MHD Linear Instability Code User's Manual

H. R. Hicks
J. W. Wooten

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Printed in the United States of America Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$2.25

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Contract No. W-7405-eng-26

COMPUTER SCIENCES DIVISION

MHD LINEAR INSTABILITY CODE USER'S MANUAL

H. R. Hicks and J. W. Wooten

JUNE 1976

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MHD LINEAR INSTABILITY CODE USER'S MANUAL**H. R. Hicks and J. W. Wooten****ABSTRACT**

This handbook tells the casual user how to run the program MHD2V106, a computer program to determine linear growth rates and eigenmodes for an ideal MHD plasma in a cylinder or toroid of rectangular cross section.

I. INTRODUCTION

The computer program MHD2V106 enables the user to determine ideal MHD instability growth rates and eigenmodes¹. The version described here assumes that the plasma is confined in a periodic cylinder or toroid with rectangular conducting walls. The code is most efficient¹ at high β ($\beta \geq 1$). The mass density may not go to zero anywhere in the device.

The exponentially growing solution is determined by iteration using a leap frog scheme on a Cartesian grid. Criteria for convergence of the iteration, as well as the size of the finite difference grid, are under programmer control.

The program can generate its own equilibrium or it can read data from the toroidal equilibrium code EQUREL. Either way, this program can provide the linear eigenmodes to MHD3V106, a non-linear MHD code. It can also generate data for the vector plotter programs PLOT10 and SQR91.

The source code is written in PL/I and is compiled by the IBM PL/I Optimizing Compiler² (Version 1, Release 2.2). The program has successfully run on an IBM 360/91 and 360/195.

The simplest way to direct the execution of the code is through the input data files. A very great variety of options is available to the user. In fact, almost all of the variables can be modified in this way. Therefore, we will describe the purpose, format and content of each file.

A more profound control over the program can be had by compiling a user-written routine, EXPERT. This routine is frequently called during execution. It provides the user an opportunity to change essentially any quantity each time it is called. To use this facility, a source listing should be obtained.

The next section gives a simple example of running the code. Later sections give more complete information.

II. SYNOPSIS AND EXAMPLES

Although a total of eight files (Table I) can be read or written during a run, much can be accomplished with only SYSIN, SYSPRINT and DIARY. Appendix A shows the minimal input deck necessary. This produces a run using default values for all quantities. The resulting output (SYSPRINT) is shown in Appendix B. The main features of the output are:

- a) A copy of the input data.
- b) A summary of the starting parameter values.
- c) Growth rate for each iteration.
- d) Contour plot of final perturbed pressure.

A run may terminate for any of several reasons:

- a) 'CONVERGENCE CRITERIA MET': the growth rate has been obtained, and the final arrays contain the linearized eigenfunctions.
- b) 'TIME EXPIRED': the CPU time remaining in the job is not enough to continue.
- c) 'NUMBER OF STEPS EXCEEDED': number of iterations has exceeded the value of NRUN (default = 2000).

The default run uses a calculated equilibrium for a square (2. x 2.) cylinder of length 2π . The central q value is .9, and the mass density is unity everywhere.

The equilibrium quantities are independent of z (the longitudinal coordinate). The perturbed quantities (eigenfunctions) are assumed to have the form

$$\xi(x,y,z) = \xi_0(x,y) \cos(z/\lambda) + \xi_1(x,y) \sin(z/\lambda) .$$

Each perturbed physical quantity, $\vec{B}$, p , $\vec{v}$, $\vec{E}$ is stored on two 'planes': 0 and 1. Thus plane 0 contains the quantities at $z=0$, plane 1 at $z=\lambda/4$.

Each array has not only plasma points, but a ring of wall points, and (on the outside) a ring of fictitious 'ghost' or 'guard' points. The arrays are printed or contour plotted such that x increases to the right, y is up and z is out of the page. If the printed arrays are more than 10 points across, they are printed in blocks from left to right. For toroidal runs, the major axis is to the left.

III. REGION AND RUN TIME

For the default run the region is 200K bytes and the run time is 30 seconds (360/91).

The maximum time for any case is given roughly by

$$250\mu\text{sec} * PI * PJ * \text{NRUN} .$$

The memory requirement is approximately given by

$$(170 + .192 * PI * PJ)K \text{ bytes} .$$

IV. SYSIN

SYSIN contains the only user-written input to the program. All other input files are written by other programs. SYSIN can be used to control the program operation, modify the physics or numerics or control the printout.

Each program run makes two reads from SYSIN using PL/I data directed input², for example

```
variable1 = value1, variable2 = value2, ...; .
```

The end of each read is indicated by a semicolon. Any variables not so assigned take on default values (Table II). Any columns may be used, with any number of items per card and any number of cards. Thus the default SYSIN consists of a card or cards containing only two semicolons (Appendix A). An example of a non-default SYSIN is shown in Appendix C.

When the job is about to terminate, an attempt is made to read again from SYSIN. If there is data for two more reads, another case is run. In this way any number of cases can be run per job. The default values are reinstated for each new case, thus the data for case 1 is not used in case 2.

Only the variable COMBAS.THIS_RUN_IS_TO_BE_RESTARTED can be read on the first read. If it is set true ('1'B), then equilibrium ρ , p and $\vec{B}$ and perturbed ρ , p , $\vec{v}$ and $\vec{B}$ are read from file IN2D. This allows continuing a previous run which saved data on OUT2D. All variables whose names begin COMBAS or COMGCV are also read from IN2D.

The second read will accept a great number of quantities. The most useful of these are given in Table II along with their default values. Following is a discussion of each of these variables.

COMBAS.EQUILIBRIUM IS CALCULATED

TRUE('1'B): A standard analytic equilibrium¹ for a cylinder of rectangular (XSIDE by YSIDE) cross section is used. The safety factor on the magnetic axis, q , parameterizes the equilibrium (see COMGCV.Q). For example, q can be varied to find the maximum growth rate, the marginal points, and even modes of differing n number (see HR, HI).

FALSE('0'B): Instead of the analytic equilibrium, an equilibrium is read from INEQ (see INEQ for details). This file is generated by a relaxation equilibrium code³, which can yield either a cylindrical or toroidal equilibrium. The aspect ratio is determined by the equilibrium code input and should not be changed. However, the q value can be varied as above.

COMGCV.LAMBDA_BAR, COMGCV.XSIDE, COMGCV.YSIDE

These fix the z , x , and y extents of the box. The extent in z is $2\pi \cdot \text{LAMBDA_BAR}$. Thus the default box is $2 \times 2 \times 2\pi$. These can all be individually varied, even for a toroid, where the toroidal mode number and major radius are given by

$$n = (\text{XSIDE}/2.) \cdot \text{ASPECT_RATIO} / \lambda$$

and

$$R_0 = n \lambda .$$

COMGCV.Q

Safety factor, q , at the magnetic axis. If all other variables have default values, an $m = 1$ mode is produced for

$$.1 \leq q \leq 1.1 .$$

Even if the equilibrium is read from INEQ, it is rescaled to have the desired q .

HI, HR

Dimensioned (0:3). The perturbed quantities are initially all zero except for the velocity field, the initialization of which depends on HR and HI. HR (HI) controls the initialization of plane 0(1). Generally the convergence of the code is facilitated by anticipating the m value (poloidal mode number) and setting all H's to zero except $HI(m) = HR(m) = 1$. This initialization is not crucial as long as the initial field is not orthogonal to the final mode.

COMGCV.PI, COMGCV.PJ

Grid is PI x PJ including wall and ghost points. Thus, only PI-4 x PJ-4 points are in the plasma. In each time step, only half of the points are advanced. PI and PJ should be chosen large enough to support the mode accurately (a finer grid is required for higher m and near marginal points), yet not so large as to waste storage. The arrays occupy roughly $4 \times 48 \times PI \times PJ$ bytes of storage.

COMGCV.PLOT, COMGCV.PUNCH, COMGCV.PRINT

Dimensioned (3). These variables control the output of the arrays at various times in the run. The subscript refers to the point in the run:

- 1: before iteration,
- 2: during iteration (see FREQOUT),
- 3: after iteration.

PRINT refers to outputting the array on SYSPRINT. PLOT refers to contour plotting the array on SYSPRINT. PUNCH refers to sending a condensed form of a vector array to PDPOUT to be subsequently vector plotted by PLT10 or SQR91. For example: PRINT(3) = 'PO,V,P', will cause the equilibrium pressure, perturbed velocity and pressure to be printed when the run completes. Table III shows which arrays can be output under each option. Any other requests will be ignored. The order of the output is not dependent on the ordering within the input character string. The 'Request Name' should be used in the character strings, rather than the notational or array names.

PLANES

This character string controls which (of the two) planes are output during the three above output options. To output

both planes:	PLANES = '0,1';
neither:	PLANES = ' ',
only plane 1:	PLANES = '1'.

COMBAS.WE _ARE _SAVING _DATA

If true ('1'B) the data structures are saved on file OUT2D to be read later to either restart MHD2V106 or to start the non-linear code MHD3V106.

COMBAS.GROWTH_BLOCK

To determine convergence, a statistical analysis is done on blocks of instantaneous growth rates. Generally the default value (60) is fine for cases which converge in <1000 steps. For longer runs, a larger value (-200) will speed convergence. The number of steps in a growth block times delta t should correspond to about 1-2 Alfvén transit times.

COMBAS.NRUN

The maximum number of time steps. It is hard to predict a good value for NRUN. Generally, it should be larger near marginal points and for higher m number (higher q).

COMGCV.STABILITY_FRAC

The code uses an explicit time advancement scheme which is numerically unstable for large time steps. The actual time step is proportional to STABILITY_FRAC, such that when STABILITY_FRAC=1 the scheme is marginally stable.

COMGCV.XLOOK, COMGCV.YLOOK

The growth rate is evaluated only for one plasma point: (XLOOK*PI, YLOOK*PJ). The default values are fine for an m=1 mode. For others, a point away from the center (.6, .6) is better, since v_y is used to calculate the growth rate and this may be zero for m=2 mode at center.

COMBAS.FREQOUT

The output called for by PUNCH(2) or PRINT(2) or PLOT(2) is done every FREQOUT time steps. If FREQOUT=0, then it is never done.

COMBAS.LABEL5, COMBAS.LABEL6

These character fields can be used to print a message in the output.

MAX_DRIFT, MAX_DRIFT_RATE

These variables control the convergence. If they are made smaller, the convergence criteria are more strict.

COMBAS.USING_DIARY

If true, the file DIARY is interrogated to obtain a unique job sequence number. Otherwise RUN_NUMBER=0.

V. SYSPRINT

The SYSPRINT generated by a default run is shown in Fig. 2. The main features of a SYSPRINT file are:

- a) Copy of SYSIN
- b) If INEQ was read, then some equilibrium variables are printed
- c) Run number
- d) LABRUN output: Gives most of the variables to be used in run.
- e) Any initial array output requested.
- f) Instantaneous growth rates, and block summaries. Intermediate output as requested.
- g) Reason for termination and final growth rate.
- h) Message if data was stored on file OUT2D.
- i) Final output as requested.
- j) Run number.
- k) Summary page. In many cases the summary is all one needs to see.
- l) If PARM.GO = 'R': Execution time storage management report.

VI. DIARY

The program reads a single fixed binary number (with record I/O) from DIARY into RUN_NUMBER. The number is incremented by 1 and rewritten onto DIARY ready for the next job.

VII. INEQ

This file is written by EQUREL and contains array sizes, α (inverse aspect ratio), current, XSIDE, YSIDE, q , and the arrays $\vec{p}^0$, $\vec{B}^0$, $(\rho^0)^{-1}$.

VIII. IN2D

This is a file which has been written (under the name OUT2D) by a previous run of MHD2V106. It contains everything needed to continue a run. Some variables may be changed in SYSIN, but beware. No harm comes from changing output options, but changing array sizes would be unpredictable.

IX. OUT2D

At the end of a run, if WE_ARE_SAVING_DATA is true ('Y'), then enough information is written in file OUT2D to allow the program to be resumed by reading it back in (under the name IN2D).

X. PDPOUT

Any PUNCH request generates output for this file. It contains (in compact form) the information to plot vector arrays with the routines SQR91 or PLT10.

XI. PLIDUMP

The storage management report is written here by PL/I. It allows a better determination of the ISA (initial storage area). However, ISA(1K) is adequate, although slow. For production runs with fixed array sizes, some improvement can be obtained by setting for ISA parameter in the JCL to that value obtained from the storage management report.

ACKNOWLEDGMENT

This work was supported by the Thermonuclear Division at ORNL.

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1. J. W. Wooten, H. R. Hicks, G. Bateman, and R. A. Dory, *Preliminary Results of the 3-D Nonlinear Ideal MHD Code*, ORNL/TM-4784 (November 1974); J. W. Wooten and H. R. Hicks, *Preliminary Description of the Linear and Nonlinear Ideal MHD Codes*, UCCND/CSD/INF-21 (May 1975); G. Bateman, W. Schneider, and W. Grossmann, "Ideal MHD Instabilities as an Initial Boundary-Value Problem," *Nuclear Fusion* 14, 669-683 (1974).
2. *PL/I Checkout and Optimizing Compilers: Language Reference Manual*, (IBM) SC33-0009.
3. R. G. Bateman, Private Communication.

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TABLE I. Files

<u>Filename</u>	<u>In/Out</u>	<u>Used If</u>	<u>Comment</u>	<u>Used In Default Run</u>
SYSIN	In	Always	Standard input	Yes
SYSPRINT	Out	Always	Standard output	Yes
DIARY	In/out	USING_DIARY='1'B	Run number to be assigned to run	Yes
INEQ	In	EQUILIBRIUM_IS_CALCULATED='0'B	Data from equilibrium code	No
IN2D	In	THIS_RUN_IS_TO_BE_RESTARTED='1'B	Data from previous run	No
OUT2D	Out	WE_ARE_SAVING_DATA='1'B	Data for nonlinear code or restart as IN2D	No
PDPOUT	Out	Punch output requested	Output to vector plotter	No
PLIDUMP	Out	PARM.GO='R'	Storage report	No

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TABLE 11

ITEM	DEFAULT	TYPE
COMBAS.EQUILIBRIUM_IS_CALCULATED	'1'B	BIT
COMGCV.LAMBDA_BAR	1.	FLOAT
COMGCV.XSIDE	2.	FLOAT
COMGCV.YSIDE	2.	FLOAT
COMGCV.Q	.9	FLOAT
HI(0:3)	0. (HI(1)=1.)	FLOAT
HR(0:3)	0. (HR(1)=1.)	FLOAT
COMGCV.P1	19	FIXED
COMGCV.PJ	19	FIXED
COMBAS.PLOT(3)	' '(PLOT(3)='P')	CHAR
COMBAS.PUNCH(3)	' '	CHAR
COMBAS.PRINT(3)	' '	CHAR
PLANES	'0'	CHAR
COMBAS.WE_ARE_SAVING_DATA	'0'B	BIT
COMBAS.GROWTH_BLOCK	60	FIXED
COMBAS.NRUN	2000	FIXED
COMGCV.STABILITY_FRAC	.8	FLOAT
COMGCV.XLOOK	.5	FLOAT
COMGCV.YLOOK	.5	FLOAT
COMBAS.FREQOUT	0	FIXED
COMBAS.LABEL5	' '	CHAR
COMBAS.LABEL6	' '	CHAR
MAX_DRIFT	.005	FLOAT
MAX_DRIFT_RATE	.001	FLOAT
COMBAS.USING_DIARY	'1'B	BIT

TABLE III

a) Output Options					
Output Options Variable	<u>Equilibrium Quantities</u>		<u>Perturbed Quantities</u>		
	Scalars (ρ^0, p^0)	Vectors (B^0, J^0)	Scalars ($\rho, p, \Delta \cdot B$)	Vectors (V, B, E)	Tensor (T)
PLOT	✓		✓	✓	
PUNCH		✓		✓	
PRINT	✓	✓	✓	✓	✓

b) Correspondance of Names											
Notational Name	ρ^0	p^0	B^0	J^0	ρ	p	$\Delta \cdot B$	V	B	E	T
Array Name	N_RH0_INV	N_PO	N_BO	N_JO	N_RH0	N_P	DIV_B	N_V	N_B	N_E	N_T
Request Name	RH00	PO	BO	JO	RH0	P	DIV(B)	V	B	E	T

Appendix A

```

//NRSDV106 JOB (14116),'SAVE200,76 9104-2'
//*CLASS CPU91=355,IC=6,L=6,R=270K
//*ROUTE PRINT REMGT=4
//A EXEC PLTALG.
// PARM.LKED='LIST,ACKREF',
// PARM.GU='ISA(1K)',REGION.GD=270K,TIME=1
//LKED.SYSLIB DD
//          DD UNIT=2314,VOL=SER=LADPK1,DISP=SHR,
// DSN=MOU.XMF14388.MHULH,SPACE=(1K,(10,20,5))
//LKED.SYSIN DD *
//  INCLUDE SYSLIB(PH02V106)
//  INCLUDE SYSLIB(PLICCN)
//  ENTRY PLISTART
/*
//GO.DIARY DD DSN=MOU.XMF14388.DIARY,
//  DISP=SHR,UNIT=2314,VOL=SER=LADPK1
//GO.SYSIN DD *
//          ;          ;
/*
//

```

Appendix B

DATE = 76/02/06 TIME = 1701:20.349

COPY OF SYSIN:

;

 

[illegible]

PHL2LD
 AUTHORS: J.W. BLIVEN, M.R. HICKS & J.F. ROBERTS
 LOCATION: ORNL OAK RIDGE, TENN, 37830
 VERSION: 1 REVISION: 6

RUN: 1-77 IS BEING STARTED

COMMON DATA

NRCL: 1
 FRLOCUT: 0
 GROWTH_BLOCK: 00
 NRCL: 2000
 NSTEP: 1
 LEAP FROM USED
 CYLINDRICAL LIMIT USED
 WE ARE NOT SAVING DATA
 EQUILIBRIUM HAS BEEN CALCULATED
 WE ARE NOT SAVING DATA ON TAPE
 NO EXPERT CALLS IN INNER LOOP

COMMON DATA

DX: 1.25000E-01
 DY: 1.25000E-01
 DZ: 1.25000E+00
 DELTA_T: 7.00332E+05
 ALPHA: 0.00000E+00
 ASPECT_RATIO: 1.00000E+03
 PLASMA_TIME: 0.00000E+00
 STABILITY_FRAC: 9.00000E-01
 FULLX: 4.00000E+00
 FULLY: 4.00000E+00
 FULLZ: 3.97000E-01
 DT: 7.00332E+05
 SCALE_FACTOR: 7.00332E+05
 XSIDE: 2.00000E+00
 YSIDE: 2.00000E+00
 ZSIDE: 6.28318E+00
 XLOOK: 5.00000E-01
 YLOOK: 5.00000E-01
 ZLOOK: 5.00000E-01
 GK: 7.00332E+05
 KZ: 1.00000E+00
 GAMMA: 1.00000E+00
 Q: 9.00000E-01
 MAX_CHANGE: 1.00000E-02

END_FRAC: 5.50000E+01
 LAMBDA_BAR: 1.00000E+00

PI: 19
 PJ: 19
 PK: 8
 MI: 18
 MJ: 18
 MK: 7
 NI: 17
 NJ: 17
 NK: 6

GLOBAL DATA

MAX_DRIFT: 5.00000E-03
 MAX_DRIFT_RATE: 1.00000E-03
 DANCE: -3.53553E-01

CONPLT: 5
 LEVDEC: 5

1.2 CLEAR VARIABLES AND ARRAYS
1.6 DEFINE PHYSICAL INIT CONDITIONS
CONSCV.MAXBETA= 5.061763E-01

CONSCV.DELTA_T= 5.221254E-02;

NSTEP: 1
 PLASMA_TIME: 0.00000E+00
 1.0 START TIME RUN

GROWTH HISTORY AT STEP= 0.2054E+00 AND STEP= 122 AT (10, 10)

5.5762E+00	-1.0735E+00	-1.8322E+00	-2.0500E+00	-4.4241E+00	-7.6205E+00	-2.2240E+01	2.3747E+01
5.0144E+00	2.5457E+00	7.0913E+00	-6.6497E-01	-2.3549E+00	-6.9915E+00	-1.6750E+02	1.0010E+01
5.1302E+00	3.4590E+00	2.5013E+00	2.6294E+00	1.6205E+00	1.2952E+00	9.7952E-01	6.5190E-01
2.9704E+01	-1.0273E+01	-5.7324E+01	-1.1400E+02	-1.9029E+00	-3.0078E+00	-6.4295E+00	-9.7945E+00
-2.2210E+01	1.1630E+01	3.9745E+00	9.9043E-01	-1.9057E+00	-1.0429E+01	2.4319E+01	7.7454E+00
4.4110E+02	3.3634E+02	2.2027E+02	1.3300E+02	1.0450E+02	6.1314E+01	3.1507E+01	6.3264E+02
-3.1350E+02	-2.1097E+01	-1.6260E+01	-5.6420E-01	-7.1549E-02	-9.6627E-01	-1.3703E+00	-1.7362E+00
-2.2019E+00	-2.6304E+00	-2.7507E+00	-2.1129E+00				

GROWTH RATE: -3.7041E+00
 DRIFT: 1.0000E+00
 DRIFT_RATE: 1.5700E-01
 # STEPS THIS RUN: 60

GROWTH HISTORY AT STEP= 1.2534E+01 AND STEP= 242 AT (10, 10)

-5.0011E-01	1.2549E+00	2.2632E+00	2.5494E+00	2.4520E+00	2.2016E+00	1.0990E+00	1.5042E+00
1.2662E+00	9.4047E-01	6.3295E-01	3.2521E-01	3.6701E-02	-2.1927E-01	-6.2726E-01	-5.0009E-01
-6.7754E-01	-7.2150E-01	-7.0003E-01	-6.2005E-01	-4.7691E-01	-2.6012E-01	-2.5315E-02	1.9003E-01
3.0473E-01	5.5491E-01	6.7774E-01	7.6103E-01	6.0750E-01	6.2337E-01	6.2129E-01	0.0995E-01
7.0025E-01	7.0010E-01	6.7257E-01	5.6122E-01	4.1533E-01	2.4572E-01	6.7971E-02	-1.0030E-01
-2.4154E-01	-3.3905E-01	-3.7979E-01	-3.5720E-01	-4.7364E-01	-1.0937E-01	2.7525E-02	2.0522E-01
3.6400E-01	5.6100E-01	5.0472E-01	6.2408E-01	6.2740E-01	6.0510E-01	5.6506E-01	5.1505E-01
6.0307E-01	6.0720E-01	1.6500E-01	3.2271E-01				

GROWTH RATE: 4.3614E-01
 DRIFT: 1.0702E+01
 DRIFT_RATE: 1.7001E+00
 # STEPS THIS RUN: 60

TIME TABLE

GROWTH HISTORY AT STEP= 1.6276E+01 AND STEP= 314 AT (10, 10)

2.9017E-01	2.5614E-01	2.1479E-01	1.6500E-01	1.1187E-01	6.5353E-02	2.7400E-02	6.7614E-03
9.0303E-03	3.2074E-02	6.7115E-02	1.2517E-01	6.9474E-01	2.7022E-01	3.4510E-01	4.1141E-01
4.6445E-01	4.9362E-01	4.9942E-01	4.6470E-01	4.4516E-01	3.7360E-01	3.3524E-01	2.7705E-01
2.2411E-01	1.0434E-01	1.0649E-01	1.5790E-01	1.5460E-01	1.5001E-01	1.0492E-01	1.7100E-01
1.0039E-01	1.1114E-01	2.3648E-01	2.1074E-01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

GROWTH RATE: 2.2030E-01
 DRIFT: 9.3060E-01
 DRIFT_RATE: 2.3940E-01
 # STEPS THIS RUN: 30

29

NSTEP:
PLASMA_TIME:

315
1.629006+01

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[illegible][illegible]

SUMMARY

PHU2V106

RUN: 017

PHYSICS

Q:	0.900000	XSIDE:	2.000000
MAXIMUM BETA:	0.500176	YSIDE:	2.000000
CYLINDRICAL LIMIT USED		LAMBDA-BAR:	1.000000
		EQUILIBRIUM WAS ANALYTIC	

THIS RUN DID NOT CONVERGE - CPU TIME EXPIRED

NUMERICS

GRID POINTS IN X:	19
GRID POINTS IN Y:	19
STABILITY FRACTION:	0.800000
STEPS RUN:	315
GROWTH LOCK:	60
DELTA T:	0.052213

STATISTICS

DATE:	760206
TIME:	170120349
CPU TIME FOR RUN:	28.983
CPU TIME/STEP:	0.092010
CPU TIME/STEP/POINT:	3.000255

Appendix C

```

//HKS4V100 JCS (14116), *SAVE200, /o 3104-2*
//*CLASS CPU=1=32S, IC=0, CARDS=30, L=0, K=2/OK
/*ROUTE PRINT REMOTE4
//A EALL PLIALG,
// PARM.LKED=*LIST,NOXREF*,
// PARM.GC=*3,ISA(1K)*, REGION.GC=2/OK, TIME=30
//LKED.SYSLIB DD
//          DD UNIT=2314, VOL=SER=CAUPK1, DISP=SHR,
//   USN=HCU.RMF1438H.PHDLIE, SPACE=(TRK,(10,20,5))
//LKED.SYSIN DD *
  INCLUDE SYSLIB(PH02V100)
  INCLUDE SYSLIB(PLTCCH)
  ENTRY PLISTART
/*
//GO.JIARY DD DSN=HCU.RMF1438H.JIARY,
//   DISP=SHR, UNIT=2314, VOL=SER=CAUPK1
//GO.PLIDUMP DD SYSOUT=A
//GO.PDPLUT DD SYSOUT=M
//GO.CUT20 DD DSN=T.HKS04116.0UT20001.S15075L1,
//*   DISP=(SHR,KEEP)
//   UNIT=SPU4, DISP=(,CATLG), SPACE=(TRK,(10,2),RLS1),
//   DCB=(RECFM=VHS, BLKSIZE=7294, LRECL=32/56) USE SPCLSCR
//GO.IREQ DD DSN=T.HKS04116.040001.S15, DISP=OLD
//GO.SYSIN DD *
;
  CUMBAS..NRUN=4000,
  CUMBAS.PRINT(3)=*PO,BO*,
  CUMBAS.Q=.45,
  CUMBAS.EQUILIBRIUM_IS_CALCULATED=*0*0,
  CUMBAS.WF_ARE_SAVING_DATA=*1*0,
/*
//

```