High-fidelity simulations of turbulent compressible flows in aerodynamics: some typical applications with ONERA CFD codes

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High-fidelity simulations of turbulent compressible flows in aerodynamics often imply a large number of discretization elements to tackle complexity arising from physics and geometry. Furthermore, the physical modeling of more and more complex phenomena and the industrial demand for accurate solutions lead to address increasingly stiff problems. In this talk, we focus on some typical CFD applications and present several robust and efficient strategies to deal with the resulting large ill-conditioned linear systems. These strategies play a crucial role as they must be capable to deliver a solution at a prescribed tolerance if required. On top of that, they still represent a large proportion of the CPU cost of CFD computations in such a context.

To start with, some mathematical backgrounds are recalled along with the governing equations of the flow and the considered operators. We mainly focus on two study cases: the searching of the fixed point of the equations by means of an inexact Newton method in the context of steady-state computations, where only approximate algebraic solutions are expected, and the resolution of algebraic linear systems as accurate as possible in the framework of adjoint-based optimization problems or global stability analyses. Resulting matrices are real or complex, non hermitian, with a block-wise structure and a symmetric pattern.

Second, the adopted strategies are described with theirs current limitations in terms of performance and CPU and memory costs. Several 2D test-cases of turbulent flows with RANS modeling are considered with the parallel sparse direct solver MUMPS. Moreover, simulations of turbulent transonic RANS flow over a 2D supercritical OAT15A airfoil and over the 3D ONERA M6 wing are conducted with the parallel FGCRO-DR iterative method with deflated restarting. The flexible preconditioning operator is defined by an inner GMRES solver that uses the Block-ILU(0) algorithm as a first-level preconditioner and the Restricted Additive Schwarz method as a second-level preconditioner.

To finish with, we depict current research activities including in particular the evaluation of MUMPS as a preconditioner for our parallel iterative strategies and the use of Block Low-Rank (BLR) factorization to leverage CPU and memory costs.