Mitteilung

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Impact of the entropy fix at no-slip wall boundaries

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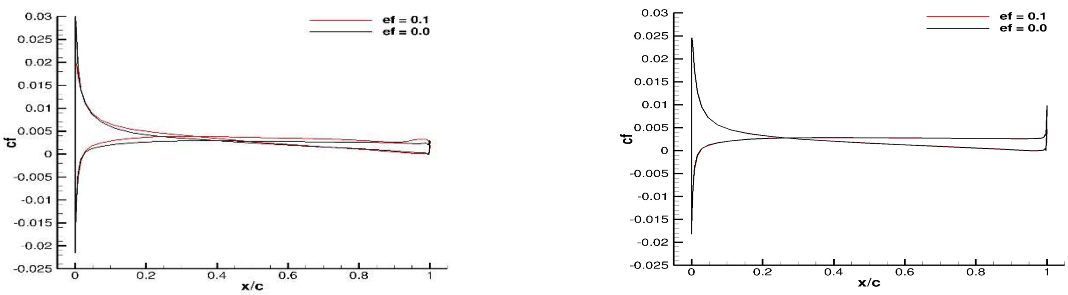
The CFD Software by ONERA, DLR and Airbus (CODA) [1] uses the Riemann solver of Roe to compute the convective flux of the Navier-Stokes or RANS equations. Although Roe´s scheme [2] can capture discontinuities such as shock and contact waves, it is known to produce entropy-violating shocks in expanding flows when one of the acoustic eigenvalues approaches zero. Harten's entropy fix [3] was therefore introduced to displace the eigenvalues away from zero hereby modifying the coefficients of the dissipation term in the Roe flux. Hence, the entropy condition is satisfied, but artificial viscosity is added to the convective flux. Mavriplilis [4] reported that the amount of artificial viscosity influences the boundary integral quantities such as lift (C_L) and drag (C_D) coefficients. Furthermore, the results of the skin friction (c_f) coefficients computed with CODA have shown to vary significantly when adding artificial viscosity by means of Harten's entropy fix to the convective flux. Concretely, this effect has been observed to be prominent at boundaries on coarse meshes when imposing adiabatic no-slip wall boundary conditions, as the addition of artificial viscosity would decrease on finer grids. Due to the fact that CODA is a cell centered code in which a weakly imposed boundary condition formulation is used as described by Hartmann et al. [5], both states entering the convective flux at the boundary have in general non-zero velocities. As the difference between these states does not vanish, artificial viscosity is added on the boundary due to non-zero eigenvalues. Instead of using a cut-off based on a fixed fraction of the largest eigenvalue, Kermani and Plett [6] proposed a more local approach based on the difference between eigenvalues on the left and right sides of the face in comparison to the values for the face-averaged state. As a third option, CODA offers a wave-based entropy fix, which inherently does not add artificial viscosity at the boundary and thus prevents the entropy fix from affecting the results. Overall, these alternative entropy fixes add less dissipation to the convective flux at boundaries compared to Harten's entropy fix at the cost of a potential robustness reduction. Due to the described effects of the entropy fix at no-slip wall boundaries, an investigation of the impact of



(a) FV (a) DG

Figure 1. The skin friction coefficient (c_f) for the FV and DG discretizations when varying the amount of artificial viscosity for a NACA 0012 airfoil at Ma = 0.15, Re = $6x10^6$ and AoA = 10°

the entropy fix on the results of the skin coefficient (c_f) has been pursued.

Figure 1 shows the skin friction coefficient (c_f) with and without artificial viscosity (ef = 0.1 and 0.0) for a NACA0012 airfoil at a Mach number of 0.15, a Reynolds number of $6x10^6$ and an angle of attack of 10 degrees for the Finite Volume (FV) and the Discontinuous Galerkin (DG) discretizations. The FV discretization shows a significant sensitivity to the addition of artificial viscosity through the entropy-fix (ef = 0.1), in contrast to the behavior observed for the DG discretization. This effect is attributed to the fact that the FV discretization uses a gradient-based piecewise linear reconstruction which relies on the neighbor and neighbors-of-neighbor cell values to compute a solution on a single degree of freedom. In contrast, the DG discretization employs more compact polynomial functions on multiple degrees of freedom. As a result, the DG discretization matches the weakly imposed boundary conditions better due to the reduced dependency on the cell neighboring values. Due to this, the difference between the values on both sides of the boundaries becomes smaller and thus less dissipation is added to the convective flux. When using a gradient-based piecewise linear reconstruction in FV, the effect of artificial viscosity at the boundary becomes more pronounced under grid metric changes. This arises because gradient computations (e.g., via least squares [4]) depend on weighting coefficients that vary with the relative positions of neighboring cells. Consequently, the boundary condition may exert weaker influence, altering the reconstructed state across the boundary and often leading to higher amounts of artificial viscosity.Therefore, a gradient computation that applies a stronger weighting on the boundary conditions is suggested to be investigated in order to reduce its impact at the wall boundaries.

In order to asses how to minimize the effect of the entropy fix at boundaries, the deactivation of Harten’s entropy fix directly at boundaries was investigated. This investigation was also compared against the Kermani and Plett method [6] and the wave-based entropy fix. The results obtained with this modification of the Roe scheme at boundaries showed an impact on the results of the skin friction (c_f) similar to the one shown by the Kermani and Plett method and the wave-based entropy fix whose modification of the eigen values results in less dissipation at wall boundaries. However, the deactivation of Harten’s entropy fix at boundaries is not recommended, as it leads to a flux computation which is inconsistent between inner and boundary faces. Furthermore, the entropy fix has shown to contribute to the overall viscous effects. This means that the viscous effects coming from the viscous flux are balanced with the artificial viscosity added to the convective flux via the entropy fix. This explains the observed changes in the skin friction coefficient (c_f) when the entropy-fix is activated. As CODA currently uses a post-processing to compute the skin friction coefficient (c_f) based only on the viscous fluxes, a consistent approach is proposed in which the contribution of the convective and viscous fluxes are included. With this approach, the results using FV discretizations varied less under the activation of the entropy fix.

According to the described effects of Harten's entropy fix at boundaries, it is suggested to use an entropy fix that reduces the addition of artificial viscosity at boundaries, a consistent flux-based post-processing in order to minimize the effects of the entropy fix at boundaries and to investigate a gradient computation with stronger weighting on the boundary conditions.

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