

Mitteilung

Fachgruppe: Numerische Aerodynamik

Recent advances of hybrid RANS/LES with Reynolds-stress background modelling

Marius Herr¹, Philipp Grotowsky^{1,2}, Axel Probst¹

¹Deutsches Zentrum für Luft- und Raumfahrt,
Institut für Aerodynamik und Strömungstechnik, C²A²S²E
Bunsenstraße 10, 37073 Göttingen

mariaus.herr@dlr.de

²RWTH Aachen University

Templergraben 55, 52062 Aachen

philipp.grotowsky@rwth-aachen.de

Introduction

The combination of statistical RANS modelling with turbulence resolving LES methods (hybrid RANS/LES) enables the efficient simulation of complex, industry-relevant flows (e.g. aircrafts in high-lift configuration). In such a hybrid form, the respective RANS model mainly serves as wall model in the near-wall regions and as background model in the LES regions away from the wall. Pure RANS models that are based on differential Reynolds-stress modelling (RSM), achieve a higher accuracy for flows with rotation, streamline curvature and secondary motion compared to simpler turbulence models (e.g. eddy-viscosity models). It is expected that this accuracy advantage is still present when combined with an LES method. Recently, in [1] the robust SSG/LRR RSM-RANS model was combined with the IDDES method, a well-established representative of hybrid RANS/LES. However, so far it was not explicitly demonstrated that this newly developed RSM-IDDES captures the aforementioned complex flow phenomena properly. This study aims to fill this gap by addressing the capability of the RSM-IDDES to resolve secondary motions arising in turbulent corner flows, such as those occurring in the intersection regions of aircraft components (e.g. between nacelle, pylon and wing). Furthermore, in order to limit the computational cost of elaborate scale resolving simulations, we focus on improving the efficiency of the RSM-IDDES. To this end, two different wall function approaches are coupled to the RSM-IDDES, principally allowing a significant coarsening of the wall-normal resolution of the corresponding computational grid.

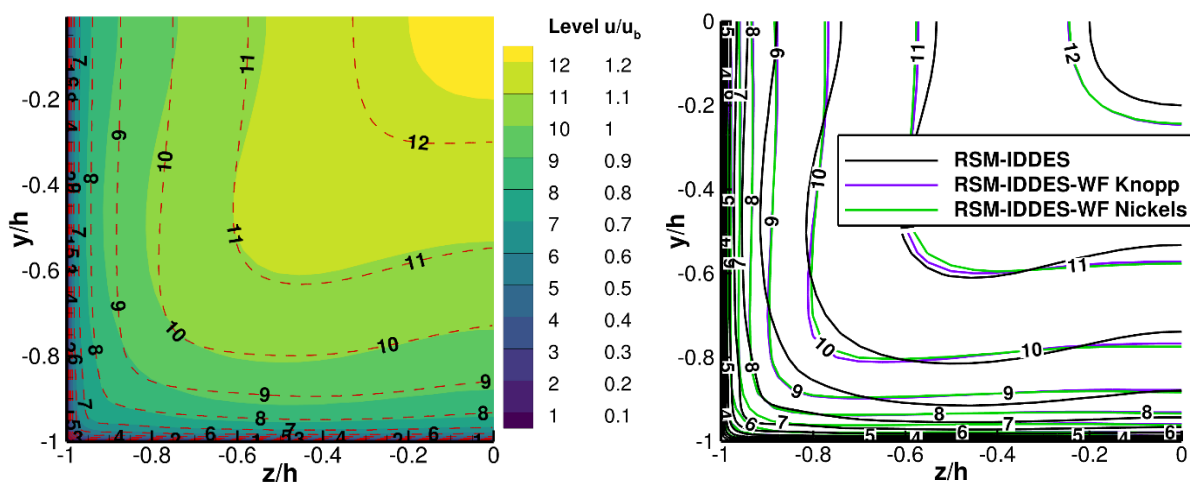


Figure 1 Streamwise velocity distributions of a periodic, square duct flow **Left:** RSM-IDDES in comparison to DNS data [2] (dashed). **Right:** Results of RSM-IDDES in combination with analytical wall functions by Knopp [3] and Nickels [4].

This work is part of the research unit FOR 2895, funded by the DFG, which addresses unsteady transonic effects at the industrial XRF1 aircraft configuration coupled to ultra large bypass ratio (UHBR) nacelles. A major research goal is to provide a hybrid RANS-LES method, which is able to cope with the complex flow across a full XRF1-UHBR configuration and its 3D intersections at high Reynolds numbers.

Proceeding and results

The validation of the RSM-IDDES with regard to the prediction of secondary motions is carried out using a periodic, square duct flow at $Re_\tau = 1055$ and compared to DNS data published in [2]. Figure 1 (left) depicts the corresponding RSM-IDDES results of the x-velocity component along the cross section of the test case. The time-averaged data were additionally averaged over each quadrant as well as in streamwise direction, so that the contour plot contains values from the entire flow field and simulated time. The effect of the secondary motions on the x-velocity is clearly visible in form of a slight bending of the isolines towards the corner region. Additionally, the DNS results are included in the contour plot as dashed lines, which shows overall good agreement. Furthermore, comparative simulations were carried out using an RSM-RANS (SSG/LRR) method and an IDDES variant combined with the SA-QCR-RANS eddy viscosity model (denoted as SA-QCR-IDDES). The results of the temporally and spatially averaged Re_τ values of these simulations are compared in Table 1 indicating that the best agreement with the DNS is obtained for the RSM-IDDES.

	Re_τ	relative deviation
DNS [2]	1055	-
RSM-RANS	1070	1.42%
SA-QCR-IDDES	1006	-4.64%
RSM-IDDES	1052	-0.28%

Table 1 Averaged Re_τ results for different simulation methods compared to DNS data.

To enable efficient scale resolving simulations, the analytical wall function approaches of Knopp [3] and Nickels [4] were coupled to the RSM-IDDES within the DLR TAU code. The particular aspect of Nickels' wall function is that it also takes the streamwise pressure gradient into account, which in principle facilitates an additional coarsening of the wall-normal grid resolution. Regarding the implementation, the wall boundary condition of the specific dissipation rate ω was adapted and Knoop's wall function was calibrated to a representative velocity profile of an RSM-RANS solution. Figure 1 (right) shows the x-velocity results for the RSM-IDDES with both wall function approaches in the periodic, square duct flow demonstrating good agreements with an RSM-IDDES reference solution.

In conclusion, the investigations show that the newly developed RSM-IDDES accurately captures secondary motions and is therefore validated for this type of flow. Additionally, this work demonstrates that the method can successfully be coupled to different wall function approaches leading to reliable results. Another more advanced validation case for the RSM-IDDES with wall functions will be the 2D Nasa hump flow, which is a particularly suitable test case for Nickels' wall law. Finally, this study represents a significant step towards RSM-IDDES with wall functions being applied to a full aircraft configuration at flight relevant Reynolds numbers.

References:

- [1] Herr, Marius, Rolf Radespiel, and Axel Probst. "Improved delayed detached eddy simulation with reynolds-stress background modelling." *Computers & Fluids* 265 (2023): 106014.
- [2] Pirozzoli, Sergio, et al. "Turbulence and secondary motions in square duct flow." *Journal of Fluid Mechanics* 840 (2018): 631-655.
- [3] Knopp, Tobias, Thomas Alrutz, and Dieter Schwamborn. "A grid and flow adaptive wall-function method for RANS turbulence modelling." *Journal of Computational Physics* 220.1 (2006): 19-40.
- [4] Nickels, T. B. "Inner scaling for wall-bounded flows subject to large pressure gradients." *Journal of Fluid Mechanics* 521 (2004): 217-239.