Mitteilung

Fachgruppe: Turbulenz und Transition

Preliminary validation and stabilization of Reynolds stress models using the CFD Software by ONERA, DLR, Airbus (CODA)

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Most industrial applications of Computational Fluid Dynamics (CFD) rely on the Reynolds-averaged Navier-Stokes (RANS) equations and turbulence modelling. Irrespective of their popularity, eddy viscosity models (EVMs) such as the Spalart-Allmaras [1] and the Shear Stress Transport model (SST) by Menter [2] can be insufficient in terms of accuracy for certain flow regimes like three-dimensional (3D) separation on aircraft wings, junction flow separation, flows over curved surfaces, and vortical flows. This has led to further development of other turbulence models on the basis of second moment closure termed as the Reynolds Stress Models (RSMs). Several RSMs have been proposed ([3] [4]) yet they are reported to be not as robust and stable as the EVMs in some CFD solvers. RSMs contain seven additional equations, six for Reynolds stresses and one for the length-scale variable (e.g. ω) which makes its implementation into a CFD solver and the numerical solution quite challenging, in particular, if an implicit solution strategy is employed.

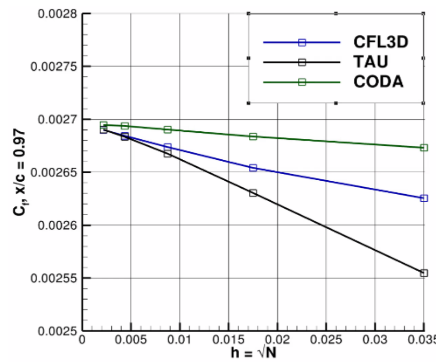

Fig 1 Grid convergence of skin friction coefficient for 2D zero pressure gradient flat plat in CODA and other legacy codes

In the present work, implementation, testing and validation of the SSG/LRR-ln(ω) [5] model into the next generation flow solver CODA are considered. CODA [6] 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. For a finite volume discretization, CODA solves the RANS equations using a cell centred approach with strong implicit methods. A steady state problem is solved by marching in fictitious pseudo time using an implicit Euler scheme and a Newton-type iteration method within each time step. The RANS equations are solved in a fully coupled manner where a single block of mean flow equations (density, momentum and energy) are solved along with the turbulent equations (Reynolds stresses and length scale variable).

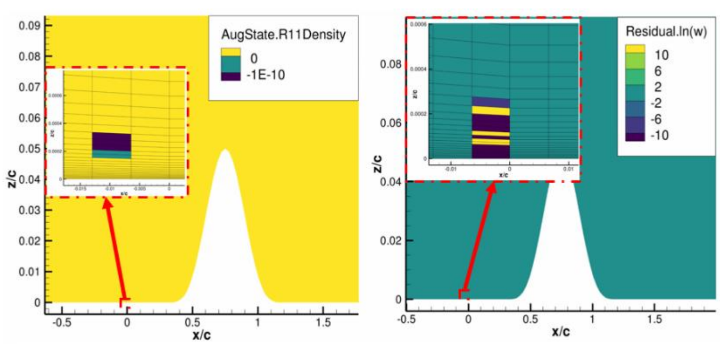

Fig 2 As the realizability gets violated in a few cells, the residuals around these cells remain high while the rest of the field has much lower residuals

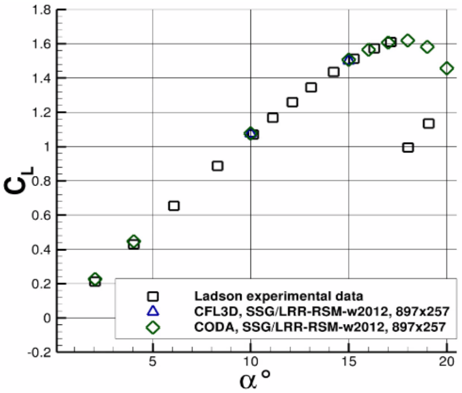

Fig 3 Validation of NACA0012

The robustness of the solver depends not only on the numerical solution method (linearization and iteration scheme, implicit/explicit treatment of turbulence model source terms, discretization scheme for the convective fluxes and the gradients), but also on details of the turbulence model. An issue arises during the solution process as the model may enter into physically unrealizable regimes [7]. We describe in detail the challenges that are faced to ensure the robustness of the implementation. The validation of the model for the 2D zero pressure gradient flat plate (2DZP) case (Fig 1) showed promising results. However, convergence issues were encountered for 2D bump in channel (Fig 2) case using the generalized gradient diffusion (GGD) model. Investigating the convergence problems for this case led to studies on realizability constraints and their violation. The usual clipping approach [8] failed for an implicit solution strategy as it affects the differentiability of the residual operator. We present the validation studies performed for some 2D airfoil cases (RAE2822, NACA0012, DLR F15, NHLP) (Fig 3) using different approaches to enforce the realizability constraints. These cases show the presence of unrealizable Reynolds stresses in the converged solution (Fig 4). Enforcing the realizability constraints removed these unphysical values and improved the robustness and convergence behaviour.

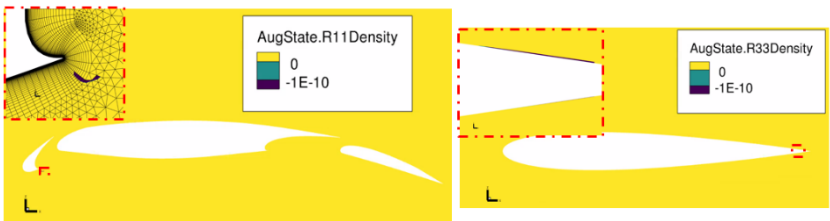

Fig 4 Presence of negative normal stresses in the converged solution of a 3-element air foil (NHLP) on the left and NACA0012 (AoA=10°) on the right.

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