Quarterly Progress Report of the PSI-Center (April - June 2007)

by

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The Plasma Science and Innovation Center (PSI-Center) has accomplished a great deal this quarter. The PSI-Center is organized into four groups: Boundary Conditions and Geometry, Two-Fluid and Transport, FLR and Kinetic Effects, and Interfacing. Each group has made good progress and the results from each group are given in detail.

BC&G Group *(U. Shumlak, G. Marklin, W. Lowrie, E. Meier)*

- Hexahedral Mesh Generator
  - Acquired CUBIT hexahedral mesh generator from Sandia
  - Created sample 3D geometry and hexahedral mesh for HIT
  - Created sample 2D geometry and quadrilateral mesh for HIT and SSPX
- Created a Finite Difference Pseudo-1D Euler Equation solver using MacCormack algorithm (for comparison with Finite Element Solver)
- Finite Element Code
  - Formulated explicit finite element method for pseudo-1D Euler equations (or any flux - source equations set)
  - Formulated non-linear solver for equations
  - Formulated Implicit solver for equations
  - Implemented calculation of basis functions
  - Implemented Jacobian calculation
- Created a Finite Difference, 3D ideal MHD non-linear dynamics solver
- Screw-pinch linear instability growth rates have been modeled in MH4D with non-linear ideal MHD simulations. The predicted rates agree within 10%.
- MH4D has been modified such that implicit resistivity can be used with an insulating boundary condition.
- Basic atomic physics terms, as described in our short-range goal, have been added to MH4D. Static simulations have been run to verity functionality. Dynamic simulations are in progress -- a spheromak simulation has been developed and tilt instability growth rates will be compared with and without atomic physics.
- A new formulation of the insulated conductor boundary condition that leads to a symmetric positive definite system of equations has been developed. The method has been applied to a spheromak tilting mode in a cylinder and works well but showed little difference from the bare conducting wall case. Further testing on an RFP formation in a torus is currently underway to understand how to handle circuit interactions.

Two-fluid and Transport Group ***(C. R. Sovinec, E. D. Held, R. A. Bayliss, and J.-Y. Ji)***

Over the quarter of funding ending on 6/30/07, the Two-fluid and Transport Group has conducted a series of DC injection computations for an approximate HIT-II configuration. We have also used the moment method to derive general parallel heat transport and have begun investigating time-dependent effects in the closures.

- A series of helicity injection simulations in a simplified geometry based on HIT-II confirms that the boundary conditions described in the previous report work over a range of injector voltages. However, while the applied injector-current is specified as a boundary condition at the injector, the net injected current must be computed from the simulation result. An imbalance between the absorber voltage and applied injector current leads to 'injector' current escaping through the absorber, effectively altering the toroidal-field rod current. With this understanding, we are now starting to find agreement with the HIT-II database. For example, with constant injector flux and just enough voltage to expand the poloidal field (bubble-burst), the net plasma current is essentially independent of toroidal-field rod current, in agreement with results reported in the manuscript by Redd, *et al.*, "Coaxial Helicity Injection in a Spherical Torus," for HIT-II shots 26449-26476. The simulation results are shown in Figure TFT 1.
- We have computed the kernel needed for calculating the nonlocal, parallel heat flow closure using a higher-order moment method. This kernel provides a quantitative response in both the collisional and nearly collisionless limits and is easily adapted to the present NIMROD implementation of the parallel heat flow closures.
- General, time-dependent closures are needed for the rapid dynamics that often characterize EC plasmas. Development of time-dependent parallel closures is underway. This theory uses a higher-order moment form of the linearized collision operator to recover the collisional limit and incorporates the Landau resonance in velocity space moments to recover collisionless physics.
- Work continues on the implementation of the nonlocal, parallel electron stress as well as improvements in efficiency to the present formulation of the existing parallel closures in NIMROD.

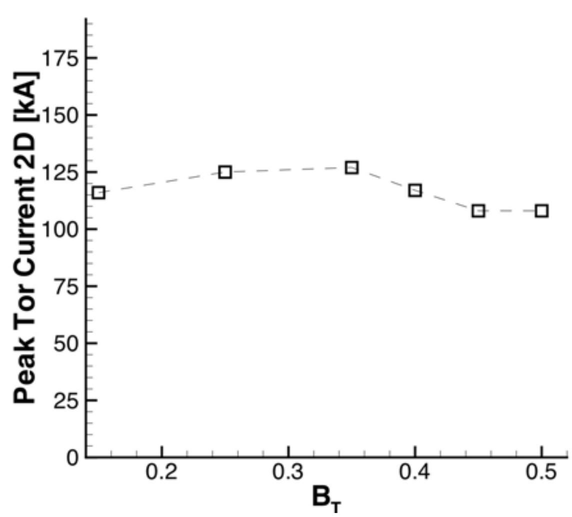
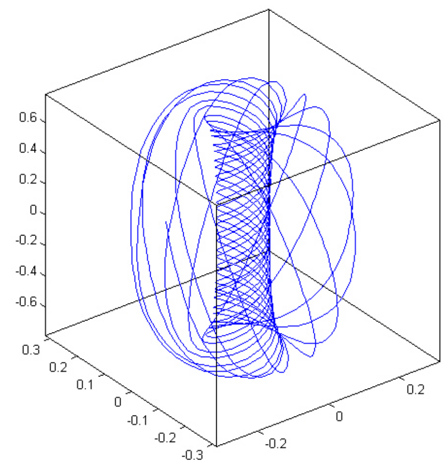


Figure TFT.1. Results on plasma current induced by helicity injection from a series of nonlinear NIMROD simulations for a HIT-II-like configuration.

FLR and Kinetic Effects Group ***(R. Milroy, A. Macnab, C. Kim)***
During this quarter the FLR and Kinetic Effects group has focused on writing two papers, beginning the implementation of outflow end boundary conditions (as required for accurate FRC simulations), and continuing a study of the n=2 rotational instability in FRCs.

Accomplishments

- Implement field line tracing ability for FRCs, both with a Matlab script, and using the NIMROD utility NIMFL. Initially, some small "bugs" in NIMFL were causing problems for the FRC geometry.
- Begin a collaboration with Loren Steinhauer to study the n=2 rotational instability in an FRC. We have found that the Hall term combined with a relatively weak toroidal field has a dramatic stabilizing effect on the n=2 rotational instability.
    - Preliminary investigation of the effect of different equilibria and q-profiles.
    - Write internal document on this work to facilitate collaboration.
    - Begin analytic derivation of n=2 growth rates with and without toroidal field, so we can benchmark the code and achieve a better fundamental understanding of this phenomena.



Field-lines for an FRC with relatively small toroidal field added.

- As a low-priority background task, we are attempting to compile and run a serial version of NIMROD using Intel Fortran and Microsoft Visual Studio on a Windows PC. This is an attractive development platform for those who are already proficient with Visual Studio. So far, we have a version running that is restricted to the "gl_diaga" solver. We hope to add the SuperLU ("seq_slu") solver soon.
- Prepared and delivered an invited talk at the 2007 International Fusion Theory Conference entitled "Extended MHD Simulations of End-Shorting Induced Rotation in Field-Reversed Configurations"
- Completed a manuscript for submission to Physics of Plasmas entitled "Hall magnetohydrodynamics simulations of end-shorting induced rotation in field-reversed configurations". Received a favorable referee review and began making minor modifications to the manuscript for final submission.
- Began to implement outflow boundary conditions in the axial end-wall region of FRC simulations. This boundary condition applies either a time dependent inhomogenous Dirichlet boundary condition to the normal component of the velocity or applies a Neumann boundary condition to the normal component of velocity. Additionally, begin implementing management routines to apply inhomogenious time dependent boundary conditions to the number density and temperature. All of these routines use a logical data type in the seam structure to distinguish between radial and axial walls. These routines achieve inhomogenious time dependent boundaries while preserving the symmetry of the operator on the left hand side of the advance equations by applying a homogenious Dirichlet condition to the change in the fields and then by altering the total field values at the management level.

- A first draft of a paper titled "A hybrid kinetic MHD simulation of the (1,1) internal kink mode" is nearing completion. This paper presents a detailed linear study of the impact of velocity space distribution on the stabilization of the (1,1) internal kink mode and excitation of the fishbone mode. We test the conventional theory of stabilization and the import of the trapped particles in particular. It is demonstrated that for shallow velocity distributions, the passing particles play a significant role in stabilization. It is only in the limit of v → infinity that the trapped particles dominate the stabilization mechanism.
- Perform drift kinetic runs (in support of paper): test drift kinetic algorithm to insure that particles can recover MHD results in limit anisotropic pressure=0.
- Modify code to test impact of trapped vs. passing particles. Contrary to conventional belief, the passing particles play strong role in stabilization of (1,1) kink mode.

Interfacing Group *(B. A. Nelson, C. C. Kim, A. Cassidy, S. D. Griffith)*

Accomplishments

- The IG is tasked with assisting in computational support for the twelve collaborating ICC experiments (along with the three physics groups). All collaborating PIs have been contacted, and development of plans for proceeding with simulations is ongoing.
- Work has continued on the Levitated Dipole Experiment (LDX).
  - Incorporated the LDX geometry into NIMlite
  - Added the capability to read LDX ASCII equilibrium files
  - Modified the LDX grid (by Prof. Sovinec *et al.*) to improve Jacobians and resultant grid quantities
  - Added Prof. Sovinec and Dr. Kesner's previous heating and fuelling sources.
  - Working with Drs. Jay Kesner and Darren Garnier on the non-linear evolution of calculated LDX equilibria at marginal stability. Initial runs have begun, with results to be reported soon.
- Work has continued on HIT-SI simulations. Dr. Kim has assisted C. Akcay in migrating V. Izzo's NIMROD simulations of HIT-SI to most current version of NIMROD.
- Progress has continued on the NimPy post-processor, which outputs NIMROD data to the Visualization Toolkit (VTK) format, which can then be read by the LLNL VisIt visualization program (http://www.llnl.gov/visit/). Improved plotting methods have been added to NimPy. Also, NimPy now has the ability to be run as a command line script, converting all NIMROD dump files in the present directory to VTK, with options chosen by a ".nimpyrc" file.
- Development of a version of NIMROD, "NIMlite" (to replace NIMPSI), is continuing. NIMlite removes vestigial elements of old coding and includes reorganization of the code for more efficient compilation. Several initialization routines have been added, including bessel function spheromak in a can, merging spheromaks, FRCs, LDX, and "Bellan's box".
- Work is continuing on hot particle stabilization of tearing mode in RFPs, exploring the parameter space and convergence studies. A paper describing these results has been accepted for publication in the Journal of Fusion Energy.