Author response to comments by Reviewer 2 of "Local Correlation-based Transition Models for High-Reynolds-Number Wind Turbine Airfoils"

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We thank Reviewer 2 for the constructive comments and suggestions which have helped to improve the manuscript. We have tried to address most of the concerns as best as possible. We hope that Reviewer 2 would be satisfied by our changes to the manuscript and our responses. Each issue raised by a specific comment in the report is addressed in detail below. Modifications of the manuscript can be tracked in the highlighted version of the revised article (red = removed, blue = added or modified). There was some degree of overlap in the comments by Reviewer 1. As a result, we have only highlighted the specific changes to the manuscript after we addressed the comments by Reviewer 1. We hope this is acceptable if the final manuscript contains all the changes requested by both reviewers

The chapter names Validation and Results seem a bit strange without a proper clarification in the name. What is being validated? Isnt the comparison under the chapter Results with all the comparisons with different airfoil computations and experiments not also a validation?

Based on this suggestion, we have reorganized the two sections into validation of the turbulence model and the transition models. Section 3 now contains only validation results for the SA turbulence model using the fully-turbulent flow assumption, while Section 4 contains the validation results for all simulations using the transition model.

The paper shows quite some comparisons of calculations, while the reason for the differences sometimes remains unclear. In the paper not a single pressure distribution is shown, while this also may shed some light on the source of the differences. I would opt for less examples and a more thorough investigation of the ins-and outs of the calculations.

We agree with the reviewer's comment. Thus, only the results for a few representative airfoils (DU25-A17 and NACA64-A17 airfoils from DU airfoil series and FFA-W3-301 airfoil from FFA-W3 airfoil series) are left in the "Results section". The comparison results for the other airfoils are moved to the "Appendix A: Additional Results".

The experimental surface pressure distributions are available for the DU00-W212 airfoil. Thus, the current predictions are compared with the experiment at 4° angle of attack where the maximum L/D ratio mostly occurs as shown in Fig RC2-1. Overall comparisons with experiment are quite satisfactory from both one- and two-equation transition models. Although there are large difference in drag coefficient and L/D between two transition models at 4° angle of attack, the difference in pressure is not significant at all Reynolds numbers. This is because the viscous drag component is dominant over the pressure drag component and the integration of small difference in pressure distribution can result in noticeable difference in drag. The noticeable difference in pressure drag can be found in Fig. RC2-2

For a more thorough investigation, the comparison of drag component breakdown between one- and two-equation transition models are performed for the DU00-W212 airfoil at 4° angle of attack as shown in Fig RC2-2. It is shown that the reason of difference between two transition models is both pressure and viscous components though the viscous component is larger than the pressure drag. Both can be affected by predicted transition onset location. It is also shown that the difference becomes severe at higher Reynolds number flows.

Therefore, in the revised manuscript, Fig. RC2-2 and the corresponding statements are added.

Figure 2 and 10 and chapter 4.2 There is no such airfoil as DU21-A17, nor do any of the other DU-airfoils mentioned in chapter 4.2 exist. Im afraid the authors confuse the aero-data file names with the airfoil data of the NREL 5MW turbine with the actual airfoil names. DU21-A17 is actually the file with airfoil characteristics of airfoil DU 93-W-210LM for a blade aspect ratio of 17. The addition LM stands for a small reduction in the trailing edge thickness done in the framework of the Dutch DOWEC study [1], where this modification originates from. NACA 64-A17 is simply the file with data for the original NACA 64 3 -618 corrected for aspect ratio. The lift, drag and moment coefficients given in the files are synthesized data on the basis of calculations and experiments (at lower Reynolds numbers). They are not the direct result of measurements in a wind tunnel for a Reynolds number of 7x10 6 . The differences between experiment and computations in figure 10e, however, will still be big, as the maximum lift coefficient for the NACA 64-618 at Re=6x10 6 is only slightly higher than 1.5 Instead maybe some older NACA airfoils can be used, for which characteristics up to Re=9x10 6 are available. If specifically wind turbine airfoils are needed, ref. 2 may be of help.

We thank the reviewer for bringing this to our attention and agree with the reviewer. The airfoil names are corrected as below in the revised manuscript:

- From DU21-A17 to DU93-W-210LM (DU21);
- From DU25-A17 to DU91-W2-250 (DU25);
- From DU30-A17 to DU97-W-300LM (DU30);
- From DU35-A17 to DU99-350 (DU35);
- From DU40-A17 to DU99-W-405LM (DU40);
- From NACA64-A17 to NACA64-618 (NACA64);

Upon further review, we found that the reference for the airfoil polars in the NREL 5MW turbine is the the DOWEC 6MW Pre-Design report [3]. Page 14 of this report states that

"Ruud van Rooij of Delft University of Technology provided 2D measured coefficients for the DU-airfoils for a Reynolds number of 7 million. Table 2 shows that the Reynolds numbers (and aerodynamic performance) for the blade part outside rotor radius 20 m are significantly more for nominal operating conditions. Even more so, the airfoil data for the NACA 64-618 as copied from appendix IV of Abbott and Von Doenhoff, apply to a Reynolds number of 6 million"

Further research into this [4] revealed that this is not true and that the airfoil polars were "synthesized" using RFOIL [5] for the Reynolds number of 7 million using correction factors on the basis of a comparison of RFOIL calculations and measurements at 3 million from the Delft wind tunnel in the clean configuration. However, we feel a comparison to this data is still relevant as it highlights the differences between the one-equation and two-equation transition models for the prediction of the glide ratio in the design range of angles of attack. Based on this, we have updated the discussion in the paper as follows:

"The predictions of HAM2D using both transition models for the airfoils in the NREL 5 MW turbine [2] are compared against data available in the DOWEC 6MW pre-design report [3] for Reynolds numbers of 6 and 7 million. Our understanding is that the reference data for the DU airfoils [4] were "synthesized" using RFOIL [5] for the Reynolds number of 7 million using correction factors on the basis of a comparison of RFOIL calculations and measurements at 3 million from the Delft wind tunnel in the clean configuration. According to the DOWEC 6MW pre-design report, the reference data for the NACA64-618 airfoil is obtained from appendix IV of Abbott and von Doenhoff [1]."

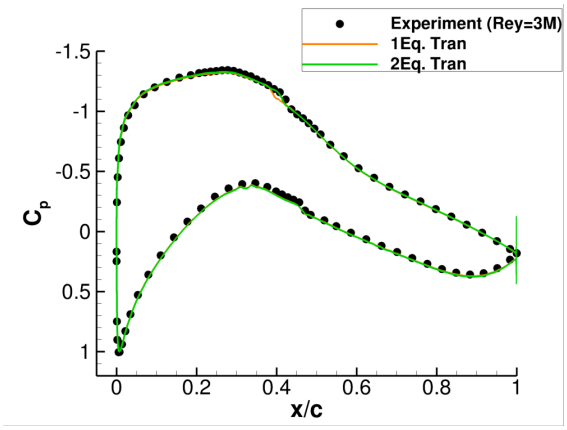
Figure 9: The authors might wish to check the post-stall drag data of DU 00 the data set. The wake rake had a fixed span position, so in stall that might give values either too high or too low because of 3D stall patterns. Using the pressure drag post stall instead of wake rake data may give at least less dramatic differences.

We appreciate the reviewer's suggestion for looking into the method of drag coefficient measurement in the experiment. In the experiment, the lift and pitching moment coefficients were calculated using 90 pressure taps along the mid span. The drag coefficient was calculated from the flow loss of momentum using the wake rake (118 total and 8 static pressure probes) which were installed 3.5 chords downstream from the test model.

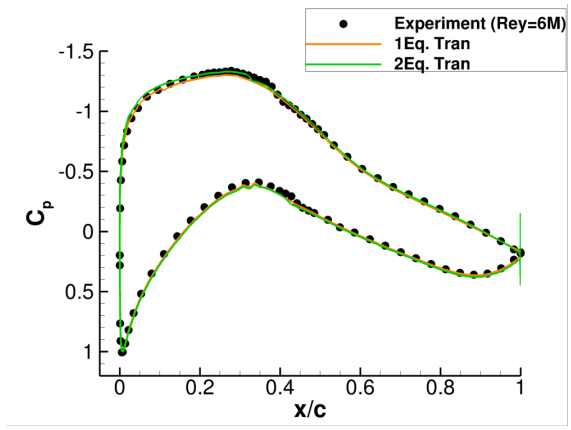
We included this brief information and the statement for the possible error from the wake rake in the revised manuscript:

"In the experiment, the lift and pitching moment coefficients were calculated using pressure taps along the airfoil and the drag coefficient was calculated from the flow loss of momentum using the wake rake. It should be noted that the drag measurement can be inaccurate at post-stall region due to the nature of 3D flows which were measured using the wake rake at a fixed span location."

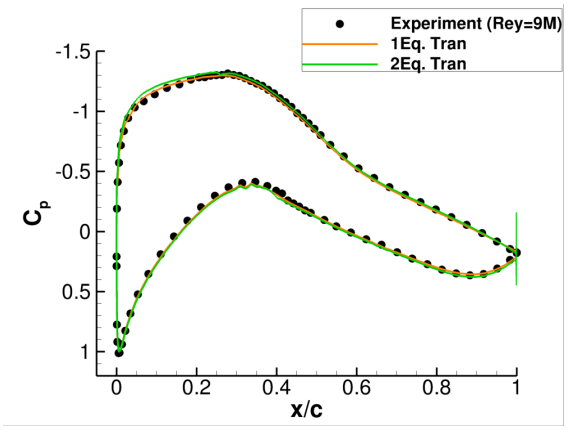
Also, for DU00-W-212 airfoil, we compared the surface pressure distribution with the experiment at 14° which is one of post-stall angle as shown in Fig. RC2-3. At both 3×10^6 and 12×10^6 Reynolds numbers, the current predictions are quite off from the experiment regardless of the transition model. This explains the limitation of current 2D RANS-CFD in stall prediction, which is already explained in "Sections 1" in the revised manuscript. Thus, we think the dramatic differences in drag between experiment and predictions might be due to the difference in pressure drag at post-stall.



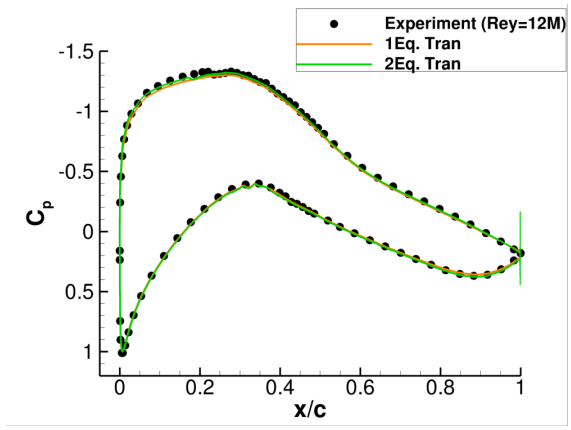
(a) $Re = 3 \times 10^6$



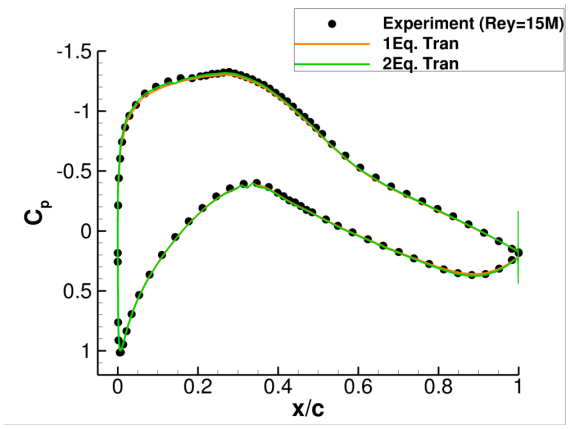
(b) $Re = 6 \times 10^6$



(c) $Re = 9 \times 10^6$

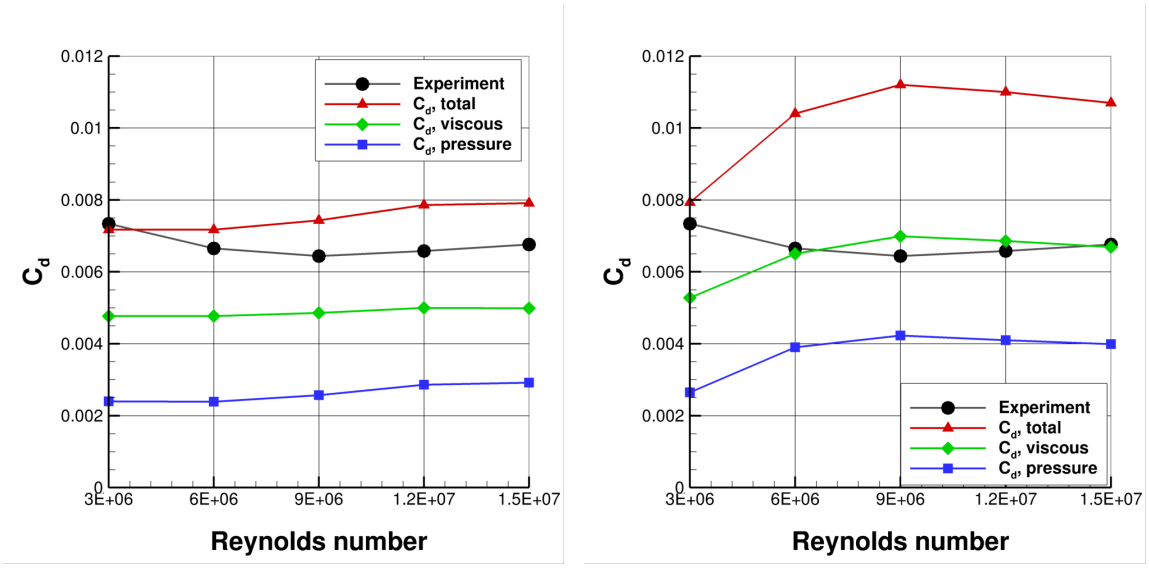


(d) $Re = 12 \times 10^6$



(e) $Re = 15 \times 10^6$

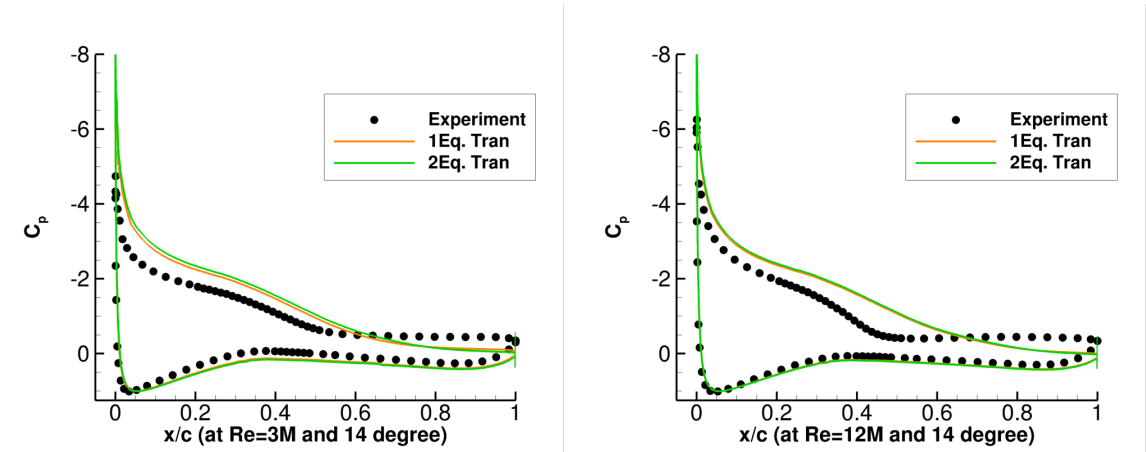
Figure RC2-1: Comparison of surface pressure distribution for DU00-W-212 airfoil at 4° angle of attack and various Reynolds number



(a) Two-equation transition model

(b) One-equation transition model

Figure RC2-2: Comparison of drag coefficient for DU00-W-212 airfoil at 4° angle of attack and various Reynolds number



(a) $Re = 3 \times 10^6$

(b) $Re = 12 \times 10^6$

Figure RC2-3: Comparison of surface pressure distribution for DU00-W-212 airfoil at 14° angle of attack

Bibliography

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[2] Jonkman, J., Butterfield, S., Musial, W., and Scott, G.: Definition of a 5-MW Reference Wind Turbine for Offshore System Development, Tech. Rep. NREL/TP-500-38060, NREL, Golden, CO, 2009.

[3] Kooijman, H. J. T., Lindenburg, C., Winkelaar, D., and van der Hooft, E. L.: Aero-elastic modelling of the DOWEC 6 MW pre-design in PHATAS, Tech. rep., ECN, 2003.

[4] Timmer, W. A.: Personal Communication, 2021.

[5] Van Rooij, R.: Modification of the boundary layer calculation in RFOIL for improved airfoil stall prediction, 1996.