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COMPUTER PROGRAMS FOR A REACTIVE TURBULENT BOUNDARY LAYER - HYDROGEN VERSION

TECHNICAL REPORT NO. 586

by

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SUMMARY

Computer programs for the calculation of properties within a constant pressure reacting compressible turbulent H_2-Air boundary layer are described. The partial differential equations for energy and species mass conservation are solved with arbitrary initial conditions by an implicit difference technique. A variable wall temperature boundary condition may be specified whereas the conditions at the edge of the boundary layer are constant.

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INTRODUCTION

This report describes an IBM-7094 computer program written in the FORTRAN II language to calculate properties within the turbulent boundary layer, with hydrogen chemistry. The analysis is described in Ref. 1. There are four versions of this program, reflecting the substructure, reference, and sublayer hypothesis, which utilize finite rate hydrogen chemistry, and the reference hypothesis using equilibrium hydrogen chemistry.

Section I of this report will describe the details common to all versions. Sections II, III, and IV will outline those features peculiar to the substructure, reference, and sublayer versions. The major differences in the four versions are the computation of the parameter $d(\ln \sigma)/d\chi$ and the input format for execution on the IBM 7094.

I. TURBULENT BOUNDARY LAYER-AIR CHEMISTRY

A. Basic Equations Used

The program solves two partial differential equations for the dependent variables, stagnation enthalpy ratio, "G", and species mass fractions, "Y_k", as functions of the two independent variables χ and ψ. These equations are:

$$\frac{\partial G}{\partial \chi} = \frac{\partial}{\partial \psi}\left[\frac{\tilde{u}}{P_e}\frac{\partial G}{\partial \psi} + \frac{u_e^2}{2h_e}\left(1-\frac{1}{P_e}\right)\tilde{u}\,\frac{\partial(\bar{u})^2}{\partial \psi}\right] - \left[\psi \frac{d}{d\chi}(\ell n\ \sigma)\right]\frac{\partial G}{\partial \psi} \qquad (1)$$

$$\frac{\partial Y_k}{\partial \chi} = \frac{\partial}{\partial \psi}\left[\frac{\tilde{u}}{S_e}\frac{\partial Y_k}{\partial \psi}\right] - \left[\psi \frac{d}{d\chi}(\ell n\ \sigma)\right]\frac{\partial Y_k}{\partial \psi} \qquad (2)$$

[k= 1 to 7 in Eq. (2) referring to species O_2, H_2O, N_2, O, H, and OH.]

Explanation of symbols:

Constants in coefficients

P_e - Prandtl number

S_e - Schmidt number

u_e - Reference velocity (ft/sec)

h_e - Reference enthalpy (ft^2/sec^2)

Parameters in coefficients that are dependent on χ , and ψ

$$G = \frac{h}{h_e} \tag{3}$$

$$\tilde{u} = \frac{\bar{u}}{\bar{u}_e} \left\{ \left(\frac{\bar{\epsilon}}{\bar{\gamma}} + 1 \right) - \varphi \frac{d}{d\chi} (\ln \sigma) \left[g(\zeta, \chi) \right] \right\} \tag{4}$$

$$\frac{d}{d\chi} (\ln \sigma) = - \frac{1}{\mu_s} \frac{d}{d\chi} (\mu_s) \, . \tag{5}$$

Equations (1) and (2) are converted to difference form and solved by a tri-diagonal matrix method. (See Section I-B for method of solution.) The species equation [EQ. (2)] is solved first, followed by the energy equation [Eq. (1)]. A two-dimensional grid of lattice points in the (ξ, ψ) plane is constructed as shown in Figure 1.

The properties of these mesh are identified by suitable subscripts and superscript as described below:

Subscript, i - mesh points in ψ direction

k - scans over 7 species

Superscript, n - mesh points in χ direction.

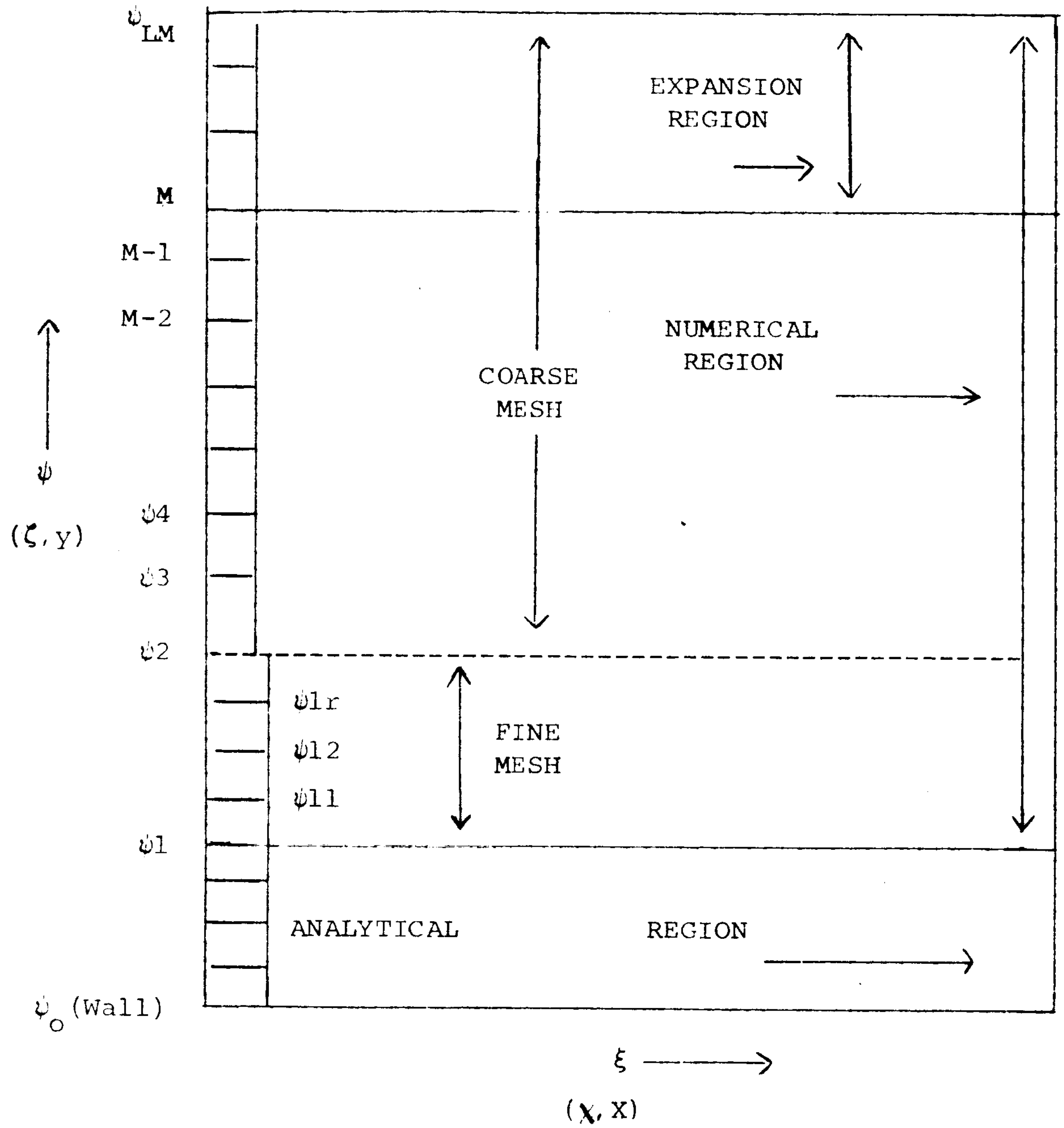

FIG. 1. LATTICE POINTS IN THE (ξ, ψ) PLANE

The difference equations are solved at each horizontal point ξ^n for all vertical points $(\psi_i)^n$ for species, $(Y_k)_i^n$ and the enthalpy ratio G_i^n .

The mesh in the ψ direction (see Figure 1) is divided into several regions. From the wall $\psi = 0$, an analytical region extends to $\psi = \psi_1$ in which species and enthalpy ratios are found from analytical expressions. For the region $\psi_1 \leq \psi \leq \psi_M$, the difference equations are solved using a fine mesh immediately above the analytical region and a coarse mesh in the remainder of the region. The fine mesh size was required to provide the necessary numerical accuracy in the solution of the equations.

There is an expansion region above $\psi = \psi_{LM}$.

1. Equations for Variables Computed in Analytical Region

$$cl = \frac{\sqrt{2\varphi}}{3\Delta\xi} \tag{6}$$

$$\gamma = -\frac{1}{\varphi^2}\left\{\frac{u_e^2}{h_e}\left[1-\frac{1}{P_e}\right]P_e\right\} \tag{7}$$

$$\beta = (cl)\ (P_e)\ \left\{G_o^{\,n+1} - G_o^{\,n}\right\} \tag{8}$$

$$\alpha = \frac{\left[G_1^{\,n+1} - G_o^{\,n+1}\right]}{\sqrt{\psi_1}} - \sqrt{\psi_1}\ (\gamma) \qquad (9)$$

The analytical region, extending from $\psi = 0$ (wall) to ψ_1 may be subdivided into an integral number of ψ steps.

In this interval the enthalpy ratio G_i and species $(Y_k)_i$ are computed from the relations:

$$G_i^{\,n+1} = G_o^{\,n+1} + \sqrt{\psi_1} \left\{ \alpha + \frac{\beta\ (\psi_i - \psi_1)}{1.0 - \left\{\frac{d}{d\chi}\ (\ln\ \sigma)\right\}\ g_i} + \sqrt{\psi_1}\ \gamma \right\} \qquad (10)$$

$$(Y_k)_i^{n+1} = (Y_k)_o^{n+1} + \frac{(c_1)\,(\psi_1)^{3/2}\ S_E \left\{(Y_k)_o^{n+1} - (Y_k)_o^{n}\right\}}{1.0 - \left\{\frac{d}{d\chi}\ (\ln\sigma)\right\}\ g_i} \qquad (11)$$

The mixture temperature, T_i, molecular weights $(WT)_i$, and density ratios, $(RH)_i$, are found from:

$$T_i = T_R + \frac{1}{\sum_k (Y_k)_i\ (CP)_k} \left\{ H_e\ G_i - \sum_k (Y_k)_i\,\Delta_k - \frac{1}{2}\ (\bar{u}_i)^2 \right\} \qquad (12)$$

$$(WT)_i = \frac{1.0}{\sum_k \frac{(Y_k)_i}{M_k}} \qquad (13)$$

$$(RH)_i = \frac{(WT)_i}{(T_i/T_e)\ \sum_k \frac{(Y_k)_e}{M_k}} \qquad (14)$$

H_e - reference stagnation enthalpy (ft^2/sec^2)

T_R - reference temperature for enthalpy curve fits (300°K)

M_k - molecular weight of k^{th} specie

$(CP)_k$ - specific heat at constant pressure of k^{th} specie

$(\Delta)_k$ - reference enthalpy of k^{th} specie

$(Y_k)_e$ - Species reference mass fraction at edge of boundary layer.

The g's in (10) and (11) and the velocities $\bar{u}$ in (12) are computed from the equations of Reference 1, Appendix III. The g's are called $G(\chi \zeta)$ in Reference 1.

The incompressible viscosity "I-VIS" is found from:

$$(I\text{-}VIS)_i = \tilde{u}_i / \bar{u}_i \tag{15}$$

If the compressible viscosities, "C-VIS", are computed (see Sense Switch 1 Option in Section V), they are found using the relation:

$$(C\text{-}VIS)_i = \left\{ \frac{(I\text{-}VIS)_i + \left[\frac{d}{d\chi} (\ell n\ \sigma) \right] g_i}{(C/\bar{\mu})^2} \right\} \left\{ \frac{\bar{\xi}\ (\rho)_o}{(\mu)_o\ (\mu)_i\ (\rho)_i} \right\} \tag{16}$$

The parameter $(C/\bar{\mu})$ is explained in Sections II and III

The viscosity μ is a mixture viscosity computed from the relations:

$$\mu_{O_2} = 2.09 \cdot 10^{-10} \left[\frac{145.8\ (T)^{3/2}}{T + 110.4} \right] \quad ; \text{ T in degree Kelvin}$$

$$\mu_{H_2} = 1.7553 \cdot 10^{-7} \left[\frac{0.1017\,(T)^{3/2}\ (T+650.39)}{(T+19.55)\ (T+1175.9)} \right]$$

$$\mu_{H_2O} = 2.09\cdot 10^{-9} \left[.361\ T - 10.2 \right]$$

$$\mu_{N_2} = \mu_{O_2}$$

$$\mu_{O} = \mu_{O_2}/\sqrt{2}$$

$$\mu_{H} = \mu_{H_2}/\sqrt{2}$$

$$\mu_{OH} = \mu_{H_2O}$$

$$\varphi_{mj} = \frac{\left[1 + \left(\frac{\mu_m}{\mu_j}\right)^{1/2} \left(\frac{M_j}{M_m}\right)^{1/4} \right]^2}{\sqrt{2}\left(1 + \frac{M_m}{M_j}\right)^{1/2}} \tag{17}$$

$$\mu_i = \sum_{m=1}^{7} \frac{\mu_m \ Y_m}{Y_m + M_m \sum_{\substack{j \\ j\neq m}}^{7} \frac{Y_j}{M_j} \varphi_{mj}}$$

$$\tilde{\xi} = \frac{\left(\frac{\mu_o}{\mu_s}\right)^2}{1.0 - \varphi^3 \tilde{\theta} \frac{d}{d\chi} (\ln \sigma)} \tag{18}$$

where $\tilde{\theta} = \int_0^\infty \frac{\bar{u}}{\bar{U}_e} \left(1 - \frac{\bar{u}}{\bar{U}_e}\right) d\zeta$

and $\phi = U_e/U_\tau$ [see Ref. 1, Eq. (31)]. The subscript s refers to edge of sublayer, explained later.

2. Difference Equations Used for Numberical Solutions

(a) Generic Form of Difference Equations

The form of the generalized difference equation used to compute species concentrations and energy in the region, $\psi_1 < \psi < \psi_{LM}$, is presented in part B of this section and is of the form

$$a\ P_{i-1} + b\ P_i + c\ P_{i+1} = d. \tag{19}$$

The coefficients of these equations are computed and then the resulting set of linear simultaneous equations are solved, first for species and then for the enthalpy ratio. The incompressible eddy viscosities, $\tilde{u}_i$, are corrected at each ψ point for compressibility:

$$\tilde{u}_{COMP} = \tilde{u}_{incomp} - \bar{u}\left[\frac{d}{d\chi}\ (\ln\ \sigma)\right] \quad (g) \tag{20}$$

These compressible $\tilde{u}$'s are used in the computation of the a, b, c coefficients in the generic difference Eq. (19) and will be referred to as $\tilde{u}$ with no subscript. For the species conservation Equations the P_i in the difference Equation (19) represents $(Y_k)_i$, and the coefficients are

$$\lambda_Y = \frac{S_e (\Delta\psi)^2}{\Delta\chi} \tag{21}$$

$$a_i = \tilde{u}^{n+1}_{i-\frac{1}{2}} + S_e \, (\Delta \psi)(\psi)_i \frac{d}{d\chi} (\ln \sigma) \tag{22}$$

$$b_i = - \left[\lambda_Y + \tilde{u}^{n+1}_{i+\frac{1}{2}} + \tilde{u}^{n+1}_{i-\frac{1}{2}} \right] \tag{23}$$

$$c_i = \tilde{u}^{n+1}_{i+\frac{1}{2}} - S_e \, (\Delta \psi)(\psi)_i \frac{d}{d\chi} (\ln \sigma) \tag{24}$$

$$(d_k)_i = - \lambda_Y (Y_k)^n_i \tag{25}$$

In the fine mesh region (Figure 1) the above relations are used from i = 11 to i = 1r with $\Delta \psi$ being the fine ψ interval. ψ_{11} is the first fine mesh point above ψ_1 and ψ_{1r} is the last fine mesh point below ψ_2.

In the coarse mesh region, the above relations are used from i = 3 to i = M with $\Delta \psi$ being the coarse ψ interval. For ψ_2,

$$\lambda_{Y_2} = \frac{S_e (\Delta \psi)^2}{2 \Delta \chi} \left(1.0 + \frac{1.0}{B} \right) \tag{26}$$

B is the total number of fine mesh intervals. Equations (22) through (25) become:

$$a_2 = B \, \tilde{u}^{n+1}_{2-\frac{1}{2}} + \frac{S_e}{2} \, (\Delta \psi)_c \, \psi_2 \frac{d}{d\chi} (\ln \sigma) \tag{27}$$

$$b_2 = - \left[\lambda_{Y_2} + \tilde{u}^{n+1}_{2+\frac{1}{2}} + B \, \tilde{u}^{n+1}_{2-\frac{1}{2}} \right. \tag{28}$$

$$c_2 = \tilde{u}^{n+1}_{2+\frac{1}{2}} - \frac{S_e}{2} \, (\Delta \psi)_c \, \psi_2 \frac{d}{d\chi} (\ln \sigma) \tag{29}$$

$$(d_{k_2}) = - \lambda_{Y_2} \, (Y_k)^n_2 \tag{30}$$

For the generic form of the enthalpy ratio difference equations, relations (21) through (24) and (26) through (29) are used with the Schmidt number "S_e" replaced by the Prandtl number "P_e".

Relation (25) for the right-hand side of (19) is replaced by:

$$d_i = - [\lambda_e (G)_i^n + (R)_i - (R)_{i-1}] \tag{31}$$

where

$$R_i = \left[P_e \frac{u_e^2}{2h_e} \left(1 - \frac{1}{P_e} \right) \tilde{u}_{i+\frac{1}{2}} \left(\bar{u}_{i+2}^2 - \bar{u}_{i+1}^2 \right) \right] \tag{32}$$

is an approximation to the term involving

$\frac{\partial}{\partial \psi} \left[\frac{u_e^2}{2h_e} \left(1 - \frac{1}{P_e} \right) \tilde{u} \frac{\partial (\bar{u})^2}{\partial \psi} \right]$ in energy Eq. (1). For the λ_e in Equation (31)

$$\lambda_e = \frac{P_e (\Delta \psi)^2}{\Delta \chi} \tag{33}$$

where the appropriate $\Delta \psi$ is used depending on coarse or fine mesh region. For i = 2, Equation (31) is used for d_2 with λ_e replaced by

$$\lambda_{e_2} = \frac{P_e (\Delta \psi)^2}{2(\Delta \chi)} \left(1.0 + \frac{1.0}{B} \right) \tag{34}$$

where B is the number of fine mesh intervals.

(b) Boundary Conditions for Difference Equations at $\psi = \psi_1$

At $\psi = \psi_1$ the generic forms of the species and energy equations are replaced by special analytical relations. For the species equation, these are:

$$a_{1s} = 0 \tag{35}$$

$$b_{1s} = \frac{\psi_1 + (\Delta\psi)_F}{2(\Delta\xi)} + \frac{u_3/_2}{(\Delta\psi)_F S_e} \tag{36}$$

$$+ \frac{1}{A}\left\{\frac{\psi_1}{2(\Delta\xi)} + \left[\frac{\psi_1 + (\Delta\psi)_F}{2}\right]\left[\frac{d}{d\chi}(\ell n\ \sigma)\right]\left[1.5(A-1)\right]\right\}$$

$$c_{1s} = -\frac{u_3{}^{n+1}/_2}{S_e(\Delta\psi)_F} \tag{37}$$

$$(d_k)_{1s} = \left[\frac{\psi_1 + (\Delta\psi)_F}{2(\Delta\xi)}\right](Y_k)_1^n + \left[\frac{\psi_1 + (\Delta\psi)_F}{2}\right][A-1.0](Y_k)_o^n$$

$$+ \frac{1}{A}\left\{\frac{3\left[1 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1\right]}{S_e\ (2\psi_1)^{1/2}\sigma[\psi_1 + (\Delta\psi)_F]}\right\} \tag{38}$$

where $(\Delta\psi)_F$ is the fine mesh interval and

$$A = 1.0 + \frac{S_e\sqrt{2}\,\sigma(\psi_1)^{3/2}}{[3(\Delta\xi)]\left[1.0 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1\right]} \tag{39}$$

After solution of the species equations for the range of ψ from ψ_1 to ψ_{LM}, the species and enthalpy values at the wall are calculated using the following two relations:

$$(Y_o^{n+1})_k = \frac{1}{A}\left[Y_1^{n+1} + (A-1.0)Y_o^n\right]_k \tag{40a}$$

$$G_o^{n+1} = T_o^{n+1} - T_R + \frac{1}{H_e}\left[\sum_k (Y_k)_o^{n+1} (\Delta)_k \sum_k (Y_k)^{n+1} (CP)_k\right] \tag{40b}$$

The energy equation is then solved for the values, G_i, with the following boundary conditions at $\psi = \psi_1$:

$$a_{1e} = 0 \tag{41}$$

$$b_{1e} = \frac{\psi_1 + (\Delta \psi)_F}{2(\Delta \xi)} + \frac{\tilde{u}_2^{n+1}/2}{(\Delta \psi)_F P_e} + \frac{1 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1}{P_e \sqrt{2\psi_1}\ \varphi} + \left[\frac{d}{d\chi}(\ell n\ \sigma)\right]\left[\frac{\psi_1 + (\Delta \psi)_F}{4\sqrt{2}}\right] \tag{42}$$

$$c_{1e} = -\frac{\tilde{u}_2/2}{P_e(\Delta \psi)_F} \tag{43}$$

$$\begin{aligned} d_{1e} = {} & \left[\frac{\psi_1 + (\Delta \psi)_F}{2(\Delta \xi)} G_1^n + \frac{-\psi_1}{6(\Delta \xi)} + \frac{1 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1}{P_e\sqrt{2\psi_1}\ \varphi}\right] G_o^{n+1} \\ & \left[+\frac{\psi_1}{6(\Delta \xi)}\right] G_o^n \\ & + \frac{1}{2}\frac{u_e^2}{h_e}\left[1 - \frac{1}{P_e}\right]\frac{\tilde{u}_5^{n+1}/2}{(\Delta \psi)_F}\left[\bar{u}_2^2 - \left(\frac{\sqrt{2\psi_1}}{\varphi}\right)^2 - \frac{\sqrt{2\psi_1}}{\varphi^2}\left(1 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1\right)\right] \\ & - \left[\frac{d}{d\chi}(\ell n\ \sigma)\right]\left[\frac{\psi_1 + (\Delta \psi)_F}{2}\right]\Bigg\{-\frac{G_o^{n+1}}{2\sqrt{2}} - \frac{\left(1 - \frac{1}{\sqrt{2}}\right) u_e^2 \left(1 - \frac{1}{P_e}\right) 2P_e(\psi_1)^{3/2}}{(2h_e)\ 6(\Delta \xi)\left(1 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1\right)} \\ & + \left[\frac{\sqrt{2}\,\varphi(\psi_1)^{3/2}\ P_e}{6(\Delta \xi)\left(1 - \frac{d}{d\chi}(\ell n\ \sigma)\cdot g_1\right)}\right]\left[G_o^{n+1} - G_o^n\right]\Bigg\} \end{aligned} \tag{44}$$

3. <u>Treatment of Psi Expansion Region</u>

To ensure that the solutions satisfy the boundary conditions at the edge, an expansion region is included in the ψ direction.

Before solution of the species equations at the current step, those solutions obtained at $\psi = \psi_{LM}$ for the previous step, are compared with $(Y_k)_e$, which are input. If these comparisons differ by more than a specified tolerance, called EPS, for any one of the species, the values $(Y_k)_e$ are prescribed at an additional ψ point which is added to the mesh (LM is increased by one). The convergence test is:

$$\text{Is} \left| \frac{(Y_k)_{LM} - (Y_k)_e}{(Y_k)_e} \right| \leq \text{EPS ?} \tag{45}$$

NO - add 1 point to mesh
YES- do not add a point to mesh.

A similar test is performed on the energy equation solution. The test is as follows:

$$\text{Is} \left| \dot{G}_{LM} - 1.0 \right| \leq \text{EPS?} \tag{46}$$

NO - add 1 point to mesh
YES- do not add a point to mesh.

At all points in the expansion region, the $\tilde{u}$ and $\bar{u}$ viscosity parameters are set equal to the values of $\tilde{u}$ and $\bar{u}$ at $\psi = \psi_M$. The compressibility correction on $\tilde{u}$ is not applied in this region.

4. Equations for Parameters Computed after Solution of Difference Equations

Upon obtaining the solutions to the species and energy equations in the numerical region the main program computes mixture temperature ratios, T_i/T_e, molecular weights, $(WT)_i$, density ratios, $(RH)_i$, and incompressible viscosities, $(I\text{-}VIS)_i$, using Equations (12) through (15). If desired, compressible viscosities are obtained, using (16). These parameters are printed as output.

The program then computes a value of $\frac{d}{d\chi}(\ln \sigma)$ to be used for the next step in the χ direction. The methods used distinguish the substructure, reference, and sublayer versions and will be detailed in Sections II and III.

Having obtained $\frac{d}{d\chi}(\ln \sigma)$, the physical coordinate "X" may be found from the coordinate χ using

$$X - X_{in.} = \frac{\mu_o}{\rho_o u_e} \int_{\chi_{in.}}^{\chi} \frac{1 - \varphi^3 \tilde{\theta} \frac{d}{d\chi}(\ln \sigma)}{\left(\frac{\sigma}{\bar{\mu}} \mu_o\right)^2} d\tilde{\chi} \qquad (47)$$

where $X_{in.}$ is the initial value of X, and $\chi_{in.}$ is the corresponding value of χ.

Other quantities computed and printed are the heat transfer $\dot{q}$, and the skin friction coefficient CF, which are defined by the following relationships:

$$\dot{q} = - \frac{.001285 \, \mu_o \frac{\sigma}{\bar{\mu}} \, \rho_o u_e h_e \alpha}{\sqrt{2} \, \varphi \, P_e} \qquad (48)$$

$$CF = \frac{2.0 \, \mu_o \left(\frac{\sigma}{\bar{\mu}}\right) T_e}{\varphi^2 \, T_o} \qquad (49)$$

The units of $\dot{q}$ are $\frac{BTU}{ft^2\text{-sec}}$.

B. Numerical Methods of Solution of Basic Equations

Partial differential Eqs. (1) and (2) are solved by an implicit second-order central difference method known as the Crank-Nicholson Difference Equation.

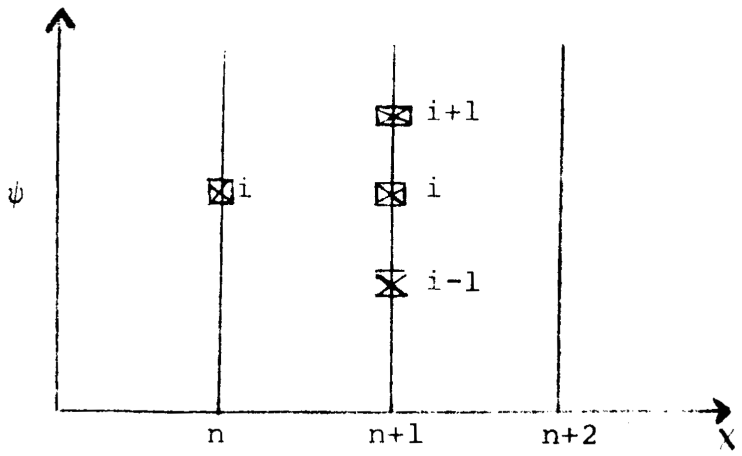

FIGURE 2. CRANK-NICHOLSON LATTICE POINTS

Assuming a two-dimensional mesh of lattice points with "n" representing the horizontal or χ direction and "i" representing the vertical, or ψ direction, we solve the equation

$$\frac{\partial P}{\partial \chi} = \frac{\partial}{\partial \psi} \left[\tilde{\bar{u}} \, (\chi, \psi) \, \frac{\partial P}{\partial \psi} \right] \tag{52}$$

at a point (n+1), i, assuming known values of P at point n for all values of i. Replace the right side of (52) by a linear relation for the derivative $\frac{\partial [P]}{\partial \psi}$ from $i-\frac{1}{2}$ to $i+\frac{1}{2}$:

$$\frac{\partial P}{\partial \chi} = \frac{\left(\tilde{u}\,\frac{\partial P}{\partial \psi}\right)^{n+1}_{i+\frac{1}{2}} - \tilde{u}\left(\frac{\partial P}{\partial \psi}\right)^{n+1}_{i-\frac{1}{2}}}{\Delta\,\psi_i} \tag{53}$$

Each term in the numerator of (53) is approximated in the same manner.

$$\left(\tilde{u}\frac{\partial P}{\partial \psi}\right)^{n+1}_{i+\frac{1}{2}} = \tilde{u}^{\,n+1}_{i+\frac{1}{2}}\left[\frac{P_{i+1}-P_i}{\Delta\,\psi_i}\right]^{n+1} \tag{54}$$

$$\left(\tilde{u}\,\frac{\partial P}{\partial \psi}\right)^{n+1}_{i-\frac{1}{2}} = \tilde{u}^{\,n+1}_{i-\frac{1}{2}}\left[\frac{P_i-P_{i-1}}{\Delta\,\psi_i}\right]^{n+1} \tag{55}$$

The left side of (2) is

$$\frac{\partial P}{\partial \chi} = \frac{P_i^{n+1}-P_i^{n}}{\Delta\,\chi}\ . \tag{56}$$

Inserting (54)-(56) into (53)

$$\frac{P_i^{n+1}-P_i^{n}}{\Delta\,\chi} = \frac{1}{(\Delta\,\psi)^2_i}\left[\tilde{u}_{i+\frac{1}{2}}\,(P_{i+1}-P_i) - \tilde{u}_{i-\frac{1}{2}}\,(P_i-P_{i-1})\right]^{n+1} \tag{57}$$

Multiplying both sides of (57) by $(\Delta\,\psi^2)$ and rearranging terms, the difference Equation becomes:

$$\tilde{u}_{i-\frac{1}{2}} P_{i-1}^{n+1} - \left[\frac{(\Delta \psi)_i^2}{\Delta \chi} + \tilde{u}_{i+\frac{1}{2}} + \tilde{u}_{i-\frac{1}{2}} \right] P_i^{n+1} + \tilde{u}_{i+\frac{1}{2}} P_{i+1}^{n+1} = - \frac{(\Delta \psi)_i^2}{\Delta \chi} P_i^n \ . \quad (58)$$

Let

$$a_i = \tilde{u}_{i-\frac{1}{2}}$$

$$b_i = -\left[\frac{(\Delta \psi)_i^2}{\Delta \chi} + \tilde{u}_{i+\frac{1}{2}} + \tilde{u}_{i-\frac{1}{2}} \right]$$

$$c_i = \tilde{u}_{i+\frac{1}{2}}$$

$$d_i = - \frac{(\Delta \psi)_i^2}{\Delta \chi} P_i^n \ .$$

Then (58) may be written in theform,

$$a_i P_{i-1}^{n+1} + b_i P_i^{n+1} + c_i P_{i+1}^{n+1} = d_i \ . \quad (59)$$

Since all P_i for a particular mesh line, n+1, are solved simultaneously for i=1 to ℓ, then we have a set of ℓ equations of type (59) for the unknown P_i's.

$$\left.\begin{array}{r} b_1 P_1 + c_1 P_2 = d_1 \\ a_2 P_1 + b_2 P_2 + c_2 P_3 = d_2 \\ a_3 P_2 + b_3 P_3 + c_3 P_4 = d_3 \end{array}\right\} \quad (60)$$

$$a_\ell P_{\ell-1} + b_\ell P_\ell = d_\ell$$

written in matrix form as

$$\begin{bmatrix} b_1 & c_1 & 0 & 0 & 0 & 0 & 0 \\ a_2 & b_2 & c_2 & 0 & 0 & 0 & 0 \\ 0 & a_3 & b_3 & c_3 & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & 0 & a_\ell & b_\ell \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \cdot \\ P_\ell \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ \cdot \\ d_\ell \end{bmatrix} \tag{61}$$

$$\text{as} \qquad A\ P = D \tag{62}$$

To solve for the unknown P's, the coefficient matrix (called A) is factored into a product of two matrices as follows:

$$\lfloor M\ N \rfloor\ P = D \tag{63}$$

$$M = \begin{bmatrix} \beta_1 & 0 & 0 & 0 & 0 \\ \alpha_2 & \beta_2 & 0 & 0 & 0 \\ 0 & \alpha_3 & \beta_3 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ & & & \alpha_\ell & \beta_\ell \end{bmatrix} \tag{64}$$

$$N = \begin{bmatrix} 1 & \gamma_1 & 0 & 0 & 0 & . \\ 0 & 1 & \gamma_2 & 0 & 0 & . \\ 0 & 0 & 1 & \gamma_3 & 0 & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ & & & & 1 & \gamma_{\ell-1} \\ & & & & & 1 \end{bmatrix} \tag{65}$$

The α, β, and γ values of M and N can be evaluated by multiplying M and N and setting the elements of this product matrix equal to the corresponding elements of A. When this is done it is found that

$$\left.\begin{aligned} \alpha_i &= a_i \\ \beta_i &= b_i - \left[\frac{c_{i-1}}{\beta_{i-1}}\right] a_i \\ \gamma_i &= \frac{c_i}{\beta_i} \end{aligned}\right\} i = 2, \ell \tag{66}$$

and

$\alpha_1 = a_1 = 0$, $\beta_1 = b_1$, $\gamma_1 = c_1/b_1$

In (63) let $Y = NP$,
Then since M is a bi-diagonal known matrix the transformed unknown column matrix Y can be solved recursively from $j = 1$ to ℓ, as follows:

$$
\begin{bmatrix}
\beta_1 & 0 & 0 & 0 & 0 \\
\alpha_2 & \beta_2 & 0 & 0 & 0 \\
0 & \alpha_3 & \beta_3 & 0 & 0 \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
 & & & \alpha_\ell & \beta_\ell
\end{bmatrix}
\begin{bmatrix}
y_1 \\ y_2 \\ y_3 \\ \cdot \\ \cdot \\ y_\ell
\end{bmatrix}
=
\begin{bmatrix}
d_1 \\ d_2 \\ d_3 \\ \cdot \\ \cdot \\ d_\ell
\end{bmatrix}
$$

$$
\begin{aligned}
y_1 &= d_1/\beta_1 \\
y_2 &= (d_2-\alpha_2 y_1)/\beta_2 \\
y_\ell &= (d_\ell - y_{\ell-1})/\beta_\ell
\end{aligned}
\tag{67}
$$

At this point, a boundary condition is imposed and y_ℓ is modified such that

$$
(y_\ell)' = \frac{y_\ell}{1+\frac{c_\ell}{\beta_\ell}} \tag{68}
$$

where $c_\ell = \tilde{u}_e$.

The solutions P_i may now be calculated from y_i by sweeping backward from ℓ to 1

$$\begin{bmatrix} 1 & \gamma_1 & 0 & 0 & 0 & \\ 0 & 1 & \gamma_2 & 0 & 0 & \\ \cdot & \cdot & \cdot & \cdot & \cdot & \\ \cdot & \cdot & \cdot & \cdot & \cdot & \\ 0 & 0 & 0 & 0 & 1 & \gamma_{\ell-1} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ \cdot \\ \cdot \\ \cdot \\ P_\ell \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y'_\ell \end{bmatrix} \tag{69}$$

Then,

$$P_\ell = Y'_\ell$$

$$P_i = Y_i - \gamma_i \; P_i + 1,$$

$$i = \ell - 1, \; \ell - 2, \; \ldots\ldots\ldots 1$$

II. SUBSTRUCTURE AND REFERENCE HYPOTHESES

A. Calculation of $d/d\chi(\ln \sigma)$

Integrals are computed over the variable ζ (which is a transformed ψ coordinate) for temperature T, species Y_k, and normal coordinate "YCORD". These integrals are:

$$T_s = \frac{1}{430} \int_o^{430} T \, d\zeta \qquad (70)$$

$$(Y_k)_s = \frac{1}{430} \int_o^{430} Y_k \, d\zeta \qquad (71)$$

where subscript s denotes some mean value across the layer. As proposed by Coles, the substructure hypothesis is

$$\frac{\sigma}{\bar{\mu}} = \frac{1}{\mu_s} \qquad (72)$$

where μ_s is the mean value of viscosity in the region $o \leq \zeta \leq 430$ and $\bar{\mu}$ is the incompressible viscosity independent of the variable χ. (See pp. 16,17 of Ref. 1 for explanation of numerical value 430 in Eqs. 70 and 71).

The normal y-coordinate is obtained using:

$$\text{YCORD} = \frac{\varphi}{\left(\frac{\sigma}{\bar{\mu}}\right) \rho_e \mu_e} \int_o^{\zeta} \left(\frac{\rho_e}{\rho}\right) d\zeta \qquad (73)$$

The computing scheme is then as follows: The finite difference equations have been solved for the properties at χ^{n+1} using the value of $\frac{d}{d\chi}$ $(\ln \sigma)$ at χ^n. (For the first step, $\frac{d}{d\chi}$ $(\ln \sigma)$ is an input value to the program.) Having now the value of μ_s^{n+1} from Eq. (17), the value $\frac{d}{d\chi}$ ($\ln \sigma$) to be used for the step χ^{n+1} to χ^{n+2} is:

$$\frac{d}{d\chi} (\ln \sigma) = - \frac{1}{\mu_s^n} \frac{\mu_s^{n+1} - \mu_s^n}{\chi^{n+1} - \chi^n} \tag{74}$$

The value of μ_s for n = 0 is computed from Eq. (17) using the input temperature and species profiles.

$\frac{d}{d\chi}$ ($\ln \sigma$) thus lags the remainder of the solution by one step. However, it is believed that this does not cause significant errors.

Referring to Fig. 1 of Section I, the fine mesh region for the substructure hypothesis extends over the interval (ψ_1, ψ_2). The ψ step size between ψ_1 and ψ_2 is

$$(\Delta \psi)_F = \frac{\psi_2 - \psi_1}{K} \tag{75}$$

where K is an input number to the program.

The integrals over the logarithmic region [Eqs. (70) and (71)] are found by trapezoidal quadrature over the values of ζ used in the finite difference mesh. Temperature and species values for the upper limit ζ_s = 430 are found by linear interpolation.

Since the definition of ζ changes at ζ = 10.6 (see Appendix III, Ref. 1), a special approximation scheme was used for the ζ interval bracketing 10.6. This interval was split into two intervals namely, ζ_1 to 10.6, and 10.6 to ζ_2 where ζ_1 and ζ_2 are the mesh values of ζ that bracket ζ = 10.6 (see Fig. 3).

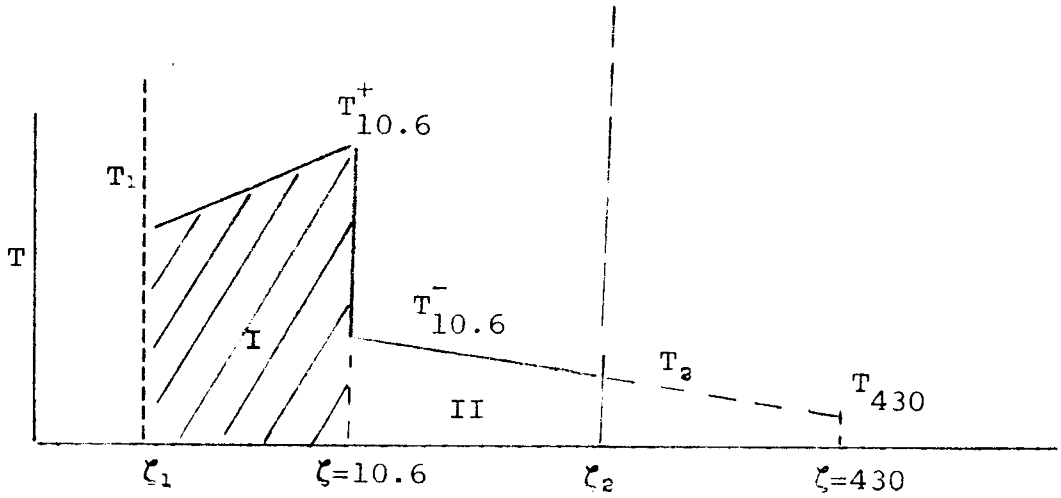

FIG. 3. QUADRATURE DIAGRAM AT ζ = 10.6

A step drop in temperature is imposed at $\zeta = 10.6$, yielding two temperature values, denoted $T^+_{10.6}$ and $T^-_{10.6}$. Two trapezoidal integrations are then performed, the first from T_1 to $T^+_{10.6}$, the second from $T^-_{10.6}$ to T_2. (See Shaded areas I and II in Fig. 3.)

The values of $T^+_{10.6}$ and $T^-_{10.6}$ are obtained as follows:

$$T^+_{10.6} = A + B\ \beta + C\ \beta^2 \tag{76}$$

where

$$\beta = \varphi/10.6 \tag{77}$$

$$A = T_o \tag{78}$$

$$C = \frac{\left[\dfrac{T_1}{\bar{u}_2} - \dfrac{T_2}{\bar{u}_2} + T_o\left\{\dfrac{1}{\bar{u}_2} - \dfrac{1}{\bar{u}_1}\right\}\right]}{\bar{u}_1 - \bar{u}_2} \tag{79}$$

$$B = \frac{T_2 - T_o}{\bar{u}_2} - C\,\bar{u}_2\ . \tag{80}$$

The value of $\bar{T}_{10.6}$ is found from a backward linear extrapolation of the temperature T_2 and T_{430}, where T_{430} is the temperature previously found by interpolation at $\zeta = 430$.

B. Modification of Grid Mesh in Normal Direction

The number of grid mesh points in the normal or ψ direction is determined by the value of ψ_M, or upper limit of ψ in the coarse mesh region (see Section I). The initial value of ψ_M is known and a ψ spacing of ψ_M/N is input as $(\Delta\psi)_C$. As calculation proceeds in ξ direction ψ_M increases and additional mesh points are added with the spacing $(\Delta\psi)_C$. When the total number of these points reaches 2M, the program automatically doubles $(\Delta\psi)_C$ and halves the number of points, keeping solution values at every alternate point of the original $\Delta\psi$.

For the fine mesh region, whose interval is also doubled, alternate points are kept for the lower half of the new region. Points for the upper half of the new fine mesh region are linearly interpolated (See Fig. 4.)

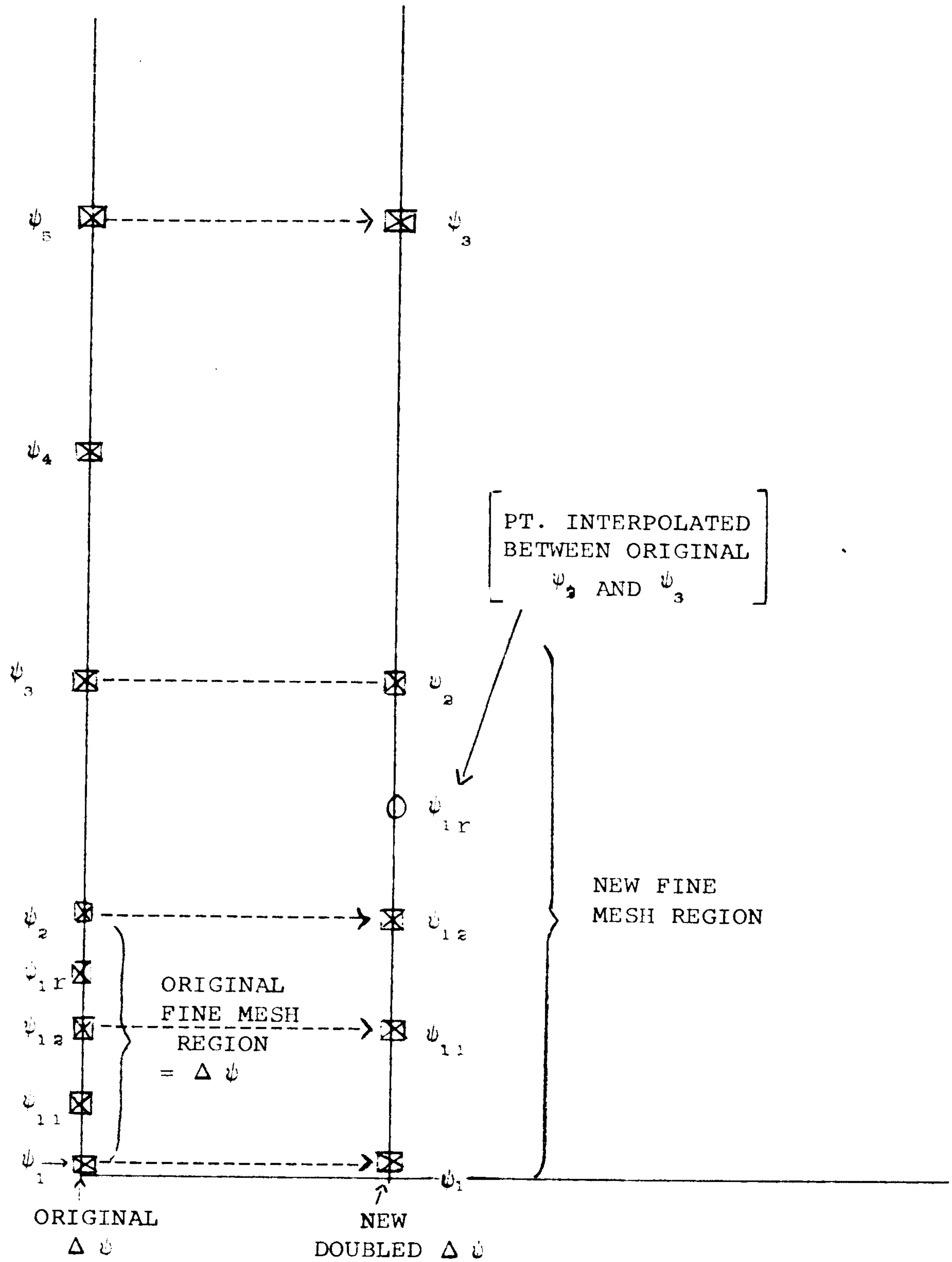

FIG. 4. DOUBLING OF $\Delta\psi$ GRID FOR SUBSTRUCTURE HYPOTHESIS

C. Finite Rate Chemistry Option

An option has been provided in the program whereby the one-dimensional finite rate kinetics and associated calculation technique is that due to G. Moretti (Refs. 2 and 3). The chemical system is comprised of the seven species H_2, O_2, H_2O, N_2, O, H, and OH where N_2 is considered an inert diluent. Using this option, the terms containing the species mass fractions are modified to reflect the coupling of the one-dimensional finite-rate chemistry relations, with the two-dimensional diffusion equations. However, since the correct time step for the chemistry equations is not known until the diffusion equations are solved, a time step iteration is required.

The iteration procedure is as follows:

(1) An approximate ΔX is computed from the previous temperature and species profiles:

$$(\Delta X)^{(1)} = \left[\frac{\mu_o}{\rho_o \mu_e}\right] \left[\frac{1-\sigma^3 \tilde{\theta} \dfrac{d}{d\chi}(\ell n\ \sigma)}{\left(\dfrac{\sigma}{\bar{\mu}}\right)_o^2}\right] (\Delta \chi) \qquad (81)$$

$$(\Delta t)_i^{(1)} = \frac{(\Delta X)^{(1)}}{(\rho_e u_e / \mu_e)\bar{u}_i} \qquad (82)$$

(2) A finite rate chemistry step is performed at each mesh point, ψ_i, on the species mass fractions, using the corresponding temperature and density profiles and the "Δt" profile computed from Eq. 82.

(3) The diffusion equations are then solved using the chemically modified species profiles.

(4) New values of $\frac{d}{d\chi}$ ($\ell n\ \sigma$) and $c/\bar{\mu}$ are computed, and then $(\Delta X)^{(2)}$ found, using (81).

(5) $(\Delta X)^{(2)}$ is compared to $(\Delta X)^{(1)}$. If they are within the specified tolerance, the species and energy solutions are printed as the correct solutions. If the tolerance is not met, steps 2-5 are repeated with the new value of (Δt). Note that in this case the new value of $\frac{d}{d\chi}$ ($\ell n\ \sigma$) from step (4) is not used in the left side matrices of the diffusion equations for the next iteration. It is only used to get a new (Δt) approximation for the chemistry calculation.

Finite rate chemistry reactions are computed at all ψ points. At the wall, a time step is used that is equal to the time step computed at the ψ value closest to the wall. See Eq. (82) for definition of the time step $(\Delta t)_i$.

D. Reference Method Option

When the reference method option is exercised, $\frac{d}{d\chi}$ ($\ell n\ \sigma$) is set equal to zero. The reference state is still given by the mean substructure values, i.e., T_s, $(Y_k)_s$, μ_s, $\sigma/\bar{\mu}$, and YCORD using relations (70), (71), (17), (72), and (73) respectively.

III. SUBLAYER HYPOTHESIS

A. Calculation of $d(\ln \sigma)/d\chi$

The sublayer assumption, proposed by Baronti and Libby, asserts that the Reynolds number based on the height of the laminar sublayer is an invariant of the compressibility transformation (see Reference 4). Instead of relation (72) for $\sigma/\bar{\mu}$, one uses the following:

$$\frac{\sigma}{\bar{\mu}} = \frac{1}{10.6}\int_0^{56.18} \frac{\rho_s}{\rho} \frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}} \tag{83}$$

and

$$\frac{d}{d\chi}(\ln \sigma) = \frac{\dfrac{\mu_s}{10.6}\displaystyle\int_0^{56.18} \frac{d}{d\chi}\left(\frac{\rho_s}{\rho}\right)\frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}} - \frac{d}{d\chi}(\mu_s)\,\frac{1}{10.6}\displaystyle\int_0^{56.18} \frac{\rho_s}{\rho}\frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}}}{\mu_s} \tag{84}$$

where

$$\frac{d}{d\chi}\frac{\rho_s}{\rho} = \frac{\rho_s}{\rho_e}\left[\frac{d}{d\chi}\left(\frac{\rho_e}{\rho}\right) - \frac{\rho_s}{\rho}\frac{d}{d\chi}\left(\frac{\rho_e}{\rho_s}\right)\right] \tag{85}$$

$$\frac{d}{d\chi}\left(\frac{\rho_e}{\rho}\right) = \frac{\partial}{\partial T}\left(\frac{\rho_e}{\rho}\right)\frac{dT}{d\chi} + \sum_k \frac{\partial}{\partial Y_k}\left(\frac{\rho_e}{\rho}\right)\frac{dY_k}{d\chi} \tag{86}$$

$$\frac{d}{d\chi}\left(\frac{\rho_e}{\rho_s}\right) = \frac{\partial}{\partial T}\left(\frac{\rho_e}{\rho_s}\right)\frac{dT}{d\chi} + \sum_k \frac{\partial}{\partial Y_k}\left(\frac{\rho_e}{\rho_s}\right)\frac{dY_k}{d\chi} \tag{87}$$

$$\frac{\partial}{\partial T}\left(\frac{\rho_e}{\rho_s}\right) = \frac{1}{T_s}\,\frac{\sum_k (Y_k/M_k)_s}{\sum_k (Y_k/M_k)_e} \tag{88}$$

$$\frac{\partial}{\partial Y_k}\left(\frac{\rho_e}{\rho_s}\right) = \frac{T_s}{T_e}\,\frac{1}{(M_k)_s}\,\frac{1}{\sum_k (Y_k/M_k)_s} \tag{89}$$

The derivatives $\frac{d}{d\chi}(\mu_s)$, $dT/d\chi$ and $dY_k/d\chi$ are evaluated numerically as:

$$\frac{d}{d\chi}(\mu_s) = \frac{(\mu_s)^{n+1} - (\mu_s)^n}{\chi^{n+1} - \chi^n} \tag{90}$$

$$\frac{dT}{d\chi} = \frac{(T)^{n+1} - (T)^n}{\chi^{n+1} - \chi^n} \tag{91}$$

$$\frac{dY_k}{d\chi} = \left[\frac{(Y_k)^{n+1} - (Y_k)^n}{\chi^{n+1} - \chi^n}\right]_i \tag{92}$$

In relations (84) to (92), the subscript s refers to parameters evaluated at $\psi = 56.18$.

The sublayer hypothesis applies to the fine and coarse mesh ψ regions, just as the substructure hypothesis does. However, the fine mesh region now extends from ψ_1 to $\psi = 56.18$ and can be divided into a prescribed number of intervals.

The normal y-coordinate is still computed from relation (73). As in the substructure hypothesis, calculation of $d/d\chi$ ($\ell n\ \sigma$) lags the remainder of the solution by one step.

B. <u>Modification of Grid Mesh in Normal Direction</u>

When the criterion for halving the number of intervals in the ψ direction is met (see paragraph 1, Section II, B), the fine mesh region is undisturbed for $0 \leq \psi \leq 56.18$).

For the coarse ψ mesh region, $56.18 < \psi \leq \psi_{LM}$, every other mesh point of the original solution is retained.

C. <u>Finite Rate Chemistry Option</u>

The finite rate chemistry option is identical to the option discussed in Section II C for the substructure and reference hypothesis.

IV. REFERENCE HYPOTHESIS WITH EQUILIBRIUM CHEMISTRY

The two partial differential diffusion equations (1) and (2) are solved for the dependent variables stagnation enthalpy "G" and element mass fraction Y_k (k = 1-3). The three elements are O_2, N_2 and H_2. The reference method is used in these solutions, i.e., $d(\ell n\ \sigma)/d\chi$ is set equal to zero.

The element equation (2) is solved first for $\psi_1 \leq \psi \leq \psi_{LM}$, using the boundary condition at ψ_1 described in Eqs. 35-39. However, the wall enthalpy required for the boundary condition at ψ_1 for solution of the enthalpy Eq. (1) is not found from Equation 40b. **Instead**, it is obtained from an equilibrium chemistry computation which requires the following input data:

(1) Element mass fractions from

$$(\tilde{Y}_k)_o^{n+1} = \frac{1}{A}\left[(\tilde{Y}_k)_o^{n+1} + (A-1)(\tilde{Y}_k)_o^{n}\right] \qquad (93)$$

where A is evaluated using Eq. 39

(2) Wall pressure found from

$$P = 5951\ \rho_e\ T_e \sum_k \frac{(Y_k)_e}{M_k} \qquad (94)$$

The pressure P is assumed constant at this value for all points in the boundary layer for all species k for all values of "χ".

(3) Wall temperature T_o^{n+1} .

Using these inputs, the equilibrium program provides wall species mass fractions $(Y_k)_o^{n+1}$ in addition to the enthalpy $(G_o)^{n+1}$. Enthalpy equation (1) may now be solved for $\psi_1 \leq \psi \leq \psi_{LM}$ using boundary condition relations (41)-(44).

Equilibrium chemistry computations are then performed, using as inputs the stagnation enthalpy solutions from Eq. (1), G_i^{n+1} , the element mass fraction solutions of Eq. (2) $(\tilde{Y}_k)_i^{n+1}$, and the constant pressure P from Eq. (94) for boundary layer points $\psi_1 \leq \psi \leq \psi_{LM}$. The chemistry calculations now give species mass fractions $(Y_k)_i$ and mixture temperatures (T_i) for points $\psi_1 \leq \psi \leq \psi_{LM}$. References 2 and 3 describe the technique used in the chemistry program.

Mixture molecular weights, densities and viscosities computed from relations (12)-(17) using the species mass fractions $(Y_k)_i$ and temperatures T_i obtained from the equilibrium chemistry computations.

All parameters described in this section are printed as output for each value of the axial coordinate "χ". In addition, the X and Y coordinates are computed using Eqs. (47) and (73). Relations (48) and (49) yield the heat transfer $\dot{q}$ and friction parameter CF.

In advancing the computation to χ^{n+1}, the element mass fractions at χ^n, i.e. $(\tilde{Y}_k)_i^n$, must be used in Eqa. (25) and (30). These expressions are the right hand sides of the difference equations used in the solution of diffusion Equation 2.

V. DESCRIPTION OF INPUTS

A. Calculation of Initial Input Data

1. Given Information

The following information must be specified:

a. External conditions (u_e, ρ_e, μ_e, T_e, Y_{ke}) $k = 1, \ldots 7$. representing species O_2, H_2, H_2O, N_2, O, H, and OH.

b. Wall conditions (T_o, $(Y_k)_o$) $k = 1, \ldots 7$.

(1) Initial compressible skin friction coefficient $c_f \equiv \tau_o/\rho_e u_e^2$.

(2) Initial compressible Reynolds number based on momentum thickness - $R_\theta = \rho_e u_e \theta/\mu_e$.

c. Initial temperature variation with velocity ration $T(u/u_e)$ through viscous layer.

d. Initial species mass fraction variation with velocity ration $Y_k(u/u_e)$ $k = 1, \ldots 7$ through viscous layer.

2. Calculation of $\sigma/\bar{\mu}$

As a first step in determining the input data the parameter $\sigma/\bar{\mu}$ must be related to the incompressible skin friction coefficient $\bar{c}_f$. This procedure varies depending on whether the substructure or sublayer hypothesis is utilized.

a. Calculation of $\sigma/\bar{\mu}$ According to Substructure Hypothesis

For the substructure hypothesis, take

$$\frac{\bar{\mu}}{\sigma} = \mu_s = \mu \left(T_s (Y_k)_s \right) \tag{95}$$

where μ_s denotes the viscosity of the mixture evaluated at the temperature T_s, and composition $(Y_k)_s$ where these latter are given by

$$T_s = \frac{1}{430} \int_0^{430} T d\zeta \tag{96}$$

$$(Y_k)_s = \frac{1}{430} \int_0^{430} Y_k d\zeta \qquad k = 1, \ldots 7 \tag{97}$$

In accordance with input items c and d, T and Y_k are known functions of u/u_e. Furthermore, fromthe Eqs. (AIII-1) through (AIII-6) given in Ref. 1 and the relations

$$\varphi = \sqrt{\frac{2}{\bar{C}_f}} \tag{98}$$

$$\zeta_\delta = \exp \left\{ \frac{\varphi - 12.35}{2.43} + 2.03 \right\} \tag{99}$$

and

$$\frac{u}{u_e} = \frac{1}{\varphi} \frac{\bar{u}}{u_\tau} \tag{100}$$

one can obtain the correspondence between the velocity ratio u/u_e and ζ for any particular value of $\bar{C}_f$;

$$\frac{u}{u_e} = \frac{u}{u_e} (\zeta; \bar{C}_f) \ . \tag{101}$$

Thus the integrals appearing in (96) and (97) can be evaluated (numerically if necessary) and will depend only on a choice of $\bar{C}_f$. Thus also $\sigma/\bar{\mu}$ will be related uniquely to $\bar{C}_f$; i.e.:

$$\frac{\bar{\mu}}{\sigma} = \frac{\bar{\mu}}{\sigma} (\bar{C}_f) \ . \tag{102}$$

b. <u>$\sigma/\bar{\mu}$ According to Sublayer Hypothesis</u>

For the sublayer hypothesis, take

$$\frac{\sigma\mu_s}{\bar{\mu}} = \frac{1}{10.6}\int_0^{56.18} \frac{\rho_s}{\rho} \frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}} \tag{103}$$

where ρ_s and μ_s denotes the density and viscosity of the mixture at $\tilde{\psi} = 56.18$. In general, the density is related to the temperature and species by

$$\frac{\rho_e}{\rho} = \frac{T}{T_e}\left(\sum_{k=1}^{7} \frac{Y_k}{M_k}\right)_e \left(\sum_{k}^{7} \frac{Y_k}{M_k}\right)^{-1} \tag{104}$$

where the M_k denote the molecular weights of the individual species and are given. Since the Y_k and T are related to the velocity ratio through (c) and (d) above, we have

$$\frac{\rho_e}{\rho} = \frac{\rho_e}{\rho}\left(\frac{u}{u_e}\right) \tag{105}$$

Now relate ρ_e/ρ to $\tilde{\psi}$ by the relation

$$\frac{u}{u_e} = \frac{\sqrt{2\tilde{\psi}}}{\omega} \tag{106}$$

so that, as in the sub-structure case, there can be written formally

$$\frac{\sigma}{\bar{\mu}} = \frac{\sigma}{\bar{\mu}}\ (\bar{C}_f). \tag{107}$$

3. Calculation of φ

a. With C_f given, solve for $\bar{C}_f$ (by iteration) from the following equation

$$\frac{C_f}{\bar{C}_f} = \frac{\rho_w \mu_w}{\rho_e} \frac{\sigma}{\bar{\mu}} \quad . \tag{108}$$

b. With R_θ given, use Eq. (108) and

$$\frac{R_\theta}{R_{\bar{\theta}}} = \frac{1}{\mu_e} \frac{\bar{\mu}}{\sigma} \tag{109}$$

$$\bar{C}_f = \bar{C}_f \; (R_{\bar{\theta}}) \tag{110}$$

where Eq. (110) is given graphically in Fig. 5. The solution for $\bar{C}_f$ is again obtained by iteration.

4. Calculation of φ, ζ_δ, ψ_M

Once an initial value of $\bar{C}_f$ has been obtained the corresponding values of φ and ζ_δ follow from (98) and (101), while ψ_M is obtained from

$$\psi_M = - 30.81 + 2.43 \; \zeta_1 \; \ln \zeta_1 + 2.47 \; \zeta_1 + \chi(\zeta_\delta - \zeta_1) \; \varphi + 1.7 \; \zeta_\delta \tag{111}$$

where $\zeta_1 = 0.131 \; \zeta_\delta$.

5. Calculation of Initial Profiles $T(\psi)$, $Y_k(\psi)$, $G(\psi)$

From the given inputs there is available $T(u/u_e)$ and $Y_k(u/u_e)$. $G(u/u_e)$ is obtained from

$$G = \frac{\sum Y_k h_k}{H_e} + \left(\frac{u}{u_e}\right)^2 \frac{u_e^2}{2H_e}$$

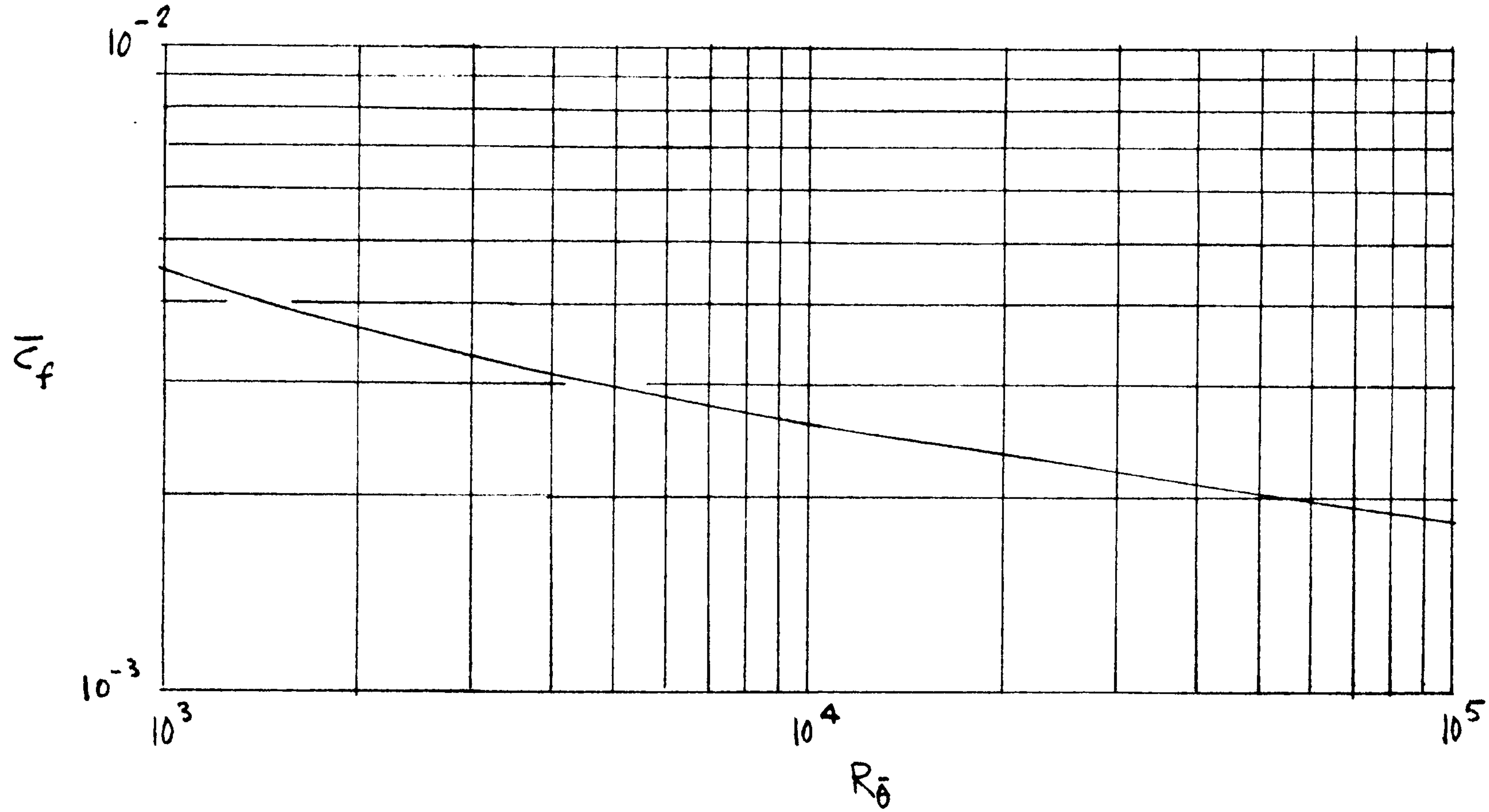

FIG. 5 - VARIATION OF $\bar{C}_f$ VS $R_{\bar{\theta}}$ FOR CONSTANT DENSITY FLOW

From the parametric relations

$$\frac{u}{u_e} = \frac{\bar{u}}{\bar{u}_e} = \text{function of } \zeta$$

$$\psi = \psi(\zeta)$$

given in Appendix III of Ref. 1 there is tabulated the relation

$$u/u_e = u/u_e \ (\psi)$$

where G, T and Y_k can be obtained as functions of ψ. These are plotted in graphical form from which the desired values corresponding to the previously selected ψ-mesh points ψ_i are read off.

6. Numberical Example (Sublayer Hypothesis)

a. External conditions

$$\rho_e = 1.344 \times 10^{-3} \text{ slugs/ft}^3$$

$$u_e = 2120 \text{ ft/sec}$$

$$T_e = 122^\circ K$$

$$\mu_e = .4926 \times 1.153 \times 10^{-6} \text{ \#/ft-sec}$$

$$(Y_1)_e = .232$$

$$(Y_4)_e = 0.768$$

$$(Y_k)_e = 0; \ k = 2, 3, 5, 6, 7$$

undissociated air

b. Wall Conditions

$$T_o = 306^\circ K$$

$$(Y_k)_o = (Y_k)_e ; \; k = 1, \ldots 7.$$

c. Skin friction coefficient

$$C_f = .0013$$

d. Temperature distribution

$$T = T_o + (T_{s_e} - T_o) \frac{u}{u_e} - (T_{s_e} - T_e) \frac{u^2}{u_e^2}$$

(Crocco integral; $P_e = 1$).

e. Species distribution

$$Y_k (u/u_e) = \text{constant} = (Y_k)_e \; .$$

Combining e, (104) and (106) gives, using the numerical data

$$\frac{\rho_e}{\rho} = 2.51 + 0.22 \frac{\sqrt{2\tilde{\psi}}}{\sigma} - 1.73 \frac{2\tilde{\psi}}{\sigma^2}$$

$$\frac{\rho_e}{\rho_s} = 2.51 + \frac{2.33}{\sigma} - \frac{194}{\sigma^2}$$

so that from (103)

$$\frac{\sigma \mu_s}{\bar{\mu}} = \frac{1}{10.6} \frac{\displaystyle\int_0^{56.18} \left[\frac{2.51}{\sqrt{2\tilde{\psi}}} + \frac{0.22}{\sigma} - 1.73 \frac{\sqrt{2\tilde{\psi}}}{\sigma^2} \right] d\tilde{\psi}}{2.51 + \dfrac{2.33}{\sigma} - \dfrac{194}{\sigma^2}}$$

$$= \frac{2.51 + \dfrac{1.165}{\sigma} - \dfrac{64.67}{\sigma^2}}{2.51 + \dfrac{2.33}{\sigma} - \dfrac{194}{\sigma^2}}$$

Now take an initial guess of $\bar{C}_f = 2 \times 10^{-3}$ so that from (98)

$$\varphi = 22.4$$

for which

$$\frac{\rho_s}{\rho_e} = 0.451$$

$$\frac{\mu_s}{\mu_e} = 2.06$$

and

$$\frac{\sigma \mu_s}{\bar{\mu}} = 1.095.$$

From the given data $\frac{\rho_o \mu_o}{\rho_e \mu_e} = 1.131$ so that from (108)

$$C_f = \frac{\rho_o \mu_o}{\rho_e \mu_e} \frac{\mu_e}{\mu_s} \frac{\mu_s \sigma}{\bar{\mu}} \bar{C}_f = .0012 < .0013.$$

A second guess of $\bar{C}_f = .0025$ yields

$$C_f = .00163 > .0013.$$

A linear interpolation gives as a third gues $\bar{C}_f = .00212$ for which one obtains

$$C_f = .00131 \approx .0013$$

which is the required result.

B. Input Formats for IBM Programs

In this section, the input formats for each of the three program decks - Substructure Reference Hypothesis Finite Rate chemistry, Sublayer Hypothesis Finite Rate Chemistry, and Reference Hypothesis Equilibrium Chemistry will be described in detail. Refer to section on Nomenclature for allied information.

The term "card" refers to the standard IBM data processing card consisting of 12 rows and 80 columns. The term "format" refers to the mode of input. Symbolically, these modes may be defined as follows:

I	integer	$\pm$ XX	(no decimal point)
E	floating point	$\pm$ X.XXX $\pm$ YY	(YY is the exponent to the base 10. $\pm$ X.XXX.10$^{(YY)}$.

For the E mode, the decimal point may be shifted from the position indicated in the above example and the maximum number of significant figures is governed by the field width assigned for each "word" of data. The plus (+) sign may be omitted in all cases, except for the sign immediately preceding the exponent for the E mode. An additional format is the Hollerith mode which consists of alpha-numerical information, and for our purposes, will be utilized exclusively for an identification input card, which will subsequently be printed as a title at the head of the output listing. It is good practice to "right-adjust" data words within the indicated field; that is, the word must be shifted to the extreme right of the field.

1. Substructure or Reference Hypothesis - Finite Rate Chemistry

CARD	COLUMN	DESCRIPTION	FORMAT
1	1	Punch the number 0	
	2-72	Title information	H
2	5	"G" - Input profile option	E
		"1" - Input temperature in $^{\circ}K$	Inputs on 8th set of cards A+1 thru C
		"2" - Input stagnation enthalpy ratios	
3	1-15	"$\Delta\ \psi$" for coarse Mesh $= (\psi_M - \psi_1)/_M$	E
	31-45	"X_F" - Final Value of "X" (ft)	E
	61-75	"ξ_o" - Initial	E
4	1-15	"ζ_{δ_o} - Initial Zeta Delta	E
	16-30	HE - Ref. Stagnation Enghalpy $[ft^2/sec^2]$	E
	31-45	"$\Delta\ \chi$" - " " Step size	E
	46-60	"DPSY" - "ψ" step size between wall and "ψ"	E
5	1-15	"TROLL" Tolerance for Iteration on "Δ X" coordinate for chemistry (Approx. .05) - See Eq. 81	E
	16-30	"EPS" - Tolerance for adding point to species or energy solution matrix (approx. 0.001) - See Eqs. 45,46	E

CARD	COLUMN	DESCRIPTION	FORMAT
6	1-15	"PE" - Prandtl number	E
	16-30	"SE" - Schmidt number	E
	31-45	"ψ_1" - First ψ value above wall	E
	46-60	T_e - Reference temp. ($^\circ$K)	E
	61-75	U_e - Reference velocity (ft/sec)	
7	1-15	ρ_e - Reference density (slugs/ft^3)	E
	16-30	μ_e - Reference viscosity (lb-sec/ft^2)	E
	31-45	TR - Reference Temperature for static enthalpy fits ($^\circ$K) (use 300.0)	E
	46-60	Initial value of $d/d\chi$ (ℓn σ) (Substruct. Version Only) (Use zero if not known)	E
	73-75	"SS" - Punch "1.0" If $d/d\chi$ (ℓn σ) (col. 46-60) is not zero	
8	14-15	"MS" - Number of coarse mesh points in "ψ" Direction for species $\leq$ 40	I
	20	"K" - Total number of species = 7	I
	55	Punch the number "1"	I
	60	Maximum number of iterations on "Δ x" if finite rate chemistry option is requested ($\leq$ 5) (see Eq. 81)	I
	64-65	Number of fine mesh points in "ψ" direction, $\leq$ 25	I
	69-70	"m" - print cycle number - print properties at every mth - step, $\leq$ 10	I
	75	Punch the number "1"	I

CARD	COLUMN	DESCRIPTION	FORMAT
9	4-5	"MG" number of coarse mesh points in "ψ" direction for "G" profile $\leq$ 40	I
9	10	Chemistry option punch "1" if finite rate chemistry requested; Punch "0" if no chemistry	I
	15	Reference or substructure hypothesis option "0" - substructure hypothesis "1" reference hypothesis	I
	19-20	Total number of species mesh points in "ψ" direction (sum of values in card #8 - Cols. 14-15 and 64-65)	I
	24-25	Total number of "G" mesh points in "ψ" direction (sum of values in card #8 - Cols. 64-65 and card #9 - Cols 4-5)	I
10...A	1-15, 16-30, ...61-75	Initial wall Values for species 1 to 7. The species are O_2, H_2, H_2O, N_2, O, H, and OH	E
A+1, A+2... ..B	1-15, 16-30...	Values of Y_i at all fine mesh points along initial ψ - Mesh line from $\psi = \psi_1$ to point immediately below $\psi = \psi_2$	E
B+1, B+2... ..C	1-15, 16-30... 61-75	Values of Y_i at all coarse mesh points along inital ψ - mesh line from $\psi = \psi_2$ to $\psi = \psi_{MS}$ inclusive	E

[Repeat cards A+1 through C for remaining species Y_2 through Y_7, and then for "G" profile. Note that the "G" coarse mesh points go from $\psi=\psi_2$ to $\psi = \psi_{MG}$. Thus there are "8" sets of cards designated A+1 through C]

CARD	COLUMN	DESCRIPTION	FORMAT
C+1...D	1-15, 16-30... 1-15, 16-30	$(Y_k)_e$ For k = 1, 2...7 (Mass fractions at edge of boundary layer)	E
D+1		Wall temperature function vs "X" $(T_w)_1 = A_1 + B_1X$, $X \leq X_1$ $(T_w)_2 = A_2 + B_2X$, $X > X_1$	E

CARD	COLUMN	DESCRIPTION	FORMAT
	1-15	A_1 (°K)	
	16-30	A_2 (°K)	
	31-45	B_1 (°K/units of X_1)	
	46-60	B_2 (°K/units of X_1)	
	61-75	$X_1 \cdot (\rho_e u_e/\mu_e)$ where X_1 is in feet	
D+2... E	1-15, 16-30... ...61-75 1-15, 16-30	Static enthalpy fit constants CP, (see Eq. 12) CP's for species 1 through 7	E
E+1...F	1-15, 16-30... ...61-75 1-15; 16-30	"DELS" for species 1 through 7	E
F+1...G	1-15,16-30,etc.	Molecular weights "M_k" for species 1 through 7 These values are M_1 = 16.0, M_2 = 2.0, M_3 = 18.0 M_4 = 28.0, M_5 = 16.0, M_6 = 1.0 M_7 = 17.0	

2. Sublayer Hypothesis - Finite Rate Chemistry

CARD	COLUMN	DESCRIPTION	FORMAT
1	1	Zero	
	2-72	Title information	H
2	4-5	Number of fine mesh points in "ψ" direction, $\leq$ 25	I
	9-10	"MS" - Number of coarse mesh points in "ψ" direction for species, $\leq$ 40	I
	14-15	<u>TOTAL</u> number of mesh points in "ψ" direction for species (sum of values in cols. 4-5 and 9-10)	I
	19-20	"MG" - Number of coarse mesh points in "ψ" direction for "G" profile $\leq$ 40	I
	24-25	<u>TOTAL</u> number of mesh points in "ψ" direction for "G" profile (sum of values in cols. 4-5 and 19-20).	I
	30	"G" input profile option Punch "1" - if temperature in degrees Kelvin are input on 8th set of cards A+1 through C Punch "2" - if stagnation enthalpy ratio h/h_e) are input on 8th set of cards A+1 through C	
	35	Punch the number "1"	I
	40	Punch the number "7"	I
	44-45	m - Print cycle number - print properties at every m^{th} - step, $\geq$ 10	I
	50	Chemistry option: Punch "1" if finite rate chemistry requested; Punch "0" if no chemistry	I

CARD	COLUMN	DESCRIPTION	FORMAT
3	11	Punch the number "1"	I
	20	Maximum number of iterations on ΔX coordinate if chemistry option is requested, ≤ 5 (see Eq. 81)	I
4	1-15	"$\Delta\psi$" for coarse mesh region between $\psi = 56.18$ and $\psi = \psi_M$	E
	31-45	"ξ_F" = final value of CSI	E
	61-75	"φ_o" - initial φ	E
5	1-15	"$\zeta\delta_o$" - initial ZETA DELTA	E
	16-30	h_e - reference stagnation enthalpy (ft^2/sec^2)	E
	31-45	"$\Delta\xi$" - ξ step size	E
	46-60	"DPSY" - $\Delta\psi$ for "ψ" between wall and $\psi = \psi_1$	E
6	1-15	"TROLL" - tolerance for iteration on ΔX coordinate if chemistry option is requested, approx. .05 see Eq. 81	E
	16-30	"EPS" - tolerance for adding pt. to solution matrix approx. 0.01 See Eqs. 44, 45.	E
7	1-15	P_e - Prandtl number	E
	16-30	S_e - Schmidt number	E
	31-45	ψ_1 - First numerical "ψ" value above wall	E
	46-60	T_e - reference temperature ($^\circ K$)	E
	61-75	u_e - reference velocity (ft/sec)	E
8	1-15	ρ_e - reference density ($slugs/ft^3$)	E

CARD	COLUMN	DESCRIPTION	FORMAT
8	16-30	μ_e - reference viscosity (lb-sec/ft)	E
	31-45	TR - reference temperature for static enthalpy fits (°K) (Use 300.)	E
	46-60	Initial value of d/dχ ($\ln \sigma$) (use zero if not know)	E
	61-75	"SS" - punch "1.0" if cols. 46-60 is not zero or blank	E
9, ..A	1-15, 16-30 ..61-75 1-15, 16-30	Initial wall species for species 1 to 7 The species are O_2, H_2, H_2O, N_2, O, H, and OH	E
A+1, A+2..B	1-15, 16-30 ..61-75 1-15, etc.	Values of Y_1 at all fine mesh points along initial ψ-mesh line from $\psi=\psi_1$ to point immediately below ψ=56.18	E
B+1, B+2 ..C	1-15, 16-30 ..61-75 1-15, etc.	Values of Y_1 at all coarse mesh points along initial ψ-mesh line from ψ=56.18 through $\psi=\psi_{MS}$	E

Repeat cards A+1 through C for remaining species Y_2 through Y_7 and then for G profile, thus there are 8 sets of cards designated A+1 through C
Note that the "G" profile coarse mesh points go from ψ =56.18 to $\psi = \psi_{MG}$

CARD	COLUMN	DESCRIPTION	FORMAT
C+1..D	1-15, 16-30 ..61-75 1-15, 16-30	$(Y_k)_e$ for K = 1, 2, ... 7 (Mass fractions for edge of boundary layer)	E
D+1		Wall temperature function vs. "X" $(T_w)_1 = A_1 + B_1 X$, for $X \leq X_1$ $(T_w)_2 = A_2 + B_2 X$, for $X \geq X_1$	E

CARD	COLUMN	DESCRIPTION	FORMAT
D+1	1-15	A_1 ($^\circ K$)	
	16-30	A_2 ($^\circ K$)	
	31-45	B_1 $^\circ K$/units of X_1	
	46-60	B_2 $^\circ K$/units of X_1	E
	61-75	$X_1 \cdot (\rho_e u_e/\mu_e)$, where X_1 is in feet	
D+2	1-15 16-30... ...61-75	Static enthalpy fit $(CP)_k$ constants for $k = 1, 2 \ldots 7$	
D+3	1-15, 16-30		
D+4	1-15, 16-30... ...61-75	Static enthalpy fit $(\Delta)_k$ constants for $k = 1, 2 \ldots 7$	
D+5	1-15, 16-30		
D+6	1-15, 16-30... ...61-75	Molecular weights M_k for $k = 1, 2 \ldots 7$ These values are $M_1 = 16.0$, $M_2 = 2.0$, $M_3 = 18.0$ $M_4 = 28.0$, $M_5 = 16.0$, $M_6 = 1.0$, $M_7 = 17.0$	
D+7	1-15, 16-30		

3. Reference Hypothesis - Equilibrium Chemistry

CARD	COLUMN	DESCRIPTION	FORMAT
1	1	Punch the number "0"	I
	2-72	Title information	H
2	5	Punch the number "2"	I
3	1-15	"$\Delta \psi$" for coarse mesh region = $(\psi_M - \psi_2)/M$	E
	31-45	"X_F" - final value of X coordinate (ft)	E
	46-60	"φ_o" - initial φ	E
	61-75	"$(\zeta\sigma)_o$" initial $\zeta\sigma$	E
4	13-15	Punch the number "1.0"	E
	16-30	"$\Delta \xi$" - ξ Step size	E
	31-45	"DPSY" - "$\Delta \psi$" for "ψ" between wall and ψ_2	E
5	13-15	"PE" - Prandtl Number - Punch the number "1.0"	E
	28-30	"SE" - Schmidt number - Punch the number "1.0"	E
	31-45	"ψ_1" - First numerical "ψ" value above wall	E
	46-60	"T_e" - Reference Temperature (K)	E
	61-75	"U_e" - Reference velocity (ft/sec)	E
6	1-15	"ρ_e" - Reference Density (slugs/ft^3)	E
7	5	Number of elements (Punch the number "7")	I

CARD	COLUMN	DESCRIPTION	FORMAT
7	9-10	Number of fine mesh points in "ψ" direction $\leq$ 25	I
	14-15	"M" - Number of coarse mesh points in "ψ" direction $\leq$ 40	I
	18-20	TOTAL number of mesh points in "ψ" direction (sum of values in cols. 9-10 and 14-15	I
	24-25	Punch same as cols. 14-15	I
	29-30	Punch same as cols. 19-20	I
8	34-35	"m" - Print cycle number - Print properties at every mth - step, $\leq$ 10	E
	40	Punch a "1"	E
9...A	1-15	Initial values of wall elements $(\tilde{Y}_k)_o$ for k = 1-7	E
	16-30... 1-15, 16-30	k = 1-3, enter blank cards, $k_4=H_2$, $k_5=O_2$, k_6 enter blank cards $k_7 = N_2$	
A+1, A+2 ...B	1-15 16-30,... ... 61-75	Values of $\tilde{Y}_1$ at all fine mesh pts. along initial ψ - mesh line from $\psi = \psi_1$ to point immediately below $\psi = \psi_2$	E
B+1	1-15	Values of $\tilde{Y}_1$ at all coarse mesh	E
B+2 ...C	16-30... ...61-75	pts. along initial ψ - mesh line from $\psi = \psi_2$ to $\psi = \psi_M$	

Repeat cards A+1 through C for remaining elements $\tilde{Y}_2$ through $\tilde{Y}_7$, and then for "G" profile. Enter correct number of blank cards for k = 1, 2, 3, 6. Thus there are 8 sets of cards designated A+1 through C

CARD	COLUMN	DESCRIPTION	FORMAT
C+1...	1-15	$(Y_k)_e$ For k=1 through 7	E
..D	16-30...	(Element Mass fractions at edge of boundary	
D+1		Wall temperature function versus X-coordinate $(T_w)_1 = A_1 + B_1 X \qquad X \le X_1$ $(T_w)_2 = A_2 + B_2 X \qquad X > X_1$	E
	1-15	A_1 (°K)	
	16-30	A_2 (°K)	
	31-45	B_1 (°K/units of X)	
	46-60	B_2 (°K/units of X)	
	61-75	$X_1 \cdot (\rho_e u_e/\mu_e)$ where X_1 is in feet	
D+2	1-15 16-30, ...61-75	Molecular weights for elements 1 through 7 These values are $M_1 = 1.0$, $M_2 = 16.0$, $M_3 = 18.0$,	E
D+3	1-15, 16-30	$M_4 = 2.0$, $M_5 = 32.0$, $M_6 = 17.0$ $M_7 = 28.0$	E

VI. DESCRIPTION OF OUTPUTS

The output of the program consists of a title page containing program title, names of originator and programmer, a title statement describing the type of computer run, date, etc., and then 19 lines listing the numerical values of all input data.

For each step in the χ direction (CSI), or horizontal coordinate, results are printed in a three page format listing the following information:

Page 1 - The value of "CSI" followed by a five column table. Each row of the table represents data for a value of "PSI," or vertical coordinate. The columns are, from left to right, (PSI), stagnation enthalpy ratio, G, temperature ratio (TEMP), density ratio (RHO), and molecular weight of the mixture, (W).

Page 2- An eight-column table where the first column contains each value of PSI, while the remaining columns are the mass fractions of each specie. The species are, from left to right, O_2, H_2, H_2O, N_2, O, H, and OH.

Page 3 - A five-column table where the first column contains the vertical ζ variable corresponding to each ψ value. The remaining columns are, from left to right, incompressible viscosity (I-VIS), compressible viscosity (C-VIS), velocity (U-BAR), and the physical vertical coordinate associated with ψ and ζ, the (Y coordinate) in feet.

Following the data table on page 2 are printed two integers, LE and LS. They indicate the number of ψ values used in the enthalpy and species solutions, respectively.

Following the data table on page 3, except for $\chi = 0$, are printed the value of X-coordinate, σ, ζ_δ, $d(\ln \sigma)/d\chi$, $\sigma/\bar{\mu}$, heat transfer $\dot{q}$ (in BTU per square foot-sec) and CF.

Of the preceding quantities, stagnation enthalpy, density, temperature, velocity, and viscosity are normalized with respect to the input edge conditions.

Examples of the output described herein, appear in Appendix 2.

VII. OPERATING PROCEDURE

The program was written for the IBM 709/90/94 digital computers and uses the IBM FORTRAN II monitor system.

The FORTRAN II monitor system has standard tape designations, which are:

- A2 - Standard input tape
- A3 - Standard BCD output tape
- A1 - Systems tape
- A5 - Binary tape for restart procedure.

An IOU subroutine is included in the object deck to ensure compatibility with the logical assignment of tapes.

"Checkpoint" Procedure

If a restart option is to be implemented a tape must be mounted on logical unit A5. Depressing sense switch 6 at any time during the course of a run will dump the contents of core memory onto tape A5 and then terminate the run. Tape A5 is dismounted and saved for future use. Tape A3 may then be listed.

To restart at a future time, the binary tape that was saved, is again mounted on logical unit A5 and a small binary object deck labelled "RESTART," is used as the program deck . For the sublayer version deck only, an additional data card must be included behind the "RESTART" binary deck containing in cols. 1-15 a value of "Δx" to be used in subsequent computation. The program will read the contents of tape A5 and processing will commence from the point where it was formerly dumped. Processing will continue until Sense Switch 6 is again depressed for a second dump onto tape A5 for a future second restart, etc.

To protect the original information on tape A5, a second tape may be mounted on a unit to be designated as A5 after the original tape has been read by the 7094. The unit with the original tape should be dialed off and the tape dismounted. Core memory will be dumped on the second tape for a future restart.

The program is normally terminated by specifying a value of ξ FINAL on input card 3. When the program has calculated the data for the first value of ξ which is greater than ξ FINAL, the program will automatically process additional sets of input data, or in the absence of such cards, will terminate. A maximum time limit should be specified in the instructions to the operator in this case, in the event of a failure of the program to achieve a value of ξ FINAL.

There are several other program stops, caused by numerical errors, wherein the program will print a code number, and in some cases an alphabetical statement describing the error. A list of these error stops is given in Appendix 1. The program will then either process the next data case, or terminate just as in the case of a normal stop at ξ FINAL.

Several options for methods of numerical calculation of the program can be specified on input card 8 and are described in Section V. There is one option controlled by Sense Switch 1 as follows:

SENSE SWITCH 1

UP - Compressible viscosities are not computed and printed. In this case, either the number 0 or the values of incompressible viscosity are printed, the latter for values of PSI greater than PSI DELTA.

DOWN - Compressible viscosities are computed and printed.

Sense Switch 1 instructions need be given to the machine operator only if the Sense Switch 1 DOWN option is desired.

See Eqs. (15) and (16) for the equations defining incompressible and compressible viscosities.

In both the substructure and sublayer hypothesis versions, the compressible eddy viscosity $\tilde{u}$ (Eq. 4) and the physical length χ (Eq. 47) depend strongly on the parameter $d(\ell n\ \sigma)/d\chi$. Past experience has indicated that positive values of $d(\ell n\ \sigma)/d\chi$ large enough in magnitude to give negative values of $\tilde{u}$ and χ may be encountered, yielding physically meaningless results. Should this occur, the user is advised to change to the reference hypothesis wherein $d(\ell n\ \sigma)/d\chi$ is set identically equal to zero. If further difficulties arise, such as negative mass fractions, a reduction in the axial step size "$\Delta\chi$" might help to remove the difficulties.

NOMENCLATURE

G	stagnation enthalpy ratio = H/H_e
H	stagnation enthalpy = $h + u^2/2$
h_k	static enthalpy of species; $h = \sum_k h_k Y_k$
P_e	effective Prandtl number
$\dot{q}$	heat transfer per unit time per unit area
S_e	effective Schmidt number
T	static temperature
u	mass averaged velocity in axial direction
M_k	molecular weight of species k
X	axial coordinate
z	normal coordinate

Greek Symbols

δ	boundary layer thickness
ζ	transformed variable defined by Eq. (35) of Ref. 1
η, s	transformed variables defined by Eq. (53) of Ref. 1
$\sigma(x)$, $\tau(x)$, $\xi(x)$	stretching function (see Eq.(15)) of Ref. 1
θ	momentum thickness
μ	laminar viscosity coefficient
ϵ	kinematic viscosity coefficient
χ	transformed variable (see Eq.(47)) of Ref. 1
ρ	mass density
$\rho\epsilon$	eddy viscosity
γ	shear stress
ω	$\bar{U}_e/U_\tau$
$\tilde{\psi}$	stream function defined by Eq. (57) of Ref. 1

Subscripts

e free stream

Superscripts

$(\bar{\ })$ incompressible

$(\tilde{\ })$ with respect to Von Mises transformation performed in Ref. 1

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3. De Groat, J., and Abbett, M., "A Computation of One-Dimensional Combustion of Methane", AIAA Journal, Vol. 3, No. 2, February 1965, pp. 381-383.

4. Libby, P.A., and Baronti, P.O., "A Transformation Theory of the Turbulent Compressible Boundary Layer with Pressure Gradient and Heat Transfer", GASL TR-455, August, 1964.

APPENDIX 1

LIST OF ERROR STOPS

APPENDIX 1

LIST OF ERROR STOPS

PRINTED NUMBER	DESCRIPTION OF ERROR
1	An element in Column 2 of species or energy difference equation matrix is equal to zero
6	The number of ζ values is greater than 149
8	A value of ζ greater than PSI DELTA plus 1/2 DELTA PSI has been computed
9	The program has taken more than 15 iterations to compute a value of ZETA
25	No. value of "ZETA" is greater than 430
26	A value of PSI DELTA is less than 1/2 DELTA PSI

APPENDIX 2

SAMPLE OUTPUT OF IBM SHEETS

[illegible]	0.	1.2924623E-01	2.[illegible]E 00	[illegible].6059136E 00	2.6423654E 01	0
1	1.0000000E 00	1.2924623E-01	1.[illegible]3901E 00	[illegible].6269903E 00	2.6423654E 01	1
[illegible]	1.[illegible]E 00	1.37[illegible]	[illegible]	[illegible].212170[illegible]E 00	2.6423197E 01	1
[illegible]	7.1727200E 02	1.6656025E-01	1.75[illegible]E 00	7.3707607E 00	2.5896567E 01	2
3	1.4335440E 03	1.6411753E-01	1.7[illegible]83927 00	7.3857921E 00	2.5611517E 01	3
4	2.1498160E 03	1.7455805E-01	1.7[illegible]2155E 00	7.39[illegible]74E 00	2.5340019E 01	4
5	2.8660879E 03	1.7662644E-01	1.6939133E 00	7.4097476E 00	2.5177179E 01	5
6	3.5823599E 03	1.8192320E-01	1.6842165E 00	7.4167540E 00	2.4982839E 01	6
7	4.2986319E 03	1.8472636E-01	1.6707203E 00	7.4204692E 00	2.4795057E 01	7
8	5.0149038E 03	1.8716752E-01	1.6581627E 00	7.4212443E 00	2.4611260E 01	8
9	5.7311758E 03	1.8939855E-01	1.6453631E 00	7.4193755E 00	2.4429972E 01	9
10	6.4474478E 03	1.9141937E-01	1.6351906E 00	7.4151231E 00	2.4250279E 01	10
11	7.1637198E 03	1.9329128E-01	1.6245476E 00	7.4087073E 00	2.4071595E 01	11
12	1.4326440E 04	2.0743184E-01	1.5335031E 00	7.2854136E 00	2.2344409E 01	12
13	2.1489159E 04	2.1985356E-01	1.4564102E 00	7.0338356E 00	2.0488300E 01	13
14	2.8651679E 04	2.3510469E-01	1.3734058E 00	6.6320807E 00	1.8217076E 01	14
15	3.5814599E 04	2.5357963E-01	1.2941056E 00	6.1055976E 00	1.5802576E 01	15
16	4.2977319E 04	2.7573021E-01	1.2241922E 00	5.5009670E 00	1.3468482E 01	16
17	5.0140039E 04	3.0195502E-01	1.1663238E 00	4.8704849E 00	1.1361125E 01	17
18	5.7302759E 04	3.3250423E-01	1.1206763E 00	4.2604232E 00	9.5491107E 00	18
19	6.4465478E 04	3.6740623E-01	1.0859222E 00	3.7030826E 00	8.[illegible]25195E 00	19
20	7.1628198E 04	4.0642301E-01	[illegible]012400 00	3.21517[illegible] 00	[illegible]109624E 00	20
21	7.8790918E 04	4.4903927E-01	1.0413156E 00	[illegible]	[illegible]30415E 00	21
22	8.5953637E 04	4.9446062E-01	1.0277851E 00	2.4506[illegible] 00	[illegible]0032E 00	22
23	9.3116357E 04	5.4179478E-01	1.0131613E 00	2.17301[illegible] 00	4.[illegible]9685E 00	23
24	1.0027908E 05	5.8987445E-01	1.011139[illegible] 00	1.94250[illegible] 00	3.[illegible]95[illegible]E 00	24
25	1.0744180E 05	6.37[illegible]E-01	1.00[illegible]719[illegible]E 00	1.7556[illegible] 00	[illegible]E 00	25
26	1.1460451E 05	6.8[illegible]E-01	1.0035[illegible] 00	1.[illegible] 00	3.[illegible]34E 00	26
27	1.2176723E 05	7.2731228E-01	1.0015013E 00	1.482[illegible] 00	2.[illegible]315E 00	27
28	1.2892995E 05	7.6[illegible]E-01	1.00024[illegible]E 00	1.38[illegible] 00	2.7[illegible]543E 00	28
29	1.3609267E 05	8.05[illegible]E-01	9.99[illegible]E-01	1.30[illegible] 00	2.6[illegible]418E 00	29
30	1.4325539E 05	8.3[illegible]E-01	9.99[illegible]E-01	1.2[illegible] 00	2.47[illegible]E 00	30
31	1.5041811E 05	8.5779630E-01	9.99258[illegible]E-01	1.1[illegible] 00	2.3772513E 00	31
32	1.5758083E 05	[illegible].9283323E-01	9.99367[illegible]E-01	1.1483[illegible] 00	2.2[illegible]2687E 00	32
33	1.6474355E 05	9.1391878E-01	9.99497[illegible]E-01	1.1157[illegible] 00	2.2304648E 00	33
34	1.7190627E 05	9.321[illegible]E-01	9.[illegible]E-01	1.[illegible]E 00	2.1774198E 00	34
35	1.7906899E 05	9.4741849E-01	9.99[illegible]E-01	1.[illegible] 00	2.1346949E 00	35
36	1.8623171E 05	9.59[illegible]E-01	9.9975[illegible]E-01	1.05046[illegible]E 00	2.1008183E 00	36
37	1.9339442E 05	9.701[illegible]21E-01	[illegible]E-01	1.[illegible]736[illegible] 00	2.0743770E 00	37
38	2.0055714E 05	9.78[illegible]511E-01	9.[illegible]E-01	1.027190[illegible]E 00	2.0540665E 00	38
39	2.0771[illegible] 05	9.8415071E-01	9.[illegible]E-01	1.[illegible]E 00	2.0387173E 00	39
40	2.1488258[illegible] 05	9.8874[illegible]E-01	9.[illegible]E-01	1.[illegible]75385 00	2.0273[illegible]E 00	40
41	2.2204[illegible] 05	9.921412[illegible]E-01	9.[illegible]E-01	1.[illegible] 00	2.0199707E 00	41
42	2.29[illegible] 05	9.94[illegible]E-01	9.[illegible]E-01	1.[illegible]56225 00	2.012[illegible]13E 00	42
43	2.3637[illegible] 05	9.96[illegible]E-01	9.[illegible]E-01	1.[illegible]44255 00	2.[illegible]7533E 00	43
44	2.435[illegible] 05	9.97[illegible]71E-01	9.[illegible]E-01	1.[illegible]297[illegible] 00	2.00[illegible] 00	44
45	2.50[illegible]17E 05	9.[illegible]E-01	9.[illegible]E-01	1.[illegible]1078[illegible] 00	2.00[illegible]E 00	45
[illegible]	2.57[illegible] 05	9.99[illegible]E-01	1.[illegible] 00	1.[illegible]125135 00	2.[illegible]25674E 00	[illegible]
[illegible]	2.6502[illegible] 05	9.99[illegible]E-01	1.[illegible]	[illegible]	2.[illegible] 00	[illegible]
[illegible]	2.[illegible]	1.[illegible]	[illegible]E-01	[illegible]	2.[illegible] 00	[illegible]

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	PSI	O2	H2	H2O	N	O	H	OH	
0	0.	1.7242813E-01	2.3318727E-03	5.8209081E-02	7.6076023E-01	4.6433397E-03	5.3208019E-04	1.0952457E-03	0
1	0.	1.7242813E-01	2.3318727E-03	5.8209081E-02	7.6076023E-01	4.6433397E-03	5.3208019E-04	1.0952457E-03	1
1	1.0000000E 00	1.7243632E-01	2.3331355E-03	5.8196326E-02	7.6076013E-01	4.6459115E-03	5.3236830E-04	1.0958242E-03	1
2	7.1727200E 02	1.9691588E-01	5.3471313E-03	3.5262901E-02	7.6041076E-01	1.1715775E-03	5.7982647E-04	3.1183691E-04	2
3	1.4335440E 03	2.0565583E-01	7.0627719E-03	2.5655342E-02	7.6002256E-01	9.1774970E-04	4.4641779E-04	2.3914178E-04	3
4	2.1498160E 03	2.1046714E-01	8.2643721E-03	2.0320653E-02	7.5961787E-01	7.6311228E-04	3.6972235E-04	1.9688174E-04	4
5	2.8660879E 03	2.1361526E-01	9.2559152E-03	1.6789007E-02	7.5920065E-01	6.5364053E-04	3.1731234E-04	1.6790767E-04	5
6	3.5823599E 03	2.1586093E-01	1.0139296E-02	1.4232213E-02	7.5877236E-01	5.7027682E-04	2.7823299E-04	1.4633981E-04	6
7	4.2986319E 03	2.1754768E-01	1.0960483E-02	1.2276830E-02	7.5833364E-01	5.0399355E-04	2.4750866E-04	1.2946731E-04	7
8	5.0149038E 03	2.1885825E-01	1.1743936E-02	1.0724497E-02	7.5788484E-01	4.4974926E-04	2.2247695E-04	1.1581861E-04	8
9	5.7311758E 03	2.1990065E-01	1.2504136E-02	9.4581385E-03	7.5742611E-01	4.0443547E-04	2.0155434E-04	1.0450692E-04	9
10	6.4474478E 03	2.2074360E-01	1.3250330E-02	8.4033459E-03	7.5695757E-01	3.6599012E-04	1.6372608E-04	9.4957561E-05	10
11	7.1637198E 03	2.2143331E-01	1.3988768E-02	7.5101558E-03	7.5647920E-01	3.3297399E-04	1.6830473E-04	8.6777648E-05	11
12	1.4326440E 04	2.2363656E-01	2.1275204E-02	3.4881453E-03	7.5129095E-01	1.7278730E-04	8.8498232E-05	4.7218676E-05	12
13	2.1489159E 04	2.2311530E-01	3.0149934E-02	1.9083975E-03	7.4463898E-01	1.0449027E-04	5.2474127E-05	2.9718740E-05	13
14	2.8651879E 04	2.2092160E-01	4.3322380E-02	1.0286366E-03	7.3461552E-01	6.2453601E-05	3.0158993E-05	1.8438697E-05	14
15	3.5814599E 04	2.1720332E-01	6.1401514E-02	5.4695705E-04	7.2078250E-01	3.6712795E-05	1.6891243E-05	1.1213544E-05	15
16	4.2977319E 04	2.1198753E-01	8.4999793E-02	2.8728963E-04	7.0268731E-01	2.1181754E-05	9.2567960E-06	6.6713377E-06	16
17	5.0140039E 04	2.0525622E-01	1.1461334E-01	1.4923980E-04	6.7995030E-01	1.1995466E-05	4.9794021E-06	3.8837380E-06	17
18	5.7302759E 04	1.9700036E-01	1.5051663E-01	7.6757736E-05	6.5239365E-01	6.6752889E-06	2.6357596E-06	2.2152391E-06	18
19	6.4465478E 04	1.8725705E-01	1.9265015E-01	3.9127098E-05	6.2001628E-01	3.6558446E-06	1.3758609E-06	1.2401433E-06	19
20	7.1628198E 04	1.7613136E-01	2.4072207E-01	1.9786672E-05	5.8312227E-01	1.9737207E-06	7.0959084E-07	6.8265232E-07	20
21	7.8790918E 04	1.6380436E-01	2.9390005E-01	9.9359453E-06	5.4220268E-01	1.0521481E-06	3.6222521E-07	3.7016095E-07	21
22	8.5953637E 04	1.5052856E-01	3.5114597E-01	4.9587200E-06	4.9831840E-01	5.5469911E-07	1.8334686E-07	1.9806940E-07	22
23	9.3116357E 04	1.3661291E-01	4.1113864E-01	2.4616045E-06	4.5224434E-01	2.8967459E-07	9.2217726E-08	1.0474389E-07	23
24	1.0027908E 05	1.2240054E-01	4.7240459E-01	1.2164721E-06	4.0519220E-01	1.5007957E-07	4.6227719E-08	5.4833169E-08	24
25	1.0744180E 05	1.0824274E-01	5.3343242E-01	5.9889696E-07	3.5832289E-01	7.7269643E-08	2.3212022E-08	2.8454636E-08	25
26	1.1460451E 05	9.4473166E-02	5.9278545E-01	2.9395739E-07	3.1273579E-01	3.9606067E-08	1.1782823E-08	1.4656261E-08	26
27	1.2176723E 05	8.1385354E-02	6.4919914E-01	1.4394731E-07	2.6951409E-01	2.0255523E-08	6.1508288E-09	7.5020223E-09	27
28	1.2892995E 05	6.9215671E-02	7.0165417E-01	7.0373376E-08	2.2912805E-01	1.0363976E-08	3.3992522E-09	3.8204193E-09	28
29	1.3609267E 05	5.8134087E-02	7.4942068E-01	3.4372603E-08	1.9244397E-01	5.3246766E-09	2.0696974E-09	1.9377525E-09	29
30	1.4325539E 05	4.8238721E-02	7.9207323E-01	1.6785260E-08	1.5966860E-01	2.7603292E-09	1.4376511E-09	9.8000078E-10	30
31	1.5041811E 05	3.9560969E-02	8.2947737E-01	8.2024444E-09	1.3096047E-01	1.4530456E-09	1.1451543E-09	4.9475569E-10	31
32	1.5758083E 05	3.2068956E-02	8.6177056E-01	4.0106483E-09	1.0615930E-01	7.8204315E-10	1.0161373E-09	2.4939254E-10	32
33	1.6474355E 05	2.5757832E-02	8.8697371E-01	1.9789019E-09	8.5267308E-02	4.3650976E-10	9.6511177E-10	1.2657504E-10	33
34	1.7190627E 05	2.0312295E-02	9.1244580E-01	9.6066356E-10	6.7249702E-02	2.4943069E-10	9.4938618E-10	6.3133889E-11	34
35	1.7906899E 05	1.5729430E-02	9.3219967E-01	4.5934339E-10	5.2069337E-02	1.4699735E-10	9.4983851E-10	3.0965446E-11	35
36	1.8623171E 05	1.1963183E-02	9.4643355E-01	2.1629373E-10	3.9602[illegible]E-02	6.9673252E-11	9.5672680E-10	1.4942730E-11	36
37	1.9339442E 05	8.9380901E-03	9.6147281E-01	1.0036110E-10	2.9588161E-02	5.6587127E-11	9.6531394E-10	7.0979680E-12	37
38	2.0055714E 05	6.5015138E-03	9.7171674E-01	4.5995533E-11	2.17[illegible]E-02	3.6714096E-11	9.7346995E-10	3.3203261E-12	38
39	2.0771986E 05	4.7340618E-03	9.7959373E-01	2.0705822E-11	1.5[illegible]1377E-02	2.4284335E-11	9.8038259E-10	1.5301919E-12	39
40	2.1488258E 05	3.3578262E-03	9.8552585E-01	9.2127912E-12	1.1115562E-02	1.6232422E-11	9.8587583E-10	6.9502220E-13	40
41	2.2204530E 05	2.3422160E-03	9.8990355E-01	4.0448989E-12	7.7535424E-03	1.0882398E-11	9.9005669E-10	3.1125132E-13	41
42	2.2920802E 05	1.6074719E-03	9.9307061E-01	1.7531144E-12	5.3212861E-03	7.2758130E-12	9.9313670E-10	1.3749273E-13	42
43	2.3637074E 05	1.0861620E-03	9.9531772E-01	7.5051519E-13	3.5955707E-03	4.8328910E-12	9.9534583E-10	5.9551716E-14	43
44	2.4353346E 05	7.2314595E-04	9.9688252E-01	3.1784305E-13	2.3938624E-03	3.1821694E-12	9.9689430E-10	2.5846304E-14	44
45	2.5069617E 05	4.7508335E-04	9.9795183E-01	1.3395648E-13	1.5726897E-03	2.0756709E-12	9.9795673E-10	1.1086348E-14	45
46	2.5785889E 05	3.1211149E-04	9.9865437E-01	5.7991482E-14	1.0331966E-03	1.3575900E-12	9.9865642E-10	4.8850116E-15	46
47	2.6502161E 05	2.2448523E-04	9.9903212E-01	3.0545022E-14	7.4312350E-04	9.7417307E-13	9.9903315E-10	2.6128370E-15	47
48	2.7218433E 05	-0.	1.0000000E 00	-0.	-0.	-0.	1.[illegible]00000E-09	-0.	48

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TURBULENT [illegible] ANALYSIS
[illegible] - H. ROSENBAUM
PROGRAMMER - B. PELLOW

CHECK OF [illegible] FOR H2 [illegible] OF 27.3/65 6/25/65

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COARSE PSI STEP=   71[illegible].72   INITIAL CSI= 0.            FINAL CSI= 0.25E 06       CSI STEP TOLERANCE=   0.20000E 04
INITIAL PHI=       [illegible]590     ZETA DELTA=   6321.010     HE=   0.9183300E 08       CSI STEP=     0.5000E 05
FINE PSI STEP=          1.000     WALL TEMP TOL= 0.05000     D-BAR TOL= 1.00E-03       PSI ONE=            1.000
DELTA=                   -0.

PRANDTL NUMBER=  1.00          SCHMIDT NUMBER= 1.00       TE=      500.00              UE=     5569.07
RHO E=  0.9525000E-04          MU E=  0.2820000E-06       TR=      300.00              DD CHI LOG SIG= -0.

MAX NO. OF CSI CUTBACKS=     5      MAX NO. OF CSI STEPS BEFORE DOUBLING=  500
NO OF SPECIES COARSE PSI POINTS=   38      NO. OF C[illegible] POINTS=   38      NO. OF FINE PSI POINTS=   10
NO. OF SPECIES=    7      MAX NO. OF WALL TEMP IT[illegible]     5      PRINT CYCLE NUMBER=    1

THE WALL TEMPERATURE FUNCTION VERSUS X IS
          1000.0000+     -0.     X FOR X LESS THAN       .2400000E 08
          1000.0000+     -0.     X FOR X GREATER THAN    .2400000E 08

THE FOLLOWING VALUES OF CP ARE FOR THE SEVEN SPECIES
      O2           H2            H2O            H              O              H              OH
 9.8692999E 03  1.[illegible] 05  2.0[illegible] 04  [illegible] 06  [illegible] 04  2.22[illegible] 04  1.[illegible]

THE FOLLOWING ARE VALUES OF [illegible] FOR THE SAME SEVEN SPECIES

 2.4394000E 06  4.5514[illegible] 07  [illegible]  [illegible]  4.5534999E 06  6.6617[illegible] 07  [illegible]

THE FOLLOWING ARE MOLECULAR WEIGHTS FOR THE SAME SPECIES
 3.2000000E 01  2.[illegible]  1.[illegible]  [illegible]  1.[illegible] 01  1.00[illegible] 00  1.7000000E 1
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	ZETA	I-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	1.4142136E 00	0.	0.	4.9299954E-02	6.5935450E-06	1
1	1.4142136E 00	1.0000000E 00	0.	4.9299954E-02	6.5935450E-06	1
2	6.0197033E 01	2.4729335E 01	0.	5.1792775E-01	2.7555914E-04	2
3	1.0608165E 02	4.3487377E 01	0.	5.6592359E-01	4.6740514E-04	3
4	1.4904790E 02	6.0963603E 01	0.	5.9473017E-01	6.4669684E-04	4
5	1.9028592E 02	7.7647948E 01	0.	6.1542158E-01	8.1849784E-04	5
6	2.3031616E 02	9.3754691E 01	0.	6.3159497E-01	9.8507150E-04	6
7	2.6942801E 02	1.0940300E 02	0.	6.4488168E-01	1.1477065E-03	7
8	3.0780441E 02	1.2466820E 02	0.	6.5616203E-01	1.3072349E-03	8
9	3.4557066E 02	1.3960191E 02	0.	6.6596580E-01	1.4642386E-03	9
10	3.8281768E 02	1.5424157E 02	0.	6.7463692E-01	1.6191476E-03	10
11	4.1961415E 02	1.6861547E 02	0.	6.8241138E-01	1.7722930E-03	11
12	7.7091626E 02	3.0108282E 02	0.	7.3393611E-01	3.2474076E-03	12
13	1.1035730E 03	3.3138716E 02	0.	7.6721488E-01	4.6811404E-03	13
14	1.4225208E 03	3.3138716E 02	0.	7.9829330E-01	6.1223074E-03	14
15	1.7297811E 03	3.3138715E 02	0.	8.2673522E-01	7.6130989E-03	15
16	2.0271069E 03	3.3138716E 02	0.	8.5257767E-01	9.1978717E-03	16
17	2.3159764E 03	3.3138716E 02	0.	8.7589122E-01	1.0922630E-02	17
18	2.5976458E 03	3.3138716E 02	0.	8.9676582E-01	1.2834360E-02	18
19	2.8731906E 03	3.3138716E 02	0.	9.1530268E-01	1.4979612E-02	19
20	3.1435389E 03	3.3138715E 02	0.	9.3160985E-01	1.7402597E-02	20
21	3.4094980E 03	3.3138716E 02	0.	9.4579995E-01	2.0143111E-02	21
22	3.6717747E 03	3.3138716E 02	0.	9.5798949E-01	2.3234566E-02	22
23	3.9309914E 03	3.3138716E 02	0.	9.6829901E-01	2.6702358E-02	23
24	4.1876976E 03	3.3138716E 02	0.	9.7685386E-01	3.0562771E-02	24
25	4.4423802E 03	3.3138716E 02	0.	9.8378547E-01	3.4822519E-02	25
26	4.6954693E 03	3.3138716E 02	0.	9.8923291E-01	3.9478925E-02	26
27	4.9473429E 03	3.3138716E 02	0.	9.9334474E-01	4.4520677E-02	27
28	5.1983295E 03	3.3138716E 02	0.	9.9628100E-01	4.9929031E-02	28
29	5.4487092E 03	3.3138716E 02	0.	9.9821541E-01	5.5679311E-02	29
30	5.6987122E 03	3.3138716E 02	0.	9.9933749E-01	6.1742503E-02	30
31	5.9485174E 03	3.3138716E 02	0.	9.9985478E-01	6.8086845E-02	31
32	6.1982484E 03	3.3138716E 02	0.	9.9999467E-01	7.4679253E-02	32
33	6.4479609E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	8.1485101E-02	33
34	6.6976557E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	8.8472813E-02	34
35	6.9473504E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	9.5616058E-02	35
36	7.1970452E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.0288879E-01	36
37	7.4467400E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.1026685E-01	37
38	7.6964347E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.1772870E-01	38
39	7.9461295E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.2525575E-01	39
40	8.1958241E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.3283250E-01	40
41	8.4455189E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.4044635E-01	41
42	8.6952136E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.4808735E-01	42
43	8.9449083E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.5574781E-01	43
44	9.1946030E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.6342194E-01	44
45	9.4442977E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.7110551E-01	45
46	9.6939924E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.7879570E-01	46
47	9.9436871E 03	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.8649140E-01	47
48	1.0193382E 04	3.3138716E 02	3.3138716E 02	9.9999998E-01	1.9419191E-01	48

CSI = 0.49999999E 05

	PSI	G	TEMP	RHO	W	
0	0.	1.3112673E-01	2.0000000E 00	6.4943712E 00	2.5977484E 01	0
1	1.0000000E 00	1.3923465E-01	2.1175493E 00	6.1338278E 00	2.5977365E 01	1
1	1.0000000E 00	1.3923465E-01	2.1175493E 00	6.1338277E 00	2.5977365E 01	1
2	7.1727200E 02	1.6130753E-01	1.7506490E 00	7.3259623E 00	2.5550378E 01	2
3	1.4335440E 03	1.6974300E-01	1.7291037E 00	7.3453674E 00	2.5401803E 01	3
4	2.1498160E 03	1.7514341E-01	1.7107710E 00	7.3598875E 00	2.5182164E 01	4
5	2.8660879E 03	1.7919833E-01	1.6944769E 00	7.3702561E 00	2.4977458E 01	5
6	3.5823599E 03	1.8249318E-01	1.6797032E 00	7.3767532E 00	2.4781512E 01	6
7	4.2986319E 03	1.8530027E-01	1.6661062E 00	7.3798093E 00	2.4591092E 01	7
8	5.0149038E 03	1.8776855E-01	1.6534460E 00	7.3798374E 00	2.4404325E 01	8
9	5.7311758E 03	1.8998847E-01	1.6415499E 00	7.3771914E 00	2.4220055E 01	9
10	6.4474478E 03	1.9201912E-01	1.6302900E 00	7.3721665E 00	2.4037538E 01	10
11	7.1637198E 03	1.9390118E-01	1.6195692E 00	7.3650104E 00	2.3856287E 01	11
12	1.4326440E 04	2.0814324E-01	1.5240732E 00	7.2359710E 00	2.2114187E 01	12
13	2.1489159E 04	2.2070513E-01	1.4514296E 00	6.9777406E 00	2.0255398E 01	13
14	2.8651879E 04	2.3610486E-01	1.3691632E 00	6.5728586E 00	1.7998633E 01	14
15	3.5814599E 04	2.5473979E-01	1.2908386E 00	6.0472087E 00	1.5611941E 01	15
16	4.2977319E 04	2.7703686E-01	1.2219477E 00	5.4475812E 00	1.3313319E 01	16
17	5.0140039E 04	3.0336613E-01	1.1649726E 00	4.8252578E 00	1.1242586E 01	17
18	5.7302759E 04	3.3395256E-01	1.1200022E 00	4.2247847E 00	9.4635365E 00	18
19	6.4465478E 04	3.6880682E-01	1.0857034E 00	3.6768468E 00	7.9839302E 00	19
20	7.1628198E 04	4.0768350E-01	1.0601773E 00	3.1971174E 00	6.7790224E 00	20
21	7.8790918E 04	4.5007150E-01	1.0415087E 00	2.7892891E 00	5.8101377E 00	21
22	8.5953637E 04	4.9521706E-01	1.0280319E 00	2.4494523E 00	5.0362306E 00	22
23	9.3116357E 04	5.4217565E-01	1.0134106E 00	2.1699122E 00	4.4197231E 00	23
24	1.0027908E 05	5.8988515E-01	1.0116222E 00	1.9417840E 00	3.9287035E 00	24
25	1.0744180E 05	6.3724929E-01	1.0069057E 00	1.7564597E 00	3.5371784E 00	25
26	1.1460451E 05	6.8322067E-01	1.0037029E 00	1.6062835E 00	3.2244628E 00	26
27	1.2176723E 05	7.2687334E-01	1.0016057E 00	1.4847593E 00	2.9742869E 00	27
28	1.2892995E 05	7.6745788E-01	1.0003140E 00	1.3865172E 00	2.7739052E 00	28
29	1.3609267E 05	8.0443555E-01	9.9960265E-01	1.3071782E 00	2.6133176E 00	29
30	1.4325539E 05	8.3749069E-01	9.9929742E-01	1.2431903E 00	2.4846337E 00	30
31	1.5041811E 05	8.6652144E-01	9.9925674E-01	1.1916758E 00	2.3815802E 00	31
32	1.5758083E 05	8.9161017E-01	9.9935821E-01	1.1503064E 00	2.2991364E 00	32
33	1.6474355E 05	9.1292509E-01	9.9949012E-01	1.1172865E 00	2.2334336E 00	33
34	1.7190627E 05	9.3117503E-01	9.9959691E-01	1.0904812E 00	2.1800833E 00	34
35	1.7906899E 05	9.4654139E-01	9.9968166E-01	1.0688889E 00	2.1370974E 00	35
36	1.8623171E 05	9.5920248E-01	9.9974904E-01	1.0517303E 00	2.1029327E 00	36
37	1.9339442E 05	9.6940545E-01	9.9980240E-01	1.0382986E 00	2.0761868E 00	37
38	2.0055714E 05	9.7745011E-01	9.9984409E-01	1.0279477E 00	2.0555749E 00	38
39	2.0771986E 05	9.8365959E-01	9.9987597E-01	1.0200982E 00	2.0399433E 00	39
40	2.1488258E 05	9.8835428E-01	9.9989961E-01	1.0142426E 00	2.0282816E 00	40
41	2.2204530E 05	9.9183263E-01	9.9991632E-01	1.0099473E 00	2.0197257E 00	41
42	2.2920802E 05	9.9435911E-01	9.9992738E-01	1.0068502E 00	2.0135542E 00	42
43	2.3637074E 05	9.9615846E-01	9.9993360E-01	1.0046560E 00	2.0091786E 00	43
44	2.4353346E 05	9.9741645E-01	9.9993730E-01	1.0031276E 00	2.0061294E 00	44
45	2.5069617E 05	9.9829118E-01	9.9995393E-01	1.0020677E 00	2.0040432E 00	45
46	2.5785889E 05	9.9893851E-01	1.0000392E 00	1.0012857E 00	2.0026500E 00	46
47	2.6502161E 05	9.9949906E-01	1.0012373E 00	1.0006108E 00	2.0016965E 00	47
48	2.7218433E 05	9.9987735E-01	1.0000551E 00	1.0001524E 00	2.0004151E 00	48

LE = 47LS= 48

	PSI	O2	H2	H2O	N	O	H	OH	
0	0.	1.8822571E-01	4.7375542E-03	4.2785216E-02	7.6027902E-01	2.7993284E-03	4.9970016E-04	6.7333649E-04	0
1	0.	1.8822998E-01	4.7382050E-03	4.2781042E-02	7.6027889E-01	2.7988296E-03	4.9969140E-04	6.7322235E-04	1
1	1.0000000E 00	1.8822998E-01	4.7382051E-03	4.2781044E-02	7.6027889E-01	2.7988296E-03	4.9969140E-04	6.7322236E-04	1
2	7.1727200E 02	2.0016250E-01	6.5552948E-03	3.1134416E-02	7.5991536E-01	1.4033176E-03	4.7500355E-04	3.5393717E-04	2
3	1.4335440E 03	2.0628019E-01	7.8779804E-03	2.4637491E-02	7.5951173E-01	1.0228613E-03	4.0859315E-04	2.6090747E-04	3
4	2.1498160E 03	2.1025431E-01	8.9664977E-03	2.0297430E-02	7.5909123E-01	8.2423226E-04	3.5498704E-04	2.1101153E-04	4
5	2.8660879E 03	2.1308115E-01	9.9264493E-03	1.7147870E-02	7.5865803E-01	6.9527169E-04	3.1255739E-04	1.7831766E-04	5
6	3.5823599E 03	2.1519921E-01	1.0809107E-02	1.4742701E-02	7.5821370E-01	6.0195727E-04	2.7831661E-04	1.5463307E-04	6
7	4.2986319E 03	2.1684110E-01	1.1642882E-02	1.2840143E-02	7.5775895E-01	5.3002068E-04	2.5009498E-04	1.3641447E-04	7
8	5.0149038E 03	2.1814441E-01	1.2444988E-02	1.1295504E-02	7.5729418E-01	4.7225412E-04	2.2640531E-04	1.2183246E-04	8
9	5.7311758E 03	2.1919672E-01	1.3226542E-02	1.0016039E-02	7.5681965E-01	4.2453964E-04	2.0621544E-04	1.0982699E-04	9
10	6.4474478E 03	2.2005686E-01	1.3995075E-02	8.9392055E-03	7.5633556E-01	3.8430871E-04	1.8879154E-04	9.9731723E-05	10
11	7.1637198E 03	2.2076593E-01	1.4755872E-02	8.0211463E-03	7.5584200E-01	3.4985031E-04	1.7359904E-04	9.1101592E-05	11
12	1.4326440E 04	2.2313452E-01	2.2252077E-02	3.7748882E-03	7.5051274E-01	1.8277714E-04	9.2767164E-05	4.9582896E-05	12
13	2.1489159E 04	2.2267382E-01	3.1340158E-02	2.0800133E-03	7.4370769E-01	1.1077866E-04	5.5614145E-05	3.1204510E-05	13
14	2.8651879E 04	2.2049234E-01	4.4743935E-02	1.1313495E-03	7.3351321E-01	6.6531114E-05	3.2367704E-05	1.9439272E-05	14
15	3.5814599E 04	2.1676067E-01	6.3055751E-02	6.0732551E-04	7.1950571E-01	3.9381541E-05	1.8356554E-05	1.1902821E-05	15
16	4.2977319E 04	2.1152283E-01	8.6855597E-02	3.2202231E-04	7.0125834E-01	2.2913704E-05	1.0181475E-05	7.1421297E-06	16
17	5.0140039E 04	2.0477460E-01	1.1660555E-01	1.6881889E-04	6.7842717E-01	1.3096684E-05	5.5397202E-06	4.1973830E-06	17
18	5.7302759E 04	1.9651767E-01	1.5255038E-01	8.7590455E-05	6.5083054E-01	7.3577436E-06	2.9641657E-06	2.4178422E-06	18
19	6.4465478E 04	1.8679632E-01	1.9464033E-01	4.5020077E-05	6.1851020E-01	4.0677468E-06	1.5630305E-06	1.3669763E-06	19
20	7.1628198E 04	1.7571889E-01	2.4248603E-01	2.2943779E-05	5.8176718E-01	2.2161588E-06	8.1374243E-07	7.5973898E-07	20
21	7.8790918E 04	1.6346574E-01	2.9535219E-01	1.1604129E-05	5.4116724E-01	1.1915928E-06	4.1899310E-07	4.1576576E-07	21
22	8.5953637E 04	1.5028506E-01	3.5219162E-01	5.8292661E-06	4.9751524E-01	6.3325586E-07	2.1373506E-07	2.2439418E-07	22
23	9.3116357E 04	1.3647872E-01	4.1171499E-01	2.9108494E-06	4.5180164E-01	3.3311626E-07	1.0823024E-07	1.1962478E-07	23
24	1.0027908E 05	1.2238119E-01	4.7248691E-01	1.4459984E-06	4.0512894E-01	1.7371008E-07	5.4549532E-08	6.3082504E-08	24
25	1.0744180E 05	1.0833480E-01	5.3303508E-01	7.1512805E-07	3.5862803E-01	8.9937992E-08	2.7484897E-08	3.2950946E-08	25
26	1.1460451E 05	9.4665123E-02	5.9195777E-01	3.5235685E-07	3.1337543E-01	4.6312066E-08	1.3953528E-08	1.7070778E-08	26
27	1.2176723E 05	8.1659418E-02	6.4801767E-01	1.7308975E-07	2.7032144E-01	2.3765601E-08	7.2432234E-09	8.7818559E-09	27
28	1.2892995E 05	6.9550233E-02	7.0021287E-01	8.4830691E-08	2.3023555E-01	1.2184078E-08	3.9442913E-09	4.4911821E-09	28
29	1.3609267E 05	5.8505350E-02	7.4782036E-01	4.1508527E-08	1.9367302E-01	6.2610509E-09	2.3394043E-09	2.2858909E-09	29
30	1.4325539E 05	4.8624297E-02	7.9041122E-01	2.0293402E-08	1.6096326E-01	3.2390276E-09	1.5699468E-09	1.1591831E-09	30
31	1.5041811E 05	3.9941302E-02	8.2783793E-01	9.9209735E-09	1.3221951E-01	1.6966366E-09	1.2093534E-09	5.8631499E-10	31
32	1.5758083E 05	3.2434371E-02	8.6019547E-01	4.8529900E-09	1.0736897E-01	9.0614246E-10	1.0469096E-09	2.9606237E-10	32
33	1.6474355E 05	2.6054963E-02	8.8769296E-01	2.3834464E-09	8.6250918E-02	4.9346997E-10	9.7939011E-10	1.4977650E-10	33
34	1.7190627E 05	2.0592043E-02	9.1124007E-01	1.1616982E-09	6.8166765E-02	2.8160193E-10	9.5591142E-10	7.5054238E-11	34
35	1.7906899E 05	1.5991992E-02	9.3106793E-01	5.5939796E-10	5.2939007E-02	1.6396432E-10	9.5255957E-10	3.7099642E-11	35
36	1.8623171E 05	1.2201798E-02	9.4740504E-01	2.6571054E-10	4.0392159E-02	9.8745608E-11	9.5760071E-10	1.8065635E-11	36
37	1.9339442E 05	9.1476010E-03	9.6056974E-01	1.2444658E-10	3.0281714E-02	6.1510075E-11	9.6533743E-10	8.6640580E-12	37
38	2.0055714E 05	6.7396290E-03	9.7094898E-01	5.7472950E-11	2.2310495E-02	3.9459103E-11	9.7314671E-10	4.0929986E-12	38
39	2.0771986E 05	4.8810437E-03	9.7896019E-01	2.6178376E-11	1.6157937E-02	2.5874955E-11	9.7995902E-10	1.9052051E-12	39
40	2.1488258E 05	3.4758160E-03	9.8501725E-01	1.1763593E-11	1.1506149E-02	1.7196991E-11	9.8546495E-10	8.7411904E-13	40
41	2.2204530E 05	2.4345216E-03	9.8950566E-01	5.2166159E-12	8.0591058E-03	1.1494186E-11	9.8970361E-10	3.9544739E-13	41
42	2.2920802E 05	1.6779388E-03	9.9276687E-01	2.2837352E-12	5.5545560E-03	7.6784070E-12	9.9285319E-10	1.7647383E-13	42
43	2.3637074E 05	1.1387075E-03	9.9509122E-01	9.8752526E-13	3.7695144E-03	5.1044056E-12	9.9512833E-10	7.7735314E-14	43
44	2.4353346E 05	7.6154990E-04	9.9671693E-01	4.2235980E-13	2.5209927E-03	3.3678765E-12	9.9673272E-10	3.3849322E-14	44
45	2.5069617E 05	5.0284721E-04	9.9783214E-01	1.7957050E-13	1.6645976E-03	2.2043359E-12	9.9783875E-10	1.4648199E-14	45
46	2.5785889E 05	3.2978067E-04	9.9857819E-01	7.7475106E-14	1.0916877E-03	1.4376554E-12	9.9858098E-10	6.4334100E-15	46
47	2.6502161E 05	2.1121376E-04	9.9908934E-01	3.5475878E-14	6.9919035E-04	9.1793249E-13	9.9909056E-10	2.9945700E-15	47
48	2.7218433E 05	5.1711745E-05	9.9977703E-01	8.6856066E-15	1.7118370E-04	2.2473863E-13	9 77733E-10	7.3316456E-16	48

	ZETA	I-VIS	E-VIS	U-BAR	Y CO-ORDINATE	
1	1.4142136E 00	0.	0.	4.9283874E-02	6.8922613E-06	1
1	1.4142136E 00	1.0000000E 00	0.	4.9283875E-02	6.8922613E-06	1
2	6.0197033E 01	2.4729533E 01	0.	5.1775882E-01	2.7757867E-04	2
3	1.0608165E 02	4.3488144E 01	0.	5.6573901E-01	4.6990218E-04	3
4	1.4904790E 02	6.0965310E 01	0.	5.9453619E-01	6.4957789E-04	4
5	1.9028592E 02	7.7650963E 01	0.	6.1522086E-01	8.2173501E-04	5
6	2.3031616E 02	9.3759387E 01	0.	6.3138897E-01	9.8865882E-04	6
7	2.6942801E 02	1.0940974E 02	0.	6.4467135E-01	1.1516474E-03	7
8	3.0780441E 02	1.2467736E 02	0.	6.5594802E-01	1.3115378E-03	8
9	3.4557066E 02	1.3961385E 02	0.	6.6574858E-01	1.4689139E-03	9
10	3.8281768E 02	1.5425666E 02	0.	6.7441688E-01	1.6242071E-03	10
11	4.1961415E 02	1.6863408E 02	0.	6.8218881E-01	1.7777487E-03	11
12	7.7091626E 02	3.0115681E 02	0.	7.3369673E-01	3.2574247E-03	12
13	1.1035878E 03	3.3266641E 02	0.	7.6687002E-01	4.6971697E-03	13
14	1.4225936E 03	3.3266641E 02	0.	7.9784567E-01	6.1461480E-03	14
15	1.7299386E 03	3.3266641E 02	0.	8.2620825E-01	7.6463599E-03	15
16	2.0273647E 03	3.3266641E 02	0.	8.5199330E-01	9.2418548E-03	16
17	2.3163421E 03	3.3266641E 02	0.	8.7526977E-01	1.0978072E-02	17
18	2.5981205E 03	3.3266641E 02	0.	8.9612594E-01	1.2901196E-02	18
19	2.8737706E 03	3.3266641E 02	0.	9.1466136E-01	1.5056800E-02	19
20	3.1442168E 03	3.3266641E 02	0.	9.3098240E-01	1.7488041E-02	20
21	3.4102634E 03	3.3266641E 02	0.	9.4520003E-01	2.0233694E-02	21
22	3.6726147E 03	3.3266641E 02	0.	9.5742905E-01	2.3326279E-02	22
23	3.9318911E 03	3.3266641E 02	0.	9.6778822E-01	2.6790521E-02	23
24	4.1886410E 03	3.3266641E 02	0.	9.7640095E-01	3.0642307E-02	24
25	4.4433498E 03	3.3266641E 02	0.	9.8339659E-01	3.4888253E-02	25
26	4.6964474E 03	3.3266641E 02	0.	9.8891193E-01	3.9525873E-02	26
27	4.9483115E 03	3.3266641E 02	0.	9.9309288E-01	4.4544294E-02	27
28	5.1992711E 03	3.3266641E 02	0.	9.9609662E-01	4.9925399E-02	28
29	5.4496073E 03	3.3266641E 02	0.	9.9809356E-01	5.5645267E-02	29
30	5.6995519E 03	3.3266641E 02	0.	9.9926949E-01	6.1675699E-02	30
31	5.9492871E 03	3.3266641E 02	0.	9.9982775E-01	6.7985752E-02	31
32	6.1989397E 03	3.3266641E 02	0.	9.9999110E-01	7.4543006E-02	32
33	6.4485732E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	8.1314180E-02	33
34	6.6981866E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	8.8267823E-02	34
35	6.9477999E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	9.5376979E-02	35
36	7.1974133E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.0261579E-01	36
37	7.4470266E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.0996038E-01	37
38	7.6966400E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.1738938E-01	38
39	7.9462533E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.2488433E-01	39
40	8.1958666E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.3242972E-01	40
41	8.4454799E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.4001291E-01	41
42	8.6950932E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.4762389E-01	42
43	8.9447064E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.5525488E-01	43
44	9.1943197E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.6290001E-01	44
45	9.4439330E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.7055501E-01	45
46	9.6935463E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.7821705E-01	46
47	9.9431596E 03	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.8588466E-01	47
48	1.0192773E 04	3.3266641E 02	3.3266641E 02	9.9999999E-01	1.9355661E-01	48

X CO-ORDINATE= [illegible].1396830E 05   PHI= 0.28695258E 02   ZETA DELTA= 0.63454030E 04

[illegible]   SIGMA OVER [illegible] = 0.17593736E 07   [illegible] 12-TH [illegible] SQUARE FT-SEC

CF= [illegible]

```
LOWEST COMMON USED     56253

        EXECUTION
           TURBULENT  TRANSPORT  ANALYSIS
                ORIGINATOR -    H. ROSENBAUM
                PROGRAMMER -  H. BELLOW

 CHECK RUN FOR NEW H2 VERSION    6/18/65

COARSE PSI STEP=   1061.66   INITIAL CSI=-0.          FINAL CSI= 0.55E 06      CSI STEP TOLERANCE=   0.20000E 04

INITIAL PHI=      24.25400   ZETA DELTA=   1012.480   HE=   0.3577000E 07      CSI STEP=     0.1000E 06

FINE PSI STEP=       0.100   WALL TEMP TOL= 0.05000   D-BAR TOL= 1.00E-03      PSI ONE=            0.100

DELTA=                 -0.

PRANDTL NUMBER=  1.00        SCHMIDT NUMBER= 1.00     TE=       121.63         UE=     2138.85

RHO L=  0.4223000E-03        MU E=  0.1758700E-06     TR=       300.00         DU CHI LOG SIG= -0.

MAX NO. OF CSI CUTBACKS=    5     MAX NO. OF CSI STEPS BEFORE DOUBLING=  500

NO OF SPECIES COARSE PSI POINTS=   20     NO. OF COARSE G POINTS=   20     NO. OF FINE PSI POINTS=   20

NO. OF SPECIES=    7     MAX NO. OF WALL TEMP ITERATIONS=    5     PRINT CYCLE NUMBER=    1

THE WALL TEMPERATURE FUNCTION VERSVS X IS
             305.8100+     -0.     X FOR X LESS THAN      0.2400000E 08
             305.8100+     -0.     X FOR X GREATER THAN   0.2400000E 08

THE FOLLOWING VALUES OF CP ARE FOR THE SEVEN SPECIES
       O2             H2             H2O             N              O              H              OH
 9.8692999E 03  1.5406000E 05  2.0075000E 04  1.1195000E 04  1.4738000E 04  2.2206000E 04  1.8908000E 04

THE FOLLOWING ARE VALUES OF DEL FOR THE SAME SEVEN SPECIES

 2.9394000E 06  4.5514000E 07  5.9559000E 06  3.3535000E 06  4.5534999E 06  6.6617000E 07  5.6188000E 06

THE FOLLOWING ARE MOLECULAR WEIGHTS FOR THE SAME SPECIES
 3.2000000E 01  2.0000000E 00  1.8000000E 01  2.8000000E 01  1.6000000E 01  1.0000000E 00  1.7000000E 01
```

CSI =-[illegible].

	PSI	G	TEMP	RHO	W	
0	0.	9.2811751E-01	2.5142025E 00	3.9774043E-01	2.8836251E 01	0
1	1.0000000E-01	9.2811751E-01	2.5136155E 00	3.9783332E-01	2.8836251E 01	1
1	1.0000000E-01	9.2362000E-01	2.5014693E 00	3.9976505E-01	2.8836251E 01	1
2	2.9040000E 00	9.2991699E-01	2.5020160E 00	3.9967770E-01	2.8836251E 01	2
3	5.7079999E 00	9.3302499E-01	2.4939503E 00	4.0097029E-01	2.8836251E 01	3
4	8.5119998E 00	9.3542299E-01	2.4839672E 00	4.0258180E-01	2.8836251E 01	4
5	1.1316000E 01	9.3744799E-01	2.4729767E 00	4.0437097E-01	2.8836251E 01	5
6	1.4120000E 01	9.3923399E-01	2.4613409E 00	4.0628261E-01	2.8836251E 01	6
7	1.6923999E 01	9.4085099E-01	2.4492486E 00	4.0828849E-01	2.8836251E 01	7
8	1.9727999E 01	9.4233799E-01	2.4368051E 00	4.1037340E-01	2.8836251E 01	8
9	2.2531999E 01	9.4372199E-01	2.4240836E 00	4.1252702E-01	2.8836251E 01	9
10	2.5335999E 01	9.4502300E-01	2.4111379E 00	4.1474193E-01	2.8836251E 01	10
11	2.8139999E 01	9.4625399E-01	2.3980031E 00	4.1701363E-01	2.8836251E 01	11
12	3.0943999E 01	9.4742399E-01	2.3847036E 00	4.1933932E-01	2.8836251E 01	12
13	3.3747998E 01	9.4854299E-01	2.3712664E 00	4.2171558E-01	2.8836251E 01	13
14	3.6551998E 01	9.4961599E-01	2.3577049E 00	4.2414128E-01	2.8836251E 01	14
15	3.9355998E 01	9.5064899E-01	2.3440355E 00	4.2661470E-01	2.8836251E 01	15
16	4.2159998E 01	9.5164599E-01	2.3302688E 00	4.2913504E-01	2.8836251E 01	16
17	4.4963998E 01	9.5260999E-01	2.3164129E 00	4.3170196E-01	2.8836251E 01	17
18	4.7767998E 01	9.5354400E-01	2.3024761E 00	4.3431503E-01	2.8836251E 01	18
19	5.0571998E 01	9.5445099E-01	2.2884663E 00	4.3697387E-01	2.8836251E 01	19
20	5.3375998E 01	9.5533400E-01	2.2743918E 00	4.3967799E-01	2.8836251E 01	20
21	5.6179997E 01	9.5619298E-01	2.2602524E 00	4.4242847E-01	2.8836251E 01	21
22	1.1178400E 03	9.7266400E-01	1.9079621E 00	5.2411942E-01	2.8836251E 01	22
23	2.1795000E 03	9.7707498E-01	1.7873285E 00	5.5949423E-01	2.8836251E 01	23
24	3.2411600E 03	9.8050300E-01	1.6859444E 00	5.9313936E-01	2.8836251E 01	24
25	4.3028200E 03	9.8357400E-01	1.5894376E 00	6.2915337E-01	2.8836251E 01	25
26	5.3644800E 03	9.8630599E-01	1.4990283E 00	6.6709881E-01	2.8836251E 01	26
27	6.4261400E 03	9.8872199E-01	1.4155617E 00	7.0643334E-01	2.8836251E 01	27
28	7.4877999E 03	9.9084098E-01	1.3395824E 00	7.4650131E-01	2.8836251E 01	28
29	8.5494598E 03	9.9268500E-01	1.2714179E 00	7.8652348E-01	2.8836251E 01	29
30	9.6111197E 03	9.9427099E-01	1.2112006E 00	8.2562704E-01	2.8836251E 01	30
31	1.0672780E 04	9.9561899E-01	1.1589181E 00	8.6287373E-01	2.8836251E 01	31
32	1.1734440E 04	9.9674599E-01	1.1144158E 00	8.9733113E-01	2.8836251E 01	32
33	1.2796099E 04	9.9766899E-01	1.0774174E 00	9.2814538E-01	2.8836251E 01	33
34	1.3857759E 04	9.9840599E-01	1.0475347E 00	9.5462233E-01	2.8836251E 01	34
35	1.4919419E 04	9.9897400E-01	1.0242658E 00	9.7630912E-01	2.8836251E 01	35
36	1.5981079E 04	9.9939299E-01	1.0070066E 00	9.9304219E-01	2.8836251E 01	36
37	1.7042739E 04	9.9968199E-01	9.9503844E-01	1.0049863E 00	2.8836251E 01	37
38	1.8104399E 04	9.9986299E-01	9.8753611E-01	1.0126212E 00	2.8836251E 01	38
39	1.9166059E 04	9.9995799E-01	9.8355567E-01	1.0167193E 00	2.8836251E 01	39
40	2.0227719E 04	1.0000000E 00	9.8265954E-01	1.0182682E 00	2.8836251E 01	40

LE= 40LS= 40

PSI	O2	H2	H2O	N	O	H	OH
0.	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	0
0.	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	1
1.0000000E-01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	1
2.9040000E 00	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	2
5.7079999E 00	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	3
8.5119998E 00	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	4
1.1316000E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	5
1.4120000E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	6
1.6923999E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	7
1.9727999E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	8
2.2531999E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	9
2.5335999E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	10
2.8139999E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	11
3.0943999E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	12
3.3747998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	13
3.6551998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	14
3.9355998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	15
4.2159998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	16
4.4963998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	17
4.7767998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	18
5.0571998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	19
5.3375998E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	20
5.6179997E 01	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	21
1.1178400E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	22
2.1795000E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	23
3.2411600E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	24
4.3028200E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	25
5.3644800E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	26
6.4261400E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	27
7.4877999E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	28
8.5494598E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	29
9.6111197E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	30
1.0672780E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	31
1.1734440E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	32
1.2796099E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	33
1.3857759E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	34
1.4919419E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	35
1.5981079E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	36
1.7042739E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	37
1.8104399E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	38
1.9166059E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	39
2.0227719E 04	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	40

	ZETA	I-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	4.4721359E-01	1.0000000E 00	0.	1.8438755E-02	0.	1
1	4.4721359E-01	1.0000000E 00	0.	1.8438756E-02	0.	1
2	2.4099792E 00	9.9999197E-01	0.	9.9364195E-02	3.6266798E-05	2
3	3.3787571E 00	9.9997790E-01	0.	1.3930721E-01	5.4140392E-05	3
4	4.1260150E 00	9.9995978E-01	0.	1.70.1689E-01	6.7877216E-05	4
5	4.7573101E 00	9.9993834E-01	0.	1.9614538E-01	7.9433402E-05	5
6	5.3141320E 00	9.9991407E-01	0.	2.1910332E-01	8.9579792E-05	6
7	5.8179033E 00	9.9988725E-01	0.	2.3987397E-01	9.8715351E-05	7
8	6.2814010E 00	9.9985811E-01	0.	2.5898412E-01	1.0707858E-04	8
9	6.7129724E 00	9.9982680E-01	0.	2.7677795E-01	1.1482563E-04	9
10	7.1184267E 00	9.9979349E-01	0.	2.9349495E-01	1.2206543E-04	10
11	7.5019996E 00	9.9975828E-01	0.	3.0930979E-01	1.2887757E-04	11
12	7.8668925E 00	9.9972128E-01	0.	3.2435443E-01	1.3532234E-04	12
13	8.2155946E 00	9.9968255E-01	0.	3.3873154E-01	1.4144671E-04	13
14	8.5500876E 00	9.9964217E-01	0.	3.5252278E-01	1.4728817E-04	14
15	8.8719782E 00	9.9960023E-01	0.	3.6579443E-01	1.5287719E-04	15
16	9.1825920E 00	9.9955676E-01	0.	3.7860114E-01	1.5823893E-04	16
17	9.4830374E 00	9.9951180E-01	0.	3.9098859E-01	1.6339450E-04	17
18	9.7742517E 00	9.9946543E-01	0.	4.0299545E-01	1.6836177E-04	18
19	1.0057037E 01	9.9941767E-01	0.	4.1465478E-01	1.7315609E-04	19
20	1.0332086E 01	9.9936858E-01	0.	4.2599512E-01	1.7779072E-04	20
21	1.0600000E 01	9.9931818E-01	0.	4.3704130E-01	1.8227721E-04	21
22	8.6340808E 01	3.4590590E 01	0.	6.4870430E-01	1.3481419E-03	22
23	1.5077327E 02	5.3082776E 01	0.	7.0539950E-01	2.2274103E-03	23
24	2.1093411E 02	5.3082776E 01	0.	7.4944825E-01	2.9990613E-03	24
25	2.6782740E 02	5.3082776E 01	0.	7.8890656E-01	3.6872241E-03	25
26	3.2208967E 02	5.3082776E 01	0.	8.2402209E-01	4.3061075E-03	26
27	3.7421403E 02	5.3082776E 01	0.	8.5506474E-01	4.8671378E-03	27
28	4.2459030E 02	5.3082776E 01	0.	8.8230258E-01	5.3796904E-03	28
29	4.7353255E 02	5.3082776E 01	0.	9.0599306E-01	5.8516002E-03	29
30	5.2129820E 02	5.3082776E 01	0.	9.2638130E-01	6.2895193E-03	30
31	5.6810154E 02	5.3082775E 01	0.	9.4370182E-01	6.6991712E-03	31
32	6.1412321E 02	5.3082776E 01	0.	9.5818156E-01	7.0855325E-03	32
33	6.5951713E 02	5.3082776E 01	0.	9.7004398E-01	7.4529615E-03	33
34	7.0441542E 02	5.3082775E 01	0.	9.7951332E-01	7.8052894E-03	34
35	7.4893181E 02	5.3082776E 01	0.	9.8681927E-01	8.1458825E-03	35
36	7.9316404E 02	5.3082776E 01	0.	9.9220172E-01	8.4776815E-03	36
37	8.3719527E 02	5.3082776E 01	0.	9.9591581E-01	8.8032203E-03	37
38	8.8109478E 02	5.3082776E 01	0.	9.9823685E-01	9.1246288E-03	38
39	9.2491796E 02	5.3082776E 01	0.	9.9946530E-01	9.4436203E-03	39
40	9.6870594E 02	5.3082776E 01	0.	9.9993159E-01	9.7614695E-03	40

CSI = 0.0999999E 00

	PSI	G	TEMP	RHO	W	
0	0.	9.2811919E-01	2.5142025E 00	3.9773972E-01	2.8836199E 01	0
1	1.0000000E-01	9.3006829E-01	2.5138872E 00	3.9699999E-01	2.8836199E 01	1
1	1.0000000E-01	9.3006830E-01	2.5138872E 00	3.9699999E-01	2.8836198E 01	1
2	2.9040000E 00	9.3712310E-01	2.5217015E 00	3.9655690E-01	2.8836198E 01	2
3	5.7079999E 00	9.4129447E-01	2.5167288E 00	3.9734043E-01	2.8836197E 01	3
4	8.5119998E 00	9.4454495E-01	2.5092692E 00	3.9852166E-01	2.8836197E 01	4
5	1.1316000E 01	9.4730163E-01	2.5004760E 00	3.9992311E-01	2.8836197E 01	5
6	1.4120000E 01	9.4973930E-01	2.4908213E 00	4.0147325E-01	2.8836197E 01	6
7	1.6923999E 01	9.5194951E-01	2.4805523E 00	4.0313526E-01	2.8836197E 01	7
8	1.9727999E 01	9.5398721E-01	2.4698173E 00	4.0488747E-01	2.8836196E 01	8
9	2.2531999E 01	9.5588837E-01	2.4587137E 00	4.0671596E-01	2.8836197E 01	9
10	2.5335999E 01	9.5767809E-01	2.4473092E 00	4.0861127E-01	2.8836198E 01	10
11	2.8139999E 01	9.5937473E-01	2.4356533E 00	4.1056671E-01	2.8836198E 01	11
12	3.0943999E 01	9.6099217E-01	2.4237836E 00	4.1257735E-01	2.8836200E 01	12
13	3.3747998E 01	9.6254120E-01	2.4117291E 00	4.1463955E-01	2.8836201E 01	13
14	3.6551998E 01	9.6403040E-01	2.3995131E 00	4.1675052E-01	2.8836203E 01	14
15	3.9355998E 01	9.6546677E-01	2.3871544E 00	4.1890814E-01	2.8836205E 01	15
16	4.2159998E 01	9.6685604E-01	2.3746685E 00	4.2111077E-01	2.8836207E 01	16
17	4.4963998E 01	9.6820302E-01	2.3620684E 00	4.2335716E-01	2.8836209E 01	17
18	4.7767998E 01	9.6951181E-01	2.3493652E 00	4.2564632E-01	2.8836212E 01	18
19	5.0571998E 01	9.7078586E-01	2.3365681E 00	4.2797756E-01	2.8836215E 01	19
20	5.3375998E 01	9.7202817E-01	2.3236854E 00	4.3035035E-01	2.8836217E 01	20
21	5.6179997E 01	9.7324140E-01	2.3107241E 00	4.3276429E-01	2.8836220E 01	21
22	1.1178460E 03	9.7630657E-01	1.9275648E 00	5.1878912E-01	2.8836241E 01	22
23	2.1795000E 03	9.7877980E-01	1.8049589E 00	5.5402914E-01	2.8836246E 01	23
24	3.2411600E 03	9.8117645E-01	1.7085321E 00	5.8529769E-01	2.8836248E 01	24
25	4.3028200E 03	9.8362476E-01	1.6169444E 00	6.1845041E-01	2.8836250E 01	25
26	5.3644800E 03	9.8597647E-01	1.5308235E 00	6.5324317E-01	2.8836251E 01	26
27	6.4261400E 03	9.8815874E-01	1.4506876E 00	6.8932827E-01	2.8836251E 01	27
28	7.4877999E 03	9.9013810E-01	1.3769262E 00	7.2625532E-01	2.8836252E 01	28
29	8.5494598E 03	9.9190271E-01	1.3098028E 00	7.6347370E-01	2.8836252E 01	29
30	9.6111197E 03	9.9345232E-01	1.2494640E 00	8.0034322E-01	2.8836252E 01	30
31	1.0672780E 04	9.9479355E-01	1.1959506E 00	8.3615499E-01	2.8836252E 01	31
32	1.1734440E 04	9.9593670E-01	1.1492061E 00	8.7016598E-01	2.8836252E 01	32
33	1.2796099E 04	9.9689455E-01	1.1030845E 00	9.0164456E-01	2.8836252E 01	33
34	1.3857759E 04	9.9768150E-01	1.0753559E 00	9.2992470E-01	2.8836252E 01	34
35	1.4919419E 04	9.9831320E-01	1.0477096E 00	9.5446303E-01	2.8836252E 01	35
36	1.5981079E 04	9.9880655E-01	1.0257561E 00	9.7489065E-01	2.8836253E 01	36
37	1.7042739E 04	9.9917924E-01	1.0090270E 00	9.9105382E-01	2.8836253E 01	37
38	1.8104399E 04	9.9944988E-01	9.9697369E-01	1.0030355E 00	2.8836252E 01	38
39	1.9166059E 04	9.9963744E-01	9.8896471E-01	1.0111585E 00	2.8836252E 01	39
40	2.0227719E 04	9.9976094E-01	9.8428160E-01	1.0159694E 00	2.8836252E 01	40
41	2.1289379E 04	9.9983686E-01	9.8210938E-01	1.0182166E 00	2.8836252E 01	41
42	2.2351038E 04	9.9988040E-01	9.8153663E-01	1.0188107E 00	2.8836252E 01	42
43	2.3412699E 04	9.9990020E-01	9.8155391E-01	1.0187928E 00	2.8836252E 01	43

LE= 43LS= 43

	PSI	O2	H2	H2O	N	O	H	OH
0	0.	2.3200043E-01-0.		-0.	7.6800138E-01-0.	-0.	-0.	0
1	0.	2.3200043E-01-0.		-0.	7.6800138E-01-0.	-0.	-0.	1
1	1.0000000E-01	2.3200043E-01-0.		-0.	7.6800139E-01-0.	-0.	-0.	1
2	2.9040000E 00	2.3200043E-01-0.		-0.	7.6800141E-01-0.	-0.	-0.	2
3	5.7079999E 00	2.3200044E-01-0.		-0.	7.6800144E-01-0.	-0.	-0.	3
4	8.5119998E 00	2.3200044E-01-0.		-0.	7.6800144E-01-0.	-0.	-0.	4
5	1.1316000E 01	2.3200044E-01-0.		-0.	7.6800144E-01-0.	-0.	-0.	5
6	1.4120000E 01	2.3200044E-01-0.		-0.	7.6800144E-01-0.	-0.	-0.	6
7	1.6923999E 01	2.3200044E-01-0.		-0.	7.6800144E-01-0.	-0.	-0.	7
8	1.9727999E 01	2.3200044E-01-0.		-0.	7.6800145E-01-0.	-0.	-0.	8
9	2.2531999E 01	2.3200044E-01-0.		-0.	7.6800144E-01-0.	-0.	-0.	9
10	2.5335999E 01	2.3200044E-01-0.		-0.	7.6800143E-01-0.	-0.	-0.	10
11	2.8139999E 01	2.3200043E-01-0.		-0.	7.6800140E-01-0.	-0.	-0.	11
12	3.0943999E 01	2.3200042E-01-0.		-0.	7.6800137E-01-0.	-0.	-0.	12
13	3.3747998E 01	2.3200040E-01-0.		-0.	7.6800132E-01-0.	-0.	-0.	13
14	3.6551998E 01	2.3200038E-01-0.		-0.	7.6800127E-01-0.	-0.	-0.	14
15	3.9355998E 01	2.3200037E-01-0.		-0.	7.6800122E-01-0.	-0.	-0.	15
16	4.2159998E 01	2.3200035E-01-0.		-0.	7.6800117E-01-0.	-0.	-0.	16
17	4.4963998E 01	2.3200034E-01-0.		-0.	7.6800111E-01-0.	-0.	-0.	17
18	4.7767998E 01	2.3200032E-01-0.		-0.	7.6800104E-01-0.	-0.	-0.	18
19	5.0571998E 01	2.3200029E-01-0.		-0.	7.6800097E-01-0.	-0.	-0.	19
20	5.3375998E 01	2.3200027E-01-0.		-0.	7.6800091E-01-0.	-0.	-0.	20
21	5.6179997E 01	2.3200025E-01-0.		-0.	7.6800084E-01-0.	-0.	-0.	21
22	1.1178400E 03	2.3200008E-01-0.		-0.	7.6800026E-01-0.	-0.	-0.	22
23	2.1795000E 03	2.3200004E-01-0.		-0.	7.6800014E-01-0.	-0.	-0.	23
24	3.2411600E 03	2.3200002E-01-0.		-0.	7.6800008E-01-0.	-0.	-0.	24
25	4.3028200E 03	2.3200001E-01-0.		-0.	7.6800004E-01-0.	-0.	-0.	25
26	5.3644800E 03	2.3200000E-01-0.		-0.	7.6800001E-01-0.	-0.	-0.	26
27	6.4261400E 03	2.3200000E-01-0.		-0.	7.6799999E-01-0.	-0.	-0.	27
28	7.4877999E 03	2.3200000E-01-0.		-0.	7.6799998E-01-0.	-0.	-0.	28
29	8.5494598E 03	2.3199999E-01-0.		-0.	7.6799998E-01-0.	-0.	-0.	29
30	9.6111197E 03	2.3199999E-01-0.		-0.	7.6799998E-01-0.	-0.	-0.	30
31	1.0672780E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	31
32	1.1734440E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	32
33	1.2796099E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	33
34	1.3857759E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	34
35	1.4919419E 04	2.3199998E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	35
36	1.5981079E 04	2.3199998E-01-0.		-0.	7.6799995E-01-0.	-0.	-0.	36
37	1.7042739E 04	2.3199998E-01-0.		-0.	7.6799995E-01-0.	-0.	-0.	37
38	1.8104399E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	38
39	1.9166059E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	39
40	2.0227719E 04	2.3199998E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	40
41	2.1289379E 04	2.3199998E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	41
42	2.2351036E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	42
43	2.3412699E 04	2.3199999E-01-0.		-0.	7.6799996E-01-0.	-0.	-0.	43

	ZETA	I-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	4.4721359E-01	1.0000000E 00	1.0004392E 00	1.8314410E-02	8.5148931E-06	1
1	4.4721359E-01	1.0000000E 00	1.0004392E 00	1.8314411E-02	8.5148931E-06	1
2	2.4099792E 00	9.9999261E-01	1.0006947E 00	9.8694118E-02	4.5941396E-05	2
3	3.3787571E 00	9.9997966E-01	1.0002173E 00	1.3836777E-01	6.4406384E-05	3
4	4.1260150E 00	9.9996300E-01	9.9950422E-01	1.6896968E-01	7.8614038E-05	4
5	4.7573101E 00	9.9994327E-01	9.9866372E-01	1.9482265E-01	9.0578070E-05	5
6	5.3141320E 00	9.9992095E-01	9.9774057E-01	2.1762577E-01	1.0109186E-04	6
7	5.8179033E 00	9.9989628E-01	9.9675792E-01	2.3825634E-01	1.1056599E-04	7
8	6.2814010E 00	9.9986945E-01	9.9573019E-01	2.5723763E-01	1.1924589E-04	8
9	6.7129724E 00	9.9984065E-01	9.9466652E-01	2.7491145E-01	1.2729226E-04	9
10	7.1184267E 00	9.9981002E-01	9.9357326E-01	2.9151573E-01	1.3481716E-04	10
11	7.5019996E 00	9.9977762E-01	9.9245548E-01	3.0722391E-01	1.4190250E-04	11
12	7.8668925E 00	9.9974358E-01	9.9131674E-01	3.2216710E-01	1.4861031E-04	12
13	8.2155948E 00	9.9970795E-01	9.9015976E-01	3.3644725E-01	1.5498893E-04	13
14	8.5500876E 00	9.9967080E-01	9.8898692E-01	3.5014549E-01	1.6107692E-04	14
15	8.8719782E 00	9.9963220E-01	9.8780022E-01	3.6332764E-01	1.6690560E-04	15
16	9.1825920E 00	9.9959221E-01	9.8660097E-01	3.7604798E-01	1.7250091E-04	16
17	9.4830374E 00	9.9955087E-01	9.8539065E-01	3.8835190E-01	1.7788452E-04	17
18	9.7742517E 00	9.9950820E-01	9.8417023E-01	4.0027779E-01	1.8307485E-04	18
19	1.0057037E 01	9.9946427E-01	9.8294095E-01	4.1185849E-01	1.8808767E-04	19
20	1.0332086E 01	9.9941911E-01	9.8170344E-01	4.2312236E-01	1.9293663E-04	20
21	1.0600000E 01	9.9937274E-01	9.8045859E-01	4.3409405E-01	1.9763362E-04	21
22	6.6340808E 01	3.4665857E 01	3.2803662E 01	6.4432967E-01	1.4119995E-03	22
23	1.5077980E 02	5.6802464E 01	5.3144646E 01	7.0003099E-01	2.3218713E-03	23
24	2.1109464E 02	5.6802464E 01	5.2692011E 01	7.4137923E-01	3.1235343E-03	24
25	2.6828266E 02	5.6802464E 01	5.2257666E 01	7.7879448E-01	3.8429630E-03	25
26	3.2291566E 02	5.6802464E 01	5.1875389E 01	8.1245372E-01	4.4935216E-03	26
27	3.7544360E 02	5.6802464E 01	5.1537686E 01	8.4256133E-01	5.0859768E-03	27
28	4.2622668E 02	5.6802464E 01	5.1245552E 01	8.6932656E-01	5.6241869E-03	28
29	4.7555804E 02	5.6802464E 01	5.0998483E 01	8.9295411E-01	6.1305769E-03	29
30	5.2367989E 02	5.6802464E 01	5.0794543E 01	9.1364077E-01	6.5964704E-03	30
31	5.7079517E 02	5.6802464E 01	5.0630530E 01	9.3157535E-01	7.0323263E-03	31
32	6.1707594E 02	5.6802464E 01	5.0502253E 01	9.4694002E-01	7.4429095E-03	32
33	6.6266971E 02	5.6802464E 01	5.0404840E 01	9.5991261E-01	7.8324154E-03	33
34	7.0770386E 02	5.6802464E 01	5.0333101E 01	9.7066931E-01	8.2045593E-03	34
35	7.5228916E 02	5.6802464E 01	5.0281931E 01	9.7938752E-01	8.5626423E-03	35
36	7.9652199E 02	5.6802464E 01	5.0246616E 01	9.8624903E-01	8.9095950E-03	36
37	8.4048623E 02	5.6802464E 01	5.0223075E 01	9.9144324E-01	9.2480075E-03	37
38	8.8425416E 02	5.6802464E 01	5.0208025E 01	9.9517051E-01	9.5801433E-03	38
39	9.2786708E 02	5.6802464E 01	5.0198934E 01	9.9764551E-01	9.9079432E-03	39
40	9.7143551E 02	5.6802464E 01	5.0133968E 01	9.9910070E-01	1.0233017E-02	40
41	1.0149367E 03	5.6802464E 01	5.0171754E 01	9.9978955E-01	1.0556626E-02	41
42	1.0584242E 03	5.6802464E 01	5.0171180E 01	9.9998950E-01	1.0879651E-02	42
43	1.1019058E 03	5.6802464E 01	5.6802464E 01	9.9999998E-01	1.1202555E-02	43

X CO-ORDINATE= 0.32469437E 06 PHI= 0.24418671E 02 ZETA DELTA= 0.10834698E 04

UECHI LOG SIGMA= 0.15840595E-06 SIGMA OVER U BAR= 0.23178472E 07 QDOT=-0.2[illegible]17E-00BTU PER SQUARE FT-SEC

CF= 0.14240[illegible]

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TURBULENT  TRANSPORT  ANALYSIS
      ORIGINATOR -   H. ROSENBAUM
      PROGRAMMER -   B. BELLOW

CHECK CASE FOR H2 EQUILIBRIUM CHEM

COARSE PSI STEP=    888.24   INITIAL CSI=-0.          FINAL CSI= 0.17E 06

INITIAL PHI=      22.36068   ZETA DELTA=     464.549   HE=   0.1322436E 0?      CSI STEP=     0.2500E 05

FINE PSI STEP=       1.000      PSI ONE=           1.000

PRANDTL NUMBER=  1.00        SCHMIDT NUMBER= 1.00      TE=      325.00           UE=     5796.40

RHO E=  0.1654400E-05        MU E=  0.4004400E-06      DD CHI LOG SIG=  0.

NO OF SPECIES COARSE PSI POINTS=   13     NO. OF COARSE G POINTS=   13     NO. OF FINE PSI POINTS=    5

NO. OF SPECIES=    7     PRINT CYCLE NUMBER=    1

THE WALL TEMPERATURE FUNCTION VERSVS X IS
          400.0000+     -0.     X FOR X LESS THAN      0.2400000E 08
          400.0000+     -0.     X FOR X GREATER THAN   0.2400000E 08

THE FOLLOWING ARE MOLECULAR WEIGHTS FOR THE SAME SPECIES
 1.0000000E 00  1.6000000E 01  1.8000000E 01  2.0000000E 00  3.2000000E 01  1.7000000E 01  2.8000000E 01
```

CSI =-0.

	PSI	G	TEMP	RHO	W	
0	0.	8.5386300E-02	1.2307691E 00	8.4518729E-01	2.8836251E 01	0
1	1.0000000E 00	8.5386300E-02	1.2118423E 00	8.5838758E-01	2.8836251E 01	1
1	1.0000000E 00	2.6222000E-01	9.0649875E-01	7.9589088E-02	2.0000000E 00	1
2	1.7864800E 02	6.4631000E-01	8.0560130E-01	8.9557216E-02	2.0000000E 00	2
3	3.5629600E 02	6.8899000E-01	7.8450036E-01	9.1966063E-02	2.0000000E 00	3
4	5.3394399E 02	7.1565999E-01	7.7030483E-01	9.3660856E-02	2.0000000E 00	4
5	7.1159198E 02	7.3516999E-01	7.5943791E-01	9.5001063E-02	2.0000000E 00	5
6	8.8923998E 02	7.5169000E-01	7.4990867E-01	9.6208261E-02	2.0000000E 00	6
7	1.7774800E 03	8.2344999E-01	7.0507823E-01	1.0232540E-01	2.0000000E 00	7
8	2.6657200E 03	8.7946999E-01	6.6619602E-01	1.0829757E-01	2.0000000E 00	8
9	3.5539600E 03	9.2216998E-01	6.3426781E-01	1.1374913E-01	2.0000000E 00	9
10	4.4421999E 03	9.5356998E-01	6.0952693E-01	1.1836624E-01	2.0000000E 00	10
11	5.3304399E 03	9.7538999E-01	5.9170390E-01	1.2193161E-01	2.0000000E 00	11
12	6.2186799E 03	9.8922000E-01	5.8013708E-01	1.2436269E-01	2.0000000E 00	12
13	7.1069199E 03	9.9668000E-01	5.7380884E-01	1.2573422E-01	2.0000000E 00	13
14	7.9951599E 03	9.9956999E-01	5.7134250E-01	1.2627699E-01	2.0000000E 00	14
15	8.8833998E 03	1.0000000E 00	5.7097883E-01	1.2635742E-01	2.0000000E 00	15
16	9.7716398E 03	1.0000000E 00	5.7097883E-01	1.2635742E-01	2.0000000E 00	16
17	1.0659880E 04	1.0000000E 00	5.7097883E-01	1.2635742E-01	2.0000000E 00	17
18	1.1548120E 04	1.0000000E 00	5.7097883E-01	1.2635742E-01	2.0000000E 00	18

LE= 18LS= 18

SPECIES MASS FRACTIONS

	PSI	H	O	H2O	H2	O2	OH	N2	
0	0.	0.	0.	-0.	0.	2.3200000E-01	0.	7.6799999E-01	0
1	0.	0.	0.	-0.	0.	2.3200000E-01	0.	7.6799999E-01	1
1	1.0000000E 00	0.	0.	0.	1.0000000E 00	0.	0.	0.	1
2	1.7864800E 02	0.	0.	0.	1.0000000E 00	0.	0.	0.	2
3	3.5629600E 02	0.	0.	0.	1.0000000E 00	0.	0.	0.	3
4	5.3394399E 02	0.	0.	0.	1.0000000E 00	0.	0.	0.	4
5	7.1159198E 02	0.	0.	0.	1.0000000E 00	0.	0.	0.	5
6	8.8923998E 02	0.	0.	0.	1.0000000E 00	0.	0.	0.	6
7	1.7774800E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	7
8	2.6657200E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	8
9	3.5539600E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	9
10	4.4421999E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	10
11	5.3304399E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	11
12	6.2186799E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	12
13	7.1069199E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	13
14	7.9951599E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	14
15	8.8833998E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	15
16	9.7716398E 03	0.	0.	0.	1.0000000E 00	0.	0.	0.	16
17	1.0659880E 04	0.	0.	0.	1.0000000E 00	0.	0.	0.	17
18	1.1548120E 04	0.	0.	0.	1.0000000E 00	0.	0.	0.	18

ELEMENT MASS FRACTIONS

	PSI	N	O	H2O	H2	O2	OH	N2	
0	0.	0.	0.	0.	-0.	2.3200000E-01	0.	7.6799999E-01	0
1	0.	0.	0.	0.	-0.	2.3200000E-01	0.	7.6799999E-01	1
1	1.0000000E 00	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	1
2	1.7864800E 02	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	2
3	3.5629600E 02	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	3
4	5.3394399E 02	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	4
5	7.1159198E 02	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	5
6	8.8923998E 02	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	6
7	1.7774800E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	7
8	2.6657200E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	8
9	3.5539600E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	9
10	4.4421999E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	10
11	5.3304399E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	11
12	6.2186799E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	12
13	7.1069199E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	13
14	7.9951599E 03	-0.	-0.	-0.	-0.	2.3200000E-01	-0.	7.6799999E-01	14
15	8.8833998E 03	-0.	-0.	-0.	2.9900000E-03	2.3125000E-01	-0.	7.6586000E-01	15
16	9.7716398E 03	-0.	-0.	-0.	2.9900000E-03	2.3125000E-01	-0.	7.6586000E-01	16
17	1.0659880E 04	-0.	-0.	-0.	2.9900000E-03	2.3125000E-01	-0.	7.6586000E-01	17
18	1.1548120E 04	-0.	-0.	-0.	2.9900000E-03	2.3125000E-01	-0.	7.6586000E-01	18

	ZETA	I-VIS	U-BAR	Y CO-ORDINATE	
1	1.4142136E 00	1.0000000E 00	6.3245552E-02	5.7541528E-04	1
1	1.4142136E 00	1.0000000E 00	6.3245552E-02	5.7541528E-04	1
2	2.1180851E 01	8.6447458E 00	5.5092362E-01	8.1855239E-02	2
3	3.4872454E 01	1.4083056E 01	6.0510789E-01	1.3414300E-01	3
4	4.7626308E 01	1.9014142E 01	6.3897994E-01	1.8176835E-01	4
5	5.9814529E 01	2.3591706E 01	6.6374250E-01	2.2654788E-01	5
6	7.1594365E 01	2.4379935E 01	6.8472031E-01	2.6924996E-01	6
7	1.2592530E 02	2.4379935E 01	7.7583650E-01	4.5910718E-01	7
8	1.7482124E 02	2.4379935E 01	8.4696231E-01	6.2014128E-01	8
9	2.2021527E 02	2.4379935E 01	9.0117973E-01	7.6192224E-01	9
10	2.6329658E 02	2.4379935E 01	9.4104669E-01	8.9061627E-01	10
11	3.0485975E 02	2.4379935E 01	9.6875023E-01	1.0105264E 00	11
12	3.4546727E 02	2.4379935E 01	9.8631305E-01	1.1248132E 00	12
13	3.8552839E 02	2.4379935E 01	9.9579062E-01	1.2358404E 00	13
14	4.2533453E 02	2.4379935E 01	9.9946004E-01	1.3453201E 00	14
15	4.6505783E 02	2.4379935E 01	9.9999999E-01	1.4543020E 00	15
16	5.0478113E 02	2.4379935E 01	9.9999999E-01	1.5632492E 00	16
17	5.4450442E 02	2.4379935E 01	9.9999999E-01	1.6721964E 00	17
18	5.8422772E 02	2.4379935E 01	9.9999999E-01	1.7811436E 00	18

CSI = 0.24999999E 05

	PSI	G	TEMP	RHO	W	
0	0.	8.5382109E-02	1.2307691E 00	8.4518709E-01	2.8836244E 01	0
1	1.0000000E 00	2.3185312E-01	1.7576033E 00	5.9184580E-01	2.8836244E 01	1
1	1.0000000E 00	2.3185312E-01	1.7565554E 00	5.9219891E-01	2.8836244E 01	1
2	1.7864800E 02	5.1654831E-01	1.4146716E 00	7.3531557E-01	2.8836242E 01	2
3	3.5629600E 02	6.1239976E-01	1.4781914E 00	7.0371808E-01	2.8836239E 01	3
4	5.3394399E 02	6.6466076E-01	1.4754134E 00	7.0504301E-01	2.8836236E 01	4
5	7.1159198E 02	6.9886138E-01	1.4516628E 00	7.1657807E-01	2.8836232E 01	5
6	8.8923998E 02	7.2392494E-01	1.4167732E 00	7.3422453E-01	2.8836228E 01	6
7	1.7774800E 03	8.1120511E-01	1.1406007E 00	9.1200013E-01	2.8836184E 01	7
8	2.6657200E 03	8.7118883E-01	8.3604276E-01	1.2442221E 00	2.8836042E 01	8
9	3.5539600E 03	9.1509882E-01	5.5893448E-01	1.8610542E 00	2.8835612E 01	9
10	4.4421999E 03	9.4717302E-01	3.3035585E-01	3.1486091E 00	2.8834339E 01	10
11	5.3304399E 03	9.6972812E-01	1.6027988E-01	6.4888192E 00	2.8830617E 01	11
12	6.2186799E 03	9.8451965E-01	5.8214462E-02	1.7858756E 01	2.8819826E 01	12
13	7.1069199E 03	9.9319434E-01	4.7239234E-02	2.1984147E 01	2.8788679E 01	13
14	7.9951599E 03	9.9746749E-01	1.9819982E-01	5.2234331E 00	2.8699118E 01	14
15	8.8833998E 03	9.9912399E-01	7.2132801E-01	1.4224614E 00	2.8443468E 01	15
16	9.7716398E 03	9.9969572E-01	9.0338731E-01	1.1323120E 00	2.8356284E 01	16
17	1.0659880E 04	9.9989094E-01	9.6542457E-01	1.0584428E 00	2.8326635E 01	17
18	1.1548120E 04	9.9995124E-01	9.8455285E-01	1.0375438E 00	2.8317489E 01	18

LE=   IHLS=   18

SPECIES MASS FRACTIONS

	PSI	H	O	H2O	H2	O2	OH	N2	
0	0.	0.	0.	3.8586940E-07	0.	2.3199967E-01	0.	7.6799995E-01	0
1	0.	0.	0.	3.8603289E-07	0.	2.3199967E-01	0.	7.6799994E-01	1
1	1.0000000E 00	2.8292302E-30	2.2243280E-19	3.8467119E-07	2.9776221E-26	2.3199964E-01	2.0752466E-16	7.6799995E-01	1
2	1.7864800E 02	5.4663972E-38	5.9781450E-25	4.7209798E-07	9.4144484E-32	2.3199956E-01	4.8367754E-20	7.6799996E-01	2
3	3.5629600E 02	0.	0.	6.0109195E-07	0.	2.3199943E-01	0.	7.6799996E-01	3
4	5.3394399E 02	0.	0.	7.5652882E-07	0.	2.3199929E-01	0.	7.6799995E-01	4
5	7.1159198E 02	0.	0.	9.4085617E-07	0.	2.3199911E-01	0.	7.6799995E-01	5
6	8.8923998E 02	0.	0.	1.1597924E-06	0.	2.3199891E-01	0.	7.6799992E-01	6
7	1.7774800E 03	0.	0.	3.3542156E-06	0.	2.3199691E-01	0.	7.6799973E-01	7
8	2.6657200E 03	0.	0.	1.0489339E-05	0.	2.3199034E-01	0.	7.6799916E-01	8
9	3.5539600E 03	0.	0.	3.2094029E-05	0.	2.3197045E-01	0.	7.6799745E-01	9
10	4.4421999E 03	0.	0.	9.6047620E-05	0.	2.3191159E-01	0.	7.6799236E-01	10
11	5.3304399E 03	0.	0.	2.8296873E-04	0.	2.3173954E-01	0.	7.6797749E-01	11
12	6.2186799E 03	0.	0.	8.2524235E-04	0.	2.3124039E-01	0.	7.6793436E-01	12
13	7.1069199E 03	0.	0.	2.3926550E-03	0.	2.2979763E-01	0.	7.6780972E-01	13
14	7.9951599E 03	0.	0.	6.9186291E-03	0.	2.2563156E-01	0.	7.6744980E-01	14
15	8.8833998E 03	0.	0.	1.9994781E-02	0.	2.1359529E-01	0.	7.6640992E-01	15
16	9.7716398E 03	0.	0.	2.4508012E-02	0.	2.0944098E-01	0.	7.6605101E-01	16
17	1.0659880E 04	0.	0.	2.6049186E-02	0.	2.0802237E-01	0.	7.6592844E-01	17
18	1.1548120E 04	0.	0.	2.6525249E-02	0.	2.0758417E-01	0.	7.6589058E-01	18

ELEMENT MASS FRACTIONS

	PSI	H	O	H2O	H2	O2	OH	N2	
0	0.	0.	0.	0.	4.2874377E-08	2.3199998E-01	0.	7.6799995E-01	0
1	0.	0.	0.	0.	4.2892544E-08	2.3199998E-01	0.	7.6799994E-01	1
1	1.0000000E 00	-0.	-0.	-0.	4.2892544E-08	2.3199998E-01	-0.	7.6799995E-01	1
2	1.7864800E 02	-0.	-0.	-0.	5.2641017E-08	2.3199999E-01	-0.	7.6799996E-01	2
3	3.5629600E 02	-0.	-0.	-0.	6.6787995E-08	2.3199999E-01	-0.	7.6799996E-01	3
4	5.3394399E 02	-0.	-0.	-0.	8.4058758E-08	2.3199998E-01	-0.	7.6799995E-01	4
5	7.1159198E 02	-0.	-0.	-0.	1.0453957E-07	2.3199998E-01	-0.	7.6799995E-01	5
6	8.8923998E 02	-0.	-0.	-0.	1.2886582E-07	2.3199997E-01	-0.	7.6799992E-01	6
7	1.7774800E 03	-0.	-0.	-0.	3.7269063E-07	2.3199990E-01	-0.	7.6799973E-01	7
8	2.6657200E 03	-0.	-0.	-0.	1.1654822E-06	2.3199970E-01	-0.	7.6799916E-01	8
9	3.5539600E 03	-0.	-0.	-0.	3.5660032E-06	2.3199910E-01	-0.	7.6799745E-01	9
10	4.4421999E 03	-0.	-0.	-0.	1.0671058E-05	2.3199732E-01	-0.	7.6799236E-01	10
11	5.3304399E 03	-0.	-0.	-0.	3.1440970E-05	2.3199211E-01	-0.	7.6797749E-01	11
12	6.2186799E 03	-0.	-0.	-0.	9.1693596E-05	2.3197699E-01	-0.	7.6793436E-01	12
13	7.1069199E 03	-0.	-0.	-0.	2.6585056E-04	2.3193331E-01	-0.	7.6780972E-01	13
14	7.9951599E 03	-0.	-0.	-0.	7.6873657E-04	2.3180717E-01	-0.	7.6744980E-01	14
15	8.8833998E 03	-0.	-0.	-0.	2.2216424E-03	2.3144273E-01	-0.	7.6640992E-01	15
16	9.7716398E 03	-0.	-0.	-0.	2.7231124E-03	2.3131694E-01	-0.	7.6605101E-01	16
17	1.0659880E 04	-0.	-0.	-0.	2.8943540E-03	2.3127398E-01	-0.	7.6592844E-01	17
18	1.1548120E 04	-0.	-0.	-0.	2.9472499E-03	2.3126072E-01	-0.	7.6589058E-01	18

	ZETA	I-VIS	U-BAR	Y CO-ORDINATE	
1	1.4142136E 00	1.0000000E 00	6.2936195E-02	1.1183915E-03	1
1	1.4142136E 00	1.0000000E 00	6.2936195E-02	1.1183915E-03	1
2	2.1180851E 01	8.6486993E 00	5.4822884E-01	1.7706783E-02	2
3	3.4872454E 01	1.4097828E 01	6.0214809E-01	2.8188353E-02	3
4	4.7626308E 01	1.9046428E 01	6.3585445E-01	3.8157041E-02	4
5	5.9814529E 01	2.3648167E 01	6.6049589E-01	4.7598055E-02	5
6	7.1599128E 01	2.5505538E 01	6.8070586E-01	5.6543549E-02	6
7	1.2609886E 02	2.5505538E 01	7.6840962E-01	9.3427147E-02	7
8	1.7526076E 02	2.5505538E 01	8.3791418E-01	1.1914311E-01	8
9	2.2091691E 02	2.5505538E 01	8.9186255E-01	1.3599763E-01	9
10	2.6421085E 02	2.5505538E 01	9.3248870E-01	1.4618662E-01	10
11	3.0591361E 02	2.5505538E 01	9.6170409E-01	1.5160183E-01	11
12	3.4657529E 02	2.5505538E 01	9.8125143E-01	1.5395362E-01	12
13	3.8660150E 02	2.5505538E 01	9.9285680E-01	1.5507179E-01	13
14	4.2629070E 02	2.5505538E 01	9.9837555E-01	1.5766042E-01	14
15	4.6584793E 02	2.5505538E 01	9.9993439E-01	1.6740036E-01	15
16	5.0537692E 02	2.5505538E 01	1.0000000E 00	1.8466013E-01	16
17	5.4490591E 02	2.5505538E 01	1.0000000E 00	2.0455081E-01	17
18	5.8443490E 02	2.5505538E 01	1.0000000E 00	2.2531925E-01	18

X CO-ORDINATE= 0.78335110E 04   PHI= 0.22470591E 02   ZETA DELTA= 0.48604366E 03

DUCHI LOG SIGMA= 0.   SIGMA OVER MU BAR= 0.42561021E 07   QDOT=-0.93462156E 00BTU PER SQUARE FT-SEC

CF= 0.49916267E-02