On Scalable Simulation Methods for MHD Modeling of Magnetic Confinement Fusion (MCF) Energy Systems

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Continuum plasma physics models are used to study important phenomena in astrophysics and in technology applications such as magnetic confinement (e.g. tokamak), and pulsed inertial confinement (e.g. NIF, Z-pinch) fusion devices. The computational simulation of these systems requires solution of the governing PDEs for conservation of mass, momentum, and energy, along with various approximations to Maxwell's equations. The resulting systems are characterized by strong nonlinear coupling of fluid and electromagnetic phenomena, as well as the significant range of time- and length-scales that these interactions produce. For effective long-time-scale integration of these systems some aspect of implicit time integration is required. These characteristics make scalable and efficient parallel iterative solution, of the resulting poorly conditioned discrete systems, extremely difficult.

In this talk I will begin with a brief discussion of plasmas and magnetic confinement fusion (MCF) energy from a very high-level perspective. I will then briefly discuss an implicit resistive magnetohydrodynamics (MHD) formulation based on a variational multiscale (VMS) finite-element (FE) approach. The solution of the strongly coupled highly nonlinear discretized system is achieved with a fully-coupled Newton nonlinear iterative method. The resulting large-scale sparse linear algebraic systems are iteratively solved by a GMRES Krylov method, preconditioned by approximate block factorization (ABF) and physics-based preconditioning approaches. To demonstrate the flexibility and performance of these methods we consider application of these techniques to various forms of resistive MHD models for challenging prototype plasma problems. These include computational results relevant to aspects of magnetic confinement fusion applications. Results are presented on robustness, efficiency, and the parallel and algorithmic scaling of the solution methods. This work is collaborative with Jesus Bonilla, Edward Phillips, Peter Ohm, Michael Crockatt, Roger P. Pawlowski, R. Tuminaro, Jonathan Hu, Xinazhu-Tang, and Luis Chacon.

* This work was partially supported by the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research, Applied Mathematics Program. It has also been partially supported by the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research and Office of Fusion Energy Sciences, Scientific Discovery through Advanced Computing (SciDAC) program.