Center for Extended Magnetohydrodynamic Modeling (CEMM)

PI: S. Jardin[1], **Co-PIs:** J. Breslau[1], J. Callen[2], J.Chen[1], G. Fu[1], C. Hegna[2], E. Held[3], C.Kim[2], S. Klasky[1], S. Kruger[5], W. Park[1], S. Parker[4], R. Samtaney[1], D. Schissel[7], D. Schnack[6], C. Sovinec[2], L. Sugiyama[8], H. Strauss[9], F. Waelbroeck[10] **Affiliated PIs**: D. Keyes[11], F. Dobrian[12], P. Colella[13], T.Ligocki[13]

[1]Princeton Plasma Physics Laboratory, [2]U. Wisconsin, [3]Utah State U., [4]U. Colorado, [5]Tek-X Corp., [6]Science Application International Corporation, [7]General Atomics, [8]Massachusetts Institute of Technology, [9]New York U., [10]U.Texas, [11]Columbia University,[12]Old Dominion University, [13]Lawrence Berkeley Laboratory

Through SciDAC-enabled collaborations, we have developed improved extended MHD physics models and made significant algorithmic advances in our major nonlinear extended MHD codes. The application of these improved models using the high-performance computers made available to us resulted in discovery on several fronts.

We highlight five new scientific results and several code improvements developed via this collaboration during the last year:

(1) The Dynamics of high-beta disruptions. We have used the NIMROD code to calculate details of a disruptive termination of the DIII-D tokamak (Fig. 1) when it is slowly heated to a pressure exceeding the ideal-MHD stability limit. The calculation of the “thermal quench” included a moving plasma/vacuum interface, and an accurate treatment of the rapid heat loss along magnetic field lines that connect with the surrounding vessel as a result of the instability. We find that the plasma thermal energy is deposited in a localized beam, in good agreement with experimental measurements. A related calculation with M3D has been used to calculate the induced currents in the vessel during the subsequent “current quench” phase of the disruption.

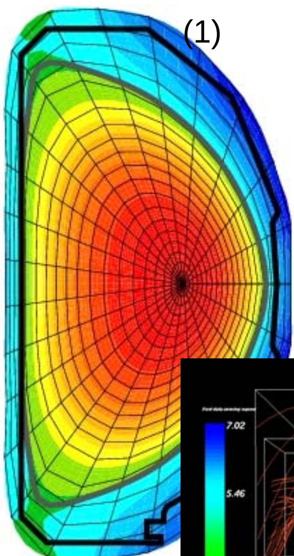
(2) Realistic limits on Stellarator performance. Extending the MHD description to two-fluids and keeping nonlinear effects has been shown to be essential in predicting the actual pressure limits in the NCSX stellarator (Fig. 2). This more complete plasma model predicts that both short wavelength ballooning and resistive modes are stable, and that a “soft” beta limit should occur due to two-fluid enhanced magnetic island growth which reduces thermal confinement and hence the ability to raise the global pressure.

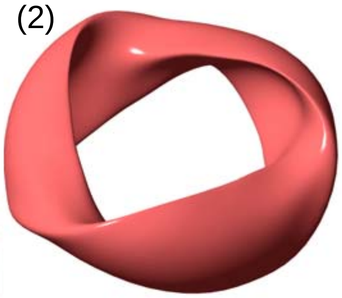
(3) Energetic particle driven modes in Spherical Tokamaks: Recent NSTX experiments show rich beam-driven Alfven instabilities in neutral beam-heated plasmas. The M3D code, with a kinetic energetic particle component included, was applied to simulate the beam ion-driven Alfven instabilities in NSTX. . In the linear regime with an isotropic beam ion distribution, the M3D simulation results show unstable Toroidal Alfven Eigenmodes (TAE) with frequencies consistent with experimental observations in NSTX. For a more realistic anisotropic distribution, the dominant linear n=2 mode has a significantly lower frequency as compared to TAE's frequency. In the nonlinear regime, the M3D simulations show that the n=2 mode's frequency chirps down as it moves out radially (See Fig. 3).

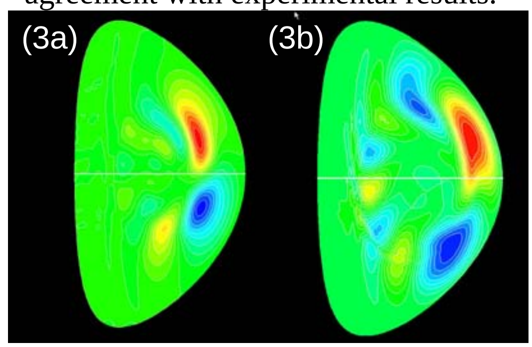
(4) MHD behavior in small laboratory experiments: Time-step and spatial resolution requirements presently preclude us from modeling all but the fastest MHD events using the actual parameters in today’s largest fusion experiments. However, we have begun an experimental verification program using data from two of the smaller, less computationally demanding experiments: SSPX (LLNL) and CDX-U (PPPL). The

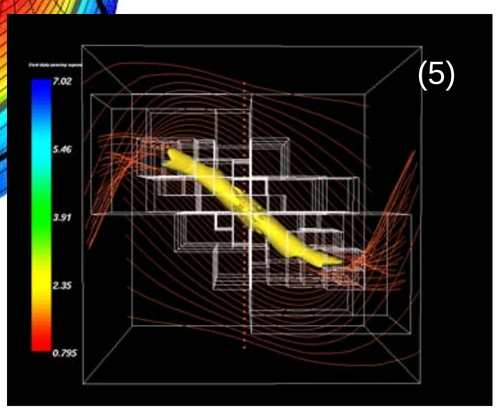
SSPX spheromak simulations demonstrate the mechanism whereby closed magnetic flux surfaces can form during the current decay phase, allowing the core plasma temperature to increase in good agreement with the experiment (Fig. 4). This close agreement is noteworthy in that it implies that the very nonlinear changing 3D magnetic topology affecting the anisotropic thermal conductivity is being computed correctly. The CDX-U small tokamak exhibits periodic central reconnections (sawtooth oscillations) that can be reproduced with the simulation codes. Matching the repetition period and crash time is presenting an excellent test for the extended MHD model.

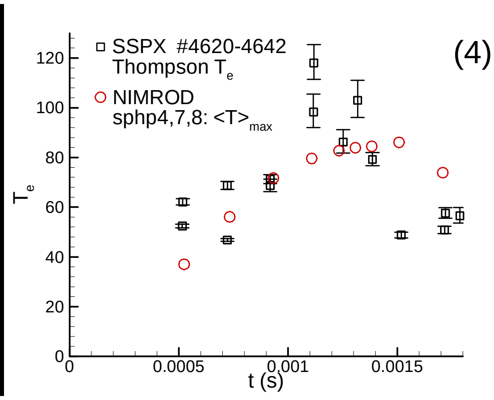
(5) Pellet fueling of a tokamak: We have used our Chombo-based Adaptive Mesh Refinement (AMR) MHD code (Fig. 5) to provide a realistic and efficient calculation of pellet fueling of a high-temperature tokamak. In this process, a very small pellet of frozen hydrogen is injected at high velocities into the large plasma torus. The pellet causes a rapid, local pressure increase which drives a localized instability that tends to redistribute the pellet mass. Initial results from this demanding simulation are in qualitative agreement with experimental results.











Linear Solvers and TOPS: Both M3D and NIMROD solution times are dominated by the sparse matrix solves. The NIMROD code had previously used the conjugate gradient method together with a global line-Jacobi preconditioning technique. This past year, it was found that because these matrices were so ill-conditioned, the optimized direct sparse matrix solver SuperLU could give a factor of 4-5 improvement in computational time for real applications. In M3D, a reformulation of the problem allowed the sparse matrices to become symmetric. This permitted use of the new PETSc ICCG solver rather than GMRES, which led to about a factor of 2 decrease in computational requirements.

Adaptive Mesh Refinement and APDEC: The APDEC center was essential in the development of the Chombo-based adaptive mesh refinement (AMR) software and high-accuracy MHD solver used in (5).

For further information on this subject contact:
Stephen C. Jardin: Jardin@pppl.gov
http://w3.pppl.gov/CEMM Phone: 609-243-2635