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# NUMERICAL ANALYSIS OF NONLINEAR LONGITUDINAL COMBUSTION INSTABILITY IN METALIZED PROPELLANT SOLID ROCKET MOTORS

## VOLUME II: COMPUTER PROGRAM USER'S MANUAL

by

Jay N. Levine and F. E. C. Culick

TECHNICAL REPORT, AFRPL-TR-72-88
JULY 1972

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**13. ABSTRACT**

The primary objective of the current effort was the development and solution of a nonlinear analytical longitudinal instability model, which would allow all of the various governing phenomena to be accounted for in a coupled manner. The two primary elements of the current instability analysis are a method of characteristics solution of the two phase flow in the combustion chamber of the motor, and a coupled calculation of a transient burning rate. The transient burning rate analysis presented, herein, is a unique and interesting development. It is based on an extension of the most popular, linear, harmonic combustion response model. The current method allows the calculation of propellant burning response to a pressure disturbance of arbitrary waveform, for all time, including the period immediately following the initiation of the disturbance. The analysis also includes a model for velocity coupled response. Therefore, for the first time, the nonlinear effects of velocity coupling on the growth of pressure waves in a combustion chamber can be computed.

The instability solution, itself, begins with the calculation of the steady state two-phase flow in the motor. The flow in the combustion chamber is calculated by numerically integrating the equations of motion. The nozzle flow is found using the constant fractional lag approximation. The steady state conditions are then perturbed and the subsequent wave motion in the motor is calculated numerically, using the method of characteristics. The nature of the engine response is dependent upon the interaction the various gain and loss mechanisms in the engine, which are, in turn, a function of the propellant burning response, the size and amount of particulate matter present, the magnitude and shape of the initial disturbance and the geometrical configuration of the motor.

The instability model is currently subject to the following limitations. Only motors with cylindrically perforated grain were considered. The gasdynamic flow was assumed to be one-dimensional and the particles in the gas stream were taken to be of uniform size and inert. The nozzle flow is assumed to be quasi-steady.

A series of instability solutions have been calculated, wherein some of the main parameters such as particle size, burning rate constants, and initial disturbance waveform and magnitude have been varied, in an attempt to qualitatively assess the behavior and validity of the present model. From all appearances, the behavior of the model is quite realistic and limited comparisons with data have been quite encouraging.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Combustion instability | | | | | | |
| Solid propellant combustion | | | | | | |
| Nonlinear | | | | | | |
| Metalized propellant | | | | | | |
| Two phase flow | | | | | | |
| Velocity coupling | | | | | | |
| Transient burning rate | | | | | | |
| Oscillatory burning | | | | | | |

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## FOREWORD

The present report is part of a two volume set which describes a nonlinear solid rocket motor instability analysis and computer program. Volume I contains the analytical basis for the computer program and a discussion of the results obtained to date: Volume II of the set describes the computer program and serves as a user's manual.

This investigation is entitled NUMERICAL ANALYSIS OF NONLINEAR LONGITUDINAL COMBUSTION INSTABILITY IN METALIZED PROPELLANT SOLID ROCKET MOTORS. The two volumes are additionally subtitled as follows:

Volume I - Analysis and Results

Volume II - Computer Program User's Manual

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under contract number F04611-71-C-0060 with Robert J. Schoner as technical monitor. Jay N. Levine of Ultrasystems (formerly Dynamic Science) was program manager.

This technical report has been reviewed and is approved.

Paul J. Daily, Lt. Col. USAF
Chief, Technology Division

TABLE OF CONTENTS

## NOMENCLATURE

| | | |
|---|---|---|
| $A$ | - | burning rate parameter, Eq. (4-14) |
| $A_b$ | - | admittance function |
| $A_n$ | - | nozzle admittance function |
| $a$ | - | gas only, sound speed |
| $a_F$ | - | sound speed based on $P_F$ and $T_F$ |
| $B$ | - | burning rate parameter, Eq. (4-32)<br>also, fractional lag parameter, Eq. (5-6) |
| $B_v$ | - | burning rate parameter for velocity coupling |
| $C$ | - | ratio of solid to gas specific heats, $C_s/C_p$ |
| $\tilde{C}$ | - | constant in steady state burning rate, Eq. (3-5) |
| $C_D$ | - | particle drag coefficient |
| $C_k$ | - | erosive burning constant, Eq. (3-5) |
| $C_m$ | - | see $\beta_1$ |
| $C_p$ | - | specific heat of gas at constant pressure |
| $C_s$ | - | specific heat of solid particles |
| $C_v$ | - | specific heat of gas at constant volume |
| $C_1$, $C_2$,<br>$C_3$, $C_4$ | - | defined in Eq. (7-34) |
| $D_p$ | - | port diameter |
| $E$ | - | normalized surface activation energy, $E_w/R_o\overline{T}_w$<br>also, integral defined by Eq. (8-16) |
| $E_w$ | - | activation energy of surface reaction |
| $e$ | - | internal energy |
| $F_p$ | - | particle-gas interaction force per unit volume, Eq. (3-8) |
| $f$ | - | frequency<br>also, as defined by Eq. (8-14) |
| $G$ | - | defined by Eq. (7-8) |
| $g$ | - | defined by Eq. (6-17) |
| $H$ | - | defined by Eq. (4-20) |
| $h$ | - | enthalpy |
| $h_{11}$ | - | defined by Eq. (8-12) |
| $K$ | - | fractional lag constant, Eq. (5-3) |
| $K'$ | - | chamber fractional lag constant, Eq.(7-44) |
| $k$ | - | thermal conductivity, also complex wave number |

| | | |
|---|---|---|
| $k_s$ | - | thermal conductivity of the solid particles |
| $L$ | - | length of the grain, also fractional lag constant, Eq. (5-4) |
| $L'$ | - | chamber fractional lag constant, Eq. (7-44) |
| $\ell$ | - | perimeter of the grain |
| $M$ | - | Mach number, also number of points on initial line |
| $M_b$ | - | Mach number at burning surface |
| $\dot{m}$ | - | particle mass, also surface mass flux |
| Nu | - | Nusselt number |
| $n$ | - | pressure exponent in steady state burning rate |
| $n_v$ | - | constant in velocity coupled analysis, Eq. (4-75) |
| $n_w$ | - | exponent of pressure dependence of surface reaction rate |
| $P$ | - | pressure |
| $P_{ref}$ | - | reference pressure in steady state burning rate |
| $P_F$ | - | chamber pressure |
| Pr | - | Prandtl number |
| $p$ | - | pressure, also used for Laplace transform variable |
| $p_{11}$ | - | defined by Equation (8-10) |
| $Q_f$ | - | heat release per unit mass |
| $Q_p$ | - | particle-gas heat transfer rate per unit volume, Eq. (3-14) |
| $Q_w$ | - | heat of reaction for processes at burning surface |
| $q$ | - | see $\ell$ |
| $R$ | - | gas constant, also normalized throat radius of curvature |
| $R_o$ | - | universal gas constant |
| $R_b$ | - | response function, Eq. (4-35) |
| Re | - | Reynolds number based on particle diameter and particle-gas relative velocity |
| RHS | - | right hand side of a characteristics compatibility relation |
| $r$ | - | linear burning rate |
| $S_b$ | - | area of burning surface |
| $s$ | - | dimensionless Laplace transform variable, $= i\kappa\omega/\bar{r}^2$ |
| $T$ | - | temperature |
| $T_F$ | - | adiabatic flame temperature |
| $t$ | - | time |
| $t_c$ | - | defined by Eq. (7-33) |
| $u$ | - | axial velocity |
| $u_t$ | - | threshold velocity |
| $W$ | - | defined by Equation (4-28) |

$w$ - reaction rate divided by gas density

$x$ - axial distance

$\alpha$ - growth constant

$\alpha_p$ - particle damping constant

$\hat{\alpha}_p$ - defined in Eq. (8-35)

$\beta_1$ - particle to gas weight flow ratio

$\beta_2$ - ratio of particle to gas mass burning rates, $w_p/w$

$\gamma$ - ratio of gas specific heats, $C_p/C_v$

$\delta$ - a small increment in time

$\delta'$ - equal to $t_c\delta$

$\epsilon_1, \epsilon_2$ - convergence criteria for characteristics calculations, also used in velocity coupling analysis (Eq. 4-[illegible])

$\kappa_s$ - thermal diffusivity of the propellant

$\Lambda$ - defined by Eq. (4-27)

$\lambda$ - complex function of frequency, Eq. (4-8)

$\mu$ - viscosity

$\xi_s$ - equals $\bar{r}x/\kappa_s$

$\rho$ - density

$\rho_F$ - density based on $P_F$ and $T_F$

$\rho_m$ - density of the metal oxide particles

$\rho_s$ - density of the solid propellant

$\sigma$ - particle radius

$\sigma_1, \sigma_2$ - defined by Eq. (4-62)

$\tau$ - nondimensional time, $\bar{r}^2 t/4\kappa_s$, also used in Section 2 to denote period of oscillation

$\tau_v$ - characteristic relaxation time for particle velocity, Eq. (3-1)

$\tau_T$ - characteristic relaxation time for particle temperature, Eq. (3-1)

$\Phi$ - defined by Eq. (5-10)

$\varphi$ - phase angle

$\Omega$ - nondimensional frequency, Eq. (4-9)

$\omega$ - mass burning rate, per unit length, per unit cross-sectional area, Eq. (3-4); also occasionally used for angular frequency

Subscripts

| | | |
|---|---|---|
| e | - | end of the propellant grain |
| f | - | flame |
| g | - | gas |
| $\ell$ | - | for the $\ell$th mode of oscillation |
| p | - | particle |
| o | - | initial or stagnation value |
| t | - | at the nozzle throat |
| w | - | at the burning surface of the propellant |

Superscripts

| | | |
|---|---|---|
| $()^*$ | - | in Sections 3, 5 and 6 only, denotes a dimensional variable |
| $()'$ | - | denotes fluctuation |
| $\bar{()}$ | - | in Section 4 denotes steady state variable, in Section 5 denotes an "equivalent" gas value, in Section 7 denotes an average quantity |
| $()^+$ | - | pertaining to a right running characteristic |
| $()^-$ | - | pertaining to a left running characteristic |
| $()^{(r)}$ | - | real part of |

# 1. INTRODUCTION

This report describes and serves as a user's manual for a new nonlinear longitudinal solid rocket motor instability program. This program is capable of treating metallized propellants and considers both pressure and velocity coupled transient burning response.

The analysis, and assumptions, upon which this program is based, are discussed in Volume 1 of this report.

This volume contains a description of all of the subroutines and program functions used in the instability program. A dictionary of all of the variables contained in blank or labeled common is also included. Descriptions of the input required to operate the program, and the output generated, are presented; followed by a sample case which serves to illustrate the text, as well as providing a method for checking out the program.

## 2. PROGRAM DESCRIPTION

Functionally, the Nonlinear Longitudinal Solid Rocket Motor Instability Program can be considered to consist of two distinct sets of subroutines: those required to solve for the steady state flow in the chamber and nozzle; and those which solve the actual instability problem. All of the subroutines and program functions which, together, comprise the Instability Program, are briefly discussed, in alphabetical order, below:

### SUBROUTINE AUXSUB

Part of the nest of routines for solving the steady state problem. This routine evaluates the derivatives in the differential equations

$$\frac{df_i}{dx} = g_i$$

by calling subroutine GFUNC to evaluate the

### SUBROUTINE BVP (NEWTI, LEGS, AUXSUB, FDET, IREAD)

Subroutine BVP and its associated subroutines AUXSUB, FCALC, FDET, GFUNC, LEGS, NEWTI, and RKAM, constitute a general package for the solution of two point boundary value problems. This package is part of the Dynamic Science library of computer programs and detailed information on any of these subroutines is available on request.

Subroutine BVP is the overall control routine for this package. In the current usage, nominal values for all of the quantities usually input to BVP have been set. This allows the user to employ the program without becoming familiar with the whole complex BVP package. In order to provide some measure of flexibility, however, the option to modify several of the input parameters has been retained, through the IREAD option. (See the discussion in the description of input section).

FUNCTION CNUSELT (RE, PR, SM)

This function computes the Nusselt number as a function of Reynolds number (RE) and Prandte number (PR). SM in the calling sequence is not currently used.

SUBROUTINE DØPLØT

This routine calls subroutine MPLØTS to plot the pressure, velocity, particle velocity and burning rate perturbations versus axial distance.

FUNCTION DRAG (RE)

This function computes the particle drag coefficient as a function of Reynolds number (RE).

SUBROUTINE FCALC (AUXSUB, FDET)

Part of the nest of subroutines for solving the steady state two point boundary value problem. This subroutine controls the integration of the differential equations and the print out of the solution. (Controls the printing of the conserved quantities and their derivatives. The printout for the actual flow variables is controlled in Subroutine FLOVARS). The printout is controlled through the ITRIG and LTRIG parameters, as discussed in the description of input.

## SUBROUTINE FDET

Part of the nest of subroutines for solving the steady state two point boundary value problem. This subroutine calculates the difference between the mach number at the end of the grain as calculated by integrating the equations of motion and the mach number calculated from the fractional lag nozzle solution. and then prints out the result.

## SUBROUTINE FLOVARS

This subroutine solves for the flow variables themselves (U, T, P, $U_p$, $T_p$, $\rho_p$ from the conserved quantities, as required by the steady state solution package.

The flow variables are also stored according to the mesh size used in the characteristics solution. (The variables are stored every NTRIG-th step). These variables are then printed out, and some are later modified in Subroutine LINEX.

The steady state solution is achieved by integrating the chamber pressure until the mach number at the end of the grain matches that calculated in Subroutine STEDYST. The flow variables at the end of each iteration are printed out.

## FUNCTION FORCE (R,RP, U, UP, T, TP, PF)

This function computes the drag force between the particles and gas as a function of local gas and particle properties.

## SUBROUTINE FPT (I, J, KP)

This subroutine solves the field point unit process which makes up the bulk of the method of characteristics solution. The arguments I, J, KP correspond to points 1, 2 and 3, respectively, in the analytical description of the field point solution.

The subroutine faithfully follows the analytical description and except for the following points, does not require further discussion.

The total burning rate at point 3 (W3) is found by extrapolating from the last time a transient burning rate calculation was made (TIMTB(NK)), using the burn rate derivatives (DWDT). Linear interpolation is used to obtain the burning rate at X locations between those at which the burn rate is found directly.

In the solution for the particle density at point 3 (RHOP3) it was convenient to drop the area terms at this time. In the future, if variable area ports are considered, this portion of the program will have to be modified.

## SUBROUTINE FRAKLAG (E, GBAR)

This subroutine calculates a fractional lag solution for the nozzle. In doing so it establishes compatible values of K (the fractional lag parameter and GBAR (the isentropic exponent of the equivalent ideal gas). The parameter E, which relates the actual gas mach number to the equivalent gas mach number, is also calculated. At the conclusion of the subroutine the results of the fractional lag solution are printed out.

SUBROUTINE GFUNCT (XXI, F, G, PF)

This subroutine is part of the set of steady state routines and it evaluates the derivatives in the differential equations (see subroutine AUXSUB). The variable XXI is the local value of X at which the derivatives are to be evaluated.

FUNCTION HEAT (U, UP, R RP, T, TP, PF)

This program function calculates the heat transfer between the particles and gas as a function of gas and particle properties.

SUBROUTINE INPUT

This subroutine performs the following functions:

1. Zeroes COMMON/CHAR/
2. Sets nominal values for some of the $DATA input variables and some other constants.
3. Reads Title Card.
4. Reads $ DATA Input
5. Calculates additional initial values
6. Writes out the $ DATA input quantities
7. Changes the units of various quantities from those input to those used internally, as follows:

Nondimensional areas at the end of the grain and throat are calculated from the input diameters.

$$A_e = \frac{\pi D_p^2}{4L^2}$$

$$A_t = \frac{\pi D_t^2}{4L^2}$$

L is changed from inches to feet

$P_{f_o}$ is changed from psi to psf

$\rho_s$ is changed from g/cc to lb $sec^2/ft^4$ (slugs)

$\rho_m$ is changed from g/cc to lb $sec^2/ft^4$ (slugs)

$\sigma$ the particle radius in feet is calculated from the input particle diameter in in microns, by multiplying it by $\frac{3.2808}{2} \times 10^{-6}$

$\tilde{C}$ is converted to feet/sec and then divided by the reference pressure (in psf) to the n th power.

$C_p$ is changed from $\frac{BTU}{lb^\circ R}$ to $\frac{ft^2}{sec^{2\circ}R}$

$\varkappa$ is changed from $\frac{cm^2}{sec}$ to $\frac{ft^2}{sec}$

SUBROUTINE INT

This subroutine is the master control routine for the instability solution.

First various initial quantities and counters are set. The initial data as computed in subroutine LINEX is then printed out, and if called for, it is stored for plotting at a later time.

A cycle of the characteristics solution is then computed in two sweeps by repetitively calling subroutine FPT. The characteristics are tested for crossing. If crossing occurs, the solution is terminated. The characteristics cycle is then completed by calling the left hand and right hand boundary point routines, LHB and RHB, respectively.

At the end of each of the above cycles the mesh point having the smallest value of time (not counting the right hand boundary point) is identified. Subroutine INTERP is then called to interpolate the results back into a rectilinear mesh, at the original x locations and time = t min.

Every NBCALC characteristics cycles, a new transient burning rate calculation is obtained. After calling subroutine TRBRNA to update counters, subroutine TRBURN is called to calculate the burning rate perturbations at each of the points called for. Burning rate solutions are obtained only for every NTB th point on the initial line. The burning rate derivatives are then calculated by simple first order differencing and the mass burning rate at each location is found by adding the perturbation to the initial value. The burning rate at those points where it is not directly calculated, is then found by linear interpolation.

At this point the solution is then printed out every NPRNT characteristics cycles. The pointers K and L, used to direct storage for subroutines FPT, LHB and RHB, are then shifted back to their original values in preparation for the next cycle.

Before the next cycle is begun, however, several tests and/or operations are performed. If the last calculation carried the solution past the next plot time, the variables of interest are stored for plotting. If the number of times this information has been stored (JPLØT) is equal to the maximum specified (NPLTF), subroutine DØPLØT is called and the stored information is plotted (NPLTF curves to each graph).

In order to reduce the storage required to compute the burning response over many cycles part of the past history is dropped, periodically. After NINT burn rate calculations have been performed the burning rate perturbation is calculated as the sum of two parts (see subroutine TRBURN). The first part due to a disturbance starting at t = o and ending at the time corresponding to the NINT th calculation ($t_{NINT}$) the second part due to a pressure and/or velocity disturbance which originates at $t_{NINT}$. After 2 * NINT calculations the effect of the disturbances during the first interval, up to $t_{NINT}$, is dropped completely (it should have become negligible if NINT has been chosen large enough). This process is accomplished by storing the second interval disturbances (PTB2 and VTB2) and their corresponding burn rate perturbations (EMTB2 and EMTBV2) over their respective first interval values. The storage for the time vector, TIMTB and time interval array, DTIM, is also shifted, and the counter NCYC is reset to NINT (it was 2 * NINT). The values of the running integrals (RUNI etc.) are also reset. This process is then replaced every additional NINT cycles. Hence, if desired, large times can be reached without running out of storage.

Before the storage shifts are effected pertinent variables from the first interval are printed out before the information is lost. (Future modification could allow this information to be saved on tape, disk or drum files).

After the above portion of the routine the current time is compared to TMAX. If TMAX has not been reached the whole integration procedure is repeated again. If TMAX has been reached the program checks to see if any plots versus axial distance have been stored and not plotted. If so, DØPLØT is called. Additionally, if le[illegible]n NINT burn rate calculations have been made when TMAX is reached PTB1 an[illegible]TB1 are plotted versus TIMTB at x = o and x = 1. If velocity coupling is being considered VTB1 and EMTBV1 are then plotted versus TIMTB at several different x locations.

SUBROUTINE INTERP

After each cycle of the characteristics solution is completed this subroutine interpolates within the characteristics mesh to obtain a set of points at the original x locations on the initial line, all at the same time (TMIN).

As a result of the mesh geometry and the velocity at the end of the grain, the right hand boundary point always occurs at a time somewhat less that all of the other characteristics intersections. The routine, therefore, extrapolates (linearly) to establish a right hand boundary values at TMIN.

Linear interpolation is then used to find values for the variables of interest at each of the original x locations. At this stage each of the points will, in general, be at a different time. Another linear interpolation is then performed to obtain a series of points, all at TMIN.

SUBROUTINE ITER (FI, XI, XNEW, NOO)

This subroutine finds the root of an equation by the secant method.

SUBROUTINE LEGS

This subroutine is part of the set of steady state routines. It is a general matrix inversion routine and called from subroutine NEWTI to aid in calculating the next guess for the chamber pressure, PF.

SUBROUTINE LHB

This subroutine is part of the method of characteristics solution and solves for points on the left hand boundary x = o. It follows the analytical description of the solution faithfully, and as such, does not require detailed discussion. (See subroutine FPT for some additional comments).

## SUBROUTINE LINEX

This subroutine performs additional computations required before the characteristics solution can be initiated, as follows:

1. If NSET = 1, the steady state solution is bypassed and uniform initial conditions with no mean flow are set up in subroutine LINEX. This option is used only under special circumatances when the program is being applied to something other than a solid rocket motor.

2. The steady state solution, calculated previously, is modified by the addition of a pressure and/or a velocity perturbation. Currently, the initial perturbations are of the form

$$P = P_o + \Delta P \cos(\pi x)$$
$$v = v_o + \Delta v \sin(\pi x)$$

P and $\Delta$P are normalized by the chamber pressure, PF; while v and $\Delta$v are normalized by the chamber sound speed, AF. In the future, the program should be modified to allow a choice between several types of initial perturbations; or the perturbation calculation could be made into a Program function, so as to be easily modifiable.

The initial gas temperature and density are modified isentropically, to reflect the initial pressure change. The initial particle velocity, temperature and density are currently not perturbed.

3. The next portion of the subroutine performs a series of initial calculations required for the transient burning rate calculation. First, blank common is zeroed. The transient burning rate parameters A, B and $B_v$ are then tested to see if they are compatible with the constraint

$$A < \frac{B + 1}{(B - 1)^2}$$

If not, the solution is terminated. The remainder of the routine either calculates initial values of quantities at t = o, or quantities which need only be calculated once.

## PROGRAM MAIN

The main program calls:

Subroutine: Input to read in and process the input data;

Subroutine: STEDYST to solve for the steady state solution;

Subroutine: LINEX to prepare the initial line data and,

Subroutine: INT to carry out the method of characteristic solution.

## SUBROUTINE MPLØTS

This subroutine is a general CALCOMP plot routine and is used as follows:

CALL MPLØTS (X,Y,N,M,NØ,LEN,TITLX,TITLY,HEAD,NX,NY,NH,FAC,LABL)

where

| | | | |
|---|---|---|---|
| X | = | vector or doubly dimensioned array (N x 1 minimum) of independent variables (see M for usage) | |
| Y | = | doubly dimensioned array of the dependent variables to be plotted. (N x NØ minimum) | |
| N | = | actual dimensioned length of the columns for the X and Y arrays. N <u>must</u> be at least 2 cells longer than the used dimensions of the X and Y arrays. | |
| M | = | a flag such that if | |
| | | $M > 0$ | there is an X vector corresponding to each Y vector curve, i.e., the Y(1,J) vector would be plotted versus the X(1,J) vector. |
| | | $M < 0$ | there is only one X vector corresponding to all of the Y(1,J) curves. |
| | | $M = 0$ | same as $M > 0$ except no legends will be plotted out. |
| | | $\|M\| = 1$ | legends will be plotted out with<br>LABL(1) = Hollerith header<br>LABL(J) = numerical value corresponding to the J-1 curve |
| | | $\|M\| = 2$ | legends will be plotted out with<br>LABL(I) = Hollerith name for the Ith curve |

| | | |
|---|---|---|
| | \|M\| = 3 | no legends will be plotted out |
| | \|M\| = 10,20 or 30 | same as \|M\| = 1,2, or 3 except that a border will be put on the plot frame |

| | | |
|---|---|---|
| NØ | = | number of curves to be plotted per frame |
| LEN(I) | = | a vector of length NO containing the length of the Ith curve (i.e., number of data points stored in the Ith column of the Y(J,I) array). |
| TITLX(I) | = | a vector containing the Hollerith label for the X-axis. |
| TITLY(I) | = | a vector containing the Hollerith label for the Y-axis. |
| HEAD(I) | = | a vector containing the Hollerith label for the master heading. |
| NX | = | number of characters in the X-axis label. |
| NY | = | number of characters in the Y-axis label. |
| NH | = | number of characters in the master heading label. |
| FAC | = | the factor by which the plot will be scaled. FAC = .8 will produce a plot compatible with an 8 1/2 x 11 page size. |
| LABL(I) | = | vector containing either Hollerith and/or floating point numerical data (see M-description). |

Common Linkage

In addition to the calling sequence, a labeled common area exists through which the user can exercise additional control over the plots. The label common area is

CØMMØN/RR1L/AXL,AYL,HT,ISYM,INC,LNTYP,NLPC,NDEC

where

| | | |
|---|---|---|
| AXL = | 10.0 | lenght of the X-axis |
| AYL = | 8.0 | lenght of the Y-axis |
| HT = | .14 | character height for header labels |
| ISYM = | 4 | ISYM+1 is the number for the starting symbol on the graphs |
| INC = | 1 | increment at which data points within a vector will be plotted. |
| LNTYP = | 1 | see the CALCØMP write up for subroutine LINE for the usage of this variable |
| NLPC = | 4 | number of curve legends per column |
| NDED = | 5 | used when \|M\| = 1 or 10. Controls the number of digits to the right of the decimal point on the values used in the legends. |

Note: The values underlined are the nominal values and have been set via DATA STATEMENTS. Therefore in order to change these values, you should use an execute statement in your program.

## SUBROUTINE NEWT1

This subroutine is part of the next of subroutines for solving the steady state two point boundary value problem. It uses Newton's method to generate new guesses for those initial values which must established in order to satisfy the boundary condition(s). In the current application, NEWT1 generates guesses for the chamber pressure, PF, until the mach number at the end of the grain matches that calculated from a fractional lag nozzle solution.

## SUBROUTINE PHIF

This subroutine is called from subroutine FRAKLAG and is used in conjunction with subroutine ITER to insure that the calculated values of K and GBAR ($\bar{\gamma}$) are compatible.

If $\gamma = \bar{\gamma}$ there are no particles, and the flag KTEST is set equal to 1. This flag is used elsewhere in the program to determine which calculations may be skipped when there are no particles.

## SUBROUTINE PRNT

This subroutine prints out the initial line, as well as the solution.

- After each NPRNT cycles of the characteristics calculation.
- At each time when the variables are stored for plotting.
- At the final time.

The header card containing case information is printed at the top of each page.

FUNCTION RATE (PF,RI,UI,TI,G,A)

This function computes the steady state mass burning rate, $\bar{\omega}$ , in nondimensional form.

SUBROUTINE RHB

This subroutine is part of the method of characteristics solution and solves for points on the right hand boundary x = 1. It follows the analytical description of the solution faithfully, and does not require detailed discussion. (See subroutine FPT for some additional comments).

FUNCTION RHS (FG,A,RHO,RHOP,U,UP,T,TP,W,DTIM,X)

This function is called by FPT, RHB and LHB to evaluate the right hand sides of the compatibility relations for both the momentum and energy equations.

The parameter FG is used to control which characteristics line is being considered, as shown below:

| | |
|---|---|
| FG = -1 | Right running characteristic |
| FG = 1 | Left running characteristic |
| FG = 2 | Energy equation along gas streamline |

## SUBROUTINE RKAM

This subroutine is part of the set of subroutines which solves the steady state two point boundary value problem. RKAM is a general subroutine for integrating simultaneous ordinary differential equations. It allows a choice between the Adams-Moulton and 4th Order Runge-Kutta methods. In the present program the Adams-Moulton method is used to integrate the six simultaneous differential equations which describe the steady state flow in the chamber.

## SUBROUTINE SCAL

Subroutine SCAL is used in conjunction with the plot subroutine MPLOTS. It is used to optimize the selection of a plot scale.

## SUBROUTINE STEDYST

This subroutine does the following:

1. Call subroutine FRAKLAG to find the fractional lag nozzle solution.
2. Solves a transcedental equation to find the mach number at the end of the grain as a function of port to throat area ratio. (Uses the results of the fractional lag solution).
3. Sets the boundary values at $x = o$ for each of the six variables FI(1) ... FI(6).
4. Calculates chamber fractional lag parameters, AK and AL. These parameters are used to obtain an approximate solution for the particle flow in the chamber when the flow is near dynamic equilibirum, and hence is subject to numerical difficulties when treated in the regular manner.

5. Subroutine BVP (which is actually a nest of subroutines) is called to solve for the steady state flow conditions in the chamber.

SUBROUTINE TFUNC

This subroutine computes gas viscosity as a function of temperature. The relationship currently contained in the program is actually Sutherland's law for air. This functional relationship should be changed to more accurately reflect the viscosity of the gas mixtures found in solid rocket motors.

SUBROUTINE TRBRNA(TMIN)

Each time a new set of transient burning rate calculations is to be made this subroutine: updates the required counters; stores the current time in the TIMTB array; calculates the size of the latest interval, DELTA, and stores it in the DTIM array. The TEM(I) array used in the trapezoidal integration procedure, is also calculated.

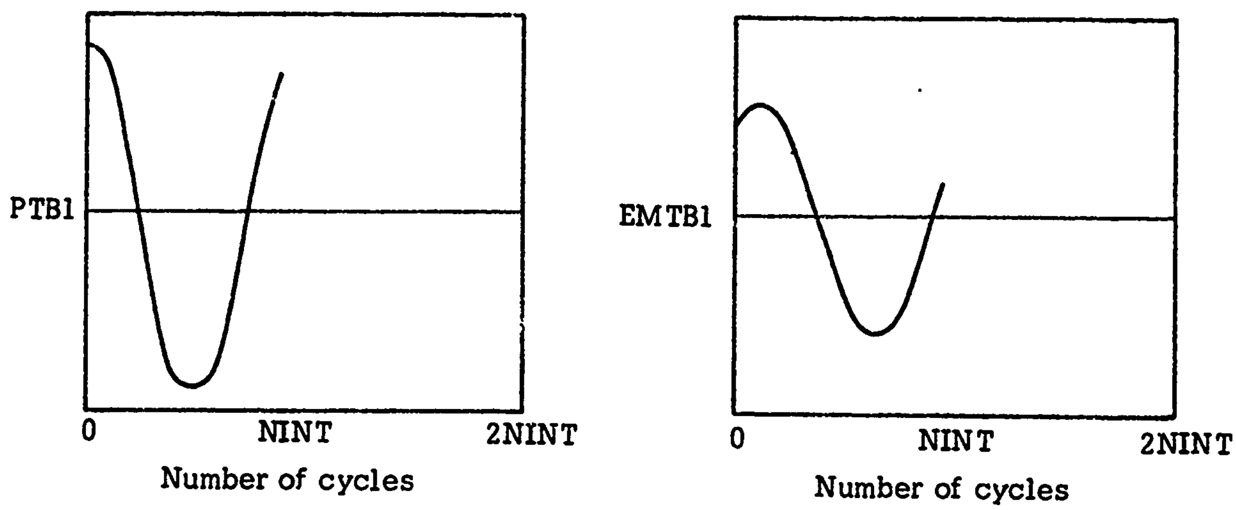
SUBROUTINE TRBURN(IK)

This subroutine calculates the transient burning rate response at the IK th x location.

The subroutine is actually divided into two distinct parts. Each part is structured identically: the first part calculates pressure coupled response; if KPRES $\neq$ 0; the second part calculates velocity coupled response, if KVEL $\neq$ 0.

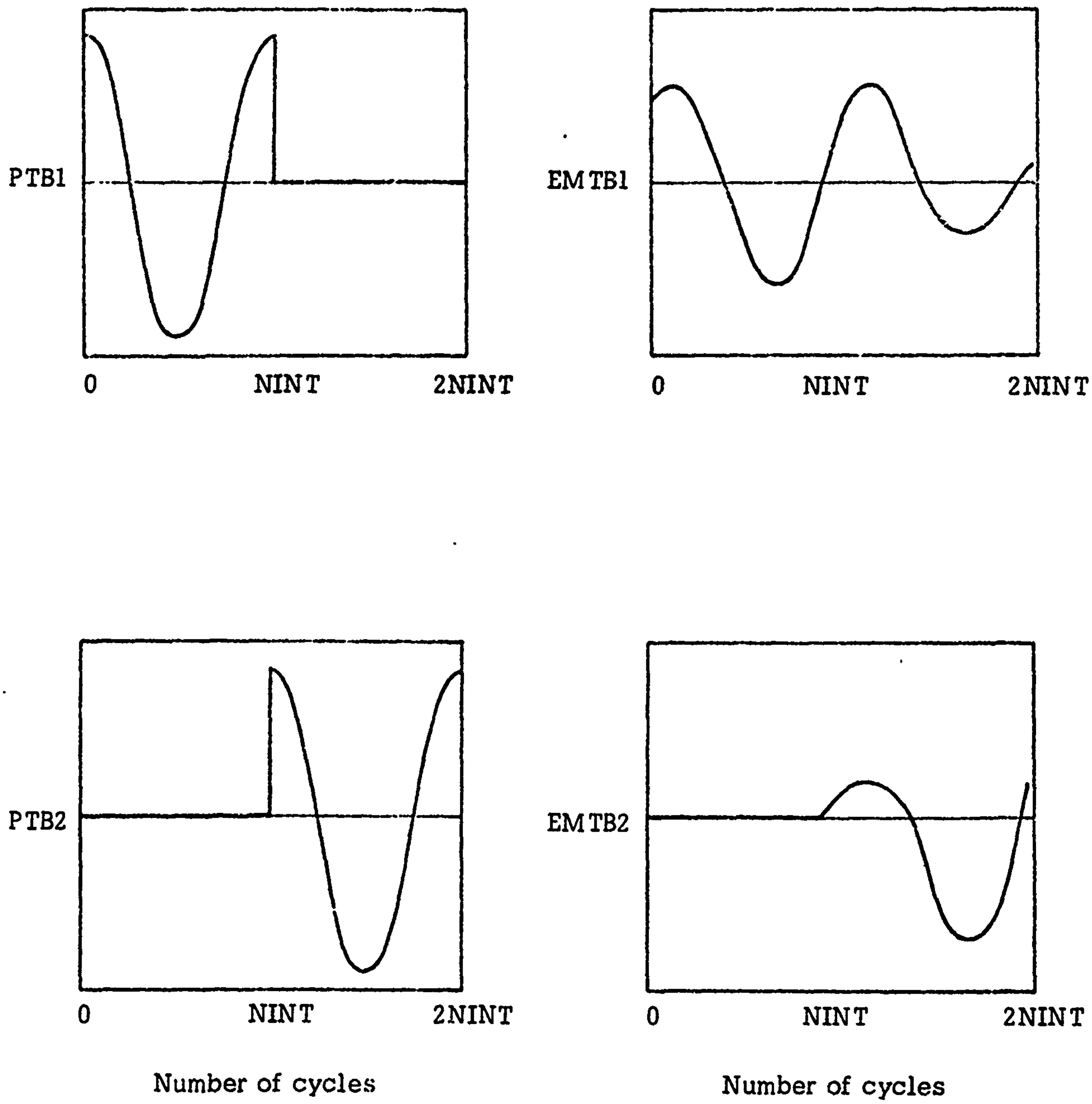
Each of these parts is further divided into subsections. When MCYC < NINT the burning rate is calculated normally as a function of a single pressure (PTB1) and/or velocity (VTB1) perturbation.

MCYC < NINT
(only pressure coupling is illustrated)




When MCYC is between NINT and 2 NINT the burning rate is calculated as the sum of the response to two perturbations, as shown below.

MCYC > NINT
(only pressure coupling is illustrated)



In an effort to minimize the computation time associated with the calculation of the burning rate, the numerical evaluation of the quadratures* is broken into two parts. The integrals in which $\tau$ is a parameter must be evaluated from $t = 0$ to $t = t_{min} - \delta$, each time (unless part of the past history has been dropped (see subroutine INT). These integrals are calculated using the Trapezoidal Rule. The integrals involving $\xi$ only can be evaluated in a running manner; the contribution from each successive interval being added to the sum of the previous ones (RUNI, RUNVI etc.).

FUNCTION VPERT (ARG1, ARG2)

The calculation of the velocity coupled transient burn rate perturbation required the following expression to be evaluated

$$\nu_1(|u| - u_t) - \nu_2(\bar{u} - u_t)$$

With ARG1 = $|u|$ and ARG2 = $u_t$ the first part of this expression is evaluated. ARG1 = $\bar{u}_o$ and ARG2 = $u_t$ yields the latter part of the expression.

*See Equation (4-68) in volume 1.

## 3. DICTIONARY OF COMMON VARIABLES

All of the variables which appear in Common* (blank or labeled) are defined in this section. Blank Common is considered first, followed by the labeled Commons in alphabetical order.

| COMMON | NAME | MATH. SYM. | DESCRIPTION |
|---|---|---|---|
| BLANK | PTB1(I,J) | $(\frac{P'}{\bar{P}})_1$ | first pressure perturbation |
| | PTB2(I,J) | $(\frac{P'}{\bar{P}})_2$ | second pressure perturbation |
| | EMTB1(I,J) | $(\frac{m'}{\bar{m}})_1$ | burning rate response to first pressure perturbation |
| | EMTB2(I,J) | | burning rate response to second pressure perturbation |
| | TIMTB(I) | | time of Ith set of burning rate calculations |
| | DTIM(I) | $\Delta t$ | TIMTB(I) - TIMTB(I-1) |
| | TEM(I) | | multiplier used in calculating burning rate integrals |
| | EMTB(I,J) | | total burning rate perturbation, J=1 next to last time, J=2 current time |
| | MTB | | total number of X locations at which transient burn rate is calculated |
| | DXTB | | distance between locations at which transient burn rate is calculated |
| | TCØN(I) | $\bar{r}^2/4\kappa$ | |
| | VTB1(I,J) | $[\epsilon_1 (\lvert U \rvert - U_t) - \epsilon_2 (\bar{U} - U_t)]_1$ | first velocity perturbation |
| | VTB2(I,J) | $[\epsilon_1 (\lvert U \rvert - U_t) - \epsilon_2 (\bar{U} - U_t)]_2$ | second velocity perturbation |
| | EMTBV1(I,J) | $(\frac{m'_v}{\bar{m}})_1$ | burning rate response to first velocity perturbation |
| | EMTBV2(I,J) | $(\frac{m'_v}{\bar{m}})_2$ | burning rate response to second velocity perturbation |

*With the exception of some common blocks used entirely within the confines of the BVP rest of subroutines for solving the steady state two point boundary value problem.

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| BLANK | C1(I), C2(I), C3(I), C4(I) | | constants in pressure coupled burning rate integral |
| | CV1(I), CV2(I), CV3(I), CV4(I) | | constants in velocity coupled burning rate integral |
| | RUN1(I) | | part of pressure coupled burning rate response integral that is evaluated in running manner |
| | RUN2(I) | | see RUN1 but for second pressure disturbance |
| | RUNV1(I) | | part of velocity coupled burning rate response integral that is evaluated in running manner |
| | RUNV2(I) | | see RUNV1 but for second velocity disturbance |
| | DWDT(I) | $\frac{d\omega}{dt}$ | time derivative of burning rate |

ACE This common contains all of the quantities which can be input to the steady state solution package (subroutine BVP). Those of interest in the current program are discussed in the description of input.

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| BNDS | K | | storage pointer in characteristics solution |
| | L, ELL | | storage pointer in characteristics solution |
| | NS1 | | set equal to 1 |
| | NE1 | | set equal to N |
| | NS2 | | set equal to 2 |
| | NE2 | | set equal to N |
| | FLAG | | not used |
| | N | | M-1 |
| | M | | number of axial locations in characteristics mesh |

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| CHAR | TIM(I,J) | $t$ | time |
| | X(I,J) | $x$ | axial distance |
| | U(I,J) | $U$ | velocity point |
| | UP(I,J) | $U_p$ | particle velocity |
| | T(I,J) | $T$ | temperature |
| | TP(I,J) | $T_p$ | particle temperature |
| | RHØ(I,J) | $\rho$ | density |
| | RHØP(I,J) | $\rho_p$ | particle density |
| | P(I,J) | $P$ | pressure |
| | W(I,J) | $\omega$ | mass burning rate |
| | WP(I,J) | $\omega_p$ | particle mass burning rate |
| | A(I,J,ADUM(I,J) | $a$ | sound speed |
| FLØS | UI | $U$ | velocity |
| | UIP | $U_p$ | particle velocity |
| | RHØI | $\rho$ | density |
| | RHØIP | $\rho_p$ | particle density |
| | TI | $T$ | temperature |
| | TIP | $T_p$ | particle temperature |
| FPLØT | NPLTF | | maximum number of plots that can be drawn on one curve |
| | TPLØT(I) | | plot times (see input descrip.) |
| | HEADER(I) | | contains case title (see input descrip.) |

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| FRAK | MEB | $\overline{M}_e$ | mach number of equivalent gas |
| | E | E | relates $\overline{M}_e$ to $M_e$ |
| FSTART | FI(6) | $f_i$ | vector of steady state variables (conserved quantities) |
| | PF | $P_f$ | chamber pressure (psf) |
| JAG | MCYC | | number of times transient burning rate has been calculated |
| | MK | | MCYC + 1 |
| | NCYC | | number of cycles over which burning rate integral must be integrated |
| | NK | | NCYC + 1 |
| | NKM2 | | NK - 2 |
| | NCYC2 | | NCYC - NINT |
| | NK2 | | NCYC2 + 1 |
| | NK2M2 | | NK2 - 2 |
| | JK | | indicates which x location is being considered |
| | DELTA | | time interval between current and last burning rate solution |
| | SQDEL | | $\sqrt{\delta}$ |
| | NPRNT, UTH, NINT, KVEL, KPRES, CNV, BV, DPV | | see description of input |

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| LBDRY | XI0 | | head end, $x = 0$ |
| | UI0 | | velocity at $x = 0$ |
| | UIP0 | | particle velocity at $x = 0$ |
| | RHØI0 | | density at $x = 0$ |
| | RHØIP0 | | particle density at $x = 0$ |
| | TI0 | | temperature at $x = 0$ |
| | TIP0 | | particle temperature at $x = 0$ |
| | UCØN1 | | not used |
| MARKET | DP, NSET | | see Description of Input |
| MATCH | ME | $M_e$ | mach number at the end of the grain |
| MAX | TMAX, MAXIT | | see Description of Input |
| MIZ | LCYC | | number of complete characteristics cycles computed |

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| NTERP | All of these arrays contain the quantities calculated at the end of the second characteristics sweep, but before interpolation | | |
| | TIMT(I) | | time |
| | XI(I) | | axial distance |
| | UT(I) | | velocity |
| | UPT(I) | | particle velocity |
| | TT(I) | | temperature |
| | TPT(I) | | particle temperature |
| | RHØPT(I) | | density |
| | PT(I) | | pressure |
| | WT(I) | | mass burning rate |
| | TMIN | | time at the end of the last characteristics cycle |
| PLØTQ | XPLØT(I,J) | | axial distance |
| | PPLØT(I,J) | $P-\overline{P}$ | pressure perturbation |
| | UPLØT(I,J) | $U-\overline{U}$ | velocity perturbation |
| | UPPLØT(I,J) | $Up-\overline{Up}$ | particle velocity perturbation |
| | WPLØT(I,J) | $W-\overline{W}$ | mass burning rate perturbation |
| | LEN(I) | | number of points stored for plotting |
| | XLABL(I) | | see subroutine MPLØTS |
| | NH | | number of Hollerith characters in Header Title |
| | JPLØT | | number of curves stored for plotting on each graph |

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| PRØX | AK | $K$ | velocity fractional lag parameter in chamber |
| | AL | $L$ | temperature fractional lag parameter in chamber |
| PRS | PFE | $P_f$ | chamber pressure (psf) |
| RR1L | see subroutine MPLØTS description | | |
| TESTING | KTEST | | KTEST = 1 if there are no particles |
| TØL | EPS1, EPS2 | $\epsilon_1, \epsilon_2$ | convergence criteria for characteristics solution |
| TZERØ | PZERØ(I) | $\overline{P} + P'_{t=0}$ | perturbed pressure at t = 0 |
| | UZERØ(I) | $\overline{U} + U'_{t=0}$ | perturbed velocity at t = 0 |
| | UPZERØ(I) | $\overline{U}_p$ | particle velocity at t = 0 |
| | WZERØ(I) | $\overline{W}$ | burning rate at t = 0 |

| COMMON | NAME | MATH SYM. | DESCRIPTION |
|---|---|---|---|
| VARS | see Description of Input | | |
| ZIN | IREAD see Description of Input | | |

## 4. DESCRIPTION OF PROGRAM INPUT

Program input for the instability program consists of two distinct groups. The first set of input controls the instability solution, while the second set controls the steady state solution which provides initial conditions for the instability solution. Many of the input quantities have been assigned preset nominal values; these quantities need be input only if it is desired to alter the preset value. Nominal values are indicated where applicable. In many cases, the second set of input can be eliminated completely, since nominal values have been preset for all of these quantities (see discussion of IREAD, below).

### 4.1 Instability Program Input

The first card of this set contains the case title in columns 1-70. This title will appear at the top of each page of output and on each computer plot. The input, itself, follows the title card, and follows the standard NAMELIST format. The first card of this set must contain $DATA starting in column 2. The last card must contain $END starting in column 2.

The input variables in the DATA namelist are described below in functional sub-groups.

Engine Geometry

| | |
|---|---|
| DPØRT | Chamber port diameter, $D_p$, in inches. |
| DTHRØT | Nozzle throat diameter, $D_t$, in inches. |
| L | Length of the grain, L, in inches. |
| RC | Nondimensional throat radius of curvature, R, $R_c/r_t$. (Nominal value = 1.0). |
| SK | Area = SK(X-1) + Ae, currently only SK=0 (constant area) should be used. |

### Steady State Burning Rate Constants

The steady state burning rate is specified as $\bar{r} = \tilde{C}(P/P_{ref})^n(1 + C_k u)$

| | |
|---|---|
| CTILDA | Constant in burning rate expression, $\tilde{C}$, in/sec. |
| CK | Erosive burning constant, $C_k$, sec/ft. |
| CN | Pressure exponent, n. |
| PREF | Normalizing pressure, psia (nominal value = 500) |

### Gas Constants

| | |
|---|---|
| CP | Gas specific heat, $C_p$, Btu/lb $^oR$. |
| Gamma | Gas isentropic exponent, $\gamma$. |
| Pr | Prandtl number, Pr, (Nominal value = 1.0). |
| TF | Adiabatic flame temperature, $T_F$, $^oR$. |

### Propellant Constants

| | |
|---|---|
| RHØS | Density of the solid propellant, $\rho_s$, g/cc. |
| RHØM | Density of the metal oxide, $\rho_m$, g/cc (Nominal value = 4). |
| CKAPA | Thermal diffusivity of the propellant, $K_s$, cm²/sec. |
| PDIA | Particle diameter in microns. |
| A | Transient burning rate parameter. |
| B | Transient burning rate parameter. |
| $B_v$ | Velocity coupling transient burn rate parameter (currently set equal to B in Subroutine Input). |
| C | Ratio of particle to gas specific heats, $C_s/C_p$. |
| CNV | Velocity coupling transient burn rate parameter (currently set equal to CN in Subroutine Input). |

| | |
|---|---|
| BETA1 | Particle to gas weight flow ratio, $B_1$. (To run a case with no particles requires only that $B_1$ be set equal to zero). |
| UTH | Threshold velocity to erosive burning response (Nominal value = 0). |

Program Constants

| | |
|---|---|
| H | Integration step size for steady state solution (Nominal value = .01). |
| IM | Total number of points at which steady solution is obtained, = 1/H+1 (Nominal value = 101). |
| EPS1 | Convergence criteria for $\rho_3$ and $a_3$, $\epsilon_1$. (Nominal value = $1 \times 10^{-5}$). |
| EPS2 | Convergence criteria for $\rho_{P_3}$, $\epsilon_2$. (Nominal value = $1 \times 10^{-5}$). |
| TMAX | Final value of time. Computation ceases when $t \geq T_{max}$. (Nominal value = 0.1). Currently the value of TMAX must be selected such that not more than 500 of the characteristics calculation cycles (not wave cycles) will be computed. In the nondimensional coordinate system used, the time increment for one computation cycle is approximately equal to the distance between points on the initial line. For this reason the total computation time goes up with the square of the number of points on the initial line. |
| PFO | Initial guess for chamber pressure, psia. |
| DP | Magnitude of the initial pressure pulse, $\Delta P/P_F$. |
| DPV | Magnitude of the initial velocity pulse, $\Delta U/a_f$. (Nominal value = 0). |

Flags and Counters

| | |
|---|---|
| NPRNT | Solution is printed every NPRNT-th calculational cycle, (Nominal value = 10). |
| MAXIT | Maximum number of iterations allowed for the characteristics solution at a given point. The solution continues, even if it has not converged. (Nominal value = 3). |

NSET — Provides an option for bypassing the steady state solution. NSET = 0 is the nominal value, and a steady state solution is obtained. NSET = 1 provides for the generation of uniform initial conditions. This option should not be used. It was set up specifically for some check out runs and is not now currently operational.

IREAD — This flag determines whether the $INPUT NAMELIST SET must be included in the input deck. If IREAD = 1 (Nominal value), the $INPUT Namelist data is not required and no attempt will be made to read it. The nominal value specified for each of the quantities is used by the program. Use IREAD = 0 , if it is desired to change one or more of the $INPUT nominal values. With IREAD = 0, the $INPUT is read, in Subroutine BVP.

NPLTF — Sets the maximum number of curves that will be drawn on one computer plot. (Nominal value = 4, can be set less than 4, but not higher, unless the necessary array dimensions are increased).

NTRIG — The steady state solution at every NTRIG-th point is stored for use on the initial line for the method of characteristics. The maximum total number of points allowed on the initial line is 200. The number of points on the initial line is given by M = 1+IM/NTRIG, done in integer arithmetic. NTRIG has been assigned a nominal value of 2, which provides 51 points on the initial line when IM = 101.

NTB — The transient burning rate integrals are evaluated starting at every NTB-th location on the initial line. Burning rate values at other locations are computed by interpolation. The total number of points on the initial line, less one, must be exactly divisible by NTB, i.e., (M-1)/NTB must be a whole number. The program will automatically terminate if there is an improper correspondence between the values of M and NTB. The maximum number of locations at which the burning rate integrals may be evaluated is currently 26.

NINT — After one transient burning rate calaulations have been performed NINT times, the burning rate is calculated as the sum of one response to two perturbations. After 2 NINT calculations the response to the first disturbance is deleted and storage is shifted. (Nominal value = 1,000,000).

| | |
|---|---|
| KVEL | ≠0 velocity coupling included, = 0 no velocity coupling (Nominal value = 0). |
| KPRES | ≠0 pressure coupling included, = 0 no pressure coupling (Nominal value = 1). |

In addition to the above quantities, an array must be specified to govern the times at which the variables will be stored for computing plotting. This array is denoted by TPLØT(I) and has the maximum dimension of 20. The variables $P' = P-P_o$, $u' = u-u_o$, $u'_p = u_p-u_{p_o}$ and $\omega' = \omega_b$ are stored at each x location, the first time a calculation cycle ends at a time greater than or equal to each successive value of TPLØT(I). Each time the variables have been stored at NPLTF different times Subroutine MPLØTS is called; which then processes the stored information and writes out the plotting instructions on tape. If 19 or less plot times are specified the program automatically inserts t = 1,000,000 as the last plot time. Therefore, if plotting is not desired TPLØT need not be input, as TPLØT(1) will be set to ..,000,000 and will never be reached.

If TPLØT(1) ≤ 99 the program also plots the pressure and transient burning rate histories at x = 0 and x = 1. One can choose to have these latter plots, and not the aforementioned set, by choosing a value for TPLØT(1) greater than TMAX, but less than 99.

Steady State Input

The quantities which control the steady state solution are also read in using the NAMELIST format. The first card of this set should read $INPUT, and the last card $END. When used, the $INPUT data immediately follows the $END card of the $DATA NAMELIST. The quantities that may be input are described below. Nominal values have been preset for each quantity and are indicated.

| | |
|---|---|
| HI | Integration step size for the steady state solution (Nominal value = .01). |
| LTRIG | Controls the locations at which the steady state integrated values and derivatives are printed. (LTRIG controls the printing of the conserved quantities and their derivatives, not the flow variables, ρ, u, P, etc., themselves).<br>LTRIG = 3, (Nominal value) print only at x = 0 and x = 1.<br>LTRIG = 2, print at every NTRIG-th step. |

| | |
|---|---|
| ITRIG | Determines the frequency at which the conserved quantities, and their derivatives, are printed. ITRIG = 1, the results are printed each iteration. ITRIG = 2, the results are printed only after the final iteration. ITRIG = 3, (Nominal value), the results are not printed. |
| NTRIG | Must be identical to NTRIG in the $DATA input set. Here it governs the printout as shown, for LTRIG = 2. (Nominal value = 2). |
| MAXIT | Not the same as MAXIT in $DATA input. Here MAXIT sets the maximum number of iterating allowed for the steady state solution. If the Mach number at the end of the grain is not matched, to within the convergence tolerance, in MAXIT iterations, the solution is terminated. (Nominal value = 10). |
| KB | If KB = 1 a bounding procedure is used in conjunction with the iterative solution. Otherwise KB = 0 (Nominal value). Unless the initial chamber pressure guess, PFO, is off by at least an order of magnitude, or more, the bounding option should not be required. |
| BSEVEN | If KB = 1, the chamber pressure will not be allowed to change by more than the value of BSEVEN on any one iteration. This bounding procedure will usually slow the convergence rate, and therefore should not always be used. However, in some cases, particularly when the initial guess is quite poor, this bounding allows a converged solution to be achieved when the iteration would, otherwise, be unstable. |

A subset of the subroutines used to solve the steady state problem consists of library subroutines designed to solve a general two point boundary value problem involving up to 20 differential equations and constraints. All of the options and features of this general routine are not required in order to solve the present problem. As a result, the list of input has been restricted to the quantities shown above. The other items, normally required as input, have all been preset in subroutine BVP (and should not be changed), or are of no consequence in the present program and have been ignored.

## 5. DESCRIPTION OF PROGRAM OUTPUT

The printed output from the instability program is described below. The output is presented in the order in which it appears. Sample output for the test case is contained in Section 6 and should be referred to in conjunction with the text.

### 5.1 Printout of Program Input

The DATA namelist input quantities are printed out in sub-groups which correspond exactly to those shown in the discussion*; i.e.,

ENGINE GEOMETRY
BURNING RATE CONSTANTS
GAS CONSTANTS
PROPELLANT CONSTANTS
PROGRAM CONSTANTS
FLAGS COUNTERS

The input units for those quantities having dimensions are indicated.

### 5.2 Fractional Lag Solution

The next page of output contains the parameters calculated as a result of the fractional lag nozzle solution. The quantities themselves are easily related to the variables in the analytical description of the solution.

### 5.3 Steady State Solution

The flow variables of interest are printed out at the end of each iteration of the steady state solution. The axial spacing of this printout corresponds to the spacing of points on the characteristics initial line and does not represent all of the points calculated, unless NTRIG = 1.

At the top of the page the current value of chamber pressure is output in psi. At the end of each iteration the number of the iteration, and the error in matching the mach numbers at the end of the grain, are printed out. When convergence has

*The quantities UTH, NINT, KVEL, KPRES, CNV, DPV, BV have yet to be integrated into the output format. These quantities are printed out after the plot times.

been achieved the message

STEADY STATE SOLUTION COMPLETED

is printed out.

## 5.4 Instability Solution

For each point on the starting line pressure, velocity, temperature, burning rate, particle velocity, particle temperature and particle density are printed out. These quantities are also printed out every time an additional NPRNT characteristics cycles have been completed.

The case title, run date, and time (in hours) are output at the top of each page, to aid in run identification.

The total number of characteristics cycles computed (LCYC) and the corresponding nondimensional time, are also printed.

The solution is also output each time quantities are stored for plotting, as well as at the end of the last cycle.

Just before the instability solution is printed at the final station a summary of the transient burning rate calculations is printed. The output quantities are as follows.

| | |
|---|---|
| TIME | time at which the results were calculated |
| PW | pressure perturbation |
| EMW | total pressure coupled burn rate perturbation |
| VW | velocity perturbation (as used in calculating velocity coupled response) |
| EMWV | total velocity coupled burn rate perturbation |
| EMW1 | pressure coupled response to the first pressure disturbance only |
| EMWV1 | velocity coupled response to the first velocity disturbance only |

If KVEL = 0, the aforementioned quantities are printed only at x=0 and x=1. If KVEL ≠ 0 transient burning rate results are also printed at several intermediate x locations.

# 6. SAMPLE CASE

Portions of the output from a sample case are presented in this section to facilitate program check-out. The sample case includes both pressure and velocity coupling.

Copies of the CALCOMP plots generated by the sample case are also included so the operation of the plotting routines can be checked out.

```
TEST CASE  P=.1COS(PI*X)  A=11.5,B=.64   V AND P COUPLING  UTH=.04            082372      12 HOURS

      ENGINE GEOMETRY                      BURNING RATE CONSTANTS                       GAS CONSTANTS
  DPORT (IN)        1.994000E+00      CTILDA (IN/SEC)    3.400000E-01      CP (BTU/LB DG-R)   4.794600E-01
  DTHROT (IN)       7.390000E-01      CK (SEC/FT)        0.                GAMMA              1.200000E+00
  L (IN)            2.350000E+01      CN                 3.000000E-01      PR                 1.000000E+00
  RC                5.000000E-01      PREF (PSIA)        5.000000E+02      TF (DEG-R)         6.110000E+03

     PROPELLANT CONSTANTS                    PROGRAM CONSTANTS                 FLAGS AND COUNTERS
  RHOS (G/CC)       1.766000E+00      H                  1.000000E-02      NPRNT          10
  RHOM (G/CC)       4.000000E+00      IM                          101      MAXIT           3
  CKAPA (CM2/SEC)   3.000000E-03      EPS1               1.000000E-05      NSET            0
  PDIA (MICRONS)    2.000000E+00      EPS2               1.000000E-05      IREAD           1
  A                 1.150000E+01      TMAX               7.460000E+00      NPLTF           4
  B                 6.400000E-01      PFO (PSIA          1.400000E+03      NTRIG           2
  C                 9.000000E-01      DP                 1.000000E-01      NTR             2
  BETAI             3.700000E-01

  VARIABLES WILL BE STORED FOR PLOTTING WHEN TIME FIRST EXCEEDS EACH OF THE FOLLOWING VALUES
          0.00000        2.40000        4.85000        7.45000  1000000.00000
UTH=  .04000    NINT=1000000    KVEL= 1    KPRES= 1    CNV= .300    BV=.6400    DPV=0.00000
```

CONVERGENT SOLUTION

```
K       =   5.6249E-01
SL      =   3.2257E-01
B       =   1.0087E+00
E       =   1.2480E+00
GBAR    =   1.1617E+00
USTAR   =   3.2972E+03
TSTAR   =   5.6531E+03
MEUSTAR =   1.6488E-06
```

```
CONVERGENT SOLUTION          MEB =     8.19822909E-02
```

CHAMBER PRESSURE = 1400.00000 PSIA

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | 1.00000 | 0.00000 | 1.00000 | .07202 | 0.00000 | 1.00000 | .37114 |
| .02000 | 1.00000 | .00144 | 1.00000 | .07202 | .00144 | 1.00000 | .37114 |
| .04000 | .99999 | .00288 | 1.00000 | .07202 | .00287 | 1.00000 | .37114 |
| .06000 | .99997 | .00432 | 1.00000 | .07202 | .00431 | 1.00000 | .37113 |
| .08000 | .99995 | .00576 | 1.00000 | .07201 | .00574 | 1.00000 | .37112 |
| .10000 | .99991 | .00720 | 1.00000 | .07201 | .00718 | 1.00000 | .37111 |
| .12000 | .99988 | .00864 | .99999 | .07201 | .00862 | .99999 | .37110 |
| .14000 | .99983 | .01008 | .99999 | .07201 | .01005 | .99999 | .37108 |
| .16000 | .99978 | .01152 | .99999 | .07201 | .01149 | .99999 | .37107 |
| .18000 | .99972 | .01297 | .99999 | .07201 | .01293 | .99999 | .37106 |
| .20000 | .99966 | .01441 | .99999 | .07201 | .01436 | .99999 | .37102 |
| .22000 | .99958 | .01585 | .99998 | .07201 | .01580 | .99998 | .37100 |
| .24000 | .99951 | .01729 | .99998 | .07201 | .01724 | .99998 | .37097 |
| .26000 | .99942 | .01873 | .99998 | .07200 | .01868 | .99998 | .37094 |
| .28000 | .99933 | .02018 | .99997 | .07200 | .02011 | .99997 | .37090 |
| .30000 | .99923 | .02162 | .99997 | .07200 | .02155 | .99997 | .37087 |
| .32000 | .99912 | .02306 | .99996 | .07200 | .02299 | .99996 | .37083 |
| .34000 | .99901 | .02451 | .99996 | .07199 | .02443 | .99996 | .37079 |
| .36000 | .99889 | .02595 | .99995 | .07199 | .02587 | .99995 | .37075 |
| .38000 | .99876 | .02740 | .99995 | .07199 | .02731 | .99995 | .37070 |
| .40000 | .99863 | .02884 | .99994 | .07199 | .02875 | .99994 | .37065 |
| .42000 | .99848 | .03029 | .99994 | .07198 | .03019 | .99994 | .37060 |
| .44000 | .99834 | .03173 | .99993 | .07198 | .03163 | .99993 | .37055 |
| .46000 | .99818 | .03318 | .99992 | .07198 | .03308 | .99993 | .37050 |
| .48000 | .99802 | .03463 | .99992 | .07197 | .03452 | .99992 | .37044 |
| .50000 | .99785 | .03607 | .99991 | .07197 | .03596 | .99991 | .37038 |
| .52000 | .99767 | .03752 | .99990 | .07197 | .03741 | .99990 | .37032 |
| .54000 | .99749 | .03897 | .99990 | .07196 | .03885 | .99990 | .37025 |
| .56000 | .99730 | .04042 | .99989 | .07196 | .04030 | .99989 | .37018 |
| .58000 | .99711 | .04187 | .99988 | .07195 | .04174 | .99988 | .37011 |
| .60000 | .99690 | .04332 | .99987 | .07195 | .04319 | .99987 | .37004 |
| .62000 | .99669 | .04478 | .99986 | .07194 | .04464 | .99986 | .36997 |
| .64000 | .99647 | .04623 | .99985 | .07194 | .04609 | .99986 | .36989 |
| .66000 | .99625 | .04768 | .99984 | .07193 | .04754 | .99985 | .36981 |
| .68000 | .99602 | .04914 | .99983 | .07193 | .04899 | .99984 | .36973 |
| .70000 | .99578 | .05059 | .99983 | .07192 | .05044 | .99983 | .36964 |
| .72000 | .99553 | .05205 | .99981 | .07192 | .05189 | .99982 | .36955 |
| .74000 | .99528 | .05351 | .99980 | .07191 | .05334 | .99981 | .36946 |
| .76000 | .99502 | .05497 | .99979 | .07191 | .05480 | .99980 | .36937 |
| .78000 | .99475 | .05643 | .99978 | .07190 | .05625 | .99978 | .36928 |
| .80000 | .99448 | .05789 | .99977 | .07190 | .05771 | .99977 | .36918 |
| .82000 | .99420 | .05935 | .99976 | .07189 | .05917 | .99976 | .36908 |
| .84000 | .99391 | .06081 | .99975 | .07188 | .06062 | .99975 | .36898 |
| .86000 | .99362 | .06228 | .99974 | .07188 | .06208 | .99974 | .36887 |
| .88000 | .99332 | .06374 | .99972 | .07187 | .06354 | .99972 | .36876 |
| .90000 | .99301 | .06521 | .99971 | .07186 | .06501 | .99971 | .36866 |
| .92000 | .99269 | .06667 | .99970 | .07186 | .06647 | .99970 | .36854 |
| .94000 | .99237 | .06814 | .99968 | .07185 | .06793 | .99969 | .36843 |
| .96000 | .99204 | .06961 | .99967 | .07184 | .06940 | .99967 | .36831 |
| .98000 | .99170 | .07108 | .99965 | .07184 | .07086 | .99966 | .36819 |
| 1.00000 | .99136 | .07256 | .99964 | .07183 | .07233 | .99964 | .36807 |

ERRORS AT END OF GRAIN

| NUMIT | F(1) = ABS(ME-MEBAR) |
|---|---|
| 0 | 8.17702581E-04 |

ERRORS AT END OF GRAIN

| NUMIT | F(1) = ABS(ME-MEBAR) |
|---|---|
| 0 | 8.69125212E-04 |

ERRORS AT END OF GRAIN

| NUMIT | F(1) = ABS(ME-MEBAR) |
| --- | --- |
| 1 | 1.21040039E-05 |

STEADY STATE SOLUTION COMPLETED

CHAMBER PRESSURE = 1377.73775 PSIA

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | 1.00000 | 0.00000 | 1.00000 | .07283 | 0.00000 | 1.00000 | .37114 |
| .02000 | 1.00000 | .00146 | 1.00000 | .07283 | .00145 | 1.00000 | .37114 |
| .04000 | .99999 | .00291 | 1.00000 | .07283 | .00290 | 1.00000 | .37114 |
| .06000 | .99997 | .00437 | 1.00000 | .07283 | .00436 | 1.00000 | .37113 |
| .08000 | .99994 | .00583 | 1.00000 | .07283 | .00581 | 1.00000 | .37112 |
| .10000 | .99991 | .00728 | 1.00000 | .07283 | .00726 | 1.00000 | .37111 |
| .12000 | .99987 | .00874 | .99999 | .07283 | .00871 | .99999 | .37110 |
| .14000 | .99983 | .01020 | .99999 | .07282 | .01017 | .99999 | .37108 |
| .16000 | .99978 | .01165 | .99999 | .07282 | .01162 | .99999 | .37106 |
| .18000 | .99972 | .01311 | .99999 | .07282 | .01307 | .99999 | .37104 |
| .20000 | .99965 | .01457 | .99999 | .07282 | .01453 | .99999 | .37102 |
| .22000 | .99958 | .01603 | .99998 | .07282 | .01598 | .99998 | .37099 |
| .24000 | .99950 | .01749 | .99998 | .07282 | .01743 | .99998 | .37096 |
| .26000 | .99941 | .01895 | .99998 | .07282 | .01889 | .99998 | .37093 |
| .28000 | .99931 | .02040 | .99997 | .07281 | .02034 | .99997 | .37090 |
| .30000 | .99921 | .02186 | .99997 | .07281 | .02180 | .99997 | .37086 |
| .32000 | .99910 | .02332 | .99996 | .07281 | .02325 | .99996 | .37082 |
| .34000 | .99899 | .02478 | .99996 | .07281 | .02471 | .99996 | .37078 |
| .36000 | .99887 | .02624 | .99995 | .07280 | .02616 | .99995 | .37074 |
| .38000 | .99874 | .02770 | .99995 | .07280 | .02762 | .99995 | .37069 |
| .40000 | .99860 | .02917 | .99994 | .07280 | .02908 | .99994 | .37065 |
| .42000 | .99845 | .03063 | .99994 | .07279 | .03053 | .99994 | .37059 |
| .44000 | .99830 | .03209 | .99993 | .07279 | .03199 | .99993 | .37054 |
| .46000 | .99815 | .03355 | .99992 | .07279 | .03345 | .99992 | .37048 |
| .48000 | .99798 | .03502 | .99992 | .07278 | .03491 | .99992 | .37043 |
| .50000 | .99781 | .03648 | .99991 | .07278 | .03637 | .99991 | .37036 |
| .52000 | .99763 | .03795 | .99990 | .07278 | .03783 | .99990 | .37030 |
| .54000 | .99744 | .03941 | .99989 | .07277 | .03929 | .99989 | .37023 |
| .56000 | .99725 | .04088 | .99989 | .07277 | .04075 | .99989 | .37017 |
| .58000 | .99705 | .04235 | .99988 | .07276 | .04222 | .99988 | .37009 |
| .60000 | .99684 | .04382 | .99987 | .07276 | .04368 | .99987 | .37002 |
| .62000 | .99663 | .04528 | .99986 | .07275 | .04515 | .99986 | .36994 |
| .64000 | .99640 | .04675 | .99985 | .07275 | .04661 | .99985 | .36986 |
| .66000 | .99618 | .04823 | .99984 | .07274 | .04808 | .99984 | .36978 |
| .68000 | .99594 | .04970 | .99983 | .07274 | .04954 | .99983 | .36970 |
| .70000 | .99570 | .05117 | .99982 | .07273 | .05101 | .99982 | .36961 |
| .72000 | .99545 | .05264 | .99981 | .07273 | .05248 | .99981 | .36952 |
| .74000 | .99519 | .05412 | .99980 | .07272 | .05395 | .99980 | .36943 |
| .76000 | .99492 | .05559 | .99979 | .07272 | .05542 | .99979 | .36934 |
| .78000 | .99465 | .05707 | .99978 | .07271 | .05689 | .99978 | .36924 |
| .80000 | .99437 | .05855 | .99976 | .07271 | .05837 | .99977 | .36914 |
| .82000 | .99409 | .06002 | .99975 | .07270 | .05984 | .99976 | .36904 |
| .84000 | .99379 | .06150 | .99974 | .07269 | .06131 | .99974 | .36894 |
| .86000 | .99349 | .06298 | .99973 | .07269 | .06279 | .99973 | .36883 |
| .88000 | .99318 | .06447 | .99972 | .07268 | .06427 | .99972 | .36872 |
| .90000 | .99287 | .06595 | .99970 | .07267 | .06575 | .99970 | .36861 |
| .92000 | .99255 | .06743 | .99969 | .07267 | .06723 | .99969 | .36849 |
| .94000 | .99222 | .06892 | .99967 | .07266 | .06871 | .99968 | .36838 |
| .96000 | .99188 | .07041 | .99966 | .07265 | .07019 | .99966 | .36826 |
| .98000 | .99154 | .07189 | .99965 | .07264 | .07167 | .99965 | .36813 |
| 1.00000 | .99119 | .07338 | .99963 | .07264 | .07316 | .99963 | .36801 |

TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04 082372 12 HOURS

LCYC = 0 TIME = 0.000000

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | 1.10000 | 0.00000 | 1.01601 | .07283 | 0.00000 | 1.00000 | .37114 |
| .02000 | 1.09980 | .00146 | 1.01598 | .07283 | .00145 | 1.00000 | .37114 |
| .04000 | 1.09920 | .00291 | 1.01589 | .07283 | .00290 | 1.00000 | .37114 |
| .06000 | 1.09820 | .00437 | 1.01574 | .07283 | .00436 | 1.00000 | .37113 |
| .08000 | 1.09680 | .00583 | 1.01553 | .07283 | .00581 | 1.00000 | .37112 |
| .10000 | 1.09502 | .00728 | 1.01525 | .07283 | .00726 | 1.00000 | .37111 |
| .12000 | 1.09285 | .00874 | 1.01492 | .07283 | .00871 | .99999 | .37110 |
| .14000 | 1.09031 | .01020 | 1.01454 | .07282 | .01017 | .99999 | .37108 |
| .16000 | 1.08741 | .01165 | 1.01409 | .07282 | .01162 | .99999 | .37106 |
| .18000 | 1.08415 | .01311 | 1.01359 | .07282 | .01307 | .99999 | .37104 |
| .20000 | 1.08055 | .01457 | 1.01304 | .07282 | .01453 | .99999 | .37102 |
| .22000 | 1.07663 | .01603 | 1.01244 | .07282 | .01598 | .99998 | .37099 |
| .24000 | 1.07239 | .01749 | 1.01178 | .07282 | .01743 | .99998 | .37096 |
| .26000 | 1.06786 | .01895 | 1.01108 | .07282 | .01889 | .99998 | .37093 |
| .28000 | 1.06306 | .02040 | 1.01033 | .07281 | .02034 | .99997 | .37090 |
| .30000 | 1.05799 | .02186 | 1.00954 | .07281 | .02180 | .99997 | .37086 |
| .32000 | 1.05269 | .02332 | 1.00871 | .07281 | .02325 | .99996 | .37082 |
| .34000 | 1.04716 | .02478 | 1.00784 | .07281 | .02471 | .99996 | .37078 |
| .36000 | 1.04144 | .02624 | 1.00693 | .07280 | .02616 | .99995 | .37074 |
| .38000 | 1.03555 | .02770 | 1.00600 | .07280 | .02762 | .99995 | .37069 |
| .40000 | 1.02950 | .02917 | 1.00503 | .07280 | .02908 | .99994 | .37065 |
| .42000 | 1.02332 | .03063 | 1.00404 | .07279 | .03053 | .99994 | .37059 |
| .44000 | 1.01704 | .03209 | 1.00303 | .07279 | .03199 | .99993 | .37054 |
| .46000 | 1.01068 | .03355 | 1.00200 | .07279 | .03345 | .99992 | .37048 |
| .48000 | 1.00426 | .03502 | 1.00096 | .07278 | .03491 | .99992 | .37043 |
| .50000 | .99781 | .03648 | .99991 | .07278 | .03637 | .99991 | .37036 |
| .52000 | .99135 | .03795 | .99885 | .07278 | .03783 | .99990 | .37030 |
| .54000 | .98491 | .03941 | .99779 | .07277 | .03929 | .99989 | .37023 |
| .56000 | .97851 | .04088 | .99673 | .07277 | .04075 | .99989 | .37017 |
| .58000 | .97218 | .04235 | .99568 | .07276 | .04222 | .99988 | .37009 |
| .60000 | .96594 | .04382 | .99463 | .07276 | .04368 | .99987 | .37002 |
| .62000 | .95981 | .04528 | .99361 | .07275 | .04515 | .99986 | .36994 |
| .64000 | .95383 | .04675 | .99260 | .07275 | .04661 | .99985 | .36986 |
| .66000 | .94800 | .04823 | .99161 | .07274 | .04808 | .99984 | .36978 |
| .68000 | .94236 | .04970 | .99066 | .07274 | .04954 | .99983 | .36970 |
| .70000 | .93692 | .05117 | .98973 | .07273 | .05101 | .99982 | .36961 |
| .72000 | .93170 | .05264 | .98884 | .07273 | .05248 | .99981 | .36952 |
| .74000 | .92673 | .05412 | .98799 | .07272 | .05395 | .99980 | .36943 |
| .76000 | .92203 | .05559 | .98719 | .07272 | .05542 | .99979 | .36934 |
| .78000 | .91760 | .05707 | .98643 | .07271 | .05689 | .99978 | .36924 |
| .80000 | .91347 | .05855 | .98572 | .07271 | .05837 | .99977 | .36914 |
| .82000 | .90965 | .06002 | .98507 | .07270 | .05984 | .99976 | .36904 |
| .84000 | .90616 | .06150 | .98448 | .07269 | .06131 | .99974 | .36894 |
| .86000 | .90301 | .06298 | .98394 | .07269 | .06279 | .99973 | .36883 |
| .88000 | .90021 | .06447 | .98347 | .07268 | .06427 | .99972 | .36872 |
| .90000 | .89776 | .06595 | .98306 | .07267 | .06575 | .99970 | .36861 |
| .92000 | .89569 | .06743 | .98273 | .07267 | .06723 | .99969 | .36849 |
| .94000 | .89399 | .06892 | .98246 | .07266 | .06871 | .99968 | .36838 |
| .96000 | .89267 | .07041 | .98225 | .07265 | .07019 | .99966 | .36826 |
| .98000 | .89173 | .07189 | .98213 | .07264 | .07167 | .99965 | .36813 |
| 1.00000 | .89119 | .07338 | .98207 | .07264 | .07316 | .99963 | .36801 |

TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04 082372 12 HOURS

LCYC = 10 TIME = .199118

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | 1.08140 | 0.00000 | 1.00979 | .08018 | 0.00000 | 1.01015 | .36744 |
| .02000 | 1.08124 | .00346 | 1.00977 | .08016 | .00325 | 1.01013 | .36797 |
| .04000 | 1.08077 | .00691 | 1.00971 | .08013 | .00651 | 1.01007 | .36825 |
| .06000 | 1.07998 | .01036 | 1.00962 | .08004 | .00975 | 1.00997 | .36838 |
| .08000 | 1.07888 | .01379 | 1.00949 | .07996 | .01299 | 1.00983 | .36845 |
| .10000 | 1.07749 | .01720 | 1.00933 | .07982 | .01621 | 1.00966 | .36849 |
| .12000 | 1.07579 | .02058 | 1.00913 | .07968 | .01940 | 1.00945 | .36853 |
| .14000 | 1.07380 | .02392 | 1.00890 | .07948 | .02256 | 1.00921 | .36857 |
| .16000 | 1.07151 | .02722 | 1.00863 | .07929 | .02566 | 1.00893 | .36861 |
| .18000 | 1.06891 | .03044 | 1.00832 | .07904 | .02872 | 1.00862 | .36866 |
| .20000 | 1.06604 | .03361 | 1.00799 | .07880 | .03173 | 1.00827 | .36870 |
| .22000 | 1.06291 | .03674 | 1.00762 | .07851 | .03469 | 1.00789 | .36876 |
| .24000 | 1.05955 | .03979 | 1.00722 | .07821 | .03760 | 1.00748 | .36882 |
| .26000 | 1.05594 | .04277 | 1.00680 | .07794 | .04044 | 1.00704 | .36888 |
| .28000 | 1.05212 | .04568 | 1.00635 | .07766 | .04321 | 1.00658 | .36896 |
| .30000 | 1.04808 | .04851 | 1.00587 | .07739 | .04591 | 1.00609 | .36904 |
| .32000 | 1.04384 | .05125 | 1.00537 | .07712 | .04852 | 1.00557 | .36913 |
| .34000 | 1.03944 | .05389 | 1.00485 | .07683 | .05106 | 1.00503 | .36922 |
| .36000 | 1.03489 | .05642 | 1.00431 | .07655 | .05349 | 1.00448 | .36932 |
| .38000 | 1.03018 | .05885 | 1.00376 | .07625 | .05583 | 1.00390 | .36943 |
| .40000 | 1.02535 | .06117 | 1.00318 | .07596 | .05807 | 1.00331 | .36954 |
| .42000 | 1.02041 | .06338 | 1.00260 | .07564 | .06021 | 1.00270 | .36966 |
| .44000 | 1.01538 | .06547 | 1.00200 | .07531 | .06224 | 1.00209 | .36978 |
| .46000 | 1.01027 | .06745 | 1.00139 | .07499 | .06417 | 1.00146 | .36989 |
| .48000 | 1.00510 | .06931 | 1.00078 | .07467 | .06598 | 1.00082 | .37000 |
| .50000 | .99990 | .07104 | 1.00016 | .07433 | .06769 | 1.00018 | .37011 |
| .52000 | .99468 | .07264 | .99953 | .07399 | .06927 | .99954 | .37021 |
| .54000 | .98945 | .07412 | .99891 | .07360 | .07074 | .99889 | .37032 |
| .56000 | .98425 | .07546 | .99829 | .07322 | .07209 | .99825 | .37043 |
| .58000 | .97909 | .07667 | .99767 | .07275 | .07332 | .99761 | .37054 |
| .60000 | .97399 | .07775 | .99706 | .07228 | .07443 | .99698 | .37066 |
| .62000 | .96897 | .07869 | .99646 | .07182 | .07541 | .99636 | .37078 |
| .64000 | .96405 | .07949 | .99587 | .07135 | .07627 | .99575 | .37090 |
| .66000 | .95924 | .08017 | .99530 | .07089 | .07701 | .99515 | .37101 |
| .68000 | .95455 | .08071 | .99474 | .07044 | .07763 | .99457 | .37111 |
| .70000 | .95001 | .08111 | .99419 | .07000 | .07812 | .99401 | .37120 |
| .72000 | .94564 | .08139 | .99367 | .06956 | .07850 | .99347 | .37128 |
| .74000 | .94145 | .08154 | .99317 | .06914 | .07876 | .99295 | .37135 |
| .76000 | .93746 | .08157 | .99270 | .06872 | .07893 | .99246 | .37142 |
| .78000 | .93368 | .08149 | .99225 | .06833 | .07899 | .99199 | .37147 |
| .80000 | .93013 | .08131 | .99183 | .06795 | .07895 | .99156 | .37152 |
| .82000 | .92692 | .08094 | .99146 | .06759 | .07879 | .99116 | .37156 |
| .84000 | .92404 | .08043 | .99112 | .06724 | .07849 | .99080 | .37162 |
| .86000 | .92143 | .07982 | .99082 | .06693 | .07808 | .99048 | .37168 |
| .88000 | .91911 | .07911 | .99056 | .06662 | .07757 | .99020 | .37174 |
| .90000 | .91709 | .07831 | .99033 | .06636 | .07699 | .98996 | .37178 |
| .92000 | .91541 | .07743 | .99015 | .06609 | .07633 | .98976 | .37183 |
| .94000 | .91407 | .07645 | .99002 | .06588 | .07559 | .98960 | .37187 |
| .96000 | .91309 | .07538 | .98993 | .06567 | .07477 | .98950 | .37191 |
| .98000 | .91247 | .07423 | .98989 | .06551 | .07389 | .98944 | .37197 |
| 1.00000 | .91223 | .07301 | .98990 | .06535 | .07297 | .98944 | .37206 |

TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04 082372 12 HOURS

LCYC = 100 TIME = 1.994652

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | 1.03837 | 0.00000 | 1.00515 | .06579 | 0.00000 | 1.00438 | .35766 |
| .02000 | 1.03824 | -.00232 | 1.00514 | .06582 | -.00250 | 1.00436 | .35777 |
| .04000 | 1.03778 | -.00462 | 1.00508 | .06585 | -.00497 | 1.00432 | .35772 |
| .06000 | 1.03704 | -.00689 | 1.00499 | .06594 | -.00740 | 1.00425 | .35762 |
| .08000 | 1.03601 | -.00912 | 1.00486 | .06603 | -.00978 | 1.00414 | .35753 |
| .10000 | 1.03472 | -.01127 | 1.00469 | .06617 | -.01208 | 1.00399 | .35748 |
| .12000 | 1.03318 | -.01335 | 1.00449 | .06632 | -.01429 | 1.00382 | .35744 |
| .14000 | 1.03142 | -.01533 | 1.00427 | .06652 | -.01637 | 1.00362 | .35743 |
| .16000 | 1.02947 | -.01719 | 1.00401 | .06672 | -.01833 | 1.00340 | .35743 |
| .18000 | 1.02734 | -.01889 | 1.00374 | .06647 | -.02019 | 1.00314 | .35743 |
| .20000 | 1.02503 | -.02048 | 1.00345 | .06622 | -.02185 | 1.00288 | .35745 |
| .22000 | 1.02270 | -.02190 | 1.00314 | .06578 | -.02332 | 1.00261 | .35748 |
| .24000 | 1.02024 | -.02316 | 1.00282 | .06535 | -.02461 | 1.00233 | .35753 |
| .26000 | 1.01772 | -.02422 | 1.00249 | .06491 | -.02570 | 1.00205 | .35760 |
| .28000 | 1.01517 | -.02509 | 1.00215 | .06448 | -.02657 | 1.00176 | .35771 |
| .30000 | 1.01262 | -.02574 | 1.00182 | .06410 | -.02722 | 1.00147 | .35785 |
| .32000 | 1.01009 | -.02617 | 1.00149 | .06373 | -.02763 | 1.00118 | .35804 |
| .34000 | 1.00759 | -.02637 | 1.00115 | .06342 | -.02780 | 1.00090 | .35828 |
| .36000 | 1.00514 | -.02634 | 1.00083 | .06312 | -.02773 | 1.00062 | .35858 |
| .38000 | 1.00276 | -.02607 | 1.00051 | .06289 | -.02742 | 1.00036 | .35892 |
| .40000 | 1.00045 | -.02555 | 1.00021 | .06266 | -.02686 | 1.00010 | .35933 |
| .42000 | .99822 | -.02480 | .99991 | .06251 | -.02605 | .99985 | .35979 |
| .44000 | .99607 | -.02380 | .99962 | .06236 | -.02501 | .99961 | .36030 |
| .46000 | .99402 | -.02257 | .99935 | .06227 | -.02372 | .99938 | .36087 |
| .48000 | .99205 | -.02110 | .99908 | .06219 | -.02221 | .99916 | .36149 |
| .50000 | .99016 | -.01941 | .99883 | .06217 | -.02047 | .99895 | .36216 |
| .52000 | .98836 | -.01750 | .99859 | .06215 | -.01851 | .99875 | .36288 |
| .54000 | .98665 | -.01538 | .99836 | .06223 | -.01635 | .99857 | .36363 |
| .56000 | .98501 | -.01305 | .99814 | .06230 | -.01398 | .99839 | .36443 |
| .58000 | .98345 | -.01053 | .99794 | .06250 | -.01141 | .99822 | .36526 |
| .60000 | .98195 | -.00781 | .99774 | .06269 | -.00866 | .99805 | .36612 |
| .62000 | .98052 | -.00492 | .99755 | .06294 | -.00573 | .99790 | .36701 |
| .64000 | .97915 | -.00185 | .99738 | .06318 | -.00263 | .99775 | .36791 |
| .66000 | .97784 | .00138 | .99721 | .06347 | .00063 | .99761 | .36883 |
| .68000 | .97657 | .00477 | .99705 | .06376 | .00404 | .99748 | .36977 |
| .70000 | .97536 | .00831 | .99689 | .06408 | .00760 | .99735 | .37070 |
| .72000 | .97418 | .01198 | .99675 | .06440 | .01130 | .99723 | .37164 |
| .74000 | .97305 | .01578 | .99661 | .06476 | .01511 | .99712 | .37258 |
| .76000 | .97196 | .01969 | .99648 | .06511 | .01905 | .99700 | .37351 |
| .78000 | .97091 | .02372 | .99636 | .06549 | .02311 | .99689 | .37442 |
| .80000 | .96988 | .02785 | .99624 | .06587 | .02726 | .99679 | .37532 |
| .82000 | .96888 | .03207 | .99612 | .06630 | .03150 | .99669 | .37620 |
| .84000 | .96792 | .03637 | .99602 | .06673 | .03582 | .99659 | .37706 |
| .86000 | .96699 | .04076 | .99592 | .06757 | .04022 | .99650 | .37789 |
| .88000 | .96608 | .04522 | .99582 | .06842 | .04469 | .99642 | .37871 |
| .90000 | .96521 | .04975 | .99573 | .06963 | .04923 | .99633 | .37950 |
| .92000 | .96436 | .05435 | .99565 | .07084 | .05384 | .99626 | .38027 |
| .94000 | .96354 | .05900 | .99557 | .07206 | .05851 | .99619 | .38102 |
| .96000 | .96275 | .06370 | .99550 | .07329 | .06322 | .99612 | .38176 |
| .98000 | .96198 | .06844 | .99544 | .07452 | .06798 | .99606 | .38250 |
| 1.00000 | .96127 | .07322 | .99541 | .07575 | .07276 | .99599 | .38325 |

TEST CASE P=.1COS(PI*X) A=11.5,R=.64 V AND P COUPLING UTH=.04 082372 12 HOURS

LCYC = 200 TIME = 3.988461

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | .92413 | 0.00000 | .99004 | .03409 | 0.00000 | .98970 | .32643 |
| .02000 | .92437 | -.00140 | .99008 | .03424 | -.00105 | .98974 | .32624 |
| .04000 | .92512 | -.00281 | .99020 | .03439 | -.00211 | .98985 | .32648 |
| .06000 | .92636 | -.00423 | .99037 | .03486 | -.00319 | .99003 | .32705 |
| .08000 | .92807 | -.00566 | .99062 | .03533 | -.00429 | .99027 | .32787 |
| .10000 | .93024 | -.00708 | .99092 | .03610 | -.00541 | .99057 | .32888 |
| .12000 | .93283 | -.00848 | .99128 | .03687 | -.00654 | .99093 | .33006 |
| .14000 | .93583 | -.00988 | .99170 | .03793 | -.00767 | .99134 | .33139 |
| .16000 | .93921 | -.01124 | .99216 | .03900 | -.00880 | .99180 | .33284 |
| .18000 | .94288 | -.01254 | .99266 | .04044 | -.00991 | .99231 | .33440 |
| .20000 | .94682 | -.01375 | .99320 | .04188 | -.01096 | .99285 | .33605 |
| .22000 | .95098 | -.01487 | .99376 | .04353 | -.01195 | .99342 | .33779 |
| .24000 | .95533 | -.01586 | .99434 | .04518 | -.01283 | .99401 | .33951 |
| .26000 | .95980 | -.01670 | .99493 | .04707 | -.01361 | .99462 | .34148 |
| .28000 | .96437 | -.01738 | .99554 | .04895 | -.01424 | .99525 | .34341 |
| .30000 | .96899 | -.01788 | .99614 | .05103 | -.01472 | .99587 | .34537 |
| .32000 | .97361 | -.01818 | .99674 | .05311 | -.01503 | .99650 | .34736 |
| .34000 | .97823 | -.01826 | .99734 | .05535 | -.01514 | .99713 | .34938 |
| .36000 | .98279 | -.01813 | .99793 | .05760 | -.01506 | .99774 | .35142 |
| .38000 | .98729 | -.01778 | .99850 | .05996 | -.01476 | .99835 | .35348 |
| .40000 | .99171 | -.01720 | .99906 | .06233 | -.01425 | .99893 | .35555 |
| .42000 | .99602 | -.01639 | .99960 | .06477 | -.01353 | .99951 | .35761 |
| .44000 | 1.00021 | -.01537 | 1.00012 | .06722 | -.01259 | 1.00006 | .35967 |
| .46000 | 1.00428 | -.01413 | 1.00062 | .06971 | -.01145 | 1.00059 | .36172 |
| .48000 | 1.00821 | -.01268 | 1.00110 | .07221 | -.01010 | 1.00110 | .36376 |
| .50000 | 1.01200 | -.01102 | 1.00157 | .07471 | -.00854 | 1.00159 | .36577 |
| .52000 | 1.01565 | -.00917 | 1.00201 | .07722 | -.00680 | 1.00206 | .36777 |
| .54000 | 1.01916 | -.00714 | 1.00243 | .07966 | -.00486 | 1.00251 | .36975 |
| .56000 | 1.02250 | -.00493 | 1.00283 | .08210 | -.00276 | 1.00293 | .37170 |
| .58000 | 1.02570 | -.00254 | 1.00320 | .08438 | -.00048 | 1.00333 | .37364 |
| .60000 | 1.02874 | .00001 | 1.00356 | .08666 | .00196 | 1.00371 | .37555 |
| .62000 | 1.03162 | .00270 | 1.00390 | .08896 | .00455 | 1.00407 | .37743 |
| .64000 | 1.03435 | .00554 | 1.00421 | .09105 | .00728 | 1.00441 | .37929 |
| .66000 | 1.03690 | .00852 | 1.00451 | .09313 | .01015 | 1.00472 | .38112 |
| .68000 | 1.03928 | .01162 | 1.00478 | .09520 | .01314 | 1.00501 | .38291 |
| .70000 | 1.04150 | .01485 | 1.00503 | .09713 | .01626 | 1.00528 | .38466 |
| .72000 | 1.04354 | .01819 | 1.00526 | .09905 | .01948 | 1.00553 | .38637 |
| .74000 | 1.04541 | .02164 | 1.00547 | .10092 | .02282 | 1.00575 | .38803 |
| .76000 | 1.04709 | .02519 | 1.00566 | .10258 | .02625 | 1.00596 | .38964 |
| .78000 | 1.04860 | .02883 | 1.00583 | .10417 | .02977 | 1.00614 | .39120 |
| .80000 | 1.04993 | .03256 | 1.00598 | .10576 | .03339 | 1.00630 | .39271 |
| .82000 | 1.05106 | .03637 | 1.00611 | .10722 | .03708 | 1.00644 | .39415 |
| .84000 | 1.05200 | .04027 | 1.00622 | .10868 | .04086 | 1.00656 | .39554 |
| .86000 | 1.05276 | .04423 | 1.00631 | .10997 | .04470 | 1.00666 | .39686 |
| .88000 | 1.05332 | .04827 | 1.00638 | .11127 | .04861 | 1.00674 | .39811 |
| .90000 | 1.05369 | .05236 | 1.00643 | .11225 | .05258 | 1.00680 | .39930 |
| .92000 | 1.05385 | .05652 | 1.00645 | .11323 | .05660 | 1.00684 | .40042 |
| .94000 | 1.05380 | .06072 | 1.00646 | .11392 | .06067 | 1.00685 | .40147 |
| .96000 | 1.05355 | .06498 | 1.00645 | .11462 | .06479 | 1.00684 | .40245 |
| .98000 | 1.05308 | .06928 | 1.00641 | .11500 | .06895 | 1.00681 | .40335 |
| 1.00000 | 1.05239 | .07362 | 1.00636 | .11539 | .07316 | 1.00673 | .40420 |

TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04 082372 12 HOURS

LCYC = 300 TIME = 5.982674

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | .94366 | 0.00000 | .99188 | .07289 | 0.00000 | .99253 | .33551 |
| .02000 | .94367 | .00466 | .99190 | .07288 | .00470 | .99255 | .33596 |
| .04000 | .94378 | .00930 | .99194 | .07287 | .00938 | .99258 | .33645 |
| .06000 | .94395 | .01391 | .99198 | .07284 | .01403 | .99261 | .33696 |
| .08000 | .94421 | .01850 | .99204 | .07282 | .01865 | .99266 | .33747 |
| .10000 | .94454 | .02303 | .99211 | .07278 | .02323 | .99272 | .33796 |
| .12000 | .94495 | .02750 | .99219 | .07274 | .02775 | .99278 | .33845 |
| .14000 | .94545 | .03190 | .99229 | .07269 | .03220 | .99286 | .33893 |
| .16000 | .94605 | .03622 | .99240 | .07264 | .03657 | .99295 | .33942 |
| .18000 | .94675 | .04044 | .99253 | .07362 | .04086 | .99306 | .33992 |
| .20000 | .94757 | .04458 | .99267 | .07460 | .04506 | .99318 | .34045 |
| .22000 | .94851 | .04861 | .99283 | .07603 | .04916 | .99332 | .34101 |
| .24000 | .94958 | .05252 | .99301 | .07745 | .05315 | .99347 | .34160 |
| .26000 | .95080 | .05629 | .99322 | .07884 | .05701 | .99364 | .34223 |
| .28000 | .95220 | .05991 | .99345 | .08023 | .06073 | .99383 | .34291 |
| .30000 | .95378 | .06335 | .99370 | .08153 | .06429 | .99404 | .34364 |
| .32000 | .95557 | .06658 | .99398 | .08293 | .06766 | .99428 | .34445 |
| .34000 | .95759 | .06960 | .99429 | .08404 | .07081 | .99455 | .34534 |
| .36000 | .95988 | .07234 | .99464 | .08525 | .07378 | .99485 | .34631 |
| .38000 | .96245 | .07482 | .99502 | .08635 | .07645 | .99518 | .34738 |
| .40000 | .96533 | .07701 | .99545 | .08744 | .07883 | .99554 | .34854 |
| .42000 | .96855 | .07887 | .99592 | .08838 | .08090 | .99595 | .34982 |
| .44000 | .97213 | .08040 | .99643 | .08933 | .08264 | .99639 | .35121 |
| .46000 | .97607 | .08158 | .99699 | .09015 | .08405 | .99688 | .35274 |
| .48000 | .98038 | .08242 | .99759 | .09096 | .08510 | .99741 | .35439 |
| .50000 | .98506 | .08290 | .99823 | .09165 | .08580 | .99799 | .35618 |
| .52000 | .99006 | .08307 | .99890 | .09234 | .08616 | .99860 | .35811 |
| .54000 | .99538 | .08293 | .99961 | .09289 | .08620 | .99925 | .36016 |
| .56000 | 1.00094 | .08253 | 1.00035 | .09343 | .08594 | .99993 | .36233 |
| .58000 | 1.00667 | .08192 | 1.00109 | .09382 | .08542 | 1.00064 | .36461 |
| .60000 | 1.01251 | .08114 | 1.00184 | .09422 | .08470 | 1.00135 | .36698 |
| .62000 | 1.01840 | .08031 | 1.00258 | .09449 | .08363 | 1.00208 | .36939 |
| .64000 | 1.02425 | .07934 | 1.00331 | .09476 | .08261 | 1.00280 | .37181 |
| .66000 | 1.02995 | .07839 | 1.00402 | .09491 | .08153 | 1.00351 | .37425 |
| .68000 | 1.03551 | .07747 | 1.00469 | .09507 | .08045 | 1.00419 | .37660 |
| .70000 | 1.04081 | .07660 | 1.00534 | .09510 | .07944 | 1.00484 | .37895 |
| .72000 | 1.04581 | .07580 | 1.00594 | .09513 | .07848 | 1.00545 | .38125 |
| .74000 | 1.05048 | .07511 | 1.00649 | .09504 | .07761 | 1.00602 | .38350 |
| .76000 | 1.05481 | .07452 | 1.00700 | .09495 | .07684 | 1.00654 | .38567 |
| .78000 | 1.05876 | .07404 | 1.00746 | .09471 | .07617 | 1.00702 | .38774 |
| .80000 | 1.06233 | .07369 | 1.00788 | .09446 | .07560 | 1.00746 | .38972 |
| .82000 | 1.06553 | .07342 | 1.00825 | .09398 | .07512 | 1.00784 | .39156 |
| .84000 | 1.06836 | .07325 | 1.00858 | .09351 | .07475 | 1.00819 | .39329 |
| .86000 | 1.07082 | .07317 | 1.00886 | .09220 | .07447 | 1.00849 | .39493 |
| .88000 | 1.07290 | .07316 | 1.00910 | .09089 | .07425 | 1.00874 | .39646 |
| .90000 | 1.07462 | .07319 | 1.00931 | .08879 | .07408 | 1.00896 | .39787 |
| .92000 | 1.07597 | .07326 | 1.00947 | .08669 | .07396 | 1.00913 | .39919 |
| .94000 | 1.07698 | .07335 | 1.00959 | .08444 | .07386 | 1.00926 | .40039 |
| .96000 | 1.07763 | .07348 | 1.00967 | .08219 | .07378 | 1.00935 | .40149 |
| .98000 | 1.07795 | .07360 | 1.00972 | .07981 | .07371 | 1.00940 | .40248 |
| 1.00000 | 1.07789 | .07374 | 1.00971 | .07743 | .07364 | 1.00943 | .40336 |

TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04 082372 13 HOURS

LCYC = 374 TIME = 7.457553

| X | P | U | T | W | UP | TP | RHOP |
|---|---|---|---|---|---|---|---|
| 0.00000 | 1.09575 | 0.00000 | 1.01105 | .09722 | 0.00000 | 1.01100 | .38344 |
| .02000 | 1.09564 | .00168 | 1.01106 | .09712 | .00150 | 1.01099 | .38413 |
| .04000 | 1.09517 | .00335 | 1.01103 | .09702 | .00300 | 1.01096 | .38451 |
| .06000 | 1.09441 | .00503 | 1.01096 | .09670 | .00451 | 1.01090 | .38463 |
| .08000 | 1.09334 | .00670 | 1.01086 | .09638 | .00601 | 1.01079 | .38457 |
| .10000 | 1.09197 | .00836 | 1.01072 | .09586 | .00750 | 1.01066 | .38436 |
| .12000 | 1.09028 | .00999 | 1.01055 | .09534 | .00897 | 1.01049 | .38405 |
| .14000 | 1.08831 | .01160 | 1.01035 | .09462 | .01042 | 1.01028 | .38365 |
| .16000 | 1.08601 | .01319 | 1.01011 | .09389 | .01184 | 1.01004 | .38320 |
| .18000 | 1.08344 | .01472 | 1.00984 | .09220 | .01321 | 1.00976 | .38267 |
| .20000 | 1.08055 | .01622 | 1.00953 | .09051 | .01454 | 1.00945 | .38205 |
| .22000 | 1.07738 | .01765 | 1.00919 | .08822 | .01580 | 1.00910 | .38135 |
| .24000 | 1.07389 | .01900 | 1.00881 | .08594 | .01700 | 1.00871 | .38056 |
| .26000 | 1.07012 | .02029 | 1.00839 | .08351 | .01812 | 1.00829 | .37969 |
| .28000 | 1.06604 | .02149 | 1.00793 | .08108 | .01915 | 1.00782 | .37874 |
| .30000 | 1.06165 | .02259 | 1.00744 | .07858 | .02010 | 1.00732 | .37772 |
| .32000 | 1.05696 | .02361 | 1.00690 | .07609 | .02090 | 1.00678 | .37663 |
| .34000 | 1.05199 | .02453 | 1.00633 | .07358 | .02160 | 1.00619 | .37537 |
| .36000 | 1.04672 | .02530 | 1.00572 | .07108 | .02220 | 1.00556 | .37404 |
| .38000 | 1.04115 | .02595 | 1.00507 | .06859 | .02268 | 1.00489 | .37260 |
| .40000 | 1.03527 | .02656 | 1.00437 | .06611 | .02284 | 1.00418 | .37105 |
| .42000 | 1.02913 | .02698 | 1.00363 | .06370 | .02306 | 1.00342 | .36943 |
| .44000 | 1.02268 | .02725 | 1.00285 | .06130 | .02316 | 1.00263 | .36775 |
| .46000 | 1.01599 | .02740 | 1.00203 | .05900 | .02313 | 1.00179 | .36601 |
| .48000 | 1.00903 | .02740 | 1.00117 | .05670 | .02299 | 1.00092 | .36421 |
| .50000 | 1.00187 | .02731 | 1.00027 | .05457 | .02277 | 1.00002 | .36234 |
| .52000 | .99452 | .02712 | .99935 | .05243 | .02248 | .99909 | .36043 |
| .54000 | .98704 | .02685 | .99839 | .05056 | .02215 | .99815 | .35849 |
| .56000 | .97950 | .02656 | .99742 | .04868 | .02184 | .99719 | .35654 |
| .58000 | .97196 | .02628 | .99644 | .04701 | .02159 | .99624 | .35459 |
| .60000 | .96449 | .02609 | .99546 | .04534 | .02147 | .99529 | .35268 |
| .62000 | .95719 | .02601 | .99450 | .04389 | .02152 | .99436 | .35087 |
| .64000 | .95011 | .02602 | .99355 | .04244 | .02200 | .99347 | .34916 |
| .66000 | .94331 | .02634 | .99263 | .04121 | .02251 | .99261 | .34755 |
| .68000 | .93690 | .02692 | .99176 | .03998 | .02334 | .99179 | .34602 |
| .70000 | .93083 | .02778 | .99093 | .03897 | .02447 | .99102 | .34467 |
| .72000 | .92518 | .02897 | .99015 | .03797 | .02589 | .99030 | .34341 |
| .74000 | .92000 | .03049 | .98944 | .03717 | .02765 | .98965 | .34226 |
| .76000 | .91525 | .03235 | .98877 | .03637 | .02975 | .98904 | .34127 |
| .78000 | .91091 | .03451 | .98817 | .03577 | .03214 | .98849 | .34043 |
| .80000 | .90701 | .03698 | .98762 | .03517 | .03482 | .98800 | .33971 |
| .82000 | .90350 | .03972 | .98713 | .03483 | .03776 | .98756 | .33909 |
| .84000 | .90037 | .04270 | .98669 | .03448 | .04095 | .98716 | .33859 |
| .86000 | .89759 | .04591 | .98631 | .03496 | .04435 | .98682 | .33820 |
| .88000 | .89515 | .04932 | .98598 | .03545 | .04794 | .98651 | .33791 |
| .90000 | .89302 | .05293 | .98569 | .03725 | .05172 | .98626 | .33773 |
| .92000 | .89120 | .05669 | .98545 | .03906 | .05565 | .98604 | .33764 |
| .94000 | .88966 | .06060 | .98526 | .04116 | .05971 | .98587 | .33766 |
| .96000 | .88841 | .06460 | .98512 | .04326 | .06388 | .98574 | .33778 |
| .98000 | .88743 | .06870 | .98502 | .04559 | .06814 | .98564 | .33802 |
| 1.00000 | .88677 | .07283 | .98498 | .04791 | .07244 | .98557 | .33838 |

TEST CASE W=.1COS(PI*X) A=11.5,H=.64 V AND P COUPLING UTH=.04 062372 13 HOURS

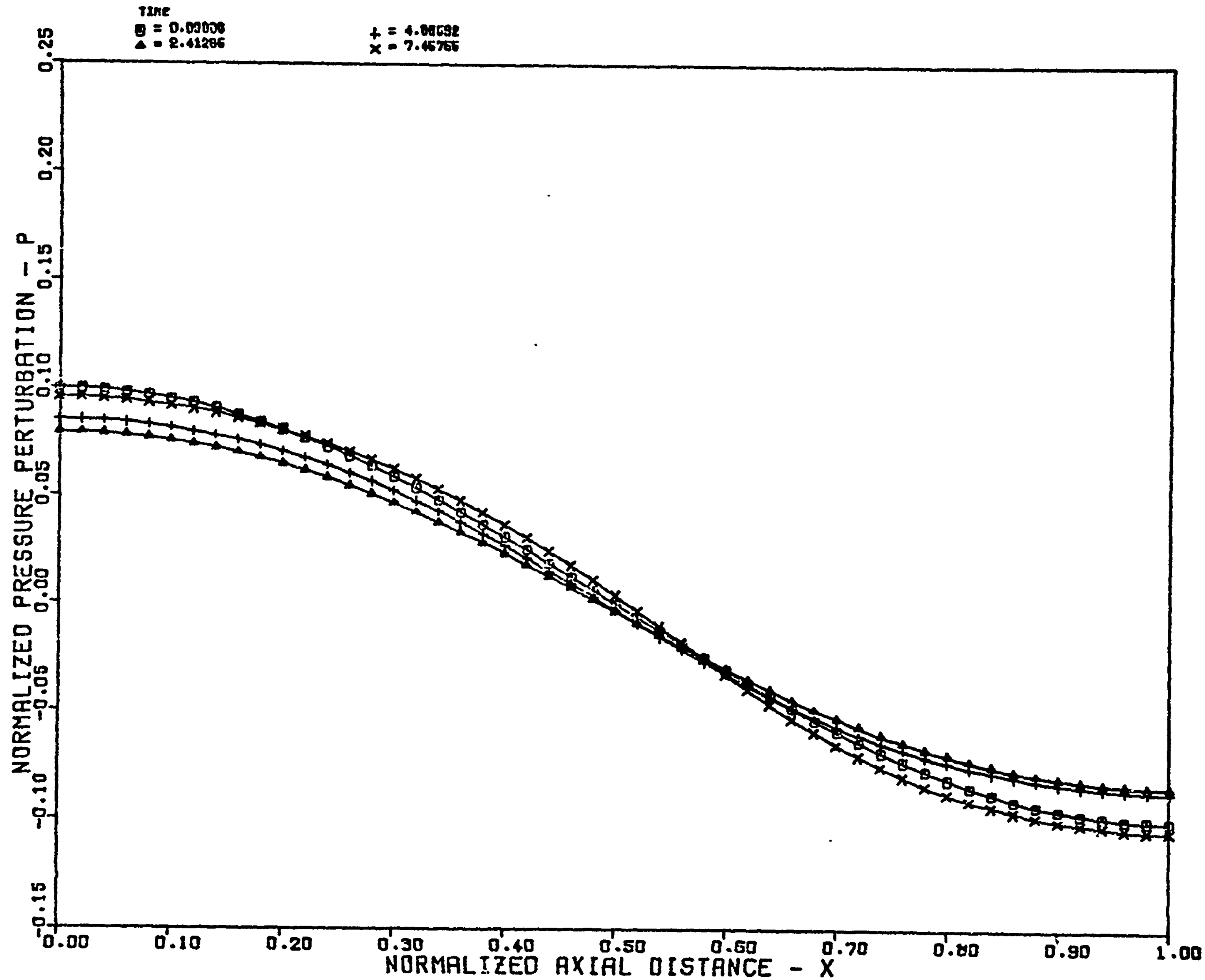
X=0.0000

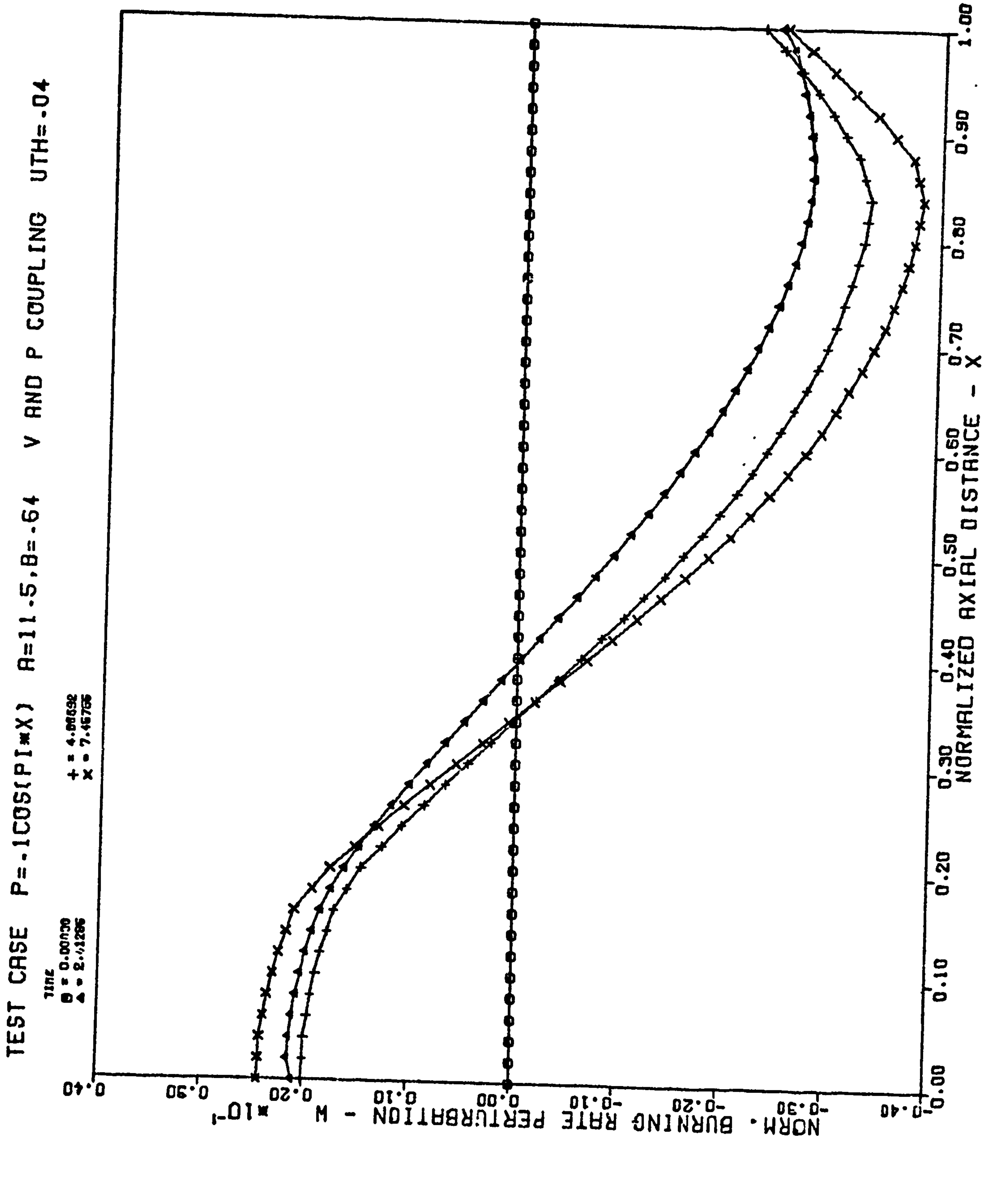
| I | TIME | PW | FMW | VW | FMWV | EMW1 | EMWV1 |
|---|---|---|---|---|---|---|---|
| 1 | 0.000000 | .100000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | .039764 | .094964 | .030758 | 0.000000 | 0.000000 | .030758 | 0.000000 |
| 3 | .079577 | .092532 | .052231 | 0.000000 | 0.000000 | .052231 | 0.000000 |
| 4 | .119407 | .089620 | .070513 | 0.000000 | 0.000000 | .070513 | 0.000000 |
| 5 | .159254 | .085903 | .086719 | 0.000000 | 0.000000 | .086719 | 0.000000 |
| 6 | .199118 | .081306 | .101009 | 0.000000 | 0.000000 | .101009 | 0.000000 |
| 7 | .239001 | .076151 | .113325 | 0.000000 | 0.000000 | .113325 | 0.000000 |
| 8 | .278905 | .070248 | .123553 | 0.000000 | 0.000000 | .123553 | 0.000000 |
| 9 | .318829 | .063776 | .131573 | 0.000000 | 0.000000 | .131573 | 0.000000 |
| 10 | .358775 | .056818 | .137276 | 0.000000 | 0.000000 | .137276 | 0.000000 |
| 11 | .398743 | .049458 | .140577 | 0.000000 | 0.000000 | .140577 | 0.000000 |
| 12 | .438733 | .041772 | .141415 | 0.000000 | 0.000000 | .141415 | 0.000000 |
| 13 | .478733 | .033853 | .139760 | 0.000000 | 0.000000 | .139760 | 0.000000 |
| 14 | .518706 | .025791 | .135623 | 0.000000 | 0.000000 | .135623 | 0.000000 |
| 15 | .558652 | .017670 | .129041 | 0.000000 | 0.000000 | .129041 | 0.000000 |
| 16 | .598574 | .009576 | .120089 | 0.000000 | 0.000000 | .120089 | 0.000000 |
| 17 | .638474 | .001575 | .108869 | 0.000000 | 0.000000 | .108869 | 0.000000 |
| 18 | .678353 | -.005278 | .095505 | 0.000000 | 0.000000 | .095505 | 0.000000 |
| 19 | .718213 | -.013932 | .080146 | 0.000000 | 0.000000 | .080146 | 0.000000 |
| 20 | .758058 | -.021340 | .062959 | 0.000000 | 0.000000 | .062959 | 0.000000 |
| 21 | .797889 | -.028458 | .044131 | 0.000000 | 0.000000 | .044131 | 0.000000 |
| 22 | .837710 | -.035249 | .023865 | 0.000000 | 0.000000 | .023865 | 0.000000 |
| 23 | .877523 | -.041676 | .002379 | 0.000000 | 0.000000 | .002379 | 0.000000 |
| 24 | .917331 | -.047706 | -.020097 | 0.000000 | 0.000000 | -.020097 | 0.000000 |
| 25 | .957136 | -.053308 | -.043320 | 0.000000 | 0.000000 | -.043320 | 0.000000 |
| 26 | .996941 | -.058455 | -.067041 | 0.000000 | 0.000000 | -.067041 | 0.000000 |
| 27 | 1.036747 | -.063118 | -.091004 | 0.000000 | 0.000000 | -.091004 | 0.000000 |
| 28 | 1.076558 | -.067270 | -.114945 | 0.000000 | 0.000000 | -.114945 | 0.000000 |
| 29 | 1.116375 | -.070871 | -.138597 | 0.000000 | 0.000000 | -.138597 | 0.000000 |
| 30 | 1.156201 | -.073876 | -.161686 | 0.000000 | 0.000000 | -.161686 | 0.000000 |
| 31 | 1.196035 | -.076235 | -.183932 | 0.000000 | 0.000000 | -.183932 | 0.000000 |
| 32 | 1.235881 | -.077900 | -.205053 | 0.000000 | 0.000000 | -.205053 | 0.000000 |
| 33 | 1.275740 | -.078825 | -.224767 | 0.000000 | 0.000000 | -.224767 | 0.000000 |
| 34 | 1.315612 | -.078960 | -.242794 | 0.000000 | 0.000000 | -.242794 | 0.000000 |
| 35 | 1.355500 | -.078254 | -.258856 | 0.000000 | 0.000000 | -.258856 | 0.000000 |
| 36 | 1.395402 | -.076657 | -.272679 | 0.000000 | 0.000000 | -.272679 | 0.000000 |
| 37 | 1.435322 | -.074123 | -.283998 | 0.000000 | 0.000000 | -.283998 | 0.000000 |
| 38 | 1.475258 | -.070614 | -.292559 | 0.000000 | 0.000000 | -.292559 | 0.000000 |
| 39 | 1.515212 | -.066106 | -.298124 | 0.000000 | 0.000000 | -.298124 | 0.000000 |
| 40 | 1.555183 | -.060595 | -.300475 | 0.000000 | 0.000000 | -.300475 | 0.000000 |
| 41 | 1.595171 | -.054104 | -.299426 | 0.000000 | 0.000000 | -.299426 | 0.000000 |
| 42 | 1.635177 | -.046681 | -.294825 | 0.000000 | 0.000000 | -.294825 | 0.000000 |
| 43 | 1.675198 | -.038413 | -.286567 | 0.000000 | 0.000000 | -.286567 | 0.000000 |
| 44 | 1.715220 | -.029422 | -.274604 | 0.000000 | 0.000000 | -.274604 | 0.000000 |
| 45 | 1.755212 | -.019870 | -.258957 | 0.000000 | 0.000000 | -.258957 | 0.000000 |
| 46 | 1.795177 | -.009941 | -.239704 | 0.000000 | 0.000000 | -.239704 | 0.000000 |
| 47 | 1.835115 | .000169 | -.216992 | 0.000000 | 0.000000 | -.216992 | 0.000000 |
| 48 | 1.875029 | .010246 | -.191032 | 0.000000 | 0.000000 | -.191032 | 0.000000 |
| 49 | 1.914921 | .020091 | -.162098 | 0.000000 | 0.000000 | -.162098 | 0.000000 |
| 50 | 1.954795 | .029518 | -.130512 | 0.000000 | 0.000000 | -.130512 | 0.000000 |
| 51 | 1.994652 | .038372 | -.096643 | 0.000000 | 0.000000 | -.096643 | 0.000000 |
| 52 | 2.034496 | .046519 | -.060895 | 0.000000 | 0.000000 | -.060895 | 0.000000 |
| 53 | 2.074330 | .053856 | -.023700 | 0.000000 | 0.000000 | -.023700 | 0.000000 |
| 54 | 2.114157 | .060311 | .014494 | 0.000000 | 0.000000 | .014494 | 0.000000 |
| 55 | 2.153979 | .065848 | .053233 | 0.000000 | 0.000000 | .053233 | 0.000000 |
| 56 | 2.193799 | .070438 | .092057 | 0.000000 | 0.000000 | .092057 | 0.000000 |

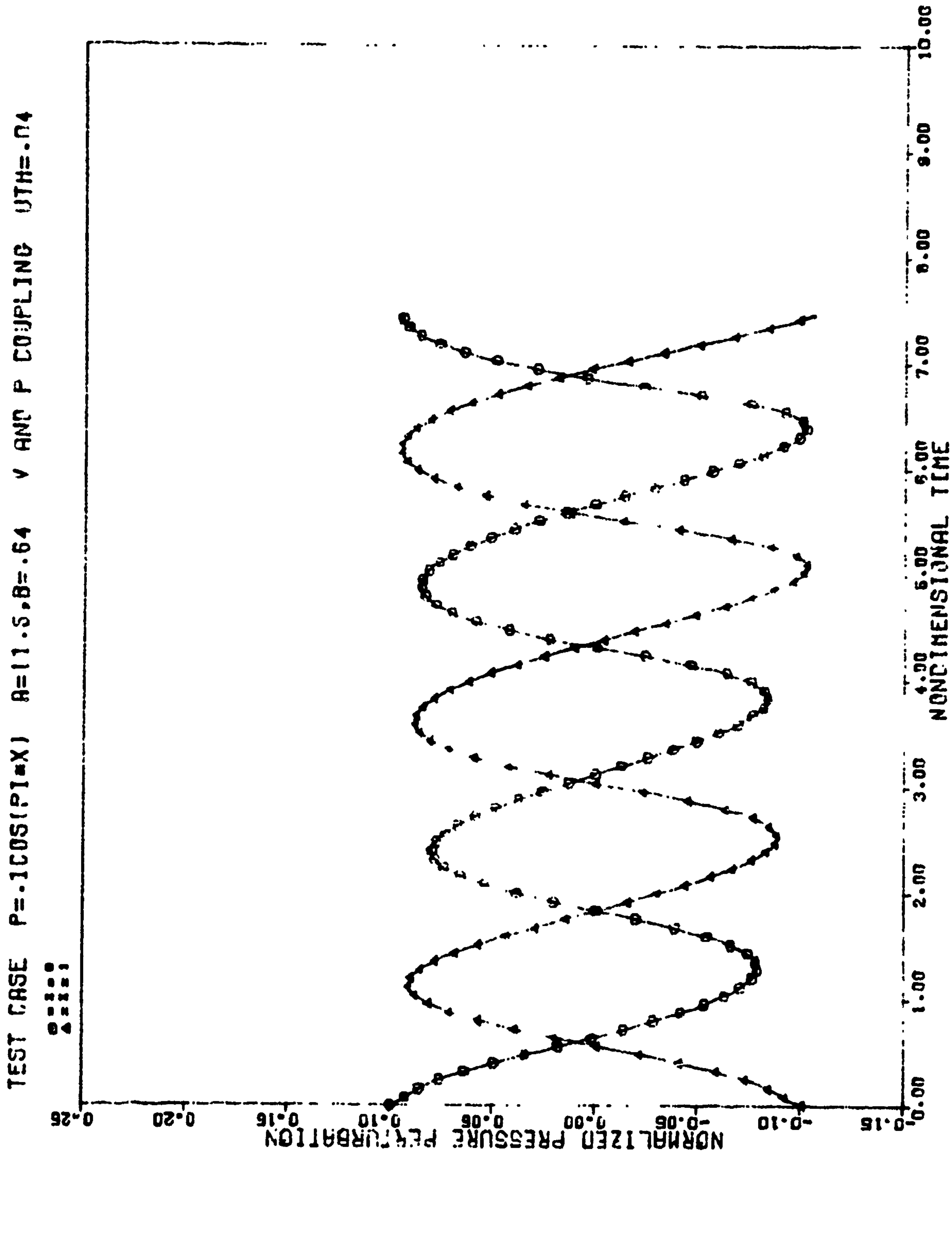
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 57 | 2.233618 | .074008 | .130515 | 0.000000 | 0.000000 | .130515 | 0.000000 |
| 58 | 2.273439 | .076828 | .168170 | 0.000000 | 0.000000 | .168170 | 0.000000 |
| 59 | 2.313265 | .078670 | .204596 | 0.000000 | 0.000000 | .204596 | 0.000000 |
| 60 | 2.353095 | .079659 | .239389 | 0.000000 | 0.000000 | .239389 | 0.000000 |
| 61 | 2.392933 | .079851 | .272173 | 0.000000 | 0.000000 | .272173 | 0.000000 |
| 62 | 2.432779 | .079306 | .302600 | 0.000000 | 0.000000 | .302600 | 0.000000 |
| 63 | 2.472634 | .078052 | .330346 | 0.000000 | 0.000000 | .330346 | 0.000000 |
| 64 | 2.512500 | .076151 | .355121 | 0.000000 | 0.000000 | .355121 | 0.000000 |
| 65 | 2.552378 | .073651 | .376665 | 0.000000 | 0.000000 | .376665 | 0.000000 |
| 66 | 2.592269 | .070601 | .394756 | 0.000000 | 0.000000 | .394756 | 0.000000 |
| 67 | 2.632173 | .067027 | .409197 | 0.000000 | 0.000000 | .409197 | 0.000000 |
| 68 | 2.672092 | .063014 | .419838 | 0.000000 | 0.000000 | .419838 | 0.000000 |
| 69 | 2.712025 | .058595 | .426564 | 0.000000 | 0.000000 | .426564 | 0.000000 |
| 70 | 2.751973 | .053800 | .429292 | 0.000000 | 0.000000 | .429292 | 0.000000 |
| 71 | 2.791938 | .048667 | .427974 | 0.000000 | 0.000000 | .427974 | 0.000000 |
| 72 | 2.831918 | .043233 | .422600 | 0.000000 | 0.000000 | .422600 | 0.000000 |
| 73 | 2.871915 | .037534 | .413194 | 0.000000 | 0.000000 | .413194 | 0.000000 |
| 74 | 2.911929 | .031610 | .399816 | 0.000000 | 0.000000 | .399816 | 0.000000 |
| 75 | 2.951923 | .025507 | .382586 | 0.000000 | 0.000000 | .382586 | 0.000000 |
| 76 | 2.991885 | .019265 | .361641 | 0.000000 | 0.000000 | .361641 | 0.000000 |
| 77 | 3.031819 | .012919 | .337155 | 0.000000 | 0.000000 | .337155 | 0.000000 |
| 78 | 3.071727 | .006501 | .309329 | 0.000000 | 0.000000 | .309329 | 0.000000 |
| 79 | 3.111613 | .000043 | .278391 | 0.000000 | 0.000000 | .278391 | 0.000000 |
| 80 | 3.151481 | -.006422 | .244593 | 0.000000 | 0.000000 | .244593 | 0.000000 |
| 81 | 3.191333 | -.012867 | .208206 | 0.000000 | 0.000000 | .208206 | 0.000000 |
| 82 | 3.231174 | -.019257 | .169524 | 0.000000 | 0.000000 | .169524 | 0.000000 |
| 83 | 3.271005 | -.025567 | .128857 | 0.000000 | 0.000000 | .128857 | 0.000000 |
| 84 | 3.310829 | -.031762 | .086532 | 0.000000 | 0.000000 | .086532 | 0.000000 |
| 85 | 3.350650 | -.037813 | .042890 | 0.000000 | 0.000000 | .042890 | 0.000000 |
| 86 | 3.390467 | -.043685 | -.001717 | 0.000000 | 0.000000 | -.001717 | 0.000000 |
| 87 | 3.430285 | -.049368 | -.046929 | 0.000000 | 0.000000 | -.046929 | 0.00[illegible] |
| 88 | 3.470104 | -.054766 | -.092375 | 0.000000 | 0.000000 | -.092375 | 0.000000 |
| 89 | 3.509926 | -.059896 | -.137683 | 0.000000 | 0.000000 | -.137683 | 0.000000 |
| 90 | 3.549752 | -.064692 | -.182473 | 0.000000 | 0.000000 | -.182473 | 0.000000 |
| 91 | 3.589584 | -.069111 | -.226363 | 0.000000 | 0.000000 | -.226363 | 0.000000 |
| 92 | 3.629424 | -.073090 | -.268972 | 0.000000 | 0.000000 | -.268972 | 0.000000 |
| 93 | 3.669271 | -.076570 | -.309914 | 0.000000 | 0.000000 | -.309914 | 0.000000 |
| 94 | 3.709128 | -.079477 | -.348808 | 0.000000 | 0.000000 | -.348808 | 0.000000 |
| 95 | 3.748995 | -.081735 | -.385273 | 0.000000 | 0.000000 | -.385273 | 0.000000 |
| 96 | 3.788873 | -.083254 | -.418930 | 0.000000 | 0.000000 | -.418930 | 0.000000 |
| 97 | 3.828766 | -.083931 | -.449400 | 0.000000 | 0.000000 | -.449400 | 0.000000 |
| 98 | 3.868667 | -.083652 | -.476307 | 0.000000 | 0.000000 | -.476307 | 0.000000 |
| 99 | 3.908584 | -.082293 | -.499277 | 0.000000 | 0.000000 | -.499277 | 0.000000 |
| 100 | 3.948515 | -.079728 | -.517940 | 0.000000 | 0.000000 | -.517940 | 0.000000 |
| 101 | 3.988461 | -.[illegible]5874 | -.531941 | 0.000000 | 0.000000 | -.531941 | 0.000000 |
| 102 | 4.028422 | -.070612 | -.540939 | 0.000000 | 0.000000 | -.540939 | 0.000000 |
| 103 | 4.068399 | -.063894 | -.544618 | 0.000000 | 0.000000 | -.544618 | 0.000000 |
| 104 | 4.108392 | -.055745 | -.542712 | 0.000000 | 0.000000 | -.542712 | 0.000000 |
| 105 | 4.148401 | -.046216 | -.535013 | 0.000000 | 0.000000 | -.535013 | 0.000000 |
| 106 | 4.188418 | -.035601 | -.521415 | 0.000000 | 0.000000 | -.521415 | 0.000000 |
| 107 | 4.228403 | -.024158 | -.501944 | 0.000000 | 0.000000 | -.501944 | 0.000000 |
| 108 | 4.268354 | -.012253 | -.476728 | 0.000000 | 0.000000 | -.476728 | 0.000000 |
| 109 | 4.308275 | -.000263 | -.446020 | 0.000000 | 0.000000 | -.446020 | 0.000000 |
| 110 | 4.348171 | .011454 | -.410183 | 0.000000 | 0.000000 | -.410183 | 0.000000 |
| 111 | 4.388044 | .022621 | -.369660 | 0.000000 | 0.000000 | -.369660 | 0.000000 |
| 112 | 4.427900 | .033016 | -.324962 | 0.000000 | 0.000000 | -.324962 | 0.000000 |
| 113 | 4.467741 | .042496 | -.276644 | 0.000000 | 0.000000 | -.276644 | 0.000000 |
| 114 | 4.507571 | .050979 | -.225288 | 0.000000 | 0.000000 | -.225288 | 0.000000 |
| 115 | 4.547393 | .058446 | -.171493 | 0.000000 | 0.000000 | -.171493 | 0.000000 |
| 116 | 4.587210 | .064895 | -.115860 | 0.000000 | 0.000000 | -.115860 | 0.000000 |
| 117 | 4.627022 | .070373 | -.058986 | 0.000000 | 0.000000 | -.058986 | 0.000000 |
| 118 | 4.666833 | .074911 | -.001462 | 0.000000 | 0.000000 | -.001462 | 0.000000 |
| 119 | 4.706644 | .078563 | .056133 | 0.000000 | 0.000000 | .056133 | 0.000000 |
| 120 | 4.746457 | .081403 | .113242 | 0.000000 | 0.000000 | .113242 | 0.000000 |
| 121 | 4.786273 | .083449 | .169318 | 0.000000 | 0.000000 | .169318 | 0.000000 |
| 122 | 4.826093 | .084765 | .223839 | 0.000000 | 0.000000 | .223839 | 0.000000 |

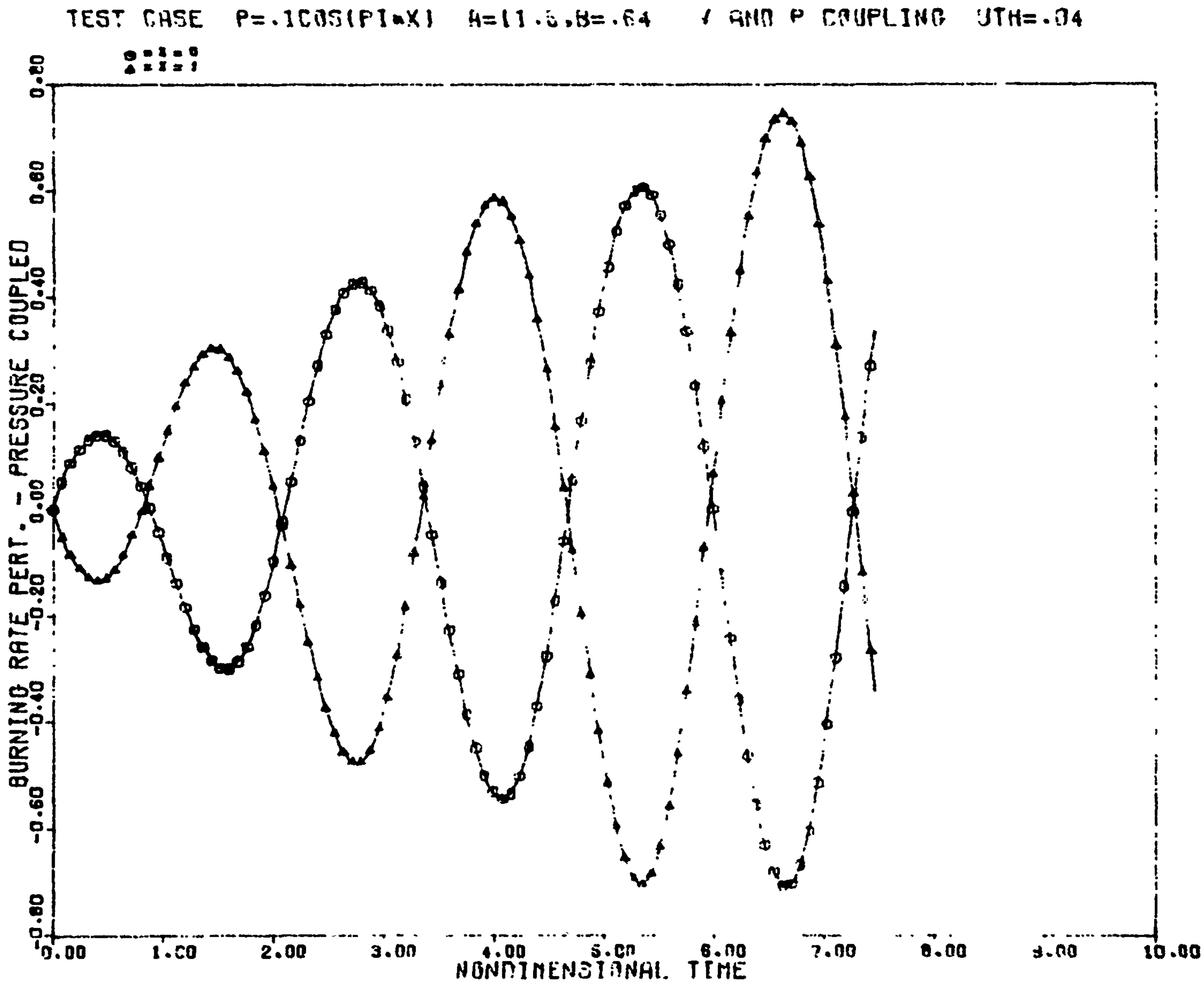
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 123 | 4.865919 | .085406 | .276311 | 0.000000 | 0.000000 | .276311 | 0.000000 |
| 124 | 4.905751 | .085405 | .326262 | 0.000000 | 0.000000 | .326262 | 0.000000 |
| 125 | 4.945592 | .084704 | .373250 | 0.000000 | 0.000000 | .373250 | 0.000000 |
| 126 | 4.985441 | .083610 | .416963 | 0.000000 | 0.000000 | .416963 | 0.000000 |
| 127 | 5.025300 | .081888 | .456722 | 0.000000 | 0.000000 | .456722 | 0.000000 |
| 128 | 5.065170 | .079648 | .492484 | 0.000000 | 0.000000 | .492484 | 0.000000 |
| 129 | 5.105052 | .076915 | .523839 | 0.000000 | 0.000000 | .523839 | 0.000000 |
| 130 | 5.144947 | .073721 | .550520 | 0.000000 | 0.000000 | .550520 | 0.000000 |
| 131 | 5.184855 | .070076 | .572296 | 0.000000 | 0.000000 | .572296 | 0.000000 |
| 132 | 5.224777 | .065994 | .588973 | 0.000000 | 0.000000 | .588973 | 0.000000 |
| 133 | 5.264715 | .061522 | .600407 | 0.000000 | 0.000000 | .600407 | 0.000000 |
| 134 | 5.304667 | .056684 | .606498 | 0.000000 | 0.000000 | .606498 | 0.000000 |
| 135 | 5.344636 | .051490 | .607185 | 0.000000 | 0.000000 | .607185 | 0.000000 |
| 136 | 5.384622 | .045950 | .602446 | 0.000000 | 0.000000 | .602446 | 0.000000 |
| 137 | 5.424625 | .040104 | .592308 | 0.000000 | 0.000000 | .592308 | 0.000000 |
| 138 | 5.464608 | .0333[illegible]3 | .576871 | 0.000000 | 0.000000 | .576871 | 0.000000 |
| 139 | 5.504557 | .027664 | .556261 | 0.000000 | 0.000000 | .556261 | 0.000000 |
| 140 | 5.544476 | .021121 | .530647 | 0.000000 | 0.000000 | .530647 | 0.000000 |
| 141 | 5.584372 | .014397 | .500240 | 0.000000 | 0.000000 | .500240 | 0.000000 |
| 142 | 5.624247 | .007516 | .465283 | 0.000000 | 0.000000 | .465283 | 0.000000 |
| 143 | 5.664106 | .000513 | .426054 | 0.000000 | 0.000000 | .426054 | 0.000000 |
| 144 | 5.703951 | -.006594 | .382861 | 0.000000 | 0.000000 | .382861 | 0.000000 |
| 145 | 5.743786 | -.013766 | .336039 | 0.000000 | 0.000000 | .336039 | 0.000000 |
| 146 | 5.783612 | -.020976 | .285954 | 0.000000 | 0.000000 | .285954 | 0.000000 |
| 147 | 5.823431 | -.028191 | .232993 | 0.000000 | 0.000000 | .232993 | 0.000000 |
| 148 | 5.863245 | -.035374 | .177567 | 0.000000 | 0.000000 | .177567 | 0.000000 |
| 149 | 5.903056 | -.042487 | .120107 | 0.000000 | 0.000000 | .120107 | 0.000000 |
| 150 | 5.942865 | -.049489 | .061061 | 0.000000 | 0.000000 | .061061 | 0.000000 |
| 151 | 5.982674 | -.056337 | .000890 | 0.000000 | 0.000000 | .000890 | 0.000000 |
| 152 | 6.022484 | -.062986 | -.059932 | 0.000000 | 0.000000 | -.059932 | 0.000000 |
| 153 | 6.062296 | -.069384 | -.120923 | 0.000000 | 0.000000 | -.120923 | 0.000000 |
| 154 | 6.102112 | -.075474 | -.181592 | 0.000000 | 0.000000 | -.181592 | 0.000000 |
| 155 | 6.141932 | -.081190 | -.241445 | 0.000000 | 0.000000 | -.241445 | 0.000000 |
| 156 | 6.181759 | -.086456 | -.299980 | 0.000000 | 0.000000 | -.299980 | 0.000000 |
| 157 | 6.221594 | -.091178 | -.356692 | 0.000000 | 0.000000 | -.356692 | 0.000000 |
| 158 | 6.261436 | -.095252 | -.411073 | 0.000000 | 0.000000 | -.411073 | 0.000000 |
| 159 | 6.301289 | -.098546 | -.462606 | 0.000000 | 0.000000 | -.462606 | 0.000000 |
| 160 | 6.341152 | -.100907 | -.510769 | 0.000000 | 0.000000 | -.510769 | 0.000000 |
| 161 | 6.381027 | -.102159 | -.555030 | 0.000000 | 0.000000 | -.555030 | 0.000000 |
| 162 | 6.420915 | -.102087 | -.594863 | 0.000000 | 0.000000 | -.594863 | 0.000000 |
| 163 | 6.460817 | -.100486 | -.629654 | 0.000000 | 0.000000 | -.629654 | 0.000000 |
| 164 | 6.500734 | -.097146 | -.658907 | 0.000000 | 0.000000 | -.658907 | 0.000000 |
| 165 | 6.540665 | -.091863 | -.682046 | 0.000000 | 0.000000 | -.682046 | 0.000000 |
| 166 | 6.580613 | -.084502 | -.698535 | 0.000000 | 0.000000 | -.698535 | 0.000000 |
| 167 | 6.620578 | -.075066 | -.707895 | 0.000000 | 0.000000 | -.707895 | 0.000000 |
| 168 | 6.660560 | -.063729 | -.709742 | 0.000000 | 0.000000 | -.709742 | 0.000000 |
| 169 | 6.700560 | -.050823 | -.703828 | 0.000000 | 0.000000 | -.703828 | 0.000000 |
| 170 | 6.740557 | -.036965 | -.690113 | 0.000000 | 0.000000 | -.690113 | 0.000000 |
| 171 | 6.780515 | -.022722 | -.668756 | 0.000000 | 0.000000 | -.668756 | 0.000000 |
| 172 | 6.820438 | -.008614 | -.640056 | 0.000000 | 0.000000 | -.640056 | 0.000000 |
| 173 | 6.860334 | .004920 | -.604460 | 0.000000 | 0.000000 | -.604460 | 0.000000 |
| 174 | 6.900207 | .017568 | -.562511 | 0.000000 | 0.000000 | -.562511 | 0.000000 |
| 175 | 6.940062 | .029184 | -.514805 | 0.000000 | 0.000000 | -.514805 | 0.000000 |
| 176 | 6.979901 | .039720 | -.461970 | 0.000000 | 0.000000 | -.461970 | 0.000000 |
| 177 | 7.019728 | .049178 | -.404649 | 0.000000 | 0.000000 | -.404649 | 0.000000 |
| 178 | 7.059546 | .057605 | -.343497 | 0.000000 | 0.000000 | -.343497 | 0.000000 |
| 179 | 7.099355 | .065044 | -.279173 | 0.000000 | 0.000000 | -.279173 | 0.000000 |
| 180 | 7.139158 | .071561 | -.212339 | 0.000000 | 0.000000 | -.212339 | 0.000000 |
| 181 | 7.178957 | .077206 | -.143655 | 0.000000 | 0.000000 | -.143655 | 0.000000 |
| 182 | 7.218753 | .082030 | -.073778 | 0.000000 | 0.000000 | -.073778 | 0.000000 |
| 183 | 7.258548 | .086084 | -.003359 | 0.000000 | 0.000000 | -.003359 | 0.000000 |
| 184 | 7.298343 | .089386 | .066960 | 0.000000 | 0.000000 | .066960 | 0.000000 |
| 185 | 7.338139 | .091985 | .136548 | 0.000000 | 0.000000 | .136548 | 0.000000 |
| 186 | 7.377939 | .093906 | .204793 | 0.000000 | 0.000000 | .204793 | 0.000000 |
| 187 | 7.417743 | .095147 | .271096 | 0.000000 | 0.000000 | .271096 | 0.000000 |
| 188 | 7.457553 | .095752 | .334885 | 0.000000 | 0.000000 | .334885 | 0.000000 |

TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04

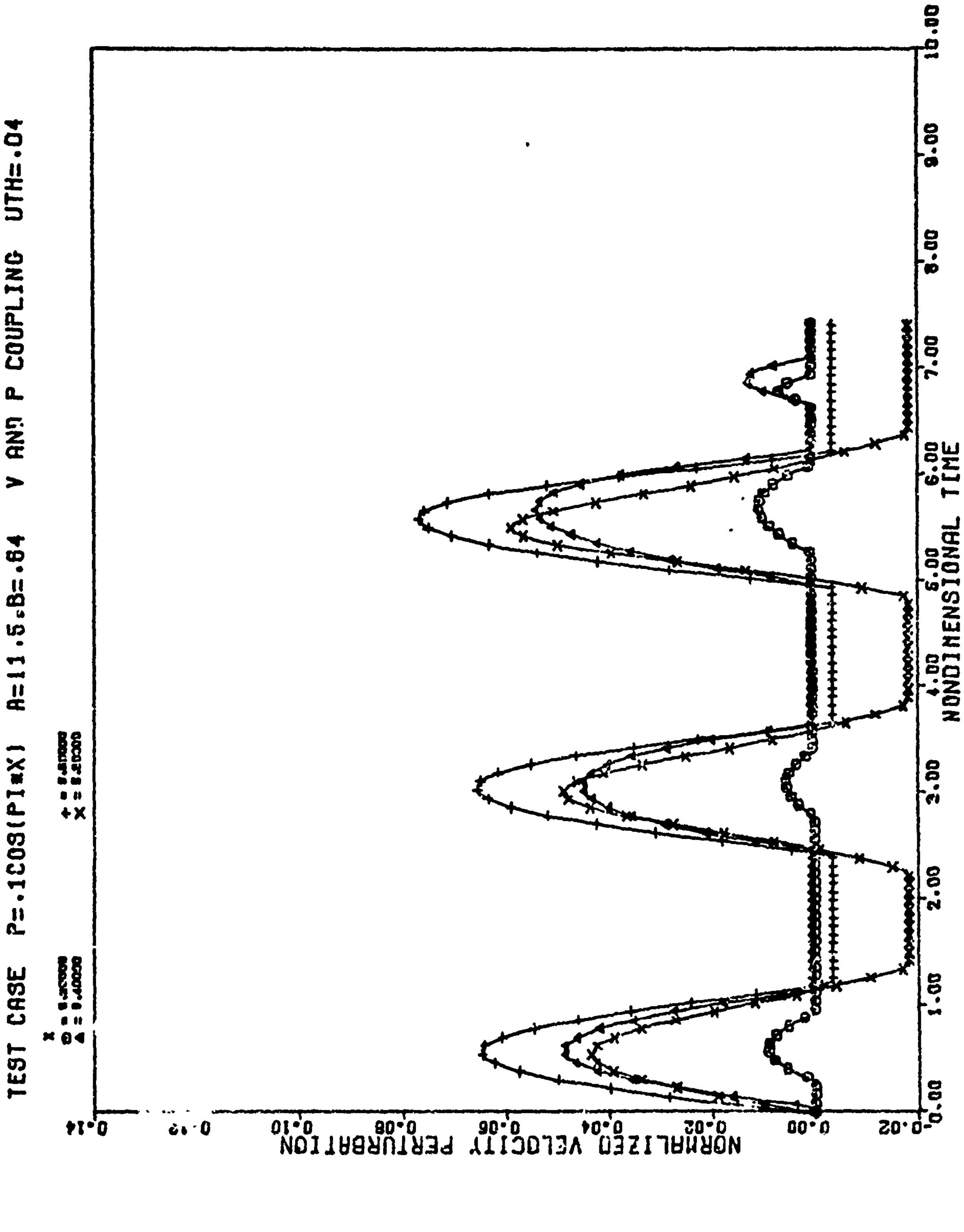


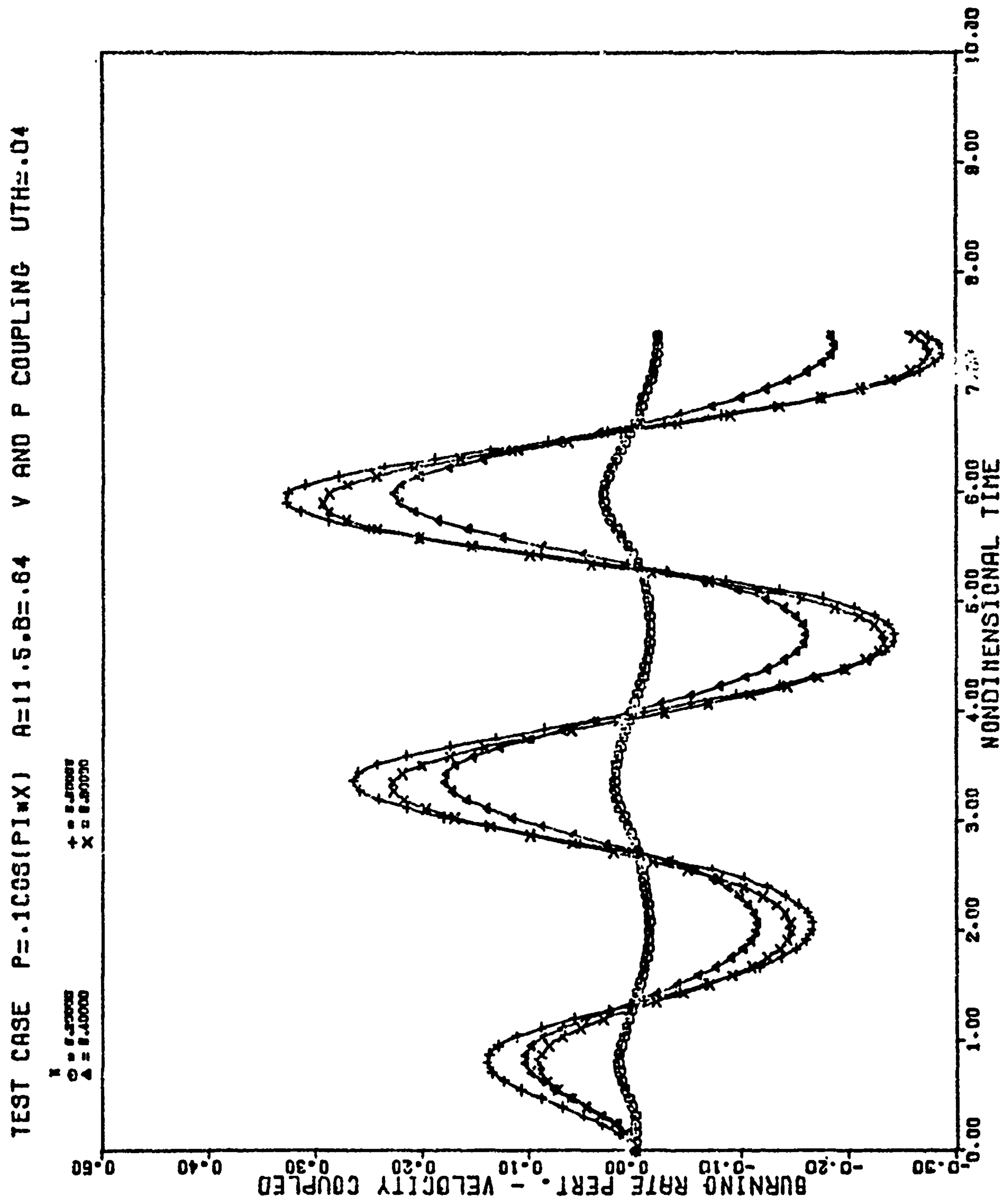

TEST CASE P=-.1COS(PI*X) A=11.5,B=-.64 V AND P COUPLING UTH=-.04
TIME
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00
NORMALIZED AXIAL DISTANCE - X
0.40 0.30 0.20 0.10 0.00 -0.10 -0.20 -0.30 -0.40
NORM. BURNING RATE PERTURBATION - W *10⁻¹


TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04
NONDIMENSIONAL TIME
NORMALIZED PRESSURE PERTURBATION
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15



TEST CASE P=.1COS(PI*X) A=11.5,B=.64 / AND P COUPLING UTH=.04
BURNING RATE PERT. - PRESSURE COUPLED
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
NONDIMENSIONAL TIME


TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04
NONDIMENSIONAL TIME
NORMALIZED VELOCITY PERTURBATION
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.14


TEST CASE P=.1COS(PI*X) A=11.5,B=.64 V AND P COUPLING UTH=.04
NONDIMENSIONAL TIME
BURNING RATE PERT. - VELOCITY COUPLED
0.00
1.00
2.00
3.00
4.00
6.00
8.00
9.00
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40