HiFi/SEL Development Update

• Scalable solver with physics based preconditioning (A.H. Glasser; V.S. Lukin)
• Verified non-linear convergence and limited scalability for visco-resistive MHD

• **Computation on self-similarly changing grid** (A.H. Glasser; V.S. Lukin)

• 2D grid adaptation in 3D simulations (spatial convergence estimator averaged in the third dimension) (V.S. Lukin, A.H. Glasser)

• Initialize/Restart from a previous computation on a grid of different size and/or with different dependent variables (V.S. Lukin)

• Parallel post-processing for HiFi (V.S. Lukin, W. Lowrie)

• Grid deformation metrics (W. Lowrie, V.S. Lukin, U. Shumlak)

• Nearly complete for 2D, manuscript in progress
HiFi/SEL Development Update

- **Dynamic plasma-neutral model** (E. Meier, U. Shumlak, B. Nelson)
- **Open boundary condition** (E. Meier, U. Shumlak, A.H. Glasser, V.S. Lukin)
  - Works for non-dissipative systems, more general approach under development
- **Evolve log\(n\) in place of \(n\) (density) in MHD equations -- attempt to cure density cavitation in simulations** (V.S. Lukin)
- **Successful preliminary test on the 3D reconnection problem**
- **Multiblock Geometry** (W. Lowrie, V.S. Lukin, U. Shumlak)
  - Works for quasi-structured collections of blocks, unstructured approach under development
Imploding FRC Simulation

(A.H. Glasser, V.S. Lukin)

- Self-similar grid deformation
- Being used by General Fusion in Vancouver, BC for experimental design

\[ r(t) = \frac{1}{2} \xi \left[ (1 - r_{\text{min}}) \cos\left(\frac{\pi t}{\tau}\right) + (1 + r_{\text{min}}) \right] \]

Initial Psi

Final Psi
Dynamic Plasma-Neutral Model
(E. Meier, U. Shumlak, B. Nelson)

• Dynamic Plasma-Neutral model has separate fluid species for neutrals

• Neutral fluid interacts with plasma through ionization, recombination, and charge exchange

• Being used for plasma propulsion studies (ELF Project) by Brian Nelson
Dynamic Plasma-Neutral Model
(E. Meier, U. Shumlak, B. Nelson)

The FRC transfers its momentum to the neutrals through charge-exchange.

SEL simulation of a translated FRC (white flux contours, black contours from translation coil) dynamic neutrals (pseudocolor), ion momentum density (white arrows), and neutral momentum density (black arrows).
Dynamic Plasma-Neutral Model
(E. Meier, U. Shumlak, B. Nelson)
Two co-axial right-handed spheromaks situated next to each other in a cylindrical flux conserver, such that their poloidal B-fields are co-directed at the midplane and their interior toroidal B-fields are oppositely directed.

- There is a single interior B-field null point at the center between the two spheromaks;
- Co-directed tilting is initially accompanied by magnetic reconnection of poloidal B-fields between the top portion of one and the bottom of the other spheromak at the null point;
- It is all 3D reconnection and relaxation from there on out...
3D Reconnection Simulations
(V.S. Lukin, Naval Research Laboratory)

✴ Visco, hyper-resistive MHD equations
Magnetic Reconnection (by V.S. Lukin with multi-fluid HiFi code)

✴ Null-point reconnection
✴ Alfvenic outflow jets

✴ Compared well to SSX experimental data
(M.R. Brown, T. Gray, C.D. Cothran)
3D Reconnection Simulations
(V.S. Lukin, Naval Research Laboratory)

More movies at: http://psicenter.org/hifisim
3D Reconnection Simulations
(V.S. Lukin, Naval Research Laboratory)

More movies at: http://psicenter.org/hifisim
Multiblock
(W. Lowrie, V.S. Lukin)

CAD Drawing

CUBIT Generated Hexahedral Mesh with Several Blocks
- Hot off the press!
- Quasi-structured collection of blocks
- Non-simply connected, Non-axisymmetric configurations possible
- Next step: unstructured
Peter Norgaard is simulating an MPD thruster using HiFi/SEL, will take advantage of the multiblock geometry flexibility
Additional Remarks

- Code released under BSD-type license and freely available to the international community
- Community Impact: HiFi/SEL code is being used for projects outside the ICC/PSI-Center
  - Two NASA proposals submitted (supernova ignition & plasma neutral solar chromosphere modeling)
  - NSF proposal submitted (kink instabilities in laboratory and astrophysical plasmas)
  - Coronal mass ejection / solar flare modeling (NRL)
  - MPD thruster simulations (Princeton University)