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Status of the Plasma Science and Innovation Center Interfacing Group

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Abstract The Interfacing Group of the Plasma Science and Innovation Center (PSI-Center—http://www.psicenter.org), facilitates simulations of collaborating Innovative Confinement Concept (ICC) experiments. This includes assisting experiments in setting up new simulations and in comparison of simulations with experimental data, acquiring and disseminating information about simulations to PSI-Center computational groups, and acting as a conduit of information between experiments.

Keywords MHD simulations · Simulation visualization

Introduction

The mission of the Plasma Science and Innovation Center (PSI-Center) is to refine present computational tools with sufficient physics, boundary conditions, and geometry to be calibrated with experiments to achieve predictive capabilities for Innovative Confinement Concept (ICC) experiments.

Present collaborating experiments include the Bellan Plasma Group (Caltech), the field reversed experiment-L (FRX-L, Los Alamos National Laboratory), the helicity injected torus-steady inductive spheromak (HIT-SI, University of Washington), the Madison Symmetric Torus (MST, University of Wisconsin–Madison), the magneto-Bernoulli experiment (MBX, Univ of Texas–Austin), the Pegasus spherical torus (University of Wisconsin–Madison), the pulsed high density FRC experiment (PHD, University of Washington), the sustained spheromak physics experiment (SSPX, Lawrence Livermore National Laboratory), the Swarthmore spheromak experiment (SSX, Swarthmore College), the translation, confinement, and sustainment FRC experiment (TCS, University of Washington), and the ZaP flow Z-pinch experiment (University of Washington).

The PSI-Center is refining two existing 3-D resistive MHD codes, NIMROD [1]—http://www.nimrodteam.org—and MH4D [2]. While development continues on MH4D boundary conditions and numerics for ICC experiments (reported elsewhere), the PSI-Center Interfacing Group is using NIMROD to simulate collaborating experiments.

The Interfacing Group has improved the Python language post-processing "NimPy" module, which can now convert NIMROD dump files to "visualization toolkit" (VTK) format, which are readable by the LLNL VisIt 3-D visualization software.

Initial NIMROD runs are being refined on the Caltech experiment [3]. "Current injection" boundary conditions are applied to a plasma in a dipole field, which pushes the flux outward into the chamber. (Only the basic setup of the simulation will be discussed here, as results are preliminary and the simulation parameters have not been optimized.)

NIMROD Post-processing Development

Post-processing with NIMROD has traditionally been through the use of programs in the NIMROD distribution (NIMPLOT, NIMFL, etc.) and an associated plotting program `xdraw`. Output from these codes can be imported into plotting routines such as Tecplot, OpenDX, FusionViewer,

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and others. The Interfacing and other PSI-Center Groups have been extending these tools to other plotting/programming languages such as the commercial product MATLAB and the open source language Python (http://www.python.org).

The Interfacing Group is continuing development of a Python module ("NimPy") that can directly read NIMROD dump files into a Python "`nimrod`" object. The `nimrod` object contains several other objects based on NIMROD Fortran95 structures, such as "seams", "rblocks", 2- and 3-D Lagrange quadrature objects, etc. The `nimrod` module can be run interactively, and interfaces well with Python modules such IPython (http://ipython.scipy.org) and Matplotlib (http://matplotlib.sourceforge.net), for object introspection, plotting, and production of publication quality figures.

The `nimrod` object has a "`to_vtk()`" method that writes a "visualization toolkit" (VTK, http://www.vtk.org) file, which can be read by the 3-D plotting program VisIt (http://www.llnl.gov/visit). VisIt is an open-source, multi-platform, parallel-capable program providing GUI-driven interactive visualization. VisIt can display scalar data as 3-D contours and pseudo-color images, and vector data as arrow and streamline plots, as well as a host of other display methods. An example of 3-D pressure contours (with transparency enabled) in an FRC with a driven $n = 2$ rotation is given in Fig. 1 and for the Caltech experiment in Fig. 2 (more details to follow). (Specifics of the FRC $n = 2$ NIMROD results will be reported later by another PSI-Center Group.)

VisIt's interface is easy to learn and very powerful. VisIt can perform "filtering" on the data (slice to a plane, clip regions to be plotted, etc.) and interactively rotated under computer "mouse" control. Time steps can be animated and converted to mpeg movie format, or exported to still images. A built-in expression evaluator can perform functions on the data and then be plotted, e.g. magnitude of a vector, or its individual components.

It is also planned to include `nimpy` methods that run the standard NIMROD post-processing programs, e.g. NIMFL, parse the output data, and export it in a format readable by VisIt. This will leverage the existing NIMROD code base, allowing bug fixes and enhancements to be independent from `nimpy`.

Initial NIMROD Simulations of the Caltech Experiment

In collaboration with Prof. P. Bellan of Caltech, the PSI-Center Interfacing Group is beginning NIMROD simulations of the the Caltech experiment [3]. Specific results are not ready to be reported, but the basic setup of the initial simulations follows.

A schematic of the experiment is given in the left-hand side of Fig. 2. The simulation boundary is an axisymmetric cylinder with a continuous toroidal break on one end, separating an inner electrode disk from the rest of the chamber. An external coil creates a dipole field with flux connecting the inner electrode with rest of the chamber. Preliminary runs use an initial plasma density

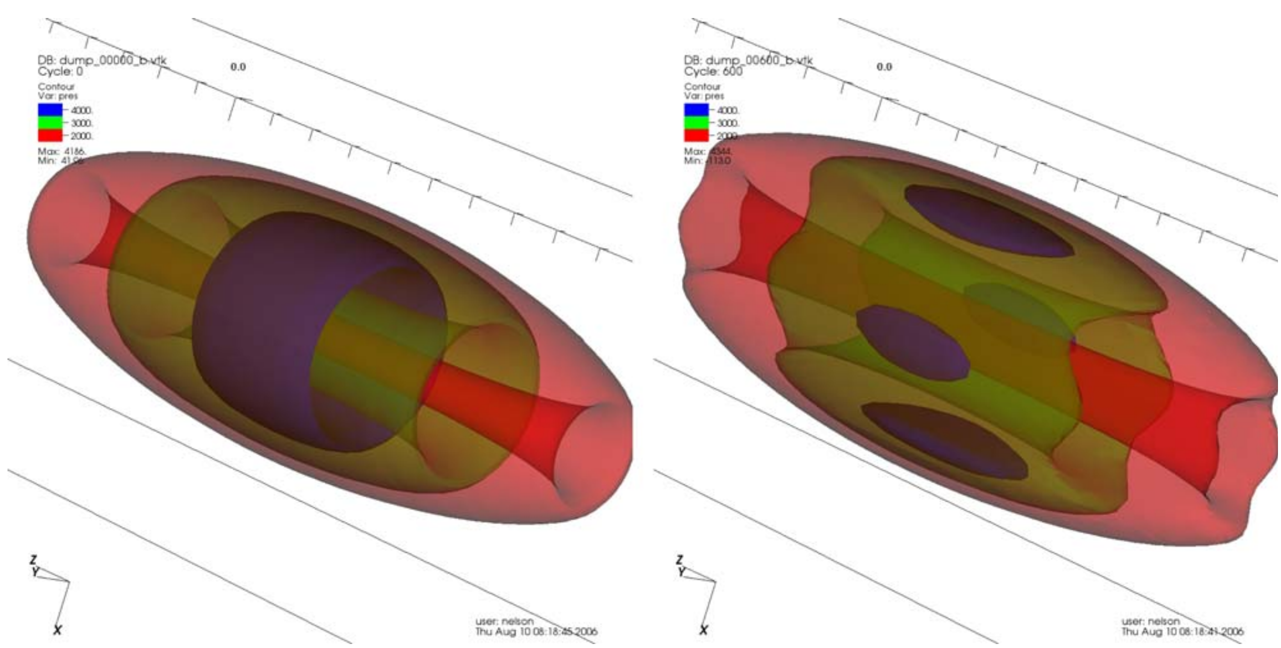

Fig. 1 Example of 3-D visualization of NIMROD data using VisIt. Pressure contours of an FRC with a driven $n = 2$ rotation are shown, with partial transparency of surfaces enabled (left, before rotation starts; right, during rotation)

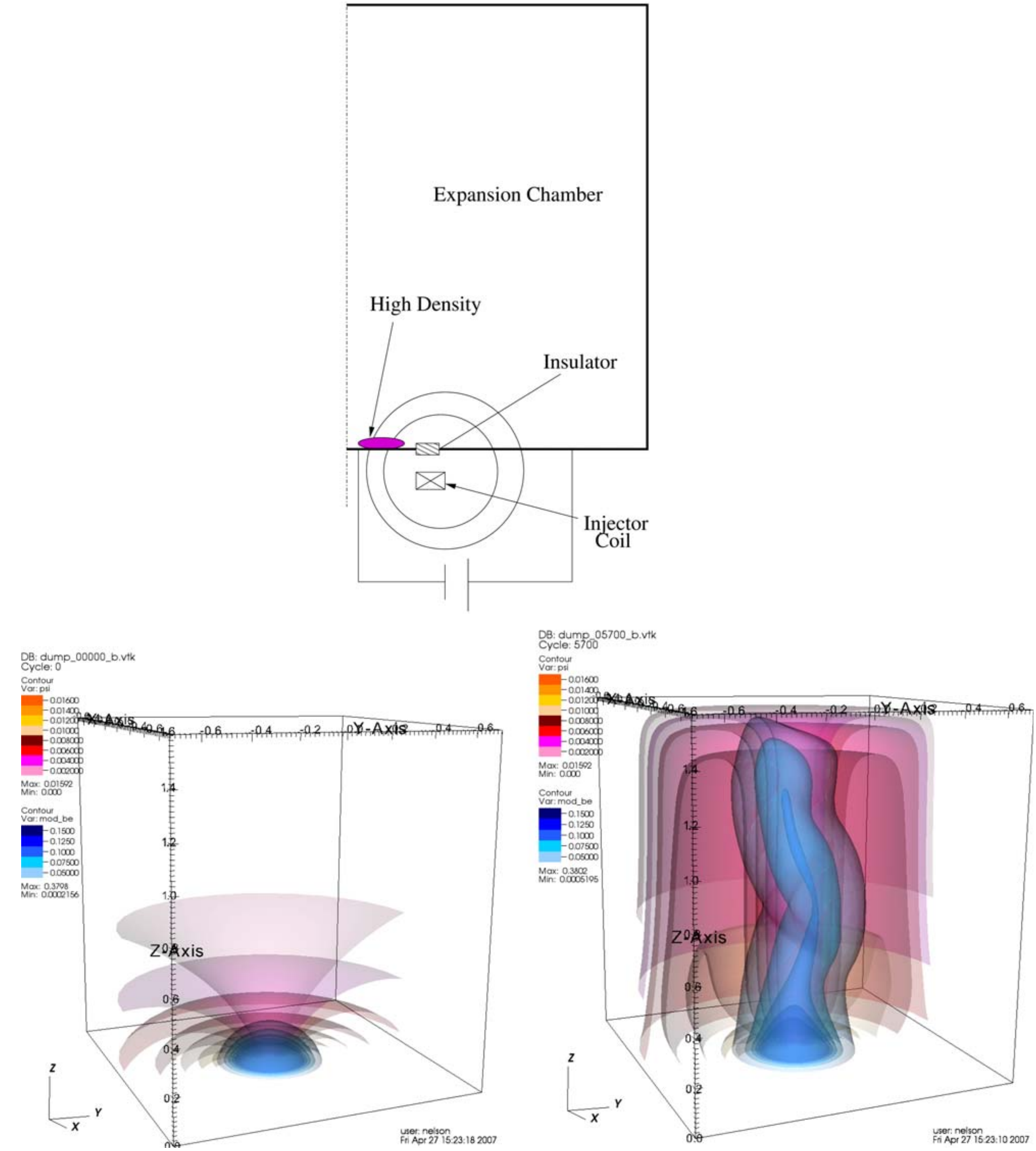

Fig. 2 Upper: Schematic of the NIMROD geometry used for the Caltech experiment (left side is the line of symmetry). Lower: Magnetic flux (cropped outer contours) and |**B**| contours (central uncropped contours) from NIMROD runs *without* density advection. Lower left is the initial conditions and lower right is after the application of current pulled the flux upward and the central column begins to kink

that is either uniform or concentrated near the inner electrode (as shown in the figure). (The actual Caltech experiment produces the plasma at eight distinct toroidally-separated gas inlet ports; this non-axisymmetric feature will be included later.) The NIMROD mesh can be packed along the R or Z axes, and is typically made denser around the toroidal break and near the inner electrode.

Current injection boundary conditions [4] are applied across the toroidal break, viz., the value of RB_φ is specified vs. time, where B_φ is the toroidal component of the magnetic flux density. Other regions have the boundary conditions of a conducting wall: $\mathbf{v} = \mathbf{E} \times \hat{\mathbf{n}} = \mathbf{0}$ and $\delta\mathbf{B} \cdot \hat{\mathbf{n}} = 0$, where $\mathbf{v}$ is the fluid velocity, $\mathbf{E}$ is the electric field, $\delta\mathbf{B}$ is the change in magnetic flux density from the initial conditions, and $\hat{\mathbf{n}}$ is the boundary normal. A thin layer with higher resistance is adjacent and along the lower chamber to allow the current to diffuse into the plasma away from the wall (where the resitivity is constant). These constraints thus specify the poloidal current flowing on the inner electrode, which is typically ramped up to 50 kA in 10μs, similar to the experiment.

Presently, parameters for the NIMROD simulation are being refined, e.g. mesh spacing, initial resistivity (including the high resistance layer boundary condition), initial density values and profiles, which NIMROD physics to include (e.g., which parameters to evolve, what terms to include in force balance, etc.). However, the simulations are generally behaving as expected, the initial flux is pushed upward and also toward the axis, where it forms a column with the embedded poloidal flux and a current channel (e.g., similar to a screw pinch). Flux and $|\mathbf{B}|$ surfaces for the case *without* density advection are given in the right-hand side of Fig. 2. Note the plasma column is beginning to kink. Preliminary results including density advection tends to prevent the flux from reaching the upper region of the chamber, but parameters are still being optimized.

Summary

The PSI-Center Interfacing group has begun new NIMROD simulations for the Caltech experiments. Other PSI-Center collaborating experiments already have NIMROD (or MH4D) gridded and/or running for them. Additional NIMROD post-processing scripts are being developed, including the Python "`nimpy`" module which can interface to the VisIt visualization program.

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