Magnetic Reconstruction of TFTR and JET Current Profiles with TRANSP

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Until now we have used a fixed boundary equilibrium model to time evolve the magnetic geometry in the TRANSP code. For this kind of TFTR analysis, for example, the plasma boundaries are usually obtained from a simple current filament analysis of magnetic probe data, and the current profile in the code is then evolved using neoclassical resistivity. We describe here a new approach, where we use a free boundary equilibrium model to directly reconstruct the plasma current profile external magnetic data, internal MSE measurements where available, and the internally self-consistent pressure profile available in TRANSP. We apply this technique to some recent TFTR and JET discharges, and present results that illustrate the degree to which agreement with measured data has improved.

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Objectives

- To integrate the magnetic analysis with the kinetic analysis within TRANSP
- To embed the technique of magnetic reconstruction of current profiles within the equilibrium loop in TRANSP
- To achieve a kinetic analysis that is consistent with the available magnetic (external) and MSE (internal) measurements for the shot. For TFTR these include flux loop, magnetic field coil, diamagnetic flux and poloidal field coil current measurements, as well as MSE B_P/B_T pitch angle measurements.
- Replace the fixed boundary equilibrium loop in TRANSP (LEVGEO=5) with a free boundary equilibrium loop (LEVGEO=8), using either the VMEC or EFIT current profile equilibrium reconstruction codes.
- VMEC : S. P. Hirshman et. al. (ORNL/PPPL) , Phys. Plasmas 1 (2277) 1994
- EFIT : L. L. Lao et. al. (GA), Nucl. Fusion 30, 1035 (1990)

Free Boundary Approach

- Use VMEC or EFIT free boundary equilibrium reconstruction codes
  - VMEC . . .
    - requires the presence of internal MSE data
    - presently works with only up-down symmetric geometries
    - uses a inverse coordinate flux surface geometry representation that excludes x-points
    - does a direct least squares fit to the TRANSP pressure profile, augmented by a rescaling of p to optimize the position of the magnetic axis
  - EFIT . . .
    - does not require internal MSE data
    - is up-down asymmetric
    - uses a Cartesian flux surface geometry representation that includes x-points
    - does a direct least squares fit to a pressure profile, if provided
- Currently under development:

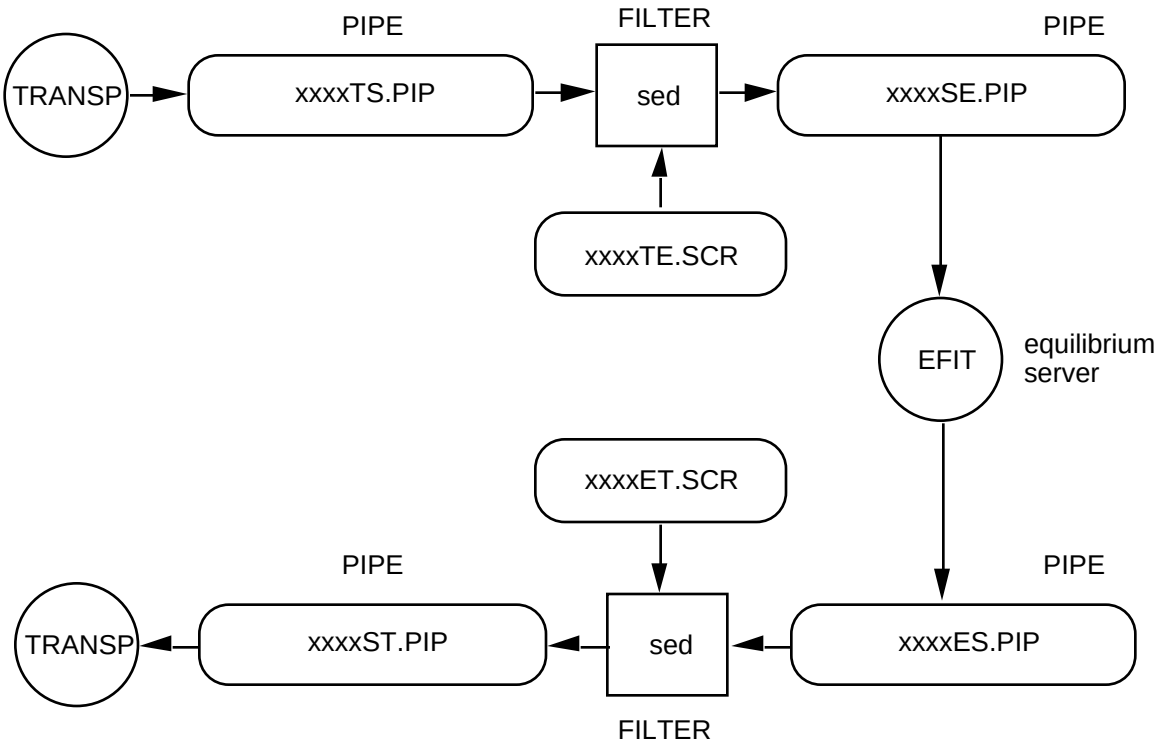
  at PPPL: TRANSP/VMEC on TFTR shots

  at JET: TRANSP/EFIT on JET shots

- Two possible modes of operation:
  - mode “0” - feed through to TRANSP complete time-dependent flux surface geometry as obtained from EFIT or VMEC
  - mode “2” - solve free-boundary equilibrium problem at each TRANSP timestep
- Use the reconstructed q profile in TRANSP. The reconstructed pressure profile can be compared to the internal pressure profile, which continues to be evolved by TRANSP.
- Run the free boundary code as a separate “equilibrium server” process, external to TRANSP. Use Unix pipes or VMS mailboxes to communicate back and forth.

The Equilibrium “server”

- use pipes to communicate between TRANSP and the Equilibrium Code
- use filters to translate variable names between the two codes
- maintenance advantages:
  - the firewall between the codes prevents name conflicts in variable names, common blocks , subroutine names, etc.
  - easier to update the equilibrium code when new versions become available



Review of Fixed-Boundary q profile options in TRANSP

* * * EXISTING OPTIONS * * *

- Predict the q profile by advancing the poloidal field diffusion equation

  NLMDIF = .TRUE.

- Evolve the q profile using B_P/B_T input data

  NLMBPB = .TRUE.

- Specify the q profile using the QPR ufile

  NLQDATA = .TRUE.

* * * WORK IN PROGRESS * * *

- Equilibrium reconstruction code returns a q profile

  NLQMHD = .TRUE.

Work in Progress ...

What has been accomplished so far:

- Several new Ufile data structures have been invented to pass in required magnetic data.
  - for Mode=0 : MMX, MPX, MQX, MTC, MPC, PLF, TRF 2- and 3-d ufiles containing the results of the stand-alone VMEC or EFIT equilibrium
  - for Mode=2 : MDF, a 3-d ufile containing all the external magnetic data needed for the curent profile reconstruction
- The TRANSP data preprocessor (TRDAT) has been modified to accomodate the new code options
- A mechanism has been developed for running EFIT and VMEC in parallel, but outside of, TRANSP. It uses Unix pipes to communicate between the equilibrium server (EFIT or VMEC) and the transport client (TRANSP)
- The TRANSP data post-processor (RPLOT) has been updated to accomodate the new data structures present as a result of this mode of operation.

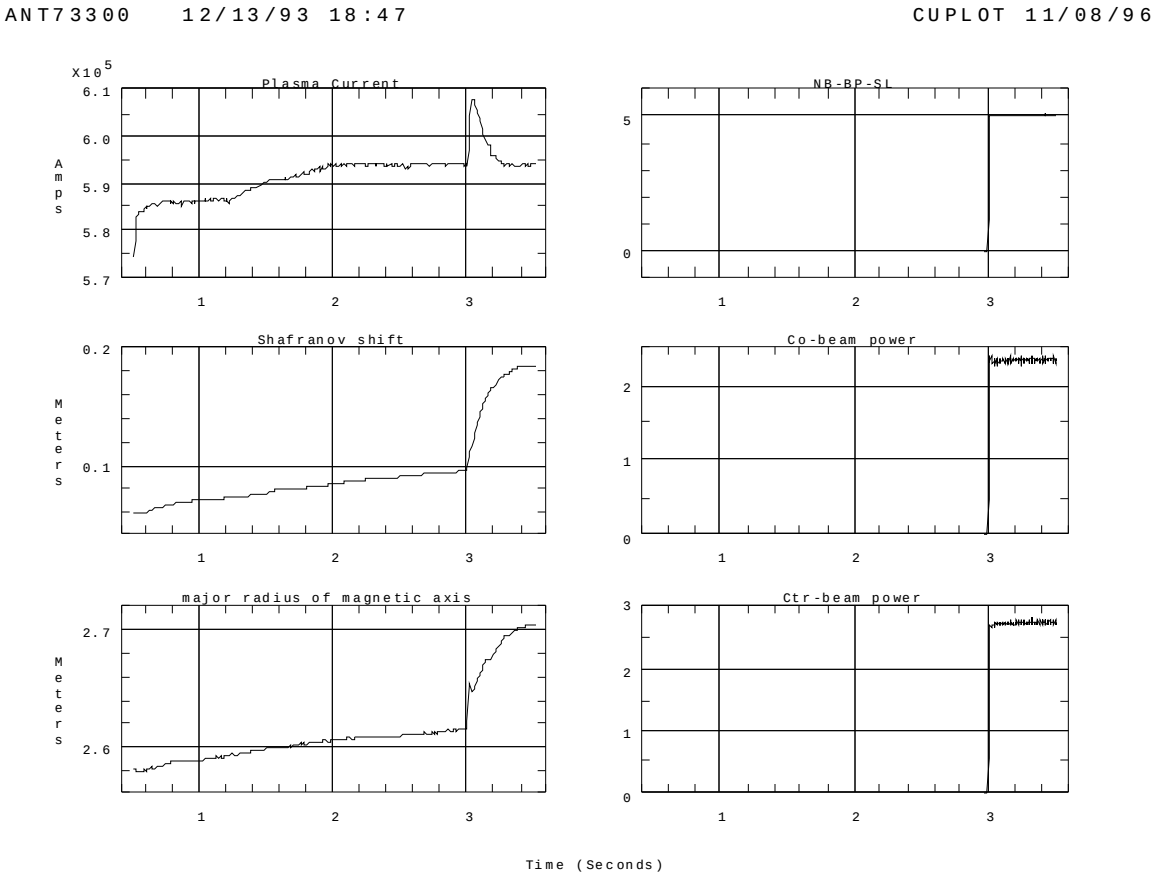
Work yet to be done ...

- Further benchmarking
- Improvement in error communication between the cooperating processes
- Development of a mechanism for transitioning between equilibrium modes (i.e., free and fixed boundary) during a run for those cases where internal data is not available continuously through the shot.
- Better mapping from EFIT cartesian solution to TRANSP moments representation
- Add EFIT option for TFTR shots

Mode “2” : Internal Free-boundary Equilibrium

TFTR / VMEC shot 73300

- 0.6 MA
- 5 MW NB
- 63 kA TF
- MSE 3.0 - 3.7 sec

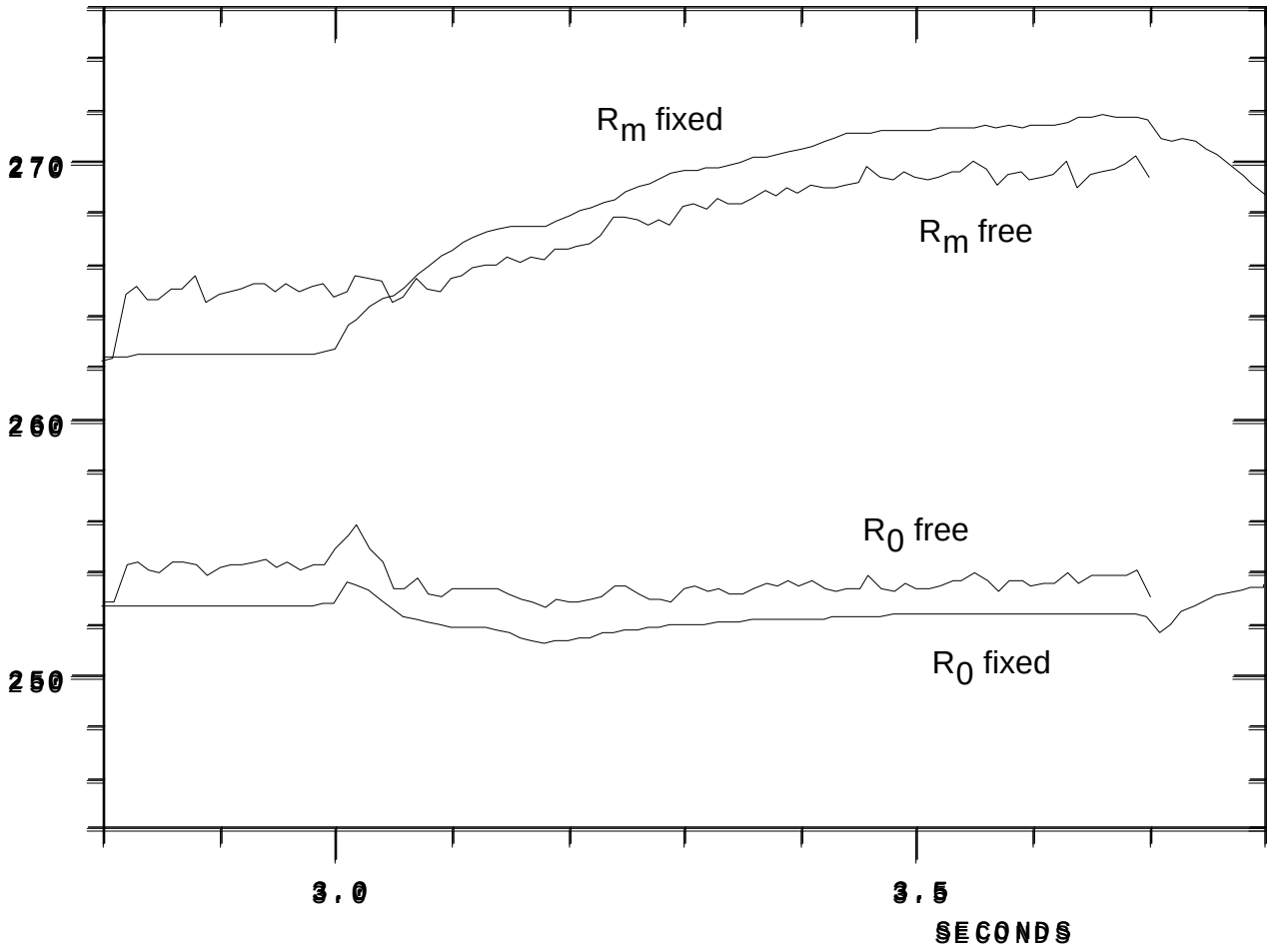


73300
R_m, R_0 comparison

- fixed boundary run (levgeo=5)
- free boundary run (levgeo=8/2)

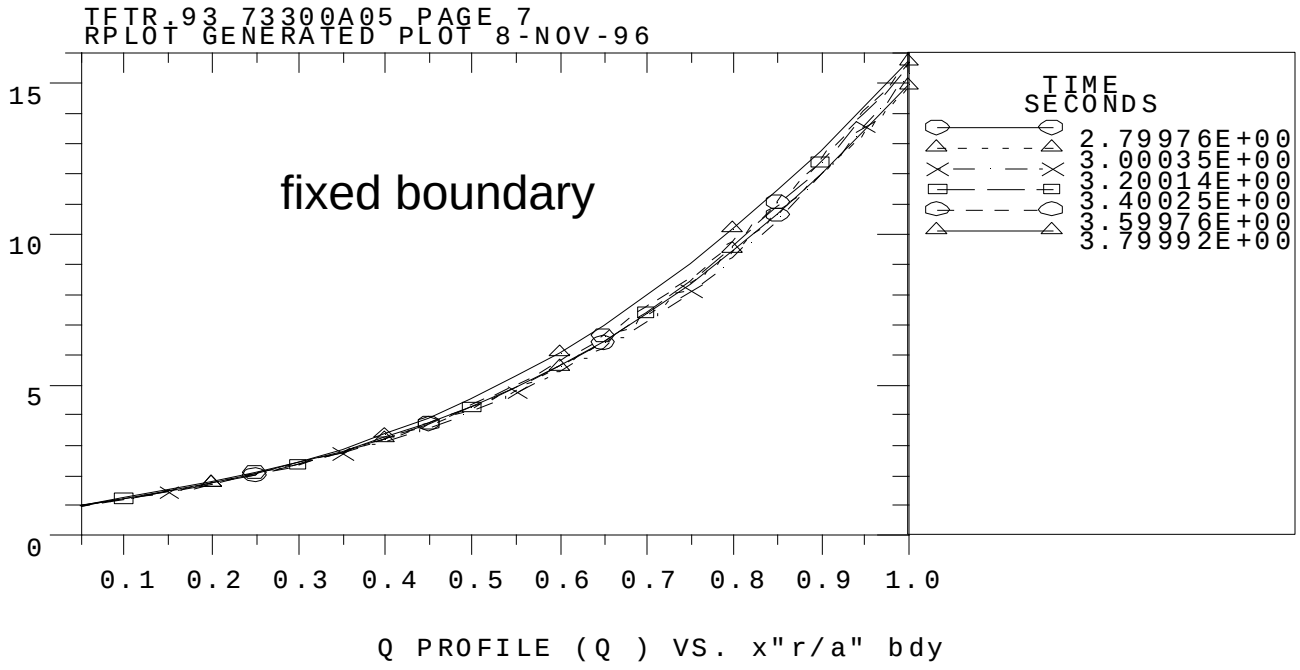
TFTR.93 73300A05 PAGE 8

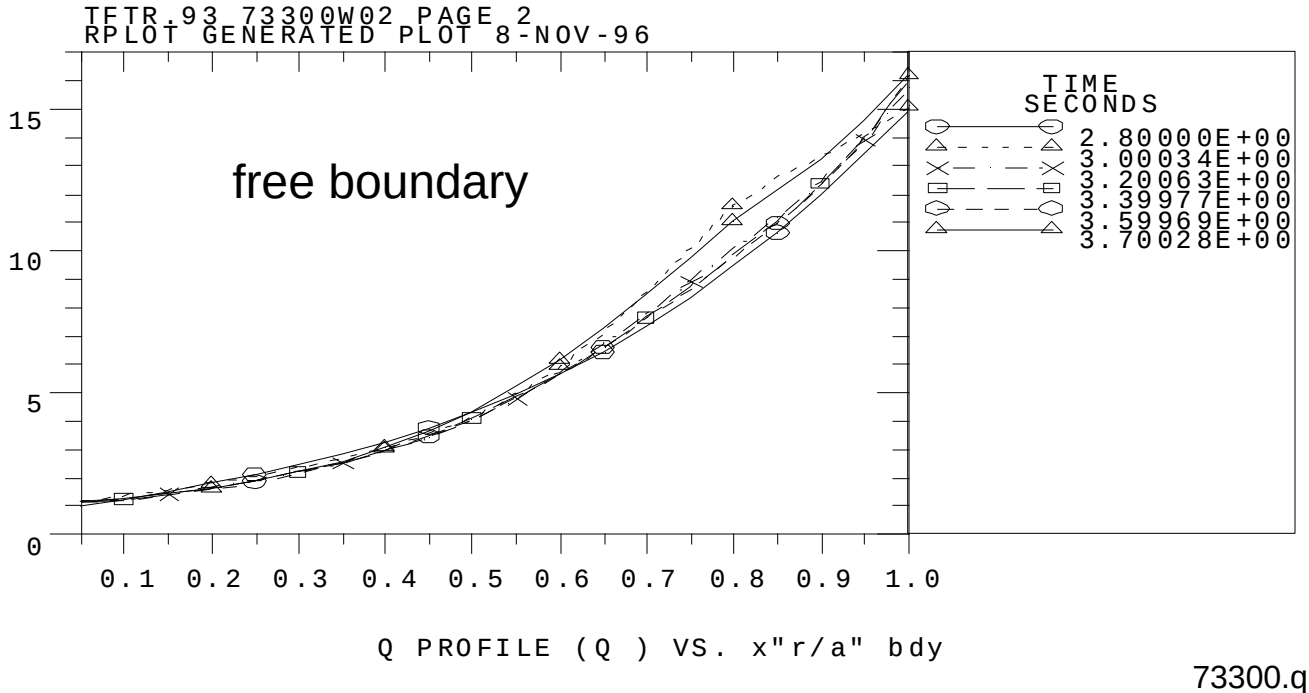
TFTR.93 73300W02 PAGE 1



73300
q profile comparison

- fixed boundary run (levgeo=5)
- free boundary run (levgeo=8/2)

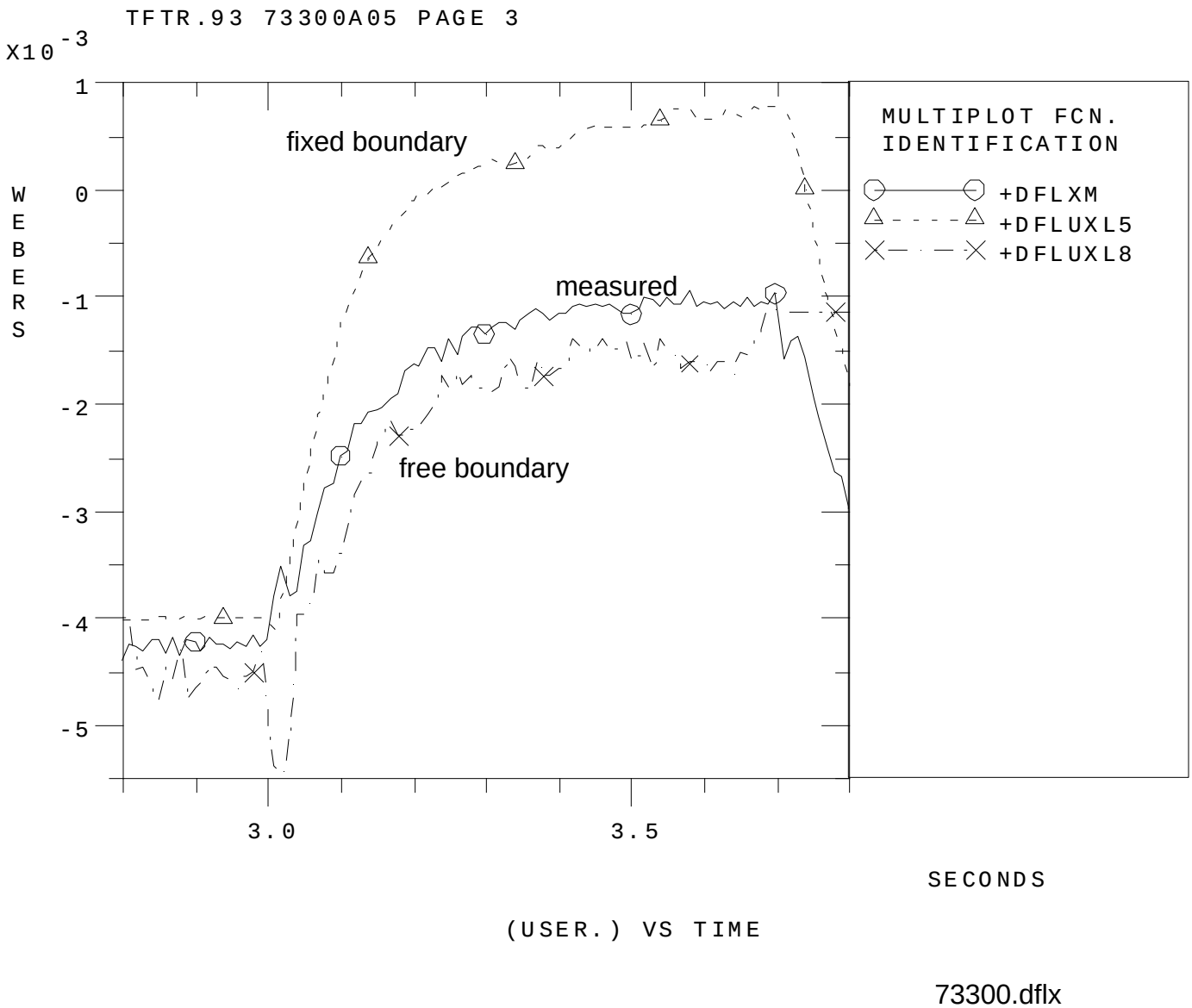




73300.q

73300
diamagnetic flux comparison

- fixed boundary run (levgeo=5)
- free boundary run (levgeo=8/2)

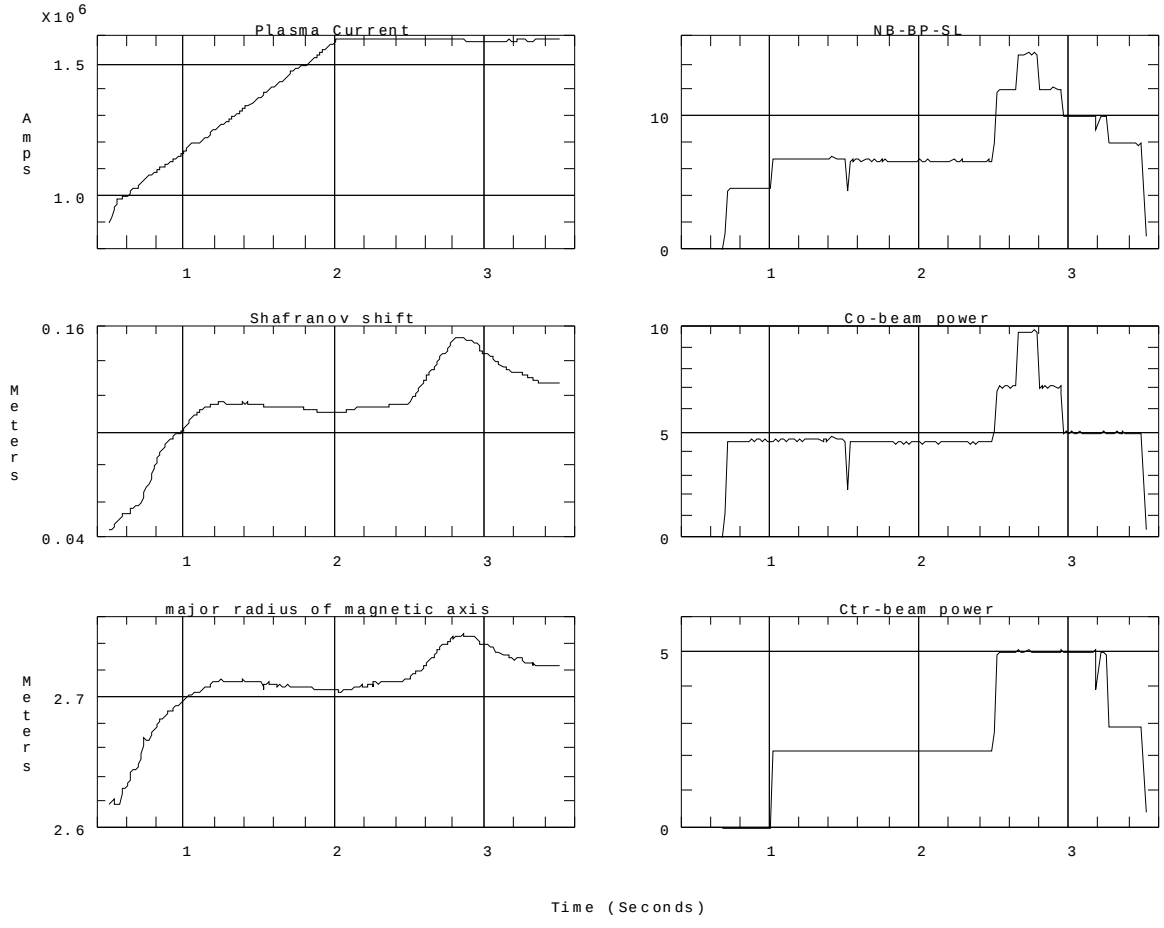


73300.dflx

Mode “0” : Free-boundary Equilibrium feed-through

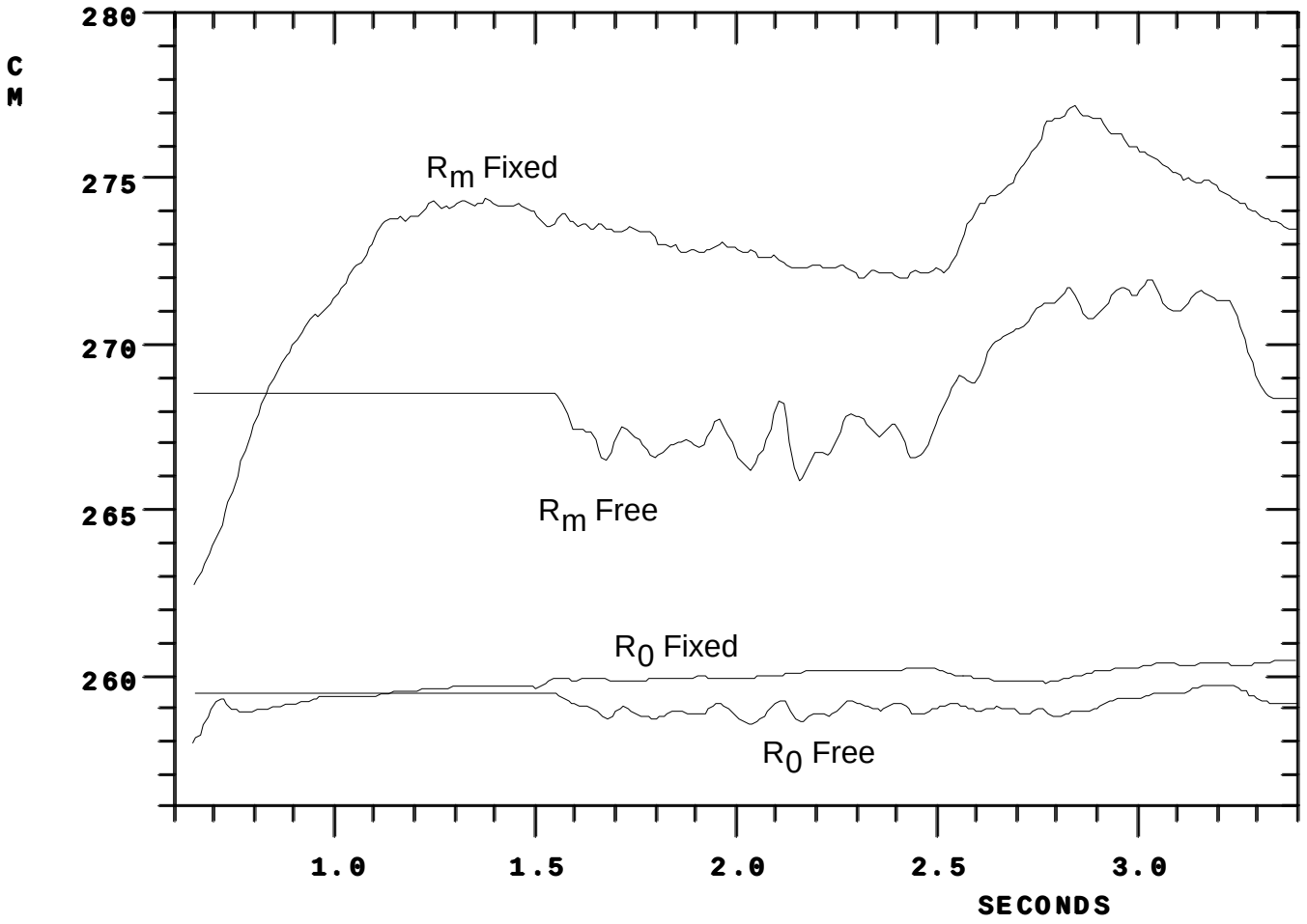
TFTR / VMEC shot 83998

- reverse shear
- 15 MW NB
- MSE 1.5 - 3.5 sec
- 1.6 MA
- 68 kA TF



83998
R_m, R_0 comparison

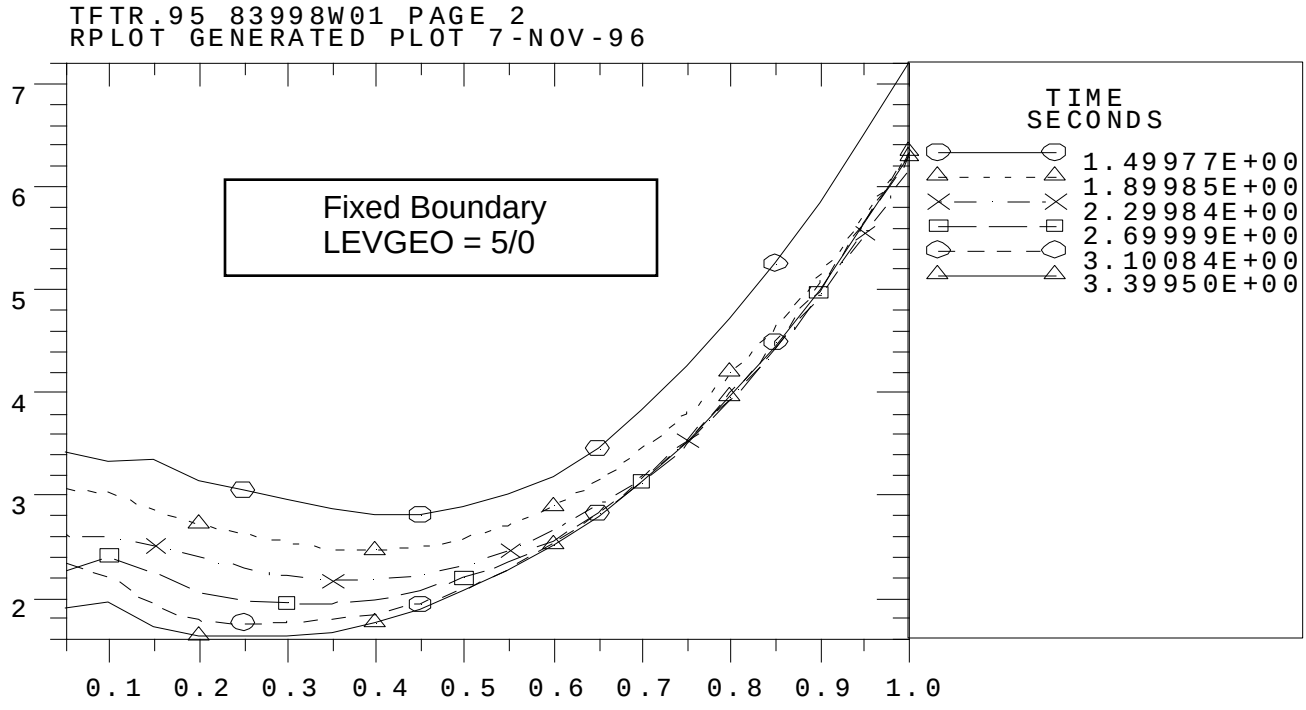
- fixed boundary run (levgeo=5)
- free boundary feed-thru (levgeo=8/0)

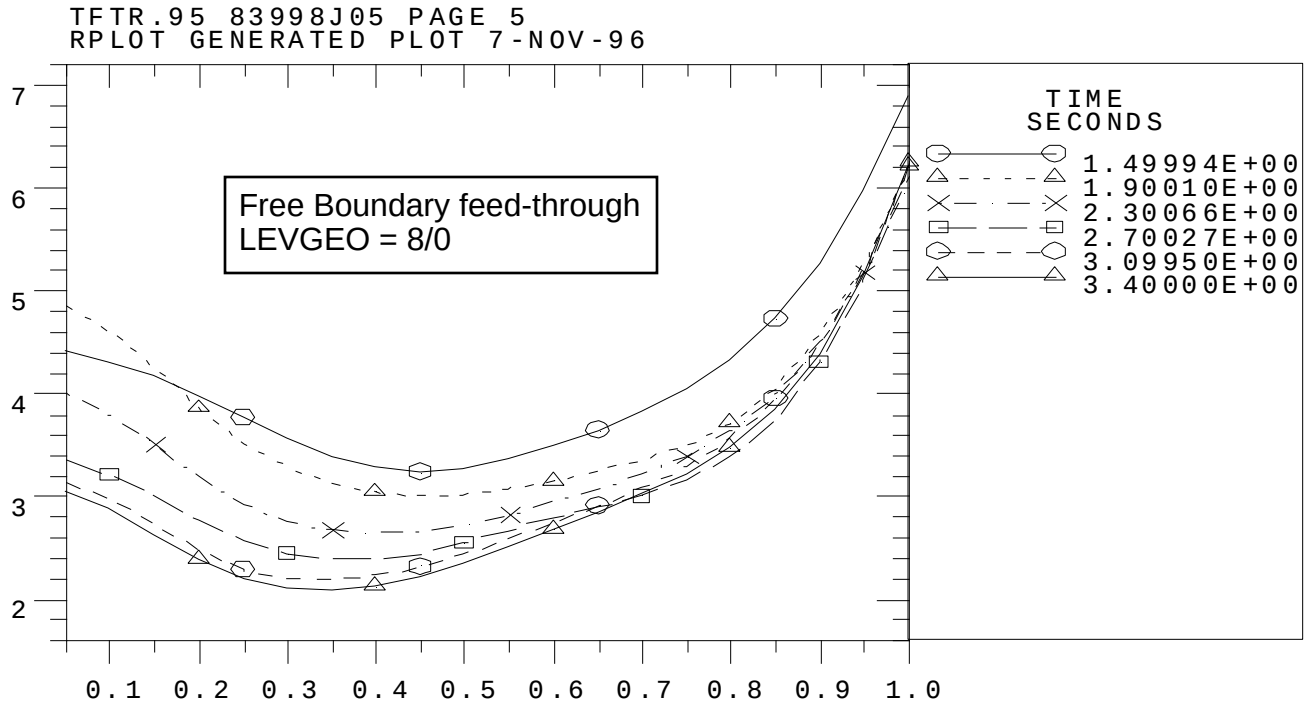


83998m00.r0r

83998
q profile comparison

- fixed boundary run (levgeo=5)
- free boundary feedthru (levgeo=8/0)





83998m00.q

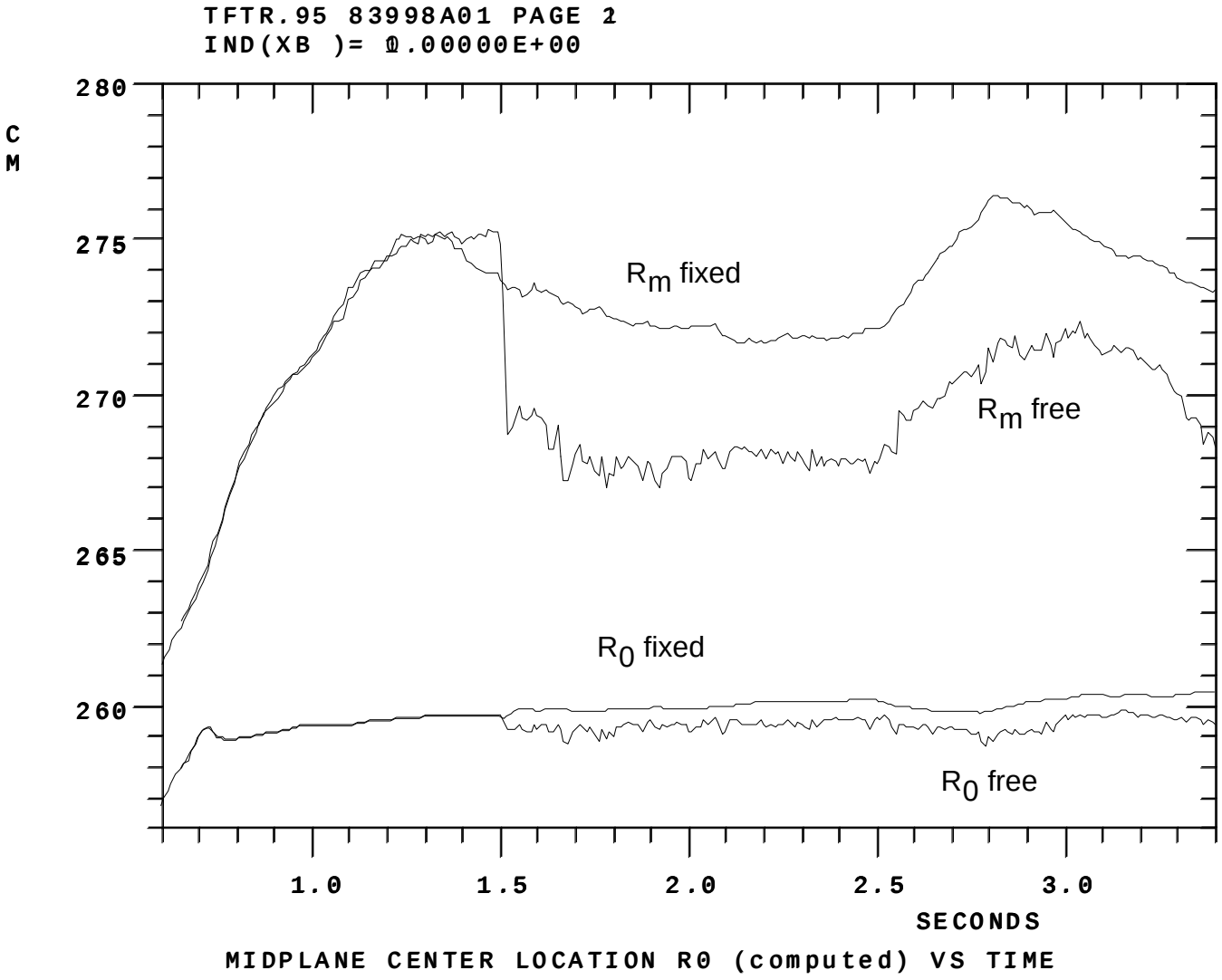
Mode “2” : Internal Free-boundary Equilibrium

TFTR / VMEC

shot 83998

83998
R_m, R_0 comparison

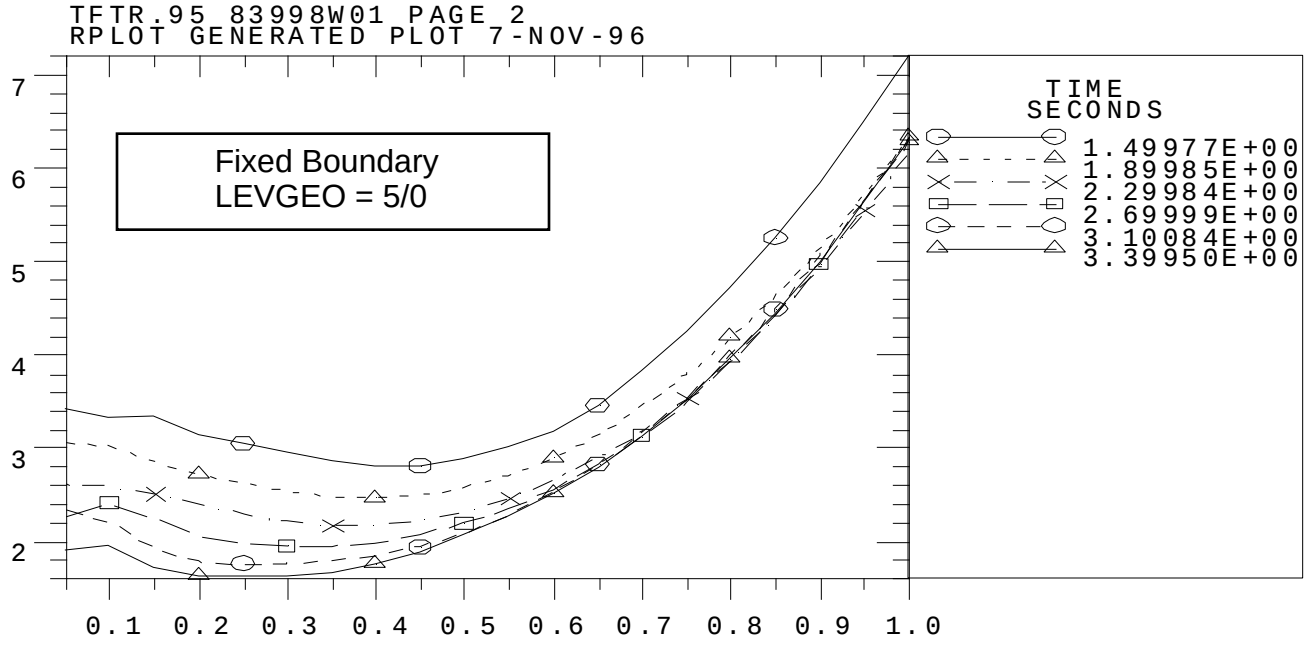
- fixed boundary run (levgeo=5)
- free boundary run (levgeo=8/2)

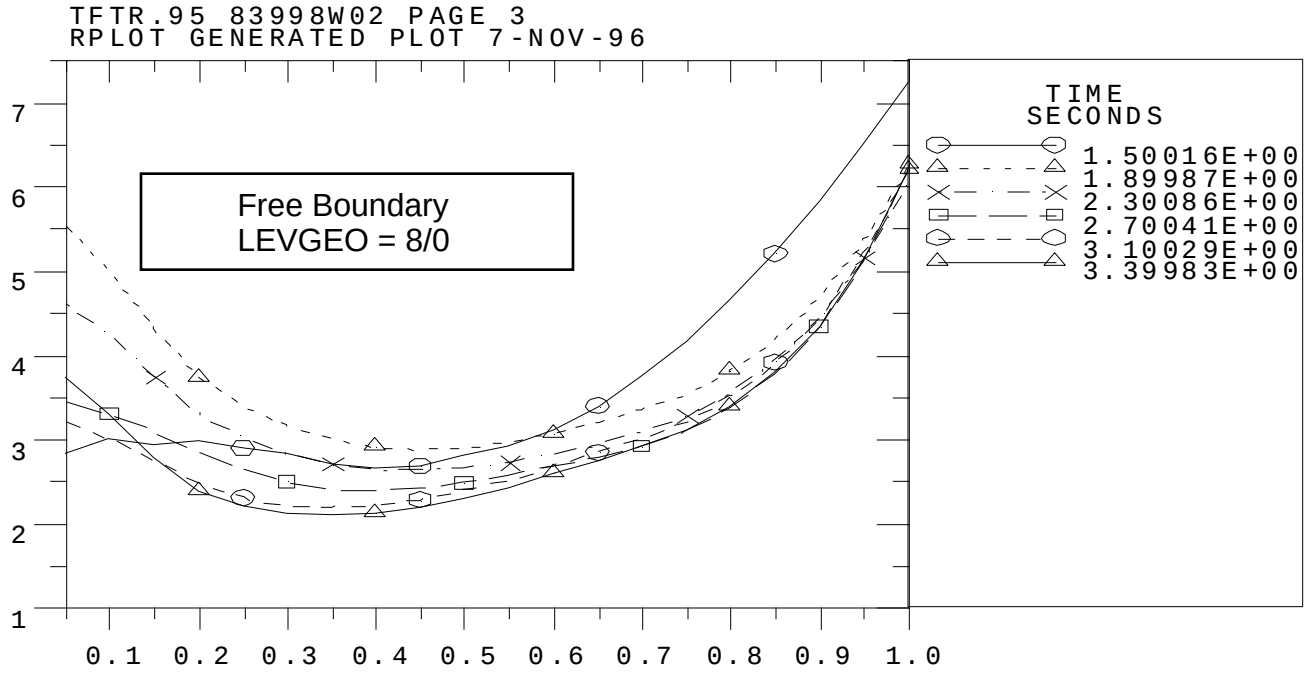


83998m02.r0r

83998
q profile comparison

- fixed boundary run (levgeo=5)
- free boundary run (levgeo=8/2)

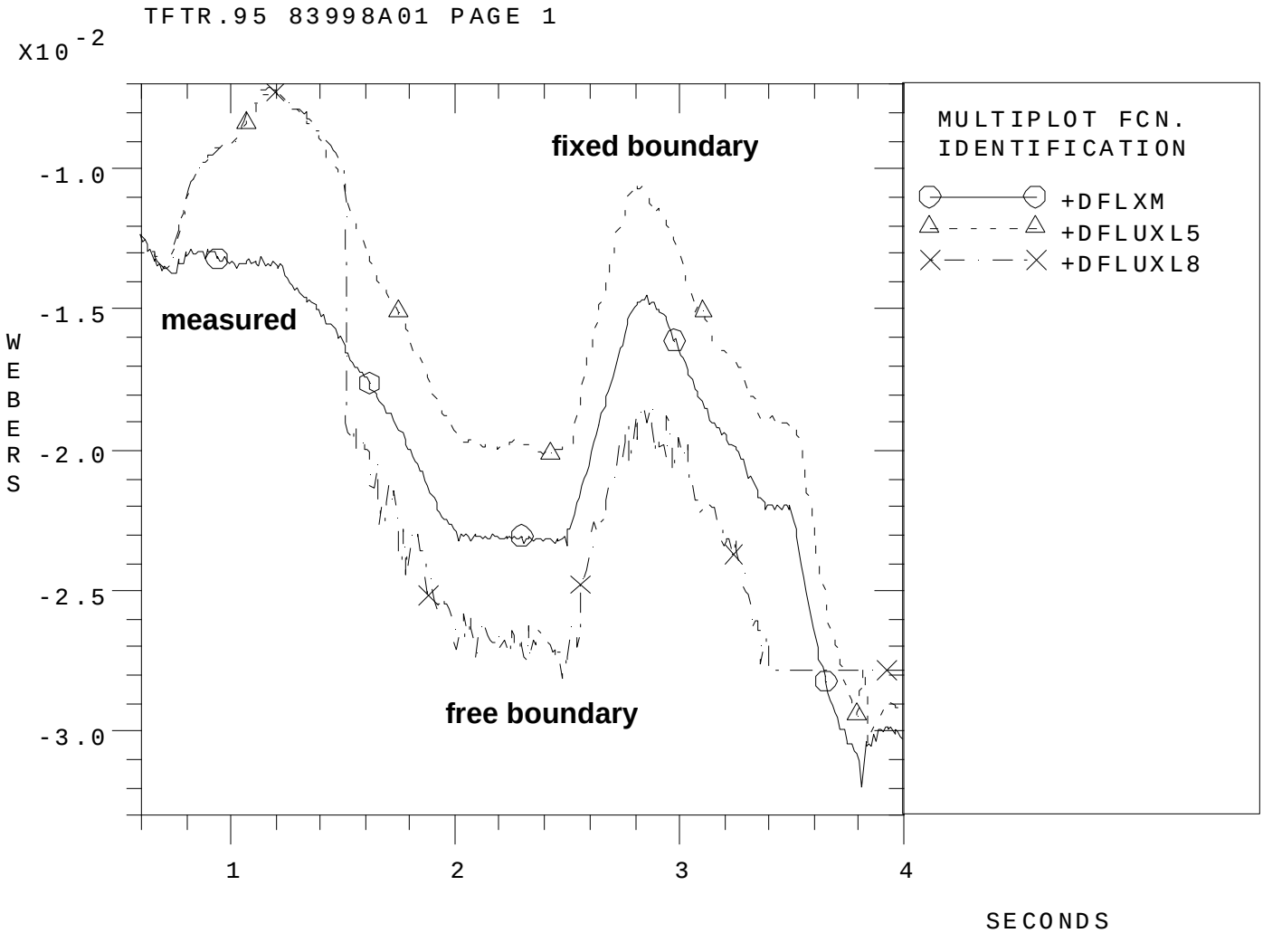




83998m02.q

83998
diamagnetic flux comparison

- fixed boundary run (levgeo = 5)
- free boundary run (levge o= 8/2)



Mode “2” : Internal Free-boundary Equilibrium

JET / EFIT
run X732 :: shot 33643

- EFIT/JET (iron core model) runs as a cooperating process
- Magnetic data and TRANSP pressure profiles are used by EFIT to reconstruct an equilibrium, including q profiles
- EFIT uses a direct representation $\Psi(R,Z)$; we Fourier analyze the EFIT solution to obtain an equivalent inverse $R(\chi,\theta)$, $Z(\chi,\theta)$ representation and feed it back to TRANSP
- work in progress to make this conversion more robust and eliminate spurious structures in the radial profiles of the Fourier moments near x-points.

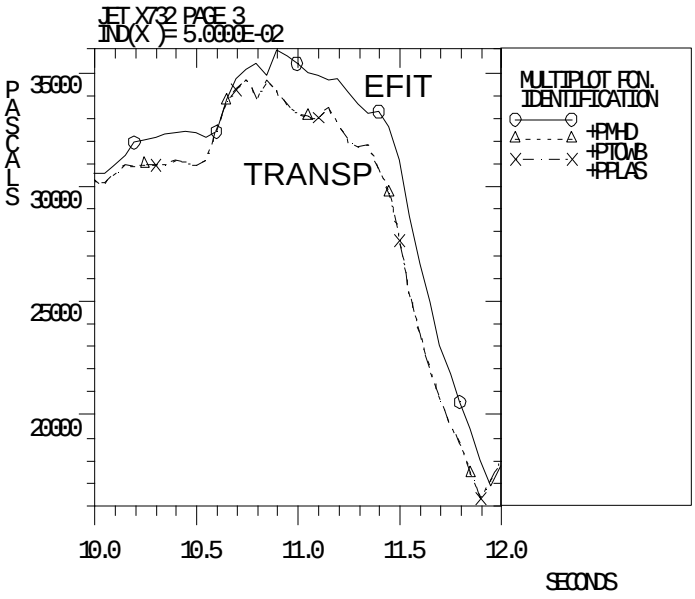
JET

X732 / shot 33643

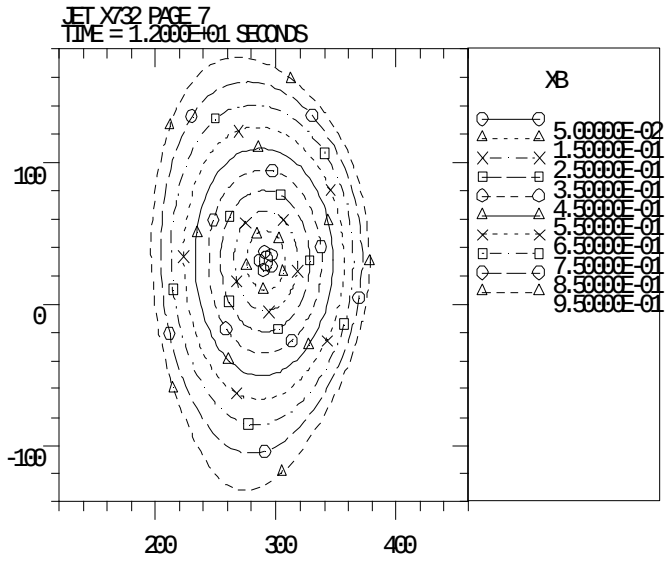
3.8 MA - 3.4 T : Hot Ion H-Mode

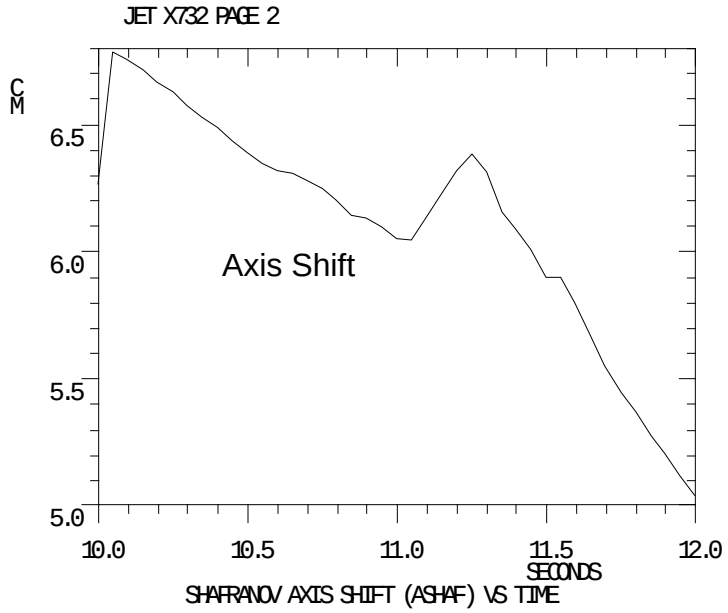
- TRANSP / EFIT
- free boundary run (levgeo=8/2)

PRESSURE

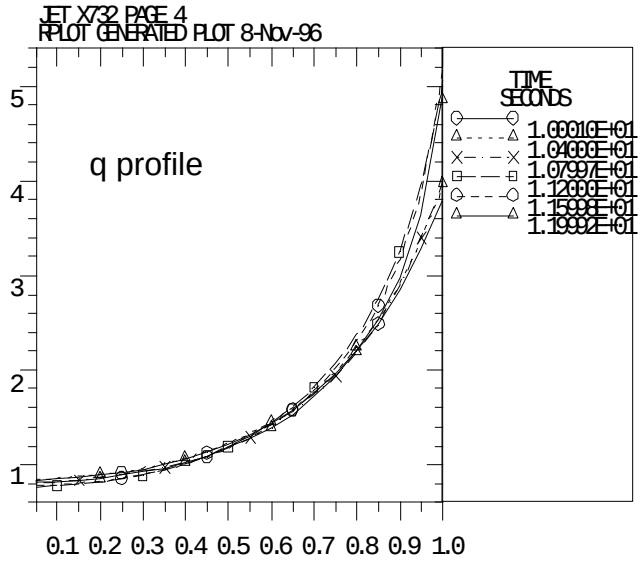


PLASMA PRESSURE (PRESS) VS TIME





SHAFRANOV AXIS SHIFT (ASHAF) VS TIME



Q PROFILE (Q) VS. x'r/a'' bdy

X732.JET

Conclusions

- **TFTR**
  - first results have been obtained using the VMEC free boundary reconstruction code on select TFTR shots
  - work is continuing to further benchmark the results and to make the operation more robust
  - EFIT operation will be added
- **JET**
  - first results have been obtained using the EFIT free boundary reconstruction code on select JET shots
  - further work is required in the area of the EFIT to TRANSP equilibrium representation interface

Reprints ...

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http://w3.pppl.gov/tftr/aps96/posters