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30 APRIL 1968

COMPUTER SIMULATION OF HIGH FREQUENCY COMBUSTION INSTABILITY AND ITS SUPPRESSION

FINAL REPORT

Prepared for
Headquarters
National Aeronautics and Space Administration
Washington, D. C.

Contract NASw-1512

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION
FLORIDA RESEARCH AND DEVELOPMENT CENTER
BOX 2691, WEST PALM BEACH, FLORIDA 33402

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SUMMARY

A digital computer program has been prepared for the simulation of gas motion driven by combustion energy within a slab rocket motor. The computer program is based on numerically integrating the laws of inviscid fluid dynamics by a two-step Lax-Wendroff technique. Provisions have been made in the program for a sound-absorbing liner at the wall of the chamber to simulate the absorption of acoustic waves. The program has been employed to illustrate the effects of some of the variables on combustion instability and its suppression. Suggestions for further use of the computer program in the investigation of unstable combustion are also included.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

SECTION I
INTRODUCTION

The theories that have been proposed to explain the observed high frequency oscillations that arise under certain conditions in the combustion chambers of liquid propellant rocket engines have been based on the laws of inviscid fluid flow. However, in general, because of the complexity of the non-linear partial differential equations it has been necessary to employ linearized or simplified versions of these equations. Many useful qualitative results were obtained by the linearized equations. For example Culick(1) was able to show the general effects of the distribution of energy in the chamber, mass flow of propellants, chamber pressure, and chamber size on the stability of gas flow.

However, to show the quantitative effects of the many variables on wave motion it is necessary to employ the non-linear equations directly. Such an approach was taken by Priem and Guentert(2) in a theoretical analysis of high frequency instability. This analysis was based on a toroidal combustion chamber and was directed toward determining the magnitude of the disturbance that was required to cause instability. Priem(3) further expanded on these results to show the effects of chemical reaction rate, vaporization, and atomization on the stability boundary.

The approach of using the non-linear gas dynamics equations has been continued. This report describes a computer program for the simulation of the time-dependent flow of gas that is driven by the combustion energy release in a slab rocket motor. The purpose of the simulation is to model high-frequency unstable combustion in a slab motor and its suppression by a sound-absorbing (acoustic) liner. The gas flow properties are computed by numerical integration of the conservation laws using a two-step Lax-Wendroff technique.

It should be noted that the computer program only provides for the calculation of the dynamics of the combustion gas assuming that the gas phase is homogeneous in a slab motor. Thus, it does not provide for the actual spray combustion mechanism when starting with liquid propellants or for other chamber geometries. It does not appear practical at this time to calculate the dynamics of a spray that would include vaporization, mixing, and the rates of chemical reaction by the inviscid flow equations for a two-dimensional geometry because of computer limitations. For this reason, the combustion process, in steady-state simulation, is represented simply as the overall rate of combustion energy release assuming that the combustion is distributed evenly throughout the chamber. In transient simulation, the combustion is represented in the steady energy release modified to account for the effect of pressure at any time on the rate of energy release. Hence, the program can be used for any propellant system, requiring only specification of the overall heat of combustion. If, for a specific propellant system, it is known that combustion is concentrated in a particular zone within the chamber, then the program can be easily modified to account for this distribution of energy.

It is necessary to prescribe or calculate the values of the dependent variables on the chamber boundary to simulate the gas flow within the motor. The injector face is the only part of the combustion chamber for which the principles of gas dynamics do not provide the basis for the "boundary conditions". Ideally, the transients of the propellant supply system and the injector should be described mathematically in detail. These models would be coupled with the inviscid flow equations at the face. However, the inclusion of this detail would greatly increase the computing time. In addition, it does not appear likely that the propellant supply system greatly influences the acoustic oscillations of the gas flowing in the combustion chamber. Therefore, for an initial study of sound wave suppression, it appears that specification of the enthalpy and the momenta at the injector face are adequate. Since propellant supply and injector system are not included in the mathematical model, the program is not intended for use in calculating starting transients. It would be necessary to add the propellant supply and injector systems to use the program to calculate starting transients.

The major benefit of the program lies in the fact that the energy release, wave motion, and wave suppression are coupled in a manner representative of that which occurs in an actual engine. Current theories used for sound-absorbing liner performance analysis or design do not provide for this coupling. Hence current theories do not provide a basis for predicting the effect of the liner design variables in conjunction with the operation and size of the combustion chamber.

The computer program has been employed to obtain simulations, included herein, for steady-state, as well as transient, gas flow within the rocket motor when energy is released within the combustion chamber. The gas flow in the transient period takes the form of acoustic waves. A simulation of the suppression of these waves by an acoustic liner installed at the wall of the chamber is also included.

Numerical integration was also attempted using a predictor-corrector technique, which is presented in Appendix C. It was found empirically that the predictor-corrector technique was unstable for all parameter values.

The investigation described in this report parallels the efforts of Dr. S. Z. Burstein, Assistant Professor of Mathematics, Courant Institute of Mathematical Sciences, New York University. Dr. Burstein's work is described in "Non-Linear Combustion Instability in Liquid-Propellant Rocket Engines," NASA TR 32-1111, 15 September 1967. His efforts are directed primarily toward the traveling transverse mode in cylindrical chambers, whereas this report is directed toward standing transverse or longitudinal waves in slab motors.

The author gratefully acknowledges the invaluable assistance rendered by Dr. Burstein, who supplied the Lax-Wendroff techniques used in this report and who provided generous guidance during the preparation and use of this computer program .

SECTION II
GAS MOTION WITHIN SLAB MOTORS AND ACOUSTIC LINERS

The slab motor for which the gas motion is to be simulated by the computer program described in this report is shown in figure 1. The dimensions refer to the specific motor for which the computed results presented in this report were obtained.

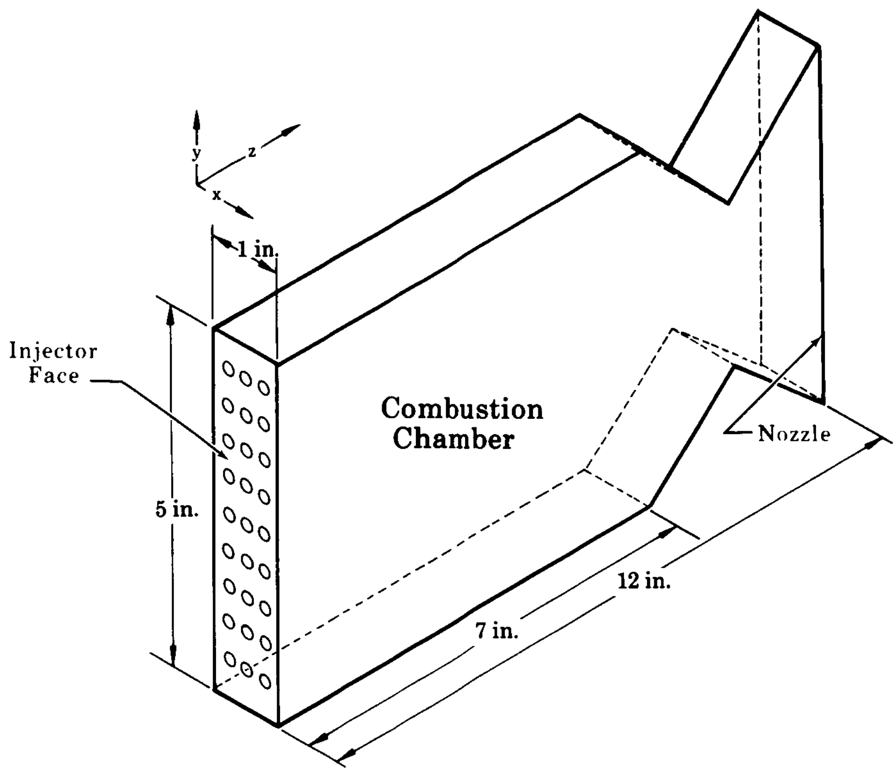

Figure 1. Slab Motor FD 23804

Normally, consideration of all three dimensions (x, y and z) would be necessary to simulate the motion of the gas within the motor. However, if the width (distance along z coordinate) is sufficiently small, the problem can be reduced to two dimensions by assuming that the flow is zero in the z direction. Difficulties in making simulations and the time required are thus reduced.

A sound-absorbing (acoustic) liner can be installed within a combustion chamber to absorb part of the energy in a propagated wave. The transverse waves are, in general, the significant mode of vibration; the liner is installed at the periphery of the chamber to absorb these waves. The acoustic liner is essentially a perforated plate that is installed a short distance from the solid wall of the chamber. The size and spacing of the apertures and the distance separating the liner and wall are design variables.

The liner installed in the slab motor is shown schematically in figure 2.

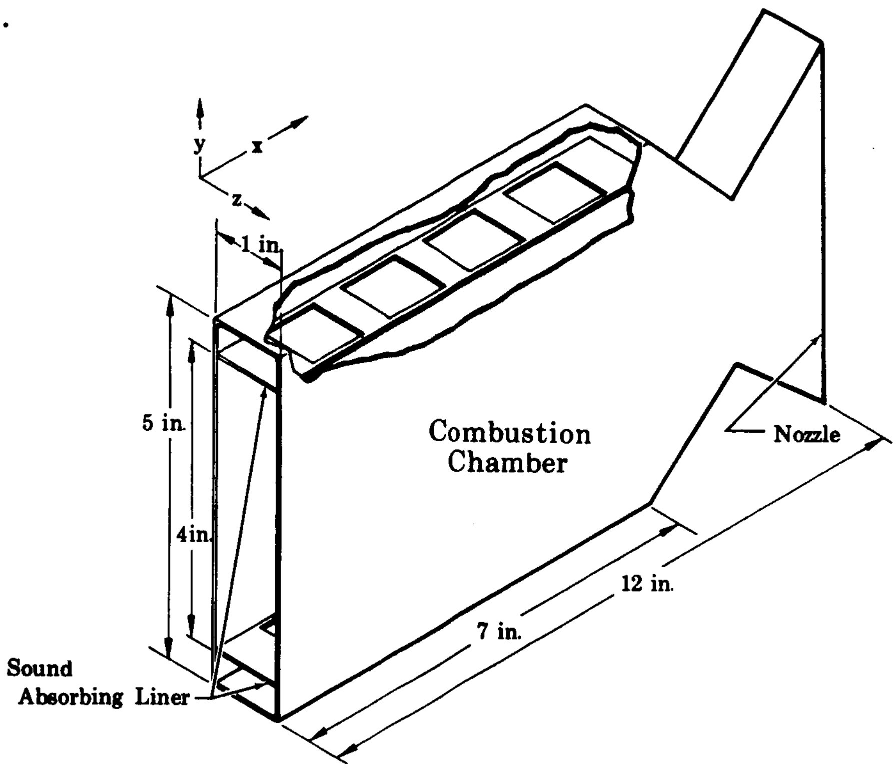

Figure 2. Slab Motor With Acoustic Liner FD 23806

The equivalent two-dimensional geometry is shown in figure 3.

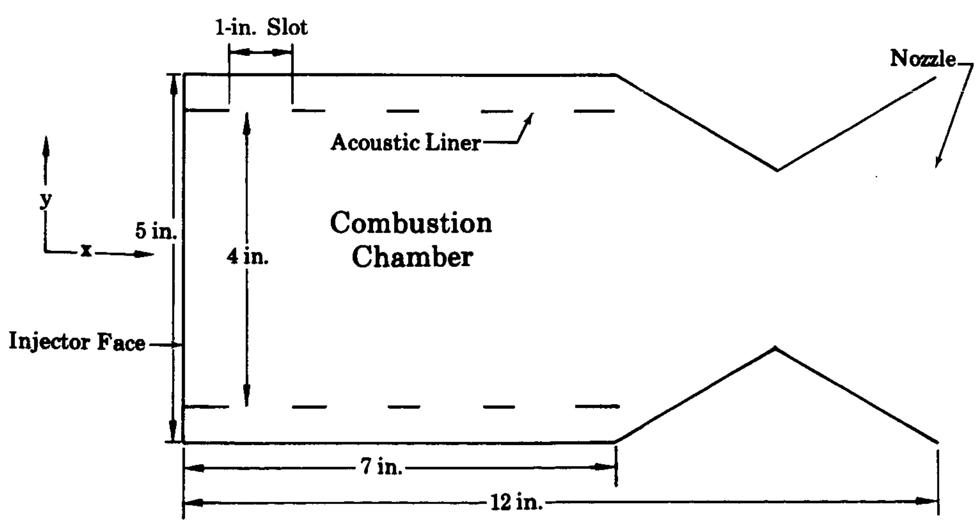

Figure 3. Two-Dimensional Representation of Slab Motor with Acoustic Liner FD 23807

The present acoustic liner design is based on the theory of the Helmholtz resonator for a wave striking the surface of the resonator. The current theory does not, however, include the coupling of the combustion energy release rate to the wave dynamics. An objective of this contract is to provide a method of coupling energy release to the suppression of the driven sound waves by the acoustic liner through the use of the nonhomogeneous conservation laws.

The gas motion within the motor and the acoustic liner (if provided) is simulated by means of the inviscid equations of fluid motion, which fulfill the principles of the conservation of mass, momentum, and energy. The equations, in divergence form (variables are nondimensional), are:

$$\rho_t = - m_x - n_y + M \tag{1}$$

$$m_t = -\left(p + \frac{m^2}{\rho}\right)_x - \left(\frac{mn}{\rho}\right)_y \tag{2}$$

$$n_t = -\left(\frac{mn}{\rho}\right)_x - \left(p + \frac{n^2}{\rho}\right)_y \tag{3}$$

$$E_t = - \left[\frac{m}{\rho}(p + E)\right]_x - \left[\frac{n}{\rho}(p + E)\right]_y + Q \tag{4}$$

where:

ρ = mass per unit volume

$m = \rho u$ = momentum in x direction per unit volume

$n = \rho v$ = momentum in y direction per unit volume

$E = \rho\left(e + \frac{m^2 + n^2}{2\rho^2}\right)$ = total energy per unit volume

$e = \int c_v dt$ = internal energy

c_v = constant volume heat capacity

$p = \rho(\gamma - 1)e = (\gamma - 1)\left(E - \frac{m^2 + n^2}{2\rho}\right)$ = pressure

$\gamma = c_p/c_v$ = ratio of specific heats

t = time

M = mass addition to the gas phase per unit volume and time due to propellant vaporization

Q = energy release rate per unit volume and time due to combustion

x,y = space coordinates

x,y,t = subscripts indicate differentiation.

The values of Q will be a function of the other dependent variables. Since propellant vaporization is not considered in this application, the value of M is set equal to zero. Q is also set equal to zero in this volume between liner and chamber wall. The conservation laws may be written in terms of ρ, m, n and E by substituting for the pressure to obtain

$$W_t = F_x + G_y + H \tag{5}$$

where:

$$W = \begin{bmatrix} \rho \\ m \\ n \\ E \end{bmatrix}$$

$$F(W) = \begin{bmatrix} -m \\ \frac{\gamma - 3}{2}\frac{m^2}{\rho} - (\gamma - 1)E + \frac{\gamma - 1}{2}\frac{n^2}{\rho} \\ \frac{-mn}{\rho} \\ -\gamma\frac{Em}{\rho} + \frac{\gamma - 1}{2}\frac{m^3 + mn^2}{\rho^2} \end{bmatrix}$$

$$G(W) = \begin{bmatrix} -n \\ \frac{-mn}{\rho} \\ \frac{\gamma - 3}{2}\frac{n^2}{\rho} - (\gamma - 1)E + \frac{\gamma - 1}{2}\frac{m^2}{\rho} \\ -\gamma\frac{En}{\rho} + \frac{\gamma - 1}{2}\frac{n^3 + nm^2}{\rho^2} \end{bmatrix}$$

$$H(W) = \begin{pmatrix} 0 \\ 0 \\ 0 \\ Q \end{pmatrix}$$

Integration of equation (5) is the means of simulating gas motion within the motor discussed in this report.

As noted in the introduction, it is necessary to specify the values of the dependent variables on the chamber boundaries to integrate equation (5). The "boundary conditions" prescribed for the chamber and nozzle walls and the nozzle exit are discussed in Section III. We have elected to specify the enthalpy and momenta at the injector face in place of a description of the propellant supply system. This permits calculation of the density at the injector face from:

$$\rho = \frac{\gamma p}{2(\gamma-1)H_o}\left\{1 + \left[1 + 2H_o\left(\frac{(\gamma-1)m}{\gamma p}\right)^2\right]^{1/2}\right\} \tag{6}$$

where

ρ = density

p = pressure

m = longitudinal momentum

H = enthalpy

γ = c_p/c_v = ratio of specific heats

and the subscript "o" refers to the initial condition at the boundary. The derivation of equation (6) is presented in Appendix B.

The foregoing provides a specification of three (ρ, m, and n) of the four dependent variables at the injector face. However, because the equation (5) is hyperbolic it is not possible to specify the value of the fourth (E, energy) at the face and this must be calculated from the properties of the internal flow field corresponding to the characteristic direction "u-c"

where: u = x-component of gas velocity

c = sonic velocity

The energy is calculated from equation (7)

$$\frac{\partial}{\partial t}(p - \rho_o c_o u) + (u-c)\frac{\partial}{\partial x}(p - \rho_o c_o u) = - v_o \frac{\partial}{\partial y}(p - \rho_o c_o u) - \rho_o c_o^2 \frac{\partial v}{\partial y} \tag{7}$$

$$E = \frac{p}{\gamma-1} + \frac{m^2 + n^2}{2\rho}$$

SECTION III
NUMERICAL INTEGRATION

Because the equations are nonlinear, their integration must be performed numerically. The numerical integration is accomplished using the two-step Lax-Wendroff technique supplied by Dr. S. Z. Burstein, Assistant Professor of Mathematics, Courant Institute of Mathematical Sciences, New York University. Another technique (Predictor-Corrector) was investigated briefly and is presented in Appendix C. Other techniques are also available (see Reference 4).

The numerical integration technique is based on the evaluation of the vector function W at time = Δt from the values at time = 0 for each point of a grid superimposed on the geometry considered. Figure 4 presents the grid for a 1/2-in. mesh for the slab motor shown in figure 1. (Any mesh spacing can be employed; the 1/2-in. mesh was chosen for illustration.) A mesh spacing of 1/4 in. will be presented in the acoustic liner discussion. Specific details of the motor shown in figure 4 will be given later in this report.

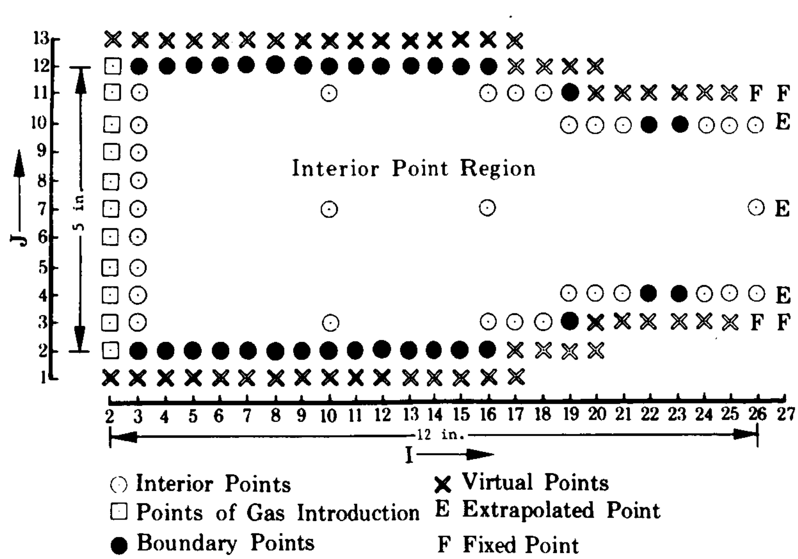

Figure 4. Configuration of Mesh Points for Unlined Chamber Based on 1/2-inch Spacing — FD 20976C

A two-step Lax-Wendroff scheme is one in which temporary values are generated by a 1st-order difference equation. These values are then used to generate a solution that is 2nd-order accurate. Several variations can be used. The specific difference equations used in this report are

$$\overset{*}{W}_{i+\frac{1}{2},j+\frac{1}{2}}(\Delta t) = \frac{1}{4}\Big[W_{i+1,j}(o) + W_{i,j+1}(o) + W_{i+1,j+1}(o) + W_{i,j}(o)\Big] + \frac{\Delta t}{2\Delta x}\Big\{F_{i+1,j}(o) - F_{i,j}(o) + F_{i+1,j+1}(o) - F_{i,j+1}(o)\Big\} + \frac{\Delta t}{2\Delta y}\Big\{G_{i+1,j+1}(o) - G_{i+1,j}(o) + G_{i,j+1}(o) - G_{i,j}(o)\Big\} + \Delta t\Big[K_{i,j}(o)\Big] \quad (8)$$

$$W_{i,j}(\Delta t) = W_{i,j}(o) + \frac{\Delta t}{4\Delta x}\Big\{F_{i+1,j}(o) - F_{i-1,j}(o) + \overset{*}{F}_{i+\frac{1}{2},j+\frac{1}{2}}(\Delta t) - \overset{*}{F}_{i-\frac{1}{2},j+\frac{1}{2}}(\Delta t) + \overset{*}{F}_{i+\frac{1}{2},j-\frac{1}{2}}(\Delta t) - \overset{*}{F}_{i-\frac{1}{2},j-\frac{1}{2}}(\Delta t)\Big\} + \frac{\Delta t}{4\Delta y}\Big\{G_{i,j+1}(o) - G_{i,j-1}(o) + \overset{*}{G}_{i+\frac{1}{2},j+\frac{1}{2}}(\Delta t) - \overset{*}{G}_{i+\frac{1}{2},j-\frac{1}{2}}(\Delta t) + \overset{*}{G}_{i-\frac{1}{2},j+\frac{1}{2}}(\Delta t) - \overset{*}{G}_{i-\frac{1}{2},j-\frac{1}{2}}(\Delta t)\Big\} + \Delta t\Big[L_{i,j}(\Delta t)\Big] \quad (9)$$

$\overset{*}{F}$ and $\overset{*}{G}$ indicate the evaluation of vectors F and G using values of $\overset{*}{W}$ and

$$K_{i,j}\ (o) = 0.25\Big[H_{i+1,j}\ (o) + H_{i,j+1}\ (o) + H_{i+1,j+1}\ (o) + H_{i,j}\ (o)\Big] \quad (10)$$

$$L_{i,j}\ (\Delta t) = 0.50\Big[H_{i,j}\ (o) + 0.25\Big(H_{i+1/2,j+1/2}\ (\Delta t) + H_{i+1/2,j-1/2}\ (\Delta t) + H_{i-1/2,j+1/2}\ (\Delta t) + H_{i-1/2,j-1/2}\ (\Delta t)\Big)\Big] \quad (11)$$

$$H_{i,j} = \begin{bmatrix} Q \\ O \\ O \\ Q \end{bmatrix}$$

References 4 and 5 present further discussions of the mathematical aspects of the Lax-Wendroff schemes. Note that the solution to the difference equations represents only the solution to equation 5 as the mesh is refined ($\Delta x \rightarrow 0$, $\Delta y \rightarrow 0$) with a fixed ratio of $\Delta t/\Delta x$ within the stability limit. The size of the mesh required to achieve convergence must be determined empirically. This aspect will be discussed in Section V, Results. Reference 4 presents a detailed mathematical description of convergence.

It can be shown (Reference 4) that the linear stability limit of the difference equations is:

$$\Delta t \leqq \Delta \left\{ \sqrt{2}\left(|\bar{U}| + C\right) \right\}^{-1} \tag{12}$$

where:

$$\Delta = \Delta x = \Delta y$$

$$|\bar{U}| = \left| \frac{1}{\rho} \sqrt{m^2 + n^2} \right|$$

$$C = \sqrt{\gamma P/\rho}$$

A smoothing operator can be introduced into the Lax-Wendroff difference equations to eliminate metastable behavior. This operator, supplied by Dr. S. Z. Burstein, may be constructed from the nonlinear diffusion equation

$$W_t = D\left\{ \left(|u_x| W_x \right)_x + \left(|v_y| W_y \right)_y \right\} \tag{13}$$

by an implicit alternating-direction technique. The equations at the mesh point (x_i, y_j) are

$$W^{(1)}_{i,j} = W^{(0)}_{i,j} + \lambda D \left\{ \left| u^{(0)}_{i+1,j} - u^{(0)}_{i,j} \right| \left(W^{(0)}_{i+1,j} - W^{(0)}_{i,j} \right) - \left| u^{(0)}_{i,j} - u^{(0)}_{i-1,j} \right| \left(W^{(0)}_{i,j} - W^{(0)}_{i-1,j} \right) \right\} \tag{14}$$

$$W^{(2)}_{i,j} = W^{(1)}_{i,j} + \lambda D \left\{ \left| v^{(1)}_{i,j+1} - v^{(1)}_{i,j} \right| \left(W^{(1)}_{i,j+1} - W^{(1)}_{i,j} \right) - \left| v^{(1)}_{i,j} - v^{(1)}_{i,j-1} \right| \left(W^{(1)}_{i,j} - W^{(1)}_{i,j-1} \right) \right\} \tag{15}$$

where $W^{(0)}_{i,j}$ is the solution of the Lax-Wendroff difference equations, $W^{(1)}_{i,j}$ is the result of smoothing in the x-direction only, and $W^{(2)}_{i,j}$ is the final smooth result obtained by sweeping in the y-direction.

In addition:

D = empirical coefficient

$$\lambda = \frac{\Delta t}{\Delta x} = \frac{\Delta t}{\Delta y}$$

It was found necessary to incorporate the smoothing operator into the computations to eliminate mathematical instability during the generation of the steady state. Two of the transient simulations (refer to Section V - Computed Results) were made with values of D equal to 0 and 3. The computed results obtained with the two different values of D were identical. It has thus been concluded that the diffusion operator, equation (13), does not affect the computed transient results in this application of the two-step Lax-Wendroff technique. Conventionally this operator is required to dampen steep gradients or discontinuities (shock waves) in the computer solution, when these are present, to maintain stability. However, steep gradients or discontinuities were not present in the transient computations made in this studies.

The difference equations provide a means of calculating the values of ρ, m, n, and E for the arrangement of mesh points shown in figure 4 at successive time intervals. Calculation of the functional values at interior mesh points follows directly from the difference equations. Special treatment is required to compute the functional values at grid points on rigid walls. To provide the necessary information to the difference equations, a "reflection" principle is employed that images the grid line immediately adjacent and parallel to the rigid wall onto a "virtual" grid line outside the boundary (see figure 4).

The virtual points are obtained from the grid points by requiring that (1) the momentum normal to a rigid wall should be zero, (2) the energy and density gradients across a rigid wall should be zero, and (3) the momentum tangent to a rigid wall should have a zero gradient across that wall.

For a wall parallel to the x-axis, these conditions are expressed mathematically as:

$$\rho_{k,i,j\pm 1} = \rho_{k,i,j\mp 1} \tag{16}$$

$$m_{k,i,j\pm 1} = m_{k,i,j\mp 1} \tag{17}$$

$$n_{k,i,j\pm 1} = -n_{k,i,j\mp 1} \tag{18}$$

$$E_{k,i,j\pm 1} = E_{k,i,j\mp 1} \tag{19}$$

and, for a wall parallel to the y-axis, as

$$\rho_{k,i\pm 1,j} = \rho_{k,i\mp 1,j} \tag{20}$$

$$m_{k,i\pm 1,j} = -m_{k,i\mp 1,j} \tag{21}$$

$$n_{k,i\pm 1,j} = n_{k,i\mp 1,j} \tag{22}$$

$$E_{k,i\pm 1,j} = E_{k,i\mp 1,j} \tag{23}$$

For a rigid boundary that makes an angle, α, with the x-axis, a more complicated construction must be used. Since the slope of the wall is known, the line normal to its surface and passing through the virtual point may be constructed. Referring to figure 5, functional values at L_0, L_1, and L_2, which are the points of intersection of the local normal with the first three interior horizontal grid lines, are obtained by quadratic interpolation along the horizontal grid lines.

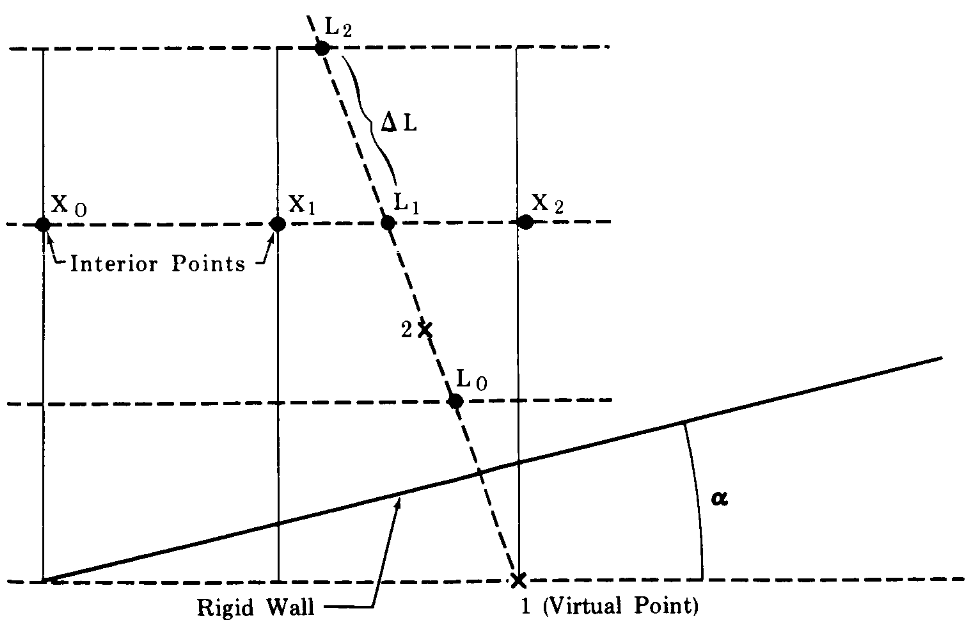

Figure 5. Reflection at an Oblique Boundary FD 20245A

The interpolation formula is

$$W(S) \cong W(S_0) + (S-S_0)W\left[S_0,S_1\right] + (S-S_0)(S-S_1)W\left[S_0,S_1,S_2\right] \tag{24}$$

where

$$W[S_0] = W(S_0)$$

$$W[S_0,S_1] = \frac{W[S_1] - W[S_0]}{S_1 - S_0}$$

$$W[S_0,S_1,S_2] = \frac{W[S_1,S_2] - W[S_0,S_1]}{S_2 - S_0}$$

hence

$$W(L_1) = W(X_0) + (L_1 - X_0)\, W[X_0,X_1] + (L_1 - X_0)(L_1 - X_1)W[X_0,X_1,X_2] \qquad (25)$$

with $W(L_0)$ and $W(L_2)$ obtained similarly.

The three points, L_0,L_1, and L_2, define a quadratic function along the normal. The functional values at the interior point, 2, are found by first calculating n, the distance along the normal from L_1 to 2 and then using a Taylor's Series Expansion to determine W(2), i.e.,

$$W(2) = W(L_1 + h) = W(L_1) + h \left.\frac{\partial W}{\partial L}\right)_{L_1} + \frac{h^2}{2} \left.\frac{\partial^2 W}{\partial L^2}\right)_{L_1} \qquad (26)$$

where $\frac{\partial}{\partial L}$ refers to differentiation along the normal and $\left.\frac{\partial W}{\partial L}\right)_{L_1}$ and $\left.\frac{\partial^2 W}{\partial L^2}\right)_{L_1}$ are found to second order accuracy from:

$$\left.\frac{\partial W}{\partial L}\right)_{L_1} = \frac{W(L_2) - W(L_0)}{2\Delta L} \qquad (27)$$

$$\left.\frac{\partial^2 W}{\partial L^2}\right)_{L_1} = \frac{W(L_2) - 2W(L_1) + W(L_0)}{2(\Delta L)^2} \qquad (28)$$

$$\Delta L = L_2 - L_1 = L_1 - L_0 \ .$$

Once the functional values at point 2 have been determined, the values at the corresponding virtual point 1 may be calculated via the reflection principle. The necessary relationships may be derived as follows:

Tangential momentum component at point 2

$$P_{T2} = M_2 \cos\alpha + n_2 \sin\alpha \tag{29}$$

Normal momentum component at point 2

$$P_{N2} = M_2 \sin\alpha - n_2 \cos\alpha \tag{30}$$

The reflection principle yields

$$P_{T1} = P_{T2} \tag{31}$$

$$P_{N1} = - P_{N2}$$

Then

$$M_1 = P_{T1} \cos\alpha + P_{N1} \sin\alpha \tag{32}$$

$$= M_2 \cos^2\alpha + N_2 \sin\alpha \cos\alpha - M_2 \sin^2\alpha + N_2 \sin\alpha \cos\alpha$$

$$M_1 = 2\left[M_2 \cos\alpha + N_2 \sin\alpha\right] \cos\alpha - M_2 \tag{33}$$

and

$$N_1 = P_{T1} \sin\alpha - P_{N1} \cos\alpha \tag{34}$$

$$= M_2 \sin\alpha \cos\alpha + N_2 \sin^2\alpha + M_2 \sin\alpha \cos\alpha - N_2 \cos^2\alpha \tag{35}$$

$$N_1 = 2\left[M_2 \cos\alpha + N_2 \sin\alpha\right] \sin\alpha - N_2 \tag{36}$$

$$\rho_1 = \rho_2 \tag{37}$$

$$E_1 = E_2 \tag{38}$$

Using equations 25, 28, 29, and 30 a virtual line parallel to an oblique boundary may be calculated.

As recommended by Dr. Burstein, the calculated flow field includes both a subsonic nozzle and a short section of a supersonic nozzle. The supersonic section is included so that extrapolation of the dependent variables in the supersonic regime, where the characteristics are all in the downstream direction, can be employed as the boundary conditions at the open end of the chamber. Thus, the error introduced by the extrapolation is not transmitted back to the flow calculations of the subsonic section. Extrapolation to the last line in the supersonic regime is accomplished by assigning the values from the next to the last line.

The following difference equation, supplied by Dr. Burstein, is enlarged to numerically integrate equation (7) to obtain the boundary conditions at the injector face.

$$
\begin{aligned}
p_{n+1,2,j} = {} & p_{n,3,j} + \rho_o c_o \left[u_{n+1,2,j} - u_{n,3,j}\right] + \\
& \frac{(1 + \lambda\bar{S})}{(1 - \lambda\bar{S})}\left[p_{n,2,j} - p_{n+1,3,j} - \rho_o c_o (u_{n,2,j} - u_{n+1,3,j})\right] - \\
& \frac{\lambda v_o}{2(1 - \lambda\bar{S})}\Big[p_{n,3,j+1} - p_{n,3,j-1} + p_{n,2,j+1} - p_{n,2,j-1} - \\
& \qquad \rho_o c_o \left(u_{n,3,j+1} - u_{n,3,j-1} + u_{n,2,j+1} - u_{n,2,j-1}\right)\Big] - \\
& \frac{\lambda \rho_o c_o^2}{2(1 - \lambda\bar{S})}\left[v_{n,3,j+1} - v_{n,3,j-1}\right]
\end{aligned}
\tag{39}
$$

where

$$\lambda = \frac{\Delta t}{\Delta x} = \frac{\Delta t}{\Delta y}$$

$$\bar{S} = \frac{1}{2}\left[u_{n,2,j} + u_{n+1,3,j} - c_{n,2,j} - c_{n+1,3,j}\right]$$

Derivations of the differential and difference equations are presented in Appendix B.

SECTION IV
COMPUTER PROGRAMS

A. GENERAL

Two computer programs have been prepared. The first program performs the numerical integration to simulate the flow field for a lined as well as an unlined chamber. The second program converts the input data or computed results, usually a steady state, for a given mesh size into input data for a mesh half as large. This arrangement has been employed to reduce the amount of input data cards necessary for small mesh sizes. Descriptions of the integration and the conversion programs are presented in the following paragraphs.

The programs have been employed with mesh sizes of 1/4 and 1/2 in. Except for the liner subroutine as presented in this report, however, any mesh size can be employed.

Selection of the mesh size should be based on the convergence of the solution. Several mesh sizes, in descending order, should be employed in separate calculations and the size selected so that the solution does not change appreciably when the size is further reduced. As discussed later in the report, it was not possible to follow this procedure in this investigation because of funding limitations.

The program has been written with a fixed slope to the wall of the supersonic nozzle to simplify programing. As noted earlier, the supersonic nozzle in this program provides a boundary condition only at the discharge end of the combustion chamber.

Flow diagrams and a listing for each subroutine are included in Appendix E.

B. INTEGRATION PROGRAM

The integration program has been subdivided into eight subroutines to perform the numerical integration described in Section III. Outlined in the following pages are the principal variables, the subroutines, and their primary purposes.

The program has been arranged so that the computation can be stopped at any desired stage, the results stored on tape, and the computation restarted.

The running time on the IBM 360, Model 65 computer is approximately 3 sec per each time interval of integration for the 1/2-in. mesh shown in figure 5. The running time is increased to 12 sec per time interval (Δt) when the mesh is reduced to 1/4 in. The integration time interval for the 1/4-in. mesh is reduced to about half that required by the 1/2-in. mesh. The computer time required to achieve the same total simulation time is therefore about 8 times longer with a 1/4-in. mesh than with a 1/2-in. mesh. The program requires 40K of storage on the IBM 360 written for single-precision arithmetic. The storage is increased if double-precision arithmetic is employed, but the running time is not significantly increased and the accuracy is unaffected.

The program requires only 0.4 sec per Δt when run on the CDC 6600 computer with single-precision arithmetic and a 1/2-in. mesh.

1. Variables Used in the Integration Program

The following variables are used to represent the number of Δx's in the various horizontal dimensions as illustrated in figures 7 and 8:

LENX1 = Number of Δx's in the length of the acoustic liner (the program is arranged so that LENX1 is to be -1 if a liner is not used)

LENX2 = Number of Δx's in the length up to the beginning of the oblique boundaries

LENX3 = Number of Δx's in the length up to the end of the oblique boundaries

LENX4 = Number of Δx's in the total length.

The following variables are used to represent the number of Δy's in the various vertical dimensions as illustrated in figures 7 and 8:

LENY1 = Number of Δy's between chamber and liner walls (LENY1 is zero if the liner is absent)

LENY2 = Number of Δy's between chamber wall and throat wall

LENY3 = Number of Δy's between chamber wall and the opposite throat wall

LENY4 = Number of Δy's between chamber wall and the opposite liner wall

LENY5 = Number of Δy's between chamber walls.

The following dependent variables and functions of dependent variables are employed:

W(K,I,J) represents the dependent variable array where I and J represent the point, I is the horizontal position, J is the vertical position and when

K = 1, W represents ρ = density

K = 2, W represents m = x-momentum

K = 3, W represents n = y-momentum

K = 4, W represents E = total energy

K = 5, W represents p = pressure

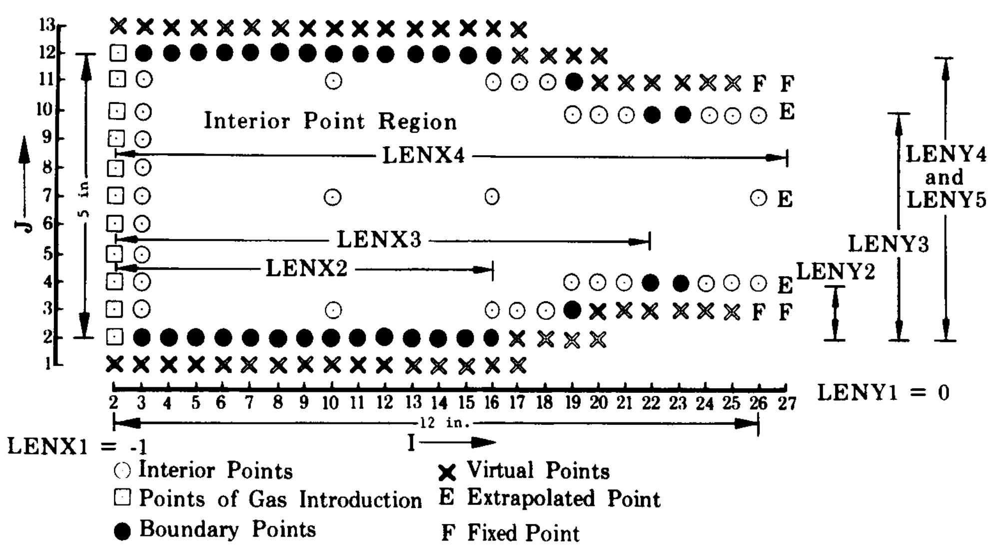

Figure 6. Configuration of Mesh Points for Unlined Chamber Based on 1/2-inch Spacing FD 20976D

FD 20981C

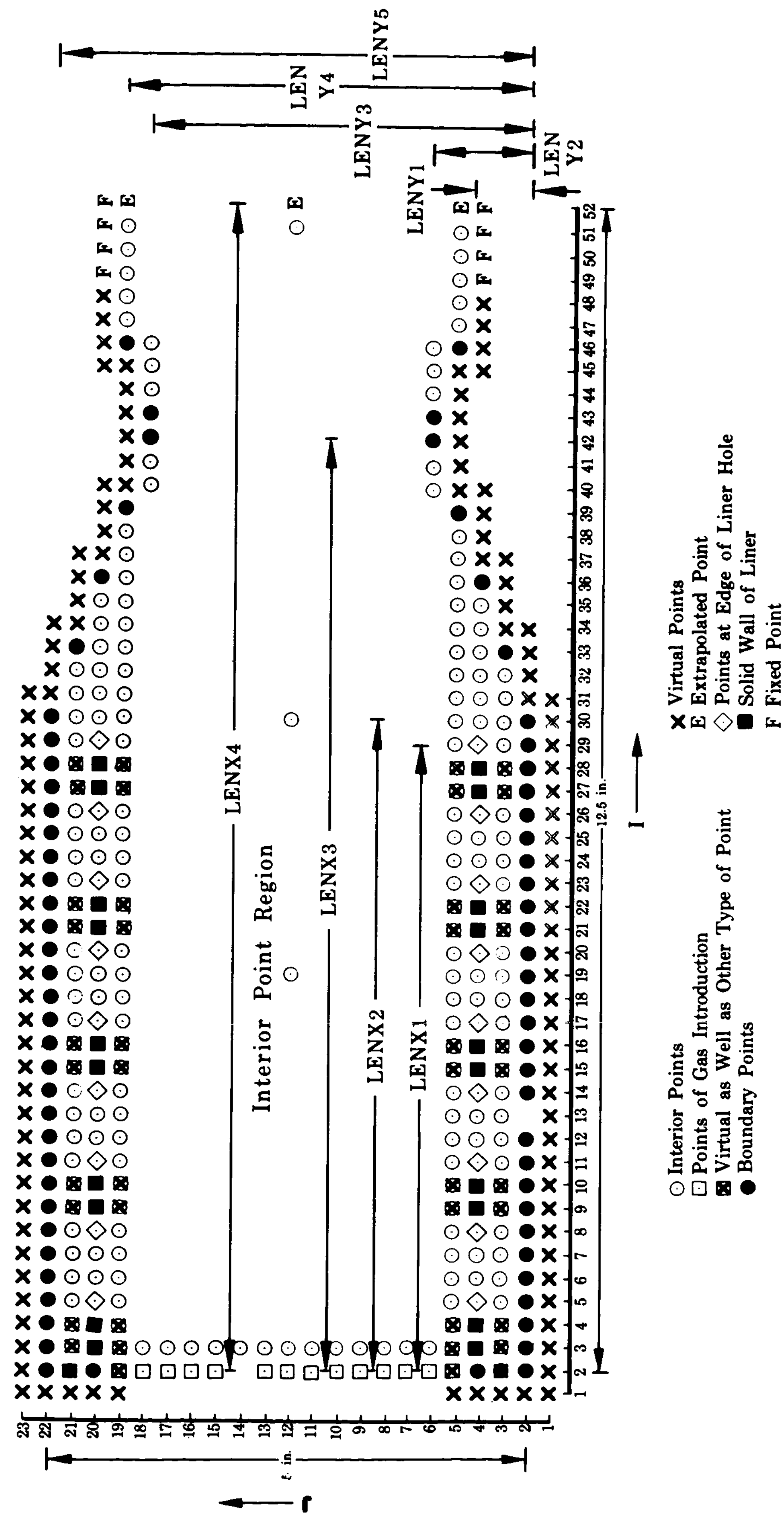

Figure 7. Configuration of Mesh Points for Lined Chamber Based on 1/4-inch Spacing

When a liner is present, W represents the values for these points in the interior of the chamber between the liner walls, and A (K,I,J) represents the dependent variables between the liner and wall. K,I, and J have the same meaning as presented above.

The following functions of the dependent variables are employed;

1. In the interior of the chamber

$$XMOM2(I,J) = \frac{m^2}{\rho}$$

$$YMOM2(I,J) = \frac{n^2}{\rho}$$

$$VSQ(I,J) = \frac{m^2 + n^2}{\rho^2}$$

2. Between the liner and the chamber wall

$$XMOM2A(I,J) = \frac{m^2}{\rho}$$

$$YMOM2A(I,J) = \frac{n^2}{\rho}$$

$$VSQA(I,J) = \frac{m^2 + n^2}{\rho^2}$$

The following real variables are employed in the program.

AO = Reference speed of sound

CON1 = $\rho_o A_o$

CON2 = $\rho_o A_o^2/g$

CON3 = XLEN/A_o

DELX = Δx

DELY = Δy

DELT = Δt

ENERO = Reference energy = E_o

FUDGE = Fraction of linear stability Δt used in integration

GAM = γ

GAM1 = $\gamma - 1$

GAM2 = $(\gamma - 1)/2$

GAM3 = $(\gamma - 3)/2$

OMEGA = Frequency

PO = Reference pressure = P_o

QUE = Energy per unit volume released by combustion

QP = Perturbed energy per unit volume

RHOO = Reference density = ρ_o

SQ = $1/\sqrt{2}$

THICK = Liner thickness

TND = Nondimensionalized total time

TTOL = Total time

TP = Length of energy addition

TO = Reference temperature

XM = Molecular weight of the gas

XMU = Viscosity

XLEN = Length of chamber

YLEN = Width of chamber

The following integer variables are employed in the program:

IDROP(I) = Number of the vertical row of mesh points where a grid point is lost or gained at the top and bottom due to the oblique boundaries; I = 1,2,..., n where n = IX4+1

IR(I) = Remainder upon dividing I by the number of mesh points in the liner hole plus liner wall. This is used in identifying the holes in the acoustical liner

KICOFF = Instability test variable

NOPT = H-function option

TCOUNT = Trip counter

T = Number of Δt's in total run

TT = Print increment; data will be printed every TTth time.

2. Subroutine MAIN

The principal function of MAIN is to call the remaining seven subroutines. In addition, the information required to restart a calculation that has been stopped to review progress is also written on tape in this subroutine.

3. Subroutine INITIAL

The purpose of INITIAL is to read in the input data, calculate the parameters that describe the chamber geometry and nondimensionalize the values of the flow variables. The input data can either be from cards only, or cards and tape, depending on whether a new run is to be made or a run in progress is to be continued.

Essentially any complete specification of the flow field will suffice to start a simulation. However, it is preferable if the calculations are started near a steady-state solution to conserve computer time. A suggested method for preparing input data is given in the following paragraphs. The program as written provides for the flow field data to be expressed in foot, pound, and second units.

In most engineering applications the following data will be available:

1. Chamber dimensions
2. Throat cross-sectional area
3. Distance between throat and chamber exit
4. Propellants and their flowrates
5. Temperature of the gas at the injector face.

From these data, the amount of heat to be evolved, as well as the molecular weights of the combustion gases, can be determined, and an approximate steady-state flow field calculated as follows:

1. The temperature of the gas at the chamber exit can be calculated by the heat balance

$$\Delta T = \Delta H / \dot{w} C_p \qquad (40)$$

where ΔH = Total heat evolved, ft lb/sec

$\dot{w}$ = Total flowrate, lb/sec

C_p = Heat capacity, ft lb/lb °R

ΔT = Temperature rise, °R

2. The chamber pressure can be computed from these data by the formula presented in Reference 6

$$P = \frac{\dot{w}\sqrt{T}}{A\sqrt{\frac{g\gamma}{R}}\, M \sqrt{\left(1 + \frac{\gamma - 1}{2} M^2\right)}} \qquad (41)$$

where $\dot{w}$ = Total flowrate, lb/sec

T = Temperature, °R

A = Chamber cross-section area, ft^2

g = Gravitational constant, ft/sec^2

γ = C_p/C_v

R = Gas constant, ft lb/lb °R

M = Mach number

3. The x-momentum, m, is simply expressed by

$$m = \frac{\dot{w}}{A} \tag{42}$$

4. The density, ρ, in the chamber can be obtained from the ideal gas law

$$\rho = \frac{P}{RT} \tag{43}$$

In general, the temperatures at each point in the chamber should be obtained by interpolating the temperatures at the injector face and the chamber exit; then the density at each point should be calculated.

5. The total energy, E, is computed from

$$E = \frac{P}{\gamma - 1} + \frac{m^2}{2g\rho} \tag{44}$$

which is obtained from the definitions following equation (4). In the absence of data and/or a means to calculate the y-momentum, n, it is assumed to be zero.

Values of the flow variables for the nozzles are calculated from the compressible flow functions defined in Reference 6. Briefly, the procedure is to

1. Calculate the Mach number corresponding to the area ratio from

$$\frac{A}{A_t} = \frac{1}{M}\left[\frac{2\left(1 + \frac{\gamma - 1}{2} M^2\right)}{\gamma + 1}\right] \tag{45}$$

where A = Area of duct

A_t = Area of throat

M = Mach number

$\gamma = C_p/C_v$

2. Calculate the temperature from

$$\frac{T}{T_o} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-1} \tag{46}$$

Where T = Temperature

T_o = Total temperature

3. Calculate the pressure from equation 41
4. The x-momentum is calculated from the continuity equation 42
5. The total energy is obtained from equation 44
6. It should be possible to calculate the starting values of the y-momentum from the steady state portion of equation (5) and accompanying boundary conditions. However, it is expected that the values will be essentially zero within the parallel-walled combustion chamber. Within the nozzle, of course, the value of the y-momentum will achieve some magnitude because of the convergence and divergence. In the results presented in Section V we have chosen to start with the assumption of a y-momentum equal to zero throughout the motor and permit the correct steady state values to be calculated as a result of the integration. This procedure provides a considerable savings in computer programing and running time since the direct calculation of a two-dimensional steady state is considerably more complicated than the integration of equation (5). Of course, the final steady state values of the flow field variables will be independent of the starting conditions.

Note that the difference equations used in the program are in nondimensional form. The following relationships are used in the program to convert from dimensional to nondimensional quantities (and vice versa) in the foot-pound-second system.

$$p' = \left(\frac{\rho_o a_o^2}{g}\right) p \tag{47}$$

$$m' = \rho_o a_o m \tag{48}$$

$$n' = \rho_o a_o n \tag{49}$$

$$\rho' = \rho_o \rho \qquad (50)$$

$$E' = \left(\frac{\rho_o a_o^2}{g} \right) E \qquad (51)$$

$$Q' = \left(\frac{\rho_o a_o^3}{\rho g} \right) Q \qquad (52)$$

where, in addition to previously defined symbols:

ρ_o = Reference density, lb/ft^3

a_o = Reference velocity of sound, ft/sec

g = Gravitational constant, ft/sec^2

ℓ = Reference length, ft

m = Momentum per unit volume in x-direction, $lb/ft^2/sec$

n = Momentum per unit volume in y-direction, $lb/ft^2/sec$

E = Total energy, ft lb/ft^3

Q = Energy addition, ft $lb/ft^3/sec$

p = Pressure, lb/ft^2

and

' represents dimensional quantity

The data to start a simulation are input to the program on cards that are presented by the data input forms on pages IV-13 - IV-15. The first five cards represent data that are required to define the chamber geometry, nondimensionalize the variables, and control the data output. The data presented on these cards are as follows.

Card 1 - An Input value of 1 indicates the run is a cold start. If a 1/4-in. mesh were employed, a value of 1 for mesh would be indicated in Column 1.

Card 2 - The values of LENX define the longitudinal chamber dimensions as described earlier in Subparagraph 1.

Card 3 - The values of LENY define the transverse chamber dimension as described earlier in Subparagraph 1.

Card 4 - The variables are:

Variable	Description
MOLWT	Molecular weight of the gas flowing in the chamber
PO	Reference pressure calculated from thermodynamic considerations

Variable	Description
T	Reference temperature calculated from thermodynamic considerations
GAMMA	C_p/C_v ratio for the gas flowing in the chamber
FUDGE	Fraction of the Δt calculated in STABLE that is to be used in the integration
ΔX	Mesh spacing used in the integration
D	Value of the empirical coefficient employed in the smoothing operator
QUE	Energy released by the combustion, ft $lb/ft^3/sec$

Card 5 - The variables are:

Variable	Description
T	Number of integration intervals (Δt's) the simulation is to encompass
TT	Number of Δt's between printout of the calculated flow field
NOPT	Value of NOPT denotes the part of Function H that is to be used. NOPT = 1 when the steady state is to be generated and is equal to 2 otherwise
IRHO, IM, IN, IE IPRESS	When these are equal to 1, the corresponding density, x-momentum, y-momentum, energy, or pressure field will be printed out

Cards 6-65 - These are the values of the flow field variables. The locations of each point are shown on the attached form.

Because the computations are lengthy, it is necessary to be able to stop, review the progress, and then to restart. This requirement has been provided for in the program by the use of tapes on which the computed results can be written for storage and then read into the computer again when the computations are to be resumed. The program has been written to provide three options for restarting. These are described below.

1. If the computations are stopped while the steady state is being generated, the output is written on tape 9. When the computations are to be resumed, the data stored on tape are read into the computer. This option is designated in the program as "Restart".

2. The program has been written so that the computed steady state can be stored on tape, designated in the program as tape 9, to be used as the starting point for several transient simulations. When the transient calculation is to be made, the data are read into the computer as tape 8. This option is designated in the program as "Steady-State Input".

3. If the computations are stopped during the transient period, the results are read out on tape 9, and the computations are restarted from tape 9. This is also designated as "Restart" in the program.

GENERAL INPUT FORM

Engineer ______ Department Name & Location ______ Extension ______ Sheet ___ of ___

Title: Sample of Input Data Cards - Cold Start ______ Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

```
    MESH                                                             INPUT
0                                                                     1
   LENX1       LENX2     LENX3     LENX4
        -1         14        20        25
   LENY1       LENY2     LENY3     LENY4     LENY5
         0         2         8        10        10
 MOL WT        PO        TO        GAMMA     FUDGE     ΔX        D         QUE
    9.6       77000.    5100.       1.2       0.8    .04165   3.0       1.52D09
    T          TT        NOPT      IRHO      IM        IN        IE        IPRES
       100         10        1         1         1         1         1         1
             THE FOLLOWING ARE THE VALUES IN THE FLOW FIELD. THE MESH POINT
            OR POINTS FOR WHICH EACH SET OF VALUES REPRESENTS THE INITIAL
            FLOW FIELD IS ALSO INDICATED TO THE RIGHT OF THE NUMBERS. THE DATA
            ARE FOR A 0.5 IN. MESH I AND J REFER TO LOCATION ON FIGURE 5.
 DENSITY  XMOMENTUM YMOMENTUM   ENERGY        FLOWFIELD LOCATION
   2.6         203.      0.0       4.20D05   I=2      J=2 THROUGH 12
   2.44        203.      0.0       4.10D05    =3       =    "
   2.27        203.      0.0       4.15D05    =4       =    "
   2.08        203.      0.0       4.13D05    =5       =    "
   1.90        203.      0.0       4.10D05    =6       =    "
   1.72        203.      0.0       4.07D05    =7       =    "
   1.54        203.      0.0       4.05D05    =8       =    "
   1.36        203.      0.0       4.02D05    =9       =    "
   1.18        203.      0.0       4.00D05    =10      =    "
   1.00        203.      0.0       3.95D05    =11      =    "
```

PWA FORM 348 REV. 12-66

GENERAL INPUT FORM

Engineer ______ Department Name & Location ______ Extension ______ Sheet ___ of ___

Title: Sample of Input Data Cards - Cold Start (Continued) Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

DENSITY	XMOMENTUM	YMOMENTUM	ENERGY	FLOW	FIELD	LOCATION
0.82	203.	0.0	3.93D05	I=12	J=2	THROUGH 12
0.65	203.	0.0	3.90D05	=13	=	"
0.46	203.	0.0	3.87D05	=14	=	"
0.28	203.	0.0	3.85D05	=15	=	"
0.094	203.	0.0	3.82D05	=16	=	"
0.093	222.	0.0	3.82D05	=17	=3	" 11
0.092	237.	0.0	3.80D05	=18	=3	" 11
0.090	254.	0.0	3.71D05	=19	=3	" 11
0.085	284.	0.0	3.52D05	=20	=4	" 10
0.080	310.	0.0	3.34D05	=21	=4	" 10
0.062	339.	0.0	2.55D05	=22	=4	" 10
0.062	339.	-10.0	2.55D05	=23	=4	
0.062	339.	-5.0	2.55D05	=23	=5	
0.062	339.	-2.0	2.55D05	=23	=6	
0.062	339.	0.0	2.55D05	=23	=7	
0.062	339.	2.0	2.55D05	=23	=8	
0.062	339.	5.0	2.55D05	=23	=9	
0.062	339.	10.0	2.55D05	=23	=10	
0.045	310.	-10.0	1.87D05	=24	=4	
0.045	310.	-5.0	1.87D05	=24	=5	
0.045	310.	-2.0	1.87D05	=24	=6	
0.045	310.	0.0	1.87D05	=24	=7	
0.045	310.	2.0	1.87D05	=24	=8	
0.045	310.	5.0	1.87D05	=24	=9	

PWA FRDC 345 REV. 12-66

GENERAL INPUT FORM

Engineer ______ Department Name & Location ______ Extension ______ Sheet ___ of ___

Title: Sample of Input Data Cards - Cold Start (Continued) Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

DECK NAME | JOB | COST CONTROL NUMBER | JOB NUMBER | COMPUTING LAB CONTACT | PRTY= | TIME=

DENSITY	XMOMENTUM	YMOMENTUM	ENERGY	FLOW FIELD LOCATION	
0.045	310.	10.0	1.87D05	I=24	J=10
0.038	284.	-10.0	1.60D05	=25	=4
0.038	284.	-5.0	1.60D05	=25	=5
0.038	284.	-2.0	1.60D05	=25	=6
0.038	284.	0.0	1.60D05	=25	=7
0.038	284.	2.0	1.60D05	=25	=8
0.038	284.	5.0	1.60D05	=25	=9
0.038	284.	10.0	1.60D05	=25	=10
0.031	254.	-10.0	1.34D05	=26	=3
0.031	254.	-8.0	1.34D05	=26	=4
0.031	254.	-5.0	1.34D05	=26	=5
0.031	254.	-2.0	1.34D05	=26	=6
0.031	254.	0.0	1.34D05	=26	=7
0.031	254.	2.0	1.34D05	=26	=8
0.031	254.	5.0	1.34D05	=26	=9
0.031	254.	8.0	1.34D05	=26	=10
0.031	254.	10.0	1.34D05	=26	=11
0.025	230.	-10.0	1.13D05	=27	=3
0.025	230.	-8.0	1.13D05	=27	=4
0.025	230.	-5.0	1.13D05	=27	=5
0.025	230.	-2.0	1.13D05	=27	=6
0.025	230.	0.0	1.13D05	=27	=7
0.025	230.	2.0	1.13D05	=27	=8
0.025	230.	5.0	1.13D05	=27	=9

PWA FRDC 3-35 REV. 12-64

GENERAL INPUT FORM

Engineer ________ Department Name & Location ________ Extension ________ Sheet ____ of ____

Title: Sample of Input Data Cards - Cold Start (Continued) Sent by ________

Job Number ________ Analyst ________ Cost Control Number ________

I.D.: JOB ... PRTY= ... TIME=

```
 DENSITY  XMOMENTUM YMOMENTUM   ENERGY     FLOW FIELD LOCATION
   0.025     230.      8.0       1.13D05    I=27  J=10
   0.025     230.      10.0      1.13D05     =27   =11
```

PWA MDC 3413 REV. 12-66

GENERAL INPUT FORM

Engineer ______ Department Name & Location ______ Extension ______ Sheet ___ of ___

Title: Sample of Input Data Cards - Run From Steady State ______ Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

CC 1–80 | DECK NAME | COST CONTROL NUMBER | JOB NUMBER | CODE NO. | DEP NO. | ANALYST NUMBER | LAB CODE | COMPUTING LAB CONTACT

I.D. card: JOB ... PRTY= ... TIME=

```
                                                                     INPUT
                                                                       3
     T       TT        NOPT      IRHO       IM        IN       IE      IPRESS
       100        10         2         1         1         1         1         1
     TP      QP        EXP
  3.00D-07   1.52D09    0.50
```

PWA FRDC 3485 REV. 12-66

GENERAL INPUT FORM

Engineer ______ Department Name & Location ______ Extension ______ Sheet ____ of ____

Title: Sample of Input Data Cards - Restart ______ Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

CC 1–2	3–10	11–16	17–27	28–33	34–35	36–37	38–40	41–42	43–45	46–61	62–68	69–70	71	72	73–80
I.D.	DECK NAME	JOB	COST CONTROL NUMBER	JOB NUMBER	OPER NO.	GRP NO.	ANALYST NUMBER	LAB CODE		COMPUTING LAB CONTACT	PRTY=				TIME=

```
                                                                INPUT
                                                                       2
     T       TT         NOPT     IRHO     IM          IN        IE        IPRES
       100        10         1*        1         1         1         1         1
```

*OR 2 DEPENDING ON WHETHER STEADY STATE OR TRANSIENT RUN IS IN PROGRESS

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Three data cards are required for the Steady-State Input.

Card 1 - An INPUT value of 3 designates the input in steady state

Card 2 - This is the same as card 5 (previously described)

Card 3 - Variables are described below

Variable	Description
TP	Length of time that the disturbance to the steady state (i.e., bombing) is to occur
QP	Amount of energy to be added to the steady-state energy as the disturbance
EXP	Exponent designated as n in the following formula for the transient energy release

$$Q = q(p/\bar{p})^n$$

where; Q = Energy Release Rate, ft lb/sec ft^3

p = Pressure, lb/ft^2

$\bar{p}$ = Average Pressure, lb/ft^2

n = Empirical Exponent

$q = \Delta H/V$

ΔH = Total Heat of Combustion, ft lb/sec

V = Combustion Chamber Volume, ft^3

Only two data cards are required for the Restart option. These are the same as Cards 1 and 2 of the Steady-State Input. A value of 2 for input is required.

The cards are further illustrated by the data input form, which follows the forms presenting the flow field data.

4. Subroutine STABLE

The purpose of STABLE is to compute the value of the integration time interval (Δt) for the numerical integration from equation 12. The value of Δt for each mesh point is computed and the minimum value is selected for the integration. However, as an additional safety factor, a fraction only (denoted as FUDGE) can be employed if desired.

5. Subroutine VRTUAL

The purpose of VRTUAL is to assign the values of the flow variables at the virtual points along the straight walls of the chamber as shown in figures 4, 6, 7, and 8. The formulae employed are equations 16 through 23.

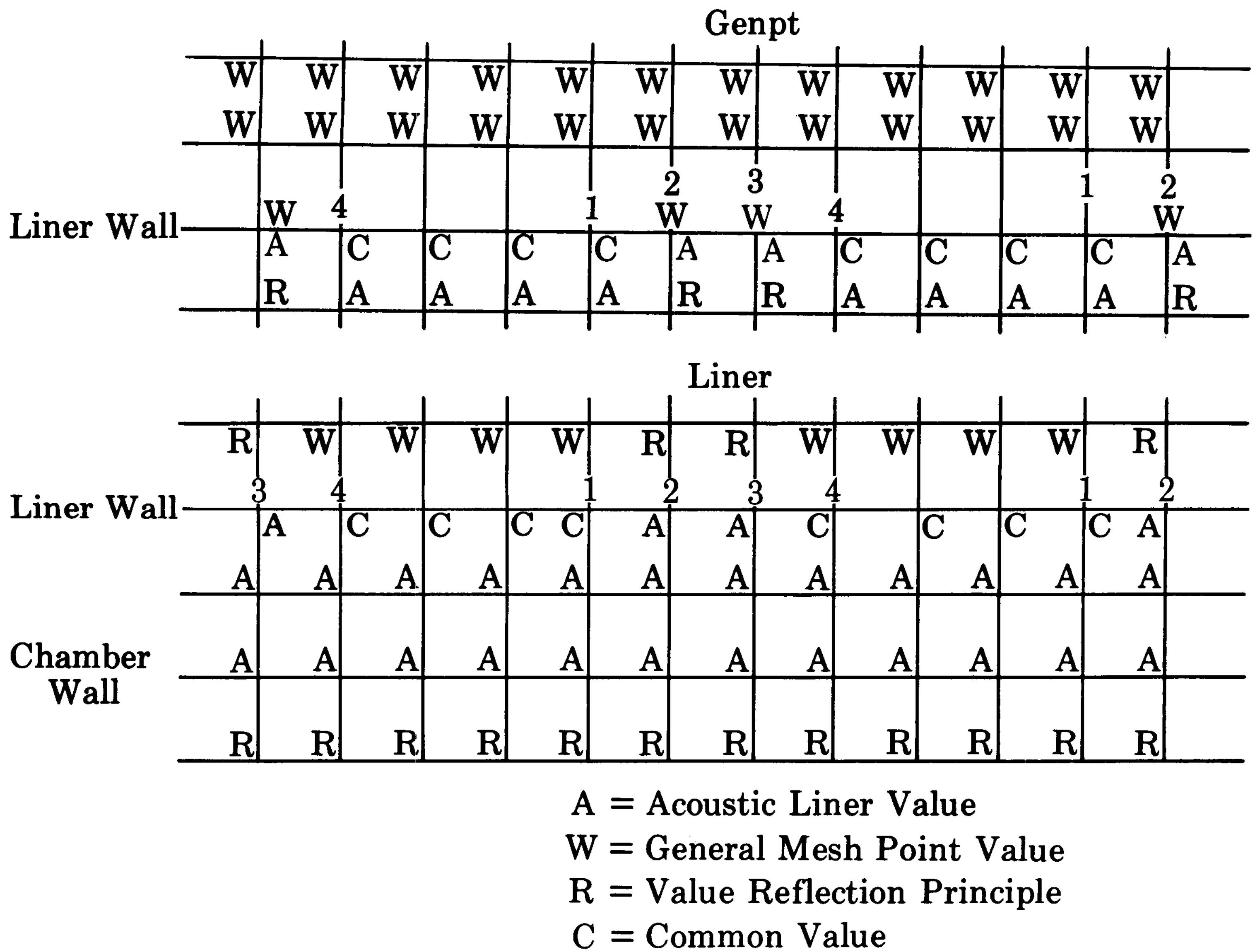


Figure 8. Configuration Using a Liner

FD 23809

As shown in figures 7 and 8, when the chamber is lined, the solid part of the liner is considered as the boundary of the chamber and the internal flow field virtual points are located in the space between the liner and chamber. Also, the virtual points for the flow field between the liner and the chamber wall are in the interior part of the chamber. The values of the flow variables at these virtual points are also calculated by equations 16 through 23.

6. Subroutine BOUND

Subroutine BOUND is called by VRTUAL; its purpose is to calculate the virtual points along the oblique boundaries. The calculation of these virtual points is somewhat complicated and a detailed description follows.

The value of the dependent variables at the virtual point V (figure 9) can be found by

1. Interpolating along three horizontal lines to get the values at the points PI (K,J) where K is the dependent variable and J = 1, 2, and 3
2. Interpolating along the normal to the boundary to get the values at the point R
3. Using the reflection principle along the normal to get the values at the point V.

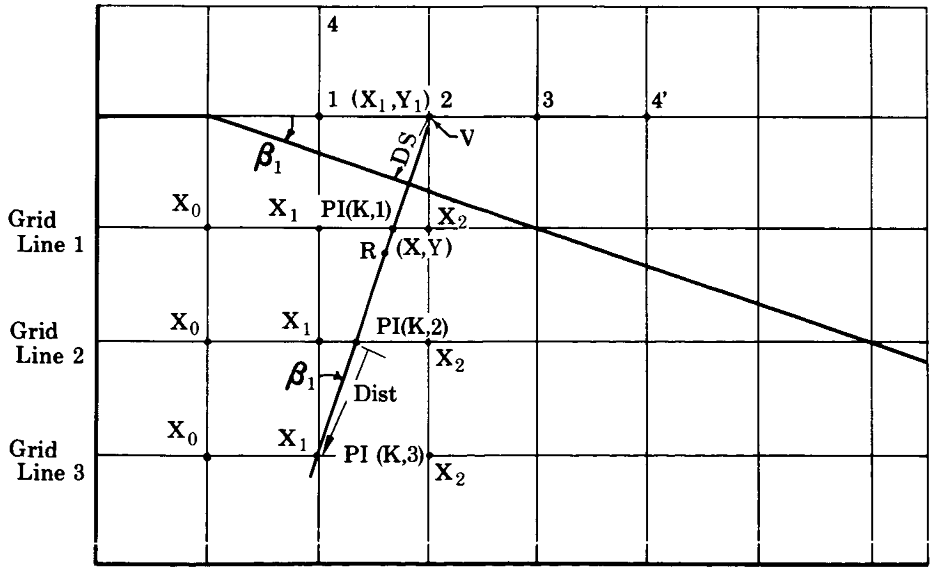


Figure 9 Geometry Used in BOUND FD 23808

To interpolate along the horizontal lines, it is necessary to know the distance between x_o and P1. This was accomplished previously in INITIAL by finding the x-coordinate of P1, assuming the origin at x_o and using the equation of the normal through the virtual point.

For the virtual point (x, y), the equation of the normal can be expressed in the point-slope form as

$$y - y_1 = m(x - x_1) \tag{53}$$

where (x, y) is the virtual point and m is the slope of the normal. Solving equation 53 for x yields

$$x = \frac{1}{m}(y - y_1) + x_1 \ . \tag{54}$$

Substituting $x_1 = 2\,\Delta x$, $y_1 = \Delta y$ and $y = 0$ into equation 54 yields

$$x = -\frac{\Delta y}{m} + 2\,\Delta x. \tag{55}$$

Thus, x is the distance from x_o to P1 on grid line 1.

Similarly, for grid lines 2 and 3 we have

$$x = -\frac{2\,\Delta y}{m} + 2\,\Delta x \quad \text{and} \tag{56}$$

$$x = -\frac{3\,\Delta y}{m} + 2\,\Delta x \tag{57}$$

respectively.

Note that equations 55, 56, and 57 express the distances from x_o to P1 no matter which point (1, 2, or 3) is under consideration. These distances are stored in XDIST(I).

For virtual point 4, the geometry is slightly different, since y has the value $2\Delta y$ for grid line 1. Thus

$$x' = -\frac{2\,\Delta y}{m} + 2\,\Delta x \tag{58}$$

$$x' = -\frac{3\,\Delta y}{m} + 2\,\Delta x \tag{59}$$

$$x' = -\frac{4\,\Delta y}{m} + 2\,\Delta x \tag{60}$$

give the respective distances for this point. These are stored in XDISTP(1).

After the values at P1 have been determined using quadratic interpolation, the values at R are found by interpolating along the normal. Again, the distance D from P1 (K, 3) to R must be known. This was accomplished in INITIAL by finding

1. Distance DS in figure 9
2. Distance DIST (refer to figure 9) along the normal to the boundary.

DIST has the value $\frac{\Delta y}{\cos \beta_1}$ as can be seen from figure 9.

The value of DS, however, is dependent upon which virtual point is being considered. In figure 10 the virtual points are 1, 2, 3, and 4, which provide the corresponding right triangles shown.

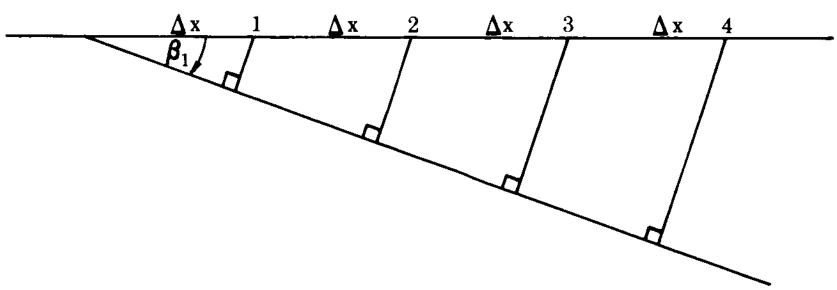


Figure 10. Virtual Point Calculation FD 23813

This yields

$$DS = n\Delta x \sin \beta_1 \qquad n = 1, 2, 3, 4 \tag{61}$$

Since R is the same distance from the boundary as V,

$$D = 3(DIST) - 2(DS) \tag{62}$$

for virtual points 1, 2, and 3 and

$$D = 4(DIST) - 2(DS) \tag{63}$$

for virtual point 4' in figure 9.

Quadratic interpolation gives us values at R. Once these values are known, they can be reflected across the boundary to V by the reflection principle. Thus, for ρ and E,

$$\rho(V) = \rho(R) \quad \text{and} \tag{64}$$

$$E(V) = E(R) \ . \tag{65}$$

For the momenta, it is necessary to resolve m and n into the directions of the boundary and the normal to the boundary.

The component parallel to the boundary at R is given by

$$P_T(R) = m(R) \cos \beta_1 + n(R) \sin \beta_1 \tag{66}$$

and the normal component is

$$P_N(R) = m(R) \sin \beta_1 - n(R) \cos \beta_1 \ . \tag{67}$$

The reflection principle yields

$$P_T(V) = P_T(R) \tag{68}$$

$$P_N(V) = - P_N(R) \ .$$

Therefore,

$$\begin{aligned} m(V) &= P_T(V) \cos \beta_1 + P_N(V) \sin \beta_1 \\ &= m(R) \cos^2 \beta_1 + n(R) \sin \beta_1 \cos \beta_1 - m(R) \sin^2 \beta_1 \\ &\qquad + n(R) \sin \beta_1 \cos \beta_1 \\ &= 2\left(m(R) \cos \beta_1 + n(R) \sin \beta_1\right) \cos \beta_1 - m(R) \end{aligned} \tag{69}$$

and

$$\begin{aligned} n(V) &= P_T(V) \sin \beta_1 - P_N(V) \cos \beta_1 \\ &= m(R) \sin \beta_1 \cos \beta_1 + n(R) \sin^2 \beta_1 + m(R) \sin \beta_1 \cos \beta_1 \\ &\qquad - n(R) \cos^2 \beta_1 \\ &= 2\left(m(R) \cos \beta_1 + n(R) \sin \beta_1\right) \sin \beta_1 - n(R) \ . \end{aligned} \tag{70}$$

7. Subroutine GENPT

The numerical integration employing equations 8 through 11 is accomplished in GENPT. A considerable economy in computation has been accomplished by calculating $W_{i,j}(\Delta t)$ at only three vertical lines (i-1, i, i+1) of mesh points at a single time.

For example, if values of W are known at (i-1,j), (i,j), (i + 1,j) (j = 1, JMAX), then the vectors F(W), G(W), and H(W) are calculated for the three vertical lines and stored in a temporary vector called TV. This is illustrated for the line corresponding to (i-1,j) as follows,

$$F(W_{i-1,j}) \rightarrow TV_{i-1,j}(1),\ TV_{i-1,j}(2),\ TV_{i-1,j}(3),\ TV_{i-1,j}(4)$$

$$G(W_{i-1,j}) \rightarrow TV_{i-1,j}(5),\ TV_{i-1,j}(6),\ TV_{i-1,j}(7),\ TV_{i-1,j}(8)$$

$$H(W_{i-1,j}) \rightarrow TV_{i-1,j}(9),\ TV_{i-1,j}(10),\ TV_{i-1,j}(11),\ TV_{i-1,j}(12)$$

TV is a three-dimensional vector whose first column contains the 12 elements of $F_{i-1,j}$, $G_{i-1,j}$, and $H_{i-1,j}$; the second column contains the next 12 elements of $F_{i,j}$, $G_{i,j}$, and $H_{i,j}$; and the third column the last 12 elements of $F_{i+1,j}$, $G_{i+1,j}$, and $H_{i+1,j}$.

The values of $\overset{*}{W}(\Delta t)$ are then computed between the first and second lines and between the second and third lines and stored in the temporary vector, TVA, which is a two-dimensional vector whose first column contains the sixteen values of $\overset{*}{W}(\Delta t)$, $\overset{*}{F}$, $\overset{*}{G}$, and $\overset{*}{H}$, computed between the first and second lines, and whose second column consists of the 16 values computed between the second and third lines as follows:

$$\overset{*}{W}_{i+\frac{1}{2},\ j+\frac{1}{2}} \longrightarrow TVA(1,\ j+\tfrac{1}{2},\ 1),\ TVA(2,\ j+\tfrac{1}{2},\ 1),\ TVA(3,\ j+\tfrac{1}{2},\ 1),\ TVA(4,\ j+\tfrac{1}{2},\ 1)$$

$$\overset{*}{F}_{i+\frac{1}{2},\ j+\frac{1}{2}} \longrightarrow TVA(5,\ j+\tfrac{1}{2},\ 1),\ TVA(6,\ j+\tfrac{1}{2},\ 1),\ TVA(7,\ j+\tfrac{1}{2},\ 1),\ TVA(8,\ j+\tfrac{1}{2},\ 1)$$

$$\overset{*}{G}_{i+\frac{1}{2},\ j+\frac{1}{2}} \longrightarrow TVA(9,\ j+\tfrac{1}{2},\ 1),\ TVA(10,\ j+\tfrac{1}{2},\ 1),\ TVA(11,\ j+\tfrac{1}{2},\ 1),\ TVA(12,\ j+\tfrac{1}{2},\ 1)$$

$$\overset{*}{H}_{i+\frac{1}{2},\ j+\frac{1}{2}} \longrightarrow TVA(13,\ j+\tfrac{1}{2},\ 1),\ TVA(14,\ j+\tfrac{1}{2},\ 1),\ TVA(15,\ j+\tfrac{1}{2},\ 1),\ TVA(16,\ j+\tfrac{1}{2},\ 1)$$

The same ordering holds for the second temporary line of values, i.e.,

$\overset{*}{W}_{i+3/2,\ j+\frac{1}{2}} \rightarrow$ TVA(1, j+½, 2), TVA(2, j+½, 2), TVA(3, j+½, 2), TVA(4, j+½, 2)

$\overset{*}{F}_{i+3/2,\ j+\frac{1}{2}} \rightarrow$ TVA(5, j+½, 2), TVA(6, j+½, 2), TVA(7, j+½, 2), TVA(8, j+½, 2)

and so forth.

After all the above values have been obtained, the final values of $W_{i,j}(\Delta t)$ on the line (I,J) are computed. After $W_{i,j}(\Delta t)$ is known, $W_{i+1,j}(\Delta t)$ is computed, by shifting column 2 to column 1 and column 3 to column 2 in TV and calculating the elements of column 3 along the vertical line (i+2,j) and similarly shifting column 2 to column 1 in TVA and calculating the elements of column 2 between the vertical lines (i+1,j) and (i+2,j).

8. Subroutine LINER

The purpose of LINER is to calculate the values of the dependent variables at grid points that fall in the acoustic liner or on the boundary between the acoustic liner and the interior of the chamber shown in figures 7 and 8. The detailed calculations are the same as previously described in GENPT. Note that the LINER subroutine has been written specifically for the configuration shown in figure 7 .

The boundary between the liner and the general mesh is handled as a rigid wall except at the points 1, 2, 3, and 4 shown in figure 8. At points 1 and 4, a value is obtained from both GENPT and LINER. These values are then averaged and results stored in both A and W. Points 2 and 3 are also calculated in both GENPT and LINER. As indicated in figure 8, these values should be identical; however, after smoothing they will differ and hence are averaged in GENPT for the final result that is stored in both W and A.

As previously noted, the liner configuration is fixed by the program to that shown by figures 2, 3, and 7. Thus, the subroutine provides four 1-in. x 1 in. slots separated by 1/2-in. of metal. The distance between the liner and the chamber wall is 1/2-in. Additional programing would be required to change these dimensions.

9. Function H

Function H is provided to compute the values of the source terms (mass and energy addition) and is called from GENPT. The function that is listed provides three periods of energy addition. The first is the steady-state energy release, which is assumed to be constant throughout the chamber. The steady-state energy release is, q, the total heat of combustion per unit time and volume; ft lb/ft^3/sec. The second period is the disturbance of the energy to initiate the transient period. The duration of the disturbance is controlled by the value of TP. The formula employed for the perturbed energy release rate is

$$Q = (q + q_p)$$

where q_p is the perturbed energy release rate. The third period is the transient period. The transient energy release rate employed in these calculations is given by

$$Q = (q)(p/\bar{p})^n$$

The terms have previously been defined on page IV-19.

A listing of the FORTRAN statements employed to obtain the results presented in this report are presented in the following pages.

10. Subroutine PRINT

The initial data and the flow field are printed by means of Subroutine PRINT. For each run, the input data and constants are printed as the first page. Sample copies of the print for 1/2- and 1/4-in. meshes are presented on the following pages.

The flow field is displayed by printing the value of each variable at each mesh point in the chamber, with certain exceptions that are discussed in the next paragraph. The number of pages required for each variable depends on the number of rows of mesh points required to describe the length of the chamber. The order of printing is the density, x- and y-momenta, energy, and pressure.

The width of the flow field displayed is restricted by the width of the paper available for printing. It is only possible to print 13 columns of data and display the computed results to four significant figures. Thus, if 13 or less rows of mesh points will represent the width of the flow field including the boundaries, then the entire flow field will be printed. However, if more than 13 are required, then the data corresponding to only the first six rows, the center row, and the last six rows are printed.

Two samples of the flow field printout are presented on pages IV-31 and IV-33. The first sample (p IV-31) is the density field based on the chamber shown in figure 4. The entire density field is displayed since only 11 rows of mesh points are required. The second sample (p IV-33) is the density field based on the chamber shown in figure 7; only 13 of the 21 rows are presented. This display also shows the sound-absorbing liner. The symbol "A" between successive entries indicates those entries were generated in LINER. The symbol "W" between entries indicates that those values were generated in GENPT. The symbol * indicates the boundary, the symbol "C" indidates the chamber centerline. Only the density field is shown since the other fields are similar in display.

The variables are redimensionalized before printing. The formulae employed in the program are:

$$TND = TND + DELT \quad \text{(nondimensionalized time)}$$

$$TTOL = TND \times \frac{XLEN}{a_o} \quad \text{(total time)}$$

$$\rho' = \rho \rho_o \tag{71}$$

$$p' = p \rho_o a_o^2 / g \tag{72}$$

$$m' = m \rho_o a_o \tag{73}$$

$$n' = n \rho_o a_o \tag{74}$$

$$E' = E \rho_o a_o^2 / g \tag{75}$$

where

TND = Nondimensional time used in program

DELT = Time interval

TTOL = Total time

ρ = Density, lb/ft^3

p = Pressure, lb/ft^2

m = x-momentum, $lb/ft^2/sec$

n = y-momentum, $lb/ft^2/sec$

E = Total energy, ft lb/ft^3

a_o = Sonic velocity, ft/sec

g = Gravitational constant, ft/sec^2

The superscript ' refers to dimensional quantities, the subscript o refers to the initial quantities used to nondimensionalize, whereas the remaining variables are nondimensional.

C. CONVERSION PROGRAM

The purpose of the conversion program is to convert the value of the flow field variables from one mesh size to another half as large. This is accomplished by quadratic interpolation to fill in the values at the intermediate mesh points. The conversion program also calculates the constants that are necessary for the LINER subroutine.

The program consists of five subroutines. However, three of the subroutines VRTUAL, BOUND, and PRINT are the same as in the integration program. The remaining two subroutines are described in the following paragraphs.

*** * * * INPUT DATA AND CONSTANTS * * * ***

LENX1 = -1	LENX2 = 14	LENX3 = 20	LENX4 = 25
LENY1 = 0	LENY2 = 2	LENY3 = 8	LENY4 = 10
LENY5 = 10	NUMBER OF TRIPS =*00	PRINT INC =300	ILEN = 6
XLEN = 10.41250E-01	YLEN = 41.65000E-02	DELX = 41.65000E-03	DELY = 41.65000E-03
SOUND SP. = 56.31606E+02	M.W. OF GAS = 96.00000E-01	FUDGE = .800	TP = 0.
PO = 77.00000E+03	TO = 51.00000E+02	RHOO = 93.81306E-03	ENERO = 38.50000E+04
GAM = 12.00000E-01	XSLOPE =-33.33333E-02	DIST = 43.90295E-03	DISTP = 43.90295E-03
SINB1 =-31.62278E-02	COSB1 = 94.86833E-02	SINE = 31.62278E-02	COSINE = 94.86833E-02
DIFCO = 30.00000E-01	MU = 0.	OMEGA = 0.	LINER THKNS = 0.
Q = 15.20000E+08	QP = 0.	N = 0.	NOPT = 1
			MESH = -0
XDIST(1) = 69.41667E-03	XDIST(2) = 55.53333E-03	XDIST(3) = 41.65000E-03	
XDISTP(1) = 55.53333E-03	XDISTP(2) = 41.65000E-03	XDISTP(3) = 27.76667E-03	

DENSITY AT TIME = 0. DELT = 0. TND = 0. TRIP NUMBER = 0

26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01	26.00E-01
24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01	24.40E-01
22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01	22.70E-01
20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01	20.80E-01
19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01	19.00E-01
17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01	17.20E-01
15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01	15.40E-01
13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01	13.60E-01
11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01	11.80E-01
10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01	10.00E-01
82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02	82.00E-02
65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02	65.00E-02
46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02	46.00E-02
28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02	28.00E-02
94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03	94.00E-03
	93.00E-03	93.00E-03	93.00E-03	93.00E-03	93.00E-03	93.00E-03	93.00E-03	93.00E-03	93.00E-03	
	92.00E-03	92.00E-03	92.00E-03	92.00E-03	92.00E-03	92.00E-03	92.00E-03	92.00E-03	92.00E-03	

FOLDOUT FRAME |

90.00E-03	90.00E-03	90.00E-03	90.00E-03	90.00E-03	90.00E-03	90.00E-03	90.00E-03	90.00E-03
	85.00E-03	85.00E-03	85.00E-03	85.00E-03	85.00E-03	85.00E-03	85.00E-03	
	80.00E-03	80.00E-03	80.00E-03	80.00E-03	80.00E-03	80.00E-03	80.00E-03	
	62.00E-03	62.00E-03	62.00E-03	62.00E-03	62.00E-03	62.00E-03	62.00E-03	
	62.00E-03	62.00E-03	62.00E-03	62.00E-03	62.00E-03	62.00E-03	62.00E-03	
	45.00E-03	45.00E-03	45.00E-03	45.00E-03	45.00E-03	45.00E-03	45.00E-03	
	38.00E-03	38.00E-03	38.00E-03	38.00E-03	38.00E-03	38.00E-03	38.00E-03	
31.00E-03	31.00E-03	31.00E-03	31.00E-03	31.00E-03	31.00E-03	31.00E-03	31.00E-03	31.00E-03
25.00E-03	25.00E-03	25.00E-03	25.00E-03	25.00E-03	25.00E-03	25.00E-03	25.00E-03	25.00E-03

FOLDOUT FRAME 2

```
* * * *  INPUT DATA AND CONSTANTS  * * * *

LENX1 = 27                 LENX2 = 28                     LENX3 = 40                 LENX4 = 50

LENY1 =  2                 LENY2 =  4                     LENY3 = 16                 LENY4 = 18

LENY5 = 20                 NUMBER OF TRIPS =*00           PRINT INC = 20             ILEN = 12

XLEN = 10.41250E-01        YLEN = 41.65000E-02            DELX = 20.82500E-03        DELY = 20.82500E-03

SOUND SP. = 56.31606E+02   M.W. OF GAS = 96.00000E-01     FUDGE = .800               TP = 40.00000E-07

PO = 77.00000E+03          TO = 51.00000E+02              RHOO = 93.81306E-03        ENERO = 38.50000E+04

GAM = 12.00000E-01         XSLOPE =-33.33333E-02          DIST = 21.95148E-03        DISTP = 21.95148E-03

SINB1 =-31.62278E-02       COSB1 = 94.86833E-02           SINE = 31.62278E-02        COSINE = 94.86833E-02

DIFCO = 30.00000E-01       MU = 10.00000E-01              OMEGA =  0.                LINER THKNS = 12.50000E-02

Q = 15.20000E+08           QP = 40.00000E+10              N = 30.00000E-01           NOPT =  2

                                                                                     MESH =  1

XDIST(1) = 34.70833E-03    XDIST(2) = 27.76667E-03        XDIST(3) = 20.82500E-03

XDISTP(1) = 27.76667E-03   XDISTP(2) = 20.82500E-03       XDISTP(3) = 13.88333E-03
```

DENSITY AT TIME = 47.93270E-05   DELT = 65.69964E-08   TND = 25.92443E-01   TRIP NUMBER = 700

33.36E-02	33.55E-02	34.64E-02	23.48E-01	22.92E-01	22.06E-01	20.31E-01	23.01E-01	24.04E-01	25.05E-01	25.42E-01	33.55E-02	33.36E-02
*		A				C				W		*
*		A				C				W		*
36.91E-02	36.36E-02	37.42E-02	18.78E-01	18.35E-01	17.88E-01	17.74E-01	18.60E-01	18.78E-01	18.90E-01	19.24E-01	36.36E-02	36.91E-02
*		A				C				W		*
*		A				C				W		*
43.99E-02	51.24E-02	56.02E-02	14.10E-01	13.36E-01	12.57E-01	11.76E-01	12.96E-01	13.46E-01	13.87E-01	16.45E-01	51.24E-02	43.99E-02
*		A				C				W		*
*		A				C				W		*
58.07E-02	63.95E-02	83.40E-02	11.74E-01	10.77E-01	99.83E-02	92.87E-02	10.05E-01	10.61E-01	11.16E-01	83.40E-02	63.95E-02	58.07E-02
*						C						*
*						C						*
58.04E-02	62.19E-02	70.88E-02	88.01E-02	85.34E-02	80.01E-02	74.60E-02	79.52E-02	81.36E-02	82.68E-02	70.88E-02	62.19E-02	58.04E-02
*						C						*
*						C						*
55.57E-02	57.82E-02	60.48E-02	65.76E-02	65.17E-02	64.41E-02	61.64E-02	62.89E-02	61.79E-02	62.46E-02	60.48E-02	57.82E-02	55.57E-02
*						C						*
*						C						*
52.28E-02	53.24E-02	52.81E-02	47.33E-02	48.07E-02	52.02E-02	50.83E-02	50.17E-02	45.34E-02	45.62E-02	52.81E-02	53.24E-02	52.28E-02
*		A				C				W		*
*		A				C				W		*
49.60E-02	50.62E-02	48.50E-02	38.02E-02	38.44E-02	43.07E-02	42.79E-02	41.41E-02	36.29E-02	36.40E-02	38.62E-02	50.62E-02	49.60E-02
*		A				C				W		*
*		A				C				W		*
45.29E-02	45.63E-02	42.97E-02	33.21E-02	33.63E-02	36.37E-02	36.48E-02	34.64E-02	32.08E-02	31.50E-02	35.14E-02	45.63E-02	45.29E-02
*		A				C				W		*
*		A				C				W		*
39.88E-02	40.13E-02	38.00E-02	29.77E-02	29.97E-02	31.22E-02	31.32E-02	29.67E-02	28.81E-02	28.40E-02	38.00E-02	40.13E-02	39.88E-02
*						C						*
*						C						*
35.83E-02	35.93E-02	34.22E-02	26.54E-02	26.57E-02	27.07E-02	27.12E-02	25.77E-02	25.63E-02	25.56E-02	34.22E-02	35.94E-02	35.83E-02
*						C						*
*						C						*
32.73E-02	32.51E-02	30.80E-02	23.77E-02	23.85E-02	23.75E-02	23.66E-02	22.60E-02	23.12E-02	23.16E-02	30.80E-02	32.51E-02	32.73E-02
*						C						*
*						C						*
30.33E-02	30.01E-02	28.51E-02	19.51E-02	20.40E-02	20.86E-02	20.80E-02	19.78E-02	19.97E-02	19.71E-02	28.51E-02	30.01E-02	30.33E-02
*		A				C				W		*
*		A				C				W		*
28.75E-02	28.31E-02	26.37E-02	17.47E-02	17.23E-02	18.37E-02	18.43E-02	17.30E-02	16.58E-02	17.51E-02	20.14E-02	28.31E-02	28.75E-02
*		A				C				W		*
*		A				C				W		*
26.70E-02	27.17E-02	25.43E-02	15.34E-02	15.46E-02	16.18E-02	16.41E-02	15.24E-02	14.91E-02	15.33E-02	17.25E-02	27.17E-02	26.70E-02
*		A				C				W		*
*		A				C				W		*
24.78E-02	23.69E-02	20.78E-02	13.77E-02	14.04E-02	14.42E-02	14.68E-02	13.64E-02	13.60E-02	14.25E-02	20.78E-02	23.69E-02	24.78E-02
*						C						*
*						C						*
22.45E-02	21.60E-02	19.31E-02	12.26E-02	12.64E-02	12.93E-02	13.22E-02	12.35E-02	12.38E-02	12.77E-02	19.31E-02	21.60E-02	22.45E-02
*						C						*
*						C						*
20.33E-02	19.63E-02	17.73E-02	11.21E-02	11.50E-02	11.71E-02	11.98E-02	11.29E-02	11.33E-02	11.80E-02	17.73E-02	19.63E-02	20.33E-02
*						C						*
*						C						*
18.81E-02	18.30E-02	16.86E-02	98.80E-03	10.52E-02	10.68E-02	10.95E-02	10.50E-02	10.71E-02	10.99E-02	16.86E-02	18.30E-02	18.81E-02
*		A				C				W		*

FOLDOUT FRAME 1

```
                                                                 C                                       W                   *
17.80E-02 17.25E-02 15.94E-02 95.48E-03 93.92E-03 98.19E-03 10.07E-02 97.83E-03 96.85E-03 10.37E-02 13.24E-02 17.25E-02 17.80E-02
     *                   A                                       C                                       W                   *
     *                   A                                       C                                       W                   *
16.82E-02 16.79E-02 16.16E-02 87.82E-03 87.21E-03 90.23E-03 93.17E-03 90.98E-03 90.55E-03 95.08E-03 10.91E-02 16.79E-02 16.82E-02
     *                   A                                       C                                       W                   *
     *                   A                                       C                                       W                   *
16.24E-02 16.02E-02 13.16E-02 80.98E-03 81.14E-03 83.51E-03 86.61E-03 85.20E-03 84.86E-03 90.16E-03 13.16E-02 16.02E-02 16.24E-02
     *                                                           C                                                           *
     *                                                           C                                                           *
15.75E-02 15.08E-02 12.54E-02 77.34E-03 76.52E-03 77.54E-03 80.91E-03 80.14E-03 80.63E-03 86.99E-03 12.54E-02 15.08E-02 15.75E-02
     *                                                           C                                                           *
     *                                                           C                                                           *
14.99E-02 14.20E-02 12.24E-02 70.88E-03 71.20E-03 72.77E-03 75.94E-03 76.02E-03 76.26E-03 81.79E-03 12.24E-02 14.20E-02 14.99E-02
     *                                                           C                                                           *
     *                                                           C                                                           *
14.19E-02 13.53E-02 11.73E-02 67.11E-03 66.88E-03 68.11E-03 71.59E-03 71.88E-03 71.89E-03 80.90E-03 11.73E-02 13.53E-02 14.19E-02
     *                   A                                       C                                       W                   *
     *                   A                                       C                                       W                   *
13.73E-02 12.72E-02 10.80E-02 65.32E-03 62.73E-03 64.36E-03 67.80E-03 68.54E-03 70.73E-03 80.22E-03 10.95E-02 12.72E-02 13.73E-02
     *                   A                                       C                                       W                   *
     *                   A                                       C                                       W                   *
13.31E-02 12.27E-02 12.26E-02 63.36E-03 59.65E-03 60.84E-03 64.47E-03 65.51E-03 67.15E-03 75.19E-03 85.49E-03 12.27E-02 13.31E-02
     *                   A                                       C                                       W                   *
     *                   A                                       C                                       W                   *
12.94E-02 12.75E-02 10.32E-02 57.79E-03 56.21E-03 57.56E-03 61.53E-03 62.48E-03 63.95E-03 71.10E-03 10.32E-02 12.75E-02 12.94E-02

12.46E-02 12.13E-02 93.96E-03 64.74E-03 54.08E-03 54.64E-03 58.91E-03 59.50E-03 62.61E-03 72.87E-03 98.74E-03 12.53E-02 12.99E-02

          12.26E-02 10.07E-02 63.76E-03 52.41E-03 52.23E-03 56.55E-03 57.43E-03 60.90E-03 72.80E-03 10.26E-02 12.46E-02

          11.90E-02 10.33E-02 67.63E-03 51.05E-03 50.15E-03 54.37E-03 55.60E-03 59.44E-03 73.53E-03 10.77E-02 12.02E-02


          10.99E-02 10.26E-02 70.43E-03 50.54E-03 48.42E-03 52.32E-03 54.13E-03 58.32E-03 75.38E-03 10.64E-02 11.23E-02

                    10.73E-02 71.93E-03 50.31E-03 46.82E-03 50.36E-03 52.52E-03 57.30E-03 76.96E-03 10.99E-02

                    10.64E-02 76.19E-03 51.65E-03 45.42E-03 48.45E-03 51.12E-03 57.93E-03 79.89E-03 10.82E-02

                    94.66E-03 78.36E-03 53.26E-03 44.63E-03 46.55E-03 49.96E-03 58.36E-03 81.57E-03 96.18E-03

                              83.38E-03 53.88E-03 43.55E-03 44.60E-03 48.40E-03 58.52E-03 85.80E-03

                              78.19E-03 59.24E-03 42.31E-03 42.59E-03 46.78E-03 62.11E-03 81.81E-03

                              69.86E-03 59.70E-03 43.23E-03 40.51E-03 47.01E-03 62.37E-03 73.11E-03

                                        57.45E-03 44.76E-03 38.32E-03 47.76E-03 59.63E-03

                                        50.90E-03 44.04E-03 36.10E-03 46.55E-03 53.05E-03

                                        42.90E-03 40.54E-03 33.88E-03 42.77E-03 44.85E-03

                                        31.57E-03 33.97E-03 31.72E-03 36.01E-03 33.36E-03
```

FOLDOUT FRAME 2

			25.58E-03	28.05E-03	29.67E-03	29.75E-03	27.07E-03			
			22.91E-03	24.77E-03	27.19E-03	26.24E-03	24.12E-03			
		22.15E-03	21.74E-03	22.54E-03	24.46E-03	23.95E-03	22.90E-03	22.70E-03		
		21.68E-03	20.92E-03	20.60E-03	21.81E-03	21.94E-03	22.09E-03	22.38E-03		
		19.75E-03	19.75E-03	18.97E-03	19.43E-03	20.26E-03	20.88E-03	20.88E-03		
	19.46E-03	18.38E-03	18.53E-03	17.42E-03	17.38E-03	18.63E-03	19.76E-03	19.38E-03	21.55E-03	
	20.52E-03	18.01E-03	16.91E-03	16.17E-03	15.70E-03	17.30E-03	18.36E-03	19.23E-03	22.56E-03	
	20.92E-03	16.39E-03	15.60E-03	14.76E-03	14.15E-03	15.85E-03	17.09E-03	17.47E-03	23.33E-03	
31.36E-03	20.92E-03	16.39E-03	15.60E-03	14.76E-03	14.15E-03	15.85E-03	17.09E-03	17.47E-03	23.33E-03	31.36E-03

FOLDOUT FRAME

Fold out FRAME 3

Note that it is necessary to employ the conversion program if it is desired to make a simulation in the presence of the acoustic liner. In this instance, the initial data are supplied to the integration program and the results, stored on tape, are then converted to suitable form by the conversion program.

1. Subroutine MAIN

The flow field and other data from the integration program that is stored on tape is read in MAIN. For each new mesh point between each two of the original mesh points, a new value of the flow field variables is determined by quadratic interpolation of the values at the original mesh. The flow field and other data for the new mesh size are also stored on tape in this subroutine for use by the integration program.

Subroutine MAIN also calls the remaining subroutines. A flow diagram and a listing are presented in Appendix E.

2. Subroutine INT

Data relative to the new mesh size that are unavailable from the integration program are read into the conversion program in INT. These data include the values of the flow variables for 22 of the mesh points that define the surface of the supersonic nozzle. Subroutine INT also generates the information necessary to describe the geometry of the combustion chamber and nozzle.

The input data required are shown by the data input form on pages IV-35 and IV-36. The data supplied by the first four cards have been described in Subroutine INITIAL. The data supplied by Cards 5 and 6 are as follows:

Card	Variable	Description
5	TCOUNT	The number of the iteration at which the conversion is being made
	XMU	The viscosity of the combustion gases
	OMEGA	The expected frequency of the oscillation
	THICK	The liner thickness
6	IFOUR	Control index used for data input
	IEIGHT	Control index for data input
	MESH	Control index for data input

The data supplied by Cards 7 through 20 are values of the flow field variables that are to be supplied externally, since it is not possible to obtain these by interpolation within the program. The values of density, x-momentum, and energy are obtained by manual interpolation of the data for the 1/2-in. mesh. Values of the y-momentum must be assigned arbitrarily, since information to calculate these is unavailable.

GENERAL INPUT FORM

Engineer ______ Department Name & Location ______ Extension ______ Sheet ___ of ___

Title: Sample Data Cards - Conversion Program   Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

CC / I.D.: DECK NAME | J O B | COST CONTROL NUMBER | JOB NUMBER | COMPUTING LAB CONTACT | P R T Y = | T I M E =

```
   LENX1     LENX2     LENX3      LENX4
        27        28        40        50
   LENY1     LENY2     LENY3      LENY4     LENY5
         2         4        16        18        20
   MOLWT     PO        TO         GAM       FUDGE    DELX      DIFCO      QUE
     9.6    77000.    5100.       1.2       0.8     0.020825    3.0       1.52D09
    T        TT        NOPT       IRHO      IM        IN         IE      IPRES
         1         1         1         1         1         1         1         1
  TCOUNT     XMU       OMEGA      THICK
         0    1.0D05    0.0       0.125
IFOUR IEIGHT MESH
    4    7    1
     THE FOLLOWING ARE THE VALUES OF THE FLOW FIELD VARIABLES AT THE WALL
     OF THE SUPERSONIC BOUNDARY.THE MESH POINT TO WHICH EACH SET OF VALUES
     CORRESPONDS IS INDICATED TO THE RIGHT OF THE DATA.I AND J REFER TO
     LOCATIONS ON FIGURE 8.
  DENSITY XMOMENTUM YMOMENTUM ENERGY         FLOW FIELD LOCATION
   0.045     310.      10.0       1.87D05     I=46    J=5 AND 19
   0.041     297.      10.0       1.73D05      =47     =5  "  19
   0.038     284.      10.0       1.60D05      =48     =5  "  19
   0.035     269.      10.0       1.47D05      =49     =5  "  19
   0.031     254.      10.0       1.34D05      =50     =5  "  19
   0.028     242.      10.0       1.23D05      =51     =5  "  19
   0.025     230.      10.0       1.13D05      =52     =5  "  19
   0.035     269.      10.0       1.47D05      =49     =4  "  20
```

PWA MISC 366 (REV. 12-66)

GENERAL INPUT FORM

Engineer: ______ Department Name & Location ______ Extension ______ Sheet ___ of ___

Title: Sample Data Cards - Conversion Program (Continued) Sent by ______

Job Number ______ Analyst ______ Cost Control Number ______

ID: JOB PRTY= TIME=

```
  DENSITY  XMOMENTUM  YMOMENTUM    ENERGY    FLOW FIELD  LOCATION
    0.031     254.       10.0     1.34D05   I= 50     J= 4  AND  20
    0.028     242.       10.0     1.23D05    = 51      = 4  "    20
    0.025     230.       10.0     1.13D05    = 52      = 4       20
```

PWA MDC 3415 REV. 12-66

SECTION V
COMPUTED RESULTS

A. GENERAL

Simulations were made to investigate the calculation of wave motion in the gas stream in a combustion chamber. A simulation consists of two periods:

1. Generation of the steady (equilibrium) state solution from the initial conditions
2. Disturbance of the equilibrium state corresponding to an upset of the system, such as that obtained by "bombing" the chamber, followed by the transient period during which the wave motion of the gas occurs.

Both aspects of the simulations have been separately studied and are discussed individually in Paragraphs B and C, respectively. As noted in Section IV, the program running time is 3 sec per Δt with an IBM 360 Mod 65 and a 1/2-in. mesh. The running time is reduced to 0.4 sec per Δt when a CDC 6600 is employed. When the mesh is reduced the running time increases as the square of the reduction.

The simulations are all based on a 1 x 5 x 7 in. combustion chamber. The throat dimensions are 1 x 3 in. so that the contraction ratio of the combustor is 1.67. The subsonic part of the nozzle is 3 in. long. Only a short section (2-in.) of the supersonic nozzle has been employed to provide a basis for extrapolation as the boundary condition at the nozzle exit.

The simulation was based on 7.1 lb/sec of oxygen and hydrogen at a mixture ratio of 3.7 and a propellant inlet temperature of 200°R. Thermodynamic data indicate that the heat evolved will be 2.83×10^7 ft lb/sec. The final temperature expected at the steady state, by a heat balance, will be 5150°R. The estimated theoretical chamber pressure based on the formula given earlier is 75,000 lb/ft^2. The energy released per unit of volume, considering the entire chamber as the combustion volume, is 1.52×10^9 ft lb/ft^3 sec.

The initial conditions in the combustion chamber were,

	Injector Face	Chamber Exit
Density, lb/ft^3	2.70	0.10
x-Momentum, $lb/ft^2 sec$	203	203
y-Momentum, $lb/ft^2 sec$	0.0	0.0
Energy, $ft\ lb/ft^3$	355,000	361,000

Values of these variables at mesh points intermediate between the injector face and the chamber exit were obtained by interpolation. Values for the convergent-divergent nozzle were obtained by the formulas presented earlier in INITIAL.

B. STEADY-STATE SIMULATION

The energy source term in the Lax-Wendroff equations to represent the combustion process was set equal to the overall heat of combustion per unit volume and time.

The energy is assumed to be released evenly throughout the chamber. Originally it was intended to base the distribution of energy release on the Priem-Heidemann Combustion Model (Reference 8) but this was not feasible because of funding limitations. However, a computer program of this model was written and is available if required.

The results of the simulation with a 1/2-inch mesh to obtain a steady state suitable for disturbance and subsequent transient calculations is presented in figures 11 through 14.

Figure 11 shows that the steady state is achieved after about 4 msec have elapsed and that the computed pressure at the injector face is essentially equal to that calculated by thermodynamic considerations as given by equation (41). Density as a function of position within the motor at three different times is shown in figure 12. The x-momentum as a function of position within the motor at four different times is presented in figure 13. The data indicate a substantial initial transient. The dip in the x-momentum near the injector face that persists is not clearly understood. The results suggest that the x-momentum, at 7.0 milliseconds, is still trending toward a constant value throughout the chamber and a much longer running time would be required to obtain the steady state. The dip as well as the strong transient may be due to fixing the momenta and enthalpy (thus adjusting the energy) at the injector face rather than permit these to fluctuate according to natural processes that may be occurring. However, as noted in the Introduction, it was not practical to completely model the propellant supply and injector system. The pressure in the motor at three different times as a function of the distance from the injector face is presented in figure 14.

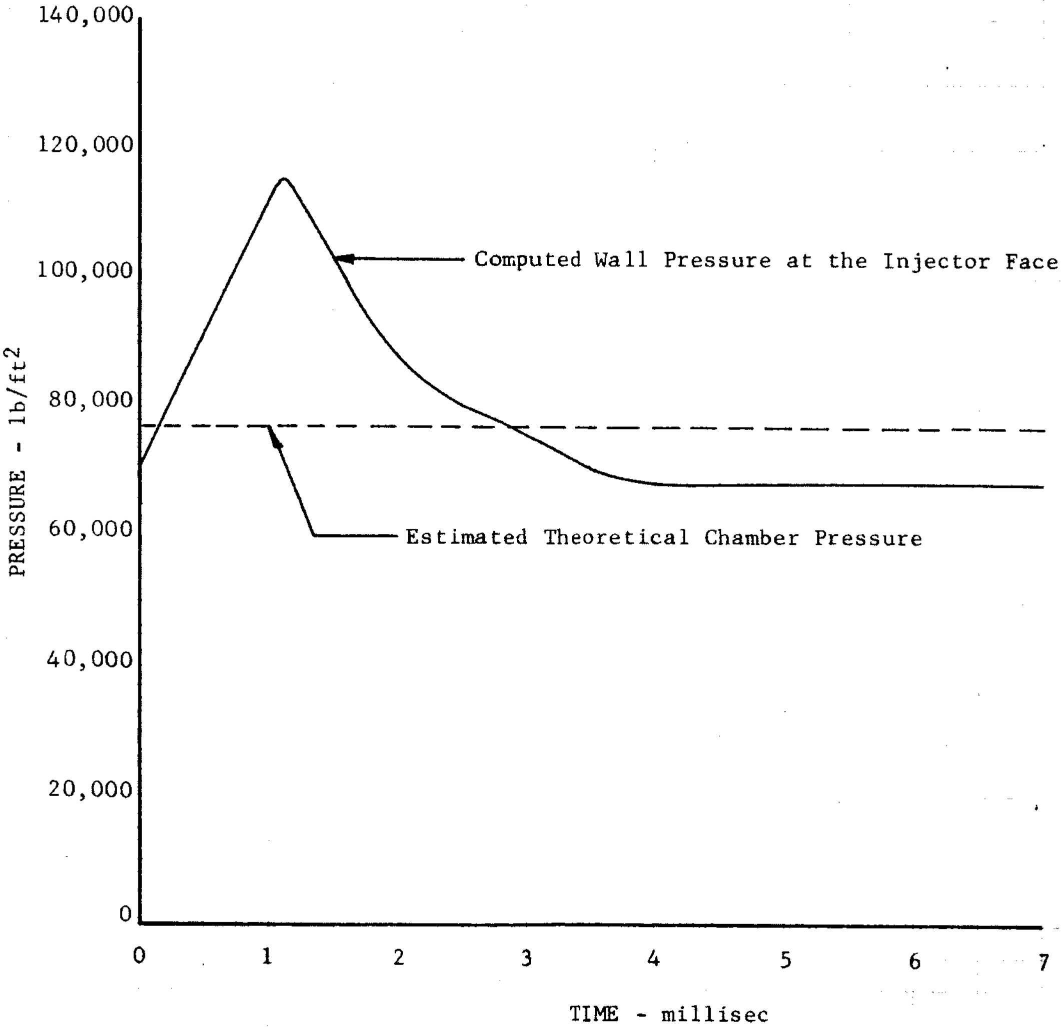


Figure 11. Chamber Pressure at Injector Face

DF 61408

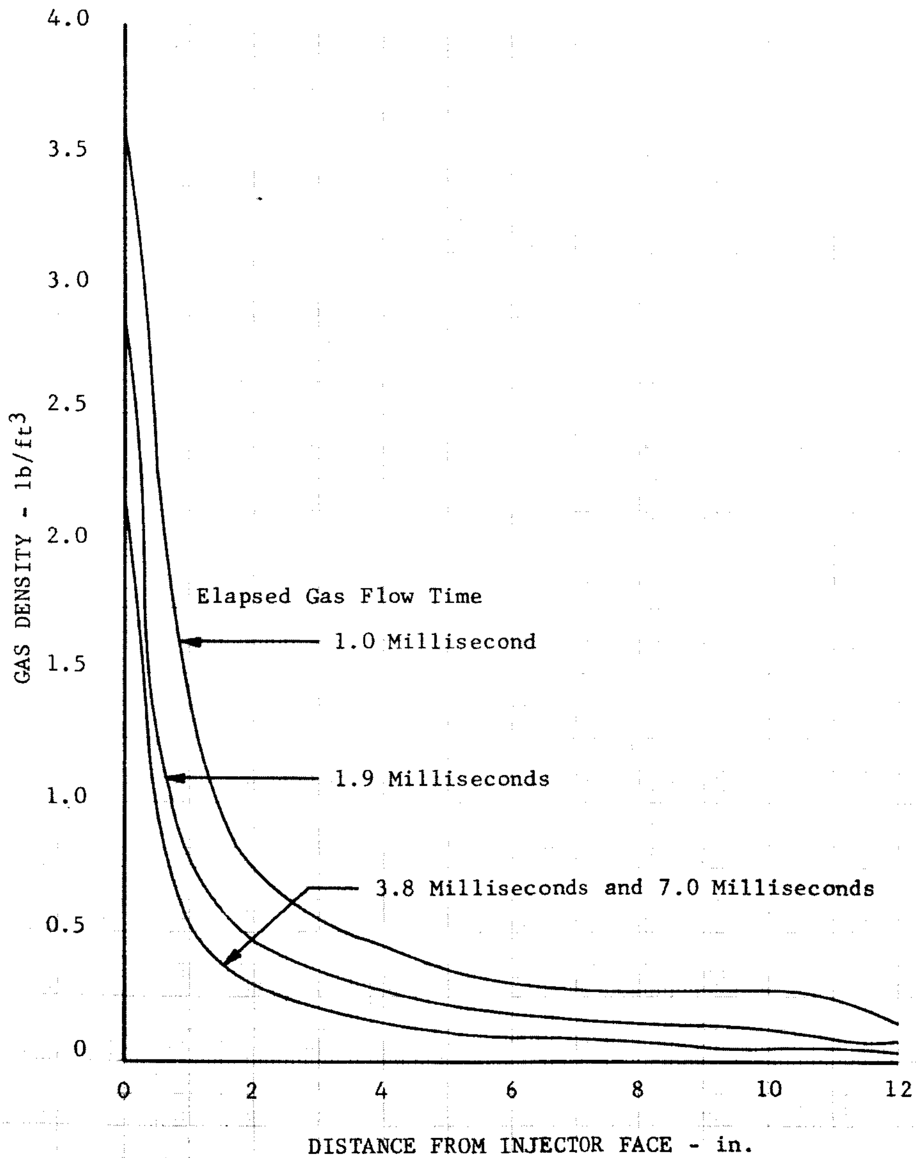


Figure 12. Gas Density as a Function of Distance from Injector Face and Time DF 61409

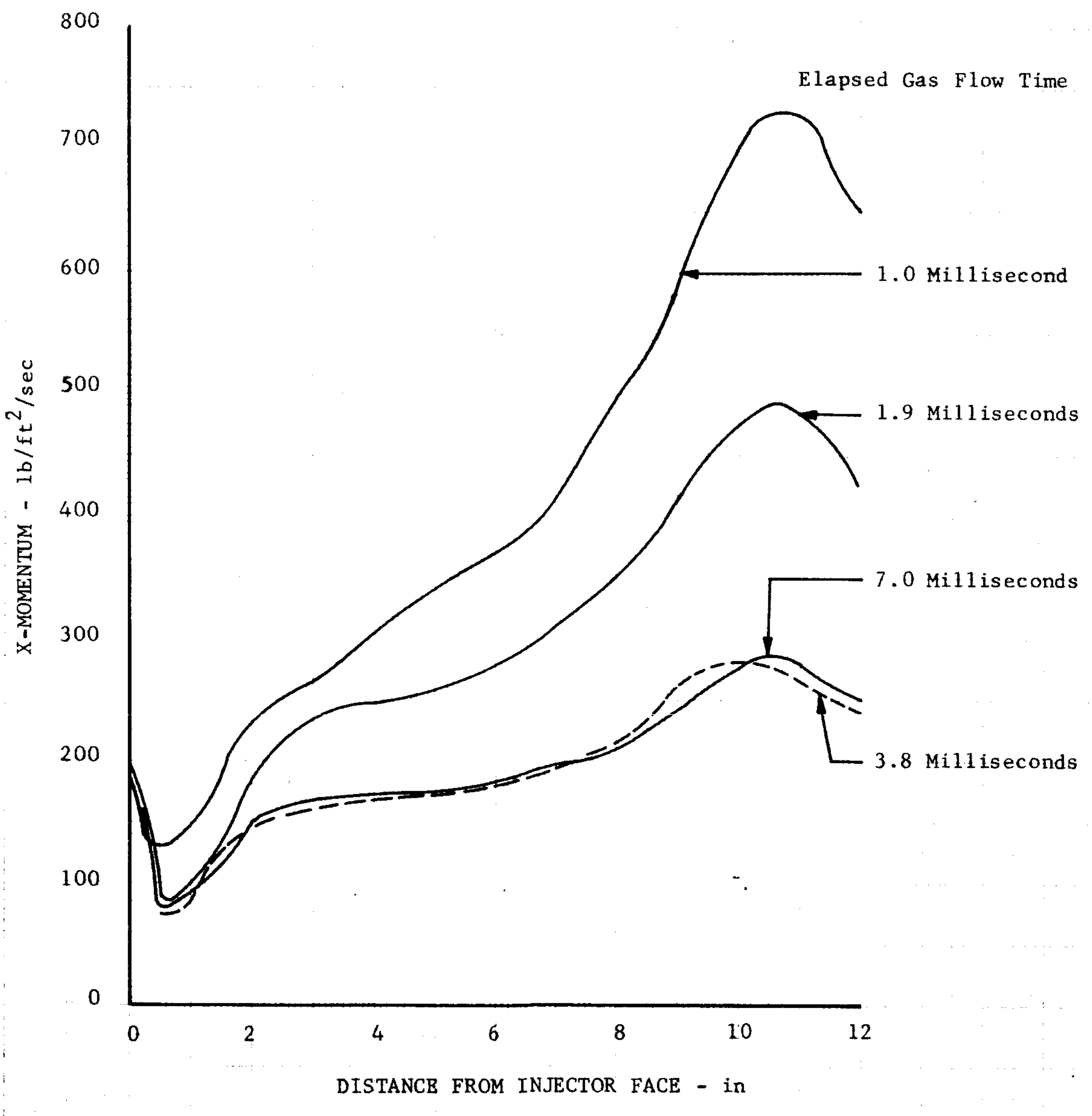


Figure 13. x-Momentum as a Function of Distance from Injector Face and Time

DF 61410

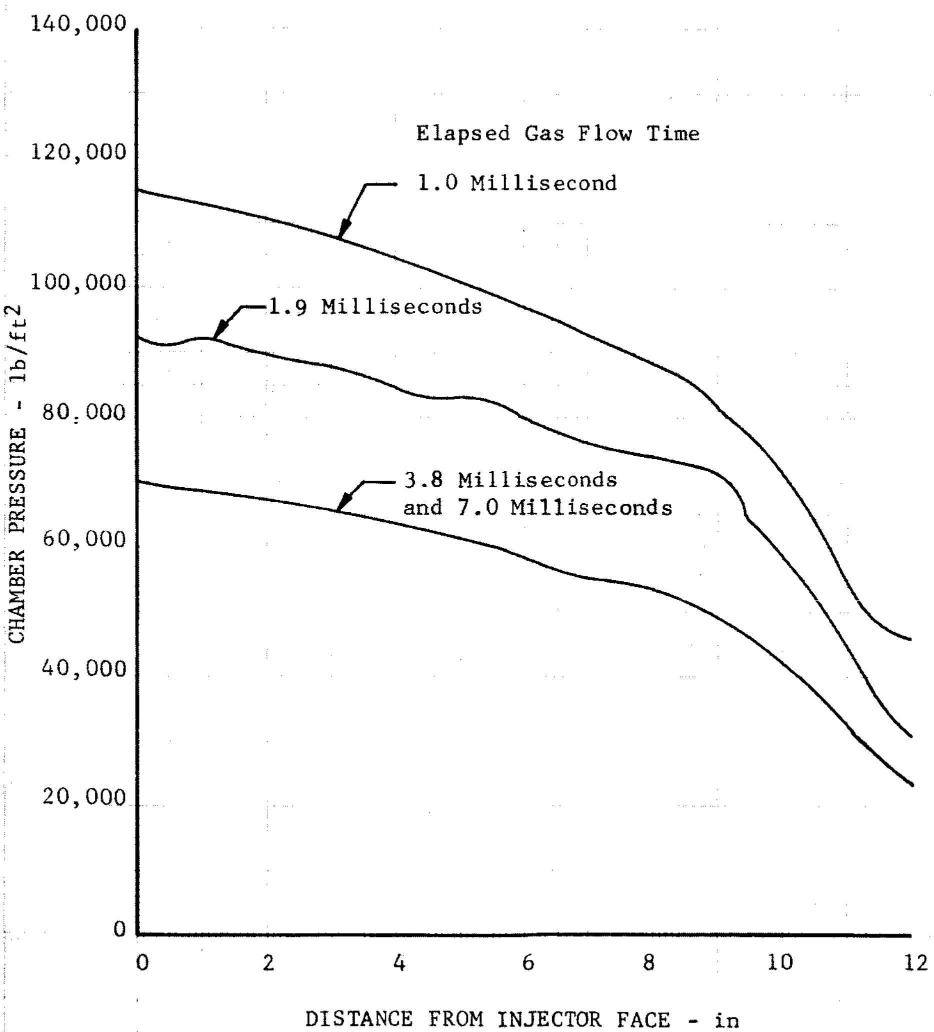


Figure 14. Chamber Pressure as a Function of Distance from Injector Face and Time

DF 61411

These data were employed as the starting point for calculations of transient gas flow. A complete printout of all the computed results at 7.0 msec is also presented in Appendix F for ready reference. Note that there are only relatively small gradients in the values of the flow variables in the transverse direction.

C. TRANSIENT SIMULATION

To make a transient simulation, the steady state must first be disturbed in a manner similar to that done experimentally when a combustion chamber is "bombed". In the calculation to be discussed, the mathematical form employed to disturb the steady gas flow was

$$Q = (q + q_p) \qquad (76)$$

where, in addition to previous symbols,

q_p = perturbed energy ft lb/ft^3/sec

The value of q_p was selected in a series of trials to provide a disturbance equal to 100% of the steady-state chamber pressure at the injector face. The magnitude of the disturbance required was 4.0×10^{10} ft lb/ft^3/sec, and the period of the disturbance was 4.1 μsec. With this disturbance, the peak pressure was reached in 0.2 msec.

Due to funding limitations, it was not feasible to further evaluate the effect of the magnitude of the disturbance on oscillations generated. It has been assumed for the purpose of this study that this disturbance is uniform over the chamber. However, with slight modifications to the function H described on page IV-26, other locations of the disturbance or magnitude and duration of disturbance can be easily simulated.

The energy source term in this transient period is

$$Q = q \left(\frac{p}{\bar{p}}\right)^n \qquad (77)$$

where the terms are defined on page IV-27. Note that the definition of the energy source term is somewhat different from that employed in the Crocco-Cheng and other theories because the average pressure is computed at each time interval.

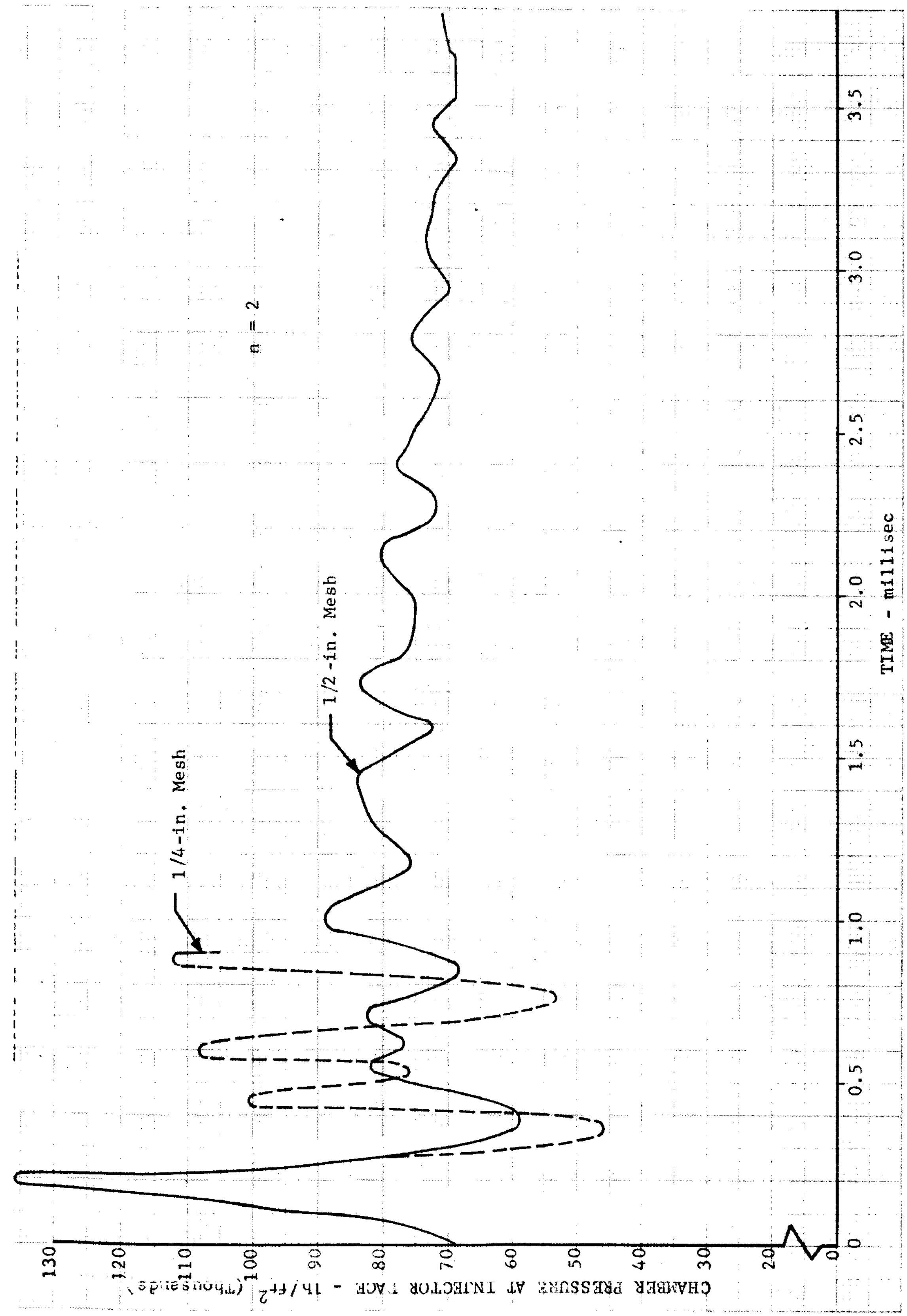
The results of the transient simulations of the gas flow in the rocket engine are summarized in figures 15 through 19. Because the waves are nonlinear, it is not possible to characterize them simply by their frequencies and damping coefficients as is the normal practice with linear oscillations. However, the frequency is generally from 3000 to 4000 Hertz.

Figure 15 compares calculated chamber pressures for 1/2- and 1/4-in. meshes when the exponent n in equation (77) was given a value of 2. This comparison shows that the solution is dependent on the mesh size within this range, and that the solution becomes more oscillatory as the mesh is refined. It is possible that the solution for a mesh size smaller than 1/4 in. may not be significantly different from that presented for the 1/4-in. mesh. However, it would be necessary to conduct a simulation with a 1/8-in. mesh, and possibly smaller meshes,until that mesh size is obtained at which the results become independent of mesh size. This was not done in this project because of the lack of funds. It can be concluded from the results of figure 15 that the system is unstable with $n = 2$.

Figure 16 presents the results of a simulation at three different locations at the chamber wall for $n = 1$. The mesh size was 1/4-in., which is the smallest that could be run in the present investigation. The data show that the oscillation is greatest at the injector face and lowest at the chamber exit. This trend is in agreement with experimental observations.

The effect of the value of n on the calculated pressure for a 1/4-in. mesh is shown in figure 17. The data show the expected result that the oscillatory motion is increased as n is increased. It should not be concluded that a value of n greater than 1 is necessary to cause divergent instability because, as previously noted, a simulation with finer mesh may result in more oscillatory behavior even with $n = 1$. For example, figure 18 presents the effect of n for a 1/2-in. mesh. These data would indicate that the value of n must be greater than 2 for the system to become unstable, but the data presented for the 1/4-in. mesh (figure 16) show considerable instability when $n = 2$.

In all of the previously discussed simulations, the value of the diffusion coefficient (D in equations 13 - 15) was equal to zero. Two of the simulations of figure 19 (n = 3 and n = 2) were made with D = 3. The computed results of the two simulations were identical to the results of the original simulations made with D = 0. These results provide the conclusions, presented on page III-4, to the effect that once steady state is established the diffusion operator does not contribute to the mathematical solution in this application.



DF 61425

Figure 15. Effect of Mesh Size on Wall Pressure at Injector Face as a Function of Time

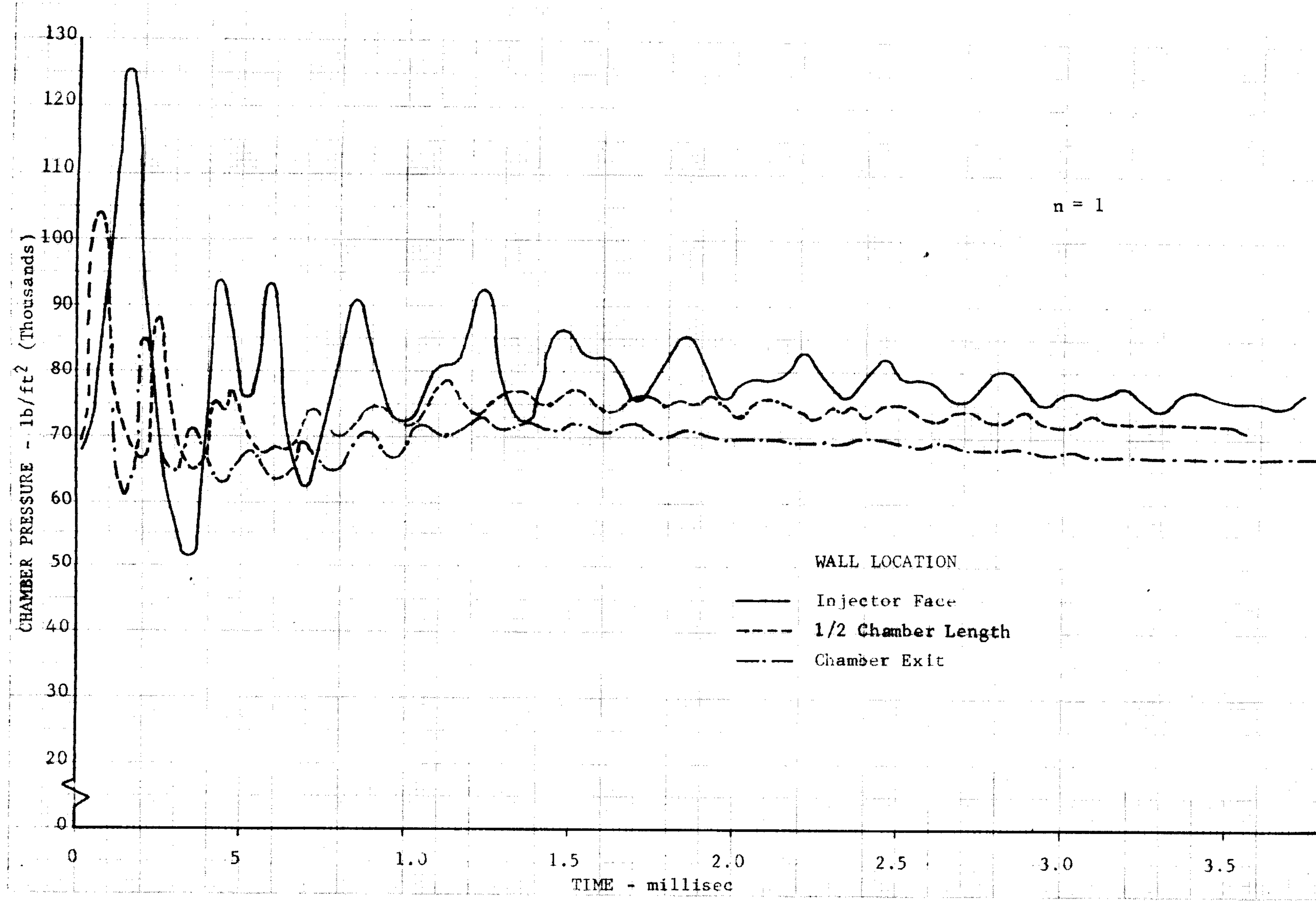
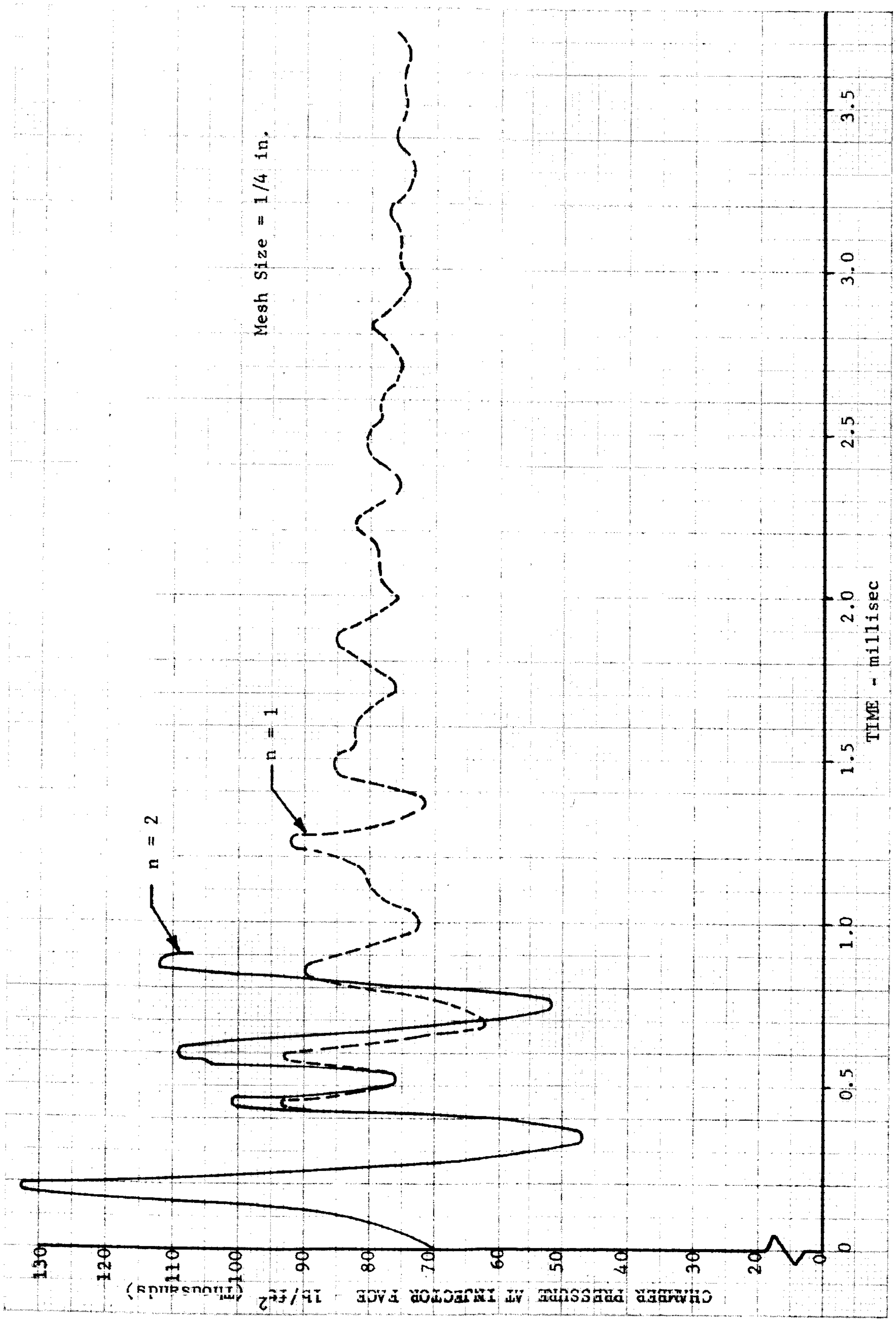


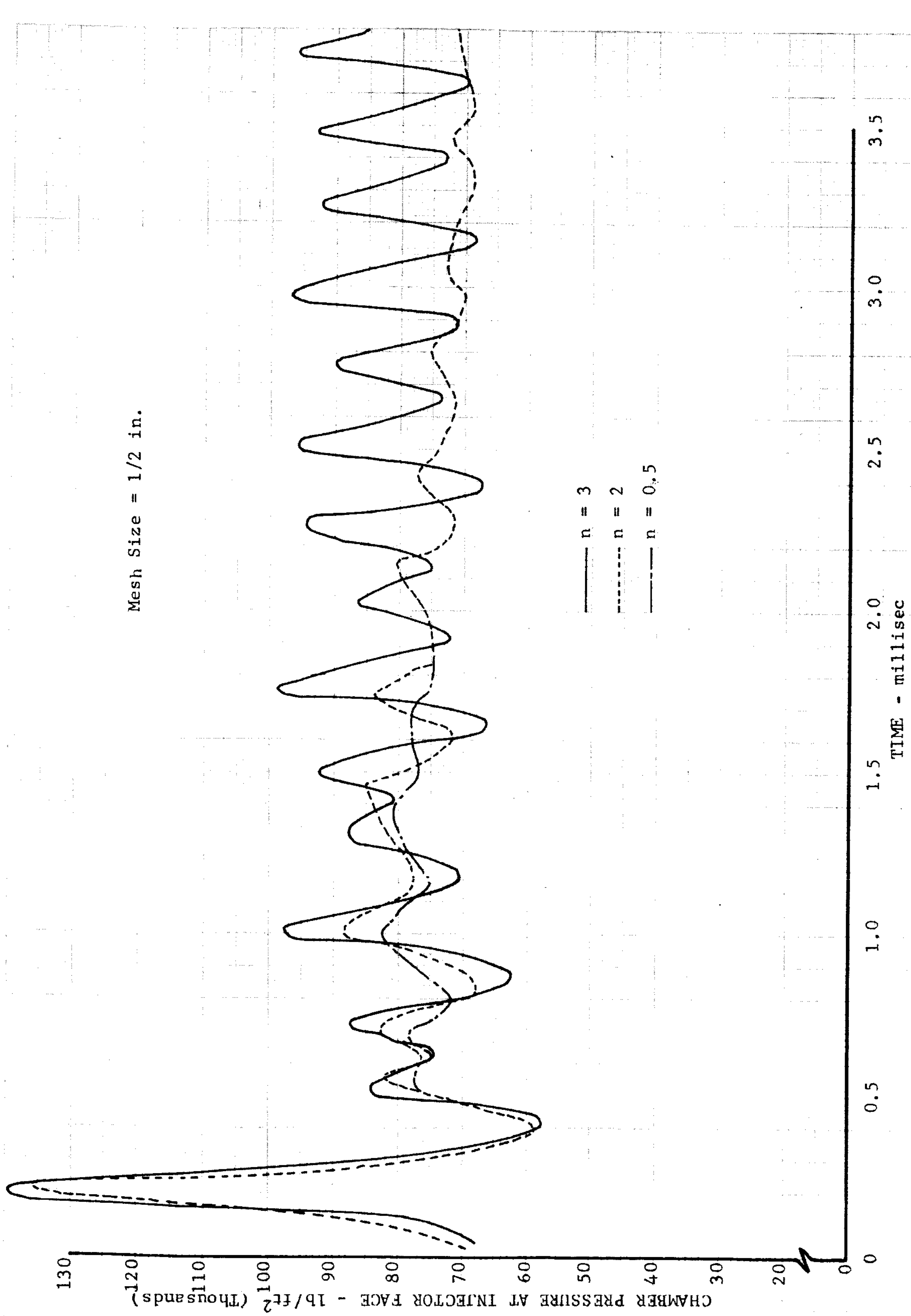
Figure 16. Effect of Location in Combustion Chamber on Wall Pressure as a Function of Time

DF 61426



DF 61427

Figure 17. Effect of n on Wall Pressure at Injector Face as a Function of Time



DF 61428

Figure 18. Effect of n on Wall Pressure at Injector Face as a Function of Time

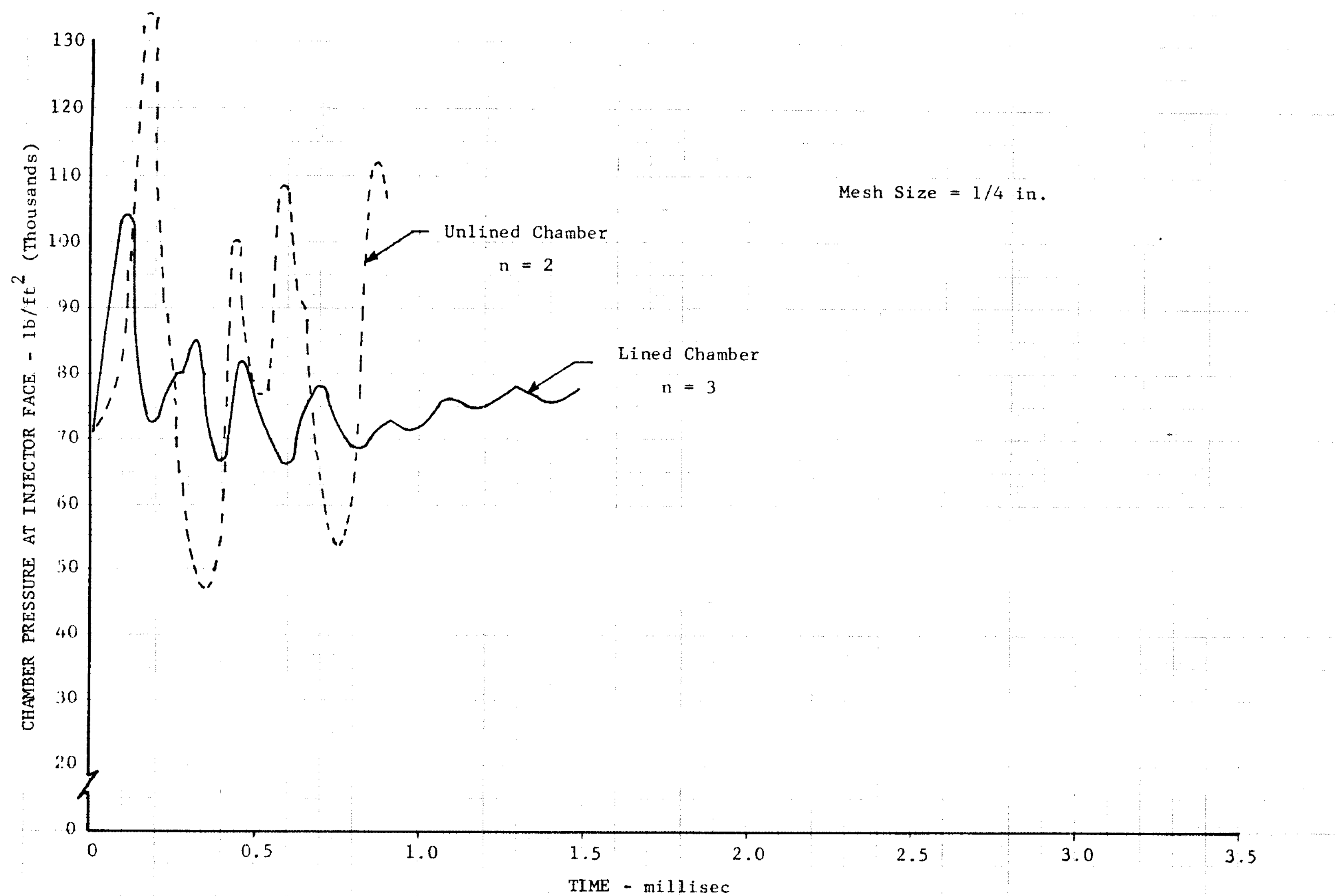


Figure 19. Effect of Sound-Absorbing Liner on Wall Pressure at Injector Face as a Function of Time

DF 61429

The effect of a sound-absorbing liner on the oscillation is presented in figure 19. The value of n in equation (77) was 3 in the simulation made with the liner and the results are compared to those for an unlined chamber with an n of 2. The damping effect of the liner is clearly evident. However, it should be noted that the damping would have been greater if the same exponent value had been used in the two simulations.

The design acoustic resistance, reactance, and absorption coefficient of the liner are presented by figures 20, 21, and 22.

Figure 23 presents a comparison of calculated and experimentally observed chamber pressures in the slab motor. The experimental pressures were obtained in Test 58.04 conducted under Contract NAS8-11024. The operating conditions employed in Test 58.04 were the same as those employed in the simulation.

The difference in frequencies of the computed and experimentally observed waves may be due to the fact that the computed wave may contain both lower-frequency longitudinal as well as transverse components, while the experimental wave contains only the transverse component. The difference in wave magnitude may be due to the fact, as noted earlier, that mass addition to the gas phase due to propellant vaporization as well as nozzle and frictional effects were neglected.

DF 62400

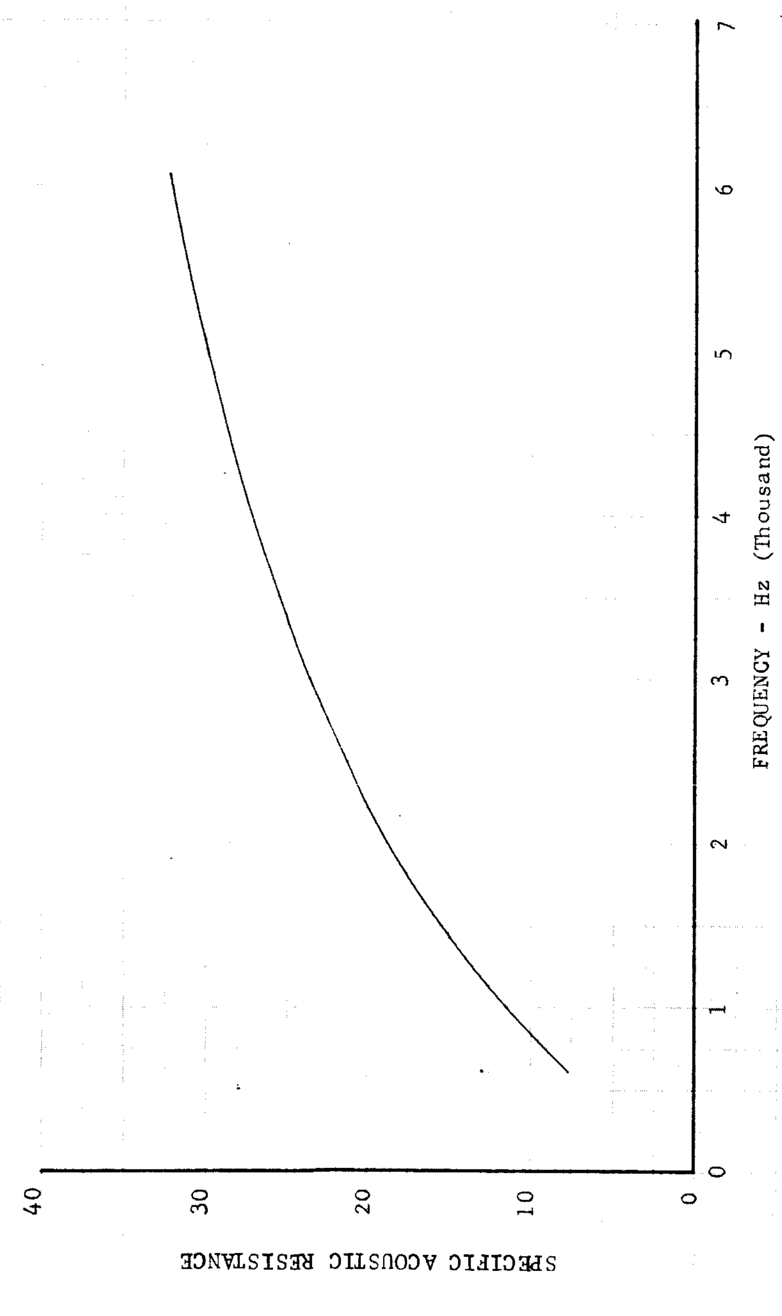


Figure 20. Specific Acoustic Resistance as a Function of Frequency

DF 62401

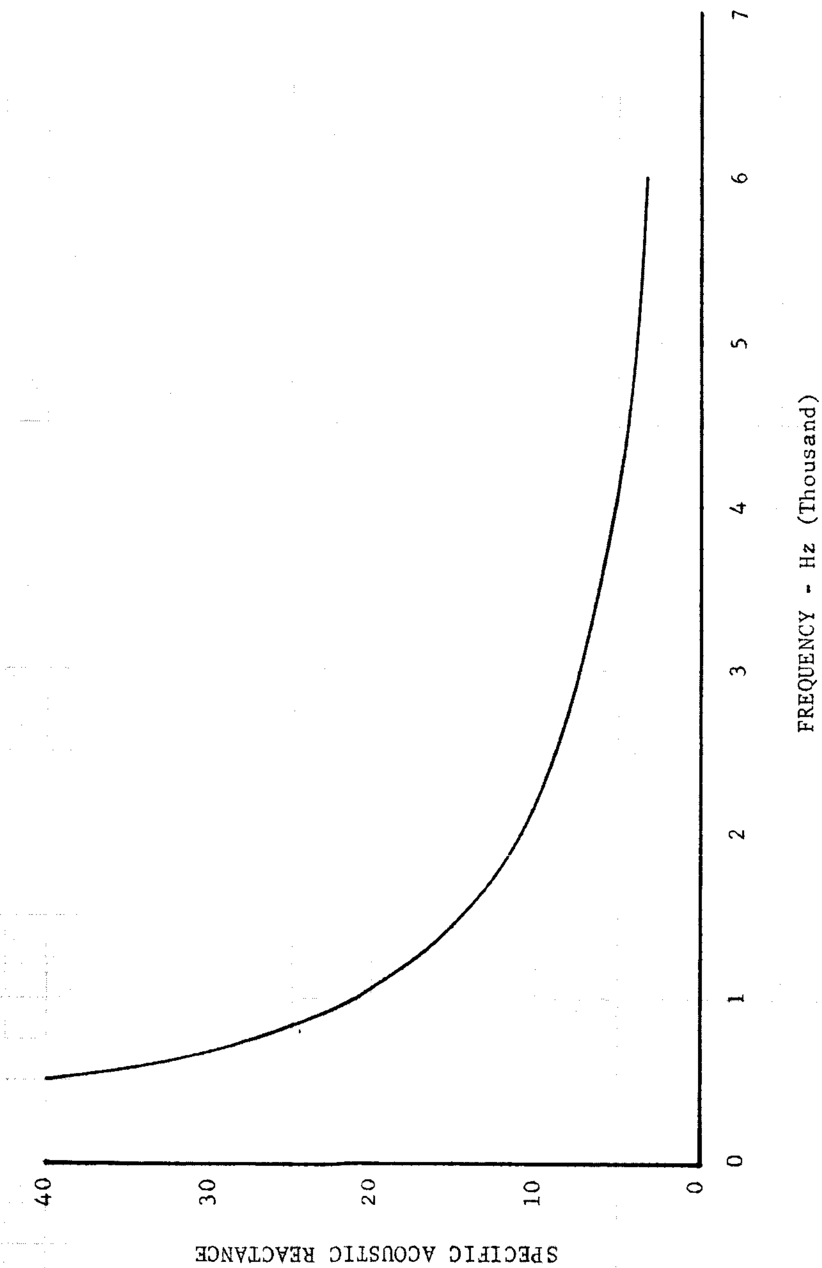


Figure 21. Specific Acoustic Reactance as a Function of Frequency

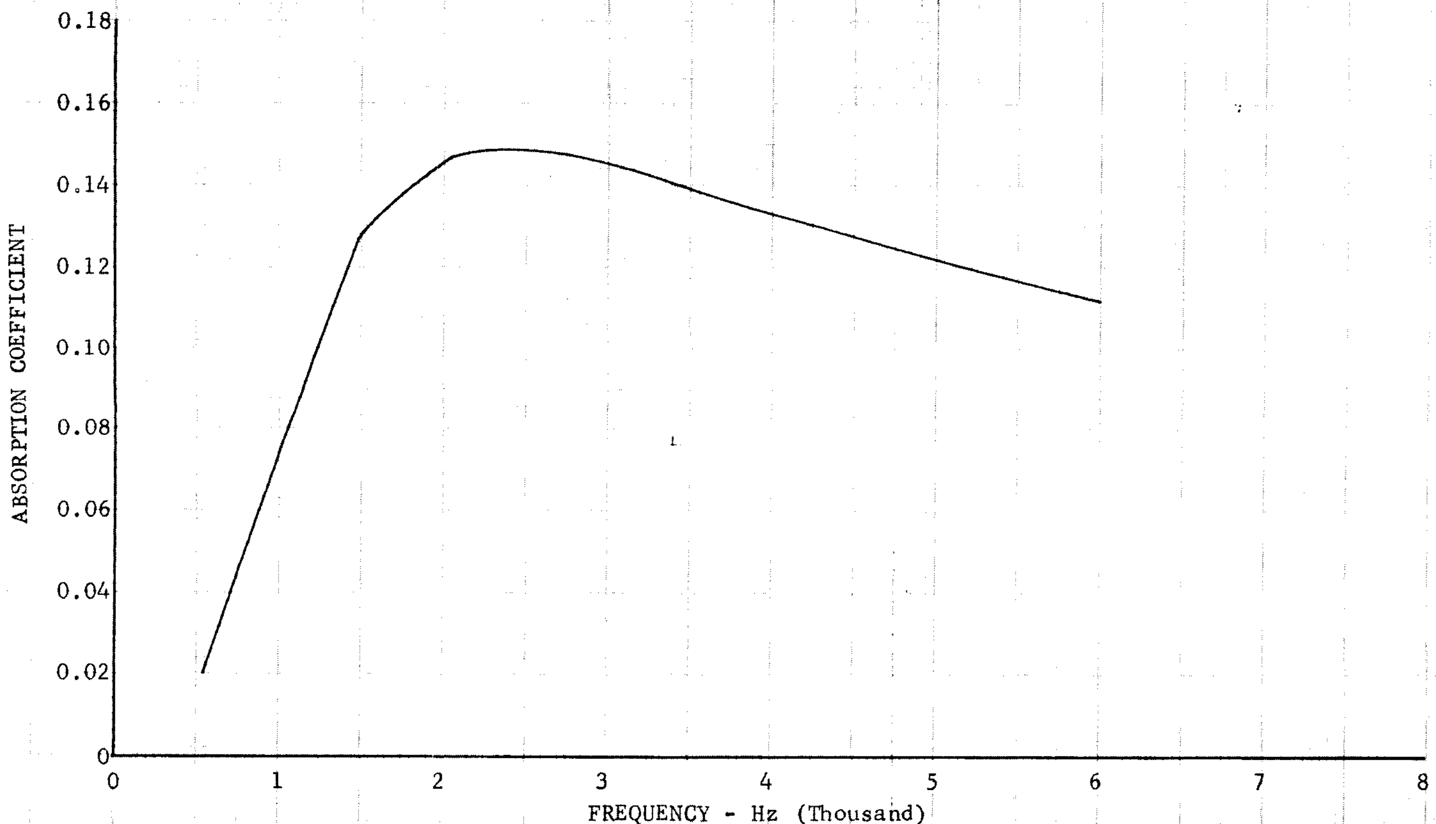


Figure 22. Absorption Coefficient as a Function of Frequency

DF 62402

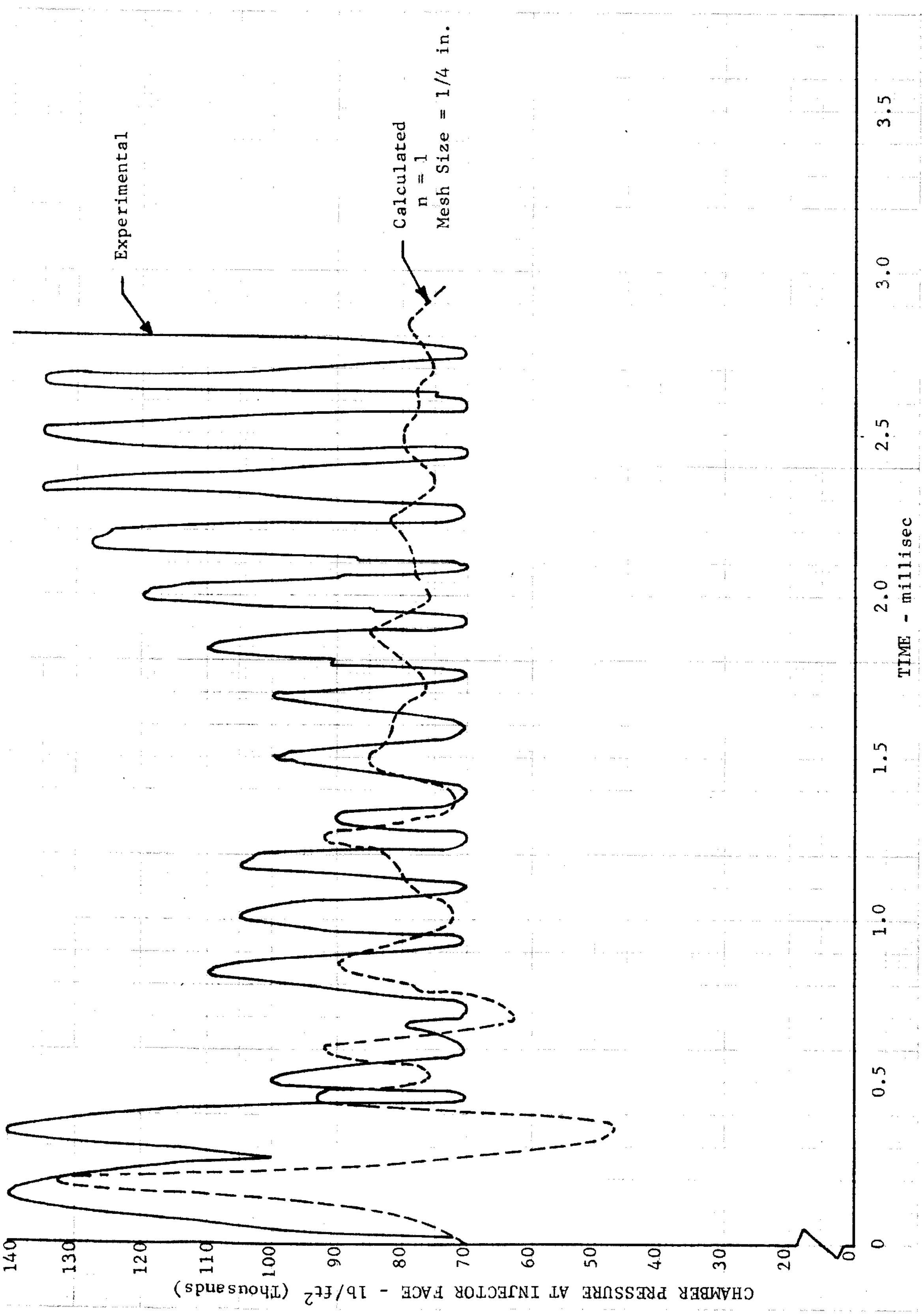


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Figure 23. Comparison of Experimental to Computed Wall Pressures at Injector Face

SECTION VI
CONCLUSIONS AND RECOMMENDATIONS

A computer program has been written to simulate (1) the time-dependent flow of a gas when coupled with combustion energy release, and (2) the suppression of acoustic oscillations in a slab rocket motor. The program is based on integrating the inviscid flow equations by a two-stage Lax-Wendroff technique. The initial predictor-corrector technique employed was unstable. A one-step Lax-Wendroff technique was also employed, but was abandoned for the two-step method to achieve greater accuracy.

Calculations of the transient and steady-state flow of gas in a slab motor have been made with the computer program. The steady-state computer solution agreed with that predicted from thermodynamic considerations. The transient calculations resulted in acoustic oscillations. The divergence of the oscillations observed during a selected rocket firing was not simulated by the computer which predicted a damped oscillation. A reduction of integration mesh size might possibly improve the simulation.

The stabilizing effect of a sound-absorbing liner was illustrated by one simulation with the liner as a boundary condition.

If further work is done with this program, it is recommended that first the mesh size required for mathematical convergence be established. After a better approximation of experimental rocket chamber oscillations is accomplished,it is recommended that the program be employed to investigate the effects of liner design variables in conjunction with combustion chamber design variables to suppress high frequency oscillations.

APPENDIX A
REDUCTION OF EULERIAN INVISCID FLOW EQUATIONS TO NORMAL FORM

The inviscid flow equations may be written

$$W_t + A(W)W_x = -B(W)W_y \tag{A-1}$$

where

$$W = \begin{bmatrix} \rho \\ u \\ v \\ p \end{bmatrix}, \quad A(W) = \begin{bmatrix} u & \rho & 0 & 0 \\ 0 & u & 0 & 1/\rho \\ 0 & 0 & u & 0 \\ 0 & \rho c^2 & 0 & u \end{bmatrix}, \quad B(W) = \begin{bmatrix} v & 0 & \rho & 0 \\ 0 & v & 0 & 0 \\ 0 & 0 & v & 1/\rho \\ 0 & 0 & \rho c^2 & v \end{bmatrix}$$

where

ρ = Density

u = Longitudinal velocity

v = Transverse velocity

p = Pressure

c = Velocity of sound

Equation (1) may be written in normal form by diagonalizing the matrix A(W). This may be done by obtaining the eigenvalues and eigenvectors of A(W) from the relations

$$\xi^i A(W) = \lambda_i \xi^i \quad (i = 1, \ldots, 4) \tag{A-2}$$

or

$$\xi^i (A - \lambda_i I) = \theta$$

where the ξ^i and λ_i are the four eigenvectors and their corresponding eigenvalues, respectively, I is the identity matrix and θ is the null vector.

Equation (2) will possess a nontrivial solution if and only if

$$\left| A - \lambda_1 I \right| = 0$$

or

$$(\lambda - u)^2 \left[\lambda - (u + c)\right] \left[\lambda - (u - c)\right] = 0 \tag{A-3}$$

which yields

$$\begin{aligned} \lambda_1 &= u \\ \lambda_2 &= u + c \\ \lambda_3 &= u - c \\ \lambda_4 &= u \end{aligned} \qquad \text{(A-4)}$$

as the eigenvalues of A(W). The corresponding eigenvectors obtained by substituting (4) into (2) are:

$$\begin{aligned} \xi^1 &= \left(\tau_1,\ 0,\ \tau_2,\ -\frac{1}{c^2}\tau_1\right) \\ \xi^2 &= \left(0,\ \tau_3,\ 0, \frac{1}{\rho c}\tau_3\right) \\ \xi^3 &= \left(0,\ \tau_4,\ 0,\ -\frac{1}{\rho c}\tau_4\right) \\ \xi^4 &= \left(\tau_5,\ 0,\ \tau_6,\ -\frac{1}{c^2}\tau_5\right) \end{aligned} \qquad \text{(A-5)}$$

Since the eigenvalues (4) are not distinct, the τ_i, must be chosen so that the eigenvalues (5) are linearly independent, i.e., it must be true that the equation

$$\alpha_1 \xi^1 + \alpha_2 \xi^2 + \alpha_3 \xi^3 + \alpha_4 \xi^4 = \theta \qquad \text{(A-6)}$$

has the trivial solution $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$ as its only solution. This condition is satisfied by choosing the τ_i to be

$$\begin{aligned} \tau_1 &= \tau_5 = -c^2 \\ \tau_2 &= -\tau_6 = 1 \\ \tau_3 &= -\tau_4 = \rho c \end{aligned} \qquad \text{(A-7)}$$

The eigenvectors are

$$\begin{aligned} \xi^1 &= (-c^2, 0, 1, 1) \\ \xi^2 &= (0, \rho c, 0, 1) \\ \xi^3 &= (0, -\rho c, 0, 1) \\ \xi^4 &= (-c^2, 0, -1, 1) \end{aligned} \qquad \text{(A-8)}$$

The matrix A(W) may now be diagonalized by a similarity transformation

$$HAH^{-1} = T \tag{A-9}$$

where H is the matrix whose rows are the vectors (8) and T is a diagonal matrix with the eigenvalues λ_i as its diagonal elements.

$$H = \begin{bmatrix} -c^2 & 0 & 1 & 1 \\ 0 & \rho c & 0 & 1 \\ 0 & -\rho c & 0 & 1 \\ -c^2 & 0 & -1 & 1 \end{bmatrix}, \quad H^{-1} = \begin{bmatrix} -\frac{1}{2c^2} & \frac{1}{2c^2} & \frac{1}{2c^2} & -\frac{1}{2c^2} \\ 0 & \frac{1}{2\rho c} & -\frac{1}{2\rho c} & 0 \\ \frac{1}{2} & 0 & 0 & -\frac{1}{2} \\ 0 & \frac{1}{2} & \frac{1}{2} & 0 \end{bmatrix} \tag{A-10}$$

$$T = \begin{bmatrix} u & 0 & 0 & 0 \\ 0 & u+c & 0 & 0 \\ 0 & 0 & u-c & 0 \\ 0 & 0 & 0 & u \end{bmatrix}$$

The equations (1) are transformed into normal form by setting

$$U = HW = \begin{bmatrix} p + v - \rho c^2 \\ p + \rho cu \\ p - \rho cu \\ p - v - \rho c^2 \end{bmatrix} \tag{A-11}$$

then

$$W = H^{-1}U \tag{A-12}$$

and

$$W_\ell = H_\ell^{-1}U + H^{-1}U_\ell \tag{A-13}$$

where the subscript "ℓ" denotes differentiation with respect to "ℓ". Substituting (13) into (1) yields

$$H^{-1}U_t + AH^{-1}U_x = -B\left[H_y^{-1}U + H^{-1}U_y\right] - \left[H_t^{-1} + AH_x^{-1}\right]U \tag{A-14}$$

which upon multiplication by H from the left becomes, using (9),

$$U_t + TU_x = -HB\left[H_y^{-1}U + H^{-1}U_y\right] - H\left[H_t^{-1} + AH_x^{-1}\right]U \tag{A-15}$$

or

$$U_t + TU_x = -GU_y - JU \tag{A-16}$$

where

$$G = HBH^{-1}$$

$$J = H\left[BH_y^{-1} + AH_x^{-1} + H_t^{-1}\right]$$

Equation (16) is the normal form of the system (1).

If differentiation in a characteristic direction is defined by

$$D_i(\ ) = \frac{\partial}{\partial t}(\ ) + \lambda_i\frac{\partial}{\partial x}(\ ) + v\frac{\partial}{\partial y}(\ ) \tag{A-17}$$

then the matrices G and J are

$$G = \begin{bmatrix} v & \frac{1}{2\rho} & \frac{1}{2\rho} & 0 \\ \frac{\rho c^2}{2} & v & 0 & \frac{-\rho c^2}{2} \\ \frac{\rho c^2}{2} & 0 & v & \frac{-\rho c^2}{2} \\ 0 & -\frac{1}{2\rho} & -\frac{1}{2\rho} & v \end{bmatrix} \tag{A-18}$$

$$J = \begin{bmatrix} -\frac{D_1(c)}{c} & \frac{D_1(c)}{c} & \frac{D_1(c)}{c} & -\frac{D_1(c)}{c} \\ 0 & -\frac{1}{2}\left[\frac{D_2(\rho)}{\rho} + \frac{D_2(c)}{c}\right] & \frac{1}{2}\left[\frac{D_2(\rho)}{\rho} + \frac{D_2(c)}{c}\right] & 0 \\ 0 & \frac{1}{2}\left[\frac{D_3(\rho)}{\rho} + \frac{D_3(c)}{c}\right] & -\frac{1}{2}\left[\frac{D_3(\rho)}{\rho} + \frac{D_3(c)}{c}\right] & 0 \\ -\frac{D_4(c)}{c} & \frac{D_4(c)}{c} & \frac{D_4(c)}{c} & -\frac{D_4(c)}{c} \end{bmatrix} \tag{A-19}$$

The differential equation corresponding to the characteristic direction, λ_3, pointing from the region of integration towards the injector face may be exhibited using (10), (11), (16), (18), and (19). It is

$$\frac{\partial}{\partial t}(p - \rho cu) + (u-c)\frac{\partial}{\partial x}(p - \rho cu)$$

$$= -\frac{1}{2}\left[\frac{D_3(\rho)}{\rho} + \frac{D_3(c)}{c}\right](p + \rho cu) + \frac{1}{2}\left[\frac{D_3(\rho)}{\rho} + \frac{D_3(c)}{c}\right](p - \rho cu) -$$

$$\frac{\rho c^2}{2}\frac{\partial}{\partial y}(p + v - \rho c^2) - v\frac{\partial}{\partial y}(p - \rho cu) + \frac{\rho c^2}{2}\frac{\partial}{\partial y}(p - v - \rho c^2) \qquad \text{(A-20)}$$

or recalling (17)

$$D_3(p - \rho cu) = -\rho cu\left[\frac{D_3(\rho)}{\rho} + \frac{D_3(c)}{c}\right] - \rho c^2\frac{\partial v}{\partial y}$$

Since characteristic differentiation as defined in (17) is a linear operation, the above equation may be written

$$D_3(p) - \rho c\, D_3(u) - \rho u\, D_3(c) - uc\, D_3(\rho)$$

$$= - uc\, D_3(\rho) - \rho u\, D_3(c) - \rho c^2\frac{\partial v}{\partial y} \qquad \text{(A-21)}$$

or

$$D_3(p) - \rho c\, D_3(u) = -\rho c^2\frac{\partial v}{\partial y}$$

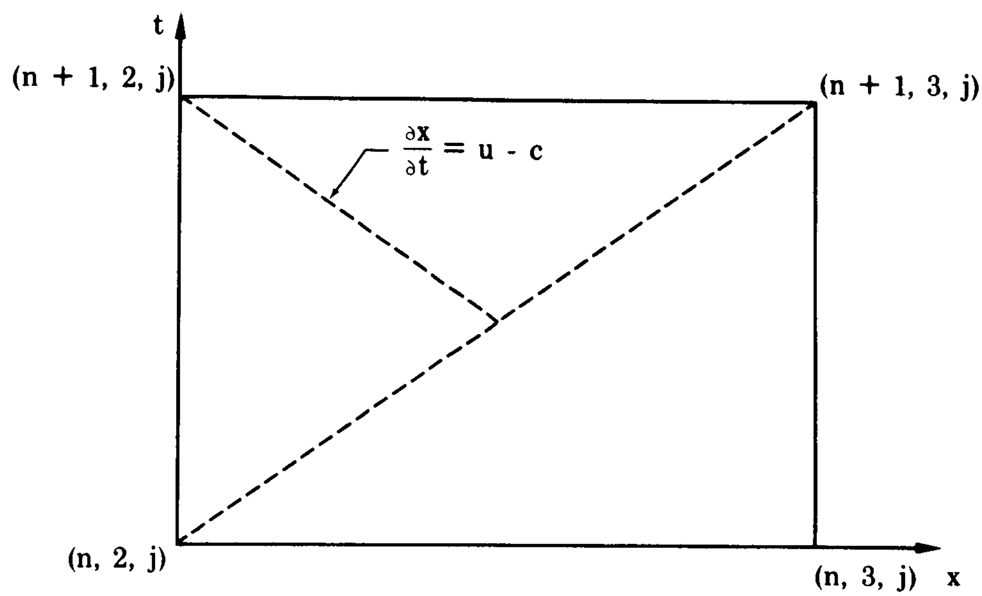
Since there are three characteristics "u", "u+c" and "u" issuing into the region of integration from the injector face, three of the dependent variables may be prescribed at this boundary. Initially, ρ, m, and n will be fixed and p will be calculated by numerically integrating equation (21). This equation may be conveniently written for the purpose of the integration as

$$\frac{\partial}{\partial t}(p - \rho_o c_o u) + (u-c)\frac{\partial}{\partial x}(p - \rho_o c_o u)$$

$$= - v_o\frac{\partial}{\partial y}(p - \rho_o c_o u) - \rho_o c_o{}^2\frac{\partial v}{\partial y} \qquad \text{(A-22)}$$

v_o, ρ_o, and c_o indicate the values of v, ρ, and c at the center of the rectangle shown below at the beginning of each time step, and they are held constant during each time step of the integration.

The difference equation to be used in the integration is based on the idea of centering the "x" and "t" differences at the center of the grid rectangle



The difference equation to represent the differential equation (22) is not unique and a number of forms are possible. The following difference equation was employed and resulted in a stable integration.

$$\begin{aligned} p_{n+1,2,j} &= p_{n,2,j} + \rho_o c_o \left(u_{n+1,3,j} - u_{n,3,j}\right) + \\ &\frac{\Delta t}{\Delta x}\left(u_o - c_o\right)\left[p_{n,2,j} - p_{n,3,j} - \rho_o c_o \left(u_{n,2,j} - u_{n,3,j}\right)\right] - \\ &v_o \frac{\Delta t}{4\Delta x}\left[p_{n,2,j+1} - p_{n,2,j-1} + p_{n+1,3,j+1} - p_{n+1,3,j-1}\right] + \\ &\rho_o c_o v_o \frac{\Delta t}{4\Delta x}\left[u_{n,2,j+1} - u_{n,2,j-1} + u_{n+1,3,j+1} - u_{n+1,3,j-1}\right] - \\ &\rho_o c_o^2 \frac{\Delta t}{4\Delta x}\left[v_{n+1,3,j+1} - v_{n+1,3,j-1}\right] \end{aligned} \qquad \text{(A-23)}$$

where

$$\rho_o = \frac{1}{2}\left(\rho_{n,2,j} + \rho_{n+1,3,j}\right)$$

$$c_o = \frac{1}{2}\left(c_{n,2,j} + c_{n+1,3,j}\right)$$

$$v_o = \frac{1}{2}\left(v_{n,2,j} + v_{n+1,3,j}\right)$$

The characteristic equation corresponding to λ_3 = u-c may also be written

$$\frac{\partial Q}{\partial t} + S\frac{\partial Q}{\partial x} = - v\frac{\partial Q}{\partial y} - \rho_c{}^2\frac{\partial v}{\partial y} \tag{A-24}$$

where

$$Q = p - \rho_o c_o u \tag{A-25}$$

$$S = u - c$$

The derivative approximations are:

$$\frac{\partial Q}{\partial t} \cong \frac{Q_{n+1,2,j} - Q_{n,2,j} + Q_{n+1,3,j} - Q_{n,3,j}}{2\Delta t}$$

$$\frac{\partial Q}{\partial x} \cong \frac{Q_{n+1,3,j} - Q_{n+1,2,j} + Q_{n,3,j} - Q_{n,2,j}}{2\Delta x} \tag{A-26}$$

$$\frac{\partial Q}{\partial y} \cong \frac{Q_{n,3,j+1} - Q_{n,3,j-1} + Q_{n,2,j+1} - Q_{n,2,j-1}}{4\Delta y}$$

$$\frac{\partial v}{\partial y} \cong \frac{v_{n,3,j+1} - v_{n,3,j-1}}{4\Delta y}$$

where the subscripts indicate the corners of the space-time rectangle.

The derivative approximations (25) may be substituted into equation (24) to yield

$$Q_{n+1,2,j} = Q_{n,3,j} + \frac{(1 + \lambda\bar{S})}{(1 - \lambda\bar{S})}\left[Q_{n,2,j} - Q_{n+1,3,j}\right] - \frac{2\Delta t\ v_o}{4(1 - \lambda\bar{S})\Delta y}\left[Q_{n,3,j+1} - Q_{n,3,j-1} + Q_{n,2,j+1} - Q_{n,2,j-1}\right] - \frac{2\Delta t\ \rho_o c_o{}^2}{4(1 - \lambda\bar{S})\Delta y}\left[v_{n,3,j+1} - v_{n,3,j-1}\right] \tag{A-27}$$

or using (25)

$$p_{n+1,2,j} = p_{n,3,j} + \rho_o c_o \left[u_{n+1,2,j} - u_{n,3,j}\right] +$$

$$\frac{(1 + \lambda \bar{S})}{(1 - \lambda \bar{S})} \left[p_{n,2,j} - p_{n+1,3,j} - \rho_o c_o (u_{n,2,j} - u_{n+1,3,j}\right] -$$

$$\frac{\lambda v_o}{2(1 - \lambda \bar{S})} \left[p_{n,3,j+1} - p_{n,3,j-1} + p_{n,2,j+1} - p_{n,2,j-1} - \right.$$

$$\left. \rho_o c_o \left(u_{n,3,j+1} - u_{n,3,j-1} + u_{n,2,j+1} - u_{n,2,j-1}\right)\right] -$$

$$\frac{\lambda \rho_o c_o^2}{2(1 - \lambda \bar{S})} \left[v_{n,3,j+1} - v_{n,3,j-1}\right] \quad \text{(A-28)}$$

where

$$\lambda = \frac{\Delta t}{\Delta x} = \frac{\Delta t}{\Delta y}$$

$$\bar{S} = \frac{1}{2}\left[u_{n,2,j} + u_{n+1,3,j} - c_{n,2,j} - c_{n+1,3,j}\right]$$

APPENDIX B
COMPUTATION OF DENSITY AT INJECTOR FACE

The pressure at the left-hand boundary is calculated from the differential equation corresponding to the characteristic direction, "u-c" as shown in Appendix A. Since the other three characteristic curves issue into the region of integration, we may prescribe any three properties of the flow field at the left-hand boundary. To more closely approximate the real physical situation in which the arrival of a pressure wave traveling with velocity "u-c" at the left-hand boundary causes a decrease in the fluid velocity and an increase in the density, we shall specify for all time values the x- and y-momenta and the enthalpy, i.e.,

$$m = m_o \tag{B-1}$$

$$n = n_o = 0 \tag{B-2}$$

$$H = H_o = \frac{\gamma}{\gamma - 1}\frac{p_o}{\rho_o} + \frac{m_o^2 + n_o^2}{2\rho_o^2} \tag{B-3}$$

Equation (3) must be satisfied at all times by the current values of p, m, and n. Since m and n are prescribed and p is calculated from the characteristic equation, equation (3) may be solved for ρ to yield the time-dependent value of the density:

$$H_o\rho^2 - \frac{\gamma}{\gamma - 1} p\rho - \frac{1}{2} m^2 = 0$$

$$\rho = \frac{\gamma}{\gamma - 1}\frac{p}{2H_o} \pm \frac{1}{2}\left\{\left(\frac{\gamma p}{(\gamma-1)H_o}\right)^2 + \frac{2m^2}{H_o}\right\}^{1/2}$$

or

$$\rho = \frac{\gamma p}{2(\gamma-1)H_o}\left\{1 \pm \left(1 + 2H_o\left[\frac{m(\gamma-1)}{p\gamma}\right]^2\right)^{1/2}\right\} \tag{B-4}$$

Since

$$\left[1 + 2H_o\left(\frac{(\gamma-1)m}{\gamma p}\right)^2\right]^{1/2} \geqq 1$$

the root in equation (4) corresponding to the negative radical is not physically meaningful. Consequently, the density may be determined from

$$\rho = \frac{\gamma p}{2(\gamma-1)H_o}\left\{1 + \left[1 + 2H_o\left(\frac{(\gamma-1)m}{\gamma p}\right)^2\right]^{1/2}\right\} \tag{B-5}$$

and the time-dependent "x" velocity, u, is determined by the relation (1),

$$u = \frac{m_o}{\rho} \tag{B-6}$$

In the above,

ρ = density

m = longitudinal momentum

n = transverse momentum

u = longitudinal velocity

H = enthalpy

and the subscript "o" refers to the initial condition at the boundary.

APPENDIX C
PREDICTOR-CORRECTOR TECHNIQUE

The numerical integration by a predictor-corrector technique was attempted initially based on the following derivative approximation.

$$\frac{\delta_1 y(j,k,\ell+1) - \left(\delta_1 + \delta_{-1}\right) y(j,k,\ell) + \delta_{-1} y(j,k,\ell-1)}{\left(\delta_1 - \delta_{-1}\right)\Delta z} = y_z(j,k,p) \qquad \text{(C-1)}$$

where:

δ_i = parameter

j,k,ℓ = indexing parameter

$\ell-1 \leqq p \leqq \ell+1$

y = dependent variable

z = subscript denotes differentiation.

The explicit and implicit difference equations follow.

$$\frac{\overset{*}{\rho}(j,k,\ell+1) - (1+\overset{*}{\alpha})\rho(j,k,\ell) + \overset{*}{\alpha}\rho(j,k,\ell-1)}{(1-\overset{*}{\alpha})\Delta t} = -\frac{\overset{*}{\gamma}_1 m(j+1,k,\ell) - (\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}) m(j,k,\ell) + \overset{*}{\gamma}_{-1} m(j-1,k,\ell)}{(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1})\Delta x}$$

$$-\frac{\overset{*}{\gamma}_1 n(j,k+1,\ell) - (\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}) n(j,k,\ell) + \overset{*}{\gamma}_{-1} n(j,k-1,\ell)}{(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1})\Delta y} \qquad \text{(C-2)}$$

$$+ W(j,k,\ell)$$

$$\frac{\hat{\rho}(j,k,\ell+1) - (1+\hat{\alpha})\rho(j,k,\ell) + \hat{\alpha}\rho(j,k,\ell-1)}{(1-\hat{\alpha})\Delta t} = -\frac{\hat{\gamma}_1 \overset{*}{m}(j+1,k,\ell+1) - (\hat{\gamma}_1 + \hat{\gamma}_{-1}) \overset{*}{m}(j,k,\ell+1) + \hat{\gamma}_{-1} \overset{*}{m}(j-1,k,\ell+1)}{(\hat{\gamma}_1 - \hat{\gamma}_{-1})\Delta x}$$

$$-\frac{\hat{\gamma}_1 \overset{*}{n}(j,k+1,\ell+1) - (\hat{\gamma}_1 + \hat{\gamma}_{-1}) \overset{*}{n}(j,k,\ell+1) + \hat{\gamma}_{-1} \overset{*}{n}(j,k-1,\ell+1)}{(\hat{\gamma}_1 - \hat{\gamma}_{-1})\Delta y} \qquad \text{(C-3)}$$

$$+ W(j,k,\ell+1)$$

$$\frac{\overset{*}{m}(j,k,\ell+1) - (1+\overset{*}{\alpha}) m(j,k,\ell) + \overset{*}{\alpha} m(j,k,\ell-1)}{(1-\overset{*}{\alpha})\Delta t} = -\frac{\overset{*}{\gamma}_1 A(j+1,k,\ell) - (\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}) A(j,k,\ell) + \overset{*}{\gamma}_{-1} A(j-1,k,\ell)}{(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1})\Delta x}$$

$$-\frac{\overset{*}{\gamma}_1 B(j,k+1,\ell) - (\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}) B(j,k,\ell) + \overset{*}{\gamma}_{-1} B(j,k-1,\ell)}{(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1})\Delta y} \qquad \text{(C-4)}$$

$$\frac{\hat{m}(j,k,\ell+1) - (1+\hat{\alpha}) m(j,k,\ell) + \hat{\alpha} m(j,k,\ell-1)}{(1-\hat{\alpha})\Delta t} = -\frac{\hat{\gamma}_1 \overset{*}{A}(j+1,k,\ell+1) - (\hat{\gamma}_1 + \hat{\gamma}_{-1}) \overset{*}{A}(j,k,\ell+1) + \hat{\gamma}_{-1} \overset{*}{A}(j-1,k,\ell+1)}{(\hat{\gamma}_1 - \hat{\gamma}_{-1})\Delta x}$$

$$-\frac{\hat{\gamma}_1 \overset{*}{B}(j,k+1,\ell+1) - (\hat{\gamma}_1 + \hat{\gamma}_{-1}) \overset{*}{B}(j,k,\ell+1) + \hat{\gamma}_{-1} \overset{*}{B}(j,k-1,\ell+1)}{(\hat{\gamma}_1 - \hat{\gamma}_{-1})\Delta y} \qquad \text{(C-5)}$$

$$\frac{\overset{*}{n}(j,k,\ell+1) - \left(1+\overset{*}{\alpha}\right)n(j,k,\ell) + \overset{*}{\alpha}n(j,k,\ell-1)}{\left(1-\overset{*}{\alpha}\right)\Delta t} = -\frac{\overset{*}{\gamma}_1 B(j+1,k,\ell) - \left(\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}\right)B(j,k,\ell) + \overset{*}{\gamma}_{-1}B(j-1,k,\ell)}{\left(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1}\right)\Delta x} - \frac{\overset{*}{\gamma}_1 D(j,k+1,\ell) - \left(\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}\right)D(j,k,\ell) + \overset{*}{\gamma}_{-1}D(j,k-1,\ell)}{\left(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1}\right)\Delta y} \qquad \text{(C-6)}$$

$$\frac{\hat{n}(j,k,\ell+1) - \left(1+\hat{\alpha}\right)n(j,k,\ell) + \hat{\alpha}n(j,k,\ell-1)}{\left(1-\hat{\alpha}\right)\Delta t} = -\frac{\hat{\gamma}_1 \overset{*}{\hat{B}}(j+1,k,\ell+1) - \left(\hat{\gamma}_1 + \hat{\gamma}_{-1}\right)\overset{*}{\hat{B}}(j,k,\ell+1) + \hat{\gamma}_{-1}\overset{*}{\hat{B}}(j-1,k,\ell+1)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta x} - \frac{\hat{\gamma}_1 \overset{*}{\hat{D}}(j,k+1,\ell+1) - \left(\hat{\gamma}_1 + \hat{\gamma}_{-1}\right)\overset{*}{\hat{D}}(j,k,\ell+1) + \hat{\gamma}_{-1}\overset{*}{\hat{D}}(j,k-1,\ell+1)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta y} \qquad \text{(C-7)}$$

$$\frac{\overset{*}{E}(j,k,\ell+1) - \left(1+\overset{*}{\alpha}\right)E(j,k,\ell) + \overset{*}{\alpha}E(j,k,\ell-1)}{\left(1-\overset{*}{\alpha}\right)\Delta t} = -\frac{\overset{*}{\gamma}_1 G(j+1,k,\ell) - \left(\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}\right)G(j,k,\ell) + \overset{*}{\gamma}_{-1}G(j-1,k,\ell)}{\left(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1}\right)\Delta x} - \frac{\overset{*}{\gamma}_1 H(j,k+1,\ell) - \left(\overset{*}{\gamma}_1 + \overset{*}{\gamma}_{-1}\right)H(j,k,\ell) + \overset{*}{\gamma}_{-1}H(j,k-1,\ell)}{\left(\overset{*}{\gamma}_1 - \overset{*}{\gamma}_{-1}\right)\Delta y} + Q(j,k,\ell) \qquad \text{(C-8)}$$

$$\frac{\hat{E}(j,k,\ell+1) - \left(1+\hat{\alpha}\right)E(j,k,\ell) + \hat{\alpha}E(j,k,\ell-1)}{\left(1-\hat{\alpha}\right)\Delta t} = -\frac{\hat{\gamma}_1 \overset{*}{\hat{G}}(j+1,k,\ell+1) - \left(\hat{\gamma}_1 + \hat{\gamma}_{-1}\right)\overset{*}{\hat{G}}(j,k,\ell+1) + \hat{\gamma}_{-1}\overset{*}{\hat{G}}(j-1,k,\ell+1)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta x} - \frac{\hat{\gamma}_1 \overset{*}{\hat{H}}(j,k+1,\ell+1) - \left(\hat{\gamma}_1 + \hat{\gamma}_{-1}\right)\overset{*}{\hat{H}}(j,k,\ell+1) + \hat{\gamma}_{-1}\overset{*}{\hat{H}}(j,k-1,\ell+1)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta y} + Q(j,k,\ell+1) \qquad \text{(C-9)}$$

where:

$$A = p + \frac{m^2}{\rho}$$

$$B = \frac{mn}{\rho}$$

$$D = p + \frac{n^2}{\rho}$$

$$G = \frac{m}{\rho}(p + E)$$

$$H = \frac{n}{\rho}(p + E)$$

α, γ = integration parameters

$*$ = predicted values of the functions obtained from the explicit equations.

$\wedge$ = corrected values, obtained by the implicit equations in which the predicted values are employed.

The predicted and corrected values are combined as follows:

$$\rho(j,k,\ell+1) = U\hat{\rho}(j,k,\ell+1) + (1 - U)\overset{*}{\rho}(j,k,\ell+1) \qquad \text{(C-10)}$$

$$m(j,k,\ell+1) = U\hat{m}(j,k,\ell+1) + (1 - U)\overset{*}{m}(j,k,\ell+1) \qquad \text{(C-11)}$$

$$n(j,k,\ell+1) = U\hat{n}(j,k,\ell+1) + (1 - U)\overset{*}{n}(j,k,\ell+1) \qquad \text{(C-12)}$$

$$E(j,k,\ell+1) = U\hat{E}(j,k,\ell+1) + (1 - U)\overset{*}{E}(j,k,\ell+1) \qquad \text{(C-13)}$$

where:

U = parameter.

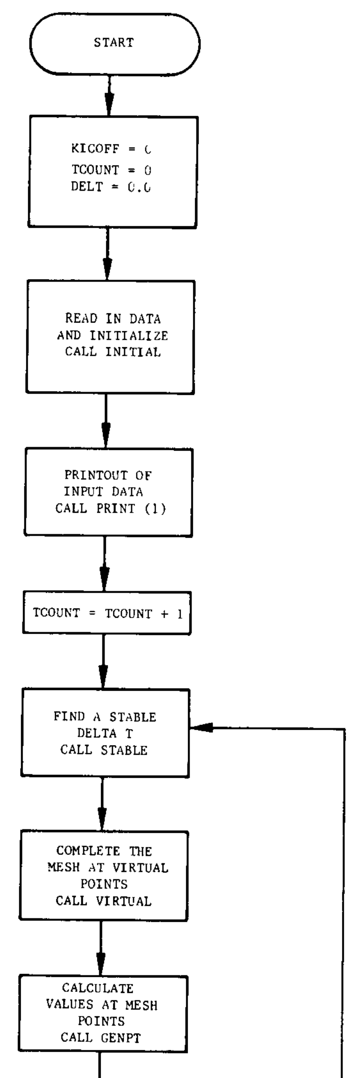
The foregoing "predictor-corrector" technique is similar to that often employed for the integration of ordinary differential equations. It is necessary to assign values to the parameters $\overset{*}{\alpha}$, $\hat{\alpha}$, $\overset{*}{\gamma}_1$, $\hat{\gamma}_1$, $\overset{*}{\gamma}_{-1}$, $\hat{\gamma}_{-1}$, Δt, Δx, and Δy, which appear in the difference equations, before numerical calculations can be made. The choices of $\overset{*}{\gamma}_1 = \hat{\gamma}_1 = 1$ and $\overset{*}{\gamma}_{-1} = \hat{\gamma}_{-1} = -1$

provides the most accurate approximation to the partial derivatives of the space variables. With these, or other choices, it remains to assign values to $\overset{*}{\alpha}$, $\hat{\alpha}$, Δt, Δx, and Δy so that the system of difference equations is numerically stable. However, a set of parameters could not be found that resulted in a stable integration.

APPENDIX D
FLOW DIAGRAMS AND SUBROUTINE LISTINGS

Figure D-1

FLOW DIAGRAM OF SUBROUTINE MAIN INTEGRATION PROGRAM



FOLDOUT FRAME 1

672211
FD 23144

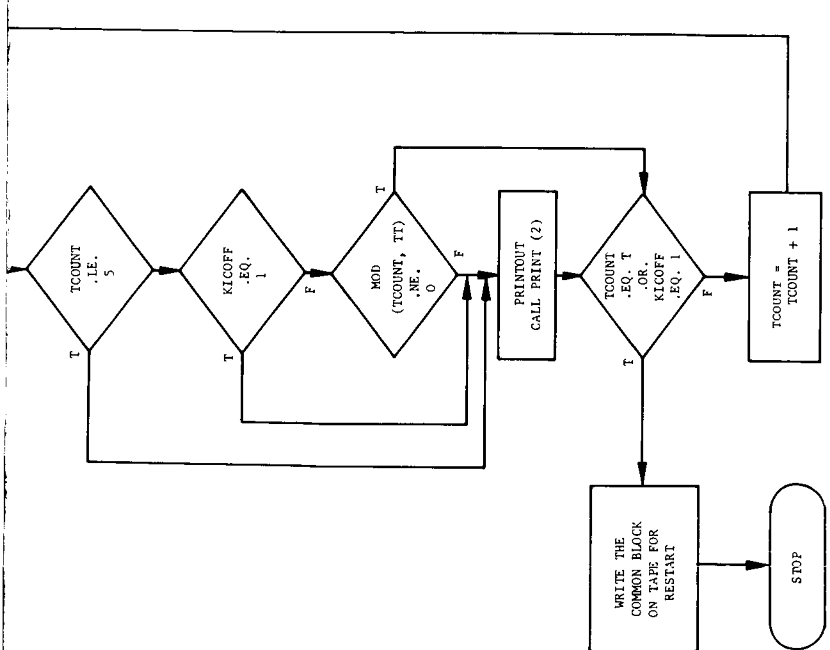
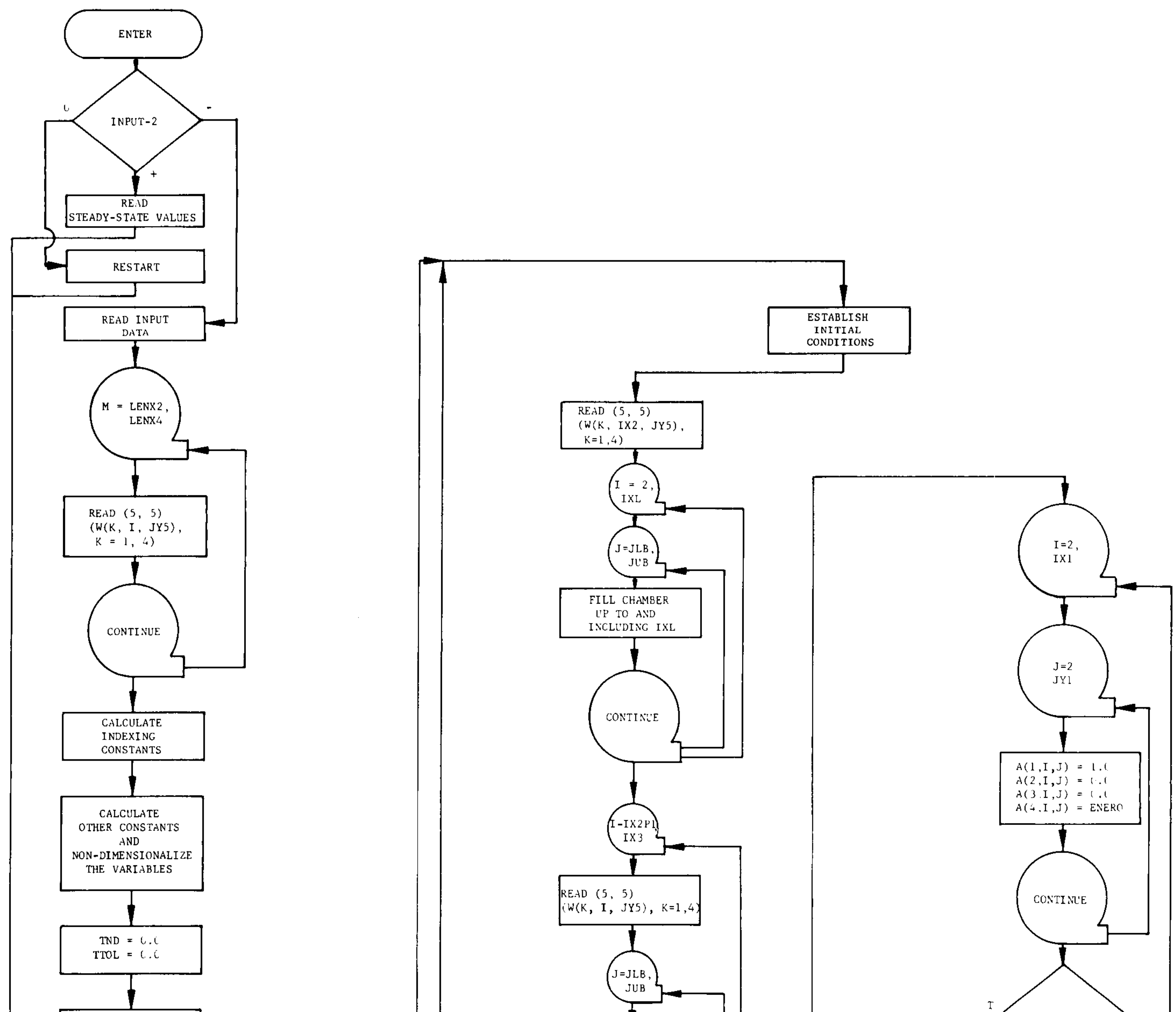
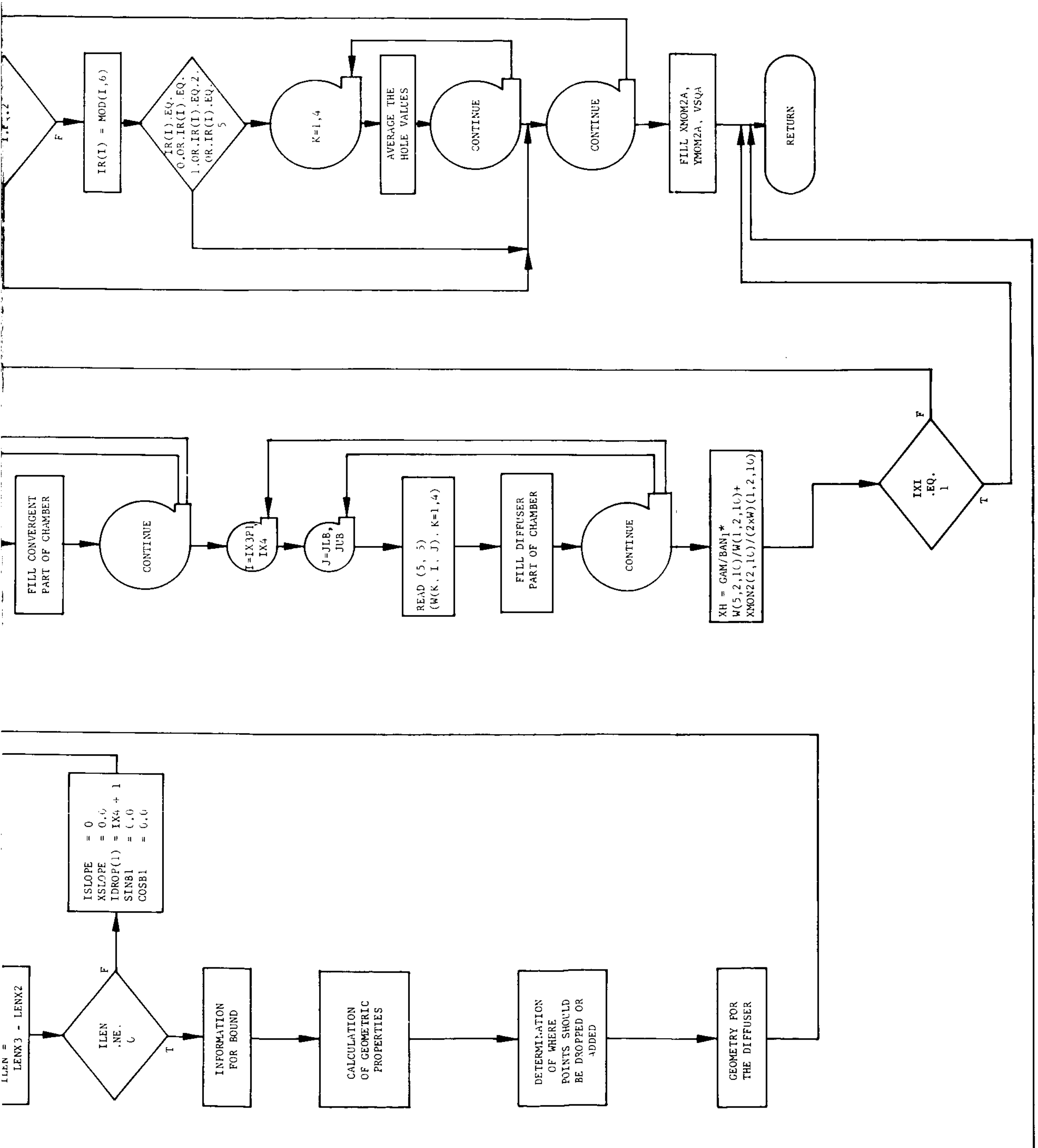


Figure D-2

FLOW DIAGRAM OF SUBROUTINE INITIAL INTEGRATION PROGRAM



FOLDOUT FRAME 1

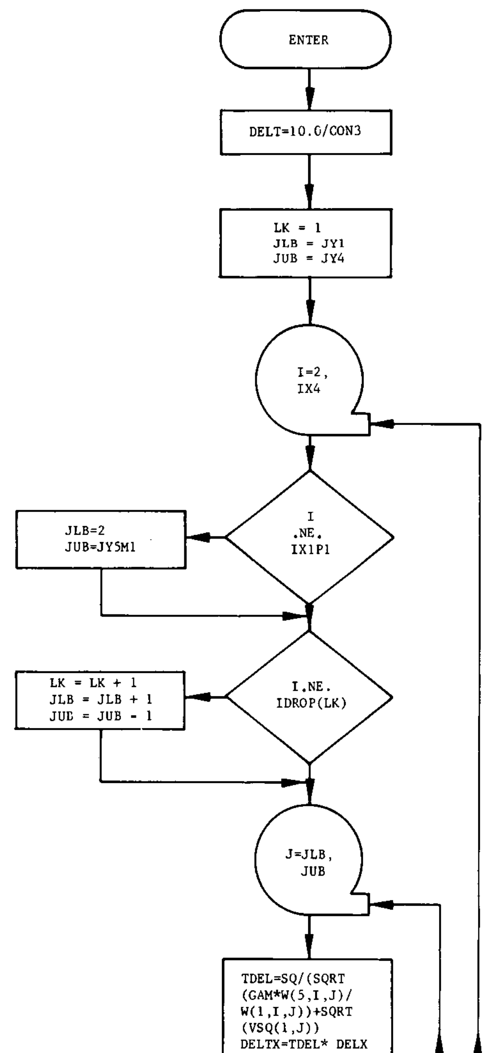


672111
FD 23145

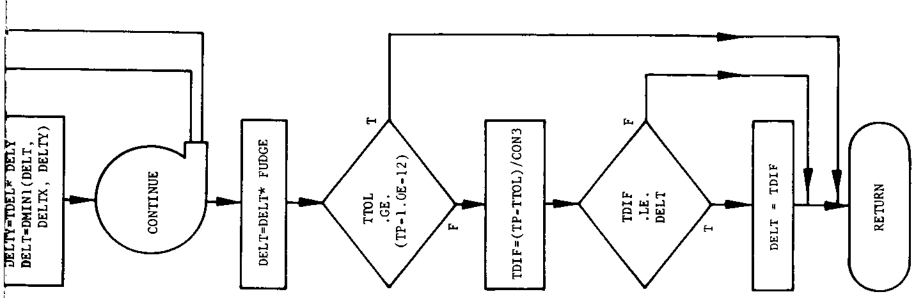
FOLDOUT FRAME 2

Figure D-3

FLOW DIAGRAM OF SUBROUTINE STABLE INTEGRATION PROGRAM



FOLDOUT FRAME /

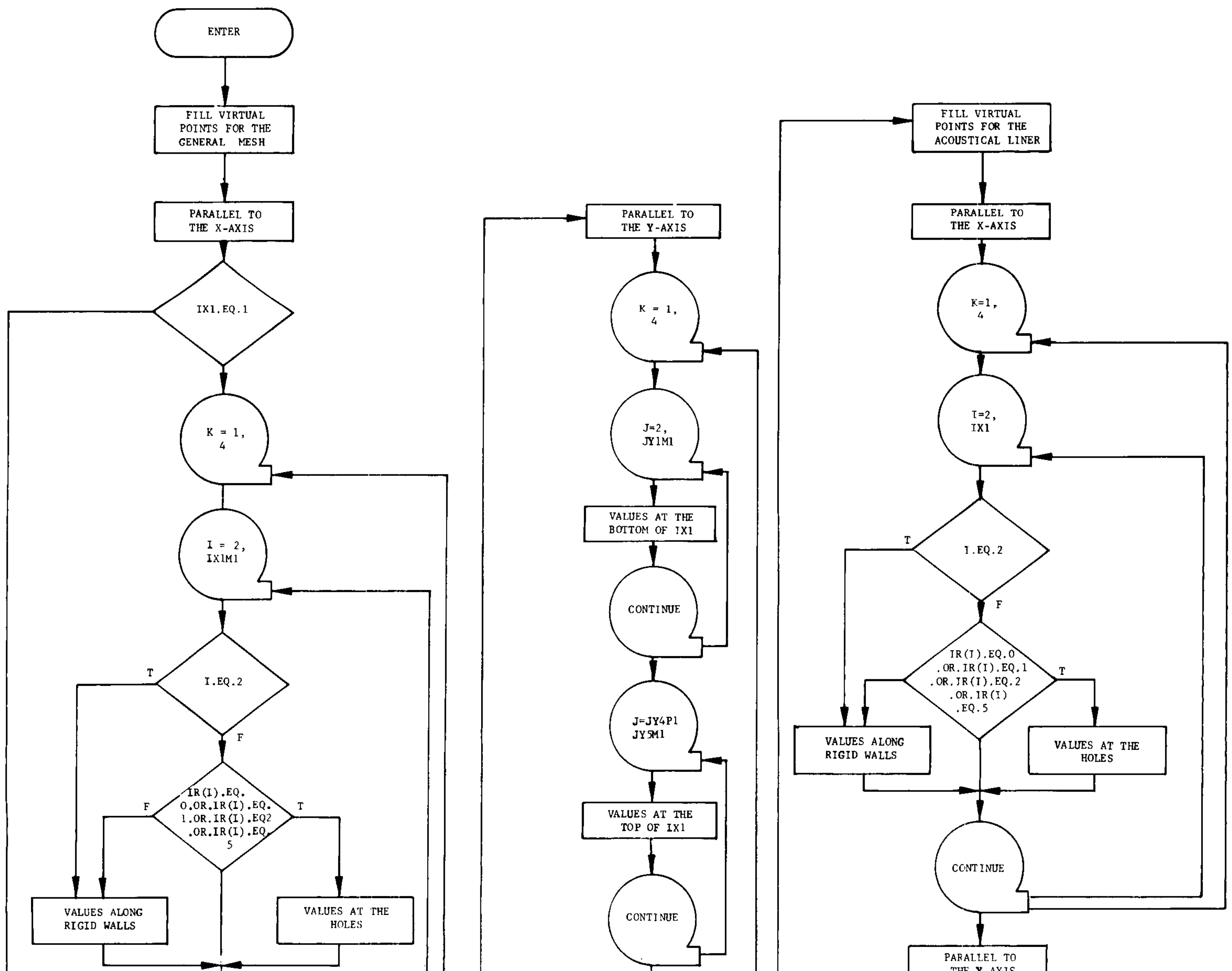


672111
FD 23148

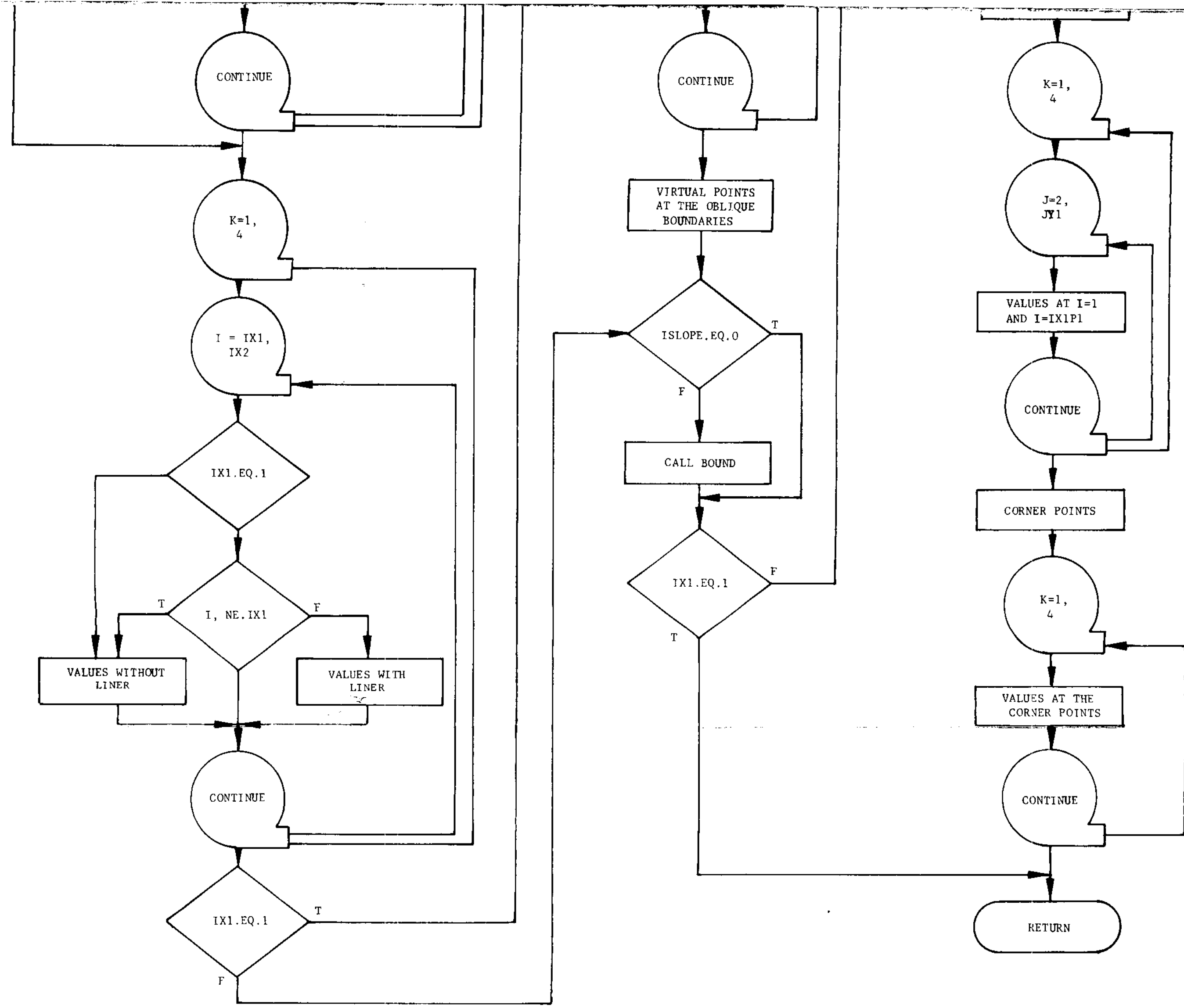
FOLDOUT FRAME 2

Figure D-4

FLOW DIAGRAM OF SUBROUTINE VIRTUAL INTEGRATION AND CONVERSION PROGRAMS



FOLDOUT FRAME 1



672211
FD 23146

FOLDOUT FRAME 2

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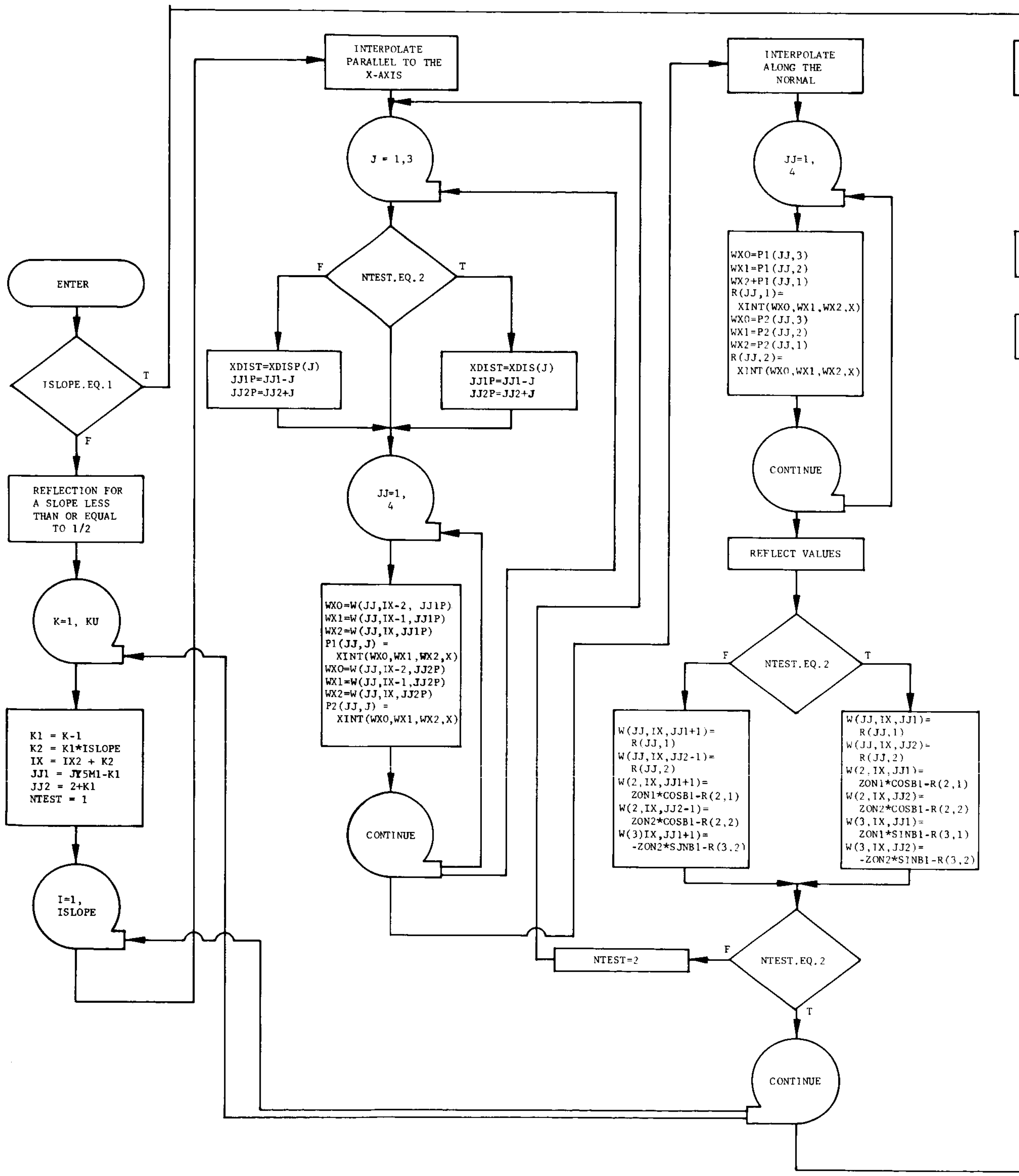
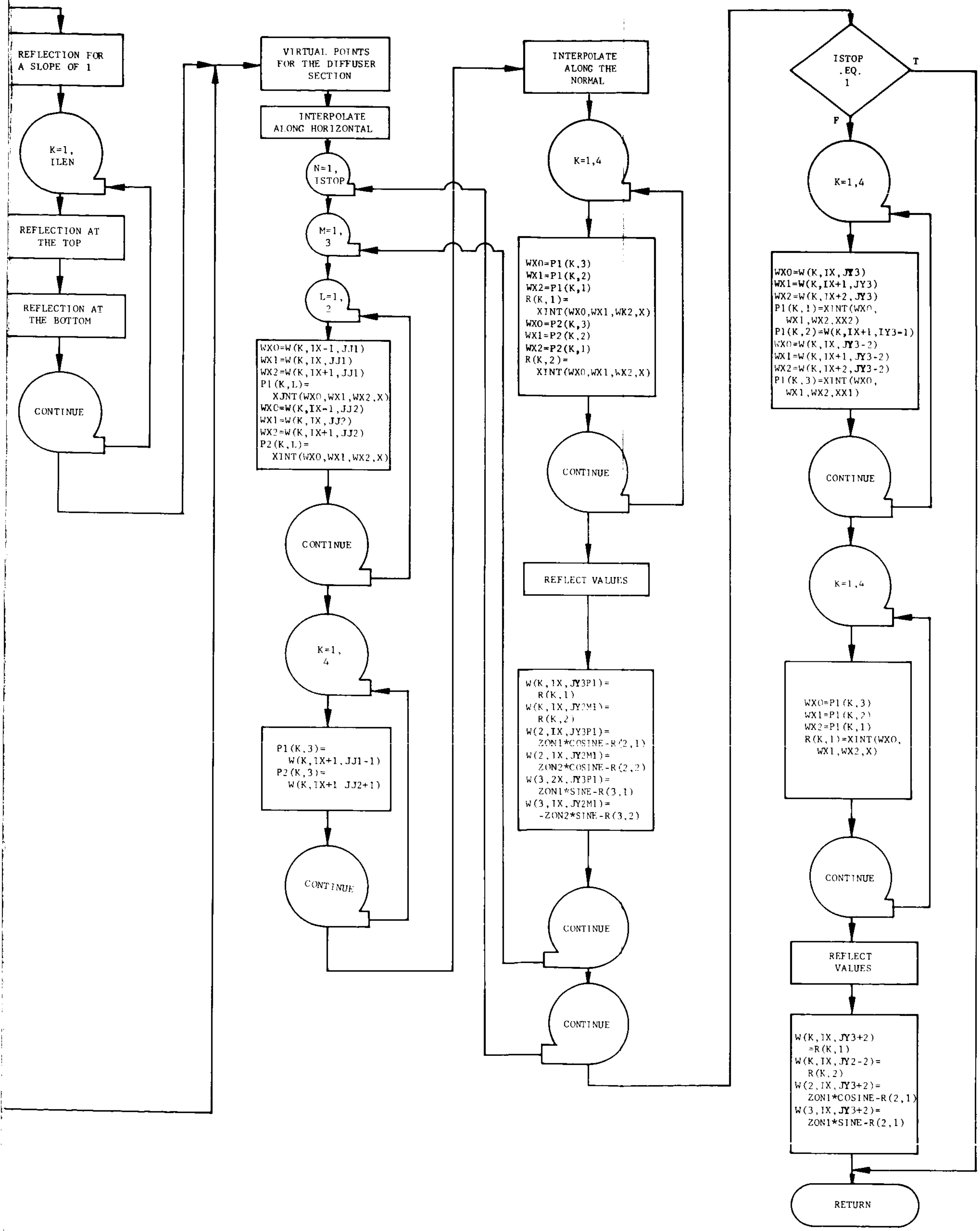
FLOW DIAGRAM OF SUBROUTINE BO



FOLDOUT FRAME |

ʳe D-5

UND INTEGRATION AND CONVERSION PROGRAMS

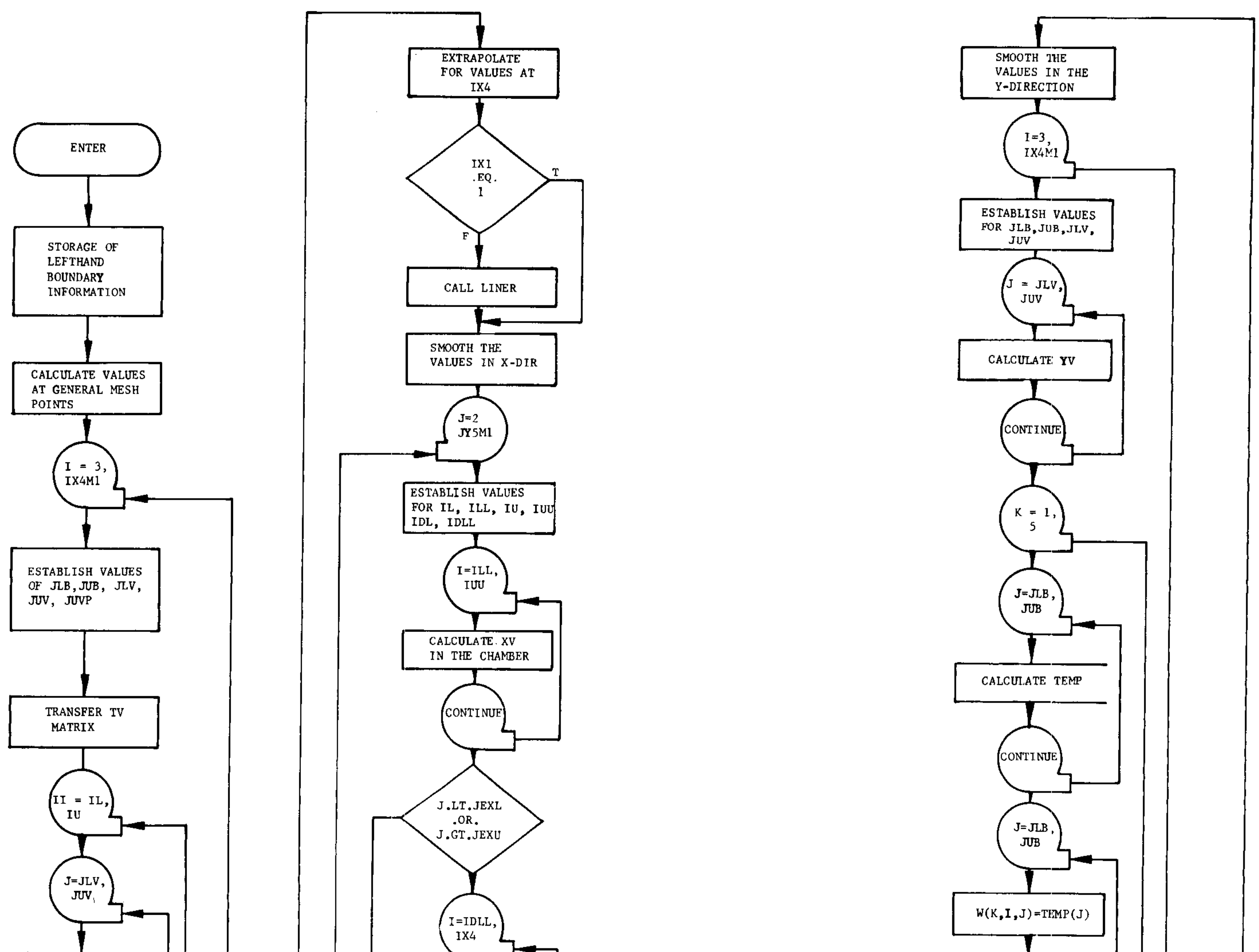


672111
FD 23147

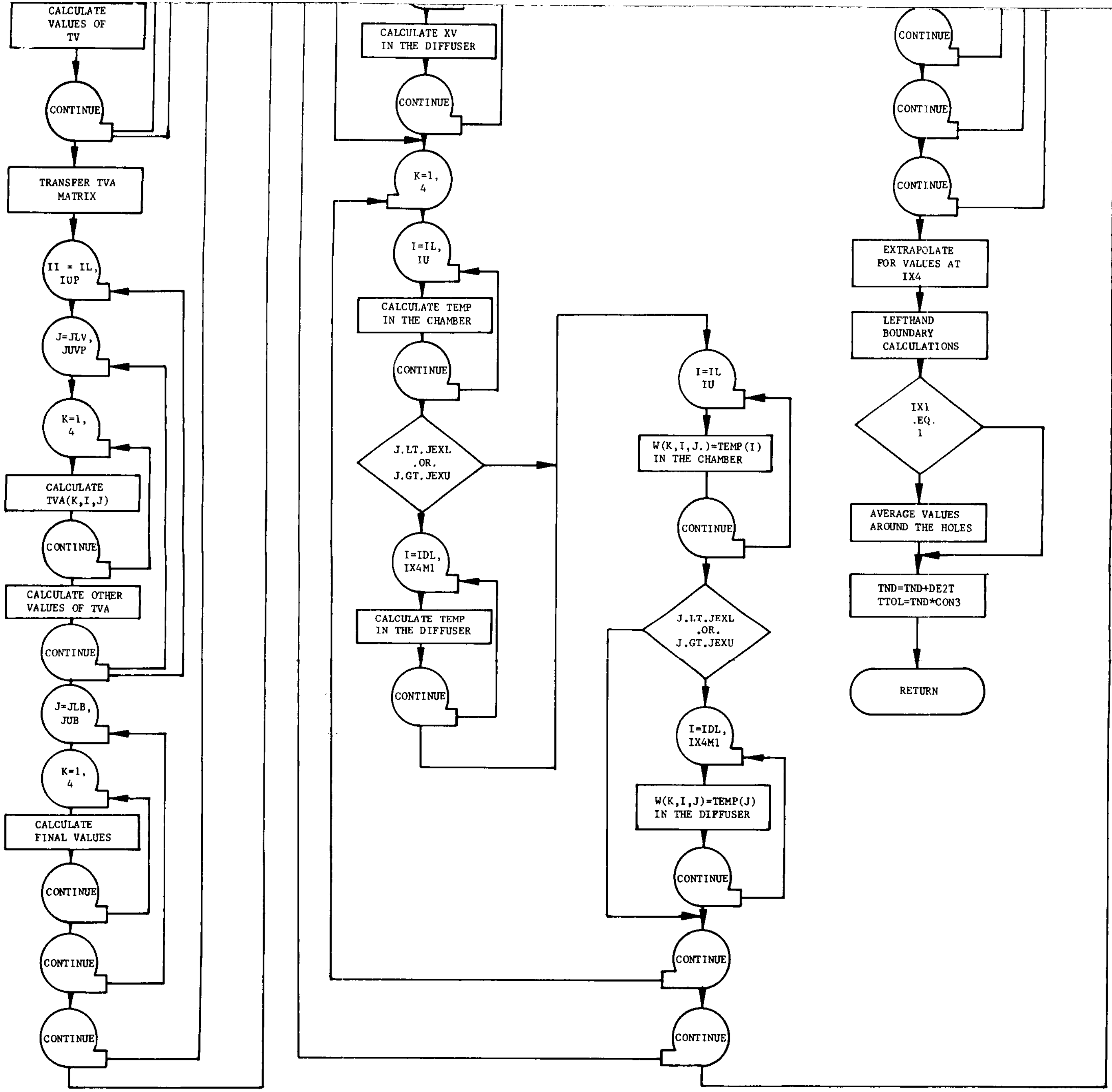
FOLDOUT FRAME 2

Figure D-6

FLOW DIAGRAM OF SUBROUTINE GENPT INTEGRATION PROGRAM



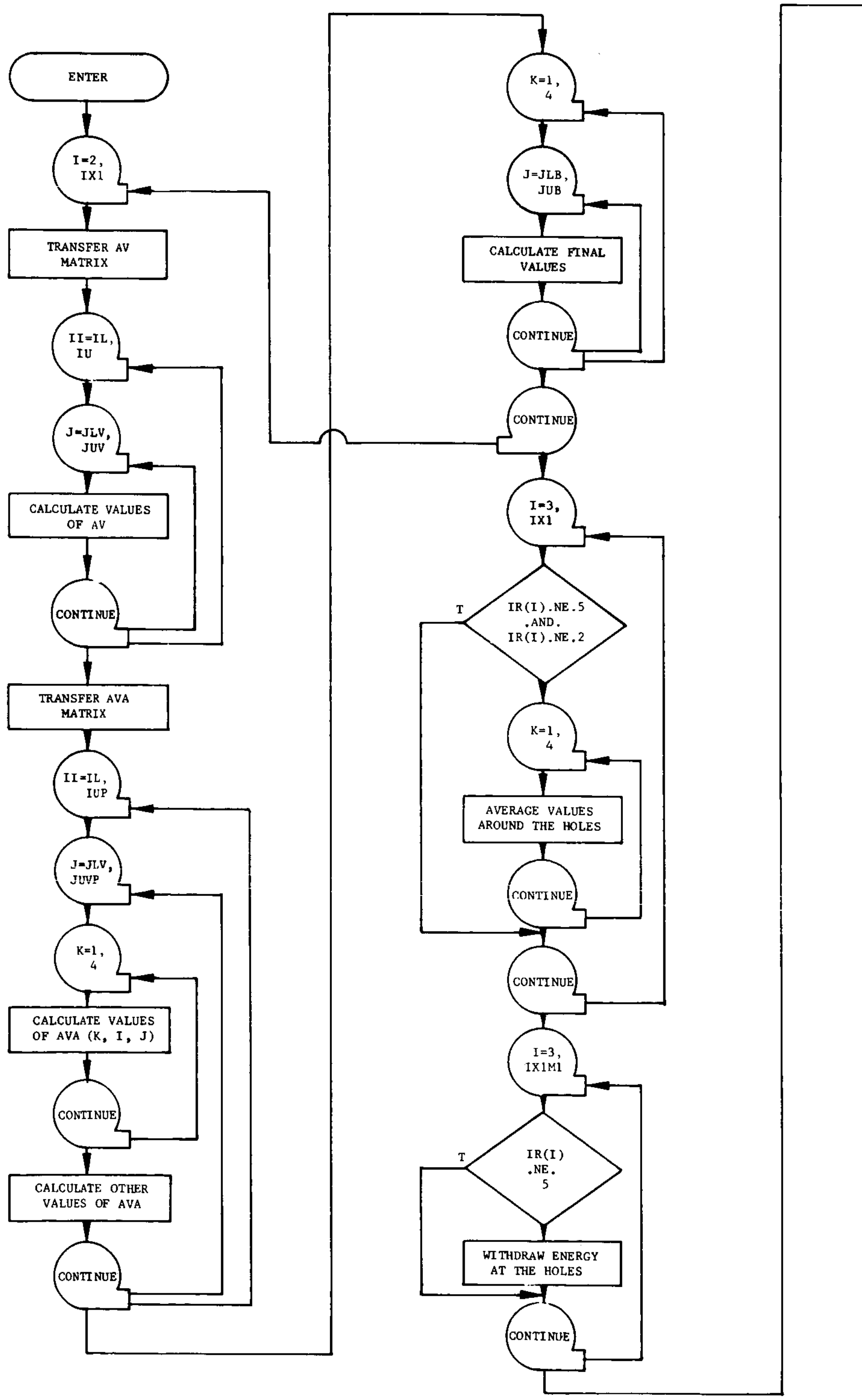
FOLDOUT FRAME



FOLDOUT FRAME 2

Figur

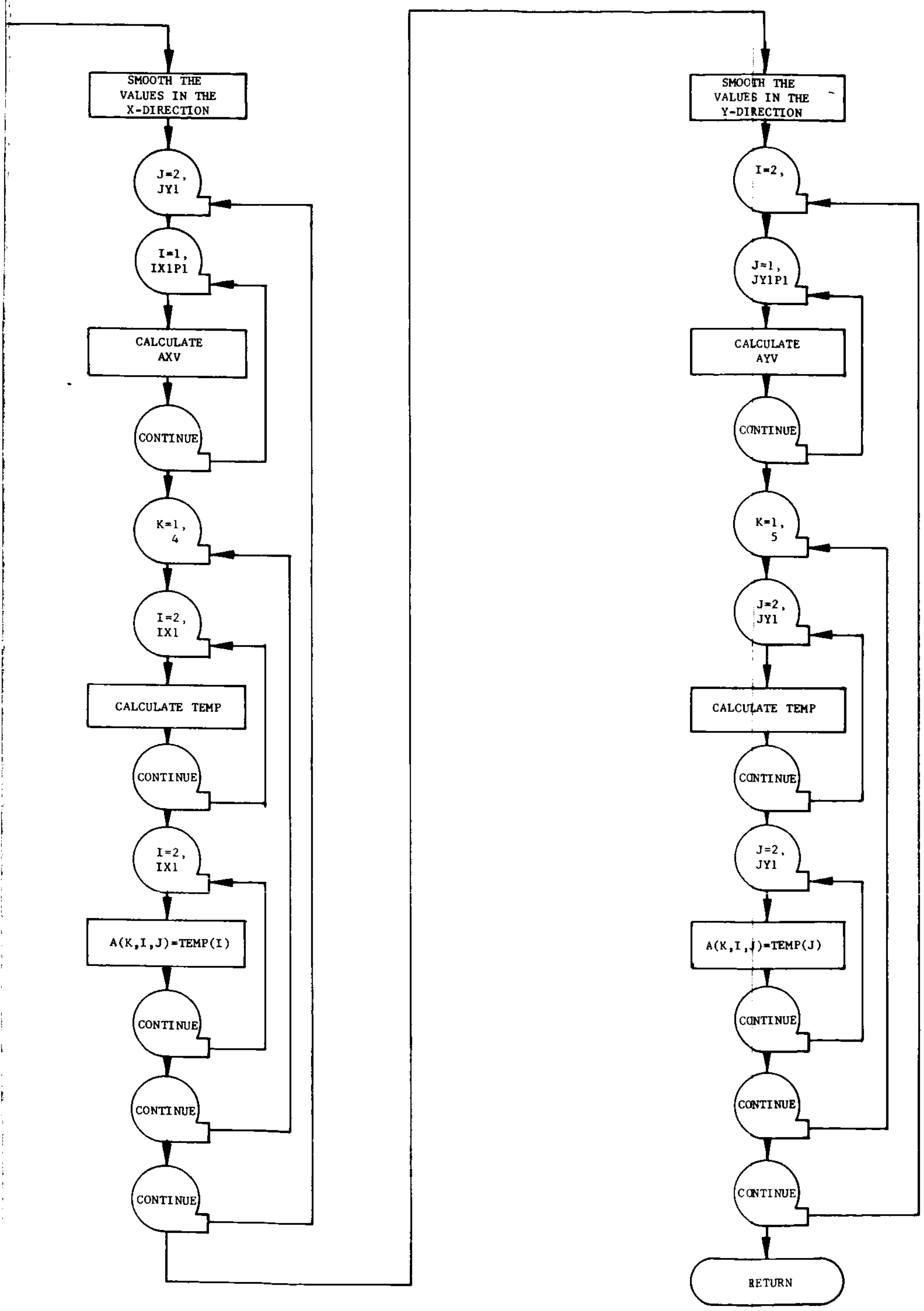
FLOW DIAGRAM OF SUBROUTI



FOLDOUT FRAME 1

re D-7

NE LINER INTEGRATION PROGRAM

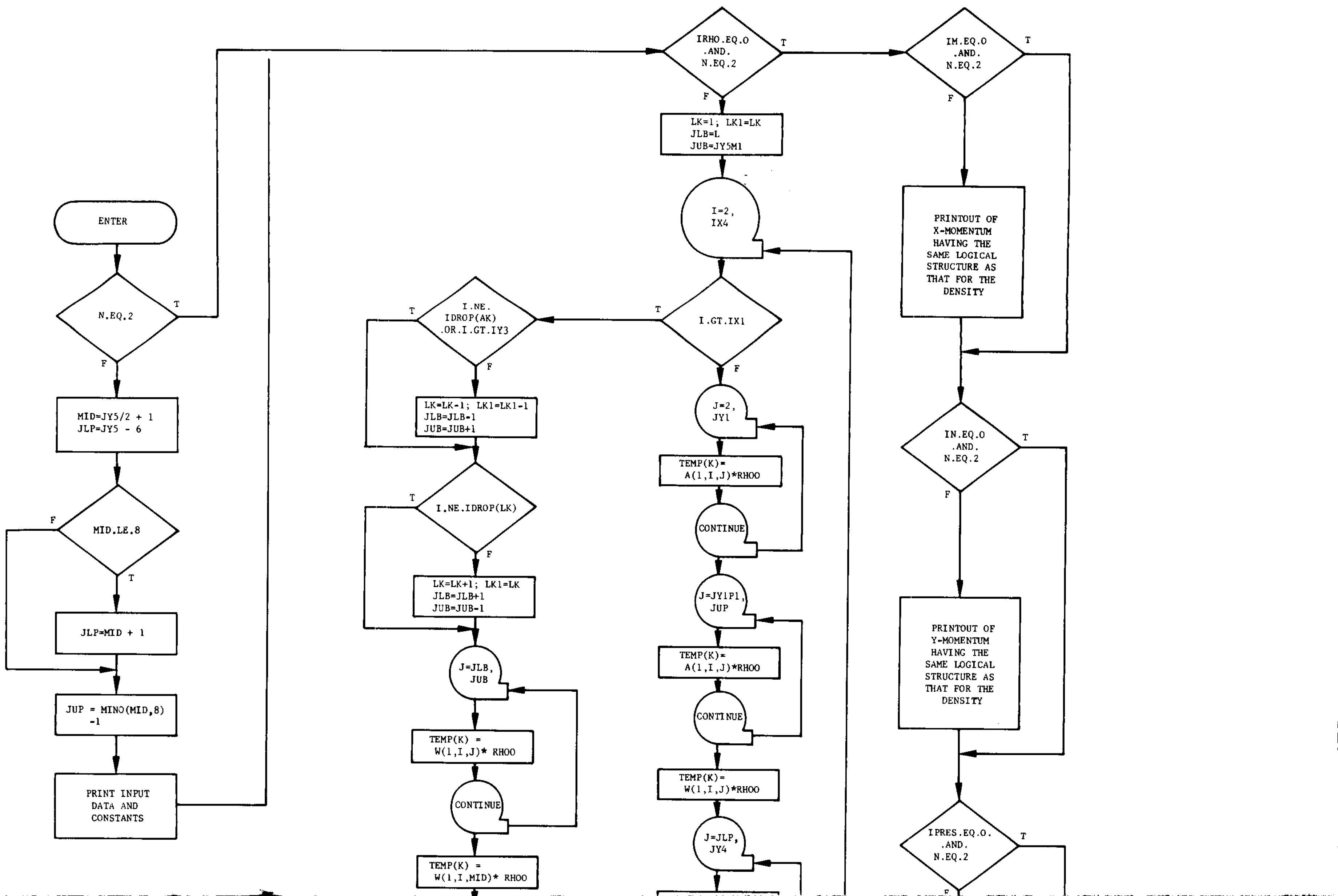


672211
FD 23150

FOLDOUT FRAME 2

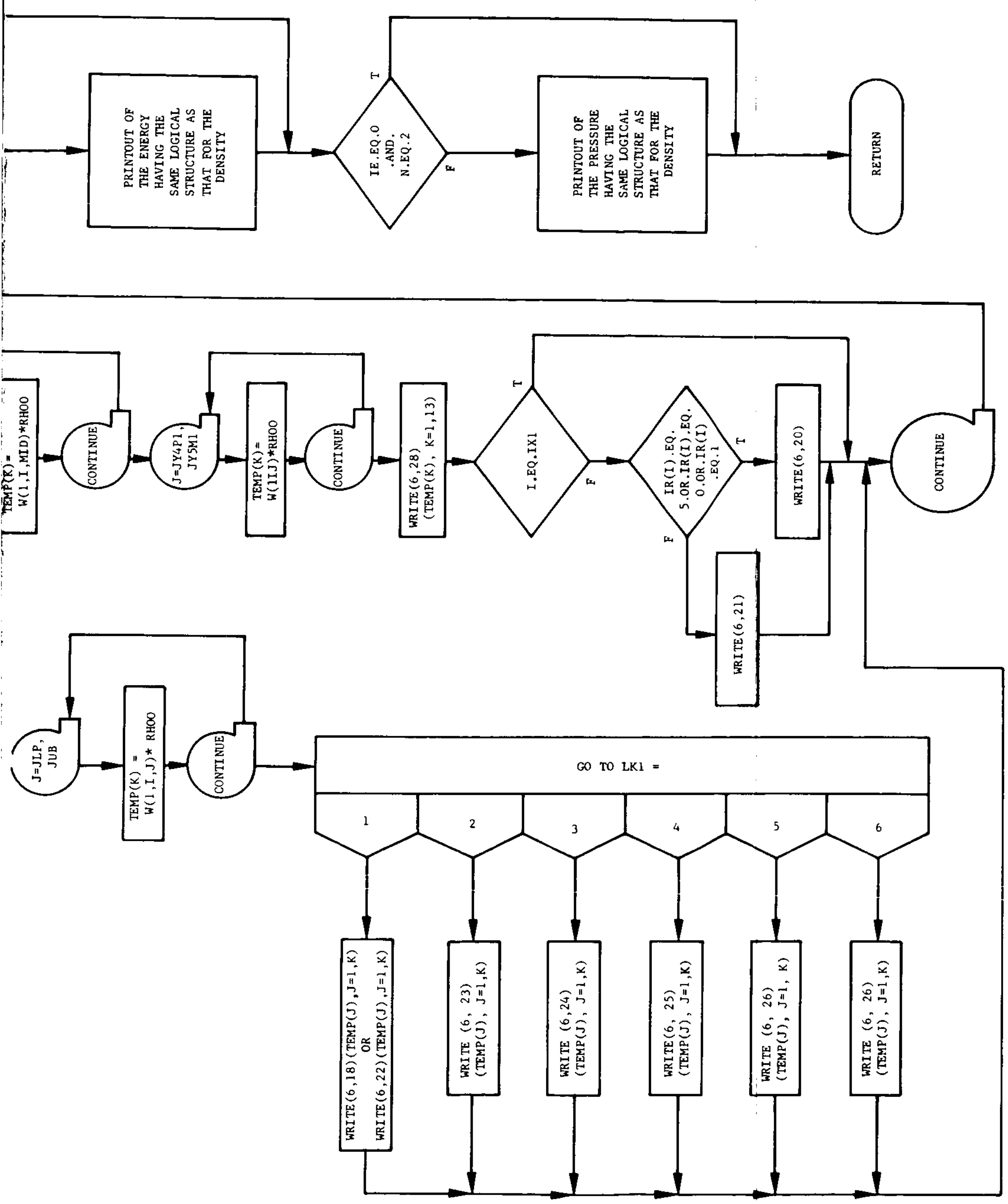
Figure D-8

FLOW DIAGRAM OF SUBROUTINE PRINT INTEGRATION AND CONVERSION PROGRAMS



FOLDOUT FRAME 1

672211
FD 23250



```
5950MAIN

 INTEGER * 4 TCOUNT,T,TT

 COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
1             VSC(52,23), XMOM2A(30,5), YMOM2A(30,5), VSCA(30,5),
2             GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
3             DELT    ,FUDGE   ,SC      ,TNC     ,TTOL    ,TP      ,
4             CON3    ,DIFCO   ,XH      ,ENERC   ,XML     ,OMEGA   ,THICK,
5             CLE     ,CP      ,EXP                       ,JMID
 COMMON/COM2/ IDROP(20)  ,IR(30),
1             IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
2             IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
3             JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
4             JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
5             JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
 COMMON/COM3/D(20),XDIS(3),XDISP(3),DFX(2),DFN(3),
1             SINB1   ,COSB1   ,SINE    ,COSINE  ,DIST    ,DISTP   ,
2             ILEN    ,MESH    ,IWISH
 COMMON/COM4/XM       ,PO      ,TO      ,RHOO    ,XMOMO   ,YMOMO   ,
1                      AO      ,XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,
2             CON1    ,CON2    ,IRHO    ,IM      ,IN      ,IE      ,
3             IPRES   ,NCPT
 COMMON/COM5/TCOUNT,T,KICOFF,TT
 COMMON/COM6/TV(12,3,23), TVA(12,2,22), XV(52), YV(23),
1             XVEL(2,2,23), YVEL(2,23), SONIC(2,2,23), PRES(2,2,23)
 COMMON/COM7/AV(12,3,10),AVA(12,2,10),AXV(35),AYV(5)

 CALL HCLOCK (HR, MIN, ISEC)
 CALL DATE (MO, IDAY, IYR)
 WRITE (6,1) MO, IDAY, IYR, HR, MIN, ISEC
 FORMAT (1H1, 4X, 21HTHIS RUN WAS MADE ON , 3A4, 3HAT , 3A4)
 KICOFF = 0
 TCOUNT = 0
 DELT = 0.0

 INITIALIZE AND READ IN DATA

 CALL INTIAL
 IF (TCOUNT .LE. T) GO TO 100
 WRITE (6,2) T, TCOUNT, T
 FORMAT (1H1, 4HT = , I4, 14H AND TCOUNT = , I4, 13H. INPUT HACK./
1        97HINCREASE T OR PROGRAM WILL RUN INTO INFINITY. INFORMATIO
2N ON TAPE IS INTACT THROUGH THE PREVIOUS , I4, 13H DELTA-T RUN.)
 STOP

 INPUT DATA PRINTOUT

 CALL PRINT (1)
 TCOUNT = TCOUNT + 1
 IF (T .EQ. 0) GO TO 475

 FIND A STABLE DELT

 CALL STABLE

 COMPLETE MATRICES AT VIRTUAL POINTS
```

```
      CALL VRTUAL
C
C     CALCULATE VALUES AT MESH POINTS
C
      CALL GENPT
C
C     PRINTOUT
C
      IF (TCOUNT.LE.5) GO TO 400
      IF (KICOFF.EQ.1) GO TO 400
      IF (MOD(TCOUNT,TT).NE.0) GO TO 450
C
  400 CALL PRINT (2)
C
C     TEST TO DETERMINE IF RUN HAS BEEN COMPLETED
C
  450 IF (TCOUNT.EQ.T.OR.KICOFF.EQ.1) GO TO 475
      TCOUNT = TCOUNT + 1
      GO TO 200
C
C     WRITE INFORMATION FOR RESTART
C
  475 IF (MESH .NE. 1) GO TO 500
  480 READ (9,END=500) SKIP
      GO TO 480
  500 WRITE (9) W       ,A      ,XMOM2  ,YMOM2  ,VSC    ,XMOM2A ,YMOM2A ,
     1           VSCA   ,GAM    ,GAM1   ,GAM2   ,GAM3   ,DELX   ,DELY   ,
     2           DELT   ,FUDGE  ,SQ     ,TND    ,TTOL   ,TP     ,CON3   ,
     3           DIFCO  ,XH     ,ENERC  ,XML    ,OMEGA  ,THICK  ,QUE    ,
     4           QP     ,EXP
      WRITE (9) IDROP   ,IR     ,
     1           IX1    ,IX1M1  ,IX1P1  ,IX2    ,IX3    ,IX4    ,IX4M1  ,
     2           IX4M2  ,IX4M3  ,JY1    ,JY1M1  ,JY1P1  ,JY2    ,JY2M1  ,
     3           JY2P1  ,JY2P2  ,JY3    ,JY3M1  ,JY3M2  ,JY3P1  ,JY4    ,
     4           JY4M1  ,JY4P1  ,JY5    ,JY5M1  ,JY5M2  ,ISLOPE ,JEXL   ,
     5           JEXU
      WRITE (9) D       ,XDIS   ,XDISP  ,DFX    ,DFN    ,SINB1  ,
     1           COSB1  ,SINE   ,COSINE ,DIST   ,DISTP  ,
     2           ILEN
      WRITE (9) XM      ,PO     ,TO     ,RHOO   ,XMOMO  ,YMOMO  ,AO     ,
     1           XLEN   ,YLEN   ,XSLOPE ,SLOPE  ,CON1   ,CON2   ,
     2           IRHO   ,IM     ,IN     ,IE     ,IPRES
      WRITE (9) TCOUNT  ,T      ,KICOFF ,TT
      WRITE (9) TV      ,TVA    ,XV     ,YV     ,XVEL   ,YVEL   ,SONIC  ,
     1           PRES
      WRITE (9) AV      ,AVA    ,AXV    ,AYV
  600 END FILE 9
      REWIND 9
C
      STOP
      END
```

```
      INTEGER * 4 TCCUNT,T,TT
C
      COMMON/CCM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1              VSC(52,23), XMCM2A(30,5), YMCM2A(30,5), VSCA(30,5),
     2              GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     3              DELT    ,FUDGE   ,SQ      ,TNC     ,TTCL    ,TP      ,
     4              CON3    ,DIFCC   ,XH      ,ENERO   ,XML     ,OMEGA   ,THICK,
     5              QUE     ,CP      ,EXP                       ,JMID
      COMMON/CCM2/ IDRCP(20)   ,IR(30),
     1              IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2              IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3              JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4              JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5              JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
      COMMON/COM3/D(20),XDIS(3),XDISP(3),DFX(2),DFN(3),
     1              SINB1   ,CCSB1   ,SINE    ,COSINE  ,DIST    ,DISTP   ,
     2              ILEN    ,MESH    ,IWISH
      COMMON/CCM4/XM        ,PO      ,TC      ,RHCO    ,XMCMC   ,YMOMO   ,
     1                       AC      ,XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,
     2              CCN1    ,CCN2    ,IRHO    ,IM      ,IN      ,IE      ,
     3              IPRES   ,NCPT
      COMMON/COM5/TCCUNT,T,KICCFF,TT
      COMMON/CCM6/TV(12,3,23), TVA(12,2,22), XV(52), YV(23),
     1              XVEL(2,2,23), YVEL(2,23), SCNIC(2,2,23), PRES(2,2,23)
      COMMON/CCM7/AV(12,3,10),AVA(12,2,10),AXV(35),AYV(5)
C
    1 FCRMAT (4I10)
    2 FCRMAT (5I10)
    3 FCRMAT (7F10.0, E10.0)
    4 FCRMAT (8I10)
    5 FCRMAT (4E10.0)
    6 FCRMAT (3F10.0)
    7 FCRMAT (I1, 2X, I1, 67X, I1)
    8 FCRMAT (I10, F10.0)
    9 FCRMAT (4F10.0)
C
C     READ IN DATA
C
      READ (5,7) MESH, IWISH, INPUT
      IF (INPUT - 2) 40, 26, 15
C
C     STEADY STATE INPUT
C
   15 IF (MESH .NE. 1) GC TC 20
   16 READ (8,END=20) SKIP
      GC TC 16
   20 READ (8)  W       ,A       ,XMCM2   ,YMCM2   ,VSC     ,XMCM2A  ,YMOM2A  ,
     1          VSCA    ,GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     2          DELT    ,FUDGE   ,SQ      ,TNC     ,TTCL    ,TP      ,CON3    ,
     3          DIFCO   ,XH      ,ENERC   ,XMU     ,CMEGA   ,THICK   ,QUE     ,
     4          CP      ,EXP
      READ (8)  IDROP   ,IR      ,
     1          IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,IX4M1   ,
     2          IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,JY2     ,JY2M1   ,
     3          JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,JY3M2   ,JY3P1   ,JY4     ,
     4          JY4M1   ,JY4P1   ,JY5     ,JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,
     5          JEXU
      READ (8)  D       ,XDIS    ,XDISP   ,DFX     ,DFN     ,SINB1   ,
```


INITIAL - I

```
     1            CCSB1   ,SINE    ,CCSINE ,CIST    ,CISTP   ,
     2            ILEN
      READ (8)    XM      ,PC      ,TC     ,RHCO    ,XMCMC   ,YMCMO   ,AO      ,
     1            XLEN    ,YLEN    ,XSLCPE ,SLCPE   ,CCN1    ,CCN2    ,
     2            IRHC    ,IM      ,IN     ,IE      ,IPRES
      READ (8)    TCCUNT  ,T       ,KICCFF ,TT
      READ (8)    TV      ,TVA     ,XV     ,YV      ,XVEL    ,YVEL    ,SONIC   ,
     1            PRES
      READ (8)    AV      ,AVA     ,AXV    ,AYV
   25 REWINC 8
C
      READ (5,4) T,TT,NCPT,IRHC,IM,IN,IE,IPRES
      READ (5,9) TP, CP, EXP
      CP = CP / CCN2 * CCN3
      IF (IX1.EQ.1) GC TC 450
      READ (5,9) XML,CMEGA,THICK
      XML = XML/(PC*AC*XLEN)
      CMEGA = CMEGA*CCN3
      THICK = THICK/XLEN
C
      GC TC 45C
C
C     RESTART VALUES
C
   26 IF (MESH .NE. 1) GC TC 3C
   27 READ (9,END=3C) SKIP
      GC TC 27
   3C READ (9)    W       ,A       ,XMCM2  ,YMCM2   ,VSC     ,XMCM2A  ,YMCM2A  ,
     1            VSCA    ,GAM     ,GAM1   ,GAM2    ,GAM3    ,CELX    ,CELY    ,
     2            CELT    ,FUCGE   ,SC     ,TNC     ,TTCL    ,TP      ,CON3    ,
     3            CIFCC   ,XH      ,ENERC  ,XML     ,CMEGA   ,THICK   ,QUE     ,
     4            CP      ,EXP
      READ (9)    ICRCP   ,IR      ,
     1            IX1     ,IX1M1   ,IX1P1  ,IX2     ,IX3     ,IX4     ,IX4M1   ,
     2            IX4M2   ,IX4M3   ,JY1    ,JY1M1   ,JY1P1   ,JY2     ,JY2M1   ,
     3            JY2P1   ,JY2P2   ,JY3    ,JY3M1   ,JY3M2   ,JY3P1   ,JY4     ,
     4            JY4M1   ,JY4P1   ,JY5    ,JY5M1   ,JY5M2   ,ISLCPE  ,JEXL    ,
     5            JEXL
      READ (9)    C       ,XCIS    ,XDISP  ,CFX     ,CFN     ,SINB1   ,
     1            CCSB1   ,SINE    ,CCSINE ,CIST    ,CISTP   ,
     2            ILEN
      READ (9)    XM      ,PC      ,TC     ,RHCO    ,XMCMC   ,YMCMC   ,AO      ,
     1            XLEN    ,YLEN    ,XSLCPE ,SLCPE   ,CCN1    ,CCN2    ,
     2            IRHC    ,IM      ,IN     ,IE      ,IPRES
      READ (9)    TCCUNT  ,T       ,KICCFF ,TT
      READ (9)    TV      ,TVA     ,XV     ,YV      ,XVEL    ,YVEL    ,SONIC   ,
     1            PRES
      READ (9)    AV      ,AVA     ,AXV    ,AYV
      REWINC 9
C
      READ (5,4) T,TT,NCPT,IRHC,IM,IN,IE,IPRES
C
      GC TC 45C
C
C     CCLC START
C
   4C READ (5,1) LENX1,LENX2,LENX3,LENX4
      READ (5,2) LENY1,LENY2,LENY3,LENY4,LENY5
```

```
      READ (5,3) XM, PC, TC, GAM, FUDGE, DELX, DIFCO, QUE
      READ (5,4) T,IT,NOPT,IRHO,IM,IN,IE,IPRES
      XMU = 0.0
      OMEGA = 0.0
      THICK = 0.0
      TP  = 0.0
      CP  = 0.0
      EXP = 0.0
      DELY=DELX
C
C     CALCULATE INDEXING CONSTANTS
C
      IX1 = LENX1 + 2
      IX1M1 = IX1 - 1
      IX1P1 = IX1 + 1
      IX2 = LENX2 + 2
      IX2P1 = IX2 + 1
      IX3 = LENX3 + 2
      IX3P1 = IX3 + 1
      IX4 = LENX4 + 2
      IX4M1 = IX4 - 1
      IX4M2 = IX4 - 2
      IX4M3 = IX4 - 3
      JY1 = LENY1 + 2
      JY1M1 = JY1 - 1
      JY1P1 = JY1 + 1
      JY2 = LENY2 + 2
      JY2M1 = JY2 - 1
      JY2P1 = JY2 + 1
      JY2P2 = JY2 + 2
      JY3 = LENY3 + 2
      JY3M1 = JY3 - 1
      JY3M2 = JY3 - 2
      JY3P1 = JY3 + 1
      JY4 = LENY4 + 2
      JY4M1 = JY4 - 1
      JY4P1 = JY4 + 1
      JY5 = LENY5 + 3
      JY5M1 = JY5 - 1
      JY5M2 = JY5 - 2
      JEXL = JY2
      JEXU = JY3
      JMID = (JY5 + 1) / 2
      IF (IX1.EQ.1) GO TO 90
      JEXL = JY2M1
      JEXU = JY3P1
      READ (5,6) XMU,OMEGA,THICK
C
C     CALCULATE CONSTANTS
C
C     NONDIMENSIONALIZE THE VARIABLES
C
   90 XLEN = LENX4*DELX
      DELX = DELX/XLEN
      DELY = DELX
      YLEN = LENY5*DELY
      GAM1 = GAM - 1.
      GAM2 = GAM1/2.
```

```
      GAM3 = (GAM - 3.)/2.
      SQ = 1./SQRT(2.)
C
      RHCO = XM/1545.*PO/TC
      AC = SQRT(GAM*32.2*PC/RHCO)
      CCN1 = RHOC*AC
      CCN2 = CON1*AC/32.2
      CON3 = XLEN/AC
      ENERC = PC/GAM1/CCN2
      XMU = XMU/(PC*AC*XLEN)
      CMEGA = CMEGA*CCN3
      THICK = THICK/XLEN
      TNC = C.C
      TTCL = 0.0
      CUE = CUE / CCN2 * CCN3
C
C     TEST TC SEE IF CBLIQUE BCUNDARIES ARE PRESENT
C
      ILEN = LENX3 - LENX2
      IF (ILEN.NE.C) GC TO 100
      ISLOPE = C
      SLCPE = ISLCPE
      XSLOPE = C.C
      ICROP(1) = IX4 + 1
      SINB1 = C.0
      COSB1 = 0.C
      GC TC 14C
C
C     INFORMATICN FCR SUBRCUTINE BCUND
C
  1CC ISLOPE = ILEN/LENY2
      SLOPE = ISLCPE
      XSLOPE = -1./SLCPE
      CIS = SQRT((ISLOPE*CELY)**2 + DELY**2)
      SINB1 = -CELY/CIS
      COSB1 = SLCPE*CELY/DIS
      CIST = CELY/CCSB1
      IU = ISLCPE + 1
C
      CO 11C I=1,ISLOPE
      R = I*CELX
      CS = -R*SINB1
  110 C(I) = 3.*DIST - 2.*CS
      C(IL) = 4.*CIST + 2.*IU*CELX*SINB1
C
      CC 112 I=1,3
      P = I
      Y = -P*DELY
  112 XCIS(I) = Y/SLCPE + 2.*DELX
C
      CC 114 I=1,3
      P = I
      Y = -(P + 1.)*CELY
  114 XCISP(I) = Y/SLCPE + 2.*CELX
C
C     CETERMINATICN CF LINES WHERE PCINTS SHCULD BE CRCPPEC
C
      IU = ILEN/ISLOPE
```

```
      CC 12C I=1,IL
      K = I - 1
  120 ICRCP(I) = IX2 + K*ISLCPE + 1
C
      ICIS = 2
      IF (IX1.EC.1) ICIS = 1
      CC 125 I=1,ICIS
      K = IL + I
  125 ICROP(K) = IX3P1 + 3*I
      ICROP(K+1) = IX4 + 1
C
C     GECMETRY FCR THE CIFFUSER
C
      CIS = SQRT((3.*CELY)**2 + DELY**2)
      SINE = CELY/CIS
      COSINE = 3.*SINE
      CISTP = CELY/CCSINE
      CISP = 1./3.*CELX
C
      CC 13C M=1,2
  130 CFX(M) = CELX + M*CISP
      CC 135 M=1,3
      P = 3 - M + 1
      R = P*CELX
      CS = R*SINE
  135 CFN(M) = 3.*DISTP - 2.*CS
C
C     ESTABLISH INITIAL CONDITICNS
C
C
  140 LK = 1
      JLB = JY1
      JUB = JY4
C
      CC 18C I = 2,IX3
      READ (5,5) (W(K,I,JY5),K=1,4)
C
      IF (I.NE.IX1P1) GC TC 16C
      JLB = 2
      JUB = JY5M1
C
  160 IF (I.NE.ICRCP(LK)) GC TC 17C
      LK = LK + 1
      JLB = JLB + 1
      JUB = JUB - 1
C
  170 CC 18C J=JLB,JUB
      W(1,I,J) = W(1,I,JY5)/RHCO
      W(2,I,J) = W(2,I,JY5)/CCN1
      W(3,I,J) = W(3,I,JY5)/CCN1
      W(4,I,J) = W(4,I,JY5)/CCN2
C
      XMOM2(I,J) = W(2,I,J)*W(2,I,J)/W(1,I,J)
      YMOM2(I,J) = W(3,I,J)*W(3,I,J)/W(1,I,J)
      VSC(I,J) = (XMCM2(I,J) + YMOM2(I,J))/W(1,I,J)
      W(5,I,J) = GAM1*(W(4,I,J) - VSC(I,J)*0.5*W(1,I,J))
C
  180 CONTINUE
```

```
C
      DO 190 I=IX3P1,IX4
C
      IF (I.NE.IDROP(LK)) GO TO 185
      LK = LK + 1
      JLB = JLB - 1
      JUB = JUB + 1
C
  185 DO 190 J=JLB,JUB
      READ (5,5) (W(K,I,J),K=1,4)
      W(1,I,J) = W(1,I,J)/RHOO
      W(2,I,J) = W(2,I,J)/CON1
      W(3,I,J) = W(3,I,J)/CON1
      W(4,I,J) = W(4,I,J)/CON2
C
      XMOM2(I,J) = W(2,I,J)*W(2,I,J)/W(1,I,J)
      YMOM2(I,J) = W(3,I,J)*W(3,I,J)/W(1,I,J)
      VSQ(I,J) = (XMOM2(I,J) + YMOM2(I,J))/W(1,I,J)
      W(5,I,J) = GAM1*(W(4,I,J) - VSQ(I,J)*0.5*W(1,I,J))
C
  190 CONTINUE
C
      XH = GAM/GAM1*W(5,2,10)/W(1,2,10) + XMOM2(2,10)/(2.*W(1,2,10))
C
      IF (IX1.EQ.1) GO TO 450
      DO 300 I=2,IX1
      DO 210 J=2,JY1
      A(1,I,J) = 1.0
      A(2,I,J) = 0.0
      A(3,I,J) = 0.0
  210 A(4,I,J) = ENERO
      IF (I.EQ.2) GO TO 300
      IR(I) = MOD(I,6)
      IF (IR(I).EQ.0.OR.IR(I).EQ.1.OR.IR(I).EQ.2.OR.IR(I).EQ.5)GO TO 260
      GO TO 300
C
C     AVERAGE VALUES AROUND THE HOLES
C
  260 DO 280 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      A(K,I,JY1) = (A(K,I,JY1) + W(K,I,JY1))/2.
      W(K,I,JY1) = A(K,I,JY1)
  280 W(K,I,JY4) = SIGN*A(K,I,JY1)
C
  300 CONTINUE
C
      IR(2) = 2
C
      DO 400 I=2,IX1
      DO 400 J=2,JY1
      XMOM2A(I,J) = A(2,I,J)*A(2,I,J)/A(1,I,J)
      YMOM2A(I,J) = A(3,I,J)*A(3,I,J)/A(1,I,J)
      VSQA(I,J) = (XMOM2A(I,J) + YMOM2A(I,J))/A(1,I,J)
  400 A(5,I,J) = PO/CON2
C
  450 RETURN
      END
```

```
      SLBRCLTINE STABLE
C
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1              VSC(52,23), XMOM2A(3C,5), YMOM2A(3C,5), VSCA(30,5),
     2              GAM     ,GAM1    ,GAM2    ,GAM3    ,CELX    ,CELY    ,
     3              CELT    ,FUDGE   ,SC      ,TNC     ,TTCL    ,TP      ,
     4              CCN3    ,CIFCC   ,XH      ,ENERO   ,XML     ,CMEGA   ,THICK,
     5              CUE     ,CP      ,EXP                       ,JMID
      CCMMON/COM2/ ICRCP(2C)    ,IR(30),
     1              IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2              IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3              JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4              JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5              JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
C
      CELT = 1C.C/CCN3
C
      LK = 1
      JLB = JY1
      JUB = JY4
      CC 2CC I=2,IX4
      IF (I.NE.IX1P1) GO TC 90
C
      JLB = 2
      JUB = JY5M1
C
   90 IF (I.NE.ICRCP(LK)) GC TC 1CC
      LK = LK + 1
      JLB = JLB + 1
      JUB = JUB - 1
C
  1CO CC 2CC J=JLB,JUB
C
      TCEL = SQ/(SCRT(GAM*W(5,I,J)/W(1,I,J)) + SCRT(VSC(I,J)))
      CELTX = TCEL*CELX
      CELTY = TCEL*CELY
      CELT = AMIN1(CELT,CELTX,CELTY)
  2CO CONTINUE
C
      CELT = CELT*FUDGE
C
      IF (TTCL.GE.(TP - 1.CE-6)) GC TO 350
      TCIF = (TP - TTCL)/CCN3
      IF (TCIF.LE.CELT) CELT = TCIF
C
  35C RETURN
      END
```


STABLE

```
      SUBROUTINE VRTUAL
C
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1             VSC(52,23), XMOM2A(30,5), YMOM2A(30,5), VSCA(30,5),
     2             GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     3             DELT    ,FUDGE   ,SC      ,TNC     ,TTOL    ,TP      ,
     4             CON3    ,DIFCO   ,XH      ,ENERO   ,XML     ,OMEGA   ,THICK,
     5             CLE     ,CP      ,EXP                       ,JMID
      COMMON/COM2/ IDROP(20)  ,IR(30),
     1             IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2             IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3             JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4             JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5             JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
C
C     VIRTUAL POINTS FOR THE GENERAL MESH
C
C     PARALLEL TO X-AXIS
C
      IF (IX1.EQ.1) GO TO 45
      DO 40 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      DO 40 I=2,IX1M1
      IF (I.EQ.2) GO TO 10
      IF (IR(I).EQ.0.OR.IR(I).EQ.1.OR.IR(I).EQ.2.OR.IR(I).EQ.5) GO TO 20
C
   10 W(K,I,JY1M1) = SIGN*W(K,I,JY1P1)
      W(K,I,JY4P1) = SIGN*W(K,I,JY4M1)
      IF (K.NE.4) GO TO 40
      XMOM2(I,JY1M1) = XMOM2(I,JY1P1)
      XMOM2(I,JY4P1) = XMOM2(I,JY4M1)
      YMOM2(I,JY1M1) = YMOM2(I,JY1P1)
      YMOM2(I,JY4P1) = YMOM2(I,JY4M1)
      VSC(I,JY1M1) = VSC(I,JY1P1)
      VSC(I,JY4P1) = VSC(I,JY4M1)
      GO TO 40
C
   20 W(K,I,JY1M1) = A(K,I,JY1M1)
      W(K,I,JY4P1) = SIGN*A(K,I,JY1M1)
C
   30 IF (K.NE.4) GO TO 40
      XMOM2(I,JY1M1) = XMOM2A(I,JY1M1)
      XMOM2(I,JY4P1) = XMOM2A(I,JY1M1)
      YMOM2(I,JY1M1) = YMOM2A(I,JY1M1)
      YMOM2(I,JY4P1) = YMOM2A(I,JY1M1)
      VSC(I,JY1M1) = VSCA(I,JY1M1)
      VSC(I,JY4P1) = VSCA(I,JY1M1)
   40 CONTINUE
C
   45 DO 70 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      DO 70 I=IX1,IX2
      IF (IX1.EQ.1) GO TO 50
      IF (I.NE.IX1) GO TO 50
      W(K,I,1) = SIGN*A(K,I,3)
```

```
      W(K,I,JY5) =       A(K,I,3)
      GO TO 60
C
   50 W(K,I,1) = SIGN*W(K,I,3)
      W(K,I,JY5) = SIGN*W(K,I,JY5M2)
C
   60 IF (K.NE.4) GO TO 70
      XMOM2(I,1) = W(2,I,1)*W(2,I,1)/W(1,I,1)
      XMOM2(I,JY5) = W(2,I,JY5)*W(2,I,JY5)/W(1,I,JY5)
      YMOM2(I,1) = W(3,I,1)*W(3,I,1)/W(1,I,1)
      YMOM2(I,JY5) = W(3,I,JY5)*W(3,I,JY5)/W(1,I,JY5)
      VSQ(I,1) = (XMOM2(I,1) + YMOM2(I,1))/W(1,I,1)
      VSQ(I,JY5) = (XMOM2(I,JY5) + YMOM2(I,JY5))/W(1,I,JY5)
   70 CONTINUE
C
      IF (IX1.EQ.1) GO TO 92
C
C     PARALLEL TO Y-AXIS
C
      DO 90 K=1,4
      DO 80 J=2,JY1M1
      W(K,IX1,J) = A(K,IX1,J)
C
      IF (K.NE.4) GO TO 80
      XMOM2(IX1,J) = XMOM2A(IX1,J)
      YMOM2(IX1,J) = YMOM2A(IX1,J)
      VSQ(IX1,J) = VSQA(IX1,J)
C
   80 CONTINUE
C
      DO 85 J=JY4P1,JY5M1
      JJ = JY5M1 - J + 2
      W(K,IX1,J) = A(K,IX1,JJ)
C
      IF (K.NE.4) GO TO 85
      XMOM2(IX1,J) = XMOM2A(IX1,JJ)
      YMOM2(IX1,J) = YMOM2A(IX1,JJ)
      VSQ(IX1,J) = VSQA(IX1,JJ)
C
   85 CONTINUE
C
   90 CONTINUE
C
C     OBLIQUE BOUNDARIES
C
   92 IF (ISLOPE.EQ.0) GO TO 95
      CALL BOUND
C
   95 IF (IX1.EQ.1) GO TO 200
C
C     VIRTUAL POINTS FOR THE ACCOUSTICAL LINER
C
C     PARALLEL TO X-AXIS
C
      DO 110 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      DO 110 I=2,IX1
```

VIRTUAL - 2

```
      A(K,I,1) = SIGN*A(K,I,3)
C
      IF (I.EQ.2) GO TO 98
      IF (IR(I).EQ.0.OR.IR(I).EQ.1.OR.IR(I).EQ.2.OR.IR(I).EQ.5)GO TO 100
C
   98 A(K,I,JY1P1) = SIGN*A(K,I,JY1M1)
C
      IF (K.NE.4) GO TO 110
      XMOM2A(I,1) = A(2,I,1)*A(2,I,1)/A(1,I,1)
      XMOM2A(I,JY1P1) = XMOM2A(I,JY1M1)
      YMOM2A(I,1) = A(3,I,1)*A(3,I,1)/A(1,I,1)
      YMOM2A(I,JY1P1) = YMOM2A(I,JY1M1)
      VSQA(I,1) = (XMOM2A(I,1) + YMOM2A(I,1))/A(1,I,1)
      VSQA(I,JY1P1) = VSQA(I,JY1M1)
      GO TO 110
C
  100 A(K,I,JY1P1) = W(K,I,JY1P1)
C
  105 IF (K.NE.4) GO TO 110
      XMOM2A(I,1) = A(2,I,1)*A(2,I,1)/A(1,I,1)
      XMOM2A(I,JY1P1) = XMOM2(I,JY1P1)
      YMOM2A(I,1) = A(3,I,1)*A(3,I,1)/A(1,I,1)
      YMOM2A(I,JY1P1) = YMOM2(I,JY1P1)
      VSQA(I,1) = (XMOM2A(I,1) + YMOM2A(I,1))/A(1,I,1)
      VSQA(I,JY1P1) = VSQ(I,JY1P1)
C
  110 CONTINUE
C
C     PARALLEL TO Y-AXIS
C
      DO 130 K=1,4
      SIGN = 1.0
      IF (K.EQ.2) SIGN = -1.0
      DO 130 J=2,JY1
      A(K,1,J) = SIGN*A(K,3,J)
      A(K,IX1P1,J) = W(K,IX1P1,J)
      IF (K.NE.4) GO TO 130
      XMOM2A(1,J) = A(2,1,J)*A(2,1,J)/A(1,1,J)
      XMOM2A(IX1P1,J) = XMOM2(IX1P1,J)
      YMOM2A(1,J) = A(3,1,J)*A(3,1,J)/A(1,1,J)
      YMOM2A(IX1P1,J) = YMOM2(IX1P1,J)
      VSQA(1,J) = (XMOM2A(1,J) + YMOM2A(1,J))/A(1,1,J)
      VSQA(IX1P1,J) = VSQ(IX1P1,J)
C
  130 CONTINUE
C
C     CORNER POINTS
C
      DO 150 K=1,4
      A(K,1,1) = (A(K,1,2) + A(K,2,1))/2.
      A(K,1,JY1P1) = (A(K,1,JY1) + A(K,2,JY1P1))/2.
      A(K,IX1P1,1) = W(K,IX1P1,1)
      A(K,IX1P1,JY1P1) = W(K,IX1P1,JY1P1)
      IF (K.NE.4) GO TO 150
      XMOM2A(1,1) = A(2,1,1)*A(2,1,1)/A(1,1,1)
      XMOM2A(1,JY1P1) = A(2,1,JY1P1)*A(2,1,JY1P1)/A(1,1,JY1P1)
      XMOM2A(IX1P1,1) = XMOM2(IX1P1,1)
      XMOM2A(IX1P1,JY1P1) = XMOM2(IX1P1,JY1P1)
```

```
      YMOM2A(1,1) = A(3,1,1)*A(3,1,1)/A(1,1,1)
      YMOM2A(1,JY1P1) = A(3,1,JY1P1)*A(3,1,JY1P1)/A(1,1,JY1P1)
      YMOM2A(IX1P1,1) = YMOM2(IX1P1,1)
      YMOM2A(IX1P1,JY1P1) = YMOM2(IX1P1,JY1P1)
      VSQA(1,1) = (XMOM2A(1,1) + YMOM2A(1,1))/A(1,1,1)
      VSQA(1,JY1P1) = (XMOM2A(1,JY1P1) + YMOM2A(1,JY1P1))/A(1,1,JY1P1)
      VSQA(IX1P1,1) = VSQ(IX1P1,1)
      VSQA(IX1P1,JY1P1) = VSQ(IX1P1,JY1P1)
C
  150 CONTINUE
C
  200 RETURN
      END
      SUBROUTINE INTIAL
```

```
      SUBROUTINE BOUND
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1             VSQ(52,23), XMOM2A(30,5), YMOM2A(30,5), VSQA(30,5),
     2             GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     3             DELT    ,FUDGE   ,SQ      ,TND     ,TTOL    ,TP      ,
     4             DON3    ,DIFCO   ,XH      ,ENERO   ,XML     ,OMEGA   ,THICK,
     5             CLE     ,CP      ,EXP                       ,JMID
      COMMON/COM2/ IDROP(20)   ,IR(30),
     1             IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2             IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3             JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4             JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5             JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
      COMMON/COM3/D(20),XDIS(3),XDISP(3),DFX(2),DFN(3),
     1             SINB1   ,COSB1   ,SINE    ,COSINE  ,DIST    ,DISTP   ,
     2             ILEN    ,MESH    ,IWISH
C
      DIMENSION P1(4,3),P2(4,3),R(4,2)
      DIMENSION XX(3)
C
      XINT (A,B,C,X) = A + X*(B - A)/DELTA +
     1                 X*(X - DELTA)*(C - 2.*B + A)/(2.*DELTA**2)
C
      IF (ISLOPE.EQ.1) GO TO 300
C
C     REFLECTION FOR A SLOPE LESS THAN OR EQUAL TO 1/2
C
      KL = JY2 - 2
      IL = ISLOPE + 1
C
C     DEFINE COORDINATES OF P AND V
C
      DO 200 K=1,KL
      K1 = K - 1
      K2 = K1*ISLOPE
      IX = IX2 + K2
      JJ1 = JY5M1 - K1
      JJ2 = 2 + K1
      NTEST = 1
C
      DO 200 I=1,ISLOPE
      DELTA = DELX
      IX = IX + 1
C
C     INTERPOLATE PARALLEL TO THE X-AXIS
C
  100 DO 130 J=1,3
      IF (NTEST.EQ.2) GO TO 110
      XDIST = XDISP(J)
      JJ1P = JJ1 - J
      JJ2P = JJ2 + J
      GO TO 120
C
  110 XDIST = XDIS(J)
      JJ1P = JJ1 - J
      JJ2P = JJ2 + J
C
```

```
  12C CC 13C JJ=1,4
      hXC = h(JJ,IX-2,JJ1P)
      hX1 = h(JJ,IX-1,JJ1P)
      hX2 = h(JJ,IX,JJ1P)
      P1(JJ,J) = XINT (hXC,hX1,hX2,XCIST)
      hXC = h(JJ,IX-2,JJ2P)
      hX1 = h(JJ,IX-1,JJ2P)
      hX2 = h(JJ,IX,JJ2P)
  130 P2(JJ,J) = XINT (hXO,hX1,hX2,XCIST)
C
C     INTERPCLATE ALCNG THE NCRMAL
C
      CELTA = CIST
      X = C(I)
      IF (NTEST.EC.1) X = C(IL)
      CC 14C JJ=1,4
      hXC = P1(JJ,3)
      hX1 = P1(JJ,2)
      hX2 = P1(JJ,1)
      R(JJ,1) = XINT (hXC,hX1,hX2,X)
      hXC = P2(JJ,3)
      hX1 = P2(JJ,2)
      hX2 = P2(JJ,1)
  140 R(JJ,2) = XINT (hXC,hX1,hX2,X)
C
C     REFLECT VALUES
C
      ZCN1 = 2.*(R(2,1)*CCSB1 + R(3,1)*SINB1)
      ZCN2 = 2.*(R(2,2)*COSB1 - R(3,2)*SINB1)
      IF (NTEST.EC.2) GC TC 18C
C
      CC 15C JJ=1,4,3
      h(JJ,IX,JJ1+1) = R(JJ,1)
  15C h(JJ,IX,JJ2-1) = R(JJ,2)
      h(2,IX,JJ1+1) = ZON1*CCSB1 - R(2,1)
      h(2,IX,JJ2-1) = ZON2*CCSB1 - R(2,2)
      h(3,IX,JJ1+1) = ZCN1*SINB1 - R(3,1)
      h(3,IX,JJ2-1) =-ZCN2*SINB1 - R(3,2)
C
      XMOM2(IX,JJ1+1) = h(2,IX,JJ1+1)*h(2,IX,JJ1+1)/h(1,IX,JJ1+1)
      YMOM2(IX,JJ1+1) = h(3,IX,JJ1+1)*h(3,IX,JJ1+1)/h(1,IX,JJ1+1)
      XMOM2(IX,JJ2-1) = h(2,IX,JJ2-1)*h(2,IX,JJ2-1)/h(1,IX,JJ2-1)
      YMOM2(IX,JJ2-1) = h(3,IX,JJ2-1)*h(3,IX,JJ2-1)/h(1,IX,JJ2-1)
      VSQ(IX,JJ1+1) = (XMOM2(IX,JJ1+1) + YMOM2(IX,JJ1+1))/h(1,IX,JJ1+1)
      VSC(IX,JJ2-1) = (XMOM2(IX,JJ2-1) + YMOM2(IX,JJ2-1))/h(1,IX,JJ2-1)
      GC TC 195
C
  180 CC 19C JJ=1,4,3
      h(JJ,IX,JJ1) = R(JJ,1)
  190 h(JJ,IX,JJ2) = R(JJ,2)
      h(2,IX,JJ1) = ZCN1*CCSB1 - R(2,1)
      h(2,IX,JJ2) = ZCN2*CCSB1 - R(2,2)
      h(3,IX,JJ1) = ZCN1*SINB1 - R(3,1)
      h(3,IX,JJ2) =-ZCN2*SINB1 - R(3,2)
C
      IF (IX.NE.IX3) GC TC 192
      CC191L=1,4
      SIGN = 1.C
```

BOUND - 2

```
      IF(L.EQ.3)SIGN=-1.0
      W(L,IX,JJ1)=(SIGN*W(L,IX,JJ1-2)+W(L,IX,JJ1))/2.
      W(L,IX,JJ2)=(SIGN*W(L,IX,JJ2+2)+W(L,IX,JJ2))/2.
  191 CONTINUE
C
  192 XMOM2(IX,JJ1) = W(2,IX,JJ1)*W(2,IX,JJ1)/W(1,IX,JJ1)
      YMOM2(IX,JJ1) = W(3,IX,JJ1)*W(3,IX,JJ1)/W(1,IX,JJ1)
      XMOM2(IX,JJ2) = W(2,IX,JJ2)*W(2,IX,JJ2)/W(1,IX,JJ2)
      YMOM2(IX,JJ2) = W(3,IX,JJ2)*W(3,IX,JJ2)/W(1,IX,JJ2)
      VSQ(IX,JJ1) = (XMOM2(IX,JJ1) + YMOM2(IX,JJ1))/W(1,IX,JJ1)
      VSQ(IX,JJ2) = (XMOM2(IX,JJ2) + YMOM2(IX,JJ2))/W(1,IX,JJ2)
C
  195 IF (NTEST.EQ.2) GO TO 200
      NTEST = 2
      GO TO 100
C
  200 CONTINUE
      GO TO 410
C
C     REFLECTION FOR A SLOPE OF 1
C
  300 I = IX2
      J1 = JY5 + 1
      J2 = 0
      DO 400 K=1,ILEN
      I = I+1
      IM1 = I - 1
      IM2 = I - 2
      J1 = J1 - 1
      J1M1 = J1 - 1
      J1M2 = J1 - 2
      J2 = J2 + 1
      J2P1 = J2 + 1
      J2P2 = J2 + 2
C
C     REFLECTION AT THE TOP BOUNDARY
C
      W(1,I,J1) =  W(1,IM2,J1M2)
      W(2,I,J1) = -W(3,IM2,J1M2)
      W(3,I,J1) = -W(2,IM2,J1M2)
      W(4,I,J1) =  W(4,IM2,J1M2)
      W(1,I,J1M1) =  W(1,IM1,J1M2)
      W(2,I,J1M1) = -W(3,IM1,J1M2)
      W(3,I,J1M1) = -W(2,IM1,J1M2)
      W(4,I,J1M1) =  W(4,IM1,J1M2)
C
C     REFLECTION AT THE BOTTOM BOUNDARY
C
      W(1,I,J2) =  W(1,IM2,J2P2)
      W(2,I,J2) = -W(3,IM2,J2P2)
      W(3,I,J2) = -W(2,IM2,J2P2)
      W(4,I,J2) =  W(4,IM2,J2P2)
      W(1,I,J2P1) =  W(1,IM1,J2P2)
      W(2,I,J2P1) = -W(3,IM1,J2P2)
      W(3,I,J2P1) = -W(2,IM1,J2P2)
      W(4,I,J2P1) =  W(4,IM1,J2P2)
C
  400 CONTINUE
```

```
C
C     FINC VIRTLAL PCINTS FCR THE CIFFUSER
C
C     INTERPCLATE ALONG THE HCRIZCNTAL
C
  410 ISTCP = 1
      IF ((IX4 - IX3).GT.5) ISTOP = 2
      IX = IX3
      CC 5CC N=1,ISTCP
      JJ1 = JY3 + N
      JJ2 = JY2 - N
C
      CC 48C M=1,3
      CELTA = CELX
      IX = IX + 1
C
      CO 43C L=1,2
      J11 = JJ1 - L
      J12 = JJ2 + L
      X = CFX(L)
      IF (N.NE.2.OR.M.NE.1.CR.L.NE.1) GO TC 420
      X = 1./3.*CELX
      IX = IX + 1
C
  420 CC 425 K=1,4
      WXC = W(K,IX-1,J11)
      WX1 = W(K,IX,J11)
      WX2 = W(K,IX+1,J11)
      P1(K,L) = XINT(WXO,WX1,WX2,X)
      WXC = W(K,IX-1,J12)
      WX1 = W(K,IX,J12)
      WX2 = W(K,IX+1,J12)
      P2(K,L) = XINT(WXO,WX1,WX2,X)
C
  425 CONTINLE
C
      IF (N.EQ.2.ANC.M.EC.1.ANC.L.EC.1) IX = IX - 1
C
  430 CCNTINUE
      CC 44C K=1,4
      P1(K,3) = W(K,IX+1,J11-1)
  440 P2(K,3) = W(K,IX+1,J12+1)
C
C     INTERPCLATE ALCNG THE NCRMAL
C
      CELTA = CISTP
      X = CFN(M)
      CO 45C K=1,4
      WXC = P1(K,3)
      WX1 = P1(K,2)
      WX2 = P1(K,1)
      R(K,1) = XINT(WXC,WX1,WX2,X)
      WXC = P2(K,3)
      WX1 = P2(K,2)
      WX2 = P2(K,1)
  450 R(K,2) = XINT(WXC,WX1,WX2,X)
C
C     REFLECT VALUES ACRCSS BCLNCARY
```

```
C
      ZCN1 = 2.*(R(2,1)*COSINE + R(3,1)*SINE)
      ZON2 = 2.*(R(2,2)*COSINE - R(3,2)*SINE)
C
      CO 46C K=1,4,3
      W(K,IX,JJ1) = R(K,1)
  460 W(K,IX,JJ2) = R(K,2)
      W(2,IX,JJ1) = ZCN1*CCSINE - R(2,1)
      W(2,IX,JJ2) = ZCN2*CCSINE - R(2,2)
      W(3,IX,JJ1) = ZCN1*SINE - R(3,1)
      W(3,IX,JJ2) =-ZCN1*SINE - R(3,2)
C
  470 XMOM2(IX,JJ1) = W(2,IX,JJ1)*W(2,IX,JJ1)/W(1,IX,JJ1)
      XMOM2(IX,JJ2) = W(2,IX,JJ2)*W(2,IX,JJ2)/W(1,IX,JJ2)
      YMOM2(IX,JJ1) = W(3,IX,JJ1)*W(3,IX,JJ1)/W(1,IX,JJ1)
      YMOM2(IX,JJ2) = W(3,IX,JJ2)*W(3,IX,JJ2)/W(1,IX,JJ2)
      VSQ(IX,JJ1) = (XMOM2(IX,JJ1) + YMOM2(IX,JJ1))/W(1,IX,JJ1)
      VSQ(IX,JJ2) = (XMOM2(IX,JJ2) + YMOM2(IX,JJ2))/W(1,IX,JJ2)
C
  480 CONTINUE
  5C0 CONTINUE
      IF (ISTOP.EQ.1) GO TC 1000
      CELTA = DELX
      IX = IX3 + 3
      XX1 = 1./3.*DELX + DELX
      XX2 = 2./3.*DELX
C
      CO 600 K=1,4
      WXC = W(K,IX,JY3)
      WX1 = W(K,IX+1,JY3)
      WX2 = W(K,IX+2,JY3)
      P1(K,1) = XINT(WXO,WX1,WX2,XX2)
      WXC = W(K,IX,JY2)
      WX1 = W(K,IX+1,JY2)
      WX2 = W(K,IX+2,JY2)
      P2(K,1) = XINT(WXO,WX1,WX2,XX2)
      P1(K,2) = W(K,IX+1,JY3-1)
      P2(K,2) = W(K,IX+1,JY2+1)
      WXC = W(K,IX,JY3-2)
      WX1 = W(K,IX+1,JY3-2)
      WX2 = W(K,IX+2,JY3-2)
      P1(K,3) = XINT(WXO,WX1,WX2,XX1)
      WXO = W(K,IX,JY2+2)
      WX1 = W(K,IX+1,JY2+2)
      WX2 = W(K,IX+2,JY2+2)
  600 P2(K,3) = XINT(WXO,WX1,WX2,XX1)
C
      CELTA = DISTP
      X = 4.*DELTA - 8.*DELX*SINE
      CO 65C K=1,4
      WXO = P1(K,3)
      WX1 = P1(K,2)
      WX2 = P1(K,1)
      R(K,1) = XINT(WXO,WX1,WX2,X)
      WXO = P2(K,3)
      WX1 = P2(K,2)
      WX2 = P2(K,1)
  650 R(K,2) = XINT(WXO,WX1,WX2,X)
```

```
C
      ZCN1 = 2.*(R(2,1)*COSINE + R(3,1)*SINE)
      ZCN2 = 2.*(R(2,2)*COSINE - R(3,2)*SINE)
C
      DO 660 K=1,4,3
      W(K,IX,JY3+2) = R(K,1)
  660 W(K,IX,JY2-2) = R(K,2)
      W(2,IX,JY3+2) = ZCN1*COSINE - R(2,1)
      W(2,IX,JY2-2) = ZCN2*COSINE - R(2,2)
      W(3,IX,JY3+2) = ZCN1*SINE - R(3,1)
      W(3,IX,JY2-2) =-ZON2*SINE - R(3,2)
C
  670 XMOM2(IX,JY3+2) = W(2,IX,JY3+2)*W(2,IX,JY3+2)/W(1,IX,JY3+2)
      XMOM2(IX,JY2-2) = W(2,IX,JY2-2)*W(2,IX,JY2-2)/W(1,IX,JY2-2)
      YMOM2(IX,JY3+2) = W(3,IX,JY3+2)*W(3,IX,JY3+2)/W(1,IX,JY3+2)
      YMOM2(IX,JY2-2) = W(3,IX,JY2-2)*W(3,IX,JY2-2)/W(1,IX,JY2-2)
      VSQ(IX,JY3+2) = (XMOM2(IX,JY3+2) + YMOM2(IX,JY3+2))/W(1,IX,JY3+2)
      VSQ(IX,JY2-2) = (XMOM2(IX,JY2-2) + YMOM2(IX,JY2-2))/W(1,IX,JY2-2)
C
 1000 RETURN
      END
```

```
      SUBROUTINE GENPT
C
      INTEGER * 4 TCOUNT,T,TT
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1            VSQ(52,23), XMOM2A(30,5), YMOM2A(30,5), VSQA(30,5),
     2            GAM    ,GAM1   ,GAM2   ,GAM3   ,DELX   ,DELY   ,
     3            DELT   ,FUDGE  ,SC     ,TNO    ,TTOL   ,TP     ,
     4            CON3   ,DIFCO  ,XH     ,ENERO  ,XML    ,OMEGA  ,THICK,
     5            CUE    ,CP     ,EXP                    ,JMID
      COMMON/COM2/ IDROP(20)  ,IR(30),
     1            IX1    ,IX1M1  ,IX1P1  ,IX2    ,IX3    ,IX4    ,
     2            IX4M1  ,IX4M2  ,IX4M3  ,JY1    ,JY1M1  ,JY1P1  ,
     3            JY2    ,JY2M1  ,JY2P1  ,JY2P2  ,JY3    ,JY3M1  ,
     4            JY3M2  ,JY3P1  ,JY4    ,JY4M1  ,JY4P1  ,JY5    ,
     5            JY5M1  ,JY5M2  ,ISLOPE ,JEXL   ,JEXU
      COMMON/COM4/XM            ,PC     ,TC     ,RHOO   ,XMOMO  ,YMOMO  ,
     1                    AO     ,XLEN   ,YLEN   ,XSLOPE ,SLOPE  ,
     2            CON1   ,CON2   ,IRHO   ,IM     ,IN     ,IE     ,
     3            IPRES  ,NCPT
      COMMON/COM5/TCOUNT,T,KICOFF,TT
      COMMON/COM6/TV(12,3,23), TVA(12,2,22), XV(52), YV(23),
     1            XVEL(2,2,23), YVEL(2,23), SONIC(2,2,23), PRES(2,2,23)
C
      DIMENSION TEMP (52)
      DIMENSION DUM(4,3,23), DUMA(4,23), DUMB(4,23)
C
C     ESTABLISH INITIAL LEFTHAND BOUNDARY DATA
C
      DO 140 J=JY1M1,JY4P1
      IF (TCOUNT.GT.1) GO TO 120
      YVEL(1,J) = W(3,3,J)/W(1,3,J)
      DO 110 I=2,3
      IF (J.EQ.JY1M1.OR.J.EQ.JY4P1) GO TO 100
      SONIC(1,I-1,J) = SQRT(GAM*W(5,I,J)/W(1,I,J))
      PRES(1,I-1,J) = W(5,I,J)
C
  100 IF (J.GT.JY1M1) GO TO 105
      PRES(1,I-1,JY1M1) = W(5,I,JY1P1)
      PRES(1,I-1,JY4P1) = W(5,I,JY4M1)
C
  105 XVEL(1,I-1,J) = W(2,I,J)/W(1,I,J)
C
  110 CONTINUE
      XVEL(2,1,J) = XVEL(1,1,J)
      GO TO 140
C
  120 DO 130 I=1,2
      SONIC(1,I,J) = SONIC(2,I,J)
      XVEL(1,I,J) = XVEL(2,I,J)
  130 PRES(1,I,J) = PRES(2,I,J)
C
      YVEL(1,J) = YVEL(2,J)
C
  140 CONTINUE
C
C     CALCULATE VALUES AT GENERAL MESH POINTS
C
```

GENPT - 1

```
  150 CCNTX = CELT/(2.*CELX)
      CONTY = CELT/(2.*CELY)
      CCNTXP = CCNTX*C.5
      CCNTYP = CCNTY*C.5
C
      LK = 1
      JLV = JY1M1
      JUV = JY4P1
      JUVP = JLV - 1
      JLB = JY1
      JUB = JY4
      IL = 2
      IU = 4
C
C     CHCOSE A VERTICAL LINE
C
      CC 5CC I=3,IX4M1
      IF (I.EQ.3) GC TC 18C
      IF (I.LT.IX1M1) GC TC 17C
      IF (I.GT.IX1M1) GC TC 16C
      JLV = 1
      JUV = JY5
      JUVP = JLV - 1
      JLB = 2
      JUB = JY5M1
      GO TC 17C
C
C     TEST TC CETERMINE IF CBLIQUE BCUNDARIES HAVE BEEN REACHED
C
  160 IF (I.GT.IX3) GC TC 165
C
      IF (I.NE.ICRCP(LK)) GC TC 17C
      LK = LK + 1
      JLV = JLV + 1
      JUV = JUV - 1
      JUVP = JUV - 1
      JLB = JLB + 1
      JUB = JUB - 1
      GC TC 17C
C
  165 IF (IX1.EQ.1.CR.I.EQ.IX4M1) GC TC 168
      IF (I.NE.ICRCP(LK)-2) GC TC 168
      LK = LK + 2
      JLV = JLV - 1
      JUV = JUV + 1
      JUVP = JUV - 1
      GC TC 17C
C
  168 IF (I.NE.ICRCP(LK-2)) GC TC 17C
      JLB = JLB - 1
      JUB = JUB + 1
C
C     TRANSFER MATRICES
C
  170 CC 175 K=1,12
      CC 175 J=1,JY5
      TV(K,1,J) = TV(K,2,J)
  175 TV(K,2,J) = TV(K,3,J)
```

GENPT - 2

```
C
  176 IL = IL + 1
      IU = IL
C
C     CALCULATE THE VALUES OF TV
C
  180 DO 200 II=IL,IL
      IA = II - 1
      IF (I.NE.3) IA = 3
C
      DO 200 J=JLV,JLV
C
      XMYM = W(2,II,J)*W(3,II,J)/W(1,II,J)
      EM = W(4,II,J)*W(2,II,J)/W(1,II,J)
      EN = W(4,II,J)*W(3,II,J)/W(1,II,J)
C
      TV(1,IA,J) = -W(2,II,J)
      TV(2,IA,J) = GAM3*XMOM2(II,J) - GAM1*W(4,II,J) + GAM2*YMOM2(II,J)
      TV(3,IA,J) = -XMYM
      TV(4,IA,J) = -GAM*EM + GAM2*W(2,II,J)*VSQ(II,J)
      TV(5,IA,J) = -W(3,II,J)
      TV(6,IA,J) = -XMYM
      TV(7,IA,J) = GAM3*YMOM2(II,J) - GAM1*W(4,II,J) + GAM2*XMOM2(II,J)
      TV(8,IA,J) = -GAM*EN + GAM2*W(3,II,J)*VSQ(II,J)
C
C
  190 TV(9,IA,J) = 0.0
      TV(10,IA,J) = 0.0
      TV(11,IA,J) = 0.0
      TV(12,IA,J) = H(2,II,J,TND  ,NCPT)
      SD=0.
      CD=0.
      HD=0.
      XDUM=TV(12,IA,J)*CON2
  200 CONTINUE
C
      IF (I.EQ.3) GO TO 240
C
C     TRANSFER MATRICES
C
      DO 220 K=1,12
      DO 220 J=1,JY5M1
  220 TVA(K,1,J) = TVA(K,2,J)
C
  240 IUP = IU - 1
C
C     CALCULATE THE VALUES OF TVA
C
      DO 400 II=IL,IUP
      IA = II - 1
      IF (I.NE.3) IA = 2
C
      DO 400 J=JLV,JLVP
      IF (I.LT.IX1.AND.(J.LT.JY1M1.OR.J.GT.JY4)) GO TO 400
C
      DO 250 K=1,4
      IF (IA.EQ.2) GO TO 245
C
```

```
  242 CONTINUE
      STAR=0.25*(W(K,3,J)+W(K,2,J+1)+W(K,3,J+1)+W(K,2,J))
      DERIV=CONTX*(TV(K,2,J)-TV(K,1,J)+TV(K,2,J+1)-TV(K,1,J+1))
     1      +CONTY*(TV(K+4,2,J+1)-TV(K+4,2,J)+TV(K+4,1,J+1)-TV(K+4,1,J))
      HEAT=0.25*(TV(K+8,2,J)+TV(K+8,1,J+1)+TV(K+8,2,J+1)+TV(K+8,1,J))
      TVA(K,1,J)=STAR+DERIV+HEAT
      GO TO 249
C
  245 CONTINUE
      STAR=0.25*(W(K,I+1,J)+W(K,I,J+1)+W(K,I+1,J+1)+W(K,I,J))
      DERIV=CONTX*(TV(K,3,J)-TV(K,2,J)+TV(K,3,J+1)-TV(K,2,J+1))
     1      +CONTY*(TV(K+4,3,J+1)-TV(K+4,3,J)+TV(K+4,2,J+1)-TV(K+4,2,J))
      HEAT=0.25*(TV(K+8,3,J)+TV(K+8,2,J+1)+TV(K+8,3,J+1)+TV(K+8,2,J))
      TVA(K,IA,J)=STAR+DERIV+HEAT
  249 CONTINUE
      IF(K.NE.4)GOTO250
      XDUM = TVA(4,IA,J) * CON2
      SD=STAR*CON2
      DD=DERIV*CON2
      HD=HEAT*CON2
  250 CONTINUE
C
  270 XM2 = TVA(2,IA,J)**2/TVA(1,IA,J)
      YM2 = TVA(3,IA,J)**2/TVA(1,IA,J)
      XMYM = TVA(2,IA,J)*TVA(3,IA,J)/TVA(1,IA,J)
      SUMSQ = (XM2 + YM2)/TVA(1,IA,J)
      EM = TVA(2,IA,J)*TVA(4,IA,J)/TVA(1,IA,J)
      EN = TVA(3,IA,J)*TVA(4,IA,J)/TVA(1,IA,J)
C
      TVA(5,IA,J) = -TVA(2,IA,J)
      TVA(6,IA,J) = GAM3*XM2 - GAM1*TVA(4,IA,J) + GAM2*YM2
      TVA(7,IA,J) = -XMYM
      TVA(8,IA,J) = -GAM*EM + GAM2*TVA(2,IA,J)*SUMSQ
      TVA(9,IA,J) = -TVA(3,IA,J)
      TVA(10,IA,J) = -XMYM
      TVA(11,IA,J) = GAM3*YM2 - GAM1*TVA(4,IA,J) + GAM2*XM2
      TVA(12,IA,J) = -GAM*EN + GAM2*TVA(3,IA,J)*SUMSQ
C
  400 CONTINUE
C
      IF (I .EQ. 3) GO TO 404
      DO 401 K = 1,4
      DO 401 J = JLV,JUV
      DUM(K,1,J) = DUM(K,2,J)
  401 DUM(K,2,J) = DUM(K,3,J)
      IB = I+1
      IC = I+1
      GO TO 405
C
  404 IB = 2
      IC = 4
C
  405 DO 409 III = IB,IC
      ID=III-1
      IF(I.NE.3)IC=3
      DO 409 J    = JLV,JUV
      DUM(1,ID,J)=0.
      DUM(2,ID,J)=0.
```

GENPT - 4

```
      DUM(3,ID,J)=0.
      DUM(4,ID,J)=H(2,III,J,IND,NCPT)
  409 CONTINUE
C
      IF (I .EQ. 3) GO TO 4100
      DO 4010 K = 1,4
      DO 4010 J = JLV,JLVP
 4010 DUMA(K,J) = DUMB(K,J)
      GO TO 4200
C
 4100 DO 4150 K = 1,4
      DO 4150 J = JLV,JUVP
      DUMA(K,J)=0.25*(DUM(K,1,J+1)+DUM(K,1,J)+DUM(K,2,J+1)+DUM(K,2,J))
      IF(K.NE.4)GOTO4150
      XDUM = DUMA(K,J) * CON2 / CON3
 4150 CONTINUE
C
 4200 DO 4250 K = 1,4
      DO 4250 J = JLV,JLVP
      IF(K.NE.4)GOTO4250
      DUMB(K,J)=0.25*(DUM(K,3,J+1)+DUM(K,3,J)+DUM(K,2,J+1)+DUM(K,2,J))
      XDUM = DUMB(K,J) * CON2 / CON3
 4250 CONTINUE
C
C     CALCULATE FINAL VALUES
C
  410 DO 450 J=JLB,JLB
      IF (I.LT.IX1P1.AND.(J.LT.JY1.OR.J.GT.JY4)) GO TO 450
      DO 420 K=1,4
      STAR=W(K,I,J)
      DERIV=CONTXP*(TV(K,3,J)-TV(K,1,J)+TVA(K+4,2,J)-TVA(K+4,1,J)+
     1     TVA(K+4,2,J-1)-TVA(K+4,1,J-1))+
     2     CONTYP*(TV(K+4,2,J+1)-TV(K+4,2,J-1)+TVA(K+8,2,J)-
     3     TVA(K+8,2,J-1)+TVA(K+8,1,J)-TVA(K+8,1,J-1))
      HEAT=0.25*(DUMA(K,J)+DUMA(K,J-1)+DUMB(K,J)+DUMB(K,J-1))
      HEAT=0.5*(TV(K+8,2,J)+HEAT)
      W(K,I,J)=STAR+DERIV+HEAT
      IF(K.NE.4)GOTO420
      SDFL=STAR*CON2
      DDFL=DERIV*CON2
      HDFL=HEAT*CON2
      XDUM=W(K,I,J)*CON2
C
  420 CONTINUE
  450 CONTINUE
C
  500 CONTINUE
      DTT=DELT*CON3
  505 FORMAT (4X,6HDTT = ,E13.4,5X,7HDELT = ,E13.4)
C
C     OPEN END OF THE CHAMBER
C
      DO 600 K=1,4
      DO 600 J=JEXL,JEXL
      W(K,IX4,J) = W(K,IX4M1,J)
      IF (K.NE.4) GO TO 600
C
      XMOM2(IX4,J) = W(2,IX4,J)*W(2,IX4,J)/W(1,IX4,J)
```

```
      YMOM2(IX4,J) = W(3,IX4,J)*W(3,IX4,J)/W(1,IX4,J)
      VSQ(IX4,J) = (XMOM2(IX4,J) + YMOM2(IX4,J))/W(1,IX4,J)
  600 CONTINUE
C
      IF (IX1.EQ.1) GO TO 610
C
C     CALCULATE VALUES DUE TO ACOUSTICAL LINER
C
      CALL LINER (CONTX,CONTY,CONTXP,CONTYP)
C
C     SMOOTH THE VALUES
C
  610 XLAMDA = DELT/DELX
      XLD = XLAMDA*DIFCO
C
C     IN THE X-DIRECTION
C
      IF (IX1.EQ.1) GO TO 615
      IL = IX1P1
      IDL = IX3 + 4
      GO TO 618
C
  615 IL = 3
      IDL = IX3 + 1
C
  618 IU = IX2 - ISLOPE
C
      DO 650 J=2,JY5M1
C
      IF (J.EQ.JY1) IL = 3
      IF (J.LE.JY2) IL = IL + ISLOPE
      IF (J.EQ.JY2) IDL = IX3 + 1
      IF (J.GT.JY3) IL = IL - ISLOPE
      IF (J.EQ.JY4P1) IL = IX1P1
      IF (J.EQ.JEXL.AND.IX1.NE.1) IDL = IX3 + 4
C
      ILL = IL - 1
      IUU = IU + 1
      IDLL = IDL - 1
C
      DO 620 I=ILL,IUU
  620 XV(I) = W(2,I,J)/W(1,I,J)
C
      IF (J.LT.JEXL.OR.J.GT.JEXU) GO TO 630
      DO 625 I=IDLL,IX4
  625 XV(I) = W(2,I,J)/W(1,I,J)
C
  630 DO 645 K=1,4
C
      DO 635 I=IL,IU
  635 TEMP(I) =  W(K,I,J) + XLD*( ABS(XV(I+1) - XV(I)) *(W(K,I+1,J) -
     1            W(K,I,J)) -   ABS(XV(I) - XV(I-1)) *(W(K,I,J) -
     2            W(K,I-1,J)))
C
      IF (J.LT.JEXL.OR.J.GT.JEXU) GO TO 641
C
      DO 640 I=IDL,IX4M1
  640 TEMP(I) = W(K,I,J) + XLD*( ABS(XV(I+1) - XV(I))*(W(K,I+1,J) -
```

```
     1             W(K,I,J)) -  ABS(XV(I) - XV(I-1))*(W(K,I,J) -
     2             W(K,I-1,J)))
C
  641 CC 642 I=IL,IL
  642 W(K,I,J) = TEMP(I)
C
      IF (J.LT.JEXL.CR.J.GT.JEXU) GC TC 645
C
      CO 643 I=IDL,IX4M1
  643 W(K,I,J) = TEMP(I)
C
  645 CONTINUE
C
  65C CONTINUE
C
C     IN THE Y-DIRECTION
C
      LK = 1
      JLB = JY1
      JUB = JY4
      JLV = JY1M1
      JUV = JY4P1
C
      CC 68C I=3,IX4M1
      IF (I.NE.IX1P1) GO TC 655
      JLB = 2
      JUB = JY5M1
      JLV = 1
      JUV = JY5
C
  655 IF (I.NE.IDRCP(LK).CR.I.GT.IX3) GC TC 658
      LK = LK+1
      JLB = JLB + 1
      JUB = JUB - 1
      JLV = JLV + 1
      JUV = JUV - 1
      GC TO 660
C
  658 IF (IX1.EQ.1) GC TC 660
      IF (I.NE.IDRCP(LK)) GC TC 66C
      LK =LK + 2
      JLB = JLB - 1
      JUB = JUB + 1
      JLV = JLV - 1
      JUV = JUV + 1
C
  66C CC 665 J=JLV,JUV
  665 YV(J) = W(3,I,J)/W(1,I,J)
C
      CO 675 K=1,5
      IF (K.EQ.5) GC TC 671
C
      CO 67C J=JLB,JUB
      TEMP(J) =   W(K,I,J) + XLC*( ABS(YV(J+1) - YV(J)) *(W(K,I,J+1) -
     1            W(K,I,J)) -   ABS(YV(J) - YV(J-1)) *(W(K,I,J) -
     2            W(K,I,J-1)))
  67C CONTINUE
C
```

GENPT - 7

```
  671 CC 674 J=JLB,JUB
      IF (K.EQ.5) GC TC 673
C
      W(K,I,J) = TEMP(J)
C
      IF (K.EQ.1.CR.K.EC.4) GC TC 672
      IF (ABS(W(K,I,J)).LT.1.CE-C6) W(K,I,J) = 0.0
      GO TC 674
C
  672 IF (W(K,I,J).LE.1.CE-06) KICCFF = 1
      GC TC 674
C
  673 XMCM2(I,J) = W(2,I,J)*W(2,I,J)/W(1,I,J)
      YMCM2(I,J) = W(3,I,J)*W(3,I,J)/W(1,I,J)
      VSC(I,J) = (XMCM2(I,J) + YMCM2(I,J))/W(1,I,J)
      W(5,I,J) = GAM1*(W(4,I,J) - VSC(I,J)*0.5*W(1,I,J))
      IF (W(5,I,J).LE.1.CE-C6) KICCFF = 1
C
  674 CCNTINUE
  675 CCNTINUE
  680 CCNTINUE
C
C     ZERC THE Y-MCMENTUM AT THE WALLS.
C
      CC 681 I = 2,IX2
      W(3,I,2) = C.C
  681 W(3,I,JY5M1) = C.C
C
C     FIX VALVES AT SUPERSCNIC NCZZLE.
C
      IF (JY5 .EC. 13) GC TC 689
      IF (JY5 .EC. 23) GC TC 685
C
      CC 682 K = 1,5
      W(K,94,8) = W(K,94,7)
  682 W(K,94,37) = W(K,94,36)
      GO TC 689
C
  685 CC 686 K = 1,5
      W(K,48,5)  = W(K,48,6)
  686 W(K,48,19) = W(K,48,18)
C
  689 CCNTINUE
C
C     EXTRAPCLATE THE VALUES
C
      CC 69C K=1,5
      CC 69C J=JEXL,JEXU
  690 W(K,IX4,J) = W(K,IX4M1,J)
C
C     LEFTHAND BCUNCARY CALCULATICNS
C
      CC 7CC J=JY1M1,JY4P1
      YVEL(2,J) = W(3,3,J)/W(1,3,J)
      XVEL(2,2,J) = W(2,3,J)/W(1,3,J)
      CC 7CC I=2,3
      IF (J.EQ.JY1M1.CR.J.EQ.JY4P1) GO TC 70C
      SCNIC(2,I-1,J) = SCRT(GAM*W(5,I,J)/W(1,I,J))
```

```
      PRES(2,I-1,J) = W(5,I,J)
  700 CONTINUE
C
      DO 705 I=2,3
      PRES(2,I-1,JY1M1) = W(5,I,JY1P1)
  705 PRES(2,I-1,JY4P1) = W(5,I,JY4M1)
C
      DO 710 J=JY1,JY4
      SBAR = 0.5*(XVEL(1,1,J) + XVEL(2,2,J) - SONIC(1,1,J) -
     1          SONIC(2,2,J))
      Z1 = 1.0 + XLAMDA*SBAR
      Z2 = 1.0 - XLAMDA*SBAR
      RHO1 = 0.5*(W(1,2,J) + W(1,3,J))
      SONICO = 0.5*(SONIC(1,1,J) + SONIC(2,2,J))
      YVELO = 0.5*YVEL(2,J)
      W(5,2,J) = PRES(1,2,J) + RHO1*SONICO*(XVEL(2,1,J) - XVEL(1,2,J)) +
     1            Z1/Z2*(PRES(1,1,J) - PRES(2,2,J) - RHO1*SONICO*
     2            (XVEL(1,1,J) - XVEL(2,2,J))) - DELT*YVELO/(2.*DELY*Z2)*
     3            (PRES(1,2,J+1) - PRES(1,2,J-1) - RHO1*SONICO*
     4            (XVEL(1,1,J+1) - XVEL(1,1,J-1)) + PRES(1,1,J+1) -
     5            PRES(1,1,J-1) - RHO1*SONICO*
     6            (XVEL(1,2,J+1) - XVEL(1,2,J-1))) - DELT*RHO1*SONICO**2/
     7            (2.*DELY*Z2)*(YVEL(1,J+1) - YVEL(1,J-1))
      W(1,2,J) = GAM*W(5,2,J)/(2.*XH*GAM1)*
     1            (1.0 + SQRT(1.0 + 2.*XH*(W(2,2,J)*GAM1/
     2            (GAM*W(5,2,J)))**2))
C
      XVEL(2,1,J) = W(2,2,J)/W(1,2,J)
C
      XMOM2(2,J) = XVEL(2,1,J)*W(2,2,J)
      YMOM2(2,J) = W(3,2,J)*W(3,2,J)/W(1,2,J)
      VSQ(2,J) = (XMOM2(2,J) + YMOM2(2,J))/W(1,2,J)
C
      W(4,2,J) = W(5,2,J)/GAM1 + VSQ(2,J)*0.5*W(1,2,J)
C
  710 CONTINUE
      IF (IX1.EQ.1) GO TO 1000
C
C     AVERAGE VALUES AROUND THE HOLES
C
      DO 900 I=3,IX1
      IF (IR(I).NE.5.AND.IR(I).NE.0.AND.IR(I).NE.1.AND.IR(I).NE.2)
     1                                                         GO TO 900
      DO 850 K=1,5
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      W(K,I,JY1) = (W(K,I,JY1) + A(K,I,JY1))/2.
      W(K,I,JY4) = SIGN*W(K,I,JY1)
      A(K,I,JY1) = W(K,I,JY1)
C
      IF (K.NE.5) GO TO 850
      XMOM2(I,JY1) = W(2,I,JY1)*W(2,I,JY1)/W(1,I,JY1)
      YMOM2(I,JY1) = W(3,I,JY1)*W(3,I,JY1)/W(1,I,JY1)
      VSQ(I,JY1) = (XMOM2(I,JY1) + YMOM2(I,JY1))/W(1,I,JY1)
      XMOM2A(I,JY1) = XMOM2(I,JY1)
      YMOM2A(I,JY1) = YMOM2(I,JY1)
      VSQA(I,JY1) = VSQ(I,JY1)
      XMOM2(I,JY4) = W(2,I,JY4)*W(2,I,JY4)/W(1,I,JY4)
```

```
      YMOM2(I,JY4) = W(3,I,JY4)*W(3,I,JY4)/W(1,I,JY4)
      VSQ(I,JY4) = (XMOM2(I,JY4) + YMOM2(I,JY4))/W(1,I,JY4)
C
  850 CONTINUE
C
  900 CONTINUE
C
 1000 TND = TND + DELT
      TTOL = TND*CON3
C
      RETURN
      END
```

GENPT - 10

```
      FUNCTION H (INDEX,I,J,SEC,N)
C
      INTEGER * 4 TCOUNT,T,TT
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1             VSQ(52,23), XMOM2A(30,5), YMOM2A(30,5), VSQA(30,5),
     2             GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     3             DELT    ,FUDGE   ,SQ      ,TNC     ,TTOL    ,TP      ,
     4             CON3    ,DIFCO   ,XH      ,ENERO   ,XMU     ,OMEGA   ,THICK,
     5             QUE     ,CP      ,EXP                       ,JMID
      COMMON/COM2/ IDROP(20)   ,IR(30),
     1             IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2             IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3             JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4             JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5             JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
      COMMON/COM4/XM       ,PO      ,TO      ,RHOO    ,XMOMO   ,YMOMO   ,
     1                      AO      ,XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,
     2             CON1    ,CON2    ,IRHO    ,IM      ,IN      ,IE      ,
     3             IPRES   ,NCPT
      COMMON/COM5/TCOUNT,T,KICOFF,TT
      DIMENSION STOR(23)
C
      H = 0.0
C
C     CALC START OPTION
C
      IF (J .LT. JY1 .OR. J .GT. JY4) GO TO 1000
      IF (I .LE. 3) GO TO 1000
      IF(JY4.EQ.12.AND.I.GE.16)GOTO1000
      IF(JY4.EQ.22.AND.I.GE.30)GOTO1000
      IF(IX1.NE.1)GOTO20
      IF(JY4.GT.12)GOTO10
      XF1=1.0
      XF2=0.5
      ALPHA = 0.04
      GOTO50
   10 XF1=1.0
      XF2=0.5
      ALPHA=0.01
      GOTO50
   20 CONTINUE
      XF1=1.0
      XF2=0.5
      ALPHA=0.01
   50 CONTINUE
      IF (N .NE. 1) GO TO 200
  100 IF(J.EQ.JY1.OR.J.EQ.JY4)GOTO105
      H=XF1*QUE*DELT
      GOTO1000
  105 H=XF2*QUE*DELT
      GOTO1000
  200 CONTINUE
      IF (TTOL .GT. (TP - 1.0D-12)) GO TO 400
      IF(I.NE.5)GOTO1000
      IF(J.EQ.JY1.OR.J.EQ.JY4)GOTO250
      IF(J.GT.JMID)GOTO210
      H=XF1*QUE*DELT+ALPHA*(J-JY1)*CP*DELT
```

H-1

```
      GCTO1CCC
  210 F=XF1*QUE*DELT+ALPHA*(JY4-J)*QP*CELT
      GCTO1CCO
  250 F=XF2*QUE*CELT
      GCTC1CCO
  400 CCNTINUE
      IF(J.NE.JY1)GOTC5CC
      SUM=C.C
      COUNT=C.C
      DC45CJJ=JY1,JY4
      PRESS=W(5,I,JJ)
      SUM=SUM+PRESS
  450 CCUNT=COUNT+1.
      AVGPRS=SUM/CCUNT
  5C0 CONTINUE
      IF(J.EQ.JY1.CR.J.EQ.JY4)GCTC55C
      F=XF1*QUE*(W(5,I,J)/AVGPRS)**EXP*CELT
      GCTO1CCO
  55C F=XF2*QUE*(W(5,I,J)/AVGPRS)**EXP*DELT
 1CCO RETURN
      ENC
```

H-2

```
      SUBROUTINE LINER (CONTX,CONTY,CONTXP,CONTYP)
C
      INTEGER * 4 TCOUNT,T,TT
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1              VSC(52,23), XMOM2A(30,5), YMOM2A(30,5), VSCA(30,5),
     2              GAM    ,GAM1   ,GAM2   ,GAM3   ,DELX   ,DELY   ,
     3              DELT   ,FUDGE  ,SC     ,TNC    ,TTCL   ,TP     ,
     4              CON3   ,DIFCO  ,XH     ,ENERO  ,XML    ,OMEGA  ,THICK,
     5              CLE    ,CP     ,EXP                    ,JMID
      COMMON/COM2/ IDROP(20)   ,IR(30),
     1              IX1    ,IX1M1  ,IX1P1  ,IX2    ,IX3    ,IX4    ,
     2              IX4M1  ,IX4M2  ,IX4M3  ,JY1    ,JY1M1  ,JY1P1  ,
     3              JY2    ,JY2M1  ,JY2P1  ,JY2P2  ,JY3    ,JY3M1  ,
     4              JY3M2  ,JY3P1  ,JY4    ,JY4M1  ,JY4P1  ,JY5    ,
     5              JY5M1  ,JY5M2  ,ISLOPE ,JEXL   ,JEXU
      COMMON/COM5/TCOUNT,T,KICOFF,TT
      COMMON/COM7/AV(12,3,10),AVA(12,2,10),AXV(35),AYV(5)
C
      DIMENSION TEMP(35)
C
C     INITIALIZE FOR CALCULATIONS
C
      JLV = 1
      JUV = JY1P1
      JUVP = JLV - 1
      JLB = 2
      JUB = JY1
      IL = 1
      IU = 3
C
C     CHOOSE A VERTICAL LINE
C
      DO 500 I=2,IX1
      IF (I.EQ.2) GO TO 180
C
C     TRANSFER AV COLUMNS
C
      DO 120 K=1,8
      DO 120 J=JLV,JUV
      AV(K,1,J) = AV(K,2,J)
  120 AV(K,2,J) = AV(K,3,J)
C
      IL = IL + 1
      IU = IL
C
C     CALCULATE VALUES OF AV
C
  180 DO 200 II=IL,IU
      IA = II
      IF (I.NE.2) IA = 3
C
      DO 200 J=JLV,JUV
C
      XMYM = A(2,II,J)*A(3,II,J)/A(1,II,J)
      EM = A(4,II,J)*A(2,II,J)/A(1,II,J)
      EN = A(4,II,J)*A(3,II,J)/A(1,II,J)
C
```

LINER - 1

```
      AV(1,IA,J) = -A(2,II,J)
      AV(2,IA,J) = GAM3*XMOM2A(II,J) - GAM1*A(4,II,J) +
     1             GAM2*YMOM2A(II,J)
      AV(3,IA,J) = -XMYM
      AV(4,IA,J) = -GAM*EM + GAM2*A(2,II,J)*VSQA(II,J)
      AV(5,IA,J) = -A(3,II,J)
      AV(6,IA,J) = -XMYM
      AV(7,IA,J) = GAM3*YMOM2A(II,J) - GAM1*A(4,II,J) +
     1             GAM2*XMOM2A(II,J)
      AV(8,IA,J) = -GAM*EN + GAM2*A(3,II,J)*VSQA(II,J)
C
  200 CONTINUE
C
      IF (I.EQ.2) GO TO 240
C
C     TRANSFER AVA COLUMNS
C
      DO 220 K=1,12
      DO 220 J=JLV,JLVP
  220 AVA(K,1,J) = AVA(K,2,J)
C
  240 IUP = IU - 1
C
C     CALCULATE VALUES OF AVA
C
      DO 400 II=IL,IUP
      IA = II
      IF (I.NE.2) IA = 2
C
      DO 400 J=JLV,JLVP
C
      DO 250 K=1,4
      IF (IA.EQ.2) GO TO 245
      AVA(K,1,J) = 0.25*(A(K,2,J) + A(K,1,J+1) + A(K,2,J+1) + A(K,1,J))+
     1             CONTX*(AV(K,2,J) - AV(K,1,J) + AV(K,2,J+1) -
     2             AV(K,1,J+1)) +
     3             CONTY*(AV(K+4,2,J+1) - AV(K+4,2,J) + AV(K+4,1,J+1) -
     4             AV(K+4,1,J))
      GO TO 250
C
  245 AVA(K,IA,J) = 0.25*(A(K,I+1,J) + A(K,I,J+1) + A(K,I+1,J+1) +
     1              A(K,I,J)) +
     2              CONTX*(AV(K,3,J) - AV(K,2,J) + AV(K,3,J+1) -
     3              AV(K,2,J+1)) +
     4              CONTY*(AV(K+4,3,J+1) - AV(K+4,3,J) + AV(K+4,2,J+1) -
     5              AV(K+4,2,J))
C
  250 CONTINUE
C
      XM2 = AVA(2,IA,J)**2/AVA(1,IA,J)
      YM2 = AVA(3,IA,J)**2/AVA(1,IA,J)
      XMYM = AVA(2,IA,J)*AVA(3,IA,J)/AVA(1,IA,J)
      SUMSQ = (XM2 + YM2)/AVA(1,IA,J)
      EM = AVA(4,IA,J)*AVA(2,IA,J)/AVA(1,IA,J)
      EN = AVA(4,IA,J)*AVA(3,IA,J)/AVA(1,IA,J)
C
      AVA(5,IA,J) = -AVA(2,IA,J)
      AVA(6,IA,J) = GAM3*XM2 - GAM1*AVA(4,IA,J) + GAM2*YM2
```

```
      AVA(7,IA,J) = -XMYM
      AVA(8,IA,J) = -GAM*EM + GAM2*AVA(2,IA,J)*SUMSQ
      AVA(9,IA,J) = -AVA(3,IA,J)
      AVA(10,IA,J) = -XMYM
      AVA(11,IA,J) = GAM3*YM2 - GAM1*AVA(4,IA,J) + GAM2*XM2
      AVA(12,IA,J) = -GAM*EN + GAM2*AVA(3,IA,J)*SUMSQ
C
  400 CONTINUE
C
C     CALCULATE FINAL VALUES
C
  410 DO 450 K=1,4
      DO 450 J=JLB,JUB
      A(K,I,J) = A(K,I,J) + CONTXP*(AV(K,3,J) - AV(K,1,J) + AVA(K+4,2,J)
     1           - AVA(K+4,1,J) + AVA(K+4,2,J-1) - AVA(K+4,1,J-1)) +
     2             CONTYP*(AV(K+4,2,J+1) - AV(K+4,2,J-1) + AVA(K+8,2,J) -
     3             AVA(K+8,2,J-1) + AVA(K+8,1,J) - AVA(K+8,1,J-1))
C
  450 CONTINUE
C
  500 CONTINUE
C
C     AVERAGE VALUES AROUND THE HOLES
C
      DO 503 I=3,IX1
      IF (IR(I).NE.5.AND.IR(I).NE.2) GO TO 503
C
      DO 502 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      A(K,I,JY1) = (W(K,I,JY1) + A(K,I,JY1))/2.
      W(K,I,JY1) = A(K,I,JY1)
      W(K,I,JY4) = SIGN*A(K,I,JY1)
C
  502 CONTINUE
  503 CONTINUE
C
C     ENERGY WITHDRAWAL AT THE HOLES
C
      DO 505 I=3,IX1M1
      IF (IR(I).NE.5) GO TO 505
C
      RHOBAR = .25*(A(1,I,JY1) + A(1,I+1,JY1) + A(1,I+2,JY1) +
     1              A(1,I+3,JY1))
      VELBAR = .25*(A(3,I,JY1)/A(1,I,JY1) + A(3,I+1,JY1)/A(1,I+1,JY1) +
     1              A(3,I+2,JY1)/A(1,I+2,JY1) + A(3,I+3,JY1)/
     2              A(1,I+3,JY1))
      R = .5*SQRT(2.*XMU*RHOBAR*OMEGA)
      TENER = 3.141592653589793 * 1.5 * DELX * THICK * R * VELBAR**2
C
      A(4,I,JY1) = A(4,I,JY1) - TENER/3.
      A(4,I+1,JY1) = A(4,I+1,JY1) - TENER/6.
      A(4,I+2,JY1) = A(4,I+2,JY1) - TENER/6.
      A(4,I+3,JY1) = A(4,I+3,JY1) - TENER/3.
C
      W(4,I,JY1) = A(4,I,JY1)
      W(4,I,JY4) = A(4,I,JY1)
      W(4,I+1,JY1) = A(4,I+1,JY1)
```

```
      W(4,I+1,JY4) = A(4,I+1,JY1)
      W(4,I+2,JY1) = A(4,I+2,JY1)
      W(4,I+2,JY4) = A(4,I+2,JY1)
      W(4,I+3,JY1) = A(4,I+3,JY1)
      W(4,I+3,JY4) = A(4,I+3,JY1)
C
  505 CONTINUE
C
C     SMOOTH THE VALUES
C
      XLD = DELT/DELX*DIFCO
C
      DO 525 J = 2,JY1
C
      DO 510 I=1,IX1P1
  510 AXV(I)= A(2,I,J)/A(1,I,J)
C
      DO 520 K=1,4
      DO 515 I = 2,IX1
  515 TEMP(I) = A(K,I,J) + XLD*( ABS(AXV(I+1) - AXV(I))*(A(K,I+1,J) -
     1          A(K,I,J)) -  ABS(AXV(I) - AXV(I-1))*(A(K,I,J) -
     2           A(K,I-1,J)))
C
      DO 516 I = 2,IX1
  516 A(K,I,J) = TEMP(I)
C
  520 CONTINUE
  525 CONTINUE
C
      DO 545 I = 2,IX1
C
      DO 530 J=1,JY1P1
  530 AYV(J) = A(3,I,J) / A(1,I,J)
C
      DO 540 K=1,5
      IF (K.EQ.5) GO TO 536
C
      DO 535 J = 2,JY1
  535 TEMP(J) = A(K,I,J) + XLD*( ABS(AYV(J+1) - AYV(J))*(A(K,I,J+1) -
     1          A(K,I,J)) -  ABS(AYV(J) - AYV(J-1))*(A(K,I,J) -
     2           A(K,I,J-1)))
C
  536 DO 537 J = 2,JY1
      IF (K .EQ. 5) GO TO 539
C
      A(K,I,J) = TEMP(J)
C
      IF (K.EQ.1.OR.K.EQ.4) GO TO 538
      IF (ABS(A(K,I,J)).LT.1.0E-06) A(K,I,J) = 0.0
      GO TO 537
C
  538 IF (A(K,I,J).LE.1.0E-06) KIDOFF = 1
      GO TO 537
C
  539 XMOM2A(I,J) = A(2,I,J)*A(2,I,J)/A(1,I,J)
      YMOM2A(I,J) = A(3,I,J)*A(3,I,J)/A(1,I,J)
      VSQA(I,J) = (XMOM2A(I,J) + YMOM2A(I,J))/A(1,I,J)
      A(5,I,J) = GAM1*(A(4,I,J) - VSQA(I,J)*0.5*A(1,I,J))
```

```
      IF (A(5,I,J).LE.1.CE-C6) KICCFF = 1
C
  537 CCNTINLE
  54C CCNTINLE
  545 CCNTINLE
C
      RETLRN
      ENC
```


LINER - 5

```
      SUBROUTINE PRINT (N)
C
      INTEGER * 4 TCCUNT,T,TT
C
      COMMON/CCM1/W(5,52,23), A(5,3C,5), XMOM2(52,23), YMOM2(52,23),
     1              VSC(52,23), XMOM2A(3C,5), YMOM2A(3C,5), VSCA(3C,5),
     2              GAM     ,GAM1    ,GAM2    ,GAM3    ,CELX    ,DELY    ,
     3              DELT    ,FUDGE   ,SC      ,TNC     ,TTCL    ,TP      ,
     4              CCN3    ,DIFCC   ,XH      ,ENERO   ,XML     ,OMEGA   ,THICK,
     5              CLE     ,CP      ,EXP                       ,JMID
      COMMON/CCM2/ IDRCP(2C)    ,IR(30),
     1              IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2              IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3              JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4              JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5              JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
      COMMON/CCM3/D(2C),XDIS(3),XDISP(3),DFX(2),DFN(3),
     1              SINB1   ,CCSB1   ,SINE    ,COSINE  ,DIST    ,DISTP   ,
     2              ILEN    ,MESH    ,IWISH
      COMMON/CCM4/XM        ,PO      ,TC      ,RHCO    ,XMOMO   ,YMOMO   ,
     1                       AC      ,XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,
     2              CCN1    ,CCN2    ,IRHO    ,IM      ,IN      ,IE      ,
     3              IPRES   ,NCPT
      COMMON/CCM5/TCCUNT,T,KICCFF,TT
      COMMON/CCM6/TV(12,3,23), TVA(12,2,22), XV(52), YV(23),
     1              XVEL(2,2,23), YVEL(2,23), SONIC(2,2,23), PRES(2,2,23)
      COMMON/COM7/AV(12,3,10),AVA(12,2,1C),AXV(35),AYV(5)

      DIMENSION TEMP(13),XD(3),XDP(3)

    1 FORMAT (   ///T45,'* * * *  INPUT DATA AND CONSTANTS  * * * *'//)
    2 FORMAT (//T5,'LENX1 ='I3,          T37 ,'LENX2 ='I3,
     1        T69,'LENX3 ='I3,          T101,'LENX4 ='I3)
    3 FORMAT (//T5,'LENY1 ='I3,          T37 ,'LENY2 ='I3,
     1        T69,'LENY3 ='I3,          T101,'LENY4 ='I3)
    4 FORMAT (//T5,'LENY5 ='I3,          T37 ,'NUMBER CF TRIPS ='I3,
     1        T69,'PRINT INC ='I3,      T101,'ILEN ='I3)
    5 FORMAT (//T5,'XLEN ='1PE13.5,      T37 ,'YLEN ='E13.5,
     1        T69,'DELX ='E13.5,        T101,'DELY ='E13.5)
    6 FORMAT (//T5,'SOUND SP. ='1PE13.5, T37 ,'M.W. CF GAS ='E13.5,
     1        T69,'FUDGE ='0PF5.3,      T101,'TP ='1PE13.5)
    7 FORMAT (//T5,'PC ='1PE13.5,        T37 ,'TO ='E13.5,
     1        T69,'RHCO ='1PE13.5,      T101,'ENERO ='E13.5)
    8 FORMAT ('1' T65, 'ENERGY' /// T3, 'TRIP' T14, 'TIME' T32, 'I = 2'
     1       T54, 'I = 5' T76, 'I = 10' T98, 'I =15' T120, 'I = 20')
    9 FORMAT (//T5,'GAM ='1PE13.5,       T37 ,'XSLOPE ='E13.5,
     1        T69,'DIST ='E13.5,        T101,'DISTP ='E13.5)
   10 FORMAT (//T5,'SINB1 ='1PE13.5,     T37 ,'COSB1 ='E13.5,
     1        T69,'SINE ='E13.5,       T1C1,'COSINE ='E13.5)
   11 FORMAT (//T5,'XDIST(1) ='1PE13.5,  T37 ,'XDIST(2) ='E13.5,
     1        T69,'XDIST(3) ='E13.5)
   12 FORMAT (//T5,'XDISTP(1) ='1PE13.5, T37 ,'XDISTP(2) ='E13.5,
     1        T69,'XDISTP(3) ='E13.5)
   13 FORMAT (//T5,'DIFCC ='1PE13.5,    T37,'MU ='1PE13.5,
     1        T69,'OMEGA ='1PE13.5,    T101,'LINER THKNS ='1PE13.5)
   14 FORMAT (//T5,'Q ='1PE13.5,    T37, 'CP ='1PE13.5,
     1        T69,'N ='1PE13.5,     T101, 'NCPT ='I3)
   15 FORMAT (//T1C1, 'MESH =' I3)
```

PRINT - 1

```
   16 FCRMAT (T4, 'NC.' T26, 'J = 12' T37, 'J = 22' T48, 'J = 12' T59,
     1        'J = 22' T7C, 'J = 12' T81, 'J = 22' T92, 'J = 12' T103,
     2        'J = 22' T114, 'J = 12' T125, 'J = 22')
   17 FCRMAT (T4, 'NC.' T26, 'J = 12' T37, 'J = 19' T48, 'J = 12' T59,
     1        'J = 19' T7C, 'J = 12' T81, 'J = 19' T92, 'J = 12' T103,
     2        'J = 19' T114, 'J = 12' T125, 'J = 19')
   19 FCRMAT (1HC, I4, 2X, 1PE14.5, 1PE11.2)
C
   20 FCRMAT (T6,'*',T66,'C',T127,'*')
   21 FORMAT (T6,'*',T27,'A',T66,'C',T106,'W',T127,'*')
   22 FCRMAT (// 1P13E1C.2)
   23 FCRMAT (// T11,1P11E10.2)
   24 FCRMAT (// T21,1P9E10.2)
   25 FORMAT (// T31,1P7E1C.2)
   26 FORMAT (// T41,1P5E1C.2)
   27 FCRMAT (// T51,1P3E1C.2)
   28 FCRMAT (1P13E1C.2)
C
   30 FCRMAT ('1DENSITY AT TIME ='1PE14.5,     T38,'CELT ='E14.5,
     1         T64,'TNC ='E14.5,               T90,'TRIP NUMBER ='I4//)
   4C FCRMAT ('1X-MCMENTUM AT TIME ='1PE14.5, T38,'CELT ='E14.5,
     1         T64,'TNC ='E14.5,               T90,'TRIP NUMBER ='I4//)
   50 FCRMAT ('1Y-MCMENTUM AT TIME ='1PE14.5, T38,'CELT ='E14.5,
     1         T64,'TNC ='E14.5,               T9C,'TRIP NUMBER ='I4//)
   60 FCRMAT ('1ENERGY AT TIME ='1PE14.5,      T38,'CELT ='E14.5,
     1         T64,'TNC ='E14.5,               T90,'TRIP NUMBER ='I4//)
   70 FCRMAT ('1PRESSURE AT TIME ='1PE14.5,    T38,'CELT ='E14.5,
     1         T64,'TNC ='E14.5,               T90,'TRIP NUMBER ='I4//)
C
   80 FCRMAT ('1'///' ERROR MESSAGE'//
     1                                  ' CNE CF THE FCLLOWING HAS BECOME LE
     2SS THAN 1.CE-1C   CENSITY,ENERGY,OR PRESSURE. THIS MAY BE THE RESU
     3LT OF INSTABILITY CR AN ERRCR.'/' CHECK INPUT CATA CARCS FCR CORRE
     4CTNESS ANC THE PRINTCUT CF THE INPUT CATA ANC CONSTANTS. FCLLOWING
     5 IS A CUMP CF THE ARRAYS IN'/' CCMMCN.'///)
   81 FCRMAT (1H+, T34,  1PE11.2)
   82 FCRMAT (1H+, T45,  1PE11.2)
   83 FORMAT (1H+, T56,  1PE11.2)
   84 FCRMAT (1H+, T67,  1PE11.2)
   85 FCRMAT (1H+, T78,  1PE11.2)
   86 FCRMAT (1H+, T89,  1PE11.2)
   87 FCRMAT (1H+, T1CC, 1PE11.2)
   88 FCRMAT (1H+, T111, 1PE11.2)
   89 FCRMAT (1H+, T122, 1PE11.2)
C
      NAMELIST/NAM1/W,       XMCM2,YMOM2,VSQ,A,XMCM2A,YMOM2A,VSQA,D,IR,
     1                 ICRCP
C
      CT = CELT*CON3
      IF (N.EQ.2) GC TC 30C
C
C     INPUT CATA PRINTCUT
C
      CU  = CUE / CCN3 * CCN2
      CPP = CP  / CCN3 * CCN2
  1C0 MIC = JY5/2 + 1
      JLP = JY5 - 6
      IF (MIC.LE.8) JLP = MID + 1
```

PRINT - 2

```
      JLP = MINC(MIC,8) - 1
C
  110 CC 12C I=1,3
      XC(I) = XCIS(I)*XLEN
  12C XCP(I) = XCISP(I)*XLEN
      YL = YLEN*XLEN
      CX = CELX*XLEN
      CY = CELY*XLEN
      LENX1 = IX1 - 2
      LENX2 = IX2 - 2
      LENX3 = IX3 - 2
      LENX4 = IX4 - 2
      LENY1 = JY1 - 2
      LENY2 = JY2 - 2
      LENY3 = JY3 - 2
      LENY4 = JY4 - 2
      LENY5 = JY5 - 3
      C = CIST*XLEN
      CP = CISTP*XLEN
      E = ENERC*CCN2
      XMLP = XML*PC*AC*XLEN
      CMEGAP = CMEGA/CCN3
      THICKP = THICK*XLEN
C
      WRITE (6,1)
      WRITE (6,2) LENX1,LENX2,LENX3,LENX4
      WRITE (6,3) LENY1,LENY2,LENY3,LENY4
      WRITE (6,4) LENY5,T,TT,ILEN
      WRITE (6,5) XLEN,YL,CX,CY
      WRITE (6,6) AC,XM,FUCGE,TP
      WRITE (6,7) PC,TC,RHCO,E
      WRITE (6,9) GAM,XSLCPE,C,DP
      WRITE (6,1C) SINB1,CCSB1,SINE,COSINE
      WRITE (6,13) CIFCC,XMLP,CMEGAP,THICKP
      WRITE (6,14) CL, CPP, EXP, NCPT
      WRITE (6,15) MESH
      WRITE (6,11) (XC(I),I=1,3)
      WRITE (6,12) (XCP(I),I=1,3)
C
C     CEPENCENT VARIABLE PRINTCUT
C
C
  3C0 IF (IRHO.EQ.C.ANC.N.EQ.2) GC TC 40C
C
C     CENSITY PRINTCUT
C
      WRITE (6,3C) TTCL,CT,TNC,TCOUNT
      LK = 1
      LK1 = LK
      JLB = 2
      JLB = JY5M1
C
      CC 39C I=2,IX4
      IF (I.GT.IX1) GO TC 360
C
      CC 33C J=2,JY1
      K = J - 1
  330 TEMP(K) = A(1,I,J)*RHCO
```

PRINT - 3

```
C
      CC 34C J=JY1P1,JLP
      K = K + 1
  34C TEMP(K) = W(1,I,J)*RHOO
C
      K = K + 1
      TEMP(K) = W(1,I,MIC)*RHCC
C
      CO 345 J=JLP,JY4
      K = K + 1
  345 TEMP(K) = W(1,I,J)*RHCO
C
      CC 35C J=JY4P1,JY5M1
      K = K + 1
      JJ = JY5M1 - J + 2
  350 TEMP(K) = A(1,I,JJ)*RHCO
C
      WRITE (6,28) (TEMP(K),K=1,13)
C
      IF (I.EQ.IX1) GC TC 39C
      IF (IR(I).EQ.5.CR.IR(I).EC.C.CR.IR(I).EQ.1) GO TC 355
      CC 352 M=1,2
  352 WRITE (6,21)
      GC TC 39C
C
  355 CC 358 M=1,2
  358 WRITE (6,2C)
      GC TC 39C
C
  360 IF (I.NE.ICRCP(LK).OR.I.GT.IX3) GC TC 365
      LK = LK + 1
      LK1 = LK
      JLB = JLB + 1
      JUB = JUB - 1
      GC TC 366
C
  365 IF (I.NE.ICRCP(LK)) GO TC 366
      LK = LK + 1
      LK1 = LK1 - 1
      JLB = JLB - 1
      JUB = JUB + 1
C
  366 CC 37C J=JLB,JLP
      K = J - JLB + 1
  370 TEMP(K) = W(1,I,J)*RHCO
C
      K = K + 1
      TEMP(K) = W(1,I,MIC)*RHCC
C
      CC 375 J=JLP,JLB
      K = K + 1
  375 TEMP(K) = W(1,I,J)*RHCO
C
      GC TC (38C,382,383,384,385,386),LK1
C
  380 IF (I.NE.2) GO TC 381
      WRITE (6,28) (TEMP(J),J=1,K)
      GC TC 39C
```

PRINT - 4

```
C
  381 WRITE (6,22) (TEMP(J),J=1,K)
      GO TO 390
C
  382 WRITE (6,23) (TEMP(J),J=1,K)
      GO TO 390
C
  383 WRITE (6,24) (TEMP(J),J=1,K)
      GO TO 390
C
  384 WRITE (6,25) (TEMP(J),J=1,K)
      GO TO 390
C
  385 WRITE (6,26) (TEMP(J),J=1,K)
      GO TO 390
C
  386 WRITE (6,26) (TEMP(J),J=1,K)
C
  390 CONTINUE
C
  400 IF (IM.EQ.0.AND.N.EQ.2) GO TO 500
C
C     X-MOMENTUM PRINTOUT
C
      WRITE (6,40) TTOL,DT,TND,TCOUNT
      JLB = 2
      JUB = JY5M1
      LK = 1
      LK1 = LK
C
      DO 490 I=2,IX4
      IF (I.GT.IX1) GO TO 460
C
      DO 430 J=2,JY1
      K = J - 1
  430 TEMP(K) = A(2,I,J)*CON1
C
      DO 440 J=JY1P1,JLP
      K = K + 1
  440 TEMP(K) = W(2,I,J)*CON1
C
      K = K + 1
      TEMP(K) = W(2,I,MID)*CON1
C
      DO 445 J=JLP,JY4
      K = K + 1
  445 TEMP(K) = W(2,I,J)*CON1
C
      DO 450 J=JY4P1,JY5M1
      K = K + 1
      JJ = JY5M1 - J + 2
  450 TEMP(K) = A(2,I,JJ)*CON1
C
      WRITE (6,28) (TEMP(K),K=1,13)
C
      IF (I.EQ.IX1) GO TO 490
      IF (IR(I).EQ.5.OR.IR(I).EQ.0.OR.IR(I).EQ.1) GO TO 455
      DO 452 M=1,2
```

```
  452 WRITE (6,21)
      GO TO 490
C
  455 DO 458 M=1,2
  458 WRITE (6,20)
      GO TO 490
C
C
  460 IF (I.NE.IDROP(LK).OR.I.GT.IX3) GO TO 465
      LK = LK + 1
      LK1 = LK
      JLB = JLB + 1
      JUB = JUB - 1
      GO TO 466
C
  465 IF (I.NE.IDROP(LK)) GO TO 466
      LK = LK + 1
      LK1 = LK1 - 1
      JLB = JLB - 1
      JUB = JUB + 1
C
  466 DO 470 J=JLB,JLP
      K = J - JLB + 1
  470 TEMP(K) = W(2,I,J)*CON1
C
      K = K + 1
      TEMP(K) = W(2,I,MID)*CON1
C
      DO 475 J=JLP,JLB
      K = K + 1
  475 TEMP(K) = W(2,I,J)*CON1
C
      GO TO (480,482,483,484,485,486),LK1
C
  480 IF (I.NE.2) GO TO 481
      WRITE (6,28) (TEMP(J),J=1,K)
      GO TO 490
C
  481 WRITE (6,22) (TEMP(J),J=1,K)
      GO TO 490
C
  482 WRITE (6,23) (TEMP(J),J=1,K)
      GO TO 490
C
  483 WRITE (6,24) (TEMP(J),J=1,K)
      GO TO 490
C
  484 WRITE (6,25) (TEMP(J),J=1,K)
      GO TO 490
C
  485 WRITE (6,26) (TEMP(J),J=1,K)
      GO TO 490
C
  486 WRITE (6,27) (TEMP(J),J=1,K)
C
  490 CONTINUE
C
  500 IF (IN.EQ.0.AND.N.EQ.2) GO TO 600
```

PRINT - 6

```
C
C      Y-MOMENTUM PRINTOUT
C
       WRITE (6,50) TTCL,DT,TND,TCCLNT
       JLB = 2
       JUB = JY5M1
       LK = 1
       LK1 = LK
C
       DO 590 I=2,IX4
       IF (I.GT.IX1) GO TO 560
C
       DO 530 J=2,JY1
       K = J - 1
  530  TEMP(K) = A(3,I,J)*CON1
C
       DO 540 J=JY1P1,JLP
       K = K + 1
  540  TEMP(K) = W(3,I,J)*CON1
C
       K = K + 1
       TEMP(K) = W(3,I,MID)*CON1
C
       DO 545 J=JLP,JY4
       K = K + 1
  545  TEMP(K) = W(3,I,J)*CON1
C
       DO 550 J=JY4P1,JY5M1
       K = K + 1
       JJ = JY5M1 - J + 2
  550  TEMP(K) = -A(3,I,JJ)*CON1
C
       WRITE (6,28) (TEMP(K),K=1,13)
C
       IF (I.EQ.IX1) GO TO 590
       IF (IR(I).EQ.5.OR.IR(I).EQ.0.OR.IR(I).EQ.1) GO TO 555
       DO 552 M=1,2
  552  WRITE (6,21)
       GO TO 590
C
  555  DO 558 M=1,2
  558  WRITE (6,20)
       GO TO 590
C
C
  560  IF (I.NE.IDROP(LK).OR.I.GT.IX3) GO TO 565
       LK = LK + 1
       LK1 = LK
       JLB = JLB + 1
       JUB = JUB - 1
       GO TO 566
C
  565  IF (I.NE.IDROP(LK)) GO TO 566
       LK = LK + 1
       LK1 = LK1 - 1
       JLB = JLB - 1
       JUB = JUB + 1
C
```

PRINT - 7

```
  566 CC 57C J=JLB,JLP
      K = J - JLB + 1
  570 TEMP(K) = W(3,I,J)*CCN1
C
      K = K + 1
      TEMP(K) = W(3,I,MIC)*CCN1
C
      CC 575 J=JLP,JLB
      K = K + 1
  575 TEMP(K) = W(3,I,J)*CCN1
C
      GC TC (58C,582,583,584,585,586),LK1
C
  580 IF (I.NE.2) GC TC 581
      WRITE (6,28) (TEMP(J),J=1,K)
      GC TC 59C
C
  581 WRITE (6,22) (TEMP(J),J=1,K)
      GO TC 590
C
  582 WRITE (6,23) (TEMP(J),J=1,K)
      GC TC 590
C
  583 WRITE (6,24) (TEMP(J),J=1,K)
      GC TC 59C
C
  584 WRITE (6,25) (TEMP(J),J=1,K)
      GC TC 590
C
  585 WRITE (6,26) (TEMP(J),J=1,K)
      GO TO 59C
C
  586 WRITE (6,27) (TEMP(J),J=1,K)
C
  590 CONTINUE
C
  6C0 IF (IE.EQ.0.ANC.N.EQ.2) GO TC 70C
C
C     ENERGY PRINTCUT
C
      ICHOSE = IWISH
      IF (N .EQ. 1) ICHOSE = C
      IF (ICHOSE .EQ. C) GC TC 602
      IF (TCCUNT .NE. 1) GC TC 6C2
      WRITE (6,8)
      IF (IX1 .NE. 1) GC TC 601
      WRITE (6,16)
      GO TC 602
  6C1 WRITE (6,17)
  6C2 IF (ICHOSE .NE. C) GC TC 6C5
      WRITE (6,6C) TTCL,CT,TNC,TCOUNT
  605 JLB = 2
      JUB = JY5M1
      LK = 1
      LK1 = LK
C
      CC 69C I=2,IX4
      IF (I.GT.IX1) GC TC 660
```

```
C
      DO 630 J=2,JY1
      K = J - 1
      TEMP(K) = A(4,I,J) * CON2
      IF (ICHOSE .EQ. 0) GO TO 630
      IF (I .EQ. 2 .OR. I .EQ. 5 .OR. I .EQ. 10 .OR. I .EQ. 15 .OR.
     1   I .EQ. 20) GO TO 620
      GO TO 630
  620 IF (J .EQ. 12 .OR. J .EQ. 19) GO TO 625
      GO TO 630
  625 IF (I .EQ. 2 .AND. J .EQ. 12) GO TO 626
      IF (I .EQ.  2 .AND. J .EQ. 19) WRITE (6,81) TEMP(K)
      IF (I .EQ.  5 .AND. J .EQ. 12) WRITE (6,82) TEMP(K)
      IF (I .EQ.  5 .AND. J .EQ. 19) WRITE (6,83) TEMP(K)
      IF (I .EQ. 10 .AND. J .EQ. 12) WRITE (6,84) TEMP(K)
      IF (I .EQ. 10 .AND. J .EQ. 19) WRITE (6,85) TEMP(K)
      IF (I .EQ. 15 .AND. J .EQ. 12) WRITE (6,86) TEMP(K)
      IF (I .EQ. 15 .AND. J .EQ. 19) WRITE (6,87) TEMP(K)
      IF (I .EQ. 20 .AND. J .EQ. 12) WRITE (6,88) TEMP(K)
      IF (I .EQ. 20 .AND. J .EQ. 19) WRITE (6,89) TEMP(K)
      GO TO 630
  626 WRITE (6,19) TCOUNT, TTOL, TEMP(K)
  630 CONTINUE
C
      DO 640 J=JY1P1,JLP
      K = K + 1
      TEMP(K) = W(4,I,J) * CON2
      IF (ICHOSE .EQ. 0) GO TO 640
      IF (I .EQ. 2 .OR. I .EQ. 5 .OR. I .EQ. 10 .OR. I .EQ. 15 .OR.
     1   I .EQ. 20) GO TO 633
      GO TO 640
  633 IF (J .EQ. 12 .OR. J .EQ. 19) GO TO 635
      GO TO 640
  635 IF (I .EQ. 2 .AND. J .EQ. 12) GO TO 638
      IF (I .EQ.  2 .AND. J .EQ. 19) WRITE (6,81) TEMP(K)
      IF (I .EQ.  5 .AND. J .EQ. 12) WRITE (6,82) TEMP(K)
      IF (I .EQ.  5 .AND. J .EQ. 19) WRITE (6,83) TEMP(K)
      IF (I .EQ. 10 .AND. J .EQ. 12) WRITE (6,84) TEMP(K)
      IF (I .EQ. 10 .AND. J .EQ. 19) WRITE (6,85) TEMP(K)
      IF (I .EQ. 15 .AND. J .EQ. 12) WRITE (6,86) TEMP(K)
      IF (I .EQ. 15 .AND. J .EQ. 19) WRITE (6,87) TEMP(K)
      IF (I .EQ. 20 .AND. J .EQ. 12) WRITE (6,88) TEMP(K)
      IF (I .EQ. 20 .AND. J .EQ. 19) WRITE (6,89) TEMP(K)
      GO TO 640
  638 WRITE (6,19) TCOUNT, TTOL, TEMP(K)
  640 CONTINUE
C
      K = K + 1
      TEMP(K) = W(4,I,MID)*CON2
C
      DO 645 J=JLP,JY4
      K = K + 1
      TEMP(K) = W(4,I,J) * CON2
      IF (ICHOSE .EQ. 0) GO TO 645
      IF (I .EQ. 2 .OR. I .EQ. 5 .OR. I .EQ. 10 .OR. I .EQ. 15 .OR.
     1   I .EQ. 20) GO TO 641
      GO TO 645
  641 IF (J .EQ. 12 .OR. J .EQ. 19) GO TO 643
```

PRINT - 9

```
      GC TC 645
  643 IF (I .EC. 2 .ANC. J .EC. 12) GC TC 644
      IF (I .EC.  2 .ANC. J .EC. 19) WRITE (6,81) TEMP(K)
      IF (I .FC.  5 .ANC. J .EC. 12) WRITF (6,82) TEMP(K)
      IF (I .EC.  5 .ANC. J .EC. 19) WRITE (6,83) TEMP(K)
      IF (I .EC. 1C .AND. J .EC. 12) WRITE (6,84) TEMP(K)
      IF (I .EC. 1C .ANC. J .EC. 19) WRITE (6,85) TEMP(K)
      IF (I .EC. 15 .ANC. J .EC. 12) WRITE (6,86) TEMP(K)
      IF (I .EC. 15 .ANC. J .EC. 19) WRITE (6,87) TEMP(K)
      IF (I .EC. 2C .ANC. J .EC. 12) WRITE (6,88) TEMP(K)
      IF (I .EC. 2C .ANC. J .EC. 19) WRITE (6,89) TEMP(K)
      GC TC 645
  644 WRITE (6,19) TCCUNT, TTCL, TEMP(K)
  645 CONTINUE
C
      CC 65C J=JY4P1,JY5M1
      K = K + 1
      JJ = JY5M1 - J + 2
      TEMP(K) = A(4,I,JJ) * CCN2
      IF (ICHOSE .EQ. C) GC TC 65C
      IF (I .EQ. 2 .CR. I .EQ. 5 .CR. I .EC. 10 .CR. I .EQ. 15 .CR.
     1   I .EQ. 2C) GC TC 646
      GC TC 65C
  646 IF (J .EQ. 12 .CR. J .EQ. 19) GO TC 647
      GC TC 650
  647 IF (I .EC. 2 .ANC. J .EC. 12) GO TC 648
      IF (I .EC.  2 .ANC. J .EC. 19) WRITE (6,81) TEMP(K)
      IF (I .FQ.  5 .AND. J .EC. 12) WRITE (6,82) TFMP(K)
      IF (I .EQ.  5 .AND. J .EC. 19) WRITE (6,83) TEMP(K)
      IF (I .EC. 1C .ANC. J .EC. 12) WRITE (6,84) TEMP(K)
      IF (I .EC. 1C .ANC. J .EC. 19) WRITE (6,85) TEMP(K)
      IF (I .FQ. 15 .ANC. J .EC. 12) WRITE (6,86) TEMP(K)
      IF (I .EQ. 15 .AND. J .EC. 19) WRITE (6,87) TEMP(K)
      IF (I .EC. 2C .ANC. J .EC. 12) WRITE (6,88) TEMP(K)
      IF (I .EC. 2C .AND. J .EC. 19) WRITE (6,89) TEMP(K)
      GC TC 65C
  648 WRITE (6,19) TCOUNT, TTCL, TEMP(K)
  650 CONTINUE
C
      IF (ICHOSE .NE. C) GC TO 651
      WRITE (6,28) (TEMP(K),K=1,13)
C
  651 IF (I .EC. IX1) GC TC 69C
      IF (IR(I).EQ.5.CR.IR(I).EQ.0.CR.IR(I).EQ.1) GO TC 655
      IF (ICHOSE .NE. C) GC TC 690
      CO 652 M=1,2
  652 WRITE (6,21)
      GC TC 69C
C
  655 IF (ICHOSE .NE. C) GC TC 690
      CC 658 M = 1,2
  658 WRITE (6,2C)
      GC TC 690
C
C
  660 IF (I.NE.ICRCP(LK).CR.I.GT.IX3) GO TC 665
      LK = LK + 1
      LK1 = LK
```

PRINT - 10

```
      JLB = JLB + 1
      JUB = JUB - 1
      GC TC 666
C
  665 IF (I.NE.ICRCP(LK)) GC TC 666
      LK = LK + 1
      LK1 = LK1 - 1
      JLB = JLB - 1
      JUB = JUB + 1
C
  666 CC 67C J=JLB,JUP
      K = J - JLB + 1
      TEMP(K) = W(4,I,J) * CCN2
      IF (ICHOSE .EC. C) GC TC 670
      IF (I .EQ. 2 .CR. I .EC. 5 .CR. I .EC. 10 .CR. I .EQ. 15 .CR.
     1   I .EQ. 2C) GC TC 667
      GC TC 670
  667 IF (J .EC. 12 .CR. J .EC. 22) GO TC 668
      GC TC 67C
  668 IF (I .EC. 2 .ANC. J .EC. 12) GO TC 669
      IF (I .EQ.  2 .ANC. J .EC. 22) WRITE (6,81) TEMP(K)
      IF (I .EC.  5 .ANC. J .EC. 12) WRITE (6,82) TEMP(K)
      IF (I .EC.  5 .AND. J .EC. 22) WRITE (6,83) TEMP(K)
      IF (I .EC. 1C .AND. J .EC. 12) WRITE (6,84) TEMP(K)
      IF (I .EQ. 1C .ANC. J .EC. 22) WRITE (6,85) TEMP(K)
      IF (I .EC. 15 .ANC. J .EC. 12) WRITE (6,86) TEMP(K)
      IF (I .EQ. 15 .ANC. J .EC. 22) WRITE (6,87) TEMP(K)
      IF (I .EQ. 2C .AND. J .EC. 12) WRITE (6,88) TEMP(K)
      IF (I .FQ. 2C .ANC. J .EC. 22) WRITE (6,89) TEMP(K)
      GC TO 67C
  669 WRITE (6,19) TCCUNT, TTCL, TEMP(K)
  670 CCNTINUE
C
      K = K + 1
      TEMP(K) = W(4,I,MID)*CON2
C
      CC 675 J=JLP,JLB
      K = K + 1
      TEMP(K) = W(4,I,J) * CCN2
      IF (ICHOSE .EC. C) GC TC 675
      IF (I .EQ. 2 .CR. I .EQ. 5 .CR. I .EC. 10 .CR. I .EQ. 15 .CR.
     1   I .EQ. 2C) GC TC 671
      GC TO 675
  671 IF (J .EC. 12 .CR. J .EC. 22) GO TC 672
      GC TC 675
  672 IF (I .EQ. 2 .ANC. J .EQ. 12) GO TC 673
      IF (I .EC.  2 .AND. J .EC. 22) WRITE (6,81) TEMP(K)
      IF (I .EC.  5 .AND. J .EC. 12) WRITE (6,82) TEMP(K)
      IF (I .EQ.  5 .AND. J .EC. 22) WRITE (6,83) TEMP(K)
      IF (I .EQ. 1C .AND. J .EC. 12) WRITE (6,84) TEMP(K)
      IF (I .EC. 1C .AND. J .EC. 22) WRITE (6,85) TEMP(K)
      IF (I .EC. 15 .AND. J .EC. 12) WRITE (6,86) TEMP(K)
      IF (I .EQ. 15 .ANC. J .EC. 22) WRITE (6,87) TEMP(K)
      IF (I .EC. 2C .ANC. J .EC. 12) WRITE (6,88) TEMP(K)
      IF (I .EC. 2C .ANC. J .EC. 22) WRITE (6,89) TEMP(K)
      GC TC 675
  673 WRITE (6,19) TCCUNT, TTCL, TEMP(K)
  675 CCNTINUE
```

```
C
      IF (ICHOSE .NE. C) GC TC 69C
C
      GC TC (680,682,683,684,685,686),LK1
C
  680 IF (I.NE.2) GC TC 681
      WRITE (6,28) (TEMP(J),J=1,K)
      GC TC 69C
C
  681 WRITE (6,22) (TEMP(J),J=1,K)
      GC TC 69C
C
  682 WRITE (6,23) (TEMP(J),J=1,K)
      GC TC 69C
C
  683 WRITE (6,24) (TEMP(J),J=1,K)
      GC TC 69C
C
  684 WRITE (6,25) (TEMP(J),J=1,K)
      GC TC 69C
C
  685 WRITE (6,26) (TEMP(J),J=1,K)
      GC TC 69C
C
  686 WRITE (6,27) (TEMP(J),J=1,K)
C
  69C CCNTINUE
C
  7C0 IF (IPRES.EQ.C.AND.N.EQ.2) GC TO 8CC
C
C     PRESSURE PRINTCUT
C
      WRITE (6,7C) TTCL,DT,TND,TCOUNT
      JLB = 2
      JUB = JY5M1
      LK = 1
      LK1 = LK
C
      DC 79C I=2,IX4
      IF (I.GT.IX1) GC TC 760
C
      DC 73C J=2,JY1
      K = J - 1
  730 TEMP(K) = A(5,I,J)*CCN2
C
      DO 74C J=JY1P1,JLP
      K = K + 1
  740 TEMP(K) = W(5,I,J)*CCN2
C
      K = K + 1
      TEMP(K) = W(5,I,MID)*CCN2
C
      DO 745 J=JLP,JY4
      K = K + 1
  745 TEMP(K) = W(5,I,J)*CCN2
C
      DO 75C J=JY4P1,JY5M1
      K = K + 1
```

PRINT - 12

```
      JJ = JY5M1 - J + 2
  750 TEMP(K) = A(5,I,JJ)*CON2
C
      WRITE (6,28) (TEMP(K),K=1,13)
C
      IF (I.EQ.IX1) GO TO 790
      IF (IR(I).EQ.5.OR.IR(I).EQ.0.OR.IR(I).EQ.1) GO TO 755
      DO 752 M=1,2
  752 WRITE (6,21)
      GO TO 790
C
  755 DO 758 M=1,2
  758 WRITE (6,20)
      GO TO 790
C
C
  760 IF (I.NE.IDRCP(LK).OR.I.GT.IX3) GO TO 765
      LK = LK + 1
      LK1 = LK
      JLB = JLB + 1
      JUB = JUB - 1
      GO TO 766
C
  765 IF (I.NE.IDRCP(LK)) GO TO 766
      LK = LK + 1
      LK1 = LK1 - 1
      JLB = JLB - 1
      JUB = JUB + 1
C
  766 DO 770 J=JLB,JUP
      K = J - JLB + 1
  770 TEMP(K) = W(5,I,J)*CON2
C
      K = K + 1
      TEMP(K) = W(5,I,MID)*CON2
C
      DO 775 J=JLP,JLB
      K = K + 1
  775 TEMP(K) = W(5,I,J)*CON2
C
      GO TO (780,782,783,784,785,786),LK1
C
  780 IF (I.NE.2) GO TO 781
      WRITE (6,28) (TEMP(J),J=1,K)
      GO TO 790
C
  781 WRITE (6,22) (TEMP(J),J=1,K)
      GO TO 790
C
  782 WRITE (6,23) (TEMP(J),J=1,K)
      GO TO 790
C
  783 WRITE (6,24) (TEMP(J),J=1,K)
      GO TO 790
C
  784 WRITE (6,25) (TEMP(J),J=1,K)
      GO TO 790
C
```

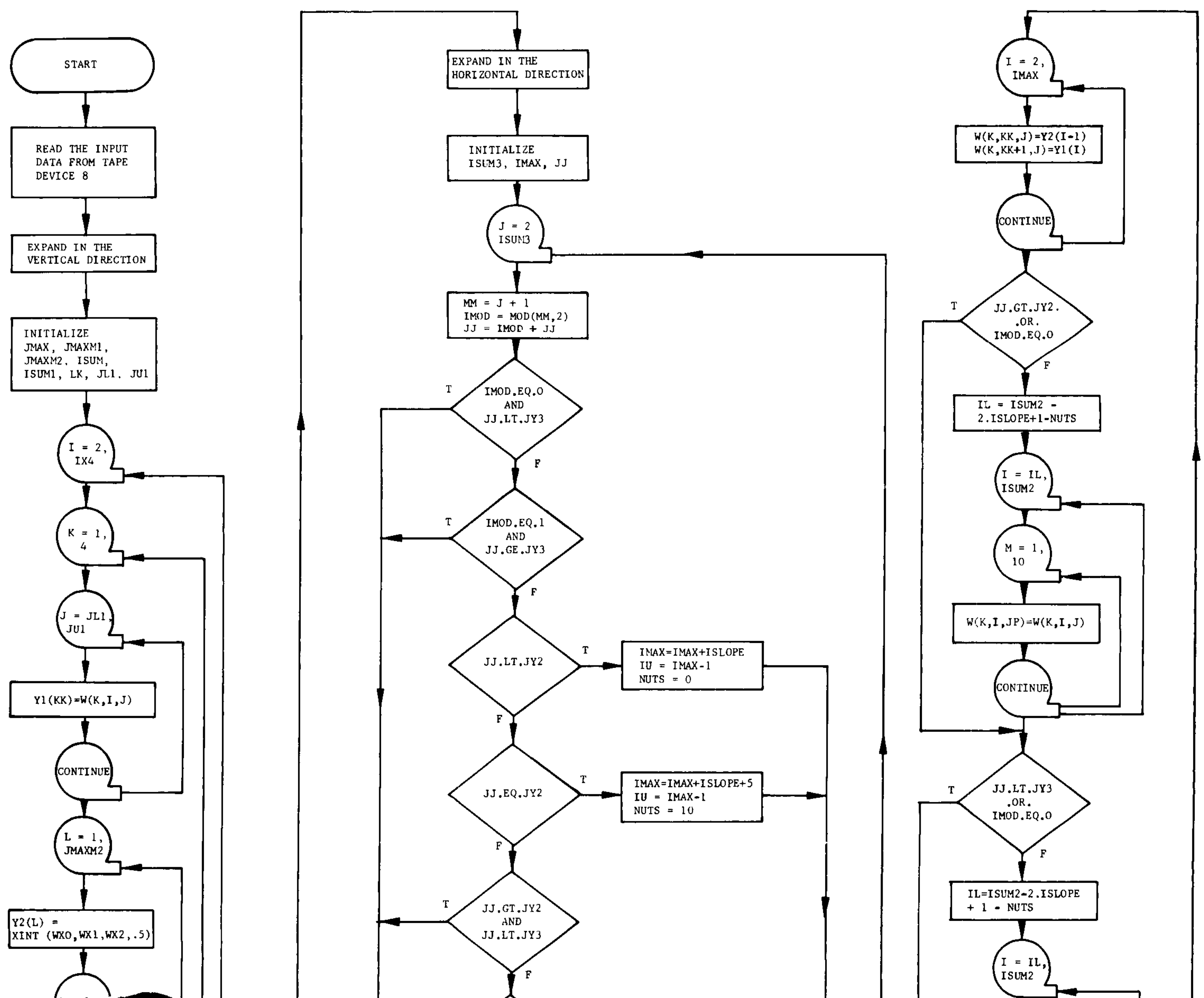
PRINT - 13

```
  785 WRITE (6,26) (TEMP(J),J=1,K)
      GC TC 79C
C
  786 WRITE (6,27) (TEMP(J),J=1,K)
C
  79C CCNTINLE
C
  800 IF (KICOFF.EC.C) GC TC 1CCC
C
C     ERRCR PRINTOLT
C
      WRITE (6,8C)
      WRITE (6,NAM1)
C
C
 1CC0 RETURN
      ENC
```

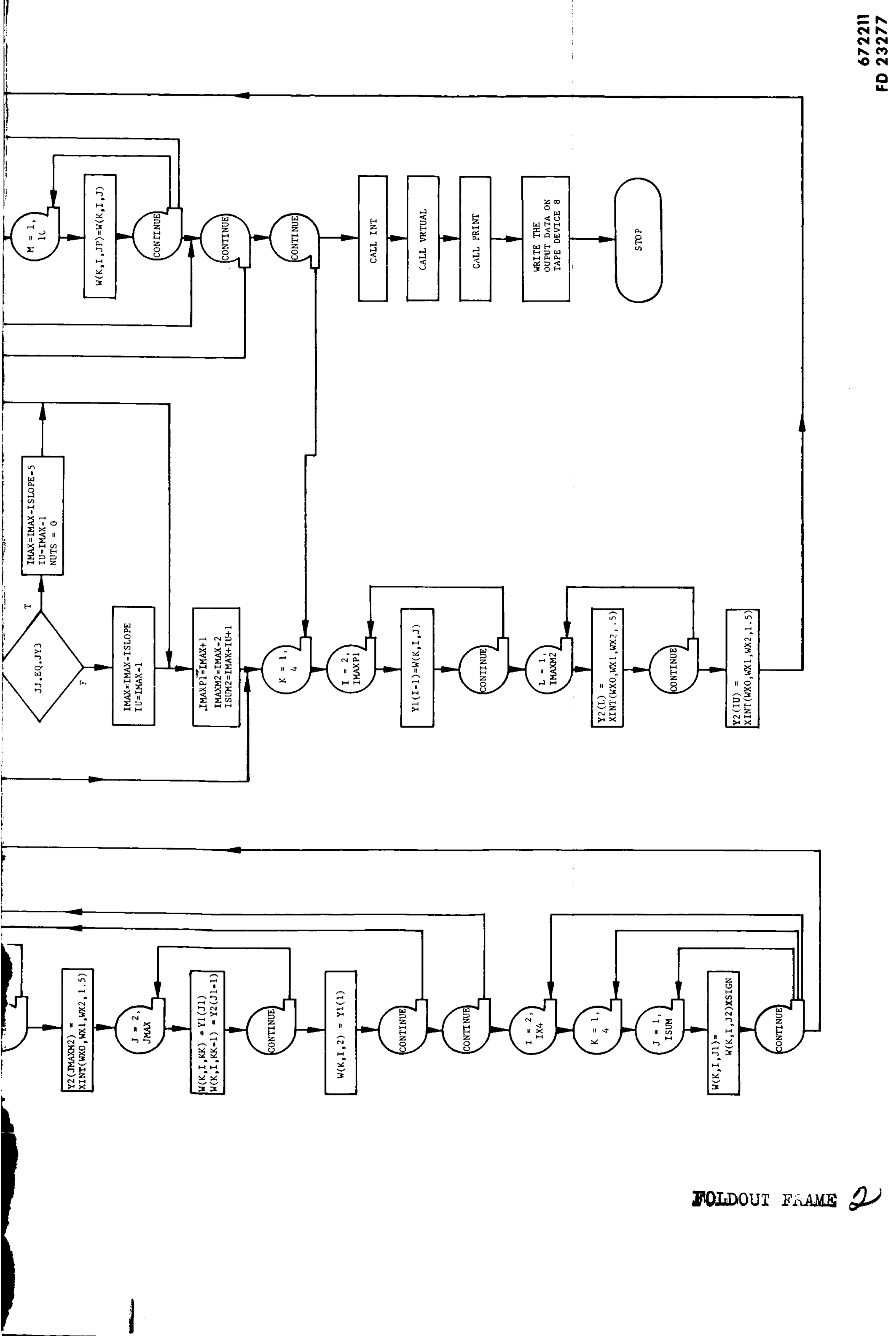

PRINT - 14

Figure D-9

DIAGRAM OF SUBROUTINE MAIN CONVERSION PROGRAM



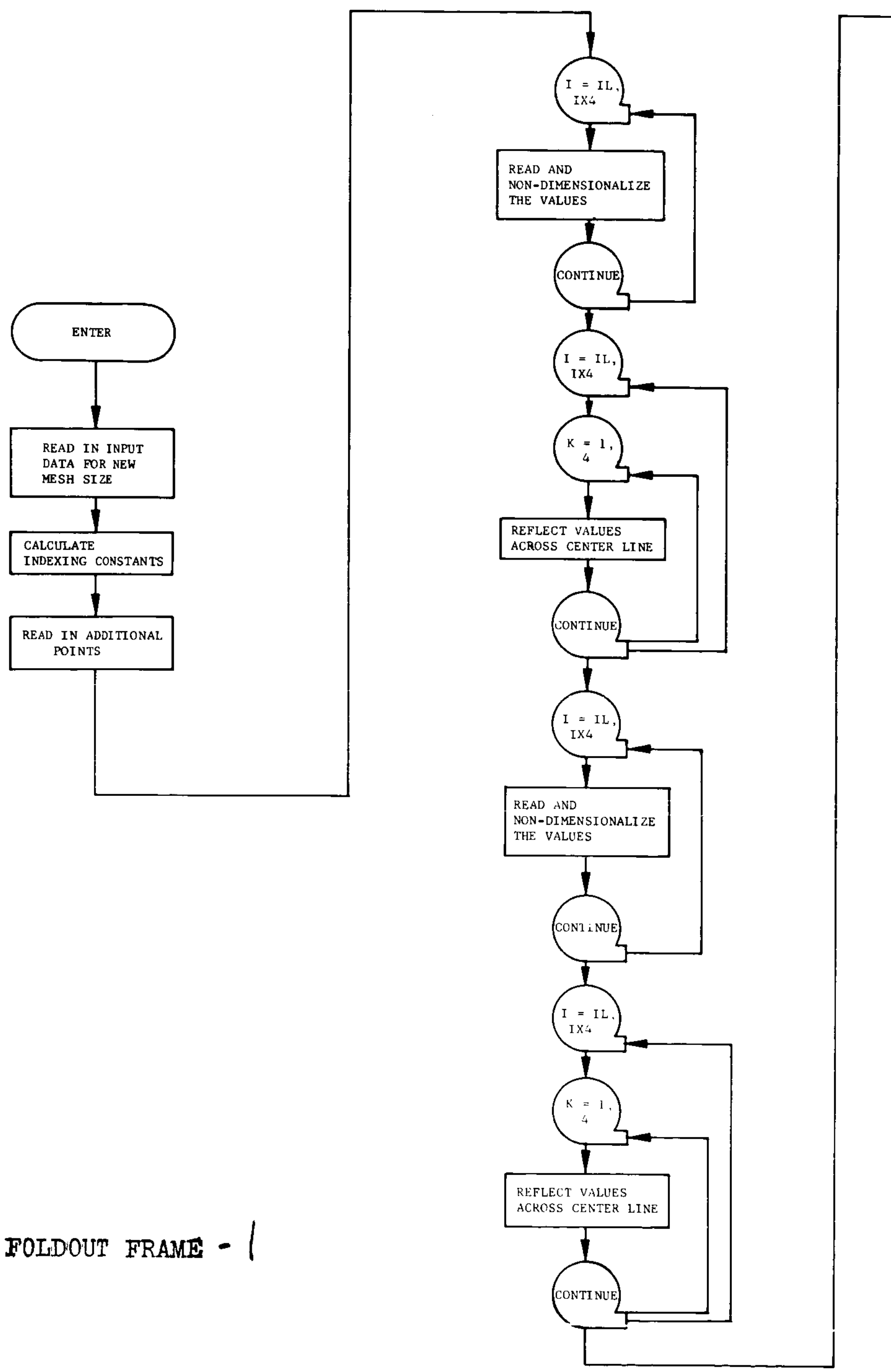
FOLDOUT FRAME



FOLDOUT FRAME 2

Figure

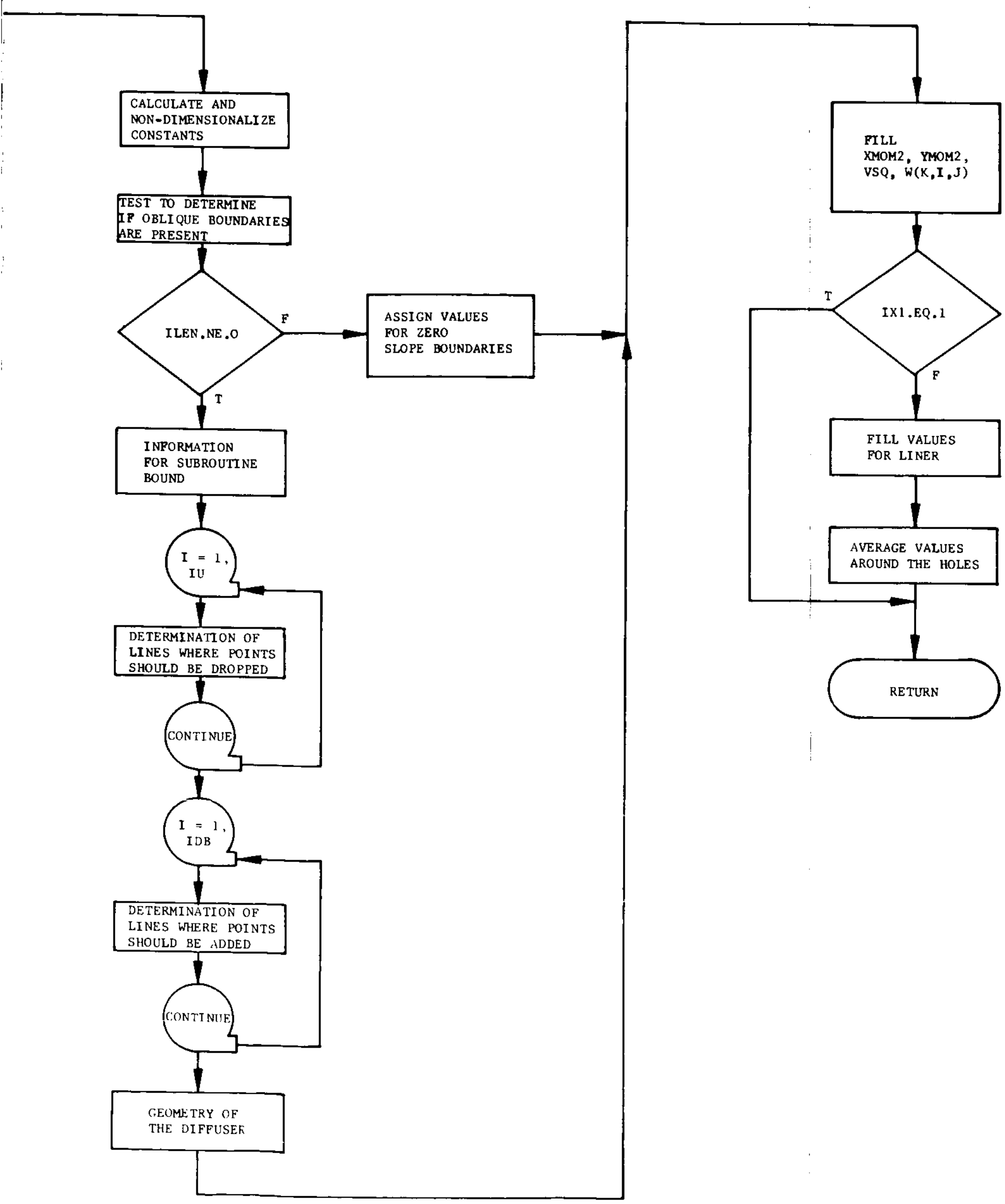
FLOW DIAGRAM OF SUBROUT



FOLDOUT FRAME - 1

e D-10

TINE INT CONVERSION PROGRAM



FOLDOUT FRAME - 2

672111
FD 23274

```
C     5964 MAIN
C
      INTEGER * 4 TCCUNT,T,TT
C
      COMMON/CCM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1           VSC(52,23), XMOM2A(30,5), YMOM2A(30,5), VSCA(30,5),
     2           GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     3           DELT    ,FUDGE   ,SC      ,TNC     ,TTCL    ,TP      ,
     4           CON3    ,DIFCC   ,XH      ,ENERO   ,XMU     ,OMEGA   ,THICK,
     5           QUE     ,QP      ,EXP     ,GUESS   ,GEE     ,IPEX
      COMMON/CCM2/ IDRCP(20)  ,IR(30),
     1           IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2           IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3           JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4           JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5           JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
      COMMON/CCM3/D(20),XDIS(3),XDISP(3),DFX(2),DFN(3),
     1           SINB1   ,COSB1   ,SINE    ,COSINE  ,DIST    ,DISTP   ,
     2           ILEN
      COMMON/CCM4/XM     ,PO      ,TO      ,RHCO    ,XMOMC   ,YMOMO   ,
     1                    AO      ,XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,
     2           CCN1    ,CCN2    ,IRHO    ,IM      ,IN      ,IE      ,
     3           IPRES   ,NOPT
      COMMON/CCM5/TCCUNT,T,KICOFF,TT
      COMMON/CCM6/TV(12,3,23), TVA(12,2,22), XV(52), YV(23),
     1           XVEL(2,2,23), YVEL(2,23), SONIC(2,2,23), PRES(2,2,23)
      COMMON/CCM7/AV(12,3,10),AVA(12,2,10),AXV(35),AYV(5)
C
      DIMENSION Y1(52), Y2(52)
C
C
      XINT(A,B,C,X) = A + X*(B - A) + X*(X - 1.0)*(C - 2.*B + A)/2.
C
      READ (8)  W       ,A       ,XMOM2   ,YMOM2   ,VSC     ,XMOM2A  ,YMOM2A  ,
     1          VSCA    ,GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     2          DELT    ,FUDGE   ,SC      ,TNC     ,TTCL    ,TP      ,CON3    ,
     3          DIFCC   ,XH      ,ENERC   ,XMU     ,OMEGA   ,THICK   ,QUE     ,
     4          QP      ,EXP
      READ (8)  IDRCP   ,IR      ,
     1          IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,IX4M1   ,
     2          IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,JY2     ,JY2M1   ,
     3          JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,JY3M2   ,JY3P1   ,JY4     ,
     4          JY4M1   ,JY4P1   ,JY5     ,JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,
     5          JEXU
      READ (8)  D       ,XDIS    ,XDISP   ,DFX     ,DFN     ,SINB1   ,
     1          COSB1   ,SINE    ,COSINE  ,DIST    ,DISTP   ,
     2          ILEN
      READ (8)  XM      ,PO      ,TO      ,RHCO    ,XMOMO   ,YMOMO   ,AO      ,
     1          XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,CCN1    ,CCN2    ,
     2          IRHO    ,IM      ,IN      ,IE      ,IPRES
      READ (8)  TCCUNT  ,T       ,KICOFF  ,TT
      READ (8)  TV      ,TVA     ,XV      ,YV      ,XVEL    ,YVEL    ,SONIC   ,
     1          PRES
      READ (8)  AV      ,AVA     ,AXV     ,AYV
      READ (8,END=120)
C
C     EXPAND IN THE VERTICAL DIRECTION
C
```

MAIN (CONV) - I

```
  120 JMAX = (JY5 - 2)/2 + 1
      JMAXM1 = JMAX - 1
      JMAXM2 = JMAX - 2
      ISUM = JMAX + JMAXM1
      ISUM1  = ISUM + 1
C
      LK = 1
      JL1 = 2
      JU1 = JY5/2 + 1
      DO 200 I=2,IX4
C
      DO 150 K=1,4
      KK = 0
      DO 130 J=JL1,JU1
      KK = KK + 1
  130 Y1(KK) = W(K,I,J)
C
      DO 135 L=1,JMAXM2
      WX0 = Y1(L)
      WX1 = Y1(L+1)
      WX2 = Y1(L+2)
  135 Y2(L) = XINT(WX0,WX1,WX2,.5)
C
      WX0 = Y1(JMAX-2)
      WX1 = Y1(JMAX-1)
      WX2 = Y1(JMAX)
      Y2(JMAXM1) = XINT(WX0,WX1,WX2,1.5)
C
C
      KK = ISUM1 + 2
      DO 140 J=2,JMAX
      J1 = JMAX - J + 2
      KK = KK - 2
      W(K,I,KK) = Y1(J1)
  140 W(K,I,KK-1) = Y2(J1-1)
      W(K,I,2) = Y1(1)
C
  150 CONTINUE
  200 CONTINUE
C
C
      DO 250 I=2,IX4
      DO 250 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
      DO 250 J=1,ISUM
      J1 = ISUM1 + J
      J2 = ISUM1 - J
      W(K,I,J1) = W(K,I,J2)*SIGN
  250 CONTINUE
C
C     EXPAND IN THE HORIZONTAL DIRECTION
C
      ISUM3 = 2*ISUM
      IMAX = IX2 - ISLOPE - 1
      JJ = 1
      DO 500 J=2,ISUM3
      MM = J + 1
```

MAIN (CONV) - 2

```
      IMOD = MOD(MM,2)
      JJ = IMOD + JJ
      IF (IMOD.EQ.0.AND.JJ.LT.JY3) GO TO 355
      IF (IMOD.EQ.1.AND.JJ.GE.JY3) GO TO 355
      IF (JJ.LT.JY2) GO TO 310
      IF (JJ.EQ.JY2) GO TO 320
      IF (JJ.GT.JY2.AND.JJ.LT.JY3) GO TO 355
      IF (JJ.EQ.JY3) GO TO 330
      GO TO 340
C
  310 IMAX = IMAX + ISLOPE
      IL = IMAX - 1
      NUTS = 0
      GO TO 350
C
  320 IMAX = IMAX + ISLOPE + 5
      IL = IMAX - 1
      NUTS = 10
      GO TO 350
C
  330 IMAX = IMAX - ISLOPE - 5
      IL = IMAX - 1
      NUTS = 0
      GO TO 350
C
  340 IMAX = IMAX - ISLOPE
      IL = IMAX - 1
C
  350 IMAXP1 = IMAX + 1
      IMAXM2 = IMAX - 2
      ISUM2 = IMAX + IL + 1
C
  355 DO 400 K=1,4
      DO 380 I=2,IMAXP1
  380 Y1(I-1) = W(K,I,J)
C
      DO 385 L=1,IMAXM2
      WX0 = Y1(L)
      WX1 = Y1(L+1)
      WX2 = Y1(L+2)
  385 Y2(L) = XINT(WX0,WX1,WX2,.5)
C
      WX0 = Y1(IMAX-2)
      WX1 = Y1(IMAX-1)
      WX2 = Y1(IMAX)
      Y2(IL) = XINT(WX0,WX1,WX2,1.5)
C
C
      KK = 1
      W(K,2,J) = Y1(1)
      DO 390 I=2,IMAX
      KK = KK + 2
      W(K,KK,J) = Y2(I-1)
  390 W(K,KK+1,J) = Y1(I)
C
      IF (JJ.GT.JY2.OR.IMOD.EQ.0) GO TO 394
      IL = ISUM2 - 2*ISLOPE + 1 - NUTS
      DO 391 I=IL,ISUM2
```

```
      CC 391 M=1,1C
      JP = J - M
      IF (JP.LE.1) GC TC 391
      W(K,I,JP) = W(K,I,J)
  391 CCNTINUE
C
  394 IF (JJ.LT.JY3.CR.IMOC.EQ.0) GC TC 400
      IL = ISUM2 - 2*ISLCPE + 1 - NUTS
      CC 395 I=IL,ISUM2
      CC 395 M=1,1C
      JP = J + M
      IF (JP.GT.ISUM3) GC TC 395
      W(K,I,JP) = W(K,I,J)
  395 CONTINUE
C
  4C0 CONTINUE
  5C0 CCNTINUE
C
C     RECIMENSICNALIZE THE CHAMBER
C
      CALL INT
C
      CALL VRTUAL
      CALL PRINT (1)
C
C     WRITE THE NEW DATA ON TAPE 8
C
      WRITE (8) W      ,A      ,XMOM2  ,YMOM2  ,VSC    ,XMOM2A ,YMOM2A ,
     1          VSCA   ,GAM    ,GAM1   ,GAM2   ,GAM3   ,DELX   ,DELY   ,
     2          DELT   ,FUDGE  ,SQ     ,TNC    ,TTCL   ,TP     ,CON3   ,
     3          DIFCC  ,XH     ,ENERO  ,XMU    ,OMEGA  ,THICK  ,QUE    ,
     4          CP     ,EXP
      WRITE (8) IDROP  ,IR     ,
     1          IX1    ,IX1M1  ,IX1P1  ,IX2    ,IX3    ,IX4    ,IX4M1  ,
     2          IX4M2  ,IX4M3  ,JY1    ,JY1M1  ,JY1P1  ,JY2    ,JY2M1  ,
     3          JY2P1  ,JY2P2  ,JY3    ,JY3M1  ,JY3M2  ,JY3P1  ,JY4    ,
     4          JY4M1  ,JY4P1  ,JY5    ,JY5M1  ,JY5M2  ,ISLOPE ,JEXL   ,
     5          JEXU
      WRITE (8) D      ,XDIS   ,XDISP  ,DFX    ,CFN    ,SINB1  ,
     1          COSB1  ,SINE   ,COSINE ,DIST   ,DISTP  ,
     2          ILEN
      WRITE (8) XM     ,PO     ,TO     ,RHOO   ,XMOMO  ,YMOMO  ,AO     ,
     1          XLEN   ,YLEN   ,XSLOPE ,SLOPE  ,CON1   ,CON2   ,
     2          IRHC   ,IM     ,IN     ,IE     ,IPRES
      WRITE (8) TCCUNT ,T      ,KICOFF ,TT
      WRITE (8) TV     ,TVA    ,XV     ,YV     ,XVEL   ,YVEL   ,SONIC  ,
     1          PRES
      WRITE (8) AV     ,AVA    ,AXV    ,AYV
C
      ENC FILE 8
      REWINC 8
C
      STCP
      ENC
```

MAIN (CONV) - 4

```
      SUBROLTINE INT
C
      INTEGER * 4 TCCUNT,T,TT
C
      COMMON/COM1/W(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23),
     1             VSC(52,23), XMCM2A(3C,5), YMCM2A(3C,5), VSCA(30,5),
     2             GAM     ,GAM1    ,GAM2    ,GAM3    ,DELX    ,DELY    ,
     3             CELT    ,FUDGE   ,SC      ,TNC     ,TTCL    ,TP      ,
     4             CCN3    ,CIFCC   ,XH      ,ENERO   ,XMU     ,CMEGA   ,THICK,
     5             CLE     ,CP      ,EXP     ,GUESS   ,GEE     ,IPEX
      CCMMON/CCM2/ ICRCP(2C)    ,IR(30),
     1             IX1     ,IX1M1   ,IX1P1   ,IX2     ,IX3     ,IX4     ,
     2             IX4M1   ,IX4M2   ,IX4M3   ,JY1     ,JY1M1   ,JY1P1   ,
     3             JY2     ,JY2M1   ,JY2P1   ,JY2P2   ,JY3     ,JY3M1   ,
     4             JY3M2   ,JY3P1   ,JY4     ,JY4M1   ,JY4P1   ,JY5     ,
     5             JY5M1   ,JY5M2   ,ISLOPE  ,JEXL    ,JEXU
      COMMON/COM3/C(2C),XDIS(3),XDISP(3),DFX(2),CFN(3),
     1             SINB1   ,CCSB1   ,SINE    ,COSINE  ,CIST    ,CISTP   ,
     2             ILEN
      COMMON/COM4/XM       ,PO      ,TO      ,RHCO    ,XMCMO   ,YMOMO   ,
     1                      AC      ,XLEN    ,YLEN    ,XSLOPE  ,SLOPE   ,
     2             CON1    ,CON2    ,IRHO    ,IM      ,IN      ,IE      ,
     3             IPRES   ,NCPT
      CCMMON/COM5/TCCUNT,T,KICCFF,TT
      COMMON/CCM6/TV(12,3,23), TVA(12,2,22), XV(52), YV(23),
     1             XVEL(2,2,23), YVEL(2,23), SCNIC(2,2,23), PRES(2,2,23)
      CCMMON/CCM7/AV(12,3,10),AVA(12,2,10),AXV(35),AYV(5)
C
    2 FORMAT (3I5)
    3 FORMAT (7F10.0, C10.C)
    4 FCRMAT (8I10)
    5 FCRMAT (4D10.C)
    9 FORMAT (I1C,3F10.0)
C
C     READ IN DATA
C
   40 READ (5,4) LENX1,LENX2,LENX3,LENX4
      READ (5,4) LENY1,LENY2,LENY3,LENY4,LENY5
      READ (5,3) XM, PC, TC, GAM, FUDGE, DELX, DIFCC, CUE
      READ (5,4) T,TT,NOPT,IRHC,IM,IN,IE,IPRES
      READ (5,9) TCOUNT,XMU,OMEGA,THICK
      READ (5,2) IFOLR, IEIGHT, MESH
C
      CP  = C.C
      EXP = C.C
      TP = C.0
      CELY=CELX
C
C     CALCULATE INCEXING CONSTANTS
C
      IX1 = LENX1 + 2
      IX1M1 = IX1 - 1
      IX1P1 = IX1 + 1
      IX2 = LENX2 + 2
      IX2P1 = IX2 + 1
      IX3 = LENX3 + 2
      IX3P1 = IX3 + 1
      IX4 = LENX4 + 2
```

INT - I

```
      IX4M1 = IX4 - 1
      IX4M2 = IX4 - 2
      IX4M3 = IX4 - 3
      JY1 = LENY1 + 2
      JY1M1 = JY1 - 1
      JY1P1 = JY1 + 1
      JY2 = LENY2 + 2
      JY2M1 = JY2 - 1
      JY2P1 = JY2 + 1
      JY2P2 = JY2 + 2
      JY3 = LENY3 + 2
      JY3M1 = JY3 - 1
      JY3M2 = JY3 - 2
      JY3P1 = JY3 + 1
      JY4 = LENY4 + 2
      JY4M1 = JY4 - 1
      JY4P1 = JY4 + 1
      JY5 = LENY5 + 3
      JY5M1 = JY5 - 1
      JY5M2 = JY5 - 2
      JEXL = JY2M1
      JEXU = JY3P1
      IF (MESH .EQ. 0) GO TO 45
      JEXL = JEXL - 1
      JEXU = JEXU + 1
   45 IL = IX3 + IFOUR
      DO 50 I=IL,IX4
      READ (5,5) (W(K,I,JY3+1),K=1,4)
      W(1,I,JY3+1) = W(1,I,JY3+1)/RHOO
      W(2,I,JY3+1) = W(2,I,JY3+1)/CON1
      W(3,I,JY3+1) = W(3,I,JY3+1)/CON1
   50 W(4,I,JY3+1) = W(4,I,JY3+1)/CON2
C
      DO 60 I=IL,IX4
      DO 60 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
   60 W(K,I,JY2-1) = SIGN*W(K,I,JY3+1)
C
      IL = IX3 + IEIGHT
      DO 70 I=IL,IX4
      READ (5,5) (W(K,I,JY3+2),K=1,4)
      W(1,I,JY3+2) = W(1,I,JY3+2)/RHOO
      W(2,I,JY3+2) = W(2,I,JY3+2)/CON1
      W(3,I,JY3+2) = W(3,I,JY3+2)/CON1
   70 W(4,I,JY3+2) = W(4,I,JY3+2)/CON2
C
      DO 80 I=IL,IX4
      DO 80 K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.0
   80 W(K,I,JY2-2) = SIGN*W(K,I,JY3+2)
C
C     CALCULATE CONSTANTS
C
C     NONDIMENSIONALIZE THE VARIABLES
C
   90 XLEN = LENX4*DELX
```

```
      CELX = DELX/XLEN
      CELY = CELX
      YLEN = LENY5*CELY
      GAM1 = GAM - 1.
      GAM2 = GAM1/2.
      GAM3 = (GAM - 3.)/2.
      SC = 1./SQRT(2.)
C
      RHOC = XM/1545.*PC/TC
      AC = SQRT(GAM*32.2*PC/RHCO)
      CCN1 = RHCO*AC
      CCN2 = CCN1*AC/32.2
      CCN3 = XLEN/AC
      ENERC = PO/GAM1/CCN2
      XML = XML/(PC*AC*XLEN)
      CMEGA = CMEGA*CCN3
      THICK = THICK/XLEN
      TNC = C.C
      TTCL = 0.0
      CUE = QUE / CCN2 * CCN3
C
C     TEST TC SEE IF CBLIQUE BCUNDARIES ARE PRESENT
C
      ILEN = LENX3 - LENX2
      IF (ILEN.NE.C) GC TC 100
      ISLOPE = C
      SLCPE = ISLOPE
      XSLOPE = C.0
      ICROP(1) = IX4 + 1
      SINB1 = 0.0
      CCSB1 = C.C
      GO TO 140
C
C     INFORMATION FOR SUBRCUTINE BCUND
C
  1C0 ISLOPE = ILEN/LENY2
      SLCPE = ISLCPE
      XSLCPE = -1./SLCPE
      CIS = SQRT((SLOPE*CELY)**2 + DELY**2)
      SINB1 = -CELY/CIS
      COSB1 = SLCPE*CELY/DIS
      CIST = DELY/CCSB1
      IU = ISLCPE + 1
C
      CO 11C I=1,ISLCPE
      R = I*CELX
      CS = -R*SINB1
  110 C(I) = 3.*CIST - 2.*CS
      C(IU) = 4.*DIST + 2.*IU*CELX*SINB1
C
      CO 112 I=1,3
      P = I
      Y = -P*DELY
  112 XCIS(I) = Y/SLOPE + 2.*DELX
C
      CO 114 I=1,3
      P = I
      Y = -(P + 1.)*CELY
```

```
  114 XDISP(I) = Y/SLOPE + 2.*DELX
C
C     DETERMINATION OF LINES WHERE POINTS SHOULD BE DROPPED
C
      IU = ILEN/ISLOPE
      DO 120 I=1,IU
      K = I - 1
  120 IDROP(I) = IX2 + K*ISLOPE + 1
C
      IDIS = 2
      IF (MESH .EQ. 1) IDIS = 3
      DO 125 I=1,IDIS
      K = IU + I
  125 IDROP(K) = IX3P1 + 3*I
      IDROP(K+1) = IX4 + 1
C
C     GEOMETRY FOR THE DIFFUSER
C
      DIS = SQRT((3.*DELY)**2 + DELY**2)
      SINE = DELY/DIS
      COSINE = 3.*SINE
      DISTP = DELY/COSINE
      DISP = 1./3.*DELX
C
      DO 130 M=1,2
  130 DFX(M) = DELX + M*DISP
      DO 135 M=1,3
      P = 3 - M + 1
      R = P*DELX
      DS = R*SINE
  135 DFN(M) = 3.*DISTP - 2.*DS
C
C     ESTABLISH INITIAL CONDITIONS
C
  140 DO 200 J=1,JY5
      DO 200 I=2,IX4
      XMOM2(I,J) = W(2,I,J)*W(2,I,J)/W(1,I,J)
      YMOM2(I,J) = W(3,I,J)*W(3,I,J)/W(1,I,J)
      VSQ(I,J) = (XMOM2(I,J) + YMOM2(I,J))/W(1,I,J)
      W(5,I,J) = GAM1*(W(4,I,J) - VSQ(I,J)*0.5*W(1,I,J))
  200 CONTINUE
C
      XH = GAM/GAM1*W(5,2,10)/W(1,2,10) + XMOM2(2,10)/(2.*W(1,2,10))
C
      IF (IX1.EQ.1) GO TO 450
      DO 300 I=2,IX1
      DO 210 J=2,JY1
      A(1,I,J) = 1.0
      A(2,I,J) = 0.0
      A(3,I,J) = 0.0
  210 A(4,I,J) = ENERO
      IF (I.EQ.2) GO TO 300
      IR(I) = MOD(I,6)
      IF (IR(I).EQ.0.OR.IR(I).EQ.1.OR.IR(I).EQ.2.OR.IR(I).EQ.5)GO TO 260
      GO TO 300
C
C     AVERAGE VALUES AROUND THE HOLES
C
```

INT - 4

```
  260 CO 28C K=1,4
      SIGN = 1.0
      IF (K.EQ.3) SIGN = -1.C
      A(K,I,JY1) = (A(K,I,JY1) + W(K,I,JY1))/2.
      W(K,I,JY1) = A(K,I,JY1)
  280 W(K,I,JY4) = SIGN*A(K,I,JY1)
C
  3CO CCNTINUE
C
      IR(2) = 2
C
      CC 4CC I=2,IX1
      CO 4CC J=2,JY1
      XMOM2A(I,J) = A(2,I,J)*A(2,I,J)/A(1,I,J)
      YMOM2A(I,J) = A(3,I,J)*A(3,I,J)/A(1,I,J)
      VSQA(I,J) = (XMOM2A(I,J) + YMOM2A(I,J))/A(1,I,J)
  400 A(5,I,J) = PC/CCN2
C
  450 RETURN
      END
```

INT - 5

APPENDIX E
STEADY-STATE RESULTS

STEADY STATE DENSITY FLOW FIELD

DENSITY AT TIME = 63.79632E-04 DELT = 20.98381E-07 TND = 34.50427E+00 TRIP NUMBER =2700

21.09E-01	21.49E-01	21.24E-01	21.45E-01	21.29E-01	21.43E-01	21.29E-01	21.45E-01	21.24E-01	21.49E-01	21.09E-01
10.50E-01	11.03E-01	10.72E-01	10.62E-01	10.63E-01	10.31E-01	10.63E-01	10.62E-01	10.72E-01	11.03E-01	10.50E-01
68.03E-02	62.88E-02	59.20E-02	58.55E-02	58.36E-02	57.54E-02	58.36E-02	58.55E-02	59.20E-02	62.88E-02	68.03E-02
51.59E-02	46.37E-02	42.83E-02	42.22E-02	41.99E-02	41.64E-02	41.99E-02	42.22E-02	42.83E-02	46.37E-02	51.59E-02
40.73E-02	35.88E-02	32.67E-02	32.06E-02	31.81E-02	31.72E-02	31.81E-02	32.06E-02	32.67E-02	35.88E-02	40.73E-02
33.28E-02	28.93E-02	26.09E-02	25.45E-02	25.21E-02	25.24E-02	25.21E-02	25.45E-02	26.09E-02	28.93E-02	33.28E-02
27.92E-02	24.03E-02	21.55E-02	20.88E-02	20.66E-02	20.75E-02	20.66E-02	20.88E-02	21.55E-02	24.03E-02	27.92E-02
23.91E-02	20.41E-02	18.24E-02	17.56E-02	17.36E-02	17.47E-02	17.36E-02	17.56E-02	18.24E-02	20.41E-02	23.91E-02
20.82E-02	17.63E-02	15.73E-02	15.06E-02	14.87E-02	14.99E-02	14.87E-02	15.06E-02	15.73E-02	17.63E-02	20.82E-02
18.40E-02	15.42E-02	13.77E-02	13.10E-02	12.94E-02	13.05E-02	12.94E-02	13.10E-02	13.77E-02	15.42E-02	18.40E-02
16.49E-02	13.61E-02	12.20E-02	11.53E-02	11.38E-02	11.49E-02	11.38E-02	11.53E-02	12.20E-02	13.61E-02	16.49E-02
14.93E-02	12.09E-02	10.94E-02	10.26E-02	10.13E-02	10.22E-02	10.13E-02	10.26E-02	10.94E-02	12.09E-02	14.93E-02
14.39E-02	10.68E-02	97.57E-03	91.47E-03	90.23E-03	91.00E-03	90.23E-03	91.47E-03	97.57E-03	10.68E-02	14.39E-02
12.16E-02	99.81E-03	89.58E-03	83.70E-03	82.27E-03	82.64E-03	82.27E-03	83.70E-03	89.58E-03	99.81E-03	12.16E-02
12.97E-02	94.66E-03	83.83E-03	78.79E-03	78.31E-03	78.78E-03	78.31E-03	78.79E-03	83.83E-03	94.66E-03	12.97E-02
	10.09E-02	89.43E-03	81.21E-03	78.37E-03	78.19E-03	78.37E-03	81.21E-03	89.43E-03	10.09E-02	
	95.60E-03	88.53E-03	80.86E-03	77.41E-03	76.79E-03	77.41E-03	80.86E-03	88.53E-03	95.60E-03	

FOLDOUT FRAME 1

91.17E-03	86.55E-03	80.15E-03	76.15E-03	75.08E-03	76.15E-03	80.15E-03	86.55E-03	91.17E-03
	83.09E-03	78.22E-03	74.31E-03	72.93E-03	74.31E-03	78.22E-03	83.09E-03	
	77.09E-03	74.42E-03	71.40E-03	70.05E-03	71.40E-03	74.42E-03	77.09E-03	
	67.56E-03	67.72E-03	66.60E-03	65.08E-03	66.60E-03	67.72E-03	67.56E-03	
	51.06E-03	55.99E-03	59.88E-03	59.30E-03	59.88E-03	55.99E-03	51.06E-03	
	41.16E-03	45.84E-03	51.44E-03	52.01E-03	51.44E-03	45.84E-03	41.16E-03	
	35.00E-03	39.60E-03	43.48E-03	44.55E-03	43.48E-03	39.60E-03	35.00E-03	
31.00E-03	31.72E-03	35.58E-03	37.32E-03	38.03E-03	37.32E-03	35.58E-03	31.72E-03	31.00E-03
25.00E-03	31.72E-03	35.58E-03	37.32E-03	38.03E-03	37.32E-03	35.58E-03	31.72E-03	25.00E-03

FOLDOUT FRAME 2

STEADY STATE X-MOMENTUM FLOW FIELD

X-MOMENTUM AT TIME = 63.79632E-04 DELT = 20.98381E-07 TND = 34.50427E+00 TRIP NUMBER =2700

20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01	20.30E+01
10.45E+01	88.03E+00	86.66E+00	84.82E+00	85.34E+00	83.66E+00	85.34E+00	84.82E+00	86.66E+00	88.03E+00	10.45E+01
11.64E+01	94.59E+00	90.64E+00	90.21E+00	89.82E+00	90.64E+00	89.82E+00	90.21E+00	90.64E+00	94.59E+00	11.64E+01
15.58E+01	13.86E+01	13.07E+01	13.11E+01	12.98E+01	13.15E+01	12.98E+01	13.11E+01	13.07E+01	13.86E+01	15.58E+01
17.77E+01	16.01E+01	14.91E+01	15.00E+01	14.78E+01	15.06E+01	14.78E+01	15.00E+01	14.91E+01	16.01E+01	17.77E+01
19.17E+01	17.23E+01	15.93E+01	15.99E+01	15.72E+01	16.07E+01	15.72E+01	15.99E+01	15.93E+01	17.23E+01	19.17E+01
20.09E+01	17.98E+01	16.58E+01	16.59E+01	16.29E+01	16.67E+01	16.29E+01	16.59E+01	16.58E+01	17.98E+01	20.09E+01
20.73E+01	18.45E+01	17.01E+01	16.96E+01	16.65E+01	17.05E+01	16.65E+01	16.96E+01	17.01E+01	18.45E+01	20.73E+01
21.18E+01	18.75E+01	17.30E+01	17.21E+01	16.90E+01	17.30E+01	16.90E+01	17.21E+01	17.30E+01	18.75E+01	21.18E+01
21.51E+01	18.94E+01	17.51E+01	17.38E+01	17.10E+01	17.49E+01	17.10E+01	17.38E+01	17.51E+01	18.94E+01	21.51E+01
21.79E+01	19.00E+01	17.65E+01	17.51E+01	17.27E+01	17.64E+01	17.27E+01	17.51E+01	17.65E+01	19.00E+01	21.79E+01
21.93E+01	18.94E+01	17.82E+01	17.65E+01	17.47E+01	17.81E+01	17.47E+01	17.65E+01	17.82E+01	18.94E+01	21.93E+01
23.11E+01	18.54E+01	17.68E+01	17.67E+01	17.59E+01	17.91E+01	17.59E+01	17.67E+01	17.68E+01	18.54E+01	23.11E+01
20.66E+01	18.95E+01	18.15E+01	18.22E+01	18.18E+01	18.41E+01	18.18E+01	18.22E+01	18.15E+01	18.95E+01	20.66E+01
21.49E+01	18.54E+01	18.12E+01	18.72E+01	19.01E+01	19.30E+01	19.01E+01	18.72E+01	18.12E+01	18.54E+01	21.49E+01
	19.86E+01	19.51E+01	19.48E+01	19.63E+01	19.85E+01	19.63E+01	19.48E+01	19.51E+01	19.86E+01	
	21.54E+01	21.53E+01	21.15E+01	20.99E+01	21.04E+01	20.99E+01	21.15E+01	21.53E+01	21.54E+01	

FOLDOUT FRAME

22.78E+01	23.3[illegible]	23.04E+01	22.65E+01	22.55E+01	22.65E+01	23.04E+01	23.34E+01	22.78E+01
	25.30E+01	25.17E+01	24.58E+01	24.32E+01	24.58E+01	25.17E+01	25.30E+01	
	27.36E+01	27.51E+01	26.68E+01	26.25E+01	26.68E+01	27.51E+01	27.36E+01	
	28.46E+01	29.23E+01	28.42E+01	27.89E+01	28.42E+01	29.23E+01	28.46E+01	
	24.49E+01	27.85E+01	29.14E+01	28.52E+01	29.14F+01	27.85E+01	24.49E+01	
	22.53E+01	25.42E+01	28.16E+01	28.16E+01	28.16E+01	25.42E+01	22.53E+01	
	20.86E+01	23.74E+01	26.15E+01	26.70E+01	26.15E+01	23.74E+01	20.86E+01	
25.40E+01	21.26E+01	22.37E+01	23.96E+01	24.53E+01	23.96E+01	22.37E+01	21.26E+01	25.40E+01
23.00E+01	21.26E+01	22.37E+01	23.96E+01	24.53E+01	23.96E+01	22.37E+01	21.26E+01	23.00E+01

STEADY STATE Y-MOMENTUM FLOW FIELD

Y-MOMENTUM AT TIME = 63.79632E-04 DELT = 20.98581E-07 TND = 34.50427E+00 TRIP NUMBER =2700

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	-17.61E+00	-51.05E-01	-83.08E-01	-83.32E-02	0.	83.32E-02	83.08E-01	51.05E-01	17.61E+00	0.
0.	-23.75E+00	-35.31E-01	-77.43E-01	-66.01E-02	0.	66.01E-02	77.43E-01	35.31E-01	23.75E+00	0.
0.	-20.60E+00	-26.50E-01	-66.11E-01	-64.19E-02	0.	64.19E-02	66.11E-01	26.50E-01	20.60E+00	0.
0.	-16.49E+00	-17.62E-01	-51.69E-01	-51.34E-02	0.	51.34E-02	51.69E-01	17.62E-01	16.49E+00	0.
0.	-13.45E+00	-10.71E-01	-39.03E-01	-33.76E-02	0.	33.76E-02	39.03E-01	10.71E-01	13.45E+00	0.
0.	-11.21E+00	-56.03E-02	-28.97E-01	-16.58E-02	0.	16.58E-02	28.97E-01	56.03E-02	11.21E+00	0.
0.	-94.56E-01	-15.31E-02	-20.74E-01	-20.72E-04	0.	20.72E-04	20.74E-01	15.31E-02	94.56E-01	0.
0.	-80.00E-01	23.52E-02	-13.38E-01	18.08E-02	0.	-18.08E-02	13.38E-01	-23.52E-02	80.00E-01	0.
0.	-66.71E-01	70.63E-02	-57.76E-02	42.66E-02	0.	-42.66E-02	57.76E-02	-70.63E-02	66.71E-01	0.
0.	-52.26E-01	13.86E-01	32.65E-02	79.00E-02	0.	-79.00E-02	-32.65E-02	-13.86E-01	52.26E-01	0.
0.	-37.13E-01	24.43E-01	15.77E-01	13.66E-01	0.	-13.66E-01	-15.77E-01	-24.43E-01	37.13E-01	0.
0.	-86.80E-02	45.03E-01	33.24E-01	22.71E-01	0.	-22.71E-01	-33.24E-01	-45.03E-01	86.80E-02	0.
0.	64.61E-01	11.36E+00	75.32E-01	40.62E-01	0.	-40.62E-01	-75.32E-01	-11.36E+00	-64.61E-01	0.
0.	-22.99E-02	38.94E-01	45.99E-01	35.32E-01	0.	-35.32E-01	-45.99E-01	-38.94E-01	22.99E-02	0.
	57.71E+00	35.44E+00	20.98E+00	10.33E+00	0.	-10.33E+00	-20.98E+00	-35.44E+00	-57.71E+00	
	65.57E+00	45.63E+00	28.38E+00	13.93E+00	0.	-13.93E+00	-28.38E+00	-45.63E+00	-65.57E+00	

FOLDOUT FRAME

76.12E+00	54.85E+00	33.91E+00	16.20E+00	0.	-16.20E+00	-33.91E+00	-54.85E+00	-76.12E+00
	65.75E+00	39.87E+00	18.27E+00	0.	-18.27E+00	-39.87E+00	-65.75E+00	
	76.24E+00	44.97E+00	19.83E+00	0.	-19.83E+00	-44.97E+00	-76.24E+00	
	57.61E+00	36.39E+00	16.02E+00	0.	-16.02E+00	-36.39E+00	-57.61E+00	
	-61.20E+00	38.26E-01	33.47E-01	0.	-33.47E-01	-38.26E-01	61.20E+00	
	-56.12E+00	-27.45E+00	-11.47E+00	0.	11.47E+00	27.45E+00	56.12E+00	
	-57.49E+00	-40.28E+00	-20.71E+00	0.	20.71E+00	40.28E+00	57.49E+00	
-10.00E+00	-38.44E+00	-40.29E+00	-22.19E+00	0.	22.19E+00	40.29E+00	38.44E+00	10.00E+00
-10.00E+00	-38.44E+00	-40.29E+00	-22.19E+00	0.	22.19E+00	40.29E+00	38.44E+00	10.00E+00

FOLDOUT FRAME 2

STEADY STATE ENERGY FLOW FIELD

ENERGY AT TIME = 63.79632E-04 DELT = 20.98381E-07 TND = 34.50427E+00 TRIP NUMBER =2700

34.06E+04	34.71E+04	34.32E+04	34.64E+04	34.39E+04	34.62E+04	34.39E+04	34.64E+04	34.32E+04	34.71E+04	34.06E+04
33.88E+04	34.16E+04	33.89E+04	34.17E+04	33.94E+04	34.17E+04	33.94E+04	34.17E+04	33.89E+04	34.16E+04	33.88E+04
34.19E+04	35.10E+04	34.63E+04	34.98E+04	34.72E+04	34.95E+04	34.72E+04	34.98E+04	34.63E+04	35.10E+04	34.19E+04
33.67E+04	34.45E+04	33.97E+04	34.31E+04	34.05E+04	34.28E+04	34.05E+04	34.31E+04	33.97E+04	34.45E+04	33.67E+04
33.26E+04	33.94E+04	33.49E+04	33.79E+04	33.55E+04	33.76E+04	33.55E+04	33.79E+04	33.49E+04	33.94E+04	33.26E+04
32.84E+04	33.46E+04	33.04E+04	33.31E+04	33.10E+04	33.28E+04	33.10E+04	33.31E+04	33.04E+04	33.46E+04	32.84E+04
32.41E+04	32.99E+04	32.59E+04	32.83E+04	32.65E+04	32.81E+04	32.65E+04	32.83E+04	32.59E+04	32.99E+04	32.41E+04
31.98E+04	32.51E+04	32.15E+04	32.36E+04	32.19E+04	32.33E+04	32.19E+04	32.36E+04	32.15E+04	32.51E+04	31.98E+04
31.55E+04	32.03E+04	31.69E+04	31.88E+04	31.73E+04	31.85E+04	31.73E+04	31.88E+04	31.69E+04	32.03E+04	31.55E+04
31.11E+04	31.54E+04	31.23E+04	31.39E+04	31.25E+04	31.36E+04	31.25E+04	31.39E+04	31.23E+04	31.54E+04	31.11E+04
30.67E+04	31.04E+04	30.75E+04	30.88E+04	30.76E+04	30.85E+04	30.76E+04	30.88E+04	30.75E+04	31.04E+04	30.67E+04
30.22E+04	30.55E+04	30.27E+04	30.37E+04	30.25E+04	30.32E+04	30.25E+04	30.37E+04	30.27E+04	30.55E+04	30.22E+04
29.87E+04	30.01E+04	29.71E+04	29.79E+04	29.67E+04	29.73E+04	29.67E+04	29.79E+04	29.71E+04	30.01E+04	29.87E+04
29.35E+04	29.71E+04	29.38E+04	29.35E+04	29.19E+04	29.20E+04	29.19E+04	29.35E+04	29.38E+04	29.71E+04	29.35E+04
29.80E+04	28.82E+04	28.35E+04	28.31E+04	28.17E+04	28.21E+04	28.17E+04	28.31E+04	28.35E+04	28.82E+04	29.80E+04
	29.51E+04	28.87E+04	28.51E+04	28.18E+04	28.11E+04	28.18E+04	28.51E+04	28.87E+04	29.51E+04	
	28.11E+04	28.01E+04	27.82E+04	27.68E+04	27.64E+04	27.68E+04	27.82E+04	28.01E+04	28.11E+04	

FOLDOUT FRAME

27.42E+04	27.17E+04	27.06E+04	26.99E+04	26.96E+04	26.99E+04	27.06E+04	27.17E+04	27.42E+04
	26.14E+04	26.06E+04	26.06E+04	26.05E+04	26.06E+04	26.06E+04	26.14E+04	
	24.72E+04	24.75E+04	24.84E+04	24.87E+04	24.84E+04	24.75E+04	24.72E+04	
	22.03E+04	22.69E+04	23.15E+04	23.28E+04	23.15E+04	22.69E+04	22.03E+04	
	16.99E+04	18.77E+04	20.92E+04	21.11E+04	20.92E+04	18.77E+04	16.99E+04	
	13.70E+04	15.48E+04	18.03E+04	18.53E+04	18.03E+04	15.48E+04	13.70E+04	
	11.71E+04	13.51E+04	15.28E+04	15.85E+04	15.28E+04	13.51E+04	11.71E+04	
13.40E+04	11.48E+04	12.18E+04	13.10E+04	13.49E+04	13.10E+04	12.18E+04	11.48E+04	13.40E+04
11.30E+04	11.48E+04	12.18E+04	13.10E+04	13.49E+04	13.10E+04	12.18E+04	11.48E+04	11.30E+04

FOLDOUT FRAME 2

STEADY STATE PRESSURE FLOW FIELD

PRESSURE AT TIME = 63.79632E-04 DELT = 20.98381E-07 TND = 34.50427E+00 TRIP NUMBER =2700

68.07E+03	69.36E+03	68.58E+03	69.23E+03	68.71E+03	69.18E+03	68.71E+03	69.23E+03	68.58E+03	69.36E+03	68.07E+03
67.73E+03	68.29E+03	67.75E+03	68.32E+03	67.85E+03	68.31E+03	67.85E+03	68.32E+03	67.75E+03	68.29E+03	67.73E+03
68.32E+03	70.15E+03	69.22E+03	69.91E+03	69.40E+03	69.86E+03	69.40E+03	69.91E+03	69.22E+03	70.15E+03	68.32E+03
67.20E+03	68.76E+03	67.81E+03	68.48E+03	67.98E+03	68.44E+03	67.98E+03	68.48E+03	67.81E+03	68.76E+03	67.20E+03
66.27E+03	67.66E+03	66.76E+03	67.35E+03	66.90E+03	67.30E+03	66.90E+03	67.35E+03	66.76E+03	67.66E+03	66.27E+03
65.33E+03	66.61E+03	65.78E+03	66.31E+03	65.90E+03	66.24E+03	65.90E+03	66.31E+03	65.78E+03	66.61E+03	65.33E+03
64.37E+03	65.55E+03	64.79E+03	65.26E+03	64.90E+03	65.20E+03	64.90E+03	65.26E+03	64.79E+03	65.55E+03	64.37E+03
63.41E+03	64.50E+03	63.80E+03	64.21E+03	63.89E+03	64.15E+03	63.89E+03	64.21E+03	63.80E+03	64.50E+03	63.41E+03
62.43E+03	63.43E+03	62.79E+03	63.15E+03	62.86E+03	63.09E+03	62.86E+03	63.15E+03	62.79E+03	63.43E+03	62.43E+03
61.44E+03	62.35E+03	61.76E+03	62.06E+03	61.81E+03	62.00E+03	61.81E+03	62.06E+03	61.76E+03	62.35E+03	61.44E+03
60.45E+03	61.25E+03	60.70E+03	60.94E+03	60.70E+03	60.87E+03	60.70E+03	60.94E+03	60.70E+03	61.25E+03	60.45E+03
59.45E+03	60.18E+03	59.64E+03	59.79E+03	59.56E+03	59.68E+03	59.56E+03	59.79E+03	59.64E+03	60.18E+03	59.45E+03
58.59E+03	59.02E+03	58.42E+03	58.52E+03	58.27E+03	58.37E+03	58.27E+03	58.52E+03	58.42E+03	59.02E+03	58.59E+03
57.61E+03	58.31E+03	57.62E+03	57.46E+03	57.13E+03	57.14E+03	57.13E+03	57.46E+03	57.62E+03	58.31E+03	57.61E+03
58.50E+03	56.50E+03	55.49E+03	55.24E+03	54.91E+03	54.96E+03	54.91E+03	55.24E+03	55.49E+03	56.50E+03	58.50E+03
	57.71E+03	56.38E+03	55.55E+03	54.83E+03	54.66E+03	54.83E+03	55.55E+03	56.38E+03	57.71E+03	

FOLDOUT FRAME 1

54.58E+03	54.31E+03	53.89E+03	53.58E+03	53.49E+03	53.58E+03	53.89E+03	54.31E+03	54.58E+03
52.88E+03	52.28E+03	52.03E+03	51.87E+03	51.82E+03	51.87E+03	52.03E+03	52.28E+03	52.88E+03
	49.73E+03	49.55E+03	49.58E+03	49.59E+03	49.58E+03	49.55E+03	49.73E+03	
	46.19E+03	46.27E+03	46.58E+03	46.69E+03	46.58E+03	46.27E+03	46.19E+03	
	40.19E+03	41.40E+03	42.52E+03	42.88E+03	42.52E+03	41.40E+03	40.19E+03	
	30.11E+03	33.23E+03	37.43E+03	37.96E+03	37.43E+03	33.23E+03	30.11E+03	
	23.33E+03	26.53E+03	31.26E+03	32.33E+03	31.26E+03	26.53E+03	23.33E+03	
	19.27E+03	22.48E+03	25.64E+03	26.73E+03	25.64E+03	22.48E+03	19.27E+03	
20.33E+03	18.40E+03	19.85E+03	21.39E+03	22.06E+03	21.39E+03	19.85E+03	18.40E+03	20.33E+03
16.02E+03	18.40E+03	19.85E+03	21.39E+03	22.06E+03	21.39E+03	19.85E+03	18.40E+03	16.02E+03

FOLDOUT FRAME 2

APPENDIX F
REFERENCES

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4. Burstein, S. Z., "Numerical Calculation of Multidimensional Shocked Flow," Preprint No. 64-2, Aerospace Science Meeting, New York, New York, January, 1964.

5. Burstein, S. Z., "Nonlinear Combustion Instability in Liquid-Propellant Rocket Engine," NASA TR 32-1111, 15 September 1967.

6. Shapiro, A. S., "Compressible Fluid Flow," Ronald Press, New York, New York.

7. Richtmyer, R. D., "Difference Methods for Initial Value Problems," McGraw Hill, New York.

8. Priem, R. J., and M. F. Heidemann, "Propellant Vaporization as a Design Criterion for Rocket-Engine Combustion Chambers," NASA TR-67.

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