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**A COMPUTER PROGRAM TO CALCULATE  
RADIATING VISCOUS STAGNATION  
STREAMLINE FLOW WITH STRONG BLOWING**

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A COMPUTER PROGRAM TO CALCULATE  
RADIATING VISCOUS STAGNATION STREAMLINE  
FLOW WITH STRONG BLOWING

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SUMMARY

A computer program (program LEE) has been developed to calculate the fully coupled solution of the radiating viscous stagnation streamline flow with strong blowing. Program LEE was developed for the study reported in NASA TR R-388. The present report describes the digital computer program, including FORTRAN IV listing, flow charts, instructions for the user, and a test case with input and output. Program LEE is available through COSMIC.

INTRODUCTION

An implicit finite difference solution to the viscous shock-layer stagnation streamline flow with radiation and strong blowing is presented in references 1 and 2. Program LEE (Langley computer program A3899) was developed to make the calculations reported in references 1 and 2. A detailed radiative transport code (RATRAP) that accounts for the important radiative exchange processes for gaseous mixtures is used (ref. 3). Chemical equilibrium of the flow is assumed, and the equilibrium composition of the air-injection products mixture is computed by a free-energy minimization routine (FEMP) within RATRAP.

The program may be used for the stagnation streamline of a two-dimensional body, an axisymmetric body, or a three-dimensional body with two orthogonal planes of symmetry. The difference between these cases is mainly in the continuity equation. For the three-dimensional case, there are two components of velocity around the body to consider, but the momentum equation is the same for both components.

A description of the computer program is presented in this paper. Included are program listing, flow charts, instructions for the user, and a test case with input and output listings. Copies of the program LEE computer deck are available through COSMIC (Computer Software Management and Information Center at Barrow Hall, University of Georgia, Athens, Georgia).

## SYMBOLS

|             |   |
|-------------|---|
| a           | tangential velocity gradient, $\frac{\partial u}{\partial x}$                               |
| b           | tangential velocity gradient, $\frac{\partial w}{\partial z}$                               |
| $c_p$       | specific heat at constant pressure  |
| $D_{12}$    | binary diffusion coefficient  |
| H           | specific total enthalpy   |
| h           | specific static enthalpy  |
| I           | index for nodal point   |
| K           | body curvature  |
| $K_z$       | body curvature in z-direction for nonaxisymmetric body                                      |
| k           | thermal conductivity  |
| N           | number of node points in finite difference solution   |
| $N_{Pr}$    | Prandtl number  |
| $N_{Re}$    | Reynolds number   |
| p           | static pressure   |
| $p'_\infty$ | free-stream static pressure, dynes/cm <sup>2</sup> (where 1 dyne = 10 <sup>-5</sup> newton) |
| $q_{R,y}$   | net radiative heat flux in y-direction  |
| $R'_b$      | radius of body, cm  |

- r radius measured from axis of symmetry of body (see fig. 1)
- $U_\infty$  free-stream velocity, cm/sec
- u component of velocity parallel to surface in x-direction
- v component of velocity normal to surface
- w component of velocity parallel to surface in z-direction
- x distance measured along body surface (see fig. 1)
- y distance measured normal to body surface (see fig. 1)
- z distance measured along body surface in plane normal to plane in which x is measured
- $a_i$  mass fraction of ith chemical species
- $\bar{a}_F$  mass fraction of foreign or ablation products
- $\beta = -\left(\frac{\partial^2 p}{\partial x^2}\right)_{x=0}$
- $\beta_z = -\left(\frac{\partial^2 p}{\partial z^2}\right)_{z=0}$
- $\delta$  transformed shock-layer thickness,  $\int_0^{y_S} \rho(y) dy$
- $\epsilon$  error criterion for density
- $\eta$  transformed coordinate normal to body surface (see fig. 2),  $\frac{1}{\delta} \int_0^y \rho(y) dy$
- $\kappa$  scale factor,  $1 + Ky$

$\kappa_i$  dummy scale factor

$\kappa_z$  scale factor for curvature in z-direction,  $1 + K_z y$

$\mu$  viscosity

$\rho$  density

Subscripts:

C carbon

H hydrogen

N nitrogen

O oxygen

n nth nodal point;  $n = 1$  at the body ( $\eta = 0$ ) and  $n = N$  at the shock ( $\eta = 1$ )

s shock

$\infty$  free-stream conditions

Superscript:

i ith iteration

Unprimed symbols are nondimensional. All dimensional symbols are primed.



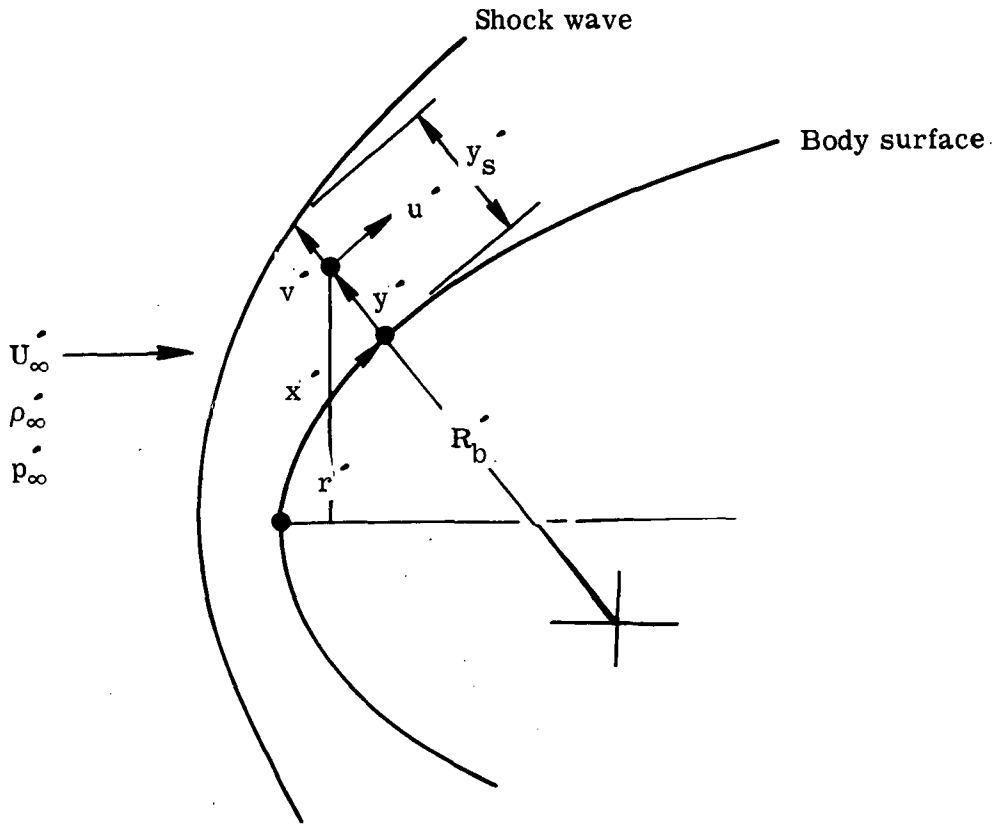


Figure 1. - Flow-field coordinate system.

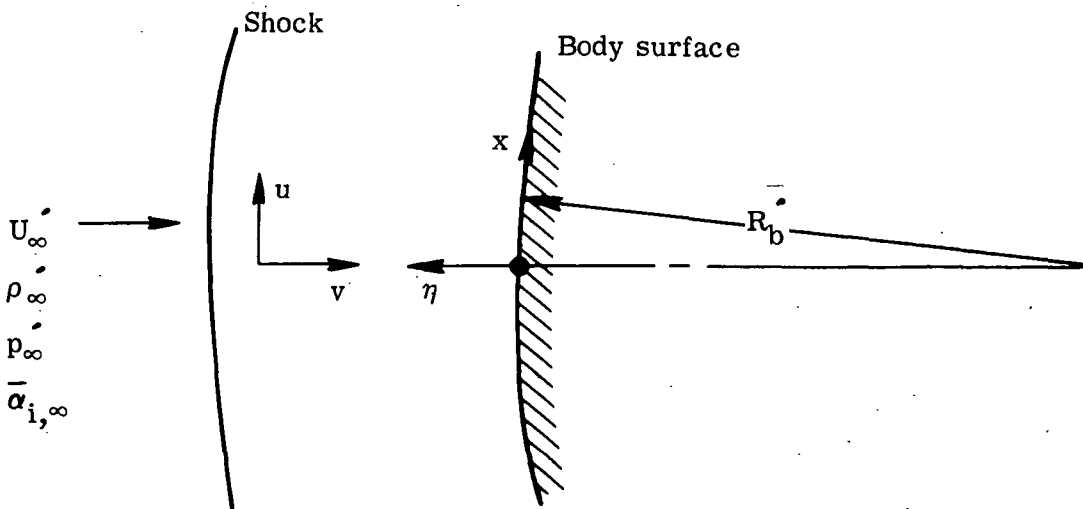


Figure 2. - Flow-field coordinate system in the transformed coordinates.

## PROBLEM DESCRIPTION

The equations which govern radiating viscous flow along the stagnation streamline of a blunt body in nondimensional form are as follows (ref. 1 or 2):

Continuity:

$$\frac{d}{dy} (\kappa \rho v) = -\kappa \rho a \quad \text{(Two dimensional)} \quad (1a)$$

$$\frac{d(\kappa^2 \rho v)}{dy} = -2 \kappa \rho a \quad \text{(Axisymmetric)} \quad (1b)$$

$$\frac{d(\kappa \kappa_z \rho v)}{dy} = -\kappa \rho a - \kappa_z \rho b \quad \text{(Three dimensional)} \quad (1c)$$

x-momentum:

$$-\frac{\kappa}{N_{Re}} \frac{d}{dy} \left( \mu \frac{da}{dy} \right) + \kappa \rho v \frac{da}{dy} + \rho a^2 + K \rho a v = \beta \quad (2a)$$

z-momentum:

$$-\frac{\kappa_z}{N_{Re}} \frac{d}{dy} \left( \mu \frac{db}{dy} \right) + \kappa_z \rho v \frac{db}{dy} + \rho b^2 + K_z \rho b v = \beta_z \quad (2b)$$

y-momentum:

$$\rho v \frac{dv}{dy} = -\frac{dp}{dy} \quad (3)$$

Energy:

$$\frac{1}{N_{Re}} \frac{d}{dy} \left( \frac{\kappa \kappa_i \mu}{N_{Pr}} \frac{dH}{dy} \right) - \kappa \kappa_i \rho v \frac{dH}{dy} = \frac{1}{N_{Re}} \frac{d}{dy} \left( \frac{\kappa \kappa_i}{N_{Pr}} v \frac{dv}{dy} \right) + \frac{d}{dy} \left( \kappa \kappa_i q_{R,y} \right) \quad (4)$$

Diffusion:

$$\frac{d}{dy} \left( \kappa \kappa_i \rho D_{12} \frac{d\bar{a}_F}{dy} \right) - \kappa \kappa_i \rho v \frac{d\bar{a}_F}{dy} = 0 \quad (5)$$

These equations are written in the coordinate system shown in figure 1. In these equations,  $\kappa_i = 1$  for the two-dimensional case,  $\kappa_i = \kappa$  for the axisymmetric case, and  $\kappa_i = \kappa_z$  for the three-dimensional case.

For the case of a three-dimensional body with two orthogonal planes of symmetry  $x$  is the distance from the stagnation point around the body in one plane of symmetry and  $z$  is the distance measured in the other plane of symmetry. There are two corresponding orthogonal components of velocity  $u$  and  $w$  parallel to the body surface. The stagnation streamline equations, which are the limit forms of the fluid-flow equations, involve the terms  $a = \frac{\partial u}{\partial x}$  and  $b = \frac{\partial w}{\partial z}$ . For two-dimensional flow,  $b$  and  $z$ -curvature vanish. For axisymmetric flow,  $b$  is identical with  $a$ . The quantities have been nondimensionalized as follows (where primes denote dimensional quantities):

$$\left. \begin{aligned} x, y, r &= \frac{x', y', r'}{R'_b} & u, v, w &= \frac{u', v', w'}{U'_\infty} \\ K &= K'R'_b & p &= \frac{p'}{p'_\infty} & p &= \frac{p'}{p'_\infty (U'_\infty)^2} \\ h, H &= \frac{h', H'}{(U'_\infty)^2} & q_{R, y} &= \frac{q'_{R, y}}{p'_\infty (U'_\infty)^3} & k &= \frac{k'}{k'_s} \\ D_{12} &= \frac{D'_{12}}{U'_\infty R'_b} & \mu &= \frac{\mu'}{\mu'_s} & a &= \frac{R'_b}{U'_\infty} \frac{\partial u'}{\partial x'} \\ N_{Re} &= \frac{p'_\infty U'_\infty R'_b}{\mu'_s} & N_{Pr} &= \frac{c'_p \mu'}{k'} & b &= \frac{R'_b}{U'_\infty} \frac{\partial w'}{\partial z'} \end{aligned} \right\} \quad (6)$$

The symbol  $R'_b$  which is used for nondimensionalization is not restricted to being the nose radius of curvature. For example, for a flat disk,  $R'_b$  can be the disk radius. The following restrictions are made on the problem:

- (1) The gas is in local thermodynamic and chemical equilibrium.
- (2) Diffusion is governed by a binary diffusion model.
- (3) Radiative energy transport occurs within a one-dimensional, infinite, planar slab (tangent-slab approximation).
- (4) The gas density must be high enough that the shock wave is thin relative to the shock layer.

The transform variable

$$\eta = \frac{1}{\hat{\delta}} \int_0^y \rho(y) dy \quad (7)$$

is defined where

$$\hat{\delta} = \int_0^{y_s} \rho(y) dy \quad (8)$$

It is seen that this transformation is defined such that the shock wave is fixed at  $\eta = 1$ . The transformation of equation (7) is applied to equations (1) to (5) so that they can be written, respectively, as follows:

Continuity:

$$\frac{d(\kappa \rho v)}{d\eta} = \hat{\delta} \kappa a \quad (\text{Two dimensional}) \quad (9a)$$

$$\frac{d(\kappa^2 \rho v)}{d\eta} = 2 \hat{\delta} \kappa a \quad (\text{Axisymmetric}) \quad (9b)$$

$$\frac{d(\kappa \kappa_z \rho v)}{d\eta} = \hat{\delta} \kappa a = \hat{\delta} \kappa_z b \quad (\text{Three dimensional}) \quad (9c)$$

x-momentum:

$$\frac{\kappa \rho}{N_{\text{Re}} \hat{\delta}^2} \frac{d}{d\eta} \left( \mu \rho \frac{da}{d\eta} \right) + \frac{\kappa \rho^2 v}{\hat{\delta}} \frac{da}{d\eta} - \rho a^2 + K \rho a v = -\beta \quad (10a)$$

z-momentum:

$$\frac{\kappa_z \rho^i}{N_{Re} \delta^2} \frac{d}{d\eta} \left( \mu \frac{db}{d\eta} \right) + \frac{\kappa_z \rho^{2v}}{\delta} \frac{db}{d\eta} - \rho b^2 + K_z \rho b v = -\beta_z \quad (10b)$$

y-momentum:

$$\frac{dp}{d\eta} = -\rho v \frac{dv}{d\eta} \quad (11)$$

Energy:

$$\begin{aligned} \frac{d}{d\eta} \frac{\kappa_i \rho^\mu}{N_{Pr}} \frac{dH}{d\eta} + \delta N_{Re} \kappa_i \rho^v \frac{dH}{d\eta} = \\ = \frac{d}{d\eta} \left( \frac{\kappa_i \mu}{N_{Pr}} \rho v \frac{dv}{d\eta} \right) + \delta N_{Re} \frac{d}{d\eta} \left( \kappa_i q_{R,\eta} \right) \end{aligned} \quad (12)$$

Diffusion:

$$\frac{d}{d\eta} \left( \kappa_i \rho^{2D_{12}} \frac{d\bar{a}_F}{d\eta} \right) + \delta \kappa_i \rho^v \frac{d\bar{a}_F}{d\eta} = 0 \quad (13)$$

The user is cautioned that the normal velocity  $v$  has been redefined as negative in the positive  $y$ - or  $\eta$ -direction in the aforementioned equations. The purpose of this sign change is to make  $v$  positive across the shock layer, except within the layer of injected products. The flow-field coordinate system is shown in figure 2. The boundary condition at the wall for the diffusion equation has been generalized from that used in references 1 and 2 for strong blowing and is

$$D_{12} \frac{d\bar{a}_F}{dy} + v \bar{a}_F = v \quad (\eta = 0)$$

This boundary condition is appropriate also for moderate blowing rates.

Equations (10), (12), and (13) are written in finite difference form by using a central-difference formula for second derivatives and windward differencing for first derivatives in convective terms. Equations (9) and (11) are integrated for  $(\kappa \kappa_1 \rho v)$  and  $p$ , respectively, subject to boundary conditions at the shock wave. Up to 100 node points may be used for the solution. These node points are evenly spaced in  $\eta$ .

## PROGRAM ORGANIZATION

The governing equations (9) to (13) are solved by an iterative scheme as shown in figure 3 and are discussed in reference 2. This section of the report describes subprograms used to carry out the computation. A flow chart of each subprogram is included except where computation is straightforward. A full listing of program LEE is given in appendix A. The input is described in appendix B, and the output is described in appendix C. Langley library subroutines which are used are described in appendixes D, E, and F. A list of each subprogram and its description is given as follows:

| <u>Subprogram</u> | <u>Description</u>   |
|-------------------|--|
| LEE               | Initializes program, iterates density and flow equations, and prints results |
| GETREDY           | Reads spectral data input for RATRAP   |
| INITIAL           | Initializes flow variables   |
| RANHUG            | Solves Rankine-Hugoniot relations for post-shock conditions                  |
| FOFXRO            | Function used by RANHUG  |
| UPDATE            | Option of input for initial profiles   |
| FLOW              | Iterates flow equations to solution  |
| CHEXRO            | Computes density, compares with previous value                               |
| MASS              | Solves continuity equation for $v$   |
| Y MOMNTM          | Solves y-momentum equation for $p$   |
| SPECIES           | Solves diffusion equation for $\bar{a}_F$ and elemental mass fractions       |

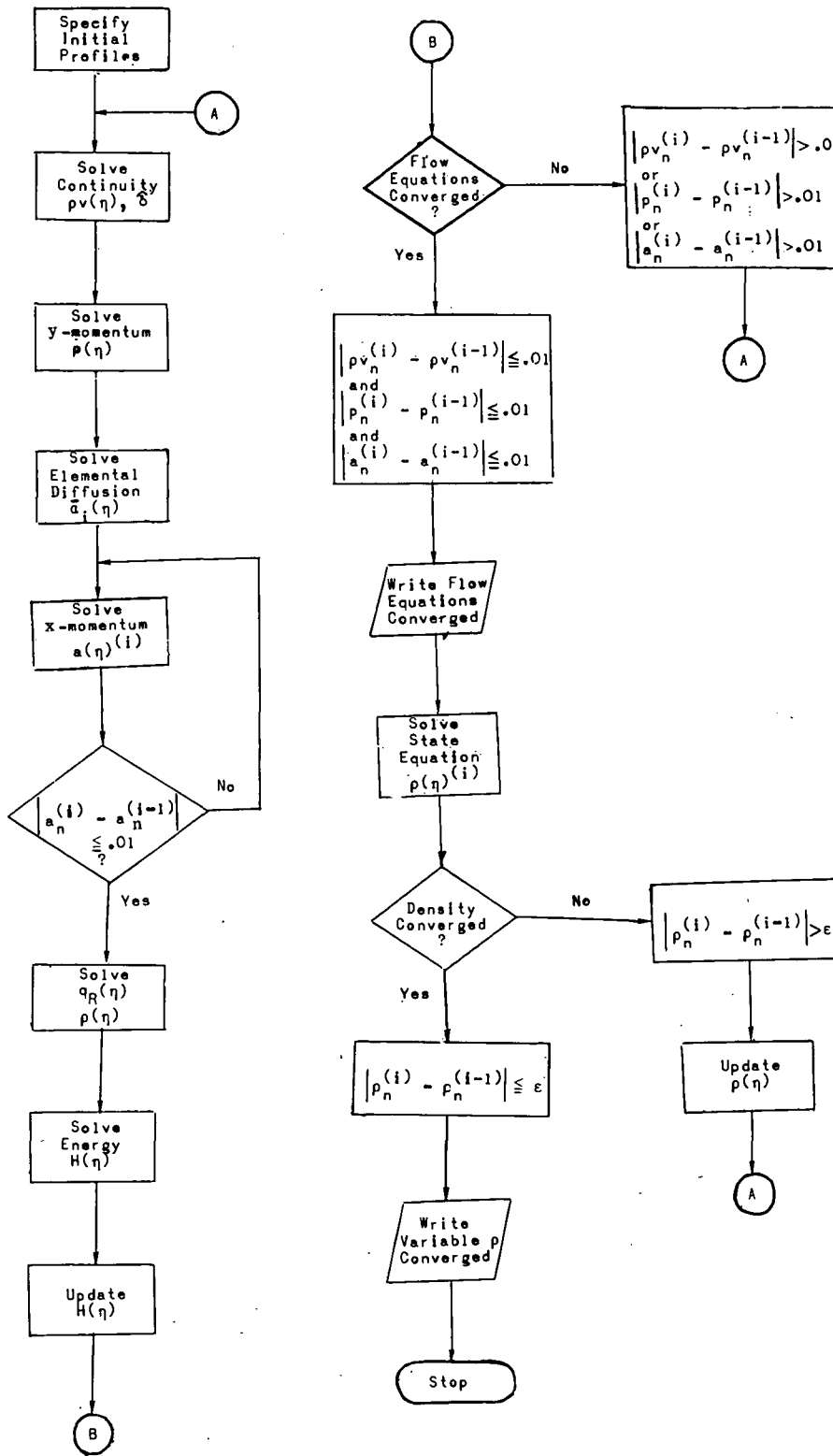


Figure 3. - Flow chart of the overall solution procedure.

| <u>Subprogram</u> | <u>Description</u>   |
|-------------------|--|
| X MOMNTM          | Solves x-momentum equation for a and, if necessary, for b  |
| ENERGY            | Solves energy equation for h and H   |
| RADARAY           | Calls RATRAP for radiation heat flux at NIC points and linearly interpolates for remainder of N points; also updates density |
| REFTEMP           | Computes post-shock temperature  |
| D2DP2             | Computes $\beta = - \frac{\partial^2 p}{\partial x^2}$   |
| DIMPROP           | Computes dimensional p' and h', given nondimensional p and h   |
| RHOSY             | Equation of state, $\rho(p, h, a_i)$   |
| DIFCOEF           | Computes binary diffusion coefficient  |
| VISPRAN           | Computes Prandtl number and nondimensional viscosity profiles, given p and h profiles  |
| VISCOS            | Computes dimensional viscosity using tables of reference 4   |
| PRANDTL           | Computes Prandtl number using tables of reference 4  |
| DIFT              | Given a profile $y_i(x_i)$ , computes profile $\frac{dy}{dx}(x_i)$   |
| TINT              | Given a profile $y_i(x_i)$ , computes profile $\int_0^{x_i} y(\xi) d\xi$ , where $\xi$ is a dummy variable                   |
| TRIDIAG           | Solves $Ax = D$ by Potter's method where A is a tridiagonal matrix and x and D are vectors                                   |



SubprogramDescription

|        |  |
|--------|--|
| SET    | Sets one array equal to another  |
| ITEST  | Computes number of C(I) differing from B(I), where C and B are arrays, by amount exceeding a specified E |
| RATRAP | Radiation transport code (ref. 3)  |

The radiation transport code RATRAP, developed by K. H. Wilson (ref. 3), is used as a subroutine. It uses a number of subprograms which are listed as part of appendix A; these are all described in reference 3. Included among these is a free-energy minimization program (FEMP) which solves for the mass fractions of the individual species. The many spectral data required for RATRAP are read in by GETREDY at the beginning of the computations. Radiative flux is computed at each of a desired number N of evenly spaced points. The N is input in NAMELIST NAM4.

Langley library subroutines of the SCOPE 3.0 operating system which are used in the LEE program are ITR1, FTLUP, and DISCOT. These are described in appendixes D, E, and F, respectively.

In some of the flow charts, the operations "damp and clip" appear. "Damp" refers to computing a value for a given variable by weighting the value most recently computed with its value from the previous iteration, for each nodal point. For example, the value computed for density would be

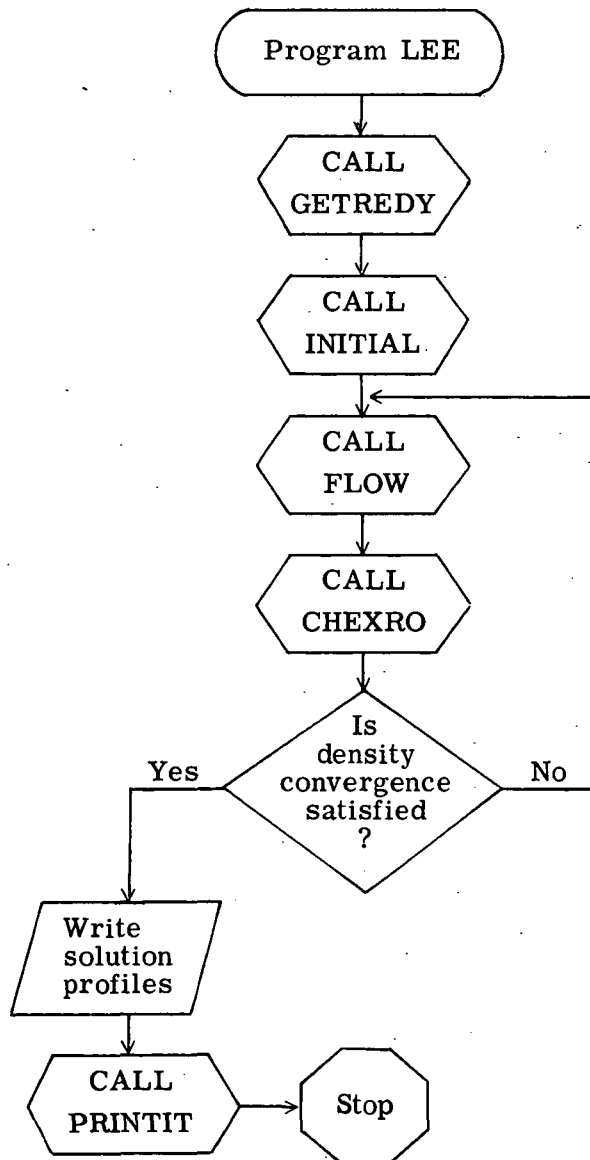
$$\rho_n = d_\rho \rho_n^{(i-1)} + (1 - d_\rho) \rho_n^{(i)}$$

where  $d_\rho$  is the damping factor for density. The purpose of damping is to suppress numerical oscillations from one iteration to the next, and thereby improve convergence. The selection of  $d_\rho$  is discussed in references 1 and 2. "Clip" refers to the requirement that a profile not go below or above some value. For example, an intermediate iteration may give an excessive radiation divergence term, thus causing an unrealistic dip in the enthalpy profile. This condition is alleviated by requiring that H(I) be at least as large as the wall value. When this adjustment is required, a message is printed.

## PRIMARY SUBPROGRAMS

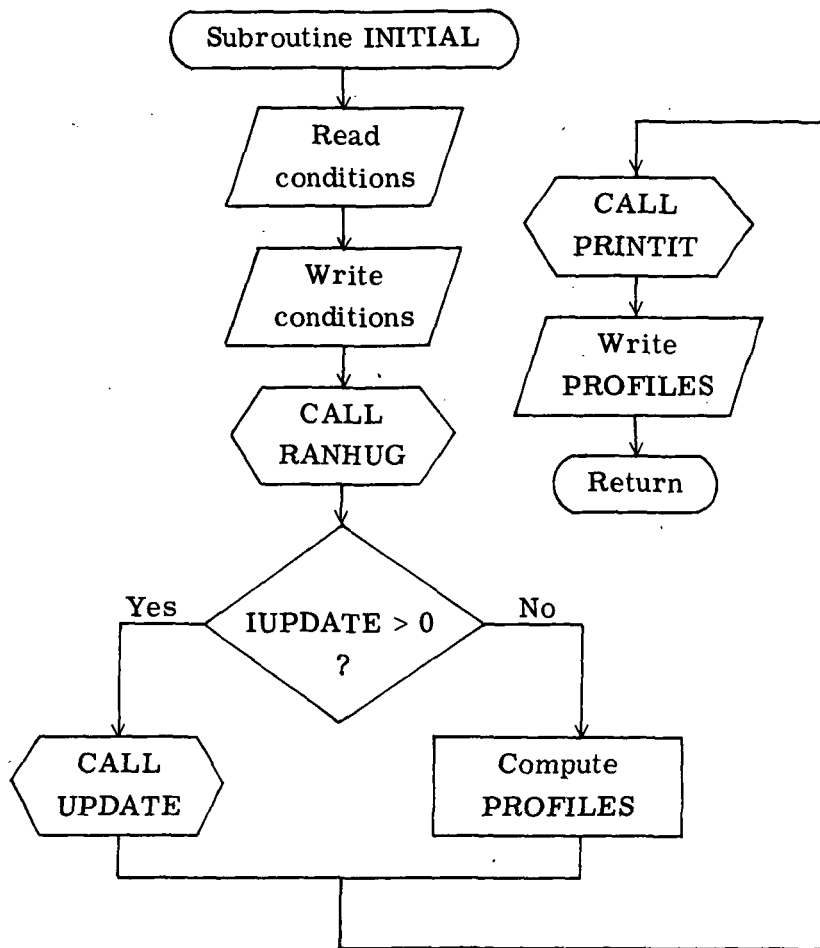
### Program LEE

LEE is the main program. It calls subroutines GETREDY and INITIAL, which input data and initialize profiles, respectively. Then, LEE directs the solution of the fluid-flow equations and the density computation by successive iteration until convergence is achieved. The flow chart for LEE is given as follows:



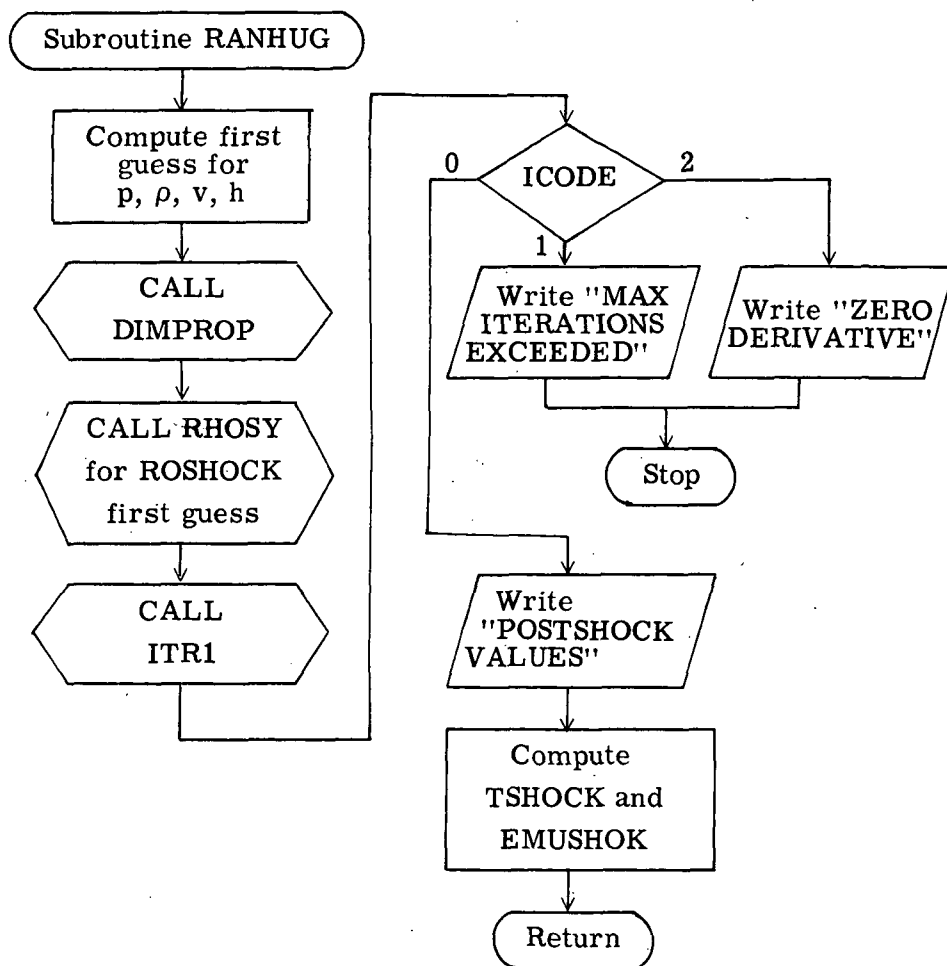
### Subroutine INITIAL

The INITIAL subroutine performs those tasks which must be done before the interaction of the profiles can begin. The conditions of the problem are read in. Post-shock conditions are computed. Profiles of various flow quantities are initialized by one of two options. If  $IUPDATE \leq 0$ , linear and second-order profiles are assumed initially across the shock layer. If  $IUPDATE > 0$ , the UPDATE subroutine is called to input profiles. The flow chart for INITIAL is given as follows:



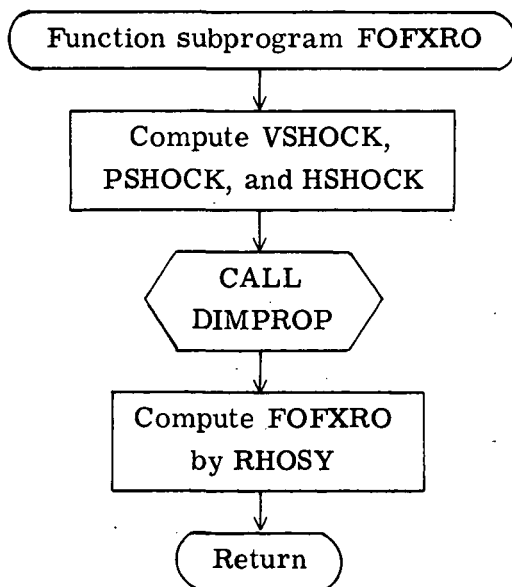
## Subroutine RANHUG

The RANHUG subroutine computes the properties behind a normal shock wave. An initial guess of pressure and static enthalpy is made and an initial guess for density ROSHOCK is computed on this basis. Starting with this value, a Newton-Raphson subroutine ITR1 iterates to compute ROSHOCK to the desired accuracy. The ITR1 subroutine is described in appendix D. The flow chart for RANHUG is given as follows:



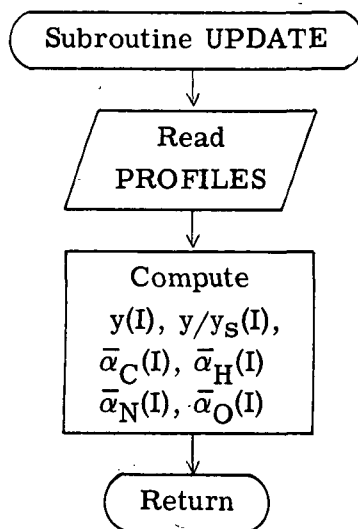
## Function Subprogram FOFXRO

The FOFXRO function subprogram calls ITR1 to compute ROSHOCK. It uses the Rankine-Hugoniot equations and equation of state (as represented by RHOSY) to evaluate density ROSHOCK. The flow chart for FOFXRO is given as follows:



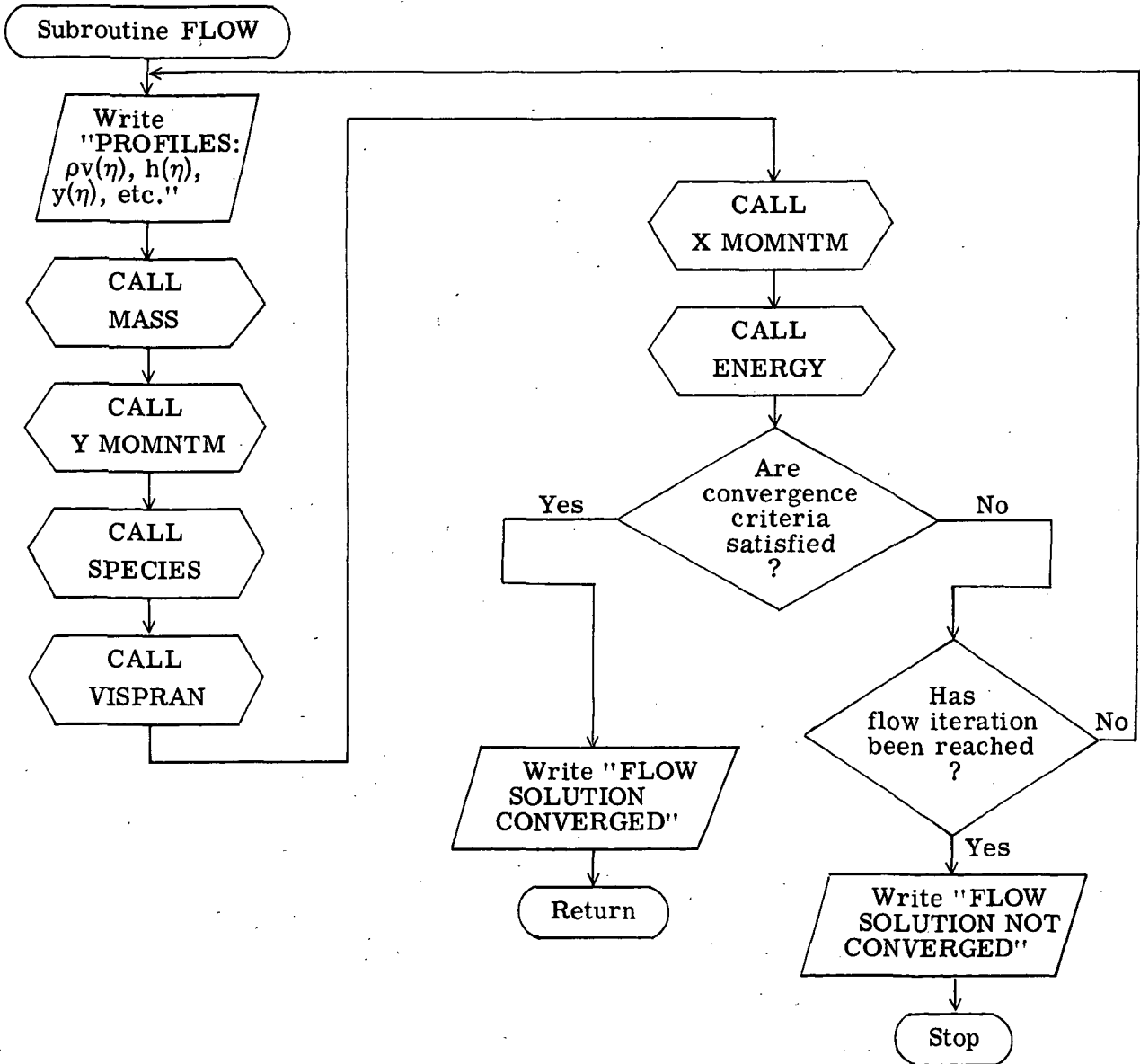
## Subroutine UPDATE

The UPDATE subroutine reads NAMELISTs for the profiles required to begin the iteration for the solution, provided that IUPDATE > 0. This option allows the user to begin the iteration with the best possible guess. The flow chart for UPDATE is given as follows:



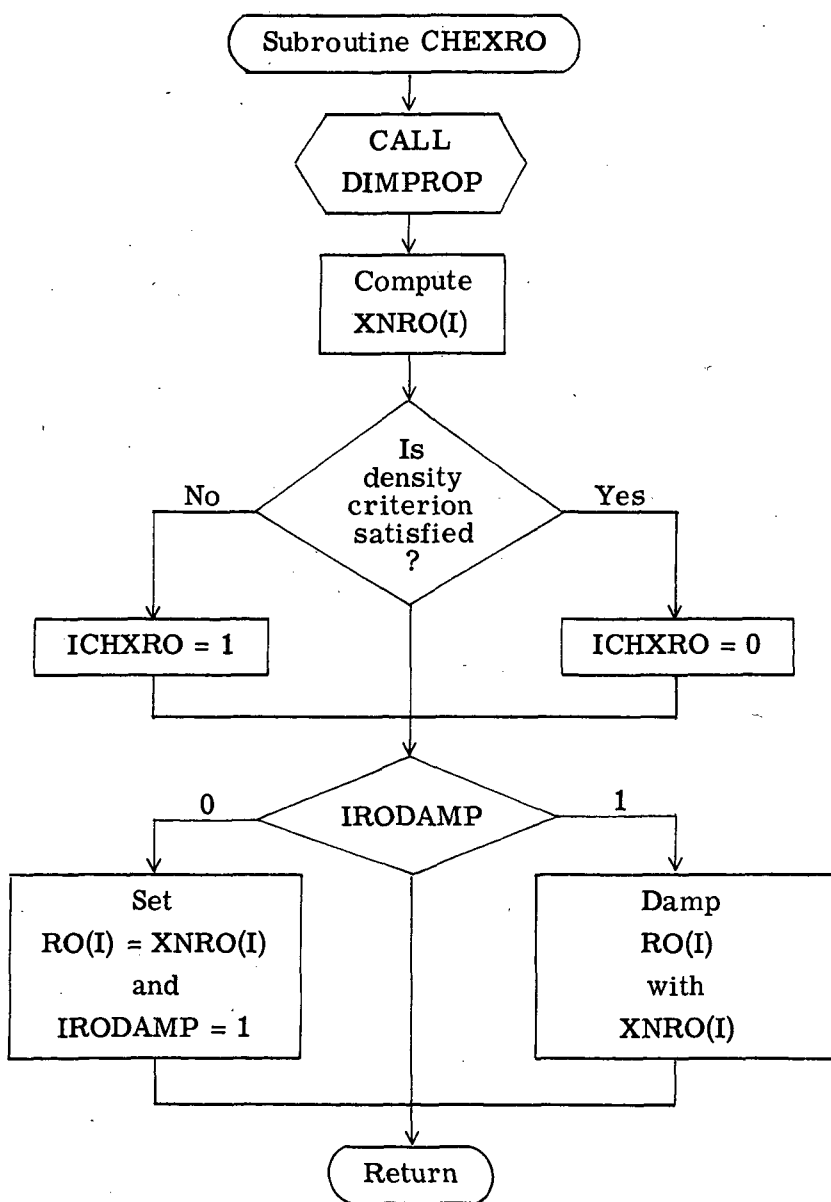
### Subroutine FLOW

The FLOW subroutine iterates the fluid-flow equations by computing the  $a(\eta)$ ,  $v(\eta)$ ,  $h(\eta)$ ,  $p(\eta)$ , and  $\bar{a}_F(\eta)$  profiles and shock-wave standoff distance for a given  $p(\eta)$  profile. The flow chart for FLOW is given as follows:



### Subroutine CHEXRO

The CHEXRO subroutine computes a density profile  $RO(I)$  from the most recent  $p(I)$ ,  $h(I)$ , and elemental profiles. This  $RO(I)$  profile is compared with the previous profile and if the accuracy criterion is satisfied,  $ICHXRO$  is set equal to 0; otherwise,  $ICHXRO$  is set equal to 1. The  $RO(I)$  profile is then damped by using the previous value. Subroutine  $ICHXRO$  is used by LEE to determine whether the solution has converged or should be continued. The flow chart for CHEXRO is given as follows:

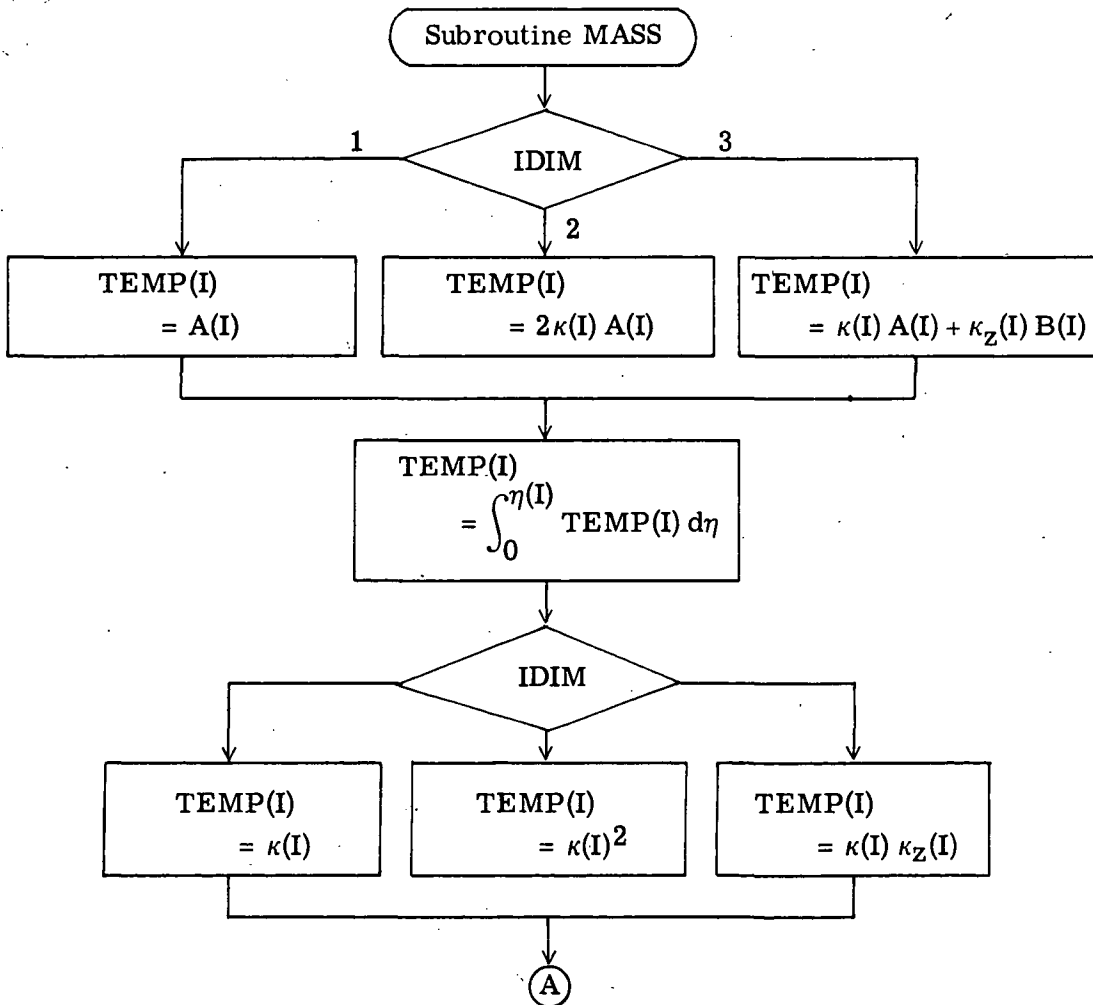


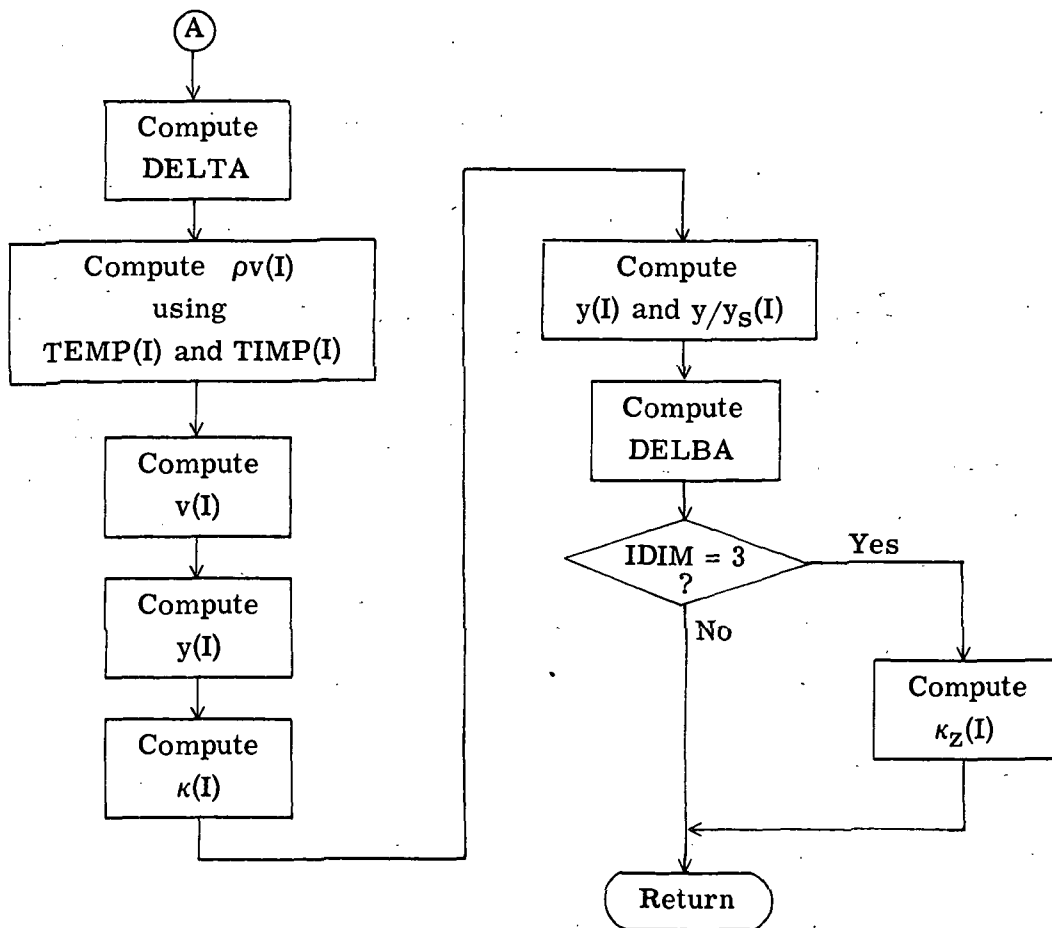


### Subroutine MASS

The MASS subroutine integrates the tangential flow gradient  $\rho a(\eta)$  to compute the normal mass flow  $\rho v(\eta)$  in accordance with the continuity equation. Also, the shock-layer thickness and the transformation from  $\eta$  to  $y$  are computed. Finally, the physical thickness of the shock layer DELBA is computed. There are three geometry options: IDIM = 1 for two-dimensional flow, IDIM = 2 for axisymmetric flow, and IDIM = 3 for the stagnation streamline of a three-dimensional body.

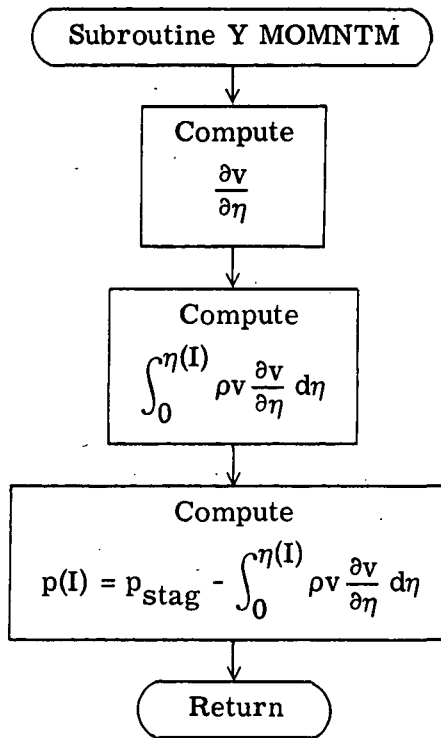
When the computation enters the MASS subroutine, the geometry option flag IDIM is checked, in effect selecting which of equations 9(a), (b), or (c) is to be used. The right-hand side of the selected equation is computed and integrated, without the factor of  $\delta$ . The appropriate scale factors are then divided out, and  $\delta$  is computed so that  $(\rho v)_s = 1$ . The remaining computations follow in sequence. The flow chart for MASS is given as follows:





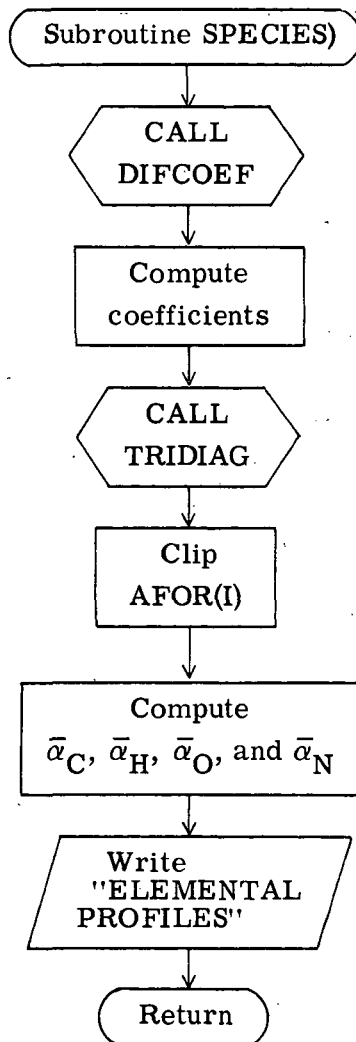
### Subroutine Y MOMNTM

The Y MOMNTM subroutine integrates the y-momentum equation by using a density  $\rho(I)$  and velocity profile  $v(I)$ . The flow chart for Y MOMNTM is given as follows:



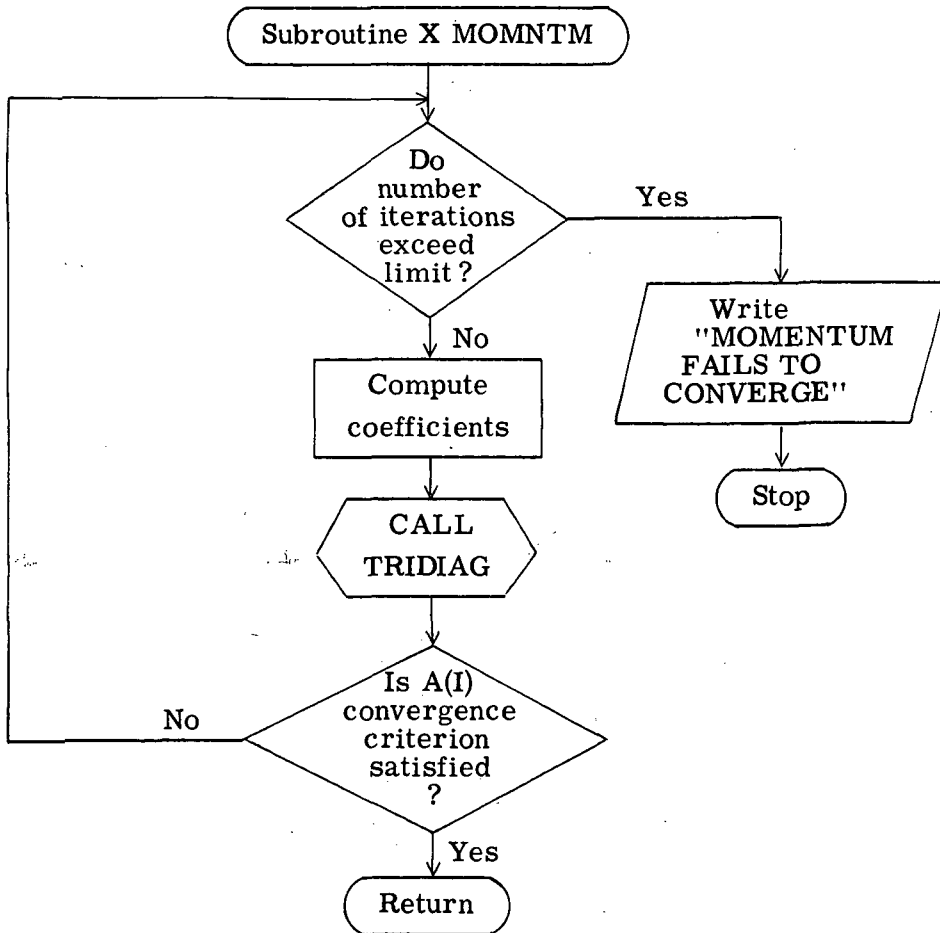
### Subroutine SPECIES

The SPECIES subroutine solves the binary diffusion equation for the mass fraction profile  $\bar{a}_F(I)$  of the injected mass. The elemental mass fractions  $\bar{a}_i(I)$  are then computed from  $\bar{a}_F(I)$ , where  $i = C, H, N,$  and  $O$ . The flow chart for SPECIES is given as follows:



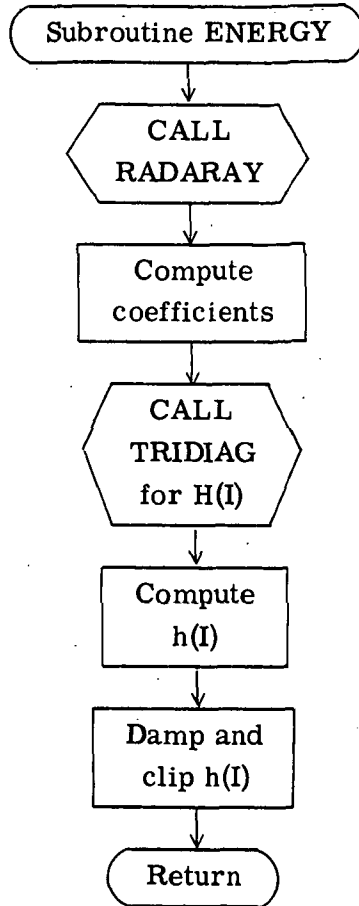
### Subroutine X MOMNTM

The X MOMNTM subroutine solves the viscous x-momentum equation for the tangential velocity gradient profile  $a(I)$ . Because this equation is nonlinear in  $a(I)$ , a quasilinear approach is used, whereby the solution is computed by iteration. The flow chart for X MOMNTM is given as follows:



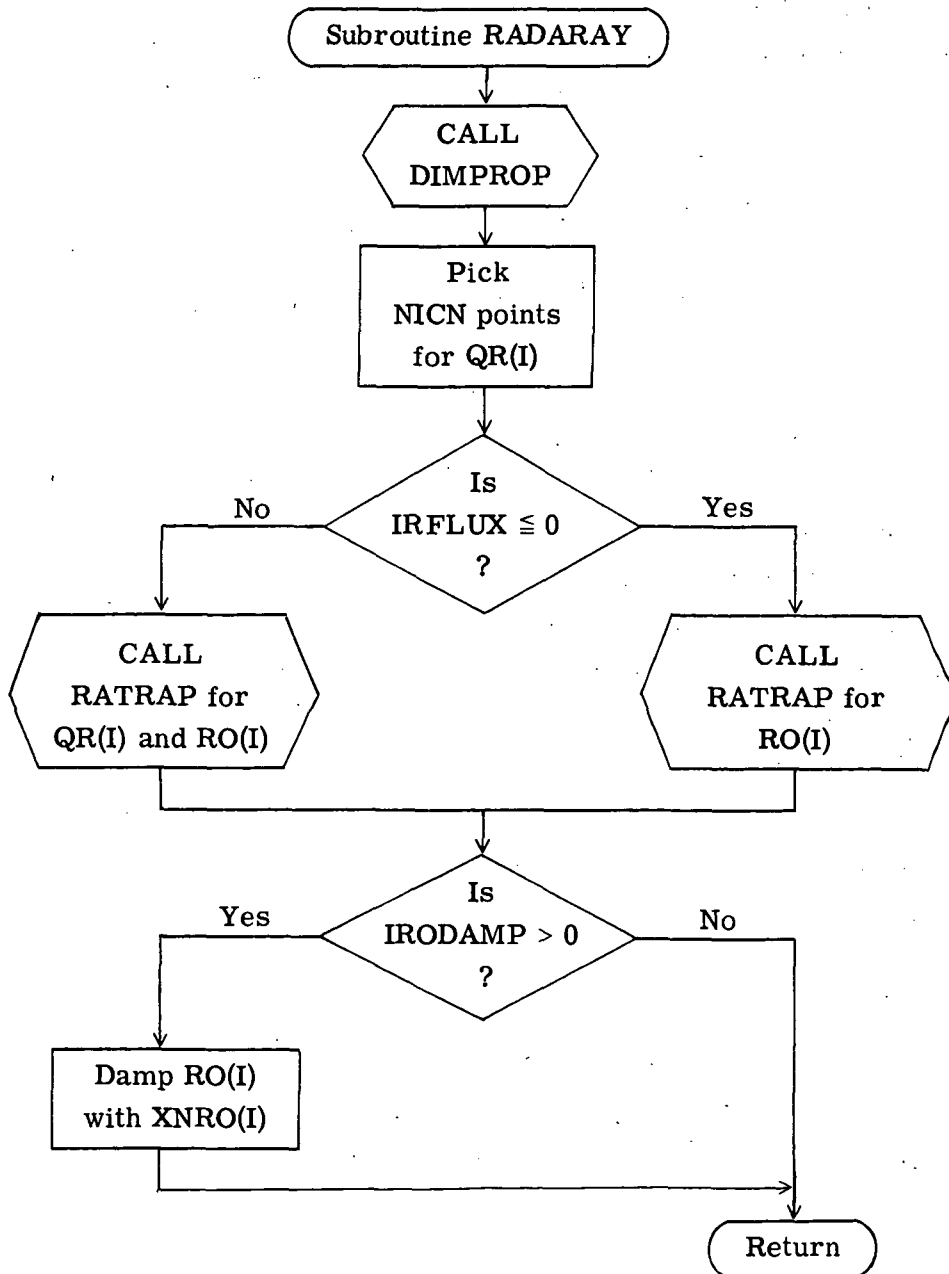
### Subroutine ENERGY

The ENERGY subroutine solves the energy equation. The RATRAP code is used to compute radiation heat fluxes  $q_{R,y}(I)$ , from which  $\frac{\partial q_{R,y}}{\partial \eta}$  is computed. The energy equation is solved for  $H(I)$ , after which  $h(I)$  is computed. The flow chart for ENERGY is given as follows:



### Subroutine RADARAY

The RADARAY subroutine calls RATRAP for the radiation heat fluxes  $QR(I)$  at NIC points and linearly interpolates for the values of  $QR(I)$  (where  $QR(I) = q_{R,y}(I)$ ) at the remaining points if  $IRFLUX > 0$ . If  $IRFLUX \leq 0$ ,  $QR(I)$  is set equal to zero. Also, density  $RO(I)$  is updated according to the most recent  $p(I)$ ,  $h(I)$ , and elemental profiles. If damping of the density profile  $RO(I)$  is desired,  $RODAMP$  is set equal to some positive integer in the NAMELIST NAM4 input. If so, the old density profile, stored in  $XNRO(I)$ , is used. The flow chart for RADARAY is given as follows:



## GAS-PROPERTIES SUBPROGRAMS

Several of the gas-properties subprograms are for specific gases, for example, air. For other gases, these subprograms should be replaced. The VISCOS and PRANDTL function subprograms select values by using tables from reference 4, which constitute most of the BLOCK DATA subprogram. The DIFCOEF subroutine computes a binary coefficient for a mixture of atomic hydrogen and atomic nitrogen.

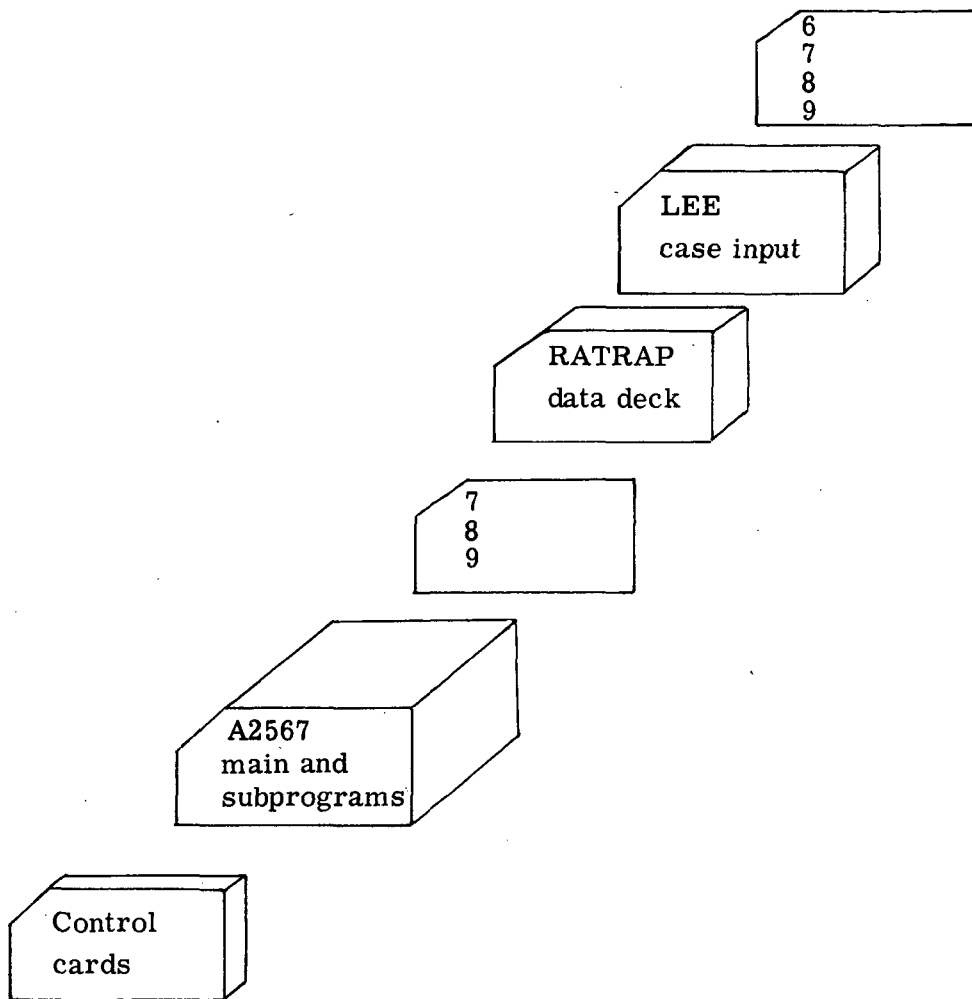
The RATRAP subroutine is used to compute the equilibrium composition, density, and temperature of a gaseous mixture of hydrogen, oxygen, nitrogen, and carbon by use of a free-energy minimization subroutine (FEMP).

### USAGE

#### Program Information and Deck Configuration

Program LEE was written in the FORTRAN IV language for the Control Data 6600 computer system under the SCOPE 3.0 operating system. A field length of 150 000<sub>8</sub> locations is required. Computing time depends on the blowing rate and the accuracy of the initial profiles assumed; but it is of the order of 20 to 30 minutes for cases with radiation for 21 node points and radiation computed at 11 node points. The vast majority of the time is spent in the very complicated radiation computations. The flow-computation time for fixed density and no radiation is approximately 1 second for each iteration within the FLOW subroutine, so that 2 to 4 seconds are required for a converged solution. The computation time using FEMP for computing the equilibrium chemistry of the air-ablation product mixture and without radiation computations was found to be  $1\frac{1}{2}$ ,  $2\frac{1}{2}$ , and  $3\frac{1}{2}$  minutes for nondimensional blowing rates of 0, -0.1, and -0.2, respectively. In this case, most of the time is spent in chemistry computations. The following sketch shows the deck configuration needed for execution:





### Input Description

The RATRAP data deck is supplied with a permanent code and is not normally modified. A listing of the input cards is included with the sample case. Following the RATRAP data deck is the LEE case-input data, which is loaded by NAMELIST. The first group of data, in NAM4, are numbers which may be varied at will but are usually left unchanged. The next group of data, in NAM5, specifies the case of interest. The final data are optional; these are the profiles which may be read in, and they are in NAM1, NAM2, and NAM3. The input symbols are nondimensional except where indicated.

The NAM4 data are given as follows:

|                        |   |
|------------------------|---|
| N                      | number of points in flow-field solution, up to 100  |
| IDIM dimension option: | (1) Plane flow<br>(2) Axisymmetric flow<br>(3) Three-dimensional flow   |
| IRODAMP                | option for damping density: 0 no damping used on density<br>1 damping used on density   |
| HDAMP                  | damping used on static enthalpy profile   |
| RODAMP                 | damping used on density profile   |
| EP                     | accuracy criterion for pressure   |
| EROV                   | accuracy criterion for $\rho v$   |
| EA                     | accuracy criterion for tangential velocity gradient, $a = \frac{\partial u}{\partial x}$ ;<br>also used for $b = \frac{\partial w}{\partial z}$ |
| EPSX                   | accuracy criterion used in solving x-momentum equation  |
| ERO                    | relative accuracy criterion for density   |
| MAXTIME                | maximum number of iterations allowed within FLOW  |
| NIC                    | number of points for which RATRAP computes radiative fluxes,<br>up to 100   |
| CURV                   | curvature of body at $x = 0$ in plane in which $x$ is measured  |
| CURVZ                  | curvature of body for three-dimensional case at $x = 0, z = 0$<br>in plane in which $z$ is measured (used only for IDIM = 3)                    |
| BS                     | $\left(\frac{\partial w}{\partial z}\right)_s$ (used only for IDIM = 3)   |
| D2PDZ                  | $\left(\frac{\partial^2 p}{\partial z^2}\right)_{x=0, z=0}$ (used only for IDIM = 3)  |

The NAM5 data are given as follows:

|        |   |
|--------|---|
| IRFLUX | radiation option: 0 no radiation computed<br>1 radiation computed |
|--------|---|

|         |   |
|---------|---|
| IUPDATE | option for inputing initial guess profiles:<br>0 no profile read in, assume linear<br>1 read in profile |
| ALPINJC | mass fraction of carbon in ablation products injected   |
| ALPINJO | mass fraction of oxygen in ablation products injected   |
| ALPINJH | mass fraction of hydrogen in ablation products injected   |
| ALPINJN | mass fraction of nitrogen in ablation products injected   |
| D2DP2C  | $\frac{\partial^2 p}{\partial x^2}$ coefficient   |
| AS      | value of a at shock wave  |
| PINP    | free-stream pressure, dynes/cm <sup>2</sup> (where 1 dyne = 10 <sup>-5</sup> newton)                    |
| RHOINP  | free-stream density, g/cm <sup>3</sup>  |
| UINP    | free-stream velocity, cm/sec  |
| RB      | body radius at x = 0, cm  |
| ROVW    | mass injection rate (negative)  |
| HW      | wall static enthalpy  |
| ALPINFN | free-stream mass fraction of nitrogen   |
| ALPINFO | free-stream mass fraction of oxygen   |
| ALPINFC | free-stream mass fraction of carbon   |
| ALPINFH | free-stream mass fraction of hydrogen   |

The NAM1 data are given as follows:

|        |  |
|--------|--|
| RO(I)  | density profile, initial guess                     |
| ROV(I) | profile of mass flow normal to body, initial guess |

The NAM2 data are given as follows:

|      |  |
|------|--|
| A(I) | profile of tangential velocity gradient, initial guess |
| H(I) | static enthalpy profile, initial guess                 |

P(I)                                    pressure profile, initial guess  
DELTA                                    initial guess of transformed shock-layer thickness

The NAM3 data are given as follows:

AFOR(I)                                profile of mass fraction of injected species where  
    I = 1, 2, ... N

A sample set of input data is given in appendix B. This case corresponds to a 304.8-cm (10-ft) nose radius body at an altitude of 60.96 km (200 000 ft) with a velocity of 15.25 km/sec (50 000 ft/sec). This is typical of a manned reentry for a Mars return. Air is being injected at a high rate (0.1 of free-stream value of mass flux).

#### Discussion of Output

The output of program LEE consists of printing only. Output for the sample case is shown in appendix C. The first page of output, printed by INITIAL, gives the conditions of the case, followed by the postshock conditions. The NAMELIST inputs NAM4 and NAM5 are printed on following pages, also by INITIAL. Next, equilibrium composition profiles as computed by FEMP from the initial pressure and static enthalpy profiles are written by RATRAP. If the radiation option is used, radiative heat fluxes are written. The next page shows the initial flow profiles, printed by INITIAL. For each pass through FLOW, the profiles of the various flow parameters are written. These are followed by profiles of elemental distribution, printed by SPECIES. If the radiation option is used, radiative heat fluxes are printed by RATRAP. Once the iteration for the full-coupled solution has converged, the message "VARIABLE DENSITY SOLN CONVERGED" is printed by LEE. The output symbols are nondimensional, except where indicated.

The symbols for postshock conditions are given as follows:

PSHOCK                                static pressure  
ROSHOCK                                density  
VSHOCK                                 velocity  
HSHOCK                                 static enthalpy

The symbols for flow profiles are given as follows:

|      |  |
|------|--|
| ETA  | $\eta$   |
| Y    | y  |
| QR   | radiative heat flux                                    |
| CAPH | total enthalpy   |
| V    | v  |
| EMU  | $\mu$  |
| PRAN | $N_{Pr}$   |
| YOYS | $y/y_s$  |
| ROV  | $\rho v$   |
| A    | a  |
| P    | p, pressure  |
| RO   | $\rho$ , density (latest value)                        |
| XNRO | $\rho$ , density (previous value)                      |
| H    | h, static enthalpy (latest value)                      |
| XNH  | h, static enthalpy (previous value)                    |
| T    | T', temperature, kelvin                                |
| AMFC | $\bar{a}_C$ , elemental mass fraction of carbon        |
| AMFN | $\bar{a}_N$ , elemental mass fraction of nitrogen      |
| AMFO | $\bar{a}_O$ , elemental mass fraction of oxygen        |
| AMFH | $\bar{a}_H$ , elemental mass fraction of hydrogen      |
| AFOR | $\bar{a}_F$ , total mass fraction of injected products |
| AONC | total mass fraction of free-stream gas                 |

The symbols for radiative output are given as follows:

|              |  |
|--------------|--|
| TOTAL QMINUS | total radiative heat flux toward shock wave due to atomic emission, $W/cm^2$ |
| TOTAL QPLUS  | total radiative heat flux toward body due to atomic line emission, $W/cm^2$  |
| QRAD         | net radiative heat flux, $W/cm^2$  |

### Error Messages

The following table gives the error diagnostics as the message and the corresponding subprogram which prints the message:

| Message                                       | Diagnosis | Subprogram |
|---|-----------|------------|
| FLOW SOLUTION NOT CONVERGED . . . . .         | Fatal     | FLOW       |
| MOMENTUM FAILS TO CONVERGE . . . . .          | Fatal     | X MOMNTM   |
| FEMP BLEW . . . . .                           | Fatal     | RATRAP     |
| MAXIMUM ITERATIONS EXCEEDED IN RANHUG . . . . | Fatal     | RANHUG     |
| ZERO DERIVATIVE IN RANHUG . . . . .           | Fatal     | RANHUG     |
| H(I) LESS THAN H(1) . . . . .                 | Nonfatal  | ENERGY     |
| AFORI(I) LESS THAN 1.E-06 . . . . .           | Nonfatal  | SPECIES    |
| AFOR(I) GREATER THAN 0.999999 . . . . .       | Nonfatal  | SPECIES    |
| TEMPERATURE TOO LARGE, T' = ? . . . . .       | Nonfatal  | VISCOS     |
| TEMPERATURE TOO LARGE, T' = ? . . . . .       | Nonfatal  | PRANDTL    |
| T DID NOT CONVERGE, T' = ? . . . . .          | Nonfatal  | FEMP       |
| N-R DID NOT CONVERGE . . . . .                | Nonfatal  | FEMP       |

If the flow solution does not converge, the enthalpy and density profiles should be checked for a sequence of iterations. Adjustment of RODAMP and HDAMP may be indicated. Also, an improved approximation for the initial profiles reduces the number of iterations required. The momentum solution is very reliable. If it should fail to converge, an improved initial profile should be an adequate fix.

Experience with FEMP has shown that the message FEMP BLEW is usually due to negative mass fractions or unrealistically low enthalpies. These problems are alleviated in the computations by the CLIP operation.

No difficulties have been experienced with the computation of postshock conditions. However, diagnostic messages are included in the RANHUG subroutine to provide for this contingency. For some conditions, the Newton-Raphson (N-R) procedure in FEMP has difficulty converging. In this case, the message "N-R DID NOT CONVERGE" is printed and the computation is reinitiated.

The nonfatal error messages are to alert the user to items of which he should be aware, but which do not disrupt the computation.

Langley Research Center,  
National Aeronautics and Space Administration,  
Hampton, Va., August 7, 1973.

# APPENDIX A

## PROGRAM LISTING

```

PROGRAM LEE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     LAYER WITH
C     EQUILIBRIUM CHEMISTRY AND
C     EQUILIBRIUM RADIATION
C
COMMON /CA/ A(101),B(101)
COMMON /CY/ Y(101),YOYS(101)
COMMON /CRO/ RO(101)
COMMON /CETA/ ETA(101)
COMMON /CV/ V(101)
COMMON /CP/ P(101)
COMMON /CROV/ ROV(101)
COMMON /CEMU/ EMU(101)
COMMON /CCAPH/ CAPH(101)
COMMON /CH/ H(101)
COMMON /CPRAN/ PRAN(101)
COMMON /CXRO/ XNRO(101)
COMMON /CXH/ XNH(101)
COMMON /CQR/ QR(101)
COMMON /CT/ T(101)
COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)
COMMON /CFORONC/ AFOR(201),AONC(201)
COMMON /MISCL/ N, IDIM, CURV, DELTA, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX
ITIME,MLDIFPT,NIC,ERO
COMMON /DAMP/ IRODAMP,RODAMP,HDAMP
COMMON /RADCGMP/ DELBA,IRFLUX
COMMON /REFVALU/ EMUSHOK
CALL GETREDY
CALL INITIAL
1 CALL FLOW
CALL CHEXRO (ICHXRO)
IF (ICHXRO.EQ.1) GO TO 1
WRITE (6,5)
WRITE (6,6) DELTA,DELBA,REY
WRITE (6,7)
DO 2 I=1,N
WRITE (6,8) ETA(I),Y(I),QR(I),CAPH(I),V(I),EMU(I),PRAN(I),YOYS(I)
2 CONTINUE
WRITE (6,9)
DO 3 I=1,N
WRITE (6,10) ETA(I),ROV(I),A(I),P(I),RO(I),XNRO(I),H(I),XNH(I)
3 CONTINUE
WRITE (6,11)
DO 4 I=1,N
WRITE (6,10) ETA(I),T(I),AMFC(I),AMFN(I),AMFO(I),AMFH(I),AFOR(I),A
1ONC(I)
4 CONTINUE
CALL PRINTIT
STOP
C
C
5 FORMAT (1H0,5X,31HVARIABLE DENSITY SCLN CONVERGED)
6 FORMAT (1H1,5X,6HDELTA=E16.8,2X,6HDELBA=E16.8,2X,4HREY=E16.8)
7 FORMAT (4X,6HETA(I),9X,4HY(I),10X,5HQR(I),8X,7HCAPH(I),10X,4HV(I),
19X,6HEMU(I),8X,7HPRAN(I),8X,7HYOYS(I))
8 FORMAT (8E14.6)
9 FORMAT (4X,6HETA(I),8X,6HROV(I),9X,4HA(I),10X,4HP(I),10X,5HRO(I),8
1X,7HXNRO(I),9X,4HH(I),9X,6HXNH(I))
10 FORMAT (8E14.6)
11 FORMAT (4X,6HETA(I),9X,4HT(I),9X,7HAMFC(I),8X,7HAMFN(I),8X,7HAMFO(
1I),6X,7HAMFH(I),7X,7HAFOR(I),7X,7HACNC(I))
END
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APPENDIX A - Continued

|   |  |   |    |
|---|--|---|----|
|   | SUBROUTINE INITIAL   | B | 1  |
|   | COMMON /CA/ A(101),B(101)  | B | 2  |
|   | COMMON /CBETA/ BETA(101)   | B | 3  |
|   | COMMON /CTEMP/ TEMP(101),TIMP(101)   | B | 4  |
|   | COMMON /CY/ Y(101),YOYS(101)   | B | 5  |
|   | COMMON /CETA/ ETA(101)   | B | 6  |
|   | COMMON /CP/ P(101)   | B | 7  |
|   | COMMON /CRC/ RO(101)   | B | 8  |
|   | COMMON /CROV/ ROV(101)   | B | 9  |
|   | COMMON /CSCH/ SCH(101),SCI(101)  | B | 10 |
|   | COMMON /CV/ V(101)   | B | 11 |
|   | COMMON /CH/ H(101)   | B | 12 |
|   | COMMON /CT/ T(101)   | B | 13 |
|   | COMMON /CFORONC/ AFOR(201),AONC(201)   | B | 14 |
|   | COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RB   | B | 15 |
|   | COMMON /CAMF1/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)                         | B | 16 |
|   | COMMON /MFINF/ ALPINFC,ALPINFN,ALPINFO,ALPINFH                                 | B | 17 |
|   | COMMON /MFINJ/ ALPINJC,ALPINJN,ALPINJO,ALPINJH                                 | B | 18 |
|   | COMMON /RANK/ RSHOCK,VSHOCK,HSOCK,TSHOCK                                       | B | 19 |
|   | COMMON /MISCL/ N,IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX             | B | 20 |
|   | 1TIME,MLDIFPT,NIC,ERO  | B | 21 |
|   | COMMON /REFVALU/ EMUSHOK   | B | 22 |
|   | COMMON /RADCOMP/ DELBA,IRFLUX  | B | 23 |
|   | COMMON /DAMP/ IRODAMP,RODAMP,HDAMP   | B | 24 |
|   | COMMON /CD2DP2/ D2DP2C   | B | 25 |
|   | COMMON /C3D/ CURVZ,BS,BETAZ(101)   | B | 26 |
|   | NAMelist /NAM4/ N, IDIM, IRODAMP, HDAMP, RODAMP, EP, EROV, EA, EPSX, ERO, MA   | B | 27 |
|   | 1XTIME, NIC, CURV, CURVZ, BS, D2PDZ  | B | 28 |
|   | NAMelist /NAM5/ IRFLUX, IUPDATE, ALPINJC, ALPINJO, ALPINJH, ALPINJN, D2D       | B | 29 |
|   | 1P2C, AS, PINP, RHOINP, UINP, RB, ROVW, HW, ALPINFN, ALPINFO, ALPINFC, ALPINFH | B | 30 |
|   | READ (5, NAM4) \$READ(5, NAM5)   | B | 31 |
|   | WRITE (6, 20)  | B | 32 |
|   | IF (IRFLUX.GT.0) WRITE (6, 19)   | B | 33 |
|   | WRITE (6, 17) RB, UINP, RHOINP, AS, D2DP2C, PINP, ROVW, ALPINJH, ALPINJC, AL   | B | 34 |
|   | IPINJN, ALPINJO  | B | 35 |
|   | WRITE (6, 18) ALPINFN, ALPINFO, ALPINFC, ALPINFH                               | B | 36 |
|   | PIN=PINP/(RHOINP*UINP*UINP)  | B | 37 |
|   | HIN=3.5*PIN+0.5  | B | 38 |
|   | CALL RANHUG  | B | 39 |
|   | WRITE (6, NAM4) \$WRITE(6, NAM5)   | B | 40 |
|   | REY=RHOINP*UINP*RB/EMUSHCK   | B | 41 |
|   | RO(N)=RCSHOCK  | B | 42 |
|   | XN=N-1   | B | 43 |
|   | DETA=1./XN   | B | 44 |
|   | ROV(N)=1.  | B | 45 |
|   | A(1)=0.  | B | 46 |
|   | TEMP=AS-A(1)   | B | 47 |
|   | ETA(1)=0.  | B | 48 |
|   | DO 1 I=2, N  | B | 49 |
| 1 | ETA(I)=ETA(I-1)+DETA   | B | 50 |
|   | DO 2 I=1, N  | B | 51 |
| 2 | BETA(I)=D2DP2(ETA(I))  | B | 52 |
|   | IF (IDIM.NE.3) GO TO 4   | B | 53 |
|   | DO 3 I=1, N  | B | 54 |
|   | BETAZ(I)=D2PDZ   | B | 55 |
| 3 | B(I)=BS*ETA(I)   | B | 56 |
| 4 | CONTINUE   | B | 57 |
|   | IF (IUPDATE.GT.0) GO TO 14   | B | 58 |
|   | DELTA=1.   | B | 59 |
|   | DELBA=.05*RB   | B | 60 |
|   | DO 5 I=1, N  | B | 61 |
|   | ROV(I)=(ROV(N)-ROV(1))*ETA(I)+ROV(1)   | B | 62 |
|   | ROV(I)=ROV(1)+(1.-ROV(1))*ETA(I)*ETA(I)  | B | 63 |
|   | H(I)=(HSHOCK-HW)*ETA(I)+HW   | B | 64 |
|   | A(I)=A(1)+TEMP*ETA(I)  | B | 65 |
| 5 | CONTINUE   | B | 66 |
|   | DO 6 I=2, N  | B | 67 |

APPENDIX A - Continued

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6   RO(I)=RCSHOCK/ETA(I)           B 68
   RO(I)=RO(2)+5.                 B 69
   DO 7 I=1,N                     B 70
   FOREIGN=0.                     B 71
   IF (ROV(I).GT..0) FOREIGN=1.   B 72
   AFOR(I)=1.-FOREIGN             B 73
7   AONC(I)=FOREIGN               B 74
   DO 8 I=1,N                     B 75
   AMFC(I)=AFOR(I)*ALPINJC+ACNC(I)*ALPINF
   AMFN(I)=AFOR(I)*ALPINJN+AONC(I)*ALPINFN
   AMFO(I)=AFOR(I)*ALPINJO+AONC(I)*ALPINFO
   AMFH(I)=AFOR(I)*ALPINJH+AONC(I)*ALPINFH
8   CONTINUE                     B 80
   DO 9 I=1,N                     B 81
   V(I)=ROV(I)/RC(I)             B 82
   SCH(I)=1.+DELTA*ETA(I)/RO(I)  B 83
   SCI(I)=1.+DELTA*ETA(I)/RC(I)  B 84
9   CONTINUE                     B 85
   TEMP=-.5*V(N)                 B 86
   PSTAG=PSHOCK-TEMP             B 87
   DO 10 I=1,N                   B 88
10  P(I)=PSTAG+TEMP*ETA(I)**2    B 89
   DO 11 I=1,N                   B 90
11  TEMP(I)=1./RO(I)            B 91
   CALL TINT (N,DETA,TEMP,TIMP)  B 92
   DO 12 I=1,N                   B 93
   Y(I)=DELTA*TIMP(I)           B 94
   SCH(I)=1.+CURV*DELTA*TIMP(I) B 95
12  CONTINUE                     B 96
   DO 13 I=1,N                   B 97
   YOYS(I)=Y(I)/Y(N)           B 98
13  CONTINUE                     B 99
   DELBA=Y(N)*RB                B 100
   GO TO 15                      B 101
14  CONTINUE                     B 102
   CALL UPDATE                   B 103
15  CONTINUE                     B 104
   WRITE (6,21)                  B 105
   CALL PRINTIT                  B 106
   WRITE (6,22)                  B 107
   WRITE (6,23) DELTA,DELBA,REY,EMUSHOK
   WRITE (6,24)                  B 109
   DO 16 I=1,N                   B 110
   WRITE (6,25) ETA(I),ROV(I),A(I),P(I),RO(I),H(I),T(I),AFOR(I)
16  CONTINUE                     B 112
   RETURN                        B 113
C                                B 114
C                                B 115
17  FORMAT (//8X,12HBODY RADIUS=,E13.5,25H CM, FREESTREAM VELOCITY=,E1
13.5,17H CM/SEC, DENSITY=,E13.5,5H G/CC/9X,18HA SHOCK (NON DIM)=,F8
2.5,19H, BETA (NON DIM)=,F8.5,1H,,16X,9HPRESSURE=,E13.5,12H DYNES
3/SQ CM/9X,24HABLATION RATE (NON DIM)=,F8.5,30H, MASS FRACTIONS-
4HYDRGEN =,F7.5,10H, OXYGEN=,F7.5,13H, NITROGEN =,F7.5,11H, CAR
5BON =,F7.5)
18  FORMAT (9X,28HFREESTREAM COMPOSITION- N= ,F7.5,7H, O= ,F7.5,7H,
1 C= ,F7.5,7H, H= ,F7.5)
19  FORMAT (50X,14HWITH RADIATION)
20  FORMAT (1H1,///38X,38HVISCOUS STAGNATION STREAMLINE SOLUTION/)
21  FORMAT (1H1,////11X,40HINITIAL EQUILIBRIUM COMPOSITION PROFILES/)
22  FORMAT (1H1,////11X,21HINITIAL FLOW PROFILES)
23  FORMAT (//5X,6HDELTA=E16.8,2X,6HDELBA=E16.8,2X,4HREY=E16.8,2X,21H
1 VISCOSITY(SHOCK)= ,E16.8)
24  FORMAT (4X,6HETA(I),8X,6HROV(I),9X,4HA(I),10X,4HP(I),10X,5HRO(I),8
1X,4HH(I),8X,4HT(I)8X,7HAFOR(I))
25  FORMAT (8E14:6)
   END

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APPENDIX A - Continued

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SUBROUTINE RANHUG                                C 1
COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100) C 2
COMMON /RANK/ RSHOCK,VSHOCK,HSOCK,TSHOCK          C 3
COMMON /MISCL/ N, IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX C 4
1TIME,MLDIFPT,NIC,ERO                            C 5
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RB           C 6
COMMON /MFINF/ ALPINF,ALPINFN,ALPINFO,ALPINFH     C 7
COMMON /MFINJ/ ALPINJC,ALPINJN,ALPINJC,ALPINJH   C 8
COMMON /REFVALU/ EMUSHOK                          C 9
EXTERNAL FOFXRO                                    C 10
EXTERNAL VISCCS                                    C 11
PSHOCK=0.95                                        C 12
VSHOCK=1.+PIN-PSHOCK                              C 13
HSOCK=HIN-(VSHOCK*VSHOCK/2.)                     C 14
CALL DIMPROP (PSHOCK,HSOCK,PSHOKP,HSOKP)          C 15
AINFC=ALPINF                                       C 16
AINFN=ALPINFN                                      C 17
AINFO=ALPINFO                                      C 18
TSHOKP=14000.                                      C 19
TSHOCK=TSHOKP                                      C 20
RSHOCK=RHCSY(PSHOKP,HSOKP*3.483E-07,AINFC,AINFN,AINFO,TSHOKP) C 21
CALL ITR1 (RSHOCK,.1,FOFXRO,.001,.001,20,ICODE)  C 22
IF (ICODE.EQ.0) GO TO 1                            C 23
IF (ICODE.EQ.1) WRITE (6,2)                        C 24
IF (ICODE.EQ.2) WRITE (6,3)                        C 25
STOP                                               C 26
1 WRITE (6,4) PSHOCK,RSHOCK,VSHOCK,HSOCK          C 27
C                                                  C 28
EMUSHOK=VISCCS(TSHOKP,PSHOKP)                    C 29
RETURN                                             C 30
C                                                  C 31
C                                                  C 32
2 FORMAT (5X,37HMAXIMUM ITERATIONS EXCEEDED IN RANHUG) C 33
3 FORMAT (5X,25HZERO DERIVATIVE IN RANHUG)        C 34
4 FORMAT (///5X,15HRANHUG SOLUTION//12H          PSHOCK=E16.8,2X,8HROSHO C 35
1CK=E16.8,2X,7HVSHOCK=E16.8,2X,7HHSOCK=E16.8)    C 36
ENC                                               C 37-

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FUNCTION FOFXRO (RSHOCK)                          D 1
COMMON /RANK/ RSHOCK,VSHOCK,HSOCK,TSHOCK          D 2
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RB           D 3
COMMON /MFINF/ ALPINF,ALPINFN,ALPINFO,ALPINFH     D 4
COMMON /MISCL/ N, IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX D 5
1TIME,MLDIFPT,NIC,ERO                            D 6
VSHOCK=1./RSHOCK                                  D 7
PSHOCK=PIN+1.-VSHOCK                              D 8
HSOCK=HIN-(VSHOCK*VSHOCK/2.)                     D 9
CALL DIMPROP (PSHOCK,HSOCK,PSHOKP,HSOKP)          D 10
AINFC=ALPINF                                       D 11
AINFN=ALPINFN                                      D 12
AINFO=ALPINFO                                      D 13
TSHOKP=TSHOCK                                      D 14
FOFXRO=RHCSY(PSHOKP,HSOKP*3.483E-07,AINFC,AINFN,AINFO,TSHOKP) D 15
TSHOCK=TSHOKP                                      D 16
RETURN                                             D 17
END                                               D 18-

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APPENDIX A - Continued

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SUBROUTINE UPDATE
COMMON /CA/ A(101),B(101)
COMMON /CY/ Y(101),YOYS(101)
COMMON /CETA/ ETA(101)
COMMON /CRO/ RO(101)
COMMON /CV/ V(101)
COMMON /CP/ P(101)
COMMON /CROV/ ROV(101)
COMMON /CH/ H(101)
COMMON /CSCH/ SCH(101),SCI(101)
COMMON /CTEMP/ TEMP(101),TIMP(101)
COMMON /CT/ T(101)
COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)
COMMON /CFORONC/ AFOR(201),AONC(201)
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RB
COMMON /MFINF/ ALPINF,ALPINFN,ALPINFO,ALPINFH
COMMON /MFINJ/ ALPINJC,ALPINJN,ALPINJO,ALPINJH
COMMON /MISCL/ N,IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX
1 TIME,MLDIFPT,NIC,ERO
COMMON /RADCOMP/ DELBA,IRFLUX
NAMELIST /NAM1/ RO,ROV
NAMELIST /NAM2/ A,H,P,DELTA
NAMELIST /NAM3/ AFOR
READ (5,NAM1)
READ (5,NAM2)
READ (5,NAM3)
DO 1 I=1,N
1 TEMP(I)=1./RO(I)
CALL TINT (N,DETA,TEMP,TIMP)
DO 2 I=1,N
Y(I)=DELTA*TIMP(I)
SCH(I)=1.+CURV*DELTA*TIMP(I)
2 SCI(I)=SCH(I)
CONTINUE
DO 3 I=1,N
3 YOYS(I)=Y(I)/Y(N)
CONTINUE
DELBA=Y(N)*RB
DO 4 I=1,N
4 AONC(I)=1.-AFOR(I)
DO 5 I=1,N
AMFC(I)=AFOR(I)*ALPINJC+AONC(I)*ALPINF
AMFN(I)=AFOR(I)*ALPINJN+AONC(I)*ALPINFN
AMFO(I)=AFOR(I)*ALPINJO+AONC(I)*ALPINFO
AMFH(I)=AFOR(I)*ALPINJH+AONC(I)*ALPINFH
5 CONTINUE
RETURN
END
E 1
E 2
E 3
E 4
E 5
E 6
E 7
E 8
E 9
E 10
E 11
E 12
E 13
E 14
E 15
E 16
E 17
E 18
E 19
E 20
E 21
E 22
E 23
E 24
E 25
E 26
E 27
E 28
E 29
E 30
E 31
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E 35
E 36
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E 38
E 39
E 40
E 41
E 42
E 43
E 44
E 45
E 46
E 47
E 48-

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APPENDIX A - Continued

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SUBROUTINE FLOW
COMMON /CA/ A(101),B(101)
COMMON /CBETA/ BETA(101)
COMMON /CY/ Y(101),YOYS(101)
COMMON /CRO/ RO(101)
COMMON /CETA/ ETA(101)
COMMON /CV/ V(101)
COMMON /CP/ P(101)
COMMON /CROV/ ROV(101)
COMMON /CDV/ DV(101)
COMMON /CSCH/ SCH(101),SCI(101)
COMMON /CTEMP/ TEMP(101),TIMP(101)
COMMON /CEMU/ EMU(101)
COMMON /CROMU/ ROMU(101)
COMMON /CCAPH/ CAPH(101)
COMMON /CH/ H(101)
COMMON /CPRAN/ PRAN(101)
COMMON /CQR/ QR(101)
COMMON /CXRO/ XNRO(101)
COMMON /CXH/ XNH(101)
COMMON /CT/ T(101)
COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)
COMMON /CFORONC/ AFOR(201),AONG(201)
COMMON /MISCL/ N, IDIM, CURV, DETA, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX
1 TIME, MLDIFPT, NIC, ERO
COMMON /MFINF/ ALPINFC, ALPINFN, ALPINFO, ALPINFH
COMMON /MFINJ/ ALPINJC, ALPINJN, ALPINJO, ALPINJH
COMMON /RADCOMP/ DELBA, IRFLUX
COMMON /DAMP/ IRODAMP, RODAMP, HDAMP
COMMON /C3D/ CURVZ, BS, BETAZ(101)
COMMON /REFVALG/ EMUSHOK
DIMENSION TAMP(101)
IZMOM=0
NTIMES=0
1 CONTINUE
WRITE (6,8)
WRITE (6,9) DELTA, DELBA, REY
WRITE (6,10)
DO 2 I=1,N
WRITE (6,11) ETA(I), Y(I), QR(I), CAPH(I), V(I), EMU(I), PRAN(I), YOYS(I)
2 CONTINUE
WRITE (6,12)
DO 3 I=1,N
WRITE (6,13) ETA(I), ROV(I), A(I), P(I), RO(I), XNRC(I), H(I), XNH(I)
3 CONTINUE
WRITE (6,14)
DO 4 I=1,N
WRITE (6,13) ETA(I), T(I), AMFC(I), AMFN(I), AMFO(I), AMFH(I), AFOR(I), B
1(I)
4 CONTINUE
CALL SET (N,RCV,TAMP)
CALL MASS
ICCNT=ITEST(N,ROV,TAMP,EROV)
CALL SET (N,P,TAMP)
CALL YMOMNTM
IYMOM=ITEST(N,P,TAMP,EP)
CALL SPECIES
CALL VISPRAN
CALL SET (N,A,TAMP)
CALL XMOMNTM (A,BETA,CURV)
IXMOM=ITEST(N,A,TAMP,EA)
IF (IDIM.NE.3) GO TO 5
CALL SET (N,B,TAMP)
CALL XMOMNTM (A,BETAZ,CURVZ)
IZMOM=ITEST(N,B,TAMP,EA)
5 CONTINUE
CALL ENERGY
IF ((ICCNT.NE.0).OR.(IYMOM.NE.0).OR.(IXMOM.NE.0).OR.(IZMOM.NE.0))
1GO TO 6
GO TO 7
6 NTIMES=NTIMES+1
IF (NTIMES.LE.MAXTIME) GO TO 1

```

APPENDIX A - Continued

|    |   |       |
|----|---|-------|
|    | WRITE (6,16)  | F 73  |
|    | STOP  | F 74  |
| 7  | CONTINUE  | F 75  |
|    | WRITE (6,15)  | F 76  |
|    | RETURN  | F 77  |
| C  |   | F 78  |
| C  |   | F 79  |
| 8  | FORMAT (1H1,////11X,13HFLOW PROFILES)                               | F 80  |
| 9  | FORMAT (///5X,6HDELTA=E16.8,2X,6HDELB=A=E16.8,2X,4HREY=E16.8/)      | F 81  |
| 10 | FORMAT (4X,6HETA(I),9X,4HY(I),10X,5HQ(R(I),8X,7HCAPH(I),10X,4HV(I), | F 82  |
|    | 19X,6HEMU(I),8X,7HPRAN(I),8X,7HYOYS(I))                             | F 83  |
| 11 | FORMAT (8E14.6)   | F 84  |
| 12 | FORMAT (4X,6HETA(I),8X,6HROV(I),9X,4HA(I),10X,4HP(I),10X,5HRO(I),8  | F 85  |
|    | 1X,7HXNRO(I),9X,4HH(I),9X,6HXNH(I))                                 | F 86  |
| 13 | FORMAT (8E14.6)   | F 87  |
| 14 | FORMAT (4X,6HETA(I),9X,4HT(I),9X,7HAMFC(I),8X,7HAMFN(I),8X,7HAMFO(  | F 88  |
|    | 1I),6X,7HAMFH(I),7X,7HAFOR(I),7X,4HB(I))                            | F 89  |
| 15 | FORMAT (5X,23HFLOW SOLUTION CONVERGED)                              | F 90  |
| 16 | FORMAT (5X,27HFLOW SOLUTION NOT CONVERGED)                          | F 91  |
|    | END   | F 92- |

|   |   |       |
|---|---|-------|
|   | SUBROUTINE CHEXRO (ICXRO)   | G 1   |
|   | COMMON /CH/ H(101)  | G 2   |
|   | COMMON /CP/ P(101)  | G 3   |
|   | COMMON /CRO/ RC(101)  | G 4   |
|   | COMMON /CXRO/ XNRO(101)   | G 5   |
|   | COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)                        | G 6   |
|   | COMMON /MISCL/ N, IDIM, CURV, DETA, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX | G 7   |
|   | ITIME, MLDIFPT, NIC, ERO  | G 8   |
|   | COMMON /DAMP/ IRODAMP, RODAMP, HDAMP  | G 9   |
|   | DIMENSION ABRAT(101), RATIO(101)  | G 10  |
|   | DIMENSION PP(101), HP(101)  | G 11  |
|   | DIMENSION AMFCP(100), AMFNP(100), AMFOP(100)                                  | G 12  |
|   | EXTERNAL RHOSY  | G 13  |
|   | ICXRO=0   | G 14  |
|   | CALL SET (N, AMFC, AMFCP)   | G 15  |
|   | CALL SET (N, AMFN, AMFNP)   | G 16  |
|   | CALL SET (N, AMFO, AMFOP)   | G 17  |
|   | TGUES=4000.   | G 18  |
|   | DO 1 I=1, N   | G 19  |
|   | CALL DIMPROP (P(I), H(I), PP(I), HP(I))                                       | G 20  |
|   | XNRO(I)=RHOSY(PP(I), HP(I))*3.483E-07, AMFCP(I), AMFNP(I), AMFOP(I), TGU      | G 21  |
|   | IES)  | G 22  |
| 1 | CONTINUE  | G 23  |
|   | DO 2 I=1, N   | G 24  |
|   | RATIO(I)=(XNRC(I)-RO(I))/XNRO(I)  | G 25  |
|   | ABRAT(I)=ABS(RATIO(I))  | G 26  |
|   | IF (ABRAT(I).GT.ERO) ICXRO=1  | G 27  |
| 2 | CONTINUE  | G 28  |
|   | IF (IRODAMP.GT.0) GO TO 4   | G 29  |
|   | DO 3 I=1, N   | G 30  |
| 3 | RO(I)=XNRO(I)   | G 31  |
|   | IRODAMP=1   | G 32  |
|   | GO TO 6   | G 33  |
| 4 | CONTINUE  | G 34  |
|   | DO 5 I=1, N   | G 35  |
|   | RO(I)=RGDAMP*RO(I)+(1.-RGDAMP)*XNRO(I)  | G 36  |
| 5 | CONTINUE  | G 37  |
| 6 | CONTINUE  | G 38  |
|   | RETURN  | G 39  |
|   | END   | G 40- |

APPENDIX A - Continued

|    |   |   |     |
|----|---|---|-----|
|    | SUBROUTINE MASS   | H | 1   |
|    | COMMON /CA/ A(101),B(101)   | H | 2   |
|    | COMMON /CETA/ ETA(101)  | H | 3   |
|    | COMMON /CY/ Y(101),YOYS(101)  | H | 4   |
|    | COMMON /CRO/ RO(101)  | H | 5   |
|    | COMMON /CROV/ ROV(101)  | H | 6   |
|    | COMMON /CSCH/ SCH(101),SCI(101)   | H | 7   |
|    | COMMON /CTEMP/ TEMP(101),TIMP(101)                                      | H | 8   |
|    | COMMON /CV/ V(101)  | H | 9   |
|    | COMMON /MISCL/ N, IDIM, CURV, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX | H | 10  |
|    | 1 TIME, MLDIFPT, NIC, ERO   | H | 11  |
|    | COMMON /FRSTRM/ HIN, PIN, RHOINP, UINP, RB                              | H | 12  |
|    | COMMON /RADCOMP/ DELBA, IRFLUX  | H | 13  |
|    | COMMON /C3D/ CURVZ, BS, BETAZ(101)                                      | H | 14  |
| C  |   | H | 15  |
| C  | MASS CONSERVATION PACKAGE   | H | 16  |
| C  | COMPRESSIBLE ETA TRANSFORMATION   | H | 17  |
| C  |   | H | 18  |
|    | IF (IDIM.EQ.2) GO TO 2  | H | 19  |
|    | IF (IDIM.EQ.3) GO TO 4  | H | 20  |
|    | DO 1 I=1,N  | H | 21  |
| 1  | TEMP(I)=A(I)  | H | 22  |
|    | GO TO 6   | H | 23  |
| 2  | DO 3 I=1,N  | H | 24  |
| 3  | TEMP(I)=2.*A(I)*SCH(I)  | H | 25  |
|    | GO TO 6   | H | 26  |
| 4  | DO 5 I=1,N  | H | 27  |
| 5  | TEMP(I)=A(I)*SCH(I)+B(I)*SCI(I)   | H | 28  |
| 6  | CONTINUE  | H | 29  |
|    | CALL TINT (N, DELTA, TEMP, TIMP)  | H | 30  |
|    | IF (IDIM.EQ.2) GO TO 7  | H | 31  |
|    | IF (IDIM.EQ.3) GO TO 9  | H | 32  |
|    | CALL SET (N, SCH, TEMP)   | H | 33  |
|    | GO TO 11  | H | 34  |
| 7  | DO 8 I=1,N  | H | 35  |
| 8  | TEMP(I)=SCH(I)**2   | H | 36  |
|    | GO TO 11  | H | 37  |
| 9  | DO 10 I=1,N   | H | 38  |
| 10 | TEMP(I)=SCH(I)*SCI(I)   | H | 39  |
| 11 | CONTINUE  | H | 40  |
|    | DELTA=(TEMP(N)-ROV(1))/TIMP(N)  | H | 41  |
|    | DO 12 I=1,N   | H | 42  |
| 12 | ROV(I)=(DELTA*TIMP(I)+ROV(1))/TEMP(I)                                   | H | 43  |
|    | DO 13 I=1,N   | H | 44  |
| C  |   | H | 46  |
| C  | MASS CONSERVATION SATISFIED   | H | 47  |
| C  |   | H | 48  |
| 13 | V(I)=ROV(I)/RC(I)   | H | 45  |
|    | DO 14 I=1,N   | H | 49  |
| 14 | TEMP(I)=1./RO(I)  | H | 50  |
|    | CALL TINT (N, DELTA, TEMP, TIMP)  | H | 51  |
|    | DO 15 I=1,N   | H | 52  |
|    | Y(I)=DELTA*TIMP(I)  | H | 53  |
|    | SCH(I)=1.+CURV*DELTA*TIMP(I)  | H | 54  |
| 15 | CONTINUE  | H | 55  |
|    | DO 16 I=1,N   | H | 56  |
|    | YOYS(I)=Y(I)/Y(N)   | H | 57  |
| 16 | CONTINUE  | H | 58  |
|    | DELBA=Y(N)*RB   | H | 59  |
|    | IF (IDIM.EQ.2) GO TO 18   | H | 60  |
|    | IF (IDIM.EQ.3) GO TO 20   | H | 61  |
|    | DO 17 I=1,N   | H | 62  |
| 17 | SCI(I)=1.   | H | 63  |
|    | GO TO 22  | H | 64  |
| 18 | DO 19 I=1,N   | H | 65  |
| 19 | SCI(I)=SCH(I)   | H | 66  |
|    | GO TO 22  | H | 67  |
| 20 | DO 21 I=1,N   | H | 68  |
| 21 | SCI(I)=1.+CURVZ*DELTA*TIMP(I)   | H | 69  |
| 22 | CONTINUE  | H | 70  |
|    | RETURN  | H | 71  |
|    | END   | H | 72- |

APPENDIX A – Continued

|   |   |   |     |
|---|---|---|-----|
|   | SUBROUTINE YMCMATM  | I | 1   |
|   | COMMON /CETA/ ETA(101)  | I | 2   |
|   | COMMON /CP/ P(101)  | I | 3   |
|   | COMMON /CRO/ RO(101)  | I | 4   |
|   | COMMON /CROV/ RCV(101)  | I | 5   |
|   | COMMON /CDV/ CV(101)  | I | 6   |
|   | COMMON /CTEMP/ TEMP(101),DP(101)  | I | 7   |
|   | COMMON /CV/ V(101)  | I | 8   |
|   | COMMON /MISCL/ N, IDIM, CURV, DETA, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX | I | 9   |
|   | 1TIME,MLDIFPT,NIC,ERC   | I | 10  |
| C | THIS SUBROUTINE INTEGRATES THE Y MOMENTUM EQUATION TO GIVE                    | I | 11  |
| C | P(Y)  | I | 12  |
|   | CALL DIFT (V,ETA,DV,N)  | I | 13  |
|   | DO 1 I=1,N  | I | 14  |
| 1 | TEMP(I)=ROV(I)*DV(I)  | I | 15  |
|   | CALL TINT (N,DETA,TEMP,DP)  | I | 16  |
|   | PSTAG=PSHOCK+DP(N)  | I | 17  |
|   | DO 2 I=1,N  | I | 18  |
|   | P(I)=PSTAG-DP(I)  | I | 19  |
| 2 | CONTINUE  | I | 20  |
|   | RETURN  | I | 21  |
|   | END   | I | 22- |



APPENDIX A – Continued

|   |   |   |    |
|---|---|---|----|
|   | SUBRCUTINE SPECIES  | J | 1  |
|   | COMMON /CRO/ RO(101)  | J | 2  |
|   | COMMON /CT/ T(101)  | J | 3  |
|   | COMMON /CETA/ ETA(101)  | J | 4  |
|   | COMMON /CROV/ ROV(101)  | J | 5  |
|   | COMMON /CSCH/ SCH(101),SCI(101)                                     | J | 6  |
|   | COMMON /CD12/ D12(101)  | J | 7  |
|   | COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)              | J | 8  |
|   | COMMON /CFORONC/ AFOR(201),AONC(201)                                | J | 9  |
|   | COMMON /MISCL/ N, IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX | J | 10 |
|   | ITIME,MLDIFPT,NIC,ERO   | J | 11 |
|   | COMMON /MFINJ/ ALPINJC,ALPINJN,ALPINJO,ALPINJH                      | J | 12 |
|   | COMMON /MFINF/ ALPINFC,ALPINFN,ALPINFO,ALPINFH                      | J | 13 |
|   | DIMENSION AS(101), BS(101), CS(101), DS(101)                        | J | 14 |
|   | DIMENSION RK(201), D12K(201), RVK(201), SHK(201)                    | J | 15 |
|   | DIMENSION ETADIF(201), AK(201), BK(201), CK(201), DK(201)           | J | 16 |
|   | DIMENSION DI(201), CO(201)  | J | 17 |
|   | CALL DIFCOEF  | J | 18 |
|   | AINF=1.0  | J | 19 |
|   | AINJ=1.0  | J | 20 |
|   | NLI=N-1   | J | 21 |
|   | DO 1 I=1,N  | J | 22 |
|   | DI(I)=SCH(I)*RO(I)*RO(I)*D12(I)*SCI(I)                              | J | 23 |
| 1 | CO(I)=DETA*SCH(I)*ROV(I)*SCI(I)                                     | J | 24 |
| C | BOUNDARY CONDITIONS   | J | 25 |
| C | DIFFUSION OF SHOCK LAYER SPECIES TO WALL PERMITTED                  | J | 26 |
|   | AS(1)=0.  | J | 27 |
|   | BS(1)=-DI(1)+CO(1)*DELTA  | J | 28 |
|   | CS(1)=DI(1)   | J | 29 |
|   | DS(1)=DELTA*CO(1)*AINJ  | J | 30 |
|   | AS(N)=0.  | J | 31 |
|   | BS(N)=1.0   | J | 32 |
|   | CS(N)=0.  | J | 33 |
|   | DS(N)=0   | J | 34 |
| C |   | J | 35 |
|   | DO 2 I=2,NLI  | J | 36 |
|   | SIGN=0.   | J | 37 |
|   | IF (ROV(I).GT.0.) SIGN=1.0  | J | 38 |
|   | AS(I)=DI(I-1)+DI(I)-2.*CO(I)*DELTA*(1.-SIGN)                        | J | 39 |
|   | BS(I)=-DI(I-1)+2*DI(I)+DI(I+1)                                      | J | 40 |
|   | BS(I)=BS(I)+2.*CO(I)*DELTA*(1.-SIGN)-2.*CO(I)*DELTA*SIGN            | J | 41 |
|   | CS(I)=DI(I)+DI(I+1)+2.*CO(I)*DELTA*SIGN                             | J | 42 |
| 2 | DS(I)=0.  | J | 43 |
|   | CALL TRIDIAG (N,AS,BS,CS,DS)  | J | 44 |
|   | DO 3 I=1,N  | J | 45 |
|   | AFOR(I)=DS(I)   | J | 46 |
| 3 | AONC(I)=1.-AFOR(I)  | J | 47 |
|   | DO 7 I=1,N  | J | 48 |
|   | IF (AFOR(I).LT.1.E-06) 4,5  | J | 49 |
| 4 | WRITE (6,10)  | J | 50 |
|   | WRITE (6,11) ETA(I),AFOR(I)   | J | 51 |
|   | AFOR(I)=0.  | J | 52 |
|   | AONC(I)=1.0   | J | 53 |
| 5 | CONTINUE  | J | 54 |
|   | IF (AFOR(I).GT..999999) 6,7   | J | 55 |
| 6 | WRITE (6,12)  | J | 56 |
|   | WRITE (6,11) ETA(I),AFOR(I)   | J | 57 |
|   | AFOR(I)=1.0   | J | 58 |
|   | AONC(I)=0.  | J | 59 |
|   | WRITE (6,11)  | J | 60 |
| 7 | CONTINUE  | J | 61 |
|   | DO 8 I=1,N  | J | 62 |
|   | AMFC(I)=AFOR(I)*ALPINJC+AONC(I)*ALPINFC                             | J | 63 |
|   | AMFN(I)=AFOR(I)*ALPINJN+AONC(I)*ALPINFN                             | J | 64 |
|   | AMFO(I)=AFOR(I)*ALPINJO+AONC(I)*ALPINFO                             | J | 65 |
|   | AMFH(I)=AFOR(I)*ALPINJH+AONC(I)*ALPINFH                             | J | 66 |
|   | AMFC(I)=AMFC(I)/(AMFC(I)+AMFN(I)+AMFO(I)+AMFH(I))                   | J | 67 |
|   | AMFN(I)=AMFN(I)/(AMFC(I)+AMFN(I)+AMFO(I)+AMFH(I))                   | J | 68 |
|   | AMFO(I)=AMFO(I)/(AMFC(I)+AMFN(I)+AMFO(I)+AMFH(I))                   | J | 69 |
| 8 | AMFH(I)=AMFH(I)/(AMFC(I)+AMFN(I)+AMFO(I)+AMFH(I))                   | J | 70 |
|   | WRITE (6,13)  | J | 71 |

APPENDIX A - Continued

|    |  |       |
|----|--|-------|
|    | DO 9 I=1,N   | J 72  |
| 9  | WRITE (6,14) ETA(I),AMFC(I),AMFN(I),AMFO(I),AMFH(I)                | J 73  |
|    | RETURN   | J 74  |
| C  |  | J 75  |
| C  |  | J 76  |
| 10 | FORMAT (1H0,5X,24HAFOR(I) LESS THAN 1.E-06)                        | J 77  |
| 11 | FORMAT (2E14.6)  | J 78  |
| 12 | FORMAT (1H0,5X,28HAFOR(I) GREATER THAN .999999)                    | J 79  |
| 13 | FORMAT (//10X,18HELEMENTAL PROFILES/5X,6HETA(I),6X,9HCARBON(I),4X, | J 80  |
|    | 111HNITROGEN(I),3X,9HOXYGEN(I),5X,11HHYDROGEN(I)/)                 | J 81  |
| 14 | FORMAT (8E14.6)  | J 82  |
|    | END  | J 83- |

APPENDIX A – Continued

|   |  |   |    |
|---|--|---|----|
|   | SUBROUTINE XMOMNTM (A,BETA,Q)  | K | 1  |
|   | COMMON /CETA/ ETA(101)   | K | 2  |
|   | COMMON /CRO/ RO(101)   | K | 3  |
|   | COMMON /CROV/ RCV(101)   | K | 4  |
|   | COMMON /CDV/ CV(101)   | K | 5  |
|   | COMMON /CEMU/ EMU(101)   | K | 6  |
|   | COMMON /CROMU/ ROMU(101)   | K | 7  |
|   | COMMON /CSCH/ SCH(101),SCI(101)                                      | K | 8  |
|   | COMMON /MISCL/ N,IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX   | K | 9  |
|   | ITIME,MLDIFPT,NIC,ERO  | K | 10 |
| C |  | K | 11 |
| C | THIS SUBROUTINE SOLVES THE VISCID X MOMENTUM EQUATION                | K | 12 |
| C |  | K | 13 |
|   | DIMENSION AM(101), BM(101), CM(101), DM(101), A(101), BETA(101), T   | K | 14 |
|   | LUMP(101), TIMP(101), AVM(101), BVM(101), CVM(101), DVM(101)         | K | 15 |
|   | DIMENSION DEL(101)   | K | 16 |
|   | TEMP=1./(2.*DELTA*DETA)  | K | 17 |
|   | NL1=N-1  | K | 18 |
|   | DELT=1./(2.*REY*DELTA*DETA*DETA)                                     | K | 19 |
|   | A(1)=0.  | K | 20 |
|   | NTIMES=0   | K | 21 |
|   | NXIT=10  | K | 22 |
|   | EPSX=.01   | K | 23 |
| 1 | CONTINUE   | K | 24 |
|   | IF (NTIMES.LT.NXIT) GO TO 2  | K | 25 |
|   | WRITE (6,8)  | K | 26 |
|   | STOP   | K | 27 |
| 2 | CONTINUE   | K | 28 |
|   | NTIMES=NTIMES+1.   | K | 29 |
|   | AM(1)=0.   | K | 30 |
|   | AM(N)=0.   | K | 31 |
|   | BM(1)=1.   | K | 32 |
|   | BM(N)=1.   | K | 33 |
|   | CM(1)=0.   | K | 34 |
|   | CM(N)=0.   | K | 35 |
|   | DM(1)=0.   | K | 36 |
|   | DM(N)=0.   | K | 37 |
|   | AVM(1)=0.  | K | 38 |
|   | AVM(N)=0.  | K | 39 |
|   | BVM(1)=1.  | K | 40 |
|   | BVM(N)=1.  | K | 41 |
|   | CVM(1)=0.  | K | 42 |
|   | CVM(N)=0.  | K | 43 |
|   | DVM(1)=0.  | K | 44 |
|   | DVM(N)=0.  | K | 45 |
|   | TUMP(1)=0.   | K | 46 |
|   | TIMP(1)=0.0  | K | 47 |
|   | DO 3 I=2,NL1   | K | 48 |
|   | CM(I)=-ROV(I)*TEMP*SCI(I)*RO(I)                                      | K | 49 |
|   | AM(I)=-CM(I)   | K | 50 |
| 3 | CONTINUE   | K | 51 |
|   | DO 4 I=1,N   | K | 52 |
| 4 | TUMP(I)=1./RO(I)   | K | 53 |
|   | CALL TINT (N,DETA,TUMP,TIMP)   | K | 54 |
|   | DO 5 I=1,N   | K | 55 |
|   | ROMU(I)=RO(I)*EMU(I)   | K | 56 |
| 5 | DEL(I)=DELT*SCI(I)*RO(I)   | K | 57 |
|   | DO 6 I=2,NL1   | K | 58 |
|   | BM(I)=2.*RO(I)*A(I)-ROV(I)*Q   | K | 59 |
|   | DM(I)=BETA(I)-RO(I)*A(I)**2+ROV(I)*(A(I+1)-A(I-1))*TEMP*SCI(I)*RO(I) | K | 60 |
|   | +ROV(I)*A(I)*Q   | K | 61 |
|   | AVM(I)=- (ROMU(I-1)+ROMU(I))*DEL(I)/DELTA                            | K | 62 |
|   | BVM(I)=(ROMU(I-1)+2.*ROMU(I)+ROMU(I+1))*DEL(I)/DELTA                 | K | 63 |
|   | CVM(I)=- (ROMU(I)+ROMU(I+1))*DEL(I)/DELTA                            | K | 64 |
|   | DVM(I)=-AVM(I)*A(I-1)-BVM(I)*A(I)-CVM(I)*A(I+1)                      | K | 65 |
|   | AM(I)=AM(I)+AVM(I)   | K | 66 |
|   | BM(I)=BM(I)+BVM(I)   | K | 67 |
|   | CM(I)=CM(I)+CVM(I)   | K | 68 |
|   | DM(I)=DM(I)+DVM(I)   | K | 69 |
| 6 | CONTINUE   | K | 70 |

## APPENDIX A - Continued

|   |  |       |
|---|--|-------|
|   | CALL TRIDIAG (N,AM,8M,CM,DM)                 | K 71  |
|   | IGOR=0                                       | K 72  |
|   | DO 7 I=1,N                                   | K 73  |
|   | A(I)=A(I)+DM(I)                              | K 74  |
|   | IF (ABS(DM(I)).LT.EPSX) GO TO 7              | K 75  |
|   | IGOR=IGOR+1                                  | K 76  |
| 7 | CONTINUE                                     | K 77  |
|   | IF (IGOR.NE.0) GO TO 1                       | K 78  |
|   | RETURN                                       | K 79  |
| C |  | K 80  |
| C |  | K 81  |
| 8 | FORMAT (10X,28HX MOMENTUM FAILS TO CONVERGE) | K 82  |
|   | ENC  | K 83- |

APPENDIX A – Continued

|   |   |   |    |
|---|---|---|----|
|   | SUBROUTINE ENERGY   | L | 1  |
| C |   | L | 2  |
| C | WINDWARD DIFFERENCE FORM OF ENERGY EQUATION                         | L | 3  |
| C |   | L | 4  |
| C | RO(I) IS UPDATED IN THIS SUBROUTINE BEFORE H IS UPDATED             | L | 5  |
|   | COMMON /CA/ A(101),B(101)   | L | 6  |
|   | COMMON /CY/ Y(101),YOYS(101)  | L | 7  |
|   | COMMON /CRO/ RO(101)  | L | 8  |
|   | COMMON /CETA/ ETA(101)  | L | 9  |
|   | COMMON /CV/ V(101)  | L | 10 |
|   | COMMON /CP/ P(101)  | L | 11 |
|   | COMMON /CT/ T(101)  | L | 12 |
|   | COMMON /CROV/ ROV(101)  | L | 13 |
|   | COMMON /CDV/ DV(101)  | L | 14 |
|   | COMMON /CSCH/ SCH(101),SCI(101)                                     | L | 15 |
|   | COMMON /CTEMP/ TEMP(101),TIMP(101)                                  | L | 16 |
|   | COMMON /CEMU/ EMU(101)  | L | 17 |
|   | COMMON /CROMU/ ROMU(101)  | L | 18 |
|   | COMMON /CPRAN/ PRAN(101)  | L | 19 |
|   | COMMON /CCAPH/ CAPH(101)  | L | 20 |
|   | COMMON /CH/ H(101)  | L | 21 |
|   | COMMON /CQR/ QR(101)  | L | 22 |
|   | COMMON /CDQR/ DQR(101)  | L | 23 |
|   | COMMON /CXH/ XNH(101)   | L | 24 |
|   | COMMON /RADCOMP/ DELBA,IRFLUX                                       | L | 25 |
|   | COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RE                              | L | 26 |
|   | COMMON /MISCL/ N,IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX  | L | 27 |
|   | 1TIME,MLDIFPT,NIC,ERO   | L | 28 |
|   | COMMON /DAMP/ IRODAMP,RODAMP,HDAMP                                  | L | 29 |
|   | DIMENSION AM(101), BM(101), CM(101), CM(101)                        | L | 30 |
|   | DIMENSION VIS(101), CONV(101), VG(101), SCHS(101)                   | L | 31 |
|   | DIMENSION DVM(101), DQRM(101)                                       | L | 32 |
|   | CALL RADARAY  | L | 33 |
|   | DO 1 I=1,N  | L | 34 |
|   | ROMU(I)=RO(I)*EMU(I)  | L | 35 |
| 1 | CONTINUE  | L | 36 |
|   | DO 2 I=1,N  | L | 37 |
|   | SCHS(I)=SCH(I)*SCI(I)   | L | 38 |
|   | VIS(I)=SCHS(I)*ROMU(I)/(PRAN(I)*DETA)                               | L | 39 |
|   | CONV(I)=DELTA*REY*SCHS(I)*ROV(I)                                    | L | 40 |
|   | VG(I)=VIS(I)*ROV(I)/RO(I)   | L | 41 |
| 2 | CONTINUE  | L | 42 |
|   | NLI=N-1   | L | 43 |
|   | DO 3 I=2,NLI  | L | 44 |
|   | SIGN=0.   | L | 45 |
|   | IF (ROV(I).GT.0.) SIGN=1.0  | L | 46 |
|   | AM(I)=VIS(I-1)+VIS(I)-2.*CONV(I)*(1.-SIGN)                          | L | 47 |
|   | BM(I)=- (VIS(I-1)+2.*VIS(I)+VIS(I+1))                               | L | 48 |
|   | BM(I)=BM(I)+2.*CONV(I)*(1.-SIGN)-2.*CONV(I)*SIGN                    | L | 49 |
|   | CM(I)=VIS(I)+VIS(I+1)+2.*CONV(I)*SIGN                               | L | 50 |
|   | DVM(I)=(VG(I-1)+VG(I))*V(I-1)-(VG(I-1)+2.*VG(I)+VG(I+1))*V(I)+(VG(I | L | 51 |
|   | I+1)+VG(I+1))*V(I+1)  | L | 52 |
|   | DQRM(I)=DELTA*REY*(-SCHS(I)*QR(I-1)+(-SCHS(I-1)+SCHS(I+1))*QR(I)+S  | L | 53 |
|   | CHS(I)*QR(I+1))   | L | 54 |
|   | DM(I)=DVM(I)+DQRM(I)  | L | 55 |
| 3 | CONTINUE  | L | 56 |
|   | AM(1)=0.  | L | 57 |
|   | AM(N)=0.  | L | 58 |
|   | BM(1)=1.  | L | 59 |
|   | BM(N)=1.  | L | 60 |
|   | CM(1)=0.  | L | 61 |
|   | CM(N)=0.  | L | 62 |
|   | DM(1)=HW+V(1)*V(1)/2.   | L | 63 |
|   | DM(N)=HIN   | L | 64 |
|   | CALL TRIDIAG (N,AM,BM,CM,DM)  | L | 65 |
|   | DO 4 I=1,N  | L | 66 |
|   | CAPH(I)=DM(I)   | L | 67 |
|   | XNH(I)=CAPH(I)-V(I)*V(I)/2.   | L | 68 |
|   | H(I)=HDAMP*H(I)+(1.-HDAMP)*XNH(I)                                   | L | 69 |
| 4 | CONTINUE  | L | 70 |

## APPENDIX A – Continued

|   |  |   |     |
|---|--|---|-----|
|   | DO 6 I=1,N                             | L | 71  |
|   | IF (H(I).LT.H(1)) 5,6                  | L | 72  |
| 5 | CONTINUE                               | L | 73  |
|   | WRITE (6,7)                            | L | 74  |
|   | WRITE (6,8) ETA(I),H(I)                | L | 75  |
|   | H(I)=H(1)                              | L | 76  |
| 6 | CONTINUE                               | L | 77  |
|   | RETURN                                 | L | 78  |
| C |  | L | 79  |
| C |  | L | 80  |
| 7 | FORMAT (1H0,5X,19HH(I) LESS THAN H(1)) | L | 81  |
| 8 | FORMAT (2E14.6)                        | L | 82  |
|   | END                                    | L | 83- |

APPENDIX A - Continued

```

SUBROUTINE RADARAY
C
C RADARAY GIVES THE RADIATION HEAT FLUX AT NIC POINTS
C AND LINEARLY INTERPOLATES FOR THE REMAINING N POINTS
C
C N MUST BE LESS THAN 100
C
COMMON /CRO/ RO(101)
COMMON /CETA/ ETA(101)
COMMON /CY/ Y(101),YOYS(101)
COMMON /CP/ P(101)
COMMON /CH/ H(101)
COMMON /CQR/ QR(101)
COMMON /CXRO/ XNRO(101)
COMMON /CT/ T(101)
COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100)
COMMON /RADCOMP/ DELBA,IRFLUX
COMMON /MISCL/ N,IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX
1 TIME,MLCIFT,NIC,ERO
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RE
COMMON /DAMP/ IRODAMP,RODAMP,HDAMP
DIMENSION PH(100),HH(100),ETAH(100),PHP(100),HHP(100),QRHP(10
10),RHOHP(100),NICN(100)
DIMENSION ETAN(100),QRP(100)
NN=N
DO 1 I=1,NN
ETAH(I)=Y(I)/Y(N)
PH(I)=P(I)
HH(I)=H(I)
CALL DIMPROP (PH(I),HH(I),PHP(I),HHP(I))
1 HHP(I)=HHP(I)*(.2389E-07)
NRAD=(NN-1)/(NIC-1)
DO 2 I=1,NIC
J=NRAD*(I-1)+1
ETAH(I)=ETAH(J)
2 CONTINUE
DO 3 I=1,NIC
NICN(I)=NRAD*(I-1)+1
3 IF (IRFLUX.LE.0) GO TO 6
CALL RATRAP (DELBA,NIC,NICN,NN,4000.0,ETAH,PHP,AMFC,AMFN,AMFO,HHP,
1 QRHP,1,2,RHOHP,1,T)
DO 4 I=1,NN
CALL FTLUP (ETAH(I),QRP(I),1,NIC,ETAN,QRHP)
4 CONTINUE
DO 5 I=1,N
5 QR(I)=QRP(I)/(RHOINP*UINP*UINP*UINP)+1.E+07
GO TO 8
6 CONTINUE
CALL RATRAP (DELBA,NIC,NICN,NN,4000.0,ETAH,PHP,AMFC,AMFN,AMFO,HHP,
1 QRHP,0,2,RHOHP,1,T)
DO 7 I=1,N
7 QR(I)=0.
8 CONTINUE
IF (IRODAMP.GT.0) GO TO 10
DO 9 I=1,N
9 RO(I)=RHOHP(I)/RHOINP
GO TO 13
10 CONTINUE
DO 11 I=1,N -
11 XNRO(I)=RHOHP(I)/RHOINP
DO 12 I=1,N
12 RO(I)=RODAMP*RO(I)+(1.-RODAMP)*XNRO(I)
13 CONTINUE
RETURN
END
M 1
M 2
M 3
M 4
M 5
M 6
M 7
M 8
M 9
M 10
M 11
M 12
M 13
M 14
M 15
M 16
M 17
M 18
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M 51
M 52
M 53
M 54
M 55
M 56
M 57
M 58
M 59
M 60
M 61
M 62
M 63
M 64
M 65
M 66-

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APPENDIX A - Continued

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SUBROUTINE PRINTIT                                N    1
C                                                    N    2
C                                                    N    3
C N MUST BE LESS THAN 100                        N    4
C                                                    N    5
COMMON /CRO/ RO(101)                             N    6
COMMON /CETA/ ETA(101)                           N    7
COMMON /CY/ Y(101),YOYS(101)                    N    8
COMMON /CP/ P(101)                               N    9
COMMON /CH/ H(101)                               N   10
COMMON /CQR/ QR(101)                             N   11
COMMON /CXRO/ XNRO(101)                          N   12
COMMON /CT/ T(101)                               N   13
COMMON /CAMFI/ AMFC(100),AMFN(100),AMFO(100),AMFH(100) N   14
COMMON /RADCOMP/ DELBA,IRFLUX                    N   15
COMMON /MISCL/ N, IDIM,CURV,DETA,DELTA,PSHOCK,REY,HW,EP,EROV,EA,MAX N   16
1 TIME,MLDIFPT,NIC,ERO                           N   17
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RB           N   18
COMMON /DAMP/ IRODAMP,RODAMP,HDAMP               N   19
DIMENSION PH(100), HH(100), ETAH(100), PHP(100), HHP(100), QRHP(10 N   20
10), RHOHP(100), NICN(100)                       N   21
DIMENSION ETAN(100), QRP(100)                    N   22
NN=N                                               N   23
DO 1 I=1,NN                                       N   24
ETAH(I)=Y(I)/Y(N)                                 N   25
PH(I)=P(I)                                        N   26
HH(I)=H(I)                                        N   27
CALL DIMPROP (PH(I),HH(I),PHP(I),HHP(I))         N   28
1 HHP(I)=HHP(I)*(.2389E-07)                       N   29
NRAD=(NN-1)/(NIC-1)                               N   30
DO 2 I=1,NIC                                      N   31
J=NRAD*(I-1)+1                                    N   32
ETAH(I)=ETAH(J)                                    N   33
2 CONTINUE                                         N   34
DO 3 I=1,NIC                                      N   35
3 NICN(I)=NRAD*(I-1)+1                            N   36
IF (IRFLUX.LE.0) GO TO 6                          N   37
CALL RATRAP (DELBA,NIC,NICN,NN,4000.0,ETAH,PHP,AMFC,AMFN,AMFO,HHP, N   38
1QRHP,1,2,RHOHP,0,T)                              N   39
WRITE (6,9)                                        N   40
DO 4 I=1,NN                                       N   41
CALL FTLUP (ETAH(I),QRP(I),2,NIC,ETAN,QRHP)      N   42
WRITE (6,10) ETA(I),Y(I),YOYS(I),QRP(I)          N   43
4 CONTINUE                                         N   44
DO 5 I=1,N                                         N   45
5 QR(I)=QRP(I)/(RHOINP*UINP*UINP*UINP)*1.E+07   N   46
GO TO 8                                            N   47
6 CONTINUE                                         N   48
CALL RATRAP (DELBA,NIC,NICN,NN,4000.0,ETAH,PHP,AMFC,AMFN,AMFO,HHP, N   49
1QRHP,0,2,RHOHP,0,T)                              N   50
DO 7 I=1,N                                         N   51
7 QR(I)=0.                                         N   52
8 CONTINUE                                         N   53
RETURN                                             N   54
C                                                    N   55
C                                                    N   56
9 FORMAT (4X,6HETA(I),9X,4HY(I),8X,7HYCYS(I),3X,15HQRAD(I),W/SQ CM) N   57
10 FORMAT (4E14.6)                                N   58
END                                                N   59-

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FUNCTION D2DP2 (X)                                O    1
COMMON /CD2DP2/ D2DP2C                            O    2
D2DP2=D2DP2C                                      O    3
RETURN                                             O    4
END                                                O    5-

```



APPENDIX A - Continued

|   |   |   |     |
|---|---|---|-----|
|   | SUBROUTINE DIFT (Y,X,DY,N)                                      | P | 1   |
|   | DIMENSION Y(101), X(101), DY(101)                               | P | 2   |
|   | DY(1)=(Y(2)-Y(1))/(X(2)-X(1))                                   | P | 3   |
|   | DY(N)=(Y(N)-Y(N-1))/(X(N)-X(N-1))                               | P | 4   |
|   | N1=N-1  | P | 5   |
|   | DO 1 I=2,N1   | P | 6   |
|   | X1=X(I-1)-X(I)  | P | 7   |
|   | X3=X(I+1)-X(I)  | P | 8   |
|   | DY(I)=((Y(I+1)-Y(I))*X1**2+(Y(I)-Y(I-1))*X3**2)/((X1-X3)*X1*X3) | P | 9   |
| 1 | CONTINUE  | P | 10  |
|   | RETURN  | P | 11  |
|   | END   | P | 12- |

|   |  |   |     |
|---|--|---|-----|
|   | SUBROUTINE TRIDIAG (N,A,B,C,D)             | Q | 1   |
|   | DIMENSION A(201), B(201), C(201), D(201)   | Q | 2   |
| C |  | Q | 3   |
| C | THIS ROUTINE SOLVES AX=D FOR A TRIDIAGONAL | Q | 4   |
|   |  | Q | 5   |
|   | N1=N-1                                     | Q | 6   |
|   | C(1)=C(1)/B(1)                             | Q | 7   |
|   | D(1)=D(1)/B(1)                             | Q | 8   |
|   | DO 1 M=2,N1                                | Q | 9   |
|   | D(M)=(D(M)-A(M)*D(M-1))/(B(M)-A(M)*C(M-1)) | Q | 10  |
| 1 | C(M)=C(M)/(B(M)-A(M)*C(M-1))               | Q | 11  |
|   | D(N)=(D(N)-A(N)*D(N-1))/(B(N)-A(N)*C(N-1)) | Q | 12  |
|   | DO 2 J=2,N                                 | Q | 13  |
|   | M=N+1-J                                    | Q | 14  |
| 2 | D(M)=D(M)-C(M)*D(M+1)                      | Q | 15  |
|   | RETURN                                     | Q | 16  |
|   | END  | Q | 17- |

|   |                          |   |    |
|---|--------------------------|---|----|
|   | SUBROUTINE SET (N,A,B)   | R | 1  |
|   | DIMENSION A(101), B(101) | R | 2  |
|   | DO 1 I=1,N               | R | 3  |
| 1 | B(I)=A(I)                | R | 4  |
|   | RETURN                   | R | 5  |
|   | END                      | R | 6- |

|   |  |   |    |
|---|--|---|----|
|   | FUNCTION ITEST (N,A,B,E)               | S | 1  |
|   | DIMENSION A(101), B(101)               | S | 2  |
|   | ITEST=0                                | S | 3  |
|   | DO 1 J=1,N                             | S | 4  |
| 1 | IF (ABS(A(J)-B(J)).GT.E) ITEST=ITEST+1 | S | 5  |
|   | RETURN                                 | S | 6  |
|   | END                                    | S | 7- |

APPENDIX A - Continued

```

SUBROUTINE DIFCOEF
COMMON /CETA/ ETA(101)
COMMON /CP/ P(101)
COMMON /CH/ H(101)
COMMON /CT/ T(101)
COMMON /CD12/ D12(101)
COMMON /MISCL/ N, IDIM, CURV, DETA, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX
ITIME, MLDIFPT, NIC, ERO
COMMON /FRSTRM/ HIN, PIN, RHCINP, UINP, RB
COMMON /COING11/ TSTR(18), OMEGA11(18)
DIMENSION TST(101), OMEG(101)
DIMENSION PHP(101), HHP(101)
REAL M1, M2, M12
C BINARY DIFFUSION COEFFICIENT
C 1-ATOMIC NITROGEN
C 2-ATOMIC HYDROGEN
M1=14.01
M2=1.008
SIGMA1=3.298
SIGMA2=2.708
EPSOK1=71.4
EPSOK2=37.0
SIGMA12=.5*(SIGMA1+SIGMA2)
EPSOK12=SQRT(EPSOK1*EPSOK2)
DO 1 I=1, N
TST(I)=T(I)/EPSOK12
CALL FTLUP (TST(I), OMEG(I), -1, 18, TSTR, OMEGA11)
1 CONTINUE
DO 2 I=1, N
CALL DIMPROP (P(I), H(I), PHP(I), HHP(I))
2 CONTINUE
M12=(M1+M2)/(2.*M1*M2)
M12=SQRT(M12)
CC=0.002628*M12/(SIGMA12*SIGMA12)
DO 3 I=1, N
D12(I)=CC/(PHP(I)*OMEG(I))*(T(I))**1.5/(RB*UINP)
3 CONTINUE
RETURN
END

```

```

T 1
T 2
T 3
T 4
T 5
T 6
T 7
T 8
T 9
T 10
T 11
T 12
T 13
T 14
T 15
T 16
T 17
T 18
T 19
T 20
T 21
T 22
T 23
T 24
T 25
T 26
T 27
T 28
T 29
T 30
T 31
T 32
T 33
T 34
T 35
T 36
T 37
T 38
T 39-

```

```

SUBROUTINE VISPRAN
COMMON /CP/ P(101)
COMMON /CH/ H(101)
COMMON /CT/ T(101)
COMMON /CEMU/ EMU(101)
COMMON /CPRAN/ PRAN(101)
COMMON /CETA/ ETA(101)
COMMON /FRSTRM/ HIN, PIN, RHOINP, UINP, RB
COMMON /MISCL/ N, IDIM, CURV, DETA, DELTA, PSHOCK, REY, HW, EP, EROV, EA, MAX
ITIME, MLDIFPT, NIC, ERO
COMMON /REFVALU/ EMUSHOK
DIMENSION PP(101), HP(101), TP(101)
EXTERNAL VISCCS
EXTERNAL PRANDTL
DO 1 I=1, N
TP(I)=T(I)
CALL DIMPROP (P(I), H(I), PP(I), HP(I))
EMU(I)=VISCCS(TP(I), PP(I))
EMU(I)=EMU(I)/EMUSHOK
PRAN(I)=PRANDTL(TP(I), PP(I))
1 CONTINUE
RETURN
END

```

```

U 1
U 2
U 3
U 4
U 5
U 6
U 7
U 8
U 9
U 10
U 11
U 12
U 13
U 14
U 15
U 16
U 17
U 18
U 19
U 20
U 21
U 22
U 23-

```

APPENDIX A - Continued

```

FUNCTION RHOSY (P,H,AFC,AFN,AFO,TGUES)
C
C      P ATMOSPHERES,H DEGREES K, RHOSY AMAGATS
C
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RB
C
C      INPUTS TO RHOSY P ATMOSPHERES,H DEGREES K
C      INPUTS TO RATRAP P ATMOSPHERES,H CAL/GM
C      OUTPUT FROM RATRAP RHOSY GM/CC
C
CALL RATRAP (1.,1,1,1,TGUES,0.,P,AFC,AFN,AFO,H/(3.483*4.19),QR,0.2
1,RHOSY,1,T)
TGUES=T
RHOSY=RHOSY/RHOINP
RETURN
END

```

```

V 1
V 2
V 3
V 4
V 5
V 6
V 7
V 8
V 9
V 10
V 11
V 12
V 13
V 14
V 15
V 16-

```

```

FUNCTION VISCOS (AT,AP)
COMMON /HANSEN/ TABT(31),TABPLOG(6),TABZH(186),TABZ(186),TABPR(186
1),TEMURAT(186)
EXTERNAL RHOSY
C      INPUT T TEMPERATURE,DEG.K
C      P PRESSURE,ATM
C      OUTPUT VISCOSITY,GM/CM/SEC
T=AT
P=AP
PLOG=ALOG10(P)
CALL DISCOT (T,PLOG,TABT,TEMURAT,TABPLOG,21,186,6,VISCOS)
IF (T.LE.15000.) GO TO 1
WRITE (6,2) T
1 VISCOS=VISCOS*(1.462E-5)*SQRT(T)/(1.+112./T)
RETURN
C
C
2 FORMAT (6X,25HTEMPERATURE TOO LARGE. T=E16.6,5HDEG.K)
END

```

```

W 1
W 2
W 3
W 4
W 5
W 6
W 7
W 8
W 9
W 10
W 11
W 12
W 13
W 14
W 15
W 16
W 17
W 18
W 19-

```

```

FUNCTION PRANDTL (AT,AP)
COMMON /HANSEN/ TABT(31),TABPLOG(6),TABZH(186),TABZ(186),TABPR(186
1),TEMURAT(186)
C      INPUT T TEMPERATURE,DEG.K
C      P PRESSURE ATMOS
T=AT
P=AP
PLOG=ALOG10(P)
CALL DISCOT (T,PLOG,TABT,TABPR,TABPLOG,21,186,6,PRAN)
PRANDTL=PRAN
IF (T.LE.15000.) GO TO 1
WRITE (6,2) T
1 RETURN
C
C
2 FORMAT (6X,25HTEMPERATURE TOO LARGE. T=E16.6,5HDEG.K)
END

```

```

X 1
X 2
X 3
X 4
X 5
X 6
X 7
X 8
X 9
X 10
X 11
X 12
X 13
X 14
X 15
X 16
X 17-

```

APPENDIX A - Continued

|   |  |   |    |
|---|--|---|----|
|   | BLOCK DATA   | Y | 1  |
|   | COMMON /HANSEN/ TABT(31),TABPLOG(6),TABZH(186),TABZ(186),TABPR(186         | Y | 2  |
|   | 1),TEMURAT(186)  | Y | 3  |
|   | COMMON /COING11/ TSTR(18),OMEGA11(18)                                      | Y | 4  |
| C | T TEMPERATURE DEGREES K  | Y | 5  |
| C | P PRESSURE, ATM  | Y | 6  |
|   | DATA TABT/100.,500.,1000.,1500.,2000.,2500.,3000.,3500.,4000.,4500         | Y | 7  |
|   | 1.,5000.,5500.,6000.,6500.,7000.,7500.,8000.,8500.,9000.,9500.,1000        | Y | 8  |
|   | 20.,10500.,11000.,11500.,12000.,12500.,13000.,13500.,14000.,14500.,        | Y | 9  |
|   | 31500./  | Y | 10 |
|   | DATA TABPLOG/-4.,-3.,-2.,-1.,0.,1./  | Y | 11 |
|   | DATA TABZH/3.52,3.52,3.65,3.80,4.41,8.02,8.19,8.03,9.82,16.80,23.4         | Y | 12 |
|   | 16,23.58,22.54,21.93,22.29,24.26,28.65,35.75,43.74,49.15,50.96,50.6        | Y | 13 |
|   | 24,49.48,48.07,46.64,45.26,43.97,42.76,41.64,40.58,39.60,3.52,3.52,        | Y | 14 |
|   | 33.65,3.80,4.07,6.16,8.02,7.77,8.09,10.55,16.68,21.58,21.97,21.24,2        | Y | 15 |
|   | 40.69,20.72,21.65,23.85,27.66,33.00,38.79,43.28,45.57,46.09,45.64,4        | Y | 16 |
|   | 54.74,43.69,42.61,41.55,40.53,39.57,2*3.52,3.65,3.80,3.97,4.81,7.13        | Y | 17 |
|   | 6,7.62,7.53,8.14,10.48,15.14,19.30,20.35,20.01,19.54,19.34,19.60,20        | Y | 18 |
|   | 7.49,22.17,24.78,28.28,32.31,36.13,39.01,40.66,41.26,41.17,40.69,40        | Y | 19 |
|   | 8.01,39.24,2*3.52,3.65,3.80,3.93,4.27,5.55,7.08,7.28,7.33,7.96,9.73        | Y | 20 |
|   | 9,12.93,16.46,18.34,18.66,18.43,18.17,18.09,18.29,18.85,19.84,21.31        | Y | 21 |
|   | \$,23.28,25.69,28.36,30.99,33.27,34.97,36.02,36.53,2*3.52,3.65,3.80,       | Y | 22 |
|   | \$3.92,4.09,4.61,5.75,6.74,6.98,7.10,7.58,8.70,10.64,13.20,15.48,16.       | Y | 23 |
|   | \$73,17.09,17.04,16.91,16.84,16.90,17.13,17.57,18.24,19.16,20.32,21.       | Y | 24 |
|   | \$72,23.29,24.98,26.66,2*3.52,3.65,3.80,3.92,4.03,4.25,4.75,5.56,6.2       | Y | 25 |
|   | \$9,6.62,6.80,7.11,7.72,8.76,10.24,11.99,13.63,14.79,15.40,15.61,15.       | Y | 26 |
|   | \$64,15.60,15.58,15.62,15.74,15.96,16.28,16.71,17.26,17.92/                | Y | 27 |
|   | DATA TABZ/4*1.,1.016,1.163,1.2,1.211,1.287,1.577,1.91,1.99,2.008,2         | Y | 28 |
|   | 1.032,2.088,2.21,2.446,2.826,3.282,3.645,3.843,3.932,3.969,3.985,3.        | Y | 29 |
|   | 2993,3.996,3.958,2*3.999,2*4.,4*1.,1.005,1.088,1.192,1.203,1.228,1.        | Y | 30 |
|   | 3337,1.622,1.898,1.983,2.006,2.027,2.067,2.144,2.284,2.51,2.832,3.2        | Y | 31 |
|   | 402,3.526,3.745,3.867,3.931,3.963,3.979,3.988,3.993,3.996,3.997,4*1        | Y | 32 |
|   | 5.,1.002,1.033,1.149,1.197,1.208,1.245,1.359,1.599,1.849,1.961,1.99        | Y | 33 |
|   | 67,2.017,2.044,2.09,2.166,2.286,2.462,2.700,2.983,3.272,3.52,3.7,3.        | Y | 34 |
|   | 7818,3.889,3.932,3.957,3.973,4*1.,1.001,1.011,1.072,1.167,1.198,1.2        | Y | 35 |
|   | 813,1.252,1.348,1.529,1.752,1.904,1.971,2.001,2.023,2.05,2.09,2.149        | Y | 36 |
|   | 9,2.234,2.351,2.505,2.694,2.91,3.135,3.347,3.527,3.667,3.769,5*1.,1        | Y | 37 |
|   | \$,004,1.026,1.092,1.092,1.165,1.196,1.214,1.248,1.316,1.437,1.607,1.778,1 | Y | 38 |
|   | \$,896,1.959,1.993,2.018,2.042,2.071,2.111,2.163,2.232,2.318,2.426,2       | Y | 39 |
|   | \$,553,2.7,2.861,3.028,5*1.,1.001,1.009,1.035,1.089,1.149,1.186,1.20       | Y | 40 |
|   | \$8,1.235,1.279,1.351,1.457,1.59,1.727,1.838,1.914,1.962,1.993,2.018       | Y | 41 |
|   | \$,2.042,2.067,2.098,2.135,2.18,2.233,2.297,2.372/                         | Y | 42 |
|   | DATA TABPR/2*.738,.756,.767,.614,.771,.714,.606,.587,.764,.993,.87         | Y | 43 |
|   | 11,.455,.392,.361,.342,.322,.279,.2,.114,.0576,.0314,.0213,.0167,.0        | Y | 44 |
|   | 2143,.0129,.0121,.011,.0108,.0109,.011,2*.738,.756,.767,.668,.654,..       | Y | 45 |
|   | 3745,.658,.58,.611,.799,.989,.891,.464,.404,.371,.351,.335,.316,.27        | Y | 46 |
|   | 49,.216,.145,.0877,.0524,.0346,.0238,.019,.0162,.0149,.013,.012,2*.        | Y | 47 |
|   | 5738,.756,.767,.724,.611,.74,.737,.619,.578,.624,.785,.969,.955,.83        | Y | 48 |
|   | 6,.424,.387,.363,.348,.336,.319,.295,.254,.201,.146,.101,.0688,.047        | Y | 49 |
|   | 7,.0345,.0245,.0129,2*.738,.756,.767,.766,.645,.636,.744,.759,.61,..       | Y | 50 |
|   | 8581,.617,.736,.906,.986,.969,.648,.411,.382,.364,.348,.339,.327,.3        | Y | 51 |
|   | 912,.292,.263,.227,.185,.144,.0986,.0819,2*.738,.756,.767,.773,.696        | Y | 52 |
|   | \$,627,.660,.762,.752,.611,.583,.602,.673,.796,.927,.983,.943,.807,        | Y | 53 |
|   | \$,497,.429,.404,.382,.369,.355,.343,.333,.319,.302,.277,.253,2*.738       | Y | 54 |
|   | \$,.756,.767,.773,.751,.680,.631,.662,.743,.767,.62,2*.592,.62,.688,       | Y | 55 |
|   | \$,788,.891,.961,.966,.872,.532,.463,.434,.412,.396,.383,.369,.36,.3       | Y | 56 |
|   | \$49,.341/   | Y | 57 |
|   | DATA TEMURAT/7*1.,1.011,1.032,1.096,1.181,1.227,1.256,1.271,1.264,         | Y | 58 |
|   | 11.21,1.072,.826,.517,.261,.118,.055,.029,.018,.012,.009,.008,2*.00        | Y | 59 |
|   | 27,2*.008,7*1.,.01,1.024,1.055,1.128,1.209,1.257,1.286,1.303,1.307         | Y | 60 |
|   | 3,1.28,1.207,1.068,.853,.595,.361,.2,.108,.063,.036,.024,.018,.015,        | Y | 61 |
|   | 4.013,.012,7*1.,1.01,1.022,1.038,1.074,1.146,1.228,1.276,1.317,1.33        | Y | 62 |
|   | 57,1.347,1.343,1.314,1.251,1.143,.983,.782,.571,.387,.249,.158,.1.,        | Y | 63 |
|   | 6067,.042,.016,7*1.,1.006,1.02,1.033,1.051,1.086,1.148,1.229,1.294,        | Y | 64 |
|   | 71.332,1.371,1.386,1.396,1.393,1.375,1.335,1.267,1.168,1.04,.881,.7        | Y | 65 |
|   | 811,.547,.408,.262,.212,7*1.,1.003,1.016,1.029,1.043,1.06,1.09,1.13        | Y | 66 |
|   | 99,1.208,1.283,1.342,1.386,1.425,1.428,1.445,1.448,1.442,1.424,1.39        | Y | 67 |
|   | \$4,1.342,1.274,1.187,1.082,.94,.828,7*1.,1.001,1.008,1.022,1.036,1.       | Y | 68 |
|   | \$052,1.067,1.09,1.124,1.175,1.238,1.307,1.368,1.418,1.468,1.496,1.5       | Y | 69 |
|   | \$01,1.511,1.52,1.516,1.508,1.492,1.468,1.415,1.387/                       | Y | 70 |

APPENDIX A - Continued

```

DATA TSTR/5.,6.,7.,8.,9.,10.,20.,30.,40.,50.,60.,70.,80.,90.,100., Y 71
1200.,300.,400./ Y 72
DATA OMEGA11/.8422,.8124,.7896,.7712,.7556,.7424,.6640,.6232,0.596 Y 73
10,0.5756,0.5596,0.5464,0.5352,0.5256,0.5170,0.4644,0.4360,0.4170/ Y 74
END Y 75-

```

```

C SUBROUTINE DIMPROP (AP,AH,PPRIME,HPRIME) Z 1
COMMON /FRSTRM/ HIN,PIN,RHOINP,UINP,RE Z 2
C INPUTS TO DIMPROP ARE DIMENSIONLESS Z 3
C OUTPUTS P ATOMOSPHERES ,H ERGS/GM Z 4
C PPRIME=AP*RHOINP*UINP*UINP/(1.01325E+06) Z 5
HPRIME=AH*UINP*UINP Z 6
RETURN Z 7
END Z 8
Z 9
Z 10-

```

```

C SUBROUTINE TINT (N,DX,A,B) AA 1
THIS SUBROUTINE INTEGRATES A TABLE TO GIVE A TABLE AA 2
DIMENSION A(102), B(102) AA 3
NHAF=N/2 AA 4
IEVEN=0 AA 5
IF (2*NHAF.EQ.N) IEVEN=1 AA 6
IF (IEVEN.EQ.1) NHAF=NHAF-1 AA 7
B(1)=0. AA 8
DO 1 I=1,NHAF AA 9
J=2*I AA 10
B(J)=B(J-1)+.08333333*DX*(5.*A(J-1)+8.*A(J)-A(J+1)) AA 11
J=J+1 AA 12
B(J)=B(J-2)+.33333333*DX*(A(J-2)+4.*A(J-1)+A(J)) AA 13
CONTINUE AA 14
IF (IEVEN.EQ.0) GO TO 2 AA 15
J=J+1 AA 16
B(J)=B(J-1)+.08333333*DX*(-A(J-2)+8.*A(J-1)+5.*A(J)) AA 17
RETURN AA 18
END AA 19-

```

APPENDIX A – Continued

```

SUBROUTINE GET REDY
DIMENSION PALH(100),PALC(100),PALN(100),PALO(100)
DIMENSION A(6,6) ,A12(16,7) ,A22(7,7) ,ALP(6) ,ALPT(16,5),FEMPO040
1BMT(16) ,C(6,16) ,CH(16,2) ,CP(16) ,DEGI(6) ,H(16) ,FEMPO050
2JAT(16,5) ,JPH(16) ,KAT(16) ,KODE(16) ,RA(16,2) ,RB(16,2) ,FEMPO060
3RC(16,2) ,RD(16,2) ,RD1(16,2) ,RE(16,2) ,RE1(16,2) ,SD(16) ,FEMPO070
4TB(3) ,TU(16,2) ,TU2(16,2) ,VN(17) ,VNE(16) ,VNT(17) ,FEMPO080
5VNU(16,6) ,W26(6) ,W3(16) ,Y(16) ,RF(16,2) ,RC1(16,2) FEMPO090
DIMENSION SAC(200) ,SAH(200)
COMMON /LOKHEED/
A A ,A12 ,A22 ,ALP ,ALPT ,BMT ,C ,CH , FEMPO100
1CP ,DEGI ,H ,HS ,IG ,IGMS ,IGMSP ,IGP ,ION , FEMPO110
2IS ,ISP ,ISPNG ,ISPNGP ,ISPNG2 ,JAT ,JPH ,KAT ,KODE , FEMPO120
3N ,NG ,NP ,PRESS ,RA ,RB ,RC ,RD ,RD1 , FEMPO130
4RE ,RE1 ,SD ,TU ,TU2 ,VN ,VNE ,VNT ,VNU , FEMPO140
5W26 ,W27 ,W3 ,Y ,RHO ,WM ,SYU ,RF ,RC1 ,TB FEMPO150
COMMON/RAD/YY(100),TEE(100),FHV(20),NHV,NY,C2,IY
COMMON/RAD/QRYP(100),QRYPL(100)
COMMON/RAD/XNN(14,100),XMOL
COMMON/RAD/NIHVC,FHVC(50),AHV(50),AHVL(20)
COMMON /RAD/C1,C3,C4,FLG,C5,FLG1
COMMON /RAD/ YDELTA,DELTA,FL1,FL2
COMMON/RAD/GEE(8),EPS(8),NU(20),ND(70),FF(70),GAMP(70),
1WOL(20),FHVM(20),FHVP(20)
COMMON/CIONCL/F(100,10),F2(100,10),HVL(70),EP,K2,K1,IFL,IYCON,
1IQI,WMI,BIJ(100,10),GMIN(100,10),GPLU(100,10) ,IAED
DIMENSION NICN(100)
DIMENSION PRES(100)
DIMENSION HH(100)
DIMENSION ZBLK(1157)
DIMENSION QRYP(100)
EQUIVALENCE (ZBLK,A)
XMOL=1.
DO 1157 I=1,1157
1157 ZBLK(I)=0.
NHV=18
DO 998 I=1,17
998 VNT(I)=0.
C4=1.273
G=1.
100 FORMAT(6E12.1)
C
C INPUT TABLES I,II
C
READ(5,100) (GEE(I),I=1,8)
READ(5,100) (EPS(I),I=1,8)
READ(5,100) (FHVM(I),I=1,NHV)
READ(5,100) (FHVP(I),I=1,NHV)
READ(5,100) ( FHV(I),I=1,NHV)
READ(5,100) (WOL(I),I=1,NHV)
READ(5,101) ( NU(I),I=1,NHV)
101 FORMAT(18I2)
IS=0
DO 1 I=1,NHV
1 IS=IS+NU(I)
READ(5,102) (ND(I),HVL(I),FF(I),GAMP(I),I=1,IS)
102 FORMAT(11,11X,3E12.1)
C
C INPUT HV VALUES AND AK FACTORS FOR CGNTM CALCULATION
C
READ(5,115) NIHVC
115 FORMAT(24I3)
READ(5,100) (FHVC(I),I=1,NIHVC)
READ(5,100) (AHV(I),I=1,NIHVC)
READ (5,100) (AHVL(I),I=1,NHV)
RETURN
END

```



## APPENDIX A - Continued

```

C      GIVEN H, GET T
7      TB(2)=TB(1)*1.2
      HS=HH(I)
3      I1=0
12     CONTINUE
      IF (TB(2).LT.6000.) GO TO 9
C
C      HIGH TEMPERATURE CALCULATION
C
      ALP(2)=PALH(I)
      ALP(3)=PALC(I)
      ALP(4)=PALN(I)
      ALP(5)=PALO(I)
      ALP(1)=ALP(3) + ALP(4) + ALP(5) +ALP(2)
      IT=1
      ITXV=-1
      CALL HTEST (ITX,ITXV,1)
      ITXV=ITX
      CALL FEMP (IHELP,I0PT)
      CALL HTEST (ITX,ITXV,2)
      IZW=2
      GO TO 10
C
C      LOW TEMPERATURE
C
9      ITSV=-1
      IT=1
      ALP(1)=PALH(I)
      ALP(2)=PALC(I)
      ALP(3)=PALN(I)
      ALP(4)=PALO(I)
      CALL LTFST (ITS,ITSV,1)
      ITSV=ITS
      CALL FEMP (IHELP,I0PT)
      CALL LTEST (ITS,ITSV,2)
      IZW=1
10     IF (I0PT.EQ.2) GO TO 32
      TB(2)=TFE(I)
      TB(1)=TB(2)
      GO TO 33
32     TFE(I)=TB(2)
      HS=HH(I)
      TB(1)=TB(2)/1.2
33     IF (IHFLP.EQ.0) GO TO 11
C
C      ERROR IN FEMP
C
      WRITE(6,110)I,PRESS,HS,TR(1),TB(2)
110    FORMAT(10HIFEMP BLEW,I10,4E20.6)
      STOP
C
C      BACK TO (12) JUST ONE TIME...LOOP COULD OCCURE OTHERWISE
C
11     IF (I1.NE.0) GO TO 13
      I1=1
      GO TO 12
C
C      CHECK FOR HIGH OR LOW TEMP CALCULATION
C      ...THEN COMPUTE NO. DENSITIES
C
13     IF (IZW.EQ.2) GO TO 15
      XNHP(I)=0.0
      XNC2H(I)=FLUT(BMT(9),W3(9),RHO)
      XNC3H(I)=FLUT(BMT(10),W3(10),RHO)
      XNC4H(I)=FLUT(BMT(11),W3(11),RHO)
      XNHCN(I)=FLUT(BMT(12),W3(12),RHO)
      XNC2H2(I)=FLUT(BMT(13),W3(13),RHO)
      XNN(1,I)=0.0
      XNN(2,I)= FLUT(BMT(6),W3(6),RHO)

```



APPENDIX A - Continued

```

XNN(3,I)=0.0
XNN(4,I)= FLUT(BHT(8),W3(8),RHO)
XNN(5,I)=0.0
XNN(6,I)= FLUT(BHT(3),W3(3),RHO)
XNN(7,I)= FLUT(BHT(4),W3(4),RHO)
XNN(8,I)= FLUT(BHT(15),W3(15),RHO)
XNN(9,I)= FLUT(BHT(14),W3(14),RHO)
XNN(10,I)= FLUT(HMT(2),W3(2),RHO)
XNN(11,I)= FLUT(HMT(1),W3(1),RHO)
XNN(12,I)= FLUT(HMT(7),W3(7),RHO)
XNN(13,I)=0.0
XNN(14,I)=FLUT(HMT(5),W3(5),RHO)
GO TO 19
15 XNN(1,I)= FLUT(BHT(6),W3(6),RHO)
XNHP(I)=FLUT(RMT(3),W3(3),RHO)
XNC2H(I)=0.0
XNC3H(I)=0.0
XNC4H(I)=0.0
XNHCH(I)=0.0
XNC2H2(I)=0.0
XNN(2,I)= FLUT(HHT(8),W3(8),RHO)
XNN(3,I)= FLUT(HMT(7),W3(7),RHO)
XNN(4,I)= FLUT(BHT(5),W3(5),RHO)
XNN(5,I)= FLUT(RMT(6),W3(6),RHO)+FLUT(RMT(7),W3(7),RHO)+
1FLUT(RMT(11),W3(11),RHO)+XNHP(I)
XNN(6,I)=0.0
XNN(7,I)= FLUT(BHT(9),W3(9),RHO)
XNN(8,I)= FLUT(BHT(10),W3(10),RHO)
XNN(9,I)=0.0
XNN(10,I)=0.0
XNN(11,I)= FLUT(HMT(4),W3(4),RHO)
XNN(12,I)= FLUT(HMT(2),W3(2),RHO)
XNN(13,I)= FLUT(HMT(11),W3(11),RHO)
XNN(14,I)=FLUT(BMT(12),W3(12),RHO)
C
C SET NEW GUESS FOR TEMP...APPLIES ONLY IF IOPT=2
C
19 TB(2)=TFE(I)
C
HH(I)=HS
RO(I)=RHO
IF ( KUT.E0.1 ) GO TO 20
C PRINT FEMP CALCULATIONS
C
WRITE (6,109)
109 FORMAT(14H0 PATH LENGTH,4X,
18HPRESSURE,3X,11HTEMPERATURE,4X,8HENTHALPY,5X,7HDENSITY)
WRITE (6,111) YY(I),PRES(I),TEE(I),HS,RHO
111 FORMAT(10E13.5)
XT=0.
DO 2 J=1,14
2 XT= XNV(J,I)+XT
XT=XT+XNC2H(I)+XNC3H(I)+XNC4H(I)+XNHCH(I)+XNC2H2(I)+XNHP(I)
DO 3 J=1,14
3 X(J)= XNN(J,I)/XT
X(15)=XNC2H(I)/XT
X(16)=XNC3H(I)/XT
X(17)=XNC4H(I)/XT
X(18)=XNHCH(I)/XT
X(19)=XNC2H2(I)/XT
X(20)=XNHP(I)/XT
WRITE (6,900) (X(I),J=1,20)
900 FORMAT (5X14HMOLE FRACTIONS /6X,2H0+.10X,1H0,13X,2HN+.11X,1HN,11X,
1 1HF,12X,2H02,12X,2HN2 / 6X,2HCO,10X,2HH2,12X,2HC2,10X,2HCH,11X,
2 1HC,12X,2HC+,12X,2H H/6X,3HC2H,9X,3HC3H,12X,3HC4H,10X,3HCH,9X,
3 4HC2H2,9X,2HH+/7E13.5/7E13.5/6E13.5)
20 CONTINUE
DO 1 I=1,NY
1 TEE(I)=TFE(I)

```

## APPENDIX A – Concluded

```

IF (TRAD.EQ.0) GO TO 1938
C
C INPUT AK FACTORS FOR LINE CALCULATIONS
C
NW=MAX0(NHV,NIHVC)
125 FORMAT(F12.3,F16.3)
127 FORMAT(34X,F12.3,F16.3)
128 FORMAT(2(F12.3,F16.3))
IF (FL31.EQ.0.) GO TO 60
C
C MULT. FACTORS BY PT FOR FLUX CALCULATIONS
C
DO 61 I=1,NHV
61 AHVL(I)=AHVL(I)*3.1416
DO 62 I=1,NIHVC
62 AHV(I)=AHV(I)*3.1416
60 C2=DELTA*FL1
C1=DELTA*FL2
C3=C1/3.1416
C5=C1
FP=.001
C
C OUTPUT TABLE II
C
120 FORMAT (1H1,60X,8HTABLE II)
121 FORMAT (6H16GROUP,4X,2HHV,12X,3HHV+,11X,3HHV-,10X,1HN,9X,
13HWOL,7X,4HK(I),4X,5HHV(I),10X,4HF(I),11X,6HGAM(I))
122 FORMAT(I4,F12.3,2F14.3,I12,F12.3,I9,F14.3,1P2E16.2)
IF (LONGRIT.EQ.0) GO TO 1066
WRITE (6,121)
124 FORMAT(68X,I9,F14.3,4X,1PE12.2,1PE16.2)
IC1=0
DO 30 I=1,NHV
IC2 = IC1 + NU(I)
IC1= IC1+1
WRITE (6,122) I,FHV(I), FHVP(I), FHVM(I), NU(I), WOL(I),
IND(IC1),HVL(IC1),FF(IC1),GAMP(IC1)
IF (IC1.EQ.IC2) GO TO 30
IC3=IC1+1
DO 25 J=IC3,IC2
25 WRITE (6,124) ND (J),HVL(J), FF(J), GAMP(J)
30 IC1=IC2
1065 CONTINUE
DO 300 L=1,NIC
IY=NICN(L)
IYCON=IY
YDELTA=YY(IY)
C
C CONTINUM CALCULATION
CALL CONTM
C
C LINE CALCULATION
CALL LINF
ORYP(L)=ORYPC(IY)+ORYPL(IY)
300 CONTINUE
IF (FLG1.EQ.0.0) RETURN
DO 434 I=1,NHV
434 AHVL(I)=AHVL(I)/3.1416
DO 435 I=1,NIHVC
435 AHV(I)=AHV(I)/3.1416
1938 CONTINUE
DO 65 I=1,NY
PALC(I)=.12*PALC(I)
PALN(I)=.14*PALN(I)
PALO(I)=.16*PALO(I)
65 CONTINUE
RETURN
END
$SUB 1

```

## APPENDIX B

### SAMPLE INPUT

The input for a sample case is shown in this appendix as follows:

| \$NAM4  |             | \$NAM5  |               |
|---------|-------------|---------|---------------|
| N       | = 21,       | IRFLUX  | = 1,          |
| IDIM    | = 2,        | IUPDATE | = 1,          |
| IRODAMP | = 0,        | ALPINJC | = 0.0,        |
| HDAMP   | = 0.7E+00,  | ALPINJO | = 0.22E+00,   |
| RODAMP  | = 0.7E+00,  | ALPINJH | = 0.0,        |
| EP      | = 0.1E-01,  | ALPINJN | = 0.78E+00,   |
| ERCV    | = 0.1E-01,  | OZOP2C  | = 0.25E+01,   |
| EA      | = 0.1E-01,  | AS      | = 0.122E+01,  |
| EPSX    | = 0.1E-01,  | PINP    | = 0.197E+03,  |
| ERO     | = 0.2E-01,  | RHOINP  | = 0.272E-06,  |
| MAXTIME | = 2,        | UINP    | = 0.1525E+07, |
| NIC     | = 11,       | RB      | = 0.3048E+03, |
| CURV    | = 0.1E+01,  | ROVM    | = -0.1E+00,   |
| CURVZ   | = 0.12E+01, | HW      | = 0.28E-01,   |
| BS      | = 0.1E+01,  | ALPINFN | = 0.78E+00,   |
| OZPDZ   | = 0.2E+01,  | ALPINFO | = 0.22E+00,   |
| \$END   |             | ALPINFC | = 0.0,        |
|         |             | ALPINFH | = 0.0,        |
|         |             | \$END   |               |



## APPENDIX C

### SAMPLE OUTPUT

In this appendix, the output for the calculation described in appendix B is given. First, identification of the case is printed out. After completion of the iterations the flow profiles are given, after which the equilibrium composition profiles are output by RATRAP. Only a sample of the composition profiles are shown here. Finally, the profile of the radiation flux vector is printed out. The output is given as follows:

VISCOUS STAGNATION STREAMLINE SOLUTION  
WITH RADIATION

BODY RADIUS= 3.04800E+02 CM, FREESTREAM VELOCITY= 1.52500E+06 CM/SEC, DENSITY= 2.72000E-07 G/CC  
 A SHOCK (NON DIM)= 1.22000, BETA (NON DIM)= 2.50000, PRESSURE= 1.97000E+02 DYNES/SQ CM  
 ABLATION RATE (NON DIM)= -.10000, MASS FRACTIONS- HYDROGEN =0.00000, OXYGEN=0.00000, NITROGEN = .78000, CARBON = .2200  
 FREESTREAM COMPOSITION- N= .78000, O= .22000, C= 0.00000, H= 0.00000

RANHUG SOLUTION

PSHOCK= 9.41589749E-01 RSHOCK= 1.70585355E+01 VSHOCK= 5.86216795E-02 HSHOCK= 4.99371747E-01

APPENDIX C - Continued

| DELTA= 1.43321101E+00 |               |               | DELBA= 1.14968608E+01 |               |              | REY= 9.48314311E+04 |              |  |
|-----------------------|---------------|---------------|-----------------------|---------------|--------------|---------------------|--------------|--|
| ETA(I)                | Y(I)          | QR(I)         | CAPH(I)               | V(I)          | EMU(I)       | PRAN(I)             | YOYS(I)      |  |
| 0.                    | 0.            | -3.989709E-02 | 2.800013E-02          | -5.122538E-04 | 6.436917E-01 | 7.079064E-01        | 0.           |  |
| 5.000000E-02          | 3.821030E-04  | -4.012594E-02 | 3.081263E-02          | -5.506918E-04 | 6.628058E-01 | 7.409187E-01        | 1.013016E-02 |  |
| 1.000000E-01          | 7.962558E-04  | -4.037401E-02 | 3.425868E-02          | -5.841457E-04 | 6.835926E-01 | 7.602514E-01        | 2.111106E-02 |  |
| 1.500000E-01          | 1.241459E-03  | -4.070109E-02 | 3.842278E-02          | -6.009434E-04 | 7.126751E-01 | 7.510083E-01        | 3.291303E-02 |  |
| 2.000000E-01          | 1.723479E-03  | -4.105524E-02 | 4.298786E-02          | -6.195919E-04 | 7.494184E-01 | 6.902536E-01        | 4.569216E-02 |  |
| 2.500000E-01          | 2.250103E-03  | -4.134844E-02 | 4.877527E-02          | -6.233564E-04 | 7.911803E-01 | 6.059531E-01        | 5.965378E-02 |  |
| 3.000000E-01          | 2.842980E-03  | -4.167853E-02 | 5.89874E-C2           | -6.340208E-04 | 8.482358E-01 | 5.900988E-01        | 7.537191E-02 |  |
| 3.500000E-01          | 3.531493E-03  | -4.238070E-02 | 7.694113E-02          | -6.257030E-04 | 9.231293E-01 | 6.346786E-01        | 9.362548E-02 |  |
| 4.000000E-01          | 4.381608E-03  | -4.324769E-02 | 1.120703E-C1          | -5.976021E-04 | 1.040424E+00 | 7.630011E-01        | 1.161634E-01 |  |
| 4.500000E-01          | 5.621403E-03  | -4.459807E-02 | 1.879635E-01          | -5.374347E-04 | 1.366311E+00 | 8.489653E-01        | 1.490323E-01 |  |
| 5.000000E-01          | 7.508546E-03  | -4.665353E-02 | 2.534619E-01          | 2.334105E-04  | 1.598428E+00 | 3.619522E-01        | 1.990634E-01 |  |
| 5.500000E-01          | 9.849560E-03  | -4.517633E-02 | 2.733345E-01          | 1.926409E-03  | 1.582374E+00 | 3.475065E-01        | 2.611274E-01 |  |
| 6.000000E-01          | 1.235369E-02  | -4.359620E-02 | 2.957819E-01          | 4.306568E-03  | 1.550140E+00 | 3.358364E-01        | 3.275159E-01 |  |
| 6.500000E-01          | 1.500765E-02  | -3.990416E-02 | 3.164136E-01          | 7.360373E-03  | 1.512331E+00 | 3.262837E-01        | 3.978765E-01 |  |
| 7.000000E-01          | 1.779896E-02  | -3.602103E-02 | 3.351319E-01          | 1.111221E-02  | 1.473444E+00 | 3.187696E-01        | 4.718786E-01 |  |
| 7.500000E-01          | 2.072241E-02  | -2.916608E-02 | 3.537244E-01          | 1.563643E-02  | 1.431549E+00 | 3.107011E-01        | 5.493838E-01 |  |
| 8.000000E-01          | 2.378199E-02  | -2.199189E-02 | 3.7204C1E-01          | 2.098853E-02  | 1.386437E+00 | 3.018466E-01        | 6.304983E-01 |  |
| 8.500000E-01          | 2.698301E-02  | -9.829270E-03 | 3.918516E-01          | 2.727595E-02  | 1.339113E+00 | 2.927529E-01        | 7.153624E-01 |  |
| 9.000000E-01          | 3.033711E-02  | 2.914981E-03  | 4.126163E-01          | 3.461759E-02  | 1.290905E+00 | 2.836595E-01        | 8.042848E-01 |  |
| 9.500000E-01          | 3.383703E-02  | 4.434637E-02  | 4.498601E-01          | 4.338700E-02  | 1.245466E+00 | 2.752380E-01        | 8.970733E-01 |  |
| 1.000000E+00          | 3.771936E-02  | 9.030465E-02  | 5.010900E-01          | 5.860377E-02  | 9.993658E-01 | 2.306848E-01        | 1.000000E+00 |  |
| ETA(I)                | ROV(I)        | AI(I)         | P(I)                  | ROI(I)        | XNRO(I)      | H(I)                | XNH(I)       |  |
| 0.                    | -1.000000E-01 | 0.            | 9.761173E-C1          | 1.951527E+02  | 1.951412E+02 | 2.800000E-02        | 2.800000E-02 |  |
| 5.000000E-02          | -9.924396E-02 | 9.536205E-03  | 9.761136E-01          | 1.804490E+02  | 1.811262E+02 | 3.138136E-02        | 3.081248E-02 |  |
| 1.000000E-01          | -9.706417E-02 | 2.005585E-02  | 9.761105E-01          | 1.662745E+02  | 1.666626E+02 | 3.458111E-02        | 3.425851E-02 |  |
| 1.500000E-01          | -9.334795E-02 | 3.119411E-02  | 9.761085E-01          | 1.548980E+02  | 1.540167E+02 | 3.770567E-02        | 3.842260E-02 |  |
| 2.000000E-01          | -8.792505E-02 | 4.347994E-02  | 9.761071E-C1          | 1.411330E+02  | 1.394664E+02 | 4.144261E-02        | 4.298767E-02 |  |
| 2.500000E-01          | -8.063055E-02 | 5.700017E-02  | 9.761064E-01          | 1.286055E+02  | 1.269916E+02 | 4.659978E-02        | 4.877507E-02 |  |
| 3.000000E-01          | -7.127089E-02 | 7.230520E-02  | 9.761060E-01          | 1.119189E+02  | 1.108515E+02 | 5.617058E-02        | 5.889854E-02 |  |
| 3.500000E-01          | -5.943349E-02 | 9.234868E-02  | 9.761055E-01          | 9.464081E+01  | 9.389961E+01 | 7.372470E-02        | 7.694093E-02 |  |
| 4.000000E-01          | -4.457677E-02 | 1.151773E-01  | 9.761081E-01          | 7.437146E+01  | 7.390891E+01 | 1.086976E-01        | 1.120702E-01 |  |
| 4.500000E-01          | -2.498915E-02 | 1.700667E-01  | 9.761166E-01          | 4.638199E+01  | 4.617658E+01 | 1.859130E-01        | 1.879634E-01 |  |
| 5.000000E-01          | 7.416170E-03  | 2.944836E-01  | 9.761195E-01          | 3.178005E+01  | 3.182610E+01 | 2.547815E-01        | 2.534619E-01 |  |
| 5.500000E-01          | 5.693602E-02  | 4.002848E-01  | 9.760655E-01          | 2.957343E+01  | 2.9641C3E+01 | 2.757263E-01        | 2.733327E-01 |  |
| 6.000000E-01          | 1.195418E-01  | 4.875373E-01  | 9.758536E-C1          | 2.775983E+01  | 2.778787E+01 | 2.969440E-01        | 2.957726E-01 |  |
| 6.500000E-01          | 1.935969E-01  | 6.875127E-01  | 9.753752E-01          | 2.629487E+01  | 2.629757E+01 | 3.165518E-01        | 3.163865E-01 |  |
| 7.000000E-01          | 2.787872E-01  | 6.556514E-01  | 9.744824E-01          | 2.507536E+01  | 2.506592E+01 | 3.346064E-01        | 3.350702E-01 |  |
| 7.500000E-01          | 3.746239E-01  | 7.369099E-01  | 9.730016E-01          | 2.394328E+01  | 2.392861E+01 | 3.527941E-01        | 3.536022E-01 |  |
| 8.000000E-01          | 4.807406E-01  | 8.159726E-01  | 9.706987E-01          | 2.288966E+01  | 2.287455E+01 | 3.709259E-01        | 3.718199E-01 |  |
| 8.500000E-01          | 5.567372E-01  | 8.941515E-01  | 9.673068E-01          | 2.185935E+01  | 2.183653E+01 | 3.899858E-01        | 3.914796E-01 |  |
| 9.000000E-01          | 7.222385E-01  | 9.706369E-01  | 9.624048E-01          | 2.084001E+01  | 2.080885E+01 | 4.099460E-01        | 4.120171E-01 |  |
| 9.500000E-01          | 8.569591E-01  | 1.046138E+00  | 9.543970E-C1          | 1.967499E+01  | 1.952243E+01 | 4.367558E-01        | 4.489189E-01 |  |
| 1.000000E+00          | 1.000000E+00  | 1.1200C0E+00  | 9.416897E-C1          | 1.705990E+01  | 1.706198E+01 | 4.992441E-01        | 4.993728E-01 |  |
| ETA(I)                | T(I)          | AMFC(I)       | AMFN(I)               | AMFO(I)       | AMFH(I)      | AFOR(I)             | AONC(I)      |  |
| 0.                    | 3.613975E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.987159E-01        | 1.284070E-03 |  |
| 5.000000E-02          | 3.810559E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.979070E-01        | 2.092989E-03 |  |
| 1.000000E-01          | 4.041588E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.964582E-01        | 3.541793E-03 |  |
| 1.500000E-01          | 4.268651E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.938745E-01        | 6.125505E-03 |  |
| 2.000000E-01          | 4.619094E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.893142E-01        | 1.068581E-02 |  |
| 2.500000E-01          | 5.004771E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.812354E-01        | 1.876461E-02 |  |
| 3.000000E-01          | 5.545945E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.666189E-01        | 3.338105E-02 |  |
| 3.500000E-01          | 6.081784E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 9.387366E-01        | 6.126344E-02 |  |
| 4.000000E-01          | 6.718330E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 8.811335E-01        | 1.188665E-01 |  |
| 4.500000E-01          | 8.567436E+03  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 7.424072E-01        | 2.575928E-01 |  |
| 5.000000E-01          | 1.135178E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 4.183161E-01        | 5.818639E-01 |  |
| 5.500000E-01          | 1.1818C9E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 1.171349E-01        | 8.828651E-01 |  |
| 6.000000E-02          | 1.21576C0E+04 | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 1.897675E-02        | 9.810233E-01 |  |
| 6.500000E-01          | 1.250550E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 1.960880E-03        | 9.980391E-01 |  |
| 7.000000E-01          | 1.276497E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 1.388550E-04        | 9.998611E-01 |  |
| 7.500000E-01          | 1.300704E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 7.089309E-06        | 9.999929E-01 |  |
| 8.000000E-01          | 1.323332E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 0.                  | 1.000000E+00 |  |
| 8.500000E-01          | 1.345444E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 0.                  | 1.000000E+00 |  |
| 9.000000E-01          | 1.367395E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 0.                  | 1.000000E+00 |  |
| 9.500000E-01          | 1.391167E+04  | 0.            | 7.800000E-C1          | 2.200000E-01  | 0.           | 0.                  | 1.000000E+00 |  |
| 1.000000E+00          | 1.460291E+04  | 0.            | 7.800000E-01          | 2.200000E-01  | 0.           | 0.                  | 1.000000E+00 |  |

APPENDIX C - Continued

|                |             |             |             |             |             |             |
|----------------|-------------|-------------|-------------|-------------|-------------|-------------|
| PATH LENGTH    | PRESSURE    | TEMPERATURE | ENTHALPY    | DENSITY     |             |             |
| 0.             | 6.09388E-01 | 3.61398E+03 | 1.55566E+03 | 5.30459E-05 |             |             |
| MOLE FRACTIONS |             |             |             |             |             |             |
| O+             | O           | N+          | N           | E           | O2          | N2          |
| CO             | H2          | C2          | CN          | C           | C+          | H           |
| C2H            | C3H         | C4H         | HCN         | C2H2        | H+          |             |
| 0.             | 2.07175E-01 | 0.          | 3.99353E-04 | 0.          | 7.38121E-02 | 7.18614E-01 |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| PATH LENGTH    | PRESSURE    | TEMPERATURE | ENTHALPY    | DENSITY     |             |             |
| 1.01302E-02    | 6.09386E-01 | 3.79647E+03 | 1.74352E+03 | 4.92326E-05 |             |             |
| MOLE FRACTIONS |             |             |             |             |             |             |
| O+             | O           | N+          | N           | E           | O2          | N2          |
| CO             | H2          | C2          | CN          | C           | C+          | H           |
| C2H            | C3H         | C4H         | HCN         | C2H2        | H+          |             |
| 0.             | 2.51558E-01 | 0.          | 8.56953E-04 | 0.          | 4.71824E-02 | 7.00402E-01 |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| PATH LENGTH    | PRESSURE    | TEMPERATURE | ENTHALPY    | DENSITY     |             |             |
| 2.11111E-02    | 6.09384E-01 | 3.99909E+03 | 1.92130E+03 | 4.57768E-05 |             |             |
| MOLE FRACTIONS |             |             |             |             |             |             |
| O+             | O           | N+          | N           | E           | O2          | N2          |
| CO             | H2          | C2          | CN          | C           | C+          | H           |
| C2H            | C3H         | C4H         | HCN         | C2H2        | H+          |             |
| 0.             | 2.86503E-01 | 0.          | 1.85118E-03 | 0.          | 2.61533E-02 | 6.85493E-01 |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| PATH LENGTH    | PRESSURE    | TEMPERATURE | ENTHALPY    | DENSITY     |             |             |
| 3.29130E-02    | 6.09383E-01 | 4.29857E+03 | 2.09490E+03 | 4.18511E-05 |             |             |
| MOLE FRACTIONS |             |             |             |             |             |             |
| O+             | O           | N+          | N           | E           | O2          | N2          |
| CO             | H2          | C2          | CN          | C           | C+          | H           |
| C2H            | C3H         | C4H         | HCN         | C2H2        | H+          |             |
| 0.             | 3.12849E-01 | 0.          | 5.09863E-03 | 0.          | 1.00510E-02 | 6.72001E-01 |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| PATH LENGTH    | PRESSURE    | TEMPERATURE | ENTHALPY    | DENSITY     |             |             |
| 4.56922E-02    | 6.09382E-01 | 4.68828E+03 | 2.30252E+03 | 3.78972E-05 |             |             |
| MOLE FRACTIONS |             |             |             |             |             |             |
| O+             | O           | N+          | N           | E           | O2          | N2          |
| CO             | H2          | C2          | CN          | C           | C+          | H           |
| C2H            | C3H         | C4H         | HCN         | C2H2        | H+          |             |
| 0.             | 3.22968E-01 | 0.          | 1.58038E-02 | 0.          | 2.93056E-03 | 6.58298E-01 |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |
| 0.             | 0.          | 0.          | 0.          | 0.          | 0.          | 0.          |



APPENDIX C – Continued

TOTAL QMINUS = 0.  
TOTAL QPLUS = 20.7296E+02

TOTAL QMINUS = 56.8029E-09  
TOTAL QPLUS = 21.0752E+02

TOTAL QMINUS = 29.7649E-07  
TOTAL QPLUS = 21.2869E+02

TOTAL QMINUS = 16.8581E-05  
TOTAL QPLUS = 21.0812E+02

TOTAL QMINUS = 11.5100E-03  
TOTAL QPLUS = 20.6813E+02

TOTAL QMINUS = 77.6169E+00  
TOTAL QPLUS = 22.1093E+02

TOTAL QMINUS = 54.7567E+01  
TOTAL QPLUS = 24.8172E+02

TOTAL QMINUS = 11.5258E+02  
TOTAL QPLUS = 27.2646E+02

TOTAL QMINUS = 18.3072E+02  
TOTAL QPLUS = 28.2948E+02

TOTAL QMINUS = 26.9051E+02  
TOTAL QPLUS = 27.4797E+02

TOTAL QMINUS = 41.3077E+02  
TOTAL QPLUS = 0.

APPENDIX C – Concluded

| ETA(I)       | Y(I)         | YOYS(I)      | QRAD(I),W/SQ CM |
|--------------|--------------|--------------|-----------------|
| 0.           | 0.           | 0.           | -3.882058E+03   |
| 5.000000E-02 | 3.821030E-04 | 1.013016E-02 | -3.909761E+03   |
| 1.000000E-01 | 7.962958E-04 | 2.111106E-02 | -3.936354E+03   |
| 1.500000E-01 | 1.241459E-03 | 3.291303E-02 | -3.960952E+03   |
| 2.000000E-01 | 1.723479E-03 | 4.569216E-02 | -3.982931E+03   |
| 2.500000E-01 | 2.250103E-03 | 5.965378E-02 | -4.004473E+03   |
| 3.000000E-01 | 2.842980E-03 | 7.537191E-02 | -4.024465E+03   |
| 3.500000E-01 | 3.531493E-03 | 9.362548E-02 | -4.076455E+03   |
| 4.000000E-01 | 4.381608E-03 | 1.161634E-01 | -4.168434E+03   |
| 4.500000E-01 | 5.621403E-03 | 1.490323E-01 | -4.294697E+03   |
| 5.000000E-01 | 7.508546E-03 | 1.990634E-01 | -4.504456E+03   |
| 5.500000E-01 | 9.849560E-03 | 2.611274E-01 | -4.497930E+03   |
| 6.000000E-01 | 1.235369E-02 | 3.275159E-01 | -4.246319E+03   |
| 6.500000E-01 | 1.500765E-02 | 3.978765E-01 | -3.947319E+03   |
| 7.000000E-01 | 1.779896E-02 | 4.718786E-01 | -3.512482E+03   |
| 7.500000E-01 | 2.072241E-02 | 5.493838E-01 | -2.925811E+03   |
| 8.000000E-01 | 2.378199E-02 | 6.304983E-01 | -2.167645E+03   |
| 8.500000E-01 | 2.698301E-02 | 7.153624E-01 | -1.123870E+03   |
| 9.000000E-01 | 3.033711E-02 | 8.042848E-01 | 2.123313E+02    |
| 9.500000E-01 | 3.383703E-02 | 8.970733E-01 | 3.505130E+03    |
| 1.000000E+00 | 3.771936E-02 | 1.000000E+00 | 8.804495E+03    |

## APPENDIX D

### LANGLEY LIBRARY SUBROUTINE ITR1

Language: FORTRAN

Purpose: To solve the single equation of the form  $x = f(x)$  for one real root by the Newton-Raphson iteration method.

Use: CALL ITR1 (X, DELTX, FOFX, E1, E2, MAXI, ICODE)

- X                    An initial guess supplied by the user. On a normal return to the calling program from ITR1, X contains the root.
- DELTX                An increment supplied by the user so that  $\frac{f(x + DELTX) - f(x)}{DELTX}$  is a reasonable approximation to the derivative of  $f(x)$ .
- FOFX                 A function subprogram to evaluate  $f(x)$ .
- E1                    Relative error criterion.
- E2                    Absolute error criterion.
- MAXI                 A maximum iteration count supplied by the user.
- ICODE                An integer supplied by ITR1 as an error code. This code should be tested by the user on return to the calling program.
- ICODE = 0: Normal return.
- ICODE = 1: Maximum iteration exceeded.
- ICODE = 2: Derivative = 0.

Restrictions: A function subprogram with a single argument  $x$  must be written by the user to evaluate  $f(x)$ . The name given to the FOFX subprogram must appear in an EXTERNAL statement in the calling program.

Method: The Newton-Raphson iteration technique (ref. (a) of this subroutine) is used where

$$x_{n+1} = q_n + (1 - q) f(x_n)$$

$$q = \frac{a}{a - 1}$$

$$a = \frac{f(x_n) - f(x_{n-1})}{x_n - x_{n-1}}$$

APPENDIX D – Concluded

Accuracy: The iteration process is continued until either of two convergence criteria are satisfied. These criteria are given as follows:

If

$$|f(x_n)| \geq \epsilon_1$$

then

$$\left| \frac{f(x_n) - x_n}{f(x_n)} \right| \leq \epsilon_1 \quad (1)$$

and if

$$|f(x_n)| < \epsilon_1$$

then

$$|f(x_n) - x_n| \leq \epsilon_2 \quad (2)$$

Reference: (a) Scarborough, James B.: Numerical Mathematical Analysis, Fourth ed., Johns Hopkins Press, 1958, p. 192.

Storage: 137<sub>8</sub> locations.

Subroutine date: August 1, 1968.

## APPENDIX E

### LANGLEY LIBRARY SUBROUTINE FTLUP

Language: FORTRAN

Purpose: Computes  $y = F(x)$  from a table of values using first or second order interpolation. An option to give  $y$  a constant value for any  $x$  is also provided.

Use: CALL FTLUP (X, Y, M, N, VARI, VARD)

X The name of the independent variable  $x$

Y The name of the dependent variable  $y = f(x)$

M The order of interpolation (an integer)

M = 0 for  $y$  a constant as explained in the NOTE below.

M = 1 or 2. First or second order if VARI is strictly increasing (not equal).

M = -1 or -2. First or second order if VARI is strictly decreasing (not equal).

N The number of points in the table (an integer).

VARI The name of a one-dimensional array which contains the  $N$  values of the independent variable.

VARD The name of a one-dimensional array which contains the  $N$  values of the dependent variable.

Note: VARD(I) corresponds to VARI(I) for  $I = 1, 2, \dots, N$ . For  $M = 0$  or  $N \leq 1$ ,  $y = F(VARI(1))$  for any value of  $x$ . The program extrapolates.

Restrictions: All the numbers must be floating point. The values of the independent variable  $x$  in the table must be strictly increasing or strictly decreasing. The following arrays must be dimensioned by the calling program as indicated: VARI(N), VARD(N).

Accuracy: A function of the order of interpolation used.

APPENDIX E - Concluded

References: (a) Nielson, Kaj L.: Methods in Numerical Analysis. The Macmillan Co., c.1956, pp. 87-91.

(b) Milne, William Edmund: Numerical Calculus. Princeton Univ. Press, c.1949, pp. 69-73.

Storage: 430g locations.

Error condition: If the VARI values are not in order, the subroutine will print "TABLE BELOW OUT OF ORDER FOR FTLUP AT POSITION xxx TABLE IS STORED IN LOCATION xxxxxx" (absolute). It then prints the contents of VARI and VARD and stops the program.

Subroutine date: September 12, 1969.



## APPENDIX F

### LANGLEY LIBRARY SUBROUTINE DISCOT

Language: FORTRAN

Purpose: DISCOT performs single or double interpolation for continuous or discontinuous functions.

Given a table of some function  $y$  with two independent variables,  $x$  and  $z$ , this subroutine performs  $K_x$ - and  $K_z$ -order interpolation to calculate the dependent variable. In this subroutine all single-line functions are read in as two separate arrays and all multiline functions are read in as three separate arrays; that is,

$$x_i \quad (i = 1, 2, \dots, L)$$
$$y_j \quad (j = 1, 2, \dots, M)$$
$$z_k \quad (k = 1, 2, \dots, N)$$

Use: CALL DISCOT (XA, ZA, TABX, TABY, TABZ, NC, NY, NZ, ANS)

XA        The  $x$  argument

ZA        The  $z$  argument (may be the same name as  $x$  on single lines)

TABX      A one-dimensional array of  $x$  values

TABY      A one-dimensional array of  $y$  values

TABZ      A one-dimensional array of  $z$  values

NC        A control word that consists of a sign (+ or -) and three digits. The control word is formed as follows:

- (1) If  $NX = NY$ , the sign is negative. If  $NX \neq NY$ , then  $NX$  is computed by DISCOT as  $NX = NY/Nz$ , and the sign is positive and may be omitted if desired.
- (2) A one in the hundreds position of the word indicates that no extrapolation occurs above  $z_{max}$ . With a zero in this position, extrapolation occurs when  $z > z_{max}$ . The zero may be omitted if desired.
- (3) A digit (1 to 7) in the tens position of the word indicates the order of interpolation in the  $x$ -direction.
- (4) A digit (1 to 7) in the units position of the word indicates the order of interpolation in the  $z$ -direction.

NY        The number of points in  $y$  array

NZ        The number of points in  $z$  array

ANS       The dependent variable  $y$

## APPENDIX F - Continued

The following programs will illustrate various ways to use DISCOT:

CASE I:        Given  $y = f(x)$   
               $NY = 50$   
               $NX$  (number of points in  $x$  array) =  $NY$   
              Extrapolation when  $z > z_{max}$   
              Second-order interpolation in  $x$ -direction  
              No interpolation in  $z$ -direction  
              Control word =  $-020$   
              DIMENSION TABX (50), TABY (50)  
1 FORMAT (8E 9.5)  
   READ (5,1) TABX, TABY  
   READ (5,1) XA  
   CALL DISCOT (XA, XA, TABX, TABY, TABY,  $-020$ , 50, 0, ANS)

CASE II:        Given  $y = f(x,z)$   
               $NY = 800$   
               $NZ = 10$   
               $NX = NY/NZ$  (computed by DISCOT)  
              Extrapolation when  $z > z_{max}$   
              Linear interpolation in  $x$ -direction  
              Linear interpolation in  $z$ -direction  
              Control word = 11  
              DIMENSION TABX (800), TABY (800), TABZ (10)  
1 FORMAT (8E 9.5)  
   READ (5,1) TABX, TABY, TABZ  
   READ (5,1) XA, ZA  
   CALL DISCOT (XA, ZA, TABX, TABY, TABZ, 11, 800, 10, ANS)

CASE III:        Given  $y = f(x,z)$   
               $NY = 800$   
               $NZ = 10$   
               $NX = NY$   
              Extrapolation when  $z > z_{max}$   
              Seventh-order interpolation in  $x$ -direction  
              Third-order interpolation in  $z$ -direction  
              Control word =  $-73$   
              DIMENSION TABX (800), TABY (800), TABZ (10)  
1 FORMAT (8E 9.5)  
   READ (5,1) TABX, TABY, TABZ  
   READ (5,1) XA, ZA  
   CALL DISCOT (XA, ZA, TABX, TABY, TABZ,  $-73$ , 800, 10, ANS)

CASE IV:        Same as Case III with no extrapolation above  $z_{max}$ . Control word =  $-173$   
              CALL DISCOT (XA, ZA, TABX, TABY, TABZ,  $-173$ , 800, 10, ANS)



## APPENDIX F – Continued

**Restrictions:** See rule (5c) of section "Method" for restrictions on tabulating arrays and discontinuous functions. The order of interpolation in the x- and z-directions may be from 1 to 7. The following subprograms are used by DISCOT: UNS, DISSER, LAGRAN.

**Method:** Lagrange's interpolation formula is used in both the x- and z-directions for interpolation. This method is explained in detail in reference (a) of this subroutine. For a search in either the x- or z-direction, the following rules are observed:

- (1) If  $x < x_1$ , the routine chooses the following points for extrapolation:

$$x_1, x_2, \dots, x_{k+1} \quad \text{and} \quad y_1, y_2, \dots, y_{k+1}$$

- (2) If  $x > x_n$ , the routine chooses the following points for extrapolation:

$$x_{n-k}, x_{n-k+1}, \dots, x_n \quad \text{and} \quad y_{n-k}, y_{n-k+1}, \dots, y_n$$

- (3) If  $x \leq x_n$ , the routine chooses the following points for interpolation:

When  $k$  is odd,

$$x_{i-\frac{k+1}{2}}, x_{i-\frac{k+1}{2}+1}, \dots, x_{i-\frac{k+1}{2}+k} \quad \text{and} \quad y_{i-\frac{k+1}{2}}, y_{i-\frac{k+1}{2}+1}, \dots, y_{i-\frac{k+1}{2}+k}$$

When  $k$  is even,

$$x_{i-\frac{k}{2}}, x_{i-\frac{k}{2}+1}, \dots, x_{i-\frac{k}{2}+k} \quad \text{and} \quad y_{i-\frac{k}{2}}, y_{i-\frac{k}{2}+1}, \dots, y_{i-\frac{k}{2}+k}$$

- (4) If any of the subscripts in rule (3) become negative or greater than  $n$  (number of points), rules (1) and (2) apply. When discontinuous functions are tabulated, the independent variable at the point of discontinuity is repeated.

- (5) The subroutine will automatically examine the points selected before interpolation and if there is a discontinuity, the following rules apply. Let  $x_d$  and  $x_{d+1}$  be the point of discontinuity.

- (a) If  $x \leq x_d$ , points previously chosen are modified for interpolation as shown:

$$x_{d-k}, x_{d-k+1}, \dots, x_d \quad \text{and} \quad y_{d-k}, y_{d-k+1}, \dots, y_d$$

- (b) If  $x > x_d$ , points previously chosen are modified for interpolation as shown:

$$x_{d+1}, x_{d+2}, \dots, x_{d+k} \quad \text{and} \quad y_{d+1}, y_{d+2}, \dots, y_{d+k}$$

- (c) When tabulating discontinuous functions, there must always be  $k+1$  points above and below the discontinuity in order to get proper interpolation.

- (6) When tabulating arrays for this subroutine, both independent variables must be in ascending order.

## APPENDIX F - Concluded

(7) In some engineering programs with many tables, it is quite desirable to read in one array of  $x$  values that could be used for all lines of a multiline function or different functions. Even though this situation is not always applicable, the subroutine has been written to handle it. This procedure not only saves much time in preparing tabular data, but also can save many locations previously used when every  $y$  coordinate had to have a corresponding  $x$  coordinate. Another additional feature that may be useful is the possibility of a multiline function with no extrapolation above the top line.

Accuracy: A function of the order of interpolation used.

Reference: (a) Nielsen, Kaj L.: Methods in Numerical Analysis. The Macmillan Co., c.1956.

Storage: 555<sub>8</sub> locations.

Subprograms used: UNS           40<sub>8</sub> locations.  
                  DISSER   110<sub>8</sub> locations.  
                  LAGRAN   55<sub>8</sub> locations.

Subroutine date: August 1, 1968.

## REFERENCES

1. Garrett, Lloyd Bernard: An Implicit Finite Difference Solution to the Viscous Radiating Shock Layer With Strong Blowing. Ph. D. Diss., North Carolina State Univ. at Raleigh, 1971. (Available as NASA TM X-67584.)
2. Garrett, L. Bernard; Smith, G. Louis; and Perkins, John N.: An Implicit Finite-Difference Solution to the Viscous Shock Layer, Including the Effects of Radiation and Strong Blowing. NASA TR-388, 1972.
3. Wilson, K. H.: RATRAP - A Radiation Transport Code. 6-77-67-12, Lockheed Missiles & Space Co., Mar. 14, 1967.
4. Hansen, C. Frederick: Approximations for the Thermodynamic and Transport Properties of High-Temperature Air. NASA TR R-50, 1959. (Supersedes NACA TN 4150.)



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