Callen: NTM Physics Discussion (Nov 14, 2000)

- Key NTM physics issues involve poloidal flow damping:

  Electrons: bootstrap current ($\omega < \nu_e$)
  Ions: poloidal ion flow damping ($\partial/\partial t < \nu_i$)
  Neo-enhanced polarization flow
  (from $\nabla\bullet J \sim \nabla\bullet[B\times\nabla\bullet\Pi\_parallel/B^2]$)
  Longer-term … kinetic-based closures
  ($\partial/\partial t > \nu_i$, $k_{parallel}\, v_T > \omega$)

- Related Physics Issues (Mainly 2-fluid effects)
  - Equilibration of plasma properties along $B_0 + B_1$
    Temperature $\chi_{parallel} >> \chi_{perp}$, diffusive to "free-streaming"
    Pressure, density (sound waves) evolution
  - Diamagnetic flow, frequency (ω^*) effects:
    ? need Landau-type closure to limit mode interactions to
    $\Delta x < (L_s/r_p)\rho_i \sim 10\rho_i$
    need gyroviscosity to obtain correct nonlinear behavior

Possible physics tests of NTM simulations:

Level 0
- Demonstrate NTM Nonlinear (Rutherford regime) growth and saturation…compare with 0D dW/dt equation

Level 1
- Explore NTM Physics Effects:
  - Seed island threshold…due to Chi_parallel, classical and neoclassical ion polarization effects
  - Flow effects…diamagnetic flows, toroidal flow, island rotation
  - Stabilization by localized current (ECCD), heating (ECH)
  - Error field, helical perturbation effects ?

Level 2
- Explore NTM Nonlinear Physics:
  - NTM excitation via mode coupling … sawtooth crash, ELMs, …(need flow differences on different rational surfaces)
  - Why does only one NTM mode occur at a time?
  - Why does 2/1 NTM mode in DIII-D evolve to a disruption?
  - NTM interactions with resistive wall modes (RWMs)

- What happens when NTM islands get large ?
  …toroidal mode coupling, island hits "limiter"?

Hegna Issues for NTM modeling (Presented at Oct APS)

Physics Elements:

- Neoclassical flow damping – damping of flows within magnetic surfaces (bootstrap current/poloidal ion flow damping)
  Current implementation of the flow damping forms encapsulates this physics – produces bootstrap current drive for NTM's – damping of flows along perturbed surfaces. Analytic forms used are based on long-timescale asymptotics ($t >> 1/\nu_c$) and quasi-equilibrium structure of helically distorted magnetic surfaces -> time and space issues for theorists to ponder.

- Anisotropic heat and particle flux-transport along field lines >> transport across field lines.
  Local diffusion coefficients with disparate scales present in NIMROD. Wave-like physics to equilibrate along field lines in M3D – mocks up free streaming physics – long mean free part regime equilibration along B is nonlocal (Held'99) – implementation ?

- Ion polarization threshold requires 2-fluid drift effects (ω^*) – differential flow between ion and electron fluids.
  In two-fluid formulation, what is the natural frequency of a nonlinear island? Depends parametrically on viscosity ? ion flow damping ? neoclassical elements? Other dissipation processes ? Island width?

- Seed island formation requires another MHD event (sawtooth crash, ELM). Differential rotation between geometrically coupled magnetic surfaces.
  Self-consistent edquilibrium with sheared flow. Accurate description of sawteeth? ELM's?

- Ultimate nonlinear evolution – isolated small island dynamics explained by Rutherford-like theory- what happens when islands gets big ? – little theoretical insight.

Disruption phenomenology ? Coupled island dynamics ? Nonlinear NTM sawtooth interaction ? NTM coupled to free boundary modes (RWM)?