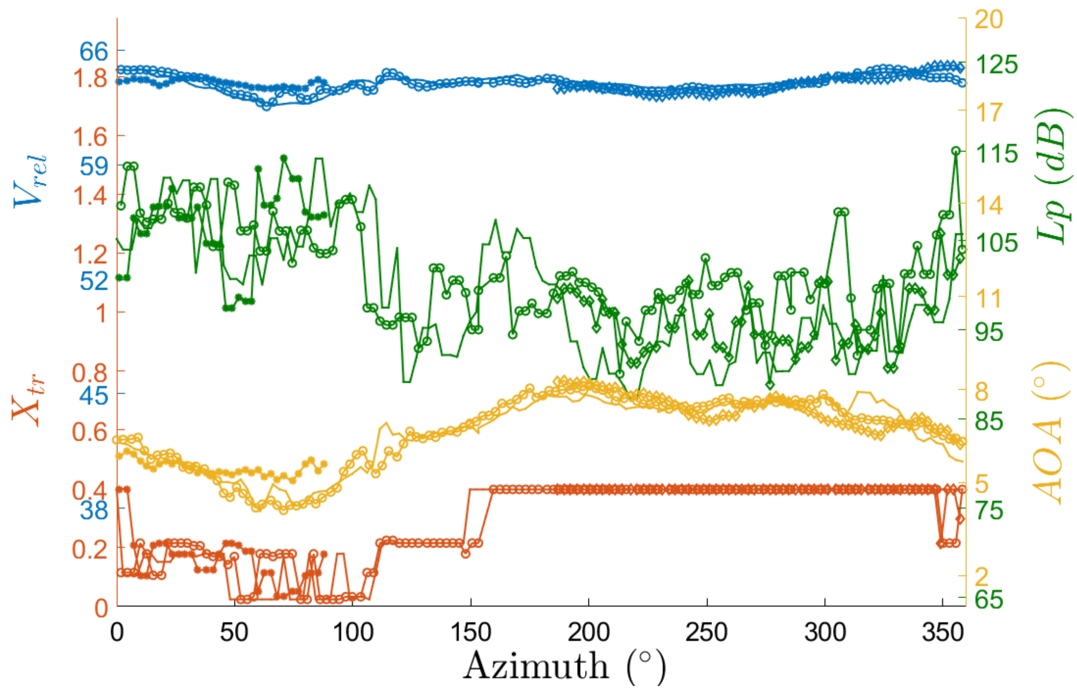

Figure 1:

- **Figure 14 adding that it is pressure side**
  This change has been made.

- **Line 271: Deriving aoa from force measurements**
  It is calculated from HAWC2 and an explanation is introduced in the text highlighted in red.

- **Section 3.3: LES on a non-rotating blade section**
  This is right, the LES has been performed on a non-rotating blade section and the text has been revised to make this very clear. The reasoning for doing this has also been elaborated.

- **Mention the relative thickness of airfoils**
  Added to the other parts of the manuscript.

- **Section 3.3: LES level of detail**
  You are right and the level of detail here was a lot higher. It has been cut down and references are made where necessary.

- **STIG: What does it mean?**
  STIG refers to Synthetic turbulence inflow generator. The abbreviation has been added on its first mention in the text.

- **Additional minor comments to the LES section**
  The following changes have been made:

  - The airfoil name corresponding to the plots has been included.
  - The label in the spanwise direction has been added.
  - The legend "up" on Fig. 18 (first version of the manuscript) refers to fluctuating velocity up(rime): u'. This has been changed to w' since the inflow velocity direction across the manuscript has been changed to "w".
  - Yes, lower frequencies of the inflow turbulence on line 398. This has been made clear.
  - Klebanoff modes or boundary layer streaks which is the boundary layer response to external disturbances. A relevant citation has been included.

- **No evidence for laminar flow from mean pressure distributions**
  This is correct and none of the experiments discussed uses pressure distributions to detect laminar flow. The conclusion has been edited accordingly.

- **Line 500: On the suction side?**
  This is correct and has been made clear.

- **Line 502: Much less fully turbulent models could lead to a smaller deviation?**
  The transition location using transition models, especially correlation based transition models depends heavily on the inflow conditions and grid. To expect similar results across different codes would in the first place require the grids to be identical which is difficult to achieve.

We gratefully acknowledge the effort of the referee and his/her contributions in enhancing the quality of our paper. Thanks a lot.

B.A. Lobo, O.S. Özçakmak, H.A. Madsen, A.P. Schaffarczyk, M. Breuer, N.N. Sørensen

Review # 2

We appreciate the effort of Ryan Scott for evaluating our manuscript in detail. In the following his remarks are answered and modifications resulting from his comments are explained. Note that in the annotated version of the manuscript all modifications (replacements, additions and deletions) regarding the remarks of reviewer # 2 are highlighted in blue.

Please note that in response to both reviewers regarding a consistent writing style, the text was in general edited to achieve this by a single author. No highlights are made to such changes as the message delivered and information contained remains unaltered.

Response to specific comments:

- **Consistent writing style**
  As described above, the text has been revised for a consistent writing style.

- **Figure formatting varies between sections**
  The figures have been edited and all graphs are now plotted using the same tool when applicable.

- **Transitory Paragraphs**
  The text has been revised to transition more smoothly between the main sections better describing what to expect. Furthermore, methodologies have been added.

- **Differences in turbulence produced by an upstream turbine and synthetic turbulence and how this might impact the PSD plots**
  The first paragraph of Section 3.3 has been edited to elaborate on the kind of results one could expect from the LES which uses synthetic turbulence in the sense that it is similar to a wind tunnel but also includes lower frequencies that are absent when using active grids for the generation of turbulence in a wind tunnel. Furthermore, on account of the length scales in the free-atmosphere being different to that which is feasible using simulations, and furthermore on account of rotational effects a direct comparison is not possible between experiment and simulation.

  However, as already discussed in the conclusions of the LES section, the PSD plots from the simulations and experiments do have their share of similarities with natural transition in both instances being very obvious while in the presence of elevated turbulence intensity it becomes difficult to distinguish what is laminar and what is turbulent.

- **Why some quantities are represented i.e. vorticity ?**
  An explanation for this choice is added to the text in Section 3.2 in blue color.

- **Are x/c in Figure 5 and X_{tr} in Figure 13 the same? Where is X_{tr} defined?**
  The legends of Figure 13 have been updated to clarify this.

Other Points:

- Possibly place Figure 4 ahead of Figure 2.

  Figure 2 is moved ahead of Figure 4 as suggested by the reviewer.

We gratefully acknowledge the effort of the referee and his contributions in enhancing the quality of our paper. Thanks a lot.

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