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
FLORIDA RESEARCH AND DEVELOPMENT CENTER
BOX 2691, WEST PALM BEACH, FLORIDA 33402

U. A.®

PRINTED IN THE UNITED STATES OF AMERICA
COMPUTER SIMULATION OF
HIGH FREQUENCY COMBUSTION INSTABILITY
AND ITS SUPPRESSION

FINAL REPORT

Prepared by: R. E. Bucher
Program Manager

Approved by: M. T. Schilling
Project Engineer

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

Contract NASw-1512
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

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLUSTRATIONS</td>
<td>iv</td>
</tr>
<tr>
<td>I    INTRODUCTION</td>
<td>I-1</td>
</tr>
<tr>
<td>II   GAS MOTION WITHIN SLAB MOTORS AND</td>
<td>II-1</td>
</tr>
<tr>
<td>ACOUSTIC LINERS</td>
<td></td>
</tr>
<tr>
<td>III  NUMERICAL INTEGRATION</td>
<td>III-1</td>
</tr>
<tr>
<td>IV   COMPUTER PROGRAMS</td>
<td>IV-1</td>
</tr>
<tr>
<td>A. General</td>
<td>IV-1</td>
</tr>
<tr>
<td>B. Integration Program</td>
<td>IV-1</td>
</tr>
<tr>
<td>C. Conversion Program</td>
<td>IV-29</td>
</tr>
<tr>
<td>V    COMPUTED RESULTS</td>
<td>V-1</td>
</tr>
<tr>
<td>A. General</td>
<td>V-1</td>
</tr>
<tr>
<td>B. Steady-State Simulation</td>
<td>V-2</td>
</tr>
<tr>
<td>C. Transient Simulation</td>
<td>V-8</td>
</tr>
<tr>
<td>VI   CONCLUSIONS AND RECOMMENDATIONS</td>
<td>VI-1</td>
</tr>
<tr>
<td>APPENDIX A - Reduction of Eulerian Inviscid</td>
<td>A-1</td>
</tr>
<tr>
<td>Flow Equations to Normal Form</td>
<td></td>
</tr>
<tr>
<td>APPENDIX B - Computation of Density at</td>
<td>B-1</td>
</tr>
<tr>
<td>Injector Face</td>
<td></td>
</tr>
<tr>
<td>APPENDIX C - Predictor-Corrector Technique</td>
<td>C-1</td>
</tr>
<tr>
<td>APPENDIX D - Flow Diagrams and Subroutine</td>
<td>D-1</td>
</tr>
<tr>
<td>Listings</td>
<td></td>
</tr>
<tr>
<td>APPENDIX E - Steady-State Results</td>
<td>E-1</td>
</tr>
<tr>
<td>APPENDIX F - References</td>
<td>F-1</td>
</tr>
</tbody>
</table>
# ILLUSTRATIONS

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>DESCRIPTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slab Motor</td>
<td>II-1</td>
</tr>
<tr>
<td>2</td>
<td>Slab Motor With Acoustic Liner</td>
<td>II-2</td>
</tr>
<tr>
<td>3</td>
<td>Two-Dimensional Representation of Slab Motor With Acoustic Liner</td>
<td>II-2</td>
</tr>
<tr>
<td>4</td>
<td>Configuration of Mesh Points for Unlined Chamber Based on 1/2-inch Spacing</td>
<td>III-1</td>
</tr>
<tr>
<td>5</td>
<td>Reflection at an Oblique Boundary</td>
<td>III-5</td>
</tr>
<tr>
<td>6</td>
<td>Configuration of Mesh Points for Unlined Chamber Based on 1/2-inch Spacing</td>
<td>IV-3</td>
</tr>
<tr>
<td>7</td>
<td>Configuration of Mesh Points for Lined Chamber Based on 1/4-inch Spacing</td>
<td>IV-4</td>
</tr>
<tr>
<td>8</td>
<td>Configuration Using a Liner</td>
<td>IV-20</td>
</tr>
<tr>
<td>9</td>
<td>Geometry Used in BOUND</td>
<td>IV-21</td>
</tr>
<tr>
<td>10</td>
<td>Virtual Point Calculation</td>
<td>IV-23</td>
</tr>
<tr>
<td>11</td>
<td>Chamber Pressure at Injector Face</td>
<td>V-4</td>
</tr>
<tr>
<td>12</td>
<td>Gas Density as a Function of Distance from Injector Face and Time</td>
<td>V-5</td>
</tr>
<tr>
<td>13</td>
<td>x-Momentum as a Function of Distance from Injector Face and Time</td>
<td>V-6</td>
</tr>
<tr>
<td>14</td>
<td>Chamber Pressure as a Function of Distance from Injector Face and Time</td>
<td>V-7</td>
</tr>
<tr>
<td>15</td>
<td>Effect of Mesh Size on Wall Pressure at Injector Face as a Function of Time</td>
<td>V-11</td>
</tr>
<tr>
<td>16</td>
<td>Effect of Location in Combustion Chamber on Wall Pressure as a Function of Time</td>
<td>V-12</td>
</tr>
<tr>
<td>17</td>
<td>Effect of n on Wall Pressure at Injector Face as a Function of Time</td>
<td>V-13</td>
</tr>
<tr>
<td>18</td>
<td>Effect of n on Wall Pressure at Injector Face as a Function of Time</td>
<td>V-14</td>
</tr>
<tr>
<td>19</td>
<td>Effect of Sound-Absorbing Liner on Wall Pressure at Injector Face as a Function of Time</td>
<td>V-15</td>
</tr>
<tr>
<td>20</td>
<td>Specific Acoustic Resistance as a Function of Frequency</td>
<td>V-17</td>
</tr>
<tr>
<td>21</td>
<td>Specific Acoustic Reactance as a Function of Frequency</td>
<td>V-18</td>
</tr>
<tr>
<td>22</td>
<td>Absorption Coefficient as a Function of Frequency</td>
<td>V-19</td>
</tr>
<tr>
<td>23</td>
<td>Comparison of Experimental to Computed Wall Pressures at Injector Face</td>
<td>V-20</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-1</td>
<td>Flow Diagram of Subroutine MAIN Integration Program</td>
<td>D-2</td>
</tr>
<tr>
<td>D-2</td>
<td>Flow Diagram of Subroutine INITIAL Integration Program</td>
<td>D-3</td>
</tr>
<tr>
<td>D-3</td>
<td>Flow Diagram of Subroutine STABLE Integration Program</td>
<td>D-4</td>
</tr>
<tr>
<td>D-4</td>
<td>Flow Diagram of Subroutine VIRTUAL Integration and Conversion Programs</td>
<td>D-5</td>
</tr>
<tr>
<td>D-5</td>
<td>Flow Diagram of Subroutine BOUND Integration and Conversion Programs</td>
<td>D-6</td>
</tr>
<tr>
<td>D-6</td>
<td>Flow Diagram of Subroutine GENPT Integration Program</td>
<td>D-7</td>
</tr>
<tr>
<td>D-7</td>
<td>Flow Diagram of Subroutine LINER Integration Program</td>
<td>D-8</td>
</tr>
<tr>
<td>D-8</td>
<td>Flow Diagram of Subroutine PRINT Integration and Conversion Programs</td>
<td>D-9</td>
</tr>
<tr>
<td>D-9</td>
<td>Diagram of Subroutine MAIN Conversion Program</td>
<td>D-60</td>
</tr>
<tr>
<td>D-10</td>
<td>Flow Diagram of Subroutine INT Conversion Program</td>
<td>D-61</td>
</tr>
</tbody>
</table>
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

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)

II-2
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:

\[ \rho_t = -m_x - n_y + M \]  
\[ m_t = -(p + \frac{m^2}{\rho})_x - \left( \frac{mn}{\rho} \right)_y \]  
\[ n_t = -(\frac{mn}{\rho})_x - \left( p + \frac{n^2}{\rho} \right)_y \]  
\[ E_t = -\left[ \frac{m}{\rho}(p + E) \right]_x - \left[ \frac{n}{\rho}(p + E) \right]_y + Q \]

where:

- \( \rho \) = 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

\( \gamma = \frac{c_p}{c_v} \) = ratio of specific heats

\( t = \) time
\[ M = \text{mass addition to the gas phase per unit volume and time due to propellant vaporization} \]
\[ Q = \text{energy release rate per unit volume and time due to combustion} \]
\[ x, y = \text{space coordinates} \]
\[ x, y, t = \text{subscripts indicate differentiation.} \]

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 \( \rho, m, n, \) and \( E \) by substituting for the pressure to obtain
\[ W_t = F_x + G_y + H \quad (5) \]

where:

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

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

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

\[ H(W) = \begin{bmatrix} 0 \\ 0 \\ 0 \\ Q \end{bmatrix} \]
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:

$$\rho = \frac{\gamma p}{2(\gamma-1)H_0} \left\{ 1 + \left[ 1 + 2H_0 \left( \frac{\gamma-1}{\gamma p} \right) \right]^{1/2} \right\}$$

where

- $\rho$ = density
- $p$ = pressure
- $m$ = longitudinal momentum
- $H$ = enthalpy
- $\gamma = c_p/c_v$ = 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 ($\rho$, $m$, 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)

$$\frac{\partial}{\partial t}(p - \rho_0 c_0 u) + (u-c) \frac{\partial}{\partial x}(p - \rho_0 c_0 u)$$

$$= -v_0 \frac{\partial}{\partial y}(p - \rho_0 c_0 u) - \rho_0 c_0 \frac{2}{\gamma} \frac{\partial v}{\partial y}$$

$$E = \frac{p}{\gamma-1} + \frac{m^2 + n^2}{2\rho}$$
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 $\Delta t$ 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](image)

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

\[
\begin{align*}
\dot{W}_{i+\frac{1}{2}, j+\frac{1}{2}}(\Delta t) &= \frac{1}{4} \left[ W_{i+1, j}(t) + W_{i, j+1}(t) + W_{i+1, j+1}(t) + W_{i, j}(t) \right] + \\
\Delta t &\left[ F_{i+1, j}(t) - F_{i, j}(t) + \\
&F_{i+1, j+1}(t) - F_{i, j+1}(t) \right] + \\
\Delta t &\left[ G_{i+1, j+1}(t) - G_{i+1, j}(t) + \\
&G_{i, j+1}(t) - G_{i, j}(t) \right] + \Delta t \left[ K_{i,j}(t) \right] \\
W_{i, j}(\Delta t) &= W_{i, j}(t) + \Delta t \frac{1}{4\Delta x} \left[ F_{i+1, j}(t) - F_{i-1, j}(t) + \\
&F_{i, j+1}(t) - F_{i, j-1}(t) \right] + \\
\dot{F}_{i+\frac{1}{2}, j+\frac{1}{2}}(\Delta t) &= \dot{F}_{i-\frac{1}{2}, j+\frac{1}{2}}(\Delta t) + \\
\dot{F}_{i+\frac{1}{2}, j-\frac{1}{2}}(\Delta t) &= \dot{F}_{i-\frac{1}{2}, j-\frac{1}{2}}(\Delta t) + \\
\Delta t &\left[ G_{i, j+1}(t) - G_{i, j-1}(t) + \\
&G_{i+\frac{1}{2}, j+\frac{1}{2}}(t) - G_{i-\frac{1}{2}, j+\frac{1}{2}}(t) \right] + \Delta t \left[ L_{i,j}(\Delta t) \right]
\end{align*}
\]

\( \dot{F} \) and \( \dot{G} \) indicate the evaluation of vectors \( F \) and \( G \) using values of \( \dot{W} \) and

\[
K_{i,j}(t) = 0.25 \left[ H_{i+1, j}(t) + H_{i, j+1}(t) + H_{i+1, j+1}(t) + H_{i, j}(t) \right]
\]

\[
L_{i,j}(\Delta t) = 0.50 \left[ H_{i, j}(t) + 0.25 \left( H_{i+1/2, j+1/2}(\Delta t) + H_{i+1/2, j-1/2}(\Delta t) \right) + H_{i-1/2, j+1/2}(\Delta t) + H_{i-1/2, j-1/2}(\Delta t) \right]
\]

\[
H_{i,j} = \begin{bmatrix} 0 \\ 0 \\ Q \end{bmatrix}
\]

III-2
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 ($\Delta x \to 0$, $\Delta y \to 0$) 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:

$$\Delta t \leq \Delta \left[ \sqrt{2(\bar{u} + C)} \right]^{-1}$$

where:

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

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

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

$$\partial_t \mathbf{W} = D \left[ \left( \frac{\partial}{\partial x} \mathbf{W}_x \right)_x + \left( \frac{\partial}{\partial y} \mathbf{W}_y \right)_y \right]$$

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

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

$$u^{(0)}_{i,j} - u^{(0)}_{i-1,j} \left( W^{(0)}_{i,j} - W^{(0)}_{i-1,j} \right)$$

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

$$v^{(1)}_{i,j} - v^{(1)}_{i,j-1} \left( W^{(1)}_{i,j} - W^{(1)}_{i,j-1} \right)$$

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:

\[ D = \text{empirical coefficient} \]

\[ \lambda = \frac{\Delta t}{\Delta x} = \frac{\Delta t}{\Delta y} \]

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 study.

The difference equations provide a means of calculating the values of \( \rho, m, n, \) 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:

\[ \rho_{k,i,j+1} = \rho_{k,i,j+1} \]  \hspace{1cm} (16)

\[ m_{k,i,j+1} = m_{k,i,j+1} \]  \hspace{1cm} (17)
\[ n_{k,i,j+1} = n_{k,i,j+1} \]  
\[ E_{k,i,j+1} = E_{k,i,j+1} \]  

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

\[ \rho_{k,i+1,j} = \rho_{k,i+1,j} \]  
\[ m_{k,i+1,j} = m_{k,i+1,j} \]  
\[ n_{k,i+1,j} = n_{k,i+1,j} \]  
\[ E_{k,i+1,j} = E_{k,i+1,j} \]  

For a rigid boundary that makes an angle, \( \alpha \), 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.

\[ W(S) \approx W(S_0) + (S-S_0)W_{S_0,S_1} + (S-S_0)(S-S_1)W_{S_0,S_1,S_2} \]  

Figure 5. Reflection at an Oblique Boundary
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
\[ W(L_1) = W(X_0) + (L_1 - X_0) W[x_0, x_1] + (L_1 - X_0)(L_1 - X_1) W[x_0, x_1, x_2] \]  \[ (25) \]

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.,
\[ W(2) = W(L_1 + h) = W(L_1) + h \frac{\partial W}{\partial L}_{L_1} + \frac{h^2}{2} \frac{\partial^2 W}{\partial L^2}_{L_1} \]  \[ (26) \]

where \( \frac{\partial}{\partial L} \) refers to differentiation along the normal and \( \frac{\partial W}{\partial L}_{L_1} \) and \( \frac{\partial^2 W}{\partial L^2}_{L_1} \) are found to second order accuracy from:
\[ \frac{\partial W}{\partial L}_{L_1} = \frac{W(L_2) - W(L_0)}{2\Delta L} \]  \[ (27) \]
\[ \frac{\partial^2 W}{\partial L^2}_{L_1} = \frac{W(L_2) - 2W(L_1) + W(L_0)}{2(\Delta L)^2} \]  \[ (28) \]

\[ \Delta L = L_2 - L_1 = L_1 - L_0 \]
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

\[ P_{T2} = M_2 \cos \alpha + n_2 \sin \alpha \quad (29) \]

Normal momentum component at point 2

\[ P_{N2} = M_2 \sin \alpha - n_2 \cos \alpha \quad (30) \]

The reflection principle yields

\[ P_{T1} = P_{T2} \quad (31) \]
\[ P_{N1} = -P_{N2} \]

Then

\[ M_1 = P_{T1} \cos \alpha + P_{N1} \sin \alpha \quad (32) \]
\[ = M_2 \cos^2 \alpha + N_2 \sin \alpha \cos \alpha - M_2 \sin^2 \alpha + N_2 \sin \alpha \cos \alpha \]
\[ M_1 = 2[M_2 \cos \alpha + N_2 \sin \alpha] \cos \alpha - M_2 \quad (33) \]

and

\[ N_1 = P_{T1} \sin \alpha - P_{N1} \cos \alpha \quad (34) \]
\[ = M_2 \sin \alpha \cos \alpha + N_2 \sin^2 \alpha + M_2 \sin \alpha \cos \alpha - N_2 \cos^2 \alpha \quad (35) \]
\[ N_1 = 2[M_2 \cos \alpha + N_2 \sin \alpha] \sin \alpha - N_2 \quad (36) \]
\[ \rho_1 = \rho_2 \quad (37) \]
\[ E_1 = E_2 \quad (38) \]

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.

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

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

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

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

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

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 programming. 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 \( \rho = \text{density} \)
- \( K = 2, W \) represents \( m = \text{x-momentum} \)
- \( K = 3, W \) represents \( n = \text{y-momentum} \)
- \( K = 4, W \) represents \( E = \text{total energy} \)
- \( K = 5, W \) represents \( p = \text{pressure} \)

---

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

\[
\begin{align*}
\text{XMOM}^2(I,J) &= \frac{m^2}{\rho} \\
\text{YMOM}^2(I,J) &= \frac{n^2}{\rho} \\
\text{VSQ}(I,J) &= \frac{m^2 + n^2}{\rho^2}
\end{align*}
\]

2. Between the liner and the chamber wall

\[
\begin{align*}
\text{XMOM}^2A(I,J) &= \frac{m^2}{\rho} \\
\text{YMOM}^2A(I,J) &= \frac{n^2}{\rho} \\
\text{VSQA}(I,J) &= \frac{m^2 + n^2}{\rho^2}
\end{align*}
\]

The following real variables are employed in the program.

- $AO =$ Reference speed of sound
- $CON1 = \frac{\rho_o A_o}{\rho_{o0}}$
- $CON2 = \frac{\rho_o A_o^2}{g}$
- $CON3 = \frac{XLEN}{A_o}$
- $DELX = \Delta x$
- $DELY = \Delta y$
- $DELT = \Delta t$
- $ENERO =$ Reference energy $= E_o$
- $FUDGE =$ Fraction of linear stability $\Delta t$ used in integration
- $GAM =$ $\gamma$
- $GAM1 = \gamma - 1$
- $GAM2 = \frac{(\gamma - 1)}{2}$
- $GAM3 = \frac{(\gamma - 3)}{2}$
- $OMEGA =$ Frequency

IV-5
PO = Reference pressure = \( P_0 \)
QUE = Energy per unit volume released by combustion
QP = Perturbed energy per unit volume
RHOO = Reference density = \( \rho_0 \)
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; \( I = 1,2,\ldots, n \)
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 \( \Delta t \)'s in total run
\( TT = \) Print increment; data will be printed every \( TT \)th time.

2. Subroutine MAIN

The principal function of MAIN is to call the remaining seven sub-
routines. 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
   \[ \Delta T = \frac{\Delta H}{\dot{\omega}C_p} \]  
   where \( \Delta H \) = Total heat evolved, ft lb/sec  
   \( \dot{\omega} \) = Total flowrate, lb/sec  
   \( C_p \) = Heat capacity, ft lb/1b °R  
   \( \Delta T \) = Temperature rise, °R

2. The chamber pressure can be computed from these data by the formula presented in Reference 6
   \[ P = \frac{\dot{\omega}\sqrt{T}}{A\sqrt{\frac{R}{\gamma}} M \sqrt{1 + \frac{\gamma - 1}{2} M^2}} \]  

IV-7
where \( \dot{W} \) = Total flowrate, lb/sec  
\( T \) = Temperature, °R  
\( A \) = Chamber cross-section area, ft\(^2\)  
\( g \) = Gravitational constant, ft/sec\(^2\)  
\( \gamma = C_p/C_v \)  
\( R \) = Gas constant, ft lb/lb °R  
\( M \) = Mach number

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

\[
m = \frac{\dot{W}}{A}
\]  \hspace{1cm} (42)

4. The density, \( \rho \), in the chamber can be obtained from the ideal gas law

\[
\rho = \frac{P}{RT}
\]  \hspace{1cm} (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

\[
E = \frac{P}{\gamma - 1} + \frac{m^2}{2g\rho}
\]  \hspace{1cm} (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

\[
\frac{A}{A_t} = \frac{1}{M} \left[ \frac{2\left(1 + \frac{\gamma - 1}{2} M^2\right)}{\gamma + 1} \right]
\]  \hspace{1cm} (45)
where $A = \text{Area of duct}$

$A_t = \text{Area of throat}$

$M = \text{Mach number}$

$\gamma = \frac{C_p}{C_v}$

2. Calculate the temperature from

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

Where $T = \text{Temperature}$

$T_o = \text{Total temperature}$

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.

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

$$m' = \rho a_o m \quad (48)$$

$$n' = \rho a_o n \quad (49)$$

IV-9
\[ \rho' = \rho_o \rho \]  
(50)

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

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

where, in addition to previously defined symbols:

- \( \rho_o \) = Reference density, lb/ft\(^3\)
- \( a_o \) = Reference velocity of sound, ft/sec
- \( g \) = Gravitational constant, ft/sec\(^2\)
- \( \ell \) = 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:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLWT</td>
<td>Molecular weight of the gas flowing in the chamber</td>
</tr>
<tr>
<td>PO</td>
<td>Reference pressure calculated from thermodynamic considerations</td>
</tr>
</tbody>
</table>
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 $\Delta t$ calculated in STABLE that is to be used in the integration
$\Delta X$ | 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 ($\Delta t$'s) the simulation is to encompass
TT | Number of $\Delta t$'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**

<table>
<thead>
<tr>
<th>Job Number</th>
<th>Date</th>
<th>Analyst</th>
<th>Control Number</th>
<th>Sheet</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>MESH</th>
<th>INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LENX1</th>
<th>LENX2</th>
<th>LENX3</th>
<th>LENX4</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>14</td>
<td>20</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LNY1</th>
<th>LNY2</th>
<th>LNY3</th>
<th>LNY4</th>
<th>LNY5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MOT WT</th>
<th>M50</th>
<th>D60</th>
<th>M100</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6</td>
<td>77000</td>
<td>51000</td>
<td>1.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T</th>
<th>TMT</th>
<th>TTHO</th>
<th>TIN</th>
<th>TIE</th>
<th>IPRES</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

| 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 1 AND REFER TO LOCATION ON FIGURE 5. |

<table>
<thead>
<tr>
<th>DENSITY</th>
<th>MOMENTUM</th>
<th>ENERGY</th>
<th>FLOW FIELD LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.20</td>
<td>203</td>
<td>4.20</td>
<td>2.0D05</td>
</tr>
<tr>
<td>4.10</td>
<td>203</td>
<td>4.10</td>
<td>2.0D05</td>
</tr>
<tr>
<td>4.07</td>
<td>203</td>
<td>4.07</td>
<td>2.0D05</td>
</tr>
<tr>
<td>4.05</td>
<td>203</td>
<td>4.05</td>
<td>2.0D05</td>
</tr>
<tr>
<td>4.02</td>
<td>203</td>
<td>4.02</td>
<td>2.0D05</td>
</tr>
<tr>
<td>4.00</td>
<td>203</td>
<td>4.00</td>
<td>2.0D05</td>
</tr>
<tr>
<td>4.05</td>
<td>203</td>
<td>4.05</td>
<td>2.0D05</td>
</tr>
</tbody>
</table>

IV-13

Pratt & Whitney Aircraft PWA FR-2534
### GENERAL INPUT FORM

<table>
<thead>
<tr>
<th>Density</th>
<th>X Moment</th>
<th>Y Moment</th>
<th>Energy</th>
<th>Flow Field Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.82</td>
<td>2.03</td>
<td>0.0</td>
<td>3.93 D05</td>
<td>I=12, J=2, THROUGH 12</td>
</tr>
<tr>
<td>0.65</td>
<td>2.03</td>
<td>0.0</td>
<td>3.90 D05</td>
<td></td>
</tr>
<tr>
<td>0.46</td>
<td>2.03</td>
<td>0.0</td>
<td>3.87 D05</td>
<td></td>
</tr>
<tr>
<td>0.28</td>
<td>2.03</td>
<td>0.0</td>
<td>3.85 D05</td>
<td></td>
</tr>
<tr>
<td>0.094</td>
<td>2.03</td>
<td>0.0</td>
<td>3.82 D05</td>
<td></td>
</tr>
<tr>
<td>0.093</td>
<td>2.22</td>
<td>0.0</td>
<td>3.82 D05</td>
<td></td>
</tr>
<tr>
<td>0.092</td>
<td>2.37</td>
<td>0.0</td>
<td>3.80 D05</td>
<td></td>
</tr>
<tr>
<td>0.090</td>
<td>2.54</td>
<td>0.0</td>
<td>3.71 D05</td>
<td></td>
</tr>
<tr>
<td>0.085</td>
<td>2.84</td>
<td>0.0</td>
<td>3.52 D05</td>
<td></td>
</tr>
<tr>
<td>0.084</td>
<td>3.16</td>
<td>0.0</td>
<td>3.34 D05</td>
<td></td>
</tr>
<tr>
<td>0.062</td>
<td>3.34</td>
<td>0.0</td>
<td>2.51 D05</td>
<td></td>
</tr>
<tr>
<td>0.062</td>
<td>3.39</td>
<td>-10.0</td>
<td>2.55 D05</td>
<td></td>
</tr>
<tr>
<td>0.062</td>
<td>3.39</td>
<td>-5.0</td>
<td>2.55 D05</td>
<td></td>
</tr>
<tr>
<td>0.062</td>
<td>3.39</td>
<td>2.0</td>
<td>2.55 D05</td>
<td></td>
</tr>
<tr>
<td>0.062</td>
<td>3.39</td>
<td>5.0</td>
<td>2.55 D05</td>
<td></td>
</tr>
<tr>
<td>0.062</td>
<td>3.39</td>
<td>10.0</td>
<td>2.55 D05</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>3.10</td>
<td>-10.0</td>
<td>1.87 D05</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>3.10</td>
<td>-5.0</td>
<td>1.87 D05</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>3.10</td>
<td>-2.0</td>
<td>1.87 D05</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>3.10</td>
<td>0.0</td>
<td>1.87 D05</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>3.10</td>
<td>2.0</td>
<td>1.87 D05</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>3.10</td>
<td>5.0</td>
<td>1.87 D05</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The table represents data from Pratt & Whitney Aircraft PWA FR-2634.
## GENERAL INPUT FORM

**Title:** Sample of Input Data Cards - Cold Start (Continued)

<table>
<thead>
<tr>
<th>Density</th>
<th>x(Momentum)</th>
<th>y(Momentum)</th>
<th>Energy</th>
<th>Flow Field</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.045</td>
<td>310.0</td>
<td>10.0</td>
<td>1.87 D05</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>-10.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>-5.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>-2.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>0.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>7</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>2.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>5.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>9</td>
</tr>
<tr>
<td>0.038</td>
<td>284.0</td>
<td>10.0</td>
<td>1.60 D05</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>-10.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>-8.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>-5.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>-2.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>0.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>2.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>5.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>8.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>10</td>
</tr>
<tr>
<td>0.031</td>
<td>254.0</td>
<td>10.0</td>
<td>1.34 D05</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>-10.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>-8.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>-5.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>-2.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>6</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>0.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>2.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>8</td>
</tr>
<tr>
<td>0.025</td>
<td>230.0</td>
<td>5.0</td>
<td>1.13 D05</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>Density</td>
<td>X Momentum</td>
<td>Y Momentum</td>
<td>Energy</td>
<td>Flow Field Location</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>0.025</td>
<td>230.</td>
<td>8.0</td>
<td>1.13 E05</td>
<td>I = 27; J = 10</td>
<td></td>
</tr>
<tr>
<td>0.025</td>
<td>230.</td>
<td>10.0</td>
<td>1.13 E05</td>
<td>I = 27; J = 11</td>
<td></td>
</tr>
</tbody>
</table>
**GENERAL INPUT FORM**

**Sample of Input Data Cards - Restart**

<table>
<thead>
<tr>
<th>Job Number</th>
<th>Analyst</th>
<th>Cost Control Number</th>
<th>Extension</th>
<th>Sheet of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T</th>
<th>TT</th>
<th>NOPT</th>
<th>IHO</th>
<th>IM</th>
<th>IN</th>
<th>IE</th>
<th>IFRES</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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

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

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

where; 
- \( Q \) = Energy Release Rate, \( \text{ft lb/sec ft}^3 \) 
- \( p \) = Pressure, \( \text{lb/ft}^2 \) 
- \( \bar{p} \) = Average Pressure, \( \text{lb/ft}^2 \) 
- \( n \) = Empirical Exponent 
- \( q = \Delta H/V \) 
- \( \Delta H = \text{Total Heat of Combustion, ft lb/sec} \) 
- \( V = \text{Combustion Chamber Volume, ft}^3 \)

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 (\( \Delta t \)) for the numerical integration from equation 12. The value of \( \Delta t \) 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 VIRTUAL

The purpose of VIRTUAL 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

<table>
<thead>
<tr>
<th>Genpt</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liner Wall</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>W</td>
<td>W</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>R</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Liner Wall</th>
<th>R</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>R</th>
<th>R</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>W</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chamber Wall</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>

- **A** = Acoustic Liner Value
- **W** = General Mesh Point Value
- **R** = Value Reflection Principle
- **C** = Common Value
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 P1 (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
To interpolate along the horizontal lines, it is necessary to know the distance between $x_0$ and $P_1$. This was accomplished previously in INITIAL by finding the $x$-coordinate of $P_1$, assuming the origin at $x_0$ 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

$$y - y_1 = m(x - x_1) \quad (53)$$

where $(x, y)$ is the virtual point and $m$ is the slope of the normal.

Solving equation 53 for $x$ yields

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

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

$$x = -\frac{\Delta y}{m} + 2\Delta x. \quad (55)$$

Thus, $x$ is the distance from $x_0$ to $P_1$ on grid line 1.

Similarly, for grid lines 2 and 3 we have

$$x = -\frac{2\Delta y}{m} + 2\Delta x \quad (56)$$

$$x = -\frac{3\Delta y}{m} + 2\Delta x \quad (57)$$

respectively.

Note that equations 55, 56, and 57 express the distances from $x_0$ to $P_1$ 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

$$x' = -\frac{2\Delta y}{m} + 2\Delta x \quad (58)$$

$$x' = -\frac{3\Delta y}{m} + 2\Delta x \quad (59)$$

$$x' = -\frac{4\Delta y}{m} + 2\Delta x \quad (60)$$

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

IV-22
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.

This yields

\[
DS = n\Delta x \sin \beta_1 \quad n = 1, 2, 3, 4
\]  \hspace{1cm} (61)

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

\[
D = 3(DIST) - 2(DS)
\]  \hspace{1cm} (62)

for virtual points 1, 2, and 3 and

\[
D = 4(DIST) - 2(DS)
\]  \hspace{1cm} (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 \( \rho \) and \( E \),

\[
\rho(V) = \rho(R) \quad \text{and} \quad E(V) = E(R) .
\]

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

\[
P_T(R) = m(R) \cos \beta_1 + n(R) \sin \beta_1
\]

and the normal component is

\[
P_N(R) = m(R) \sin \beta_1 - n(R) \cos \beta_1 .
\]

The reflection principle yields

\[
P_T(V) = P_T(R)
\]

\[
P_N(V) = -P_N(R) .
\]

Therefore,

\[
m(V) = P_T(V) \cos \beta_1 + P_N(V) \sin \beta_1
\]

\[
= m(R) \cos^2 \beta_1 + n(R) \sin \beta_1 \cos \beta_1 - m(R) \sin^2 \beta_1
\]

\[
+ n(R) \sin \beta_1 \cos \beta_1
\]

\[
= 2(m(R) \cos \beta_1 + n(R) \sin \beta_1) \cos \beta_1 - m(R)
\]

and

\[
n(V) = P_T(V) \sin \beta_1 - P_N(V) \cos \beta_1
\]

\[
= m(R) \sin \beta_1 \cos \beta_1 + n(R) \sin^2 \beta_1 + m(R) \sin \beta_1 \cos \beta_1
\]

\[
- n(R) \cos^2 \beta_1
\]

\[
= 2(m(R) \cos \beta_1 + n(R) \sin \beta_1) \sin \beta_1 - n(R) .
\]
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 $W(\Delta t)$ 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 $W(\Delta t)$, $F$, $G$, and $H$, 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:

$$W_{i+\frac{1}{2}, j+\frac{1}{2}} \rightarrow TVA(1, j+\frac{1}{2}, 1), TVA(2, j+\frac{1}{2}, 1), TVA(3, j+\frac{1}{2}, 1), TVA(4, j+\frac{1}{2}, 1)$$

$$F_{i+\frac{1}{2}, j+\frac{1}{2}} \rightarrow TVA(5, j+\frac{1}{2}, 1), TVA(6, j+\frac{1}{2}, 1), TVA(7, j+\frac{1}{2}, 1), TVA(8, j+\frac{1}{2}, 1)$$

$$G_{i+\frac{1}{2}, j+\frac{1}{2}} \rightarrow TVA(9, j+\frac{1}{2}, 1), TVA(10, j+\frac{1}{2}, 1), TVA(11, j+\frac{1}{2}, 1), TVA(12, j+\frac{1}{2}, 1)$$

$$H_{i+\frac{1}{2}, j+\frac{1}{2}} \rightarrow TVA(13, j+\frac{1}{2}, 1), TVA(14, j+\frac{1}{2}, 1), TVA(15, j+\frac{1}{2}, 1), TVA(16, j+\frac{1}{2}, 1)$$
The same ordering holds for the second temporary line of values, i.e.,

\[ W_{i+3/2, j+\frac{1}{2}} \rightarrow \text{TVA}(1, j+\frac{1}{2}, 2), \text{TVA}(2, j+\frac{1}{2}, 2), \text{TVA}(3, j+\frac{1}{2}, 2), \text{TVA}(4, j+\frac{1}{2}, 2) \]

\[ F_{i+3/2, j+\frac{1}{2}} \rightarrow \text{TVA}(5, j+\frac{1}{2}, 2), \text{TVA}(6, j+\frac{1}{2}, 2), \text{TVA}(7, j+\frac{1}{2}, 2), \text{TVA}(8, j+\frac{1}{2}, 2) \]

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; \( \text{ft lb/ft}^3/\text{sec} \). 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 corre-
sponding 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 sym-
bol "A" between successive entries indicates those entries were generated in
LINER. The symbol "W" between entries indicates that those values were gen-
erated in GENPT. The symbol * indicates the boundary, the symbol "C" indi-
dates 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:

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

\[
TTOL = TND \times \frac{\text{XLEN}}{a_0} \quad \text{(total time)}
\]

\[
\rho' = \rho \rho_o \quad \text{(71)}
\]

\[
p' = \rho_o a_o^2 / g \quad \text{(72)}
\]

\[
m' = m \rho_o a_o \quad \text{(73)}
\]

\[
n' = n \rho_o a_o \quad \text{(74)}
\]

\[
E' = \rho_o a_o^2 / g \quad \text{(75)}
\]

where

TND = Nondimensional time used in program

DELT = Time interval

TTOL = Total time

\[
\rho = \text{Density, lb/ft}^3
\]

\[
p = \text{Pressure, lb/ft}^2
\]

\[
m = x\text{-momentum, lb/ft}^2/\text{sec}
\]

\[
n = y\text{-momentum, lb/ft}^2/\text{sec}
\]
E = Total energy, ft lb/ft³
\( a_0 \) = Sonic velocity, ft/sec
\( g \) = Gravitational constant, ft/sec²

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**

<table>
<thead>
<tr>
<th>LENX1</th>
<th>LENX2</th>
<th>LENX3</th>
<th>LENX4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>LENY1</td>
<td>LENY2</td>
<td>LENY3</td>
<td>LENY4</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>LENY5</td>
<td></td>
<td>PRINT INC</td>
<td>308</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XLEN</td>
<td>YLEN</td>
<td>DELX</td>
<td>D-LY</td>
</tr>
<tr>
<td>10.41250E-01</td>
<td>41.05000E-02</td>
<td>41.65000E-03</td>
<td>41.65000E-03</td>
</tr>
<tr>
<td>SOUND SP.</td>
<td>M.W. OF GAS</td>
<td>FUDGE</td>
<td>TP</td>
</tr>
<tr>
<td>56.31606E+02</td>
<td>96.00000E-01</td>
<td>.800</td>
<td>0.</td>
</tr>
<tr>
<td>p = 77.00000E+03</td>
<td>T0 = 51.00000E+02</td>
<td>RMD0 = 93.81306E+03</td>
<td>ENERG = 3.13300E+04</td>
</tr>
<tr>
<td>GAM = 12.00000E+01</td>
<td>XSLOPE = -33.33333E-02</td>
<td>DIST = 43.90295E-03</td>
<td>UYSTDP = 43.90295E-03</td>
</tr>
<tr>
<td>SINB1 = -31.62278E-02</td>
<td>COSB1 = 94.86083E-02</td>
<td>SINE = 31.62278E-02</td>
<td>GUS1H = 94.86083E-02</td>
</tr>
<tr>
<td>DIFCO = 30.00000E+01</td>
<td>MU = 0.</td>
<td>OMEGA = 0.</td>
<td>LINER THKAS = 0.</td>
</tr>
<tr>
<td>Q = 15.20000E+08</td>
<td>QP = 0.</td>
<td>N = 0.</td>
<td>NUNIT = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MESH = -0</td>
</tr>
<tr>
<td>XDIST(1) = 69.41667E-03</td>
<td>XDIST(2) = 55.33333E-03</td>
<td>XDIST(3) = 41.65000E-03</td>
<td></td>
</tr>
<tr>
<td>XDISTP(1) = 55.33333E-03</td>
<td>XDISTP(2) = 41.65000E-03</td>
<td>XDISTP(3) = 27.76667E-03</td>
<td></td>
</tr>
</tbody>
</table>
### INPUT DATA AND CONSTANTS

<table>
<thead>
<tr>
<th>LENX1</th>
<th>LENX2</th>
<th>LENX3</th>
<th>LENX4</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>28</td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LENY1</th>
<th>LENY2</th>
<th>LENY3</th>
<th>LENY4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ILEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XLEN</th>
<th>YLEN</th>
<th>DELX</th>
<th>DLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.41250E-01</td>
<td>41.65000E-02</td>
<td>20.82500E-03</td>
<td>20.8/500E-03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SOUND SP.</th>
<th>M.W. OF GAS</th>
<th>FUDGE</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>56.31666E+02</td>
<td>94.00000E+01</td>
<td>.800</td>
<td>40.00000E-07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PO</th>
<th>T0</th>
<th>RH0</th>
<th>DIST</th>
<th>DISTP</th>
<th>LINER THKNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>77.00000E+03</td>
<td>51.00000E+02</td>
<td>93.01366E+03</td>
<td>21.95148E-03</td>
<td>21.05148E-03</td>
<td>12.50000E-02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GAM</th>
<th>XSLOPE</th>
<th>SINB1</th>
<th>COSB1</th>
<th>MUF</th>
<th>QP</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.00000E+01</td>
<td>-33.33333E-02</td>
<td>-31.62278E-02</td>
<td>94.86833E-02</td>
<td>10.00000E-01</td>
<td>40.00000E+00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIFCO</th>
<th>OMEGA</th>
<th>N</th>
<th>MESH</th>
</tr>
</thead>
<tbody>
<tr>
<td>3V.00000E+01</td>
<td>0.0</td>
<td>30.00000E+01</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XDIST(1)</th>
<th>XDIST(2)</th>
<th>XDIST(3)</th>
<th>XDISTP(1)</th>
<th>XDISTP(2)</th>
<th>XDISTP(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.70833E-03</td>
<td>27.76667E-03</td>
<td>20.82500E-03</td>
<td>27.76667E-03</td>
<td>20.82500E-03</td>
<td>13.86833E-03</td>
</tr>
</tbody>
</table>
DENSITY AT TIME = 47.93270E-05  DELT = 65.69904E-08  TN = 25.92443E+01  TRIP NUMBER = 700

33.36E-02  33.55E-02  34.04E-02  23.48E-01  22.92E-01  22.6E-01  20.31E-01  23.01E-01  22.04E-01  25.09E-01  25.46E-01  33.95E-02  33.36E-02
36.91E-02  36.36E-02  37.42E-02  18.78E-01  18.35E-01  17.82E-01  17.74E-01  18.6E-01  18.78E-01  18.9E-01  19.24E-01  36.36E-02  36.91E-02
43.99E-02  51.24E-02  56.02E-02  14.1E-01  13.36E-01  14.57E-01  11.76E-01  12.96E-01  13.46E-01  13.87E-01  16.45E-01  51.24E-02  43.99E-02
58.07E-02  63.95E-02  83.4E-01  11.74E-01  10.77E-01  99.83E-02  92.87E-02  10.05E-01  10.61E-01  11.16E-01  83.4E-02  63.95E-02  58.07E-02
58.04E-02  62.19E-02  70.88E-02  86.01E-02  85.34E-02  80.01E-02  74.6E-02  79.52E-02  81.36E-02  82.68E-02  70.88E-02  62.19E-02  58.04E-02
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
52.28E-02  53.24E-02  52.81E-02  47.33E-02  48.07E-02  52.02E-02  50.03E-02  50.17E-02  45.34E-02  45.62E-02  52.01E-02  53.24E-02  52.28E-02
49.69E-02  50.62E-02  48.56E-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  49.69E-02
45.29E-02  45.63E-02  42.47E-02  33.21E-02  33.63E-02  36.37E-02  36.48E-02  34.64E-02  32.08E-02  31.51E-02  35.15E-02  45.63E-02  45.29E-02
39.83E-02  40.13E-02  38.1E-02  29.77E-02  29.97E-02  31.22E-02  31.32E-02  29.67E-02  28.81E-02  28.40E-02  30.06E-02  40.13E-02  39.83E-02
35.81E-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  35.93E-02  35.81E-02
32.73E-02  32.51E-02  30.86E-02  23.77E-02  23.85E-02  23.75E-02  23.66E-02  22.60E-02  23.12E-02  23.16E-02  30.86E-02  32.51E-02  32.73E-02
30.31E-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  30.31E-02
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
26.71E-02  27.17E-02  25.43E-02  15.34E-02  15.46E-02  10.18E-02  16.41E-02  15.24E-02  14.91E-02  15.33E-02  17.29E-02  27.17E-02  26.71E-02
22.45E-02  21.60E-02  19.31E-02  12.26E-02  12.64E-02  12.93E-02  13.29E-02  12.35E-02  12.38E-02  12.77E-02  19.31E-02  21.60E-02  22.45E-02
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
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
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:

<table>
<thead>
<tr>
<th>Card</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>TCOUNT</td>
<td>The number of the iteration at which the conversion is being made</td>
</tr>
<tr>
<td></td>
<td>XMU</td>
<td>The viscosity of the combustion gases</td>
</tr>
<tr>
<td></td>
<td>OMEGA</td>
<td>The expected frequency of the oscillation</td>
</tr>
<tr>
<td></td>
<td>THICK</td>
<td>The liner thickness</td>
</tr>
<tr>
<td>6</td>
<td>IFOUR</td>
<td>Control index used for data input</td>
</tr>
<tr>
<td></td>
<td>IEIGHT</td>
<td>Control index for data input</td>
</tr>
<tr>
<td></td>
<td>MESH</td>
<td>Control index for data input</td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>JOB NUMBER</th>
<th>PWA FR-2634</th>
<th>ENGINEER</th>
<th>DEPARTMENT NAME &amp; LOCATION</th>
<th>EXTENSION</th>
<th>SHEET</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>CO</th>
<th>CON</th>
<th>CSB</th>
<th>CON</th>
<th>CSB</th>
<th>CO</th>
<th>CON</th>
<th>CSB</th>
<th>CON</th>
<th>CSB</th>
<th>CO</th>
<th>CON</th>
<th>CSB</th>
<th>CON</th>
<th>CSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEXI</td>
<td>LEX2</td>
<td>LEX3</td>
<td>LEX4</td>
<td>LEX5</td>
<td>MOLWT</td>
<td>PO</td>
<td>TO</td>
<td>GAM</td>
<td>FUDGE</td>
<td>DELY</td>
<td>DIFCO</td>
<td>QUE</td>
<td>9.0</td>
<td>77000</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2.7</td>
<td>2.8</td>
<td>4.0</td>
<td>5.0</td>
<td>4</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>1</td>
<td>1.2</td>
<td>1.2</td>
<td>0.8</td>
<td>0.020825</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>IPRES</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>TCOUNT</td>
<td>XMU</td>
<td>OMEGA</td>
<td>THICK</td>
<td>T</td>
<td>0.024</td>
<td>0.0</td>
<td>0.0</td>
<td>0.125</td>
<td>T</td>
<td>0.024</td>
<td>0.0</td>
<td>0.0</td>
<td>0.125</td>
</tr>
</tbody>
</table>

**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 CORRESPOND IS INDICATED TO THE RIGHT OF THE DATA I AND J REFER TO LOCATIONS ON FIGURE 8.**

<table>
<thead>
<tr>
<th>DENSITY X</th>
<th>MOMENTUM X</th>
<th>Y MOMENTUM</th>
<th>ENERGY</th>
<th>FLOW FIELD LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>310</td>
<td>1.0</td>
<td>1.87</td>
<td>1.0 and 1.9</td>
</tr>
<tr>
<td>0.006</td>
<td>257</td>
<td>1.0</td>
<td>1.53</td>
<td>1.0</td>
</tr>
<tr>
<td>0.028</td>
<td>284</td>
<td>1.0</td>
<td>1.60</td>
<td>1.0</td>
</tr>
<tr>
<td>0.035</td>
<td>269</td>
<td>1.0</td>
<td>1.47</td>
<td>1.0</td>
</tr>
<tr>
<td>0.031</td>
<td>254</td>
<td>1.0</td>
<td>1.44</td>
<td>1.0</td>
</tr>
<tr>
<td>0.028</td>
<td>242</td>
<td>1.0</td>
<td>1.23</td>
<td>1.0</td>
</tr>
<tr>
<td>0.025</td>
<td>230</td>
<td>1.0</td>
<td>1.23</td>
<td>1.0</td>
</tr>
<tr>
<td>0.015</td>
<td>229</td>
<td>1.0</td>
<td>1.23</td>
<td>1.0</td>
</tr>
<tr>
<td>Column</td>
<td>Data 1</td>
<td>Data 2</td>
<td>Data 3</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Data 1.1</td>
<td>Data 2.1</td>
<td>Data 3.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Data 1.2</td>
<td>Data 2.2</td>
<td>Data 3.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Data 1.3</td>
<td>Data 2.3</td>
<td>Data 3.3</td>
<td></td>
</tr>
</tbody>
</table>

**Continued...**
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 $\Delta t$ with an IBM 360 Mod 65 and a 1/2-in. mesh. The running time is reduced to 0.4 sec per $\Delta t$ 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°F. Thermodynamic data indicate that the heat evolved will be $2.83 \times 10^7$ ft lb/sec. The final temperature expected at the steady state, by a heat balance, will be 5150°F. 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 $1.52 \times 10^9$ ft lb/ft$^3$ sec.
The initial conditions in the combustion chamber were,

<table>
<thead>
<tr>
<th></th>
<th>Injector Face</th>
<th>Chamber Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, lb/ft$^3$</td>
<td>2.70</td>
<td>0.10</td>
</tr>
<tr>
<td>x-Momentum, lb/ft$^2$sec</td>
<td>203</td>
<td>203</td>
</tr>
<tr>
<td>y-Momentum, lb/ft$^2$sec</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Energy, ft lb/ft$^3$</td>
<td>355,000</td>
<td>361,000</td>
</tr>
</tbody>
</table>

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

Compared Wall Pressure at the Injector Face

Estimated Theoretical Chamber Pressure

TIME - millisecond

PRESURE - lb/ft²
Figure 12. Gas Density as a Function of Distance from Injector Face and Time
Figure 13. x-Momentum as a Function of Distance from Injector Face and Time
Figure 14. Chamber Pressure as a Function of Distance from Injector Face and Time
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

\[ Q = (q + q_p) \]  

(76)

where, in addition to previous symbols,

\[ q_p = \text{perturbed energy ft \text{ lb/ft}^3/\text{sec}} \]

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 \( 4.0 \times 10^{10} \text{ ft \text{ lb/ft}^3/\text{sec}} \), and the period of the disturbance was 4.1 \( \mu \text{sec} \). 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

\[ Q = q \left( \frac{P}{P_0} \right)^n \]  

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

Pratt & Whitney Aircraft
PWA FR-2634

V-13
Figure 19. Effect of Sound-Absorbing Liner on Wall Pressure at Injector Face as a Function of Time
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.
Figure 20. Specific Acoustic Resistance as a Function of Frequency
Figure 21. Specific Acoustic Reactance as a Function of Frequency
Figure 23. Comparison of Experimental to Computed Wall Pressures at Injector Face

Experimental

Calculated

\( n = 1 \)

Mesh Size = 1/4 in.

CHAMBER PRESSURE AT INJECTOR FACE - 1000 psf (Thousands)

TIME - millisecond
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.

VI-1
APPENDIX A
REDUCTION OF EULERIAN INVISCID
FLOW EQUATIONS TO NORMAL FORM

The inviscid flow equations may be written

\[ W_t + A(W)W_x = -B(W)W_y \]  \hspace{1cm} (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

- \( \rho \) = 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

\[ \xi^i A(W) = \lambda_i^i \xi^i \quad (i = 1, \ldots, 4) \]  \hspace{1cm} (A-2)

or

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

where the \( \xi^i \) and \( \lambda_i \) are the four eigenvectors and their corresponding eigenvalues, respectively, \( I \) is the identity matrix and \( \theta \) is the null vector.

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

\[ |A - \lambda_1 I| = 0 \]

or

\[(\lambda - u)^2 \left[ \lambda - (u + c) \right] \left[ \lambda - (u - c) \right] = 0 \]  \hspace{1cm} (A-3)
which yields

\[
\begin{align*}
\lambda_1 &= u \\
\lambda_2 &= u + c \\
\lambda_3 &= u - c \\
\lambda_4 &= u
\end{align*}
\]  

(A-4)

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

\[
\begin{align*}
\xi^1 &= (0, \tau_2, 0, -\frac{1}{c^2} \tau_1) \\
\xi^2 &= (0, \tau_3, 0, \frac{1}{\rho c} \tau_3) \\
\xi^3 &= (0, \tau_4, 0, -\frac{1}{\rho c} \tau_4) \\
\xi^4 &= (\tau_5, 0, \tau_6, -\frac{1}{c^2} \tau_5)
\end{align*}
\]  

(A-5)

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

\[
\alpha_1 \xi^1 + \alpha_2 \xi^2 + \alpha_3 \xi^3 + \alpha_4 \xi^4 = \theta
\]  

(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 \( \tau_i \) to be

\[
\begin{align*}
\tau_1 &= \tau_5 = -c^2 \\
\tau_2 &= -\tau_6 = 1 \\
\tau_3 &= -\tau_4 = \rho c
\end{align*}
\]  

(A-7)

The eigenvectors are

\[
\begin{align*}
\xi^1 &= (-c^2, 0, 1, 1) \\
\xi^2 &= (0, \rho c, 0, 1) \\
\xi^3 &= (0, -\rho c, 0, 1) \\
\xi^4 &= (-c^2, 0, -1, 1)
\end{align*}
\]  

(A-8)
The matrix \( A(W) \) may now be diagonalized by a similarity transformation

\[
HAH^{-1} = T
\]

(A-9)

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

\[
H = \begin{bmatrix}
-c^2 & 0 & 1 & 1 \\
0 & \rho c & 0 & 1 \\
0 & -\rho c & 0 & 1 \\
-c^2 & 0 & -1 & 1 \\
\end{bmatrix}, \quad H^{-1} = \begin{bmatrix}
-\frac{1}{2c^2} & -\frac{1}{2c^2} & -\frac{1}{2c^2} & -\frac{1}{2c^2} \\
\frac{1}{2c^2} & \frac{1}{2c^2} & \frac{1}{2c^2} & \frac{1}{2c^2} \\
0 & \frac{1}{2\rho c} & -\frac{1}{2\rho c} & 0 \\
\frac{1}{2} & 0 & 0 & -\frac{1}{2} \\
0 & \frac{1}{2} & \frac{1}{2} & 0 \\
\end{bmatrix}
\]

(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 (i) are transformed into normal form by setting

\[
U = HW = \begin{bmatrix}
p + v - \rho c^2 \\
p + \rho cu \\
p - \rho cu \\
p - v - \rho c^2 \\
\end{bmatrix}
\]

(A-11)

then

\[
W = H^{-1}U
\]

(A-12)

and

\[
W_{\ell} = H_{\ell}^{-1}U + H_{\ell}^{-1}U_{\ell}
\]

(A-13)

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

\[
H_{\ell}^{-1}U_{x} + AH_{\ell}^{-1}U_{x} = -B \left[ H_{\ell}^{-1}U + H_{\ell}^{-1}U_{\ell} \right] - \left[ H_{\ell}^{-1} + AH_{\ell}^{-1} \right]U
\]

(A-14)
which upon multiplication by \( H \) from the left becomes, using (9),

\[
U_t + TU_x = \mathbf{H} \left[ \mathbf{H}^{-1}U + \mathbf{H}^{-1}U \right] - \mathbf{H} \left[ \mathbf{H}^{-1} + \mathbf{AH}^{-1} \right]U 
\]

(A-15)

or

\[
U_t + TU_x = -GU_y - JU 
\]

(A-16)

where

\[
G = \mathbf{HBH}^{-1}
\]

\[
J = \mathbf{H} \left[ \mathbf{BH}^{-1} + \mathbf{AH}^{-1} + \mathbf{H}^{-1} \right]
\]

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

If differentiation in a characteristic direction is defined by

\[
D_1(\cdot) = \frac{\partial}{\partial t} (\cdot) + \lambda \frac{\partial}{\partial x}(\cdot) + v \frac{\partial}{\partial y}(\cdot)
\]

(A-17)

then the matrices \( G \) and \( J \) are

\[
G = \begin{bmatrix}
\nu & \frac{1}{2} \rho & \frac{1}{2} \rho & 0 \\
\rho \frac{\partial c^2}{\partial x} & v & 0 & -\rho \frac{\partial c^2}{\partial y} \\
\rho \frac{\partial c^2}{\partial y} & 0 & v & -\rho \frac{\partial c^2}{\partial y} \\
0 & -\frac{1}{2} \rho & -\frac{1}{2} \rho & v \\
\end{bmatrix}
\]

(A-18)

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

(A-19)
The differential equation corresponding to the characteristic direction, \( \lambda_3 \), pointing from the region of integration towards the injector face may be exhibited using (10), (11), (16), (18), and (19). It is

\[
\frac{\partial}{\partial t} (p - \rho \text{cu}) + (u-c) \frac{\partial}{\partial x} (p - \rho \text{cu}) = - \frac{1}{2} \left[ \frac{D_3(p)}{\rho} + \frac{D_3(c)}{c} \right] (p + \rho \text{cu}) + \frac{1}{2} \left[ D_3(p) + D_3(c) \right] (p - \rho \text{cu}) - \frac{\rho c^2}{2} \frac{\partial}{\partial y} (p + v - \rho c^2) - v \frac{\partial}{\partial y} (p - \rho \text{cu}) + \frac{\rho c^2}{2} \frac{\partial}{\partial y} (p - v - \rho c^2) \quad (A-20)
\]

or recalling (17)

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

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

\[
D_3(p) - \rho c D_3(u) - \rho u D_3(c) - uc D_3(p) = - uc D_3(p) - \rho u D_3(c) - \rho c^2 \frac{\partial v}{\partial y} \quad (A-21)
\]

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, \( \rho \), \( m \), 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

\[
\frac{\partial}{\partial t} (p - \rho_0 c_0 u) + (u-c) \frac{\partial}{\partial x} (p - \rho_0 c_0 u) = - v_0 \frac{\partial}{\partial y} (p - \rho_0 c_0 u) - \rho_0 c_0^2 \frac{\partial v}{\partial y} \quad (A-22)
\]

A-5
\( v_o, \rho_o, \) and \( c_o \) indicate the values of \( v, \rho, \) 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

\[
\frac{\Delta x}{\Delta t} = u - c
\]

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.

\[
P_{n+1,2,j} = P_{n,2,j} + \rho_o c_o \left( u_{n+1,3,j} - u_{n,3,j} \right) + \\
\frac{\Delta t}{\Delta x} \left( u_o - c_o \right) \left[ P_{n,2,j} - P_{n,3,j} - \rho_o c_o \left( u_{n,2,j} - u_{n,3,j} \right) \right] - \\
\frac{\Delta t}{\Delta x} v_o \left[ P_{n,2,j+1} - P_{n,2,j-1} + P_{n+1,3,j+1} - P_{n+1,3,j-1} \right] + \\
\rho_o c_o v_o \frac{\Delta t}{\Delta x} \left[ u_{n,2,j+1} - u_{n,2,j-1} + u_{n+1,3,j+1} - u_{n+1,3,j-1} \right] - \\
\rho_o c_o \frac{\Delta t}{\Delta x} \left[ v_{n+1,3,j+1} - v_{n+1,3,j-1} \right] \quad (A-23)
\]
where
\[
\rho_0 = \frac{1}{2} \left( \rho_{n,2,j} + \rho_{n+1,3,j} \right)
\]
\[
c_0 = \frac{1}{2} \left( c_{n,2,j} + c_{n+1,3,j} \right)
\]
\[
v_0 = \frac{1}{2} \left( v_{n,2,j} + v_{n+1,3,j} \right)
\]

The characteristic equation corresponding to \( \lambda_3 = u - c \) may also be written

\[
\frac{\partial \rho_0}{\partial t} + S \frac{\partial \rho_0}{\partial x} = -v \frac{\partial \rho_0}{\partial y} - \rho_0^2 \frac{\partial v}{\partial y} \tag{A-24}
\]

where
\[
Q = p - \rho_0 c_0 u \tag{A-25}
\]
\[
S = u - c
\]

The derivative approximations are:
\[
\frac{\partial Q}{\partial t} \approx \frac{Q_{n+1,2,j} - Q_{n,2,j} + Q_{n+1,3,j} - Q_{n,3,j}}{2\Delta t} \tag{A-26}
\]
\[
\frac{\partial Q}{\partial x} \approx \frac{Q_{n+1,3,j} - Q_{n+1,2,j} + Q_{n,3,j} - Q_{n,2,j}}{2\Delta x}
\]
\[
\frac{\partial Q}{\partial y} \approx \frac{Q_{n,3,j+1} - Q_{n,3,j-1} + Q_{n,2,j+1} - Q_{n,2,j-1}}{4\Delta y}
\]
\[
\frac{\partial v}{\partial y} \approx \frac{v_{n,3,j+1} - v_{n,3,j-1}}{4\Delta y}
\]

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

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

\[
Q_{n+1,2,j} = Q_{n,3,j} + \frac{1 + \lambda S}{1 - \lambda S} \left[ Q_{n,2,j} - Q_{n+1,3,j} \right] - \frac{2\Delta t}{4(1 - \lambda S)\Delta y} \left[ Q_{n,3,j+1} - Q_{n,3,j-1} + Q_{n,2,j+1} - Q_{n,2,j-1} \right] - \frac{2\Delta t}{4(1 - \lambda S)\Delta y} \left[ v_{n,3,j+1} - v_{n,3,j-1} \right] \tag{A-27}
\]
or using (25)

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

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

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

\[ \frac{\lambda \rho_o c_o^2}{2(1 - \lambda s)} \left[ v_{n,3,j+1} - v_{n,3,j-1} \right] \]

(A-28)

where

\[ \lambda = \frac{\Delta t}{\Delta x} = \frac{\Delta t}{\Delta y} \]

\[ \overline{s} = \frac{1}{2} \left[ u_{n,2,j} + u_{n+1,3,j} - c_{n,2,j} - c_{n+1,3,j} \right] \]
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.,

\[ m = m_0 \]  
\[ n = n_0 = 0 \]  
\[ H = H_0 = \frac{\gamma \rho_o}{\gamma - 1} \left( \frac{m_o^2 + n_o^2}{2 \rho_o^2} \right) \]

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 \( \rho \) to yield the time-dependent value of the density:

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

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

or

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

Since

\[ 1 + 2H_o \left( \frac{\gamma - 1}{\gamma p} \right)^2 \geq 1 \]
the root in equation (4) corresponding to the negative radical is not physically meaningful. Consequently, the density may be determined from

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

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

\[ u = \frac{m_o}{\rho} \] (B-6)

In the above,

- \( \rho \) = 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.

\[
\frac{\delta_1 y(j, k, \ell + 1) - (\delta_1 + \delta_{-1}) y(j, k, \ell) + \delta_{-1} y(j, k, \ell - 1)}{(\delta_1 - \delta_{-1}) \Delta z} = y_z(j, k, p)
\]  

(C-1)

where:

\begin{align*}
\delta_1 &= \text{parameter} \\
j, k, \ell &= \text{indexing parameter} \\
\ell - 1 &\leq p \leq \ell + 1 \\
y &= \text{dependent variable} \\
z &= \text{subscript denotes differentiation.}
\end{align*}

The explicit and implicit difference equations follow.
\[
\hat{\rho}(j,k,l+1) - (1 + \hat{\alpha})\rho(j,k,l) + \hat{\alpha}\rho(j,k,l-1) = \frac{\hat{\gamma}_1 \hat{\rho}(j+1,k,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho(j,k,l) + \hat{\gamma}_{-1}\rho(j-1,k,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta x}
\]

\[
+ \frac{\hat{\gamma}_1 \hat{\rho}(j,k+1,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho(j,k,l) + \hat{\gamma}_{-1}\rho(j,k-1,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta y}
\]

\[
+ \omega(j,k,l)
\]

\[
\hat{\rho}(j,k,l+1) - (1 + \hat{\alpha})\rho(j,k,l) + \hat{\alpha}\rho(j,k,l-1) = \frac{\hat{\gamma}_1 \hat{\rho}(j+1,k,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho(j,k,l) + \hat{\gamma}_{-1}\rho(j-1,k,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta x}
\]

\[
+ \frac{\hat{\gamma}_1 \hat{\rho}(j,k+1,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho(j,k,l) + \hat{\gamma}_{-1}\rho(j,k-1,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta y}
\]

\[
+ \omega(j,k,l+1)
\]

\[
\hat{\rho}_m(j,k,l+1) - (1 + \hat{\alpha})\rho_m(j,k,l) + \hat{\alpha}\rho_m(j,k,l-1) = \frac{\hat{\gamma}_1 \hat{\rho}_m(j+1,k,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho_m(j,k,l) + \hat{\gamma}_{-1}\rho_m(j-1,k,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta x}
\]

\[
+ \frac{\hat{\gamma}_1 \hat{\rho}_m(j,k+1,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho_m(j,k,l) + \hat{\gamma}_{-1}\rho_m(j,k-1,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta y}
\]

\[
+ \omega(j,k,l+1)
\]

\[
\hat{\rho}(j,k,l+1) - (1 + \hat{\alpha})\rho(j,k,l) + \hat{\alpha}\rho(j,k,l-1) = \frac{\hat{\gamma}_1 \hat{\rho}(j+1,k,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho(j,k,l) + \hat{\gamma}_{-1}\rho(j-1,k,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta x}
\]

\[
+ \frac{\hat{\gamma}_1 \hat{\rho}(j,k+1,l) - (\hat{\gamma}_1 + \hat{\gamma}_{-1})\rho(j,k,l) + \hat{\gamma}_{-1}\rho(j,k-1,l)}{\left(\hat{\gamma}_1 - \hat{\gamma}_{-1}\right)\Delta y}
\]

\[
+ \omega(j,k,l+1)
\]
where:

\[ A = p + \frac{m^2}{\rho} \]
\[ B = \frac{m_n}{\rho} \]
\[ D = p + \frac{n^2}{\rho} \]
\[ G = \frac{n}{\rho}(p + E) \]
\[ H = \frac{n}{\rho}(p + E) \]

\( \alpha, \gamma \) = integration parameters

\( \checkmark \) = predicted values of the functions obtained from the explicit equations.

\( \checkmark \) = corrected values, obtained by the implicit equations in which the predicted values are employed.

The predicted and corrected values are combined as follows:

\[ \rho(j,k,l+1) = U\checkmark \rho(j,k,l+1) + (1 - U)\checkmark \rho(j,k,l+1) \quad \text{(C-10)} \]
\[ m(j,k,l+1) = Um(j,k,l+1) + (1 - U)m(j,k,l+1) \quad \text{(C-11)} \]
\[ n(j,k,l+1) = Un(j,k,l+1) + (1 - U)n(j,k,l+1) \quad \text{(C-12)} \]
\[ E(j,k,l+1) = UE(j,k,l+1) + (1 - U)E(j,k,l+1) \quad \text{(C-13)} \]

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 \( \checkmark, \checkmark, \gamma_1, \gamma_{-1}, \gamma_{-1} \), \( \Delta t, \Delta x, \) and \( \Delta y \), which appear in the difference equations, before numerical calculations can be made. The choices of \( \gamma_1 = \gamma_{-1} = 1 \) and \( \gamma_{-1} = \gamma_{-1} = -1 \)
provides the most accurate approximation to the partial derivatives of the space variables. With these, or other choices, it remains to assign values to $\alpha^*, \Delta t, \Delta x,$ and $\Delta y$ 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

START

KEOFF = .6
TOUWT = 0
DELT = 6.6

READ IN DATA
AND INITIALIZE
CALL INITIAL

PRINTOUT OF
INPUT DATA
CALL PRINT (1)

TOUWT = TOUWT + 1

FIND A STABLE
DELTAD T
CALL STABLE

COMPLETE THE
MESH AT VIRTUAL
POINTS
CALL VIRTUAL

CALCULATE
VALUES AT MESH
POINTS
CALL GENPT
Figure D-2

FLOW DIAGRAM OF SUBROUTINE INITIAL INTEGRATION PROGRAM

FLOW DIAGRAM

- ENTER
- INPUT-2
- READ STEADY-STATE VALUES
- RESTART
- READ INPUT DATA
- M = LENS, LENS
- READ (5, 5)
  (WKR, I, JFR)
  (K = 1, 4)
- CONTINUE
- CALCULATE INDICING CONSTANTS
- CALCULATE OTHER CONSTANTS AND NON-DIMENSIONALIZE THE VARIABLES
- END
- END
Figure D-3
FLOW DIAGRAM OF SUBROUTINE STABLE INTEGRATION PROGRAM

ENTER

DEL1=0.0 (OOS3)

LK = 1
JLB = JY1
JUB = JX4

I=2
JX4

JLB=JYES

I=I+1
JX11

LK = 1K + 1
JLB = JLB + 1
JUB = JUB + 1

J=JLB
JUB

THEN-GU/SORT
(CPARMV(1,1,1))
WX(1,1,1)3450RT
(YTR1,1,1)
DELTA-THED* DELX
Figure D-4

Flow Diagram of Subroutine Virtual Integration and Conversion Programs
Fig. 1

FLOW DIAGRAM OF SUBROUTINE BOI

ENTER

IF SLOPE < 1/2
    REFLECT VALUES
    ENTER
    IF SLOPE = 1/2
        INTERPOLATE PARALLEL TO THE X-AXIS
        J = 1, 3
    END IF
    TEST, EQ. 2
    J = J + 4
    K = K + 1
    IF K = K1
        W0 = W(JJ, IX, 2), W1 = W(JJ, IX, 3), W2 = W(JJ, IX, 1)
        P(JJ, 1) = XINT(W0, W1, W2, X)
        W0 = P2(JJ, 1)
        W1 = P2(JJ, 2)
        W2 = P2(JJ, 3)
    END IF
    IF TEST = 1
        INTERPOLATE ALONG THE NORMAL
        J = J + 4
        K = K + 1
        IF K = K1
            W0 = W(JJ, IX, 2), W1 = W(JJ, IX, 1), W2 = W(JJ, IX, 1)
            P(JJ, 1) = XINT(W0, W1, W2, X)
            W0 = P(JJ, 1)
            W1 = P(JJ, 2)
            W2 = P(JJ, 3)
        END IF
    END IF
    CONTINUE

IF SLOPE ≥ 1/2
    INTERPOLATE ALONG THE NORMAL
    J = J + 4
    K = K + 1
    IF K = K1
        W0 = W(JJ, IX, 2), W1 = W(JJ, IX, 1), W2 = W(JJ, IX, 1)
        P(JJ, 1) = XINT(W0, W1, W2, X)
        W0 = P(JJ, 1)
        W1 = P(JJ, 2)
        W2 = P(JJ, 3)
    END IF
    IF TEST = 1
        INTERPOLATE PARALLEL TO THE X-AXIS
        J = J + 4
        K = K + 1
        IF K = K1
            W0 = W(JJ, IX, 2), W1 = W(JJ, IX, 3), W2 = W(JJ, IX, 1)
            P(JJ, 1) = XINT(W0, W1, W2, X)
            W0 = P2(JJ, 1)
            W1 = P2(JJ, 2)
            W2 = P2(JJ, 3)
        END IF
    END IF
    CONTINUE

FOLDOUT FRAME
REFLECTION AT THE BOTTOM INTEGRATION AND CONVERSION PROGRAMS

VIRTUAl. POINTS FOR THE DIFFUSER SECTION

INTERPOLATE AI ON(7, HORIZONTAL _vXO=W (K WX2=WfK,IX+I, JJl) ]
PI (K I.)=
XJNT(WX0,WXI ,WX2.X)]]
WX0=W(K,IX- I ,JJ2)

WX=W(K,IX,JY3PI)

R(K,I)=
XINT(WX0,WXI ,WX2,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
WXO=P2 (K,3)
WXI=P2 (K,2)
WX2=P2(K, 1)
R(K,2)=
XINT(WX0
WX 1 ,_X2 ,X)
Figure D-6

FLOW DIAGRAM OF SUBROUTINE GENPT INTEGRATION PROGRAM
FLOW DIAGRAM OF SUBROUTINE

ENTER

$T=2$, $I_{x1}$

TRANSFER AV MATRIX

$I_{i}=I_{i1}$, $I_{o}$

$J_{i}=J_{i1}$, $J_{o}$

CALCULATE VALUES OF $AF$

CONTINUE

TRANSFER AVA MATRIX

$I_{x}=I_{x1}$, $I_{x1}$

$J_{x}=J_{x1}$, $J_{x1}$

$K=1$, $A$

CALCULATE VALUES OF AVA $(K, I, J)$

CONTINUE

CALCULATE OTHER VALUES OF AVA

CONTINUE

$K+1$, $A$

CALCULATE FINAL VALUES

CONTINUE

CONTINUE

$T=3$, $I_{x1}$

IF $IR(1)$ NE 5 AND $IR(1)$ NE 2

$K=1$, $A$

AVERAGE VALUES AROUND THE HOLES

CONTINUE

CONTINUE

$T=3$, $I_{x1}$

IF $IR(1)$ NE 5

WITHDRAW ENERGY AT THE HOLES

CONTINUE
LINER INTEGRATION PROGRAM

D-7

VALUES IN THE X-DIRECTION

CALCULATE AVG

CONTINUE

I=1, J=1

I=2, J=1

CALCULATE TEMP

CONTINUE

CONTINUE

CONTINUE

CONTINUE

A(X,I,J)=TEMP(J)

CONTINUE

CONTINUE

CONTINUE

CONTINUE

RETURN

VALUES IN THE Y-DIRECTION

CALCULATE AVG

CONTINUE

I=1, J=1

I=2, J=1

CALCULATE TEMP

CONTINUE

CONTINUE

CONTINUE

CONTINUE

A(X,I,J)=TEMP(J)

CONTINUE

CONTINUE

CONTINUE

CONTINUE

RETURN

672211
FD 23150

D-8
Figure D-8
FLOW DIAGRAM OF SUBROUTINE PRINT INTEGRATION AND CONVERSION PROGRAMS
INTEGER * 4 TCCLAT, T, IT

COMMON/CCP1/ (52, 23), A(5, 3, 5), XMPM(52, 23), YMPM(52, 23),
1 VSC(52, 23), XMPM2(3, 5), YMPM2(3, 5), VSCA(3, 5),
2 GAM, GAM1, GAM2, GAM3, DELX, DELY,
3 CELT, FUCPE, SC, INC, TICL, TP,
4 CCN3, CIFCC, X, EXERC, XM, CMICA, TFFF,
5 CLE, CP, EXP, JMC

COMMON/CCPM/ ITP(2C), IR(3C),
1 IX1, IX1P1, IX1P2, IX2, IX3, IX4,
2 IX4P1, IX4P2, IX4P3, JY1, JY1P1, JY1P2,
3 JY2, JY2P1, JY2P2, JY3, JY3P1, JY4,
4 JY3P2, JY5P1, JY5P2, ISLCPE, JEXL, JEXU

COMMON/CCP3/ (2C), XDIS(3), XDISP(3), DFX(2), CFN(3),
1 SINB1, CCBS1, SINE, CCSS1, CS1, CIST,
2 IFLH, MESH, IWISH

COMMON/CCPM/ (2C), XVEL(2, 2, 23), YVEL(2, 23), SCNIC(2, 2, 23), PRES(2, 2, 23)

COMMON/CCPM/ (12, 3, 10), AVA(12, 2, 1C), AXV(35), AVV(5)

CALL PCCCK (HR, MIN, ISEC)
CALL CATC (MC, ICAY, IYR)
WRITE (6, 1) MC, ICAY, IYR, HR, MIN, ISEC
FOMAT (1I-1, MC, ICAY, IYR, HR, MIN, ISEC
KICCFF = C
TCCLAT = C
CELT = C

INITIALIZE AND REAC IN DATA

CALL INITIAL
IF (TCCUNT .LE. T) GC TC 100
WRITE (6, 2) T, TCCUNT, T
FOMAT (1I-1, MC, ICAY, IYR, HR, MIN, ISEC
KICCFF = C
TCCLAT = C
CELT = C

INPUT DATA PRECUR

CALL PRINT (I)
TCCUNT = TCCLAT + 1
IF (T .EQ. 0) GC TC 475

FIN A STABLE CELT

CALL STABLE

COMPLETE MATRICES AT VIRTUAL PCINTS
CALL VRTLAL
CALL CALCULATE VALLES AT MESH POINTS
CALL GENPT
PRINTCLT
IF (TCCOUNT.LT.5) GC TC 400
IF (KICOFF.EQ.1) GC TC 400
IF (MCC(TCCOUNT,TI).NE.0) GC TC 450

400 CALL PRINT (2)
TEST TC DETERMINE IF RLHA HAS BEEN COMPLETED

450 IF (TCCOUNT.EQ.T.Ct.KICOFF.EQ.1) GC TC 475
TCCOUNT = TCCOUNT + 1
GC TC 200

WRITE INFORMATICA FOR RESTART

475 IF (MESH .NE. 1) GC TC 500
480 REAC (9,ENC=5CC) SKIP
GC TC 48C

500 WRITE (9) ,A ,XMCM2 ,YMCM2 ,VSC ,XMCM2A ,YMCM2A ,
1 VSAC ,GAM ,GAM1 ,GAM2 ,GAM3 ,CELX ,CELLY ,
2 CELT ,FUCGE ,SQ ,TNC ,TTCR ,TP ,CCN3 ,
3 CIFCC ,XH ,ENERC ,XML ,CMEGA ,THICK ,QUE ,
4 QP ,EXP ,
WRITE (9) ICROP ,IR ,
1 IX1 ,IX1M1 ,IX1P1 ,IX2 ,IX3 ,IX4 ,IX4M1 ,
2 IX4M2 ,IX4M3 ,JY1 ,JY1M1 ,JY1P1 ,JY2 ,JY2M1 ,
3 JY2P1 ,JY2P2 ,JY3 ,JY3M1 ,JY3P2 ,JY3P1 ,JY4 ,
4 JY4M1 ,JY4P1 ,JY5 ,JY5M1 ,JY5P2 ,ISLOPE ,JEXL ,
5 JEXU ,
WRITE (9) C ,XDIS ,DXDSP ,CFX ,CFN ,SINB1 ,
1 CCSB1 ,SINE ,CCSINE ,CIST ,CISTP ,
2 ILEN ,
WRITE (9) XM ,PC ,TC ,RMC0 ,XMCMC ,YMCMO ,AO ,
1 XM ,PC ,XMCMC ,XMCMO ,AO ,
2 XLEN ,YLEN ,XSLCE ,YSLCE ,CCCN1 ,CCCN2 ,
WRITE (9) TCCOUNT ,T ,KICOFF ,TT ,
WRITE (9) TV ,TVA ,XV ,YY ,XVEL ,YVEL ,SONIC ,
1 PRES ,
WRITE (9) AV ,AVA ,AXV ,AYV ,
600 END FILE 9
REWIRE 9

STOP
END
INTEGER * 4 TCCLNT, TT

CCMON/CCM1/TV(5, 52, 23), AT(5, 53, 5), XMCM2(52, 23), YMOM2(52, 23),
VSC(52, 23), XMCM2A(53, 5), YMCM2A(53, 5), VSCA(53, 5),
1 GAA, GAM1, GAM2, GAM3, CELX, CELY,
2 DELT, FLGGE, SQ, TNC, TTCL, TP,
3 CON3, CIFCC, XM, ENERO, XM, OMEGA, THICK,
4 CLE, GP, EXP, J/ID

CCMON/CCM2/ TV(5, 52, 23), 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, JY5P2, ISLCPE, JEXL, JEXU

CCMON/CCM3(12C), XDISH(3), XDISH(3), DFX(2), CFN(3),
1 SINB1, CCSB1, SINE, COSINE, CFN, CISPL

1 ILEN, MESH, IWISH,
2 CCN1, CCN2, IRFO, IM, IN, IE
3 IPRES, NCP
CCMON/CCM4/TV(12, 3, 23), TVA(12, 2, 22), XV(52), YV(23),
1 XVEL(2, 2, 23), YVEL(2, 23), SCN(1, 2, 23), PRES(2, 2, 23)
CCMON/CCM7/TV(12, 3, 10), AVA(12, 2, 10), AXV(35), AYV(5)

C

1 FCRMAI (4110)
2 FCRMAI (5110)
3 FCRMAI (7F10.C, E10.C)
4 FCRMAI (E10.C)
5 FCRMAI (4E10.C)
6 FCRMAI (3F10.C)
7 FCRMAI (11, 2X, 11, 67X, 11)
8 FCRMAI (110, F10.C)
9 FCRMAI (4F10.C)

READ IN DATA

READ (5, 7) MESH, IWISH, INPUT
IF (INPUT = 2) 40, 26, 15

STEADY STATE INPUT

15 IF (MESH .NE. 1) GC TC 2C
16 READ (8, EAC = 20) SKIP

GC TC 16

20 READ (8) h, a, XMCM2, YMCM2, VSC, XMCM2A, YMCM2A,
1 VSCA, GAM, GAM1, GAM2, GAM3, CELX, CELY,
2 DELT, FLGGE, SQ, TNC, TTCL, TP,
3 CIFCC, XM, ENER, XM, OMEGA, THICK,
4 GP, EXP, J/ID

READ (8) ICRCPE, 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 (8) D, XDISH, XDISH, DFX, CFN, SINB1,
CCSB1, SINE, CCSINE, CIST, CISTP,
ILEX
READ (E) XM, PC, TC, RHCC, XMCMC, YMCMC, AO,
XLEN, YLEN, XSLCPE, SLCPE, CCA1, CCN2,
IRHC, IP, IN, IE, IPRES
READ (E) TCCLNT, T, KCFF, IT
READ (E) TV, TVA, XV, YV, XVEL, YVEL, SONIC,
PRES
READ (E) AV, AVA, AXV, AYV

25 RFCINC 8

C
READ (5, 4) T, TT, ACPT, IRHC, IP, IN, IE, IPRES
READ (5, 5) TF, CF, EXP
CP = CP / CCN2 * CCN3
IF (IX1.EQ.1) GC TC 450
READ (5, 9) XML, CMPE, THICK
XML = XML/((PC*AC*XLEN)
CMPE = CMPE/CCN3
THICK = THICK/XLEN

C
CC TC 450
C
RESTART VALUES
C
26 IF (MESH .NE. 1) GC TC 3C
27 READ (5, EAC=3C) SKIP
CC TC 27
30 READ (S) W, A, XMCMC, YMCMC, VSC, XMCMC2A, YMCMC2A,
1 VSCL, GAM, GPM2, GPM3, GPM3, CELX, CELV,
2 CELT, CLEN, SC, TN1, TTCL, TP, CON3,
3 CIFCC, SH, ENERG, XML, CMPE, THICK, QUE,
4 CP, EXP
READ (S) ICRP, IR,
1 I, IX1, IX2, IY1, IY2, IX2, IY2, IX3, IY3,
2 IX4, JY1, JY2, JY3, JY4, JY4, JY5, JY5,
3 JY5, JY5, JY5, JY5, JY5, JY5, JY5, JY5,
4 JY5, JY5, JY5, JY5, JY5, JY5, JY5, JY5,
5 JXCL
READ (S) C, XDISP, XDISP, CFX, CFN, SINBI,
1 CCSB1, SINE, CCSINE, CIST, CISTP,
2 ILEX
READ (S) XM, PC, TC, RHCO, XMCMC, YMCMC, AO,
XLEN, YLEN, XSLCPE, SLCPE, CCA1, CCN2,
IRHC, IP, IN, IE, IPRES
READ (S) TCCLNT, T, KCFF, IT
READ (S) TV, TVA, XV, YV, XVEL, YVEL, SONIC,
PRES
READ (S) AV, AVA, AXV, AYV
RFCINC 9

C
READ (5, 4) T, TT, ACPT, IRHC, IP, IN, IE, IPRES
C
CC TC 450
C
CCE C START
C
40 READ (5, 1) LENX1, LENX2, LENX3, LENX4
READ (5, 2) LENY1, LENY2, LENY3, LENY4, IFHY, IFHY5

D-13 INITIAL - 2
REAC (5,3) XM, PC, TC, GAM, FUDGE, DELX, DIFCC, CUE
REAC (5,4) T, TN, NOPT, IRH, IK, IN, IE, IPRES
XML = C.C
OMEGA = C.C
THICK = C.C
TP = C.C
CP = C.C
EXP = C.C
CELY = CELX

CALCULATE INDEXING CONSTANTS

IX1 = LENX1 + 2
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
JY2P1 = JY2 - 1
JY2P2 = JY2 + 1
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
JM1C = (JY5 + 1) / 2
IF (IX1.EQ.1) GC TC 90
JEXL = JY2M1
JEXU = JY3P1
READ (5,6) XML, OMEGA, THICK

CALCULATE CONSTANTS

NDIMENSIONALIZE THE VARIABLES

90 XLEN = LENX4*DELX
CELX = DELX/XLEN
CELY = DELX
YLEN = LENY5*CELY
GAM1 = GAM - 1.
GAM2 = GAM1/2.
GA_3 = (GAP - 3o)/2.
SQ = 1./SQR(2.)

RHCO = X*/1545.*P0/TC
AC = SQRT(GA_3*32.2*P0/RHCO)
CCN1 = RHCO*AC
CCN2 = CCN1*AC/32.2
CCN3 = XLEN/AC
ENPERC = PC/GAMY1/CCK2
XMU = XML/(PC*AC*XLEN)
CMEGA = CMEGA*CCK3
THICK = THICK/XLEN
TNC = C*C
ITCL = 0.0
CUE = CUE / CCN2 * CCN3

TEST TO SEE IF OBLIQUE BOUNDARIES ARE PRESENT

ILEN = LENX3 - LENX2
IF (ILEN.NE.C) GC TO 100
ISLOPE = C
SLOPE = ISLOPE
XSLOPE = C*C
ICROP(1) = I*4 + 1
SINBI = C.C
COSBI = C.C
GC TO 140

INFORMATION FOR SUBRUTINE BCUD

1CC ISLOPE = ILEN/LENY2
SLOPE = ISLOPE
XSLOPE = -1./SLOPE
CLP = SQRT((SLOPE*DELY)**2 + DELY**2)
SINBI = -DELY/CLP
COSBI = SLOPE*DELY/CLP
CIST = DELY/CCSBI
IU = ISLOPE + 1

CC 11C I=1,ISLOPE
R = I*CELX
CS = -R*SINBI
11G C(I) = 3.*DIST - 2.*CS
C(TL) = 4.*CIST + 2.*IU*CELX*SINBI

CC 112 I=1,3
P = I
Y = -P*DELY
112 XDIS(I) = Y/SLOPE + 2.*CELX

CC 114 I=1,3
P = I
Y = -(P + 1.)*DELY
114 XDIS(I) = Y/SLOPE + 2.*CELX

DETERMINATION OF LINES WHERE POINTS SHOULD BE CRPPEC

IU = ILEN/ISLOPE
CC 12C I=1,1L
K = I - 1
120 ICROP(I) = IX2 + K*ISLCPE + 1
C
ICIS = 2
IF (IX1*EC.I) ICIS = 1
CC 125 I=1,ICIS
K = IL + I
125 ICROP(K) = IX3PI + 3*I
ICROP(K+1) = IX4 + 1
C
GEOMETRY FOR THE DIFFUSER
C
CIS = SQRT((3.*CELX)**2 + DELY**2)
SINE = DELY/CIS
COSINE = 3.*SINE
CISTP = DELY/COSINE
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.*CISTP - 2.*CS
C
ESTABLISH INITIAL CONDITIONS
C
140 LK = 1
JLB = JY1
JUB = JY4
C
CC 16C I = 2,IX3
REA(5,5) (k(K,I,J5),K=1,4)
C
IF (I.NE.IXIPI) GO TO 16C
JLB = 2
JLB = JY51
C
160 IF (I.NE.ICRCP(LK)) GO TO 17C
LK = LK + 1
JLB = JLB + 1
JUB = JUB - 1
C
170 CC 18C J=JLB,JLB
w(1,I,J) = w(1,I,J5)/RICO
w(2,I,J) = w(2,I,J5)/CCH1
w(3,I,J) = w(3,I,J5)/CCH1
w(4,I,J) = w(4,I,J5)/CCH2
C
XPM2(1,J) = w(2,I,J)*w(2,I,J)/w(1,I,J)
YPM2(1,J) = w(3,I,J)*w(3,I,J)/w(1,I,J)
VSC(1,J) = (XPM2(1,J) + YPM2(1,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

D-16

INITIAL - 5
CC 190 I=IX3P1,IX4

IF (I*NE.I0) GC TC 185
LK = LK + 1
JLB = JLB - 1
JLB = JLB + 1

CC 19C J=JLB,JLB
READ (5,5) (K(K,I,J),K=1,4)
W(1,I,J) = W(1,I,J)/RHCC
W(2,I,J) = W(2,I,J)/CC1
W(3,I,J) = W(3,I,J)/CC1
W(4,I,J) = W(4,I,J)/CC2

XMCN2(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) = (XMCN2(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)

190 CONTINUE

XH = GAM1/GAM1/W(5,2,10)/W(1,2,10) + XMCN2(2,10)/(2.*W(1,2,10))

IF (IX1.EQ.1) GC TC 45C
CO 30C I=2,IX1
CO 21C J=2,JY1
A(1,I,J) = 1.C
A(2,I,J) = 1.C
A(3,I,J) = 1.C
210 A(4,I,J) = ENERG

IF (I.EQ.2) GC TC 3CC
IR(1) = MCD(I,6)
IF (IR(1).EQ.3) SIGN = -1.C
W(K,I,JY1) = A(K,I,JY1)

280 W(K,I,JY4) = SIGN*A(K,I,JY1)

300 CONTINUE

IR(2) = 2

CC 40C I=2,IX1
CO 40C J=2,JY1
XMCN2A(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)
VSCA(I,J) = (XMCN2A(I,J) + YMOM2A(I,J))/A(1,I,J)
400 A(5,I,J) = PC/CC2

450 RETURN
END
SCLRTLTIME STABLE

COMMON/CCM1/W(5,52,23), A(5,30,5), XMC(52,23), YM(52,23),
1 VSC(52,23), XMCP2A(3C,5), YMC(2A(3C,5), VSCA(30,5),
2 GAM ,GAM1 ,GAM2 ,GAM3 ,CELX ,CELY ,
3 CELT ,FLDGE ,SC ,TNC ,TTCL ,TP ,
4 CCA3 ,CFCC ,XH ,ENERO ,XPL ,MEGA ,THICK ,
5 CLE ,CP ,EXP ,JMED

COMMON/CCM2/ ICRCP(2C) ,IA(30),
1 IX1 ,IX1P1 ,IX1P2 ,IX2 ,IX3 ,IX4 ,
2 IX4M1 ,IX4P2 ,IX4M3 ,JY1 ,JY1M1 ,JY1P1 ,
3 JY2 ,JY2P1 ,JY2P2 ,JY3 ,JY3M1 ,
4 JY3M2 ,JY3P1 ,JY4 ,JY4M1 ,JY4P1 ,JY5 ,
5 JY5P1 ,JY5P2 ,ISLOPE ,JEXL ,JEXU

CEL = 1G.C/CNA3

LK = 1
JLB = JY1
JLB = JY4
CC 2CC I=2,IX4
IF (I.NE.IXIP1) GC TC 90

JLB = 2
JUB = JY5M1

90 IF (I.NE.ICRCP(LK)) GC TC 1CC
LK = LK + 1
JLB = JLB + 1
JUB = JUB - 1

1CC CC 2CC J=JLB,JLB

TDEL = SQ/(SCRT(GAMW(5,1,J)/W(1,1,J)) + SCRT(VSC(1,J)))
CELTX = TDEL*CELX
CELTY = TDEL*CELY
CEL = AMIN(CDEL,CELTX,CELTY)

2CC CONTINUE

CEL = CELT*FLDGE

IF (TTCL*GE.(TP - 1.0E-6)) GC TO 350
TCIF = (TP - TTCL)/CCM3
IF (TCIF*LE.CELT) CELT = TCIF

35C RETURN
END

D-18 STABLE
SUBRCLTNE VRTIAL

COMMON/COM1(5,52,23), A(5,30,5), XMOM2A(3C,5), YOMM2A(3C,5), VSQA(30,5),
1 VSC(5,23), XMOM2A(3C,5), YOMM2A(3C,5), VSQA(30,5),
2 CAPS, CAP2, CAP3, CELX, CELY,
3 DELE, FLDCGE, SC, TNC, TCC, TP,
4 CCN3, CIFCL, XH, ENERC, XNRL, CMEGA, THICK,
5 GLE, C6, EXP, JMIC

CCMCH/CCM2/ IRCP2(2C), IR(30),
1 IX1, IX1P1, IX2, IX3, IX4
2 IX4P1, IX4P2, IX4P3, JY4, JY4PI, JY5
3 JY2, JY2P1, JY2P2, JY3, JY3P1, JY4
4 JY3P2, JY3P3, JY4, JY4P1, JY4P2, JY5
5 JY5P1, JY5P2, ISLCPE, JEXL, JEXU

VIRTUAL POINTS FOR THE GENERAL MESH

PARALLEL TC X-AXIS

IF (IX1.EQ.1) GC TC 45
CC 4C K=1,4
SIGN = 1.0
IF (K.EQ.3) SIGN = -1.0
CC 4C I=2,IX1P1
IF (I.EQ.2) GC TC 10
IF (IR(I).EQ.CR.IR(I).EQ.1.CR.IR(I).EQ.2.CR.IR(I).EQ.5) GO TO 20

10 W(K,I,JY1P1) = SIGN*A(K,I,JY1P1)
W(K,I,JY4P1) = SIGN*A(K,I,JY4P1)
IF (K.NE.4) GC TC 40
XMOM2(I,JY1P1) = XMOM2(I,JY1P1)
XMOM2(I,JY4P1) = XMOM2(I,JY4P1)
YOMM2(I,JY1P1) = YOMM2(I,JY1P1)
YOMM2(I,JY4P1) = YOMM2(I,JY4P1)
VSC(I,JY1P1) = VSC(I,JY1P1)
VSC(I,JY4P1) = VSC(I,JY4P1)
CC TC 40

20 W(K,I,JY1P1) = A(K,I,JY1P1)
W(K,I,JY4P1) = SIGN*A(K,I,JY1P1)

30 IF (K.NE.4) GC TC 40
XMOM2(I,JY1P1) = XMOM2A(I,JY1P1)
XMOM2(I,JY4P1) = XMOM2A(I,JY1P1)
YOMM2(I,JY1P1) = YOMM2A(I,JY1P1)
YOMM2(I,JY4P1) = YOMM2A(I,JY1P1)
VSC(I,JY1P1) = VSQA(I,JY1P1)
VSC(I,JY4P1) = VSQA(I,JY4P1)
CC TC 40

40 CONTINUE

45 DC 7C K=1,4
SIGN = 1.0
IF (K.EQ.3) SIGN = -1.0
DC 7C I=IX1,IX2
IF (IX1.EQ.1) GC TC 50
IF (I.NE.IX1) GC TC 5C
W(K,I,1) = SIGN*A(K,I,3)
\( w(K, I, JY5) = A(K, I, J) \)

CC TC 60

C

50 \( w(K, I, I) = \text{SIGA} \cdot w(K, I, J) \)

\( w(K, I, JY5) = \text{SIGN} \cdot w(K, I, JY5 \cdot M) \)

C

60 IF (K.NE.4) CC TC 70

\( XMOM2(I, J) = w(2, I, I) \cdot w(2, I, J) / w(1, I, J) \)

\( XMOM2(I, JY5) = w(2, I, JY5) \cdot w(2, I, J) / w(1, I, JY5) \)

\( YMOM2(I, J) = w(3, I, I) \cdot w(3, I, J) / w(1, I, J) \)

\( YMOM2(I, JY5) = w(3, I, JY5) \cdot w(3, I, J) / w(1, I, JY5) \)

\( VSC(I, J) = (XMCM2(I, J) + YMOM2(I, J)) / w(1, I, J) \)

\( VSC(I, JY5) = (XMCM2(I, JY5) + YMOM2(I, JY5)) / w(1, I, JY5) \)

70 CONTINUE

C

IF (I*X1.EQ.1) GC TC 92

C

PARALLEL TO Y-AXIS

C

CC 92 K=1,4

CC 80 J=2, JY1*K

\( w(K, I, I, J) = A(K, I, I, J) \)

C

IF (K.NE.4) CC TC 80

\( XMOM2(IXI, J) = XMOM2A(IXI, J) \)

\( YMOM2(IXI, J) = YMOM2A(IXI, J) \)

\( VSC(IXI, J) = VSCA(IXI, J) \)

C

80 CONTINUE

C

CC 85 J=JY4*1, JY5*1

\( JJ = JY5 \cdot M1 - J + 2 \)

\( w(K, I, I, J) = A(K, I, I, J) \)

C

IF (K.NE.4) CC TC 85

\( XMOM2(IXI, J) = XMOM2A(IXI, J) \)

\( YMOM2(IXI, J) = YMOM2A(IXI, J) \)

\( VSC(IXI, J) = VSCA(IXI, J) \)

C

85 CONTINUE

C

90 CONTINUE

C

CBLIGLE BOUNDARIES

C

92 IF (ISLOPE.EQ.C) GC TC 95

CALL BCUNC

C

95 IF (I*X1.EQ.1) GC TC 200

C

VIRTUAL POINTS FCR THE ACCUSTICAL LINER

C

PARALLEL TO X-AXIS

C

CC 11C K=1,4

\( \text{SIGN} = 1.0 \)

IF (K.EQ.3) \( \text{SIGN} = -1.0 \)

EC 11C I=2, I*X1
A(K,I,1) = SIGN*A(K,I,3)

IF (I.EQ.2) GC TC 98
IF (IR(I).EQ.1.OR.IR(I).EQ.2.OR.IR(I).EQ.5) GC TC 100

98 A(K,I,JY1P1) = SIGN*A(K,I,JY1P1)

IF (K.NE.4) GC TC 11C
XMOM2A(I,1) = A(2,1,1)*A(2,1,1)/A(1,1,1)
XMOM2A(I,JY1P1) = XMCM2A(I,JY1P1)
YMOM2A(I,1) = A(3,1,1)*A(3,1,1)/A(1,1,1)
YMOM2A(I,JY1P1) = YMCM2A(I,JY1P1)
VSCA(I,1) = (XMOM2A(I,1) + YMCM2A(I,1))/A(1,1,1)
VSCA(I,JY1P1) = VSCA(I,JY1P1)

GO TC 11C

100 A(K,I,JY1P1) = w(K,I,JY1P1)

105 IF (K.NE.4) GC TC 11C
XMOM2A(I,1) = A(2,1,1)*A(2,1,1)/A(1,1,1)
XMOM2A(I,JY1P1) = XMCM2A(I,JY1P1)
YMOM2A(I,1) = A(3,1,1)*A(3,1,1)/A(1,1,1)
YMOM2A(I,JY1P1) = YMCM2A(I,JY1P1)
VSCA(I,1) = (XMOM2A(I,1) + YMCM2A(I,1))/A(1,1,1)
VSCA(I,JY1P1) = VSCA(I,JY1P1)

CONTINUE

PARALLEL TC Y-AXIS

GD 13C K=1,4
SIGN = 1.C
IF (K.EQ.2) SIGN = -1.0
GD 13C J=2,JY1
A(K,J,J) = SIGN*A(K,3,J)
A(K,1X1P1,J) = w(K,IX1P1,J)
IF (K.NE.4) GC TC 13C
XMOM2A(I,J) = A(2,1,J)*A(2,1,J)/A(1,1,J)
XMCM2A(1X1P1,J) = XMCM2(1X1P1,J)
YMOM2A(I,J) = A(3,1,J)*A(3,1,J)/A(1,1,J)
YMCM2A(1X1P1,J) = YMCM2(1X1P1,J)
VSCA(I,J) = (XMOM2A(I,J) + YMCM2A(I,J))/A(1,1,J)
VSCA(1X1P1,J) = VSCA(1X1P1,J)

CONTINUE

CORNER POINTS

GD 15C 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,1X1P1,1) = w(K,IX1P1,1)
A(K,1X1P1,JY1P1) = w(K,IX1P1,JY1P1)
IF (K.NE.4) GC TC 15C
XMOM2A(I,1) = A(2,1,1)*A(2,1,1)/A(1,1,1)
XMCM2A(1X1P1,1) = XMCM2(1X1P1,1)
XMCM2A(1X1P1,JY1P1) = XMCM2(1X1P1,JY1P1)

VIRTUAL - 3
C 150 CONTINUE

C 200 RETURN

ENC

SLBRCUTINE INTIAL
SLBRLTINE BCLNC

CCMN/COM1/h(5,52,23), A(5,30,5), XMOM2(52,23), YMOM2(52,23), VSC(52,23), XMOM2A(3C,5), YMOM2A(3C,5), VSCA(30,5),
1 VSC(52,23), XMOM2A(3C,5), YMOM2A(3C,5), VSCA(30,5),
3 CELT, FUCGE, SQ, TNC, TTCL, TP,
4 CCM2, DIFCC, XM, ENERG, XM, CMegra, THICK,
5 CLE, CP, EXP, JMIE

CCMN/CCM2/ IDRCP(2C), IR(30),
1 IX1, IX1P1, IX1P1, IX2, IX3, IX4
2 IX4P1, IX4P2, IX4P3, IX5
3 JY1, JY1P1, JY1P2, JY2P1, JY2P2, JY2
4 JY3P1, JY3P2, JY3P3, JY3P4, JY3P5
5 JY5P1, JY5P2, ISLCPE, JEXL, JEXU

CCMN/CCM3/C(2C), XDIS(3), XDISP(3), DFX(2), DFN(3),
1 SINE1, COSB1, SINE, COSINE, CIST, CISTP
2 ILEH, RESH, IWHISH

DIMENSION P1(4,3), P2(4,3), R(4,2)
DIMENSION XX(3)

XINT(A,B,C,X) = A + X*(B - A)/DELTA +
1 X*(X - CELTA)*(C - 2.0*B + A)/(2.0*DELTA**2)

IF (ISLOPE.EQ.0) GO TO 300

REFLECTION FOR A SLOPE LESS THAN OR EQUAL TO 1/2

KL = JY2 - 2
IL = ISLCPE + 1

DEFINE COORDINATES OF P AND V

CC 2CC K=1,KL
K1 = K - 1
K2 = K1*ISLCPE
IX = IX2 + K2
JJ1 = JY5M1 - K1
JJ2 = 2 + K1
NTEST = 1

CC 2CC I=1, ISLOPE
CELTA = CELX
IX = IX + 1

INTERPCLATE PARALLEL TO THE X-AXIS

1CC CC 1CC J=1,3
IF (NTEST.EQ.2) GO TO 11C
XCI = XCI(J)
JJ1P = JJ1 - J
JJ2P = JJ2 + J
GO TO 12C

11C XCI = XCI(J)
JJ1P = JJ1 - J
JJ2P = JJ2 + J

D-23
12C EC 13C JJ=1,4
  hXc = h(JJ,IJX,2,JJIP)
  hX1 = h(JJ,IX-1,JJIP)
  hX2 = h(JJ,IX,JJIP)
  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 INTERPOLATE ALONG THE NORMAL
C
DELTA = CIST
X = C1(I)
IF (NTEST.EQ.1) X = C(IL)
C 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)*SINBI)
ZCN2 = 2.*(R(2,2)*CCSB1 - R(3,2)*SINBI)
IF (NTEST.EQ.2) GC TC 16C
C
CC 15C JJ=1,4,3
  h(JJ,IX,JJ1+1) = R(JJ,1)
  150 h(JJ,IX,JJ2-1) = R(JJ,2)
  h(2,IX,JJ1+1) = ZCN1*CCSB1 - R(2,1)
  h(2,IX,JJ2-1) = ZCN2*CCSB1 - R(2,2)
  h(3,IX,JJ1+1) = ZCN1*SINBI - R(3,1)
  h(3,IX,JJ2-1) = -ZCN2*SINBI - 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)
VSC(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*SINBI - R(3,1)
  h(3,IX,JJ2) = -ZCN2*SINBI - R(3,2)
C
IF (IX.NE.IX3) GC TC 192
CC19IL=1,4
STGN = 1.C

BOUND - 2

D-24
IF(L.EQ.3)SIGN=-1.C
   W(L+1,I,X,JI2)=(SIGN*W(L,I+1,X,JI2+2)+W(L,I,X,JI2))/2.
C
191 CONTINUE
C
192 XMOM2(I,X,JI1)=W(2,I+1,X,JI1)*W(2,I,X,JI1)/W(1,I,X,JI1)
   XMOM2(I,X,JI1)=W(3,I+1,X,JI1)*W(3,I,X,JI1)/W(1,I,X,JI1)
   XMOM2(I,X,JI2)=W(2,I+1,X,JI2)*W(2,I,X,JI2)/W(1,I,X,JI2)
   XMOM2(I,X,JI2)=W(3,I+1,X,JI2)*W(3,I,X,JI2)/W(1,I,X,JI2)
   VSC(I,X,JI1)=(XMOM2(I,X,JI1)+XMOM2(I,X,JI1))/W(1,I,X,JI1)
   VSC(I,X,JI2)=(XMOM2(I,X,JI2)+XMOM2(I,X,JI2))/W(1,I,X,JI2)
C
195 IF (I.EQ.2) GO TO 20C
   XCTST = 2
   GO TO 0C
C
20C CONTINUE
C
   GO TO 41C
C
C REFLECTION FOR A SLOPE OF 1
C
30C I = IX2
   J1 = JY5 + 1
   J2 = C
   GO CC 4CC 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,IP1,J1MP2)
   W(2,I,J1MP1) = -W(3,IP1,J1MP2)
   W(3,I,J1MP1) = -W(2,IP1,J1MP2)
   W(4,I,J1MP1) = W(4,IP1,J1MP2)
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,IP1,J2P2)
   W(2,I,J2P1) = -W(3,IP1,J2P2)
   W(3,I,J2P1) = -W(2,IP1,J2P2)
   W(4,I,J2P1) = W(4,IP1,J2P2)
C
40C CONTINUE

BOUND - 3
FINC VIRTUAL POINTS FOR THE DIFFUSER

INTERPCLATE ALONG THE HORIZONTAL

410 ISTCP = 1
IF ((IX4 - IX3) GT .5) ISTCP = 2
IX = IX3
CC 5CC N=1, ISTCP
JJ1 = JY3 + H
JJ2 = JY2 - H
C
CC 48C M=1,3
CELTA = CELX
IX = IX + 1
C
CC 43C L=1,2
J11 = JJ1 - L
J12 = JJ2 + L
X = CFX(L)
IF (N NE 2 OR H.E.1 OR L.NE.1) GO TO 420
X = 1./3.*CELX
IX = IX + 1
C
420 CC 425 K=1,4
WX1 = w(K,IX-1,J11)
WX = w(K,IX,J11)
WX2 = w(K,IX+1,J11)
P1(K,L) = XINT(wX0,wX1,wX2,X)
WX1 = w(K,IX-1,J12)
WX1 = w(K,IX,J12)
WX2 = w(K,IX+1,J12)
P2(K,L) = XINT(wX0,wX1,wX2,X)
C
425 CONTINUE
C
IF (N.EQ.2 AND L.EQ.1) IX = IX - 1
C
430 CONTINUE
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
INTERPCLATE ALONG THE NORMAL
C
CELTA = CISTP
X = CFN(M)
CC 45C K=1,4
WX1 = P1(K,3)
WX = P1(K,2)
WX2 = P1(K,1)
R(K,1) = XINT(wX0,wX1,wX2,X)
WX1 = P2(K,3)
WX1 = P2(K,2)
WX2 = P2(K,1)
450 R(K,2) = XINT(wX0,wX1,wX2,X)
C
REFLECT VALUES ACROSS BOUNDARY

D-26
C
ZCN1 = 2.*(R(2,1)*COSINE + R(3,1)*SINE)
ZCN2 = 2.*(R(2,2)*CCSINE - 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) = h(2,IX,JJ1)*h(2,IX,JJ1)/h(1,IX,JJ1)
XMOM2(IX,JJ2) = h(2,IX,JJ2)*h(2,IX,JJ2)/h(1,IX,JJ2)
YMOM2(IX,JJ1) = h(3,IX,JJ1)*h(3,IX,JJ1)/h(1,IX,JJ1)
YMOM2(IX,JJ2) = h(3,IX,JJ2)*h(3,IX,JJ2)/h(1,IX,JJ2)
VSC(IX,JJ1) = (XMOM2(IX,JJ1) + YMOM2(IX,JJ1))/h(1,IX,JJ1)
VSC(IX,JJ2) = (XMOM2(IX,JJ2) + YMOM2(IX,JJ2))/h(1,IX,JJ2)
C
480 CONTINUE
500 CONTINUE
IF (ISTOP.EQ.1) GO TO 1000
DELTA = CELX
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(WX0,WX1,XX2,XX2)
WXC = W(K,IX,JY2)
WX1 = W(K,IX+1,JY2)
WX2 = W(K,IX+2,JY2)
P2(K,1) = XINT(WX0,WX1,XX2,XX2)
P1(K,2) = h(K,IX,JY3-1)
P2(K,2) = h(K,IX,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(WX0,WX1,XX2,XX1)
WXC = W(K,IX,JY3-2)
WX1 = W(K,IX,JY3-2+1)
WX2 = h(K,IX+2,JY3-2)
600 P2(K,3) = XINT(WX0,WX1,XX2,XX1)
C
DELTA = CISTP
X = 4.*DELTA - 8.*DELX*SINE
CO 650 K=1,4
WX0 = P1(K,3)
WX1 = P1(K,2)
WX2 = P1(K,1)
R(K,1) = XINT(WX0,WX1,XX2,X)
WX0 = P2(K,3)
WX1 = P2(K,2)
WX2 = P2(K,1)
650 R(K,2) = XINT(WX0,WX1,XX2,X)
C

ZN1 = 2 * (R(2, 1) * COSINE + R(3, 1) * SINE)
ZN2 = 2 * (R(2, 2) * COSINE - R(3, 2) * SINE)

C

CC 66C 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) = ZCN2 * 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)
VSC(IX, JY3+2) = (XMOM2(IX, JY3+2) + YMOM2(IX, JY3+2)) / w(1, IX, JY3+2)
VSG(IX, JY2-2) = (XMOM2(IX, JY2-2) + YMOM2(IX, JY2-2)) / w(1, IX, JY2-2)

C

1CC0 RETURN
ENC

BOUND - 6
SUBROUTINE GENPT
C
INTEGER * 4 TCCLAT,T,TT
C
COMMON/CCM1/W(5,52,23), A(5,30,5), XMCW2(52,23), YMCW2(52,23),
1 VSC(52,23), XMCW2A(30,5), YMCW2A(30,5), VSCA(30,5),
2 GAM ,GM1 ,GM2 ,GM3 ,CELX ,CELY ,
3 CELT ,FDCGE ,SC ,TNC ,TTC ,TP ,
4 CCN3 ,CIFCC ,XH ,ENERG ,XML ,CMEGA ,THICK ,
5 CLE ,CP ,EXP ,JNID
COMMON/CCM2/ IRCCP(2C) ,IR(3C),
1 IX1 ,IX1W1 ,IX1P1 ,IX2 ,IX3 ,IX4 ,
2 IX4W1 ,IX4W2 ,IX4M3 ,JY1 ,JY1P1 ,JY1P1 ,JY3 ,
3 JY2 ,JY2P1 ,JY2P2 ,JY3 ,JY3M1 ,JY5,
4 JY3M2 ,JY3P1 ,JY4 ,JY4M1 ,JY4P1 ,JY5 ,
5 JY5M1 ,JY5M2 ,ISLOPE ,JEXL ,JEXU
COMMON/CCM4/XN
1 AO ,XLEN ,YLEN ,XSLOPE ,SLOPE ,
2 CCN1 ,CCN2 ,IRHO ,IM ,IN ,IE
3 IPRES ,KCP
COMMON/CCM5/TCCLAT,T,KICFF,TT
COMMON/CCM6/TV(12,3,23), TBA(12,2,22), XV(52), YV(23),
1 XVEL(2,2,23), YVEL(2,2,23), SNCIC(2,2,23), PRES(2,2,23)
C
DIMENSION TEMP (52)
DIMENSION CURM(4,3,23), CLMA(4,23), CLMB(4,23)
C
ESTABLISH INITIAL LEFTHAND BOUNDARY DATA
C
DO 14C J=JY1P1,JY4P1
IF (TCCLNT.GT.1) GO TO 120
YVEL(1,J) = W(3,3,J)/W(1,3,J)
DO 11C I=2,3
IF (J.EQ.JY1P1.OR.J.EQ.JY4P1) GO TO 100
SNCIC(1-I-1,J) = SCRT(GAM*W(5,I,J)/W(I,I,J))
PRES(1-I-1,J) = W(5,I,J)
C
100 IF (J.GT.JY1P1) GO TO 105
PRES(1-I-1,JY1P1) = W(5,I,JY1P1)
PRES(1-I-1,JY4P1) = W(5,I,JY4P1)
C
105 XVEL(1-I-1,J) = W(2,I,J)/W(1,I,J)
C
110 CONTINUE
XVEL(2-I,J) = XVEL(1,I,J)
GO TO 14C
C
120 IC IC = I-1,2
SNCIC(1,I,J) = SNCIC(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
14C CONTINUE
C
CALCULATE VALUES AT GENERAL MESH POINTS

D-29
ccntx = cel/(2.*celx)
cnty = cel/(2.*cefy)
ccntxp = ccntx*c.5
ccntyp = ccnty*c.5
l = 1
jlv = jy1w1
juv = jy4p1
jvvp = jlv - 1
jlb = jy1
jlb = jy4
il = 2
iu = 4

cccede a vertical line

cc 5cc i=3,ix4p1
if (i.eq.2) gc tc 1cc
if (i.lt.ix1p1) gc tc 1cc
if (i.gt.ix1p1) gc tc 1cc
jlv = 1
jvvp = jly5
jlb = jy1
jub = jy5p1
gc tc 1cc

test to determine if oblique boundaries have been reached

160 if (i.gt.ix3) gc tc 165

if (i.ne.ircp(lk)) gc tc 17c
lk = lk + 1
jlv = jlv + 1
jlv = juv - 1
jvvp = jlv - 1
jlb = jlb + 1
jub = jub - 1
gc tc 17c

165 if (ix1.eq.1.cr.1.eq.ix4p1) gc tc 168
if (i.ne.ircp(lk)-2) gc tc 168
lk = lk + 2
jlv = jlv - 1
juv = juv + 1
jvvp = jlv - 1
gc tc 17c

168 if (i.ne.ircp(lk-2)) gc tc 17c
jlb = jlb - 1
jlb = jub + 1

transfer matrices

170 cc 175 k=1,12
cc 175 j=1,jy5
iv(k,1,j) = iv(k,2,j)
175 iv(k,2,j) = iv(k,3,j)
176 IL = IL + 1
IU = IL

CALCULATE THE VALUES OF TVA

180 GO 2CC II=IL,IL
IA = II - 1
IF (I.E.3) IA = 3

GO 2CC J=JLV,JLV

CML = 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)

TV(1,IA,J) = -W(2,II,J)
TV(2,IA,J) = GAP3*XMCM(II,J) - GAM1*W(4,II,J) + GAM2*YMCM(II,J)
TV(3,IA,J) = -XMYM
TV(4,IA,J) = -GAM*GAM + GAM2*W(12,II,J)*VSC(II,J)
TV(5,IA,J) = -W(3,II,J)
TV(6,IA,J) = -XMYM
TV(7,IA,J) = GAP2*YMCM(II,J) - GAM1*W(4,II,J) + GAM2*YMCM(II,J)
TV(8,IA,J) = -GAM*EN + GAM2*W(3,II,J)*VSC(II,J)

190 TV(9,IA,J) = C.C
TV(10,IA,J) = C.C
TV(11,IA,J) = C.C
TV(12,IA,J) = H(2,II,J)*TND*KCPT)
SC=C
CD=0*
EC=0*
XCLN=TV(12,IA,J)*CCN2

200 CONTINUE

IF (I.E.3) GO TC 240

TRANSFER MATRICES

220 CC 22C K=1,12
CC 22C J=1,JY5M1
TVA(K,1,J) = TVA(K,2,J)

240 ILP = IU - 1

CALCULATE THE VALUES OF TVA

400 CC II=IL,ILP
IA = II - 1
IF (I.E.3) IA = 2

GO 4CC J=JLV,JLV
IF (I.LT.IXL1*ANC(I.LT.JY1M1*CR,J.GT.JY4)) GC TO 400

250 CC K=1,4
IF (IA.EQ.2) GC TC 245

GENPT - 3
242 CONTINUE
STAR=C.25*(h(K,3,J)+h(K,2,J)+1)+h(K,3,J+1)+h(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)+TV(K+4,1,J+1)-TV(K+4,1,J+1))
FEAT=C.25*(TV(K+E,2,J)+TV(K+E,1,J+1)+TV(K+8,2,J+1)+TV(K+8,1,J+1))
TV(A,1,J,1)=STAR+DERIV+FEAT
GC TC 249

245 CONTINUE
STAR=C.25*(h(K,1+1,J)+h(K,1,J+1)+1+h(K,1,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)+TV(K+4,2,J+1)-TV(K+4,2,J+1))
FEAT=C.25*(TV(K+E,3,J)+TV(K+E,2,J)+TV(K+8,3,J)+TV(K+8,2,J))
TV(A,I,J,1)=STAR+DERIV+FEAT

249 CONTINUE
IF(K.NE.4)GCTC25C
X MMA = TVA(4,1,J) + CCN2
SD=STAR*CCN2
CD=DERIV*CCN2
FEAT*CCN2
250 CONTINUE

270 XM2 = TVA(2,1,1,J)**2/TVA(1,1,J,1)
YM2 = TVA(3,1,1,J)**2/TVA(1,1,J,1)
XM2 = TVA(2,1,1,J)*TVA(3,1,1,J)/TVA(1,1,J,1)
SLM2C = (XM2 + YM2)/TVA(1,1,J,1)
EM = TVA(2,1,1,J)*TVA(4,1,1,J)/TVA(1,1,J,1)
FN = TVA(3,1,1,J)*TVA(4,1,1,J)/TVA(1,1,J,1)

C TVA(5,1,1,J) = -TVA(2,1,1,J)
TVA(6,1,1,J) = GAM3*YM2 - GAM1*TVA(4,1,1,J) + GAM2*YM2
TVA(7,1,1,J) = -YM2
TVA(8,1,1,J) = -GAM2*TV(A2,1,1,J)*SUMC
TVA(9,1,1,J) = -TVA(3,1,1,J)
TVA(10,1,1,J) = -TVA(1,1,1,J)
TVA(11,1,1,J) = -TVA(3,1,1,J)

C 400 CONTINUE
C IF(I.EC. 3) GC TC 404
CC 401 K = 1,4
CC 401 J = JLV,JLV
CUM(K+1,J) = CLM(K+2,J)
401 CLM(K+2,J) = CLM(K+3,J)
IF = I+1
IC = I+1
GC TO 405

C 404 IB = 2
IC = 4
C 405 CC 409 III = IB,IC
ID=III+1
IF(I.EC.3)IC=3
CC 409 J = JLV,JLV
CUM(I,1,J,1)=C.
CLM(2,1,1,J)=C.

GENPT - 4
CLU(3, ID, J) = C.
CLU(4, IC, J) = F(2, I, III, J, INC, NCPT)
409 CONTINUE

C
IF (I .EQ. 3) GC TC 410C
CO 401C K = 1, 4
CC 401C J = JLV, JLVP

410C CUMA(K, J) = DLMB(K, J)
GC TC 420C

C
410C CC 415C K = 1, 4
CC 415C J = JLV, JLVP
CUMA(K, J) = C.25*(CLM(K, 1, J, J, J, J) + DLMB(K, 1, J, J) + CLM(K, 2, J, J, J, J) + DLMB(K, 2, J, J, J, J))
IF (K .NE. 4) GC TC 415C
XCL = DLMB(K, J) * CCN2 / CCN3

415C CONTINUE

C
420C CC 425C K = 1, 4
CC 425C J = JLV, JLVP

425C CONTINUE

C
CALCULATE FINAL VALUES

C
410C CC 45C J = JLB, JLB
IF (K .LT. JY1, K = 1, 4
STAR = C(K, 1, J, J)
CERIV = CONTXP*(TV(K, 3, J, J, J, J) - TV(K, 1, J, J) + TVA(K+4, J, J) - TVA(K+4, 1, J, J, J) +
1 TVA(K+4, 2, J, J) - TVA(K+4, 1, J, J, J) +
2 CTNXP*(TV(K+4, 2, J, J) - TVA(K+4, 2, J, J, J) -
3 TVA(K+8, 1, J, J) - TVA(K+8, 1, J, J, J))
FHEAT = C.25*(CLM(K, 1, J, J, J, J) + DLMB(K, 1, J, J, J, J) + DLMB(K, 1, J, J, J, J))
FHEAT = C.5*(TV(K+8, 2, J, J) + FHEAT)
W(K, 1, J, J, J, J) = STAR*CERIV*FHEAT
IF (K .NE. 4) GC TC 420C
CERIF = CERIV*CCN2
CERIF = CCN2
FDFL = FHEAT*CCN2
XCL = C(K, 1, J, J, J, J)

420 CONTINUE

450 CONTINUE

C
500 CONTINUE

C
505 CONTINUE

C
CP EN EN DC T E CHAMBER

C
CC 60C K = 1, 4
CO 60C J = JEXL, JEXL
W(K, 1X4, J) = W(K, 1X4, J, J)
IF (K .NE. 4) CC TC 60C

C
XOM2(1X4, J) = W(2, 1X4, J) + W(2, 1X4, J, J, J, J, J, J, J)

D-33

GENPT - 5
YMCP2(IX4,J) = h(3,IX4,J)*h(3,IX4,J)/w(1,IX4,J)
VSQ1(IX4,J) = (YMCP2(IX4,J) + YMCP2(IX4,J))/w(1,IX4,J)
600 CONTINUE
C
IF (IX1.EQ.1) GC TC 61C
C CALL LINER (CCNTX,CCNTY,CCNTXP,CCNTYP)
C SMCCF THE VALUES
C
610 XLAMCA = CELT/EELX
XLC = XLAMCA*DFC0
C
IN THE X-DIRECTION
C
IF (IX1.EQ.1) GC TC 615
IL = IX1P1
IDL = IX3 + 4
CC TC 618
C
615 IL = 3
ICL = IX3 + 1
C
618 IU = IX2 - ISLCPE
C
CC 65C J=2,JY5P1
C
IF (J.EQ.JY1) IL = 3
IF (J.LE.JY2) IL = IL + ISLOPE
IF (J.EQ.JY2) ICL = IX3 + 1
IF (J.GT.JY3) IL = IL - ISLOPE
IF (J.EQ.JY4P1) IL = IX1P1
IF (J.EQ.JY5P1) ICL = IX3 + 4
C
ILL = IL - 1
ILU = IU + 1
ICLL = ICL - 1
C
CC 62C I=ILL,ILL
620 XV(I) = w(2,I,J)/w(1,I,J)
C
IF (J.LT.JEXL.CR.J.GT.JEXU) GC TC 630
CC 625 I=IDLL,IX4
625 XV(I) = w(2,I,J)/w(1,I,J)
C
630 CC 645 K=1,4
C
CC 635 I=IL,IL
635 TEMP(I) = w(K,I,J) + XLC*(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.CR.J.GT.JEXU) GC TC 641
C
CC 64C I=IDL,IX4P1
640 TEMP(I) = w(K,I,J) + XLC*(ABS(XV(I+1) - XV(I)) *(w(K,I+1,J) -
1 \[ \frac{w(K, i, j)}{w(K, i-1, j)} - \frac{\text{ABS}(xv(i) - xv(i-1))\times(w(K, i, j) - w(K, i-1, j))}{w(K, i, j)} \]

C

641 CC 642 I=1, I-1
642 \[ w(K, i, j) = \text{TEMP}(i) \]

C

IF (J.LT.JEXL*CR.J.GT.JEXL) GC TC 645

C

GO 643 I=ICL, I=4M1
643 \[ w(K, i, j) = \text{TEMP}(i) \]

C

645 CONTINUE

C

650 CONTINUE

C

IN THE Y-DIRECTION

C

LK = 1
JLB = JY1
JLB = JY4
JLV = JY1M1
JLV = JY4P1

C

68C I=3, I=4M1
IF (I.NE.IX1P1) GO TC 655
JLB = 2
JLB = JY5M1
JLV = 1
JLV = JY5

C

655 IF (I.NE.IDRCP(LK)*CR.I.GT.IX3) GC TC 658
LK = LK+1
JLB = JLB + 1
JLB = JUB - 1
JLV = JLV + 1
JLV = JLV - 1
GC TC 660

C

658 IF (IX1.EQ.1) GC TC 660
IF (I.NE.IDRCP(LK)) GC TC 660
LK = LK + 2
JLB = JLB - 1
JUB = JUB + 1
JLV = JLV - 1
JLV = JLV + 1

C

66C CC 665 J=JLV, JLV
665 \[ YV(J) = w(3, i, j) \times w(1, i, j) \]

C

CG 675 K=1,5
IF (K.EQ.5) GO TC 671

C

CG 67C J=JLB, JLB
\[ \text{TEMP}(J) = \frac{w(K, i, j) + XLH*(\text{ABS}(yv(J+1) - yv(J)) \times (w(K, i, j+1) - w(K, i, j)) - \text{ABS}(yv(J) - yv(J-1)) \times (w(K, i, j) - w(K, i, j-1)))}{2} \]

67C CONTINUE

C

GENPT - 7
671 CC 674 J=JLB,JLB
   IF (K.EQ.5) GC TC 673
   K(K,I,J) = TEMP(J)
   IF (K.EQ.1 .CR.K.EC.4) GC TC 672
   IF (ABS(W(K,I,J)).LT.1.EC-06) K(K,I,J) = 0.0
   GO TC 674
   IF (W(K,I,J).*LE.1.EC-06) KICCFF = 1
672 GO TC 674
674 CONTINUE
675 CONTINUE
680 CONTINUE
   IF (W(K,I,J).LE.1.EC-06) KICCFF = 1
   IF (W(K,I,J).*LE.1.EC-06) KICCFF = 1

673 XMC2(I,J) = k(2,I,J)*h(2,I,J)/h(1,I,J)
   YMCM2(I,J) = h(3,I,J)*h(3,I,J)/h(1,I,J)
   VSC(I,J) = (XMC2(I,J) + YMCM2(I,J))/h(1,I,J)
   h(5,I,J) = GAM1*k(4,I,J) - VSC(I,J)*0.5*h(1,I,J)
   IF (h(5,I,J).LE.1.EC-06) KICCFF = 1

674 CONTINUE
675 CONTINUE
680 CONTINUE
   IF (JY5 .EC. 13) GC TC 689
   IF (JY5 .EC. 23) GC TC 685
   CC 682 K = 1,5
   h(K,94,8) = h(K,54,7)
   h(K,94,37) = h(K,94,36)
   GO TC 689
   CC 686 K = 1,5
   h(K,48,5) = h(K,48,6)
   h(K,48,19) = h(K,48,18)
   GO TC 689

685 CONTINUE
686 CONTINUE
   IF (JY5 .EC. 13) GC TC 70C
   IF (JY5 .EC. 23) GC TC 70C
   CC 69C K=1,5
   CC 69C J=JEXL,JEXU
   h(K,144,J) = h(K,144,J)

   CC 70C I=2,3
   IF (J.EQ.JY1M1 .CR.J.EQ.JY4P1) GO TC 70C
   SCN(I,J) = SCN(I,J)
   SCN(I,J) = SCN(I,J)

D-36

GENPT - 8
PRES(2,1-I,J) = \(w(5,1,J)\)

7CC CONTINUE

C

7CC 7CC I=2,3
PRES(2,1-I,JY1P1) = \(w(5,1,JY1P1)\)

7CC 7CC I=2,3

PRES(2,1-I,JY4P1) = \(w(5,1,JY4P1)\)

C

CC 7IC J=JY1,JY4
SBAR = 0.5*(XVEL(1,1,J) + XVEL(2,2,J) - SCNJC(1,1,J) -
1 SCNJC(2,2,J))
Z1 = 1.0 + XAMCA*SBAR
Z2 = 1.0 - XAMCA*SBAR
RHC1 = 0.5*(w(1,2,J) + w(1,3,J))
SCNJC = 0.5*(SCNJC(1,1,J) + SCNJC(2,2,J))
YVELC = C.5*YVEL(2,J)
\(w(5,2,J) = \text{PRES}(1,2,J) + RHC1*SCNJC*(XVEL(2,1,J) - XVEL(1,2,J)) +
1 Z1/Z2*(\text{PRES}(1,1,J) - \text{PRES}(2,2,J) - RHC1*SCNJC*}
2 (XVEL(1,1,J) - XVEL(2,2,J))) - CELT*YVLC/2.*DELY*Z2*
3 (\text{PRES}(1,2,J+1) - \text{PRES}(1,2,J-1) - RHC1*SCNJC*}
4 (XVEL(1,1,J+1) - XVEL(1,1,J-1)) + \text{PRES}(1,1,J+1) -
5 \text{PRES}(1,1,J-1) - RHC1*SCNJC*
6 (XVEL(1,2,J+1) - XVEL(1,2,J-1)) - CELT*RHO1*SCNJC**2/2
7 (2.*DELY*Z2)*(YVEL(1,J+1) - YVEL(1,J-1))
\(w(1,2,J) = \text{GAM}^*w(5,2,J)/(2.*XH*GAML)***
1 (1.0 + SCNJC(1,1,J) + 2.*XH*(w(2,2,J)*GAML/)
2 (GAML*w(5,2,J))**2))

C

XVEL(2,1,J) = \(w(2,2,J)/w(1,2,J)\)

C

XMCM2(2,J) = XVEL(2,1,J)*w(2,2,J)
YCM2(2,J) = \(w(3,2,J)*w(1,2,J)/w(1,2,J)\)
VSC(2,J) = (XMCM2(2,J) + YMCM2(2,J))/w(1,2,J)

C

\(w(4,2,J) = w(5,2,J)/GAML + \text{VSQ}(2,J)*C.5*w(1,2,J)\)

C

710 CONTINUE
IF (IX1.EQ.1) GC TC 1CC

C

AVERAGE VALLES ARCLNC THE HCLES

C

7CC 9CC I=3,IX1
1 CO 85C K=1,5
SIGN = 1.C
IF (K.EQ.3) SIGN = -1.C
\(w(K,1,JY1) = (w(K,1,JY1) + A(K,1,JY1))/2.\)
\(w(K,1,JY4) = \text{SIGN}^*w(K,1,JY1)\)
A(K,1,JY1) = \(w(K,1,JY1)\)

C

IF (K.NE.5) GC 85C
XMUM2(1,JY1) = \(w(2,1,JY1)*w(2,1,JY1)/w(1,1,JY1)\)
YMUM2(1,JY1) = \(w(3,1,JY1)*w(3,1,JY1)/w(1,1,JY1)\)
VSCI(1,JY1) = (XMUM2(1,JY1) + YMUM2(1,JY1))/w(1,1,JY1)
XMUM2A(1,JY1) = XMUM2(1,JY1)
YMUM2A(1,JY1) = YMUM2(1,JY1)
VSCA(1,JY1) = VSCI(1,JY1)
XMUM2(1,JY4) = \(w(2,1,JY4)*w(2,1,JY4)/w(1,1,JY4)\)

C

GENPT - 9
\[ Y_{\text{MCM2}}(I, J, Y_4) = k(3, I, J, Y_4) * k(3, I, J, Y_4) / k(1, I, J, Y_4) \]

\[ V_{\text{SC}}(I, J, Y_4) = (X_{\text{MCM2}}(I, J, Y_4) + Y_{\text{MCM2}}(I, J, Y_4)) / k(1, I, J, Y_4) \]

\begin{verbatim}
C E50 CCATINLE
C 
C SCO CONTINLE
C 
1CC0 TNC = TNC + CELT
TTCL = TNC*CCN3
C 
RETURN
END
\end{verbatim}
FUNCTION INEX(I,J,SEC,N)
C
INTEGER * 4 TCCII, T
C
COMMCM/CM1(52,23), A(52,30,5), XMCM2(23), YMCM2(52,23),
1 VSC(52,23), XMCM2A(30,5), YMCM2A(30,5), VSCA(30,5),
2 CAP * Gam1, Gam2, Gam3, CELX, CELE, CELY,
3 CELI, FLCGE, SC, TNC, ITCL, TP,
4 CCN3, C1FCC, XH, ENERO, XPL, OMEGA, THICK,
5 CLE, GC, EXP, JMID
COMMCM/CM2/ TCRCP(2C), IN(3C),
1 IX1, IX1P1, IX1P2, IX2, IX3, IX4,
2 IX4M1, IX4P1, IX4M2, JY1, JY1M1, JY1P1,
3 JY2, JY2P1, JY2P2, JY3, JY3M1,
4 JY3M2, JY3P1, JY4, JY4P1, JY5,
5 JY5M1, JY5P2, ISLOPE, JEXL, JEXU
COMMCM/CM4/ XP, PO, TC, RHC0, XMCMO, YMCMO,
1 AC, YLEN, XLEN, XSLOPE, SLCP,
2 CCA1, CCA2, IRHO, IP, IN,
3 IPRES, ICPI
COMMCM/CM5/ TCCII, T, KICCII, IT
DIMENSION STCR(23)
C
I = C.C
C
CCLC START CPTIIC
C
IF (J < LT, JY1 < CR, J > GT, JY4) GO TO 1CC0
IF (I .LE. 3) GO TO 1CC0
IF (JY4 .EQ. 12 AND J .GE. 16) GCTC1CC0
IF (JY4 .EQ. 22 AND J .GE. 30) GCTC1CC0
IF (IX1 .NE. 1) GCTC2C
IF (JY4 .GT. 12) GCTC1CC
XF1 = 1.C
XF2 = 0.5
ALPHA = C.C4
GCTC5C
C0 XF1 = 1.C
XF2 = 0.5
ALPHA = C.C1
GCTC5C
20 CONTINUE
XF1 = 1.C
XF2 = 0.5
ALPHA = C.C1
50 CONTINUE
IF (N .NE. 1) GO TO 2CC0
100 IF (J .EQ. JY1 .CR. J .EQ. JY4) GCTC105
= XF1 * CUE * DELT
GCTC1CC0
125 F = XF2 * CUE * DELT
GCTC1CC0
C200 CONTINUE
IF (ITCL .GT. (IP - 1.0D-12)) GO TO 400
IF (I .NE. 5) GCTC1CC0
210 IF (J .EQ. JY1 .FR. J .EQ. JY4) GCTC25C
IF (J .GT. JMIHD) GCTC210
F = XF1 * CUE * DELT * ALPHA * (J - JY1) * CP * CELT

H-1
GCTC1CCO
210 \( T = X F 1 \cdot C U E \cdot D E L T + A L P H A \cdot ( J Y 4 - J ) \cdot Q P \cdot C E L T \)
GCTC1CCO
250 \( T = X F 2 \cdot C U E \cdot C E L T \)
GCTC1CCO
400 CCNTINUE
   IF(J.NE.JYI)GCTC5CC
   SLM=C.C
   COLAT=C.C
   CC45C,J=JY1*,JY4
   PRESS=K(5*,I*,JJ)
   SUP=SLM*PRESS
450 CCNT=COUNT+1.
   AVGPRS=SUM/CCLNT
500 CCNTINUE
   IF(J.EQ.JY1+CR*J.EQ.JY4)GCTC5CC
   \( T = X F 1 \cdot C U E \cdot \left( h(5*,I*,J) / AVGPRS \right)^2 \cdot \exp \cdot CELT \)
   GCTC1CCO
550 \( T = X F 2 \cdot C U E \cdot \left( h(5*,I*,J) / AVGPRS \right)^2 \cdot \exp \cdot DELT \)
1000 RETURN
END
INTEGER * 4 TCC,NT,T,T

COMMON/CMM1/(5,52,23), A(5,30,5), XMM2(52,23), YMM2(52,23),
1 VS(52,23), YMP2A(30,5), YMP2A(30,5), VSPI(30,5),
2 CAM', GAP1, GAP2, GAP3, GELX, GELY ;
3 CELT, FUGCE, SC, TNE, TTP, TP ;
4 CCN3, CIFCC, XH, ENERO, XML, OMEGA, THICK,
5 CLE, CPE, EXP, f5HID

COMMON/CCM2/ ICRCMP(2C), IR(3C),
1 IX1, IX1:*1, IX1P1, IX2, IX3, IX4 ;
2 IX2, IX2:*1, IX2P1, IX3, IX4 ;
3 JY2, JY2P1, JY2P1, JY3, JY3 ;
4 JY3, JY3P1, JY4, JY4P1, JY5P1 ;
5 JY5P1, JY5P2, ELCPE, JEXL, JEXU

COMMON/CMP5/TCC,NT, T, KICCC, F, T

C DIMENSION TEMP(35)

C INITIALIZE FOR CALCULATIONS

JLV = 1
JUV = JY1P1
JUVF = JLV - 1
JLE = 2
JLE = JY1
IL = 1
IU = 3

C CHCCSE A VERTICAL LINE

CC SCC I=2,1X1
IF (I.EQ.2) GO TO TC 1BC

C TRANSFER AV CLLLMS

CC 12C K=1,8
CC 12C J=JLV, JLV
AV(K,1,J) = AV(K,2,J)
12C AV(K,2,J) = AV(K,3,J)

C IL = IL + 1
IU = IL

C CALCULATE VALUES OF AV

C 120 CC IA=IL,IL
IA = I
IF (I.NE.2) IA = 3

C CO 2CC J=JLV, JLV

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)

SUBRCLINE LINER (CCONTX, CCNTY, CCACTXP, CCNTYP)
AV(1, IA, J) = -A(2, II, J)
AV(2, IA, J) = GAP3*XCMC2A(II, J) - GAM1*A(4, II, J) + 1
               CAP2*YCMC2A(II, J)
AV(3, IA, J) = -XMYW
AV(4, IA, J) = -GAM*EM + GAM2*A(2, II, J)*VSCA(II, J)
AV(5, IA, J) = -A(3, II, J)
AV(6, IA, J) = -XMYW
AV(7, IA, J) = GAP3*YCMC2A(II, J) - GAM1*A(4, II, J) + 1
               CAP2*YCMC2A(II, J)
AV(8, IA, J) = -GAM*EN + GAM2*A(3, II, J)*VSCA(II, J)

200 CONTINUE
C
IF (I.EQ.2) CC TC 24C
C
TRANSFER AVA CCLLMNS
C
EG 22C K=1,12
EG 22C J=JLV, JLV
22C AVA(K, 1, J) = AVA(K, 2, J)
C
240 ILP = IU - 1
C
CALCULATE VALUES OF AVA
C
EG 4CC II=IL, ILP
IA = II
IF (I.NE.2) IA = 2
C
EG 4CC J=JLV, JLV
C
EG 25C K=1,4
IF (IA.EQ.2) CC TC 245
AVA(K, 1, J) = C.25*(A(K, 2, J) + A(K, 1, J+1) + A(K, 2, J+1) + A(K, 1, J)) + 1
       CCNTX*(AV(K, 2, J) - AV(K, 1, J) + AV(K, 2, J+1) - 2
         AV(K, 1, J+1)) + 3
       CCNTY*(AV(K+4, 2, J+1) - AV(K+4, 2, J) + AV(K+4, 1, J+1) - 4
         AV(K+4, 1, J))
EG TC 25C
C
245 AVA(K, IA, J) = C.25*(A(K, IA+1, J) + A(K, IA, J+1) + A(K, IA+1, J+1) + 1
       A(K, IA, J)) + 2
       CCNTX*(AV(K, 3, J) - AV(K, 2, J) + AV(K, 3, J+1) - 3
         AV(K, 2, J+1)) + 4
       CCNTY*(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)
XMYW = AVA(2, IA, J)*AVA(3, IA, J)/AVA(1, IA, J)
SMSG = (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) = GAP3*XMP2 - GAM1*AVA(4, IA, J) + GAP2*YMW
AVA(7,IA,J) = -XMYM
AVA(8,IA,J) = +CAP*EM + GAM_2*AVA(2,IA,J)*SLMSG
AVA(9,IA,J) = -AVA(3,IA,J)
AVA(10,IA,J) = -XMYM
AVA(11,IA,J) = GAM_2*YM2 - GAM_1*AVA(4,IA,J) + GAM_2*XM2
AVA(12,IA,J) = -CAP*EM + GAM_2*AVA(3,IA,J)*SLMSG

C 4CC CONTINUE
C
CALCULATE FINAL VALUES
C
41C CC 45C K=1,4
C CC 45C J=JLB,JLE
A(K,1,J) = A(K,1,J) + CCNTYP*(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 CCNTYP*(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 5CC CONTINUE
C
AVERAGE VALUES ACROSS THE HCLES
C
503 I=3,IX1
IF (IR(I).NE.5.AND.IR(I).NE.2) GC TC 503
C
5C2 K=1,4
SIGN = 1.C
IF (K.EQ.3) SIGN = -1.C
A(K,1,JY1) = (h(K,1,JY1) + A(K,1,JY1))/2.
W(K,1,JY1) = A(K,1,JY1)
W(K,1,JY4) = SIGN*A(K,1,JY1)
C
5C2 CONTINUE
5C3 CONTINUE
C
ENERGY WITHDRAWAL AT THE HCLES
C
5C5 I=3,IX1
IF (IR(I).NE.5) GC TC 505
C
RHCBAR = .25*(A(1,I,JY1) + A(1,I+1,JY1) + A(1,I+3,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*SCRT(2.*XPL*RHCBAR*CMQGA)
TENER = 3.141592653589793 * 1.5 * CELX * 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.
C
W(4,I,JY1) = A(4,I,JY1)
W(4,I+1,JY4) = A(4,I,JY1)
W(4,I+1,JY4) = A(4,I+1,JY1)
\[ h(4, I+1, JY4) = A(4, I+1, JY1) \]
\[ h(4, I+2, JY1) = A(4, I+2, JY1) \]
\[ h(4, I+2, JY4) = A(4, I+2, JY1) \]
\[ h(4, I+3, JY1) = A(4, I+3, JY1) \]
\[ h(4, I+3, JY4) = A(4, I+3, JY1) \]

C 505 CONTINUE

C THE VALUES

C XLC = CELT/CSEL*CIFCC

C CC 525 J = 2, JY1

C CC 51C I =1, IY1P1

510 AXV(I) = A(2, I, J)/A(1, I, J)

C CC 52C K = 1, 4

C 515 TEMP(I) = A(K, I, J) + XLC*(ABS(AXV(I+1) - AXV(I))*(A(K, I+1, J) - 
A(K, I, J)) - ABS(AXV(I) - AXV(I-1))*(A(K, I, J) - 
2 A(K, I-1, J)))

C CC 516 I = 2, IY1

C 516 A(K, I, J) = TEMP(I)

C 52C CONTINUE

525 CCONTINUE

C CC 545 I = 2, IY1

C CC 53C J = 1, JY1P1

530 AYV(J) = A(3, I, J)/A(1, I, J)

C CC 54C K = 1, 5

C IF (K.EQ.5) CC TC 536

C CC 555 J = 2, JY1

535 TEMP(J) = A(K, I, J) + XLC*(ABS(AVY(J+1) - AVY(J))*(A(K, I+1, J) - 
A(K, I, J)) - ABS(AVY(J) - AVY(J-1))*(A(K, I, J) - 
2 A(K, I-1, J)))

C 536 CC 537 J = 2, JY1

C IF (K.EQ. 5) CC TC 539

C A(K, I, J) = TEMP(J)

C IF (K.EQ.1.CK.EQ.4) CC TC 538

C IF (ABS(A(K, I, J)).LT.1.CE-C6) A(K, I, J) = 0.0

C CC TC 537

C 538 IF (A(K, I, J).LE.1.CE-C6) KICCF = 1

C CC TC 537

C 539 XPMQ2A(I, J) = A(2, I, J)*A(2, I, J)/A(1, I, J)

C YPMQ2A(I, J) = A(3, I, J)*A(3, I, J)/A(1, I, J)

C VSCA(I, J) = (XPMQ2A(I, J) + YPMQ2A(I, J))/A(1, I, J)

C A(5, I, J) = GM1*(A(4, I, J) - VSCA(I, J)*C.5*A(1, I, J))
IF (A5, I, J) .LE. 1.0E-6) K1CCFF = 1

537 CONTINUE
540 CONTINUE
545 CONTINUE
C
RETURN
END
INTEGER * 4 TCCL_T, T, TT

COMMON/CM2/TV(12, 3, 23), XV1(12, 2, 22), XV(52), YV(23),

COMMON/CM6/TV(12, 3, 23), TVA(12, 2, 22), XV(52), YV(23),

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

1 FORMAT ( //T5, 'INPUT DATA AND CONSTANTS * * * */)

2 FORMAT ( //T5, 'LENX1 = *13, T37, 'LENX2 = *13,

1 T69, 'LENX3 = *13, T101, 'LENX4 = *13)

3 FORMAT ( //T5, 'LENY1 = *13, T37, 'LENY2 = *13,

1 T69, 'LENY3 = *13, T101, 'LENY4 = *13)

4 FORMAT ( //T5, 'NUMER CF TRIPS = *13,

1 T69, 'PRINT INC = *13, T101, 'ILEN = *13)

5 FORMAT ( //T5, 'YLEN = *E13.5, T37, 'TP = *E13.5,

1 T69, 'DELX = *E13.5, T101, 'DELY = *E13.5)

6 FORMAT ( //T5, 'SCNCA .SP = *E13.5, T37, 'W. CF GAS = *E13.5,

1 T69, 'FUGGE = *E13.5, T101, 'TP = *E13.5)

7 FORMAT ( //T5, 'PC = *E13.5, T37, 'TO = *E13.5,

1 T69, 'RHO = *E13.5, T101, 'ENERO = *E13.5)

8 FORMAT ( 'T5, 'ENERGY // T3, 'TRIP* T14, 'TIME* T32, 'I = 2'

1 T54, 'I = 5, T76, 'I = 10, T98, 'I = 15 T120, 'I = 20)

9 FORMAT ( //T5, 'CAW = *E13.5, T37, 'XCL(3) = *E13.5,

1 T69, 'DIST = *E13.5, T101, 'DISTP = *E13.5)

10 FORMAT ( //T5, 'SINBI = *E13.5, T37, 'CCSB = *E13.5,

1 T69, 'SINE = *E13.5, T101, 'CCSINE = *E13.5)

11 FORMAT ( //T5, 'XCIST(1) = *E13.5, T37, 'XCISTP(2) = *E13.5,

1 T69, 'XCIST(3) = *E13.5)

12 FORMAT ( //T5, 'XCISTP(1) = *E13.5, T37, 'XCISTP(2) = *E13.5,

1 T69, 'XCISTP(3) = *E13.5)

13 FORMAT ( //T5, 'CIFCC = *E13.5, T37, 'MU = *E13.5,

1 T69, 'OMEGA = *E13.5, T101, 'LINER THNS = *E13.5)

14 FORMAT ( //T5, 'G = *E13.5, T37, 'CP = *E13.5,

1 T69, 'N = *E13.5, T101, 'NCPT = *13)

15 FORMAT ( //T1C1, 'WAGE = * 13)
16 FORMAT (T4, 'NC.', T26, 'J = 12', T37, 'J = 22', T48, 'J = 12', T59, 1 2 'J = 22', T7C, 'J = 12', T81, 'J = 22', T92, 'J = 12', T103, 2 1 'J = 15', T114, 'J = 12', T125, 'J = 15') 17 FORMAT (T4, 'NC.', T26, 'J = 12', T37, 'J = 19', T48, 'J = 12', T59, 1 2 'J = 15', T7C, 'J = 12', T81, 'J = 19', T92, 'J = 12', T103, 2 1 'J = 15', T114, 'J = 12', T125, 'J = 19') 19 FORMAT (IC, I4, 2X, IPE14.5, IPE11.2) C 20 FORMAT (T6,'*',T66,'C',T127,'&&') 21 FORMAT (T6,'*',T27,'A',T66,'C',T106,'W',T127,'&&') 22 FORMAT (// T1I,IP1E1C.2) 23 FORMAT (// T1I,IP1E1C.2) 24 FORMAT (// T21,IP5E1C.2) 25 FORMAT (// T31,IP7E1C.2) 26 FORMAT (// T41,IP5E1C.2) 27 FORMAT (// T51,IP3E1C.2) 28 FORMAT (IP13E1C.2) C 30 FORMAT ('IDENSITY AT TIME = IPE14.5, T64,'TNC = E14.5, 1 T38,'CELT = E14.5, T90,'TRIP NUMBER = I4//') 40 FORMAT ('IX-MCM2 AT TIME = IPE14.5, T64,'TNC = E14.5, 1 T38,'CELT = E14.5, T90,'TRIP NUMBER = I4//') 50 FORMAT ('IX-MCM2 AT TIME = IPE14.5, T64,'TNC = E14.5, 1 T38,'CELT = E14.5, T90,'TRIP NUMBER = I4//') 60 FORMAT ('IENERGY AT TIME = IPE14.5, T64,'TNC = E14.5, 1 T38,'CELT = E14.5, T90,'TRIP NUMBER = I4//') 70 FORMAT ('IPRESSURE AT TIME = IPE14.5, T64,'TNC = E14.5, 1 T38,'CELT = E14.5, T90,'TRIP NUMBER = I4//') C 80 FORMAT ('1//'/' ERROR MESSAGE'// 1 'ONE OF THE FOLLOWING HAS BECOME LESS THAN 1.0E-10 DENSITY, ENERGY, OR PRESSURE. THIS MAY BE THE RESULT OF INSTABILITY OR AN ERROR. CHECK INPUT DATA CARDS FOR CORRECTNESS AND THE PRINT OUT OF THE INPUT DATA AND CONSTANTS. FOLLOWING IS A CUMP OF THE ARRAYS IN COMMON.///) 81 FORMAT (1H+, T34, 1PE11.2) 82 FORMAT (1H+, T45, 1PE11.2) 83 FORMAT (1H+, T56, 1PE11.2) 84 FORMAT (1H+, T67, 1PE11.2) 85 FORMAT (1H+, T78, 1PE11.2) 86 FORMAT (1H+, T89, 1PE11.2) 87 FORMAT (1H+, T100, 1PE11.2) 88 FORMAT (1H+, T111, 1PE11.2) 89 FORMAT (1H+, T122, 1PE11.2) C NAMELIST/NAMI1/N, XMCM2, YMOM2, VSG, A, XMCM2A, YMOM2A, VSGA, C, IR, 1 ICRCP C CT = CELT*CCN3 IF (N.EQ.2) GC TC 30C C C INPUT DATA PRINTOUT C CL = CUE / CCN3 * CCN2 CPP = CP / CCN3 * CCN2 100 MTC = JYS/2 + 1 JLP = JYS - 6 IF (MIC.EQ.8) JLP = MID + 1
JLP = INC(MIC,E) - 1

C

110 CC 12C I=1,3
XC(I) = XCISP(I)*XLEN
12C XCP(I) = XCISP(I)*XLEN
YL = YLEN*XLEN
CX = CEL*XLEN
CY = CELY*XLEN
LENX1 = IX1 - 2
LENX2 = IX2 - 2
LFNX3 = IX3 - 2
LFNX4 = IX4 - 2
LENY1 = JY1 - 2
LFAY2 = 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,T,TILEN
WRITE (6,5) XLEN,YL,CX,CY
WRITE (6,6) AC,XM,FLUDGE,TP
WRITE (6,7) PC,TC,RHCO,E
WRITE (6,8) GAM,XSLOPE,C,DP
WRITE (6,10) SINB1,COSB1,SINE,COSINE
WRITE (6,13) DIFCC,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

DEPENDENT VARIABLE PRINTCLT

C

300 IF (IRHO*EQ.C.ANC.N.EQ.2) GC TC 40C

C

CENSITY PRINTCLT

C

WRITE (6,3C) TTCL,CT,TNC,TCOLTNT
LK = 1
LKI = LK
JLB = 2
JLR = JY5#1

C

CC 35C I=2,IX4
IF (I*CT.IX1) GO TC 360

C

CC 33C J=2,JY1
K = J - 1
33C TEMP(K) = A(I,I,J)*RHCO

PRINT - 3
CC 34C J=JY1P1,JLP
K = K + 1
34C TEMP(K) = w(1,I,J)*RHCC
C
K = K + 1
TEMP(K) = w(1,I,KIC)*RHCC
C
CC 345 J=JLP,JY4
K = K + 1
345 TEMP(K) = w(1,I,J)*RHCC
C
CC 35C J=JY4P1,JY5M1
K = K + 1
JJ = JY5M1 - J + 2
350 TEMP(K) = a(1,I,JJ)*RHCC
C
WRITE (6,28) (TEMP(K),K=1,13)
C
IF (I.EQ.IXI) GC TC 390
IF (IR(I).EQ.5.CR.IR(I).EC.CR.IR(I).EC.1) GO TC 355
CC 352 M=1,2
352 CC 355 M=1,2
358 WRITE (6,21)
GC TC 390
C
355 CC 358 M=1,2
358 WRITE (6,2C)
GC TC 390
C
360 IF (I.NE.ICRCP(LK).OR.I.GT.IX3) GO TC 365
LK = LK + 1
LK1 = LK
JLB = JLB + 1
JLB = JUB - 1
GC TC 366
C
365 IF (I.NE.ICRCP(LK)) GO TC 366
LK = LK + 1
LK1 = LK1 - 1
JLB = JLB - 1
JUE = JUB + 1
C
366 CC 37C J=JLB,JLP
K = J - JLB + 1
370 TEMP(K) = w(1,I,J)*RHCC
C
K = K + 1
TEMP(K) = w(1,I,KIC)*RHCC
C
CC 375 J=JLP,JL8
K = K + 1
375 TEMP(K) = w(1,I,J)*RHCC
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 390
C
PRINT - 4
C 381 WRITE (6,22) (TEMP(J),J=1,K)
   GC TO 390
C 382 WRITE (6,23) (TEMP(J),J=1,K)
   GC TO 390
C 383 WRITE (6,24) (TEMP(J),J=1,K)
   GC TO 390
C 384 WRITE (6,25) (TEMP(J),J=1,K)
   GC TO 390
C 385 WRITE (6,26) (TEMP(J),J=1,K)
   GC TO 390
C 386 WRITE (6,26) (TEMP(J),J=1,K)
C 390 CONTINUE
C 400 IF (I.REQ.N.AN.D.N.EQ.2) GC TO 500
C 410 X-MOMENTUM PRINTOUT
C WRITE (6,40) TTN,TTT,TTT,TTT
JLB = 2
JUB = JY5M1
LK = 1
LK1 = LK
C CC 49C I=2,IX4
   IF (I.GT.IX1) GC TO 460
C CC 43C J=2,JY1
   K = J - 1
430 TEMP(K) = A(2,I,J)*CCN1
C CC 44C J=JY1P1,JLYP
   K = K + 1
440 TEMP(K) = W(2,I,J)*CCN1
C   K = K + 1
   TEMP(K) = W(2,I,MIC)*CCN1
C CC 445 J=JLP,JY4
   K = K + 1
445 TEMP(K) = W(2,I,J)*CCN1
C CC 45C J=JY4P1,JY5M1
   K = K + 1
   JJ = JY5M1 - J + 2
450 TEMP(K) = A(2,I,JJ)*CCN1
C WRITE (6,28) (TEMP(K),K=1,13)
C IF (I.REQ.IX1) GC TO 490
IF (IR(I).EQ.5.CR. IR(I).EQ.0.CR IR(I).EQ.1) GC TO 455
CC 452 M=1,2

PRINT - 5
452 WRITE (6,21)  
   CC TC 49C  
C 455 CC 456 M=1,2  
458 WRITE (6,22)  
   CC TC 49C  
C C 460 IF (I.NE.ICRCP(LK).CR.I.GT.1X3) GO TC 465  
   LK = LK + 1  
   LKI = LK  
   JLB = JLB + 1  
   JUB = JUB - 1  
   CC TC 466  
C C 465 IF (I.NE.ICRCP(LK)) GO TC 466  
   LK = LK + 1  
   LKI = LKI - 1  
   JLB = JLB - 1  
   JUB = JUB + 1  
C C 466 CC 47C J=JLB,JLP  
   K = J - JLB + 1  
470 TEMP(K) = w(2,I,J)*CCN1  
C  
   K = K + 1  
   TEMP(K) = w(2,I,KID)*CCN1  
C C 475 J=JLP,JLB  
   K = K + 1  
475 TEMP(K) = w(2,I,J)*CCN1  
C C 480 IF (I.NE.2) GO TC 481  
   WRITE (6,28) (TEMP(J),J=1,K)  
   GO TC 49C  
C C 481 WRITE (6,22) (TEMP(J),J=1,K)  
   GO TC 49C  
C C 482 WRITE (6,23) (TEMP(J),J=1,K)  
   GO TC 49C  
C C 483 WRITE (6,24) (TEMP(J),J=1,K)  
   GO TC 49C  
C C 484 WRITE (6,25) (TEMP(J),J=1,K)  
   GO TC 49C  
C C 485 WRITE (6,26) (TEMP(J),J=1,K)  
   GO TC 49C  
C C 486 WRITE (6,27) (TEMP(J),J=1,K)  
C C 490 CONTINUE  
C 500 IF (IN.EQ.0.AND.N.EQ.2) GO TC 60C  
D-51
C Y-MOMENTLY PRINTCL1
C WRITE (6,5C) TTCL,CT,INC,TCLNT
JLB = 2
JUB = JYSP1
LK = 1
LK1 = LK
C CG 59C I=2,IX4
IF (I.GT.IX1) GO TC 560
C CG 530 J=2,JY1
K = J - 1
530 TEMP(K) = A(3,I,J)*CCN1
C CG 54C J=JYIP1,JLP
K = K + 1
540 TEMP(K) = W(3,I,J)*CCN1
C K = K + 1
TEMP(K) = W(3,I,J)*CCN1
C CG 545 J=JLP,JY4
K = K + 1
545 TEMP(K) = W(3,I,J)*CCN1
C CG 55C J=JY4P1,JYSP1
K = K + 1
JJ = JYSP1 - J + 2
550 TEMP(K) = -A(3,I,JJ)*CCN1
C WRITE (6,28) (TEMP(K),K=1,13)
C IF (I.EQ.IX1) GO TC 590
IF (IR(I)).EQ.5.CR.IR(I).EQ.0.CR.IR(I).EQ.1) GO TC 555
CG 552 M=1,2
552 WRITE (6,21)
GO TC 590
C 555 CG 558 M=1,2
558 WRITE (6,2C)
GO TC 590
C CG 560 IF (I.NE.ICRCP(LK).OR.I.GT.IX3) GO TC 565
LK = LK + 1
LK1 = LK
JLB = JLB + 1
JUB = JUB - 1
CG TC 566

C 565 IF (I.NE.ICRCP(LK)) GO TC 566
LK = LK + 1
LK1 = LK1 - 1
JLB = JLB - 1
JUB = JUB + 1
C PRINT - 7
566 CC 570 J=JLB, JLP
K = J - JLB + 1
570 TEMP(K) = h(I3, I, J)*CEH1
C
K = K + 1
TEMP(K) = h(I3, I, PIC)*CEH1
C
CC 575 J=JLP, JLB
K = K + 1
575 TEMP(K) = h(I3, I, J)*CEH1
C
GC TC (580, 582, 583, 584, 585, 586, 587, 588, 589, 590, LK1
C
580 IF (I,.NE.2) GC IC TC 581
WRITE (6,28) (TEMP(J), J=1,K)
GC TC 590
C
581 WRITE (6,22) (TEMP(J), J=1,K)
GC 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 590
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 590
C
586 WRITE (6,27) (TEMP(J), J=1,K)
C
590 CONTINUE
C
600 IF (IE.EQ.0.AND. A.EQ.2) GC TC 700
C
ENERGY PRINT CUT
C
ICHOSE = IWHISH
IF (N .EQ. 1) ICHOOSE = 0
IF (ICHOSE .EQ. 0) GC TC 602
IF (TCCUNT .NE. 1) GC TC 602
WRITE (6, 8)
IF (IҲ1 .NE. 1) GC TC 601
WRITE (6, 16)
GO TC 602
601 WRITE (6, 17)
602 IF (ICHOSE .NE. 0) GC TC 605
WRITE (6, 6C) TCOL, CT, TNG, TCOLNT
605 JLB = 2
JUB = JY5W1
LK = 1
LK1 = LK
C
CC 650 I=2, IX4
IF (J.GT.IX1) GC TC 660

PRINT - 8

D-53
C
EC 63C J=2,JY1
K = J - 1
TEMP(K) = A(I,J,J) * CCN2
IF (I.EQ. 2 .AND. J .EQ. 5 .OR. I .EQ. 10 .OR. I .EQ. 15 .OR.
1 .EQ. 20) GC TC 620
GO TO 630
620 IF (J .EQ. 12 .OR. J .EQ. 19) GO TC 625
GC TC 630
625 IF (I .EQ. 2 .AND. J .EQ. 12) GC TC 626
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,81) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,82) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,83) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,84) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,85) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,86) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,87) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,88) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,89) TEMP(K)
CC TC 630
626 WRITE (E,19) TCCNTL, TTCL, TEMP(K)
630 CONTINUE
C
EC 64C J=1,JY1,JLP
K = K + 1
TEMP(K) = h(I,J,J) * CCN2
IF (I.EQ. 2 .AND. J .EQ. 5 .OR. I .EQ. 10 .OR. I .EQ. 15 .OR.
1 .EQ. 20) GC TC 640
GO TO 630
633 IF (J .EQ. 12 .OR. J .EQ. 19) GC TC 635
GC TC 640
635 IF (I .EQ. 2 .AND. J .EQ. 12) GC TC 638
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,81) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,82) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,83) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,84) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,85) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,86) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,87) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,88) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (E,89) TEMP(K)
GO TO 640
638 WRITE (E,19) TCCNTL, TTCL, TEMP(K)
640 CONTINUE
C
K = K + 1
TEMP(K) = h(I,J,K)*CCN2
C
EC 645 J=JLP,JY4
K = K + 1
TEMP(K) = h(I,J,J) * CCN2
IF (I.EQ. 2 .AND. J .EQ. 5 .OR. I .EQ. 10 .OR. I .EQ. 15 .OR.
1 .EQ. 20) GC TC 645
CC TC 645
641 IF (J .EQ. 12 .OR. J .EQ. 19) GC TC 643

PRINT - 9
IF (I .EQ. 2 .AND. J .EQ. 12) WRITE (6,81) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (6,82) TEPP(K)
IF (I .EQ. 1 .AND. J .EQ. 10) WRITE (6,83) TEM(K)
IF (I .EQ. 15 .AND. J .EQ. 1) WRITE (6,84) TEPP(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (6,86) TEM(K)
IF (I .EQ. 1 .AND. J .EQ. 10) WRITE (6,87) TEPP(K)
IF (I .EQ. 15 .AND. J .EQ. 1) WRITE (6,88) TEPP(K)
IF (I .EQ. 2C .AND. J .EQ. 19) WRITE (6,89) TEPP(K)

WRITE (6,19) TCCLNT, TICL, TEMP(K)
CONTINUE

K = K + 1
JJ = J + 2
 TEMP(K) = A(4, I, JJ) * CCA2
IF (I .EQ. 2 .AND. J .EQ. 19) WRITE (6,81) TEMP(K)
IF (I .EQ. 5 .AND. J .EQ. 19) WRITE (6,82) TEPP(K)
IF (I .EQ. 15 .AND. J .EQ. 1) WRITE (6,83) TEM(K)
IF (I .EQ. 5 .AND. J .EQ. 12) WRITE (6,84) TEPP(K)
IF (I .EQ. 1 .AND. J .EQ. 10) WRITE (6,86) TEM(K)
IF (I .EQ. 15 .AND. J .EQ. 1) WRITE (6,87) TEPP(K)
IF (I .EQ. 2C .AND. J .EQ. 19) WRITE (6,88) TEPP(K)
IF (I .EQ. 2C .AND. J .EQ. 19) WRITE (6,89) TEPP(K)

WRITE (6,19) TCCLNT, TICL, TEMP(K)
CONTINUE

C

IF (I .NE. ICRCP(LK).OR.I .GT. IX3) GO TO 665
LK = LK + 1
LK = LK + 1

END
JLB = JLB + 1
JUB = JUB - 1
GO 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 670 J=JLB, JLP
K = J - JLB + 1
TEMP(K) = W(4, I, J) * CCN2
IF (ICPOSE .EC. C) GC TC 670
IF (I .EQ. 2 .CR. I .EQ. 5 .CR. I .EQ. 10 .CR. I .EQ. 15 .CR.
1 I .EQ. 20) GC TC 667
GO TC 670
667 IF (J .EQ. 12 .CR. J .EQ. 22) GO TC 668
GO TC 670
668 IF (I .EQ. 2 .ANC. J .EQ. 12) GC TC 669
IF (I .EQ. 2 .ANC. J .EQ. 22) WRITE (6,81) TEMP(K)
IF (I .EQ. 5 .ANC. J .EQ. 12) WRITE (6,82) TEMP(K)
IF (I .EQ. 5 .ANC. J .EQ. 22) WRITE (6,83) TEMP(K)
IF (I .EQ. 10 .ANC. J .EQ. 12) WRITE (6,84) TEMP(K)
IF (I .EQ. 10 .ANC. J .EQ. 22) WRITE (6,85) TEMP(K)
IF (I .EQ. 15 .ANC. J .EQ. 12) WRITE (6,86) TEMP(K)
IF (I .EQ. 15 .ANC. J .EQ. 22) WRITE (6,87) TEMP(K)
IF (I .EQ. 20 .ANC. J .EQ. 12) WRITE (6,88) TEMP(K)
IF (I .EQ. 20 .ANC. J .EQ. 22) WRITE (6,89) TEMP(K)
GO TC 670
669 WRITE (6,19) TCCLNT, TTCL, TEMP(K)
670 CONTINUE
C
K = K + 1
TEMP(K) = W(4, I, KID) * CCN2

C
670 IF (I .EQ. 2 .ANC. J .EQ. 12) GO TC 671
IF (I .EQ. 2 .ANC. J .EQ. 22) WRITE (6,81) TEMP(K)
IF (I .EQ. 5 .ANC. J .EQ. 12) WRITE (6,82) TEMP(K)
IF (I .EQ. 5 .ANC. J .EQ. 22) WRITE (6,83) TEMP(K)
IF (I .EQ. 10 .ANC. J .EQ. 12) WRITE (6,84) TEMP(K)
IF (I .EQ. 10 .ANC. J .EQ. 22) WRITE (6,85) TEMP(K)
IF (I .EQ. 15 .ANC. J .EQ. 12) WRITE (6,86) TEMP(K)
IF (I .EQ. 15 .ANC. J .EQ. 22) WRITE (6,87) TEMP(K)
IF (I .EQ. 20 .ANC. J .EQ. 12) WRITE (6,88) TEMP(K)
IF (I .EQ. 20 .ANC. J .EQ. 22) WRITE (6,89) TEMP(K)
GO TC 675
671 IF (J .EQ. 12 .CR. J .EQ. 22) GO TC 672
GO TC 675
672 IF (I .EQ. 2 .ANC. J .EQ. 12) GO TC 673
IF (I .EQ. 2 .ANC. J .EQ. 22) WRITE (6,81) TEMP(K)
IF (I .EQ. 5 .ANC. J .EQ. 12) WRITE (6,82) TEMP(K)
IF (I .EQ. 5 .ANC. J .EQ. 22) WRITE (6,83) TEMP(K)
IF (I .EQ. 10 .ANC. J .EQ. 12) WRITE (6,84) TEMP(K)
IF (I .EQ. 10 .ANC. J .EQ. 22) WRITE (6,85) TEMP(K)
IF (I .EQ. 15 .ANC. J .EQ. 12) WRITE (6,86) TEMP(K)
IF (I .EQ. 15 .ANC. J .EQ. 22) WRITE (6,87) TEMP(K)
IF (I .EQ. 20 .ANC. J .EQ. 12) WRITE (6,88) TEMP(K)
IF (I .EQ. 20 .ANC. J .EQ. 22) WRITE (6,89) TEMP(K)
GO TC 675
673 WRITE (6,19) TCCLNT, TTCL, TEMP(K)
675 CONTINUE

PRINT - II
C
IF (ICHOS E .AE. C) GC TC 66C
C
GC TC (68C, 662, 663, 664, 665, 666), LK1
C
680 IF (I, AE. 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
690 CONTINUE
C
700 IF (IPRES.EC.C.ANC.N.EC.2) GC TO 88C
C
PRESSURE PRINTCLT
C
WRITE (6, 7C) TICL, CT, TND, TCOLNT
JLB = 2
JUB = JY5M1
LK = 1
LK1 = LK
C
CC 79C I=2, IX4
IF (I, CT, IX1) GC TC 760
C
CC 73C J=2, JY1
K = J - 1
730 TEMP(K) = A(5, I, J)*CCN2
C
CC 74C J=JYIP1, JLP
K = K + 1
740 TEMP(K) = w(5, I, J)*CCN2
C
K = K + 1
TEMP(K) = w(5, I, WID)*CCN2
C
CC 745 J=JLP, JY4
K = K + 1
745 TEMP(K) = w(5, I, J)*CCN2
C
CC 75C J=JY4P1, JY5M1
K = K + 1

D-57

PRINT - 12
JJ = JY5P1 - J + 2
750 TEMP(K) = A(5,1, JJ)*CCN2
C WRITE (6,28) (TEMP(K), K=1,13)
C
IF (I.EQ.IX1) GC TC 790
IF (IR(I).EQ.5.CR.IR(I).EC.CR.IR(I).EQ.1) GC TC 755
C 752 WRITE (6,21)
GC TC 790
C
C 755 GC 758 M=1,2
758 WRITE (6,2C)
GC TC 790
C
C
760 IF (I.NE.CRCP(LK).OR.I.GT.IX3) GC TC 765
LK = LK + 1
LKI = LK
JLB = JLB + 1
JUB = JUB - 1
GC TC 766
C
C 765 IF (I.NE.CRCP(LK)) GC TC 766
LK = LK + 1
LKI = LKI - 1
JLB = JLB - 1
JUB = JUB + 1
C
C 766 GC 770 J=JLB,JLP
K = J - JLB + 1
770 TEMP(K) = W(5,1,J)*CCN2
C
K = K + 1
TEMP(K) = W(5,1,KIC)*CCN2
C
CC 775 J=JLP,JLB
K = K + 1
775 TEMP(K) = W(5,1,J)*CCN2
C
GC TC (780,762,783,784,785,786),LKI
C
780 IF (I.NE.2) GC TC 781
WRITE (6,28) (TEMP(J), J=1,K)
GC TC 790
C
781 WRITE (6,22) (TEMP(J), J=1,K)
GC TC 790
C
782 WRITE (6,23) (TEMP(J), J=1,K)
GC TC 790
C
783 WRITE (6,24) (TEMP(J), J=1,K)
GC TC 790
C
784 WRITE (6,25) (TEMP(J), J=1,K)
GC TC 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 CONTINUE
C
800 IF (KICOFF.EQ.C) GC TC 1CC
C
     ERROR PRINTOLT
C
     WRITE (6,80)
     WRITE (6,NAMI)
C
C
1CC O RETURN
ENC
Figure D-9

DIAGRAM OF SUBROUTINE MAIN CONVERSION PROGRAM

START

READ THE INPUT
DATA FROM TAPE
DEVICE 8

EXPAND IN THE
VERTICAL DIRECTION

INITIALIZE
JMAX, JMAXI, JMAX2, ISUM,        
ISUMI, IJX, JLY, JLY1

I = 2, IAX

K = 1, 4

J = JLY1, JLY1

Y1(KX) = Y(K,1,1)

CONTINUE

I = 1, IMAX

CONTINUE

Y2(L) = Y2 INT [Y2(L), Y2(L), 0.5]

CONTINUE

EXPAND IN THE
HORIZONTAL DIRECTION

INITIALIZE
ISUM3, IMAX, JJ

T = 1, ISUM3

MM = J + 1

IMOD = MOD/MM, J)

JJ = IMOD + JJ

T = 1, MOD, QQ, AND

JJ, LT, JJ

T = 1, MOD, QQ, AND

JJ, GT, JJ

IMAX = IMAX + ISLOPE

TH = IMAX

NUTS = 0

T = 1, JJ, LT, JJ

T = 1, JJ, EQ, JJ

IMAX = IMAX + ISLOPE + 5

IU = IMAX

NUTS + 10

T = 1, JJ, LT, JJ

T = 1, JJ, EQ, JJ

IL = ISUM2 - 2.5 ISUMG - 1.5 NUTS

I = 1, IL

ISUM

M = 1, 10

W(K,1,1) = W(K,1,1)

CONTINUE

T = 1, JJ, LT, JJ

T = 1, JJ, EQ, JJ

IL = ISUM2 - 2.4 ISOPE + 1 NUTS

I = 1, IL

ISUM

CONTINUE

CONTINUE
FLOW DIAGRAM OF SUBROUTINE
5564 MAIN

INTEGER * 4 TCCLAT, TT

COMMON/CCM1/IC(5,52,23), A(5,30,5), XMCM2(52,23), YMCM2(52,23),
1 VSCA(52,23), XMCM2A(3C,5), YMCM2A(3C,5), VSCA(30,5),
2 GAP*ICAP1, ICAP2, ICAP3, ICEx, ICEl,
3 CELT, FLGCE, SC, TNC, TTCL, TP,
4 CCN3, CIFCC, XH, ENERG, XM, CMega, THICK,
5 CLE, CP, EXP, GUESS, GEE, IPEX

COMMON/CCM2/ ICRCP(2C), IR(30),
1 IX1, IX1P1, IX1P2, IX2, IX3, IX4,
2 IX4P1, IX4P2, IX4P3, JY1, JY1M1, JY1P1,
3 JY2, JY2P1, JY2P2, JY3, JY3M1,
4 JY3P1, JY3P2, JY4, JY4P1, JY4P2,
5 JY5P1, JY5P2, ISLOPE, JEXL, JEXU

COMMON/CCM3/ XCIS(3), XCIISP(3), CFX(2), CFN(3),
1 SINB1, CCBS1, SINE, CCSINE, DUST, DUSTP,
2 ILEN

COMMON/CCM4/ X, PO, TO, RHC0, XMCMC, YMCMC,
1 AO, XLEn, YLEn, XSLOPE, SLOPE,
2 CCN1, CCN2, IRHC, IP, IN, IE,
3 IPRES, IOPT

COMMON/CCM5/TCCLAT, T, KICGFF, TT

COMMON/CCM6/ 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/ AVA(12,2,10), AXV(35), AVY(5)

DIMENSION YI(52), Y2(52)

XI(x,A,B,C,X) = A + X*(B - A) + X*(X - 1.0)*(C - 2.0*B + A)/2.

READ (8) W, A, XMCM2, YMCM2, VSCA, XMCM2A, YMCM2A,
1 VSCA, GAP, GAP1, GAP2, GAP3, CELX, CELY,
2 CELT, FLGCE, SC, TNC, TTCL, TP, CCN3,
3 CIFCC, XH, ENERG, XM, CMega, THICK, QUE,
4 CP, EXP

READ (E) ICRCP, IR,
1 IX1, IX1P1, IX1P2, IX2, IX3, IX4,
2 IX4P1, IX4P2, IX4P3, JY1, JY1M1, JY1P1,
3 JY2, JY2P1, JY2P2, JY3, JY3M1,
4 JY3P1, JY3P2, JY4, JY4P1, JY4P2,
5 JY5P1, JY5P2, ISLOPE, JEXL

READ (B) C, XCIS, XCIISP, CFX, CFN, SINB1,
1 CCBS1, SINE, CCSINE, DUST, DUSTP,
2 ILEN

READ (E) XM, PO, TO, RHC0, XMCMC, YMCMC, AO,
1 XLEn, YLEn, XSLOPE, SLOPE, CCN1, CCN2,
2 IRHC, IP, IN, IE, IPRES

READ (E) TCCLAT, T, KICGFF, TT

READ (E) TVA, T, AVA, AXV, AVY

READ (E, ENC=12C)

EXPAND IN THE VERTICAL DIRECTION

D-62

MAIN (CONV) - I
12C JMAX = (JY5 - 2)/2 + 1
   JMAXP1 = JMAX - 1
   JMAXP2 = JMAX - 2
   ISLM = JMAX + JMAXP1
   ISLP1 = ISLM + 1
C
   LK = 1
   JL1 = 2
   JL1 = JY5/2 + 1
C 2CC I=2,IX4
C
   CC 15C K=1,4
   KK = C
   CC 13C J=JL1,JL1
   KK = KK + 1
13C Y1(KK) = W(K,1,J)
C
   CC 135 L=1,JMAXP2
   WXC = Y1(L)
   WX1 = Y1(L+1)
   WX2 = Y1(L+2)
135 Y2(L) = XINT(WXC,WX1,WX2,5)
C
   WXC = Y1(JMAX-2)
   WX1 = Y1(JMAX-1)
   WX2 = Y1(JMAX)
   Y2(JMAXP1) = XINT(WXC,WX1,WX2,1.5)
C
   KK = ISLP1 + 2
   CC 14C J=2,JMAX
   J1 = JMAX - J + 2
   KK = KK - 2
   W(K,1,KK) = Y1(J1)
140 W(K,1,KK-1) = Y2(J1-1)
   W(K,1,2) = Y1(1)
C
   15C CCNTILE
   2CC CCNTILE
C
   CC 25C I=2,IX4
   CC 25C K=1,4
   SIGN = 1.C
   IF (K.EQ.3) SIGN = -1.C
   CC 25C J=1,ISLP
   J1 = ISLP1 + J
   J2 = ISLP1 - J
   W(K,1,J1) = W(K,1,J2)*SIGN
25C CCNTILE
C
   EXPAND IN THE +CRI2C DIRECTION
C
   ISLM3 = 2*ISLM
   IMAX = IX2 - ISLCP - 1
   JJ = 1
   CC 5CC J=2,ISLM3
   MM = J + 1

MAIN (CONV) - 2
\[ IMCC = \text{MCD}(M,2) \]
\[ JJ = IMCC + JJ \]
\[ \text{IF} (IMCC \geq JJ \text{AND} JJ > JY3) \text{ GC TO 355} \]
\[ \text{IF} (IMCC < JJ \text{AND} JJ > JY3) \text{ GC TO 355} \]
\[ \text{IF} (JJ > JY2) \text{ GC TO 310} \]
\[ \text{IF} (JJ > JY2) \text{ GC TO 320} \]
\[ \text{IF} (JJ \geq JY2 \text{AND} JJ < JY3) \text{ GC TO 355} \]
\[ \text{IF} (JJ < JY3) \text{ GC TO 330} \]

**C**

310  \[ IMAX = IMAX + ISLOPE \]
\[ IL = IMAX - 1 \]
\[ NUTS = 0 \]
\[ \text{GC TO 35C} \]

320  \[ IMAX = IMAX + ISLOPE + 5 \]
\[ IL = IMAX - 1 \]
\[ NUTS = 1C \]
\[ \text{GC TO 35C} \]

330  \[ IMAX = IMAX - ISLOPE - 5 \]
\[ IL = IMAX - 1 \]
\[ NUTS = 0 \]
\[ \text{GC TO 35C} \]

340  \[ IMAX = IMAX - ISLOPE \]
\[ IL = IMAX - 1 \]

350  \[ IMAXP1 = IMAX + 1 \]
\[ IMAXP2 = IMAX - 2 \]
\[ ISUM2 = IMAX + IL + 1 \]

355  \[ CC 4CC K=1,4 \]
\[ CC 38C I=2, IMAXP1 \]
\[ 380 Y1(1-1) = w(K, I, J) \]

365  \[ CC 365 L=1, IMAXM2 \]
\[ \text{WXC} = Y1(L) \]
\[ \text{WX1} = Y1(L+1) \]
\[ \text{WX2} = Y1(L+2) \]

385  \[ Y2(L) = \text{XINT} (\text{WXC}, \text{WX1}, \text{WX2}, 0.5) \]

\[ \text{WXC} = Y1(IMAX-2) \]
\[ \text{WX1} = Y1(IMAX-1) \]
\[ \text{WX2} = Y1(IMAX) \]
\[ Y2(IL) = \text{XINT} (\text{WXC}, \text{WX1}, \text{WX2}, 1.5) \]

390  \[ KK = 1 \]
\[ w(K,2,J) = Y1(I) \]
\[ CC 395 I=2, IMAX \]
\[ KK = KK + 2 \]
\[ w(K, KK, J) = Y2(I-1) \]

399  \[ \text{IF} (JJ \geq JY2 \text{AND} IMCC < 0) \text{ GC TO 394} \]
\[ \text{IL = ISUM2 - 2*ISLOPE + 1 - NUTS} \]
\[ CC 391 I=IL, ISLP2 \]

**MAIN (CONV) - 3**

D-64
DE
N=ltlC
JP = J - N
IF (JP.LE.1) GC TC
391 CONTINUE
C
394 IF (JJ.LT.JY3.CE.1) GC TC 400
IL = ISUM2 - 2*ISLOPE + 1 - NUTS
CL 355 I=IL,ISLM2
DO 395 M=1,1C
JP = J + M
IF (JP.GT.ISLM3) GC TC 395
\n(k(K,JP)) = k(K_I•J)
395 CONTINUE
C
400 CONTINUE
500 CONTINUE
C
RECDIMENSIONALIZE THE CHAMBER
C
CALL INT
C
CALL VRTLAL
CALL PRINT (1)
C
WRITE THE NEW DATA ON TAPE 8
C
WRITE (8) h ,A ,XMCM2 ,YMCM2 ,VSC ,XMCM2A ,YMCM2A ,
1 VSCA ,GAM ,GAM1 ,GAM2 ,GAM3 ,CELX ,DELY ,
2 DELT ,FUGE ,SQ ,TNC ,TTC ,TP ,CON3 ,
3 CIFCC ,XH ,ENERO ,XNL ,OMEGA ,THICK ,QUE ,
4 GP ,EXP
WRITE (8) IDROP ,IR ,
1 IX1 ,IXIM1 ,IXIPI ,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 JEXL ,JEXL
WRITE (8) D ,XDIS ,XDISP ,CFX ,CFN ,SINB1 ,
1 COSB1 ,SINE ,COSINE ,DIST ,DISTP ,
2 ILEN
WRITE (8) XM ,PC ,T0 ,RHO0 ,XMCM0 ,YMCM0 ,AO ,
1 XLEN ,YLEN ,XSLOPE ,SLOPE ,CON1 ,CON2 ,
2 IRC ,IN ,IE ,IPRES
WRITE (8) TCCUNT ,T ,KICOFF ,TT
WRITE (8) TV ,TVA ,AXV ,AYV ,XVEL ,YVEL ,SONIC ,
1 PRES ,AV ,AVA ,AXV ,AYV
C
END FILE 8
REWIND 8
C
STCP
END
C
SUBROUTINE INT
C
INTEGER / 4 TCCUNT,T,TT
C
COMMON/COM1/ (5,52,23), A(5,30,5), XMON(52,23), XMCH(52,23),
1 VSC(52,23), XMONA(3C,5), XMCHA(3C,5), VSCA(30,5),
2 GAM, GAM1, GAM2, GAM3, DEEX, DELY,
3 CELT, FUDGE, SC, INC, TCCUT, TP,
4 CCA3, CIFCC, XH, ENERO, XMU, CMEGA, THICK,
5 CLE, CP, EXP, GUESS, GEE, IPEX
COMMON/COM2/ ICRC(2C), IR(30),
1 IX1, IX1M1, IX1P1, IX2, IX3, IX4,
2 IX4M1, IX4M2, IX4M3, JY1, JY1M1, JY1P1,
3 JY2, JY2M1, JY2P1, JY2P2, JY3,
4 JY3M2, JY3P1, JY4, JY4M1, JY4P1,
5 JY5M1, JY5P2, ISLOPE, JEXL, JEXU
COMMON/COM3/ (2C), XDIS(3), XDISP(3), DFX(2), CFN(3),
1 SINA1, CCB1, SINE, COSINE, CIST, DISTP,
2 ILEN
COMMON/COM4/ (XH, PO, TO, RHCO, XMCMO, YMOMO,
1 AC, XLEN, YLEN, XSLOPE, SLOPE,
2 CON1, CON2, ITRO, IM, IN, IE,
3 IPRES, NCP T
COMMON/COM5/ TCCUNT, T, KICCOFF, TT
COMMON/COM6/ TV(12,2,2), TVA(12,2,22), XV(52), YY(23),
1 VVEL(2,2,23), VVEL(2,23), SGNC(2,2,23), PRES(2,2,23)
COMMON/COM7/ AVAL(12,2,10), AVA(12,2,10), AXV(35), AVY(5)
C
2 FORMAT (315)
3 FORMAT (7F10,0, C1C.C)
4 FORMAT (8I10)
5 FORMAT (4D10.0)
9 FORMAT (1I10, 4D10.0)
C
READ IH DATA
C
40 READ (5,4) LENX1, LENX2, LENX3, LENX4
READ (5,4) LENY1, LENY2, LENY3, LENY4, LENY5
READ (5,3) XM, PC, TO, GAM, FUDGE, DEEX, DIFCC, GUE
READ (5,4) T, TT, NOPT, IRHC, IM, IN, IE, IPRES
READ (5,9) TCCUNT, XMU, OMEGA, THICK
READ (5,2) IFOLR, IEIGHT, MESH
C
CP = C.C
EXP = C.C
TP = C.C
CELY = CELEX
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

INT - 1

D-66
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 + IFQLR
CC 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)/RC0
  w(2,I,JY3+1) = w(2,I,JY3+1)/C01
  w(3,I,JY3+1) = w(3,I,JY3+1)/C01
  w(4,I,JY3+1) = w(4,I,JY3+1)/C02
50

CC 60 I=IL,IX4
CC 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)

CC
IL = IX3 + IEIGHT
CC 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)/RC0
  w(2,I,JY3+2) = w(2,I,JY3+2)/C01
  w(3,I,JY3+2) = w(3,I,JY3+2)/C01
  w(4,I,JY3+2) = w(4,I,JY3+2)/C02
70

CC 80 I=IL,IX4
CC 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)

CALCULATE CONSTANTS
NCNDDIMENSIONALIZE THE VARIABLES

90 XLEN = LENX4*DELX

INT - 2
CELX = DELX/XLEN
CELY = CELX
YLEN = LENY*CELY
GAM1 = GAM - 1.
GAM2 = GAM1/2.
GAM3 = (GAM - 3.)/2.
SG = 1./SQRT(2.)

C
RHO = XM/1545.*PC/P0
AC = SQRT(GAM*32.2*PC/RH0)
CCN1 = RHO*AC
CCN2 = CCN1*AC/32.2
CCN3 = XLEN/AC
ENERC = PO/CAM1/CCH2
XMI = XM/(PC*AC*XLEN)
CMEGA = CMEGA*CCN3
THICK = THICK/XLEN
TNC = C.C
TTC = 0.
CUE = CUE / CCN2 * CCN3

C
TEST TC SEE IF CELIQUE BOUNDARIES ARE PRESENT

C
ILEN = LENX3 - LENX2
IF (ILEN.NE.0) GO TO 100
ISLOPE = 0
SLCPE = ISLOPE
XSLOPE = 0.
ICRCP(I) = IX4 + 1
SINB1 = 0.
CCSB1 = 0.
GO TO 140

C

C INFORMATION FOR SUBROUTINE BOUND

C
100 ISLOPE = ILEN/LENY2
SLCPE = ISLOPE
XSLOPE = -1./SLCPE
CIS = SQRT((ISLOPE*DEL))**2 + DEL**2)
SINB1 = -DEL/CIS
COSB1 = SLCPE*DEL/YDIS
CIST = DELY/CCSB1
IU = ISLOPE + 1

C
GO 111 I=1,ISLCOPE
R = I*CELX
CS = -R*SINB1

110 D(I) = 3.*CIST - 2.*CS
D(IU) = 4.*DIST + 2.*IU*CELX*SINB1

C
GO 112 I=1,3
P = I
Y = -P*DEL

112 XCIS(I) = Y/SLOPE + 2.*DELX

C
GO 114 I=1,3
P = I
Y = -(P + 1.)*CELX

INT - 3
Ilk XCISPI = ¥/SLCPE ÷ 2. VCELX

CETERVENAIICh CF LINES WHERE POINTS SHOULD BE CRCPPEC

IU = ILEN/ISLCE
CG 12C I=1,1L
K = I - 1

12C ICROP(I) = IX2 + K*ISLCE + 1

C
ICIS = 2
IF (MESH .EQ. 1) ICIS = 3
CG 125 I=1,ICIS
K = 1L + 1
125 ICROP(K) = IX3P1 + 3*I
ICRP(K+1) = IX4 + 1

C
GEOMETRY FOR THE DIFFUSER

C
CIS = SQRT((3.*CELY)**2 + CELY**2)
SINE = DELY/CIS
COSINE = 3.*SINE
CISP = CELY/COSINE

C
CC 13C M=1,2
130 DEFX(M) = CELX + M*CISP
CG 135 M=1,3
P = 3 - M + 1
R = P*CELY
CS = R*SINE
135 CFN(M) = 3.*CISP - 2.*CS

C
ESTABLISH INITIAL CONDITIONS

C
140 CG 2CC J=1,JY5
CG 2CC I=2,IX4
XMCX2(I,J) = h(2,1,J)w(2,1,J)/w(1,1,J)
YMOM2(I,J) = h(3,1,J)w(3,1,J)/w(1,1,J)
VSC(I,J) = (XMCX2(I,J) + YMOM2(I,J))/w(1,1,J)
w(5,I,J) = GAM1*(W(4,1,J) - VSC(I,J)*0.5*W(1,1,J))

200 CONTINUE

C
XH = GAM/GAM1*w(5,2,10)/w(1,2,10) + XMCX2(2,10)/w(1,2,10)

C
IF (IX1-.EQ.1) GO TO 450
CG 3CC I=2,IX1
CG 21C J=2,JY1
A(1,I,J) = 1.*C
A(2,I,J) = 0.*C
A(3,I,J) = 0.*C
210 A(4,I,J) = ENERO
IF (I.EQ.2) GO TO 300
IR(I) = MCD(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 3CC

C
AVERAGE VALUES AROUND THE HICLES

INT = 4
260 CC 28C K=1,4
  SIGN = 1.0
  IF (K.EQ.3) SIGN = -1.0
  W(K,I,JY1) = A(K,I,JY1)
  280 W(K,I,JY4) = SIGN*A(K,I,JY1)
C 300 CONTINUE
C 402 IR(2) = 2
C 504 CC 4CC I=2,IX1
CC 4CC J=2,JY1
XPM2A(I,J) = A(2,I,J)*A(2,I,J)/A(I,I,J)
YPM2A(I,J) = A(3,I,J)*A(3,I,J)/A(I,I,J)
VSGA(I,J) = (XPM2A(I,J) + YPM2A(I,J))/A(I,I,J)
  400 A(5,I,J) = PC/CCN2
C 540 RETURN
ENC
APPENDIX E
STEADY-STATE RESULTS
STEADY STATE DENSITY FLOW FIELD

DENSITY AT TIME = 63.79632E-04 DELT = 20.48381E-07 T/D = 34.50427E+00 TRIP NUMBER =2700

10.50E-01 11.03E-01 10.72E-01 10.82E-01 10.63E-01 10.31E-01 10.63E-01 10.82E-01 10.72E-01 11.03E-01 10.50E-01
60.03E-02 62.98E-02 59.26E-02 58.55E-02 58.36E-02 57.94E-02 58.36E-02 58.55E-02 59.26E-02 62.98E-02 60.03E-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 25.12E-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 17.56E-02 18.24E-02 20.41E-02 23.91E-02
20.32E-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 20.32E-02
18.40E-02 15.42E-02 13.77E-02 13.12E-02 12.94E-02 13.05E-02 12.94E-02 13.12E-02 13.77E-02 15.42E-02 18.40E-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 83.75E-03 82.27E-03 82.76E-03 83.75E-03 82.27E-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 78.78E-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 76.79E-03 77.41E-03 80.86E-03 88.53E-03 95.60E-03
### Steady State X-Momentum Flow Field

**X-Momentum at Time = 63,79632E-04**

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>20.3E+01</td>
</tr>
<tr>
<td>10.4E+01</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>88.03E+00</td>
</tr>
<tr>
<td>11.6E+01</td>
</tr>
<tr>
<td>94.59E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>90.64E+00</td>
</tr>
<tr>
<td>15.5E+01</td>
</tr>
<tr>
<td>13.86E+01</td>
</tr>
<tr>
<td>13.11E+01</td>
</tr>
<tr>
<td>12.98E+01</td>
</tr>
<tr>
<td>12.98E+01</td>
</tr>
<tr>
<td>12.98E+01</td>
</tr>
<tr>
<td>12.98E+01</td>
</tr>
<tr>
<td>12.98E+01</td>
</tr>
<tr>
<td>17.7E+01</td>
</tr>
<tr>
<td>16.01E+01</td>
</tr>
<tr>
<td>14.91E+01</td>
</tr>
<tr>
<td>15.00E+01</td>
</tr>
<tr>
<td>14.78E+01</td>
</tr>
<tr>
<td>14.78E+01</td>
</tr>
<tr>
<td>14.78E+01</td>
</tr>
<tr>
<td>14.78E+01</td>
</tr>
<tr>
<td>19.17E+01</td>
</tr>
<tr>
<td>17.23E+01</td>
</tr>
<tr>
<td>15.93E+01</td>
</tr>
<tr>
<td>15.99E+01</td>
</tr>
<tr>
<td>15.72E+01</td>
</tr>
<tr>
<td>15.07E+01</td>
</tr>
<tr>
<td>15.2E+01</td>
</tr>
<tr>
<td>15.99E+01</td>
</tr>
<tr>
<td>15.99E+01</td>
</tr>
<tr>
<td>15.99E+01</td>
</tr>
<tr>
<td>15.99E+01</td>
</tr>
<tr>
<td>15.99E+01</td>
</tr>
<tr>
<td>17.73E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>20.09E+01</td>
</tr>
<tr>
<td>17.98E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>16.58E+01</td>
</tr>
<tr>
<td>20.73E+01</td>
</tr>
<tr>
<td>18.45E+01</td>
</tr>
<tr>
<td>17.01E+01</td>
</tr>
<tr>
<td>16.96E+01</td>
</tr>
<tr>
<td>16.65E+01</td>
</tr>
<tr>
<td>16.96E+01</td>
</tr>
<tr>
<td>16.96E+01</td>
</tr>
<tr>
<td>16.96E+01</td>
</tr>
<tr>
<td>17.01E+01</td>
</tr>
<tr>
<td>18.45E+01</td>
</tr>
<tr>
<td>20.73E+01</td>
</tr>
<tr>
<td>21.18E+01</td>
</tr>
<tr>
<td>18.75E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.21E+01</td>
</tr>
<tr>
<td>16.90E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>16.90E+01</td>
</tr>
<tr>
<td>17.21E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>17.30E+01</td>
</tr>
<tr>
<td>21.51E+01</td>
</tr>
<tr>
<td>18.94E+01</td>
</tr>
<tr>
<td>17.51E+01</td>
</tr>
<tr>
<td>17.38E+01</td>
</tr>
<tr>
<td>17.10E+01</td>
</tr>
<tr>
<td>17.49E+01</td>
</tr>
<tr>
<td>17.10E+01</td>
</tr>
<tr>
<td>17.38E+01</td>
</tr>
<tr>
<td>17.51E+01</td>
</tr>
<tr>
<td>18.94E+01</td>
</tr>
<tr>
<td>21.91E+01</td>
</tr>
<tr>
<td>21.79E+01</td>
</tr>
<tr>
<td>19.00E+01</td>
</tr>
<tr>
<td>17.65E+01</td>
</tr>
<tr>
<td>17.51E+01</td>
</tr>
<tr>
<td>17.27E+01</td>
</tr>
<tr>
<td>17.04E+01</td>
</tr>
<tr>
<td>17.27E+01</td>
</tr>
<tr>
<td>17.51E+01</td>
</tr>
<tr>
<td>17.65E+01</td>
</tr>
<tr>
<td>19.00E+01</td>
</tr>
<tr>
<td>21.79E+01</td>
</tr>
<tr>
<td>21.93E+01</td>
</tr>
<tr>
<td>18.94E+01</td>
</tr>
<tr>
<td>17.92E+01</td>
</tr>
<tr>
<td>17.65E+01</td>
</tr>
<tr>
<td>17.47E+01</td>
</tr>
<tr>
<td>17.81E+01</td>
</tr>
<tr>
<td>17.47E+01</td>
</tr>
<tr>
<td>17.65E+01</td>
</tr>
<tr>
<td>17.82E+01</td>
</tr>
<tr>
<td>18.94E+01</td>
</tr>
<tr>
<td>21.93E+01</td>
</tr>
<tr>
<td>23.11E+01</td>
</tr>
<tr>
<td>18.54E+01</td>
</tr>
<tr>
<td>17.68E+01</td>
</tr>
<tr>
<td>17.67E+01</td>
</tr>
<tr>
<td>17.59E+01</td>
</tr>
<tr>
<td>17.91E+01</td>
</tr>
<tr>
<td>17.59E+01</td>
</tr>
<tr>
<td>17.67E+01</td>
</tr>
<tr>
<td>17.68E+01</td>
</tr>
<tr>
<td>18.54E+01</td>
</tr>
<tr>
<td>23.11E+01</td>
</tr>
<tr>
<td>20.66E+01</td>
</tr>
<tr>
<td>18.95E+01</td>
</tr>
<tr>
<td>18.15E+01</td>
</tr>
<tr>
<td>18.22E+01</td>
</tr>
<tr>
<td>18.18E+01</td>
</tr>
<tr>
<td>18.41E+01</td>
</tr>
<tr>
<td>18.18E+01</td>
</tr>
<tr>
<td>18.22E+01</td>
</tr>
<tr>
<td>18.15E+01</td>
</tr>
<tr>
<td>18.95E+01</td>
</tr>
<tr>
<td>20.66E+01</td>
</tr>
<tr>
<td>21.49E+01</td>
</tr>
<tr>
<td>18.54E+01</td>
</tr>
<tr>
<td>18.12E+01</td>
</tr>
<tr>
<td>18.72E+01</td>
</tr>
<tr>
<td>19.01E+01</td>
</tr>
<tr>
<td>19.30E+01</td>
</tr>
<tr>
<td>19.11E+01</td>
</tr>
<tr>
<td>18.72E+01</td>
</tr>
<tr>
<td>18.12E+01</td>
</tr>
<tr>
<td>18.54E+01</td>
</tr>
<tr>
<td>21.54E+01</td>
</tr>
<tr>
<td>19.86E+01</td>
</tr>
<tr>
<td>19.51E+01</td>
</tr>
<tr>
<td>19.48E+01</td>
</tr>
<tr>
<td>19.63E+01</td>
</tr>
<tr>
<td>19.85E+01</td>
</tr>
<tr>
<td>19.63E+01</td>
</tr>
<tr>
<td>19.48E+01</td>
</tr>
<tr>
<td>19.51E+01</td>
</tr>
<tr>
<td>19.86E+01</td>
</tr>
<tr>
<td>21.54E+01</td>
</tr>
<tr>
<td>21.15E+01</td>
</tr>
<tr>
<td>20.99E+01</td>
</tr>
<tr>
<td>20.99E+01</td>
</tr>
<tr>
<td>21.04E+01</td>
</tr>
<tr>
<td>20.99E+01</td>
</tr>
<tr>
<td>21.15E+01</td>
</tr>
<tr>
<td>21.54E+01</td>
</tr>
<tr>
<td>21.54E+01</td>
</tr>
</tbody>
</table>
## STEADY STATE Y-MOMENTUM FLOW FIELD

Y-MOMENTUM AT TIME = 63.79632E-04 DELT = 20.48381E-07

<table>
<thead>
<tr>
<th>i</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-17.61E+00-51.35E-01-83.08E-01-83.32E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-23.75E+00-35.31E-01-77.43E-01-66.01E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-20.60E+00-26.56E-01-66.11E-01-64.19E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-16.49E+00-17.62E-01-51.69E-01-51.34E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-13.45E+00-10.71E-01-39.03E-01-33.76E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-11.21E+00-56.03E-02-28.97E-01-16.58E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-94.56E-01-15.31E-02-20.74E-01-19.72E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-58.00E-01 23.52E-02 13.38E-01 18.08E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-66.71E-01 70.63E-02 57.76E-02 42.66E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-52.26E-01 13.86E-01 32.65E-02 79.00E-02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-37.13E-01 24.43E-01 19.77E-01 13.66E-01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-86.89E-02 45.33E-01 33.24E-01 22.71E-01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-64.61E-01 11.36E+00 75.32E-01 40.62E-01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>-22.99E-02 38.94E-01 45.99E-01 35.32E-01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>57.71E+00 35.44E+00 20.98E+00 10.33E+00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>65.37E+00 45.63E+00 28.38E+00 13.93E+00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

TVD = 34.50427E+00 TRIP NUMER = 2760
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>76.12E+00</td>
<td>54.45E+00</td>
<td>33.91E+00</td>
<td>16.20E+00</td>
<td>-15.20E+00</td>
</tr>
<tr>
<td>65.75E+00</td>
<td>39.87E+00</td>
<td>18.27E+00</td>
<td>0.00E+00</td>
<td>-18.7E+00</td>
</tr>
<tr>
<td>76.24E+00</td>
<td>44.97E+00</td>
<td>19.83E+00</td>
<td>0.00E+00</td>
<td>-19.3E+00</td>
</tr>
<tr>
<td>57.61E+00</td>
<td>36.39E+00</td>
<td>16.02E+00</td>
<td>0.00E+00</td>
<td>-16.0E+00</td>
</tr>
<tr>
<td>-61.20E+00</td>
<td>38.26E+00</td>
<td>33.47E+00</td>
<td>0.00E+00</td>
<td>-33.5E+00</td>
</tr>
<tr>
<td>-56.12E+00</td>
<td>-27.45E+00</td>
<td>11.47E+00</td>
<td>0.00E+00</td>
<td>11.5E+00</td>
</tr>
<tr>
<td>-57.49E+00</td>
<td>-40.28E+00</td>
<td>-20.71E+00</td>
<td>0.00E+00</td>
<td>20.7E+00</td>
</tr>
<tr>
<td>-10.00E+00</td>
<td>-38.44E+00</td>
<td>-40.29E+00</td>
<td>22.19E+00</td>
<td>22.2E+00</td>
</tr>
<tr>
<td>-10.00E+00</td>
<td>-38.44E+00</td>
<td>-40.29E+00</td>
<td>22.19E+00</td>
<td>22.2E+00</td>
</tr>
</tbody>
</table>
STEADY STATE ENERGY FLOW FIELD

ENERGY AT TIME = 63.79632E-04   DELT = 20.9838E-07   TVD = 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 34.03E+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 33.10E+04 33.28E+04 33.10E+04 33.04E+04 33.28E+04 33.46E+04 32.84E+04
32.41E+04 32.99E+04 32.59E+04 32.63E+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 31.86E+04 31.73E+04 31.45E+04 31.73E+04 31.86E+04 31.69E+04 32.03E+04 31.55E+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 30.32E+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
29.51E+04 28.87E+04 28.51E+04 28.18E+04 28.11E+04 28.18E+04 28.11E+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 27.64E+04 27.82E+04 28.01E+04 28.11E+04
APPENDIX F
REFERENCES


## APPENDIX G
### DISTRIBUTION LIST

<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NASA Headquarters, Washington, D. C. 20546</td>
<td>(X)</td>
</tr>
<tr>
<td>1</td>
<td>Contracting Officer, BCA</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Patent Office, AGP</td>
<td>(X)</td>
</tr>
</tbody>
</table>

| 1      | NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, Ohio 44135 | (X) |
| 1      | Office of Technical Information                      | |
| 1      | Contracting Officer                                 | (X) |
| 1      | Patent Office                                      | (X) |

| 2      | NASA Marshall Space Flight Center, Huntsville, Alabama 35812 | ( ) |
| 1      | Office of Technical Information, MS-IP              | |
| 1      | Technical Library                                   | ( ) |
| 1      | Purchasing Office, PR-EC                            | ( ) |
| 1      | Patent Office, M-PAT                                | ( ) |
| 1      | Keith Chandler, R-P&E-V-PA                           | ( ) |
| 1      | Technology Utilization Office, MS-T                  | ( ) |

| 1      | NASA Pasadena Office, 4800 Oak Grove Drive, Pasadena, California 91103 | ( ) |
| 1      | Patents and Contracts Management                     | |

| 1      | Western Support Office, 150 Pico Boulevard, Santa Monica, California 90406 | ( ) |
| 1      | Office of Technical Information                      | |

| 1      | Technical Monitor, Marshall Burrows, Lewis Research Center, 21000 Brookpark Road, Cleveland, Ohio 44135 | (X) |

| 4      | Chief, Liquid Propulsion Technology, RPL              | (X) |
| 4      | Office of Advanced Research and Technology           | |
| 1      | NASA Scientific and Technical Information Facility   | (X) |
| 25     | NASA Scientific and Technical Information Facility   | |
| 1      | Mr. Vincent L. Johnson                                | (X) |
| 1      | Director, Launch Vehicles and Propulsion, SV         | |
| 1      | NASA Headquarters, Washington, D. C. 20546            | |

G-1
<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
</table>
| 1      | Mr. Edward Z. Gray  
Director, Advanced Manned Missions, MT  
Office of Manned Space Flight  
NASA Headquarters, Washington, D. C. 20546 | (X) |
| 1      | Leonard Roberts  
Mission Analysis Division  
NASA Ames Research Center  
Moffett Field, California 24035 | (X) |

**NASA FIELD CENTERS**

<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
</table>
| 2      | Ames Research Center  
Moffett Field, California 94035 | H. J. Allen  
Mission Analysis Division |
| 2      | Goddard Space Flight Center  
Greenbelt, Maryland 20771 | Merland L. Moseson  
Code 620 |
| 2      | Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive  
Pasadena, California 91103 | Henry Burlage, Jr.  
Propulsion Div., 38 |
| 2      | Langley Research Center  
Langley Station  
Hampton, Virginia 23365 | Dr. Floyd L. Thompson  
Director |
| 2      | Lewis Research Center  
21000 Brookpark Road  
Cleveland, Ohio 44135 | Dr. Abe Silverstein  
Director |
| 2      | Marshall Space Flight Center  
Huntsville, Alabama 35812 | Hans G. Paul  
Code R-P&VED |
| 2      | Manned Spacecraft Center  
Houston, Texas 77001 | Dr. Robert R. Gilruth  
Director |
| 2      | Western Operations Office  
150 Pico Boulevard  
Santa Monica, California 90406 | Robert W. Kamm  
Director |
| 2      | John F. Kennedy Space Center, NASA  
Cocoa Beach, Florida 32931 | Dr. Kurt H. Debus |

**GOVERNMENT INSTALLATIONS**

<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
</table>
| 1      | Aeronautical Systems Division  
Air Force Systems Command  
Wright-Patterson Air Force Base  
Dayton, Ohio 45433 | D. L. Schmidt  
Code ASRCNC-2 |
<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Commander</td>
<td>L. J. Ullian</td>
</tr>
<tr>
<td></td>
<td>Office of Research Analyses (OAR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attn: RRRD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Holloman Air Force Base, New Mexico 88330</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Air Force Missile Test Center</td>
<td>Colonel Clark</td>
</tr>
<tr>
<td></td>
<td>Patrick Air Force Base, Florida</td>
<td>Technical Data Center</td>
</tr>
<tr>
<td>1</td>
<td>Air Force Systems Division</td>
<td>Dr. H.K. Doetsch</td>
</tr>
<tr>
<td></td>
<td>Air Force Unit Post Office</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Los Angeles 45, California</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Arnold Engineering Development Center</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arnold Air Force Station</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tullahoma, Tennessee</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Bureau of Naval Weapons</td>
<td>J. Kay</td>
</tr>
<tr>
<td></td>
<td>Department of the Navy</td>
<td>RTMS-41</td>
</tr>
<tr>
<td></td>
<td>Washington, D. C.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Defense Documentation Center Headquarters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cameron Station, Building 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5010 Duke Street</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alexandria, Virginia 22314</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attn: TISIA</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Headquarters, U. S. Air Force</td>
<td>Col. C.K. Stambaugh</td>
</tr>
<tr>
<td></td>
<td>Washington 25, D. C.</td>
<td>AFRST</td>
</tr>
<tr>
<td>1</td>
<td>Picatinny Arsenal</td>
<td>I. Forsten, Chief</td>
</tr>
<tr>
<td></td>
<td>Dover, New Jersey 07801</td>
<td>Liquid Propulsion Laboratory, SMUPA-DL</td>
</tr>
<tr>
<td>1</td>
<td>Air Force Rocket Propulsion Laboratory</td>
<td>RPF, Mr. H. Main</td>
</tr>
<tr>
<td></td>
<td>Research and Technology Division</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Force Systems Command</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Edwards, California 93523</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Union Carbide Corporation</td>
<td>A. P. Huber</td>
</tr>
<tr>
<td></td>
<td>Nuclear Division</td>
<td>Oak Ridge</td>
</tr>
<tr>
<td></td>
<td>ORGDP Records Department</td>
<td>Gaseous Diffusion Plant</td>
</tr>
<tr>
<td></td>
<td>P. O. Box P</td>
<td>(ORGDP) P.O. Box P</td>
</tr>
<tr>
<td></td>
<td>Oak Ridge, Tennessee 37830</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>U. S. Army Missile Command</td>
<td>Dr. Walter Wharton</td>
</tr>
<tr>
<td></td>
<td>Redstone Arsenal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alabama 35809</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>U. S. Naval Ordnance Test Station</td>
<td>Code 4562</td>
</tr>
<tr>
<td></td>
<td>China Lake</td>
<td>Chief, Missile</td>
</tr>
<tr>
<td></td>
<td>California 93557</td>
<td>Propulsion Div.</td>
</tr>
</tbody>
</table>
**CPIA**

<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chemical Propulsion Information Agency Applied Physics Laboratory 8621 Georgia Avenue Silver Spring, Maryland 20910</td>
<td>Neil Safeer</td>
</tr>
</tbody>
</table>

**INDUSTRY CONTRACTORS**

<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aerojet-General Corporation P. O. Box 296 Azusa, California 91703</td>
<td>L. F. Kohrs</td>
</tr>
<tr>
<td>1</td>
<td>Aerojet-General Corporation P. O. Box 1947 Technical Library, Bldg. 215, Dept. 2410 Sacramento, California 95809</td>
<td>R. Stiff</td>
</tr>
<tr>
<td>1</td>
<td>Aeronutronic Philco Corporation Ford Road Newport Beach, California 92663</td>
<td>Librarian</td>
</tr>
<tr>
<td>1</td>
<td>Aerospace Corporation 2400 East El Segundo Boulevard P. O. Box 95085 Los Angeles, California 90045</td>
<td>John G. Wilder MS-2293 Propulsion Dept.</td>
</tr>
<tr>
<td>1</td>
<td>Arthur D. Little, Inc. 20 Acorn Park Cambridge, Massachusetts 02140</td>
<td>E. Karl Bastress</td>
</tr>
<tr>
<td>1</td>
<td>Astropower Laboratory Douglas Aircraft Company 2121 Paularino Newport Beach, California 92663</td>
<td>Dr. George Moc Director, Research</td>
</tr>
<tr>
<td>1</td>
<td>Astrosystems International, Inc. 1275 Bloomfield Avenue Fairfield, New Jersey 07007</td>
<td>A. Mendenhall</td>
</tr>
<tr>
<td>1</td>
<td>Atlantic Research Corporation Edsall Road and Shirley Highway Alexandria, Virginia 22314</td>
<td>A. Scurlock</td>
</tr>
<tr>
<td>1</td>
<td>Beech Aircraft Corporation Boulder Division Box 631 Boulder, Colorado</td>
<td>J. H. Rodgers</td>
</tr>
<tr>
<td>1</td>
<td>Bell Aerosystems Company P. O. Box 1 Buffalo, New York 14240</td>
<td>W. M. Smith</td>
</tr>
<tr>
<td>COPIES</td>
<td>RECIPIENT</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-----------</td>
<td></td>
</tr>
</tbody>
</table>
| 1      | Bendix Systems Division  
Bendix Corporation  
3300 Plymouth Road  
Ann Arbor, Michigan |
| 1      | Boeing Company  
P. O. Box 3707  
Seattle, Washington 98124 |
| 1      | Missile Division  
Chrysler Corporation  
P. O. Box 2628  
Detroit, Michigan 48231 |
| 1      | Wright Aeronautical Division  
Curtiss-Wright Corporation  
Wood-Ridge, New Jersey 07075 |
| 1      | Missile and Space Systems Division  
Douglas Aircraft Company, Inc.  
3000 Ocean Park Boulevard  
Santa Monica, California 90406 |
| 1      | Aircraft Missiles Division  
Fairchild Hiller Corporation  
Hagerstown, Maryland 10 |
| 1      | General Dynamics/Astronautics  
Library & Information Services (128-00)  
P. O. Box 1128  
San Diego, California 92112 |
| 1      | Re-Entry Systems Department  
General Electric Company  
3198 Chestnut Street  
Philadelphia, Pennsylvania 19101 |
| 1      | Advanced Engine & Technology Dept.  
General Electric Company  
Cincinnati, Ohio 45215 |
| 1      | Grumman Aircraft Engineering Corporation  
Bethpage, Long Island  
New York |
| 1      | Ling-Temco-Vought Corporation  
Astronautics  
P. O. Box 5907  
Dallas, Texas 75222 |
| 1      | Lockheed California Company  
2555 North Hollywood Way  
Burbank, California 91503 |

**DESIGNEE**

- John M. Brueger
- J. D. Alexander
- John Gates
- G. Kelley
- R. W. Hallet
- J. S. Kerr
- Frank Dore
- F. E. Schultz
- D. Suichu
- Joseph Gavin
- Warren C. Trent
- G. D. Brewer
<table>
<thead>
<tr>
<th>COPIES</th>
<th>RECIPIENT</th>
<th>DESIGNEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lockheed Missiles and Space Co.</td>
<td>Y. C. Lee</td>
</tr>
<tr>
<td></td>
<td>Attn: Technical Information Center</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P. O. Box 504</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sunnyvale, California 94088</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lockheed Propulsion Company</td>
<td>H. L. Thackwell</td>
</tr>
<tr>
<td></td>
<td>P. O. Box 111</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Redlands, California 92374</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>The Marquardt Corporation</td>
<td>Warren P. Boardman, Jr.</td>
</tr>
<tr>
<td></td>
<td>16555 Saticoy Street</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Van Nuys, California 91409</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Baltimore Division</td>
<td>John Calathes (3214)</td>
</tr>
<tr>
<td></td>
<td>Martin Marietta Corporation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baltimore, Maryland 21203</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Denver Division</td>
<td>J. D. Goodlette (A-241)</td>
</tr>
<tr>
<td></td>
<td>Martin Marietta Corporation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P. O. Box 179</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Denver, Colorado 80201</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>McDonnell Aircraft Corporation</td>
<td>R. A. Herzmark</td>
</tr>
<tr>
<td></td>
<td>P. O. Box 516</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Municipal Airport</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Louis, Missouri 63166</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Space &amp; Information Systems Division</td>
<td>H. Storms</td>
</tr>
<tr>
<td></td>
<td>North American Aviation, Inc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12214 Lakewood Boulevard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Downey, California 90241</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Rocketdyne (Library 586-306)</td>
<td>E. B. Monteath</td>
</tr>
<tr>
<td></td>
<td>North American Aviation, Inc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6633 Canoga Avenue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canoga Park, California 91304</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Northrop Space Laboratories</td>
<td>Dr. William Howard</td>
</tr>
<tr>
<td></td>
<td>3401 West Broadway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hawthorne, California</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Astro-Electronics Division</td>
<td>S. Fairweather</td>
</tr>
<tr>
<td></td>
<td>Radio Corporation of America</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Princeton, New Jersey 08540</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Reaction Motors Division</td>
<td>Arthur Sherman</td>
</tr>
<tr>
<td></td>
<td>Thiokol Chemical Corporation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Denville, New Jersey 07832</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Republic Aviation Corporation</td>
<td>Dr. William O'Donnell</td>
</tr>
<tr>
<td></td>
<td>Farmingdale Long Island, New York</td>
<td></td>
</tr>
<tr>
<td>COPIES</td>
<td>RECIPIENT</td>
<td>DESIGNEE</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
</tbody>
</table>
| 1      | Space General Corporation  
9200 East Flair Avenue  
El Monte, California  91734 | C. E. Roth                    |
| 1      | Stanford Research Institute  
333 Ravenswood Avenue  
Menlo Park, California  94025 | Lionel Dickinson              |
| 1      | TRW Systems Group  
TRW Incorporated  
One Space Park  
Redondo Beach, California  90278 | G. W. Elverum                 |
| 1      | TAPCO Division  
TRW, Incorporated  
23555 Euclid Avenue  
Cleveland, Ohio  44117 | P. T. Angell                  |
| 1      | Thiokol Chemical Corporation  
Huntsville Division  
Huntsville, Alabama | John Goodloe                  |
| 1      | Research Laboratories  
United Aircraft Corporation  
400 Main Street  
East Hartford, Connecticut  06108 | Erle Martin                   |
| 1      | United Technology Center  
587 Methilda Avenue  
P. O. Box 358  
Sunnyvale, California  94088 | B. Adelman                    |
| 1      | Aerospace Operations  
Walter Kidde and Company, Inc.  
567 Main Street  
Belleville, New Jersey  07109 | R. J. Hanville  
Director of Research Engineering |
| 1      | Florida Research and Development  
Pratt and Whitney Aircraft  
United Aircraft Corporation  
P. O. Box 2691  
West Palm Beach, Florida  33402 | R. J. Coar                    |
| 1      | Rocket Research Corporation  
520 South Portland Street  
Seattle, Washington  98108 | Foy McCullough, Jr.            |