Response to Reviewer's Comments concerning wes-2020-107

Thales Fava Mikaela Lokatt Niels Sørensen
Frederik Zahle Ardeshir Hanifi Dan Henningson

We would like to thank the reviewer for careful and thorough reading of this paper. Our response follows.

Referee #2 Comments

Comments:

- **Comment:** 1. Introduction – The linear stability of the flow over swept wings could have been further reviewed considering that the 3D boundary layer and PSE formulation was initially made for these kind of problems
Answer: The authors are thankful for the comment and have included a more extended review of the stability of the flow over swept wings in the fourth paragraph of the Introduction of the revised document.

- **Comment:** 2. Equation 29 – subscript 1 missing for the streamwise coordinate and γ has been used both for the frequency and as intermittency factor in the RANS modelling.
Answer: α is only a function of x_1 and x' is a dummy variable of integration. For this reason, there is no index for it. We have changed the variable describing the frequency from γ to ω to avoid confusion with the intermittency factor γ. We have also changed the angular velocity from ω to Ω and the wave propagation angle from η to Ψ.

- **Comment:** 3. Overall, the discussion is quite thorough, however a bit prolix. For instance, a lot of effort has been placed in describing the shape of the velocity profiles but what are their implications in terms of boundary layer transition. As already reported on swept wings the highly inflectional nature of the profile of the transverse component (in this case u2), in the in-board region in figure 6(a) and 6(b) is also an indication of the potential crossflow instability. In fact, there is very little discussion on the behaviour of the mean flow and the possible route to transition, mainly focused towards the end of section 4.2.
Answer: Thank you for this observation. We have included a more thorough discussion relating the velocity profiles to possible transition mechanisms in Section 4.4 (formerly 4.2).

- **Comment:** 4. Similarly, the discussion on the flow over geometry 1 and geometry 2 are completely segregated. Since the topology of the flow is quite different from each other it will be interesting to compare them right from the beginning and this will already set the scene for how the modification of the mean flow by varying different parameter will favour a particular route to transition.
Answer: We have changed the text in Section 4.4 (formerly 4.2) to include a comparison between the flows in Geometries 1 and 2 and how this may favor a particular transition mechanism.

- **Comment:** 5. The sentence starting at line 349 and ending at line 350 is a bit of a contradictory statement.
Answer: The sentence is "This fact means that the RANS base-flow becomes turbulent (stable) too early, before a mode could reach N_{crit}". The intended meaning of this sentence was that, in

the PSE analysis of the RANS base-flow, the modes do not amplify enough to reach the critical N-factor because the RANS transition model indicates earlier transition, rendering the velocity profiles linearly stable. We have removed this sentence as well as references to the PSE RANS approach. This was done because we believe that there are not enough converged modes in this PSE analysis to generate a reliable envelope of N-factors.

- **Comment:** 6. Line 353 – "These differences arise from the pressure distribution from XFOIL not exactly matching those from RANS, although they are close to each other". Any idea why there is this mismatch?
  Answer: A possible source of those differences is a small mismatch between the angles of attack (AoA) of XFOIL and RANS. The XFOIL computations are for an AoA calculated based on the inflow velocity and that generated by the blade rotation, which may differ from the actual AoA in the RANS simulation. Moreover, XFOIL C_p distributions were obtained for a two-dimensional section of the wing, without considering its spanwise variation and the three-dimensionality of the flow present in the RANS results. Those effects are particularly important for Geometry 1 at $r_0/R = 0.26$. This explanation has been included in the first paragraph of Section 4.2 of the revised document.

- **Comment:** 7. Figures 10 and 11 can be combined and similarly figures 15 and 16
  Answer: We have merged figures 10 and 11 (now figure 10) and figures 15 and 16 (now figure 14) in the revised document. We have also combined figures 4 and 5 (now figure 5), figures 13 and 14 (now figure 13), and figures 18 and 19 (now figure 16).

- **Comment:** 8. Figures 12 and 17 can be rearranged so that they do not occupy a full page.
  Answer: We have rearranged figures 12 and 17 (now figures 11 and 15) to reduce their space.

- **Comment:** 9. The angle η could be described in the schematic in Figure 1 for readers who are not used to the 3D flow topology, may be just sketch of the flow topology such as the development of the skin friction lines. In fact, why not show the skin friction lines from the RANS simulation also to complement some of the arguments about the three-dimensionality being more pronounced on some part of the rotor.
  Answer: For clarity, we have included in Figure 1 a diagram of a 3D boundary layer, describing the angle η (now Ψ) between the wave propagation direction and the inviscid streamline. We agree with the referee that it would be interesting to present the skin friction lines or the streamlines over the blade surface to describe the three-dimensionality of the flow. However, in order to increase the conciseness of the article, we cited in the third paragraph of Section 4.3 two references [3, 1] that have numerically studied the flow in Geometry 2 for the same operating conditions of the present work. They present the streamlines over the blade surface and discuss three-dimensionality effects.

- **Comment:** 10. The sentence starting from line 402 could be rephrased to be more explicit.
  Answer: The original sentence is "The smaller sensitivity of transition to variations in the rotation speed ensues from the fact that the airfoils of Geometry 2 maintain favorable pressure gradients over a larger chordwise extent, which makes the rotation effects have smaller relative importance." We have changed it in the tenth paragraph of Section 4.5 of the revised article to: "The transition location moves less with the rotation speed for Geometry 2 because this blade maintains a non-negligible pressure gradient over a larger chordwise extent, overtaking rotation effects."

- **Comment:** 11. The splitting of the near-wall lobe of the TS eigenfunction is also observed in the presence of the large adverse streamwise pressure gradient; therefore it might be worth tying this with the strong 2D mode amplification.
  Answer: We are thankful for the suggestion. We have included a discussion in the sixth paragraph of Section 4.5 of the revised document linking the appearance of a second peak in the eigenfunction to the two-dimensional amplification of the mode in the presence of an adverse

pressure gradient. We have also added to Fig. 13 the modes obtained with the PSER 2D approach to show that the appearance of a near-wall peak is related to 2D TS waves.

- **Comment:** 12. The attachment line has been mentioned on quite a few occasions however there is no mention of whether it is below the threshold for contamination, keeping in mind that the leading edge radius of curvature can be quite considerable in the inboard region of the rotor.

  Answer: Thanks for the remark. We can define $\overline{R} = \left(\frac{u_\infty R \sin\phi \tan\phi}{2\nu}\right)^{1/2}$, where u_∞ is the incoming infinite velocity, R is the curvature radius of the leading edge, ϕ is the sweep angle, and ν is the kinematic viscosity. Contamination occurs for $\overline{R} \gtrapprox 250$ [2]. In the analyzed wind-turbine blades, $\overline{R}$ is well below this threshold. The maximum values of this parameter for Geometries 1 and 2 are $\overline{R} = 41$ and $\overline{R} = 15$ at $r/R_0 = 0.26$ and $r/R_0 = 0.40$, respectively. Thus, attachment-line contamination is not expected to occur. We have included this analysis in the first paragraph of Section 4.1 of the revised document.

- **Comment:** 12. Although the method developed here will be useful in the design and optimisation of wind turbine rotor blades, the linear PSE has its limitations which D. Henningson and A. Hanifi will definitely agree, therefore it might be worth mentioning those, just to keep the reader informed and avoid any bias within the transition community.
  Answer: We appreciate the remark. We have stated the limitations of the PSE in predicting transition in the third paragraph of the Introduction of the revised document: "However, there are limitations in the linear PSE approach, which are the inability to predict: i) transition in strongly non-parallel flows with rapid variation in the streamwise direction; ii) transition in strong three-dimensional flows; iii) transition caused by global instability, as in the case of strong separation bubbles."

References

[1] S. G. Horcas et al. "Rotor-tower interactions of DTU 10MW reference wind turbine with a non-linear harmonic method". In: *WIND ENERG* 20 (2017), pp. 619–636. DOI: `10.1002/we.2027`.

[2] D. I. A. Poll. "Some aspects of the flow near a swept attachment line with particular reference to boundary layer transition". In: *CoA Report 7805, Cranfield University* (1978). URL: `https://dspace.lib.cranfield.ac.uk/handle/1826/832`.

[3] F. Zahle et al. "Comprehensive Aerodynamic Analysis of a 10 MW Wind Turbine Rotor Using 3D CFD". In: *Proceedings of the 32nd ASME Wind Energy Symposium, National Harbor, Maryland, 13-17 January 2014*. 2014.