Multiple timescale calculations of sawteeth and other global macroscopic dynamics of tokamak plasmas

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The M3D-C^1 [1] code is designed in order to perform 3D nonlinear magnetohydrodynamics (MHD) calculations of a tokamak plasma that span the timescales associated with ideal and resistive stability as well as parallel and perpendicular transport. This requires a scalable fully implicit time advance where the time step is not limited by a Courant condition based on the MHD wave velocities or plasma flow but is chosen instead to accurately and efficiently resolve the physics. In order to accomplish this, we make use of several techniques to improve the effective condition number of the implicit matrix equation that is solved each time-step. The split time advance known as the differential approximation [2] reduces the size of the matrix and improves its diagonal structure. A particular choice of velocity variables and annihilation operators approximately split the large matrix into 3 sub-matrices, each with a much improved condition number. A final block Jacobi preconditioner further dramatically improves the condition number of the final matrix, making it converge in a Krylov solver with a small number of iterations. As an illustration, we have performed transport timescale simulations of a plasma which periodically undergoes sawtooth oscillations [3]. We specify the transport coefficients and apply a "current controller" that adjusts the boundary loop-voltage to keep the total plasma current fixed. We have performed series of runs to determine the dependence of the sequence on the form and magnitude of the resistivity, parallel and cross-field thermal conductivity, and viscosity. We are presently investigating the effect of the plasma shape on the sawtooth behavior, and the effects of two-fluid terms on the dynamics.

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