DISCUSSION OF MHD RESEARCH STRATEGY FOR NEXT 10 YEARS

Fluid Closures Workshop, ORNL, Oak Ridge, TN, 22-24 March 2006

Topics To Discuss:

- **Do we really need an MHD model? Do everything with gyrokinetics?**
- **What type of extended MHD model should be developed?**
- **Roles of full, reduced and ordered extended MHD models?**
- **How to self-consistently include RF and NBI sources?**
- **Inclusion of micro-turbulence and multi-scale effects?**
- **Another Fluid Closures Workshop in the future? — topics, when, where**

Is MHD-Type Model Really Needed? All gyrokinetics?

- **Can global gyrokinetics do it all?**

  Present issues for gyrokinetics simulating MHD phenomena in realistic geometries:

  Comp. Alfvén waves, resolution/noise, long times, separatrix topologies, $q\tilde{\phi}/T << 1$;

  Time scales for Fast MHD simulations $\gtrsim$ 10 years, Slow MHD simulations $>$ 10 yrs?

  For next 10 years answer seems likely to be no.

- **Likely scenarios for gyrokinetic, MHD developments over next 10 years?**

  Mostly independent development efforts,

  But Fast MHD benchmark comparisons for realistic geometries possible in 10 years?

  Also, projective integration of gyrokinetics could provide transport fluxes for inclusion in extended MHD simulations — in 10 years?

- **Time Frames (years)**

  1: Some gyrokinetic, extended MHD test problems? — kink, interchange in slab;

  3: a) Gyrokinetic, extended MHD tests in tokamak geometry — kink, ballooning,
  b) Some projective integration tests for simple problems — drift turb. + tearing;

  10: a) Fast MHD benchmarks between extended MHD and global gyrokinetics,
  b) Should we have GUTS (Grand Unified Toroidal Simulation) via projective integration of gyrokinetics for transport fluxes to be used in extended MHD?

What Type Of Extended MHD Model Should Be Developed?

- **What needs to be included in an extended MHD model?**

  All MHD effects plus relevant kinetic effects for all macroscopic phenomenologies,
  Realistic geometry with divertor separatrix, bounding walls, and
  Sources (RF and NBI) and sinks (edge neutrals, radiation).
  Unresolved issue: what should be done on open field line regions outside separatrix?

- **What fluid quantities should be dependent variables advanced in time?**

  Fast MHD: n, $\vec{V}$, p, $p_\parallel$?, or n, $\vec{V}$, $p_\parallel$, $p_\perp$?; plus closure moments from components of $\mathbf{Q}$.
  Slow MHD: n, $\vec{V}$, p?; plus closure moments for $q_\parallel$, $\pi_\parallel \equiv p_\parallel - p_\perp$.

- **How should anisotropic components of closures be determined?**

  Parallel — from parallel drift-kinetic equation: analytic, numerical continuum or PIC?,
  shouldn't induce δn, $\delta\vec{V}$, δT— use Chapman-Enskog-like or other procedure,
  Cross, perpendicular — from perpendicular fluid moments.

- **Time Frames (years)**

  1: a) General extended MHD model framework developed in terms of MHD variables,
  b) Cross and perpendicular closure moments determined;
  3: a) Relevant DKE and procedures developed for determining parallel closure relations,
  b) Procedures developed for effects of RF and NBI sources on closures;
  10: Full closures with source effects determined, implemented, tested and used.

Roles Of Full, Reduced & Ordered Extended MHD Models?

- **A full extended MHD model is probably needed for**

  A framework for what we might be working toward,

  As a reference for developing criteria for validity of approximations, and

  For deciding where to truncate moment hierarchy and do kinetics beyond.

- **Reduced MHD description (eliminate compressional Alfvén waves):**

  For what problems would this not be sufficient? — 1/1 & 3D $\delta\vec{B}$, near separatrix/islands?

  But it is a more efficient model when it is applicable.

- **Drift and other orderings?**

  We mostly want "maximal ordering" except $\epsilon_\perp \sim \varrho/L_\perp << 1$ and $\omega/\omega_c \sim \nu/\omega_c << 1$.

  But also develop other approximations that lead to useful models for particular problems — and identify test problems for which such approximate models would be useful.

- **Time Frames (years)**

  1: Identify some key test problems that would benefit from approximate models.

  3: Develop overall extended MHD model; Do test problems with approximate models.

  10: Use full extended MHD model in initial value simulations.

How To Self-consistently Include RF and NBI Sources?

- **Why do they need to be included?**

  Because they provide important current, momentum, and heat inputs to plasmas.

- **What issues arise in trying to include them?**

  These sources can introduce significantly non-Maxwellian ion or electron distributions.

  Fast MHD: mainly via equil. changes in current profile, anisotropic pressure component?

  Slow MHD: main effects on transport time scale, so "static" source inputs just added?

  But, some specific situations may be problematical:

  Fast MHD: resonant fast ion effects on 1/1 modes $\Longrightarrow$ fishbones, sawtooth crashes;

  Slow MHD: modulated, helically-resonant ECCD for NTM stabilization.

- **What kind of development is needed for the long term?**

  Some form of Chapman-Enskog-type drift-kinetic equation with Fokker-Planck Coulomb collision operator, RF heating operator, and NBI fast ion source – with diffusion, $\vec{E}$, ...

  Can solution methods be developed for solving this 5D phase space problem efficiently?

  After solving 5D F-P equation for f, include only moments of it in extended MHD?

- **Time Frames (years)**

  1: Figure out how to include source effects; couple "static" RF effects with MHD.

  3: Develop procedures for including source effects self-consistently; benchmark tests.

  10: Include source effects in extended MHD simulations – Fast MHD, Slow MHD.

Inclusion of Micro-turbulence and Multi-scale Effects?

- **Why does micro-turbulence need to be included?**

  Simulation codes need diffusion coefficients, dissipation in all fluid moment equations.

  Most toroidal plasmas have micro-turbulence at high $\vec{k}$, which causes locally diffusive-type transport and (via inverse cascade) added free energy, excitation of MHD modes.

  At high plasma temperatures linear layer widths are likely to be determined by anomalous-transport-induced diffusion.

- **What problems arise in trying to include micro-turbulence in MHD model?**

  Need criteria for when low/high $\vec{k}$ separation, or projective integration, is feasible.

  General methodology needs to be developed — for $\vec{k}$ separation, projective integration.

- **What kind of development is needed?**

  Need to agree on some simple test problems – micro-turbulence + tearing mode?

  Within MHD framework, do separation between high n resistive-g and tearing mode.

  Systematic multi-scale development for including micro-turbulence effects in MHD — in density, momentum (Reynolds stress), energy fluid moment equations.

- **Time Frames (years)**

  1: Decide what is feasible and what really needs to be done in this area.

  3: Test problems — resistive-g + tearing?, drift turbulence + tearing modes?

  10: Include all relevant micro effects in extended MHD sim. — Fast MHD, Slow MHD.