Mitteilung

Fachgruppe: Turbulenz und Transition

Progress with verification and stabilization of Reynolds stress models using the CFD Software by ONERA, DLR, Airbus (CODA)

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Turbulence modelling stands as the cornerstone of Computational Fluid Dynamics (CFD) enabling accurate flow simulations and design optimization across a wide range of industrial applications. A CFD simulation software, also known as flow solver, offers several turbulence models to owing to the varying complexity and capabilities of different models. An industrial CFD software must deliver stable simulations across various cases providing accurate, reliable results. These key aspects, namely robustness and accuracy, also depend on the different turbulence models provided within the software, thereby demanding the software developers to perform extensive testing and validation of each model. The testing, in general, includes the fundamental verification and validation cases but not restricted to more complex verification cases involving several flow features like three-dimensional (3D) separation, vortices, etc. The main aim of this work is to present the experience obtained from the verification of three-dimensional test cases for the

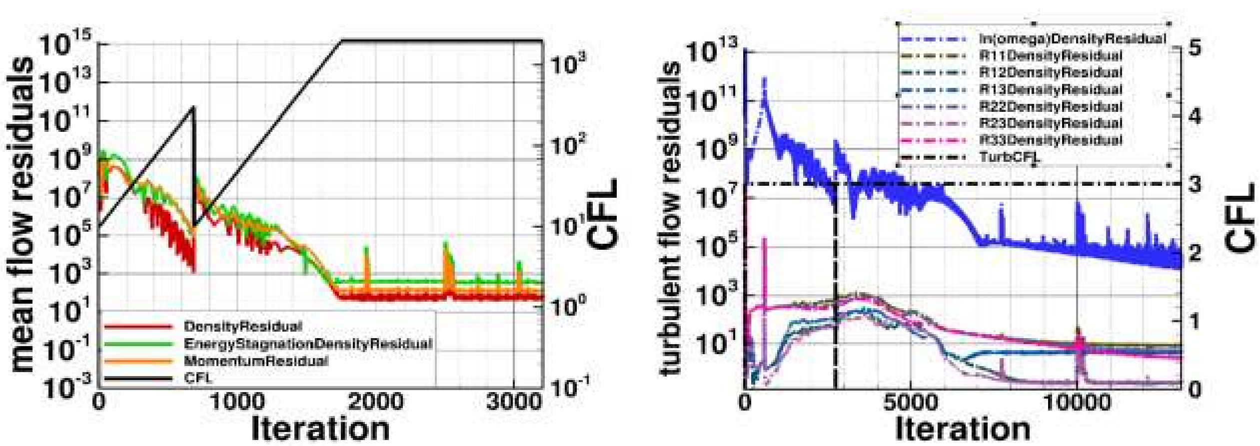

Figure 1 Left: Convergence of mean flow residuals for ONERA M6 wing on the finest mesh with 11 million elements with the weak coupling of mean flow and turbulent equations in CODA. Right: Convergence of turbulence residuals for the same case where we perform 4 iterations on the turbulent equations for 1 iteration on the mean flow

Reynolds stress turbulence model available in the next generation flow solver CODA. The focus is on robustness and accuracy issues as well as on efficiency aspects.

CODA [1] is the CFD software being developed as part of a collaboration between the French Aerospace Lab ONERA, the German Aerospace Center (DLR), Airbus, and their European research partners. CODA is jointly owned by ONERA, DLR and Airbus. CODA offers a few industrially relevant turbulence models such as the eddy viscosity models (EVMs) of Spalart-Allmaras and Shear Stress Transport model (SST) by Menter which are known for their simplicity, efficiency and performance. When higher accuracy is needed for complex turbulent flows involving separation, flow over curved surfaces, vortical flows, Reynolds stress models (RSM) come into

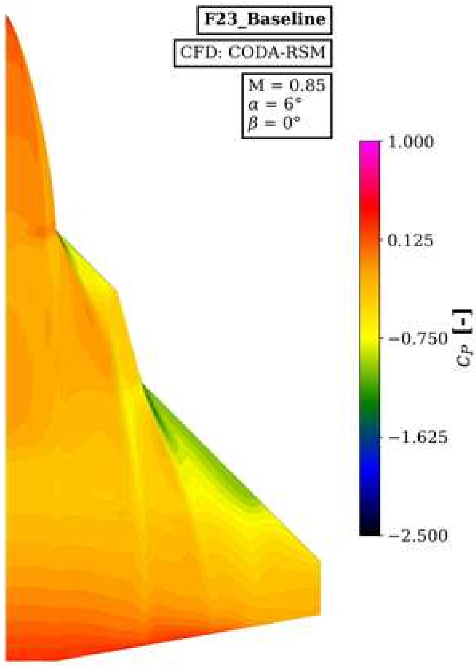

Figure 2 Coefficient of pressure (Cp) distribution for DLR F23 configuration for angle of attack 6° and Mach 0.85

play where the EVMs can fall short. CODA provides the mostly widely used industrial RSM model: Speziale-Sarkar-Gatsky/Launder-Reece-Rodi(SSG/LRR) [2] model with the ln(ω) variant of the length scale equation. The preliminary verification and validation of the SSG/LRR-ln(ω) in CODA has been provided in a previous work. The current work targets verification of the model with 3D test cases like the transonic flow around the ONERA M6 wing, the DLR-F23 and the transonic drag-prediction workshop (DPW) CRM case using reference results from the DLR TAU code and CFL3D. We also describe several challenges encountered while performing these verification tests. Some strategies were attempted to navigate the difficulties and the ongoing efforts are focused to gain a better understanding from the experience. Enforcement of realizability constraints [3] was necessary for cases with flow features like shock-induced separation, vortical flows, etc. We enforced the realizability constraints using a smoothed-clipping approach to guarantee the differentiability of the Reynolds stress equations for automatic differentiation. CODA implements a strongly coupled system for mean flow and turbulence equations, hence the other strategy adopted was to have a weak coupling of the equations following the studies from Langer et al [4]. We observed that the weak coupling could improve the robustness of the system but may degrade the performance of the simulation depending on the test case simulated. For 3D transonic cases, we encountered severe restriction of the turbulent CFL number (see Figure 1). The restriction was partially circumvented by changing the convection scheme for the turbulence equations. A Roe scheme [5] for mean flow and a more dissipative convective flux for the turbulence equations like local Lax–Friedrichs (LLF) or simplified upwind scheme helped to navigate the restriction for a few cases like the ONERA M6 and DLR-F23 (see Figure 2). We conclude with the importance of realizability constraints for the stability of the RSM model along with our findings on the coupling strategies of the mean flow and turbulence equations and the CFL number dependence of the turbulence equations. Finally, we also emphasize the importance of an appropriate convection scheme for the turbulence equations.

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