Scalable Implicit / IMEX Resistive MHD with Stabilized Finite Element Methods and Fully-coupled Solution Methods

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The computational solution of the governing balance equations for mass, momentum, heat transfer and magnetic induction for resistive magnetohydrodynamics (MHD) systems can be extremely challenging. These difficulties arise from both the strong nonlinear coupling of fluid and electromagnetic phenomena, as well as the significant range of time- and length-scales that the interactions of these physical mechanisms produce. This talk explores the development of a scalable implicit variational multiscale (VMS) unstructured finite element (FE) capability for 3D incompressible resistive MHD that includes an integrated adjoint analysis capability. The VMS formulation and the fully-coupled Newton-Krylov (NK) solution methods allow the simulation of flow systems that range from incompressible to low Mach number compressible flows, as well as the development of a number of solution methods beyond forward simulation.

To enable robust, scalable and efficient solution of the large-scale sparse linear systems generated by the Newton linearization, fully-coupled multilevel preconditioners are developed. The multilevel preconditioners are based on two differing approaches. The first technique employs a graph-based aggregation method applied to the nonzero block structure of the Jacobian matrix. The second approach utilizes approximate block decomposition methods and physics-based preconditioning approaches that reduce the coupled systems into a set of simplified systems to which multilevel methods are applied. To demonstrate the performance of the solution methods representative results, that include the parallel and algorithmic scaling of these methods, for a set of challenging MHD problems are presented. These results include weak-scaling studies on up to 256K cores. (This is joint work with Roger Pawlowski, Eric Cyr, Edward Phillips, Ray Tuminaro, Paul Lin, and Luis Chacon.)

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