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Physics-based Preconditioning and Newton-Krylov methods for Extended MHD

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Abstract

The equations of extended MHD present significant challenges for accurate and efficient time integration. The equation system contains multiple time scales, multiple waves, and nonlinear anisotropic transport coefficients. We have been developing the algorithmic approach of physics-based preconditioning and Jacobian-free Newton-Krylov methods with the goal of overcoming some of these numerical challenges. In this presentation, we will cover some of our recent progress and outline our future directions. In computational MHD, one would like to follow the dynamical time scale on which the system is evolving. This time scale is typically much slower than many of the normal mode time scales in the system. Recent work has shown that second-order-in-time, nonlinearly-converged, implicit methods can use time steps on the order of the dynamical time scale while achieving high accuracy [1].

In physics-based preconditioning we employ the classic semi-implicit method for stiff waves. Thus while the outer Jacobian-free Newton-Krylov method is working on a stiff, ill-conditioned, hyperbolic system, the preconditioning matrix comes from a parabolic problem with an improved condition number. The methodology behind, and the effectiveness of, physics-based preconditioning has been established. The first stiff-wave systems considered were the shallow water equations [2] and the reduced MHD equations [3]. While each system only supports one wave, the reduced MHD problem is more complicated as a result of anisotropic wave propagation. More recently, a physics-based preconditioner has been developed for the Hall MHD system, including the stiff whistler wave [4]. Currently we are developing a preconditioner for an equation system which describes low-β collisionless reconnection. Additionally, we will describe our strategy for developing a preconditioner for 3-D compressible MHD, and nonlinear anisotropic electron conduction. The depth and variety of equations systems which have been solved by this approach indicates that it is becoming a mature technology waiting to be utilized by a larger computational physics community.

[1] D.A. Knoll , et. al., *J. Comput. Phys.* vol. 185, pp. 583-611 (2003)

[2] V. Mousseau, et. al., *Mon. Wea. Rev.*, vol. 130, pp. 2611-2625 (2002)

[3] L. Chacón, et. al., *J. Comput. Phys.*, vol. 178, pp. 15-36 (2002)

[4] L. Chacón and D.A. Knoll, " A 2-D incompressible Hall MHD implicit nonlinear solver " (accepted to *J. Comput. Phys.*, 2003)