Extension of a Compressible Solver To Low Mach Number Flows

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A common strategy for solving steady equations is to march the associated unsteady equations in time until the solution converges to a stationary result. In the case of the compressible Euler equations, this approach has the important advantage of transforming the problem from a mixed hyperbolic-elliptic problem in the steady state to a strictly hyperbolic problem in the transient stages. Unfortunately, this approach also introduces stiffness due to the unsteady equations into the convergence process for the steady state. For compressible flow with mixed low and high Mach number flow conditions, this stiffness occurs because of large differences between acoustic wave speeds and the wave convected at the fluid speed. For the time-marching procedure this can significantly slow down or even inhibit convergence to a steady state. Moreover, in upwind biased flux-difference schemes, the dissipation terms are ill-proportioned at low Mach number conditions. This causes an inadequate magnitude of the dissipation terms for the discretized Euler and Navier-Stokes equations, which degrades the accuracy of the solution.

The goal of this project was to implement a preconditioning method into the VKI COSMIC code, to give the possibility to compute low Mach number flows as well as flows with mixed high/low Mach number regimes. The application of preconditioning changes the eigenvalues of the system of compressible flow equations in order to remove the large disparity of wave speed. Hence, at low Mach number all the waves have a speed of the same order and the system remains well-conditioned. Moreover, preconditioning introduces a suitable modification of the dissipation terms, which scales them in such a way to obtain a good accuracy solution. The following figures present the predicted Mach number contours for the flow in a channel with bump for an inlet Mach number equal to 10^{-3}. These computations have been performed with Ist order *Roe-type* scheme. Fig. a) presents the result obtained with non-preconditioned system, while Fig. b) show the result of calculations for preconditioned system. Here we can observe that in case of the non-preconditioned calculations, the excess of dissipation does not allow to obtain accurate solution. On the other hand, modifications introduced by preconditioning cause that solution remains physically correct and unaffected in low Mach number conditions.