M3D/NIMROD Nonlinear Benchmark

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TOPICS

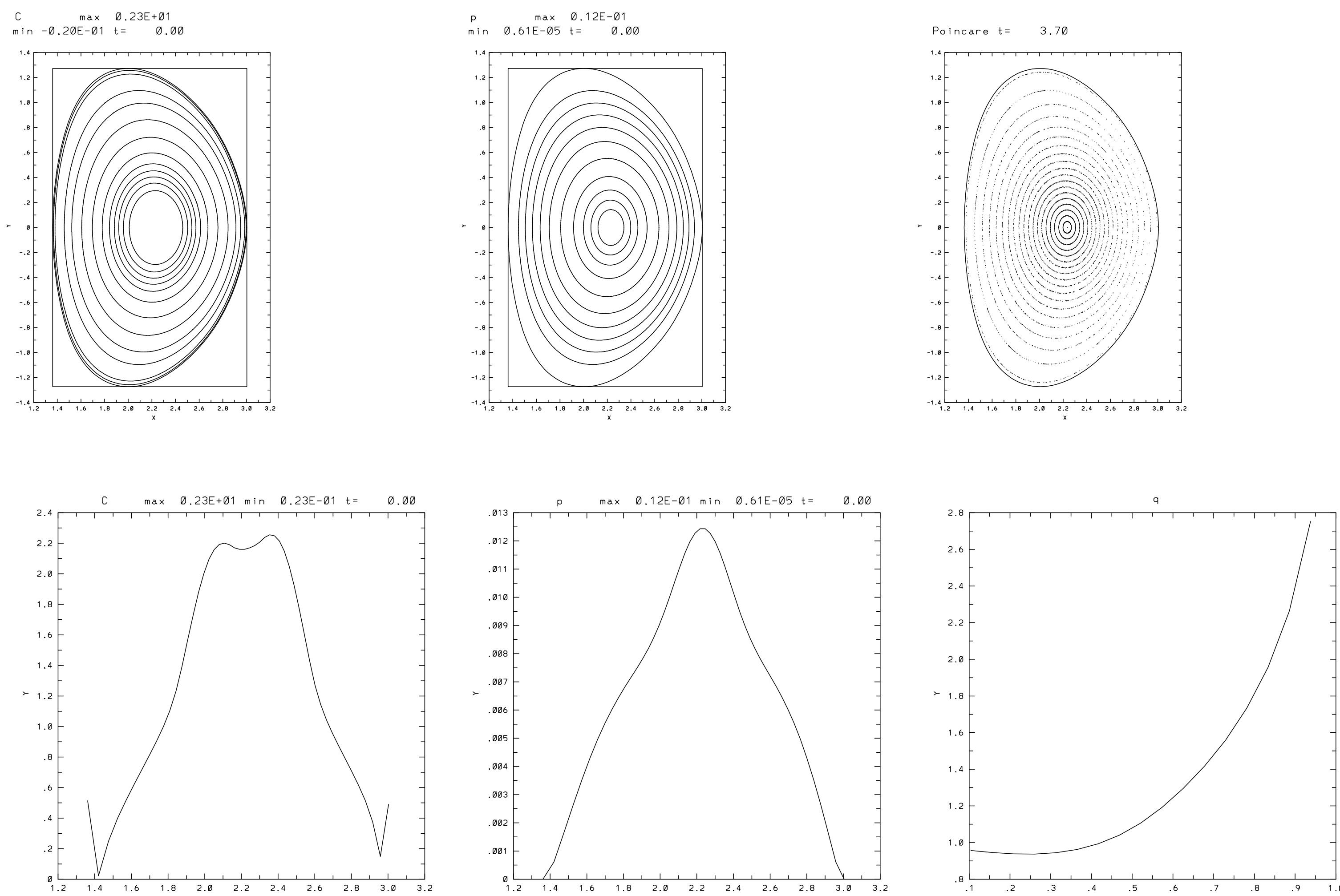
- **DIII-D discharge 097741 — background**
  MHD nonlinear codes are useful in analyzing experimental data.
- **Benchmark NIMROD/M3D: resistive MHD, preliminary studies**
  - **Linear $n = 1$ mode growth rate**
  - **Nonlinear dissipative relaxation**
- **M3D two-fluid nonlinear relaxation**
- **NIMROD MHD relaxation (Carl)**

DIII-D discharge — background

- Experimental study of low beta tearing mode onset in DIII-D (M. S. Chu, R. J. La Haye, M. E. Austin et al., Phys. Plasmas 9, 4584 (2002).
  - Limited plasma.
  - Well diagnosed, analyzed. Low beta chosen to eliminate neoclassical effects.
  - Originally chosen for M3D to look at two-fluid simulation models, with Dylan Brennan.
  - Background to future NTM studies?
- Discharge was continually heated and the plasma current raised inductively until a 2/1 island appeared (grew, locked, plasma disrupted). Chu et al. found that 2/1 tearing mode onset correlated well with change of the 2/1 mode Δ' parameter from negative to positive. (Δ' from PEST3 code.)

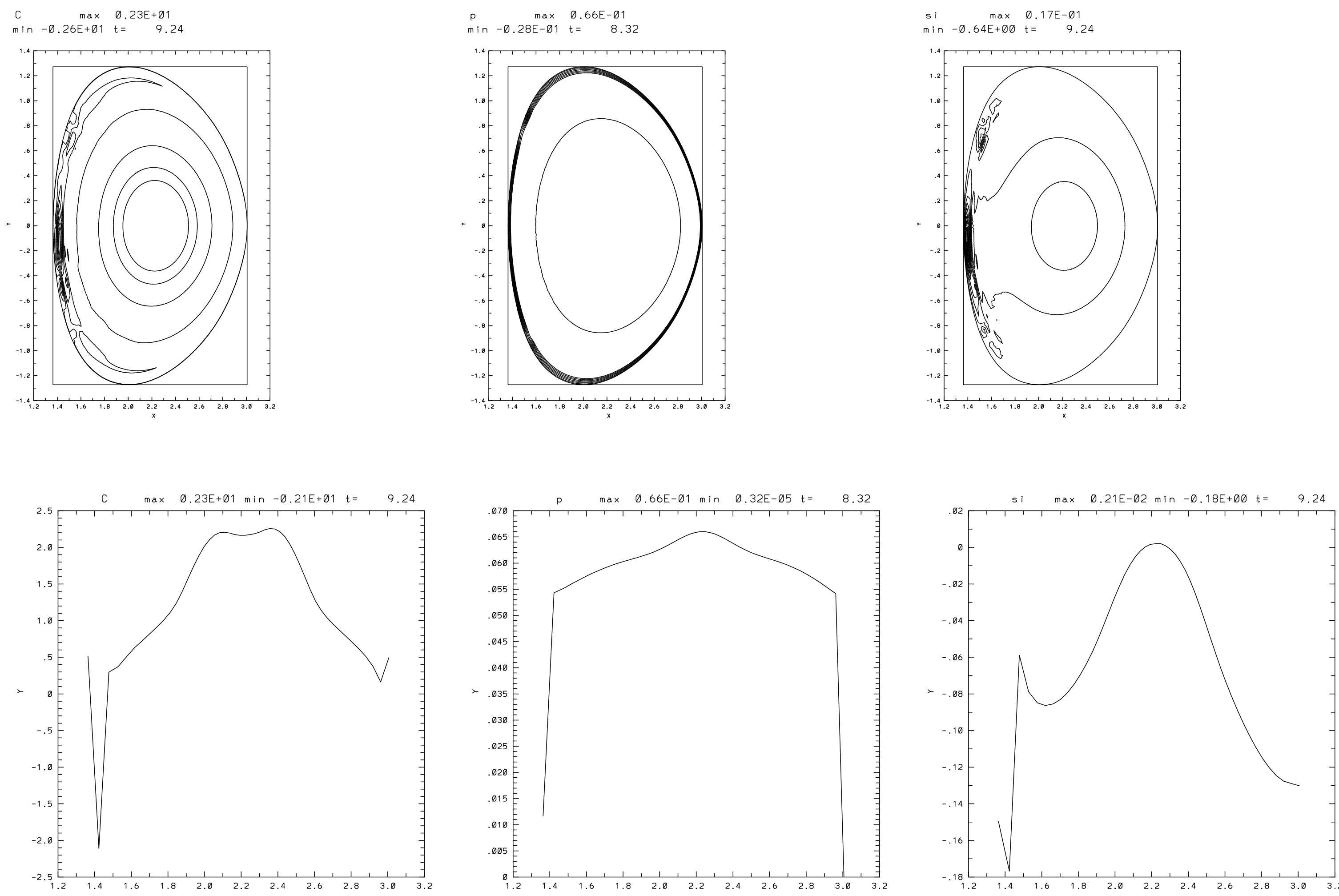
Original early time equilibrium reconstruction had increasing toroidal current density near plasma edge.

RJ_ϕ p q



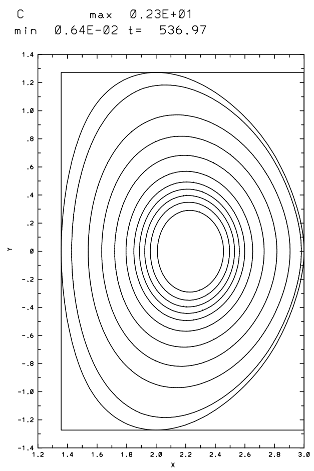
- **Nonlinear relaxation with M3D (ideal MHD and with resistivity/ion viscosity) found that the ideal MHD equilibria used by the original study were not good MHD steady states. Rapidly self-destructed.**

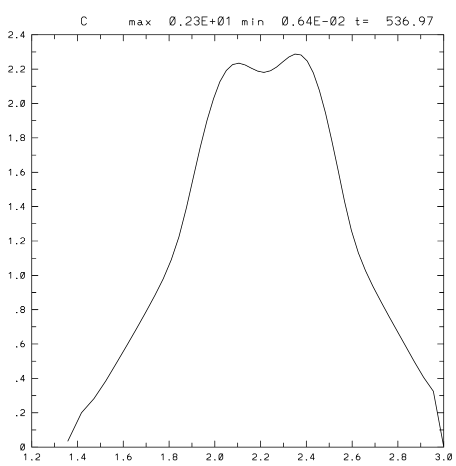
RJ_ϕ $\quad\quad$ p $\quad\quad$ $\tilde{I}$



- D. Brennan made new reconstructions, smoothing the toroidal current density near the plasma edge and making edge current near zero. New equilibria were stable under M3D relaxation.

RJ_ϕ





- But, now the 2/1 Δ' is positive before the 2/1 island appears.
- Further analysis, matching the PEST3 ideal MHD outer region solution to (one of) Glasser-Greene-Johnson (1975) resistive inner region solutions, shows that the resistive MHD growth rate is stable at early time before island appears, unstable at later time.
- Analysis is continuing on the effect of toroidal mode coupling on 2/1 island in MHD and two-fluid, including the ongoing central sawteeth.

M3D/NIMROD Benchmarks look good so far

- Results are preliminary. Studies just started.
- Easy tests first. Relatively small $S = 10^4$, Prandtl number $P_M = 1$ (ion viscosity * S).
- Good agreement on the numbers shows that the different normalizations in the two codes are understood.

  There are some differences in the code models/assumptions that we have tried to minimize.
- TEST 1: Linear resistive MHD mode with toroidal mode number $n = 1$.

  NIMROD $\gamma = 0.011\tau_A^{-1}$, M3D $\gamma = 0.0077$. (Not fully converged.)

  Mode eigenfunctions look quite similar (not shown).

TEST 2: Nonlinear MHD resistive/viscous relaxation of the ideal MHD equilibrium at $S = 10^4$.

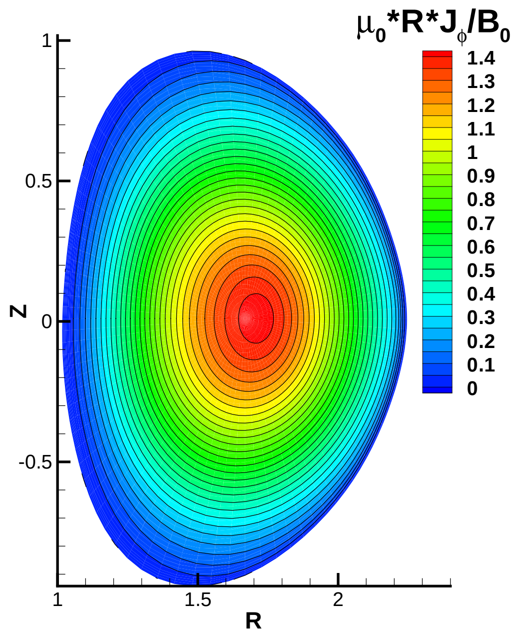
q-profile evolution

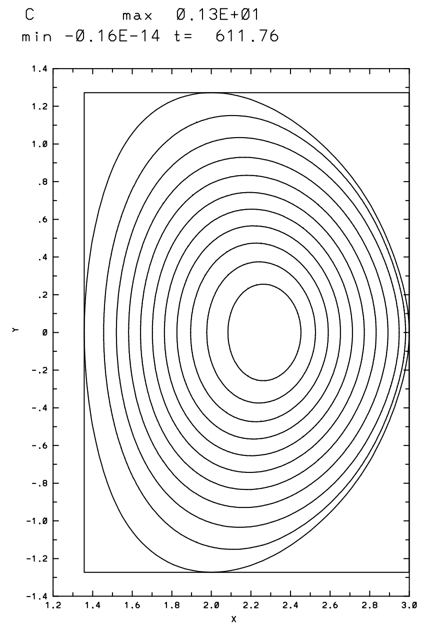
t (10^{-4} sec)	$r/a = 0.1$		$r/a = 0.9$	
	NIMROD	M3D	NIMROD	M3D
0	0.93	0.94	2.54	2.47
0.5	1.02	1.02	2.74	2.61
1.0	1.17	1.17	2.95	2.83
1.5	1.33	1.35	3.20	3.01
2.0	1.49	1.48	3.50	3.41

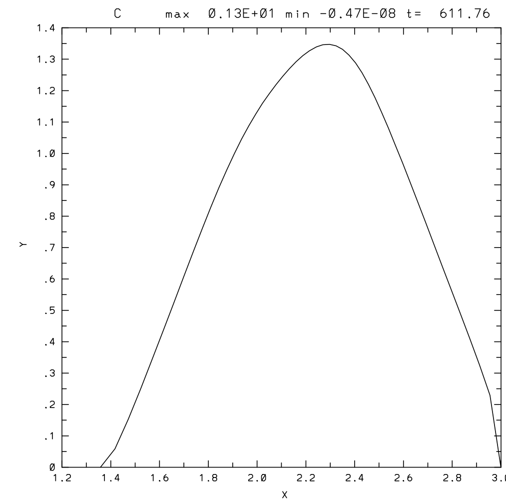
Preliminary numbers, interpolated from different times in M3D, NIMROD. ($\tau_A = 3.46 \times 10^{-7}$ sec, 2 sec $\simeq 600\tau_A$).

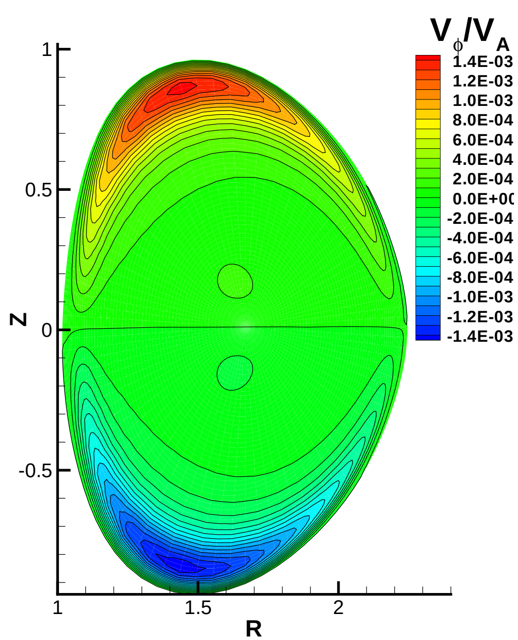
- **NIMROD and M3D use different definitions for relative minor radius. Difference is larger at large r/a, where magnetic shear $q'(r)$ is also large. To be checked.**
- **q_o rapidly rises above unity at this S. Transitory $m = 1$, $n = 1$ mode seen. Higher $m = 4, 5$ grow later.**

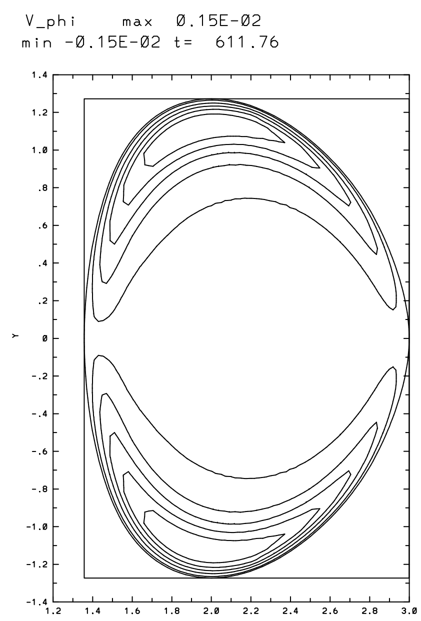
- Profiles also agree well ($t = 2 \times 10^{-4}$ sec; NIMROD on left, color).





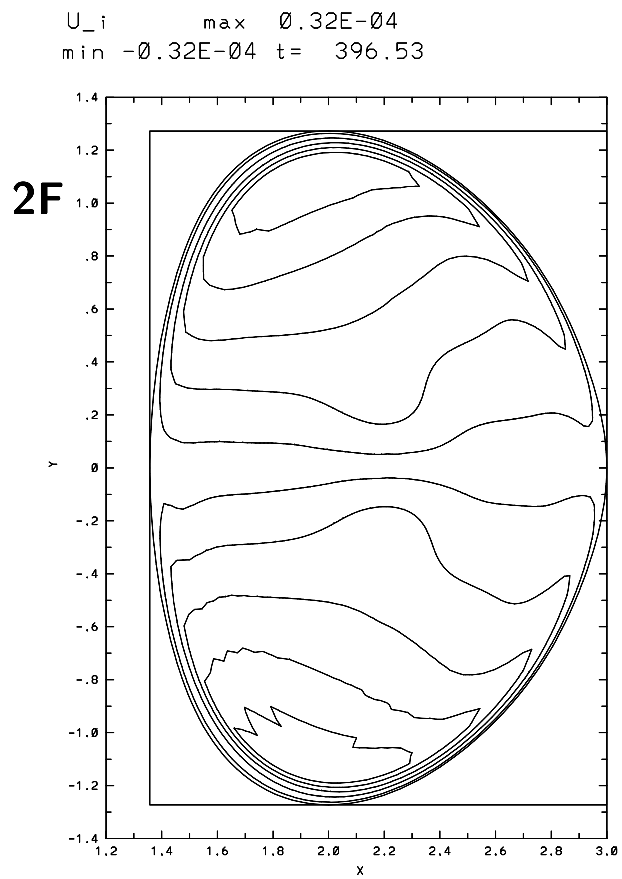


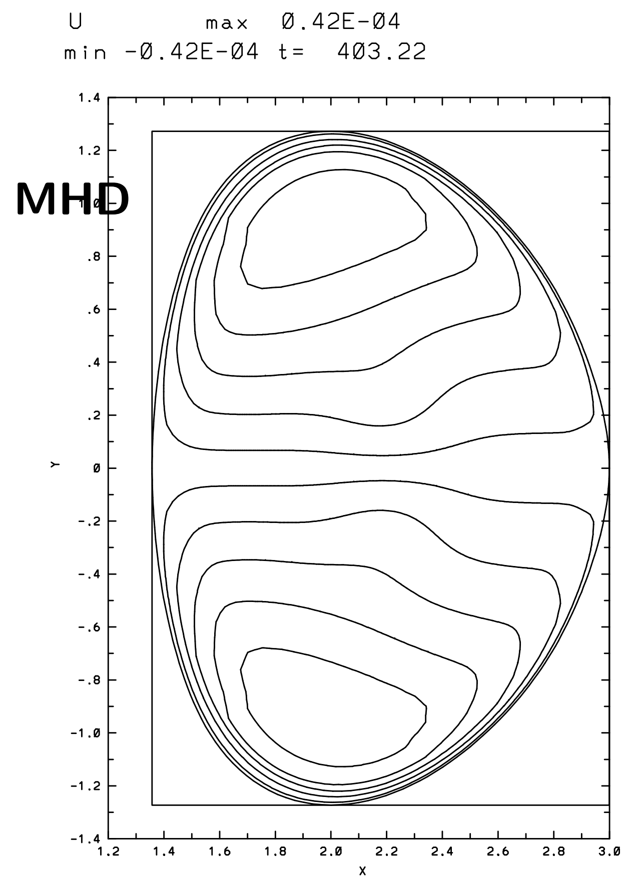




- Max $RJ_\phi \simeq 1.35$ is close.
- Max $v_\phi/v_A \simeq 1.4 \times 10^{-4}$. NIMROD slightly smaller than $v_\phi/v_A \simeq 1.4 \times 10^{-4}$ M3D; consistent with NIMROD's non-slip velocity bc with a high-viscosity bndy layer vs M3D's tangential slip bc.

- **M3D two-fluid run with small two-fluid strength $H = 1/(\Omega_{ci}\tau_A) = c/(\omega_{pi}R) = 0.002$. Actual $H \simeq 0.025$.**
- **Overall evolution is similar to MHD, but there are differences, as expected. Transitory 4/3 mode appears in two-fluid, less visible in MHD. Plasma flow patterns are different (eg, poloidal [ion] flow stream function U).**





- **Problems with computer time.**
  Haven't been able to run M3D two-fluid seriously since spring.
- **NERSC Seaborg slow since last year before APS-DPP.**
  - **Response went to practically zero at beginning of July 2004.**
  - **September and October, M3D broken by problems with compiler optimization (turning on optimization gave wrong answers!).**
    Fixed last week in Oct by NERSC ACTS/PETSc people.
    For first time, Seaborg and Cheetah M3D gave identical answers to 18 significant digits (after 10 timesteps)! (Note: Jin Chen ported PETSc 2.1.6 to Cheetah.)
    But, last week recompiling gave strange numbers again...
- **M3D situation is complicated because we checked in a major revision just before the September OS upgrade on Seaborg.**