Developments in M3D

Linda Sugiyama
MIT

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Topics

- Plasma edge simulation (especially non-ELMing)
  - Finite plasma at magnetic separatrix (n, J_ϕ, v_ϕ)
  - Plasma in unconfined field region
  - Edge dissipation: μ/ρ
- Plasma separatrix as simulation boundary (with X-pts)
- Non-axisymmetric magnetic field data – error and error-correction fields (DIII-D)
- Higher order connections in finite elements – full ghost vertices in MPP M3D
- Interior 1/1 mode – sawtooth/snake with X-point bdy
- Visualization improvements

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- Non-axisymmetric magnetic field data – error and error-correction (DIII-D)
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Plasma near nominal edge

- Expanding range of discharges available for edge instability simulation
  - Some consistently have signficant plasma parameters at the plasma separatrix, eg Alcator C-Mod EDA H-modes.
  - Finite values of n_e, J_ϕ, v_ϕ on the magnetic separatrix, significant plasma n, T, v_ϕ and maybe J_ϕ outside on outboard side
- Infinite radial gradients across separatrix, if vacuum outside
- No good models, poor experimental data
- Trying various approaches

Ion viscosity and density variation

- Perpendicular viscosity μ typically taken to be uniform, but edge plasma density is less than central and the in the outer region smaller yet.
  - Does μ/ρ make a difference?
- For fixed boundary or small perturbations, a toroidally-averaged density works well
- Strong edge instabilities with ballooning – numerically unstable since density varies from 'vacuum' value to the top-of-pedestal values
- Looking for good nonlinear solution....

Plasma separatrix as simulation boundary

- Magnetic separatrix, with X-points, used as simulation boundary
  - Test free boundary effects
  - Linear growth rates
    - Careful! Extra dissipation very near boundary to damp spurious oscillations. May need to set boundary δr outside separatrix.
    - Test ideal MHD, $\eta=0$
  - Smaller simulation for interior modes. Shaping effects are important for driving poloidal rotation, etc.

Separatrix as simulation boundary

- Preliminary results for edge instabilities (C-Mod QCM, but looks like it should also apply to ELMs and other instabilities)
  - Nonlinear mode is much more unstable than free boundary mode; doesn't saturate easily.
    - Mode held away from exact edge by dissipation, affects top of pedestal and inner half most strongly.
  - Stabilized by toroidal rotation at experimental level (finite at separatrix). Is it the shear or just the rotation?
    - Consistent with linear results for DIII-D ballooning mode with free boundary

1/1 mode with X-point fixed boundary

- Sawtooth with nonmonotonic, non-axisymmetric density in C-Mod-shape plasma (profiles not realistic)
  - Large $q<1$ central region, $q_o=0.5$; relatively flat central density
  - Apply non-axisymmetric density perturbation to model heavy impurity ion concentration, $\delta n/n=0.1*0.5(1+\cos(\phi-\theta))$. No other heavy-ion inertial effects.
- Triggers MHD sawtooth (onset time relatively insensitive to resistivity over $\eta=10^{-6}$-10^{-8}, compared to $\delta n=0$ sawtooth)
- Slow kink displacement, followed by very fast crash
  - Concentric circular core reforms in the field, J_ϕ, T, but density remains non-axisymmetric, roughly 1/1, around q=1
  - Later poloidal rotation of core (ω_{*e}-direction)
  - Is this density a steady state over longer time scales?
- New SXR snake study: L. Delgado, poster Thursday afternoon

Non-axisymmetric fields

- Dmitri Orlov (USCD/GA): DIII-D now can provide all the known non-axisymmetric fields in the experiment in A_ϕ, B_ϕ form for M3D (vacuum fields on poloidal planes)
  - I-coil (eg, RMP n=3 field)
  - C-coil, Bus-work, F-coil (error field)
- New, more accurate algorithm for A_ϕ from the external coils (I, C)
- M3D analysis finds strong toroidal Fourier aliasing effect in B_ϕ from I-coil (nearly a δ-function near the coils); need many harmonics if want lower harmonics n≤9 accurately
- Starting to look at the lower n=1,2 fields

Higher order operators in M3D

- Full 'ghost' vertices now implemented for M3D poloidal domains on each CPU
  - *All* adjacent vertices to the base ones in the poloidal domain are now available on a given CPU.
    - PETSc matrix solutions only need some of them
- Allows very efficient use of higher order for 'upwind advection' type flux limiters to reduce oscillations that include effects on the adjacent finite elements
  - Working, fast
  - Need a better flux limiter condition to reduce oscillations for difficult cases (especially vorticity)
    - Various possibilities exist in the literature
    - Hank Strauss uses one for disruption simulations

Visualization – new tools

- New diagnostics in VisIt
  - Wall load and wall fluxes $v \cdot \nabla f$, already reported at Sherwood (H. Krishnan, H. Childs)
- Fan array sampling along chords ('Line Sampler') newly developed by A. Sanderson
  - Synthetic diagnostic for comparing to 2D experimental arrays
    - Sample a specified function or quantity along chords; integrated or actual value; simple or 'real' sampling
    - Multiple arrays with specified orientations
    - Time plots of results
- Both will be in VisIt 2.4 later this month at NERSC

Summary

- Several improvements, changes being made for plasma edge simulations
  - Some need more information/ideas to implement
- Plasma magnetic separatrix with X-point as simulation fixed boundary
- Higher order operators in M3D using full poloidal ghosts
- 1/1 sawtooth and 'snake' with X-point fixed boundary
- New diagnostics in VisIt
  - Wall load and wall fluxes
  - Fan array sampling along chords