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Scalable Non-linear Solution Techniques for Higher-Order Accurate Finite-Element Reynolds-Averaged Navier-Stokes Problems

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Although second-order accurate finite-volume methods for structured and unstructured grids are well established as the dominant approach for solving the Reynolds-averaged Navier-Stokes (RANS) equations for the simulation of turbulent flow problems, interest in higher-order finite-element discretizations has been growing over the last decade. Considered methods include both continuous and discontinuous Galerkin discretizations, with the continuous methods being based on the streamwise-upwind Petrov Galerkin approach (SUPG). The advantages of these discretizations include the use of a nearest neighbor stencil, straight forward extension to high-order accuracy, and the generation of dense computations kernels that are more suitable for emerging exascale architectures. However, the resulting non-linear equations that must be solved for steady-state and time-implicit RANS problems have proven to be much stiffer and more difficult to converge efficiently and robustly.

In this work we examine several non-linear solution techniques for SUPG and DG discretizations of the RANS equations with a single equation turbulence model. The approach relies on a preconditioned Newton-Krylov method, where the exact Jacobian of the discretization is assembled and used in the GMRES phase of the Newton Krylov solver. Incomplete factorization (ILU) with various levels of fill is used as a preconditioner, as well as simpler and more scalable approaches such as line preconditioning where lines are extracted from the Jacobian matrix using a graph algorithm. Non-linear continuation is incorporated into the solver by controlling the pseudo time step applied to the diagonal of the Jacobian matrix, while a line search is used to ensure suitable non-linear updates for the Newton solver. We compare the performance and scalability of the current approach with the performance of similar and other multigrid solvers applied to traditional second-order accurate finite-volume unstructured mesh RANS discretizations, and discuss possible future avenues for improving the efficiency and scalability of higher-order RANS solvers.