Center for Extended Magnetohydrodynamic Modeling (CEMM)

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

[1]Princeton Plasma Physics Laboratory, [2]U. Wisconsin, [3]Utah State U., [4]U. Colorado, [5]Science Application International Corporation, [6]Los Alamos National Laboratory, [7]General Atomics, [8]Massachusetts Institute of Technology, [9]New York U., [10]U.Texas, [11]Old Dominion U., [12]Rensselear Polytechnic Institute, [13]Lawrence Berkeley Laboratory

High temperature magnetized plasma is an exceedingly complex medium. The numerical modeling difficulties of simulating global phenomena in these configurations follow from the wide range of space and time scales, the extreme anisotropy introduced by the magnetic field, and the inherent non-locality of the underlying collisionless physics. Through SciDAC-enabled collaborations, we have assembled a world-class team to address all of these challenges using a combination of theoretical investigation, advanced algorithms, and high-performance computers.

We highlight five new scientific results developed via this collaboration:

(1) Magnetic Island Thermalization at Realistic Parameters: Development of the high-order finite element representation in NIMROD has enabled the use of realistic ratios (up to 10^{11}) for the parallel ($\chi_{\|}$) to perpendicular ($\chi_{\perp}$) thermal conductivity for the first time in a fully 3D global calculation. Figure (1) illustrates a benchmark result on the width of a helical magnetic structure (called a "magnetic island") w_d required to influence the temperature profile. This verified the theoretical prediction that the required anisotropy ratio for flattening the temperature profile within the island will scale as $\chi_{\|}/\chi_{\perp} \sim w_d^{-4}$.

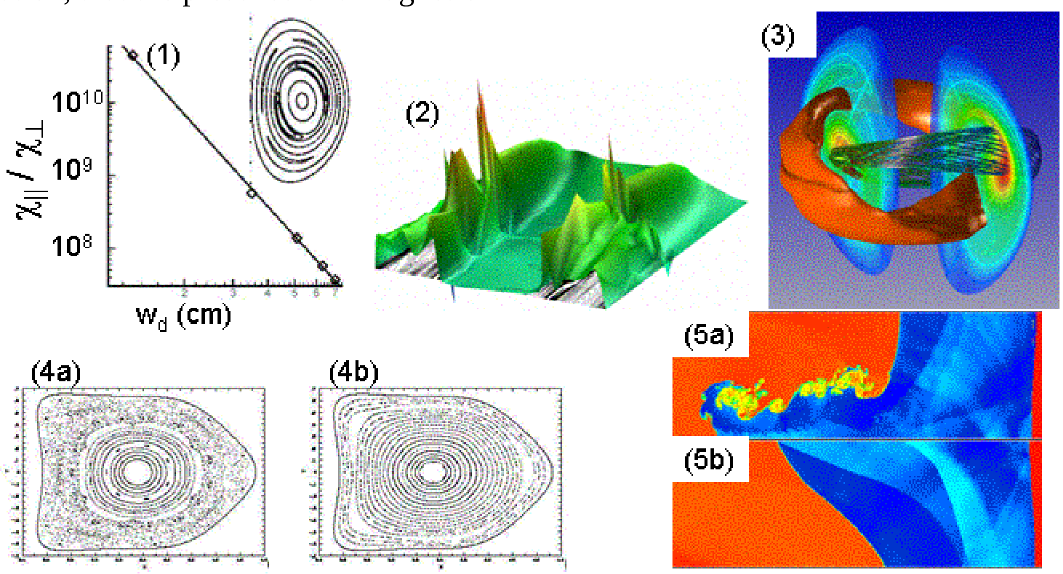
(2) Physics of the Current Hole: It has recently been observed in large experimental facilities in Europe and Japan that the current density in the center of a tokamak cannot be made to reverse sign, regardless of what current-drive sources are applied to it. We have used the M3D code to explain this curious phenomenon by showing that as the current density begins to reverse, strong flows develop that cause a form of magnetic reconnection to occur that has the effect of clamping the current density near zero, as shown in the midplane current density plots in Figure (2). This is important since these configurations with near-zero central current density have very good energy confinement and other properties that may form the basis for a more attractive fusion reactor.

(3) Effects of Strong Toroidal Shear on MHD Modes: New stabilizing effects have been demonstrated by including the effects of rapid rotation in the calculation of Spherical Torus (ST) stability. The sheared toroidal flow can have a strong stabilizing effect nonlinearly and, as shown in Figure (3), can cause saturation of otherwise unstable modes if the rotation profile is maintained. These simulations may account for phenomena recently observed in high-pressure discharges in the National Spherical Torus Experiment.

(4) Diamagnetic Stabilization of Instabilities in Stellarators: Extending the MHD description to the 2-fluid model has been shown to be essential in predicting the stabilization of an important class of localized instabilities in stellarators (confinement configurations with intrinsically 3D structure). Figure (4) contrasts two simulations of the National Compact Stellarator Experiment. The figure on the left

shows stochastic field line traces for a pure resistive MHD simulation. The one on the right, which is seen to have good surfaces, included the 2-fluid terms. The more complete plasma model generates self-consistent large-scale (diamagnetic) plasma flows that stabilize the localized instabilities.

(5) Suppression of the Richtmyer-Meshkov Instability by a Magnetic Field: We have been the first to demonstrate, through simulation, that the presence of a magnetic field will suppress the growth of the Richtmyer-Meshkov instability when a shock wave interacts with a contact discontinuity separating ionized gases of different densities. The top and bottom images in Figure (5) contrast the interface without (5a) and with (5b) the magnetic field. In the presence of the field, the vorticity generated at the interface is transported away by the fast and slow MHD shocks, removing the drive of the instability.



This work would have been impossible without the efforts of the above-listed team of analytical and computational physicists and applied mathematicians. The TOPS center has supplied routines that support interfacing high-order finite elements with the AZTEC parallel solver library and interfacing efficient algebraic multi-grid methods from HYPRE into PETSc. The TSTT center is facilitating introduction of high-order elements into M3D by way of interfacing with the Trellis software package. The APDEC center was essential in the development of the adaptive mesh refinement (AMR) software and high-accuracy MHD solver used in (5).

The successes reported here will be built upon in the near future in performing new and more comprehensive simulations enabled by these continuing collaborations and access to high-performance computers. These include (i) a more sophisticated model for the parallel heat flux that solves the electron kinetic distribution along characteristics, (ii) application of a hybrid fluid-particle method for calculating essential kinetic effects of ions, (iii) higher accuracy and longer time simulations and detailed comparison with experimental discharges, and (iv) a comprehensive 3D model of the physics of the injection of fuel pellets into a discharge.

NERSC equivalent computer usage and requirements: FY2002 3.9 M Hrs (actual), FY 2003 1.2 M Hrs (3-months); FY 2004 6 M Hrs (anticipated).

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