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TEBASCO USER'S GUIDE

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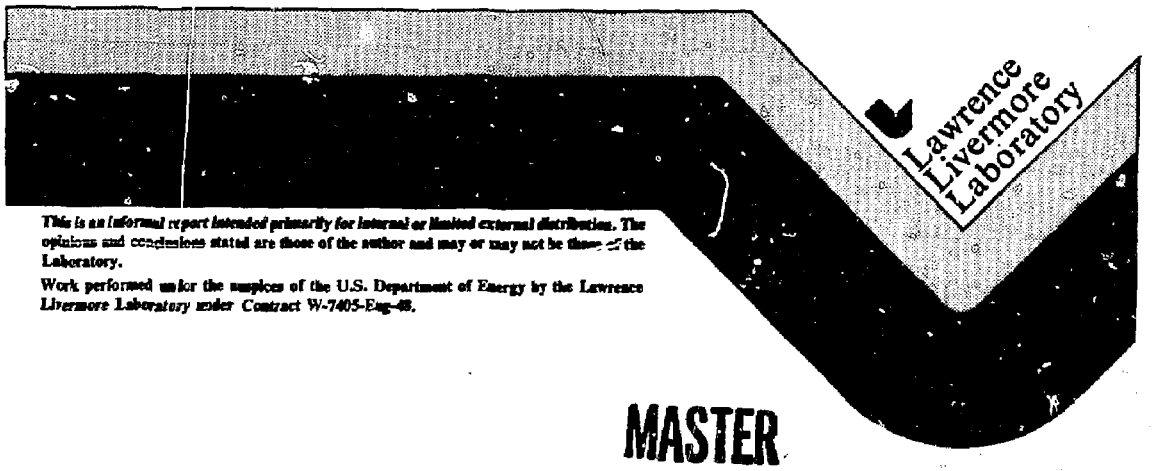

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TEBASCO USER'S GUIDE

TEBASCO was originally written by L. D. Pearlstein and extensively modified by L. LoDestro. Additional contributions were made by T. B. Kaiser and W. M. Nevins. Information about the code can be obtained from any of the above.

I. Introduction

TEBASCO is a Tandem mirror Equilibrium and BAllooning Stability COde. TEBASCO allows you to compute tandem-mirror MHD equilibria (see Refs. 1 and 6 for a discussion of the algorithms used); and to analyze both the flute-averaged and ballooning-mode stability of these equilibria. (See Ref. 2 for a description of flute-average and infinite-n ballooning stability algorithms, and Ref. 5 for the $m = 1$ ("rigid") mode.) This stability analysis is directed toward the computation of marginal stability boundaries.

Users of TEBASCO require a binary output file from the EFFI[3] code which describes the vacuum magnetic field (see Appendix D). In making this EFFI file the user will have defined a system of units for lengths (e.g., meters) and magnetic field (e.g., Tesla). In TEBASCO, all magnetic field strengths are normalized to the vacuum center-cell midplane value, and times are defined in units of the time for an Alfvén wave in this field to transit one EFFI unit of length.

TEBASCO is designed to be an interactive code. Hence, much useful output (equilibrium parameters, points on the marginal stability boundary, etc.) will appear on your terminal. In addition, all of this information, along with any plots that are made in a TEBASCO run are stored in an FR80 output file. TEBASCO will send this output file to your local user service center and/or to

the non-impact printer (see Sec. V). This file will also be output to the microfiche camera if you wish (see Sec. II).

Users who wish to use TEBASCO in designing tandem mirrors should understand that TEBASCO extrapolates the vacuum field geometry from the coordinates of a single near-axis magnetic field line, together with the assumption of quadrupole symmetry and a long-thin expansion. Hence, TEBASCO does not provide the best information about the vacuum field geometry. Tandem mirror designers should use a code like EFFI, which computes the vacuum field from a prescribed coil configuration, to determine clearances between the vacuum flux surfaces and the structure of the proposed device. In addition, TEBASCO obtains its finite-beta equilibria from an expansion in beta (except for a square profile general beta equilibrium). The information to be gained from the beta expansion about finite-beta distortions in the flux surfaces can be qualitative rather than quantitative if distortions are large. Designers should adjust their coil sets to produce equilibria that are "robust"; i.e., equilibria in which the finite-beta distortions of flux surfaces are small. Large distortions are an indication that the small-beta expansion is breaking down. We recommend that tandem mirror designers avoid using the plots of finite-beta flux surfaces to determine clearances between the plasma and structures since when these clearances differ greatly from those of the vacuum flux surfaces the small-beta expansion is probably failing to converge. As a general rule, we find that the small-beta expansion overstates the finite-beta distortions of the flux surfaces.

In Sec. II we describe how to access and initialize the TEBASCO code. In Sec. III we describe the equilibrium calculation. In Sec. IV A we discuss the calculation of flute-averaged stability boundaries, in Sec. IV B we describe the infinite-n ballooning calculations, and in Sec. IV C we describe the n = 1

ballooning calculation. Finally in Sec. V we describe how to end a TEBASCO run, and control the disposition of the output files.

In addition there are several appendices. Appendix A contains a list of all input variables together with a short description of their meaning and default values. Appendix B contains a sample TEBASCO run. Appendix C contains the FR80 output file from this sample run. Appendix D tells how to run EFFI and produce the EFFI binary file describing the vacuum field geometry that is input to TEBASCO. Appendix E describes the pressure modes available to the user.

II. Getting Started with TEBASCO

In this section we describe how to access the TEBASCO controllee (which is called XCPT), and how to enter the first group of basic commands needed to start up a TEBASCO run. In this and all following sections we use the following

CONVENTIONS:

Messages from the controllee (XCPT) appear in UPPER CASE CHARACTERS and are underlined in this report. Values returned by XCPT, which I am denoting by a symbol (e.g., ϕ) are enclosed in angular brackets in the report (but not on your terminal) i.e., in this report I will write <ϕ> to denote the value of ϕ. Your responses appear in lower case characters. If I am using a symbol to denote a value you are to enter it will be enclosed in angular brackets. Note that these brackets should not be typed when entering input. Comments and suggestions appear on the right half of the page. ! denotes the LINEFEED key on your keyboard.

First get the controllee (note that TEBASCO runs only on CRAY-1 computers, so you must be logged in to either the C or D machine):

filem rds 353 .tebasco tebasco!end / <t> <v>

1. READ TEBASCO

RDS

ALL DONE

If file is on tape or mass, FILEM may write additional messages, but you do not have to enter anything more.

lib tebasco / <t> <v>

<.....>

OK x xcpt!end

ALL DONE

(now execute the controllee)

xcpt / <t> <v>

BOX AND ID?

box = <uxx> id = <idfield*>

<uxx> is your box number, and <idfield*> is an arbitrary identifier supplied by you (with no embedded blanks or *'s). <idfield> will appear as the label on output from TEBASCO. If you do not append an asterisk (*) to <idfield>, then a microfiche copy of the FR80 output file will automatically be produced and sent to your box.

INPUT FOR EFFI BINARY FILE

At this point XCPT needs information to process the EFFI file. From here on XCPT accepts data in namelist format, so several variables can be set on one line and the order is not important. A dollar sign ($) at the end of your last input line terminates the namelist and starts XCPT on the next

calculation. In this manual we set only one variable on each line in order to leave room for comments. Many variables have reasonable default values which are given in Appendix A.

? infile = "<name>"

<name> is the name of the EFFI binary file describing the vacuum magnetic field. Note that <name> must be enclosed by quotation marks. (see Appendix D.)

? numax = <j>

<j> is the number of magnetic wells in each half of the machine. E.g., for TMX <j> = 2 (center cell + MHD anchor cell); for A-cell designs <j> = 3 (center cell + MHD anchor cell + A-cell); and for axicell designs <j> = 4 (center cell + axicell + transition region + MHD anchor cell). Note that <j> must be less than or equal to 8.

? zmaxs = <zmaxs>

<zmaxs> is the half length of the vacuum field described in the EFFI file <name>. If <zmaxs> = 0, XCPT will use the data up through NUMAX.

? bflor = <bflor(1)> <bflor(2)> ••• <bflor(2*numax-1)>

The elements of the array BFLOR are used to search for extrema of the vacuum magnetic field. Proceeding from the center-cell midplane toward the end of the machine, the first magnetic field maximum (i.e., the first extremum) must be greater than BFLOR(1), the first minimum (i.e., the second extremum) must be less than BFLOR(2), etc. Remember that all magnetic field strengths are normalized to the vacuum center-cell midplane value. With default value of zero, the code will find extrema using

? dflor = <dflor>

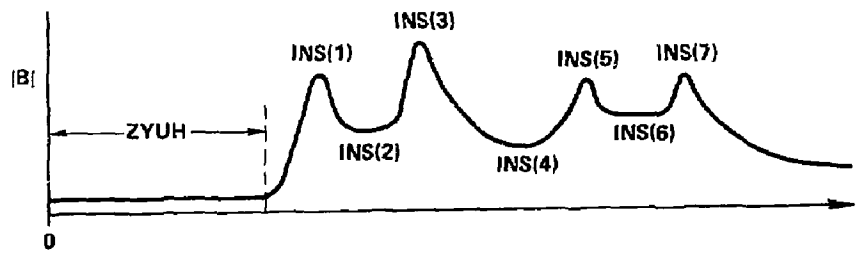
the required change in mod-B to admit the next-in-z extremum. If DFLOR is too small, or BFLOR(I) = 1, the code may find "secondary" extrema. (Default=.15)

? $

You must end this and all following input sequences with a $.

INS = <INS(1)> <INS(2)> <INS(3)> ••• <INS(2*NUMAX-1)>

The elements of the array INS returned by XCPT are the indices of the various magnetic field extrema. This information will prove useful later when making plots and/or further describing the thermal barrier (see discussion of N4 below).



CHANGE NI AND ZYUH FOR GRIDDING? DIST(<INS(1)>) = <VAL>

?

It is not necessary to make any changes at this point. If you are not satisfied with the INS array, you may try again by resetting BFLOR or DFLOR, and setting

NZONE = -1 $. If you wish to speed up the computation to come, you can reduce the number of grid points by setting

ni = <i> <j>

and

zyuh = <zyuh>

where <zyuh> is a real number (see previous sketch). Generally, <zyuh> should be chosen to be somewhat less than <VAL>, the distance from the midplane of the center cell to the first magnetic field maximum. The number of grid points between 0 and ZYUH will then be reduced by a factor of <i> and the number of grid points beyond ZYUH will be reduced by a factor of <j>. Always pick <i> to be an odd integer, while <j> is any integer; <i>, <j> > 0.

? logt = <k>

<k> + 1 is the number of the magnetic well where the thermal barrier occurs counting the center cell as the 1st well, e.g., for TMX-Upgrade <k> = 1; for axicell designs operated in the TARA-mode <k> = 1, for axicells operated in the MARS mode <k> = 3.

? rstar = <rstar(1)> •••

The mirror ratio (total mod-B relative to vacuum midplane center-cell value) where trapped pressure in the ith cell goes to zero, where again i=1 is the center cell. If RSTAR = 0 (default value) then the trapped pressure will go to zero at the outboard peak of the ith cell.

$

At this point you may get the error message

BAD ZONING. TOO MANY POINTS.

ZYUH = <ZYUH> <NI(1)> <NI(2)> <LYUH> <LZ> <NMAX>

This occurs when there isn't enough storage space in XCPT's internal arrays to store information on the grid that you have chosen, i.e., <LZ> is greater than <NMAX>. You can correct this problem by increasing NI(1), NI(2), and/or ZYUH. <LYUH> is the index of the grid point corresponding to the position Z = ZYUH. If <LYUH> is less than <LZ> - <NMAX>, then it is necessary to increase NI(2) and/or ZYUH.

(I BVD JPAR C)

<I> <BVD> <JPAR> <C> ...

. ...

. ...

. ...

XCPT is returning the index <I>, vacuum field <BVD>, cumulative integral of the geodesic curvature <JPAR>, and log of the ellipticity <C> at each magnetic field minimum. The parallel current is proportional to <JPAR> (see Ref. 1).

IN = <IN(1)> <IN(2)> ... <IN(2*NUMAX-1)>

Elements of IN array have same significance as those of INS array described above. The values of IN will differ from INS if you have rezoned, i.e., if you set NI to something other than 1 1.

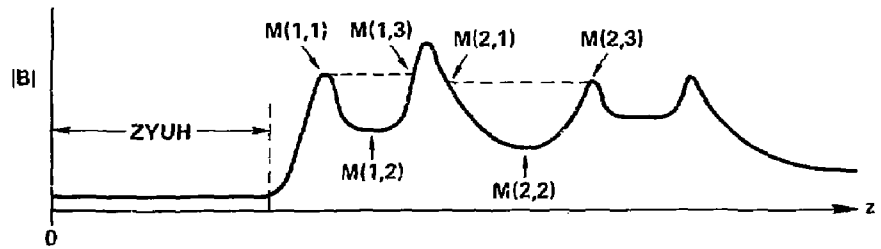
DIST = <Z(IN(1)> <Z(IN(2)> ••• Z-values corresponding to indices in IN array.

BVD = <B(IN(1))>, ••• Vacuum B-values corresponding to indices in IN array.

<M(1,1)> <M(1,2)> <M(1,3)> *** <BVD(M(1,1))> < •••>

<M(2,1)> <M(2,2)> <M(2,3)> ***

XCPT is returning the locations where the magnetic field takes the values sketched below. These are the positions at which the trapped pressures go to zero.



N4 = <N4> DO YOU WISH TO CHANGE IT FOR BARRIER?

?

N4 labels the point where pumping of thermal ions starts. N4 is defaualted to the index of the magnetic field maximum on the inboard side of the thermal barrier cell, (i.e., you do not need to change N4). However,

for axicell in MARS mode set N4 equal to the position of the high field mirror. You can determine the position from the IN array printed out above. If the high field mirror is the second magnetic maximum counting out from the midplane of the center cell, then set N4 = <in(3)>. For no thermal barrier, set LOGT = <numax> and N4 = <in(2*numax-1)>.

At this point you may simply proceed (resetting LOGT and/or N4 or not) with a

$

or, if you are dissatisfied with the zoning information printed out, try again, resetting NI, ZYUH, and/or RSTAR. To do this (now or at any later time) it is also necessary to set

NZONE = 1 $.

III. Equilibrium Calculations

Congratulations! You have now reached the basic computational loop of this code. From now on the prompt that you will receive from XCPT is

INPUT

?

Input data is still via namelist.

To proceed with equilibrium and stability calculations, you must now describe the pressure profile by entering values into the BETAD array (see Appendix E):

betad = <betac> <beta2> <beta3> <beta4>

where <betac> is the peak beta, i.e., midplane on-axis value, of the maxwellian component in the center cell,

<beta2> is the peak beta of the magnetically confined plasma in the magnetic well neighboring the center cell,

<beta3> is the peak beta of the magnetically confined plasma in the next cell out, etc.

If you wish to model a system, like TDF, in which there is a magnetically confined plasma in the center cell in addition to the maxwellian component, set

betacm = <betacm>

where <betacm> is the peak beta value of this magnetically trapped plasma; or

betasl = <betasl>

where <betasl> is the center-cell midplane value of β attributable to sloshing ions trapped in the center cell. If you set BETASL, you will also want to set

xmu = <xmu>

xnu = <xnu>

where <xmu> and <xnu> are parameters used to define the center-cell sloshing particle model (see Appendix E).

If you have a thermal barrier in your system, set

zlam = <zlam>

where <zlam> is a parameter used to define the pressure model in the transition region (see Appendix E).

You may also want to set the plasma radius by entering

radius = <radius>

where <radius> is the plasma radius in whatever units of length were used in producing the EFFI file. The value of RADIUS determines ψ_B, the flux at the plasma boundary. <radius> defaults to 0.3 which is usually the appropriate value for MFTF-B computations.

Having described your plasma, you may now wish to calculate an equilibrium. This is accomplished by setting

ipow = 0 (the default value)

sbeta = <sbeta>

If SBETA > 0, the sharp-boundary general beta equilibrium model described in Ref. 6 is used. If SBETA is less than or equal to 0 (the default), the equilibrium will be beta-expanded, and

n6 = <n6>

controls the flux dependence of the pressure profiles (see Appendix E).

$

For these latter equilibria, XCPT will return with

<NSTP> PHI/PI = <ϕ1> <ϕ2> <π>
<J(1,1)> <J(1,2)> ••• <J(1, 2*NUMAX-1)>
<J(2,1)> <J(2,2)> ••• <J(2, 2*NUMAX-1)>

BVAC(<N4>) = <BV> Perp = <P (1)> <P (2)> <P (3)>
BVAC(<N4>) = <BV> P = <P(1)> <P(2)> <P(3)>

where <NSTP> is the number of steps used in the field line integrations (i.e., you can safely ignore <NSTP>).

<ϕ1> and <ϕ2> describe the distortion of the equilibrium flux geometry through

$$2\psi = r_0^2 \left[1 + \left(\phi_1 \frac{r_0^2}{r_p^2} + \phi_2 \frac{r_0^4}{r_p^4}\right)\cos 4\theta\right]$$

(ψ,θ are the magnetic field line labels, and r_0 is the radius of the magnetic field line at the midplane of the center cell)

<π> is the flute stability integral. Negative values of <π> correspond to stable equilibria.

The J array contains the values of the parallel current to first [J(1,i)] and second [J(2,i)] order in β at the various extrema of the magnetic field:
i = 1--midplane of center cell
i = 2--1st mirror throat, etc.
The last value is at the peak at which the integration ends, not at its initial condition.

If all of these values are zero, it is probably because we are evaluating them at θ = 0, where the parallel current vanishes. Try θ = π/4 = .7853981635 (default). (See below.)

<BV> is the value of magnetic field where pumping starts, normalized to the center-cell midplane value.
<$P_\perp$(i)> is the value of $\beta_\perp$ in the ith cell out from the center cell.

<P(i)> is the value of β in the ith cell.

INPUT

?

We are now back to the "INPUT" prompt. If you wish to investigate the value of the parallel current on other field lines, you can reset the field line labels by entering

rsq = <r^2>

theta = <θ>

$

where <r^2> is the radius squared of the field line at the midplane of the center cell, and <θ> is the polar angle at the midplane of the center cell (in radians). Note that you could have set both RSQ and THETA before the first equilibrium calculations, and that you can reset these or any other variable anytime you are at the INPUT prompt.

The currents and beta values on the new field line will be displayed and you are returned to the INPUT prompt. If you wish to make plots of equilibrium quantities set

nplot = 1

n1 = <i> n2 = <j> plots from z(i) to z(j) (recall IN array); if not set, full range is plotted.

ngrid = <m> controls coordinate system used for contour plots of parallel current:

m = 0 for flux coordinates

m = 1 for local polar coordinates (default)

nzed = <n> controls plotting of parallel current contours:

n ≤ 0 for no plot

n > 0 for plot at Z = DIST(n) (default: n = 1)

lop = <ijkℓ>b

$

where <ijkℓ>b is a single octal integer (the b indicates that it is octal to XCPT). i controls plotting of the parallel current;

i = 1 for parallel current plots

i = 0 for no parallel current plots

similarly

j controls plots of field lines and curvature

k controls plots of pressure profiles, parallel current contours, and mod-B

ℓ controls plots of the x-coord of field lines at different ψ values, both equil and vacuum. E.g., enter lop = 1111b to get plots of everything.

When i = 1, XCPT produces plots in the upper half frame of the parallel current in both the vacuum fields (dashed line) and beta-corrected equilibrium fields (solid line). These parallel currents are computed by integrating the geodesic curvature,

$$j_{\parallel} = - 2 B \int_{z}^{zmaxs} \frac{dz'}{B} \, \square \, \frac{\partial p}{\partial \psi}$$

To find the current in amp/cm^2 multiply by B_c*10/(4π)*(Effi length unit in cm), where B_c is the center-cell midplane vacuum field in Effi units.

The integrand, $\frac{\square}{B} \frac{\partial p}{\partial \psi}$, is also plotted by XCPT in the lower half frame, for both the vacuum (dashed line) and beta-corrected equilibrium (solid line) fields.

When j = 1, XCPT will produce plots of both the x (upper half frame) and y (lower half frame) coordinates of the field line labeled by RSQ and THETA versus z for both the vacuum (dashed line) and beta-corrected equilibrium (solid line) fields. Next you obtain a plot of the dimensionless normal

curvature, 2ψ $\mathcal{A}$ ("YAH") versus z for both the vacuum (dashed line) and beta-corrected (solid line) fields. Finally, you obtain plots of the geodesic curvature, $\mathcal{K}$, ("YOU") in the vacuum and beta-corrected fields.

When k = 1, XCPT plots cross sections of the plasma at each of the magnetic field extrema. The plots are each labeled by the value of z (both in the units of length and by the index in the IN array) and the value of the axis ratio, y_{max}/x_{max} of the elliptical vacuum flux surface cross-sections. The vacuum flux surface is shown by a dashed line, while the finite-beta equilibrium flux surface is shown by a solid line. Large distortions of the equilibrium flux surfaces away from the vacuum flux surfaces are an indication that the equilibrium expansion is breaking down. These plasma cross sections are followed by plots of the equilibrium r and θ components of the magnetic field at z = 0 and z = DIST(100) as functions of θ for $\psi = \psi_B$. The r(θ) component is shown solid (dashed), normalized to the center-cell vacuum field. Next follows a contour plot of i, the parallel current per unit magnetic flux, at z = DIST(nzed). Either flux coordinates (r_0^2, θ_0) or local (in z) polar coordinates (r, θ) can be used. The current contours are followed by a plot of mod-B versus z for the right half of the system (in upper half frame) for both the vacuum (dashed line) and equilibrium fields (solid line). In the lower left quarter frame is a plot of both $P_\perp$ (dashed line) and $P_\perp = 1/2\ (P_\perp + P_{||})$ (solid line) versus z; while in the lower right quarter frame is a plot of $\beta_\perp$ (dashed line) and P/B (solid line) versus z.

When ℓ = 1, XCPT will make a plot of the x-coordinates of an array of field lines vs. z for both the vacuum (lower half frame) and finite-beta equilibrium (upper half frame) fields.

IV. Stability Boundaries

To do any stability calculation you must set ipow = 1. XCPT can be used either to compute the dispersion relation (i.e., calculate ω^2 vs. some parameter) or to compute marginal stability boundaries. The dispersion relation is obtained by setting

```
ipow = 1
vl = "comeg"
```

In ideal MHD marginal stability always occurs at $\omega^2 = 0$. Hence, you can obtain a stability boundary by setting

```
comeg = 0
vl = "<vl>"
```

where <vl>, the name of the dependent variable, is not COMEG. XCPT will then solve for the value of <vl> at marginal stability. In addition, you should set

```
ivs   = <ivs>
dvs   = <dvs>
vs    = "<vs>"
<vl> = <val1>
<vs> = <vals>
```

where <ivs> is the number of calculations to be performed,

<dvs> is the increment in the value of <vs> between each calculation, and

<vs> is the name of the independent variable e.g.,

```
vs = "BETAD(4)"
```

BETAD(4) = .25

Vl and VS may be set to any of the (sensible) real variable names in Appendix A. Appendix A also includes a short description of each variable.
<vals> is the initial value for the independent variable, <vs>, while <vall> is your initial guess for the value of <vl> at marginal stability.

IV. A. Flute Averaged Stability Boundaries

For flute-averaged (i.e., interchange) stability boundaries set

ndimpow = 1 (default). Explained in Sec. IVB.

lflute = 1

sbeta = <sbeta>

SBETA controls both which mode and which equilibrium model are being studied. If SBETA = 0, calculate infinite-m stability for beta-expanded equilibria. If SBETA < 0 calculate m = 1 stability with vacuum fields (or, if N6 = 0, beta expanded fields) and pressure profiles controlled by N6 (see Appendix E). If SBETA > 0, calculate m = 1 stability for the general beta sharp-boundary equilibrium (see also Sec. IVB).

Flute-averaged infinite-m stability boundaries are relatively insensitive to the field-line labels, RSQ and THETA. The most unstable flux surface is generally near the plasma boundary, at

rsq = $<(\text{radius})^2>$

Since the low beta equilibrium expansion fails to converge on the flute-averaged marginal stability boundary, one generally does the flute-averaged stability calculation in the vacuum fields. This is accomplished by setting

beta = 0. (uses only vacuum field)

When these vacuum fields are employed, the flute-averaged stability boundary is independent of THETA. Upon concluding the input sequence with a

The code will respond with <ivs> repetitions of the following two lines:

<V1> = <VAL1> <V2> = <VAL2> <V3> = <VAL3>

<VS> = <VALS> COMEG = <COMEG> IER = <IER>

where <V1> and <VS> are the variable names that you just entered.

<VAL1> and <VALS> are the values that these variables take at convergence (provided that the calculations converged - see discussion of IER below).
<comeg> is the value of ω^2. For marginal stability this must be 0. If it is not, you can reset it to zero by entering

comeg = 0.

If <IER> > 0, the calculation converged in <IER> iterations. If <IER> < 0, the calculation failed to converge after |<IER>| iterations. If the current value of <v1> looks reasonable, you can try another ten iterations by simply entering a

$

or else, you can start over with a new initial guess for <v1>.

Sometimes you get an error message like

<V1> WAS TOO [BIG / SMALL] TRY A [SMALLER / BIGGER] VALUE <VMIN> <VMAX>

If you have already found one or more points on the marginal stability boundary, it is best to go back to your last good point and use a smaller step size (i.e., smaller value of <dvs>).

If you are trying to find your first point on the marginal stability boundary, and XCPT says your guess was too big, you should change <val1> such that the system is more stable.

If XCPT says your guess was too small, then you should change <val1> so as to make the system more unstable. In this case two real numbers, <vmin> and <vmax> will be printed out. The marginally stable value of <v1> will usually be bracketed by these numbers.

IV. B. Infinite-m Ballooning Stability

For infinite-m ballooning set

```
ndimpow = 1
beta    = 1. e-20
```

to include plasma effects on the geometry and mod-B.

```
sbeta   = 0
lflute  = 0
```

for vacuum (i.e., insulating) boundary condition; or

```
lflute  = -1
```

for line-tied (i.e., conducting) boundary conditions. IPOW, V1, VS, <V1>, <VS>, IVS and DVS must be set as above. The mechanics are similar to those described above for calculating flute-averaged stability, although there are some new options available.

The orientation of the wave vector, CKAY, is a very important parameter in infinite-m ballooning stability. You can find the worst value of CKAY [in general, the worst value of CKAY $\simeq$ (tan θ)/rsq] by setting

```
vs = "ckay"
$
```

and sweeping as described above. Once you have found this value of CKAY you can track this most unstable orientation by setting

```
ndimpow = 2
v2 = "ckay"
$
```

<vs> can then be set to something other than "ckay", and XCPT will solve for both <v1> and for the most unstable value of CKAY.

You can maximize over a third variable (e.g. RSQ) by entering

```
ndimpow = 3
v3      = "rsq"
```

XCPT will now solve for the value of <v1>, and the most unstable values of both CKAY and RSQ.

```
$
```

Note that the radius of convergence can be quite small when you are attempting to solve for <v1>, CKAY, and <v3> simultaneously. You may have to find one "worst" value of <v3> before setting ndimpow = 3. This can be done when ndimpow = 2 by setting VS equal to the variable that you wish to maximize over, and sweeping (by setting IVS and DVS). When you find a local maximum, set V3 and <v3> equal to the name and extremal value at this variable; reset VS to some other variable name, and set NDIMPOW = 3. In general, this is not necessary.

IV. C. M = 1 Ballooning Stability

Our experience with calculations which involve finite larmor radius effects[4] indicates that the infinite-m ballooning calculation is overly pessimistic. Currently, our best estimates of center-cell beta limits are provided by the m = 1 ballooning calculation. For a discussion of the theoretical model employed, see Ref. 5. This calculation may be performed by setting

sbeta = -100.
beta = $1.e^{-20}$

to include plasma effects on the geometry and on mod-B (relevant if you are working with square profiles- SBETA > 0 or SBETA < 0 with N6 = 0). Or, set

beta = 0.

for strict vacuum fields.

IPOW, V1, VS, <V1>, <VS>, IVS, and DVS (*see beginning of Sec. IV*), as well as LFLUTE, NDIMPOW, V2, <V2>, ••• (see Sec. IVB) must again be set as above.

Wall stabilization is important for the m = 1 ballooning mode. The absolute distance from the plasma to the wall at the midplane of the center cell is then determined by setting

sbeta = <sbeta>

where $|\langle sbeta \rangle| = (R_w - R_p)/R_p$ measures the vacuum gap between the plasma and a conducting wall at the midplane of the center cell; R_p is the radius of the plasma at the midplane of the center cell, and R_w is the radius of the wall.

The sign of <sbeta> controls the equilibrium model. If <sbeta> < 0, then the vacuum fields are used in the calculation (unless N6 = 0); the flux dependence of the pressure is controlled by N6 (see Appendix E). If <sbeta> > 0, then the sharp-boundary equilibrium model of Pearlstein and Newcomb[6] (which allows for arbitrary β) is employed.

There are several options available for mapping this conducting wall axially. These options are controlled by setting the parameter

nwall = <nwall>
$

Analytic simplicity requires that the cross-section of the conducting wall be an ellipse, sharing the same foci as the elliptical plasma cross-section, at each value of z. If <nwall> = 1, the ellipticity of the wall is chosen such that the flux enclosed by the wall is constant for all z; when <nwall> = 2, the gap between the plasma and the conducting wall at the major axis of the elliptical flux surface is held constant; and when <nwall> = 3 the vacuum gap at the minor axis is held constant.

Note that m=1 ballooning modes are global perturbations, so that the field line labels, RSQ and THETA, as well as the orientation of the wave vector, CKAY are <u>not</u> used in this calculation.

Plots of any eigenfunction may be obtained by first setting

```
kric = 0
$
```

so that you solve the wave equations directly (a related Riccati equation is solved when KRIC = 1).

Next set

```
nplot = 1
lop   = 1000b
```

Finally, you may wish to set

```
n1 = <n1>
n2 = <n2>
```

to restrict the plotting range as described in Sec. III.

```
$
```

Remember to reset KRIC = 1 if you go on to do another stability calculation.

V. Output Control and Termination

At any stage in a TEBASCO run you can output a copy of your plot file to your user service center by entering

usc = "<usc>"

ndat = 1

$

where <usc> is your user service center. This defaults to your user service center. Users visiting locations must set USC or else their output will be lost. [Mysterious error messages are sometimes printed on your at terminal during output of plot files. They are harmless and should be ignored.]

If you have already output your FR80 file one or more times, you can suppress the output of frames that you have already seen by entering

moss = "<frame> -)"

where <frame> is the number of the last frame that you have seen so far.

If you wish to view your output on a TV monitor, set

moss(2) = "tv = <itv>"

where <itv> is the number of your tv monitor (e.g., 16001). On execution TEBASCO will start up NETPLOT and your file will be displayed on the TV monitor. You may view any frame by using the usual interactive NETPLOT commands (see NETPLOT document). Enter "end" to return control to TEBASCO.

$

When you have finished your TEBASCO run, you can terminate the job by setting

ndat = - 1

which will cause XCPT to output a copy of the FR80 file to the non-impact printer (NIP) before termination; or else set

ndat = 0

to terminate the run with no output from the NIP. You will receive a copy of the FR80 file on microfiche when you terminate the run by setting NDAT equal to 0 or - 1 if you did <u>not</u> append a star to your <idfield> as described in Sec. II.

VI. References

1. L.D. Pearlstein, T.B. Kaiser, and W. A. Newcomb, Phys. Fluids 24, 1326 (1981).

2. T. B. Kaiser and L.D. Pearlstein, LLNL Report UCRL-87659 (1982), submitted to Phys. Fluids.

3. S.J. Sackett, LLNL Report, UCRL-52402 (1978).

4. R.H. Bulmer, T.B. Kaiser, W.M. Nevins, W.A. Newcomb, L.D. Pearlstein, et al., 9th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Baltimore, Maryland, 1-8 September 1982.

5. T.B. Kaiser, W.M. Nevins, and L.D. Pearlstein, Phys. Fluids 20, 351 (1983).

6. L.D. Pearlstein and W.A. Newcomb, in preparation.

APPENDIX A: TEBASCO Input Variables

Hollerith Variables

infile - Name of EFFI binary file describing vacuum fields (defaults to "egl71," the MFTF-B FIELDS, see Appendix E).

usc - User Service Center for versetec output.

v1 - Dependent variable for stability calculations. (defaults to "betad(1)").

v2 - A second dependent variable for stability calculations (see discussion in Sec. IVb). (defaults to "rsq").

v3 - A third dependent variable for stability calculations (defaults to "rsq").

vs - Independent variable for stability calculations (defaults to "betad(2)".

moss - Controls output of plot file to your usc. Set moss(1) = "<frame> -)" to output frames <frame> through the current frame to your User Service Center (see discussion in Sec. V). Set moss(2) = " " if you don't want plot file packed (four frames to a page). Set moss(2) = <"tv = #"> if you want to plot this file online using the Zenith TV's at LLNL (defaults to "1-)").

Integer Variables

ipow - Set ipow = 0 for equilibrium calculation; ipow = 1 for stability calculations (defaults to 0).

ivs - Number of iterations in sweep on vs. Used only when ipow = 1 (defaults to 1).

kric - When doing stability, kric = 1 solves Ricatti equation, kric = 0 solves wave equation (defaults to 1).

kuadf - If kuadf $\neq$ 0, smooth Effi data near origin. Assume x, y are cubic in z up to the $|\text{kuadf}|^{\text{th}}$ Effi point. If kuadf < 0, force σ, τ to have quadrupole symmetry on TEBASCO grid. (defaults to 0)

lflute - Flag to control stability calculations. lflute = 1 for flute-averaged stability calculations; lflute = 0 for ballooning with insulating boundary conditions; and lflute = -1 for ballooning with line-tied boundary conditions (defaults to 1).

logt - Locates the cell containing the thermal barrier (see description in Sec. II). For no thermal barrier, put logt = numax (defaults to numax-1).

lop = Plotting flag. See description in Sec. III for plots of equilibrium quantities. Set lop = 1000b when plotting eigenfunctions (defaults to 1110b).

ndat - Controls output and ends run. Set ndat = 1 to output plot file to User Service Center; ndat = -1 to terminate run and send plot file to non-impact printer; ndat = 0 to terminate run with no further output. See discussion in Sec. V.

ndimpow - Controls number of variables over which maximization of vl is carried out. See description in Sec. IVB.

ngrid - Controls coordinates of parallel current contour plot.

ni - Controls grid spacing in equilibrium calculations. See discussion in Sec. II (defaults to 1 1).

nplot - Controls plotting of equilibrium quantities and eigenfunctions. Set nplot = 1 to plot equilibrium/eigenfunction that you found on previous loop. See discussion in Secs. III and IV. Remember that you must set kric = 0 to compute an eigenfunction before plotting it.

numax - Number of maxima in the magnetic field from the midplane of the center cell up to (and including) the outboard mirror (defaults to 3).

nwall - Controls wall model for m = 1 ballooning calculation (see discussion in Sec. IV.c). Set nwall = 1 for fixed flux inside confocal elliptical wall; nwall = 2 for fixed vacuum gap at major axis of elliptical flux surface; nwall = 3 for fixed vacuum gap at minor axis of elliptical flux surface (defaults to 1).

nzed - Controls parallel current contour plot.

nzone - Set nzone = - 1 to reset the ins array and set nzone = 1 if you wish to cycle through the latter part of the code described in Sec. II again. This will allow you to reset ni and/or n4.

n1(n2) - Starting (finishing) point for plotting (defaulted to full range) if n1 = 1 plots from midplane of machine to n2 = (recall array in)

n4 - Controls thermal barrier configuration. See discussion in Sec. II (defaults to the first peak inboard of the well with the barrier).

n6 - Controls $p(\psi,B)$ model. $p(\psi,B) = (1 - \psi/\psi_B)^{n6}\ \hat{p}(B)$ for n6 = 0,1,2; $p(\psi,B) = (1 - (\psi/\psi_B)^2)\ \hat{p}(B)$, n6 = 4 (defaults to 2).

n7 - Controls $\hat{p}(B)$ for the pressure of mirror trapped plasma in all but the central cell. $\hat{p}_{\parallel}(B) \sim (B_M - B)^{n7+1}$, n7 = 0,1,2 (see Appendix E) (defaults to 1).

Real Variables

beta - This is both a flag (set beta = 0 to use vacuum fields when doing stability calculations) and, for beta $\neq$ 0, the value of beta for an axially uniform plasma component that appears in all cells. To get finite-β equilibria without such a component, set beta to a small, but nonzero value (defaults to 10^{-20}). Note that beta must not be set to zero on first equilibrium calculation.

betad - An array with one element for each cell. Betad(1) is the peak value of beta for a Maxwellian plasma in the center cell; betad(2) is the peak beta of a magnetically trapped species in the adjacent cell, etc.; (defaults to .25 .25 .0 .55).

betacm - Peak value of beta for a magnetically trapped species in the center cell. (Defaults to 0.)

betasl - Peak value of beta for sloshing ions in center cell. Note that TEBASCO contains no provision for sloshing ions anywhere except in the center cell. (Defaults to 0.)

bflor - An array with one element for each extremum of B. If you want TEBASCO to ignore an unimportant minimum (maximum) when setting up its axial pressure model, set bflor(i) to a value less than (greater than) that of the ignorable extremum (normalized to the center-cell midplane value). The ith extremum in B that TEBASCO finds will then be smaller than (larger than) bflor(i). (defaults to 0) See also dflor, and discussion in Sec. II.

ckay - Determines orientation of perpendicular wave vector, ∇S, for infinite-m ballooning calculations. ckay = $-2\psi\ S_\psi/S_\theta$, where ψ is the enclosed magnetic flux, $S_\psi = \partial S/\partial\psi$, $S_\theta = \partial S/\partial\theta$, and $S(\theta,\psi)$ is the eikonal describing perpendicular structure of the normal mode. See discussion in Sec. IVB (defaults to 0).

comeg - For infinite-m stability, comeg = ω^2, i.e., the square of the normal mode frequency. For the rigid mode, comeg = ω. Set to zero to compute marginal stability boundaries (defaults to 0).

dflor - The relative change in mod-B to find the next-in-z extremum, used when bflor = 0 (defaults to .15).

dvs - Increment in v2 between successive iterations. See discussion in Sec. IV (defaults to .05).

radius - Plasma radius at midplane of center cell. Use same units as used in making EFFI binary file (defaults to 0.3).

rsq - Flux surface label for stability calculations. Rsq is radius squared (in EFFI units) of flux surface at midplane of the center cell (defaults to .045).

rstar - An array with one element for each cell starting at the center cell. Rstar(i) is the value of the total magnetic field (normalized to the vacuum center-cell midplane value) at which the trapped-particle pressure in the ith cell vanishes.
If rstar(i) = 0, the pressure vanishes at a field strength equal to the lower maximum bounding the cell (defaults to 0).

sbeta - Set SBETA = 0 for infinite-m ballooning. For m = 1 ballooning set sbeta equal to $(R_{wall}-R_{plasma})/R_{plasma}$ evaluated at the midplane of the center cell (sbeta defaults to 0).

smtest2 - Controls accuracy of eigen-value finder. If small changes in vs do not produce changes in the value of v1, try reducing smtest2 (defaults to 10^{-8}).

theta - A flux coordinate for stability calculations. Theta is the polar angle (in radians) of the field line at the midplane of the center cell (defaults to $\pi/4$).

xmu,xnu - Parameters used to define center-cell sloshing ion model. See Appendix E. (defaults to 2. 1.)

zmaxs - Maximum z position in EFFI binary file. See discussion in Sec. II. (defaults to 0)

zlam - Controls pressure model in transition region. Set zlam to a large number to reduce perpendicular pressure in transition region. (defaults to 2.)

zyuh - Value of z delimiting a courser grid (for z < zyuh) from a finer grid (for z > zyuh) see discussion in Sec. II (defaults to distance to first maximum in B).

APPENDIX B. Sample Run

```
TEBASCO / 3 4
ENTER BOX & ID
U18 RHB3◆
INPUT FOR EFFI BINARY FILE
INFILE="ESD12" NUMAX=6 ZLAM=3.16 N6=4 NYUH=0 RAK=0 DFLOR=.001$
INS =     241    326    380    392    411    465    519    537    550    616
          681
CHANGE NI AND ZYUH FOR GRIDDING?  DIST( 241)=     12.000
$
(  I     BVD   JPAR    C  )
(   1  1.00 -0.00  0.00) ( 326  0.89 -0.12  0.75) ( 392  1.48  0.37  1.93)
( 465  0.84  0.96 -0.00) ( 537  1.51  0.39 -1.93) ( 616  0.63 -0.13 -0.08)
IN =     241    326    380    392    411    465    519    537    550    616
          681
DIST =   12.00  16.25  18.95  19.55  20.50  23.20  25.90  26.80  27.45  30.75
         34.00
BVD  =    5.10   0.89   1.50   1.48   1.55   0.84   1.56   1.51   1.53   0.63
          1.59
      290      326      380  ***      1.501    0.894    1.501
      380      392      400  ***      1.501    1.480    1.501
      411      465      514  ***      1.547    0.838    1.547
      528      537      550  ***      1.533    1.505    1.533
      550      616      672  ***      1.531    0.630    1.531
N4: N5; LSTAR =   550   616   681.  DO YOU WISH TO CHANGE THEM FOR BARRIER?
N4=241$
INPUT
RADIUS=.53 RSD=.14
BETAD=.25 0 0 .5 0 .5$
       680 PHI/PI =  0.          1.398E-01-1.876E-01
Y; EX; & E  AT RIGHT EXTREMA AND LEFT BOUNDARY
 4.91E-05 5.53E-05 2.43E-02-1.18E-02-7.63E-02-1.78E-01-1.47E-01
-1.75E-01-7.97E-02-9.50E-03-2.55E-03 2.01E-07
 1.02E-01 1.02E-01 1.29E-01 8.77E-02 1.45E-02-9.96E-02-4.16E-02
-1.93E-01-2.41E-02 1.01E-01 5.96E-02 1.48E-07
 4.50E-05 5.16E-05 2.42E-02-1.22E-02-7.65E-02-1.77E-01-1.47E-01
-1.74E-01-8.00E-02-1.08E-02-2.51E-03 0.
BVAC( 241)= 5.1E+00      PPERP= 3.9E-05 1.9E-04 5.0E-01 2.0E-04 5.0E-01
BVAC( 241)= 5.1E+00           P= 3.4E-02 2.1E-02 3.4E-01 2.0E-02 3.8E-01
INPUT
LOP=1111B N1=161 NPLOT=1 NZED=465$
INPUT
IPOW=1 V1="BETAD(1)" V2="BETAD(6)" BETA=0$
BETAD(1)= 3.322E-01 RSD      = 1.400E-01 RSD      = 1.400E-01
BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =      1
INPUT
LOP=1000B N1=160 NPLOT=1$
INPUT
LFLUTE=0 NWALL=1 SBETA=-.28$
BETAD(1)= 3.139E-01 RSD      = 1.400E-01 RSD      = 1.400E-01
BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =      3
```

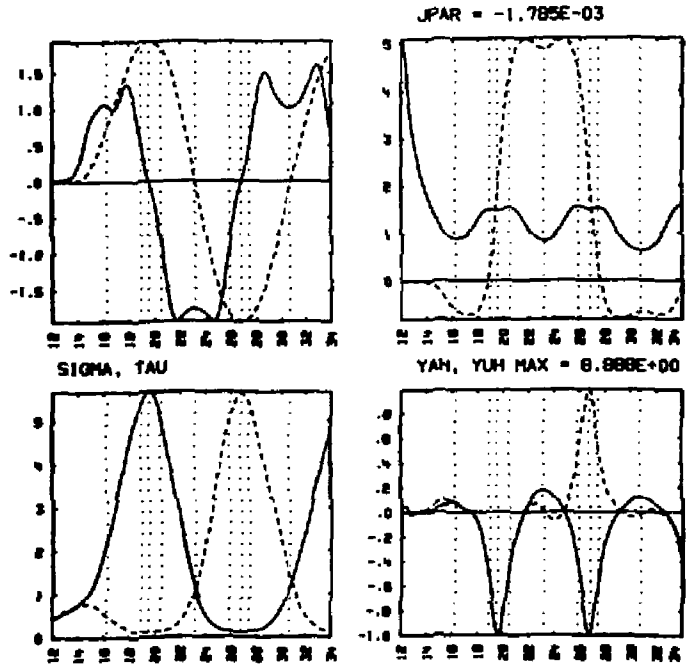
```
 INPUT
 KRIC=0$
 BETAD(1)= 3.139E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
 BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =      0
 INPUT
 LOP=1000B NPLOT=1$
 INPUT
 KRIC=1 SBETA=.28 BETA=1.E-20 BETAD=.3$
 BETAD(1)= 3.104E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
 BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =      6
 INPUT
 KRIC=0$
 BETAD(1)= 3.104E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
 BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =      0
 INPUT
 LOP=1000B NPLOT=1$
 INPUT
 IPOW=0 BETAD=.25$
 EQUI-1.562E-02 1.850E-01 8.224E-02

 INPUT
 LOP=1111B N1=161 NPLOT=1$
 INPUT
 NDAT=1 MOSS(2)=" "$

  INTER-RECORD WORD ERROR FOR FILE  F8PZZE0X.

F8PZZE0X HAS TERMINATED PREMATURELY - END-OF-FRAME ASSUMED.


F8PZZE0X : FILE-ID  RHB3 - RXLLL/AA  #FRAMES= 32


  ALL DONE
MOSS=1-)    # OF FILES=    1
INPUT
NDAT=0$
  TOTAL CPU TIME USED IS         18460448  MICROSECONDS
  TOTAL CPU TIME USED IS       18.4604480 SECONDS

  ALL DONE
```

APPENDIX C. Output From Sample Run

```
CONTROLLEE   XCP50
LOADED AT          09:03:40  09/01/83
EXECUTION STARTED  15:00:30  09/07/83 ON C MACHINE.


INPUT FILE =   TRHB3

$

EFFI BINARY FILE NAME = EQD12
MARS MODEL D12
15:00:20C       01/03/83   EFFI.07/23/80
B(0) =  4.700 ZMAX = 34.000

 IECHO    = 100
 INFILE   = 730801900200900030M
 INR      = 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 IPOH     = 0
 ITERMX   = 10
 IVS      = 1
 IVST     = 1
 IYES     = 0
 JPOHL    = 0
 J1       = 0
 J2       = 0
 J3       = 0
 KAN      = 1
 KAXSYM   = 0
 KFX1BOL  = 1
 KBEO     = 1
 KJPP     = 1
 NRIC     = 1




KUADF    = 0
LFLUTE   = 1
LIN      = 2
LLEN     = 57
LOGI     = 1
LOGT     = 5
LOP      = 4680
LOMM     = 1
LSTAR    = 0
MBAD     = 2006
MF       = 10
MIT      = 1
MM       = 0
MOBS     = 3543533899785116960 233747528623221148B
MBUOP    = 0
MDAT     = 1000
MDIMPON  = 1
MD3      = 6
MFILT    = 0
MGEAR    = 1
MGRID    = 1
MI       = 1 1 0 1 0 0
MJACK    = 0
MPLOT    = 0
MREAL    = 1
MSPL     = 1
MUMAX    = 6
MWALL    = 1
MYUM     = 0
MZ       = 0
MZED     = 1
MZONE    = 0
```

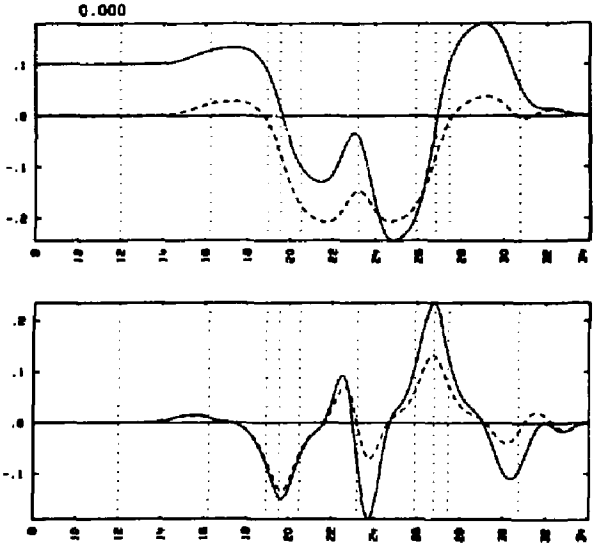
```
 NI       = 0
 N2       = 0
 N4       = 0
 N5       = 0
 N6       = 4
 N7       = 1
 N8       = 100
 ALPHA    = 0.
 ATOL     = 1.E-08
 BETA     = 1.E-20
 BETACM   = 0.
 BETAD    = 0.25 0.25 0. 0.55 0. 0. 0.
 BETASL   = 0.
 BFLOR    = 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 CKAY     = (0.,0.)
 CAYR     = 0.
 CAYI     = 0.
 COMEG    = (0.,0.)
 COMEGR   = 0.
 COMEGI   = 0.
 DELRB    = 1.
 DFLOR    = 1.E-03
 DVS      = 5.E-02
 ENCM     = 0.
 ENMD     = 1. 1. 0. 1. 0. 0. 0.
 ERROR    = 0.
 ERRORB   = 1.E-05
 FTOL     = 0.
 OMCYC    = 5.
 OMEXB    = 1. 0. 0.
 RADIUS   = 0.3
 RAK      = 0.
```

```
 RMR      = 0.
 RSQ      = 4.5E-02
 RSTAR    = 0. 0. 0. 0. 0. 0. 0.
 RTOL     = 1.E-08
 RWALL    = 0.
 SBETA    = 0.
 SLOPE    = 1.
 SMTEST   = 1.E-08
 SMTEST2  = 1.E-08
 STFAC    = 1.E-04
 STMETA   = 0.
 TMETA    = 0.7853981635
 USC      = R.
 VS       = R. 0.
 V1       = R. 0.
 V2       = R. 0.
 V3       = R. 0.
 VN       = R. 0.
 XMU      = 2.
 XNU      = 1.
 ZLAM     = 3.16
 ZMAXS    = 0.
 ZPEAK    = 10.
 ZSP      = 0.
 ZYUM     = 12.
$
```

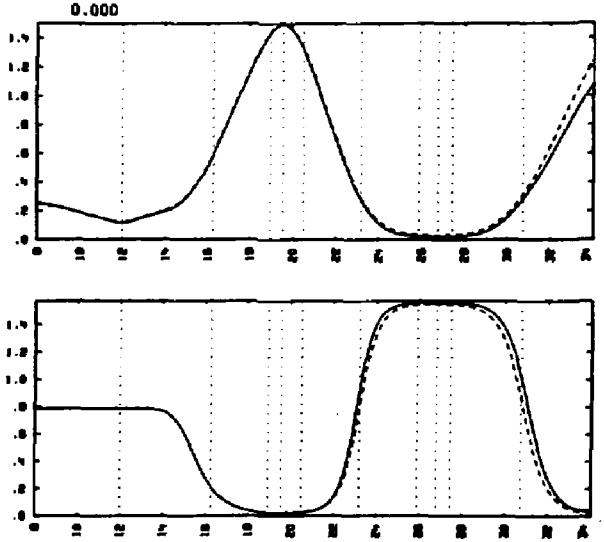


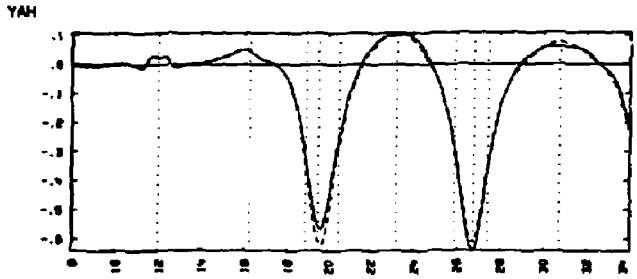

```
 IN =    241   326   380   392   411   465   519   537   550   616
         681
 DIST =  12.00 16.25 18.95 19.55 20.50 23.20 25.90 26.80 2
         34.00
 BVD  =   5.10   0.89   1.50   1.48   1.55   0.84   1.56   1.51
          1.59
      290      326      380  ***      1.501   0.894   1.501
      380      392      400  ***      1.501   1.480   1.501
      411      465      514  ***      1.547   0.838   1.547
      528      537      550  ***      1.533   1.505   1.533
      550      616      672  ***      1.531   0.630   1.531
NN=241$
RADIUS=.53 RSQ=.14
BETAD=.25 0 0 .5 0 .5$
       680 PHI/PI =  0.          1.388E-01-1.278E-01
Y, EX, & E  AT RIGHT EXTREMA AND LEFT BOUNDARY
 4.91E-05 5.53E-05 2.43E-02-1.18E-02-7.63E-02-1.78E-01-1.47E-01
-1.75E-01-7.97E-02-9.50E-03-2.55E-03 2.01E-07
 1.02E-01 1.02E-01 1.29E-01 8.77E-02 1.45E-02-9.98E-02-4.18E-02
-1.93E-01-2.41E-02 1.01E-01 5.98E-02 1.48E-07
 4.50E-05 5.18E-05 2.42E-02-1.22E-02-7.65E-02-1.77E-01-1.47E-01
-1.74E-01-8.00E-02-1.08E-02-2.51E-03 0.
BVAC( 241)= 5.1E+00      PPERP= 3.9E-05 1.9E-04 5.0E-01 2.0E-04 5.
BVAC( 241)= 5.1E+00           P= 3.4E-02 2.1E-02 3.4E-01 2.0E-02 3.
LOP=11118 NI=161 NPLOT=1$
```

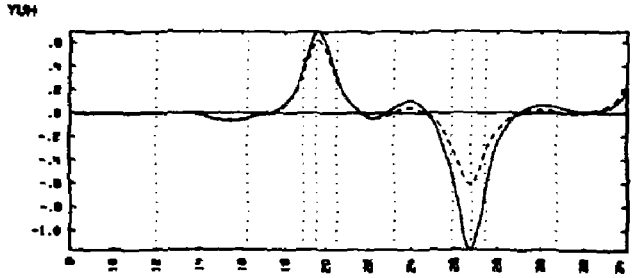
PARALLEL CURRENT RSQ = 1.400E-01 THETA = 7.854E-01
BETAD = 0.250 0.000 0.000 0.500 0.000 0.500 0.000
0.000

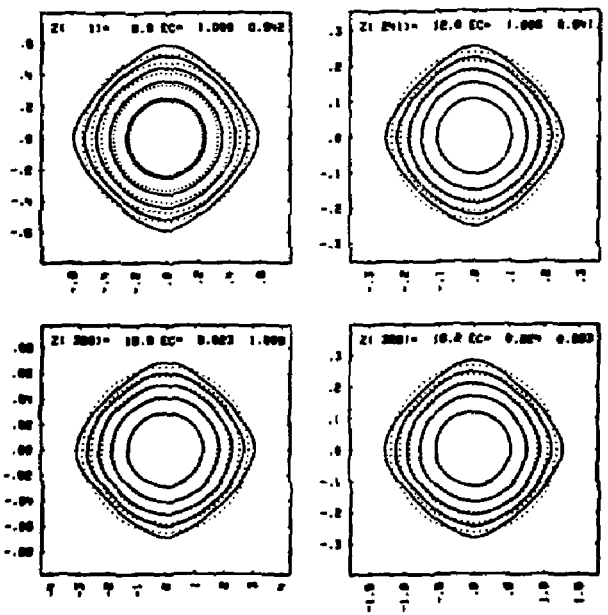


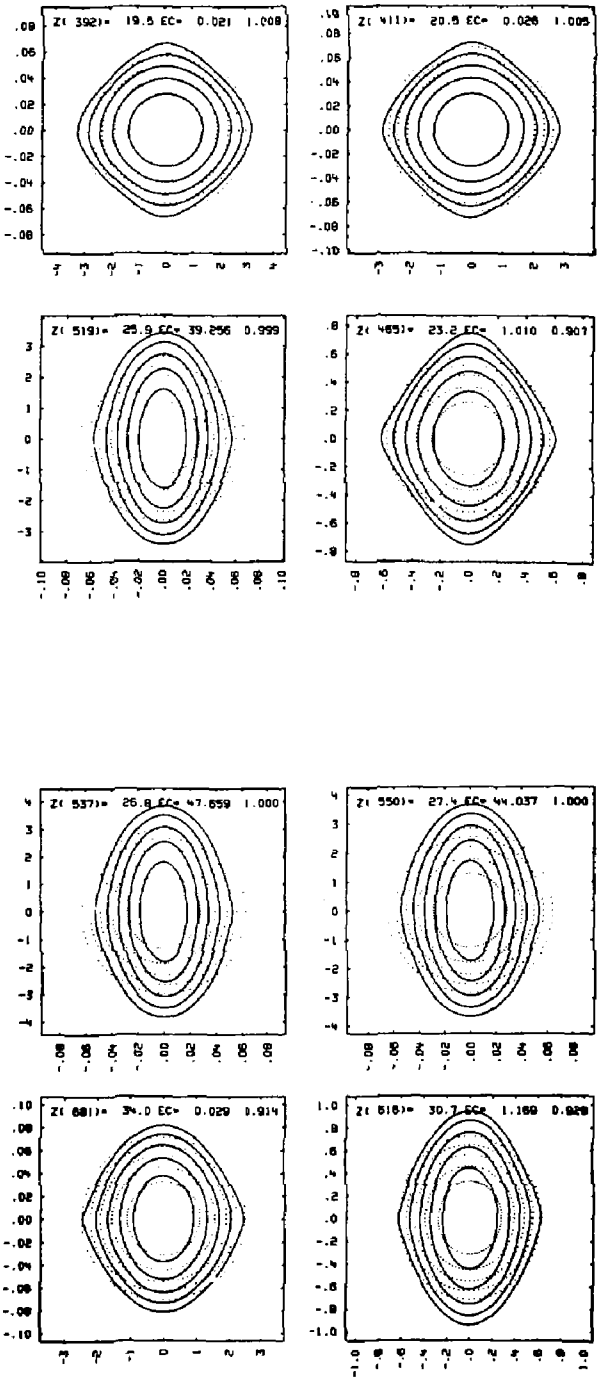
FIELD LINE VS Z RSQ= 1.400E-01 THETA= 7.854E-01
BETAD = 0.250 0.000 0.000 0.500 0.000 0.500 0.000
0.000

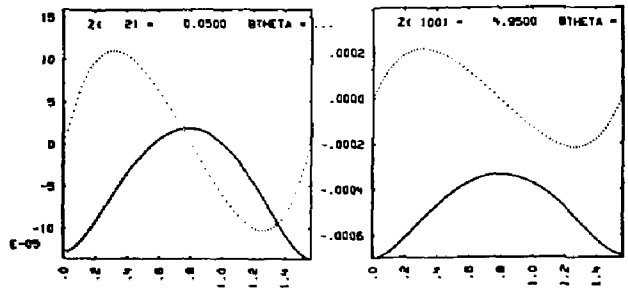


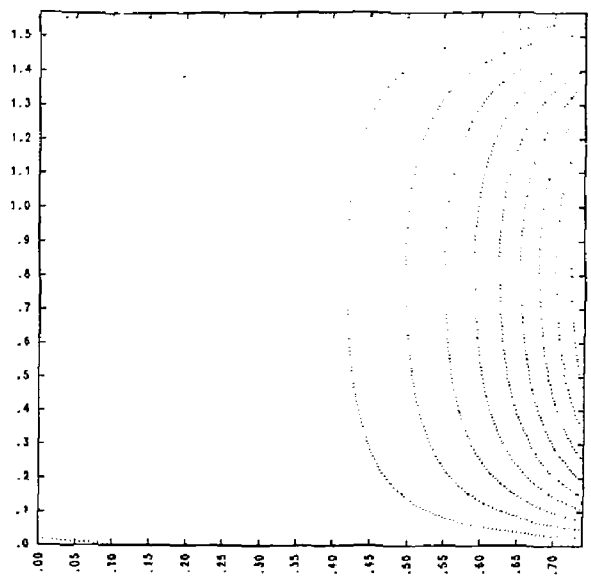

YAH


YLH




Z(392)= 19.5 EC= 0.021 1.008
Z(411)= 20.8 EC= 0.026 1.005
Z(519)= 25.9 EC= 39.256 0.999
Z(465)= 23.2 EC= 1.010 0.901
Z(537)= 26.8 EC= 47.659 1.000
Z(550)= 27.4 EC= 44.037 1.000
Z(681)= 34.0 EC= 0.029 0.914
Z(618)= 30.7 EC= 1.169 0.929


Z(21 = 0.0500 BTHETA =
Z(1001 = 0.9500 BTHETA =
E-05



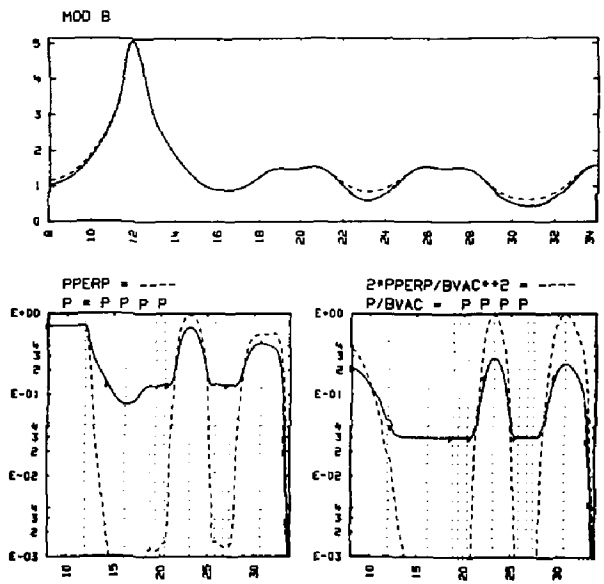
PARALLEL CURRENT CONTOURS AT Z = 2.320E+01, PLOTTED IN LOCAL POLAR COORDINATES, (R,THETA).

CONTOUR	CURRENT	R	THETA	CURRENT
1	-5.609E-01	3.77E-01	2.54E-01	-2.61E-02
2	-5.048E-01	5.33E-01	2.54E-01	-1.04E-01
3	-4.487E-01	6.51E-01	2.54E-01	-2.35E-01
4	-3.926E-01	3.77E-01	7.98E-01	-3.69E-02
5	-3.365E-01	5.33E-01	7.98E-01	-1.48E-01
6	-2.804E-01	6.51E-01	7.98E-01	-3.32E-01
7	-2.244E-01	3.77E-01	1.30E+00	-2.61E-02
8	-1.683E-01	5.33E-01	1.30E+00	-1.04E-01
9	-1.122E-01	6.51E-01	1.30E+00	-2.35E-01
10	-5.609E-02			
11	-3.553E-15			

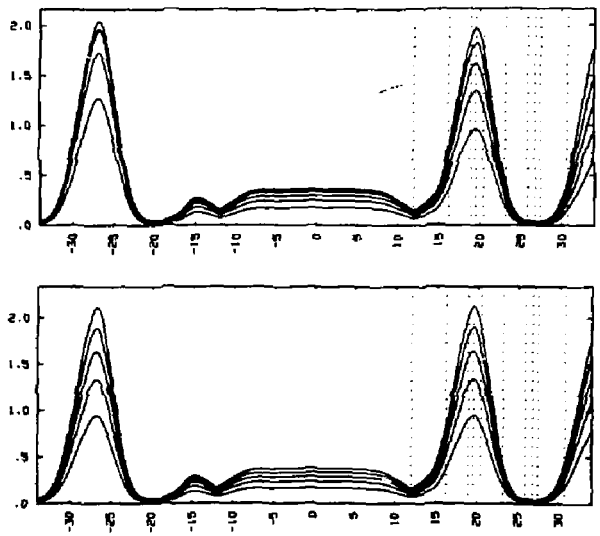
TO EXPRESS CURRENT IN AMP/CM**2, MULTIPLY VALUES BY:

BC*(10/4PI)*(EFFI LENGTH UNIT IN CM)

WHERE BC IS THE CENTRAL CELL MIDPLANE FIELD IN EFFI UNITS.

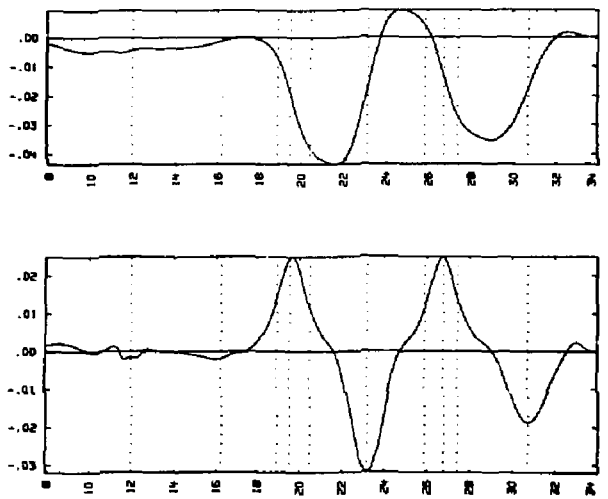


EX COORD. OF FIELD LINES VS Z FOR THETA= 7.854E-01
BETAD= 0.250 0.000 0.000 0.500 0.000 0.500 0.000 0.000



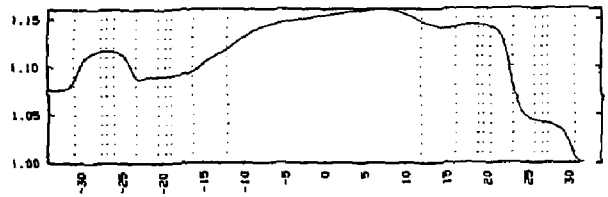
IPOW=1 V1="BETAD(1)" VS="BETAD(6)" BETA=0$
BETAD(1)= 3.322E-01 RSQ = 1.400E-01 RSQ = 1.400E-01
BETAD(6)= 5.000E-01 COMEG = 0. LITR = 1
LOP=1000B N1=160 NPLOT=1$

```
EIGEN OMEGA =  0.          RSQ =  1.400E-01 THETA =  7.854E-01
BETA= 0.332 0.000 0.000 0.500 0.000 0.500 0.000 0.000
```

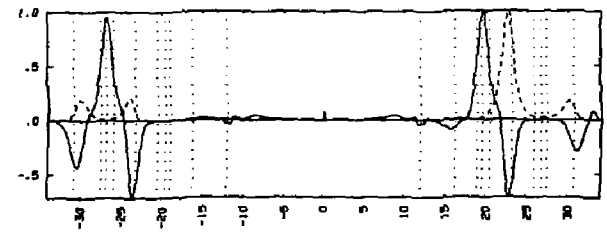



```
LFLUTE=0 NWALL=1 SBETA=-.28$
BETAD(1)= 3.139E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =     3
KRIC=0$
BETAD(1)= 3.139E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =     0
LOP=10008 NPLOT=1$
```

```
EIGEN OMEGA =  0.          RSQ =  1.400E-01 THETA =  7.854E-01
BETA= 0.314 0.000 0.000 0.500 0.000 0.500 0.000 0.000
```

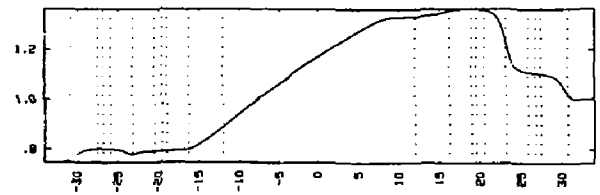



```
DRIVE=-2.12E-01 2.96E-01    BEND= 1.36E-02
```

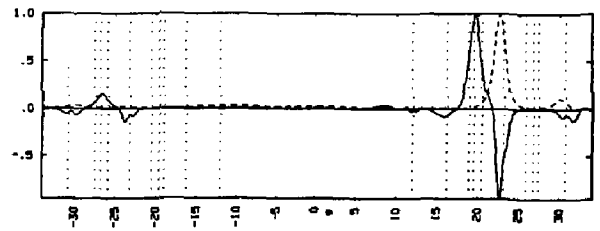



```
KRIC=1 SBETA=.28 BETA=1.E-20 BETAD=.3$
BETAD(1)= 3.104E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =     6
KRIC=0$
BETAD(1)= 3.104E-01 RSQ      = 1.400E-01 RSQ      = 1.400E-01
BETAD(6)= 5.000E-01 COMEG    = 0.        LITR =     0
LOP=10000 NPLOT=1$
```

EIGEN OMEGA = 0. RSQ = 1.400E-01 THETA = 7.854E-01
BETA= 0.310 0.000 0.000 0.500 0.000 0.500 0.000 0.000



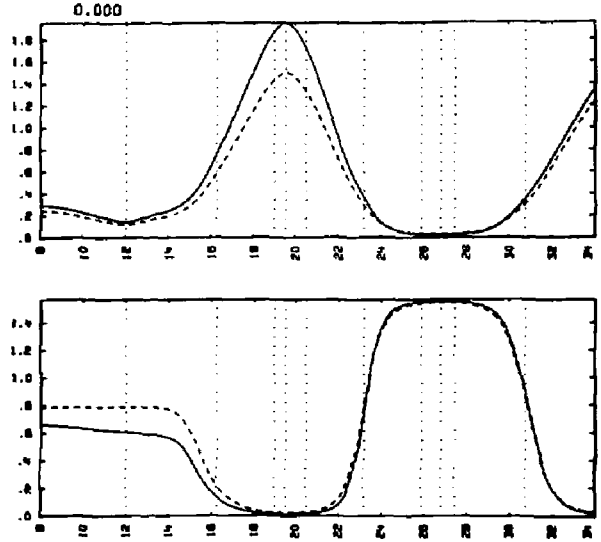
DRIVE=-1.54E+00 1.62E+00 BEND= 1.29E-01



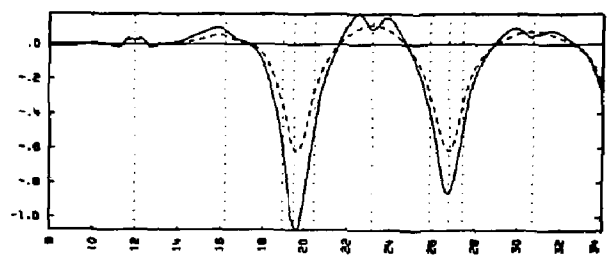
IPOH=0 BETAD=.255
EQUI-1.562E-02 1.858E-01 8.224E-02

LOP=1111B N1=161 NPLOT=1$

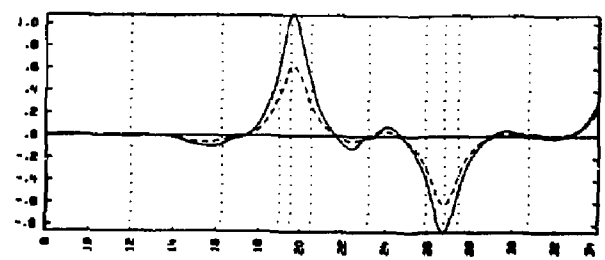
FIELD LINE VS Z RSQ= 1.400E-01 THETA= 7.854E-01
BETAD = 0.250 0.000 0.000 0.500 0.000 0.500 0.000
0.000

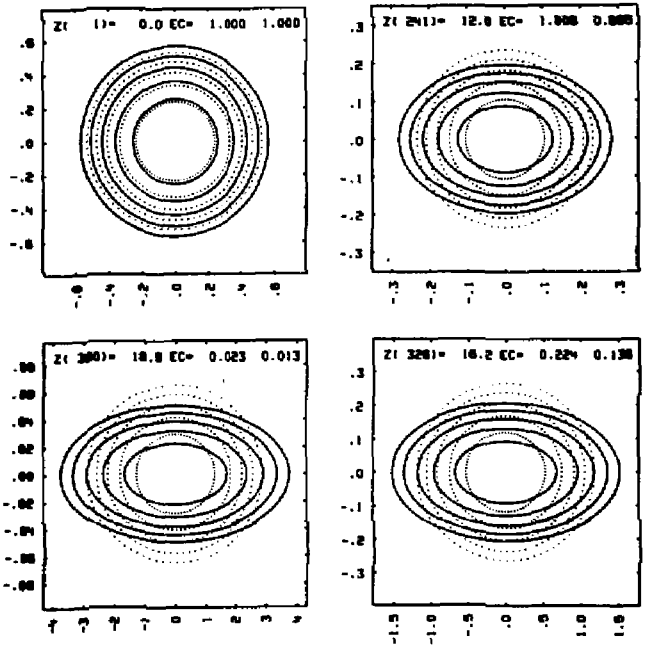


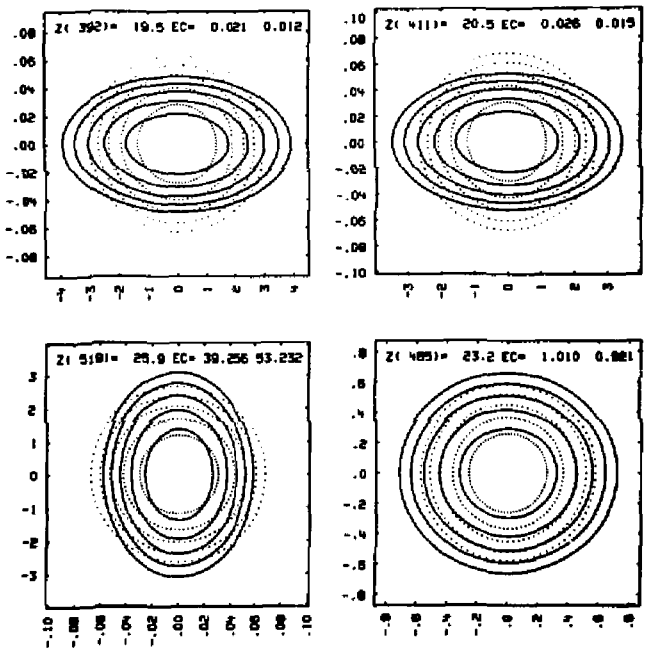
YAH

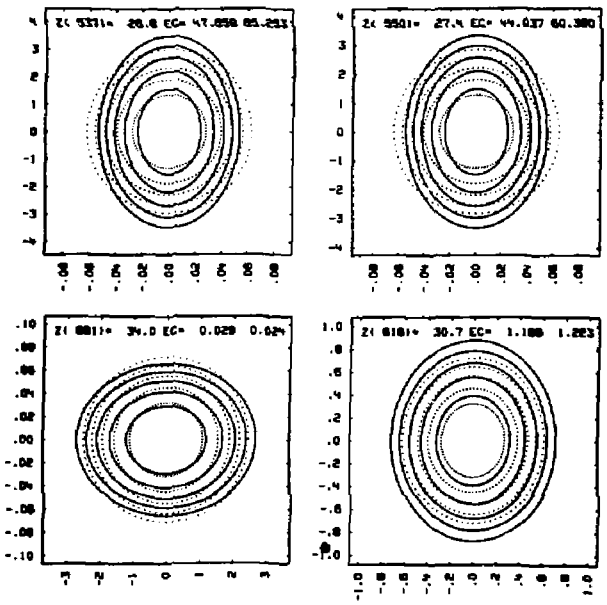


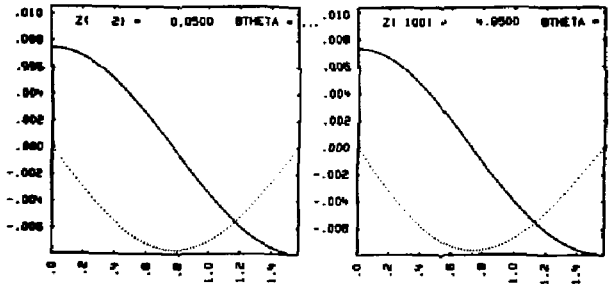
UH

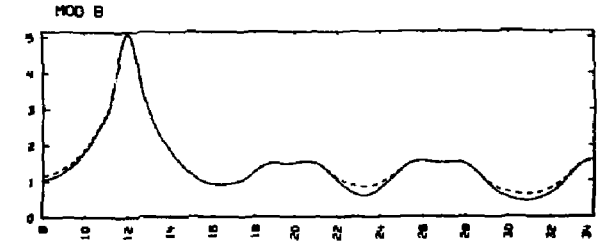


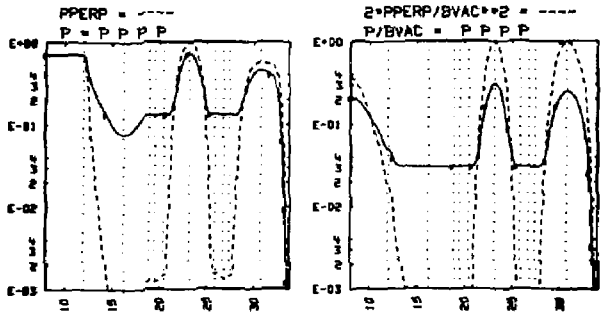




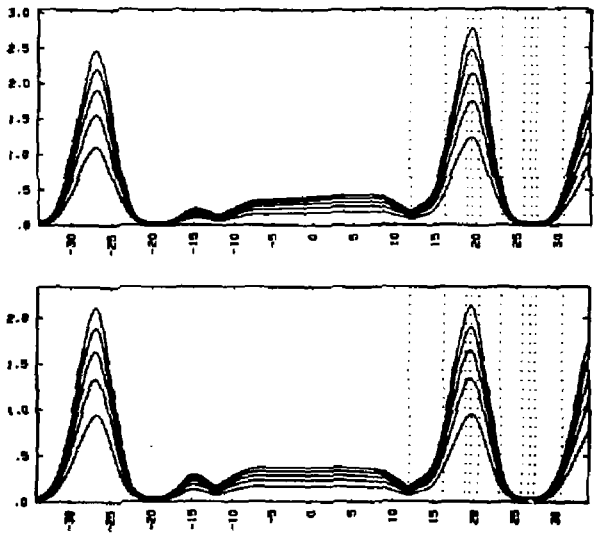








EK COORD. OF FIELD LINES VS Z FOR THETA= 7.854E-01
BETAD= 0.250 0.000 0.000 0.500 0.000 0.500 0.000 0.000



```
NDAT=1 MOSS(2)=" "$
```

```
              LDP

80X U18 RHB3

TV80L18.MFE.CRAY - VERSION 3.0

FR80 OUTPUT... 15:00:30 09/07/83C

       0039 FRAMES PLOTTED
```

APPENDIX D: Running EFFI

To produce an EFFI binary file you must execute the version of EFFI called XEFFI, which can be obtained as follows:

```
filem rds 365 .myeffi xeffi
```

The execute line for XEFFI is

```
xeffi i=file1,o=file2,p=file3 / <t> <v>
```

where

file1 = input file specifying units, accuracy criteria, coil geometry and currents, and flux line parameters.

file2 = printed output file

file3 = binary output file (i.e., <name>)

The parameters that define units and specify accuracy criteria can have their default values with two exceptions:

$P1 = 0.0,$

$P4 = 10^{-10}.$

Only one flux line need be computed. Its starting point should be

$$x_0 = a_c \times 10^{-3},$$

$$y_0 = a_c \times 10^{-3},$$

$$z_0 = 0.0,$$

where a_c is the radius of the circular coils in the central cell in consistent units. The length of the line, S, should be great enough that the line extends in z beyond the maximum in mod-B farthest from the central cell midplane, and the step size, ΔS, as small as possible without violating

$$\Delta S > S/1200.$$

APPENDIX E: Pressure Models

As many as three different plasma components can be present in each region of the machine, as summarized in Tables E1 and E2. It is assumed that the ψ and B dependence of the pressure is separable:

$$p_{\perp,\parallel}(\psi,B) = \nu(\psi)\hat{p}_{\perp,\parallel}(B) \quad ;$$

and that the radial profile, $\nu(\psi)$, is common to all regions, and is controlled by input parameter N6 as follows:

$$\nu(\psi) = \left(1 - \frac{\psi}{\psi_B}\right)^{N6} \qquad N6 = 0,1,2$$

$$\nu(\psi) = 1 - \left(\frac{\psi}{\psi_B}\right)^2 \qquad N6 = 4$$

The analytic forms used to model the B-dependence of each of the various components are as follows:

I. Maxwellian

$$\hat{p}_\perp^I = \hat{p}_\parallel^I = \frac{1}{2}\beta_c B_c^2$$

where B_c is the vacuum magnetic field strength on-axis at the midplane of the center cell.

II. Trapped, non-Sloshing

$$\hat{p}_\perp^{II} = \frac{1}{2}\beta_{II}\,B_{\substack{min\\vac}}^{\ 2}\left[\frac{B_{max}^2 - B^2}{B_{max}^2 - B_{min}^2}\right]^{1+n_7}$$

$$\hat{p}_{\parallel}^{II} = \frac{1}{2}\beta_{II} B_{\underset{vac}{min}}^{2} \frac{B_{max}^{2n_7-1}}{B_{max}^{2} - B_{min}^{2}} (B_{max} - B)\left\{1 + \left(1 + \frac{44}{15} n_7 - \frac{34}{15} n_7^2\right)\frac{B}{B_M}\right.$$

$$\left. + \frac{n_7}{15}(4 + n_7)\left(\frac{B}{B_M}\right)^2 \left(1 + \frac{B}{B_M}\right) + \frac{n_7}{10}(1 - n_7)\left(\frac{B}{B_M}\right)^4 \left(1 + \frac{B}{B_M}\right)\right\}$$

where $B_{\underset{vac}{min}}$ and B_{min} are respectively the vacuum and total minimum magnetic field strengths in the region, and B_{max} is the total field strength above which the pressure due to this component vanishes. The index n_7 (the input parameter, N7) can take the values zero ("ideal" model), 1 or 2.

III. Sloshing

$$\hat{p}_{\perp}^{III} = \frac{1}{2}\beta_{III} B_{\underset{vac}{min}}^{2} \left(\frac{B}{B_{min}}\right)^{\nu} \left(\frac{B_{max} - B}{B_{max} - B_{min}}\right)^{\mu-1} \frac{(\mu + \nu - 1)\frac{B}{B_{min}} - (\nu - 1)\frac{B_{max}}{B_{min}}}{(\mu + \nu - 1) - (\nu - 1)\frac{B_{max}}{B_{min}}}$$

$$\hat{p}_{\parallel}^{III} = \frac{1}{2}\beta_{III} B_{\underset{vac}{min}}^{2} \frac{B_{max} - B_{min}}{B_{min}} \frac{1}{\mu + \nu - 1 - (\nu - 1)\frac{B_{max}}{B_{min}}} \left(\frac{B}{B_{min}}\right)^{\nu} \left(\frac{B_{max} - B}{B_{max} - B_{min}}\right)^{\mu}$$

where B_{min} and B_{max} have the same meaning as in II, and μ and ν correspond to the input parameters XMU and XNU, respectively. The latter parameters are uniquely determined by specifying the mirror ratio at which $p_{\perp}^{III}$ has its peak value, and the ratio of this peak value to the value of $p_{\perp}^{III}$ at $B = B_{min}$.

IV. Passing

$$\left.\begin{aligned}
\hat{p}_{\perp}^{IV} &= \frac{1}{2}\,\beta_c\,B_c^2\left(\frac{B}{B_4}\right)^{2+\lambda} \\
\hat{p}_{\parallel}^{IV} &= \frac{1}{2}\,\beta_c\,B_c^2\,\frac{1}{1+\lambda}\left[(2+\lambda)\,\frac{B}{B_4} - \left(\frac{B}{B_4}\right)^{2+\lambda}\right]
\end{aligned}\right\} \quad z_4 \le z \le z_5$$

$$\left.\begin{aligned}
\hat{p}_{\perp}^{IV} &= \left[(2+n_7)\,\frac{B}{B_6 - B_5} - (1+\kappa)\right] B\,\hat{p}_{\parallel}^{IV} \\
\hat{p}_{\parallel}^{IV} &= \frac{1}{2}\,\beta_c\,B_c^2\left[\frac{2+\lambda}{1+\lambda}\,\frac{B_5}{B_4} - \frac{1}{1+\lambda}\left(\frac{B_5}{B_4}\right)^{2+\lambda}\right]\left(\frac{B}{B_5}\right)^{1+\kappa}\left(\frac{B_6 - B}{B_6 - B_5}\right)^{2+n_7}
\end{aligned}\right\} \quad z_5 \le z \le z_6$$

where λ is the input parameter ZLAM, n_7 is the same as in II, and κ is determined by the code using continuity of $p_{\perp}^{IV}$ at $z = z_5$. The positions z_4, z_5, and z_6 are, respectively, the inboard edge of the pumping region, the location of minimum magnetic field in the thermal barrier, and the point at which the passing plasma pressure vanishes. The field strengths B_4, B_5, and B_6 correspond to these positions. The code chooses z_5 and z_6 automatically, based on the value of the input parameter LOGT. The boundary of the pumping region, z_4, is determined by the input parameter N4.

MODEL	DESCRIPTION
I	MAXWELLIAN
II	MAGNETICALLY TRAPPED, NON-SLOSHING
III	MAGNETICALLY TRAPPED, SLOSHING*
IV	PASSING

Table E-1. Plasma Components Available

*in center cell only

	CONFIGURATION			
	TMX-U	MARS	TARA	TDF (KELLY)
CENTER CELL	I, II, III	I, II, III	I, II, III	I, II, III
AXICELL		I, II, IV	II, IV	
TRANSITION REGION		II, IV	II, IV	II, IV
MHD ANCHOR	II, IV	II, IV	II, IV	II, IV

Table E-2. Plasma Components Available in Various Regions of Four Different Tandem Configurations