Progress on Simulation Efforts

Nick Roberds
Auburn University

Outline

1. Sawtooth Simulation Progress
2. Disruption Simulation Progress
3. Convergence Study for Equilibrium with a 3D Perturbation

Sawtooth Simulations

- Many self-consistent resistive MHD sawtooth simulations performed in the 80s
  - Found to be very sensitive to choice of diffusion coefficients/transport model (Vlad,Bondeson 89')
- Possible direction for further work:
  - Obtain scaling information vs. increasing amount of perturbing helical stellarator field

Sawtooth Simulation 1

mx/my/poly_degree = 30/20/5

lphi = 4

eta_model = 'eta full'

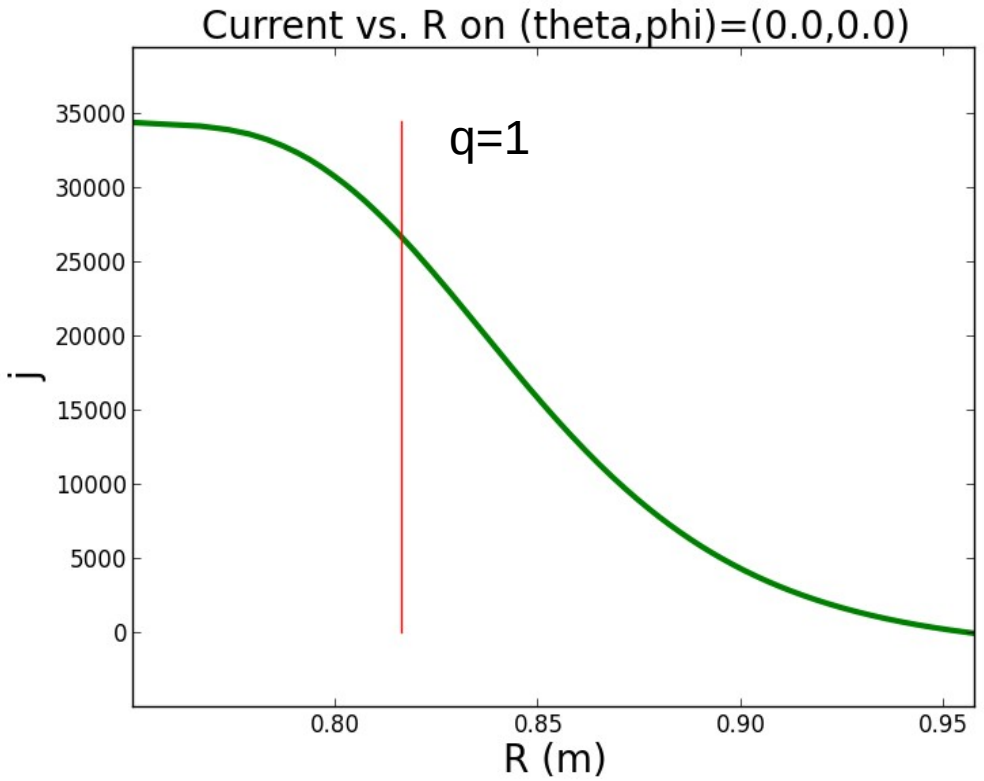
p_model = 'aniso1'

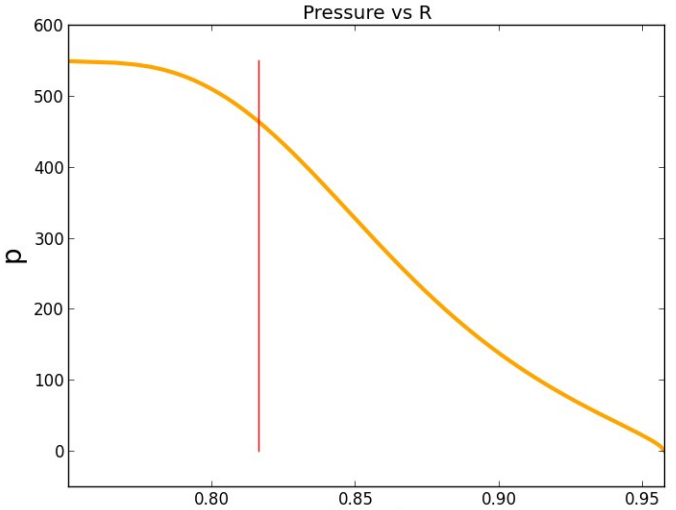
k_perp = 1

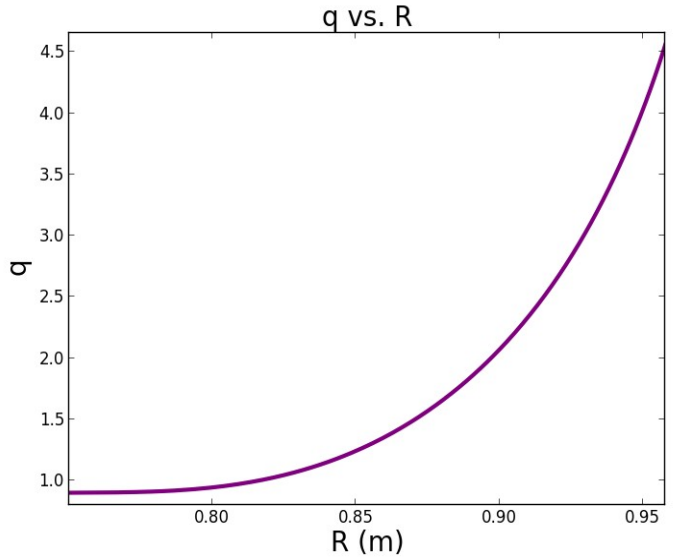
k_pll = 1E7

loop_volt = 5

Sawtooth Simulation 1 Initial Profiles







Sawtooth Simulation

- Workflow for loading initial data (for all results in this presentation)
  - Identify a cylindrical, low-beta, large aspect ratio equilibrium using Mathematica script
  - Use output from script in VMEC and V3FIT to generate the corresponding toroidal, finite beta equilibrium
  - Load VMEC output into NIMROD

Sawtooth Simulation 1

Movies

Numerical Parameters Needed for Simulation

nl_cfl_lim = 20

- To decrease time step size so that accuracy and numerical stability is obtained during periods of rapid MHD activity

si_fac_nl = 2 or 2.5

- With lower values, perpendicular “sound” (?) waves sometimes appear (at first for high n) and cause simulation to crash

n_dt_release = 100

- To prevent repeatedly “slamming” into cfl limit which can cause the simulation to crash

Sawtooth Simulation 2

k_perp = 0.1

loop_volt = 2

Sawtooth Simulation 2

Movies

Disruption Simulations

- In the 80s, simulations of disruptions were undertaken
  - Initial profiles are steep inside the q=2 surface to encourage non-linear interaction between tearing modes
- Phases of activity in these sorts of simulations

  1) Linear growth of 2/1 and 3/2 tearing modes
  2) Non-linear growth 2/1 and 3/2 islands
  3) 2/1 and 3/2 islands overlap, causing rapid growth
  4) Tearing modes with rational surfaces closer to magnetic axis are then successively destablized.
     - Sometimes described as a inward propagating front that leaves behind stochastic fields.

Disruption Simulations

- Carreras, et. al. (1980) used following parameterization for q in these studies:

$$q(r) = q(o)\left\{1 + r^{2\lambda}\left[\left(\frac{q_\ell}{q(o)}\right)^{\lambda} - 1\right]\right\}^{1/\lambda}$$

Disruption Run 1

S = 2E5

k_pll = 1E6

k_perp = 0.1

Disruption Run 1

Movies

Convergence Study for 3D Equilibrium

- **Explicit** methods
  - Time steps limited to a value related to the speed of the waves of system
  - Little computation work required at each time step
  - **Lots of computational work required for a long-time integration**

- **Implicit** methods
  - Any size time step can be taken
  - Lots of computation work required at each time step
    - Large matrix inversion at each time step
  - **Lots of computational work required for a long-time integration**

- NIMROD uses a **semi-implicit** method
  - Stabilizing “error term” is added to discretized equations for the explicit scheme
    - Is still consistent with original equations
    - Form of “error term” chosen to make the method numerically stable for large time steps
    - Technically makes the method implicit
      - Matrix inversion at each time step is easy with appropriate choice of “error term”
  - Little computation work needed for each time step
  - **Less computational work required for a long-time integration**

Convergence Study for 3D Equilibrium

- Choice of semi-implicit “error term” (or “operator”) affects accuracy when taking large time steps

- Sub-optimal choice can result in
  - Exaggerated artificial slowing of growth rates/frequencies
  - Exaggerated artificial mode coupling

From Schnack, Barnes, et. al.1987

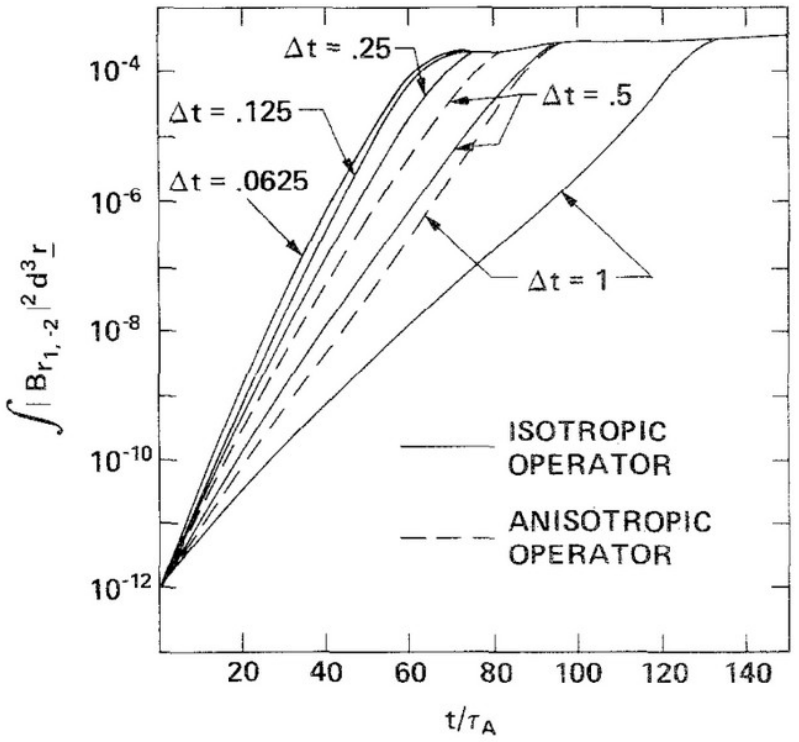
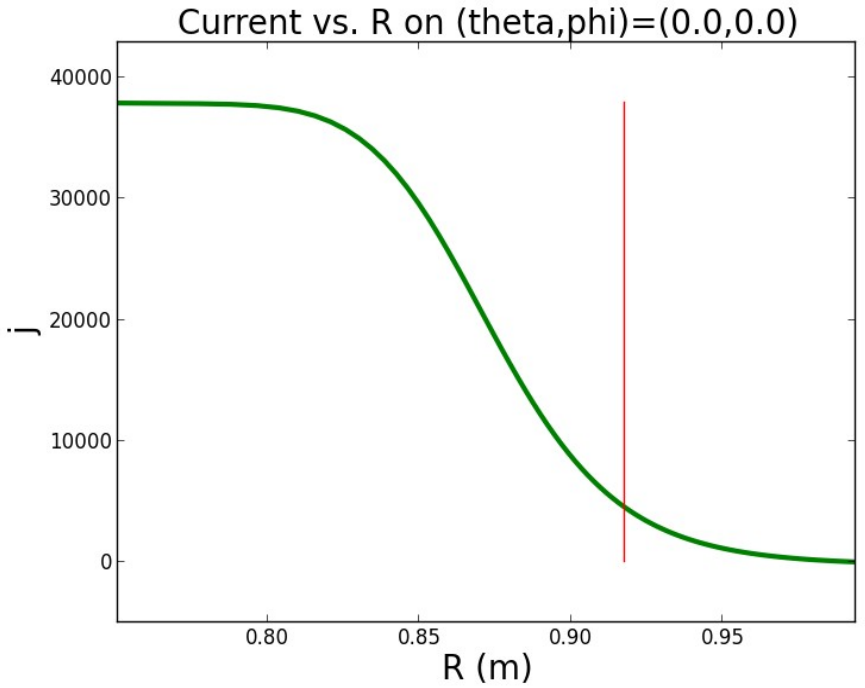
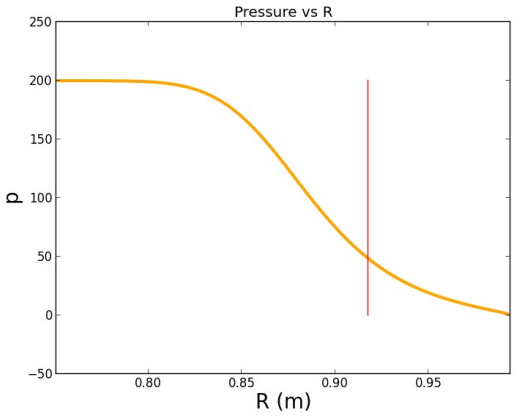


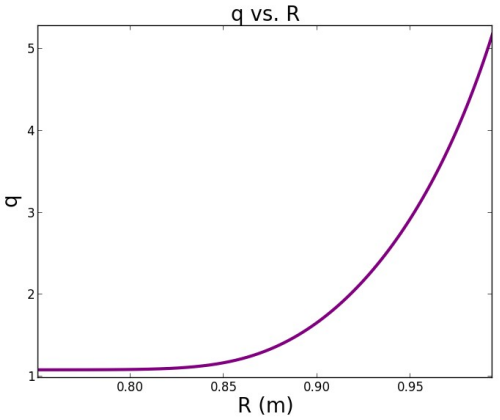
FIG. 4. Radial magnetic energy versus time for the unstable $m = 1$, $n = -2$ tearing mode for various time-steps using both the isotropic (solid lines) and anisotropic (dashed lines) forms of the semi-implicit operator.

Convergence Study for 3D Equilibrium

Initial Profile (of axisymmetric case):







Convergence Study for 3D Equilibrium

Run Parameters:

S = 2.8E4
Pr = 1

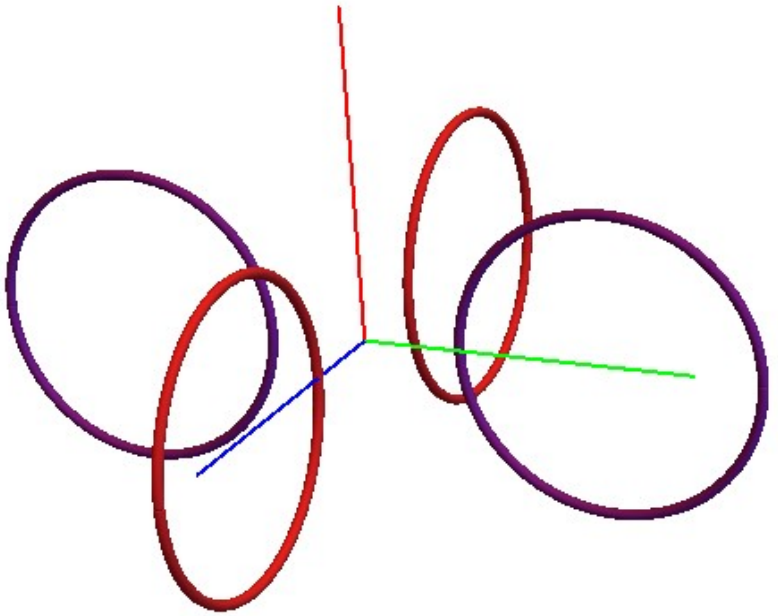
mx/my/poly_degree = 60/40/4
lphi = 4
eta_model = 'fixed'
geom/R/a = 'tor'/0.75/0.295

Coils Giving n=2 Perturbation to Equilibrium

Positive Current

Negative Current

n=2 perturbation suggested by Carl Sovinec



Growth Rates