Combustion of Hydrogen-Air Jets in Local Chemical Equilibrium
(A Guide to the CHARNAL Computer Program)

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Describes and gives listing in FORTRAN IV for a finite-difference computer program to predict flow properties for turbulent mixing with combustion of a circular jet of hydrogen into a co-flowing stream of air. The program, which is based upon the Imperial College group's PASSA series, solves differential equations for diffusion and dissipation of turbulent kinetic energy and also of the R.M.S. fluctuation of hydrogen concentration. The effective turbulent viscosity for use in the shear stress equation is computed from the equation \( \mu_e = C \rho k^2/\varepsilon \), where \( C \) is a constant, \( \rho \) is density, \( k \) is turbulent kinetic energy, and \( \varepsilon \) is the dissipation rate. Chemical equilibrium is assumed throughout the flow.
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COMBUSTION OF HYDROGEN-AIR JETS
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(A Guide to the CHARNAL Computer Program)

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1. Introduction

The computer program CHARNAL (Calculator of Hydrogen-Air Reactions for NASA Langley) generates finite-difference predictions of turbulent, coaxial hydrogen-air jets undergoing combustion. The jets may be free, as indicated in Figure 1a (in which case the external stream is assumed to extend to arbitrarily large radius from the symmetry axis) or enclosed as in Figure 1b. At any point in the flow the mass fraction of the constituents of combustion is found on the assumption that chemical equilibrium prevails, the constituents being H\(_2\), O\(_2\), H\(_2\)O, O, H, OH and N\(_2\).

The present report details the mathematical and physical basis of CHARNAL, discusses some sample predictions and provides a guide to the computer program itself. Section 2 is concerned with the first of these aspects: the basic conservation equations of momentum, stagnation enthalpy and chemical species are presented first and these are followed by a description of the turbulence and combustion models employed. A user's guide to the computer program appears in Section 3 while definitions of FORTRAN symbols and a listing of the program itself are contained in the Appendices. Thereafter, Section 4 presents and discusses the outcome of some test cases and, finally, Section 5 suggests some directions that further developments to the CHARNAL program might take.
2. The Mathematical and Physical Model

2.1 The Mean Flow Conservation Equations

CHARNAL calculates the steady state distributions within the jet of mean streamwise velocity, temperature and mass fraction of elemental hydrogen by reference to the conservation laws of momentum, energy and chemical species. These laws are expressed in terms of the following set of parabolic partial differential equations expressing respectively the transport of streamwise momentum, stagnation enthalpy and hydrogen mass fraction.

\[
\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial r} - \frac{1}{r} \frac{\partial}{\partial r} \left( \mu r \frac{\partial u}{\partial r} \right) = -\frac{dp}{dr} \tag{2.1-1}
\]

\[
\rho u \frac{\partial h}{\partial x} + \rho v \frac{\partial h}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left( \mu r \frac{\partial h}{\partial r} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left\{ r \left[ \left( \mu - \frac{\partial h}{\partial x} \right) \frac{2}{\partial r} \right] + \left( \gamma - \gamma_h \right) \frac{dt}{dr} + \sum_j \left( \gamma - \gamma_h \right) \frac{d f}{dr} \right\} \tag{2.1-2}
\]

\[
\rho u \frac{\partial f}{\partial x} + \rho v \frac{\partial f}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left( \mu r \frac{\partial f}{\partial r} \right) \tag{2.1-3}
\]

The mass fraction of elemental hydrogen, \( f \), is used as a variable for the reason that, unlike \( H_2 \), even during chemical reaction it remains a conserved property. The method of determining the individual chemical constituents of the flow is described in Section 2.3.

The set of partial differential equations is completed by the continuity equation in which the streamwise and radial velocities are connected by:

\[
\frac{\partial}{\partial x} \rho u + \frac{1}{r} \frac{\partial}{\partial r} (\rho vr) = 0 \tag{2.1-4}
\]
In fact CHARNAL solves the parabolic transport equations cast in a Von Mises system of coordinates (i.e., x and stream function as independent variables). This transformation has the effect of eliminating the radial velocity v from the equations, and, hence no explicit recourse needs to be made to equation (2.1-4).

The temperature of the mixture, \( T \), is obtained from known values of \( h \), \( u \) and the mass fractions of the chemical constituents of the mixture from the expression:

\[
T = \left[ h - \frac{u^2}{2} - k - \sum_{m} \left( \Delta h f - \Delta h \right) \right] \epsilon \sum_{m} c_{pj}
\]

(2.1-5)

and \( c_{pj} = \frac{1}{T} \int_{0}^{T} c_{pj} dT \)

(2.1-6)

2.2 The Turbulence Model

The effective turbulent transport coefficients \( \mu_t \), \( \Gamma_h \), \( \Gamma_u \) and \( \Gamma_k \) are determined by means of the k-\( \epsilon \) model of turbulence which has been presented and applied to numerous turbulent free shear flows in Reference [2]. According to this model the magnitude of the viscosity depends only on the local values of the turbulence kinetic energy, \( k \) the dissipation rate of turbulence energy, \( \epsilon \) and the fluid density. They are connected by the formula:

\[
\mu_t = C \mu \rho k^2 / \epsilon
\]

(2.2-1)

The quantities \( k \) and \( \epsilon \) are found by way of the following pair of transport equations which are both similar to (and solved simultaneously with) those governing the mean flow:

\[
\rho u \frac{\partial k}{\partial x} + \rho v \frac{\partial k}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial r} \right) + \mu_t \left( \frac{\partial u}{\partial r} \right)^2 - \rho \epsilon
\]

(2.2-2)

\[
\rho u \frac{\partial \epsilon}{\partial x} + \rho v \frac{\partial \epsilon}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{\mu_t}{\sigma_\epsilon} \frac{\partial \epsilon}{\partial r} \right) + \frac{C_1}{k} \epsilon \mu_t \left( \frac{\partial u}{\partial r} \right)^2 - \frac{C_2 \rho \epsilon^2}{k}
\]

(2.2-3)
The quantities $C_\mu$, $C_1$, $C_2$, $\sigma_k$ and $\sigma_\epsilon$ are dimensionless and are given the constant values below:

<table>
<thead>
<tr>
<th>$C_\mu$</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$\sigma_k$</th>
<th>$\sigma_\epsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.09</td>
<td>1.43</td>
<td>1.92</td>
<td>1.0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

These values are the same as those recommended in [2]. Equations (2.2-2) and (2.2-3) do not provide a physically exact prescription for finding $k$ and $\epsilon$. Such a prescription is not possible because the exact equations for $k$ and $\epsilon$ contain correlations whose magnitude is not directly ascertainable. These correlations are therefore approximated in terms of $k, \epsilon$ and the mean velocity field; the approximated terms in (2.2-2) and (2.2-3) are the ones with the empirically determined coefficients. Models of the above kind, while being sufficiently simple not to affect computer costs significantly, have been found (see for example, references [2] and [3]) to possess considerable width of applicability, precisely the same model predicting features of both wall and free turbulence. It is probably the best model available at present for the kind of shear flows that CHARNAVL is designed to compute.

The transport coefficients in the hydrogen-element and stagnation-enthalpy equations are given by

$$\Gamma_h = \mu_t/\sigma_h; \quad \Gamma_m = \mu_t/\sigma_m \quad (2.2-4)$$

In the free jets and in the confined jets (provided the jet has not spread to the pipe wall)

$$\sigma_h = \sigma_m = 0.7 \quad (2.2-5)$$

Once the jet has filled the pipe the effective Prandtl/Schmidt number is obtained from the formula:

$$\sigma_h = \sigma_m = 0.95 - 0.45 (y/R)^2 \quad (2.2-6)$$
where $y$ is distance in the radial direction measured from the pipe wall. The above variation, proposed by Rotta [4] and used by several workers since, is generally in accord with experimental data of the turbulent Prandtl number in fully-developed pipe flow. Note that because the same numerical values are assigned to $\Gamma_n$ and $\Gamma_m$, one of the source terms in equation (2.1-2) vanishes.

2.3 The Combustion Model

The equilibrium composition of the hydrogen air mixture can be calculated by reference to the set of reversible reactions:

\begin{align*}
H_2 & \rightleftharpoons H + H \\
O_2 & \rightleftharpoons O + O \\
OH & \rightleftharpoons O + H \\
H_2O & \rightleftharpoons OH + H
\end{align*}

The relative mass fractions of the above constituents are found by presuming that chemical equilibrium prevails at each point in the flow. Thus:

\begin{align*}
\frac{m_{H_2}}{m_H} &= K_1 \quad (2.3-5) \\
\frac{m_{O_2}}{m_O} &= K_2 \quad (2.3-6) \\
\frac{m_{OH}}{m_Om_H} &= K_3 \quad (2.3-7) \\
\frac{m_{H_2O}}{m_{OH}m_{OH}} &= K_4 \quad (2.3-8)
\end{align*}

where the $K_*$s are functions of temperature and pressure. In addition we have by definition

\begin{align*}
x &= m_{O_2} + m_O + \frac{\nu}{\nu_{H_2O}} \left( \frac{m_{H_2O}}{m_{OH}} \right) + \frac{\nu}{\nu_{OH}} \left( \frac{m_{OH}}{m_{OH}} \right) \quad (2.3-9)
\end{align*}

and

\begin{align*}
 f &= m_{H_2} + \frac{\nu}{\nu_{H_2O}} \left( \frac{m_{H_2O}}{m_{OH}} \right) + \frac{\nu}{\nu_{OH}} \left( \frac{m_{OH}}{m_{OH}} \right) \quad (2.3-10)
\end{align*}
In the above equation set, the quantities \( f \) and \( X \) are to be considered known: \( f \) is found from the conservation equation for total hydrogen (equation 2.1-3) and \( X \) is simply \( OFAC (1-f) \) where \( OFAC \) is the mass fraction of oxygen in the external stream. The equilibrium "constants" \( K_1 \ldots K_4 \) are functions of temperature and pressure. **CHARMAL** incorporates the dependencies proposed by McBride [5].

Equations (2.3-5) - (2.3-10) thus provide a set of six equations in the six unknowns \( m_{H_2}, m_H, m_{H_2O}, m_{OH}, m_O, m_{O_2} \). The equations are non-linear (indeed, highly non-linear for regions of flow where the fuel/air ratio is nearly stoichiometric); their solution must therefore proceed iteratively. The solution technique adopted is described in Section 3-4.

The mass fraction of \( N_2 \) (which is considered to be entirely inert) is simply \( (1-X-f) \).

Because the flow is turbulent, the level of hydrogen and of other variables will be continuously fluctuating about their mean values. The magnitude of the mean square hydrogen fluctuations, \( g \), is found from the following transport equation developed and tested by Spalding [6]

\[
\rho u \frac{\partial g}{\partial x} + \rho v \frac{\partial g}{\partial y} = \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{\partial g}{\partial r} r \right) + C_{g1} \mu_t \left( \frac{\partial f}{\partial r} \right)^2 - C_{g2} \frac{\rho g}{k} \quad (2.3-11)
\]

where the constants \( \sigma_g, C_{g1}, \) and \( C_{g2} \) are assigned the values of 0.7, 2.8 and 2.0 respectively. Solution of the \( g \) equation enables the region of the flame over which stoichiometric conditions occur to be calculated. The inner boundary to this region occurs at a radius from the axis where \( f-g^{1/2} = f_{\text{stoich}} \) and the outer boundary where \( f+g^{1/2} = f_{\text{stoich}} \). The predicted path of these two surfaces for a hydrogen jet burning in an air stream is shown in Figure 10.

3.0 Details of the CHARMAL Computer Program

**CHARMAL** is a custom-developed version of the Patankar-Spalding PASSA program which, in turn, is a newer, more economical and flexible version of GENMIX published in Reference [1].

Section 3.1 below gives a brief summary of the general Patankar and Spalding method of solving the boundary layer equations. Section 3.2 lists the major differences between **CHARMAL** and the original GENMIX program, while Section 3.3 discusses in detail the listing of the present program (which is to be found in Appendix 2). Section 3.4 is devoted to
a discussion of subroutine LAi'iGLEY, which has been developed exclusively for the current work. Finally Section 3.4 gives overall instructions for the running of the program, in particular the input information that the user must provide.

3.1 The Patankar-Spalding Boundary Layer Procedure

The main features of the computational method are as follows:

(i) The primary differential equations (i.e., the transport equations for \( u, h, f, g, k \) and \( \varepsilon \)) are transformed so that the independent variables are the longitudinal distance, \( x \) and the dimensionless stream function, \( \omega \) defined as:

\[
\omega = (\psi - \psi_I)/(\psi_E - \psi_I) \tag{3.1-1}
\]

where \( \psi \) itself is obtained from the relation,

\[
\frac{\partial \psi}{\partial y} = \rho ur \tag{3.1-2}
\]

Subscripts I and E refer respectively to the "inner" and "outer" boundaries of the flow; for axisymmetric flows the inner surface is always the one nearer the symmetry axis. The resulting differential equations are all of the basic form,

\[
\frac{\partial \phi}{\partial x} + (a+b \omega) \frac{\partial \phi}{\partial \omega} = \frac{\partial}{\partial \omega} \left( c \frac{\partial \phi}{\partial \omega} \right) + d, \tag{3.1-3}
\]

where the terms on the left-hand side represent convection by the mean flow and those on the right-hand-side express respectively the diffusion and source of the entity \( \phi \). The coefficients, \( (a) \) and \( (b) \) are functions of the entrainment rates, whilst \( (c) \) involves the effective diffusion coefficient.

(ii) The differential equations are expressed as finite-difference equations, connecting the values of the dependent variables which prevail at the intersection points of a grid defined by lines of constant \( x \) and \( \omega \). These finite-difference equations are formed by integrating the differential equations over small control volumes associated with each grid node.
(iii) The integration proceeds by "marching" downstream, the values of the variables at grid points at the next downstream station being calculated from those at the upstream station and placed into the array locations occupied by the latter. At each forward step, new values are ascribed to $\psi_E$ and $\psi_I$, the stream functions at the grid boundaries. These values, together with the continuity equation, determine the geometrical location of the boundaries; and this determination is so arranged that the boundaries enclose all the fluid having a significant value of the shear stress (or other flux) without enclosing appreciably more than this. This feature allows the method to achieve good numerical accuracy without employing an excessively fine grid.

(iv) The finite-difference equations are formulated in an implicit manner, and solved by means of the well-known algorithm for tri-diagonal matrices. This allows large forward steps to be made without instability. The equations are linearized, upstream values of the transport properties being supposed to prevail over the whole of the forward step.

(v) The source terms are usually (but not necessarily) expressed as linear functions of the upstream and downstream values of the dependent variables. For example in the turbulent kinetic equation,

$$\text{Source of } (k) = \left[ \mu_t \left( \frac{\partial u}{\partial y} \right) \right]_U^2 - \left[ \left( \frac{\rho \varepsilon}{k} \right)_U \right] k_D \tag{3.1-4}$$

where the subscripts $U$ and $D$ denote upstream and downstream values. This practice allows large forward step sizes to be used without the onset of inaccuracy or instability.

For further information on the general structure of the solution procedure the reader is referred to Reference [1].

3.2 New and Improved Features of the PASSA family of programs

PASSA programs retain the general width of applicability of the basic procedure, but are arranged to be more economical in terms of both execution time and storage capacity. The principal differences between the new method and its predecessor may be summarized:

(i) In PASSA, the finite-difference equations are solved sequentially. That is, for any variable, the coefficients of finite-difference equations are formed and the equations solved before moving on to the next differential equation. This contrasts with the former procedure where the coefficient for all the differential equations were stored simultaneously and then the matrix was inverted for each equation in turn.
(ii) The PASSA program does not make use of "slip nodes" in the formulation of the difference equations at the boundaries. In the earlier program, these nodes were employed to obtain the correct gradients of the dependent variables at the edge regions. PASSA treats the nodes near each flow boundary in exactly the same way as the interior nodes.

(iii) In PASSA all diffusivities and gradients of the dependent variables, such as the viscosity and the velocity gradient are evaluated at the actual grid nodes, whereas in the earlier program these quantities were evaluated at the edges of the control volumes (which by definition were midway between individual nodes in terms of ω). PASSA also contains the option of using castellated profiles instead of linear variations of ϕ between the grid nodes.

3.3 Details of the CHARNAL Program

A flow diagram for CHARNAL is provided in Table 1. The program consists of a MAIN program and a number of subroutines of which the most important are AUX, STRIDE, OUTPUT and LANGLEY.

3.3-1 The MAIN Program

MAIN contains the starting and stopping points of the computation and communicates directly or indirectly with all the other subroutines. It comprises twelve "chapters", each performing a specific function in the computational procedure. The most important of the operations are mentioned below:

Chapter 1. Values are assigned to various indices which control aspects of the computation throughout the program. The main categories are:

(i) the specification of the number of grid nodes and differential equations to be solved.

(ii) the nature of the flow boundaries (wall, free boundary or axis of symmetry)

(iii) the control of input, and

(iv) the designation of the flow type (number of chemical species, nature of initial conditions, etc.). This topic is discussed in more detail in Section 3.4.

Chapter 2. This chapter selects the primary dependent variables and auxiliary quantities to be calculated in the program. Comment cards have been included here for the user's benefit.

Chapter 3. Material constants such as molecular weights and the universal gas constant, turbulence parameters and Prandtl/Schmidt numbers are assigned values. The S.I. system of unit is used throughout the program. Subroutine LANGLEY
is called to provide data for the enthalpies of the chemical species and the equilibrium reaction constants.

Chapter 4. Specified here are the flow geometry (plane or axisymmetric), inclination of the streamlines to the axis of symmetry and the cross-stream distances for the initial profiles.

Chapter 5. The initial profiles are read in from data cards. Values are assigned to the axial velocity, absolute temperature and species concentrations at the grid nodes. All the data input are in dimensionless form, having been normalized with the largest value of each dependent variable at the initial station. In developing CHARNL, fifteen test cases (specified by NASA Langley) have been run which required two different types of initial-profile specification.

(i) Continuous profiles (Test Case nos. 1-10, 13)

Figure 2a shows the initial-velocity-profile typical of these test cases. The two streams are separated by a wake region caused by the interaction of the boundary layers on the dividing wall. Since the velocity is uniform near the jet centreline, the computation starts from a mixing-layer region with entrainment at the inner flow boundary until this boundary grows to the axis of the jet (i.e., the end of the potential core).

(ii) Step profiles (Test Case nos. 11-12, 14-15)

In these four test cases, the boundary layers on the dividing wall are ignored and a step-change in the velocity profile is assumed (see Figure 2b). In these cases, the computation starts from a very thin mixing layer (with an assumed linear velocity profile) in the immediate vicinity of the step-change.

The initial profiles of turbulent kinetic energy are then evaluated by assuming a constant ratio with the shear stress (as expressed by the mixing length hypothesis), whence

\[ k = 3.33 \left( k_m \left( \frac{\partial u}{\partial y} \right) \right)^2 \]  

(3.3-1)

The dissipation rates are then given by the Prandtl-Kolmogorov relationship

\[ \epsilon = k^{3/2}/\mu \epsilon \]  

(3.3-2)
Both the mixing length and dissipation length scale are assumed to be proportional to a typical width of the shear region. The scheme adopted is shown in Figure 2.

The free-stream turbulent kinetic energy is taken as $4 \times 10^{-4}$ of the square of the free-stream velocity. The same constant is used to determine the initial profile of concentration fluctuations from the local concentrations of hydrogen element, i.e., $g/f^2 = 4 \times 10^{-4}$.

A variable of major importance in the computational procedure is OFAC, which is the ratio of oxygen element to nitrogen in the outer stream, since this ratio is assumed to be constant across the flow.

Chapter 5 also calls subroutine LANGL2 to evaluate the initial enthalpy profile.

Chapter 6. The dimensionless stream function array is filled by integration of the profiles of density and velocity according to equations (3.1-1) and (3.1-2). The density is obtainable from the ideal gas relationship,

$$\rho = \frac{p\mu}{RT} \quad (3.3-3)$$

where the mean molecular weight of the mixture, $\mu$ is given by,

$$\frac{1}{\mu} = \sum \frac{m_j}{W_j} \quad (3.3-4)$$

Subroutine STRID1 is called to evaluate useful quantities relating the individual $W$'s.

Chapter 7. This marks the starting point of the main computation; it is the point to which control is returned after the execution of each forward step. The most important functions of this chapter are,

(i) to call LANGL3, which employs the chemical reaction constants relevant to the upstream conditions. (i.e., pressure and temperature) to determine the local mass fractions,

(ii) to call LANGL4 to calculate the temperatures corresponding to these concentrations (by way of the upstream specific heats) and
(iii) to evaluate the density profile from the local temperatures and mass concentrations

Chapter 8. This chapter performs two main tasks. First it fixes the size of the forward step and secondly it calls subroutine STRID2 to calculate transverse distances. The forward step is usually made proportional to the width of the flow, with the constant of proportionality small in the initial region to avoid instabilities at the start of the calculation. For confined flows, the streamwise pressure gradient, which is a source term in the axial momentum equation, is not known a priori. CHARNAL adopts the same non-iterative practice employed in CEMIX, (see reference [1]). An estimate of the pressure change to be experienced over a forward step is obtained by reference to a 1-dimensional analysis. This usually results in the area of the flow differing from the pipe cross sectional area at the end of the forward step. However by adjusting the level of dp/dx over the next step the difference in area can be kept negligible (typically 0.01% of the pipe area).

Chapter 9. This chapter fixes the conditions at the flow boundaries. Only when a boundary is a wall must information (either the value of \( \phi \) or its diffusional flux) be specified at this point. In the case of a free boundary, the relevant information is provided in STRID3 (based on the free-stream source terms) while at an axis of symmetry, the zero gradient condition usually applies.

Chapter 10. The first chapter of AUX is called to determine the effective viscosity (regarded as the sum of the turbulent and shear viscosities) at each node and to formulate the source term based on the axial pressure gradient. For a free boundary the entrainment rate is calculated via the degenerate form of the conservation equation for whichever of the dependent variables shows the largest changes near the edge of the flow. The entrainment is subject to certain controls to prevent the formation of 'tails' to the profiles and to prevent the onset of instability.

Chapter 11. This chapter deals with the output of information. At the first step, subroutine OUTP 1 is called to print-out information regarding the initial conditions. At certain axial positions (designated in Chapter 1) OUTP 2 is called to print-out such quantities as the entrainment rates, jet spreading rate, centreline values of the velocity, temperature and species concentrations and the fluxes of the dependent variables. Also OUTP 3 may be called (not necessarily at the same stations) to print-out the profiles of quantities of interest (velocity, temperature, concentrations, etc.).
Chapter 12. The last chapter terminates the execution after a specific axial distance has been covered. Otherwise, control is returned to Chapter 7.

3.3-2 AUX, STRIDE and '.IF

Only brief description is provided of these general-purpose subroutines as they are similar in structure and function to the correspondingly named subroutines in GEM/IX (reference [1]). Subroutine AUX is called initially from Chapter 10 of MAIN to provide the effective viscosities at the grid nodes. Chapter 2 is subdivided into five parts, one for each of the dependent variables other than the velocity. Each section evaluates the appropriate effective diffusivity and formulates the source arrays and is called in turn from STRIDE 3 as the finite difference equations are solved sequentially. The source terms for turbulent kinetic energy, dissipation rate and mean square concentration fluctuations are linearized according to equation (3.1-4), while that for stagnation enthalpy is loaded entirely into the upstream array.

Subroutine STRIDE is divided into four parts, of which the first two are largely preparatory, while the latter two contain the core of the numerical method of the program. STRID 0 merely sets to zero arrays such as those for the dependent variables and auxiliary quantities. It is here that the decision is made as to whether to employ linear \((KAST (J) = 0)\) or castellated \((KAST (J) = 1)\) profiles between the grid nodes. STRID 1 evaluates useful relationships between the values of \(\omega\) at neighboring nodes, these of course remaining constant for the whole of the calculation as the grid is always constrained to lie between limits of \(\omega=0\) and \(\omega=1\). STRID 2 calculates the cross-stream distances at each axial station with but minor differences from the original program [1]. STRID 3 contains the basic finite-difference formulation and technique of solution of the differential equations. Although different in appearance from the version published in reference [1], the differences are largely only ones of arrangement. It is not proposed to dwell on points of detail here, but suffice it to say that STRIDE is a subroutine which the user has very seldom any need to change. STRID 3 terminates by determining conditions at the flow boundaries and by initiating the forward step.

Subroutine HIF provides wall-function relationships to relate the fluxes (diffusional and convective) through the wall with the values of the dependent variables at the near-wall nodes. As appropriate to the high-Reynolds-number form of the turbulence model employed in this work, the wall functions are based on the assumption of a log-law velocity profile in the fully turbulent region of the flow.

3.3-3 OUTPUT and related Subroutines

Subroutine OUTPUT is divided into three parts, concerned respectively with the print-out of initial values of interest and station and profile variables. It communicates with PROFIL and thence with subroutine
PLOTS, which together may be used to provide non-dimensional plots of the profiles. OUTP1 reads alphanumeric information from data cards to provide the headings for the print-out. The meaning of the quantities printed from OUTP2 and CUTF3 is given in Appendix 1. Subroutine OUTP2 performs the useful function of checking for the overall conservation of fluxes of the dependent variables; in this analysis the concentration of hydrogen element is a conserved property as are the axial momentum and stagnation enthalpy (but for free flows only).

There is a large number of comment cards in OUTPUT, PROFIL and PLOTS to assist the reader in understanding the interlinkage between these subroutines. PROFIL is used to normalize the profiles and communicates with PLOTS which scales both the abscissa (transverse distance) and ordinate ($\phi$ values) of the dimensionless plots into the range 0 to 1, (with negative values printed as zero). Either the normalized (IPROF = 1) or the full dimensional (IPROF = 2) values of the dependent and auxiliary variables may be printed out in OUTP3. If the former approach is adopted, the full dimensional values are still printed at the first and last nodes (designated 1 and NP1 respectively). The cross-stream distances $Y(I)$ are treated in this way, the first quantity printed being the radius of the internal flow boundary and the last the distance between the internal and external boundaries.

Subroutine YINT may be called at any point in the program and is merely an interpolation subroutine. It is useful in the determination of such quantities as the half-width of the jet or locating the exact position where the value of an entity $\phi$ is a linear combination of the values of $\phi$ at the inner and outer boundaries of the flow.

3.3-4 Subroutine LANGLEY

Subroutine LANGLEY has been developed exclusively for the present work and is subdivided into four parts, whose purposes are respectively

(i) the loading of the individual species and the chemical equilibrium constants for the stipulated reactions.

(ii) the evaluation of the initial enthalpies by simple interpolation amongst the input data.

(iii) the calculation of the species mass fractions by solution of six simultaneous equations.

(iv) the evaluation of the cross-stream temperatures from the enthalpies and the upstream specific heats.

Data for enthalpies and chemical-reaction constants are those proposed by McBride [5]. The enthalpy of each species may be written in the form
\[ h - h_{\text{ref}} = \int_{T_{\text{ref}}}^{T} C_p \, dT + \Delta h_f, \quad T_{\text{ref}} \]  

(3.3-5)

where \( \Delta h_f, T_{\text{ref}} \) denotes the heat of formation of the species at the reference temperature. It is usual to take the datum of enthalpy as zero at a reference temperature of 298.15°K, whence

\[ h = \int_{298.15°K}^{T} C_p \, dT + \Delta h_f, 298.15°K \]  

(3.3-6)

\[
= \int_{0°K}^{T} C_p \, dT + \left[ \Delta h_f, 298.15°K - (h_{298.15°K} - h_{0°K}) \right]
\]

\[ \equiv C_p \, T + H_0 \]  

(3.3-7)

where \( C_p (= 1/ \int_{0°K}^{T} C_p \, dT) \) denotes a mean specific heat and \( H_0 \) is the composite of the remaining terms. Values of \( h \) are read in at intervals of 100°K for temperatures of up to 6000°K, together with the value of \( H_0 \) for each species. The mean specific heats are then evaluated from equation (3.3-7) and stored (see Appendix 1 for array locations).

LANGL2 is called to obtain the initial enthalpy profile by linear interpolation of the \( h/T \) data. The enthalpy of the mixture is then given by

\[ h = \sum m_j h_j \]

\[ = \sum m_j C_{p,j} T + \Sigma m_j H_0,j \]  

(3.3-8)
LANGL1 is also used to store data for the chemical equilibrium for the four reactions involved in the combustion process. These are again taken from McBride [5] and are in the form of constants relating the partial pressures of the individual species, i.e., for the reaction

\[ aX + bY = Z \]

(implies the formation of 1 unit of substance Z from (a) units of X and (b) units of Y), the partial pressures of the species are linked by a constant, \( K_p \) given by the relation

\[ K_p = \frac{p_Z}{p_X^a p_Y^b} \] (3.3-10)

(Because \( K_p \) (which is a function of temperature) varies markedly, numbers on the data cards refer to \( \log_{10} K_p \). \( K_p \)'s may be transformed into constants relating the species mass fractions by use of the ideal gas law, whence

\[ K_m = \frac{m_z}{m_x^a m_y^b} = K_p (pW)^{a+b-1} \frac{W_z}{W_x^a W_y^b} \] (3.3-11)

where \( W_j \) denotes the individual molecular weights and \( W \) is the mean molecular weight of the mixture. Values of \( (K_p W_z W_x^a W_y^b) \) are stored for each reaction involved. In using Equation (3.3-11), it is to be remembered that the total pressure, \( p \) must always be expressed in atmospheres.

LANGL3 evaluates the concentrations of the individual species by six simultaneous algebraic equations, viz.

\[ K_{m,1} = \frac{m_{O_2}}{m_H^2} \] (3.3-12)

\[ K_{m,2} = \frac{m_{H_2}}{m_0} \] (3.3-13)

\[ K_{m,3} = \frac{m_{OH}}{m_0 m_H} \] (3.3-14)
\[ K_{m,4} = \frac{m_{H_2O}}{m_{H-H_2O}} \] (3.3-15)

\[ x = m_{O_2} + m_0 + \frac{W_0}{W_{H_2O}} m_{H_2O} + \frac{W_0}{W_{OH}} m_{OH} \] (3.3-16)

\[ f = m_{H_2} + m_H + \frac{W_{H_2}}{W_{H_2O}} m_{H_2O} + \frac{W_H}{W_{OH}} m_{OH} \] (3.3-17)

in which the equilibrium constants (which are functions of pressure, temperature and concentrations) are based on the upstream conditions, since the temperatures can only be calculated once the mass fractions have been found.

The first function performed by LAMGL3 is to evaluate the reaction constants and mean specific heats by linear interpolation amongst the input data. Equations (3.3-12) to (3.3-17) are then solved iteratively until convergence to within 1% is obtained for all species present to an extent of more than 10^{-6}, or until the number of iterations exceeds a certain limit. The actual iterative scheme is of necessity rather elaborate since the relative concentrations of the species can vary markedly. The following practices are adopted:

(i) The concentration of nitrogen is easily calculable as \((1-GFAC)(1-f)\).

(ii) The concentrations of the remaining species at the previous axial position are used as a first estimate of the downstream values.

(iii) The equations for \(f\) and \(x = OFAC(1-f)\) are examined to determine the largest term on the right-hand side of each. For example, suppose that \(\frac{W_0}{W_{H_2O}} \cdot m_{H_2O}\) and \(m_{H_2}\) are the largest quantities.
(iv) Using the values of \( m_{H_2O} \) and \( m_{H_2} \), equations (3.3-12) to (3.3-15) can then be solved to determine the concentrations of the remaining four species.

(v) \( m_{H_2O} \) and \( m_{H_2} \) can then be re-evaluated from Equations (3.3-16) and (3.3-17).

(vi) The right-hand sides of the X and f equations are then re-examined and the next iteration cycle made to operate on the two largest quantities.

(vii) Iteration is repeated until the convergence criteria are satisfied or the number of iterations becomes excessive.

Convergence is usually rapid (2 iterations), but instability occurs whenever two of the terms in either of the additive equations [(3.3-16) and (3.3-17)] become of approximately equal magnitude. This happens (a) at high temperatures (> 3000°K) where the concentration of atoms approaches that of the molecules and (b) in the region of the stoichiometric point where the concentration of combustion products becomes large. In the flows under investigation, the maximum predicted temperature was approximately 2600°K; (b) was therefore the main source of instability. It often happened that on successive iterations different constituents were the largest terms in Equations (3.3-16) and (3.3-17). Oscillatory rather than convergent behavior would then result. However, under-relaxation of the species concentrations between successive iteration cycles generally achieved the required degree of convergence within 12 iterations. A warning message is printed out whenever the iteration process fails to converge within this limit.

When the species concentrations have been found, LANGL4 is called to evaluate the cross-stream temperatures. These are obtained from enthalpy profile via the relationship,

\[
T = \left( h - \sum_{j} m_{j} H_{0,j} \right) / \sum_{j} m_{j} \bar{C}_{p,j},
\]  

(3.3-18)

for which the mean specific heats are evaluated in LANGL3 on the basis of the upstream temperatures. One could regard this value of temperature as a first estimate of the actual value, since a more accurate estimate could be obtained by re-evaluating the \( K_n \)'s to obtain new values of the constituent mass fractions, a new mean specific heat, and from (3.3-18) a new \( T \). LANGLEY does not incorporate such an iteration cycle (though it would not be difficult for a user to add). Instead, under-relaxation of the temperature between upstream and downstream stations damps out any
temperature spikes which would otherwise appear at positions close to the stoichometric point.

3.4 Use of the Present Program

CHARNAL solves 6 simultaneous partial differential equations and employs typically 25 nodes (although the storage blocks have been dimensioned to allow for as many as 40). The program is written in basic CDC Fortran language and requires approximately 12 seconds compilation time on a CDC 6600 machine (FUN compiler). Linear profiles are assumed for the variation of the dependent variables between the grid nodes and a typical forward step size of 0.1 times the local shear layer width is employed. Approximately 15 axial steps can be executed per second. Conservation of the individual fluxes is generally good to within ±0.1%. In the present work, the profiles have been printed out in full dimensional form and are plotted at only one axial position (corresponding to the end of the potential core region). The program has a modest storage requirement, needing only approximately 24000 decimal storage locations.

The remainder of this section is concerned with the information that the user has to provide via data cards in subroutines MAIN and LANGLEY. In Chapter 1 of MAIN, control indices which have to be set are:

(i) Details of the grid and nature of the flow

KASENO : Test case number
NEQ : number of differential equations
M : number of grid nodes
KASE : type of flow; = 1 (free jet), = 2 (confined flow)
KIN : specification of internal flow boundary
   = 1 (wall)
   = 2 (free)
KEX : specification of external flow boundary
   = 3 (axis of symmetry)
KONFIN : denotes presence of confining duct wall;
   = 1 (wall present), = 2 (no wall)
IN2, IO2, IH2O : denote presence of individual species;
   = 0 (not present), = 1 (present)
WR : number of reactions
NS : number of chemical species
INUF : nature of initial profiles = 0 (continuous)  
= 1 (step-change)

XU : initial axial distance (in nozzle diameters)

XU-LAST : last axial distance (in nozzle diameters)

YIN : radius of internal flow boundary (in nozzle diameters)

YOUT : diameter of jet nozzle

RDUCT : radius of confining duct

PRESS : static pressure (in atmospheres)

TA : maximum temperature at initial station

UIN : maximum velocity at initial station

YW1 : extent of inner shear region (in nozzle diameters) i.e., distance-from axis of symmetry to minimum in velocity profile

UW1 : velocity at position denoted by YW1

I'Ull : grid node corresponding to YW1 and UW1

TDUCT : temperature of duct wall (for confined flows only)

(ii) Output parameters

HSTAT, NPROF, NPLot : number of axial stations between print-out of (i) station variables, (ii) profile variables and (iii) non-dimensional plots

XSTAT, XPROF, XPLOT : the corresponding axial distances (in nozzle diameters)

The next data cards are read in from LAMGL1 and refer to the chemical equilibrium constants for the 4 (NR) reactions and the enthalpies for the 7 (NS) species; these must be in the same order as the auxiliary variables are data-typed in Chapter 2 of MAIN. The data are read in at intervals of 100°K for temperatures up to 6000°K, so that for example, HT (2.35) refers to the enthalpy of species 2 (oxygen) at 3500°K.

Further data cards provide the initial profiles in Chapters 4 and 5 of MAIN. For those test cases involving step profiles, only the cross-
stream distances are required together with the values of velocity, temperature and species concentrations in each free stream. Appropriate profiles for the thin mixing layer under consideration are then generated internally. For cases with continuous profiles, the cross stream distances, velocities, temperatures and the concentrations (of those species whose presence has been previously indicated) are read in and converted to full dimensional form.

The remaining data cards contain alphanumeric data which are used to provide headings for the print-out. These are read in from LANGL1 and supply information on

(i) the test case number and description (2 cards)
(ii) the dependent variables of the calculation (10 cards)
(iii) the chemical reactions assumed (NR cards)
(iv) the species present (NS cards) and
(v) their chemical symbols (1 card).

4. Discussion of Sample Predictions

To examine the general capabilities of CHARNL, fifteen test cases, prescribed by NASA Langley, involving the mixing and combustion of a hydrogen jet with various coaxial gas streams have been computed. The computer outputs of these runs have been forwarded separately to the contracting agency. In this section we examine various features of the numerical predictions, the main attention being given to test cases 1 and 4, for which the prescribed initial profiles of velocity and temperature are given in Table 2.

Jet velocity and temperature profiles for Case 1 at four downstream stations are shown in Figures 3 and 4. The wake region of the profile arises from the wall boundary layers that are present on wall of the hydrogen pipe. As the shear flow develops downstream the jet spreads and the velocity level falls. Notice that the jet region is still present at x/D = 50*. From the temperature profiles shown in Figure 4 the region of

* In this case there is a slight momentum deficit in the shear flow so, far enough downstream, the velocity within the shear flow would be everywhere less than the free stream velocity.
combustion is clearly evident through the sharp peak in the temperature level. It is seen that the maximum temperature remains virtually constant as the shear flow develops downstream.

The decay of mass fraction $m_{H_2}$ is shown in Figure 5. Comparison is drawn between predictions for Case 1 and Case 3 in which initial conditions are similar to Case 1 except that the surrounding gas is nitrogen (which is non-reacting) rather than air. Also shown is a prediction from reference [2] obtained, with the same model of turbulence as that used here, for a non-reacting hydrogen air jet with velocity ratio similar to Case 1 but where the total temperature of the external stream was only 300°K; the density of the air is thus approximately 3 times that for Case 1. (The prediction from [2] was in satisfactory agreement with the experimental data of Eggers [7], which for clarity are omitted from Figure 5). Clearly, because of the smaller density of the external stream, the rate of dilution of the hydrogen jet is appreciably slower for the present test cases than in the reference [2] computation. The decay rate is seen to be faster for the hydrogen/nitrogen mixing than for the hydrogen/air jet. This behavior is attributable to the fact that combustion does not take place in Case 3, hence temperatures within the jet are lower and density correspondingly higher (if reaction is suppressed in test Case 1 the rate of decay of $m_{H_2}$ is nearly identical with that of Case 3).

Distributions of some of the important dependent variables affecting the flow development are shown in Figures 6-9. The station selected is 20 jet diameters downstream from the exit (through the profile shapes vary only slightly with streamwise position). It is seen from Figure 6 that the turbulence energy $k$ reaches its maximum value at the axis. This is generally a feature of axisymmetric jets and is in contrast with the behavior of plane jets where the peak energy level occurs near the position of maximum shear stress. (The different behavior is attributable to the more rapid axial decay that occurs in the round jet). Profiles of mean and mean-square-fluctuation levels of hydrogen element are shown in Figure 7. It is noted that the rapid decrease in the level of fluctuations in the outer part of the jet is the reason that the $f_+$ line in Figure 10 lies much closer than does $f$ to the stoichiometric line.

The calculated distributions of radicals and atomic species are shown in Figure 9. Their level is very sensitive to temperature and this is why a logarithmic scale is adopted for the ordinate. The peak calculated concentration of OH is approximately 1% by mass, about ten times as large as the maximum mass fractions of O and H. The corresponding distributions of molecular concentrations ($H_2$, $N_2$, $O_2$ and $H_2O$) are shown in Figure 10. The figure includes predictions for "case 8" as well as Case 1. Initial conditions for the former differ from Case 1 principally through the presence of appreciable water vapor in the external stream. It is seen that, as a result, the level of $H_2O$ is higher throughout the jet than in Case 1 and
the level of \( \text{H}_2 \) and \( \text{O}_2 \), correspondingly lower. The hydrogen profiles for the two cases are virtually identical.

Turning now to the confined flows, it must be said at the outset that, for the conditions prescribed in the test cases, the rate of spread of the jet was so slow that in no case do the predictions show the jet having reached the pipe wall by the downstream end of the field of computation. There are, nevertheless, some effects of the flow confinement through these are mainly seen in the velocity development (Figure 5 shows that the centreline mass fraction of \( \text{H}_2 \) is only slightly diminished by the presence of the pipe wall). Because the flow is supersonic, the exothermic reaction leads to a rise in static pressure with distance along the duct. This adverse pressure gradient causes a reduction in the level of velocity as the jet develops along the duct; velocity profiles at three stations are shown in Figure 3. The variation of centre line velocity with \( x \) is shown in Figure 11 for four test cases. Note that, for Case 6 in which confined streams of hydrogen and nitrogen mix without chemical reaction, the variation of \( U \) is virtually identical with the corresponding unconfined flow, Case 3.

To convey an impression of the capabilities of CHARNAL for predicting both free and wall flows, Figure 12 shows predictions obtained for the mixing of subsonic \( \text{H}_2/\text{air} \) streams. In order to achieve a faster rate of spread than in any of the prescribed test cases the initial core jet velocity is set to five times that of the surrounding stream; moreover the diameter of the confining pipe has been reduced to 49mm. Figure 12 shows the development of the velocity and temperature profiles along the duct. The jet reaches the pipe wall about 33 jet diameters from the start and by 40 diameters downstream the velocity profile looks generally like that found in pipe flow. By 75 diameters combustion is virtually complete and the temperature is uniform except in the vicinity of the wall.

5. Suggestions for Further Extensions and Refinements of CHARNAL

CHARNAL provides numerical predictions of how combustion will proceed in reacting hydrogen jets. It ought to be emphasized, however, that this behavior will not necessarily coincide - nor, sometimes, even approximate to - the actual development of the flow. Validation and comparison of the predicted behavior with available experimental data ought therefore to precede any use of the program for detailed design calculations. Without in any way preempting the outcome of such a series of comparisons, it may be helpful to indicate briefly some areas where improvements to the present version could be made. These are outlined briefly below.

(i) Combustion model

While the equilibrium combustion model embodied in CHARNAL may be adequate in high temperature flows, it evidently leads to unrealistically fast rates of combustion at low temperatures. The argument in favor of
assuming chemical equilibrium is that the chemical constituents may then be determined from solution of algebraic rather than differential equations with corresponding savings in computer time. The savings however are relatively modest because the algebraic set of equations are significantly non-linear and require iteration at each node to solve.

A further important point is that only with a differential reaction scheme can one take proper account of the role of species fluctuations on the progress of the chemical reaction. It is thus recommended that in the future CHARNAL be extended to include a finite-rate reaction model. At the same time consideration should be given to the inclusion of a more elaborate reaction model than that implied by equations (2.3-1 - 2.3-4).

Turning now to the turbulence-model, it must be said that there are a number of areas of uncertainty. The Proceedings of the Langley Conference on Free Shear Flows (of which reference [2] forms a small part) suggests that the Mach number of the fluid may exert an influence on the shear flow development—at any rate for flows, such as the mixing layer, where turbulence levels are high. It is also known (see Reference [2]), that the quantity \( C_u \), although assumed constant in the present work, increases appreciably when the average level of turbulence energy production at any station becomes small compared with the dissipation rate. Now it happens that in many of the test cases examined by CHARNAL the momentum excess due to the hydrogen jet moving faster than the external stream is just about balanced by the momentum deficient of the boundary layers on the nozzle walls. This situation leads to a rapid decrease in rate of energy production with x.

If these circumstances are the ones that prevail in the majority of tests to which CHARNAL is to be put it would therefore be desirable to replace the present constant \( C_u \) by the elaborate dependency on energy production: dissipation rates presented in [2] (associated with the model designated \( k\varepsilon 2 \) in that reference). Such a change would produce a somewhat faster rate of spread of the jet than does the present model from about 15 diameters downstream of the jet exit to the point at which the jet reaches the pipe wall (if present). There is in addition the possibility that combustion will affect in some way the turbulence transport. There seems no conclusive evidence on this point yet but this perhaps mainly reflects the lack of sufficiently well documented experimental data.

A separate, albeit related, point to those discussed in the above paragraphs is the importance of accurate upstream profiles. An abiding feature of weak shear flows such as those tested by CHARNAL is their inability to 'forget' the nature of their origin. For example the far field behavior of axisymmetric wakes depends crucially on the shape of the wake-generating object. It follows, therefore, that in order to obtain reliable predictions of the present hydrogen/air jets it is necessary that the upstream values of the mean velocity and turbulence quantities be known accurately. However, no information was provided on the profiles of turbulence quantities and so "best estimates" had to be made estimates,
however, that may give the wrong levels of $k$ or $\varepsilon$ by a factor of two or three. It would certainly be helpful in clarifying the degree of realism provided by the present model of turbulence if a few more experiments could be performed for conditions similar to those examined by Eggers [7] in which especial attention was given to a full documentation of the upstream flow conditions.

6. References


7. Nomenclature

$C_\mu, C_1, C_2, C_{g1}, C_{g2}$ constant coefficients appearing in turbulence model.

$\bar{c}_p$ mean specific heat of species $j$.

$D_j$ diameter of jet nozzle.

$f$ mass fraction of elemental hydrogen.

$g$ mean square fluctuations in $f$.

$h$ enthalpy.
\( \hat{h} \) stagnation enthalpy.

\( \Delta h \) difference between enthalpy of species at 298.15°K and 0°K.

\( \Delta h_f \) heat of formation of species \( j \).

\( k \) kinetic energy of turbulence.

\( \epsilon \) dissipation length scale \( k^{3/2}/\epsilon \).

\( L_m \) mixing length.

\( m_j \) mass fraction of species \( j \).

\( p \) static pressure.

\( r \) radius (measured from axis of jet).

\( R \) radius of pipe enclosing jets.

\( T \) temperature.

\( u \) local streamwise velocity.

\( \overline{uv} \) local turbulent shear stress.

\( v \) velocity normal to axis of jet.

\( W_j \) molecular weight of species \( j \).

\( x \) distance along center axis.

\( X \) mass fraction of elemental oxygen.

\( Y_{W1}, Y_{W2} \) effective widths of shear flow, see Figure 2.

\( \Gamma \) effective turbulent flow transport coefficient (subscript denotes diffused quantity).

\( \epsilon \) rate of turbulence energy dissipation.

\( \mu_t \) turbulent viscosity.

\( \rho \) density of mixture.
σ effective Prandtl/Schmidt (subscript denotes diffused quantity).

ψ any of the primary dependent variables.

ψ stream function defined by equations (3.1-2).

ω dimensionless stream function defined by equation (3.1-1).

Subscripts

ξ conditions on the jet axis.

D downstream.

E external edge of shear flow.

i value of quantity at initial station.

I internal edge of shear flow.

ref reference value of quantity.

U upstream.

∞ conditions prevailing beyond the outer edge of shear flow.
Table 1: Flow Chart of GEARVAL Program.

AUX
1. Laminar and turbulent viscosities, axial pressure gradient source term
2. Diffusivity and source terms for variables other than velocity

LANGLEY
1. Loading of thermodynamic data and chemical equilibrium constants, evaluation of mean specific heats
2. Initial entropy distribution
3. Evaluation of local equilibrium constants and mean specific heats, solution of six simultaneous equations for local mass fractions
4. Determination of local temperatures

MAIN
1. Parameters and control indices
2. Dependent and auxiliary variables
3. Material and turbulence constants
4. Flow geometry (transverse distances)
5. Initial conditions
6. Omega distribution
7. State of main integration loop (thermodynamic properties)
8. Spreading rate, axial pressure gradient, forward step
9. Boundary conditions
10. Transverse coefficients, entrainment
11. Output
12. Continuation/termination

STRIDE
0. Zeroing of important arrays
1. Omega relationships
2. Setting up of finite difference coefficients
3. Solution of matrices
4. Assignment of free boundary conditions
5. Calculation of dependent variables, or fluxes at flow boundaries
6. Initiation of forward step

OUTPUT
1. Initial conditions and headings for output
2. Station variables, calculation of fluxes of dependent variables
3. Profile variables

PROFIL
Output of individual profiles, assignment of arrays for plotting subroutine

PLOTS
Plotting of dimensionless profiles

WFL
Wall function, relationships between near-wall values of \( \phi \) and boundary fluxes

YINT
Interpolation subroutine
Table 2 Initial Profiles for Cases 1 and 4

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Free Stream
Figure 1. The Flow Geometry Treated by CHARNAL

Wall Heat Fluxes and Friction Computed from Here Onwards

Air  Fuel

a. Free

Air  Fuel

b. Confined

Air  Fuel

i i i

Initial Profiles Prescribed

End of Potential Core

Jet Spreads to Pipe Wall

c. Finite Difference Grid
At A, $U = 0.9 \, U_I + 0.1 \, \bar{U}$
At B, $U = \bar{U}$
At C, $U = 0.9 \, U_E + 0.1 \, \bar{U}$

$y_{W1}$ = Characteristic Shear Width for Inner Region of Flow (Axis $\rightarrow$ B)

$y_{W2}$ = Characteristic Shear Width for Outer Region of Flow (B $\rightarrow$ Free Stream)

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Figure 2. Initial Velocity Profiles and Characteristic Flow Widths
Figure 3. Velocity Profiles
Figure 4. Temperature Profiles (Test Case No. 1)

- a, x/Dj = 6.13 (End of Potential Core)
- b, x/Dj = 10
- c, x/Dj = 20
- d, x/Dj = 50
Figure 5. Decay of Centreline Mass Fraction of Hydrogen

- [a] Test Case No. 1 (H$_2$/air) Unconfined
- [b] Test Case No. 2 (H$_2$/nitrogen) Unconfined
- [c] Test Case No. 3 (H$_2$/air) Confined
Figure 6. Profiles of Velocity, Turbulent Kinetic Energy and Reynolds Shear Stress (Test Case No. 1)
Figure 7. Profiles of Temperature and Density and Hydrogen Element Concentration (Mean and Fluctuating) Test Case Number 1
Figure 8. Profiles of Radical and Atomic Concentrations (Test Case No. 1)
Figure 9. Mass Fractions of Molecular Species

a. Case No. 1 $x/D_j = 20$

b. Case No. 8 (H$_2$ Vitiated Air) $x/D_j = 15$
Figure 10. Location of Flame Front and Jet Half-Width (Test Case Number 1)
Figure 11. Decay of Centreline Velocity Excess

- Test Case No. 1 (H$_2$/air) Unconfined
- Test Case No. 4 (H$_2$/air) Confined
- Test Case No. 3 (H$_2$/nitrogen) Unconfined
- Test Case No. 6 (H$_2$/nitrogen) confined
Figure 12. Velocity and Temperature Profiles in Ducted Subsonic Jet. Initial Profiles (a) $x/D_j = 0$, (b) $x/D_j = 20$, (c) $x/D_j = 40$, (d) $x/D_j = 75$
Appendix 1: Listing of Fortran Variables
Appendix 1. Listing of Fortran Variables

Listed below are some of the most important Fortran variables used in the computer program. To prevent an excessive list, attention has been confined to those variables which are neither (a) self-evident in meaning, (b) indicated by comment cards in the program, (c) discussed in Section 3.5 or (d) connected solely with the finite difference formulation of the equations. Arrays are shown with the maximum numerical values of their subscripts.

<table>
<thead>
<tr>
<th>Fortran Symbol</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK</td>
<td>constant of proportionality in near-wall mixing length formulation, ( \gamma_m = \kappa y_G ).</td>
</tr>
<tr>
<td>ALMG</td>
<td>constant of proportionality in free shear layer mixing length formulation, ( \gamma_m = \lambda y_G ).</td>
</tr>
<tr>
<td>AMACH</td>
<td>Mach number, ( u/(\gamma RT)^{1/4} ).</td>
</tr>
<tr>
<td>CE1 CE2</td>
<td>constants in the dissipation rate equation</td>
</tr>
<tr>
<td>CFA</td>
<td>conversion factor from calories/gram, mole to joules/kg.</td>
</tr>
<tr>
<td>CFAC</td>
<td>pressure x molecular weight of mixture</td>
</tr>
<tr>
<td>CG1 CG2</td>
<td>constants in mean square concentration fluctuations equation.</td>
</tr>
<tr>
<td>CLINE</td>
<td>local centreline mass fraction of molecular hydrogen ÷ initial value.</td>
</tr>
<tr>
<td>CHU</td>
<td>constant in Prandtl-Kolmogorov viscosity formulation</td>
</tr>
<tr>
<td></td>
<td>( \nu_T = C_\mu \rho k^2/\epsilon )</td>
</tr>
<tr>
<td>CONST</td>
<td>constant of proportionality, ( -\frac{U V}{k} ) (( = C_\mu^{1/2} ))</td>
</tr>
<tr>
<td>CPBAR (7,60)</td>
<td>mean specific heats of chemical species at intervals of 100°K.</td>
</tr>
<tr>
<td>CPBAR (10)</td>
<td>mean specific heats of chemical species at upstream temperatures.</td>
</tr>
<tr>
<td>CSALFA</td>
<td>cosine of angle of inclination of streamlines to axis of symmetry.</td>
</tr>
<tr>
<td>Fortran Symbol</td>
<td>Significance</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>DPDX</td>
<td>axial pressure gradient, ( \Delta p/\Delta x )</td>
</tr>
<tr>
<td>DUDY (40)</td>
<td>mean velocity gradient, ( \Delta u/\Delta y )</td>
</tr>
<tr>
<td>DX</td>
<td>forward step size</td>
</tr>
<tr>
<td>DXLIM</td>
<td>limit of entrainment rates (bound to size of forward step)</td>
</tr>
<tr>
<td>DYHA</td>
<td>growth parameter of jet, ( dy_{0.5}/dx ) (see also YHA)</td>
</tr>
<tr>
<td>DDYHA</td>
<td>( \frac{d}{dx} (dy_{0.5}/dx) )</td>
</tr>
<tr>
<td>ENUL (40)</td>
<td>laminar viscosity, ( \mu )</td>
</tr>
<tr>
<td>ENUUT (40)</td>
<td>turbulent viscosity, ( \mu_T )</td>
</tr>
<tr>
<td>ENTH (40)</td>
<td>static enthalpy, ( h )</td>
</tr>
<tr>
<td>F (10,40)</td>
<td>dependent variables (see Chapter 2 of MAIN)</td>
</tr>
<tr>
<td>FA1</td>
<td>constant for determination of free-stream turbulent kinetic energy and profile of mean square concentration fluctuations</td>
</tr>
<tr>
<td>FA2</td>
<td>constant of proportionality in a free shear layer dissipation length scale formulation, ( \lambda_e=\lambda y_G )</td>
</tr>
<tr>
<td>FACI</td>
<td>location where ( f-g^{1/2} = f_{\text{stoich}} )</td>
</tr>
<tr>
<td>FACE</td>
<td>location where ( f+g^{1/2} = f_{\text{stoich}} )</td>
</tr>
<tr>
<td>FACM</td>
<td>location where ( f = f_{\text{stoich}} )</td>
</tr>
<tr>
<td>FRA</td>
<td>constant of proportionality between forward step size and width of shear layer</td>
</tr>
<tr>
<td>FS (10,40)</td>
<td>auxiliary variables (see Chapter 2 of MAIN)</td>
</tr>
<tr>
<td>FSTOICH</td>
<td>stoichiometric fuel composition</td>
</tr>
<tr>
<td>GAM (40)</td>
<td>effective diffusion coefficient</td>
</tr>
<tr>
<td>Fortran Symbols</td>
<td>Significance</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>GAMMA</td>
<td>ratio of principal specific heats, $C_p/C_v$</td>
</tr>
<tr>
<td>GASCON</td>
<td>universal gas constant</td>
</tr>
<tr>
<td>HO (10)</td>
<td>the quantities $\Delta h_{f,298.15^\circ K} - (h_{298.15^\circ K} - h_0^o K)$ (see Section 3.3-4)</td>
</tr>
<tr>
<td>IAX</td>
<td>axial step number corresponding to end of potential core region</td>
</tr>
<tr>
<td>IEND</td>
<td>axial step corresponding to point where jet edge reaches duct wall</td>
</tr>
<tr>
<td>INDE (10)</td>
<td>indices denoting nature of boundary conditions</td>
</tr>
<tr>
<td>INDI (10)</td>
<td>$= 1 \ (\phi \ stated), = 2 \ (gradient \ \phi \ stated)$</td>
</tr>
<tr>
<td>IPD</td>
<td>turbulence model parameter; $= 3 \ (use \ of \ plane \ flow \ constants), = 1 \ or \ 2 \ [see \ Launder \ et \ al \ (2)]$</td>
</tr>
<tr>
<td>IPROF</td>
<td>profile index; $= 1 \ (normalized \ values), = 2 \ (full \ dimensional \ values)$</td>
</tr>
<tr>
<td>ISTAR (40)</td>
<td>number of iteration cycles allowed for convergence at each node</td>
</tr>
<tr>
<td>ISTEP</td>
<td>axial step number</td>
</tr>
<tr>
<td>J1</td>
<td>species with largest concentration in equation (3.3-16)</td>
</tr>
<tr>
<td>J2</td>
<td>species with largest concentration in equation (3.3-17)</td>
</tr>
<tr>
<td>KRAD</td>
<td>flow geometry index; $= 1 \ (plane), = 2 \ (asixymmetric)$</td>
</tr>
<tr>
<td>N</td>
<td>number of grid nodes, $n$</td>
</tr>
<tr>
<td>NP1</td>
<td>$n+1$</td>
</tr>
<tr>
<td>NF1</td>
<td>$n-1$</td>
</tr>
<tr>
<td>OFAC</td>
<td>ratio of oxygen element/nitrogen in outer stream</td>
</tr>
<tr>
<td>OH (40)</td>
<td>non-dimensional stream function</td>
</tr>
<tr>
<td>P (40)</td>
<td>static pressure</td>
</tr>
<tr>
<td>PEI</td>
<td>change in stream function across flow, $\psi_E - \psi_I$</td>
</tr>
<tr>
<td>Fortran Symbols</td>
<td>Significance</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>PR (10)</td>
<td>molecular Prandtl/Schmidt numbers</td>
</tr>
<tr>
<td>PRDRP</td>
<td>pressure drop, $p_i - p$</td>
</tr>
<tr>
<td>PRT (10)</td>
<td>turbulent Prandtl/Schmidt numbers</td>
</tr>
<tr>
<td>PSIE</td>
<td>value of stream function at external boundary $\psi_E$</td>
</tr>
<tr>
<td>PSII</td>
<td>value of stream function at internal boundary $\psi_I$</td>
</tr>
<tr>
<td>PSIR</td>
<td>value of stream function at duct wall $\psi_R$</td>
</tr>
<tr>
<td>QE</td>
<td>wall heat transfer rate</td>
</tr>
<tr>
<td>R (40)</td>
<td>distance from axis of symmetry ($= r_i + y \cos \alpha$)</td>
</tr>
<tr>
<td>RC (5,60)</td>
<td>chemical equilibrium constants for each reaction at intervals of 100°K</td>
</tr>
<tr>
<td></td>
<td>[N.B. RC (5,1) contains constants for the global reaction, $H_2 + \frac{1}{2}O_2 = H_2O$]</td>
</tr>
<tr>
<td>RCON (10)</td>
<td>chemical equilibrium constants at upstream conditions</td>
</tr>
<tr>
<td>REXD</td>
<td>dimensionless excess radius in pressure gradient formulation for confined flows</td>
</tr>
<tr>
<td>RFLOH</td>
<td>flow radius (see REXD)</td>
</tr>
<tr>
<td>RJE (10)</td>
<td>diffusive flux at external boundary</td>
</tr>
<tr>
<td>RJI (10)</td>
<td>diffusive flux at internal boundary</td>
</tr>
<tr>
<td>RJTE (10)</td>
<td>total flux (convective and diffusive) at external boundary</td>
</tr>
<tr>
<td>RJTI (10)</td>
<td>total flux (convective &amp; diffusive) at internal boundary</td>
</tr>
<tr>
<td>RME</td>
<td>mass entrainment rate (radius mass flow rate)</td>
</tr>
<tr>
<td>RMI</td>
<td>mass entrainment rate (radius mass flow rate) at internal boundary</td>
</tr>
<tr>
<td>ROUBAR</td>
<td>mass flux for confined flows ($= \text{mass flow rate}/X$-sectional area of duct)</td>
</tr>
<tr>
<td>RTW (40)</td>
<td>turbulence frequency (dissipation rate/turbulent kinetic energy), $\varepsilon/k$</td>
</tr>
<tr>
<td>Fortran Symbols</td>
<td>Translation</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>SCH (40)</td>
<td>Prandtl/Schmidt number array for near-wall flows</td>
</tr>
<tr>
<td>SD (40)</td>
<td>storage location for &quot;downstream&quot; source terms</td>
</tr>
<tr>
<td>SU (40)</td>
<td>storage location for &quot;upstream&quot; source terms</td>
</tr>
<tr>
<td>TAUE</td>
<td>shear stress at wall</td>
</tr>
<tr>
<td>TBAR</td>
<td>bulk temperature ($\int_{\text{duct}} r U T dy / \int_{\text{duct}} r U dy$)</td>
</tr>
<tr>
<td>TLINE</td>
<td>local centreline temperature/initial value</td>
</tr>
<tr>
<td>UBAR</td>
<td>bulk velocity ($= \int_{\text{duct}} r U^2 dy / \int_{\text{duct}} r U dy$)</td>
</tr>
<tr>
<td>UEIN</td>
<td>initial centreline velocity excess ($u_i^* - u_\infty$)</td>
</tr>
<tr>
<td>ULINE</td>
<td>limit on entrainment at external boundary (to prevent formation of profiles with 'long tails')</td>
</tr>
<tr>
<td>ULINE</td>
<td>limit on entrainment at external boundary (to prevent formation of profiles with 'long tails')</td>
</tr>
<tr>
<td>ULINE</td>
<td>local centreline velocity excess ($u_i^* - u_\infty)/(u_i^* - u_\infty)$</td>
</tr>
<tr>
<td>VMIX</td>
<td>reciprocal of molecular weight</td>
</tr>
<tr>
<td>$M_i$ (10)</td>
<td>molecular weight</td>
</tr>
<tr>
<td>X</td>
<td>concentration of oxygen element</td>
</tr>
<tr>
<td>XAX</td>
<td>length of potential core (in nozzle diameters)</td>
</tr>
<tr>
<td>XD</td>
<td>axial distance at downstream station</td>
</tr>
<tr>
<td>XU</td>
<td>axial distance at upstream station</td>
</tr>
<tr>
<td>XUD</td>
<td>upstream axial distance/jet nozzle diameter</td>
</tr>
<tr>
<td>Y (40)</td>
<td>transverse distance from internal flow boundary</td>
</tr>
<tr>
<td>YHA</td>
<td>jet half-width, $y_{0.5}$</td>
</tr>
</tbody>
</table>
**Program Channl (Input=Output, Tapes=Input=Tape=Output)**

**Chapter 1**

**Parameters and Control Indices**

CHAPTER 2 - SELECTION OF DEPENDENT VARIABLES

DATA JU, JS, JH, JG, JTE, JLE, JUV, JU; 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

C

C *** AUXILIARY VARIABLES

C

C FS(JH2,I) .. CONCENTRATION OF H2
C FS(JH,I) .. CONCENTRATION OF H
C FS(JOH,I) .. CONCENTRATION OF OH
C FS(JH2O,I) .. CONCENTRATION OF H2O
C FS(JO,I) .. CONCENTRATION OF O
C FS(JN2,I) .. CONCENTRATION OF N2

C

DATA JH2, JO2, JOH, JH2O, JH, JO, JN2; 1, 2, 3, 4, 5, 6, 7

C *** MOLECULAR WEIGHTS (AND THEIR RATIOS)

DATA (WM(J) * J = 1, 7) / 0.16, 32.0, 17.008, 18.016, 1.008, 16.028, 0.16

C

C *** SPECIFICATION OF PRANDTL/SCHMIDT NUMBERS

PRT(JU) = 1.0
PRT(JK)=1.0
PRT(JM)=1.3
PRT(JHS)=.7
PRT(JA)=.7
PRT(JR)=.7
PRT(JG)=.7
DO 40 J=1,NEQ
40  PR(J)=1.0
FA1=4.E-04
FA2=.875
F'ALL=9.
H=9
CRIT=.0

CHAPTER 4
SPECIFICATION OF GEOMETRY

KRAU=2
CSALFA=1.
R(I)=YIN
RFAC(5,500) (Y(I),I=1,NP1)
DO 40 I=1,NP1
IF(I(NF.EQ.1) Y(I)=.18Y(I).
40  Y(I)=Y(I)*YOUT-YIN
IF(KFAU.EQ.2) GO TO 183
Do 192 I=1,NP1
192 R(I)=1.
GO TO 191
193 DO 200 I=1,NP1
200 R(I)=R(I)+Y(I)*CSALFA

CHAPTER 5
INITIAL CONDITIONS
181 DO 450 I=1,NP1
450 P(I)=PRES
IF(I(NF.EQ.1) GO TO 723

CONTINUOUS PROFILES

YWL=YWL*YOUT
YWL=YWL*YIN
UW1=(UW1*YIN
UW2=UW1+1
READ(5,500) F(JU*,I),I=1,NP1)
READ(5,500) F(JTE*,I),I=1,NP1)
READ(5,500) F(SH2*,I),I=1,NP1)
IF(IH2O.EQ.1) READ(5,500) F(SJH20*,I),I=1,NP1)
IF(IN02.EQ.1) READ(5,500) F(SJN2*,I),I=1,NP1)
IF(IH2O.EQ.1) READ(5,500) F(SJH20*,I),I=1,NP1)

MASS FRACTION OF HYDROGEN ELEMENT
DO 105 I=1,NP1
105 F(JA*,I)=F(SH2*,I)+F(SJH20*,I)+F(J02*,I)+F(JN2*,I)

RATIO OF HYDROGEN ELEMENT TO NITROGEN IN OUTER STREAM
OFAC=F(SJN2*,I)+F(SH20*,NP1)
OFAC=OFAC/(OFAC+F(SJN2*,NP1))

CONVERSION OF INITIAL PROFILES
DO 45 I=1,NP1
45 F(JU*,I)=F(JU*,I)*WIN

TURBULENT KINETIC ENERGIES BY MIXING LENGTH HYPOTHESIS
DO 1080 J=2,N
```
C DEFINE CHARACTERISTIC SHEAR LAYER WIDTHS
UREF = (F(JU,I)-F(JU,I-1))/(Y(I)-Y(I-1))

DO 1062 I=1,NPI
IF(F(JU,I),LT,UREF) GO TO 1063
1062 CONTINUE
1063 YW2 = Y(I-1) + (Y(I)-Y(I-1)) * (UREF - F(JU,I-1)) / (F(JU,I)-F(JU,I-1))
YW2 = ALMG*YW2
IF(KASENO.EQ.16) GO TO 8702
UREF = Y(I) + ?F(JU,NPI)
DO 1064 I=IW1,NPI
IF(F(JU,I),GT,UREF) GO TO 8702
1064 CONTINUE
1065 YW3 = Y(I-1) + (Y(I)-Y(I-1)) * (UREF - F(JU,I-1)) / (F(JU,I)-F(JU,I-1))
YW3 = YW3+YW1
YW3 = ALMG*YW3
8702 IF(KASENO.EQ.16) YW3 = YW2
DO 1066 I=1,IW1
1066 F(JK,I) = F(JK,I)+YW2*DYDY(I)
DO 1067 I=1,NPI
1067 F(JK,I) = F(JK,I)+YW3*DYDY(I)
DO 1068 I=1,NPI
AKMIN = F(JU,I)*F(JU,I)
1068 F(JK,I) = F(JK,I)+AKMIN
C D I S S I P A T I O N R A T E S
YW2 = YW2/ALMG*FA2
YW3 = YW3/ALMG*FA2
DO 1069 I=1,IW1
1069 F(JD,I) = F(JD,I)+SORT(F(JK,I))/YW2
DO 1070 I=IW2,NPI
1070 F(JD,I) = F(JD,I)+SORT(F(JK,I))/YW3
GO TO 417
773 CONTINUE
C S T E P P R O F I L E S
READ(5,500) UI,UE,TI,TE,O2E,AN2E,H2OE,NPI=NP1/2
C C O N S T R U C T L I N E A R V E L O C I T Y P R O F I L E
DO 11 I=1,NPI
YRATE = (Y(I)/Y(NP1))
F(JU,I) = UI*YRATE*(UE-UI)
IF(I,GT,NP1/2) GO TO 454
11 F(JU,I) = TI
FS(JH2,I) = 1.
FS(JH2,I) = 0.
FS(JH2,I) = 0.
FS(JH2,I) = 0.
GO TO 11
454 F(JH2,I) = TE
FS(JH2,I) = 0.
FS(JH2,I) = 0.
FS(JH2,I) = 0.
11 F(JA2,I) = FS(JH2,I) + FS(JH2,I) + WQ0*FS(JH2O,I) + WSO*FS(JH2O,NP1)
OFAC = FS(JN2,NP1) + WSO*FS(JH2O,NP1)
OFAC = OFAC/(OFAC+FS(JN2,NP1))
```
ALNTH = 80*Y(NP1)
UGRAD = !*U1(*P1)
UGRAD = UGRAD * ALNTH
UGRAD = Const * UGRAD

C *** TURBULENT KINETIC ENERGIES
    DO 472 I = 1, N
472   F(JK, I) = UGRAD
    DO 473 J = 1, NPI
473   AKMIN = F(JJ, J) * F(JJ, I)
    IF (F(JK, I) < AKMIN) F(JK, I) = AKMIN
    ALNTH = F(JJ) * ALNTH

C *** DISSIPATION RATES
    DO 474 I = 1, NP1
474   F(JD, I) = F(JK, I) * SORT(F(JK, I)) / ALNTH

C *** STAGNATION ENTHALPIES
    DO 417 I = 1, NP1
417   CALL LANGL2

C *** MEAN SQUARE CONCENTRATION FLUCTUATIONS (OF H ELEMENT)
    DO 12 I = 1, NP1
12    F(JO, I) = FA1 * F(JA, I) * F(JA, I)

CHAPTER 6

C *** OMEGA DISTRIBUTION
    DO 50 I = 1, NP1
50    VMIX = h
    DO 107 J = 1, NS
107   VMIX = VMIX * FS(J, I) / WM(J)
    RHO(J) = P(J) / GAMCON * VMIX / F(JT, I)

C *** THEA(I) = RHO(I) * F(JF, I) * R(I)
    DO 505 I = 1, NP1
505   ZETA(I) = P(JH, J) * F(JF, I) / RHO(I)

C *** OM(I) = OM(I-1) + ZETA
    DO 504 I = 1, NP1
504   OM(I) = OM(I-1) / PEI
    CALL STRID1

CHAPTER 7

C *** THERMODYNAMIC AND TURBULENCE PROPERTIES (START OF MAIN LOOP)
    DO 108 CONTINUE
108   IF (NSTEP,GE, INAX) KIN = 3
    IF (NSTEP,GE, IEND) KEK = 1

C *** LIMITS ON SPECIES MASS FRACTION
    FAMMAX = 1.0
    FAMMAX = 1.0
    DO 455 I = 1, NP1
455   F(JA, I) = FAMMIN(F(JA, I), FAMMAX)

C *** LIMITS ON TURBULENCE PROPERTIES
    FGMIN = 1.0
    FKMIN = 1.0
    DO 600 I = 1, NP1
600   F(JG, I) = FKMAX(F(JG, I), FGMIN)
    FKMAX = F(JU, I) * F(JU, I)

53
F(JK,T) = AMIN(*F(JK,I), FKMAX)
F(JK,T) = AMAX(*F(JK,I), FKMIN)
FMIN = F(JK,I) * SQRT(F(JK,I)) / Y(NP1)
400 F(JL,I) = AMAX(*F(JD,I), FMIN)
DP = UPDX*OX
IF(ISTEP.EQ.0) GO TO 425

C *** LOCAL MASS FRACTIONS
CALL LANGL3
C *** LOCAL PRESSURES AND TEMPERATURES
DO 601 I = 1, NP1
P(I) = P(I)*DP
601 FNTJ(I) = F(JHS*I) + 5*F(JU, I)**2 - F(JK, I)
CALL LANGL4
DO 602 I = 1, NP1
IF(F(JTE, I) .GT. 0.) GO TO 1083
WRTE(6, 2702) F(JTE, I), I, ISTEP, TFIN = 1
1083 CONTINUE
IF(TFIN .EQ. 1.E+0) GO TO 117

C********************************************

CHAPTER A
C*** TRANSPORT PROPERTIES, PRESSURE GRADIENT AND FORWARD STEP
IF(IN1 .NE. 2) GO TO 522
IF(KRAU, EQ. 2) GO TO 521
YN = SIN(RHO(I)*F(JU, I))
GO TO 522
521 YN = SQRT(ABS(2.*PSII/(RHO(I)*F(JU, I))))
R(I) = YN
C *** SPREADING RATE
522 CONTINUE
CALL YINT(5, YHA, JU)
IF(ISTEP .EQ. 0) GO TO 239
DYHAI = (YHA - YHALS) / (XU - PXU)
DDYHA = (OYHA - DYA) / DYA
239 YHALS = YHA
DYHAI = DYHA
PXU = XU
238 CALL STRIN2
IF(ISTEP .NE. 0) GO TO 1370
IF(KASE .NE. 2) GO TO 1370
C *** STREAM FUNCTION AT DUCT WALL
PSIIN = PSIE + 5*RHO(NP1)*F(JU, NP1)*(RODUCT**2 - R(NP1)**2)
ROHAR = 2.*PSII/RODUCT**2
1370 IF(KEX , EQ. 1) KONFIN = 1
GO TO (71, 72, KONFIN)
71 IF(ISTEP .EQ. 1) RDUCT = R(NP1)
IF(IVCF .EQ. 2) GO TO 1338
C *** PASSA VERSION OF PRESSURE GRADIENT FOR CONFINED FLOWS
C *** CALCULATION OF PRESSURE ADJUSTMENT
C *** VERSION WITH GRID FILLING THE DUCT
IF(ISTEP .EQ. 0) GO TO 72
ADUCT = 5*(RODUCT**2 - R(1)**2)
AFLOW = 5*Y/NP1*R(NP1) - Q(1)*R(1)
PDISIF = PEI

54
ROUHR=PSIDIF/ADUCT
UHRAN=0.
DO 73 I=2,N
73 UHRA=UHAR*.5**OM(I)*F(JU,I)
ROBAR=ROUHR/UHAR
DUDP=1./((ROUHR+RJE(JU)-RJI(JU))*DX/ADUCT/UHAR)
UHRODP=ROUHR/GAMMA/PRESS
DROU=ROUHR*(AFLO*ADUCT-1.)
DP=DROP/(ROUHR*DUDP+UHRODP)
IFAC=DP*DP/UHAR+1.
C ***ADJUSTMENT OF VELOCITY, PRESSURE AND DENSITY
DO 74 I=1,NP1
F(JU,I)=F(JU,I)+UFAC
P(I)=P(I)+DP
74 RH0(I)=RH0(I)*((1.+GAMMA*DP/P(I))/DP)
C *PECALCULATION OF DISTANCES
CALL STRID2
GO TO 72
C ***GENMIN VERSION OF PRESSURE GRADIENT FOR CONFINED FLOWS
133A <STORF=THAB
THAR=0
UBAR=0.
DO 1340 I=2,N
THAR=THAR+.5**OM(I)*F(JTE,I)
1340 UBAR=UBAR+.5**OM(I)*F(JU,I)
IF (ISTEP.GE.IEND) HFLOW=.9(NP1)
TF (ISTEP.GE.IEND) GO TO 9719
THAR=(PSI*F(JTE,I)+PEU*THAB*PSI-PSIE)*F(JTE,NP1))/PSIR
UBAR=(PSI*F(JU,I)+PEU*UBAR*PSI-PSIE)*F(JU,NP1))/PSIR
TF (ISTEP.EQ.0) GO TO 72
DP=-ROUHR*UBAR*(1.-STORF/THAB)
HFLOW=SQRT(R(NP1)**2+2.*(PSI-PSIE)/(RHO(NP1)*F(JU,NP1)))
9719 CONTINUE
TF (ISTEP.GE.IEND) DP=-ROUHR*UBAR*(1.-STORF/THAB)
REXO=(HFLOW-ROUCT)/ROU&T
DP=DP-FA*ROUHR@UBAR@REXO
TF (ISTEP.EQ.IEND) DP=DP+2.*RJE(JU)/R(NP1)**2*DX
DP=DP/(1.-ROUHR*UBAR/P(1))
DPDX=DP/DX
C ***FORWARD STEP
73 DX=FA@Y(NP1)
IF (INF.EQ.1) DX=FRA@R(NP1)
IF (ISTEP.LT.50) DX=D*X*FLOAT(ISTEP+1)/50.
IF (ISTEP.EQ.IEND.AND.ISTEP.LT.9) DX=1.*DX*FLOAT(ISTEP-IEND+1)
IF (ARS(REXO).GT.0.005) DX=DX*.005/ABS(REXO)
DX=AMIN1(DX*XULAST-XU)
XO=XU+DX
C**********************************************
CHAPTER 9
C***ADJUSTMENT OF BOUNDARY CONDITIONS
C ***FREE BOUNDARY VALUES ADJUSTED IN STRIDE (3)
TF(KIN.EQ.2) GO TO 95
RM1=0.
TF(KPAU.EQ.2) R(1)=0.
YN=0.
PSII=0.
95 IF(KFX.NE.1) GO TO 106
F(JU,NP1)=0.
RJF(JA)=0.
F(JK,NP1)=0.
F(JD,NP1)=0.
F(JG,NP1)=0.
F(JTE,NP1)=TDUCT
I=NP1
CALL LANG2
F(JHS,NP1)=ENTH(NP1).

CHAPTER 10
C********TRANSPORT AND ENTRAINMENT PROPERTIES
94 CALL AUX(JU)
C********TRANSIENT CONTROL
C ********ATTENTION TO VELOCITY AND TEMPERATURE CHANGES
IF(KIN=NE.2) GO TO 94
RME=R(M3)*A(N3)/Y3)
RME=R(M1)/PRT(JA)
RAT=ABS(F(JU,2)-F(JU,1))/(F(JU,NP1)-F(JU,1)+1.E-30)
AMGN=ABS(F(JTE,2)-F(JTE,1))/(F(JTE,NP1)-F(JTE,1)+1.E-30)
RAT=AMX1(RAT+AMGN)
TF(RAT-LT,ULIN) RMI=RMI-RAT/ULIM
94 IF(KASE.EQ.1) GO TO 96
RME=R(M1)*GAMN/(Y(NP1)-Y(NM1))
RME=RME/PRT(JA)
RAT=ABS(F(JU,NP1)-F(JU,1))/(F(JU,NP1)-F(JU,1)+1.E-30)
AMGN=ABS(F(JTE,NP1)-F(JTE,1))/(F(JTE,NP1)-F(JTE,1)+1.E-30)
RAT=AMX1(RAT+AMGN)
TF(RAT-LT,ULIN) RME=RME-RAT/ULIM
97 IF((XH=RMF)*DX,LTP,EI*DXLI) GO TO 96
DX=DXLI*PEI/(RMI-RMF)
96 CONTINUE
IF(KASE.EQ.1) GO TO 960
IF(ISTEP.EQ.1) GO TO 960
C ********ADJUSTMENT OF FORWARD STEP FOR JET TO REACH DUCT WALL
IF(R(NP1),LT,999*RDUC) GO TO 960
IEND=ISTEP+1
XEND=X+YNOUT
WHITE(0,598) IEND,XEND
960 CONTINUE
C ********ADJUSTMENT OF FORWARD STEP TO REACH AXIS OF SYMMETRY
IF(KIN=NE.2) GO TO 195
IF(PSI1.1*RMF*DX) GO TO 195
DX=PSI1/RMI
XD=X+DX
IAX=ISTEP+1
XAX=XD/YOINT
WHITE(6,597) IAX,XAX

CHAPTER 11
C********OUTPUT
195 IF(ISTEP,NE.4) GO TO 193
CALL OUTP1
CALL OUTP2
CALL OUTP3
GO TO 113

56
193 XUD=XU/Y0U1T
   IF (XUD.LT.XSTAT(KS)) GO TO 110
   KS=KS+1
   CALL OUTP2
321 IF (XUD.LT.XPROF(KP)) GO TO 112
   KP=KP+1
   CALL OUTP3
113 IF (ISTEP.NE.IAX.AND.ISTEP.NE.IEND) GO TO 113
117 CALL OUTP2
   CALL OUTP3
   IF (IFIN.EQ.1) GO TO 1001
C******************************************************************************
C ***FORMAT STATEMENTS
C 500 FORMAT(7F10.3)
C 501 FORMAT(2F10.3,14)
C 507 FORMAT(/1HO---MIXING LAYER REGION ENDS AT ISTEP=,I5,3X,LENGTH =
      1F POTENTIAL CORE =9,F7.2,9 DIAMETERS*/)
C 508 FORMAT(/1HO---JET REACHES DUCT WALL AT ISTEP=,I5,3X,DOWNSTREAM
      1DISTANCE =9,F7.2,9 DIAMETERS*/)
1150 FORMAT(1A74)
1151 FORMAT(1P7E11.3)
2703 FORMAT(/1HO---NEGATIVE TEMPERATURE OF=1PE11.3, AT
      1NODE=,13, AT ISTEP=,I5)
C******************************************************************************
CHAPTER 12
C***CONTINUATION/TERRMINATION
113 IF (ISTEP.GE.LASTEOR.XUGE.XULAST) GO TO 1001
   CALL STRIP3
   GO TO 100
1001 CONTINUE
   STOP
   END

COMPILER SPACE
SUBROUTINE AUX(J)
COMMON/GENERAL/ACC,CSALFA,DPDX,DX,ENTH(40),F(10,40),FS(10,40),GAM3,
GAMM,GAM(40),*,IFIN,IND10,INDI10,ISTEP,IUTRAP,ITEST,KEA,KIN,
KRA(10),N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,NP1,NP2,NP3,NP4,NP5,NP6,
NP7,NP8,NP9,NP10,NP11,NP12,NP13,NP14,NP15,NP16,NP17,NP18,NP19,
NP20,NP21,NP22,NP23,NP24,NP25,ND(40),NOM(40),OMD(40),OM(40),OPI(10),
PSIE,PSII,P(40),R(40),RH(40),RJE(20),RJI1(10),RMI,SM(40),SU(40),WM(10),
X0,X1,Y0,Y1,YDIF(40),YE,YL,RJTE(10),RJI1(10),
COMMON/CJS,J1,J2,J3,J4,J5,J5,J6,J7,J8,J9,
COMMON/CF,JH2,JH20,JOH,JH200,JH3,JH4,JH5,JH6,
COMMON/CTJ,AK,ALMG,CMU,CHUIN,CF1,CE2,CG1,CG2,CRT,DUDY(40),
1DUDYS(40),EMUL(40),EMUT(40),IPD,PR(10),PRT(10),RTW(40),
COMMON/AUXT/YDA(40),UIP,
COMMON/CIGHA/S(40)
C***********************************************************************
C********AXIAL VELOCITY
C IF(JH.10) GO TO 299
C ***LAMINAR VISCOITY (APPROXIMATE POWER LAW RELATIONSHIPS)
C ---IGNORE ATOMIC AND RADICAL CONCENTRATIONS
DO 66 I=1,NP1
SUM=FS(JH2,I)*FS(J02,I)*FS(JN2,I)*FS(JH20,I)
66 EMUL(I)=0.
C ---HYDROGEN (H2)
EMUL(I)=EMUL(I)*FS(JH2,I)*8.42E-06*(F(JTE,I)/273.)**0.675
C ---OXYGEN (O2)
EMUL(I)=EMUL(I)*FS(J02,I)*1.92E-05*(F(JTE,I)/273.)**0.735
C ---NITROGEN (N2)
EMUL(I)=EMUL(I)*FS(JN2,I)*1.66E-05*(F(JTE,I)/273.)**0.690
C ---MATER VAPOR
EMUL(I)=EMUL(I)+FS(JH20,I)*1.75E-05*(F(JTE,I)/500.)**1.050
69 EMUL(I)=EMUL(I)/SUM
C ***DETERMINATION OF ACCELERATION PARAMETER
ACC=ARS(ACC-AHS(ACC))
CALL YINT(19,YRS,JU)
ACC=5*YR*SACC/AHS(F(JU+1)-F(JU+NP1))
ACC=ACC**0.2
IF(ISTEP,EQ.1) GO TO 74
C ***EVALUATION OF INTEGRATED PRODUCTION/DISSIPATION RATIO
IF(IPN.NE.2) GO TO 73
IF(ISTEP.EQ.3) GO TO 74
IF(ISTEP.EQ.4) GO TO 152
IF(MOD(ISTEP,10).NE.0) GO TO 123
153 TPER=TPER+TR=TRI=0.
DO 5A I=2,NP1
TRP=TR
TR=EMUL(I)*DUDY(I)*R(I)
TRI=TRI+.5*(TR+TRP)*(Y(I)-Y(I-1))
TPER=TPER
TPER=TPER+TR
5A TPERI=TPERI+.5*(TPER+TPERP)*(Y(I)-Y(I-1))
PUMP=PDE
PDE=TPERI/TR
IF(ISTEP.NE.5) PDE=5*(PDE+PUMP)
=2.8
ALPHA=55
AH=50*(1.1454*(PDE**0.5)-1.
IF(PDE.LE.10) ALPHA=55+.214*AH
G=1-(1.-ALPHA*PDE)**W
G=6/(1.**PDE-1.)**W**2
G=7.4407*G**W**W
C ***AXIAL VELOCITY GRADIENTS

DUDY(1) = 0.
DUDY(NP1) = 0.
DUDYSA(1) = 0.
DUDYSA(NP1) = 0.
YMIF = Y(I+1) - Y(I)
DUDYP = ABS((F(JU+I) - F(JU,I))/YMIF + 1.E-30)
GO To (1,?,2), KIN
1 DUDY(P) = (0.5*YMIF + YE)/YE*DUDYP
GO To 3
3 DUDYSQ(2) = DUDY(2)**2
DO 9 I = 3, NM1
YMIFM = YMIF
YMIF = Y(I+1) - Y(I)
DUDYM = DUDYP
DUDYP = ABS((F(JU+I+1) - F(JU,I))/YMIF + 1.E-30)
9 DUDY(I) = (Y(I+1) - Y(I-1))/(YMIF/DUDYM+YMIF/DUDYP)
GO To (4,5,5), KEX
4 DUDY(N) = (0.5*YMIF + YE)/YE*DUDYP
GO To 17
5 DUDY(N) = YE/(0.5*YMIF + YE)*DUDYP
17 DUDYSQ(N) = DUDY(N)**2
DO 12 I = 1, NP1
DUDYSQ(I) = DUDY(I)**2
12 RTW(I) = F(JU*I)/(F(JK,I)+1.E-30)
C ***TURBULENT VISCOSITY FORMULATION

DO 1030 I = 2, N
EMUT(I) = CMU*HHO(I)*F(JK,I)/RTW(I)
1030 IF(F(JU,I).LT.F(JU,I-1)) F(JUV,I) = F(JUV+I)
C ***ADD LAMINAR AND TURBULENT COMPONENTS

IF(CHIT) 1050, 1050, 1052
1050 DO 1051 I = 2, N
1051 GAM(I) = EMUL(I)*EMUT(I)
GO To 1065
1052 DO 106 I = 2, N
106 IF(EMUT(I) = EMUL(I)*CHIT) 1060, 1060, 1061
1060 GAM(I) = EMUL(I)
EMUT(I) = 0.
GO To 106
1061 GAM(I) = EMUL(I)*EMUT(I)
GO To 106
106 CONTINUE
1062 EMUT(I) = 0.
EMUT(NP1) = 0.
C *** AXIAL PRESSURE GRADIENT (SOURCE TERM)

GAM3 = GAM(3)
GAMNL = GAM(NH1)
C* TURBULENT KINETIC ENERGY

299 IF(J,NE,JK) GO TO 399
   DO 201 I=1,N
201 GAM(I)=EMIL(I)/PR(JK)*EMUT(I)/PRT(JK)
   DO 202 I=1,NP1
   SU(I)=EMUT(I)*DUDYS(I)
212 SD(I)=RTH(I)*RHO(I)
   IF(KTN,NE,1) GO TO 215
   FJK2=RJ(IJU)/(R(I)*RHO(I)*RTCMU)
   SU(I)=1.E30*FJK2
   SD(I)=-1.E30
215 IF(KFX,NE,1) RETURN
   FJKN=RJ(JU)/(R(NP1)*RHO(NP1)*RTCMU)
   SU(N)=1.E30*FJKN
   SD(N)=-1.E30
RETURN

C* DISSIPATION RATE

399 IF(J,NE,JD) GO TO 499
   DO 401 I=1,N
401 GAM(I)=FMI(L(I))/PR(JD)*EMUT(I)/PRT(JD)
   DO 402 I=1,NP1
   SU(I)=CE1*EMUT(I)*RTH(I)*DUDYS(I)
   CE2=1.92-0.667*ACC
   IF(IPD.EQ.2) CE2=1.92-.1336*ACC
   IF(IPD.EQ.3) CE2=1.92
416 SD(I)=CE2*RHO(I)*RTH(I)
   IF(KTN,NE,1) GO TO 419
   IF(KFX,NE,1) GO TO 419
   FJK=0.5/ACDQ/(Y(2)*1.E30)
   SD(I)=-1.E30
419 IF(KFX,NE,1) RETURN
   SU(N)=FJKN *1.5/ACDQ/(Y(NP1)-Y(N)) *1.E30
   SD(N)=-1.E30
RETURN

C* STAGNATION ENTHALPY

499 IF(J,NE,JHS) GO TO 599
C *** PRANDTL/SCHMITT NUMBERS FOR NEAR-WALL REGION (ROTTA)
C --- AXISYMMETRIC FLOWS ONLY
C --- N.B. SAME RELATIONSHIP FOR SPECIES DIFFUSION

IF(KRAD,NE,1) GO TO 331
IF(KFX,NE,1) GO TO 331
   DO 330 I=1,NP1
   Y=1.-R(I)/K(NP1)
330 SCH(I)=.95+.45*Y*Y*Y
   GO TO 332
331 DO 333 I=1,NP1
333 SCH(I)=PRT(JHS)
332 DO 333 I=1,NP1
301 GAM(I)=FMI(L(I))/PR(JHS)*EMUT(I)/SCH(I)
   DO 302 I=1,NP1
302 DO 303 I=1,NP1
303 I=2,NP1
FA\(C_2 = (S/H(I)) \times \frac{(G/M(I) + G/M(I+1))}{(Y/D(I) + 1.0E-30)}
\)

\(DO(I) = FA\(C_2 \times (S/D(I) + 1.0) - S/D(I)) \times 0.5\)

DO 307 I = 2, NM1
FA\(C_2 = (S/H(I)) \times \frac{(G/M(I) + G/M(I+1))}{(Y/D(I) + 1.0E-30)}
\)

\(DO(I) = S/D(I) + S(D(I+1) - S/D(I)) \times 0.5\)

DO 307 I = 2, NM1
FA\(C_2 = (S/H(I)) \times \frac{(G/M(I) + G/M(I+1))}{(Y/D(I) + 1.0E-30)}
\)

SD(I) = 0.
SD(N) = 0.
DO 304 I = 2, N
SD(I) = SD(I-1) \#2/TDA(I)
DO 304 I = 1, NP1
SD(I) = 0.
SU(I) = 0.
SU(NP1) = 0.
RETURN

C::*MASS FRACTION OF HYDROGEN ELEMENT

IF(J, NE, JA) GO TO 699
DO 901 I = 3, NM1
GAM(I) = EML(I) / PR(JA) * EMUT(I) / SCH(I)
DO 901 I = 1, NP1
SU(I) = SD(I) = 0.
RETURN

C::*FAN SQUARE CONCENTRATION FLUCTUATIONS (OF H ELEMENT)

IF(J, NE, JA) GO TO 799
YDIFP = Y(J) - Y(I)
DCDY = AH/(F(JA, I+1) - F(JA, I)) / YDIFP + 1.0E-30
IF(KF.X.EQ.1) GO TO 711
DCDY = Y(I) / \(S/YDIFP \times Y(I)\) * DCDYP
DCDY = 0.
SU(2) = CG1 * DCDYSQ * EMUT(2)
SD(2) = CG2 * H/I(2) * RHO(2)
SU(I) = 0.
SD(I) = CG2 * H/I(1) * RHO(1)
GO TO 712
711 G2 = (DJP(J) / R/H0(2)) * 2 * CG1 / CG2 / FJK2
SU(2) = G2 * 1.0E+30
SD(2) = 1.0E+30
DO 710 I = 3, NM1
YDIFP = Y(I+1) - Y(I)
DCDY = S/YDIFP
DCDY = AH/(F(JA, I+1) - F(JA, I)) / YDIFP + 1.0E-30
IF(KF.X.EQ.1) GO TO 713
DCDY = Y(I) / \(S/YDIFP \times Y(I)\) * DCDYP
DCDY = 0.
SU(N) = CG1 * DCDYSQ * EMUT(N)
SD(N) = CG2 * H/I(N) * RHO(N)
SU(NP1) = 0.
SD(NP1) = CG2 * H/I(NP1) * RHO(NP1)
RETURN
713 GN = (FJL(J) / R/H0(N)) * 2 * CG1 / CG2 / FJKN
SU(N) = GN * 1.0E+30
SD(N) = 1.0E+30
CONTINUE
SUBROUTINE STRIDE
DIMENSION AHL(40), HOMT3(40), OMS(40), PHOM(40), PGOM(40), THL(40)
DIMENSION A(40), H(40), C(40), D(40)
COMMON/GENRAL/ACC,CSALPHA,DIDX,DX,ENTH(40),F(10,40),FS(10,40),GAH3,
1AMN,AMG(40),I,IFIN,INDE(10),INDI(10),ISTEP,KPITP,ITEST,KEMA,KIN,
2KRAH,NOMH,NP1,NM1,OM(40),OMD(40),OMT(40),KAST(10),PSIE,PSII,
3P(40),R(40),RHI(40),RJE(10),RJI(10),RAE,RME,RAI,SD(40),SU(40),WNI(10),
4XN,XI,Y(40),YDF(40),YE,YI,RJT(10),RJTI(10)
COMMON/CJ/JJ,JK,JL,JHS,JA,JG,JF,JE,UV,JB
COMMON/CF/JP,JQ,JR,JO,JH20,JA,JO,JN2
COMMON/AUXST/THA(40),U1P
COMMON/WF/TDF/TS(20,2),TS(20,2),BP(2)
COMMON/CPROP/IO2,IN2,IN20,OFAC,NS,NS,NS,BW,BW,GA2,GAMGA

C*** STRIDE (1)
C*** CONTROL INDICES
ENTRY STRIDE
NP1=N+1
NM1=N-1
OM1(1)=0.
OM(NP1)=1.
GAM3=0.
GAM4=0.
ISTEP=0
IFIN=0
ITRAPP=2

C*** ZEROING OF IMPORTANT ARRAYS
DO 353 J=1,NEQ
KAST(J)=0
353 HJE(J)=RJI(J)=0.
DO 354 I=1,NP1
DO 354 J=1,NS
354 FS(I,J)=0.
DO 355 J=1,NS
DO 355 J=1,10
355 F(J,J)=0.
DO 356 J=1,NP1
356 ENTH(J)=0.
RETURN
C*** STRIDE (2)
C*** OMEGA RELATIONSHIPS
ENTRY STRIDE
DO 100 I=1,N
OMD(I)=OM(I+1)-OM(I)
100 OMS(I)=OM(I+1)+OM(I)
DO 101 I=3,NM1
OMT(I)=OM(I+1)-OM(I-1)
101 CONTINUE
OMT(2)=OM(3)+OM(2)
OMT(N)=2.-OM(N)-OM(NM1)
OM2=OM(3)/OMD(2)
OM3=1.-OM2
OMS2=OM2**2
OMS3=OM2**2
OMS2=OMS2/(OMS2-OMS3)
OMS3=1.-OMS2
**OMN** = (OMD(N) + OMD(NM1))**2

**OMN1** = OMD(N)**2

**OMN2** = OMN/(OMN - OMN1)

**OMNH** = 1. - OMN

**Y(1)** = 0.

**RP(1)** = 1.

**RP(2)** = 1.

**TNDE(JU)** = 1

**INDI(JU)** = 1

RETURN

C** STRIDE (2)

ENTRY STRID2

C TEST FOR NEGATIVE VELOCITIES

1010 IF((IUTKAP.EQ.0)) GO TO 1011

DO 1012 I = 2, N

IF(F(JU*I).GT.0.) GO TO 1012

1011 FORMAT(1HO,**--- NEGATIVE VELOCITY OF*, IPE11.3,*)

IF((IUTKAP.GT.1)) IFIN=1

1015 IF((IUTKAP.GT.2)) ITEST=1

C CROSS-STREAM DISTANCES (Y*S AND R*S)

C CROSS-STREAM

1011 RUP = RHO(JU2) * F(JU2)

R1 = RHO(JU1) * F(JU1)

RURAT = R1/RUP

GO TO (1013*1014,1014), KIN

1012 GO TO (1012,1019), KRAD

1016 BP(1) = 0.333333 + 0.666667*RURAT

GO TO 1013

1019 BP(1) = (R(1)**(5.*RURAT+1.))+3.*R(2)**(RURAT+1.))/(R(1)+R(2))/6.

1013 YI = PE1 * OMD(1)/(NP1(1)**RUP)

RUNP1 = RHO(NP1) * F(JU,NP1)

RUN = RHO(N) * F(JU,N)

RURAT = RUNP1/RUN

GO TO (1020*1021,1021), KEX

1021 GO TO (1024,1025), KRAD

1026 BP(2) = 0.333333 + 0.666667*RURAT

GO TO 1027

1025 BP(2) = (R(NP1)**(5.*RURAT+1.))+3.*R(N)**(RURAT+1.))/(R(NP1)+R(N))/6.

1027 YE = PE1*O(M(N))/BP(2)**RUN)

C Y*S, R*S, TUA*S AND YDIF*S

C YDIF(I) = 2.**(Y(I+1)-Y(I))/R(I+1.5)

Y(2) = YI

YDIF(1) = 2.* YI

DO 1017 I = 2, NP1

TDA(I) = PE1*OBDM(I)/RUP

RUP = RHO(I+1) * F(JU1+1)

YDIF(T) = PE1*OBDM(T)/RUP

1017 Y(I+1) = Y(I) + YDIF(T)/RUP

YDIF(N) = 2.* YE

IF(KRAD.FA.1) RETURN

C MODIFICATIONS FOR AXIAL SYMMETRY
1123 IF(CSALFA.EQ.0.) GO TO 1110
C ***CSALFA *NE. ZERO
   COSD2=5*CSALFA
   IF(R(I).NE.0.) GO TO 1105
C ***R(I) *EQ. ZERO
   DO 1106 I = 2, NP1
      Y(I)=SQRAT(ABS(Y(I)/COSD2))
1104 R(I)=Y(I)*CSALFA
   GO TO 1107
C ***R(I) *NE. ZERO
1105 R1D2=.5*R(I)
   R1D2SG=R1D2*R1D2
   DO 1109 I = 2, NP1
      Y(I)=Y(I)/(R1D2+SQRT(ABS(R1D2SG*COSD2*Y(I))))
1104 R(I)=R(I)+Y(I)*CSALFA
1107 DO 1108 I = 1, N
   1106 YDIF(I)=YDIF(I)**4./((R(I)+R(I+1))*2)
   GO TO 1112
C. ***CSALFA *Eq. ZERO
1117 DO 1111 I = 2, NP1
   Y(I)=Y(I)/R(I)
1111 R(I)=P(I)
   R1SQ=P(I)**2
   DO 1108 I = 2, N
1109 YDIF(I)=YDIF(I)/R1SQ
1112 Y(I)=Y(2)
   YF= Y(NP1)-Y(N)
   RTUPH
C.---------------------------------------------------------------
C. ** STRIDE (3)
C. ***MAIN NUMERICAL METHOD
   FNTHY STR1D3
   IF (KIN .EQ. 1) CALL WF(1)
   IF (KFX .EQ. 1) CALL WF(2)
C. ***PFLIMINARIES
3000 G=RMI=RNFE
   PX=PF1/DX
   PD4=.25*PX
   RD4=.25*G
   PGD4=PD4*RD4
   RM1D2=5*RM1
   PGM(1)=0.
C.---------------------THL, AHL, PGOM AND PBOM
   THL(I) = 0.
   DO 3010 I = 2, N
       HL=RMTD2-6D4*OMS(I)
       THL(I) = 2.*HL
       AHL(I) = ABS(HL)
       PGOM(I)=PGD4*MOD(I)
3010 PBOM(I)=PX*BP0M(I)
C. ** START OF J LOOP
   DO 3320 J=1,NEQ
      IF(J.NE.JT) CALL AUX(J)
      TTP=G
      PGOMP = 0.
      GAM(MP1) = 0.
C. ** SETTING UP COEFFICIENTS
   AKAST = FLOAT(1.-KAST(J))
KAST1 = KAST(I) * 1
INDEX=IND(J)
INDEXF=INDF(J)
DO 304 I=2*N
SU(I) = SU(I) * TDA(I)
SD(I) = SD(I) * TDA(I)
PGOMM = PGOMP
PGOMP = PGOM(I) * AKAST
THP=TP
TP = (GAM(I) + GAM(I+1))/YUIF(I)
TPP = TP + AHL(I) + ABS(TP-AHL(I))
A(I)=TPP-THL(I)-PGOMP
B(I)=TPP+THL(I-1)-PGOMP
IND1=2/I
IND2=1/(NP1-I)
INDEX=1*IND1*IND2
GO TO (304,304), KAST1
304 C(I)=P*PHOM(I)*F(J,I)*OMD(I)*F(J,I+1)*OMD(I-1)*F(J,I-1)*SU(I)
GO TO 306
306 C(I)=PHOM(I)*F(J+I)*SU(I)
304 D(I)=PHOM(I)-SD(I)
C ***MODIFICATIONS FOR BOUNDARIES
INDEX=1*IND1*2*IND2
GO TO (304,304), INDEX
304 A(I)=A(I)*PGOM(2)*AKAST
B(I)=P*RUI
GO TO (304,304), KIN
304 GO TO (304,304), INDEX
301 TT=2.*TS(J,1)
B(I)=AMAX1(TT+B(I),0.)
C(I)=C(I)-TT*FDIFS(J,1)
GO TO 3004
3004 B(I)=0.
D(I)=D(I) * 2.*HMI
C(I)=C(I) * 2.*RJTF(J)
GO TO 3004
3004 B(I)=B(I)*PGOM(NP1)*AKAST
A(I)=2.*RME
GO TO (304,304), KEX
3015 GO TO (304,304), INDEX
3013 TT=2.*TS(J+2)
A(I)=AMAX1(TT+A(I),0.)
C(I)=C(I)-TT*FDIFS(J+2)
GO TO 3004
3004 A(I)=0.
D(I)=D(I) * 2.*HME
C(I)=C(I) * 2.*RJTF(J)
3004 D(I)=D(I)+A(I)+B(I)
C ***ADJUST FREE-BOUNDARY VALUES
RUN = RH0(I) + F(JU+1)
IF(KIN+ME,2.*OH.RU1.EQ.0.) GO TO 3006
F(JU+1) = (F(JU+1)+SU(I)+DX/RU1)/(1.-SD(I)+DX/RU1)
3006 RUNP1 = RH0(NP1)+F(JU+NP1)
IF(KP+ME,2.*OH.RUNP1.EQ.0.) GO TO 3007
F(JU+NP1) = (F(JU+NP1)+SU(NP1)+DX/RUNP1)/(1.-SD(NP1)+DX/RUNP1)
C ***SOLVE FOR DOWNSTREAM F#S
3007 R(2)=(R(2)+F(JU+1)+C(?)*)/NP(2)
A(2)=A(2)/L(2)
DO 3021 I = 3, N
T=D(I)-B(I)*A(I-1)
A(I)=A(I)/T
3021 B(I)=(B(I)+H(I-1)+C(I))/T
DO 3022 IDASH=1, NM1
I=NP1-IDASH
3022 F(J+I)=A(I)*F(J,I+1)+B(I)
C  *** ADJUST BOUNDARY VALUES
GO TO (3210,3220,3230), KIN
3210 GO TO (30A,3211)*INDEXI
3211 RMT=RMI+TS(J,1)
RJI(J)=RJTI(J)-RMI*F(J,1)
IF (PMT=.LT.0.) GO TO 307
F(J,1)=F(J,2)
GO TO 3220
307 F(J,1)= (RJTI(J) + TS(J,1)*(F(J,2) + FDIFS(J,1)))/RMT
GO TO 3220
30A RJI(J)=TS(J,1) *(F(J,1)-F(J,2)-FDIFS(J,1))
RJTI(J)=RJI(J) + RMI*F(J,1)
GO TO 3220
3230 IF (R(J,NP1,0,0,0,0) .GT. 0.) GO TO 309
F(J,1)=F(J,2)*OM2+F(J,3)*OM3
GO TO 3220
309 F(J,1)=F(J,2)*OM2+F(J,3)*OM3
3225 GO TO (3310,3320,3330), EX
3310 GO TO (31A,3311)*INDEXEX
3311 RMT=RME+TS(J,2)
RJE(J)=RJTE(J)-RME*F(J,NP1)
IF (RMT=.LT.0.) GO TO 317
F(J,NP1)=F(J,N)
GO TO 3320
317 F(J,NP1)= (-RJTE(J) + TS(J,2)*(F(J,N)+FDIFS(J,2)))/RMT
GO TO 3320
31A RJE(J)=TS(J,2)*(F(J,NP1)-F(J,N)-FDIFS(J,2))
RJTE(J)=RJE(J) + RME*F(J,NP1)
GO TO 3320
333A F(J,NP1)=F(J,N)*OMN+F(J,NM1)*OMNM1
3320 CONTINUE
XU=XU
ACC=(F(JU,1)-H1P)/DX
PSII=PSII-RMI*DX
PSIF=PSIE-RME*DX
PEI=PSIE-PSII
ISTEP=ISTEP+1
RETURN
END

COMPILER SPACE
SUBROUTINE WF(K)
COMMON/GENERAL/ACC,CSALFA,DPDX,DX,ENTH(40),F(10,40),FS(10,40),GAM3,
GAMN,GAM(40)*1,IFIN,INDE(10),INDI(10),ISTEP,IUTRAP,TEST,KEX,KIN,
PKRAD(N),RHEQ(NP),N1,K1,KM-D(40),UMD(40),BOM(40),KAST(10),PEI,PSIE,PSII,
3P(40),R(4n),RMO(40),RJE(10),RIJ(10),RME,RMI,SD(40),SU(40),WM(10),
4AD,XJ,Y(4n)+YJIF(40)+YJ+RIJTE(10)+RIJTI(10)
COMMON/CJ<:/JU+JK,JO+JH+JA+JG+JTE+JLE+JUV+JB
COMMON/ZES/JH2,JO2,JH10,JH20,JH,JO,JO2
COMMON/CHR/RHR/AMG,CMUIN,CE1,CE2,CG1,CG2,CRT,DUDY(40),
1DUDYSQ(40),EMUL(40),EMUT(40),IPD,PR(10),PRT(10),RTW(40)
COMMON/CWRF/YH(2),IRIF(2),EWALL+H
COMMON/WFS/IFS(20,2),TS(20,2),BF(2)
COMMON/CIGMA/SCH(40)

10UOYSQ<40>EMUL(40)MUT<40>P[PR(10)]PRT(10)RTW(40)
COMMOM/CWRF/YH(2)IRIF(2)EWALL+H
COMMON/WFS/IFS(20,2),TS(20,2),BF(2)
COMMON/CIGMA/SCH(40)

C*************************************************

DATA SHALF/.04/
GO TO (10,11)*K

10 JN=1
IN=2
GO TO 12
11 JN=NP1
IN=N
12 CONTINUE

C ****REFERENCE QUANTITIES
123 REF=AHS(F(JU,IN)-F(JU,IN))
124 RHORFF=R80*8(RHO(IW)-RHO(IN))
125 RUREF=RHO*REF*URFF
126 RREF=R(IN)
127 RHURFF=URFF*RUREF
128 VREF=MUL(IW)
129 YREF=AHS(Y(IN)-Y(IN))
130 REF=RUREF*YREF*VREF
131 A:=RMI-(RME-RMI)*OM(IW))/HRUREF
132 FF=-SU(IW)*YREF/RUREF/URFF
133 IF(RELF.LT.132.25) GO TO 110

C ****LOG LAW ASSUMPTION
121 CONTINUE
134 LAM=0
135 NIT=n
101 SHALF=SHALF
YRP=RY*SHALF

C ****CALCULATION OF E FOR ROUGHNESS
F=EWALL
IF(IPRF(K).EQ.0) GO TO 16

C ****SAND-GRAIN ROUGHNESS
IF(YRP.EQ.3333) E=30/YRP
16 FR=REF*E
S=SHALF**2
SLOCES*AM*EF
1T(SLOC+GT.0.) GO TO 104
SLOC=1.E-30
SHALF=SURT(ABS(AM*EF))
103 BEE=SORT(SLOC/AD)
ARG=FR*(SHALF*(AM/(1.+BEE))*50E)/SHALF
IF(ARG.GT.11.00) GO TO 106
GO TO 110
104 SHALF=AK/ALOG(ARG)
105 IF (ARS(SHALF=SHALF1).LT.0.001.OH.NIT.GT.10) GO TO 102
NIT=NIT+1
GO TO 101

HP(K)=1./(1.+AMRE)
GO TO 103

C ***LAMINAR FLOW

110 LAM=1
AMRE=AMRE
FRE=FRE
IF(AMS(AMRE)*LT.01) GO TO 111
EXPFRE=EXP(AMRE)
STORE=EXPFRE-1.-AMRE
AMRESQ=AMRE*AMRE
SRE=AMRE*3.6*STORE+FRE/AMRESQ/(EXPFRE-1.)
OUT1=SRE*STORE/AMRESQ+FRE*(STORE-5*AMRESQ)/(AMRESQ*AMRE)
GO TO 112
111 SRE=FRE*(1.+AMRE/3.)/(2.+AMRE)
OUT1=SRE*(.5+AMRE/6.)*FRE*(.1667+AMRE/24.)
112 IF(SF*GT.1.E-30) GO TO 113
SF=1.E-30
OUT1=.33333
113 S=SRE/FRE
AP(K)=OUT1
103 DO 500 J=1,NEQ
FDIFS(J,K)=0.
IF(J,NE,JHS) FDIFS(J,K)=(H-1.)*.5*UREREF**2
IF(J,NE,JH) GO TO 200
TS(J,K)=S*HRUREF
GO TO 500

C ***STAGNATION ENTHALPY AND MASS FRACTION

200 CONTINUE
IF(RF.LT.132.25) GO TO 210
IF(LAM.EQ.1) GO TO 210
201 CONTINUE
PRHAT=PH(J)/PTH(J)
IF(KPAV*LT.2) PRHAT=PR(J)/SCH(N)
PJAVA=9.*(PRHAT-1.)/PRHAT**.25
SF=S/(PTH(J)**(1.+PJAVA*SHALF))
IF(KPAV*GT.2) SF=S/(SCH(N)**(1.+PJAVA*SHALF))
GO TO 213

C ***LAMINAR FLOW

210 IF(AMS(AMRE)*LT.01) GO TO 211
SF=AM*EXP(PH(J)*AMRE)-1.*
GO TO 212
211 SF=1.*PR(J)/RE/(1.+5*PR(J)*AMRE)
212 CONTINUE
213 TS(J,K)=SF*HRUREF
500 CONTINUE
RETURN
END

COMPILED SPACE
C

DIMENSION CMW(7,60), PTEMP(40), RCON(10), STORE(10), REM(10)

COMMON/GENERAL/ACC, CSALFA, DPDX, DX, ENTH(40), F(10,40), FS(10,40), GAM3, GAMM, GAM(40), IFIN, INDE(10), INDI(10), ISTEP, IUTRAN, ITEST, KEX, KIN,

2KHAD, NENCO, NPL, NPL1, CM(40), CMD(40), ROM(40), KAST(10), PEI, PSIE, PSI(10), RP(40), RH(40), RHRO(40), RJE(10), RJ(10), RME, RMI, SU(40), SU(40), WM(10),

4X0, X(1,Y(40), YDIF(40), YE, YI, RJET(10), RJ(10),

COMMON/CJCK, JU, JK, JD, JHS, JA, JR, JF, JBE, JUV, JB

COMMON/CFC, JH1, JH2, JH1H, JH20, JH, J0, JN2

COMMON/STAR/HO(7), CPBAR(7,60), HT(7,60), HC(5,60), ISTAR(40), FACN

COMMON/CUT(40), AK, ALM, CMU, CHUN, CE1, CE2, CG1, CG2, CRIT, DUDY(40),

1DIDY50(40), EMLT(40), EMUT(40), IPD, PR(10), IPD(10), RTW(40)

COMMON/CPROP/102, IN2, IH20, OFAC, NR, NS, #00, #01, #02, #03, #04, #05, #06, #07, #08, GASCON, GAMA

C

CHAPTER 1

LOADING OF EQUILIBRIUM CONSTANTS, ENTHALPIES AND SPECIFIC HEATS
ENTRY LANL

C

REFERENCE ENTHALPIES
DATA (HO(J), J=1,7)/-2023.8,-2074.7,7205.6,-6016.4,750616.5,57949.1, -2072.0/

C

CHEMICAL EQUILIBRIUM CONSTANTS
DO 20 J=1,7
READ(5,10)(RC(J,I),I=1,60)
DO 20 I=1,60
RC(J, I)=AMN(1, RC(J, I), 100)
20 RC(J, I)=1.0**RC(J, I)

C

CONSTANTS FOR GLOBAL REACTION
DO 15 I=1,60
15 RC(5, I)=RC(4, I)**RC(3, I)/RC(1, I)**SORT(RC(2, I))

C

CONVERSION INTO CONSTANTS FOR CONCENTRATION RATIOS
A10=WJ(JH/F)/WJ(JF)**A20
A30=WJ(JM/J02)/WJ(J0)/WJ(JF)
A40=WJ(JHJ)/WJ(J0)/WJ(JH)
A50=WJ(JH)/WJ(JH/2)/SORT(WJ(J0))
DO 571 I=1,60
RC(1, I)=RQ(1, I)**A10
RC(2, I)=RQ(2, I)**A20
RC(3, I)=RQ(3, I)**A30
RC(4, I)=RQ(4, I)**A40
571 RC(5, I)=RQ(5, I)**A50

C

ENTHAPLIES AND MEAN SPECIFIC HEATS
DO 3n J=1,NS
CFA=0.187/WJ(J)
HO(J)=HO(J)*CFA
READ(5,20)(HT(J, I), I=1,60)
DO 3n I=1,60
HT(J, I)=HT(J, I)*CFA
3n CPBAR(J, I)=0.1*(HT(J, I)-HO(J))/FLOAT(I)

C

ITERATION PARAMETERS
HREG=3
ITMAX=12
CC=.01
HP=.5
RPD=1.0-HPR
FSTOICH=2.0*WM(JH2)/WM(JO2)
NRPM=NP+1
RETURN

CHAPTER 2

C*****INITIAL ENTHALPIES
ENTRY LANdL2
FNTH(I)=0.
FA=0.01*F(JTE,I)
IFACX=FACX
FAC=FACX-FLOAT(IFACX)
DO 115 J=1,NS
FNTL=HT(J,IFACX)+FAC*(HT(J,IFACX+1)-HT(J,IFACX))
115 FNTH(I)=ENTH(I)+FS(J,I)*FNTL
RETURN

CHAPTER 3

C*****LOCAL MASS FRACTIONS
ENTRY LANdL3

C ****LOCATE POSITION WHERE HYDROGEN CONCENTRATION IS STOICHIOMETRIC
X=1.-F(JA,1)
X=X*0.5
IF(F(JA,1)/X*1.E-10).LT.FSTOICH GO TO 625
DO 621 I=1,NP1
X=1.-F(JA,I)
X=X*0.5
PARA=RAT*1.E-10
RAT=F(JA,T)/X*1.E-10
IF(HAT.T*) FSTOICH) GO TO 1060
621 CONTINUE
1060 TLOCM=I-1
TLOCN=1
IF(Y(I-1)+Y(I-1))/RAT*PARA*(FSTOICH-PARA)
GO TO 626
625 TLOCN=0
TLOCN=1
626 DO 21A I=1,IDM
1=NP1-1-IDM
IF(I.LT.TLOCN) GO TO 740
GO TO 757
740 T=1-TLOCN
757 TSM=MAD(F(JTE,I),250.)

C ****CONCENTRATIONS OF OXYGEN ELEMENT AND NITROGEN
XN2PO=1.-F(JA,1)
X=0.5X
FS(JN2PO)=XN2PO-X
RAT=F(JA,T)/X*1.E-10
DO 304 L=1,NS
304 STOHL(L)=X.

C ****EQUILIBRIUM CONSTANTS AND MEAN SPECIFIC HEATS FOR UPSTREAM STATE
FA=0.01*TSM
IFACX=FACX
FAC=FACX-FLOAT(IFACX)
DO 1055 L=1,NRP
1055 RCON(L)=RCON(L)*FA+FAC*(RCON(L,IFACX+1)-RCON(L,IFACX))
DO 1056 L=1,NRP
1056 RCON(L)=RCON(L)*CFAC

71
**SOLUTION OF QUADRATIC EQUATION FOR HYDROGEN-NITROGEN MIXTURES**

```plaintext
FS(JH,I) = SQRT(1.0 - FS(JA,I) * RCON(I))
FS(JH2,I) = FS(JH,I) + 1.0 / RCON(I)
```

**START OF ITERATION CYCLE**

**DETERMINE LARGEST TERM IN EACH GROUP**

```plaintext
IF (FS(JH2,I) > FS(J02,I)) GO TO 175
```

**START OF OXYGEN ELEMENT**

```plaintext
J1 = J0
FM1 = FS(J0,I)
IF (FS(J0,I) < FS(J02,I)) GO TO 210
```

**START OF HYDROGEN ELEMENT**

```plaintext
J2 = JH
FM2 = FS(JH,I)
IF (FS(JH,I) < FS(JH2,I)) GO TO 253
```

**PRECAUTION IF H2O IS LARGEST OF BOTH GROUPS**

```plaintext
IF (.NOT. (J1.EQ.JH20 AND J2.EQ.JH20)) GO TO 279
```

**CONTINUE**

```plaintext
J1 = J0
FM1 = FS(J0,I)
IF (FS(J0,I) < FS(J02,I)) GO TO 622
```

```plaintext
J2 = JH
FM2 = FS(JH,I)
IF (FS(JH,I) < FS(JH2,I)) GO TO 361
```

**CONTINUE**

```plaintext
J1 = J0
FM1 = FS(J0,I)
```

```plaintext
J2 = JH
FM2 = FS(JH,I)
```

**CONTINUE**

```plaintext
J1 = J0
FM1 = FS(J0,I)
```

**CONTINUE**

```plaintext
J2 = JH
FM2 = FS(JH,I)
```

**CONTINUE**

```plaintext
J1 = J0
FM1 = FS(J0,I)
```

**CONTINUE**

```plaintext
J2 = JH
FM2 = FS(JH,I)
```

**CONTINUE**

```plaintext
J1 = J0
FM1 = FS(J0,I)
```

**CONTINUE**

```plaintext
J2 = JH
FM2 = FS(JH,I)
```
**PRECAUTION IF OH IS LARGEST OF BOTH GROUPS**

IF (.NOT. (J1.EQ.JOH.AND.J2.EQ.JH2)) GO TO 379
J1=J2
FM1=FS(JO2,I)
IF (FS(JO2,I)*LT.FS(J02,I)) GO TO 358
J1=J0
FM1=FS(JO2,I)

35A IF (FS(JH20,I)*WSO.LT.FM1) GO TO 379
J1=JH20
FM1=FS(JH20,I)*WSO
GO TO 379

367 J2=JH2
FM2=FS(JH2,I)
IF (FS(JH1,I)*LT.FS(JH2,I)) GO TO 381
J2=JH
FM2=FS(JH1,I)

381 IF (FS(JH20,I)*WSO.LT.FM2) GO TO 379
J2=JH20
FM2=FS(JH20,I)*WSO

379 CONTINUE

**C **VERIFICATION PRECAUTION**

IF (F(JA,I)*JG.99999) J1=JH20
IF (F(JA,I)*LT.0001) J2=JH20

C----------------------------------------- H2 OR H AS J2

IF (J1.NE.JH2.AND.J2.NE.JH1) GO TO 240
IF (J1.EQ.JH2) FS(JH1,I)=SQRT(FS(JH2,I)/RCON(1))
IF (J2.EQ.JH2) FS(JH2,I)=FS(JH1,I)**2*RCON(1)
IF (J1.EQ.JH20) GO TO 233
IF (J1.EQ.JOH) GO TO 427
IF (J1.EQ.JO) FS(JO2,I)=FS(J0,I)**2*RCON(2)
IF (J1.EQ.J02) FS(J02,I)=SQRT(FS(J02,I)/RCON(2))
FS(JH20,I)=FS(JH2,I)**2*RCON(5)
FS(JH1,I)=FS(J0,I)*FS(JH1,I)*RCON(3)
GO TO 290

233 FS(J10,I)=(FS(JH20,I)/FS(JH2,I)/RCON(5))**2
FS(J01,I)=SQRT(FS(J02,I)/RCON(2))
FS(J0H,I)=FS(J0,I)**3*RCON(3)
GO TO 290

427 FS(J0,I)=FS(J0H,I)/FS(JH1,I)/RCON(3)
FS(J07,I)=FS(J0,I)**2*RCON(2)
FS(JH20,I)=FS(JH1,I)**2/RCON(4)/RCON(3)
GO TO 290

24A IF (J2.NE.JH20) GO TO 250

C----------------------------------------- H20 AS J2

IF (J1.EQ.JO) FS(J02,I)=FS(J0,I)**2*RCON(2)
IF (J1.EQ.J02) FS(J02,I)=SQRT(FS(J02,I)/RCON(2))
IF (J1.NE.JOH) GO TO 430
FS(JO,I)=FS(JOH1,I)**2/FS(JH20,I)/RCON(4)/RCON(3)
FS(JO2,I)=FS(J0,I)**2*RCON(2)

GO TO 290

43A CONTINUE

FS(JH20,I)=FS(JH20,I)/FS(JH20,I)/RCON(5)
FS(JH1,I)=SQRT(FS(JH20,I)/RCON(1))
IF (J1.EQ.JOH) GO TO 290
FS(JOH1,I)=FS(J0,I)**3/RCON(3)
260 CONTINUE
   IF(J1.EQ.J02) FS(J02,I)=FS(J01,I)*RCON(2)
   IF(J1.EQ.J01) FS(J01,I)=SQRT(FS(J02,I)/RCON(2))
   IF(J1.EQ.JH20) GO TO 501
   FS(JH2,I)=FS(J0H,I)/FS(J01,I)/RCON(3)
   FS(JH21,I)=FS(JH2,I)*RCON(1)
   FS(JH20,I)=FS(JH2,I)*FS(J0H,I)*RCON(4)
   GO TO 240
501 FS(JH2,I)=FS(JH20,I)/FS(J0H,I)/RCON(4)
   FS(JH21,I)=FS(JH2,I)*RCON(1)
502 FS(J01,I)=FS(J0H,I)/FS(JH2,I)/RCON(3)
   FS(J02,I)=FS(J01,I)*RCON(2)
299 CONTINUE
C ***RE-EVALUATE LARGEST TERMS FROM ADDITIVE EQUATIONS
   IF(MAT*LE.FSTOICH) GO TO 810
A30 CONTINUE
   FM1=FM1*FS(J0H,I)
   IF(J1.EQ.J01) FM1=FM1-FS(J0H,I)*WRO
   IF(J1.EQ.J02) FM1=FM1-FS(J02,I)
   IF(J1.EQ.J00) FM1=FM1-FS(J01,I)
   IF(J1.EQ.JH20) FM1=FM1-FS(JH20,I)*WSO
   FS(J1,I)=FM1
   IF(J1.EQ.JH20) FS(J1,I)=FS(J1,I)/WSO
   IF(J1.EQ.J0H) FS(J1,I)=FS(J1,I)/WRO
   IF(MAT*LE.FSTOICH) GO TO 820
B10 CONTINUE
   FM2=FS(J0H,I)
   IF(J2.EQ.J01) FM2=FM2-FS(J0H,I)*WTO
   IF(J2.EQ.J02) FM2=FM2-FS(J02,I)
   IF(J2.EQ.J00) FM2=FM2-FS(J01,I)
   IF(J2.EQ.JH20) FM2=FM2-FS(JH20,I)*WQO
   FS(J2,I)=FM2
   IF(J2.EQ.JH20) FS(J2,I)=FM2/WQO
   IF(J2.EQ.J0H) FS(J2,I)=FM2/WTO
   IF(MAT*LE.FSTOICH) GO TO 830
B20 CONTINUE
   ITER=ITER+1
   ISTAP(I)=ITER
   IF(ITER.LT.1HF6IN) GO TO 6A9
C ***UNDERRELAXATION OF MASS FRACTIONS
   DO 6A9 L=1,NS
      AAA FS(L,I)=RPM*FS(L,I)*HPD*STORE(L)
   6A9 CONTINUE
   DO 325 L=1,NS
      FM=FS(L,I)-STORE(L)
      FM/=FS(L,I)+1.E-40
   325 CONTINUE
C ***LIMITS ON MASS FRACTIONS
   DO 339 L=1,NS
      FS(L,I)=AAX1(FS(L,I)+1.)
   339 CONTINUE
   DO 326 L=1,NS
      STORE(L)=FS(L,I)
      RMAX=E0
   326 CONTINUE
      DO 327 L=1,NS
      IF(FS(L,I).LT.1.E-6) GO TO 327
      RMAX=AAX1(RMAX,ABS(REM(L)))
   327 CONTINUE
74
C  ***CONVERGENCE CRITERION
   IF (ITER.GT.ITMAX .OR. ABS(RMAX) .GT. 1.0E-10) GO TO 208
   GO TO 175
208 CONTINUE
   DO 345 J=1,NS
   DO 345 I=1,NP1
   345 FS(J+I) = AMAX1(FS(J+I),0.0)
C  ***TEST FOR POOR CONVERGENCE
   DO 8227 I=1,NP1
6227 IF (ISTAR(I).GT.ITMAX) WRITE (6,8228) ISTAR(I),I,ISTEP
   8228 FORMAT(10X,'*** POOR CONVERGENCE (*** ISTEPS *** ITERATIONS) AT NODE ***I***
   RETURN
C******************************************************

CHAPTER 4
C********LOCAL TEMPERATURES
   ENTRY LNL4
9613 PTMP(I) = F(JTE,I)
   DO 405 I=1,NP1
   SMCM = 0.
   DO 405 J=1,NS
   ENTH(I) = ENTH(I) - FS(J+I)*HO(J)
405 ENTH(I) = ENTH(I)/SMCM
   SF = EnTH(I)*CPMN(J,I)
   406 F(JTE+I) = EnTH(I)*SMCM
C  ***UNDER-RELAXATION OF TEMPERATURES IN REACTION ZONE
   IIEM = IUCM-3
   ILP = IUPC+3
   DO 149 I=1,NP1
   IF (.NOT. (T.I.E.IEM .AND. I.LE.ILP)) GO TO 149
   F(JTE+I) = .5*(F(JTE,I)*PTMP(I))
149 CONTINUE
C  ***FORMAT STATEMENTS
   1001 FORMAT(7F10.4)
   2001 FORMAT(7F10.1)
   RETURN
END
C **INITIAL VALUES OF INTEREST
ENTRY OUTP1
FSTOICH=2.*WM(JH2)/WM(J02)
FSTOICH=FSTOICH/1.*FSTOICH
READ(5,1153) (ATITL1(K),K=1,13)
READ(5,1153) (ATITL2(K),K=1,13)
READ(5,1154) ((AVRHL(K,L),K=1,6),L=1,10)
RFY=HU(1)*F(JU,1)*Y(NP1)/EMUL(1)
VMIX=*
DO 1016 J=1,NS
1014 VMIX=VMIX*FS(J+1)/FS(J)
AMACH=AMACH+F(JU,1)/SORT(GAMMA*GAMMA+F(JE,1)*VMIX)
PRESS=PRESS
INF=INF(F(JU,1))
INF=INF(F(JU,1))=F(JU,NP1)
CIN=FS(JH2,1)
TIN=F(JTJE,1)
C **OUTPUT OF ALPHANUMERIC DATA
WRITE(6,1121) (ATITL1(K),K=1,13),(ATITL2(K),K=1,13)
WRITE(6,1122) (L,(AVRHL(K,L),K=1,6),L=1,NEQ)
WRITE(6,1123) (CMU1,CE1,CE2,CG1,CG2,AK,ALMG,CRIT,IPD)
WRITE(6,1132) (OM(I),I=1,NP1)
WRITE(6,1133) NH,NS
READ(5,1154) ((AVRHL(K,L),K=1,6),L=1,NR)
WRITE(6,1134)
WRITE(6,1122) (L,(AVRHL(K,L),K=1,6),L=1,NEQ)
READ(5,1154) ((AVRHL(K,L),K=1,6),L=1,NS)
WRITE(6,1135)
WRITE(6,1122) (L,(AVRHL(K,L),K=1,6),L=1,NS)
WRITE(6,1136)
WRITE(6,1123) (CMU,CE1,CE2,CG1,CG2,AK,ALMG,CRIT,IPD)
READ(5,1153) (ASYMBL(K),K=1,7)
DO 1017 J=1,40
1017 WRITE(6,1129) J,RH(J),PR(J),KAST(J)
WRITE(6,1137) RFY,AMACH,YIN,YOUT,REDUCT,PRESS1,UN1,CIN,GIN,TIN
RETURN
C **STATION VARIABLES**
ENTRY OUTP2
XUD=XY/YOUT
C **MEAN SQUARE FLUCTUATIONS (OF H ELEMENT)
IF(IN2.EQ.0.AND.IN20.EQ.0) GO TO 165
C ***LOCATE POSITION OF FLAME FRONT
C -=-ASSUMING #-BATTLEMENT# VARIATION OF SPECIES CONCENTRATION
DO 161 I=1,NP1
RAT=FS101CH*(1.-FS(JN2,I))
PARA SFH2=1.E-10
SFH2=(F(JA,I)+SORT(F(JG,I)))/RAT
IF(SFH2.LT.1.) GO TO 162
161 CONTINUE
162 FACExY(I-1)*(Y(I)-Y(I-1))*R*(1.-PARA)/(SFH2-PARA)
DO 163 I=1,NP1
RAT=FS101CH*(1.-FS(JN2,I))
PARA SFH2=1.E-10
SFH2=(F(JA,I)+SORT(F(JG,I)))/RAT
IF(SFH2.LT.1.) GO TO 164
163 CONTINUE
164 FACE=YY(I-1)*(Y(I)-Y(I-1))*R*(1.-PARA)/(SFH2-PARA)
CONTINUE
165 CONTINUE
PRDH=PRESL-P(1)
ULINE=(F(JU+1)-F(JU,NP1))/UEIN
CLINE=FS(JH2+1)/(CIN+1,E=30)
TLINE=F(JT+1)/TIN
WRITE(6,1006) KST,(X,XUD,DX,YHA,DDYHA,DDYHA,YDX)
WRITE(6,1007) KST,KEY,FINY(JH2+1),PDE,ACC,CFU,CF2
WRITE(6,1008) PSI1,PS1E,PE1,RMI,RME,FAC,FACE,FACM
WRITE(6,1009) F(JU,1),F(JA,1),F(JT,1),ULINE,CLINE,TLINE,PRDH
C ***CHECK FOR FLUX CONSERVATION
DO 1027 J=1,NEQ
FLUX(J)=(F(J,2)+OM(2))*(F(J,N)-OM(N))
1027 DO 1028 J=1,NEQ
FLUX(J)=(F(J,2)+OM(2))*(F(J,N)-OM(N))
1028 IF(KST(J)) 1029,1029,1029
1029 FLUX(J)=(F(J,2)+OM(2))*(F(J,N)-OM(N))
1030 IF(KST(J)) 1030,1030,1030
1031 PRINT(6,11155) RFLUX,REDUCT,REXD,P(1),DPDX
IF(KFX.NE.1) RETURN
IF(KAE,EN,2) WRITE(6,1155) RFLUX,REDUCT,REXD,P(1),DPDX
IF(KAE,EN,1) RETURN
IF(KAE,EN,2) WRITE(6,1155) RFLUX,REDUCT,REXD,P(1),DPDX
IF(KAE,EN,1) RETURN
TAUE=TAUH(J)/H(NP1)
WRITE(6,11010) INE(JH2),F(JT,NP1),AE,TAUE
RETURN
C~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ENTRY OUTP3
C ***PROFILE VARIABLES
C/ INFORMATION (TEMPORARY) ON NEW OUTPUT ROUTINE.
C/ SIMROUTINE PROFI assigns values for plot* and also writes
C/ PROFILES. IT IS CALLED BY ... 
C/ CALL PROFI(JPROF,TITLE,FIRST,ADD,HIV,FINAL,KPLOT,SYM)
C/ WHERE JPROF=J REFERS TO THE F(J,I) ARRAY
C/ JPROF,GT,0 MEANS USE F(JPROF+1) ARRAY AND WRITE PROFILE.
C/ JPROF,LT,0 MEANS USE OUT(1)+ARRAY AND WRITE PROFILE.

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C / J PROF = 0 MEANS NO ACTION UNLESS K PLOT LT 0
C / 0*0* OUT ( I ) ARRAY IS OVERWRITTEN BY PROFIL.
C / TITLE JS TH' NAME OF THE PROFILE, PLOTTED BY SYMBOL.
C / FJPST AND FINAL ARE FIRST AND LAST VARIABLES WRITTEN IN PROFILE
C / ADD AND DIV MODIFY PROFILES FROM I = 2 TO I = N
C / K PLOT GT 0 MEANS ASSIGN YTPLOT ( K PLOT , I ) ARRAY.
C / K PLOT = 0 MEANS NO PLOT ASSIGNMENTS.
C / Y PLOT LT 0 MEANS ASSIGN THE Y ( I ) ARRAY TO THE XT PLOT ( I ) ARRAY.
C / SYMBOL IS THE CHARACTER USED IN PLOT.

C ***ZERO YT PLOT ARRAYS
IF ( ISTEP GT 1 ) GO TO 401
DO 402 I = 1, N P 1
403 OUT ( I ) = 0.
DO 403 K = 1, 10
403 CALL PROFIL ( 0, 1 H 0, 0, 0, 1, 0, K, 1 H 0 )
401 CONTINUE

C ***DISTANCES ( Y )
CALL PROFIL ( 0, 6 HY / ( Y ( N P 1 ) + ( Y ( N P 1 ) + 1, 0 )
C ***AXIAL VELOCITIES ( JU )
DIV = F ( J U , 1 ) - F ( J U , N P 1 ) + 1, E - 3 0
CALL PROFIL ( J U , 6 H U V E L O , F ( J U , 1 ) = F ( J U , N P 1 ) , DIV , F ( J U , N P 1 ) , 1, 1 H U )
C ***STAGMATION ENTHALPIES ( JHS )
DIV = F ( J H S , 1 ) - F ( J H S , N P 1 )
CALL PROFIL ( J H S , 6 H H STAG , F ( J H S , 1 ) = F ( J H S , N P 1 ) , DIV , F ( J H S , N P 1 ) , 0, 1 )
C ***TURBULENT KINETIC ENERGIES ( JK )
DIV = F ( J K , 1 ) - F ( J K , N P 1 ) + 1, E - 3 0
CALL PROFIL ( J K , 6 H K E . E T I ) , F ( J K , 1 ) = F ( J K , N P 1 ) , S, 1 H K )
C ***DISSIPATION RATES ( JD )
CALL PROFIL ( J D , 6 H D I S S , F ( J D , 1 ) = F ( J D , N P 1 ) , 6, 1 M D )
C ***DISSIPATION LENGTH SCALES ( JLE )
DO 1201 I = 1, N
1201 F ( J L E , I ) = SQRT ( F ( J K , I ) ) / ( R T W ( I ) + 1, E - 3 0 )
F ( J L E , I ) = 0.
DIV = Y ( N P 1 )
CALL PROFIL ( J L E , 6 H LENGTH , F ( J L E , 1 ) = F ( J L E , N P 1 ) , DIV , F ( J L E , N P 1 ) , 10, 1 H L )
C ***TURBULENT VISOSITIES ( EMUT )
WRITE ( 9, 6 2 A ) ( EMUT ( I ) , I = 1, N P 1 )
C ***DENSITIES
WRITE ( 9, 6 5 9 ) ( RHO ( I ) , I = 1, N P 1 )
C ***REYNOLDS STRESS CORRELATION ( JUV )
DIV = F ( J U , 1 ) - F ( J U , N P 1 ) + 1, E - 3 0
CALL PROFIL ( J U , 6 H U V , F ( J U , 1 ) = F ( J U , N P 1 ) , 2, 1 H S )
C ***SPECIES MASS FRACTIONS ( JA )
DIV = F ( J A , 1 ) - F ( J A , N P 1 ) + 1, E - 3 0
CALL PROFIL ( J A , 7 H F ( J A , I ) = F ( J A , N P 1 ) , DIV , F ( J A , N P 1 ) , 3, 1 H A )
C ***R . M . S. CONCENTRATION FLUCTUATIONS ( OF H ELEMENT )
DIV = F ( J A , 1 ) - F ( J A , N P 1 ) + 1, E - 3 0
CALL PROFIL ( J G , 7 H F ( J G , I ) = F ( J G , N P 1 ) , DIV , F ( J G , N P 1 ) , 9, 1 H G )
C ***ABSOLUTE TEMPERATURES ( JTE )
DIV = F ( J T E , 1 ) - F ( J T E , N P 1 ) + 1, E - 3 0
CALL PROFIL ( J T E , 4 H T E M P , F ( J T E , 1 ) = F ( J T E , N P 1 ) , 8, 1 M T )
C ***OUTPUT OF INDIVIDUAL SPECIES CONCENTRATIONS
DO 425 J = 1, N S
425 WRITE ( 9, 6 2 6 ) ( ASY H L ( J ) , ( FS ( J , I ) , I = 1, N P 1 )
WRITE ( 9, 6 2 7 ) ( ISTAH ( I ) , I = 1, N P 1 )
C ***PLOTTING OF PROFILES

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SUBROUTINE PROFIL(JPHOF,TITLE,FIRST,ADD,DIV,FINAL,KPLOT,SYMBOL)  
COMMON/GENRAL/ACC,CSALFA,DPDX,DY,ENTH(40),F(10,40),FS(10,40),GAME,  
INAM1,INAM2(40),I,IFIN,INDE(10),INDI(10),ISTEP,ITRAP,ITEST,KE,KIN,  
PKEEP,EMP,EPN1,EPN2,OM(40),OMD(40),OMH(40),KAST(10),PEI,PS1E,PS1I,  
P3P(40),R(40),RHO(40),RJE(10),RJI(10),RME,RMI,SD(40),SU(40),WM(10),  
X,XX,Y(40),YH(40),YIF(40),YJ,M,JPE,JRI,RIJ,EJ,RIJ,RIJ,RIJ,RIJ,  
COMMON/TPLOTb/XTAXIS,XTPLOT(40),YTPAXES(10),YTPLOT(10,40),  
YPMAX(10),YTSYMA(10),OUT(40),IPHOF  
C------------SUBROUTINE TO WRITE PROFILES AND ASSIGN TRANSVERSE PLOT ARRAYS  
C------------  
100 IF(KPLOT) 500,700,700  
700 IF(JPHOF) 200,200,100  
100 DO 101 I=1,NP1  
101 OUT(I)=F(JPHOF,I)  
200 YMAX=1.E-30  
DO 201 I=1,NP1  
YMAX=AMAX1(YMAX,OUT(I))  
201 OUT(I)=(OUT(I)+ADD)/DIV  
IF(JPHOF,NE.0.AND.I.PHOF.EQ.1) WRITE(6,900) TITLE,FIRST,(OUT(I),I=2  
1,N),FINAL  
IF(JPHOF,NE.0.AND.I.PHOF.EQ.2) WRITE(6,900) TITLE,(F(JPHOF,I),I=1,N  
101)  
IF(KPLOT) 500,600,400  
400 DO 401 I=1,NP1  
401 YTPLOT(KPLOT,I)=OUT(I)  
YTPAXES(KPLOT)=TITLE  
YTSYMA(KPLOT)=SYMBOL  
YTPMAX(KPLOT)=YMAX  
RETURN  
500 DO 501 I=1,NP1  
501 XTPLOT(I)=(Y(I)+ADD)/DIV  
XTAXIS=TITLE  
WHITE(9,900) TITLE,FIRST,(XTPLOT(I),I=2,N),FINAL  
600 RETURN  
900 FORMAT(1H,A6,1P11E11.3/(7X,1P11E11.3))  
END  

COMPILER SPACE
SUBROUTINE PLOTS(X, IDIM, IMAX, XAXIS, Y, YMAX, JDIM, JMAX, YAXES, SYMBOL)
C
SUBROUTINE FOR PLOTTING J CURVES OF Y(J,I) AGAINST X(I)
C
X AND Y ARE ASSUMED TO BE IN ANY RANGE EXCEPT THAT NEGATIVE VALUES
ARE PLOTTED AS ZERO
X AND Y ARE SCALING TO THE RANGE 0. TO 1. BY DIVISION BY THE MAXIMA
WHICH ARE ALSO PRINTED
IDIM IS THE VARIABLE DIMENSION FOR X,
IMAX IS THE NUMBER OF X VALUES
XAXIS STORES THE NAME OF THE X-AXIS
JDIM IS THE VARIABLE DIMENSION FOR Y,
JMAX IS THE NUMBER OF CURVES TO BE PLOTTED, (UP TO 10).
THE ARRAY YAXES(J) STORES THE NAME OF THE CURVES,
THE ARRAY SYMBOL(J) STORES THE SINGLE CHARACTERS USED FOR PLOTTING
C
DIMENSION X(IDIM), Y(JDIM, IDIM), YMAX(JDIM), YAXES(JDIM), SYMBOL(JDIM)
1. A(11))
DATA DOT, CROSS, BLANK/1H, 1H, 1H /
C
SCALING X ARRAY TO THE RANGE 0 TO 50
XMAX=1.0E-30
DO 1 I=1, IMAX
1 IF(X(I) .GT. XMAX) XMAX=X(I)
DO 2 I=1, IMAX
2 IF(X(I) .LT. O.) X(I)=0.
SCALING Y ARRAY TO THE RANGE 0 TO 100
DO 3 J=1, JMAX
AYMAX=1.0E-30
40 4 I=1, JMAX
AYMAX=AYMAX*(AYMAX+Y(J, I))
AYMAX=AMAX1(Y(J, I))
AYMAX=AYMAX*(AYMAX+Y(J, I))
4 I=1, JMAX
3 Y(J, I)=AMAX1(Y(J, I))
IDENTIFYING THE VARIOUS CURVES TO BE PLOTTED
WRITE(6, 113) XAXIS, XMAX
WRITE(6, 110) (YAXES(I), I=1, JMAX)
WRITE(6, 116) (SYMBOL(I), I=1, JMAX)
WRITE(6, 112) (YMAX(I), I=1, JMAX)
5 I=1, 11
5 A(I)=0.1*FLOAT(I-I)
WRITE(6, 111) (A(I), I=1, 11)

MAIN LOOP. EACH PASS PRODUCES AN X-CONSTANT LINE
DO 40 I=1, 151
IF(I.EQ.1.0*E.51) GO TO 32
GO TO 33

ALLOCATE . OR * AS MARKER ON THE Y-AXIS
32 DO 30 K=1, 101
30 A(K)=DOT
31 A(K)=CROSS

ALLOCATE . OR * MARK ON THE X-AXIS, ALSO THE APPROPRIATE X VALUE
33 A(I)=DOT
34 A(101)=DOT
K=I
44 K=K-5
IF(K) 4A, 47, 46
A(1)=CHSS
A(101)=CHSS
42 XL=0,02*FLOAT(I=1)
C***** CHECK IF ANY Y( X(I) ) VALUE LIES ON THIS X-CONSTANT LINE
C***** IF YES GO TO 41, OTHERWISE GO TO 42
DO 43 K=1,JMAX
IF(IFIX(X(K)+1,5)-I) 43,41,43
C***** LOCATE Y( X(I) )
41 DO 44 J=1,JMAX
NY=Y(J)+K*1.5
A(NY)=SYMBOL(J)
44 CONTINUE
GO TO 42
43 CONTINUE
C***** PRINT X-CONSTANT LINE
42 WRITE(6,165) XL,(A(K),K=I,101),XL
C***** PUTTING BLANKS INTO X-CONSTANT LINE
DO 49 K=1,101
A(K)=BLANK
49 CONTINUE
DO 50 I=1,11
A(I)=.1*FLOAT(I=1)
WRITE(6,164) (A(J),J=I,11)
RETURN
100 FORMAT(1H Y-AXES ARE ,5X,10(1X,A10))
101 FORMAT(1H MAXIMUM VALUES,1P1E11.3)
102 FORMAT(3X,11F10.1)
103 FORMAT(2H X-AXIS IS ,A8,17H ,MAXIMUM VALUE =,1PE10.3)
104 FORMAT(7H SYMBOL,11X,10(1X,A10))
END

COMPILFR SPACE
SUBROUTINE YINT(FRAC,YFRAC,JJ)
COMMON/GENERAL/ACC,CSALFA,DPDX,DX,ENTH(40),F(10,40),FS(10,40),GAM(40),
1 GAMN,GAH(40),I,IFIN,INDE(10),INDI(10),ISTEP,IUTRIP,ITEST,KEX,KIN,
2 KRAU,N,NET,NPL,NMI,OM(40),OMD(40),OMF(40),OMH(40),OMH(10),
3 P(40),R(40),RHO(40),RJF(10),RJ1(10),RME,RLI,SM(40),SU(40),WORK(10),
4 XJ,XJ1,Y(40),YDF(40),YF,Y1,RJTE(10),RJTR(10)
COMMON/CJS/JJ,JK,JD,JHS,JA,JTG,JE,JE1,JU,JU1,JB
COMMON/CF,JH2,J02,JOH,JH20,JH,J0,JN2
C-------------------------------INTERPOLATION SUBROUTINE
C-------------------------------
REDF1=Frac^AHs(F(JJ,NPL)-F(JJ,1))
IF(REDF1,NE.O.) GO TO 10
YFRAC=Frac^AHs(Y(NPL))
WRITE(6,1) YFRAC
1 FORMAT(7H ISTEP=P,14,4H XU=,1PE10.3,52H IN SUBROUTINE YINT, REDF1=
10, SO YFRAC=Frac^AHs(Y(NPL)=,E10.3)
WRITE(6,2) FRAC,JJ,NPL,F(JJ,NPL),F(JJ,1)
2 FORMAT(6H FRAC=,1PE10.3,4H JJ=,I3,5H NPL=,I4,
1 11H F(JJ,NPL)=,E10.3,9H F(JJ,1)=,E10.3)
RETURN
16 IF(FRAC.GT.5) GO TO 30
DO 20 I=2,N
DIF=ABS(F(JJ,I)-F(JJ,1))
20 IF(DIF=REDF1) 20+21,21
21 T=ABS(F(JJ,I)-F(JJ,1))
IF(T) 22,23,22
25 T=(DIF=REDF1)/T
23 YFRAC=Y(I)-T*(Y(I)-Y(I-1))
RETURN
26 CONTINUE
36 DO 44 IADAH=2,N
I=N+1-IADAH
DIF=ABS(F(JJ,I)-F(JJ,1))
IF(DIF=REDF1) 41,41,40
41 T=ABS(F(JJ,I)-F(JJ,1))
IF(T) 42,43,42
45 T=(DIF=REDF1)/T
43 YFRAC=Y(I)-T*(Y(I+1)-Y(I))
RETURN
46 CONTINUE
RETURN
END

COMPIER SPACE
"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—National Aeronautics and Space Act of 1958

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