11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Low-Mach preconditioned boundary conditions for compressible solvers

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Key Words: *numerical methods, compressible flows, preconditioned characteristic boundaries, acceleration methods.*

Approaching the incompressibility limit in CFD applications where compressible, density based solution methods are employed, is accompanied very often not only by slow convergence of the residuals but also by a strong degradation of the solution quality. This issue is particularly severe in turbo-machinery applications, where large variations of flow regimes occur. Low-Mach preconditioning methods can be applied to the Euler- and Navier-Stokes equations to alleviate such difficulties.

As noted by several authors, these techniques can cause stability problems especially in proximity of the domain's boundaries [4, 6]. In particular, it has been demonstrated that an appropriate scaling treatment is also required for characteristic-based boundary conditions (see for example [1], [2], [3] and [6]).

In the current work we present the theoretical development and application of preconditioned impermeable boundaries [5] in combination with preconditioned far-field conditions in the in-house CFD code TRACE [7].

The validity and robustness of the method is demonstrated on a set of classical test-cases such as the inviscid flow around a NACA0012 airfoil. In figure (1) the L_1 residuals of the current configuration using an inflow Mach $M_\infty = 0.01$ and an angle of attack equal to 5° with increasing CFL number is shown. The surface pressure distribution obtained by a low Mach preconditioned calculation at CFL 100 perfectly matches the analytical solution obtained by Hejranfar et. al [1], figure (2). Moreover, it is shown that low Mach preconditioning methods in conjunction with suitably modified boundary conditions yields an extremely fast convergence rate and strong improvement of stability at high CFL numbers.

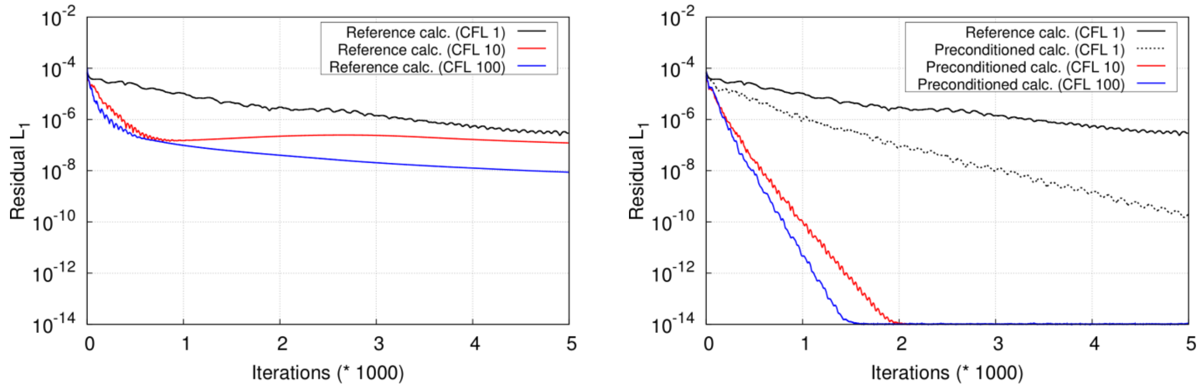

Figure 1. Residue L_1 of non-preconditioned (left) and preconditioned calculations of an inviscid flow around a NACA0012 airfoil profile at inflow Mach number $M_\infty = 0.01$ and increasing CFL number.

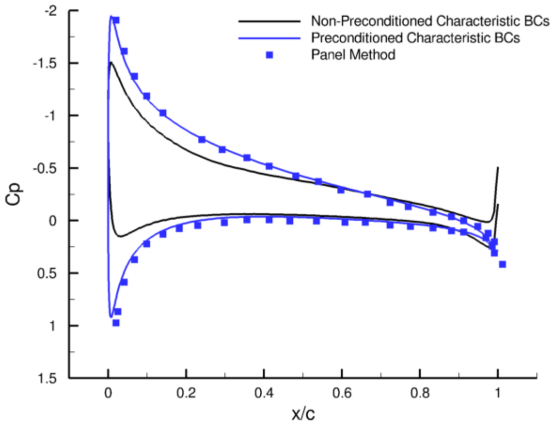

Figure 2. Surface pressure coefficient for a non-preconditioned (black) and preconditioned calculation (blue). The panel method data are taken from [1].

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