Preconditioners for Plasma Physics and Magnetohydrodynamics: Handling Multiple Timescales

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Models in plasma physics, including magnetohydrodynamics (MHD), describe the evolution of a fluid interacting with electromagnetic fields. They are notable not only for the application space (astrophysics, tokamak reactors, and industrial applications), but also for the broad and complex range of temporal and spatial mechanisms they are composed of. The temporal scales themselves evolve with the physics over the course of the simulation often leading to stiff dynamics at critical points in time. As a result, these models are hard to simulate with traditionally successful operator split approaches used for typical fluid models where the time scale separation is more consistent. Thus, monolithic schemes are often required for plasma systems.

To address the challenge presented by multiple timescales, we take a Newton-Krylov approach that demands effective preconditioners to achieve good scalability and performance. This talk will focus on the preconditioning approaches that have been developed to attack this difficult class of problems. We will consider two approaches. In the first approach, block preconditioners are developed to localize strongly coupled stiff components to a Schur complement whose is then approximated. The second approach is based on a fully coupled multigrid strategy where physics coupling is encoded in the restriction/prolongation operators and relaxation schemes. We will present results showing the effectiveness of both approaches. Finally, we will close with a discussion of the multi-fluid plasma model and our approach to dealing with very stiff modes in that system.

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