Response to the Review on the Paper wes-2021-30

Investigation Into Boundary Layer Transition Using Wall-Resolved LES and Modeled Inflow Turbulence

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Review

We appreciate the effort of the reviewer for evaluating our manuscript in detail. In the following his/her remarks are answered and modifications resulting from his/her comments are explained. Note that in the annotated version of the manuscript all modifications (replacements, additions and deletions) regarding the remarks of the reviewer will be highlighted in red when the upload of an annotated version is an option.

Response to specific comments:

- **Include information from the responses in the updated manuscript**
  The reviewer is right! In order to make the manuscript self-containing, all relevant remarks from the previous reviewer responses have now been added to the manuscript.
- **Abstract as a stand-alone text**
  The statement "first step of this objective" has been removed from the abstract which now makes it stand-alone. This information continues to be available to interested readers in Section 3.1 (Description of the flow case).
- **Grid resolution**
  Streamwise oriented structures:
  The high frequency streamwise components seen around the separation region are caused by numerical noise. They are only visible near the region of breakdown to turbulence and according to our analysis do not directly affect the transition process which is the focus of our study. The cause was found to be some minor numerical oscillations due to the application of the central second-order accurate scheme. This scheme has the advantage of low numerical dissipation, which is important for LES. On the other hand, it is prone to numerical oscillations. Furthermore, this issue, albeit minor, is strongest in the case without added inflow turbulence. Therefore, the case of $TI = 0$ % was additionally simulated using a blended scheme with 98 % central differencing and an upwind scheme (2 %). The extra plots have been added to the manuscript and a better agreement between the standard and refined grid is seen in the c_p and c_f plots.

  Grid resolution affecting c_p:
  As detailed above, using a blended 2 % upwind scheme a closer match between the c_p and c_f plots of the predicted data on both grids is found, especially on the suction side and beyond the onset of the adverse pressure gradient region. The deviation in the laminar region of the airfoil, as has now been discussed in the manuscript, is very likely due to a geometrical issue of the airfoil smoothness. The peak in the c_f plot at around 10 % chord is similar to what is seen in preliminary studies for a Reynolds number of

500k of the same airfoil. This deviation is caused by the airfoil geometry not being sufficiently smooth, an issue that becomes increasingly prominent with increasing grid resolution. By fixing the airfoil smoothing issue, the case at Re = 500k experiences an increase in the favorable pressure gradient and a smoothening of the c_f distribution. It is very likely that the same issue is at play on the refined grid at Re = 100k.

Fig. 5 and Table 3:
The shape factor obtained from the refined grid has now been added to Fig. 5 and details on separation and reattachment have been added to Table 3. From the newly added plot of the displacement and momentum thicknesses (Figs. 5e and 5f of the updated manuscript) it is obvious that the boundary layer properties in the laminar region converge quite well, further indicating that the c_p and c_f distributions found on the blade surface arise due to airfoil smoothing issues. The shape factor from the standard grid with 98 % CDS and the refined grid agree quite well, but a clear discrepancy between the predicted data on the standard grid at 100 % CDS and 98 % CDS is visible. This is a result of the amplification of small variations in the displacement and momentum thicknesses on account of the way in which the shape factor is calculated. However, the location of the separation bubble (see Table 3 of the manuscript) and the corresponding location of transition onset indicated by the peak in the shape factor match quite well for these cases. As discussed in [1], the grid resolution of the standard grid is sufficient for the study of transition including separation bubbles, but a finer grid resolution could better capture the vortex development. This explains the slight difference in the shape factor between the standard and the refined grid within the region of the separation bubble. However, this does not affect the mode of transition.

Comparison of grid resolution:
Table 2 of the manuscript shows the grid parameters used for both the standard and the refined grid. Section 3.2.1 also compares the grid resolution to the recommendations proposed by Piomelli et al. [2]. The updated version of the manuscript also includes the suggested grid resolution from the study by Asada et al. [1] for flows involving separation bubbles. The standard grid employed for the simulations is well within the suggested parameter ranges for studies of transitional flows.

- **Additional Comments**
  To further support our simulations, in addition to the references already included, an experimental study by Boutilier et al. [3] is now added to the manuscript in which the frequency range of the separated shear layer also at a Reynolds number of 100k and a similar angle of attack on the NACA 0018 matches that of our simulations at 50 % chord in the absence of added inflow turbulence.

  Line 325:
  The crucial transition onset between 58 and 64 % chord refers to the standard grid and not the refined grid. It is now made clear that the results section only refers to the results from the standard grid. The refined grid is used solely for the purpose of the grid refinement study.

  Other minor points:
  Thank you for the comments regarding Figures 10 and 11. They have been taken into account.

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

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References

[1] K. Asada and S. Kawai. Large-eddy simulation of airfoil flow near stall condition at Reynolds number 2.1 $\times 10^6$. *Phys. Fluids*, 30(8):1139–1145, 2018.

[2] U. Piomelli and J. R. Chasnov. Large–eddy simulations: Theory and applications. In M. Hallbäck, D.S. Henningson, A.V. Johansson, and P.H. Alfredson, editors, *Turbulence and Transition Modeling*, pages 269–331. Kluwer, 1996.

[3] M. S. H. Boutilier and S. Yarusevych. Separated shear layer transition over an airfoil at a low Reynolds number. *Phys. Fluids*, 24(8):084105, 2012.