Disruption-Related NIMROD Activities

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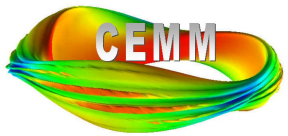
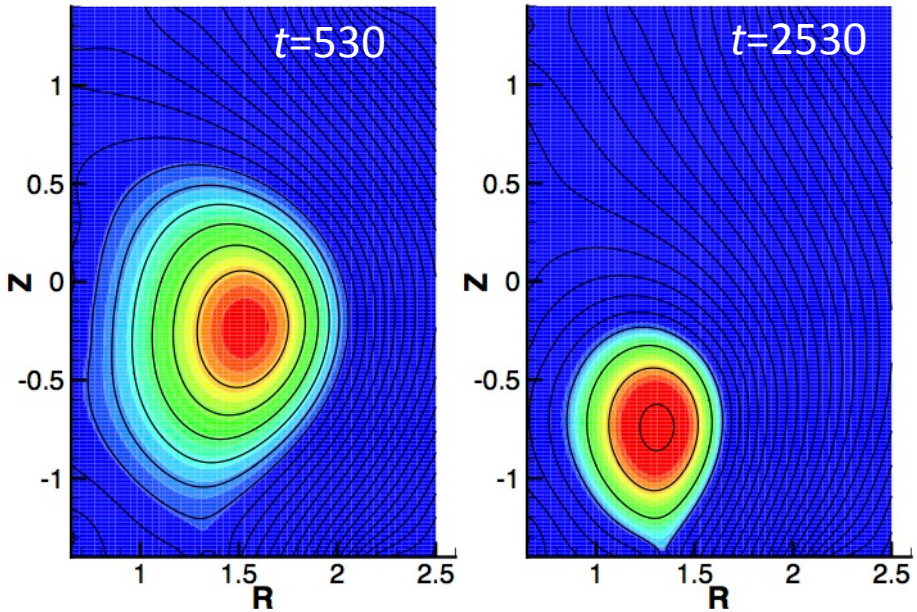


Introduction: Detailed modeling of tokamak disruption is a form of integrated simulation.

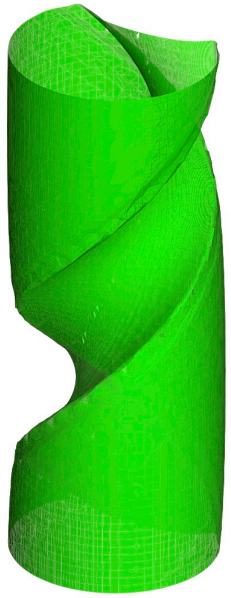
- A disruption physics laundry list includes:
  - Macroscopic dynamics
    - Axisymmetric displacement
    - External kink
    - Island growth, overlap, locking
  - Parallel heat transport
  - Plasma-neutral interaction
  - Radiation
  - Runaway electron generation and confinement
  - External electromagnetics
  - Plasma-surface interaction
- This talk briefly summarizes NIMROD's status and plans in disruption-related modeling.

Modeling axisymmetric displacement and external kink distinguish plasma shape through $n(\mathbf{x},t)$ and $T(\mathbf{x},t)$.

- We have been using a capped Spitzer $\eta(T)$.



Computed axisymmetric VDE with $\tau_A << \tau_w << \tau_r$ retains central pressure.



Isosurfaces of density from a nonlinear external kink computation.

VDE and external kink - status

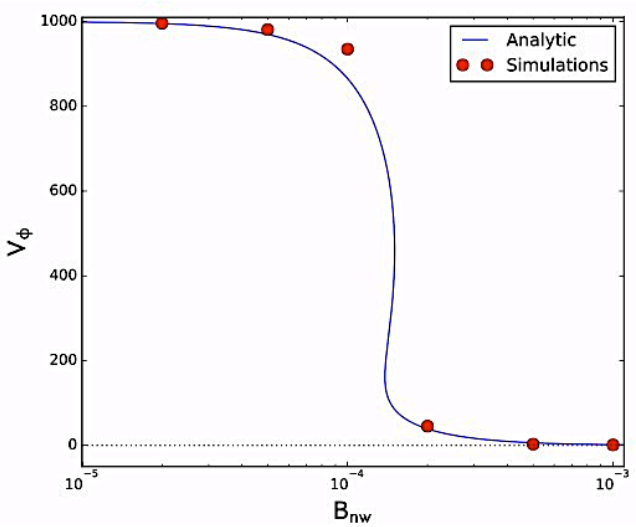
- Least-squares formulation of *n* and *T* equations improves robustness.
- While recent preconditioner improvements help, solving the **B**-advance with strongly 3D η is still challenging.

➢ Blocks of unstructured elements would facilitate realistic boundary shaping.

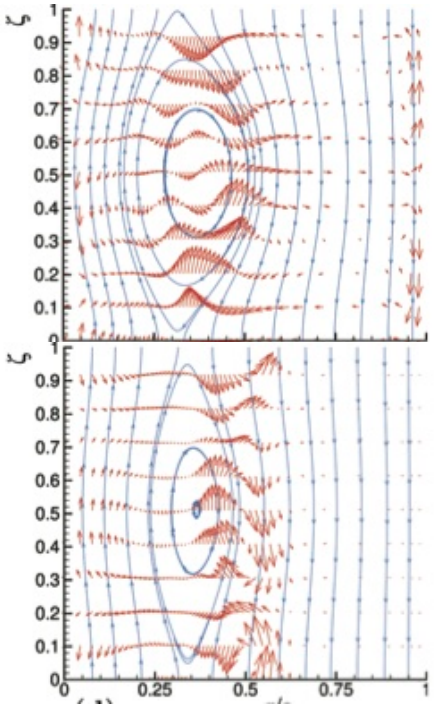
➢ Incorporating sheath physics is needed for boundaries.

Matt Beidler's recent test of locking is our latest work on magnetic islands.

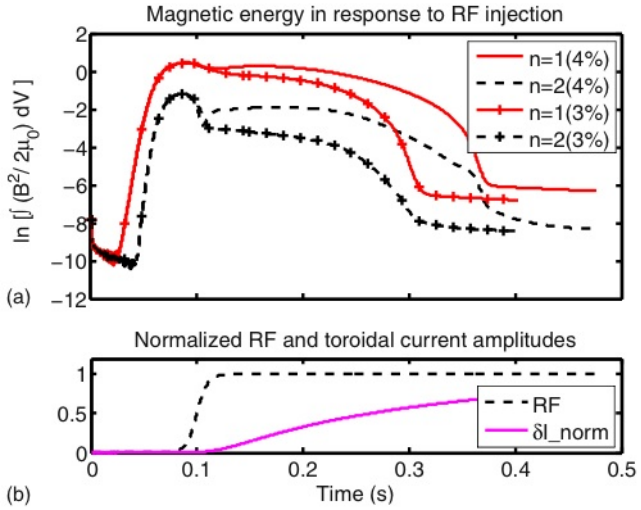
- Previous work includes two-fluid effects on island saturation in pinch profiles and modeling RF suppression.



Beidler has reproduced bifurcation of states from flows.



Islands and ion flows without and with warm-ion effects. [King, PoP 18].



Magnetic fluctuation energies show island response to simulated RFCD. [Jenkins, PoP 17].

Magnetic islands - status

- Cylindrical forced-reconnection benchmarking with M3D-C1 is in progress.

➢ Held's drift kinetic modeling will enable detailed NTM studies.

➢ A relatively simple fluid version of $\Pi_{||e}$ may provide a useful approximation.

Two approaches to kinetic parallel heat transport are in development.

- Eric Held solves drift-kinetic equations to provide closure information (including **q**) for NIMROD's low-order moment equations. [Held, *et al.*, PoP **22**, 032511]
- Jeong-Young Ji is developing integral closures with fitted kernel functions. [Ji, *et al.*, PoP **23**, 032124]

- ➢ Apply to nonlinear island evolution.
- ➢ Apply to disruption thermal quench problem.

Neutral and radiation effects are important for mitigation and for disruption more generally.

- Val Izzo has used a tight-coupling approximation in simulating MGI effects. [for example, YI2.00002, Friday morning]
  - KPRAD is used to compute radiative losses.
- Sina Taheri of the Plasma Science and Innovation Center is implementing a coupled neutral fluid model [Meier & Shumlak, PoP **19**].
  - Model includes ionization, recombination, and charge exchange.

Neutrals and radiation - status

- Izzo's tight-coupling model with radiation from multiple charge states has been fully functioning.
- Taheri's implementation has neutral continuity, momentum, and energy equations with coupling to plasma moment equations.

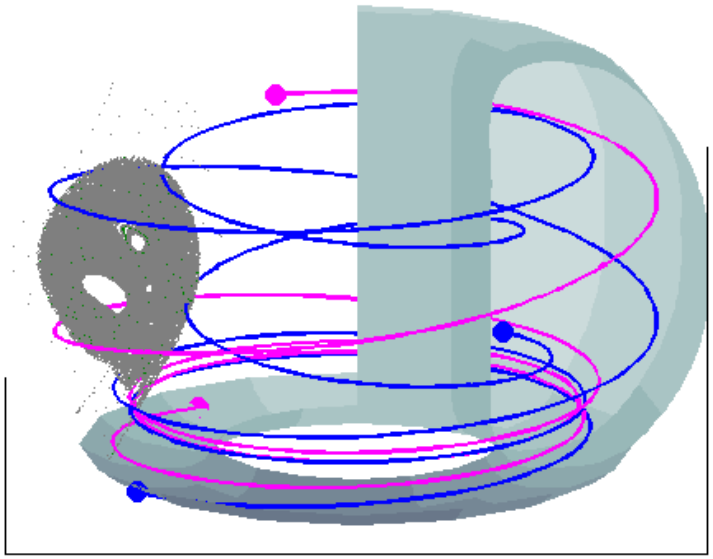
- ➢ 0-D testing of energy and momentum exchange is in progress [TP10.00096].
- ➢ Consideration of numerical stability with the coupled plasma/dynamic neutral model is needed for NIMROD's implicit leapfrog algorithm.

Runaway electron generation and deposition is another important topic.

- Val Izzo has used a drift-kinetic model for tracing RE trajectories during NIMROD-simulated disruption dynamics.

➢ Modeling RE current in nonlinear macroscopic simulations is being developed.

Example RE orbits calculated during NIMROD run; typically thousands per simulation



When magnetic fields become stochastic, REs escape, striking outer divertor

External electromagnetics influence external kink and locking.

- NIMROD assumes a symmetric boundary.

- The most straightforward approximate implementation of external 3D structures is a toroidal Fourier expansion of wall and external-region resistivity.
- More detailed modeling will need coupling to an electromagnetics code.
  - Our experience with coupling GRIN is that there can be significant changes in convergence properties.

Plasma-surface effects includes sheath and neutral physics.

- Sheaths influence open current -- also energy and particle transport.
  - ➢ The spatial scales are too small for macroscopic simulation, so effects need to be represented by boundary conditions.

- The dynamic neutral model will be useful for edge modeling.
  - ➢ Neutral generation from plasma-surface interaction will be needed.