# Quarterly Progress Report of the PSI-Center (Oct.–Dec. 2006)

by

*Thomas Jarboe, Richard Milroy, Brian Nelson, Uri Shumlak, and Carl Sovinec*

The Plasma Science and Innovation Center (PSI-Center) has accomplished much this quarter. The PSI-Center is organized into four groups: Boundary Conditions and Geometry, Two-Fluid and Transport, FLR and Kinetic Effects, and Interfacing. Progress from each group, for this quarter, is given in detail.

***Boundary Conditions and Geometry Group*** **(U. Shumlak, G. Marklin, W. Lowrie, E. Meier)**

- A resistive MHD simulation with insulated conductor boundary conditions was set up on Comsol Multiphysics (CM - formerly called Femlab), a commercial software product for finite element solution of partial differential equations on a tetrahedral mesh. Numerical instabilities that were seen previously when running this problem on the explicit finite volume code, M4, were not present in the fully implicit CM simulation indicating that implicit treatment may be necessary for this boundary condition. Unfortunately, simulations with a realistic level of resolution are not yet practical on CM since a fully parallel version is not yet available and the current version is too slow.
- The M4 code is being upgraded to run fully implicitly and in parallel and will be able to handle the insulated conductor boundary condition in a finite volume resistive MHD simulation. Eventually, this code will be further upgraded to a spectral element code with the full extended MHD equations and will replace MH4D.
- Periodic boundary conditions, applicable to parallel and non-parallel planes have been developed. Mode selection can now be achieved by modeling a “slice” of a domain. For instance, modeling a 1/4-slice of a cylindrical Z-pinch geometry eliminates the $m$ = 1, 2, and 3 modes. $m$ = 0, 4 and higher harmonic modes will still be captured.
- Chodura resistivity has been implemented with an appropriate time step limit for explicit solutions. Work is under way to properly couple boundary points in the implicit solution procedure for Ohm's law. Implicit solutions of the numerically stiff Ohm's law will reduce computational work and will allow more realistic resistivity profiles.
- Setup new subversion repository (tagged version numbers for older versions of code, cleaned existing database of old/unnecessary files, created new trunk and branches for the most up-to-date version.
- Created a flowchart of the MH4D code which outlines the major subroutines and shows the basic flow of the code.
- Documented subroutines and interfaced subroutines and listed which subroutines are involved with each file (i.e. mh4d.F). Made spreadsheet referencing the interfaced subroutines to their parent subroutine.

- Setup a Couette geometry and flow for testing of the semi-implicit operators in the code. Added Couette test case in the loader program, which sets the correct boundary conditions. This test case is a lead into a Hartmann flow test case for semi-implicit operators.
- Data structures are being developed that allow an extension of the tetrahedral MHD code to use finite element methods. The resulting code will combine the essential features of MH4D with the advances made in finite element MHD codes, such as SELS.

***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 12/31/06, the Two-fluid and Transport Group has performed simulations of helicity injection in low-aspect ratio configurations with vacuum toroidal field for the purposes of model validation and theoretical study. We have also developed a new analytical approach for dealing with the Coulomb collision operator in moment-based analysis of closure terms.

**Accomplishments**

- Computations of axisymmetric helicity injection into a vacuum magnetic field with a toroidal component have been completed and successfully reproduce the n=1 kink mode that eventually leads to relaxation. The location of the current channel is determined by the surface temperature along one of the electrodes, which affects plasma resistivity through the Spitzer model. A version with non-axisymmetric surface temperature (required for modeling current driven by miniature plasma guns in the Pegasus experiment, for example) remains more challenging computationally.
- A simulation study of coaxial helicity injection relevant for HIT-II and NSTX, where current is driven from poloidally narrow but axisymmetric gaps, has been initiated. The computations have progressed through the ‘bubble-burst’ phase, as shown in Fig. TFT.1.
- We derived analytical expressions of general parallel closures from the linearized two-fluid moment equations with arbitrary number of moments.
- The convergence properties of the closures were studied in various collisionalities as the number of moments increases.
- We developed hybrid approach for exact, linearized Coulomb collision operator that inverts the angular scattering part of the operator but uses a moment approach for the remaining terms.
- We tested parallel closures derived from a kinetic equation involving this operator and found quantitative agreement with previous collisional and collisionless results.

**Future Work**

- Work on parallel closures to be completed within the next quarter includes:

- o Implement parallel heat flow closures derived using (i) full moment approach and (ii) hybrid moment/kinetic-distortion approach and apply in SSPX transport calculations.
- o Compare and contrast the two approaches for the above problem.
- o Implement full closure model for parallel heat flows and stresses and identify interesting applications for EC experiments and the PSI-Center.

- Work related to the two-fluid algorithm to be completed within the next quarter includes:
  - o Run simulations of coaxial helicity injection in parameters relevant to HIT-II and begin comparisons with published data from the experiment.
  - o Complete testing of the temperature-dependent parallel viscosity coefficient. We expected to complete this sooner, but applications work was given precedence.
  - o Improve computational efficiency by incorporating toroidal coupling in the preconditioning operations used for algebraic system solves.

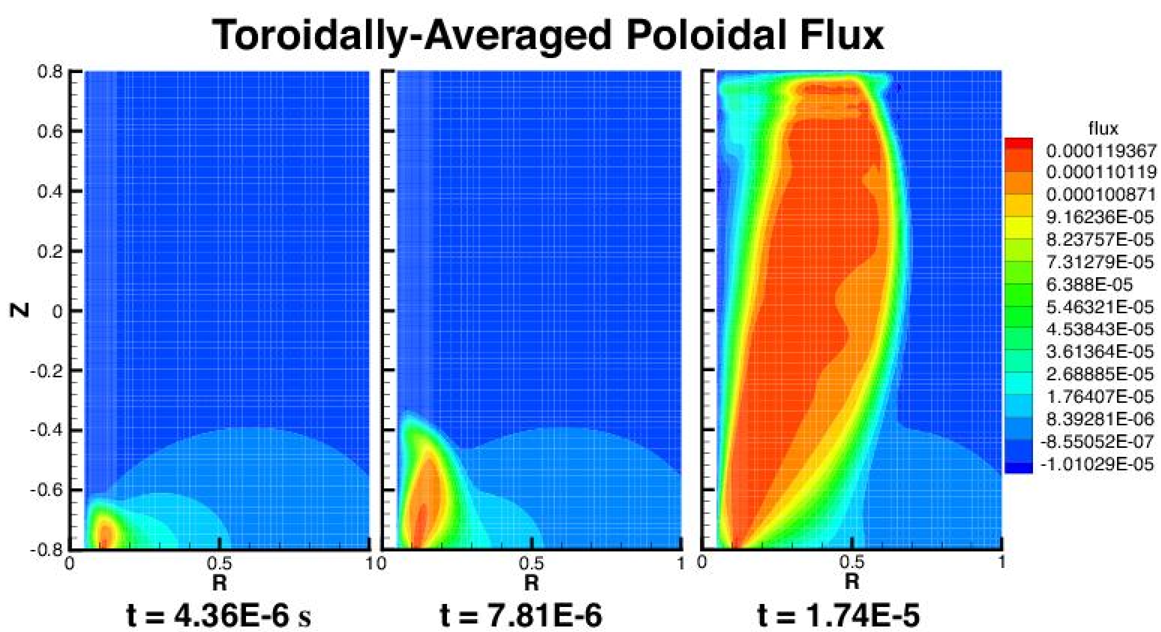



Figure TFT.1. Contours of toroidally averaged poloidal flux from a simulation of coaxial injection in small-aspect-ratio tori. The three frames show three different times during the evolution.

***FLR and Kinetic Effects Group* (R. Milroy, A. Macnab, C. Kim)**

Over this quarter the FLR and Kinetic Effects group has focused on the FLR stabilization of tearing modes in the RFP, and on the accurate simulation of FRC spin-up due to end-shorting. The FRC spin-up problem required us to carefully examine the implementation of boundary conditions where field lines penetrate the boundary, and the Hall term is turned on.

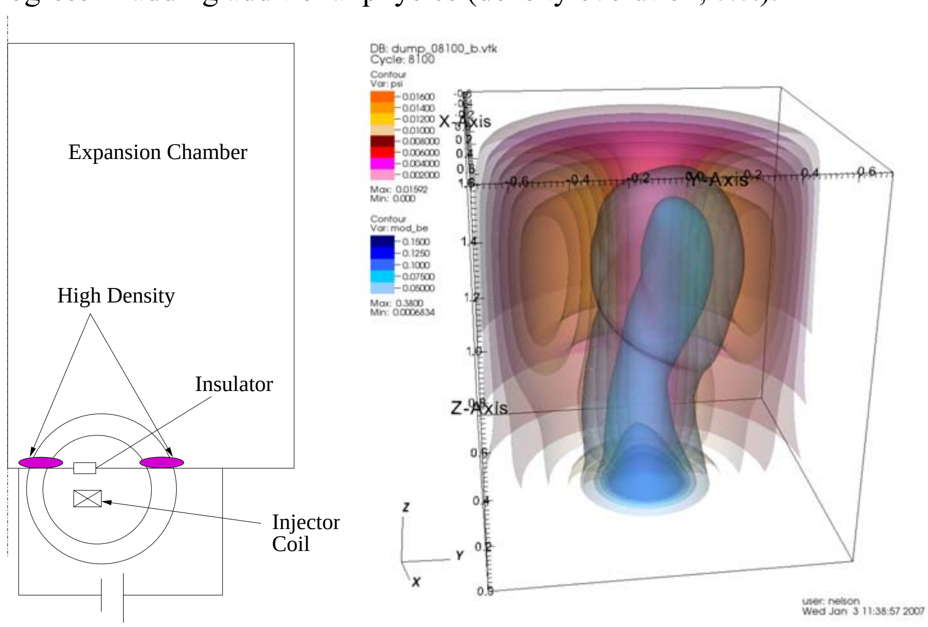
**Accomplishments**

- Merge Boris particle and drift particle subroutines to allow for the selection of particle type in the input file. Further unification and streamlining is in progress.
- Work continues on exploring the parameter space of FLR stabilization of tearing modes in RFP. We are mapping out the linear growth rate dependence on the Larmor radius of the energetic particles. Our first scans involve initializing with a δ-function in the perpendicular velocity and zero initial parallel velocity. In contrast to the analytic treatment, the initial value nature of the simulation results in a finite velocity spread due to particle dynamics and their finite Larmor excursions. These scans show that $v_{perp0} > 20\%\ v_{Alfven}$ stabilizes the tearing mode ($S\sim10^4$). We are in the process of scanning with non-zero initial parallel velocity to examine if co- vs. counter- has any impact, apart from the initial energy loading of the particles. After some consideration, it is possible that initial claims of "washing out" due to finite distributions may have been hasty. Convergence studies are also under way to examine whether the "washing out" was due to a lack of phase space resolution.
- Work has begun on a paper on the implementation of hybrid kinetic particles in the NIMROD code.
- Merged the $E_{tangential}$ changes (radial boundary conditions to simulate the effect of multiple discrete coils) into the new implicit advance version of NIMPSI. We have regression tested the code for the uniform compression case and for FRC translation.
- Worked through the theoretical background for finite element Hall MHD boundary conditions for a perfectly conducting wall, where the magnetic field lines penetrate the axial end-wall.
- Executed a series of spin-up simulations to study FRC spin-up due to end-shorting in the presence of Hall physics, spin-up due to evolution from MHD to Hall MHD (without end-shorting), and a resistive MHD control case. Have begun work on a paper that documents this work.
- We presented two papers at the APS meeting in Philadelphia, and one paper at the US-Japan meeting at Swarthmore.

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

**Accomplishments**

- The IG is tasked with assisting in computational support for the eleven collaborating EC experiments (along with the three physics groups). All collaborating PIs have been contacted, and development of plans for proceeding with simulations is ongoing.
- Progress has continued on the NimPy post-processor, which outputs NIMROD data to the Visualization Toolkit (VTK) format, that can be read by the LLNL VisIt visualization program (http://www.llnl.gov/visit/). Progress was reported at the 2006 Philadelphia APS-DPP meeting, which generated great interest.
- NimPy is being extended to be a "steering program" for existing NIMROD post-processors, including nimplot and nimfl.
- A version of NIMROD, "NIMlite" (to replace NIMPSI), has involved removing vestigial elements of old coding and reorganization of the code for more efficient compilation. Several initialization routines have been added, including bessel function spheromak in a can, merging spheromaks, and "Bellan's box".
- Spheromak formation simulations have continued with "Bellan's box", with progress in adding additional physics (density evolution, *etc*.).




Left: sketch of calculation setup ("Bellan's box"); Right: toroidally-averaged flux surfaces (brownish) and mod-**B** surfaces in kink-mode (bluish).

- Work is continuing on FLR stabilization of tearing mode in RFPs, exploring the parameter space and convergence studies.