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Implementation and Evaluation of Different Preconditioning Methods in the Compressible CFD Solver Edge

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ABSTRACT

Many compressible CFD solvers suffer of poor convergence rates and deficiency in robustness and accuracy as the Mach number goes to zero.[1] In this paper several different preconditioning methods are evaluated and implemented into the compressible CFD solver Edge[2]. Various test cases for the different preconditioning methods are used to draw conclusions about their performances. Among these test cases are mesh topology, turbulence model, angle of attack and Mach number varied in order to reveal potential differences.

Preconditioning of the Euler equations in order to speed up convergence and alleviate numerical stiffness has been performed and analyzed for the last 20 years.[3] Some of the motivations and needs for this development are; 1) flow situation with mixed incompressible and compressible forced convection (flow over an airfoil) 2) natural convection (surface or volumetric heating) and 3) the preference of engineers to use the existing compressible codes over the widest flow condition range.[4] In order to be able to achieve all of these objectives, a robust and effective preconditioner is required for compressible CFD codes. Robustness has been a problem with some of these preconditioning methods. This is manifested by some of the parameters are problem dependent.[3] Some elements of the preconditioning matrix are inversely proportional to the velocity and it is therefor important to limit these parameters away from zero. Near a stagnation point or at a wall are typical regions where the flow velocity is low. The accuracy and robustness of the solution could depend on how this limiting is performed (see Turkel [1]), this is here investigated in detail for the different preconditioners implemented. In order to obtain a solution to the RANS equations, artificial viscosity needs to be added to the solution. Here it is done by using two different approaches, basing the artificial viscosity on the spectral radius (a scalar type) or the different eigenvalues (a matrix type of artificial viscosity). The scalar based artificial viscosity scales the acoustic and convective waves with the same amount, while the matrix based type allows for different amounts of artificial viscosity. The influence of using either of these two different approaches together with a preconditioner is investigated.

The preconditioning methods examined and implemented into the CFD solver Edge are:

- Turkel type with scalar viscosity and variations of primitive variables.[4]

- Turkel type of preconditioner with viscous corrections.[3]
- A novel preconditioner (based on ref [3]) with corrections added for local pressure gradients.
- Weiss and Smith preconditioner with scalar viscosity.[5]
- Turkel type preconditioner with matrix viscosity.[6]

In figure 1 drag and convergence history of the LA203A airfoil are presented. Here the benefits with increased robustness and convergence acceleration due to the preconditioning methods are clearly visible. The convergence history is plotted until c_d differs with less than 0.01% compared to the result at the last iteration. This occurs at the 3916, 4019 and 4405th iteration for standard preconditioning, scalar preconditioning with viscous corrections and the preconditioner using a matrix based viscosity respectively (the case with no preconditioning does not reach a converged solution within 20.000 iterations). In this paper several different preconditioning methods have been implemented into the CFD

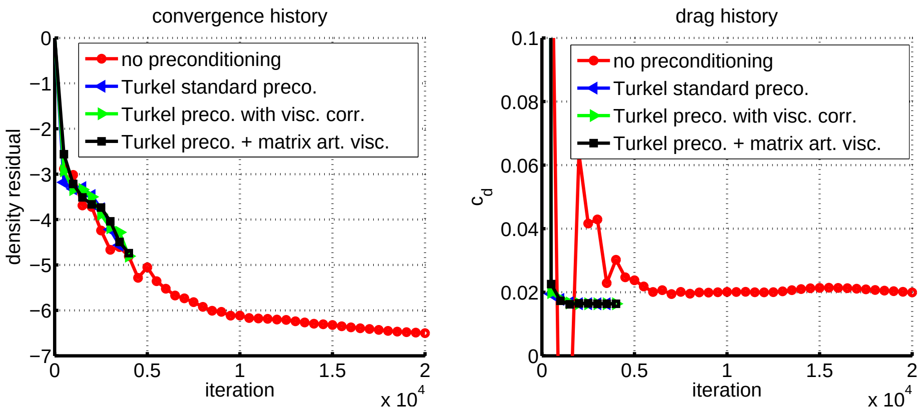

Figure 1: Convergence history of density residual and C_d for the LA203A profile. Flow case: $Re_\infty = 330.000$, $M_\infty = 0.014$ and $\alpha = 0°$.

code Edge. They have been evaluated using several different test cases. A novel preconditioner (based on ref [3]) with corrections added for local pressure gradients has been developed and tested. A set of numerical parameters which gives fast and robust convergence for the current test cases is also presented and discussed.

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