Comparison of RANS Turbulence Models for the Simulation of Smooth Wall Boundary-Layers in Pressure Gradients at Moderate and High Reynolds Numbers

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ABSTRACT

Recently, experimental measurements of boundary-layers under non-equilibrium pressure gradients have been performed at Virginia Tech [1]. The pressure gradient imposed to the boundary-layers is induced by a rectangular wing with a NACA 0012 section placed in the middle of a wind tunnel at angles of attack ranging between -10 and 12 degrees. A comparison of simulations performed by several RANS flow solvers using different turbulence models with the experimental data has been reported in [2]. The study reported in [2] assumed a two-dimensional geometry and the proposed computational domain included a tilted top wall to take into account the displacement thickness of the side walls boundary-layers. The Reynolds number based on the velocity of the incoming flow, airfoil chord and fluid kinematic viscosity is $Re = 2 \times 10^6$, which for most naval applications corresponds to model scale.

In this work, our focus is to assess the Reynolds number effect on the performance of different RANS turbulence models in the simulation of viscous flows. To this end, we have selected the experiments reported in [1] at angles of attack of -10, 0 and 12 degrees and the two-dimensional domain proposed in [2] to simulate the flows at Reynolds numbers of $Re = 2 \times 10^6$ and $Re = 10^9$ using four RANS turbulence models: the one-equation, eddy-viscosity Spalart & Allmaras model; the two-equation, eddy-viscosity $k - \omega$ SST model; the two-equation, eddy-viscosity $k - \sqrt{k}L$ model and the seven-equation, Reynolds Stress SSG-LRR$-\omega$ model. The goal of the study is to quantity the differences between the results obtained with the four turbulence models at model scale ($Re = 2 \times 10^6$) and full scale ($Re = 10^9$) numbers. Numerical uncertainties are estimated for all selected quantities of interest and validation metrics for pointwise and global assessment of modelling errors are used to quantify the discrepancies between solutions obtained with different turbulence models.

For the present test cases, discrepancies between solutions of the four selected turbulence models at model scale Reynolds number are significantly larger than those observed at full scale Reynolds number. Therefore, modelling error assessments (validation) performed at model scale Reynolds number cannot be extrapolated to full scale.

REFERENCES

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[2] Fritsch D.J., Vishwanathan V., Roy C.J., Lowe K.T., Devenport W.J., Nishi Y., Knopp T., Stroer P., Krumbein A., Sandberg R.D., Lav C., Bensow R.E., Eça L., Toxopeus S.L., Kerkvliet M., Slama M., Bordier L., "Experimental and Computational Study of 2D Smooth Wall Turbulent Boundary Layers in Pressure Gradient", AIAA Science and Technology Forum and Exposition, AIAA SciTech Forum 2022.