MASTER

Research Report

SC-RR-70-754

CHEMICALLY REACTING VISCOUS FLOW PROGRAM FOR MULTI-COMPONENT GAS MIXTURES

F. G. Blottner
Margaret Johnson
Molly Ellis
Numerical Fluid Dynamics Division

Date Published - December 1971

SANDIA LABORATORIES

OPERATED FOR THE UNITED STATES ATOMIC ENERGY COMMISSION BY SANDIA CORPORATION | ALBUQUERQUE, NEW MEXICO, LIVERMORE, CALIFORNIA

*Issued by Sandia Corporation,
a prime contractor to the United States Atomic
Energy Commission*

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SC-RR-70-754

CHEMICALLY REACTING VISCOUS FLOW PROGRAM FOR MULTI-COMPONENT GAS MIXTURES*

F. G. Blottner
Margaret Johnson
Molly Ellis
Numerical Fluid Dynamics Division, 5643
Sandia Laboratories, Albuquerque, New Mexico
87115

December 1971

ABSTRACT

The methods used for solving the laminar boundary layer equations are presented and a detailed description of the resulting computer program is given. This program can be used to calculate the thin viscous shock layer at a stagnation point or the boundary layer flow along an arbitrary body shape. The gas model is of a general form where the mixture can consist of as many as 30 species with finite reactions occurring. Several boundary conditions at the surface are available as options in the program to account for material ablation.

Key Words: Boundary layer, shock layer, finite-difference

*This work was supported by the United States Atomic Energy Commission.

TABLE OF CONTENTS

NOMENCLATURE

A_n, B_n, C_n, D_n	coefficient matrices in the difference equation 25
c_i	mass fraction of species i, ρ_i/ρ
c_{p_i}	specific heat at constant pressure of species i, $\frac{\text{ft-lb}}{\text{slug }^{\circ}\text{R}}$
$\bar{c}_p$	frozen specific heat at constant pressure of the mixture, $\sum_i c_i\, c_{p_i}$, $\frac{\text{ft-lb}}{\text{slug }^{\circ}\text{R}}$
D_{ij}	multicomponent diffusion coefficient, ft^2/sec.
$\mathcal{D}_{ij}$	binary diffusion coefficient, ft^2/sec.
D_i^T	thermal diffusion coefficient, lb sec/ft.
e	$2\xi/\left(u_e \frac{d\xi}{dx}\right)$
f'	velocity ratio, u/u_e
h	enthalpy, $\sum_i h_i c_i$ (ft-lb/slug)
h_i	enthalpy of species i, (ft-lb/slug)
j_i	mass flux relative to the mass-average velocity, slug/(ft^2-sec)
k	thermal conductivity of mixture, lb/(sec $^{\circ}$R)
k_{f_r}, k_{b_r}	forward and backward rate constants (see Eq. 88)
ℓ	density-viscosity product, $\rho\mu/(\rho\mu)_r$
L_{ij}	multicomponent Lewis-Semenov number, $\bar{c}_p \rho D_{ij}/k$
$\mathcal{L}_{ij}$	binary Lewis-Semenov number, $\bar{c}_p \rho \mathcal{D}_{ij}/k$
L_i^T	thermal Lewis-Semenov number, $\bar{c}_p D_i^T/k$
$\bar{M}$	molecular weight of the mixture, $1/(\sum_i c_i/M_i)$, lb/lb-mole
M_i	molecular weight of species i, lb/lb-mole
NE	number of chemical elements in gas model
NI	number of chemical species in gas model
NR	number of chemical reactions
Pr	Prandtl number, $\bar{c}_p\, \mu/k$
p	pressure, lb/ft^2
$\bar{p}$	pressure, atmospheres
p_o'	normal shock stagnation pressure, atmospheres
R	universal gas constant, lb ft^2/(lb-mole sec^2 $^{\circ}$R)
R_N	nose radius, ft.
Re_s	shock Reynolds number, $\rho_\infty V_\infty R_N/\mu_{sh}$
r	distance from axis in axisymmetric problems, ft.
T	temperature, $^{\circ}$R
T_o'	normal shock stagnation temperature, $^{\circ}$K
TK	temperature, $^{\circ}$K
u, v	velocity components tangent and normal to body surface, ft/sec.
V	transformed normal velocity (Eq. 16a)
V_∞	freestream velocity, fps

w_i	mass rate of formation of species i, lb $sec^2/(ft^4\ sec)$
W_n	vector for dependent variables
x	distance along surface from leading edge or stagnation point, ft.
X_i	mole fraction of species i, $\bar{M}c_i/M_i$
y	distance along normal from surface, ft.
α	$u_e^2/(\bar{c}_p\ T_e)$
α_{ri},β_{ri}	forward and backward stoichiometric coefficients
β	pressure gradient parameter
γ_i	mass concentration of species i, c_i/M_i, lb-mole/lb.
ϵ	density ratio across shock, ρ_∞/ρ_{sh}
η	transformed y coordinate
ξ	transformed x coordinate, $lb^2\ sec^2/ft^{2(2-j)}$
$\Delta\eta,\Delta\xi$	step sizes in transformed coordinates
θ	temperature ratio, T/T_e
κ_c	curvature of body, 1/ft.
μ	viscosity, lb sec/ft^2
ρ	density, lb sec^2/ft^4
ρ_i	density of species i, lb sec^2/ft^4
Δ	shock standoff distance, ft.

SUBSCRIPTS

A	atom
b,w	conditions at body surface
e	conditions at outer edge of shock layer or boundary layer
eq	chemical equilibrium
m	designation of mesh point in ξ-direction, $\xi = (m - 1)\Delta\xi$
n	designation of mesh point in η-direction, $\eta = (n - 1)\Delta\eta$
r	quantities evaluated at a reference condition which is taken as the outer edge of shock layer or boundary layer
sh	conditions behind shock wave
∞	freestream conditions

SUPERSCRIPTS

j = 0	two-dimensional body
j = 1	axisymmetric body

I. Introduction

A general computer program has been developed for solving the laminar boundary layer equations with a finite-difference method. The governing equations are solved in an uncoupled manner in order that a gas mixture with a large number of chemical species can be readily handled. The program has been written with various options to provide a flexibility that allows a variety of problems to be solved with only a change in the input data. This program has evolved over a period of time with earlier versions described by Meyer and Ten Broeck[1], Ten Broeck and Blottner[2], and Blottner[3]. Since these earlier programs have proved to be useful to a number of people, this report is intended to provide sufficient details of the present program so that it can easily be used by others. The present program is sufficiently different in capabilities and ease of use as to make the earlier versions obsolete. The major improvements in this program are:

1. Numerical schemes are improved
2. Initial profiles can be obtained by program
3. Thin viscous shock layer can be solved at the stagnation point
4. Variable step sizes across layer and variable boundary layer thicknesses are available
5. Complete multicomponent diffusion is included
6. Additional boundary layer properties are determined
7. Updated transport properties are employed
8. Arbitrary body shape option is available

Some parts of the present report have been published previously by Blottner[4,5]. These parts are repeated in order to provide a unified treatment of this problem and to include modifications which have occurred since these papers were published. However, these papers provide additional information not included in this report and should be utilized along with the present report. In reference 4, the thin viscous shock layer problem is discussed while in reference 5 a survey of finite difference methods for solving the boundary layer equations is given. In both of these references, results obtained with the present program are presented. Additional results from the program have been given in papers by Davis[6] and Blottner[7].

The form of this report is intended to satisfy the needs of various people by the appropriate use of certain parts of the write-up. For a reader interested in knowing the governing equations being solved and the numerical techniques being used, Chapter II is the appropriate place to start. Also in this chapter boundary conditions are given, the transformation and linearization of the equations are presented, and the finite difference form of the equations at a stagnation point, tip of sharp body or along a body (initial profiles) are formulated. The derivation of the species boundary conditions corresponding to various surface materials is described in Chapter III. A general form of the boundary condition for each species equation is used where two parameters (P_i and Q_i) are required. Additional boundary conditions can be readily added to the program by providing the evaluation of these two parameters. The boundary conditions at the outer edge of the layer are described in Chapter IV. For the boundary layer solution along a blunt body, the swallowing of the inviscid flow can be taken into account by the proper specification of the edge conditions. In this chapter, the evaluation of quantities which are a function of the distance along the surface is given and various body geometries considered. Also the method of changing the step-size smoothly along the surface is described. Finally, in this chapter the shock layer edge conditions are presented in terms of the transformed coordinate with shock slip effects included. The methods for evaluating transport properties, thermodynamic properties and chemical kinetics are given in Chapter V. In addition, the properties for an air gas model are tabulated. After the boundary layer or shock layer solutions are obtained, various properties of the flow are determined from relations described in Chapter VI.

For a person interested in solving problems with the program, the appropriate place to start is Chapter VII where the program options, input and output are described. With an understanding of this chapter, the program can be utilized to obtain boundary layer and shock layer computations. To help set up input data and understand the usage of the program, three sample problems are presented. For these problems the input data is given and some of the computer output is also given. If greater details of the programming are required, Appendix D is available to provide this information.

While the program was being developed, the question arose whether the finite difference procedure being employed was as good as the nonlinear overrelaxation method for solving the initial profiles. An investigation of the solution of the boundary layer equations at a stagnation point for a binary gas mixture was performed. The results of this study are presented in Appendix B and indicate the finite-difference method is slightly preferable to the nonlinear overrelaxation method.

The choice of whether the flow is in local chemical equilibrium or in nonequilibrium has been included in the initial profile part of the computer program. The case of equilibrium is a special case of the non-equilibrium problem and only requires slight modification to the method of solution and is described in Appendix C. This option is of interest in predicting the boundary layer on cones far downstream where the equilibrium and locally similar assumptions are reasonable. Also, in the stagnation region at low altitudes, the assumption of chemical equilibrium becomes valid. In these cases, it should be noticed that it is necessary to assume that the flow is in equilibrium at the surface which implies certain restrictions on the surface chemical reactions.

II. Solution of Governing Equations

A. Conservation Equations

The general equations for a multicomponent nonequilibrium gas are given in Reference 8 and these equations for the boundary layer along a body and the stagnation point thin shock layer become the following:

Continuity

$$\frac{\partial}{\partial x}\left(\rho u r_b^j\right) + \frac{\partial}{\partial y}\left(\rho v r_b^j\right) = 0 \tag{1a}$$

Tangential Momentum

$$\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = - \frac{dp_e}{dx} + \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) \tag{1b}$$

Normal Momentum

$$\frac{\partial p}{\partial y} = 0 \qquad \text{boundary layer}$$

$$\frac{\partial p}{\partial y} - \varkappa_c \rho u^2 = 0 \qquad \text{shock layer} \tag{1c}$$

Energy

$$\bar{c}_p \rho u \frac{\partial T}{\partial x} + \bar{c}_p \rho v \frac{\partial T}{\partial y} = u \frac{dp_e}{dx} + \mu \left(\frac{\partial u}{\partial y}\right)^2 + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) - \sum_{i=1}^{NI} c_{p_i} j_i \frac{\partial T}{\partial y} - \sum_{i=1}^{NI} h_i w_i \tag{1d}$$

Species Continuity

$$\rho u \frac{\partial c_i}{\partial x} + \rho v \frac{\partial c_i}{\partial y} = - \frac{\partial}{\partial y}(j_i) + w_i \qquad i = 1, 2, \ldots (NI - 1) \tag{1e}$$

There are only (NI - 1) independent species continuity equations (1e) with the NI^{th} species determined from the relation $\sum_{i=1}^{NI} c_i = 1$. For two-dimensional flow, $j = 0$ and for axisymmetric flow, $j = 1$. The expression for the relative mass flux j_i in a multicomponent mixture of perfect gases is given in Reference (8) and becomes the following for the boundary layer:

$$j_i = - \frac{\mu}{Pr} \left\{ \sum_{k=1}^{NI} \bar{\bar{b}}_{ik} \frac{\partial c_k}{\partial y} + \frac{L_i^T}{T} \frac{\partial T}{\partial y} \right\} \tag{2}$$

where

$$\bar{\bar{b}}_{ik} = \begin{cases} Le_i & i = k \\ \Delta\bar{\bar{b}}_{ik} & i \neq k \end{cases}$$

$$Le_i = \sum_{\substack{j=1\\ j\neq i}}^{NI} \frac{c_j}{M_j} \Bigg/ \sum_{\substack{j=1\\ j\neq i}}^{NI} \frac{c_j}{M_j \mathscr{L}_{ij}}$$

$$\Delta\bar{\bar{b}}_{ik} = Le_i - \left[\frac{M_i}{\bar{M}} L_{ik} + \left(1 - \frac{M_i}{M_k}\right) \sum_{j=1}^{NI} L_{ij} c_j\right]$$

If the binary Lewis-Semenov numbers, $\mathscr{L}_{ij}$, are constant for all of the species or if a trace species is being considered, the term $\Delta\bar{\bar{b}}_{ik}$ is zero. In the above Equation (2), the pressure diffusion term is neglected due to the boundary layer assumption; and the forced diffusion term is assumed zero. The equation of state is also required and is written as

$$\rho = \frac{p_e}{RT \sum_{i=1}^{NI} (c_i/M_i)} = \frac{p_e \bar{M}}{RT} \tag{3}$$

where it is assumed the gas consists of a mixture of chemically-reacting perfect gases with the pressure change across the boundary layer and stagnation point shock layer neglected as a result of Equation (1c).

The stoichiometric relations for a multicomponent gas with NI distinct chemical species and NR simultaneous chemical reactions are

$$\sum_{i=1}^{NJ} \alpha_{ri} X_i \underset{k_{b_r}}{\overset{k_{f_r}}{\rightleftarrows}} \sum_{i=1}^{NJ} \beta_{ri} X_i \qquad r = 1, 2, \ldots NR \tag{4}$$

The quantities X_i represent the chemical species and catalytic bodies and α_{ri} and β_{ri} are the stoichiometric coefficients. The summation limit NJ is equal to the number of species plus the number of catalytic bodies. The net mass rate of production of species "i" per unit volume, w_i, is written as

$$\frac{w_i}{\rho} = M_i \sum_{r=1}^{NJ} (\beta_{ri} - \alpha_{ri})\left(L_{f_r} - L_{b_r}\right) \tag{5}$$

where

$$\alpha_r = \sum_{j=1}^{NJ} \alpha_{rj} - 1$$

$$\beta_r = \sum_{j=1}^{NJ} \beta_{rj} - 1$$

$$L_{f_r} = k_{f_r} \bar{\rho}^{\alpha_r} \prod_{j=1}^{NJ} (\gamma_j)^{\alpha_{rj}}$$

$$L_{b_r} = k_{b_r}\, \bar{\rho}^{\beta_r} \prod_{j=1}^{NJ} (\gamma_k)^{\beta_{rj}}$$

$$\bar{\rho}(gm/cm^3) = 0.51536\ \rho(slug/ft^3)$$

The mass concentration γ_j for the NI species is

$$\gamma_j = c_j/M_j \qquad j = 1, 2, \ldots NI$$

whereas for the catalytic bodies, the following expression is used:

$$\gamma_j = \sum_{i=1}^{NI} Z_{(j-NI)i}\, \gamma_i \qquad j = (NI + 1), \ldots NJ \tag{6}$$

The quantity $Z_{(j-NI)i}$ is the third body efficiencies relative to argon and are determined from the reactions being considered.

The production term can be written as

$$w_i/\rho = W_i^{\,0} - W_i^{\,1}\, c_i \tag{7}$$

where

$$W_i^{\,0} = M_i \sum_{r=1}^{NR} \left(\Gamma_{ri}^{+}\, L_{f_r} + \Gamma_{ri}^{-}\, L_{b_r} \right)$$

$$W_i^{\,1} = \sum_{r=1}^{NR} \left[\Gamma_{ri}^{+} \left(L_{b_r} / \gamma_i \right) + \Gamma_{ri}^{-} \left(L_{f_r} / \gamma_i \right) \right]$$

$$\Gamma_{ri}^{+} = \begin{cases} (\beta_{ri} - \alpha_{ri}) & \text{if } (\beta_{ri} - \alpha_{ri}) > 0 \\ 0 & \text{if } (\beta_{ri} - \alpha_{ri}) \le 0 \end{cases}$$

$$\Gamma_{ri}^{-} = \begin{cases} 0 & \text{if } (\beta_{ri} - \alpha_{ri}) \ge 0 \\ -(\beta_{ri} - \alpha_{ri}) & \text{if } (\beta_{ri} - \alpha_{ri}) < 0 \end{cases}$$

It should be noticed that $W_i^{\,0}$ and $W_i^{\,1}$ are positive quantities and the quantities L_{b_r} and L_{f_r} in the relation for $W_i^{\,1}$ will contain γ_i to a power one or greater depending upon the chemical reaction. The term $W_i^{\,0}$ is not a function of the mass fraction c_i but $W_i^{\,1}$ can be a function of the mass fraction c_i.

The conditions at the surface and outer edge of the boundary layer or shock layer determine the necessary boundary conditions for the foregoing equations. At the wall, it is assumed that the tangential velocity is zero and the surface temperature is specified and these conditions are expressed as

$$u(x, 0) = 0 \tag{8a}$$

$$T(x, 0) = T_b(x) \tag{8b}$$

In addition, the boundary condition on the mass flux of a species "i" at the surface, $(\rho_i v_i)_b$, is

$$(\rho_i v_i)_b = \dot{m}_i = (c_i \rho v)_b + (j_i)_b \qquad (i = 1, 2, \ldots NS) \tag{9}$$

The mass flux at the surface of all of the NI species cannot be specified arbitrarily as the net mass flux of any chemical element normal to the surface must vanish at the surface, except for the surface elements and this is true whether chemical reactions take place there or not. These restrictions are written as

$$\alpha^k (\rho v)_b = \sum_{i=1}^{NI} \alpha_i^k \frac{M^k}{M_i} (\dot{m}_i)_b \qquad k = 1, 2, \ldots NE \tag{10}$$

where α^k is the ratio of the mass flux of element k to the total mass flux at the surface and is known from the chemical composition and characteristics of the wall material. With this relation, NE of the species mass flux at the surface, $(\dot{m}_i)_b$, are known; the remaining species mass flux are determined from the chemical reactions (catalytic recombination, oxidation, sublimation, etc) and transpiration mass transfer occurring at the surface as is discussed subsequently.

The total mass flux at the surface can be determined from

$$\rho v = \sum_{i=1}^{NI} (\dot{m}_i)_b \tag{11}$$

and this is the boundary condition employed with the continuity equation.

The flow at the edge of the boundary layer is determined from the inviscid non-equilibrium flow around the body and is discussed in more detail in Chapter IV. The boundary conditions at the outer edge of the boundary layer are

$$u \rightarrow u_e \tag{12a}$$

$$T \rightarrow T_e \tag{12b}$$

$$c_i \rightarrow c_{i_e} \tag{12c}$$

For the shock layer solution, the above relations must be satisfied where the edge conditions correspond to the properties behind the shock wave. In addition, the distance from the body to shock must be adjusted until the normal velocity from the shock layer solution matches the normal velocity behind the shock wave. These boundary conditions are expressed as

$$u(y_{sh}) = u_{sh} \tag{13a}$$

$$T(y_{sh}) = T_{sh} \tag{13b}$$

$$c_i(y_{sh}) = c_{i_{sh}} \tag{13c}$$

$$v(y_{sh}) = v_{sh} \tag{13d}$$

B. Transformation of equations

The boundary layer equations (1) are transformed with the Mangler, Görtler, Howarth-Dorodnitsyn, Levy, and Lees transformation in order to obtain them in a form more appropriate for numerical solution. The new independent variables introduced are

$$\xi(x) = \int_0^x (\rho\mu)_r \, u_e \, r_b^{2j} \, dx \tag{14a}$$

$$\eta(x,y) = \frac{u_e \, r_b^j}{\eta_e \, (2\xi)^{1/2}} \int_0^y \rho dy \tag{14b}$$

and the derivatives become

$$\frac{\partial}{\partial x} = (\rho\mu)_r \, u_e \, r_b^{2j} \frac{\partial}{\partial \xi} + \frac{\partial \eta}{\partial x} \frac{\partial}{\partial \eta} \tag{15a}$$

$$\frac{\partial}{\partial y} = \frac{\rho u_e \, r_b^j}{\eta_e \, (2\xi)^{1/2}} \frac{\partial}{\partial \eta} \quad . \tag{15b}$$

When the new dependent variables

$$V = \frac{2\xi}{(\rho\mu)_r \, u_e \, r_b^{2j}} \left(\eta_e \, f' \, \frac{\partial \eta}{\partial x} + \frac{\rho v \, r_b^j}{(2\xi)^{1/2}} \right) \tag{16a}$$

$$f' = u/u_e \tag{16b}$$

$$\theta = T/T_e \tag{16c}$$

are introduced and the transformations are applied, the boundary layer equations become the following in the transformed plane:

Continuity

$$2\xi \frac{\partial f'}{\partial \xi} + \frac{1}{\eta_e} \frac{\partial V}{\partial \eta} + f' \left(1 + \frac{2\xi}{\eta_e} \frac{d\eta_e}{d\xi} \right) = 0 \tag{17a}$$

Tangential Momentum Equation

$$2\xi \frac{\partial f'}{\partial \xi} + \left(\frac{V - \ell'}{f'}\right)\frac{1}{\eta_e}\frac{\partial f'}{\partial \eta} + \beta\left[f' + \frac{\bar{M}_e}{\bar{e}\bar{\bar{M}}}\frac{\theta}{f'}\right] - \frac{\ell}{f'}\frac{1}{\eta_e^2}\frac{\partial^2 f'}{\partial \eta^2} = 0 \tag{17b}$$

Normal Momentum

$$\frac{\partial p}{\partial \eta} - (\kappa_c\, u_e\, \eta_e\, \sqrt{2\xi}/r_b^j)(f')^2 = 0 \qquad \text{Shock Layer}$$

$$\frac{\partial p}{\partial \eta} = 0 \qquad \text{Boundary Layer} \tag{17c}$$

Energy Equation

$$2\xi f' \frac{\partial \theta}{\partial \xi} + \left(V - \frac{\bar{c}'}{\bar{c}_p} + d + b\right)\frac{1}{\eta_e}\frac{\partial \theta}{\partial \eta} - \frac{\alpha\ell}{\eta_e^2}\left(\frac{\partial f'}{\partial \eta}\right)^2 + \left(-\alpha\beta\frac{\bar{M}_e}{\bar{M}\bar{\bar{e}}} + \bar{e}\right)\theta f'$$

$$-\frac{\bar{c}}{\eta_e^2\,\bar{c}_p}\frac{\partial^2\theta}{\partial \eta^2} - \frac{a}{\eta_e^2\theta}\left(\frac{\partial \theta}{\partial \eta}\right)^2 + \frac{e}{\bar{c}_p T_e}\sum_{i=1}^{NI} h_i\left(\frac{w_i}{\rho}\right) = 0 \tag{17d}$$

Species Equations $(i = 1, 2, \ldots NI-1)$

$$2\xi f' \frac{\partial c_i}{\partial \xi} + \frac{(V - b_i')}{\eta_e}\frac{\partial c_i}{\partial \eta} - \frac{b_i}{\eta_e^2} - \frac{\partial^2 c_i}{\partial \eta^2} - \frac{\bar{a}_i}{\theta\,\eta_e^2}\frac{\partial^2\theta}{\partial \eta^2} - \frac{\bar{a}_i'}{\theta\eta_e}\frac{\partial \theta}{\partial \eta} + \frac{1}{\eta_e^2}\left(\frac{\bar{a}_i}{\theta^2}\right)\left(\frac{\partial \theta}{\partial \eta}\right)^2 - \bar{b}_i' - e\left(\frac{w_i}{\rho}\right) = 0 \tag{17e}$$

$$c_{NI} = 1 - \sum_{i=1}^{NI} c_i \tag{17f}$$

where the mass flux (2) in the transformed plane has been expressed as

$$\frac{r_b^j\,(2\xi)^{\frac{1}{2}}\,j_i}{d\xi/dx} = \frac{\ell}{\eta_e Pr}\left\{\sum_{k=1}^{NI}\bar{\bar{b}}_{ik}\frac{\partial c_k}{\partial \eta} + \frac{L_i^T}{\theta}\frac{\partial \theta}{\partial \eta}\right\}$$

and where

$$\bar{a}_i = \frac{\ell L_i^T}{Pr}\ , \quad a = \frac{1}{\bar{c}_p}\sum_{i=1}^{NI}\bar{a}_i\, c_{p_i}\ , \quad b_i = \frac{\ell Le_i}{Pr}\ , \quad \bar{b}_i = \frac{\ell}{\eta_e Pr}\sum_{\substack{k=1\\k\neq i}}^{NI}\Delta\bar{\bar{b}}_{i,k}\frac{\partial c_k}{\partial \eta}$$

$$b = -\sum_{i=1}^{NI}\frac{c_{p_i}\bar{b}_i}{\bar{c}_p}\ , \quad \bar{c} = \frac{\ell\bar{c}_p}{Pr}$$

$$e = \frac{2\xi}{u_e \frac{d\xi}{dx}} \quad , \quad \bar{e} = \frac{2\xi}{T_e}\frac{dT_e}{d\xi} \quad , \quad \bar{\bar{e}} = \rho_e u_e \frac{du_e/dx}{dp/dx} \quad , \quad d = -\sum_{i=1}^{NI} \frac{c_{p_i}}{\bar{c}_p}\frac{b_i}{\eta_e}\frac{\partial c_i}{\partial \eta}$$

$$\alpha = \frac{u_e^2}{\bar{c}_p T_e} \quad , \quad \beta = \frac{2\xi}{u_e}\frac{du_e}{d\xi} = e\,\frac{du_e}{dx}\ \left[\text{at stagnation point } \beta = 1/(1+j)\right]$$

$$\ell' = \frac{1}{\eta_e}\frac{\partial \ell}{\partial \eta} \quad , \quad \bar{a}_i' = \frac{1}{\eta_e}\frac{\partial \bar{a}_i}{\partial \eta} \quad , \quad b_i' = \frac{1}{\eta_e}\frac{\partial b_i}{\partial \eta} \quad , \quad \bar{b}_i' = \frac{1}{\eta_e}\frac{\partial \bar{b}_i}{\partial \eta} \quad , \quad \bar{c}' = \frac{1}{\eta_e}\frac{\partial \bar{c}}{\partial \eta}$$

The boundary-layer equations, with the exception of the continuity equation and the normal momentum equation, are of the following form:

$$\frac{1}{\eta_e^2}\frac{\partial^2 W}{\partial \eta^2} + \frac{\alpha_1}{\eta_e}\frac{\partial W}{\partial \eta} + \alpha_2 W + \alpha_3 + \alpha_4\, 2\xi\,\frac{\partial W}{\partial \xi} = 0 \tag{18}$$

where W represents any of the dependent variables. The coefficients in the above equation are obtained after the boundary-layer equations (17) have been linearized, with the following relations:

$$\frac{1}{f'} = \frac{1}{f'_{m,n}}\left(2 - \frac{f'}{f'_{m,n}}\right) \tag{19a}$$

$$\frac{1}{f'}\,W = \left(\frac{W}{f'}\right)_{m,n} + \frac{W}{f'_{m,n}} - \left(\frac{W}{f'}\right)_{m,n}\frac{f'}{f'_{m,n}} \tag{19b}$$

$$e\sum_{i=1}^{NI} h_i\,(w_i/\rho) = \sum_{i=1}^{NI}\left[\bar{W}_i\,\Delta h_i^F - e\theta h_i\,\frac{\partial}{\partial \theta}\left(\frac{w_i}{\rho}\right) - \bar{W}_i\,T_e\,\theta_{m,n}^2\,\frac{\partial C_{1_i}}{\partial \theta}\right]_{\theta_{m,n}} + \theta\sum_{i=1}^{NI}\left[\bar{W}_i\,C_{1_i}\,T_e\right.$$

$$\left. + e h_i\,\frac{\partial}{\partial \theta}\left(\frac{w_i}{\rho}\right) + \bar{W}_i T_e\,\theta_{m,n}\,\frac{\partial C_{1_i}}{\partial \theta}\right]_{\theta_{m,n}} \tag{19c}$$

$$\frac{w_i}{\rho} = W_i^0 - W_i^1 c_i \qquad \text{and} \qquad \bar{W}_i = e(w_i/\rho) \tag{19d}$$

In the above and subsequent coefficients, the quantities without subscripts are evaluated at the point $(m + \Theta, n)$. The quantities in the bracket in equation (19c) should all be evaluated at $(m + \Theta, n)$ except the quantities which are a function of θ and these should use $\theta_{m,n}$. The term $\partial C_{1_i}/\partial\theta$ has been neglected in the subsequent development as it is usually a small term.

The coefficients in equation (18) become

Momentum Equation

$$\alpha_1 = -(V - \ell')/\ell \tag{20a}$$

$$\alpha_2 = -2\beta f'_{m,n}/\ell - F/f'_{m,n} \tag{20b}$$

$$\alpha_3 = -\frac{\beta}{\ell}\left[-(f'_{m,n})^2 + \frac{\bar{M}_e\theta}{\bar{\bar{e}}\bar{M}}\right] + F \tag{20c}$$

$$\alpha_4 = -f'_{m,n}/\ell \tag{20d}$$

where

$$F = \frac{1}{\eta_e^2}\left(\frac{\partial^2 f'}{\partial\eta^2}\right)_{m,n} + \frac{\alpha_1}{\eta_e}\left(\frac{\partial f'}{\partial\eta}\right)_{m,n} - \frac{\beta}{\ell}\left[(f'_{m,n})^2 + \frac{\bar{M}_e\theta}{\bar{\bar{e}}\bar{M}}\right]$$

Energy Equation

$$\alpha_1 = \left[\bar{c}' - \bar{c}_p\,(V + d + b)\right]\Big/\bar{c} \tag{20e}$$

$$\alpha_2 = \left\{\bar{c}_p f'\left(\alpha\beta\frac{\bar{M}_e}{\bar{\bar{e}}\bar{M}} - \bar{e}\right) - \sum_{i=1}^{NI}\left[\bar{W}_i C_{1_i} + \frac{eh_i}{T_e}\frac{\partial}{\partial\theta}\left(\frac{w_i}{\rho}\right)\right]_{\theta_{m,n}}\right\}\Big/\bar{c} \tag{20f}$$

$$\alpha_3 = \left\{\bar{c}_p\,\alpha\ell\left(\frac{1}{\eta_e}\frac{\partial f}{\partial\eta}\right)^2 - \frac{1}{T_e}\sum_{i=1}^{NI}\left[\bar{W}_i\,\Delta h_i^F - \theta e h_i\frac{\partial}{\partial\theta}\left(\frac{w_i}{\rho}\right)\right]_{\theta_{m,n}}\right\}\Big/\bar{c} \tag{20g}$$

$$\alpha_4 = -f'\bar{c}_p\Big/\bar{c} \tag{20h}$$

where

$$\frac{\partial}{\partial\theta}\left(\frac{w_i}{\rho}\right) = \frac{M_i}{\theta}\sum_{r=1}^{NR}(\beta_{ri} - \alpha_{ri})\left[\left(C2_r + \frac{C1_r \times 10^3}{T_K} - \alpha_r\right)L_{f_r}\right.$$

$$\left. - \left(D2_r + \frac{D1_r \times 10^3}{T_K} - \beta_r\right)L_{b_r}\right]$$

Species Equation with $L_i^T = 0$

$$\alpha_1 = -(V - b_i')/b_i \tag{20i}$$

$$\alpha_2 = -eW_i^1/b_i \tag{20j}$$

$$\alpha_3 = \left(eW_i^0 + \bar{b}_i'\right)\Big/ b_i \tag{20k}$$

$$\alpha_4 = -f'/b_i \tag{20l}$$

The value of $\bar{\bar{e}}$ is determined from the normal momentum equation (17c). For boundary layer flow, equation (17c) shows that the pressure gradient in the x-direction is only a function of x. Therefore, $\bar{\bar{e}}$ is constant across the boundary layer and equal to -1 when the flow at the edge of the boundary layer is determined from the inviscid body streamline. When swallowing of the inviscid flow is taken into account, the value of $\bar{\bar{e}}$ is determined from the edge conditions and the definition of $\bar{\bar{e}}$ in terms of these quantities. For the stagnation point shock layer, the pressure is constant across the layer. However, there is a variation of the rate of change of the tangential pressure gradient across the layer at the stagnation point, which can be determined from Equation (17c). When the pressure is solved from Equation (17c) and differentiated with respect to x, the following is obtained at the stagnation point where the velocity gradient behind the shock (see Appendix A, equation A12) has also been used.

For the stagnation point shock layer

$$\bar{\bar{e}} = \rho_e u_e \frac{du_e}{dx}\Big/\frac{\partial p}{\partial x} = \frac{1}{2\epsilon}\left\{\frac{(1-\epsilon)D^2}{\left[1-\epsilon\left(1-\frac{1}{s}\right)\right]^2} + \frac{D^{\frac{1}{2}}\eta_e \int_{\eta}^{\eta_s} (f')^2\, d\eta}{\left\{(i+j)Re_s\epsilon\left[s(1-\epsilon)+\epsilon\right]\right\}^{\frac{1}{2}}}\right\}^{-1} \tag{21}$$

where

$$D = 1 + \frac{1}{Re_s}\left\{\frac{1}{\eta_e}\left[(1+j)\frac{Re_s}{\epsilon}\left(\frac{R_N}{V_\infty}\frac{du_{sh}}{dx}\right)\right]^{\frac{1}{2}}\frac{df'}{d\eta} - \frac{(1-s)}{s(R_{sh}/R_N)} + \frac{(1-s)(1+j)\rho_{sh}}{\eta_e}\frac{d}{d\eta}\left(\frac{V}{\rho}\right)\right\}_{sh}$$

$$s = \frac{R_N}{R_{sh}}\left(1 + \frac{\Delta}{R_N}\right)$$

For boundary layer flow along a body

$$\bar{\bar{e}} = \begin{cases} -1 & \text{without swallowing} \\ \rho_e u_e \dfrac{du_e/dx}{dp_e/dx} & \text{with swallowing} \end{cases} \tag{22a}$$

If $\frac{du_e}{dx} = 0$, then the combination of $\bar{\bar{e}}$ with β is required which gives

$$\beta/\bar{\bar{e}} = \frac{e}{\rho_e u_e} \frac{dp_e}{dx} \qquad (22b)$$

C. Finite Difference Procedure

The boundary layer or shock layer is divided with a grid of variable size $\Delta\eta_n$ and $\Delta\xi$ (see Figure 1.1). It is assumed that f', θ, and c_i's are known at the grid points in the m^{th} column and unknown in the $(m + 1)^{th}$ column. In the present implicit scheme, the derivatives are replaced with linear difference quotients, and the partial differential equations are evaluated at $(m + \Theta, n)$. The equations are written with a parameter Θ which will give the various finite-difference schemes as indicated below:

$$\Theta = \begin{cases} 0 & \text{Explicit (not in program)} \\ \frac{1}{2} & \text{Crank Nicholson} \\ 1 & \text{Implicit} \end{cases}$$

With the function $W(\xi,\eta)$ representing the dependent variables, the difference quotients are written for a variable step size in the η-direction at the point $(m + \Theta)$ as

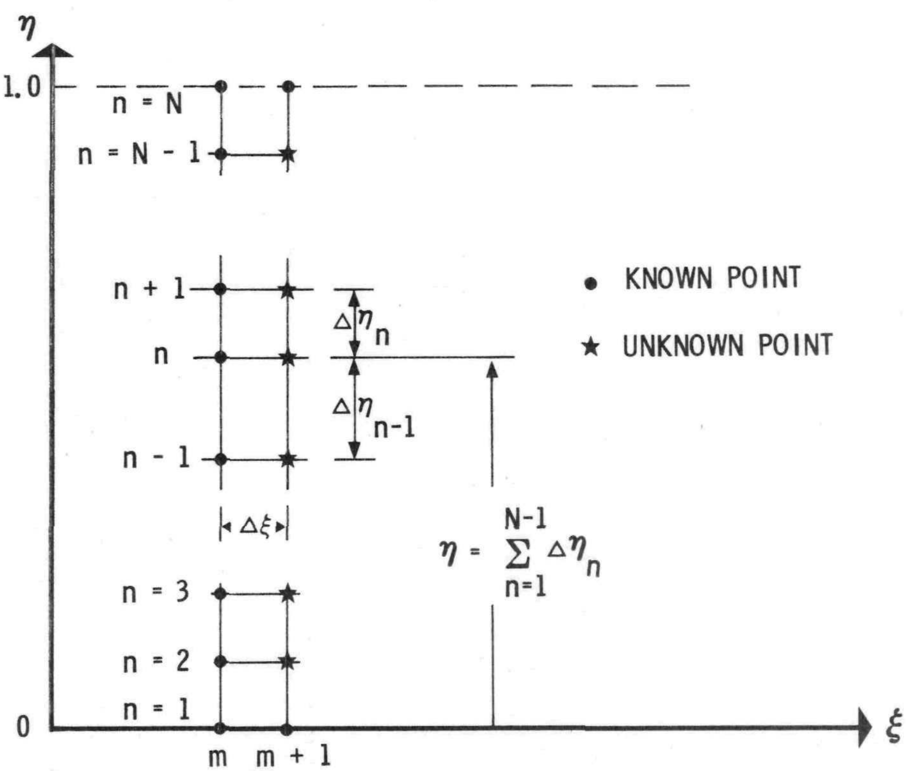


FIG. 1.1 GRID SYSTEM

$$\frac{\partial W}{\partial \xi} = \left(W_{m+1,n} - W_{m,n}\right) / \Delta\xi \qquad (23a)$$

$$\frac{\partial W}{\partial \eta} = \Theta \left(a_1 W_{m+1,n+1} + b_1 W_{m+1,n} + c_1 W_{m+1,n-1}\right) + (1 - \Theta) \left(a_1 W_{m,n+1} + b_1 W_{m,n} + c_1 W_{m,n-1}\right) \qquad (23b)$$

$$\frac{\partial^2 W}{\partial \eta^2} = \Theta \left(a_2 W_{m+1,n+1} + b_2 W_{m+1,n} + c_2 W_{m+1,n-1}\right) + (1 - \Theta) \left(a_2 W_{m,n+1} + b_2 W_{m,n} + c_2 W_{m,n-1}\right) \qquad (23c)$$

where

$$a_1 = \Delta\eta_{n-1}/(\Delta\eta_n \cdot \Delta\eta_T)$$

$$b_1 = (\Delta\eta_n - \Delta\eta_{n-1})/(\Delta\eta_n \cdot \Delta\eta_{n-1})$$

$$c_1 = - \Delta\eta_n/(\Delta\eta_{n-1} \cdot \Delta\eta_T)$$

$$a_2 = 2/(\Delta\eta_n \cdot \Delta\eta_T)$$

$$b_2 = - 2/(\Delta\eta_n \cdot \Delta\eta_{n-1})$$

$$c_2 = 2/(\Delta\eta_{n-1} \cdot \Delta\eta_T)$$

$$\Delta\eta_T = \Delta\eta_n + \Delta\eta_{n-1}$$

$$\Delta\eta_n = \eta_{n+1} - \eta_n$$

Also the function W is evaluated at $(m + \Theta)$ as

$$W = \Theta W_{m+1,n} + (1 - \Theta)W_{m,n} \qquad (24)$$

When the above difference quotients and expressions are used with the partial differential equations (18), the finite-difference equations become the simultaneous (involving only one dependent variable across the layer) linear algebraic equations

$$A_n W_{m+1,n+1} + B_n W_{m+1,n} + C_n W_{m+1,n-1} = D_n \qquad (25)$$

where

$n = 2, 3, \dots N - 1$

Momentum Equation	$W = f'$
Energy Equation	$W = \theta$
First Species Equation	$W = c_1$
Second Species Equation	$W = c_2$
....	.....
NI - 1 Species Equation	$W = c_{NI - 1}$

The coefficients in the above equations with $L_i^T = 0(\bar{a}_i = a = 0)$ are

$$A_n = \Theta\bar{A}_n P \tag{26a}$$

$$B_n = \bar{\delta} + \Theta\bar{B}_n P \tag{26b}$$

$$C_n = \Theta\bar{C}_n P \tag{26c}$$

$$D_n = \bar{\delta}W_{m,n} - (1 - \Theta)P\left(\bar{A}_n W_{m,n+1} + \bar{B}_n W_{m,n} + \bar{C}_n W_{m,n-1}\right) - \eta_e^2 \alpha_3 P \Delta\eta_n \Delta\eta_{n-1} \tag{26d}$$

where

$$\bar{A}_n = \frac{2\Delta\eta_{n-1}}{\Delta\eta_T}\left(1 + \eta_e \alpha_1 \Delta\eta_{n-1}/2\right)$$

$$\bar{B}_n = \left[- 2 + \left(\Delta\eta_n - \Delta\eta_{n-1}\right)\eta_e \alpha_1 + \Delta\eta_n \Delta\eta_{n-1} \eta_e^2 \alpha_2\right]$$

$$\bar{C}_n = \frac{2\Delta\eta_n}{\Delta\eta_T}\left(1 - \eta_e \alpha_1 \Delta\eta_n/2\right)$$

$$P = \Delta\xi/\left(2\xi_{m+\Theta}\,\Delta\eta_n\,\Delta\eta_{n-1}\,\alpha_4 \eta_e^2\right)$$

$$\xi_{m+\Theta} = \Theta\xi_{m+1} + (1 + \Theta)\xi_m$$

$$\bar{\delta} = 1$$

In the above coefficients the α's are determined from relations (20) where all quantities are evaluated at the m^{th} column of grid points across the boundary layer. In the relation (20g) it was found necessary to express the following derivative in the energy equation as

$$\left(\frac{\partial f'}{\partial\eta}\right)^2 = \left(f'_{m,n+1} - f'_{m,n-1}\right)\left(f'_{m+1,n+1} - f'_{m+1,n-1}\right)/4\Delta\eta^2$$

It should be noted that the momentum equation is solved before the energy equation in order that the values of f' at the $(m + 1)^{th}$ column are available for the above expression.

From truncation error considerations, the mass fraction in relation (19d) would be evaluated as shown; however, such a form can encounter stability problems. Although stability is usually considered to be practically unaffected by lower order terms as discussed by Richtmyer[9], in actual computations with finite step size these terms can control the stability. As considered by Richtmyer, stability is concerned with what happens in the limit as the mesh sizes approach zero. Therefore, such stability analyses cannot be completely satisfactory when finite mesh sizes are employed. If W_1^0 and W_1^1 were constants, then it appears that stable solutions are obtained without any restrictions on the step sizes. However, W_1^0 and W_1^1 are not constant and stability problems can occur if the step size becomes too large, but the formulation below appears to minimize unstable solutions. In relation (19d) the mass fraction is evaluated at (m + 1) for all difference schemes and the evaluation of relation (20j) must be changed. For the species equation, the value of α_2 becomes

$$\alpha_2 = \begin{cases} - e\, W_i^1/(\Theta b_i) & \text{in } B_n \\ 0 & \text{in } D_n \end{cases} \tag{27}$$

The relations (7) for W_i^0 and W_i^1 are not the appropriate form to employ. The following discussion indicates how these terms are modified for several gas models. For a binary mixture of oxygen, the only reaction is the first of Equation (87) and relations (7) become

$$W_O^0 = 2M_O\, k_{f_1}\, \bar{\rho}\gamma_{O_2}\, \gamma_{M_1} \tag{28a}$$

$$W_O^1 = 2k_{b_1}\, \bar{\rho}^2\, \gamma_O\, \gamma_{M_1} \tag{28b}$$

For the case of an air mixture, reactions 4, 5, 6, and 7 contribute to the chemical production term of atomic oxygen. In each reaction, either the forward or backward term involves the mass fraction of atomic oxygen and allows the chemical production term to be expressed as relation (19d). Similar comments can be made about the production term for other species. For stability and convergence of the finite-difference solution, it is desirable that the terms W_i^0 and W_i^1 be as nearly constant as possible. For the case of oxygen, the value of W_O^0 is proportional to γ_{O_2} and when the oxygen is highly dissociated, the value of γ_{O_2} changes rapidly for a small change in γ_O, since $\gamma_{O_2} = (1 - c_O)/M_{O_2}$. Therefore, it was found better to write the terms W_O^0 and W_O^1 for oxygen as

$$W_O^0 = 2M_O\, k_{f_1}\, \bar{\rho}\gamma_{M_1} \left(\gamma_{O_2} + \frac{1}{2}\gamma_O\right) = k_{f_1}\, \bar{\rho}\gamma_{M_1} \tag{29a}$$

$$W_O^1 = 2k_{b_1}\, \bar{\rho}^2\, \gamma_O\, \gamma_{M_1} + k_{f_1}\, \bar{\rho}\gamma_{M_1} \tag{29b}$$

For the case of the air mixture, the terms W_i^0 and W_i^1 were expressed in a similar manner to relations (28). Then the W_i^0 and W_i^1 for atomic oxygen were modified by adding $M_O\, k_{f_1}\, \bar{\rho}\gamma_{M_1}\, \gamma_O$ and $k_{f_1}\, \bar{\rho}\gamma_{M_1}$, respectively, to these terms, as has been done in relations (29).

A carbon-air gas mixture with the air reactions (87) and the additional reactions,

$$r = 8 : CO + O + M_4 \rightleftarrows CO_2 + M_4$$

$$= 9 : CO_2 + O \rightleftarrows CO + O_2$$

is now considered. The parameters for the production terms for CO and CO_2 as determined from Equation (7) are

$$\left(W_{CO}^0\right)_7 = M_{CO}\, \gamma_{CO_2}\, W_1$$

$$\left(W^1_{CO}\right)_7 = k_{f_8}\,\bar{\rho}^2\,Y_O\,Y_{M_4} + k_{b_9}\,\bar{\rho}Y_{O_2} = W_2$$

$$\left(W^0_{CO_2}\right)_7 = M_{CO_2}\,Y_{CO}\,W_2$$

$$\left(W^1_{CO_2}\right)_7 = \bar{\rho}\left(k_{b_8}\,Y_{M_4} + k_{f_9}\,Y_O\right) = W_1$$

The above parameters are modified by adding quantities which give terms involving the following

$$Y^c = Y_{CO} + Y_{CO_2}$$

Since Y^c is the mass concentration of the element carbon, in any small region of the flow this quantity will be nearly constant. The production term parameters become

$$W^0_{CO} = \left(W^0_{CO}\right)_7 + M_{CO}\,Y_{CO}\,W_1 = M_{CO}\,Y^C W_1 \qquad (30a)$$

$$W^1_{CO} = \left(W^1_{CO}\right)_7 + W_1 \qquad (30b)$$

$$W^0_{CO_2} = \left(W_{CO_2}\right)_7 + M_{CO_2}\,Y_{CO_2}\,W_2 = M_{CO_2}\,Y^C W_2 \qquad (30c)$$

$$W^1_{CO_2} = \left(W^1_{CO_2}\right)_7 + W_2 \qquad (30d)$$

The above production term parameters are more nearly constant and numerical results are obtained without stability problems.

To complete the system of Equations (25), the boundary conditions are required and are written in the form

$$B_1 W_{m+1,1} + A_1 W_{m+1,2} + W_{m+1,3} = D_1 \qquad (31a)$$

$$W_{m+1,N-2} + C_N W_{m+1,N-1} + B_N W_{m+1,N} = D_N \qquad (31b)$$

The determination of B_1, A_1, D_1, C_N, B_N and D_N for the various governing boundary conditions is given in Chapters III and IV.

The difference equations (25) and the boundary conditions (31) form a system of linear algebraic equations of the tridiagonal type. These are readily solved with the standard technique which has been discussed by a number of authors. The particular relations employed in this study are now presented. The boundary condition parameters at the wall A_1, B_1 and D_1 are determined, the boundary condition parameters at the outer edge B_N, C_N and D_N are determined, and the coefficients A_n, B_n, C_n, and D_n are determined, from (26) across the layer for N = 2, 3, ... N-1. The following parameters are determined from the wall to the outer edge of the layer:

$$E_1 = -\left(C_2 - A_2B_1\right)^{-1}\left(B_2 - A_2A_1\right) \tag{32a}$$

$$e_1 = \left(C_2 - A_2B_1\right)^{-1}\left(D_2 - A_2D_1\right) \tag{32b}$$

$$E_n = -\left(C_nE_{n-1} + B_n\right)^{-1} A_n \tag{32c}$$

$$e_n = \left(C_nE_{n-1} + B_n\right)^{-1}\left(D_n - C_ne_{n-1}\right) \tag{32d}$$

$$n = 2,\ 3,\ \ldots\ (N-1)$$

The dependent variables are then obtained from the following relations where the solution starts at the outer edge and proceeds toward the wall:

$$W_{m+1,n} = \left[\left(A_{N-1} - C_{N-1}B_N\right) + \left(B_{N-1} - C_{N-1}C_N\right)E_{N-1}\right]^{-1}\left[\left(D_{N-1} - C_{N-1}D_N\right) - \left(B_{N-1} - C_{N-1}C_N\right)e_{N-1}\right] \tag{33a}$$

$$W_{m+1,n} = E_nW_{m+1,n+1} + e_n \qquad n = N-1,\ N-2,\ \ldots,\ 1 \tag{33b}$$

For the case that relations (31) are replaced with

$$B_1W_{m+1,1} + A_1W_{m+1,2} = D_1 \tag{34a}$$

$$C_NW_{m+1,N-1} + B_NW_{m+1,N} = D_N \tag{34b}$$

The relations (32a), (32b) and (33a) become

$$E_1 = -B_1^{-1}A_1 \tag{35a}$$

$$e_1 = B_1^{-1}D_1 \tag{35b}$$

$$W_{m+1,N} = (B_N + C_NE_{N-1})^{-1}(D_N - C_Ne_{N-1}) \tag{35c}$$

When the conservation equations are uncoupled and the dependent variables are solved one at a time, the order in which the variables f', θ, and c_i's are solved must be chosen. The present investigation has shown that the species equations should be solved before the energy equation. The mass fraction of species obtained from the solution of the species equations are used in Equation (19d) to evaluate the chemical production term which is required in the energy equation. The terms W_i^0 and W_i^1 are not recalculated in Equation (19d).

The transformed velocity V remains to be determined and is obtained from the continuity equation which is written in finite-difference form as

$$V_{m+\Theta,n} = V_{m+\Theta,n-1} - \Delta\eta_{n-1}\left(\frac{\xi_{m+\Theta}}{\Delta\xi} + \frac{\Theta}{2}\sigma\right)\left(f'_{m+1,n} + f'_{m+1,n-1}\right)\left(\eta_e\right)_{m+\Theta}$$
$$+ \Delta\eta_{n-1}\left(\frac{\xi_{m+\Theta}}{\Delta\xi} - \frac{(1-\Theta)}{2}\sigma\right)\left(f'_{m,n} + f'_{m,n-1}\right)\left(\eta_e\right)_{m+\Theta} \tag{36}$$

with

$$\sigma = 1 + \left(\frac{2\xi}{\eta_e}\frac{d\eta_e}{d\xi}\right)_{m+\Theta}$$

$$\frac{d\eta_e}{d\xi} = \frac{d\eta_e}{d(x/R_N)} \Big/ \left[(\rho\mu)_r\, u_e\, r_b^{2j}\, R_N\right]$$

In the foregoing finite-difference procedure, the coefficients α_1, α_2, α_3 and α_4 (see Eqs. 20) have quantities which should be evaluated at $(m + \Theta)$ but must be determined with the known quantities at m. With this procedure employed, the dependent variables at $(m + 1)$ can be determined and the method is first-order accurate (truncation error is of the order of the step size). The quantities at $(m + \Theta)$ can now be evaluated with the use of equation (24) and the calculation of the dependent variables at $(m + 1)$ determined again. If $\Theta = \frac{1}{2}$, this iteration procedure will make the method second-order accurate. This is only true if the modification to α_2 as given by relation (27) is not made. Also for certain derivative type boundary conditions with $\Theta = \frac{1}{2}$, stability problems can be encountered. Therefore, the present method does not use iteration at each step and hence is of first-order accuracy. The program is set up to handle $0 < \Theta \leq 1$ but generally a value of $\Theta = 1$ is recommended.

To start the boundary layer solution along the body or to obtain the shock layer solution at the stagnation point, profiles of the dependent variables are required across the layer. At a stagnation point or at the tip of a sharp body $\xi = 0$ and the partial differential equations (17) become ordinary differential equations. These equations can be solved with nearly the same finite-difference procedure employed for the partial differential equations and the coefficients (26) of the difference equation (25) are the same except the following quantities become

$$\Theta = P = 1 \quad , \quad \bar{\delta} = 0 \quad , \quad \text{and } F = 0 \tag{37}$$

When $\xi = 0$, the values of e and $\bar{\bar{e}}$ are of indeterminate form and require special consideration which gives

$$e = \frac{2\xi}{u_e d\xi/dx} = \begin{cases} 0 \text{ (tip of sharp body)} \\ \\ \dfrac{1}{(1+j)du_e/dx} \text{ (stagnation point)} \end{cases} \tag{38a}$$

where for a blunt body

$$\frac{du_e}{dx} = \begin{cases} (u_e/x)_{\text{edge table}} & \text{(boundary layer with swallowing)} \\ \dfrac{1}{R_N}\left[2\left(p_{e_s} - p_\infty\right)\Big/\rho_{e_s}\right]^{\frac{1}{2}} & \text{(boundary layer-Newtonian pressure)} \\ \dfrac{V_\infty}{R_N D}\left[s(1-\varepsilon)+\varepsilon\right] & \text{(shock layer)} \end{cases} \tag{38b}$$

$$\bar{\bar{e}} = -\left[\rho_e\left(R_N\frac{du_e}{dx}\right)^2\Big/(2p_2)\right] = -\frac{1}{2}\rho_e\left[u_e(6)\right]^2\Big/\left[p_{e_s} - p_e(6)\right]$$

and p_2 is defined by

$$p_e = p_{e_s} - p_2\,(x/R_N)^2 + \dots$$

In the evaluation of $\bar{\bar{e}}$, the value of u_e and p_e at the sixth entry in the edge table is employed. For a sharp body the quantity $\beta/\bar{\bar{e}}$ should be employed and this is determined when $\xi = 0$ from equation 22b.

The evaluation of V for the initial profiles requires that equation (36) be modified. The continuity equation (17a) with $\xi = 0$ is integrated to give

$$V = V_b - \eta_e \int_0^{\eta} f' \, d\eta \quad .$$

In finite-difference notation and consistent with equation (36), the above becomes

$$V_{0,1} = V_b$$
$$V_{0,n+1} = V_{0,n} - \frac{1}{2}\eta_e \Delta\eta_{n-1} \left(f'_{0,n+1} + f'_{0,n}\right) \qquad n = 2,3, \ldots N \qquad (39)$$

When the difference equations are solved for the initial profiles of the dependent variables, initial estimates of the dependent variables, $\bar{W}$, are required to evaluate the coefficients α_1, α_2 and α_3 as given by equations (20). The terms with subscript (m) and the other quantities which should be evaluated at $(m + \Theta)$ are all evaluated with the initial estimate of the variables. For a first estimate of the profile variables, the procedure given below can be used if better values are not available. For the velocity profile f', the Blasius result can be assumed or some previously determined profile employed. The transformed velocity V is determined from equation (39). The temperature in the boundary layer is estimated from a second degree polynomial. The coefficients of the polynomial are specified such that the edge and wall temperature conditions are satisfied and the temperature gradient at the outer edge of the boundary layer is assumed zero. With these conditions, the temperature profile is obtained from

$$\theta = \theta_w + (1 - \theta_w)\left(\frac{\eta}{\eta_e}\right)(2 - \eta/\eta_e) \qquad (40)$$

The species profiles for the non-equilibrium case are determined by assuming the flow is frozen ($w_i/\rho = 0$) and local similarity applies. In addition, binary type of diffusion is assumed and $\ell = Pr = Le = 1$ which allows the following relation to be obtained

$$c_i = c_{i_b} + \left(c_{i_e} - c_{i_b}\right) f' \quad . \qquad (41)$$

The mass fraction of species at the wall, c_{i_b}, in the above relation is determined corresponding to the boundary condition being employed.

Since the calculated variables, W, will most likely be different from the initial estimates, $\bar{W}$, the solution is repeated with the coefficients (20) evaluated with the calculated variables. This procedure is repeated until the difference between the calculated and assumed variables is a small number. This is expressed as

$$|1 - \bar{W}/W| < \epsilon$$

where W is any of the dependent variables. For some problems it is necessary to weigh the assumed and calculated solutions to obtain a new assumed solution for the next iteration as follows:

$$\bar{W}_{New} = \bar{W} + \omega(W - \bar{W}) \quad . \qquad (42)$$

The weight factor ω should be 1 for fast convergence of the iteration procedure but values of approximately 0.1 are required for some cases to make the procedure stable.

The method of nonlinear overrelaxation (see Appendix B) has also been used to solve Equation (18). An investigation was made for a binary gas of oxygen to compare the nonlinear overrelaxation method with the finite-difference procedure. It appears that the finite-difference procedure generally converges faster, as one would expect. For example, for a linear ordinary differential equation, the finite-difference procedure would give the solution directly, while the nonlinear overrelaxation method would still require an iteration procedure. The nonlinear overrelaxation method, however, will probably give convergent solutions for cases where the finite-difference method diverges.

III. Species Boundary Conditions at the Wall

A. General Relations

The appropriate form for the boundary conditions has been given in equations (31) or (34). The boundary conditions for the momentum and energy equations [conditions (8a) and (8b)] are readily written in the form of (34). The boundary condition at the wall for the species equations was given (Equation 9) as

$$\dot{m}_i = c_i \rho v + j_i \tag{43}$$

where all terms are evaluated at the surface. The mass flux of species i at the wall is expressed as

$$\dot{m}_i = P_i + Q_i \, (c_i)_b \tag{44}$$

where the values of P_i and Q_i depend on the surface material characteristic and are considered subsequently. The relative mass flux with $L_i^T = 0$ is written as

$$j_i = -\frac{1}{\bar{W}} \left\{ \frac{Le_i}{\eta_e} \frac{\partial c_i}{\partial \eta} + \Delta b_i \right\} \tag{45}$$

where

$$\bar{W} = \frac{Pr_b \sqrt{2\xi}}{\ell_b (\rho\mu)_r \, r_b^j \, u_e} \text{ at } \xi = 0 \quad , \quad \bar{W} = \begin{cases} 0 & \text{(tip of sharp body)} \\ (Pr/\ell)_b \Big/ \sqrt{(1+j)(\rho\mu)_r \dfrac{du_e}{dx}} & \text{(stagnation point)} \end{cases}$$

$$\Delta b_i = \sum_{\substack{k=1 \\ k \neq i}}^{NI} \frac{\Delta \bar{\bar{b}}_{ik}}{\eta_e} \left(\frac{\partial c_k}{\partial \eta} \right)_{m,1}$$

For a trace species ($c_i < 10^{-4}$), the term Δb_i is neglected in relation (45). The derivative in the above expressions is written as

$$\left(\frac{\partial c_i}{\partial \eta} \right)_W = a_3 c_{i_1} + b_3 c_{i_2} + c_3 c_{i_3} + \frac{1}{6} \Delta\eta_1 (\Delta\eta_1 + \Delta\eta_2) \, W''' + \ldots \tag{46}$$

where

$a_3 = -(\Delta\eta_2 + 2\Delta\eta_1)/\Delta\eta_1(\Delta\eta_1 + \Delta\eta_2)$

$b_3 = (\Delta\eta_1 + \Delta\eta_2)/\Delta\eta_1 \, \Delta\eta_2$

$c_3 = -\Delta\eta_1/\Delta\eta_2 \, (\Delta\eta_1 + \Delta\eta_2)$

The above relations (43) through (46) can now be employed to determine the wall boundary condition coefficients A_1, B_1 and D_1 in relation (31) for the species equations. These same coefficients for the momentum and energy equation for relation (34) are also given below.

Tangential Momentum

$$A_1 = 0 \quad , \quad B_1 = 1 \quad \text{and} \quad D_1 = 0 \tag{47a}$$

Energy

Use with Eq. 34

$$A_1 = 0 \quad , \quad B_1 = 1 \quad \text{and} \quad D_1 = T_b/T_e \tag{47b}$$

Species

$$A_1 = -\left(1 + \Delta\eta_2/\Delta\eta_1\right)^2$$

$$B_1 = \frac{\Delta\eta_2}{\Delta\eta_1}\left[2 + \frac{\Delta\eta_2}{\Delta\eta_1} + \frac{\eta_e \bar{W}}{Le_i}\left(\Delta\eta_1 + \Delta\eta_2\right)\left(\rho v - Q_i\right)\right] \tag{47c}$$

$$D_1 = \frac{\eta_e}{Le_i}\left(\frac{\Delta\eta_2}{\Delta\eta_1}\right)\left(\Delta\eta_1 + \Delta\eta_2\right)\left(\bar{W} P_i + \Delta b_i\right)$$

The above coefficients are used with relation (31). The quantities in the above relation should be evaluated at (m + 1) but are determined at (m) to avoid an iteration process.

The boundary condition that is used with the continuity equation (36) is

$$V_b = \frac{\sqrt{2\xi}\,(\rho v)_b}{(\rho\mu)_r\, u_e\, r_b^{\,j}} \tag{48}$$

The total mass flux $(\rho v)_b$ is determined from the sum of the individual species mass flux as given by equation (11) where equation (44) is used to determine $\dot{m}_i$.

The mass flux of a species at the surface can be due to the phenomena illustrated in Figure 3.1.

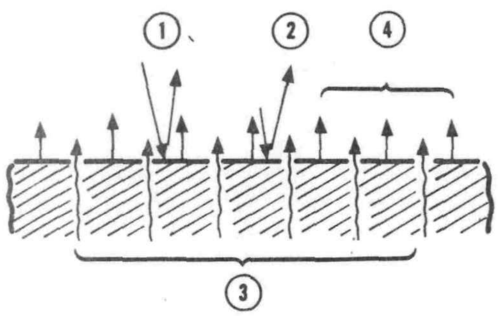


FIG. 3.1 - SURFACE PHENOMENA

(1) Catalytic reactions with no net mass transfer such as recombination of atoms.

(2) Heterogeneous reactions such as the oxidation of carbon or metals by oxygen.

(3) Mass transfer through the surface as occurs with transpiration cooling and pyrolysis gases.

(4) Vaporization and sublimation of the surface material.

B. Catalytic Surface Reactions

The chemical kinetics of heterogeneous catalytic reactions is exceedingly complicated, and knowledge of the details of the phenomena is inadequate. With the exception of certain atom recombinations on a limited number of materials as obtained from experimental results, the relations required to predict the mass flux of the various species at the surface are not available. The usual procedure employed in fluid mechanic investigations has been to assume the wall is non-catalytic or "fully" catalytic, which gives the two extreme conditions, with the actual situation in between these limits. For a non-catalytic wall, the mass flux of all the species, $\dot{m}_i$, are zero. The appropriate conditions for a "fully" catalytic wall and a clear definition of what this expression means is not given in the literature.

Therefore, a fully catalytic recombination surface for a diatomic gas is such that every dissociated and ionized species that strikes the surface is converted to a molecular species due to the heterogeneous reactions. The gas near the surface tends to be undissociated and un-ionized according to this definition of a fully catalytic surface. It should be noted that some materials under certain conditions atomize molecular species upon contact with the surface[10] so that one could also consider fully catalytic dissociation surfaces.*

For a wall at low temperature, the above definition of a fully catalytic wall is nearly in agreement with other relations employed, such as, the gas is completely undissociated or the gas composition corresponds to the equilibrium value at the surface temperature. For higher wall temperatures, the later type of relation can be substantially different from the present proposed relation for a fully catalytic wall.

The boundary conditions on species mass flux at the surface for air for the two extreme cases can be expressed as

Non-Catalytic Wall

$$\dot{m}_i = 0 \quad i = 1, 2, \ldots NI \tag{49}$$

Fully Recombined Catalytic Wall

$$\dot{m}_{NO} = 0 \quad \text{(NO is non-catalytic with surface)}$$

$$\dot{m}_i = -(\rho c_i)_b \sqrt{\frac{RT_b}{2\pi M_i}} \quad i = O, N, NO^+ \tag{50a}$$

$$\dot{m}_j = -\sum_i \frac{\alpha_i^{\,j}}{2} \frac{M_j}{M_i} \dot{m}_i \quad j = O_2, N_2 \tag{50b}$$

where

$\alpha_i^{\,j}$ = amount of element j in species i

For a pure air boundary layer flow with a "fully" catalytic recombination surface, the heterogeneous reactions are expressed phenomenologically in the following form:

$2O \rightarrow O_2$

$2N \rightarrow N_2$

$2NO^+ + 2e^- \rightarrow O_2 + N_2$

With the use of (43), the values of P_i and Q_i become

*The fully catalytic recombination should only be used when the wall temperature is sufficiently low that the equilibrium composition for this temperature is much less than the composition at the surface.

$$P_O = 0 \qquad Q_O = -\rho_b \sqrt{\frac{RT_b}{2\pi M_O}}$$

$$P_N = 0 \qquad Q_N = -\rho_b \sqrt{\frac{RT_b}{2\pi M_N}}$$

$$P_{NO} = 0 \qquad Q_{NO} = 0$$

$$P_{NO^+} = 0 \qquad Q_{NO^+} = -\rho_b \sqrt{\frac{RT_b}{2\pi M_{NO^+}}} \tag{51}$$

$$P_{O_2} = -c_O Q_O - c_{NO^+} Q_{NO^+} \qquad Q_{O_2} = 0$$

$$P_{N_2} = -c_N Q_N - c_{NO^+} Q_{NO^+} \qquad Q_{N_2} = 0$$

If a fully catalytic dissociation wall is defined as a surface where molecular species that hit the surface are dissociated ($O_2 \rightarrow 2O$ and $N_2 \rightarrow 2N$), the above relations become

$$P_O = -c_{O_2} Q_{O_2} \qquad Q_O = 0$$

$$P_N = -c_{N_2} Q_{N_2} \qquad Q_N = 0$$

$$P_{NO} = 0 \qquad Q_{NO} = 0$$

$$P_{NO^+} = 0 \qquad Q_{NO^+} = 0 \tag{52}$$

$$P_{O_2} = 0 \qquad Q_{O_2} = -\rho_b \sqrt{\frac{RT_b}{2\pi M_{O_2}}}$$

$$P_{N_2} = 0 \qquad Q_{N_2} = -\rho_b \sqrt{\frac{RT_b}{2\pi M_{N_2}}}$$

If a catalytic wall is interpreted as the condition where the gas is in chemical equilibrium, the boundary condition cannot be written in terms of P_i's and Q_i's. The relations (47c) are replaced with the following:

$$A_1 = 0$$

$$B_1 = 1$$

$$D_1 = c_{i_{eq}}$$

The quantities $c_{i_{eq}}$ are determined from the equilibrium composition of the gas corresponding to the surface temperature. The exact application of this condition is difficult to apply since the element composition is not known generally at the surface.

C. Heterogeneous Reactions

The appropriate heterogeneous reactions that can occur at a surface depend on the surface material composition and the chemical species available in the boundary layer flow.

For a graphite surface, the following oxidation reactions are considered:

(1) $2C(S) + O_2 \rightarrow 2CO$

(2) $C(S) + O \rightarrow CO$

The detail chemical kinetic mechanisms occurring are not understood for this relatively simple system and many additional chemical species can produce gasification of graphite.

The mass flux of the chemical species at the surface are zero except for the following:

$$\dot{m}_{O_2} = -\frac{M_{O_2}}{2M_C} \epsilon_{O_2} \rho_b \sqrt{\frac{RT_b}{2\pi M_{O_2}}} c_{O_2} \tag{53a}$$

$$\dot{m}_O = -\frac{M_O}{M_C} \epsilon_O \rho_b \sqrt{\frac{RT_b}{2\pi M_O}} c_O \tag{53b}$$

$$\dot{m}_{CO} = -\frac{M_{CO}}{M_O} \left(\dot{m}_{O_2} + \dot{m}_O\right) \tag{53c}$$

where

$$\epsilon_i = \frac{\text{flux of carbon atoms away from surface}}{\text{collision flux of i with the surface}} \qquad (i = O, O_2)$$

There have been a large number of experimental papers concerned with the oxidation of carbon or graphite, but adequate information to estimate the oxidation probabilities ϵ_{O_2} and ϵ_O is not available. The best information available on these quantities can be obtained from Rosner and Allendorf[11], but the range of applicability is limited.

The parameters in equation (44) become

$$P_i = Q_i = 0 \qquad \text{(all i except } O_2\text{, O and CO)}$$

$$\left.\begin{aligned} P_{O_2} &= 0 & Q_{O_2} &= -\frac{M_{O_2}}{2M_C} \epsilon_{O_2} \rho \sqrt{\frac{RT_b}{2\pi M_{O_2}}} \\ P_O &= 0 & Q_O &= -\frac{M_O}{M_C} \epsilon_O \rho \sqrt{\frac{RT_b}{2\pi M_O}} \\ P_{CO} &= -\frac{M_{CO}}{M_O}\left(Q_{O_2} c_{O_2} + Q_O c_O\right) & Q_{CO} &= 0 \end{aligned}\right\} \tag{54}$$

For non-volatile oxidation of a metal the oxygen in the boundary layer flow is absorbed. If it is assumed that only oxygen in the form of atomic and molecular oxygen will react with the metal, then the mass flux of these species can be expressed as

$$\dot{m}_O = -\epsilon_O \rho_b \sqrt{\frac{RT_b}{2\pi M_O}} c_O \tag{55a}$$

$$\dot{m}_{O_2} = -\epsilon_{O_2} \rho_b \sqrt{\frac{RT_b}{2\pi M_{O_2}}} c_{O_2} \tag{55b}$$

In this relation ϵ_i is the flux of species i absorbed on the metal divided by the collision flux of species i with the surface. The mass flux of all the other species is zero. The parameters in equation (44) become

$$P_i = Q_i = 0 \quad \text{(for all i except O and } O_2\text{)}$$

$$P_O = 0 \quad ; \quad Q_O = -\epsilon_O \rho_b \sqrt{\frac{RT_b}{2\pi M_O}} \tag{56}$$

$$P_{O_2} = 0 \quad ; \quad Q_{O_2} = -\epsilon_{O_2} \rho_b \sqrt{\frac{RT_b}{2\pi M_{O_2}}}$$

D. Injection of Gases

Some types of materials decompose and form pyrolysis gases which are injected in the boundary layer flow. The amount and composition of these gases are assumed known and can be obtained from an ablation program. The present approach is to uncouple the boundary layer problem from the ablation problem but an iteration procedure could be employed to couple the present nonequilibrium boundary layer program with an ablation program. The species mass fraction of the pyrolysis gases is determined by assuming the gas is in equilibrium at the surface temperature, with the amount of the various material elements in the pyrolysis gas determined from composition of the original material. With the total mass flux of the pyrolysis gas assumed known and the composition determined from the equilibrium composition, the mass flux, $\dot{m}_i$, of the various species of the pyrolysis gas can be determined at the surface from

$$\dot{m}_i = \left(c_{i_{eq}}\right)_p (\rho v)_p \tag{57}$$

When the composition of the pyrolysis gases are known from experimental results, the above relation (57) can be replaced with this information. The parameters in equation (44) become

$$P_i = \left(c_{i_{eq}}\right)_p (\rho v)_p$$

$$Q_i = 0 \tag{58}$$

When a surface uses transpiration cooling, the mass flux of the individual species can be determined assuming the injected gases are in chemical equilibrium. Again it is assumed the total mass flux of the gas injected is known.

E. Evaporation

The sublimation of a material results in the evaporation of a surface species which is written as

$$\dot{m}_i = \frac{\alpha_i \, p_e \, \bar{M}_b}{\sqrt{2\pi M_i \, RT_b}} \left(c_{i_{SV}} - c_i \Phi\right) \tag{59}$$

where

α_i = condensation coefficient

$c_{i_{SV}}$ = mass fraction of species i corresponding to the equilibrium vapor pressure

Φ = correction factor for non-equilibrium evaporation

The usual relation employed for non-equilibrium evaporation is the above relations with $\Phi = 1$. A more appropriate relation is the expressions[3,12 13] which is considered in detail in Reference 3. The parameter Φ is introduced to modify the relation that is usually applied to obtain the number of molecules hitting a surface with zero mass transfer at the surface to the case with surface mass transfer. In the first case, the Maxwellian distribution function is for a gas at rest while a more proper form is the Maxwellian distribution for a moving gas. The parameters in equation (44) become

$$P_i = \frac{\alpha_i \, p_e \, \bar{M}_b \, c_{i_{SV}}}{\sqrt{2 \pi M_i \, RT_b}}$$

$$Q_i = - \frac{\alpha_i \, p_e \, \bar{M}_b \, \Phi}{\sqrt{2 \pi M_i \, RT_b}} \tag{60}$$

IV. Boundary Conditions at the Outer Edge.

A. Boundary Layer

The conditions at the outer edge of the boundary layer depend upon the shape of the body and the resulting inviscid flow field. The present work is concerned with slender bodies with a sharp tip or with a blunt nose. For a sharp conical body, the edge conditions can be determined from perfect gas solutions as given by Kopal[14], Sims[15] and Jones[16], or equilibrium solutions as given by Romig[17] and Hudgins[18]. For slender cones at velocities below 25,000 fps, the inviscid flow is only slightly dissociated and perfect gas or equilibrium solutions give nearly the same edge conditions. The conical solutions give edge conditions which are constant along the body.

For a blunted body, the edge conditions for the classical boundary approach (inviscid streamline along body is used as edge conditions) can be obtained from the non-equilibrium inviscid flow or from the following equations, which govern the inviscid chemically reacting flow for a streamtube:

$$\frac{dU}{ds} = - \frac{1}{\rho U} \frac{dp}{ds} \tag{61a}$$

$$\frac{dT}{ds} = \frac{1}{\bar{c}_p} \left[\frac{dp}{ds} \Big/ \rho - \frac{1}{U} \sum_{i=1}^{NI} \left(h_i \cdot \frac{w_i}{\rho} \right) \right] \tag{61b}$$

$$\frac{dc_i}{ds} = \frac{1}{U} \left(\frac{w_i}{\rho} \right) \tag{61c}$$

$$\rho = \frac{p}{RT \displaystyle\sum_{i=1}^{NI} \frac{c_i}{M_i}} \tag{61d}$$

The initial conditions for these equations are the temperature, pressure, and equilibrium composition at the stagnation point, which can be obtained from Lomax and Inouye[19] for a number of cases. These equations then can be solved along the body if the pressure distribution is known. As a first approximation, the Newtonian pressure can be employed and more appropriately the pressure obtained from an inviscid flow field solution should be used. The chemical model employed for the flow field solution will only have a small effect on the pressure distribution.

The employment of the classical boundary layer approach is especially questionable for chemically reacting flows on blunted conical bodies. When the body streamline flow is determined for this type of body, the gas will remain dissociated and ionized at large distances downstream from the nose. The appropriate boundary condition at the edge of the boundary layer at large distances downstream is the same as the sharp cone edge conditions of undissociated and un-ionized air. Therefore, the appropriate edge conditions on a blunt conical vehicle require that the swallowing of the inviscid flow be considered with the appropriate non-equilibrium solutions of the streamlines entering the boundary layer employed.

The point at which a streamline crosses the shock wave, r_{sh}, is determined by matching the mass flow in the boundary layer with the mass flow entering the shock wave which gives (see Figure 4.1)

$$r_{sh}^{1+j} = \frac{2^j \sqrt{2\xi}\, \eta_e}{\rho_\infty V_\infty} \int_0^1 f' \left(1 + \frac{y \cos \theta_b}{r_b} \right)^j d\eta - \frac{2^j}{\rho_\infty V_\infty} \int_0^x (\rho v)_b \, r_b^j \, dx \tag{62}$$

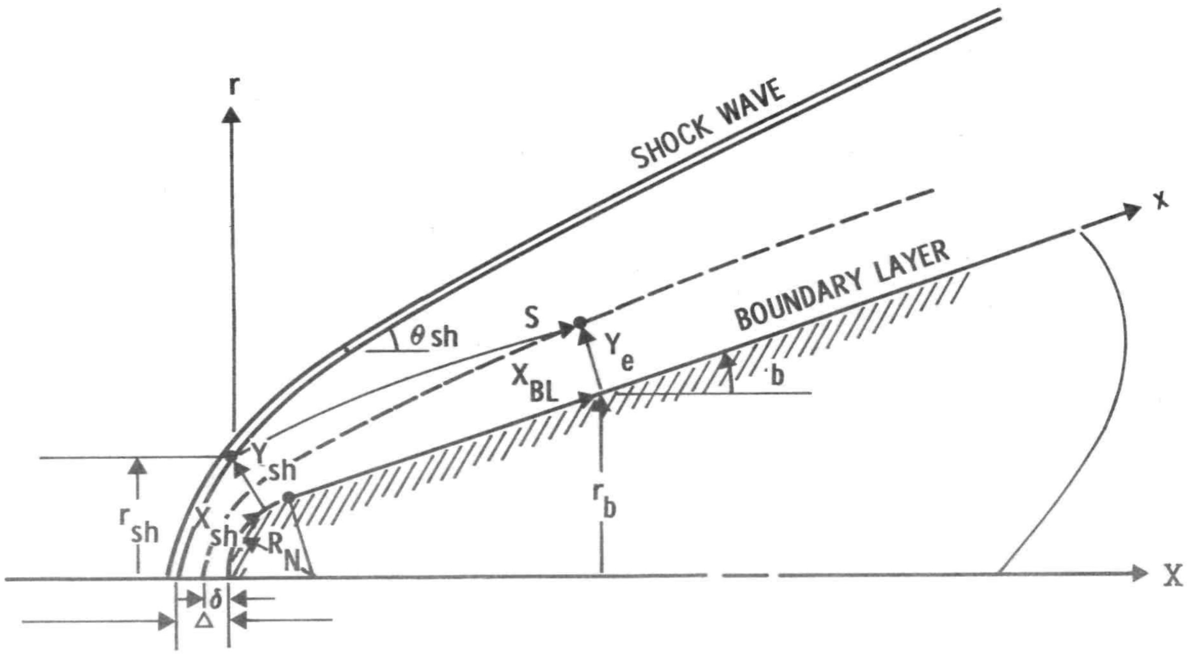


FIG. 4.1 - BODY GEOMETRY

The right side of this equation is evaluated at $x = x_{BL}$ which is the location along the body where the streamline enters the boundary layer.

There are a number of ways to obtain the non-equilibrium inviscid flow. The simplest method is to assume the pressure across the shock layer is given by the Maslen relation and use the pressure behind an assumed shock-shape and the body pressure to estimate the pressure along streamlines. The length of the streamline, s_ℓ, can be estimated as

$$s_\ell = \sqrt{\Delta^{*2} + (x_{BL} - x_{sh})^2}$$

where

δ = boundary layer thickness at stagnation point

Δ = shock wave stand-off distance

$\Delta^* = \Delta - \delta$

x_{BL} = distance along body where the streamline enters the boundary layer

x_{sh} = distance along body where the streamline crosses the shock wave.

The conditions behind the shock-wave which are obtained from the frozen Rankine-Hugoniot relations are used as initial conditions to start the solution of the streamtube equations (61). When the solution along the streamline is obtained to s_ℓ, the conditions at the edge of the boundary layer will be known at x_{BL}. The total velocity along the streamline U is known and the desired boundary condition is u_e which can be obtained from

$$u_e = \sqrt{U^2 - v_e^2}$$

The value of v_e is obtained from the boundary layer solution with the relation

$$\rho_e v_e = - \frac{\rho_\infty V_\infty}{2^j (r_b + y_e \cos \theta_b)^j} \frac{d r_{sh}^{1+j}}{dx} + \rho_e u_e \frac{dy_e}{dx} \tag{63}$$

A more accurate procedure would be to employ an inviscid flow field solution to estimate the length and pressure distribution along streamlines. Then this procedure would follow the approach given above. The most accurate procedure is to employ a nonequilibrium flow field program to obtain the inviscid flow where the thickness of the boundary layer is added to the body to give an effective body shape. Also, there is mass transfer across this effective body shape such that the mass flow between streamlines is conserved. From such a solution, the edge conditions for the boundary layer flow along a blunted vehicle is determined again and a new value of the mass flux in the boundary layer is obtained. If the mass flux is nearly the same as the previous result, the solution is considered converged. Otherwise, new edge conditions are determined and a new boundary layer solution is obtained. This process is repeated until convergence is obtained.

The conditions at the edge of the boundary layer u_e, T_e, p_e, and c_{i_e}'s (air species only) are generally a function of x. As analytical expressions are not usually available, a table of the edge conditions as a function of x is employed. The Lagrange's interpolation formula (parabolic form) is used to obtain the edge conditions and the derivatives of the edge conditions. Let y represent any of the edge conditions and subscript "i" will indicate the position of the variables x and y in the table. The Lagrange interpolation formula gives

$$y(x_M) = \frac{(x_M - x_i)(x_M - x_{i+1})}{(x_{i-1} - x_i)(x_{i-1} - x_{i+1})} y_{i-1} + \frac{(x_M - x_{i-1})(x_M - x_{i+1})}{(x_i - x_{i-1})(x_i - x_{i+1})} y_i + \frac{(x_M - x_{i-1})(x_M - x_i)}{(x_{i+1} - x_{i-1})(x_{i+1} - x_i)} y_{i+1} \tag{64a}$$

$$\left(\frac{dy}{dx}\right)_{x_M} = \left[\frac{(x_M - x_i) + (x_M - x_{i+1})}{(x_{i-1} - x_i)(x_{i-1} - x_{i+1})}\right] y_{i-1} + \left[\frac{(x_M - x_{i-1}) + (x_M - x_{i+1})}{(x_i - x_{i-1})(x_i - x_{i+1})}\right] y_i + \left[\frac{(x_M - x_{i-1}) + (x_M - x_i)}{(x_{i+1} - x_{i-1})(x_{i+1} - x_i)}\right] y_{i+1}$$

(64b)

where

$$x_{i-\frac{1}{2}} \le x_M \le x_{i+\frac{1}{2}}$$

The edge conditions at $(m + \frac{1}{2})$ are required for the evaluation of the parameters that are employed in the finite difference procedure. Therefore the following approximation is made for the edge conditions at $\xi_{m+\frac{1}{2}}$ and it should be noticed that this point is not the same as $(x_m + \frac{1}{2}\Delta x)$:

$$y_{m+\frac{1}{2}} = \frac{1}{2}(y_{m+1} + y_m) \tag{65a}$$

$$\left(\frac{dy}{dx}\right)_{m+\frac{1}{2}} = \frac{1}{2}\left[\left(\frac{dy}{dx}\right)_{m+1} + \left(\frac{dy}{dx}\right)_m\right] \tag{65b}$$

where

$$y = p_e, u_e, T_e \text{ or } c_{i_e}$$

Additional quantities which are required and are a function of the edge conditions are the following:

$$e = \Theta e_{m+1} + (1 - \Theta)e_m \tag{66a}$$

where

$$e_m = \left[\frac{2\xi}{u_e \frac{d\xi}{dx}}\right]_m = \left[\frac{2\xi}{(\rho\mu)_r u_e^2 r_b^{2j}}\right]_m$$

$$\beta = e\left(\frac{du_e}{dx}\right)_{m+\frac{1}{2}} \tag{66b}$$

$$\bar{e} = \left[\frac{2\xi}{T_e}\frac{dT_e}{d\xi}\right] = e\left(\frac{u_e}{T_e}\frac{dT_e}{dx}\right)_{m+\frac{1}{2}} \tag{66c}$$

$$\bar{\bar{e}} = \left[\rho_e u_e \frac{du_e/dx}{dp_e/dx}\right]_{m+\frac{1}{2}} \tag{66d}$$

If $\frac{dp_e}{dx} \le 10^{-8}$, then relation (66d) is replaced with $\bar{\bar{e}} = -1$.

B. ξ and r_b

In solving the boundary layer equations, the finite-difference procedure is applied in the transformed ξ, η coordinate system. The results must be related back to the physical x, y coordinate system. Also the edge conditions are given as a function of x and are required for the finite-difference solution as a function of ξ. The procedure of specifying $\Delta x (x_{m+1} = x_m + \Delta x)$ and then finding $\Delta\xi$ has been employed. The transformed coordinate ξ is related to x by the ordinary differential equation

$$\frac{d\xi}{dx} = (\rho\mu)_r\, u_e\, r_b^{2j} \quad . \tag{67}$$

For a sharp cone of half angle θ_c, the radius of the body is

$$r_b = x \sin \theta_c \tag{68}$$

and for a flat plate or sharp cone the following is obtained:

$$\xi = \frac{1}{(1 + 2j)} (\rho\mu)_e\, u_e\, (\sin \theta_c)^{2j}\, x^{1+2j} \quad .$$

In this relation the conditions at the edge of the boundary layer are assumed constant (no interaction with the inviscid flow is considered) and $(\rho\mu)_r$ is evaluated at the edge.

For a spherically blunted conical body of nose radius R_N, the body radius is

$$r_b = R_N \sin (x/R_N) \text{ for } 0 \le x \le R_N\varphi_s \tag{69a}$$

$$r_b = R_N (\sin \varphi_s - \varphi_s \sin \theta_c) + x \sin \theta_c \text{ for } x > R_n\varphi_s \tag{69b}$$

where

$$\varphi_s = \frac{90 - \theta_c}{57.29578} \quad .$$

For a hyperboloid with nose radius R_N and asymptotic half-angle θ_A, the radius of the body must be obtained from the numerical solution of the following ordinary differential equation:

$$\frac{dr_b}{dx} = \left[1 + \frac{(r_b/R_N)^2}{1 + (r_b/R_N)^2 \tan^2 \theta_A} \right]^{-\frac{1}{2}} \tag{70}$$

The solution can be obtained with any of the standard methods, such as the Runge-Kutta or Predictor-Corrector.

For the value of ξ as a function of x, the ordinary differential equation (67) has to be solved numerically for most body shapes. When the Runge-Kutta method is applied to this equation the following is obtained:

$$\xi_{m+1} = \xi_m + \Delta\xi \tag{71a}$$

where

$$\Delta\xi = \frac{1}{6} \Delta x \left[\lambda(x_m) + 4\lambda(x_m + \frac{1}{2} \Delta x) + \lambda(x_m + \Delta x) \right] \tag{71b}$$

$$\lambda(x_m) = \left[(\rho\mu)_r \, u_e \, r_b^{2j} \right]_{x = x_m} . \qquad (71c)$$

The value of ξ at $(m + \frac{1}{2})$ can be obtained from

$$\xi_{m+\frac{1}{2}} = \xi_m + \tfrac{1}{2}\Delta\xi \quad . \qquad (72)$$

C. Step-Size Δx Specification

An indicated earlier, the step-size Δx is specified and then $\Delta\xi$ is determined. For many problems it is advantageous to change this step-size in order to reduce the computation time. An automatic procedure has not been developed to change the step-size; but from experience, the following procedure has been successful:

$$\Delta x_{m+1} = \Delta x_m + \epsilon \qquad m = 0, 1, 2, \dots M \qquad (73)$$

$$= (x_{m+1} - x_m) \quad .$$

In order to obtain the solution at various values of x, the distance along the body is broken into major intervals with coordinates denoted by X_i and $i = 0, 1, 2, \dots I$. At X_i the solution of the governing equations is obtained. Between X_i and X_{i+1} the interval is divided into M_i steps which are of variable size as given by relation 73 and this is illustrated in Fig. 4.2. The value of x_m and Δx_m are obtained from

$$x_{m_o+m_i} = x_{m_o} + m_i \, \Delta x_{m_o+1} + \tfrac{1}{2} \epsilon \, m_i(m_i - 1) \qquad m_i = 0, 1, 2 \dots M_i \qquad (74a)$$

$$\Delta x_{m_o+m_i} = \Delta x_{m_o+1} + \epsilon(m_i - 1) \qquad m_i = 1, 2, \dots (M_i + 1) \qquad (74b)$$

The number of steps M_i between X_i and X_{i+1} must be chosen and, of course, must be an integer. Therefore, the parameter ϵ must be chosen such that the interval between X_i and X_{i+1} is divided into an even number of steps. The values of M_i and ϵ are determined by specifying the X_i and estimating the Δx_{m_o+1} desired at the beginning of the interval. The following equation is obtained from (74b) where δ is introduced as indicated:

$$\delta = \frac{\epsilon \, M_i}{\Delta x_{m_o+1}} - 1 = \left(\frac{\Delta x_{m_o+M_i+1}}{\Delta x_{m_o+1}} \right)_{Est} - 2 \qquad (75)$$

Equation (74a) is used to obtain

$$M_i = (2\beta + 1 + \delta_{Est})/(3 + \delta_{Est}) \qquad (76)$$

where

$$\beta = \left(x_{m_o+m_i} - x_{m_o} \right) \Big/ \Delta x_{m_o+1} \quad .$$

The above relation for M_i will not give an integer value; therefore, the calculated value is rounded off to an integer. With M_i known, equation (76) is used to determine δ as

$$\delta = (2B + 1 - 3M_i) \;/\; (M_i - 1) \tag{77}$$

The step sizes between X_i and X_{i+1} are determined with the use of (74b) and (75) to obtain

$$\Delta x_{m_o+m_i} = \left[1 + \frac{\delta+1}{M_i} \; (m_i - 1)\right] \Delta x_{m_o+1} \qquad m_i = 1,2,\ldots(M_i+1) \tag{78}$$

The result of applying the foregoing relations is illustrated in Table I-IV. The values in the second interval cannot be determined until the values in the first interval have been calculated.

A geometric progression has been used previously to vary the step size and this can be recovered by taking

$$\delta + 1 = 2M_i$$

Then the step size becomes

$$\Delta x_{m_i} = (2m_i - 1)\,\Delta x_1 \qquad m_i = 1,2,\ \ldots\ (M_i + 1)$$

and the total distance along the body becomes

$$x_{M_i} = x_o + \Delta x_1\, M_i^2$$

D. Shock Layer

The flow at the edge of the shock layer is obtained from the modified Rankine-Hugoniot relations. These relations have been given by Cheng[20] and correspond to a one dimensional shock wave with gradients of the flow properties behind it. It has been shown by Cheng[21] and Tolstykh[22] that these relations are also valid for a curvilinear shock wave if the shock thickness is much less than the radius of curvature of the shock. This requires that $R_{e_s} \gg 1$ for the following relations to be appropriate:

$$p_{sh} = p_\infty + \rho_\infty V_\infty^2 \left(1 - \frac{\rho_\infty}{\rho_{sh}}\right) + S_p \tag{79a}$$

$$h_{sh} = h_\infty + \frac{1}{2}\, V_\infty^2 \left[1 - \left(\frac{\rho_\infty}{\rho_{sh}}\right)^2\right] - S_h \tag{79b}$$

$$T_{sh} = \left(h_{sh} - \sum_{i=1}^{NI} c_i \Delta h_i^F\right) \Bigg/ \sum_{i=1}^{NI} c_i c_{1_i} \tag{79c}$$

$$\frac{\rho_\infty}{\rho_{sh}} = \frac{p_\infty T_{sh}\, \overline{M}_\infty}{p_{sh} T_\infty \overline{M}_{sh}} \tag{79d}$$

where the slip terms are

$$S_p = \frac{4}{3}\left(\frac{\rho_\infty V_\infty}{V_{sh}}\right)^2 \frac{1}{\eta_e}\frac{d}{d\eta}\left(\frac{V}{\rho}\right)_{sh}$$

$$S_h = S_p/\rho_{sh} + \frac{1}{V_{sh}\eta_e}\left\{\frac{\bar{c}_p T_e}{Pr}\frac{d\theta}{d\eta} + \frac{1}{Pr}\sum_{i=1}^{NI} h_i\left[Le_i\frac{dc_i}{d\eta} + \sum_{\substack{k=1\\k\neq 1}}^{NI}\overset{=}{\Delta b}_{ik}\frac{dc_k}{d\eta}\right]\right\}_{sh}$$

The above slip terms are not known until the viscous shock layer solution has been determined and thus an iteration procedure is required in the solution. In order to locate where the above modified Rankine-Hugoniot relations (79) are to be applied, the interface behind the shock transition zone is defined as where the usual Rankine-Hugoniot pressure jump is completed as used by Cheng.[21] The foregoing relations (79) are solved with $S_p = S_h = 0$. An iteration process is used to solve these equations where, initially, (ρ_∞/ρ_{sh}) is assumed zero and the denominator in Equation (79c) is taken equal to 7000. For this solution the mass fraction of species across the shock are taken constant and provide the usual Rankine-Hugoniot pressure. For the viscous shock layer solution, the above equations (79) are employed with S_h included but with equation (79a) replaced with the previously determined Rankine-Hugoniot pressure. The velocities behind the shock are $v_{sh} = -(\rho_\infty/\rho_{sh}) V_\infty$ and $u_{sh} = 0$. The mass fraction of chemical species is also required at the interface which requires the solution of the species conservation equations across the shock transition zone. When chemical reactions are neglected in the shock transition zone, a relation for the mass fraction of a chemical species at the interface is readily obtained and has been given by Cheng.[20] The present analysis neglects the chemical reactions and pressure and thermal diffusion effects in the shock transition zone. For air flows, the neglect of the chemical reactions is a reasonable assumption as the results of Lee and Zierten[23] and Chung[24] have shown. Also Chung states that the thermal and pressure diffusion of atoms are in opposite directions and the neglect of these effects does not imply an excessive approximation. The transformed velocity V_{sh} behind the shock has been determined in Appendix A, and its value and the other boundary conditions at the outer edge of the shock layer become

$$V(\eta_e) = -\{\epsilon\, Re_s D/(1+j)\,[s(1-\epsilon)+\epsilon]\}^{\frac{1}{2}} \tag{80a}$$

$$f'(\eta_e) = 1 \tag{80b}$$

$$\theta(\eta_e) = 1 \tag{80c}$$

$$c_i(\eta_e) = c_{i_\infty} - \frac{1}{Pr\eta_e V_{sh}}\left\{Le_i\frac{dc_i}{d\eta} + \sum_{\substack{k=1\\k\neq 1}}^{NI}\overset{=}{\Delta b}_{ik}\frac{dc_k}{d\eta}\right\}_{sh} \tag{80d}$$

For the shock-layer flow, the value of $\eta_e = \eta_{sh}$ is determined from

$$\eta_e = - V(\eta_e) / \int_0^1 f' d\eta \tag{80e}$$

When equation (39) is used to solve for $V(\eta)$, the relation (80a) is satisfied.

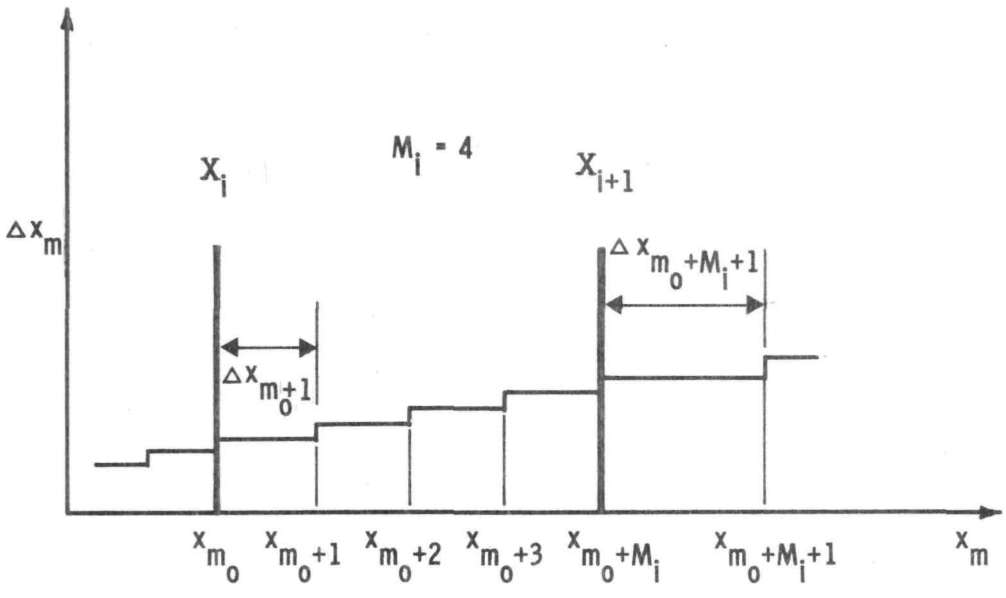


FIG. 4.2 - VARIABLE STEP SIZE NOTATION

TABLE 1-IV

VARIABLE STEP SIZE

X	$(\Delta x_{M_0} + 1)_{EST}$	δ Est	β	M_i	δ	$\Delta x_{M_0} + 1$
0	0.010					0.010
		0.5	10	6	0.60	
0.1	0.025					0.026
		0	15.4	11	-0.12	
0.5	0.050					0.049
		0	10.02	7	0.067	
1.0	0.100					0.101

V. THERMODYNAMIC AND TRANSPORT PROPERTIES AND CHEMICAL KINETICS

The relations presented in this chapter generally apply for an arbitrary gas model. The data required to apply these relations is given for the case of a 7 species slightly ionized air mixture.

A. Enthalpy and Specific Heat

The thermodynamic properties of enthalpy and specific heat of a species "i" are obtained from tabulated values. A table of C_{1_i} and C_{2_i} as a function of temperature is obtained from the tabulated values of enthalpy and specific heat as given by Browne[25-27] where

$$C_{1_i} = \frac{49686}{1.98726 M_i} \left(\frac{H - H^*}{T}\right)$$

$$C_{2_i} = \frac{49686}{1.98726 M_i} CP$$

The variation of the enthalpy and specific heat of the various species with temperature is given in Figures 5.1 and 5.2 as obtained from Browne. The enthalpy and specific heat of species i is obtained from the following relations:

$$h_i = T \cdot C_{1_i} + \Delta h_i^F \quad \text{(ft-lb/slug)} \tag{81a}$$

$$C_{p_i} = C_{2_i} \quad (\text{ft-lb/slug } ^\circ R) \tag{81b}$$

where a second-degree Langrangian interpolation is used in the table look-up for C_{1_i} and C_{2_i}. The heats of formation are given in Table 5-I.

B. Viscosity and Thermal Conductivity

The viscosity and thermal conductivity of the gaseous mixture is calculated from Wilke's semiempirical relations (see references 8 and 28 for this and other approximate expressions).

$$\mu = \sum_{i=1}^{NI} \frac{X_i \mu_i}{\sum_{j=1}^{NI} X_j \varphi_{ij}} (.00208855) \left(\frac{\text{slug}}{\text{ft-sec}}\right) \tag{82a}$$

$$k = \sum_{i=1}^{NI} \frac{X_i k_i}{\sum_{j=1}^{NI} X_j \varphi_{ij}} (103.873424) \left(\frac{\text{lb}}{\text{sec } ^\circ R}\right) \tag{82b}$$

where

$$X_i = c_i \bar{M}/M_i$$

$$\varphi_{ij} = \left[1 + \sqrt{\frac{\mu_i}{\mu_j}} \left(\frac{M_j}{M_i}\right)^{1/4}\right]^2 \left[\sqrt{8}\sqrt{1 + \frac{M_i}{M_j}}\right]^{-1}$$

$$k_i = \frac{\mu_i}{M_i}\left[C_{p_i}\frac{M_i}{R} + 1.25\right] \quad , \quad \left(\frac{\text{gm-mole}}{\text{cm sec}}\right)$$

It has been pointed out by Fay[29] that the above mixture rules are inappropriate for partially ionized gases. Therefore, only slightly ionized gases are considered. The viscosities of the individual species i are obtained from a curve fit relation

$$\mu_i = e^{C_{\mu_i}}\, TK^{\left(A_{\mu_i}\ \ln TK + B_{\mu_i}\right)} \quad , \quad \frac{\text{gm}}{\text{cm sec}} \tag{83}$$

where A_{μ_i}, B_{μ_i}, and C_{μ_i} are curve fit coefficients and are given in Table 5-II for the various chemical species. The data that these coefficients are based upon was obtained from references 30 to 33. Since the gas is only slightly ionized, the amount of NO^+ is small and it will not effect the mixture properties. The variation of the species viscosity with temperature is given in Figure 5.3.

C. Multicomponent Diffusion

The multicomponent Lewis-Semenov numbers were obtained from relations given in Reference 34, which are written as

$$L_{ij} = \bar{F}_{ij} - \frac{M_i}{M_j}\bar{\bar{F}}_{ii} \tag{84}$$

The quantities $\bar{F}_{ij}$ are coefficients in a matrix which is the inverse of the matrix with the following coefficients:

$$F_{ij} = \frac{c_i}{\mathcal{L}_{ij}} + M_j \sum_{\substack{\ell=1 \\ \ell \neq i}}^{NI} \frac{c_\ell}{M_\ell \mathcal{L}_{i\ell}} \qquad i \neq j \tag{85a}$$

$$F_{ij} = 0 \qquad i = j \tag{85b}$$

The binary Lewis-Semenov numbers are obtained using the definition and binary diffusion coefficients which are expressed as

$$\mathcal{D}_{ij} = (\bar{\mathcal{D}}_{ij}/\bar{p})\ 1.0764 \times 10^{-3} \quad (\text{ft}^2/\text{sec}) \tag{86}$$

where

$\bar{p}$ = pressure in atmospheres

$\bar{\mathcal{D}}_{ij} = e^{C}\ TK^{(A\ \ln TK + B)}$ $(\text{cm}^2\ \text{atm/sec})$

The above expression for $\bar{\mathcal{D}}_{ij}$ was used to curve-fit tabulated binary diffusion coefficients given by Yos[30]. A revised table of values was used for the NO-NO^+ interaction as given in a later paper by Yos[31]. The collision cross sections for the atomic and molecular interactions in these results were obtained from calculations of Mason, et al.[32,33] Some of the interaction cross sections were calculated as averages of the other interaction cross sections, while the cross sections for the interactions $N-O_2$ and N-NO were assumed the same as $N-N_2$. Also, the interaction cross sections for NO^+ with a neutral species have been taken the same as the $N-O^+$ and $O-N^+$ cross sections.* The curve-fit coefficients for the various binary diffusion coefficients are given in Table 5-III.

D. Comparison of Thermodynamic and Transport Properties

The thermodynamic and transport properties based on the air model employed in this paper have been compared to the results of several other authors. These properties have been determined for an equilibrium composition at a pressure of one atmosphere and a temperature up to 20,000°K. The thermodynamic properties of enthalpy and frozen specific heat are given in Figures 5.4 and 5.5. The present results for enthalpy are compared with predictions of Predvoditelev[36] and Hansen[37]. These authors are in close agreement except at temperatures around 4000°K. The present frozen specific heat at constant pressure is compared to the results of Hansen in Figure 5.5. The present results are in good agreement with the predictions of these authors except at temperatures above 10,000°K. This is expected as the present gas model is only valid when there is a slight amount of ionization. To improve the thermodynamic properties at the higher temperatures it is necessary to include the thermodynamic properties of these species in the gas mixture calculations.

The present frozen thermal conductivity** and viscosity of equilibrium air at one atmosphere pressure are compared to results of Hansen[37] and Yos[30] in Figures 5.6 and 5.7, respectively. The present results for the transport properties are not appropriate when the temperature is greater than approximately 10,000°K. Again these properties can be improved at the higher temperatures by including additional chemical species as discussed above.

The thermodynamic and transport properties employed in the shock-layer solutions are more accurate than is indicated by the equilibrium properties. When the temperature behind the shock is very high, the predominant species are molecular oxygen and nitrogen which are included in the gas model with reasonable accuracy. The temperature decreases toward the body, and probably no significant amounts of ionized atomic and molecular species have time to be produced. Therefore, the present gas model is considered reasonable for the cases investigated in this paper.

E. Chemical Reactions and Rates

The net mass rate of production of chemical species per unit volume is obtained from the usual relations as given by equation (5) or (7). The following chemical reactions are used for the pure air gas model:

$$\begin{array}{ll} r = 1 & O_2 + M_1 \rightleftarrows 2O + M_1 \\ 2 & N_2 + M_2 \rightleftarrows 2N + M_2 \\ 3 & N_2 + N \rightleftarrows 2N + N \\ 4 & NO + M_3 \rightleftarrows N + O + M_3 \\ 5 & NO + O \rightleftarrows O_2 + N \\ 6 & N_2 + O \rightleftarrows NO + N \\ 7 & N + O \rightleftarrows NO^+ + e^- \end{array} \qquad (87)$$

In these reactions the following chemical species are employed and are numbered 1 to 7 in the order indicated:

O_2, N_2, O, N, NO, NO^+, e^-
(NI = 6 as electrons are a special case)

*A slightly different approach for obtaining the NO^+ neutral collisions has been given by Moore[35].
**This quantity should not be confused with the equilibrium or total thermal conductivity.

The stoichiometric coefficients for these reactions are given in Table 5-IV.

The forward and backward rate constants are written as:

$$k_{f_r} = TK^{C2_r} e^{(\ln CO_r - C1_r \times 10^3/TK)} \frac{1}{\sec} \left(\frac{\text{mole}}{\text{cm}^3}\right)^{-\alpha_r} \tag{88a}$$

$$k_{b_r} = TK^{D2_r} e^{(\ln DO_r - D1_r \times 10^3/TK)} \frac{1}{\sec} \left(\frac{\text{mole}}{\text{cm}^3}\right)^{-\beta_r} \tag{88b}$$

with the coefficients given in Table 5-V taken from Reference 38. These reaction rate coefficients use the catalytic bodies as determined from expression (6). The quantity $Z_{(j-NI)}$ is the third body efficiencies relative to argon, given in Table 5-VI and based on Reference 39.

TABLE 5-I

MOLECULAR WEIGHTS AND HEATS OF FORMATION AT ABSOLUTE ZERO FOR SPECIES

SPECIES	M_i	$H^* \left(\frac{\text{Kcal}}{\text{mole}}\right)$	Δh_i^F (ft-lb/slug)
O_2	32.000	0	0
N_2	28.016	0	0
NO	30.008	21.477	0.3225×10^8
NO^+	30.008	235.836	3.5341×10^8
O	16.000	58.9725	1.661×10^8
N	14.008	112.507	3.619×10^8
e^-	0.000549	0	0

$$\Delta h_i^F = \frac{10.388 \times 10^8}{23.053\, M_i} H^*$$

TABLE 5-11

VISCOSITY CURVE FIT CONSTANTS

(TEMPERATURE 1000°K TO 30000°K)

SPECIES	A_i	B_i	C_i
O_2	0.0449290	-0.0826158	- 9.2019475
N_2	0.0268142	0.3177838	-11.3155513
O	0.0203144	0.4294404	-11.6031403
N	0.0115572	0.6031679	-12.4327495
NO	0.0436378	-0.0335511	- 9.5767430
NO^+	0.3020141	-3.5039791	- 3.7355157

FOR SUTHERLAND'S LAW, COEFFICIENTS ARE THE SAME FOR ALL SPECIES AND ARE

$$A_i = -0.1045186$$

$$B_i = 1.9790489$$

$$C_i = -16.48024$$

TABLE 5-III

DIFFUSION CURVE FIT CONSTANTS

INTERACTION	A	B	C
N-O	-0.0043383	1.9119177	-11.891342
$N-N_2$	0.0191055	1.4904448	-10.358828
$N-O_2$	0.0191055	1.4904448	-10.358828
N-NO	0.0191055	1.4904448	-10.358828
$O-O_2$	0.0216586	1.3875747	- 9.7389971
$O-N_2$	0.0168907	1.5276702	-10.629306
N_2-O_2	0.0435927	0.9784219	- 8.3354916
O-NO	0.0183441	1.4750189	-10.265935
O_2-NO	0.0410864	1.0124720	- 8.4455480
N_2-NO	0.0315955	1.2225368	- 9.4862934
$O-NO^+$	0.0003467	1.8941393	-12.978394
$N-NO^+$	0.0003467	1.8941393	-12.978394
O_2-NO^+	0.0003467	1.8941393	-12.978394
N_2-NO^+	0.0003467	1.8941393	-12.978394
$NO-NO^+$	0.0039930	1.5689336	-11.441502

TABLE 5-IV

STOICHIOMETRIC COEFFICIENTS

FORWARD

α_{ri}	O_2	N_2	O	N	NO	NO^+	e^-	M_1	M_2	M_3	α_r
	i = 1	2	3	4	5	6	7	8	9	10	
r = 1	1							1			1
2		1							1		1
3		1		1							1
4					1					1	1
5			1		1						1
6		1	1								1
7			1	1							1

BACKWARD

β_{ri}	O_2	N_2	O	N	NO	NO^+	e^-	M_1	M_2	M_3	β_r
	i = 1	2	3	4	5	6	7	8	9	10	
r = 1			2					1			2
2				2					1		2
3				3							2
4			1	1						1	2
5	1			1							1
6				1	1						1
7						1	1				1

NOTE: ALL BLANKS ARE ZERO.

TABLE 5-V

REACTION RATE COEFFICIENTS

REACTION	CO(r)	C1(r)	C2(r)	DO(r)	D1(r)	D2(r)
r = 1	3.61×10^{18}	59.4	-1.0	3.01×10^{15}	0	-0.5
2	1.92×10^{17}	113.1	-0.5	1.09×10^{16}	0	-0.5
3	4.15×10^{22}	113.1	-1.5	2.32×10^{21}	0	-1.5
4	3.97×10^{20}	75.6	-1.5	1.01×10^{20}	0	-1.5
5	3.18×10^{9}	19.7	1.0	9.63×10^{11}	3.6	0.5
6	6.75×10^{13}	37.5	0	1.50×10^{13}	0	0
7	9.03×10^{9}	32.4	0.5	1.80×10^{19}	0	-1.0

TABLE 5-VI

THIRD BODY EFFICIENCIES RELATIVE TO Ar

	O_2	N_2	O	N	NO	NO^+
$Z_{(j-NI)i}$	i = 1	2	3	4	5	6
(j - NI) = 1						
e^-	0	0	0	0	0	1
2						
M_1	9	2	25	1	1	0
3						
M_2	1	2.5	1	0	1	0
4						
M_3	1	1	20	20	20	0

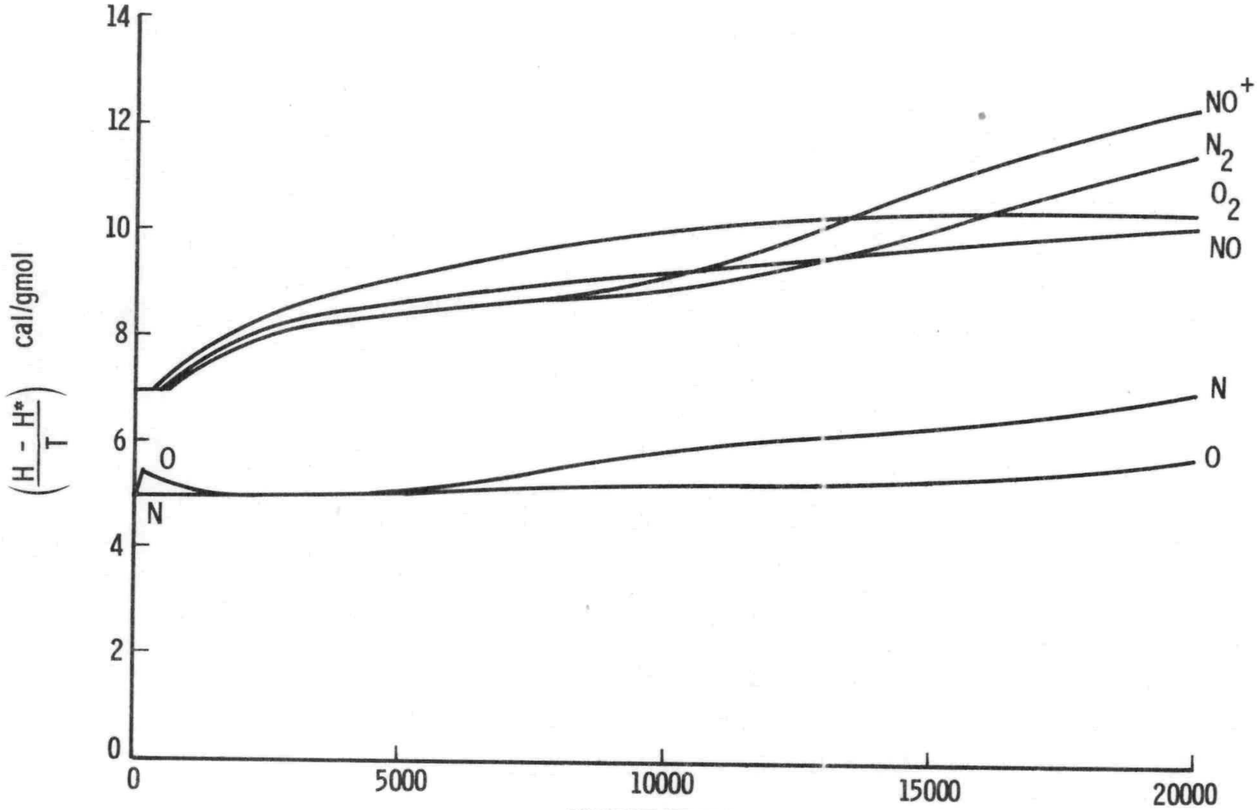


FIG. 5.1 - ENTHALPY OF CHEMICAL SPECIES

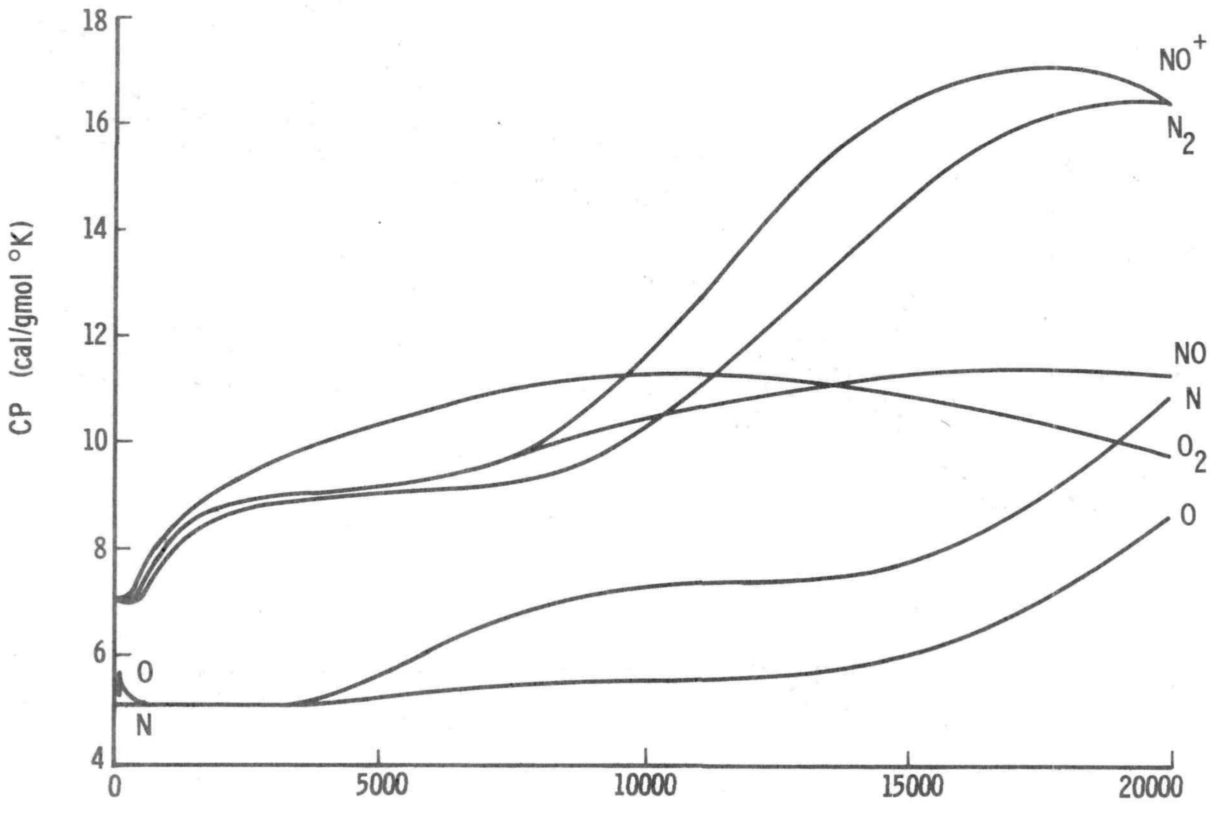


FIG. 5.2 - SPECIFIC HEAT OF CHEMICAL SPECIES

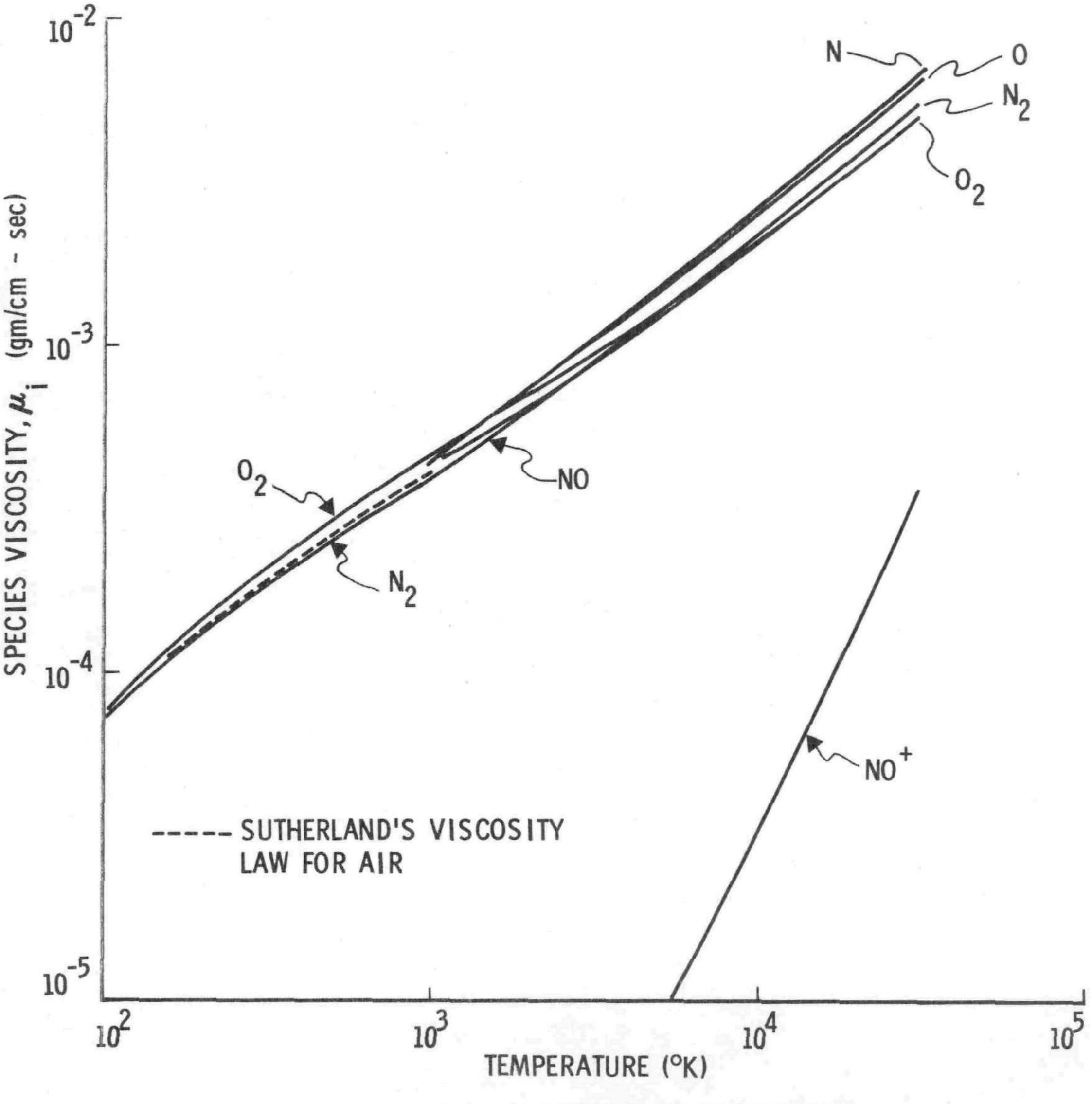


FIG. 5.3 - VISCOSITY OF AIR SPECIES

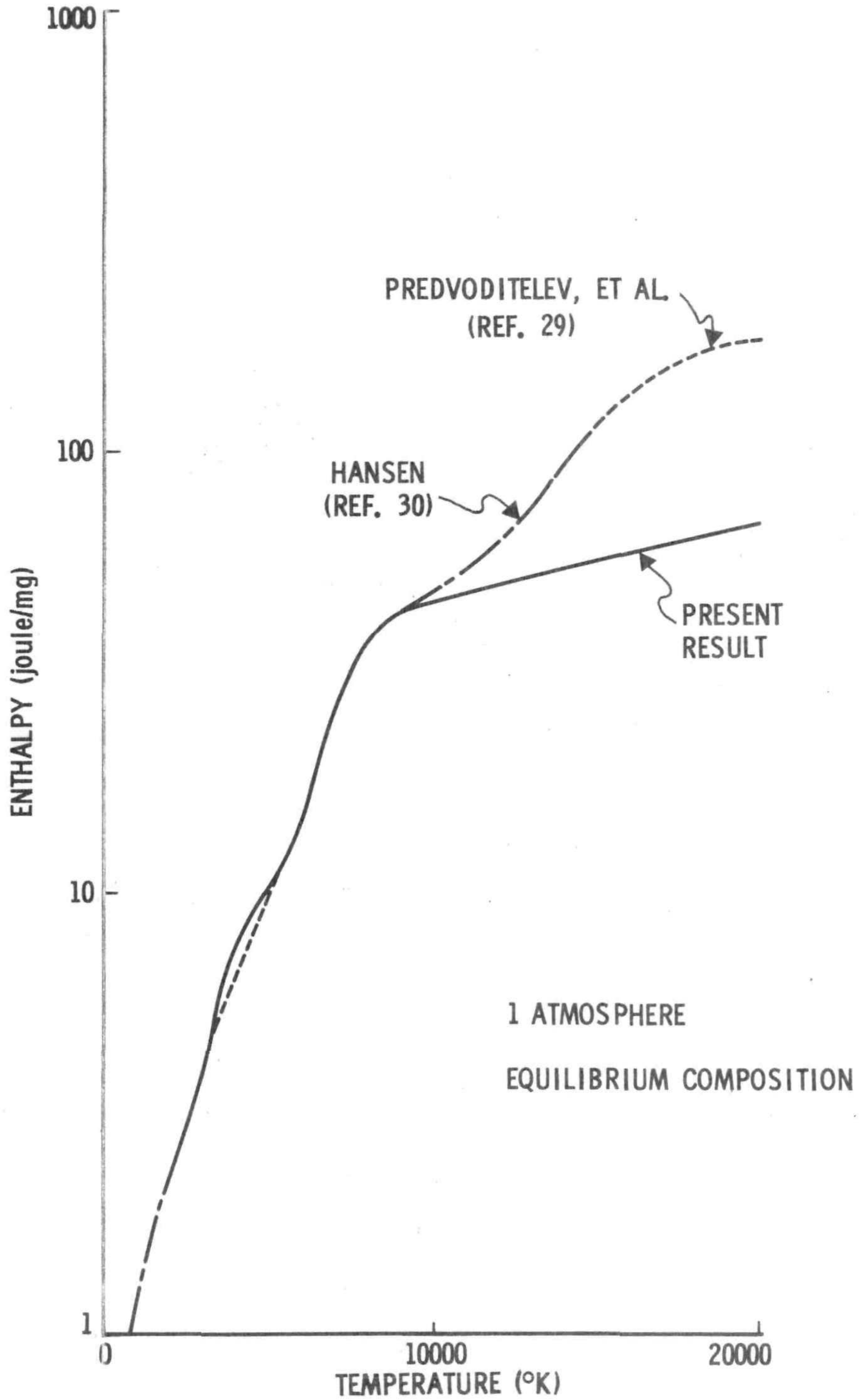


FIG. 5.4 - ENTHALPY OF AIR

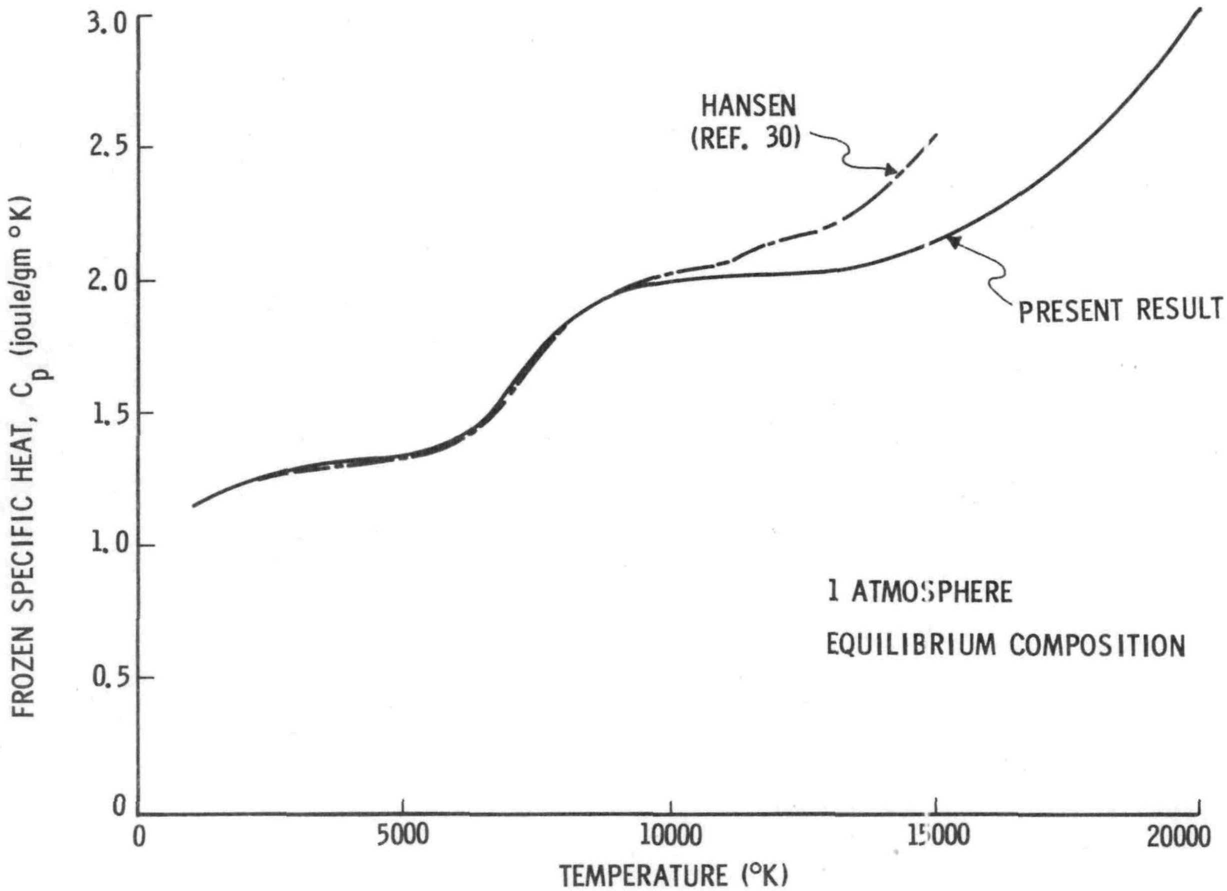


FIG. 5.5 - FROZEN SPECIFIC HEAT OF AIR

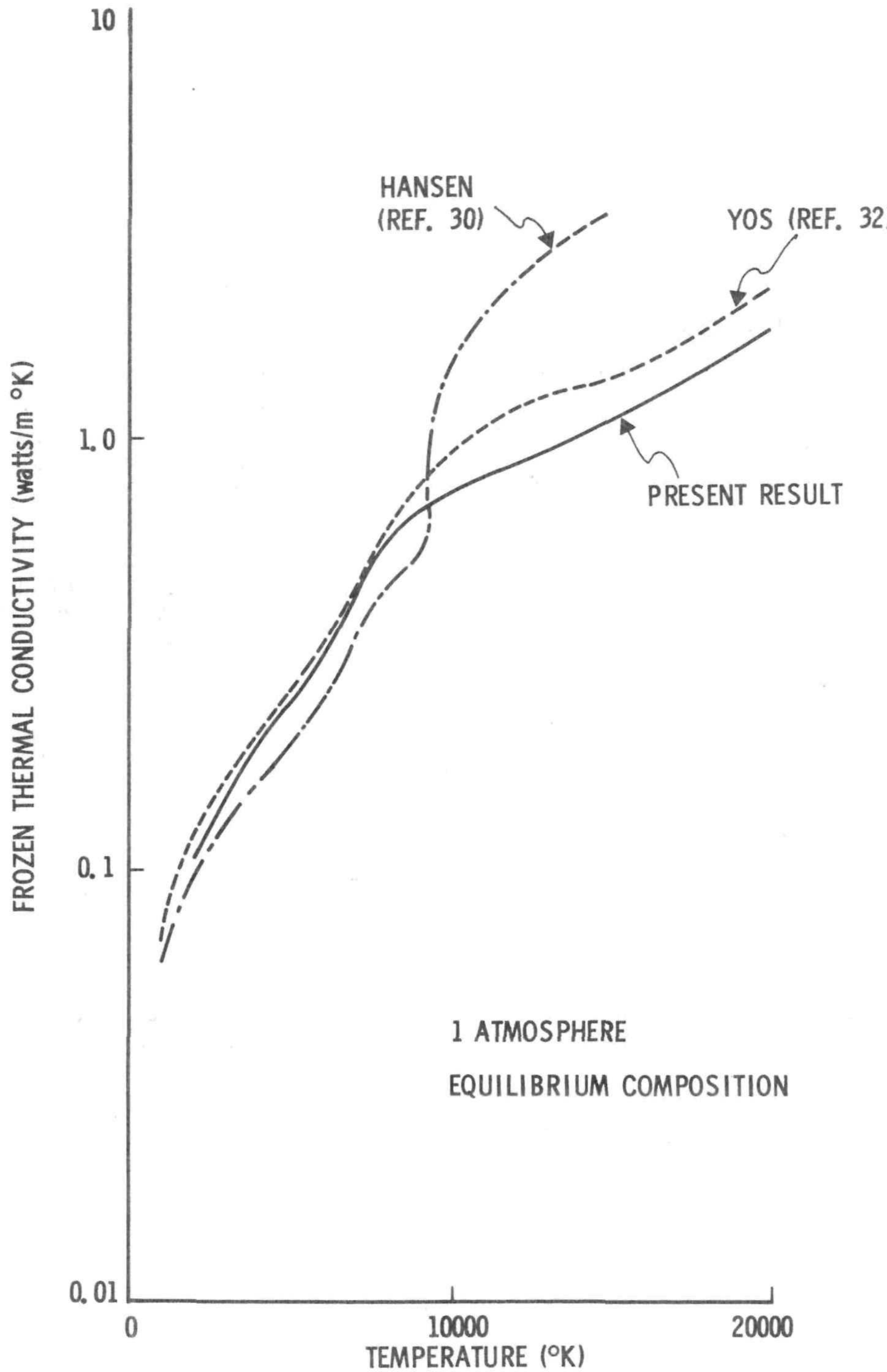


FIG. 5.6 - FROZEN THERMAL CONDUCTIVITY OF AIR

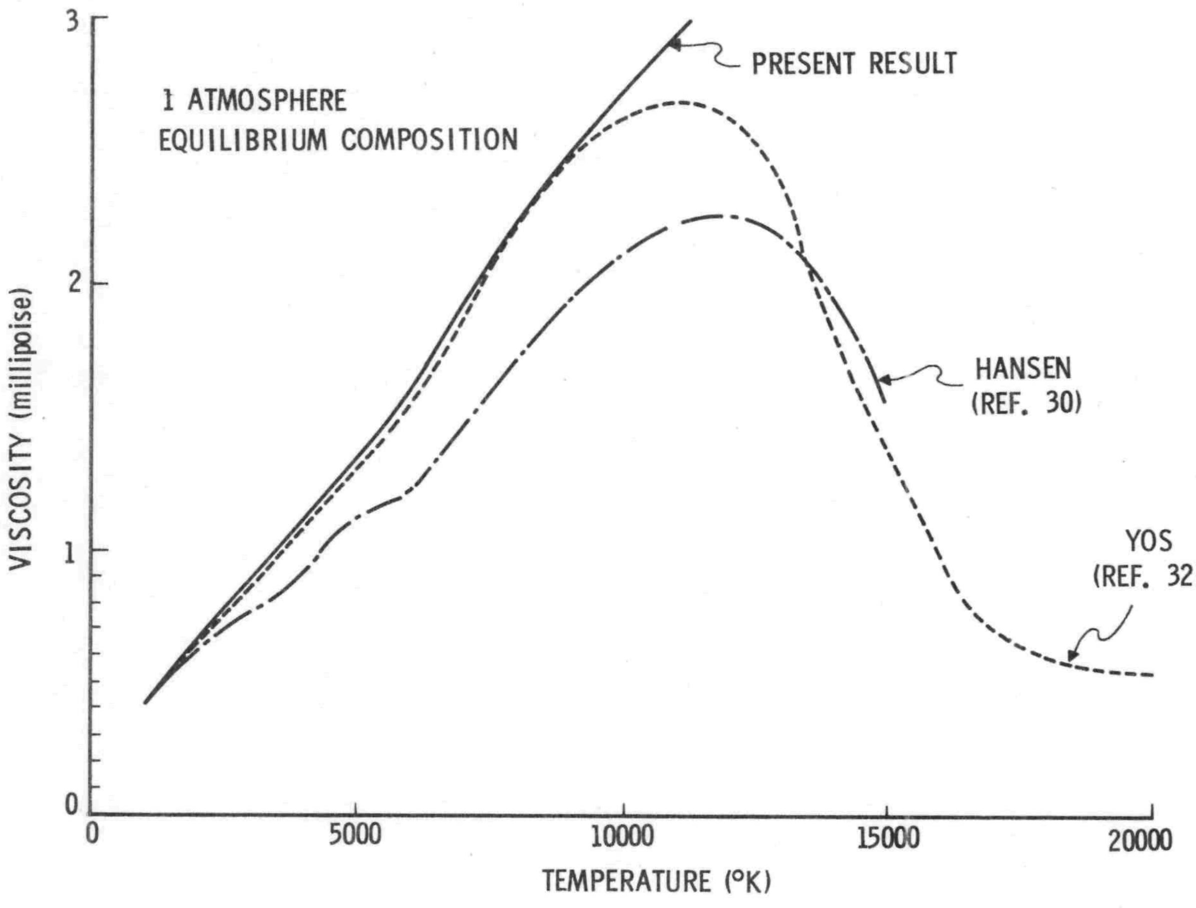


FIG. 5.7 - VISCOSITY OF AIR

VI. Boundary Layer Characteristics

After the solution to the boundary layer or shock layer equations has been obtained, there are a number of quantities that should be determined which characterize the flow. Their quantities are discussed and defined below.

A. Heat Transfer

The heat or energy flux from the gas to the surface in a multi-component gas mixture for stationary coordinates is approximately

$$q = -k \frac{\partial T}{\partial y} + \sum_{i=1}^{NI} h_i j_i + \rho v H \tag{89}$$

where the Dufour effect (usually considered small), work of the shear stresses (occurs when there is slip at the wall), and radiation are neglected. The above expression includes the energy transported by conduction, diffusion, and convection. For boundary layer flows without mass transfer, the last term in the above expression is zero. For an energy balance at the surface a similar expression as given above (without the diffusion term) is written for the energy flux into the condensed phase and this must be equal to the energy flux from the gas to the surface.

The Nusselt number is defined in terms of either conditions at the body or at the edge of the boundary layer or shock layer as follows:

$$Nu_e = - \frac{q\, x\, \bar{c}_{p_e}}{k_e\, (H_o - H_b)} \quad \text{(Edge Nusselt No.)} \tag{90a}$$

$$Nu_b = - \frac{q\, x\, \bar{c}_{p_b}}{k_b\, (H_o - H_b)} \quad \text{(Body Nusselt No.)} \tag{90b}$$

where

$$H_o = h_\infty + \tfrac{1}{2} V_\infty^2$$

$$H_b = h_o$$

with the Reynold's numbers defined as:

$$Re_{x_e} = \rho_e u_e\, x/\mu_e$$

$$Re_{x_b} = \rho_b u_e\, x/\mu_b$$

the Nusselt numbers become:

$$\frac{Nu_e}{\sqrt{Re_{x_e}}} = \frac{Pr_e}{Pr_b} \frac{\ell_b}{(H_o - H_b)\eta_e} \sqrt{\frac{(\rho\mu)_e u_e r_b^{2j} x}{2\xi}} \left\{ \bar{c}_p T_e \frac{\partial\theta}{\partial\eta} + \sum_{i=1}^{NI} h_i \sum_{k=1}^{NI} \bar{\bar{b}}_{ik} \frac{\partial c_k}{\partial\eta} \right\}_b \tag{91a}$$

and

$$\frac{Nu_b}{\sqrt{Re_{x_b}}} = \frac{Pr_b}{Pr_e} \sqrt{\frac{\rho_e\mu_e}{\rho_b\mu_b}} \frac{Nu_e}{\sqrt{Re_{x_e}}} \tag{91b}$$

In the above expressions the energy flux due to convection is not included and thermal diffusion effects have been neglected. The square root term in (91a) is of indeterminate form at x = 0 but the appropriate values are:

$$\sqrt{(\rho\mu)_e u_e r_b^{2j} x/(2\xi)} = \begin{cases} \sqrt{1+j} & \text{Blunt Body} \\ \sqrt{\frac{1}{2}+j} & \text{Sharp Body} \end{cases} \tag{92}$$

The derivatives in relation (91a) are evaluated at the body with equation (46). If more grid points are used to evaluate the derivatives at the surface one expects a more accurate evaluation. However, this is not necessarily correct; in fact, the relation using four grid points has given the wrong sign for the derivative for certain cases.

Another parameter which is used to characterize the heat transfer is the Stanton number which is defined as:

$$St = - \frac{q}{\rho_\infty V_\infty (H_o - H_b)} \tag{93}$$

The Stanton number is related to the Nusselt number by the relation:

$$St = \frac{1}{Pr_e} \frac{1}{\rho_\infty V_\infty} \left(\frac{\rho_e u_e}{\sqrt{Re_{x_e}}} \right) \frac{Nu_e}{\sqrt{Re_{x_e}}} \tag{94}$$

where at x = 0:

$$\left(\frac{\rho_e u_e}{\sqrt{Re_{x_e}}} \right) = \begin{cases} \sqrt{\rho_e \mu_e \frac{du_e}{dx}} & \text{Blunt Body} \\ \infty & \text{Sharp Body} \end{cases}$$

B. Local Skin Friction and Drag

The local skin friction is defined as:

$$c_{f_\infty} = \frac{\tau_b}{\frac{1}{2}\rho_\infty V_\infty^2} \tag{95a}$$

or

$$c_{f_e} = \frac{\tau_b}{\frac{1}{2}\rho_e u_e^2} \tag{95b}$$

where the shearing stress is:

$$\tau_b = \left(\mu_b \frac{\partial u}{\partial y}\right)_b$$

The parameters to describe local skin friction are the following:

$$c_{f_e}\sqrt{Re_{x_e}} = 2\ell_b \sqrt{(\rho\mu)_e u_e r_b^{2j} x/(2\xi)} \left(\frac{\partial f'}{\partial \eta}\right)_b \frac{1}{\eta_e} \tag{96a}$$

and:

$$c_{f_\infty} = \frac{\rho_e}{\rho_\infty}\left(\frac{u_e}{V_\infty}\right)^2 \frac{1}{\sqrt{Re_{x_e}}} \left(c_{f_e}\sqrt{Re_{x_e}}\right) \tag{96b}$$

where at x = 0:

$$c_{f_\infty} = \begin{cases} 0 & \text{Blunt Body} \\ \infty & \text{Sharp Body} \end{cases}$$

In relation (96a) the square root at x = 0 is determined from relation (92) while the derivative is evaluated with relation (46).

The drag of a body due to the pressure and shearing stress at the surface with length x, is written in terms of a drag coefficient as:

$$C_D = \frac{\text{Drag}}{\frac{1}{2}\rho_\infty V_\infty^2 A} = \frac{(2\pi)^j}{A}\int_0^x \left[c_{f_\infty} \cos\theta_b + \frac{p_e}{\frac{1}{2}\rho_\infty V_\infty^2} \sin\theta_b\right] r_b^j dx \tag{97}$$

where the reference area is the cross sectional area at x and is

$$A = \begin{cases} x & \text{flat plate} \\ r_b & \text{reference length when } j = 0 \\ \pi r_b^2 & \text{reference area when } j = 1 \end{cases}$$

The first term in the integral results from the shearing stress at the surface while the second term results from the pressure acting on the surface.

C. Boundary Layer Normal Coordinate

The distance along the normal from the surface of the body to the edge of the boundary layer is obtained from the transformed coordinate relations (14).

These are written as

$$\frac{y(\xi,\eta)}{R_N} = \frac{\sqrt{2\xi}\ \eta_e}{u_e r_b^{\,j} R_N} \int_o^{\eta} \frac{1}{\rho}\, d\eta \tag{98}$$

where

$$\xi = \int_o^x (\rho\mu)_r u_e r_b^{2j} dx$$

D. Displacement and Momentum Thicknesses

The displacement thickness is defined as:

$$\delta^* = \int_o^{y_e} \left(1 - \frac{\rho u}{\rho_e u_e}\right) dy + \frac{1}{\rho_e u_e r_b^{\,j}(x_o)} \int_o^{x_o} (\rho v)_b\, r_b^j\, dx \tag{99a}$$

while the momentum thickness is defined as:

$$\theta_M = \int_o^{y_e} \frac{\rho u}{\rho_e u_e}\left(1 - \frac{u}{u_e}\right) dy \tag{99b}$$

In the transformed coordinate system, these relations become:

$$\delta^* = \frac{\sqrt{2\xi}\ \eta_e}{\rho_e u_e r_b^{\,j}} \int_o^1 \left(\frac{\bar{M}_e}{\bar{M}}\,\theta - f'\right) d\eta + \frac{1}{\rho_e u_e r_b^{\,j}(x_o)} \int_o^{x_o} (\rho v)_b r_b^{\,j}\, dx \tag{100a}$$

$$\theta_M = \frac{\sqrt{2\xi}\,\eta_e}{\rho_e u_e r_b^{\,j}} \int_o^1 f'(1 - f')\, d\eta \qquad (100b)$$

At x = 0, the following term is indeterminate numerically but has the values shown:

$$\frac{\sqrt{2\xi}}{\rho_e u_e r_b^{\,j}} = \begin{cases} 0 & \text{For Sharp Body} \\ \sqrt{\dfrac{(\rho\mu)_e}{(1+j)\rho_e^2 \dfrac{du_e}{dx}}} & \text{For Blunt Body} \end{cases}$$

E. Mass Flow Rate in the Boundary Layer

The total mass flow rate $\left(\frac{\text{slug}}{\text{ft}^{(1-j)}\ \text{sec}}\right)$ in the boundary layer at x or ξ is:

$$\dot{M}_t = (2\pi)^j \sqrt{2\xi}\,\eta_e \int_o^1 f'\left(1 + \frac{y}{r_b} \cos\theta_b\right)^j d\eta \qquad (101a)$$

while the mass flow rate of species "i" is:

$$\dot{M}_i = (2\pi)^j \sqrt{2\xi}\,\eta_e \int_o^1 c_i f' \left(1 + \frac{y}{r_b} \cos\theta_b\right)^j d\eta \qquad (101b)$$

The mass flow rate of species "i" in particles per seconds is obtained from (101b) by the relation:

$$\dot{M}_i\left(\frac{\text{particles}}{\text{sec ft}^{(1-j)}}\right) = 1.45939 \times 10^4\, \dot{M}_i\, \tilde{N}/M_i \qquad (102)$$

where:

$$\tilde{N} = 6.025 \times 10^{23}\ (\text{molecules/gm-mole})$$

The total mass flow rate in the boundary layer is related to r_{sh} (the radical distance from the axis to the streamline in the freestream which enters the boundary layer where the mass flow is being determined) and the mass transfer at the surface by:

$$\dot{M}_t = \rho_\infty V_\infty r_{sh} (\pi r_{sh})^j + (2\pi)^j \int_0^x (\rho v)_b \, r_b^{\,j} \, dx \tag{103}$$

F. Electron Density

To indicate the amount the gas is ionized, it is useful to determine the electron density. It is obtained from the mass fractions of the ionized species by the following relation:

$$Ne = \bar{\rho} \, \tilde{N} \, \gamma_{e^-} \tag{104}$$

where:

$$\bar{\rho} \, (gm/cm^3) = 0.51536 \, \rho(slug/ft^3)$$

$$\gamma_{e^-} = \sum_{j=1}^{NI} Z_j \gamma_j$$

The value of Z_j is determined from the linear dependence of the electrons on the NI chemical species and is based on the conservation of charge.

G. Mass and Energy Flux Densities at the Surface

The mass flux density of species "i" at the surface was given in relation (43) and is:

$$\dot{m}_i = \rho v c_i + j_i \qquad (slug/ft^2 - sec) \tag{105}$$

where

$$j_i = \frac{\ell(\rho\mu)_r u_e r_b^{\,j}}{Pr\sqrt{2\xi}\,\eta_e} \left\{ \sum_{k=1}^{NI} \bar{\bar{b}}_{ik} \frac{\partial c_k}{\partial \eta} + \frac{L_i^T}{\theta} \frac{\partial \theta}{\partial \eta} \right\}$$

The energy flux at the surface can be obtained from (89) and is expressed in terms of the various contributions:

$$q_c = \frac{\ell}{Pr} \frac{(\rho\mu)_r \bar{c}_p T_e u_e r_b^{\,j}}{\sqrt{2\xi}\,\eta_e} \frac{\partial \theta}{\partial \eta} \qquad \text{(Conduction)} \tag{106a}$$

$$q_D = \sum_{i=1}^{NI} h_i j_i \qquad \text{(Diffusion)} \tag{106b}$$

$$q_v = \rho v(h + \tfrac{1}{2}v^2) \quad \text{(Convection)} \tag{106c}$$

where:

$$q = q_c + q_D + q_v$$

$$q(\text{Btu/ft}^2\text{-sec}) = 1.28509 \times 10^{-3} \; q(\text{ft-lb/ft}^2\text{-sec})$$

H. Total Enthalpy

The total enthalpy is often used as one of the dependent variables rather than the temperature and is defined as

$$H = h + \tfrac{1}{2}u^2 + \tfrac{1}{2}v^2 \tag{107}$$

The term $\frac{1}{2}v^2$ has been neglected in the evaluation as it is generally small in the boundary layer. The enthalpy in other units can be obtained from

$$H(\text{Btu/lb}) = 3.99417 \times 10^{-5} \; H(\text{ft-lb/slug})$$

$$H(\text{Joule/kg}) = 9.2903 \times 10^{-2} \; H(\text{ft-lb/slug})$$

I. Chemical Reaction Parameters

Since the chemical model for many gas mixtures is not well understood, it is of value to know the importance of the various chemical reactions employed. A useful parameter to have available is the following:

$$X_r = w_i / \left[\rho M_i(\beta_{ri} - \alpha_{ri})\right] = (L_{f_r} - L_{b_r}) \tag{108}$$

where the various quantities are defined in equation (5). The above relation for X_r gives the effectiveness of reaction r in producing certain chemical species. The production of species i from the various chemical reactions is obtained by multiplying X_r by $(\beta_{ri} - \alpha_{ri})$. The relative size of these terms determines which reactions are important in the production of species i.

J. Relation for Normal Velocity

The normal velocity is obtained from the relation (16a) which defines the transformed normal velocity V. Before this relation can be used, the terms $\frac{\partial\eta}{\partial x}$ must be determined. Since $\eta = \eta(x,y)$, the following relation is obtained with $d\eta = 0$:

$$\frac{\partial \eta}{\partial x} = - \frac{\partial \eta}{\partial y} \frac{dy}{dx}\Big|_{\eta} = \text{constant}$$

When equation (14b) is employed in this relation and the differentials are written in finite-difference form, the partial derivative becomes

$$\frac{\partial \eta}{\partial x} = - \frac{u_e r_b^{\,j} \rho}{\eta_e \sqrt{2\xi}} \left(\frac{y_{m+1,n} - y_{m,n}}{x_{m+1} - x_m} \right) \tag{109}$$

With this derivative used in equation (16a), the normal velocity becomes

$$v = \frac{(\rho\mu)_r \, r_b^{\,j} \, u_e}{\sqrt{2\xi}} \; \frac{V}{\rho} + u_e f'(y_{m+1,n} - y_{m,n})/(x_{m+1} - x_m) \tag{110}$$

VII. Computer Program

A. Introduction

The purpose of this chapter is to describe the computer program with only sufficient detail to allow operation as a "black-box". This type of operation is not advocated by the authors and can lead to misuse of the program. However, as an initial step in the use of this program an understanding of the input and output is a logical place to start. This part of the program is discussed in this chapter and the remaining details of the program are given in Appendix D.

The program is written with the idea to be as general as possible within reasonable limitations. The program solves the boundary layer equations along a body and always starts at $\xi = 0$ for an arbitrary (this will be described subsequently) multi-component gas mixture. At a stagnation point or the tip of a blunt body, the similar boundary layer equations are solved to obtain initial profiles. At a stagnation point the thin viscous shock layer equations with shock slip are solved as determined on OPTN card. The program will not solve the thin viscous shock layer along a body. The program will handle either two-dimensional or axi-symmetric bodies of the type: flat plate, blunt wedge with cylindrical leading edge, and hyperbola or cone, sphere-cone, and hyperboloid respectively. In addition, bodies of arbitrary shape can be handled with the use of a table of values of the body radius given as a function of the distance along the surface. Also the nose radius or reference length for a flat plate or cone, RN, must be specified. To complete the body geometry, the half-angle or asymptotic half-angle for the blunt body is required.

The program will handle solutions in an arbitrary freestream where the velocity, pressure, temperature and species mass fraction define the environment. For the shock layer solution, no additional information is required. For a boundary layer solution, the conditions at the outer edge must be specified consistent with the freestream conditions. The determination of the boundary layer outer edge conditions are to be made by the user. The pressure, tangential velocity, temperature and mass fraction of the various species are required as a function of the distance along the body. The usual relation between the pressure gradient and velocity gradient is not used since swallowing of the inviscid flow can be taken into account. Another computer code has been developed to obtain edge conditions and is described in Reference 40 and has been used in the examples in the next chapter.

At the wall a variety of boundary conditions have been included in the program and have been discussed in Chapter III. If gas models other than a binary mixture of oxygen, air or carbon-air are employed, special care should be taken to be sure the boundary conditions employed are appropriate. The subroutine QPR should be investigated to be sure the desired species boundary conditions are being satisfied as this subroutine is not general. For all cases it is assumed that the wall temperature is known as a function of the distance along the body in tabular form. The case of an energy balance or a specified heat transfer have not been considered but could be handled with suitable changes in the program. For the first four wall options the mass transfer at the surface is zero. For the case of mass transfer of ablation products, the surface mass flux density must be specified as a function of the distance along the body in tabular form. For the remaining wall options, the program will determine the surface mass flux density as part of the solution.

To start the solution along a body or to generate initial profiles, values of the tangential velocity, temperature and species mass fractions must be read in. If OPTN(4) is INITIAL, an iteration procedure is performed to obtain initial profiles. If OPTN(4) is BODY CAL, one iteration is performed on the initial profiles and then the solution proceeds along the body. If a first estimate of the profiles for the iteration of initial profiles is not available, the program will generate profiles for θ and c_i's where the value f' read in is used. If the sum of the first two species at the wall is zero, c_1 is set equal to 0.2328 and c_2 is set equal to 0.7672. If the sum is not zero, the wall values of the c_i's read in are used in determining the species mass fraction profiles.

In the iteration procedure employed to obtain the initial profiles, a choice is available on the procedure to be followed. There is always an iteration performed where the momentum equation is solved first with the species equations solved next and finally the energy equation is solved. This iteration is stopped whenever the convergence tolerance (TOL) has been satisfied or KOPE iterations have been performed. An iteration of each equation within this larger iteration is possible depending on the values of KOPT, AMOM, AENE and ASPE. In this iteration, a fixed number may be performed or a convergence criterion can be utilized. In the iteration for initial profiles it is necessary in many cases to weigh the calculated solution with the assumed solution as was discussed at the end of Chapter II. The appropriate values to employ can be determined only from experience.

The gas model allowed in the program has been set up as general as possible. The multi-component gas mixture can consist of as many as 30 species and 30 homogeneous chemical reactions. For each chemical species certain thermodynamic and transport properties are required. The specific heat and enthalpy of each species is required and must be given in block data. Data for the following species are presently stored in the program: O_2, N_2, O, N, NO, NO^+, CO, CO_2, CN, C_1, C_2, C_3, N^+, N_2^+, H, H_2, OH, H_2O, A and A^+. The viscosity of each species and the binary diffusion coefficients between the various species is determined from curve fits. For each curve fit three coefficients are required and values of these parameters that have been used are given in Tables 5-II and 5-III. Additional information such as the molecular weight and heats of formation of each species is required. For each chemical reaction, the names of the species involved in the reaction are read in and also six coefficients to determine the reaction rate coefficients. For reactions involving third bodies and with reaction rates only differing by a constant for the various third bodies, the use of third body efficiencies reduces the amount of computing and is the recommended procedure to be employed. The subroutine CHEMPR, which utilizes the reaction rate data and determines the chemical production terms, is not a general subroutine. It must be used with care, especially for gas models different from ones presented in the examples in this report. Since the computing time nearly doubles when multi-component diffusion coefficients are being used as compared to Fick's law, these two options are available. For multi-component diffusion, the binary diffusion coefficient information must be supplied for interactions between species. When Fick's law is being used, the value of the Lewis-Semenov numbers for each species is required. In addition to the solution of flows with finite chemical reactions, frozen flows (chemical product terms are zero) can be solved. Also for similar boundary layer solutions with constant Lewis-Semenov numbers, solutions can be obtained for the gas in local chemical equilibrium. If this option is used, the appropriate EQUIL subroutine must be used to determine the equilibrium composition.

Finally, certain information for the finite-difference procedure is required in the input. For many cases the thickness of the boundary layer in terms of the transformed η coordinate is nearly constant. For cases where the thickness changes along the body, the value of η_e as a function of x/R_N is required in tabular form. The step-sizes along the body and across the boundary layer or shock layer are required input. The appropriate values to be used depends upon the desired accuracy and are determined from experience with the program. Typical values employed are given in the sample problems. The program also has an option where the step-size across the boundary layer or shock layer can be variable. A variable step-size can be read in or the program can be used to generate a variable step-size as indicated in the input write-up. Other options such as when profiles of the dependent variables are printed and when to punch on cards the final iteration of the initial profiles are available.

B. Input

The necessary information for setting up the data cards is given in this section. First some general comments are given below about the input. Then the input for the program is given in the order that it is read into the program. For each card the FORTRAN name of the input quantity is given, format used, location on the card and a brief description of the quantity.

All Read statements are written without designating a unit, which normally will default to the standard logical input unit. All Read statements are in subroutines INPUT and INPBOD.

All Write statements (Print) are on logical unit NTO, which is set to 61 by a data statement in subroutine INPUT.

The Write statements (Punch) are on logical unit IP, which is set to 62 by a data statement in subroutines PCH and BLC.

All input is read from the data cards and all cards must be supplied for each problem, except the values of DN, ($\Delta\eta$). The cards are read only when "k", on second input card, is equal to 0.

Multiple problems can be done in one run, but, as noted, all input cards must be supplied for each problem.

Columns 1 through 5 are used for card name. These card names are not checked by the program, so any characters are acceptable. These were chosen for convenience, with the two exceptions of (1) the binary diffusion coefficient cards where these five columns should contain the "interaction" (see sample output), and (2) the cards containing the forward and backward rate coefficients must have the chemical reaction description in columns 1-29 (see sample input).

Input for Program - The information required on all cards in the input data deck is described below:

Card Name Col. 1-5	Fortran Name	Format	Column	Description
TITLE	TITLE	9A8	6-77	Problem name - Any information to be printed on output.
LIMTS	NMAX	I5	6-10	Number of points across the boundary layer ≤ 50.
	NI	I5	11-15	Number of species ≤ 30.
	NR	I5	16-20	Number of reactions ≤ 30.
	NJ	I5	21-25	Number of reactants (includes electrons if present) plus catalysts ≤ 40.
	TOL	F10.0	26-35	ε, test for convergence tolerance (initial profiles).
	CK	F10.0	36-45	k, factor for computing $\Delta\eta$, $\begin{cases} 0 \text{ - read in DN's} \\ 1.0 \text{ - calculate constant DN} \\ > 1.0 \text{ - calculate DN's using k} \end{cases}$ when $k > 1.0$, $DN(1) = \dfrac{k - 1.0}{(k)^{N-1} - 1.0}$, and $DN(N) = DN(N - 1)\cdot k$.
SPNA	SPN(j)	15A5	6-10 11-15 etc.	Names of Species, Electron (EL) and Catalytic bodies (M1, M2, ...) in the order that the rest of the data is given. The species must come first and the second species is the one which will be adjustable so that $\sum_{i=1}^{NI} c_i = 1.0$. Names must be left-justified in the field. j = 1, NJ
DNS	DN(N)	E10.C	6-15 16-25 etc.	$\Delta\eta$'s across the boundary layer. N = 1, NMAX - 1. (These cards should only be included in the "data" deck when CK = 0.)
CONTR	IPRT	I5	6-10	Print every "IPRT" iteration (initial profile).
	IPUN	I5	11-15	0, don't punch initial profiles; 1, punch initial profiles.
	IREAD	I5	16-20	1, use first estimate of profiles read in; 0, use f' read in and compute the c_i's and θ for first estimate of profiles.
	KOPE	I5	21-25	Maximum iterations allowed for initial profiles.
	KOPT	I5	26-30	1, Initial profiles may be iterated KMOM times; 2, Initial profiles iterated till converged (AMOM).
	AMOM	F5.1	31-35	Convergence criterion for Momentum equation. KMOM = AMOM, if KOPT = 1.
	AENE	F5.1	36-40	Convergence criterion for Energy equation. KENE = AENE, if KOPT = 1.
	ASPE	F5.1	41-45	Convergence criterion for species equation. KSPE = ASPE, if KOPT = 1.

Card Name Col. 1-5	Fortran Name	Format	Column	Description	
CONTR (cont'd)	IWC	I5	46-50	Wall Condition Switch	1 - non-catalytic wall 2 - catalytic wall equilibrium (Subroutine EQUIL used) 3 - fully catalytic dissociation wall 4 - fully catalytic recombination wall Species NO is non-catalytic 5 - mass transfer of ablation products {RVPT(K) and Subroutine EQU2 are used} 6 - oxidation of graphite, EIO and EIO2 are oxidation prohibitives 7 - oxidation of metals, EIO and EIO2 are needed and are: $E_i = \frac{\text{flux of species i absorbed on metals}}{\text{collision flux of species i with surface}}$ 8 - vaporization of surface carbon 9 - mass transfer of ablation products with oxidation of graphite (5 + 6) 10 - oxidation of graphite with vaporization of surface (6 + 8) 11 - oxidation of metals with vaporization of surface (7 + 8)
	EIO	F10.0	51-60	ϵ_0	Where these two numbers have different meaning depending on the wall condition option (IWC). If IWC = 6, IWC = 9 and IWC = 10, they are the oxidation prohibitives for O and O2. If IWC = 7 or IWC = 11, they are the values of $\epsilon_i = \frac{\text{flux of species i absorbed on metals}}{\text{collision flux of species i with surface}}$ where i is O or O2.
	EIO2	F10.0	61-70	ϵ_{02}	
OPTN	OPTN(1)	A8	6-13	EQUILIBR or NON-EQUI	- All words describing options are to be left-justified.
	OPTN(2)	A8	16-23	FROZEN or NON-FROZ	
	OPTN(3)	A8	26-33	BOUNDARY or SHOCK LA	
	OPTN(4)	A8	36-43	INITIAL or BODY CAL	
	OPTN(5)	A8	46-53	CONE SPHERE C HYPERBOID SHARP AX BLUNT AX	j = 1 (j is set in program)
				FLAT PLA BLUNT WE HYPERBOLA SHARP 2D BLUNT 2D	j = 0

Card Name Col. 1-5	Fortran Name	Format	Column	Description
OPTN (cont'd)	OPTN(6)	A8	56-63	CAL LEWI or CON LEWI { CAL LEWIS, calculate Lewis numbers; CON LEWIS, use constant Lewis numbers }
				NOTE: If OPTN(1) is EQUILIBR, OPTN(6) must be CON LEWIS and IWC = 2. (These are forced by the program regardless of input values on cards.)
SIZE	RN	F10.0	6-15	Nose radius or reference length (ft).
	RS	F10.0	16-25	Radius of shock (ft). } Used for shock layer calculations only.
	DELTA	F10.0	26-35	Shock stand-off distance (ft). } Used for shock layer calculations only.
	TKW	F10.0	36-45	Temperature at wall ($^{\circ}K$).
FRSTR	VINF	F10.0	6-15	Freestream velocity (ft/sec).
	PINF	F10.0	16-25	Pressure in freestream (psf).
	TKINF	F10.0	26-35	Freestream temperature ($^{\circ}K$).
WFACS	WFA(k)	F5.2	6-10 . . . 76-80	Weight factors, - 1st for momentum (f') and 2nd for energy (θ), then one for each species. K = 1, NI + 2.
FPRIM	FPRIME(N)	7E10.0	6-15 . . . 66-75	First estimate or initial profile of $\frac{u}{u_e}$, N = 1, NMAX. Seven values per card. These cards always used to start calculation
THETA	THETA(N)	7E10.0	6-15 . . . 66-75	First estimate or initial profile of $\frac{T}{T_e}$, N = 1, NMAX.
CLIL	CLIL(N,I)	7E10.0	6-15 . . . 66-75	First estimate or initial profile of $c_{n,i}$, N = 1, NMAX: I = 1, NI. Start new I value on new card.
CINF	CINF(I)	7E10.0	6-15 . . . 66-75	Species mass fraction in freestream, I = 1, NI.

Card Name Col. 1-5	Fortran Name	Format	Column	Description
HEAT	HF(I)	7E10.0	6-15 . . . 66-75	Heats of formation of species, I = 1, NI
LEWIS	FLEJ(I)	7E10.0	6-15 . . . 66-75	Lewis number of species, I = 1, NI.
MOLWT	FMOLWT(I)	7E10.0	6-15 . . . 66-75	Molecular weight of species, I = 1, NI.
XXXXX	AMD(K)	3E10.0	6-15	The three coefficients for approximation to a binary diffusion coefficient on one card. $KKM = \frac{NI^2 - NI}{2}$. K = 1, KKM. The card name from these cards (XXXXX) is printed as the "INTERACTION" with the coefficients so the two species names should be here. Since $D_{ij} = D_{ji}$ and D_{ii}'s are not used, only the upper triangular matrix without the diagonal is required. This matrix is read in as an array with one subscript by taking the elements of the first row, then the second row, then the third row etc., until (NI - 1) rows are included.
	BMD(K)		16-25	
	CMD(K)		26-35	
VC	AMU(I)	3E10.0	6-15	Curve fit coefficients for SPECIES VISCOSITY. One card for each SPECIES in the order that SPECIES are named. SPECIES name may be punched in Cols. 3-5.
	BMU(I)		16-25	
	CMU(I)		26-35	
No card	AR(1,K)	A4	1-4	Species names (left-justified) on left side of reaction K. K = 1, NR
Name	AR(2,K)	A4	6-9	
	AR(3,K)	A4	11-14	
	AR(4,K)	A4	16-19	Species names (left-justified) on right side of reaction K.
	AR(5,K)	A4	21-24	
	AR(6,K)	A4	26-29	
	CO(K)	E10.0	31-40	Forward rate coefficients for reaction described in Cols. 1-29. (See Eq. 88a)
	C1(K)	F5.0	41-45	
	C2(K)	F5.0	46-50	
	DO(K)	E10.0	51-60	Backward rate coefficients for this reaction (see Eq. 88b)
	D1(K)	F5.0	61-65	
	D2(K)	F5.0	66-70	

Card Name Col. 1-5	Fortran Name	Format	Column	Description	
				NOTE: The stoichiometric coefficients are computed using the AR's. AR(1,K), AR(2,K), AR(3,K) to compute $\alpha_{N,J}$ and AR(4,K), AR(5,K), AR(6,K) to compute $\beta_{N,J}$.	
Z	$Z(I,\ell)$	I5F5.2	6-10 11-15 . . . 76-80	Third body efficiencies relative to argon. I = 1, NI; ℓ = 1, NJ - NI.	
NWC	NTP	I5	6-10	Number of entries in four following tables, $3 \le NTP \le 50$.	
XRN	XRN(K)	7E10.0	6-15 . . . 66-75	Table of X/RN.	
TWT	TWT(K)	7E10.0	6-15 . . . 66-75	Temperature ^{o}K at wall vs. X/RN	
RVPT	RVPT(K)	7E10.0	6-15 . . . 66-75	(ρv) of pyrolysis gas vs. X/RN. (used when IWC = 5)	K = 1, NTP
TETE	TETE(K)	7E10.0	6-15 . . . 66-75	η_e vs. X/RN.	
XRB	XRB(K)	7E10.0	6-15 . . . 66-75	r_b vs. X/RN { optional: these cards needed only if geometry is an arbitrary body; i.e., SHARP AX, BLUNT AX, SHARP 2D, BLUNT 2D.	

Card Name Col. 1-5	Fortran Name	Format	Column	Description
BODSP	NDX	I5	6-10	Number of XDELT AND DELXT (step) cards to read. NDX $\leq$ 20.
	IPRTB	I5	11-15	Print body profiles every "IPRTB"th time.
	XMAX	E10.0	16-25	Distance along the body at which solution is to be terminated (ft).
	ANGLC	E10.0	26-35	Cone half angle or asymptotic half angle of hyperboloid (degrees).
STEP	XDELT	E10.0	6-15	Value of x/RN at which Δx step size is to be changed (ft). 1st value must be 0.0. ("NDX" of these cards)
	DELXT	E10.0	16-25	New value of Δx till next XDELT is reached (ft). ("NDX" of these cards)
PTMRO	PO	E10.0	6-15	Pressure to be used with PA(ND) such that PE is in psf.
	TO	E10.0	16-25	Temperature to be used with TA(ND) such that TE is in ^{o}R.
	UO	E10.0	26-35	Velocity to be used with VA(ND) such that UE is in fps.
	NED	I5	36-40	Number of entries in following edge tables. 6 $\leq$ NED $\leq$ 110.
SURXA	X(ND)	7E10.0	6-15 . . . 66-75	Distance along surface X/RN. (ND = 1, NED.)
SURPA	PA(ND)	7E10.0	6-15 . . . 66-75	Pressure at edge PE/PO. (ND = 1, NED.)
SURVA	VA(ND)	7E10.0	6-15 . . . 66-75	Velocity at edge UE/UO. (ND = 1, NED.)
SURTA	TA(ND)	7E10.0	6-15 . . . 66-75	Temperature at edge TE/TO. (ND = 1, NED.)
SURCA	CA(ND,j)	7E10.0	6-15 . . . 66-75	Species mass fraction: All CA(ND,1). ND = 1, NED, j = 1. Then CA(ND,2). ND = 1, NED, j = 2. Till CA(ND,j). ND = 1, NED, j = NI. (ND = 1, NED.)

NOTE: The first value in each of the edge tables must be for X/RN = 0.0 (value at stagnation point), and the 6th value of X/RN $\approx$ .1.

C. Output

The quantities that are printed out from the program are now described. The first information in the output is a print-out of all the input data. In addition, the stoichiometric coefficients are determined from the reactions in the gas model and this is included in the input data. The initial profile information is next in the output. There is a slight difference in the output depending on whether a boundary layer or shock layer solution is being obtained. Also, there is a choice on whether to print all of the information or a limited amount of information for each iteration. For the boundary layer solutions along the body, additional information is obtained in the output and this is next discussed. The program also punches certain information on cards and this is described in the final section.

1. Initial Profile Output - The following output is obtained while the iteration procedure is being applied to the initial profiles for both a boundary layer and shock layer: The first estimates of profiles are printed where the columns are:

I - sequence number of points across the boundary layer,
ETA, - η, value of this quantity across the boundary layer,
FPRIME - f' or u/u_e, for each η,
THETA - θ or T/T_e at η
O_2
.
. c_i, mass fraction of each species at η .
.
NO^+

The following five variables are printed and are constant for the initial profile (x = 0) for a boundary layer.
SMALLE - e
DUEDX - du_e/dx (1/sec.)
HO - $h_\infty + \frac{1}{2} V_\infty^2$, total enthalpy (ft-lb/slug)
ETE - η_e
CTH - Θ
RHOMUREF - $(\rho\mu)_e$ ($slug^2/ft^4$-sec)
REYN NO(S) - Reynolds number = $\rho_\infty V_\infty R_N/\mu_e$

When IPRT, on card named CONTR, is > 1, the entire print for an initial profile iteration is printed only every IPRT-th iteration. When the entire print is skipped, one line of information is written which gives:

ITERATION - iteration number
STANTON NO. } useful as an indication of rate of convergence; defined in Subroutine BLC.
SKIN FRICTION }
TIME LEFT - the time left for this run. If IPUN > 0 and the time left is less than 10 seconds, the profiles are punched. They can be used for restarting the problem.

The entire initial profile iteration print consists of:

PROFILES AFTER __XX__ ITERATIONS, where XX is the number of iterations done.
X(K) - Production terms from the chemical reactions at x_m
X(reaction number) $X_k = (L_{f_k} - L_{b_k})$ for each reaction (k) at each η across the boundary layer.

Profile Print - I, ETA, FPRIME, THETA, and c_i at each point across the boundary layer.

Also, for each point across the boundary layer,

I - sequence number

ETA - η

Y/RN - Boundary layer thickness/nose radius

V - transformed normal velocity

BETA/EBB - $\beta/\bar{\bar{e}}$

DENSITY - $\rho(\text{slug/ft}^3)$

ELECTRON DENSITY - number of electrons per cubic centimeter

TOTAL ENTHALPY - $h + \frac{1}{2} u^2$ (ft-lb/slug)

Single valued variables printed are:

TIME LEFT - number of seconds left for machine run.

QCOND - energy flux at the surface due to conduction
QDIFF - energy flux at the surface due to diffusion
QCONV - energy flux at the surface due to convection
QTOTAL - total energy flux at the surface
(the four above in $\text{ft-lb/ft}^2\text{-sec}$)

QTOTAL(BTU/FT2-SEC) - total energy flux at the surface in units shown

STANTON NUMBER - St

RHO V - ρv $(\text{slug/ft}^2\text{-sec})$

HEAT TRANSFER - $\dfrac{Nu_e}{\sqrt{Re_{x_e}}}$

HEAT TRANSFER, BODY - $\dfrac{Nu_b}{\sqrt{Re_{x_b}}}$

DISPLACEMENT THICKNESS/RN - δ^*/R_N

MOMENTUM THICKNESS - θ_m (ft.)

ℓ at body - $\dfrac{(\rho\mu)_b}{(\rho\mu)_r}$

SKIN FRICTION - $C_{f_e}\sqrt{Re_{x_e}}$

Finally the WALL MASS FLUX $(\text{slug/ft}^2\text{-sec})$ is printed for each species.

When the solution for a shock layer is being obtained, some additional information is in the output. Some quantities which are constant for a boundary layer solution change with each iteration in the shock layer solution and appear in the output. The additional output for the shock layer is:

PE - p_e, pressure at shock

TE - T_e, temperature at shock

RHOE - ρ_e, density at shock

UE - u_e, tangential velocity at shock

RHOMUREF and REYN NO(S) - same as above

VS - V_{sh}, transformed normal velocity at shock from shock relations

SH - S_h, shock slip term (see Eq. 79)

DUEDX - same as above

TS1 - $s(1 - \varepsilon) + \varepsilon$, shock shape parameter (see Eq. 21)

EPSI - ε, density ratio across shock

ETE - η_e

2. Output along the body - For this case the initial profile output quantities are given again. In addition, other information is included which is a function of the distance along the body. Since the finite-difference method along the body can either be the Crank-Nicholson or implicit type and is determined by the value of Θ, this quantity is given by the value of CTH in the output. The body output is printed every IPRTB-th step along the body and gives the following information:

M - TH BODY PROFILE S = XXXX

where M is the sequence number of profile and S is X/RN.

When the initial profiles are converged, the full profile is printed with the information that the profiles are converged. When less than 10 seconds are left for the computer run, the entire profile print is printed with the information that the time is about gone. Also when KOPE profiles have been done, a message is printed and the entire profile printed. In any of these three situations, the profiles are punched if requested (IPUN = 1), and the calculation of body profiles is attempted (except for a shock layer problem).

RHOMUREF - $(\rho\mu)_e$ at $m + \frac{1}{2}$ ($slug^2/ft^4$-sec)

INTERPOLATED EDGE CONDITIONS:

PE - $p_{e_{m+\frac{1}{2}}}$ (psf)

TE - $T_{e_{m+\frac{1}{2}}}$ (^{o}R)

UE - $u_{e_{m+\frac{1}{2}}}$ (fps)

DPEO - $\left.\frac{dp_e}{dx}\right)_m$ (lb/ft^3)

DPE1 - $\left.\frac{dp_e}{dx}\right)_{m+1}$ (lb/ft^2)

BEB - $\bar{\bar{e}}$

ETE - η_e

XO - x_m

X 1/2 - $x_{m+\frac{1}{2}}$ } distance along surface of body (ft.)

X1 - x_{m+1}

RBO - r_{b_m}

RB 1/2 - $r_{b_{m+\frac{1}{2}}}$ } radial distance to body surface (ft.)

RB1 - $r_{b_{m+1}}$

LAMBDA - λ_m
LAMBDA 1/2 - $\lambda_{m+\frac{1}{2}}$
LAMBDA + 1 - λ_{m+1}

(the three LAMBDA values above are bracketed together with: $(\rho\mu)_r \, u_e \, r_b^{\,2j}$)

BETA - $\beta_{m+\frac{1}{2}}$
MU - (μ, mixture viscosity)$_{m+\frac{1}{2}}$ (slug/ft-sec.)
RHOE - $\rho_{e_{m+1}}$ (slug/ft^3)
DELXI - $\Delta\xi_{m+1}$
XIO - ξ_m
XI 1/2 - $\xi_{m+\frac{1}{2}}$
XI1 - ξ_{m+1}
SMALL E - $e_{m+\frac{1}{2}}$
EBAR - $\bar{e}_{m+\frac{1}{2}}$
RHOMUREF - $(\rho\mu)_e$ at m + 1 (slug^2/ft^4-sec)
η, f', θ, c_i for each point across the boundary layer.
η, Y/RN, V, $\beta/\bar{\bar{e}}$, ρ, ELECTRON DENSITY and TOTAL ENTHALPY for each point across the boundary layer.

The single value variables, in addition to those printed for the initial profiles, are:

RS**(1+J) - $\dot{m}_T$, total mass flow in the boundary layer (slug/ft$^{(1+j)}$sec)
REYNOLDS NUMBER - Re_{x_e}
CF-INF - C_{f_∞}
T DRAG COEF - drag resulting from the shearing stress at the surface
P DRAG COEF - drag resulting from the pressure acting on the surface
TOTAL DRAG - sum of the above drags

For each species there is a print of:

WALL MASS FLUX - $\dot{m}_i$ (slug/ft^2-sec)
TOTAL MASS FLOW - $\dot{M}_t$ (slug/ft^{1-j}-sec)
FLOW (PAR/SEC) - $\dot{M}_i$ (particles/ft^{1-j}-sec)

3. Punched Output - In order to have a collection of the best available initial profiles for the solution of problems, the profiles and some information to identify the problem can be punched. When IPUN = 1, the following cards will be punched in the correct format to be used as input.

TITLE
LIMTS
SPNA
DNS
CONTR
OPTN
SIZE
FRSTR
WFACS
FPRIME

THETA

CLIL

BODSP

The following card will be punched for each step along the body (except the last step). FORMAT (I5,5E15.7)

M - sequence number

x/R_N

$r_{sh}^{(1+j)}$

$\rho_e v_e$

ξ_m

$(y/R_N)_e$

This information is used in another program that determines the edge conditions for a blunt body.

D. Sample Input and Output

To illustrate the program input and output, the results for three sample problems are presented. For each example a listing of the data deck cards is given, then the listing of the print-out of the input quantities is given, and finally a listing of the output of the program. For these examples only a part of the listing is given to keep the length within reason. For all three cases the freestream conditions are for an altitude of 100 kft (standard atmosphere), undissociated gas mixture, and a velocity of 20 kfps.

(1) Example 1 - This problem corresponds to the calculation of the thin viscous shock layer at the stagnation point on a blunt body. It is assumed that the shock is concentric with the body and this requires $R_{Sh} = R_N + \Delta$ and gives S = 1. Also with $R_N = R_{Sh}$ and $\Delta = 0$, S = 1 and the program performs the calculation for the shock concentric with the body. The gas model is a binary mixture of oxygen atoms and molecules with one chemical reaction. The wall temperature is 1000°K and the wall is catalytic with the gas in chemical equilibrium. For the first estimate of the initial profiles f' is assumed, then θ and c_i's are estimated by the program. After 49 iterations the solution converges and requires ≈ 17 seconds of central processing time on the CDC 6600.

```
TITLE           BINARY GAS MODEL        SHOCK LAYER
LIMTS   50    2    1    3  .0002          1.0
SPNA O     O2    M1
CONTR   20    1    0  100    1 1.0   1.0  1.0     2
OPTN NON-EQUI  NON-FROZ  SHOCK LA  INITIAL    HPERBOID  CON LEWI
SIZE  .08333333 .08333333   0.0         1000.
FRSTR  20000.       21.05      226.98
WFAC  1.0  1.0  1.0  1.0
FPRIM 0.0000000  .2266449  .3903192  .4174480  .4338277  .4522379  .4680812
FPRIM  .4833311  .4974342  .5110891  .5240831  .5367945  .5490583  .5611276
FPRIM  .5728817  .5844873  .5958723  .6071622  .6183517  .6296167  .6410856
FPRIM  .6529361  .6649799  .6769560  .6888359  .7008249  .7129191  .7250234
FPRIM  .7371207  .7493025  .7615213  .7737608  .7860399  .7983724  .8107230
FPRIM  .8231189  .8355504  .8480165  .8605154  .8730557  .8856234  .8982318
FPRIM  .9108707  .9235460  .9362534  .9489970  .9617712  .9745813  .9874054
FPRIM 1.0000000
THETA  .0624120  .2270027  .2673927  .2802845  .2819829  .2849162  .2890939
THETA  .2929277  .2966701  .3002663  .3036725  .3071065  .3104409  .3137871
THETA  .3171348  .3204070  .3234915  .3258550  .3264769  .3238877  .3183319
THETA  .3140556  .3148291  .3177661  .3178155  .3159941  .3160771  .3172002
THETA  .3168275  .3162704  .3167640  .3168553  .3164910  .3166804  .3167798
THETA  .3165830  .3166866  .3167264  .3166247  .3166988  .3166937  .3166530
THETA  .3167056  .3166794  .3166743  .3166992  .3167698  .3184227  .3462670
THETA 1.0000000
CLIL   .0000000  .1540315  .4676795  .5930016  .6089173  .6356604  .6721221
CLIL   .7036516  .7324477  .7581731  .7807302  .8016964  .8203809  .8375286
CLIL   .8531607  .8670587  .8790202  .8875703  .8900144  .8814784  .8597449
CLIL   .8395497  .8425188  .8560212  .8567580  .8485864  .8485890  .8537341
CLIL   .8522998  .8496421  .8517864  .8523352  .8506699  .8514480  .8519676
CLIL   .8510761  .8514988  .8517211  .8512532  .8515671  .8515708  .8513726
CLIL   .8516070  .8515032  .8514663  .8515533  .8513254  .8493654  .8148769
CLIL   .0107477
CLIL  1.0000000  .8459685  .5323205  .4069984  .3910827  .3643396  .3278779
CLIL   .2963484  .2675523  .2418269  .2192698  .1983036  .1796191  .1624714
CLIL   .1468393  .1329413  .1209798  .1124297  .1099856  .1185216  .1402551
CLIL   .1604503  .1574812  .1439788  .1432420  .1514136  .1514110  .1462659
CLIL   .1477002  .1503579  .1482136  .1476648  .1493301  .1485520  .1480324
CLIL   .1489239  .1485012  .1482789  .1487468  .1484329  .1484292  .1486274
CLIL   .1483930  .1484968  .1485337  .1484467  .1486746  .1506346  .1851231
CLIL   .9892523
CINF     0.0         1.0
HEAT  1.661  E8      0.0
LEWIS     1.4        1.4
MOLWT    16.        32.
O  O2  .0216586  1.38757    -9.739
VC O    .0203144   .4294404 -11.60314
VC O2   .0449290 -.0826158 - 9.20195
      O2  +M1   =0    +O    +M1        3.61+18 59.4 -1.     3.01+15  0.  -.5
Z       25.  9.
NWT       4
XRN       .0         10.       50.0      250.
TWT     1000.      1000.     1000.      1000.
RVPT     .001       .001      .001       .001
TETE     5.4        5.4       5.4        5.4
BODSP    10     1    5.0       10.0
STEP1     .0         .01
STEP2     .1         .025
STEP3     .5         .05
STEP4    1.0         .1
STEP5    3.0         .25
STEP6    6.0         .5
STEP7   10.        1.0
STEP8   25.0         2.0
STEP9    50.         5.0
STP10   240.        10.
PTMRO    1.0         1.0       1.0        6
XAEDG    0.0        10.       20.        30.       45.       60.
PAEDG  456.       456.      456.       456.      456.      456.
VAEDG  19600.     19600.    19600.     19600.    19600.    19600.
TAEDG  1665.       1665.     1665.     1665.     1665.     1665.
CA  O     0.0        0.0       0.0        0.0       0.0       0.0
CA O2     1.0        1.0       1.0        1.0       1.0       1.0
```

BINARY GAS MODEL SHOCK LAYER

INPUT 07/13/70

NMAX = 50	IWC = 2	K = 1.00	RN = .083333330	VINF = 20000.0000	NON-EQUILIBRUM
NI = 2	IPRT = 20	TOL = .000200	RS = .083333330	PINF = 21.0500	NON-FROZEN
NR = 1	IPUN = 1		DELTA =0.000000000	TKINF = 226.9800	SHOCK LAYER
NJ = 3	IREAD = 0	AMOM = 1.0000	TKW = 1000.0000		COMPUTE INITIAL PROFILE
	KOPE =100	AENE = 1.0000	E O = -0.0000		HYPERBOLOID
	KOPT = 1	ASPE = 1.0000	E O2 = -0.0000		CON LEWIS NOS.

K	INTERACTION	AMD	BMD	CMD
1	O O2	2.16586E-02	1.38757E+00	-9.73900E+00

GAS MODEL

SPEC	HF	FLEJ	FMOL WT	AMU	BMU	CMU	WFAC 1.00(FPRIME) 1.00(THETA)	CINF
O	1.66100E+08	1.40000E+00	1.60000E+01	2.03144E-02	4.29440E-01	-1.16031E+01	1.00	0.
O2	0.	1.40000E+00	3.20000E+01	4.49290E-02	-8.26158E-02	-9.20195E+00	1.00	1.00000E+00

K	REACTION	C0	C1	C2	D0	D1	D2	CSALPH	CSBETA
1	O2 M1 =O O M1	3.610E+18	59.40	-1.00	3.010E+15	0.00	-.50	1.00	2.00

STOICHIOMETRIC COEF.

FORWARD - CALPH(NR,NJ)

NJ/NR	1
O	0.00
O2	1.00
M1	1.00

BACKWARD - CBETA(NR,NJ)

NJ/NR	1
O	2.00
O2	0.00
M1	1.00

THIRD BODY EFFECIENCIES - Z(NI,NL)

NL/NI	1	2
M1	25.0000	9.0000

K	X/RN	T-WALL	RV(PYR)	ETA(EDGE)
1	0.	1.00000E+03	1.00000E-03	5.40000E+00
2	1.00000E+01	1.00000E+03	1.00000E-03	5.40000E+00
3	5.00000E+01	1.00000E+03	1.00000E-03	5.40000E+00
4	2.50000E+02	1.00000E+03	1.00000E-03	5.40000E+00

BODY DATA

IPRTB = 1   XMAX = 5.00000   NORM SH PRESS = 1.0000
CONE ANGLE = 10.00000   NORM SH TEMP = 1.0000
NORM SH VEL = 1.0000

X = 0.00 .10 .50 1.00 3.00 6.00 10.00 25.00 50.00 240.00
DELT X = .010 .025 .050 .100 .250 .500 1.000 2.000 5.000 10.000

EDGE TABLES

	XA	PA	VA	TA	CA(SPECIES) O	O2
1	0.	4.5600E+02	1.9600E+04	1.6650E+03	0.	1.0000E+00
2	1.0000E+01	4.5600E+02	1.9600E+04	1.6650E+03	0.	1.0000E+00
3	2.0000E+01	4.5600E+02	1.9600E+04	1.6650E+03	0.	1.0000E+00
4	3.0000E+01	4.5600E+02	1.9600E+04	1.6650E+03	0.	1.0000E+00
5	4.5000E+01	4.5600E+02	1.9600E+04	1.6650E+03	0.	1.0000E+00
6	6.0000E+01	4.5600E+02	1.9600E+04	1.6650E+03	0.	1.0000E+00

NOTE --- XA, PA, TA AND VA ARE CHANGED IN SUBROUTINE INPBOD

XA(K) = XA(K) * RN
PA(K) = PA(K) * NORM SH PRESS.
VA(K) = VA(K) * NORM SH VEL.
TA(K) = TA(K) * NORM SH TEMP.

END OF INPUT

PE = 1.15797E+04   TE = 2.90286E+04   RHOE = 2.56914E-04   UE = 0.

INITIAL PROFILE

N	ETA	FPRIME	THETA	O	O2
1	0.0000	0.	6.2008E-02	0.	1.0000E+00
2	.0204	2.2664E-01	9.9903E-02	0.	1.0000E+00
3	.0408	3.9032E-01	1.3702E-01	0.	1.0000E+00
4	.0612	4.1745E-01	1.7335E-01	0.	1.0000E+00
5	.0816	4.3383E-01	2.0890E-01	0.	1.0000E+00
6	.1020	4.5224E-01	2.4367E-01	0.	1.0000E+00
7	.1224	4.6808E-01	2.7766E-01	0.	1.0000E+00
8	.1429	4.8333E-01	3.1086E-01	0.	1.0000E+00
9	.1633	4.9743E-01	3.4329E-01	0.	1.0000E+00
10	.1837	5.1109E-01	3.7493E-01	0.	1.0000E+00
11	.2041	5.2408E-01	4.0580E-01	0.	1.0000E+00
12	.2245	5.3679E-01	4.3588E-01	0.	1.0000E+00
13	.2449	5.4906E-01	4.6518E-01	0.	1.0000E+00
14	.2653	5.6113E-01	4.9370E-01	0.	1.0000E+00
15	.2857	5.7288E-01	5.2143E-01	0.	1.0000E+00
16	.3061	5.8449E-01	5.4839E-01	0.	1.0000E+00
17	.3265	5.9587E-01	5.7456E-01	0.	1.0000E+00
18	.3469	6.0716E-01	5.9996E-01	0.	1.0000E+00
19	.3673	6.1835E-01	6.2457E-01	0.	1.0000E+00
20	.3878	6.2962E-01	6.4840E-01	0.	1.0000E+00
21	.4082	6.4109E-01	6.7145E-01	0.	1.0000E+00
22	.4286	6.5294E-01	6.9372E-01	0.	1.0000E+00
23	.4490	6.6498E-01	7.1520E-01	0.	1.0000E+00
24	.4694	6.7696E-01	7.3591E-01	0.	1.0000E+00
25	.4898	6.8884E-01	7.5583E-01	0.	1.0000E+00
26	.5102	7.0082E-01	7.7498E-01	0.	1.0000E+00
27	.5306	7.1292E-01	7.9334E-01	0.	1.0000E+00
28	.5510	7.2502E-01	8.1092E-01	0.	1.0000E+00
29	.5714	7.3712E-01	8.2772E-01	0.	1.0000E+00
30	.5918	7.4930E-01	8.4373E-01	0.	1.0000E+00
31	.6122	7.6152E-01	8.5897E-01	0.	1.0000E+00
32	.6327	7.7376E-01	8.7342E-01	0.	1.0000E+00
33	.6531	7.8604E-01	8.8710E-01	0.	1.0000E+00
34	.6735	7.9837E-01	8.9999E-01	0.	1.0000E+00
35	.6939	8.1072E-01	9.1210E-01	0.	1.0000E+00
36	.7143	8.2312E-01	9.2343E-01	0.	1.0000E+00
37	.7347	8.3555E-01	9.3398E-01	0.	1.0000E+00
38	.7551	8.4802E-01	9.4374E-01	0.	1.0000E+00
39	.7755	8.6052E-01	9.5273E-01	0.	1.0000E+00
40	.7959	8.7306E-01	9.6093E-01	0.	1.0000E+00
41	.8163	8.8562E-01	9.6836E-01	0.	1.0000E+00
42	.8367	8.9823E-01	9.7500E-01	0.	1.0000E+00
43	.8571	9.1087E-01	9.8086E-01	0.	1.0000E+00
44	.8776	9.2355E-01	9.8594E-01	0.	1.0000E+00
45	.8980	9.3625E-01	9.9023E-01	0.	1.0000E+00
46	.9184	9.4900E-01	9.9375E-01	0.	1.0000E+00
47	.9388	9.6177E-01	9.9648E-01	0.	1.0000E+00
48	.9592	9.7458E-01	9.9844E-01	0.	1.0000E+00
49	.9796	9.8741E-01	9.9961E-01	0.	1.0000E+00
50	1.0000	1.0000E+00	1.0000E+00	0.	1.0000E+00

```
  SMALLE = 2.08333E-06      DUEDX = 2.40000E+05       HO = 2.02207E+08       ETE = 5.40000E+00      CTH = 1.00000E+0

 RHOMUREF =  1.64871E-09    REYN NO(S) =  8.61788E+03          VS = -2.35909E+01
      ETE =  3.42753E+01

 RHOMUREF =  1.64871E-09    REYN NO(S) =  8.61788E+03          VS = -2.35909E+01
       PE =  1.15797E+04            TE =  2.90285E+04        RHOE =  2.56914E-04               UE =  0.
       SH =  1.98343E+02         DUEDX =  2.39819E+05         TS1 =  1.00000E+00             EPSI =  1.29158E-01
      ETE =  4.53506E+01
ITERATION    1             STANTON NO. =  2.14162E-02  SKIN FRICTION =  4.58926E-01      TIME LEFT = 58.101 SEC

 RHOMUREF =  1.64871E-09    REYN NO(S) =  8.61789E+03          VS = -2.35909E+01
       PE =  1.15797E+04            TE =  2.74601E+04        RHOE =  2.71589E-04               UE =  0.
       SH = -1.13496E+07         DUEDX =  2.39254E+05         TS1 =  1.00000E+00             EPSI =  1.29157E-01
      ETE =  3.27907E+01
ITERATION    2             STANTON NO. =  1.30987E-02  SKIN FRICTION =  6.83804E-01      TIME LEFT = 57.898 SEC

 RHOMUREF =  1.55482E-09    REYN NO(S) =  8.63478E+03          VS = -2.36140E+01
       PE =  1.15797E+04            TE =  2.73266E+04        RHOE =  2.43945E-04               UE =  0.
       SH = -1.64983E+07         DUEDX =  2.39771E+05         TS1 =  1.00000E+00             EPSI =  1.22179E-01
      ETE =  3.11271E+01
ITERATION    3             STANTON NO. =  2.53683E-02  SKIN FRICTION =  7.84689E-01      TIME LEFT = 57.693 SEC

 RHOMUREF =  1.53216E-09    REYN NO(S) =  8.58845E+03          VS = -2.29055E+01
       PE =  1.15797E+04            TE =  2.73631E+04        RHOE =  2.37620E-04               UE =  0.
       SH = -1.64990E+07         DUEDX =  2.39885E+05         TS1 =  1.00000E+00             EPSI =  1.36024E-01
      ETE =  3.12847E+01
ITERATION    4             STANTON NO. =  2.64800E-02  SKIN FRICTION =  7.33797E-01      TIME LEFT = 57.491 SEC

 RHOMUREF =  1.53375E-09    REYN NO(S) =  8.58605E+03          VS = -2.41652E+01
       PE =  1.15797E+04            TE =  2.74952E+04        RHOE =  2.36974E-04               UE =  0.
       SH = -1.42251E+07         DUEDX =  2.39853E+05         TS1 =  1.00000E+00             EPSI =  1.39645E-01
      ETE =  3.39758E+01
ITERATION    5             STANTON NO. =  2.40100E-02  SKIN FRICTION =  6.54178E-01      TIME LEFT = 57.285 SEC
```

PROFILES AFTER 49 ITERATIONS. ++++++++PROFILES CONVERGED++++++++

X(K)

N	ETA	1
1	0.0000	-8.3304E-28
2	.0204	-4.5706E+02
3	.0408	-1.0231E+03
4	.0612	-1.2224E+03
5	.0816	-4.5224E+02
6	.1020	3.1194E+01
7	.1224	1.4637E+02
8	.1429	1.3288E+02
9	.1633	8.2973E+01
10	.1837	4.0743E+01
11	.2041	1.6748E+01
12	.2245	5.6924E+00
13	.2449	1.4951E+00
14	.2653	2.5005E-01
15	.2857	-1.6225E-02
16	.3061	-4.7558E-02
17	.3265	-4.2317E-02
18	.3469	-3.5302E-02
19	.3673	-2.9625E-02
20	.3878	-2.5025E-02
21	.4082	-2.1224E-02
22	.4286	-1.8037E-02
23	.4490	-1.5329E-02
24	.4694	-1.3001E-02
25	.4898	-1.0975E-02
26	.5102	-9.1801E-03
27	.5306	-7.5273E-03
28	.5510	-5.8436E-03
29	.5714	-3.7006E-03
30	.5918	4.5864E-05
31	.6122	8.4586E-03
32	.6327	2.9565E-02
33	.6531	8.3850E-02
34	.6735	2.2217E-01
35	.6939	5.6739E-01
36	.7143	1.4086E+00
37	.7347	3.4088E+00
38	.7551	8.0521E+00
39	.7755	1.8583E+01
40	.7959	4.1949E+01
41	.8163	9.2739E+01
42	.8367	2.0119E+02
43	.8571	4.2973E+02
44	.8776	9.0902E+02
45	.8980	1.9263E+03
46	.9184	4.1885E+03
47	.9388	9.8775E+03
48	.9592	2.9437E+04
49	.9796	1.8766E+05
50	1.0000	6.9233E+06

N	ETA	FPRIME	THETA	O	O2
1	0.0000	0.	6.5772E-02	4.7615E-11	1.0000E+00
2	.0204	6.7463E-02	1.2385E-01	6.3947E-02	9.3605E-01
3	.0408	1.5142E-01	1.8851E-01	1.5362E-01	8.4638E-01
4	.0612	2.4050E-01	2.4241E-01	2.7138E-01	7.2862E-01
5	.0816	3.2214E-01	2.7303E-01	4.1207E-01	5.8793E-01
6	.1020	3.8704E-01	2.9083E-01	5.5063E-01	4.4937E-01
7	.1224	4.3218E-01	3.0426E-01	6.6499E-01	3.3501E-01
8	.1429	4.6075E-01	3.1481E-01	7.4481E-01	2.5519E-01
9	.1633	4.7912E-01	3.2205E-01	7.9150E-01	2.0850E-01
10	.1837	4.9287E-01	3.2603E-01	8.1424E-01	1.8576E-01
11	.2041	5.0509E-01	3.2774E-01	8.2340E-01	1.7660E-01
12	.2245	5.1696E-01	3.2830E-01	8.2641E-01	1.7359E-01
13	.2449	5.2882E-01	3.2845E-01	8.2720E-01	1.7280E-01
14	.2653	5.4073E-01	3.2848E-01	8.2735E-01	1.7265E-01
15	.2857	5.5271E-01	3.2848E-01	8.2737E-01	1.7263E-01
16	.3061	5.6475E-01	3.2848E-01	8.2736E-01	1.7264E-01
17	.3265	5.7686E-01	3.2848E-01	8.2736E-01	1.7264E-01
18	.3469	5.8902E-01	3.2848E-01	8.2736E-01	1.7264E-01
19	.3673	6.0124E-01	3.2848E-01	8.2735E-01	1.7265E-01
20	.3878	6.1351E-01	3.2848E-01	8.2735E-01	1.7265E-01
21	.4082	6.2584E-01	3.2848E-01	8.2735E-01	1.7265E-01
22	.4286	6.3821E-01	3.2848E-01	8.2735E-01	1.7265E-01
23	.4490	6.5063E-01	3.2848E-01	8.2735E-01	1.7265E-01
24	.4694	6.6310E-01	3.2847E-01	8.2735E-01	1.7265E-01
25	.4898	6.7562E-01	3.2847E-01	8.2734E-01	1.7266E-01
26	.5102	6.8817E-01	3.2847E-01	8.2734E-01	1.7266E-01
27	.5306	7.0078E-01	3.2847E-01	8.2734E-01	1.7266E-01
28	.5510	7.1342E-01	3.2847E-01	8.2734E-01	1.7266E-01
29	.5714	7.2611E-01	3.2847E-01	8.2734E-01	1.7266E-01
30	.5918	7.3884E-01	3.2847E-01	8.2734E-01	1.7266E-01
31	.6122	7.5161E-01	3.2847E-01	8.2734E-01	1.7266E-01
32	.6327	7.6442E-01	3.2847E-01	8.2734E-01	1.7266E-01
33	.6531	7.7727E-01	3.2847E-01	8.2734E-01	1.7266E-01
34	.6735	7.9016E-01	3.2847E-01	8.2734E-01	1.7266E-01
35	.6939	8.0309E-01	3.2848E-01	8.2734E-01	1.7266E-01
36	.7143	8.1605E-01	3.2848E-01	8.2733E-01	1.7267E-01
37	.7347	8.2906E-01	3.2848E-01	8.2733E-01	1.7267E-01
38	.7551	8.4210E-01	3.2849E-01	8.2731E-01	1.7269E-01
39	.7755	8.5518E-01	3.2852E-01	8.2728E-01	1.7272E-01
40	.7959	8.6829E-01	3.2858E-01	8.2721E-01	1.7279E-01
41	.8163	8.8145E-01	3.2871E-01	8.2706E-01	1.7294E-01
42	.8367	8.9463E-01	3.2899E-01	8.2675E-01	1.7325E-01
43	.8571	9.0786E-01	3.2957E-01	8.2608E-01	1.7392E-01
44	.8776	9.2111E-01	3.3075E-01	8.2471E-01	1.7529E-01
45	.8980	9.3439E-01	3.3319E-01	8.2191E-01	1.7809E-01
46	.9184	9.4768E-01	3.3818E-01	8.1614E-01	1.8386E-01
47	.9388	9.6098E-01	3.4882E-01	8.0390E-01	1.9610E-01
48	.9592	9.7424E-01	3.7382E-01	7.7529E-01	2.2471E-01
49	.9796	9.8738E-01	4.5098E-01	6.8805E-01	3.1195E-01
50	1.0000	1.0000E+00	1.0000E+00	8.8527E-02	9.1147E-01

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	0.	-1.6406E-01	4.1433E-03	0.	1.0485E+07
2	.0204	1.8227E-04	-2.4002E-02	-1.6406E-01	2.0680E-03	0.	3.2022E+07
3	.0408	5.0917E-04	-1.0487E-01	-1.6403E-01	1.2531E-03	0.	5.9725E+07
4	.0612	1.0045E-03	-2.5069E-01	-1.6395E-01	8.8420E-04	0.	9.0578E+07
5	.0816	1.6573E-03	-4.6041E-01	-1.6379E-01	7.0682E-04	0.	1.2114E+08
6	.1020	2.4437E-03	-7.2466E-01	-1.6352E-01	6.0428E-04	0.	1.4893E+08
7	.1224	3.3441E-03	-1.0295E+00	-1.6318E-01	5.3793E-04	0.	1.7169E+08
8	.1429	4.3372E-03	-1.3614E+00	-1.6277E-01	4.9611E-04	0.	1.8787E+08
9	.1633	5.3960E-03	-1.7102E+00	-1.6232E-01	4.7232E-04	0.	1.9757E+08
10	.1837	6.4936E-03	-2.0708E+00	-1.6184E-01	4.6071E-04	0.	2.0239E+08
11	.2041	7.6100E-03	-2.4410E+00	-1.6133E-01	4.5601E-04	0.	2.0435E+08
12	.2245	8.7335E-03	-2.8201E+00	-1.6079E-01	4.5447E-04	0.	2.0500E+08
13	.2449	9.8593E-03	-3.2080E+00	-1.6023E-01	4.5407E-04	0.	2.0517E+08
14	.2653	1.0986E-02	-3.6047E+00	-1.5965E-01	4.5400E-04	0.	2.0520E+08
15	.2857	1.2112E-02	-4.0102E+00	-1.5904E-01	4.5399E-04	0.	2.0520E+08
16	.3061	1.3238E-02	-4.4247E+00	-1.5840E-01	4.5399E-04	0.	2.0520E+08
17	.3265	1.4365E-02	-4.8481E+00	-1.5774E-01	4.5399E-04	0.	2.0520E+08
18	.3469	1.5491E-02	-5.2805E+00	-1.5704E-01	4.5400E-04	0.	2.0520E+08
19	.3673	1.6618E-02	-5.7220E+00	-1.5632E-01	4.5400E-04	0.	2.0520E+08
20	.3878	1.7744E-02	-6.1725E+00	-1.5557E-01	4.5400E-04	0.	2.0520E+08
21	.4082	1.8870E-02	-6.6322E+00	-1.5478E-01	4.5400E-04	0.	2.0520E+08
22	.4286	1.9997E-02	-7.1011E+00	-1.5396E-01	4.5400E-04	0.	2.0520E+08
23	.4490	2.1123E-02	-7.5791E+00	-1.5312E-01	4.5400E-04	0.	2.0520E+08
24	.4694	2.2249E-02	-8.0663E+00	-1.5224E-01	4.5400E-04	0.	2.0520E+08
25	.4898	2.3376E-02	-8.5629E+00	-1.5132E-01	4.5400E-04	0.	2.0520E+08
26	.5102	2.4502E-02	-9.0687E+00	-1.5037E-01	4.5400E-04	0.	2.0520E+08
27	.5306	2.5629E-02	-9.5839E+00	-1.4938E-01	4.5400E-04	0.	2.0520E+08
28	.5510	2.6755E-02	-1.0108E+01	-1.4836E-01	4.5400E-04	0.	2.0520E+08
29	.5714	2.7881E-02	-1.0642E+01	-1.4731E-01	4.5400E-04	0.	2.0520E+08
30	.5918	2.9008E-02	-1.1186E+01	-1.4621E-01	4.5400E-04	0.	2.0520E+08
31	.6122	3.0134E-02	-1.1738E+01	-1.4507E-01	4.5400E-04	0.	2.0520E+08
32	.6327	3.1260E-02	-1.2301E+01	-1.4390E-01	4.5400E-04	0.	2.0520E+08
33	.6531	3.2387E-02	-1.2873E+01	-1.4269E-01	4.5400E-04	0.	2.0520E+08
34	.6735	3.3513E-02	-1.3454E+01	-1.4143E-01	4.5400E-04	0.	2.0520E+08
35	.6939	3.4640E-02	-1.4045E+01	-1.4014E-01	4.5400E-04	0.	2.0520E+08
36	.7143	3.5766E-02	-1.4645E+01	-1.3880E-01	4.5400E-04	0.	2.0520E+08
37	.7347	3.6892E-02	-1.5256E+01	-1.3742E-01	4.5399E-04	0.	2.0520E+08
38	.7551	3.8019E-02	-1.5875E+01	-1.3599E-01	4.5398E-04	0.	2.0520E+08
39	.7755	3.9145E-02	-1.6505E+01	-1.3452E-01	4.5395E-04	0.	2.0520E+08
40	.7959	4.0272E-02	-1.7144E+01	-1.3300E-01	4.5389E-04	0.	2.0520E+08
41	.8163	4.1399E-02	-1.7793E+01	-1.3144E-01	4.5374E-04	0.	2.0520E+08
42	.8367	4.2526E-02	-1.8452E+01	-1.2983E-01	4.5344E-04	0.	2.0520E+08
43	.8571	4.3654E-02	-1.9120E+01	-1.2817E-01	4.5281E-04	0.	2.0520E+08
44	.8776	4.4785E-02	-1.9799E+01	-1.2646E-01	4.5152E-04	0.	2.0521E+08
45	.8980	4.5920E-02	-2.0487E+01	-1.2470E-01	4.4892E-04	0.	2.0522E+08
46	.9184	4.7065E-02	-2.1185E+01	-1.2289E-01	4.4368E-04	0.	2.0524E+08
47	.9388	4.8228E-02	-2.1893E+01	-1.2103E-01	4.3307E-04	0.	2.0529E+08
48	.9592	4.9432E-02	-2.2611E+01	-1.1912E-01	4.1063E-04	0.	2.0541E+08
49	.9796	5.0733E-02	-2.3338E+01	-1.1715E-01	3.5796E-04	0.	2.0577E+08
50	1.0000	5.2432E-02	-2.4075E+01	-1.1514E-01	2.5035E-04	0.	2.0417E+08

TIME LEFT =	47.837 SEC	RHO V =	0.
QCOND =	-1.24327E+06	HEAT TRANSFER =	5.68186E-01
QDIFF =	-1.55904E+06	HEAT TRANSFER, BODY =	3.53301E-01
QCONV =	0.	DISPLACEMENT THICKNESS/RN =	-1.38637E-02
QTOTAL =	-2.80231E+06	MOMENTUM THICKNESS =	1.44790E-03
QTOTAL(BTU/FT2-SEC) =	-3.60122E+03	L AT BODY =	2.65813E+00
STANTON NUMBER =	2.20245E-02	SKIN FRICTION =	6.00163E-01

SPECIES	WALL MASS FLUX
O	-9.19647E-03
O2	9.19647E-03

END OF THIS PROBLEM

(2) Example 2 - This problem is for the solution of the boundary layer equations along a sphere-cone body with 1-inch nose radius and 10^{o} half-angle cone. The gas model for this case is air with the species O_2, N_2, O, N, NO, NO^+, and e^-. Seven homogeneous chemical reactions are used and multi-component diffusion coefficients are employed. The wall temperature is $1000^{o}K$ and constant along the body. The wall is taken as fully catalytic recombination except for NO which is non-catalytic. The first estimates of the initial profiles are profiles available from a previous computer solution. The profiles are iterated 87 times before convergence. The entire profiles are printed-out every 40 iterations. The solution proceeds until x is 20 ft. and this requires 95 steps along the body with variable step-sizes employed. The edge tables are for the case where the inviscid flow is being swallowed into the boundary layer with the mass flows matched. Central processing time for this solution on a CDC 6600 computer was 3 minutes, 38 seconds.

```
TITLE       10 DEGREE SPHERE CONE          20 KFP    100 KFT ALT
LIMTS    28      6     7    10    .000200  1.000000
SPNA O2     N2     O      N      NO     NO+  EL     M1    M2     M3
CONTR    40      1      1  100       11.0001.0001.000       4
OPTN NON-EQUI   NON-FROZ  BOUNDARY   INITIAL    SPHERE C   CAL LEWI
SIZE   .08333333 .083333330.00000000 1000.0000
FRSTR 20000.000     23.2719    226.9800
WFACS   .50   .50   .50   .50   .50   .50   .50   .50
FPRIM 0.0000000   .0643218   .1364384   .2139848   .2948325   .3768725   .4579282
FPRIM   .5357512   .6081539   .6733539   .7302951   .7786597   .8187091   .8511347
FPRIM   .8769247   .8972275   .9132174   .9259825   .9364512   .9453598   .9532551
FPRIM   .9605197   .9674074   .9740782   .9806284   .9871139   .9935655 1.0000000
THETA   .1437240   .2144035   .2913007   .3731785   .4586296   .5456635   .6311686
THETA   .7104272   .7773516   .8288073   .8675993   .8978728   .9221016   .9415112
THETA   .9568691   .9688110   .9779159   .9847113   .9896682   .9931969   .9956453
THETA   .9972993   .9983864   .9990807   .9995112   .9997697   .9999190 1.0000000
CLIL    .2526824   .2302043   .2033737   .1724144   .1375319   .0994559   .0610320
CLIL    .0293145   .0112070   .0043302   .0022060   .0014750   .0011420   .0009514
CLIL    .0008277   .0007420   .0006807   .0006365   .0006044   .0005813   .0005648
CLIL    .0005533   .0005454   .0005401   .0005366   .0005343   .0005330   .0005322
CLIL    .6824520   .6859462   .6911066   .6977529   .7056856   .7144820   .7231980
CLIL    .7296557   .7297318   .7204656   .7039980   .6845349   .6650329   .6470453
CLIL    .6313429   .6182577   .6078206   .5998431   .5939948   .5898791   .5870960
CLIL    .5852864   .5841543   .5834724   .5830768   .5828555   .5827357   .5826728
CLIL    .0015748   .0201073   .0411806   .0647545   .0908062   .1190747   .1483681
CLIL    .1753753   .1956996   .2084989   .2164326   .2218741   .2259155   .2289408
CLIL    .2310983   .2324971   .2332636   .2335444   .2334895   .2332353   .2328910
CLIL    .2325340   .2322116   .2319462   .2317429   .2315964   .2314963   .2314300
CLIL   -.0000000   .0000005   .0000031   .0000191   .0001055   .0004990   .0019976
CLIL    .0065015   .0162835   .0313204   .0492943   .0679881   .0860547   .1027118
CLIL    .1174787   .1300894   .1404686   .1487068   .1550184   .1596913   .1630387
CLIL    .1653616   .1669246   .1679452   .1685924   .1689912   .1692302   .1693700
CLIL    .0632907   .0637386   .0643293   .0650476   .0658526   .0664603   .0653610
CLIL    .0590854   .0469723   .0352256   .0278455   .0238355   .0214949   .0199280
CLIL    .0187745   .0178893   .0172040   .0166775   .0162792   .0159835   .0157689
CLIL    .0156166   .0155113   .0154402   .0153935   .0153637   .0153452   .0153350
CLIL    .0000002   .0000032   .0000067   .0000115   .0000181   .0000280   .0000433
CLIL    .0000676   .0001058   .0001593   .0002237   .0002924   .0003600   .0004227
CLIL    .0004780   .0005247   .0005624   .0005918   .0006137   .0006296   .0006406
CLIL    .0006480   .0006529   .0006560   .0006578   .0006589   .0006596   .0006600
CINF     .2328      .7672
HEAT    0.0        0.0       1.661E+08 3.619E+08 .3225E+083.5341E+08
LEWIS   1.4        1.4        1.4        1.4        1.4        1.4
MOLWT 32.          28.016     16.        14.008     30.008     30.008
N2 O2 .0435927   .9784219 -8.3354916
O  O2 .0216586 1.3875747 -9.7389971
N  O2 .0191055 1.4904448 -10.358828
NO O2 .0410864 1.0124720 -8.4455480
NO+O2 .0003467  1.8941393-12.978394
O  N2 .0168907 1.5276702 -10.629306
N  N2 .0191055 1.4904448 -10.358828
NO N2 .0315955 1.2225368 -9.4862934
NO+N2 .0003467  1.8941393-12.978394
N   O-.0043383 1.9119177 -11.891342
NO  O .0183441 1.4750189 -10.265935
```

```
NO+ O .0003467  1.8941393-12.978394
NO  N .0191055 1.4904448 -10.358828
NO+ N .0003467  1.8941393-12.978394
NO+NO .0039930 1.5689336 -11.441502
VC O2  .0449290 -.0826158 - 9.20195
VC N2  .0268142  .3177838 -11.31555
VC O   .0203144  .4294404 -11.60314
VC N   .0115572  .6031679 -12.43275
VC NO  .0436378 -.0335511 - 9.57674
VCNO+  .3020141 -3.503979 - 3.73552
      O2  +M1  =O    +O   +M1      3.61+18 59.4 -1.    3.01+15  0.  -.5
      N2  +M2  =N    +N   +M2      1.92+17113.1 -.5    1.09+16  0.  -.5
      N2  +N   =N    +N   +N       4.15+22113.1 -1.5   2.32+21  0.  -1.5
      NO  +M3  =N    +O   +M3      3.97+20 75.6 -1.5   1.01+20  0.  -1.5
      NO  +O   =O2   +N            3.18 +9 19.7  1.    9.63+11 3.6   .5
      N2  +O   =NO   +N            6.75+13 37.5  0.    1.5 +13  0.   .0
      N   +O   =NO+ +EL            9.03 +9 32.4  .5    1.8 +19  0.  -1.0
Z  E- 0.0  0.0  0.0  0.0  0.0  1.0
Z  M1 9.0  2.0  25.0 1.0  1.0  0.0
Z  M2 1.0  2.5  1.0  0.0  1.0  0.0
Z  M3 1.0  1.0  20.0 20.0 20.0 0.0
NWT       4
XRN       .0         10.        50.0       250.
TWT     1000.      1000.      1000.      1000.
RVPT      .0         .0         .0        .0
TETE      6.0        6.0        6.0        6.0
BODSP    10     1    20.        10.
STEP1     .0        .01
STEP2     .1        .025
STEP3     .5        .05
STEP4    1.0        .1
STEP5    3.0        .25
STEP6    6.0        .5
STEP7   12.        1.0
STEP8   26.0        2.0
STEP9    50.        5.0
STP10   240.        10.
PTMRO   1.0         1.0        1.0        74
XAEDG0.        1.0000E-023.8000E-027.6667E-021.2600E-011.8422E-012.5073E-01
XAEDG3.2553E-014.0862E-015.0000E-016.0514E-017.4046E-019.0594E-011.0000E+00
XAEDG1.1016E+001.2150E+001.3403E+001.4774E+001.6263E+001.7871E+001.9596E+00
XAEDG2.1440E+002.3403E+002.5484E+002.7683E+003.0000E+003.2436E+003.5096E+00
XAEDG3.7980E+004.1089E+004.4422E+004.7980E+005.1762E+005.5769E+006.0000E+00
XAEDG6.4455E+006.9464E+007.5025E+008.1139E+008.7805E+009.5025E+001.0280E+01
XAEDG1.2000E+011.2943E+011.3988E+011.5134E+011.6382E+011.7731E+011.9182E+01
XAEDG2.0734E+012.2388E+012.6000E+012.7958E+013.0407E+013.3346E+013.6774E+01
XAEDG4.0693E+014.5101E+015.0000E+016.0997E+016.6826E+017.9142E+018.5630E+01
XAEDG9.9265E+011.0641E+021.2137E+021.2917E+021.4545E+021.5391E+021.7150E+02
XAEDG1.8063E+021.9954E+022.1933E+022.2956E+02
PAEDG1.2754E+041.2752E+041.2730E+041.2661E+041.2512E+041.2249E+041.1836E+04
PAEDG1.1244E+041.0449E+049.4503E+038.2018E+036.5404E+034.6217E+033.6733E+03
PAEDG2.7932E+031.9960E+031.3306E+031.0605E+039.9558E+029.3344E+028.7425E+02
PAEDG8.1888E+027.6737E+027.2013E+026.7669E+026.3666E+026.0008E+025.6520E+02
PAEDG5.3232E+025.0194E+024.7409E+024.4893E+024.2625E+024.0596E+023.8794E+02
PAEDG3.7207E+023.5732E+023.4396E+023.3231E+023.2261E+023.1449E+023.0805E+02
```

```
PAEDG3.0020E+022.9884E+022.9914E+023.0081E+023.0235E+023.0696E+023.1368E+02
PAEDG3.2329E+023.3505E+023.6722E+023.8637E+024.1088E+024.3850E+024.6464E+02
PAEDG4.8297E+024.8987E+024.8575E+024.7013E+024.6630E+024.6509E+024.6592E+02
PAEDG4.6799E+024.6883E+024.6975E+024.6999E+024.7014E+024.7017E+024.7016E+02
PAEDG4.7018E+024.7021E+024.7025E+024.7029E+02
VAEDG  0.0        96.212     365.61     737.63     1212.27    1772.42    2412.32
VAEDG3.1772E+033.9632E+034.8106E+035.7601E+036.9412E+038.3042E+039.0291E+03
VAEDG9.7653E+031.0525E+041.1286E+041.1685E+041.1815E+041.1939E+041.2063E+04
VAEDG1.2185E+041.2306E+041.2423E+041.2538E+041.2650E+041.2759E+041.2869E+04
VAEDG1.2980E+041.3090E+041.3198E+041.3309E+041.3419E+041.3523E+041.3623E+04
VAEDG1.3720E+041.3812E+041.3917E+041.4027E+041.4138E+041.4253E+041.4370E+04
VAEDG1.4616E+041.4745E+041.4894E+041.5045E+041.5212E+041.5384E+041.5559E+04
VAEDG1.5727E+041.5901E+041.6287E+041.6523E+041.6824E+041.7201E+041.7601E+04
VAEDG1.7964E+041.8279E+041.8554E+041.8980E+041.9126E+041.9339E+041.9414E+04
VAEDG1.9529E+041.9571E+041.9612E+041.9627E+041.9654E+041.9664E+041.9684E+04
VAEDG1.9692E+041.9707E+041.9708E+041.9705E+04
TAEDG1.2524E+041.2524E+041.2521E+041.2511E+041.2493E+041.2458E+041.2403E+04
TAEDG1.2320E+041.2199E+041.2030E+041.1784E+041.1363E+041.0678E+041.0191E+04
TAEDG9.5918E+038.8524E+037.9840E+037.5374E+037.4333E+037.3264E+037.2181E+03
TAEDG7.1105E+037.0036E+036.8998E+036.7989E+036.7001E+036.6061E+036.5105E+03
TAEDG6.4158E+036.3235E+036.2346E+036.1498E+036.0694E+035.9951E+035.9268E+03
TAEDG5.8644E+035.8277E+035.7726E+035.7253E+035.6795E+035.6410E+035.6089E+03
TAEDG5.5665E+035.5560E+035.5355E+035.5410E+035.5443E+035.5595E+035.5484E+03
TAEDG5.4658E+035.4005E+035.3351E+035.3296E+035.3376E+035.4111E+035.5195E+03
TAEDG5.4071E+034.9700E+034.3609E+033.3152E+032.9415E+032.3820E+032.1785E+03
TAEDG1.8606E+031.7400E+031.6237E+031.5774E+031.4953E+031.4622E+031.4048E+03
TAEDG1.3798E+031.3398E+031.3381E+031.3463E+03
O2 EG5.3219E-045.3229E-045.3388E-045.3824E-045.3870E-045.4059E-045.3944E-04
O2 EG5.3726E-045.3292E-045.2457E-045.0643E-044.6419E-043.7097E-042.9501E-04
O2 EG2.1165E-041.3033E-047.2520E-054.7327E-054.2890E-054.0870E-053.9571E-05
O2 EG3.8135E-053.6918E-053.5924E-053.5345E-053.5108E-053.4213E-053.3784E-05
O2 EG3.3546E-053.3417E-053.3521E-053.3817E-053.4225E-053.4678E-053.5278E-05
O2 EG3.6034E-053.8582E-054.0294E-054.2580E-054.5365E-054.7507E-055.1198E-05
O2 EG6.2810E-057.2283E-058.2462E-051.0324E-041.5175E-043.1878E-041.5840E-03
O2 EG6.8719E-031.4665E-023.7702E-025.2361E-027.6041E-021.1919E-011.7519E-01
O2 EG2.1542E-012.3046E-012.3263E-012.3280E-012.3280E-012.3280E-012.3280E-01
O2 EG2.3280E-012.3280E-012.3280E-012.3280E-012.3280E-012.3280E-012.3280E-01
O2 EG2.3280E-012.3280E-012.3280E-012.3280E-01
N2 EG5.8267E-015.8267E-015.8262E-015.8252E-015.8334E-015.8456E-015.8690E-01
N2 EG5.9026E-015.9481E-016.0067E-016.0827E-016.1873E-016.3081E-016.3725E-01
N2 EG6.4329E-016.4880E-016.5338E-016.5633E-016.5817E-016.5989E-016.6157E-01
N2 EG6.6326E-016.6496E-016.6667E-016.6838E-016.6976E-016.7184E-016.7363E-01
N2 EG6.7548E-016.7738E-016.7937E-016.8152E-016.8379E-016.8600E-016.8823E-01
N2 EG6.9052E-016.9244E-016.9510E-016.9779E-017.0080E-017.0485E-017.0881E-01
N2 EG7.1777E-017.2285E-017.2898E-017.3568E-017.4283E-017.5013E-017.5595E-01
N2 EG7.5539E-017.5307E-017.4496E-017.3947E-017.3479E-017.3956E-017.5413E-01
N2 EG7.6460E-017.6708E-017.6720E-017.6720E-017.6720E-017.6720E-017.6720E-01
N2 EG7.6720E-017.6720E-017.6720E-017.6720E-017.6720E-017.6720E-017.6720E-01
N2 EG7.6720E-017.6720E-017.6720E-017.6720E-01
O  EG2.3143E-012.3145E-012.3171E-012.3246E-012.3253E-012.3297E-012.3304E-01
O  EG2.3322E-012.3358E-012.3415E-012.3508E-012.3666E-012.4099E-012.4315E-01
O  EG2.4537E-012.4737E-012.4883E-012.4957E-012.4971E-012.4976E-012.4981E-01
O  EG2.4987E-012.4990E-012.4993E-012.4993E-012.5049E-012.4987E-012.4984E-01
O  EG2.4978E-012.4974E-012.4965E-012.4957E-012.4945E-012.4935E-012.4923E-01
O  EG2.4908E-012.5108E-012.5120E-012.5162E-012.5183E-012.5065E-012.5016E-01
```

```
O  EG2.4902E-012.4829E-012.4591E-012.4430E-012.4320E-012.4223E-012.3796E-01
O  EG2.2658E-012.1210E-011.7386E-011.5106E-011.2043E-018.1885E-024.2475E-02
O  EG1.4371E-022.1994E-031.6493E-041.6219E-072.9064E-092.9816E-132.4848E-15
O  EG2.9537E-194.0002E-203.6950E-204.5746E-205.2968E-207.2996E-205.7342E-20
O  EG5.2219E-203.6191E-202.9099E-202.9665E-20
N  EG1.6937E-011.6936E-011.6912E-011.6842E-011.6755E-011.6591E-011.6359E-01
N  EG1.6020E-011.5551E-011.4946E-011.4159E-011.3084E-011.1702E-011.1039E-01
N  EG1.0439E-019.9268E-029.5244E-029.2628E-029.0849E-028.9199E-028.7560E-02
N  EG8.5909E-028.4263E-028.2609E-028.0957E-027.9068E-027.7677E-027.5975E-02
N  EG7.4219E-027.2403E-027.0538E-026.8499E-026.6369E-026.4283E-026.2194E-02
N  EG6.0068E-025.6144E-025.3368E-025.0266E-024.7048E-024.4178E-024.0705E-02
N  EG3.2862E-022.8480E-022.4698E-021.9536E-021.3308E-026.3980E-031.1474E-03
N  EG2.7078E-041.5844E-048.5187E-056.6592E-054.6954E-052.6446E-058.2071E-06
N  EG1.0671E-064.6354E-086.5391E-109.0495E-151.6340E-171.4077E-231.1135E-26
N  EG1.1794E-321.7771E-342.1471E-351.5006E-351.3534E-351.4964E-351.8546E-35
N  EG2.0669E-352.4813E-352.5019E-352.4068E-35
NO EG1.5335E-021.5337E-021.5354E-021.5400E-021.5388E-021.5375E-021.5299E-02
NO EG1.5174E-021.4968E-021.4641E-021.4054E-021.2862E-021.0470E-028.6309E-03
NO EG6.5059E-034.2469E-032.3401E-031.3307E-031.1441E-031.0346E-039.4851E-04
NO EG8.5842E-047.7690E-047.0410E-046.4828E-045.9552E-045.4030E-044.9138E-04
NO EG4.4927E-044.1071E-043.8089E-043.5455E-043.3067E-043.0873E-042.9131E-04
NO EG2.7748E-042.7642E-042.6920E-042.6441E-042.6072E-042.5678E-042.5868E-04
NO EG2.7817E-042.9985E-043.1927E-043.7463E-045.0317E-049.1996E-043.3511E-03
NO EG1.0886E-022.0000E-024.3386E-025.7038E-026.8687E-025.9332E-022.8206E-02
NO EG5.6083E-032.6709E-043.6439E-063.9494E-115.4261E-147.1132E-205.6340E-20
NO EG5.0982E-205.6320E-206.0394E-207.7018E-209.0586E-201.2815E-199.8790E-20
·NO EG8.9182E-205.9121E-204.5819E-204.6881E-20
NO+EG6.5998E-046.5994E-046.5937E-046.5748E-046.5298E-046.4496E-046.3206E-04
NO+EG6.1303E-045.8647E-045.5176E-045.0487E-044.3704E-043.4226E-042.8863E-04
NO+EG2.3401E-041.8038E-041.3374E-041.0098E-048.4775E-057.5093E-056.8211E-05
NO+EG6.2578E-055.7668E-055.3265E-054.9342E-054.5715E-054.2420E-053.9228E-05
NO+EG3.6223E-053.3403E-053.0822E-052.8422E-052.6202E-052.4189E-052.2373E-05
NO+EG2.0725E-051.9381E-051.7854E-051.6448E-051.5064E-051.3836E-051.2674E-05
NO+EG1.0573E-059.5932E-068.5767E-067.6139E-066.4898E-065.1311E-063.7291E-06
NO+EG2.9939E-062.5789E-061.9771E-061.7150E-061.3289E-066.4863E-078.5033E-08
NO+EG2.2752E-095.3620E-121.3874E-151.0000E-201.0000E-201.0000E-201.0000E-20
NO+EG1.0000E-201.0000E-201.0000E-201.0000E-201.0000E-201.0000E-201.0000E-20
NO+EG1.0000E-201.0000E-201.0000E-201.0000E-20
```

10 DEGREE SPHERE CONE 20 KFP 100 KFT ALT

INPUT 06/18/70

NMAX = 28	IWC = 4	K = 1.00	RN = .083333330	VINF = 20000.0000	NON-EQUILIBRUM
NI = 6	IPRT = 40	TOL = .000200	RS = .083333330	PINF = 23.2719	NON-FROZEN
NR = 7	IPUN = 1		DELTA =0.000000000	TKINF = 226.9800	BOUNDARY LAYER
NJ = 10	IREAD = 1	AMOM = 1.0000	TKW = 1000.0000		COMPUTE INITIAL PROFILE
	KOPE =100	AENE = 1.0000	E 0 = -0.0000		SPHERE CONE
	KOPT = 1	ASPE = 1.0000	E 02 = -0.0000		CAL LEWIS NOS.

K	INTERACTION	AMD	BMD	CMD
1	N2 O2	4.35927E-02	9.78422E-01	-8.33549E+00
2	O O2	2.16586E-02	1.38757E+00	-9.73900E+00
3	N O2	1.91055E-02	1.49044E+00	-1.03588E+01
4	NO O2	4.10864E-02	1.01247E+00	-8.44555E+00
5	NO+O2	3.46700E-04	1.89414E+00	-1.29784E+01
6	O N2	1.68907E-02	1.52767E+00	-1.06293E+01
7	N N2	1.91055E-02	1.49044E+00	-1.03588E+01
8	NO N2	3.15955E-02	1.22254E+00	-9.48629E+00
9	NO+N2	3.46700E-04	1.89414E+00	-1.29784E+01
10	N O	-4.33830E-03	1.91192E+00	-1.18913E+01
11	NO O	1.83441E-02	1.47502E+00	-1.02659E+01
12	NO+ O	3.46700E-04	1.89414E+00	-1.29784E+01
13	NO N	1.91055E-02	1.49044E+00	-1.03588E+01
14	NO+ N	3.46700E-04	1.89414E+00	-1.29784E+01
15	NO+NO	3.99300E-03	1.56893E+00	-1.14415E+01

GAS MODEL

SPEC	HF	FLEJ	FMOLWT	AMU	BMU	CMU	WFAC .50(FPRIME) .50(THETA)	CINF
O2	0.	1.40000E+00	3.20000E+01	4.49290E-02	-8.26158E-02	-9.20195E+00	.50	2.32800E-01
N2	0.	1.40000E+00	2.80160E+01	2.68142E-02	3.17784E-01	-1.13155E+01	.50	7.67200E-01
O	1.66100E+08	1.40000E+00	1.60000E+01	2.03144E-02	4.29440E-01	-1.16031E+01	.50	-0.
N	3.61900E+08	1.40000E+00	1.40080E+01	1.15572E-02	6.03168E-01	-1.24327E+01	.50	-0.
NO	3.22500E+07	1.40000E+00	3.00080E+01	4.36378E-02	-3.35511E-02	-9.57674E+00	.50	-0.
NO+	3.53410E+08	1.40000E+00	3.00080E+01	3.02014E-01	-3.50398E+00	-3.73552E+00	.50	-0.

K	REACTION					C0	C1	C2	D0	D1	D2	CSALPH	CSBETA
1	O2	M1	=O	O	M1	3.610E+18	59.40	-1.00	3.010E+15	0.00	-.50	1.00	2.00
2	N2	M2	=N	N	M2	1.920E+17	113.10	-.50	1.090E+16	0.00	-.50	1.00	2.00
3	N2	N	=N	N	N	4.150E+22	113.10	-1.50	2.320E+21	0.00	-1.50	1.00	2.00
4	NO	M3	=N	O	M3	3.970E+20	75.60	-1.50	1.010E+20	0.00	-1.50	1.00	2.00
5	NO	O	=O2	N		3.180E+09	19.70	1.00	9.630E+11	3.60	.50	1.00	1.00
6	N2	O	=NO	N		6.750E+13	37.50	0.00	1.500E+13	0.00	0.00	1.00	1.00
7	N	O	=NO+	EL		9.030E+09	32.40	.50	1.800E+19	0.00	-1.00	1.00	1.00

STOICHIOMETRIC COEF.

FORWARD - CALPH(NR,NJ)

NJ/NR	1	2	3	4	5	6	7
O2	1.00	0.00	0.00	0.00	0.00	0.00	0.00
N2	0.00	1.00	1.00	0.00	0.00	1.00	0.00
O	0.00	0.00	0.00	0.00	1.00	1.00	1.00
N	0.00	0.00	1.00	0.00	0.00	0.00	1.00
NO	0.00	0.00	0.00	1.00	1.00	0.00	0.00
NO+	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EL	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M1	1.00	0.00	0.00	0.00	0.00	0.00	0.00
M2	0.00	1.00	0.00	0.00	0.00	0.00	0.00
M3	0.00	0.00	0.00	1.00	0.00	0.00	0.00

BACKWARD - CBETA(NR,NJ)

NJ/NR	1	2	3	4	5	6	7
O2	0.00	0.00	0.00	0.00	1.00	0.00	0.00
N2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O	2.00	0.00	0.00	1.00	0.00	0.00	0.00
N	0.00	2.00	3.00	1.00	1.00	1.00	0.00
NO	0.00	0.00	0.00	0.00	0.00	1.00	0.00
NO+	0.00	0.00	0.00	0.00	0.00	0.00	1.00
EL	0.00	0.00	0.00	0.00	0.00	0.00	1.00
M1	1.00	0.00	0.00	0.00	0.00	0.00	0.00
M2	0.00	1.00	0.00	0.00	0.00	0.00	0.00
M3	0.00	0.00	0.00	1.00	0.00	0.00	0.00

THIRD BODY EFFECIENCIES - Z(NI,NL)

NL/NI	1	2	3	4	5	6
EL	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
M1	9.0000	2.0000	25.0000	1.0000	1.0000	0.0000
M2	1.0000	2.5000	1.0000	0.0000	1.0000	0.0000
M3	1.0000	1.0000	20.0000	20.0000	20.0000	0.0000

K	X/RN	T-WALL	RV(PYR)	ETA(EDGE)
1	0.	1.00000E+03	0.	6.00000E+00
2	1.00000E+01	1.00000E+03	0.	6.00000E+00
3	5.00000E+01	1.00000E+03	0.	6.00000E+00
4	2.50000E+02	1.00000E+03	0.	6.00000E+00

BODY DATA

IPRTB = 1

XMAX = 20.00000
CONE ANGLE = 10.00000

NORM SH PRESS = 1.0000
NORM SH TEMP = 1.0000
NORM SH VEL = 1.0000

X =	0.00	.10	.50	1.00	3.00	6.00	12.00	26.00	50.00	240.00
DELT X =	.010	.025	.050	.100	.250	.500	1.000	2.000	5.000	10.000

EDGE TABLES

					CA(SPECIES)					
	XA	PA	VA	TA	O2	N2	O	N	NO	NO+
1	0.	1.2754E+04	0.	1.2524E+04	5.3219E-04	5.8267E-01	2.3143E-01	1.6937E-01	1.5335E-02	6.5998E-04
2	1.0000E-02	1.2752E+04	9.6212E+01	1.2524E+04	5.3229E-04	5.8267E-01	2.3145E-01	1.6936E-01	1.5337E-02	6.5994E-04
3	3.8000E-02	1.2730E+04	3.6561E+02	1.2521E+04	5.3388E-04	5.8262E-01	2.3171E-01	1.6912E-01	1.5354E-02	6.5937E-04
4	7.6667E-02	1.2661E+04	7.3763E+02	1.2511E+04	5.3824E-04	5.8252E-01	2.3246E-01	1.6842E-01	1.5400E-02	6.5748E-04
5	1.2600E-01	1.2512E+04	1.2123E+03	1.2493E+04	5.3870E-04	5.8334E-01	2.3253E-01	1.6755E-01	1.5388E-02	6.5298E-04
6	1.8422E-01	1.2249E+04	1.7724E+03	1.2458E+04	5.4059E-04	5.8456E-01	2.3297E-01	1.6591E-01	1.5375E-02	6.4496E-04
7	2.5073E-01	1.1836E+04	2.4123E+03	1.2403E+04	5.3944E-04	5.8690E-01	2.3304E-01	1.6359E-01	1.5299E-02	6.3206E-04
8	3.2553E-01	1.1244E+04	3.1772E+03	1.2320E+04	5.3726E-04	5.9026E-01	2.3322E-01	1.6020E-01	1.5174E-02	6.1303E-04
9	4.0862E-01	1.0449E+04	3.9632E+03	1.2199E+04	5.3292E-04	5.9481E-01	2.3358E-01	1.5551E-01	1.4968E-02	5.8647E-04
10	5.0000E-01	9.4503E+03	4.8106E+03	1.2030E+04	5.2457E-04	6.0067E-01	2.3415E-01	1.4946E-01	1.4641E-02	5.5176E-04
11	6.0514E-01	8.2018E+03	5.7601E+03	1.1784E+04	5.0643E-04	6.0827E-01	2.3508E-01	1.4159E-01	1.4054E-02	5.0487E-04
12	7.4046E-01	6.5404E+03	6.9412E+03	1.1363E+04	4.6419E-04	6.1873E-01	2.3666E-01	1.3084E-01	1.2862E-02	4.3704E-04
13	9.0594E-01	4.6217E+03	8.3042E+03	1.0678E+04	3.7097E-04	6.3081E-01	2.4099E-01	1.1702E-01	1.0470E-02	3.4226E-04
14	1.0000E+00	3.6733E+03	9.0291E+03	1.0191E+04	2.9501E-04	6.3725E-01	2.4315E-01	1.1039E-01	8.6309E-03	2.8863E-04
15	1.1016E+00	2.7932E+03	9.7653E+03	9.5918E+03	2.1165E-04	6.4329E-01	2.4537E-01	1.0439E-01	6.5059E-03	2.3401E-04
16	1.2150E+00	1.9960E+03	1.0525E+04	8.8524E+03	1.3033E-04	6.4880E-01	2.4737E-01	9.9268E-02	4.2469E-03	1.8038E-04
17	1.3403E+00	1.3306E+03	1.1286E+04	7.9840E+03	7.2520E-05	6.5338E-01	2.4883E-01	9.5244E-02	2.3401E-03	1.3374E-04
18	1.4774E+00	1.0605E+03	1.1685E+04	7.5374E+03	4.7327E-05	6.5633E-01	2.4957E-01	9.2628E-02	1.3307E-03	1.0098E-04
19	1.6263E+00	9.9558E+02	1.1815E+04	7.4333E+03	4.2890E-05	6.5817E-01	2.4971E-01	9.0849E-02	1.1441E-03	8.4775E-05
20	1.7871E+00	9.3344E+02	1.1939E+04	7.3264E+03	4.0870E-05	6.5989E-01	2.4976E-01	8.9199E-02	1.0346E-03	7.5093E-05
21	1.9596E+00	8.7425E+02	1.2063E+04	7.2181E+03	3.9571E-05	6.6157E-01	2.4981E-01	8.7560E-02	9.4851E-04	6.8211E-05
22	2.1440E+00	8.1888E+02	1.2185E+04	7.1105E+03	3.8135E-05	6.6326E-01	2.4987E-01	8.5909E-02	8.5842E-04	6.2578E-05
23	2.3403E+00	7.6737E+02	1.2306E+04	7.0036E+03	3.6918E-05	6.6496E-01	2.4990E-01	8.4263E-02	7.7690E-04	5.7668E-05
24	2.5484E+00	7.2013E+02	1.2423E+04	6.8998E+03	3.5924E-05	6.6667E-01	2.4993E-01	8.2609E-02	7.0410E-04	5.3265E-05
25	2.7683E+00	6.7669E+02	1.2538E+04	6.7989E+03	3.5345E-05	6.6838E-01	2.4993E-01	8.0957E-02	6.4828E-04	4.9342E-05
26	3.0000E+00	6.3666E+02	1.2650E+04	6.7001E+03	3.5108E-05	6.6976E-01	2.5049E-01	7.9068E-02	5.9552E-04	4.5715E-05
27	3.2436E+00	6.0008E+02	1.2759E+04	6.6061E+03	3.4213E-05	6.7184E-01	2.4987E-01	7.7677E-02	5.4030E-04	4.2420E-05
28	3.5096E+00	5.6520E+02	1.2869E+04	6.5105E+03	3.3784E-05	6.7363E-01	2.4984E-01	7.5975E-02	4.9138E-04	3.9228E-05
29	3.7980E+00	5.3232E+02	1.2980E+04	6.4158E+03	3.3546E-05	6.7548E-01	2.4978E-01	7.4219E-02	4.4927E-04	3.6223E-05
30	4.1089E+00	5.0194E+02	1.3090E+04	6.3235E+03	3.3417E-05	6.7738E-01	2.4974E-01	7.2403E-02	4.1071E-04	3.3403E-05
31	4.4422E+00	4.7409E+02	1.3198E+04	6.2346E+03	3.3521E-05	6.7937E-01	2.4965E-01	7.0538E-02	3.8089E-04	3.0822E-05
32	4.7980E+00	4.4893E+02	1.3309E+04	6.1498E+03	3.3817E-05	6.8152E-01	2.4957E-01	6.8499E-02	3.5455E-04	2.8422E-05
33	5.1762E+00	4.2625E+02	1.3419E+04	6.0694E+03	3.4225E-05	6.8379E-01	2.4945E-01	6.6369E-02	3.3067E-04	2.6202E-05
34	5.5769E+00	4.0596E+02	1.3523E+04	5.9951E+03	3.4678E-05	6.8600E-01	2.4935E-01	6.4283E-02	3.0873E-04	2.4189E-05
35	6.0000E+00	3.8794E+02	1.3623E+04	5.9268E+03	3.5278E-05	6.8823E-01	2.4923E-01	6.2194E-02	2.9131E-04	2.2373E-05
36	6.4455E+00	3.7207E+02	1.3720E+04	5.8644E+03	3.6034E-05	6.9052E-01	2.4908E-01	6.0068E-02	2.7748E-04	2.0725E-05

37	6.9464E+00	3.5732E+02	1.3812E+04	5.8277E+03	3.8582E-05	6.9244E-01	2.5108E-01	5.6144E-02	2.7642E-04	1.9381E-05
38	7.5025E+00	3.4396E+02	1.3917E+04	5.7726E+03	4.0294E-05	6.9510E-01	2.5120E-01	5.3368E-02	2.6920E-04	1.7854E-05
39	8.1139E+00	3.3231E+02	1.4027E+04	5.7253E+03	4.2580E-05	6.9779E-01	2.5162E-01	5.0266E-02	2.6441E-04	1.6448E-05
40	8.7805E+00	3.2261E+02	1.4138E+04	5.6795E+03	4.5365E-05	7.0080E-01	2.5183E-01	4.7048E-02	2.6072E-04	1.5064E-05
41	9.5025E+00	3.1449E+02	1.4253E+04	5.6410E+03	4.7507E-05	7.0485E-01	2.5065E-01	4.4178E-02	2.5678E-04	1.3836E-05
42	1.0280E+01	3.0805E+02	1.4370E+04	5.6089E+03	5.1198E-05	7.0881E-01	2.5016E-01	4.0705E-02	2.5868E-04	1.2674E-05
43	1.2000E+01	3.0020E+02	1.4616E+04	5.5665E+03	6.2810E-05	7.1777E-01	2.4902E-01	3.2862E-02	2.7817E-04	1.0573E-05
44	1.2943E+01	2.9884E+02	1.4745E+04	5.5560E+03	7.2283E-05	7.2285E-01	2.4829E-01	2.8480E-02	2.9985E-04	9.5932E-06
45	1.3988E+01	2.9914E+02	1.4894E+04	5.5355E+03	8.2462E-05	7.2898E-01	2.4591E-01	2.4698E-02	3.1927E-04	8.5767E-06
46	1.5134E+01	3.0081E+02	1.5045E+04	5.5410E+03	1.0324E-04	7.3568E-01	2.4430E-01	1.9536E-02	3.7463E-04	7.6139E-06
47	1.6382E+01	3.0235E+02	1.5212E+04	5.5443E+03	1.5175E-04	7.4283E-01	2.4320E-01	1.3308E-02	5.0317E-04	6.4898E-06
48	1.7731E+01	3.0696E+02	1.5384E+04	5.5595E+03	3.1878E-04	7.5013E-01	2.4223E-01	6.3980E-03	9.1996E-04	5.1311E-06
49	1.9182E+01	3.1368E+02	1.5559E+04	5.5484E+03	1.5840E-03	7.5595E-01	2.3796E-01	1.1474E-03	3.3511E-03	3.7291E-06
50	2.0734E+01	3.2329E+02	1.5727E+04	5.4658E+03	6.8719E-03	7.5539E-01	2.2658E-01	2.7078E-04	1.0886E-02	2.9939E-06
51	2.2388E+01	3.3505E+02	1.5901E+04	5.4005E+03	1.4665E-02	7.5307E-01	2.1210E-01	1.5844E-04	2.0000E-02	2.5789E-06
52	2.6000E+01	3.6722E+02	1.6287E+04	5.3351E+03	3.7702E-02	7.4496E-01	1.7386E-01	8.5187E-05	4.3386E-02	1.9771E-06
53	2.7958E+01	3.8637E+02	1.6523E+04	5.3296E+03	5.2361E-02	7.3947E-01	1.5106E-01	6.6592E-05	5.7038E-02	1.7150E-06
54	3.0407E+01	4.1088E+02	1.6824E+04	5.3376E+03	7.6041E-02	7.3479E-01	1.2043E-01	4.6954E-05	6.8687E-02	1.3289E-06
55	3.3346E+01	4.3850E+02	1.7201E+04	5.4111E+03	1.1919E-01	7.3956E-01	8.1885E-02	2.6446E-05	5.9332E-02	6.4863E-07
56	3.6774E+01	4.6464E+02	1.7601E+04	5.5195E+03	1.7519E-01	7.5413E-01	4.2475E-02	8.2071E-06	2.8206E-02	8.5033E-08
57	4.0693E+01	4.8297E+02	1.7964E+04	5.4071E+03	2.1542E-01	7.6460E-01	1.4371E-02	1.0671E-06	5.6083E-03	2.2752E-09
58	4.5101E+01	4.8987E+02	1.8279E+04	4.9700E+03	2.3046E-01	7.6708E-01	2.1994E-03	4.6354E-08	2.6709E-04	5.3620E-12
59	5.0000E+01	4.8575E+02	1.8554E+04	4.3609E+03	2.3263E-01	7.6720E-01	1.6493E-04	6.5391E-10	3.6439E-06	1.3874E-15
60	6.0997E+01	4.7013E+02	1.8980E+04	3.3152E+03	2.3280E-01	7.6720E-01	1.6219E-07	9.0495E-15	3.9494E-11	1.0000E-20
61	6.6826E+01	4.6630E+02	1.9126E+04	2.9415E+03	2.3280E-01	7.6720E-01	2.9064E-09	1.6340E-17	5.4261E-14	1.0000E-20
62	7.9142E+01	4.6509E+02	1.9339E+04	2.3820E+03	2.3280E-01	7.6720E-01	2.9816E-13	1.4077E-23	7.1132E-20	1.0000E-20
63	8.5630E+01	4.6592E+02	1.9414E+04	2.1785E+03	2.3280E-01	7.6720E-01	2.4848E-15	1.1135E-26	5.6340E-20	1.0000E-20
64	9.9265E+01	4.6799E+02	1.9529E+04	1.8606E+03	2.3280E-01	7.6720E-01	2.9537E-19	1.1794E-32	5.0982E-20	1.0000E-20
65	1.0641E+02	4.6883E+02	1.9571E+04	1.7400E+03	2.3280E-01	7.6720E-01	4.0002E-20	1.7771E-34	5.6320E-20	1.0000E-20
66	1.2137E+02	4.6975E+02	1.9612E+04	1.6237E+03	2.3280E-01	7.6720E-01	3.6950E-20	2.1471E-35	6.0394E-20	1.0000E-20
67	1.2917E+02	4.6999E+02	1.9627E+04	1.5774E+03	2.3280E-01	7.6720E-01	4.5746E-20	1.5006E-35	7.7018E-20	1.0000E-20
68	1.4545E+02	4.7014E+02	1.9654E+04	1.4953E+03	2.3280E-01	7.6720E-01	5.2968E-20	1.3534E-35	9.0586E-20	1.0000E-20
69	1.5391E+02	4.7017E+02	1.9664E+04	1.4622E+03	2.3280E-01	7.6720E-01	7.2996E-20	1.4964E-35	1.2815E-19	1.0000E-20
70	1.7150E+02	4.7016E+02	1.9684E+04	1.4048E+03	2.3280E-01	7.6720E-01	5.7342E-20	1.8546E-35	9.8790E-20	1.0000E-20
71	1.8063E+02	4.7018E+02	1.9692E+04	1.3798E+03	2.3280E-01	7.6720E-01	5.2219E-20	2.0669E-35	8.9182E-20	1.0000E-20
72	1.9954E+02	4.7021E+02	1.9707E+04	1.3398E+03	2.3280E-01	7.6720E-01	3.6191E-20	2.4813E-35	5.9121E-20	1.0000E-20
73	2.1933E+02	4.7025E+02	1.9708E+04	1.3381E+03	2.3280E-01	7.6720E-01	2.9099E-20	2.5019E-35	4.5819E-20	1.0000E-20
74	2.2956E+02	4.7029E+02	1.9705E+04	1.3463E+03	2.3280E-01	7.6720E-01	2.9665E-20	2.4068E-35	4.6881E-20	1.0000E-20

NOTE --- XA, PA, TA AND VA ARE CHANGED IN SUBROUTINE INPBOD

```
XA(K) = XA(K) * RN
PA(K) = PA(K) * NORM SH PRESS.
VA(K) = VA(K) * NORM SH VEL.
TA(K) = TA(K) * NORM SH TEMP.
```

END OF INPUT

INITIAL PROFILE

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+
1	0.0000	0.	1.4372E-01	2.5268E-01	6.8245E-01	1.5748E-03	-0.	6.3291E-02	2.0000E-07
2	.0370	6.4322E-02	2.1440E-01	2.3020E-01	6.8595E-01	2.0107E-02	5.0000E-07	6.3739E-02	3.2000E-06
3	.0741	1.3644E-01	2.9130E-01	2.0337E-01	6.9111E-01	4.1181E-02	3.1000E-06	6.4329E-02	6.7000E-06
4	.1111	2.1398E-01	3.7318E-01	1.7241E-01	6.9775E-01	6.4754E-02	1.9100E-05	6.5048E-02	1.1500E-05
5	.1481	2.9483E-01	4.5863E-01	1.3753E-01	7.0569E-01	9.0806E-02	1.0550E-04	6.5853E-02	1.8100E-05
6	.1852	3.7687E-01	5.4566E-01	9.9456E-02	7.1448E-01	1.1907E-01	4.9900E-04	6.6460E-02	2.8000E-05
7	.2222	4.5793E-01	6.3117E-01	6.1032E-02	7.2320E-01	1.4837E-01	1.9976E-03	6.5361E-02	4.3300E-05
8	.2593	5.3575E-01	7.1043E-01	2.9315E-02	7.2966E-01	1.7538E-01	6.5015E-03	5.9085E-02	6.7600E-05
9	.2963	6.0815E-01	7.7735E-01	1.1207E-02	7.2973E-01	1.9570E-01	1.6284E-02	4.6972E-02	1.0580E-04
10	.3333	6.7335E-01	8.2881E-01	4.3302E-03	7.2047E-01	2.0850E-01	3.1320E-02	3.5226E-02	1.5930E-04
11	.3704	7.3030E-01	8.6760E-01	2.2060E-03	7.0400E-01	2.1643E-01	4.9294E-02	2.7845E-02	2.2370E-04
12	.4074	7.7866E-01	8.9787E-01	1.4750E-03	6.8453E-01	2.2187E-01	6.7988E-02	2.3836E-02	2.9240E-04
13	.4444	8.1871E-01	9.2210E-01	1.1420E-03	6.6503E-01	2.2592E-01	8.6055E-02	2.1495E-02	3.6000E-04
14	.4815	8.5113E-01	9.4151E-01	9.5140E-04	6.4705E-01	2.2894E-01	1.0271E-01	1.9928E-02	4.2270E-04
15	.5185	8.7692E-01	9.5687E-01	8.2770E-04	6.3134E-01	2.3110E-01	1.1748E-01	1.8775E-02	4.7800E-04
16	.5556	8.9723E-01	9.6881E-01	7.4200E-04	6.1826E-01	2.3250E-01	1.3009E-01	1.7889E-02	5.2470E-04
17	.5926	9.1322E-01	9.7792E-01	6.8070E-04	6.0782E-01	2.3326E-01	1.4047E-01	1.7204E-02	5.6240E-04
18	.6296	9.2598E-01	9.8471E-01	6.3650E-04	5.9984E-01	2.3354E-01	1.4871E-01	1.6678E-02	5.9180E-04
19	.6667	9.3645E-01	9.8967E-01	6.0440E-04	5.9399E-01	2.3349E-01	1.5502E-01	1.6279E-02	6.1370E-04
20	.7037	9.4536E-01	9.9320E-01	5.8130E-04	5.8988E-01	2.3324E-01	1.5969E-01	1.5984E-02	6.2960E-04
21	.7407	9.5326E-01	9.9565E-01	5.6480E-04	5.8710E-01	2.3289E-01	1.6304E-01	1.5769E-02	6.4060E-04
22	.7778	9.6052E-01	9.9730E-01	5.5330E-04	5.8529E-01	2.3253E-01	1.6536E-01	1.5617E-02	6.4800E-04
23	.8148	9.6741E-01	9.9839E-01	5.4540E-04	5.8415E-01	2.3221E-01	1.6692E-01	1.5511E-02	6.5290E-04
24	.8519	9.7408E-01	9.9908E-01	5.4010E-04	5.8347E-01	2.3195E-01	1.6795E-01	1.5440E-02	6.5600E-04
25	.8889	9.8063E-01	9.9951E-01	5.3660E-04	5.8308E-01	2.3174E-01	1.6859E-01	1.5394E-02	6.5780E-04
26	.9259	9.8711E-01	9.9977E-01	5.3430E-04	5.8286E-01	2.3160E-01	1.6899E-01	1.5364E-02	6.5890E-04
27	.9630	9.9357E-01	9.9992E-01	5.3300E-04	5.8274E-01	2.3150E-01	1.6923E-01	1.5345E-02	6.5960E-04
28	1.0000	1.0000E+00	1.0000E+00	5.3219E-04	5.8267E-01	2.3143E-01	1.6937E-01	1.5335E-02	6.5998E-04

SMALLE = 4.33071E-06   DUEDX = 1.15454E+05   HO = 2.02460E+08   ETE = 6.00000E+00   CTH = 1.00000E+00

RHOMUREF = 1.59720E-09   REYN NO(S) = 1.47678E+04

ITERATION	1	STANTON NO. = 2.02413E-02	SKIN FRICTION = 1.73549E+00	TIME LEFT =288.084 SEC
ITERATION	2	STANTON NO. = 2.02413E-02	SKIN FRICTION = 1.73549E+00	TIME LEFT =287.070 SEC
ITERATION	3	STANTON NO. = 2.02414E-02	SKIN FRICTION = 1.73550E+00	TIME LEFT =286.056 SEC
ITERATION	4	STANTON NO. = 2.02414E-02	SKIN FRICTION = 1.73550E+00	TIME LEFT =285.043 SEC
ITERATION	5	STANTON NO. = 2.02415E-02	SKIN FRICTION = 1.73551E+00	TIME LEFT =284.028 SEC
ITERATION	6	STANTON NO. = 2.02415E-02	SKIN FRICTION = 1.73551E+00	TIME LEFT =283.012 SEC
ITERATION	7	STANTON NO. = 2.02416E-02	SKIN FRICTION = 1.73552E+00	TIME LEFT =282.001 SEC
ITERATION	8	STANTON NO. = 2.02417E-02	SKIN FRICTION = 1.73552E+00	TIME LEFT =280.994 SEC
ITERATION	9	STANTON NO. = 2.02417E-02	SKIN FRICTION = 1.73553E+00	TIME LEFT =279.983 SEC
ITERATION	10	STANTON NO. = 2.02418E-02	SKIN FRICTION = 1.73553E+00	TIME LEFT =278.972 SEC
ITERATION	11	STANTON NO. = 2.02419E-02	SKIN FRICTION = 1.73554E+00	TIME LEFT =277.958 SEC
ITERATION	12	STANTON NO. = 2.02419E-02	SKIN FRICTION = 1.73554E+00	TIME LEFT =276.951 SEC
ITERATION	13	STANTON NO. = 2.02420E-02	SKIN FRICTION = 1.73554E+00	TIME LEFT =275.939 SEC
ITERATION	14	STANTON NO. = 2.02421E-02	SKIN FRICTION = 1.73555E+00	TIME LEFT =274.931 SEC
ITERATION	15	STANTON NO. = 2.02421E-02	SKIN FRICTION = 1.73555E+00	TIME LEFT =273.921 SEC
ITERATION	16	STANTON NO. = 2.02422E-02	SKIN FRICTION = 1.73556E+00	TIME LEFT =272.907 SEC
ITERATION	17	STANTON NO. = 2.02423E-02	SKIN FRICTION = 1.73556E+00	TIME LEFT =271.890 SEC
ITERATION	18	STANTON NO. = 2.02424E-02	SKIN FRICTION = 1.73557E+00	TIME LEFT =270.880 SEC
ITERATION	19	STANTON NO. = 2.02424E-02	SKIN FRICTION = 1.73557E+00	TIME LEFT =269.868 SEC
ITERATION	20	STANTON NO. = 2.02425E-02	SKIN FRICTION = 1.73558E+00	TIME LEFT =268.855 SEC
ITERATION	21	STANTON NO. = 2.02426E-02	SKIN FRICTION = 1.73558E+00	TIME LEFT =267.846 SEC
ITERATION	22	STANTON NO. = 2.02426E-02	SKIN FRICTION = 1.73558E+00	TIME LEFT =266.837 SEC
ITERATION	23	STANTON NO. = 2.02427E-02	SKIN FRICTION = 1.73559E+00	TIME LEFT =265.824 SEC
ITERATION	24	STANTON NO. = 2.02428E-02	SKIN FRICTION = 1.73559E+00	TIME LEFT =264.810 SEC
ITERATION	25	STANTON NO. = 2.02429E-02	SKIN FRICTION = 1.73560E+00	TIME LEFT =263.798 SEC
ITERATION	26	STANTON NO. = 2.02429E-02	SKIN FRICTION = 1.73560E+00	TIME LEFT =262.789 SEC
ITERATION	27	STANTON NO. = 2.02430E-02	SKIN FRICTION = 1.73561E+00	TIME LEFT =261.773 SEC
ITERATION	28	STANTON NO. = 2.02431E-02	SKIN FRICTION = 1.73561E+00	TIME LEFT =260.762 SEC
ITERATION	29	STANTON NO. = 2.02432E-02	SKIN FRICTION = 1.73561E+00	TIME LEFT =259.750 SEC
ITERATION	30	STANTON NO. = 2.02432E-02	SKIN FRICTION = 1.73562E+00	TIME LEFT =258.742 SEC
ITERATION	31	STANTON NO. = 2.02433E-02	SKIN FRICTION = 1.73562E+00	TIME LEFT =257.734 SEC
ITERATION	32	STANTON NO. = 2.02434E-02	SKIN FRICTION = 1.73563E+00	TIME LEFT =256.723 SEC
ITERATION	33	STANTON NO. = 2.02434E-02	SKIN FRICTION = 1.73563E+00	TIME LEFT =255.711 SEC
ITERATION	34	STANTON NO. = 2.02435E-02	SKIN FRICTION = 1.73563E+00	TIME LEFT =254.703 SEC
ITERATION	35	STANTON NO. = 2.02436E-02	SKIN FRICTION = 1.73564E+00	TIME LEFT =253.698 SEC
ITERATION	36	STANTON NO. = 2.02437E-02	SKIN FRICTION = 1.73564E+00	TIME LEFT =252.688 SEC
ITERATION	37	STANTON NO. = 2.02437E-02	SKIN FRICTION = 1.73564E+00	TIME LEFT =251.673 SEC
ITERATION	38	STANTON NO. = 2.02438E-02	SKIN FRICTION = 1.73565E+00	TIME LEFT =250.659 SEC
ITERATION	39	STANTON NO. = 2.02439E-02	SKIN FRICTION = 1.73565E+00	TIME LEFT =249.649 SEC

PROFILES AFTER 87 ITERATIONS. ++++++++PROFILES CONVERGED++++++++

X(K)

N	ETA	1	2	3	4	5	6	7
1	0.0000	-5.1877E-01	1.7095E-39	0.	6.2991E-24	3.8934E-06	1.7874E-11	-1.2417E-03
2	.0370	-3.5575E+01	-5.1196E-08	-3.6348E-12	-1.5370E-02	-1.1667E+00	-1.5939E+00	-1.9015E-01
3	.0741	-7.8346E+01	-9.3418E-07	-3.0572E-10	-8.2965E-02	-8.5217E+00	-7.3297E+00	-4.5904E-01
4	.1111	-1.1628E+02	-1.8550E-05	-2.8733E-08	-3.9856E-01	-4.2667E+01	-3.2195E+01	-7.9141E-01
5	.1481	-1.4503E+02	-3.2570E-04	-2.2258E-06	-1.7011E+00	-1.9433E+02	-1.0804E+02	-1.2791E+00
6	.1852	-1.1861E+02	-4.2292E-03	-1.1275E-04	-5.6427E+00	-7.4289E+02	-2.7216E+02	-2.0886E+00
7	.2222	5.7679E+01	-3.2544E-02	-2.9280E-03	-1.0786E+01	-1.9313E+03	-6.5489E+02	-3.4414E+00
8	.2593	2.6327E+02	-1.2536E-01	-3.1355E-02	-3.7725E+00	-2.8022E+03	-1.4758E+03	-5.1347E+00
9	.2963	2.2724E+02	-2.6472E-01	-1.4140E-01	1.4197E+01	-2.0074E+03	-2.0859E+03	-5.8021E+00
10	.3333	8.9491E+01	-4.8471E-01	-4.3596E-01	1.2153E+01	-7.7482E+02	-1.6263E+03	-4.5989E+00
11	.3704	1.9984E+01	-8.5117E-01	-1.1251E+00	-5.0124E+00	-2.1238E+02	-8.2208E+02	-2.7367E+00
12	.4074	1.4388E+00	-1.1316E+00	-1.9154E+00	-1.5849E+01	-5.7669E+01	-3.3447E+02	-1.3110E+00
13	.4444	-5.3879E-01	-1.1086E+00	-2.0277E+00	-1.6158E+01	-1.8090E+01	-1.2832E+02	-4.4557E-01
14	.4815	1.0343E+00	-8.3735E-01	-1.1474E+00	-1.0998E+01	-5.1225E+00	-4.7295E+01	4.0210E-02
15	.5185	2.6121E+00	-5.0121E-01	3.4874E-01	-5.1635E+00	3.4372E-01	-1.2913E+01	2.9216E-01
16	.5556	3.5162E+00	-2.3916E-01	1.8624E+00	-9.5020E-01	2.8110E+00	2.7020E+00	3.9770E-01
17	.5926	3.8410E+00	-9.9233E-02	2.9866E+00	1.2157E+00	3.8124E+00	9.3929E+00	4.1262E-01
18	.6296	3.8154E+00	-6.7171E-02	3.6041E+00	1.7726E+00	4.0717E+00	1.1382E+01	3.7562E-01
19	.6667	3.6246E+00	-1.0580E-01	3.7919E+00	1.3522E+00	3.9769E+00	1.0901E+01	3.1386E-01
20	.7037	3.3831E+00	-1.7934E-01	3.6977E+00	4.7683E-01	3.7383E+00	9.2518E+00	2.4561E-01
21	.7407	3.1505E+00	-2.6236E-01	3.4599E+00	-5.1328E-01	3.4651E+00	7.2014E+00	1.8194E-01
22	.7778	2.9518E+00	-3.4011E-01	3.1774E+00	-1.4340E+00	3.2099E+00	5.1769E+00	1.2845E-01
23	.8148	2.7937E+00	-4.0586E-01	2.9080E+00	-2.2069E+00	2.9940E+00	3.3923E+00	8.6813E-02
24	.8519	2.6735E+00	-4.5795E-01	2.6785E+00	-2.8159E+00	2.8223E+00	1.9286E+00	5.6302E-02
25	.8889	2.5849E+00	-4.9749E-01	2.4952E+00	-3.2770E+00	2.6915E+00	7.8636E-01	3.4760E-02
26	.9259	2.5205E+00	-5.2692E-01	2.3533E+00	-3.6198E+00	2.5933E+00	-9.9511E-02	1.8709E-02
27	.9630	2.4748E+00	-5.4924E-01	2.2418E+00	-3.8726E+00	2.5087E+00	-9.8630E-01	9.4373E-04
28	1.0000	2.4601E+00	-5.6838E-01	2.1425E+00	-4.0246E+00	2.2821E+00	-3.4031E+00	-4.3040E-02

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+
1	0.0000	0.	1.4372E-01	2.5143E-01	6.8398E-01	1.5726E-03	0.	6.3012E-02	1.7069E-07
2	.0370	6.4367E-02	2.1455E-01	2.2897E-01	6.8748E-01	2.0086E-02	5.0132E-07	6.3457E-02	3.1802E-06
3	.0741	1.3654E-01	2.9161E-01	2.0215E-01	6.9265E-01	4.1139E-02	3.1827E-06	6.4045E-02	6.7810E-06
4	.1111	2.1414E-01	3.7367E-01	1.7121E-01	6.9931E-01	6.4689E-02	1.9601E-05	6.4760E-02	1.1531E-05
5	.1481	2.9504E-01	4.5931E-01	1.3635E-01	7.0726E-01	9.0709E-02	1.0814E-04	6.5558E-02	1.8233E-05
6	.1852	3.7713E-01	5.4653E-01	9.8325E-02	7.1606E-01	1.1893E-01	5.1181E-04	6.6146E-02	2.8164E-05
7	.2222	4.5822E-01	6.3218E-01	6.0049E-02	7.2475E-01	1.4813E-01	2.0473E-03	6.4981E-02	4.3527E-05
8	.2593	5.3605E-01	7.1144E-01	2.8644E-02	7.3111E-01	1.7495E-01	6.6425E-03	5.8588E-02	6.8029E-05
9	.2963	6.0843E-01	7.7820E-01	1.0892E-02	7.3096E-01	1.9503E-01	1.6553E-02	4.6451E-02	1.0639E-04
10	.3333	6.7360E-01	8.2945E-01	4.2135E-03	7.2145E-01	2.0766E-01	3.1686E-02	3.4837E-02	1.6002E-04
11	.3704	7.3050E-01	8.6811E-01	2.1596E-03	7.0481E-01	2.1551E-01	4.9698E-02	2.7598E-02	2.2444E-04
12	.4074	7.7883E-01	8.9831E-01	1.4514E-03	6.8525E-01	2.2094E-01	6.8390E-02	2.3675E-02	2.9311E-04
13	.4444	8.1884E-01	9.2249E-01	1.1274E-03	6.6568E-01	2.2502E-01	8.6436E-02	2.1382E-02	3.6060E-04
14	.4815	8.5123E-01	9.4186E-01	9.4141E-04	6.4763E-01	2.2810E-01	1.0306E-01	1.9843E-02	4.2314E-04
15	.5185	8.7700E-01	9.5717E-01	8.2038E-04	6.3186E-01	2.3034E-01	1.1779E-01	1.8708E-02	4.7832E-04
16	.5556	8.9728E-01	9.6906E-01	7.3653E-04	6.1870E-01	2.3183E-01	1.3036E-01	1.7837E-02	5.2489E-04
17	.5926	9.1326E-01	9.7812E-01	6.7666E-04	6.0819E-01	2.3270E-01	1.4070E-01	1.7163E-02	5.6258E-04
18	.6296	9.2601E-01	9.8488E-01	6.3340E-04	6.0014E-01	2.3309E-01	1.4890E-01	1.6646E-02	5.9188E-04
19	.6667	9.3647E-01	9.8980E-01	6.0212E-04	5.9423E-01	2.3313E-01	1.5517E-01	1.6255E-02	6.1381E-04
20	.7037	9.4537E-01	9.9330E-01	5.7963E-04	5.9005E-01	2.3296E-01	1.5981E-01	1.5966E-02	6.2964E-04
21	.7407	9.5327E-01	9.9572E-01	5.6366E-04	5.8722E-01	2.3269E-01	1.6313E-01	1.5756E-02	6.4066E-04
22	.7778	9.6053E-01	9.9735E-01	5.5251E-04	5.8537E-01	2.3239E-01	1.6542E-01	1.5608E-02	6.4808E-04
23	.8148	9.6741E-01	9.9842E-01	5.4486E-04	5.8421E-01	2.3212E-01	1.6697E-01	1.5505E-02	6.5292E-04
24	.8519	9.7408E-01	9.9910E-01	5.3974E-04	5.8351E-01	2.3189E-01	1.6797E-01	1.5436E-02	6.5597E-04
25	.8889	9.8063E-01	9.9952E-01	5.3638E-04	5.8310E-01	2.3171E-01	1.6861E-01	1.5391E-02	6.5784E-04
26	.9259	9.8712E-01	9.9978E-01	5.3425E-04	5.8286E-01	2.3158E-01	1.6900E-01	1.5363E-02	6.5894E-04
27	.9630	9.9357E-01	9.9992E-01	5.3292E-04	5.8274E-01	2.3149E-01	1.6923E-01	1.5345E-02	6.5959E-04
28	1.0000	1.0000E+00	1.0000E+00	5.3219E-04	5.8267E-01	2.3143E-01	1.6937E-01	1.5335E-02	6.5998E-04

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	0.	0.	4.1372E-03	7.3070E+12	1.3580E+07
2	.0370	6.7207E-05	-7.0073E-03	0.	2.7244E-03	8.9653E+13	2.3040E+07
3	.0741	1.6402E-04	-2.9229E-02	0.	1.9662E-03	1.3796E+14	3.3839E+07
4	.1111	2.9397E-04	-6.8133E-02	0.	1.5022E-03	1.7923E+14	4.5779E+07
5	.1481	4.6043E-04	-1.2469E-01	0.	1.1942E-03	2.2529E+14	5.8692E+07
6	.1852	6.6642E-04	-1.9939E-01	0.	9.7900E-04	2.8531E+14	7.2379E+07
7	.2222	9.1423E-04	-2.9227E-01	0.	8.2462E-04	3.7140E+14	8.6545E+07
8	.2593	1.2044E-03	-4.0284E-01	0.	7.1390E-04	5.0253E+14	1.0072E+08
9	.2963	1.5343E-03	-5.3014E-01	0.	6.3688E-04	7.0112E+14	1.1437E+08
10	.3333	1.8987E-03	-6.7274E-01	0.	5.8431E-04	9.6752E+14	1.2719E+08
11	.3704	2.2915E-03	-8.2891E-01	0.	5.4691E-04	1.2702E+15	1.3919E+08
12	.4074	2.7084E-03	-9.9677E-01	0.	5.1861E-04	1.5729E+15	1.5030E+08
13	.4444	3.1458E-03	-1.1744E+00	0.	4.9644E-04	1.8524E+15	1.6040E+08
14	.4815	3.6009E-03	-1.3601E+00	0.	4.7896E-04	2.0971E+15	1.6932E+08
15	.5185	4.0710E-03	-1.5522E+00	0.	4.6526E-04	2.3028E+15	1.7699E+08
16	.5556	4.5534E-03	-1.7495E+00	0.	4.5470E-04	2.4696E+15	1.8334E+08
17	.5926	5.0457E-03	-1.9507E+00	0.	4.4670E-04	2.6003E+15	1.8845E+08
18	.6296	5.5457E-03	-2.1551E+00	0.	4.4078E-04	2.6995E+15	1.9240E+08
19	.6667	6.0514E-03	-2.3621E+00	0.	4.3650E-04	2.7724E+15	1.9536E+08
20	.7037	6.5614E-03	-2.5712E+00	0.	4.3348E-04	2.8242E+15	1.9750E+08
21	.7407	7.0743E-03	-2.7822E+00	0.	4.3142E-04	2.8599E+15	1.9900E+08
22	.7778	7.5892E-03	-2.9948E+00	0.	4.3004E-04	2.8838E+15	2.0001E+08
23	.8148	8.1055E-03	-3.2090E+00	0.	4.2915E-04	2.8993E+15	2.0068E+08
24	.8519	8.6227E-03	-3.4248E+00	0.	4.2859E-04	2.9091E+15	2.0110E+08
25	.8889	9.1404E-03	-3.6419E+00	0.	4.2825E-04	2.9150E+15	2.0136E+08
26	.9259	9.6584E-03	-3.8606E+00	0.	4.2804E-04	2.9186E+15	2.0152E+08
27	.9630	1.0177E-02	-4.0807E+00	0.	4.2793E-04	2.9206E+15	2.0161E+08
28	1.0000	1.0695E-02	-4.3022E+00	-3.7571E-01	4.2787E-04	2.9219E+15	2.0166E+08

TIME LEFT =200.642 SEC
QCOND = -1.48616E+06
QDIFF = -1.04368E+06
QCONV = 0.
QTOTAL = -2.52984E+06
QTOTAL(BTU/FT2-SEC) = -3.25107E+03
STANTON NUMBER = 2.02469E-02

RHO V = 0.
HEAT TRANSFER = 7.13537E-01
HEAT TRANSFER, BODY = 5.00003E-01
DISPLACEMENT THICKNESS/RN = 6.59882E-04
MOMENTUM THICKNESS = 1.30894E-04
L AT BODY = 2.25551E+00
SKIN FRICTION = 1.73579E+00

SPECIES	WALL MASS FLUX
O2	6.13720E-03
N2	-3.14773E-07
O	-6.13662E-03
N	2.27625E-07
NO	-4.38492E-09
NO+	-4.86776E-07

CTH = 1.00000E+00, BODY PROFILES.

1-TH BODY PROFILE.   S = 1.0000E-02

RHOMUREF = 1.59693E-09

INTERPOLATED EDGE CONDITIONS

PE =	1.27520E+04	X0 =	0.	LAMBDA =	0.	DELXI =	2.22286E-17
TE =	1.25240E+04	X 1/2 =	4.16667E-04	LAMBDA 1/2 =	1.33381E-14	XI0 =	0.
UE =	9.62120E+01	X1 =	8.33333E-04	LAMBDA + 1 =	1.06693E-13	XI 1/2 =	1.11143E-17
DPE0 =	0.	RB0 =	0.	BETA =	5.00019E-01	XI1 =	2.22286E-17
DPE1 =	-4.24962E+03	RB 1/2 =	4.16665E-04	MU =	3.73293E-06	SMALL E =	4.33087E-06
BEB =	-4.47121E-01	RB1 =	8.33319E-04	RHOE =	4.27795E-04	EBAR =	-2.25115E-05
ETE =	6.00000E+00						

RHOMUREF = 1.59694E-09

X(K)

N	ETA	1	2	3	4	5	6	7
1	0.0000	-5.2066E-01	1.7108E-39	0.	6.2937E-24	3.8999E-06	1.7923E-11	-1.2538E-03
2	.0370	-3.5623E+01	-5.1198E-08	-3.6351E-12	-1.5367E-02	-1.1683E+00	-1.5933E+00	-1.9158E-01
3	.0741	-7.8358E+01	-9.3275E-07	-3.0510E-10	-8.2800E-02	-8.4968E+00	-7.3214E+00	-4.6190E-01
4	.1111	-1.1621E+02	-1.8507E-05	-2.8645E-08	-3.9736E-01	-4.2219E+01	-3.2061E+01	-7.9569E-01
5	.1481	-1.4467E+02	-3.2479E-04	-2.2182E-06	-1.6939E+00	-1.9183E+02	-1.0655E+02	-1.2853E+00
6	.1852	-1.1651E+02	-4.1964E-03	-1.1184E-04	-5.5817E+00	-7.3479E+02	-2.6405E+02	-2.0976E+00
7	.2222	6.3864E+01	-3.1606E-02	-2.8428E-03	-1.0364E+01	-1.9131E+03	-6.2958E+02	-3.4519E+00
8	.2593	2.7161E+02	-1.1490E-01	-2.8645E-02	-2.2013E+00	-2.7752E+03	-1.4240E+03	-5.1294E+00
9	.2963	2.3355E+02	-2.1419E-01	-1.1150E-01	1.7359E+01	-1.9841E+03	-2.0097E+03	-5.7242E+00
10	.3333	9.3694E+01	-3.5464E-01	-2.9625E-01	1.6428E+01	-7.6244E+02	-1.5391E+03	-4.3676E+00
11	.3704	2.3180E+01	-6.2535E-01	-7.5543E-01	-4.8476E-02	-2.0682E+02	-7.3793E+02	-2.2949E+00
12	.4074	4.0721E+00	-8.1872E-01	-1.2197E+00	-1.0396E+01	-5.4866E+01	-2.6026E+02	-6.4319E-01
13	.4444	1.6689E+00	-7.3316E-01	-9.7638E-01	-1.0463E+01	-1.6559E+01	-6.6023E+01	4.2350E-01
14	.4815	2.8747E+00	-4.3304E-01	2.0508E-01	-5.3729E+00	-4.3814E+00	2.9329E+00	1.0521E+00
15	.5185	4.1225E+00	-1.0277E-01	1.8788E+00	9.0403E-02	5.4020E-01	2.5871E+01	1.3676E+00
16	.5556	4.7311E+00	1.2510E-01	3.4182E+00	3.7047E+00	2.6436E+00	3.1265E+01	1.4544E+00
17	.5926	4.7965E+00	2.1296E-01	4.4327E+00	5.1427E+00	3.4259E+00	2.9372E+01	1.3813E+00
18	.6296	4.5493E+00	1.8577E-01	4.8488E+00	4.9394E+00	3.5790E+00	2.4581E+01	1.2100E+00
19	.6667	4.1750E+00	8.9247E-02	4.7951E+00	3.8030E+00	3.4615E+00	1.9060E+01	9.9279E-01
20	.7037	3.7863E+00	-3.5311E-02	4.4620E+00	2.3048E+00	3.2565E+00	1.3895E+01	7.6979E-01
21	.7407	3.4392E+00	-1.5979E-01	4.0160E+00	8.0777E-01	3.0505E+00	9.5644E+00	5.6711E-01
22	.7778	3.1547E+00	-2.6888E-01	3.5689E+00	-5.0121E-01	2.8790E+00	6.2105E+00	3.9827E-01
23	.8148	2.9346E+00	-3.5651E-01	3.1814E+00	-1.5532E+00	2.7531E+00	3.8095E+00	2.6730E-01
24	.8519	2.7718E+00	-4.2220E-01	2.8770E+00	-2.3468E+00	2.6738E+00	2.2786E+00	1.7227E-01
25	.8889	2.6556E+00	-4.6835E-01	2.6569E+00	-2.9147E+00	2.6408E+00	1.5260E+00	1.0832E-01
26	.9259	2.5737E+00	-4.9903E-01	2.5078E+00	-3.3060E+00	2.6556E+00	1.3932E+00	6.9082E-02
27	.9630	2.5131E+00	-5.2123E-01	2.3967E+00	-3.5844E+00	2.7114E+00	1.1574E+00	4.3741E-02
28	1.0000	2.4872E+00	-5.5224E-01	2.2305E+00	-3.8054E+00	2.4690E+00	-3.5183E+00	-2.0409E-03

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+
1	0.0000	0.	1.4372E-01	2.5103E-01	6.8441E-01	1.5763E-03	0.	6.2982E-02	1.7154E-07
2	.0370	6.7411E-02	2.1480E-01	2.2856E-01	6.8787E-01	2.0135E-02	5.0210E-07	6.3428E-02	3.1963E-06
3	.0741	1.4279E-01	2.9213E-01	2.0174E-01	6.9299E-01	4.1239E-02	3.1878E-06	6.4015E-02	6.8152E-06
4	.1111	2.2358E-01	3.7447E-01	1.7080E-01	6.9960E-01	6.4842E-02	1.9634E-05	6.4729E-02	1.1589E-05
5	.1481	3.0747E-01	4.6037E-01	1.3596E-01	7.0748E-01	9.0913E-02	1.0835E-04	6.5526E-02	1.8322E-05
6	.1852	3.9224E-01	5.4778E-01	9.7981E-02	7.1620E-01	1.1917E-01	5.1297E-04	6.6110E-02	2.8297E-05
7	.2222	4.7562E-01	6.3355E-01	5.9794E-02	7.2479E-01	1.4838E-01	2.0528E-03	6.4939E-02	4.3717E-05
8	.2593	5.5530E-01	7.1286E-01	2.8507E-02	7.3104E-01	1.7518E-01	6.6629E-03	5.8539E-02	6.8290E-05
9	.2963	6.2908E-01	7.7961E-01	1.0843E-02	7.3083E-01	1.9521E-01	1.6608E-02	4.6404E-02	1.0673E-04
10	.3333	6.9519E-01	8.3082E-01	4.2009E-03	7.2127E-01	2.0777E-01	3.1794E-02	3.4803E-02	1.6042E-04
11	.3704	7.5267E-01	8.6940E-01	2.1566E-03	7.0459E-01	2.1558E-01	4.9866E-02	2.7579E-02	2.2488E-04
12	.4074	8.0126E-01	8.9950E-01	1.4505E-03	6.8499E-01	2.2099E-01	6.8614E-02	2.3665E-02	2.9356E-04
13	.4444	8.4130E-01	9.2357E-01	1.1270E-03	6.6539E-01	2.2504E-01	8.6701E-02	2.1375E-02	3.6103E-04
14	.4815	8.7353E-01	9.4281E-01	9.4116E-04	6.4733E-01	2.2812E-01	1.0335E-01	1.9839E-02	4.2354E-04
15	.5185	8.9895E-01	9.5799E-01	8.2020E-04	6.3156E-01	2.3035E-01	1.1809E-01	1.8705E-02	4.7868E-04
16	.5556	9.1873E-01	9.6975E-01	7.3640E-04	6.1842E-01	2.3184E-01	1.3065E-01	1.7835E-02	5.2520E-04
17	.5926	9.3404E-01	9.7869E-01	6.7657E-04	6.0794E-01	2.3270E-01	1.4096E-01	1.7161E-02	5.6283E-04
18	.6296	9.4596E-01	9.8532E-01	6.3334E-04	5.9993E-01	2.3308E-01	1.4912E-01	1.6644E-02	5.9208E-04
19	.6667	9.5541E-01	9.9014E-01	6.0207E-04	5.9405E-01	2.3312E-01	1.5536E-01	1.6254E-02	6.1397E-04
20	.7037	9.6312E-01	9.9354E-01	5.7960E-04	5.8991E-01	2.3296E-01	1.5995E-01	1.5965E-02	6.2975E-04
21	.7407	9.6963E-01	9.9589E-01	5.6364E-04	5.8712E-01	2.3269E-01	1.6324E-01	1.5755E-02	6.4074E-04
22	.7778	9.7530E-01	9.9747E-01	5.5249E-04	5.8530E-01	2.3239E-01	1.6550E-01	1.5607E-02	6.4814E-04
23	.8148	9.8037E-01	9.9850E-01	5.4485E-04	5.8416E-01	2.3212E-01	1.6702E-01	1.5505E-02	6.5296E-04
24	.8519	9.8499E-01	9.9915E-01	5.3973E-04	5.8347E-01	2.3189E-01	1.6801E-01	1.5436E-02	6.5599E-04
25	.8889	9.8924E-01	9.9956E-01	5.3638E-04	5.8308E-01	2.3171E-01	1.6863E-01	1.5391E-02	6.5785E-04
26	.9259	9.9315E-01	9.9980E-01	5.3424E-04	5.8286E-01	2.3158E-01	1.6901E-01	1.5362E-02	6.5895E-04
27	.9630	9.9674E-01	9.9994E-01	5.3293E-04	5.8273E-01	2.3150E-01	1.6923E-01	1.5345E-02	6.5958E-04
28	1.0000	1.0000E+00	1.0000E+00	5.3229E-04	5.8266E-01	2.3145E-01	1.6936E-01	1.5337E-02	6.5994E-04

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	0.	0.	4.1363E-03	7.3417E+12	1.3580E+07
2	.0370	6.7265E-05	-7.6592E-03	0.	2.7205E-03	8.9977E+13	2.3071E+07
3	.0741	1.6425E-04	-3.1532E-02	0.	1.9621E-03	1.3837E+14	3.3906E+07
4	.1111	2.9449E-04	-7.3112E-02	0.	1.4985E-03	1.7969E+14	4.5883E+07
5	.1481	4.6136E-04	-1.3333E-01	0.	1.1910E-03	2.2580E+14	5.8831E+07
6	.1852	6.6789E-04	-2.1261E-01	0.	9.7640E-04	2.8589E+14	7.2546E+07
7	.2222	9.1633E-04	-3.1084E-01	0.	8.2253E-04	3.7208E+14	8.6729E+07
8	.2593	1.2072E-03	-4.2743E-01	0.	7.1224E-04	5.0328E+14	1.0092E+08
9	.2963	1.5379E-03	-5.6124E-01	0.	6.3552E-04	7.0184E+14	1.1456E+08
10	.3333	1.9029E-03	-7.1073E-01	0.	5.8316E-04	9.6803E+14	1.2740E+08
11	.3704	2.2965E-03	-8.7403E-01	0.	5.4592E-04	1.2703E+15	1.3940E+08
12	.4074	2.7140E-03	-1.0492E+00	0.	5.1774E-04	1.5727E+15	1.5052E+08
13	.4444	3.1521E-03	-1.2342E+00	0.	4.9568E-04	1.8517E+15	1.6062E+08
14	.4815	3.6079E-03	-1.4272E+00	0.	4.7828E-04	2.0961E+15	1.6954E+08
15	.5185	4.0786E-03	-1.6266E+00	0.	4.6468E-04	2.3016E+15	1.7719E+08
16	.5556	4.5615E-03	-1.8310E+00	0.	4.5421E-04	2.4683E+15	1.8353E+08
17	.5926	5.0543E-03	-2.0392E+00	0.	4.4629E-04	2.5991E+15	1.8861E+08
18	.6296	5.5546E-03	-2.2503E+00	0.	4.4044E-04	2.6984E+15	1.9254E+08
19	.6667	6.0607E-03	-2.4638E+00	0.	4.3622E-04	2.7713E+15	1.9547E+08
20	.7037	6.5709E-03	-2.6790E+00	0.	4.3326E-04	2.8233E+15	1.9759E+08
21	.7407	7.0840E-03	-2.8956E+00	0.	4.3124E-04	2.8591E+15	1.9906E+08
22	.7778	7.5991E-03	-3.1134E+00	0.	4.2990E-04	2.8831E+15	2.0006E+08
23	.8148	8.1156E-03	-3.3323E+00	0.	4.2903E-04	2.8987E+15	2.0071E+08
24	.8519	8.6328E-03	-3.5520E+00	0.	4.2849E-04	2.9085E+15	2.0112E+08
25	.8889	9.1506E-03	-3.7724E+00	0.	4.2816E-04	2.9145E+15	2.0138E+08
26	.9259	9.6687E-03	-3.9935E+00	0.	4.2797E-04	2.9180E+15	2.0153E+08
27	.9630	1.0187E-02	-4.2151E+00	0.	4.2785E-04	2.9201E+15	2.0161E+08
28	1.0000	1.0705E-02	-4.4371E+00	-4.4712E-01	4.2780E-04	2.9213E+15	2.0166E+08

TIME LEFT =198.883 SEC
QCOND = -1.49118E+06
QDIFF = -1.04586E+06
QCONV = 0.
QTOTAL = -2.53705E+06
QTOTAL(BTU/FT2-SEC) = -3.26033E+03
STANTON NUMBER = 2.03046E-02
RS**(1+J) = 8.88355E-08
REYNOLDS NUMBER = 9.18832E+00
CF-INF = 1.79761E-04

RHO V = 0.
HEAT TRANSFER = 7.15624E-01
HEAT TRANSFER, BODY = 5.01497E-01
DISPLACEMENT THICKNESS/RN = 4.57427E-04
MOMENTUM THICKNESS = 1.21446E-04
L AT BODY = 2.25519E+00
SKIN FRICTION = 1.82051E+00
T DRAG COEF = 1.03786E-06
P DRAG COEF = 1.92781E+00
TOTAL DRAG = 1.92781E+00

SPECIES	WALL MASS FLUX	TOTAL MASS FLOW	FLOW(PAR/SEC)
O2	6.13653E-03	2.14485E-09	5.89351E+17
N2	1.30869E-05	1.16188E-07	3.64655E+19
O	-6.14960E-03	3.99648E-08	2.19627E+19
N	2.27942E-07	2.17920E-08	1.36788E+19
NO	2.43424E-07	4.44513E-09	1.30249E+18
NO+	-4.89116E-07	8.74800E-11	2.56330E+16

95-TH BODY PROFILE.   S = 2.4000E+02

RHOMUREF = 1.44158E-10

INTERPOLATED EDGE CONDITIONS

PE =	4.70344E+02	XO =	1.91296E+01	LAMBDA =	3.25844E-05	DELXI =	2.96142E-05
TE =	1.36105E+03	X 1/2 =	1.95648E+01	LAMBDA 1/2 =	3.40194E-05	XIO =	2.04776E-04
UE =	1.96995E+04	X1 =	2.00000E+01	LAMBDA + 1 =	3.54836E-05	XI 1/2 =	2.19583E-04
DPEO =	5.46378E-02	RBO =	3.38368E+00	BETA =	-4.26453E-03	XI1 =	2.34390E-04
DPE1 =	7.04100E-02	RB 1/2 =	3.45926E+00	MU =	7.18372E-07	SMALL E =	6.70635E-04
BEB =	1.05483E-05	RB1 =	3.53483E+00	RHOE =	2.00673E-04	EBAR =	1.61642E-01
ETE =	6.00000E+00						

RHOMUREF = 1.43658E-10

X(K)

N	ETA	1	2	3	4	5	6	7
1	0.0000	-9.4399E-07	1.3196E-40	0.	1.5771E-25	3.6536E-09	3.3615E-14	-1.7395E-11
2	.0370	-3.8672E-04	-5.8261E-14	-1.1918E-19	-2.8291E-08	-3.3969E-04	-1.0059E-03	-1.7892E-08
3	.0741	1.2007E-02	2.9789E-10	1.1626E-14	7.3628E-06	-3.5969E-03	3.1541E-03	-3.5668E-08
4	.1111	3.6962E-01	2.9684E-07	6.0868E-11	6.0427E-04	-1.7914E-01	2.1019E-01	4.1115E-08
5	.1481	1.3579E+00	4.2695E-06	2.0107E-09	3.2578E-03	-6.6885E-01	7.3250E-01	6.1968E-07
6	.1852	1.5843E+00	5.7733E-06	3.3716E-09	3.7230E-03	-9.4593E-01	9.4973E-01	9.8603E-07
7	.2222	7.9368E-01	1.3490E-06	5.8893E-10	1.2732E-03	-6.8806E-01	6.1133E-01	3.6681E-07
8	.2593	1.7354E-01	5.8750E-08	1.2446E-11	1.3542E-04	-2.8240E-01	2.0943E-01	-1.2941E-07
9	.2963	1.2662E-02	3.8726E-10	2.7285E-14	2.9107E-06	-6.7934E-02	3.6192E-02	-2.8500E-07
10	.3333	-3.6167E-03	-3.0483E-12	-5.0608E-17	-4.7808E-07	-1.0474E-02	2.3641E-03	-3.7093E-07
11	.3704	-4.8648E-03	-1.3773E-13	-4.3060E-19	-1.2193E-07	-1.2706E-03	-1.3715E-04	-4.4850E-07
12	.4074	-5.3446E-03	-3.7026E-15	-1.8174E-21	-2.3164E-08	-1.4627E-04	-4.1092E-05	-5.0438E-07
13	.4444	-5.4106E-03	-7.8938E-17	-5.4355E-24	-3.7437E-09	-1.6522E-05	-4.8553E-06	-5.2075E-07
14	.4815	-4.9816E-03	-1.8560E-18	-1.8913E-26	-5.9972E-10	-2.1563E-06	-5.1276E-07	-4.8995E-07
15	.5185	-4.1426E-03	-1.5402E-19	-4.3862E-28	-1.6932E-10	-5.9829E-07	-9.6850E-08	-4.1914E-07
16	.5556	-3.1077E-03	-8.5023E-20	-1.7546E-28	-1.1555E-10	-3.5417E-07	-4.6018E-08	-3.2645E-07
17	.5926	-2.1089E-03	-7.6523E-20	-1.4685E-28	-9.4602E-11	-2.4508E-07	-2.7365E-08	-2.3220E-07
18	.6296	-1.3002E-03	-5.9379E-20	-9.8810E-29	-6.7838E-11	-1.6310E-07	-1.4790E-08	-1.5136E-07
19	.6667	-7.3171E-04	-3.6156E-20	-4.6384E-29	-4.0828E-11	-1.0129E-07	-6.9127E-09	-9.0633E-08
20	.7037	-3.7710E-04	-1.7195E-20	-1.5073E-29	-2.0647E-11	-5.8353E-08	-2.7795E-09	-4.9894E-08
21	.7407	-1.7815E-04	-6.4278E-21	-3.4216E-30	-8.8187E-12	-3.1069E-08	-9.6140E-10	-2.5207E-08
22	.7778	-7.6945E-05	-1.8955E-21	-5.4517E-31	-3.1862E-12	-1.5209E-08	-2.8544E-10	-1.1627E-08
23	.8148	-3.0131E-05	-4.3869E-22	-6.0483E-32	-9.6790E-13	-6.7868E-09	-7.2149E-11	-4.8439E-09
24	.8519	-1.0499E-05	-7.8097E-23	-4.5321E-33	-2.4257E-13	-2.7206E-09	-1.5224E-11	-1.7853E-09
25	.8889	-3.1263E-06	-1.0205E-23	-2.1377E-34	-4.8019E-14	-9.5368E-10	-2.5693E-12	-5.5789E-10
26	.9259	-7.2048E-07	-8.8534E-25	-5.4591E-36	-6.7972E-15	-2.7733E-10	-3.1460E-13	-1.3365E-10
27	.9630	-9.2243E-08	-3.9316E-26	-5.1094E-38	-5.1186E-16	-5.8626E-11	-2.0855E-14	-1.7595E-11
28	1.0000	3.2997E-26	1.6421E-56	9.8907E-89	-5.9610E-51	-2.7205E-31	1.1486E-34	-2.7340E-31

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+
1	0.0000	0.	1.3297E+00	2.1418E-01	7.4809E-01	6.0489E-05	0.	3.7666E-02	1.0606E-10
2	.0370	9.1765E-02	2.5681E+00	2.1068E-01	7.4886E-01	2.7660E-03	1.9564E-08	3.7698E-02	6.5776E-09
3	.0741	2.0029E-01	3.6458E+00	2.0638E-01	7.5005E-01	5.8373E-03	5.2252E-07	3.7729E-02	1.3466E-08
4	.1111	3.1676E-01	4.4132E+00	2.0170E-01	7.5149E-01	9.0805E-03	3.3341E-06	3.7721E-02	2.0467E-08
5	.1481	4.3464E-01	4.8095E+00	1.9756E-01	7.5312E-01	1.2087E-02	8.3662E-06	3.7223E-02	2.7153E-08
6	.1852	5.4792E-01	4.8586E+00	1.9605E-01	7.5499E-01	1.3909E-02	1.0503E-05	3.5039E-02	3.2678E-08
7	.2222	6.5122E-01	4.6285E+00	1.9803E-01	7.5713E-01	1.4184E-02	7.4918E-06	3.0650E-02	3.6288E-08
8	.2593	7.4045E-01	4.2024E+00	2.0210E-01	7.5938E-01	1.3499E-02	3.3047E-06	2.5019E-02	3.8044E-08
9	.2963	8.1340E-01	3.6759E+00	2.0675E-01	7.6137E-01	1.2417E-02	9.6018E-07	1.9453E-02	3.8150E-08
10	.3333	8.6996E-01	3.1384E+00	2.1131E-01	7.6292E-01	1.1139E-02	1.9725E-07	1.4633E-02	3.6753E-08
11	.3704	9.1176E-01	2.6511E+00	2.1552E-01	7.6402E-01	9.7450E-03	3.1299E-08	1.0718E-02	3.4109E-08
12	.4074	9.4139E-01	2.2430E+00	2.1924E-01	7.6479E-01	8.3091E-03	4.1568E-09	7.6647E-03	3.0581E-08
13	.4444	9.6169E-01	1.9187E+00	2.2241E-01	7.6533E-01	6.9045E-03	4.9872E-10	5.3595E-03	2.6564E-08
14	.4815	9.7524E-01	1.6699E+00	2.2501E-01	7.6573E-01	5.5919E-03	6.4215E-11	3.6671E-03	2.2411E-08
15	.5185	9.8411E-01	1.4833E+00	2.2709E-01	7.6604E-01	4.4145E-03	1.5936E-11	2.4551E-03	1.8402E-08
16	.5556	9.8985E-01	1.3452E+00	2.2871E-01	7.6629E-01	3.3963E-03	1.0470E-11	1.6070E-03	1.4721E-08
17	.5926	9.9352E-01	1.2439E+00	2.2993E-01	7.6649E-01	2.5451E-03	9.0011E-12	1.0270E-03	1.1476E-08
18	.6296	9.9588E-01	1.1699E+00	2.3084E-01	7.6667E-01	1.8561E-03	7.3400E-12	6.3981E-04	8.7118E-09
19	.6667	9.9741E-01	1.1160E+00	2.3149E-01	7.6681E-01	1.3156E-03	5.3974E-12	3.8776E-04	6.4294E-09
20	.7037	9.9841E-01	1.0768E+00	2.3195E-01	7.6692E-01	9.0475E-04	3.5584E-12	2.2810E-04	4.6020E-09
21	.7407	9.9907E-01	1.0485E+00	2.3226E-01	7.6701E-01	6.0223E-04	2.1037E-12	1.2990E-04	3.1844E-09
22	.7778	9.9952E-01	1.0281E+00	2.3247E-01	7.6707E-01	3.8656E-04	1.1145E-12	7.1370E-05	2.1205E-09
23	.8148	9.9982E-01	1.0138E+00	2.3261E-01	7.6712E-01	2.3786E-04	5.2682E-13	3.7630E-05	1.3496E-09
24	.8519	1.0000E+00	1.0043E+00	2.3269E-01	7.6715E-01	1.3883E-04	2.1966E-13	1.8863E-05	8.1158E-10
25	.8889	1.0001E+00	9.9864E-01	2.3274E-01	7.6717E-01	7.5246E-05	7.8843E-14	8.8190E-06	4.5113E-10
26	.9259	1.0001E+00	9.9631E-01	2.3277E-01	7.6719E-01	3.6024E-05	2.3154E-14	3.6683E-06	2.2029E-10
27	.9630	1.0001E+00	9.9686E-01	2.3279E-01	7.6720E-01	1.2900E-05	4.8826E-15	1.1538E-06	7.9970E-11
28	1.0000	1.0000E+00	1.0000E+00	2.3280E-01	7.6720E-01	3.3216E-20	2.2354E-35	5.3543E-20	1.0000E-20

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	0.	0.	1.5094E-04	1.6564E+08	1.2558E+07
2	.0370	8.1178E-03	-1.1762E-02	0.	7.7954E-05	5.3056E+09	2.6795E+07
3	.0741	2.1113E-02	-4.9394E-02	0.	5.4751E-05	7.6288E+09	4.4605E+07
4	.1111	3.8007E-02	-1.1619E-01	0.	4.5090E-05	9.5490E+09	6.4946E+07
5	.1481	5.7373E-02	-2.1303E-01	0.	4.1257E-05	1.1591E+10	8.6858E+07
6	.1852	7.7690E-02	-3.3881E-01	0.	4.0769E-05	1.3785E+10	1.0923E+08
7	.2222	9.7618E-02	-4.9068E-01	0.	4.2785E-05	1.6065E+10	1.3072E+08
8	.2593	1.1613E-01	-6.6453E-01	0.	4.7154E-05	1.8562E+10	1.4999E+08
9	.2963	1.3261E-01	-8.5559E-01	0.	5.3965E-05	2.1303E+10	1.6607E+08
10	.3333	1.4683E-01	-1.0592E+00	0.	6.3285E-05	2.4067E+10	1.7857E+08
11	.3704	1.5888E-01	-1.2713E+00	0.	7.5016E-05	2.6476E+10	1.8764E+08
12	.4074	1.6904E-01	-1.4888E+00	0.	8.8789E-05	2.8096E+10	1.9382E+08
13	.4444	1.7768E-01	-1.7095E+00	0.	1.0393E-04	2.8567E+10	1.9778E+08
14	.4815	1.8511E-01	-1.9321E+00	0.	1.1956E-04	2.7727E+10	2.0018E+08
15	.5185	1.9164E-01	-2.1555E+00	0.	1.3476E-04	2.5659E+10	2.0152E+08
16	.5556	1.9749E-01	-2.3795E+00	0.	1.4873E-04	2.2655E+10	2.0222E+08
17	.5926	2.0284E-01	-2.6036E+00	0.	1.6097E-04	1.9115E+10	2.0254E+08
18	.6296	2.0783E-01	-2.8277E+00	0.	1.7125E-04	1.5437E+10	2.0264E+08
19	.6667	2.1255E-01	-3.0517E+00	0.	1.7960E-04	1.1948E+10	2.0264E+08
20	.7037	2.1709E-01	-3.2757E+00	0.	1.8621E-04	8.8669E+09	2.0260E+08
21	.7407	2.2148E-01	-3.4996E+00	0.	1.9130E-04	6.3033E+09	2.0255E+08
22	.7778	2.2577E-01	-3.7233E+00	0.	1.9512E-04	4.2814E+09	2.0251E+08
23	.8148	2.2998E-01	-3.9469E+00	0.	1.9790E-04	2.7636E+09	2.0247E+08
24	.8519	2.3415E-01	-4.1702E+00	0.	1.9979E-04	1.6778E+09	2.0244E+08
25	.8889	2.3829E-01	-4.3934E+00	0.	2.0093E-04	9.3795E+08	2.0242E+08
26	.9259	2.4241E-01	-4.6163E+00	0.	2.0141E-04	4.5910E+08	2.0241E+08
27	.9630	2.4653E-01	-4.8390E+00	0.	2.0130E-04	1.6657E+08	2.0239E+08
28	1.0000	2.5065E-01	-5.0614E+00	1.0548E-05	2.0067E-04	2.0764E-02	2.0238E+08

TIME LEFT =	78.574 SEC	RHO V =	0.
QCOND =	-3.04700E+04	HEAT TRANSFER =	3.36935E-01
QDIFF =	-1.46366E+03	HEAT TRANSFER, BODY =	3.58252E-01
QCONV =	0.	DISPLACEMENT THICKNESS/RN =	1.60073E-01
QTOTAL =	-3.19337E+04	MOMENTUM THICKNESS =	6.48261E-04
QTOTAL(BTU/FT2-SEC) =	-4.10377E+01	L AT BODY =	9.04953E-01
STANTON NUMBER =	2.54641E-04	SKIN FRICTION =	8.35616E-01
RS**(1+J) =	3.20275E-01	T DRAG COEF =	3.10388E-03
REYNOLDS NUMBER =	1.10441E+08	P DRAG COEF =	7.11961E-02
CF-INF =	4.68016E-04	TOTAL DRAG =	7.42999E-02

SPECIES	WALL MASS FLUX	TOTAL MASS FLOW	FLOW(PAR/SEC)
O2	8.89389E-06	1.48829E-01	4.08945E+25
N2	-2.87134E-07	5.08938E-01	1.59730E+26
O	-8.60665E-06	3.05726E-03	1.68012E+24
N	8.28651E-10	5.71424E-07	3.58682E+20
NO	-9.28981E-10	4.78637E-03	1.40248E+24
NO+	-1.10213E-11	1.01206E-08	2.96548E+18

M	X/RN	RS**(1+J)	REVE	XI	YF(EDGE)
1	0.	0.	-8.3728245E-02	0.	1.0694925E-02
2	1.0000000E-02	8.8835536E-08	-8.4464955E-02	2.2228614E-17	1.0705289E-02
3	2.2666667E-02	4.5920021E-07	-8.4173077E-02	5.8649808E-16	1.0719463E-02
4	3.8000000E-02	1.2873976E-06	-8.3573768E-02	4.6284741E-15	1.0732869E-02
5	5.6000000E-02	2.7834619E-06	-8.2866220E-02	2.1792988E-14	1.0748666E-02
6	7.6666667E-02	5.1888857E-06	-8.2056711E-02	7.6349291E-14	1.0768917E-02
7	1.0000000E-01	8.7746564E-06	-8.1157205E-02	2.2010754E-13	1.0796982E-02
8	1.2600000E-01	1.3843959E-05	-8.0183309E-02	5.5165911E-13	1.0837111E-02
9	1.5407273E-01	2.0571127E-05	-7.9085173E-02	1.2241832E-12	1.0890437E-02
10	1.8421818E-01	2.9217243E-05	-7.7763533E-02	2.4778782E-12	1.0961033E-02
11	2.1643636E-01	4.0048017E-05	-7.5926941E-02	4.6641085E-12	1.1053524E-02
12	2.5072727E-01	5.3247224E-05	-7.4266489E-02	8.2730147E-12	1.1171980E-02
13	2.8709091E-01	6.8957037E-05	-7.3028866E-02	1.3978516E-11	1.1257909E-02
14	3.2552727E-01	8.7539646E-05	-6.9504658E-02	2.2676675E-11	1.1358190E-02
15	3.6603636E-01	1.0939356E-04	-6.4257835E-02	3.5417133E-11	1.1604294E-02
16	4.0861818E-01	1.3454446E-04	-6.0284838E-02	5.3357179E-11	1.1941393E-02
17	4.5327273E-01	1.6292523E-04	-5.6282436E-02	7.7837226E-11	1.2306607E-02
18	5.0000000E-01	1.9450216E-04	-5.1268366E-02	1.1031301E-10	1.2747896E-02
19	5.4880000E-01	2.2916457E-04	-4.5575101E-02	1.5221959E-10	1.3264437E-02
20	6.0514286E-01	2.7076947E-04	-3.8784114E-02	2.1105175E-10	1.3964937E-02
21	6.6902857E-01	3.1930507E-04	-3.0722560E-02	2.9111472E-10	1.4871499E-02
22	7.4045714E-01	3.7424652E-04	-2.1477315E-02	3.9603897E-10	1.6121369E-02
23	8.1942857E-01	4.3454540E-04	-1.0965401E-02	5.2762367E-10	1.7762662E-02
24	9.0594286E-01	4.9858689E-04	3.3150609E-04	6.8425070E-10	2.0115765E-02
25	1.0000000E+00	5.6392208E-04	1.1048682E-02	8.5993515E-10	2.3276747E-02
26	1.1016000E+00	6.2827528E-04	2.1767053E-02	1.0449534E-09	2.7716474E-02
27	1.2150303E+00	6.9152110E-04	3.1615151E-02	1.2329729E-09	3.4362373E-02
28	1.3402909E+00	7.5133042E-04	3.0690534E-02	1.4069996E-09	4.4467292E-02
29	1.4773818E+00	8.0153468E-04	1.5160871E-02	1.5649392E-09	5.2416096E-02
30	1.6263030E+00	8.4126868E-04	5.7815340E-03	1.7238057E-09	5.6214047E-02
31	1.7870545E+00	8.7770637E-04	5.9058848E-03	1.8945006E-09	6.0095961E-02
32	1.9596364E+00	9.1402139E-04	5.5109644E-03	2.0787046E-09	6.4085344E-02
33	2.1440485E+00	9.5175693E-04	4.9747301E-03	2.2768533E-09	6.8212851E-02
34	2.3402909E+00	9.9144677E-04	4.4052622E-03	2.4895608E-09	7.2466908E-02
35	2.5483636E+00	1.0330666E-03	3.8755210E-03	2.7176226E-09	7.6814935E-02
36	2.7682667E+00	1.0764178E-03	3.4239241E-03	2.9619739E-09	8.1238983E-02
37	3.0000000E+00	1.1213238E-03	3.0298568E-03	3.2236275E-09	8.5731138E-02
38	3.2435636E+00	1.1676756E-03	2.6464516E-03	3.5037513E-09	9.0265166E-02
39	3.5095697E+00	1.2173755E-03	2.2935712E-03	3.8162514E-09	9.5004028E-02
40	3.7980182E+00	1.2702958E-03	1.9430996E-03	4.1635398E-09	9.9922291E-02
41	4.1089091E+00	1.3263349E-03	1.5898068E-03	4.5484771E-09	1.0493126E-01
42	4.4422424E+00	1.3853727E-03	1.2308838E-03	4.9745274E-09	1.0999823E-01
43	4.7980182E+00	1.4471969E-03	8.7294576E-04	5.4459402E-09	1.1499086E-01
44	5.1762364E+00	1.5120268E-03	5.7485043E-04	5.9677731E-09	1.1991855E-01
45	5.5768970E+00	1.5803315E-03	2.9334887E-04	6.5456372E-09	1.2479474E-01
46	6.0000000E+00	1.6523281E-03	-3.5973558E-05	7.1859186E-09	1.2955430E-01

47	6.4455455E+00	1.7282867E-03	-2.0891881E-04	7.8961470E-09	1.3405477E-01
48	6.9463712E+00	1.8143633E-03	-4.6882379E-04	8.7415685E-09	1.3912609E-01
49	7.5024773E+00	1.9097941E-03	-8.6107827E-04	9.7429854E-09	1.4363891E-01
50	8.1138636E+00	2.0153899E-03	-1.0798815E-03	1.0929606E-08	1.4819215E-01
51	8.7805303E+00	2.1319952E-03	-1.3235106E-03	1.2334713E-08	1.5237621E-01
52	9.5024773E+00	2.2608625E-03	-1.5029167E-03	1.4000527E-08	1.5639141E-01
53	1.0279705E+01	2.4030859E-03	-1.6834239E-03	1.5977260E-08	1.6009774E-01
54	1.1112212E+01	2.5598899E-03	-1.8737107E-03	1.8326450E-08	1.6349961E-01
55	1.2000000E+01	2.7326028E-03	-2.0494666E-03	2.1124754E-08	1.6639476E-01
56	1.2943068E+01	2.9227024E-03	-2.2763981E-03	2.4466678E-08	1.6896044E-01
57	1.3987677E+01	3.1418187E-03	-2.4217726E-03	2.8668150E-08	1.7064727E-01
58	1.5133826E+01	3.3954022E-03	-2.3680870E-03	3.3957143E-08	1.7268654E-01
59	1.6381515E+01	3.6868410E-03	-2.4795954E-03	4.0593753E-08	1.7485305E-01
60	1.7730745E+01	4.0202409E-03	-2.7198106E-03	4.8941319E-08	1.7623703E-01
61	1.9181515E+01	4.4026837E-03	-3.1356782E-03	5.9490276E-08	1.7693681E-01
62	2.0733826E+01	4.8434390E-03	-3.4617448E-03	7.2924819E-08	1.7563814E-01
63	2.2387677E+01	5.3538861E-03	-3.5587723E-03	9.0151138E-08	1.7469275E-01
64	2.4143068E+01	5.9406088E-03	-3.8061657E-03	1.1225006E-07	1.7314789E-01
65	2.6000000E+01	6.6133863E-03	-4.0104274E-03	1.4071963E-07	1.7107053E-01
66	2.7958472E+01	7.3834213E-03	-4.1909641E-03	1.7747390E-07	1.6879380E-01
67	3.0406978E+01	8.4415121E-03	-4.1958734E-03	2.3503036E-07	1.6586606E-01
68	3.3345516E+01	9.8615886E-03	-3.7693553E-03	3.2447648E-07	1.6416832E-01
69	3.6774087E+01	1.1727129E-02	-3.4801947E-03	4.6152442E-07	1.6530336E-01
70	4.0692692E+01	1.4118896E-02	-3.7718158E-03	6.6686331E-07	1.6634358E-01
71	4.5101329E+01	1.7115295E-02	-4.0147027E-03	9.6807824E-07	1.6565097E-01
72	5.0000000E+01	2.0770912E-02	-3.6495052E-03	1.3993760E-06	1.6531953E-01
73	5.5388704E+01	2.5133608E-02	-2.8862115E-03	2.0029431E-06	1.6742438E-01
74	6.0997230E+01	3.0004343E-02	-2.4100938E-03	2.7867155E-06	1.7179314E-01
75	6.6825580E+01	3.5413296E-02	-2.4736978E-03	3.7894510E-06	1.7589601E-01
76	7.2873752E+01	4.1418023E-02	-2.5384882E-03	5.0623183E-06	1.7882500E-01
77	7.9141747E+01	4.8081348E-02	-2.4496815E-03	6.6674387E-06	1.8188792E-01
78	8.5629565E+01	5.5433276E-02	-2.5104783E-03	8.6695888E-06	1.8471276E-01
79	9.2337206E+01	6.3512325E-02	-2.4644507E-03	1.1146060E-05	1.8693461E-01
80	9.9264670E+01	7.2352817E-02	-2.3638561E-03	1.4182960E-05	1.8958570E-01
81	1.0641196E+02	8.1973227E-02	-2.1808059E-03	1.7869842E-05	1.9184848E-01
82	1.1377907E+02	9.2390489E-02	-1.3544415E-03	2.2297683E-05	1.9504208E-01
83	1.2136600E+02	1.0353053E-01	-1.1784485E-03	2.7528732E-05	2.0082586E-01
84	1.2917275E+02	1.1533638E-01	-1.6589131E-03	3.3650065E-05	2.0424138E-01
85	1.3719933E+02	1.2790696E-01	-1.6107332E-03	4.0823421E-05	2.0751060E-01
86	1.4544573E+02	1.4124662E-01	-1.4754709E-03	4.9174932E-05	2.1081318E-01
87	1.5391196E+02	1.5537472E-01	-1.3605619E-03	5.8847014E-05	2.1439048E-01
88	1.6259800E+02	1.7029762E-01	-1.2888039E-03	6.9992035E-05	2.1790921E-01
89	1.7150387E+02	1.8604043E-01	-1.2137485E-03	8.2783757E-05	2.2153887E-01
90	1.8062957E+02	2.0262574E-01	-1.1488055E-03	9.7406276E-05	2.2513960E-01
91	1.8997508E+02	2.2007136E-01	-1.1371337E-03	1.1405898E-04	2.2883578E-01
92	1.9954042E+02	2.3839992E-01	-9.9827141E-04	1.3294728E-04	2.3226759E-01
93	2.0932558E+02	2.5762479E-01	-6.9048438E-04	1.5426032E-04	2.3650609E-01
94	2.1933056E+02	2.7768898E-01	-6.0998797E-04	1.7813968E-04	2.4134436E-01
95	2.2955537E+02	2.9856903E-01	-6.2248699E-04	2.0477561E-04	2.4589683E-01

END OF THIS PROBLEM

(3) Example 3 - This problem is for the solution of the boundary layer equations along a hyperboloid with ablation of a carbon surface. The radius of curvature at the stagnation point is 1-inch and the asymptotic half-angle is 10^{o}. The gas model for this case is a carbon-air mixture with 26 homogeneous reactions and with the chemical species O_2, N_2, O, N, NO, NO^+, CO, CO_2, C_1, C_2, C_3 and CN. The surface is assumed to be at a temperature of $3000^{o}K$ and constant along the body. The oxidation probabilities are assumed equal to one and the resulting mass transfer calculated in the program will be a maximum. The first estimate for the initial profiles was obtained from a previous solution and the iteration on the initial profiles was stopped after 50 iterations. The solution is close to a converged result. It should be noticed that a large value of η_e is used and in the outer part of the boundary layer some c_i are zero when others nearby are very small. If any $c_i < 0$, it is set to zero which explains why these occur. The step-size across the layer is too large and a slight instability occurs; however, this has only a small effect on the results. Central processing time for this solution on a CDC 6600 computer was 8 minutes, 25 seconds.

```
TITLE  150K  BOUNDARY LAYER    20KFPS    CARBON OXIDATION
LIMTS   28    12    26    21    .000200  1.000000
SPNA1O2   N2    O     N     NO    NO+  CO   CO2  C1   C2   C3   CN   EL   M1   M2
SPNA2M3   M4    M5    M6    M7    M8
CONTR   20    1     1    50     11.0001.0001.000    6    1.0000    1.0000
OPTN NON-EQUI  NON-FROZ  BOUNDARY  INITIAL   HPERBOID  CON LEWI
SIZE .083333333.083333333   .0            3000.
FRSTR 20000.000    23.2719   226.9800
WFACS  .50  .50  .50  .50  .50  .50  .50  .50  .50  .50  .50  .50  .50  .50
FPRIM 0.0000000  .1445466  .2840606  .4075249  .5069917  .5798436  .6292875
FPRIM  .6621165  .6853867  .7041943  .7213040  .7378796  .7543124  .7707122
FPRIM  .7871057  .8034983  .8198903  .8362814  .8526714  .8690601  .8854471
FPRIM  .9018318  .9182130  .9345895  .9509594  .9673200  .9836683 1.0000000
THETA  .4274858  .5814251  .7179102  .8285052  .9059578  .9524708  .9774781
THETA  .9898347  .9950197  .9961997  .9953995  .9939455  .9925944  .9916564
THETA  .9911544  .9909747  .9909773  .9910584  .9911698  .9913109  .9915092
THETA  .9918062  .9922543  .9929204  .9938930  .9952902  .9972660 1.0000000
CLIL  0.0000000  .0000018  .0000109  .0000477  .0001169  .0001885  .0002468
CLIL   .0002977  .0003475  .0003965  .0004410  .0004767  .0005014  .0005160
CLIL   .0005229  .0005254  .0005258  .0005258  .0005258  .0005263  .0005272
CLIL   .0005286  .0005309  .0005342  .0005392  .0005464  .0005570  .0005745
CLIL   .6612069  .6697346  .6728263  .6702357  .6623185  .6506251  .6373765
CLIL   .6244985  .6131232  .6036907  .5962857  .5908525  .5872221  .5850877
CLIL   .5840393  .5836565  .5835997  .5836540  .5837199  .5837732  .5838235
CLIL   .5838881  .5839833  .5841250  .5843326  .5846311  .5850514  .5856134
CLIL   .0008802  .0246247  .0502644  .0761953  .1013708  .1252550  .1474313
CLIL   .1675385  .1852009  .1999932  .2115848  .2199307  .2253447  .2284240
CLIL   .2298866  .2304016  .2304732  .2304049  .2303323  .2302884  .2302641
CLIL   .2302437  .2302167  .2301767  .2301181  .2300331  .2299102  .2297200
CLIL   .0664385  .0705408  .0805900  .0959386  .1153561  .1359072  .1536611
CLIL   .1659163  .1722907  .1741863  .1736014  .1721895  .1708991  .1700625
CLIL   .1696527  .1695138  .1694974  .1695105  .1695124  .1694916  .1694458
CLIL   .1693702  .1692541  .1690807  .1688266  .1684607  .1679426  .1672300
CLIL  -.0000000  .0002380  .0012711  .0037365  .0067900  .0092089  .0108031
CLIL   .0119242  .0128322  .0136042  .0142288  .0146853  .0149787  .0151406
CLIL   .0152143  .0152397  .0152452  .0152467  .0152515  .0152622  .0152808
CLIL   .0153103  .0153552  .0154224  .0155210  .0156639  .0158710  .0161900
CLIL   .0000319  .0000468  .0000902  .0001688  .0002735  .0003827  .0004780
CLIL   .0005508  .0006003  .0006301  .0006460  .0006533  .0006563  .0006573
CLIL   .0006577  .0006578  .0006579  .0006580  .0006581  .0006583  .0006586
CLIL   .0006591  .0006598  .0006609  .0006625  .0006648  .0006679  .0006721
CLIL   .2663558  .2295541  .1893423  .1476649  .1077454  .0731401  .0460294
CLIL   .0267216  .0141927  .0068198  .0029265  .0011063  .0003633  .0001021
CLIL   .0000241  .0000047  .0000007  .0000001  .0000000  .0000000  .0000000
CLIL   .0000000  .0000000  .0000000  .0000000  .0000000  .0000000 0.0000000
CLIL   .0004450  .0004077  .0002808  .0001601  .0000818  .0000405  .0000205
CLIL   .0000105  .0000054  .0000026  .0000011  .0000004  .0000002  .0000000
CLIL   .0000000  .0000000  .0000000  .0000000  .0000000  .0000000  .0000000
CLIL   .0000000  .0000000  .0000000  .0000000  .0000000  .0000000 0.0000000
CLIL   .0043427  .0043718  .0043115  .0042812  .0041536  .0036660  .0028067
CLIL   .0018370  .0010304  .0004996  .0002112  .0000783  .0000255  .0000072
CLIL   .0000018  .0000004  .0000001  .0000000  .0000000  .0000000  .0000000
CLIL   .0000000  .0000000  .0000000  .0000000  .0000000  .0000000 0.0000000
CLIL   .0000003  .0000003  .0000001  .0000001  .0000001  .0000000  .0000000
CLIL   .0000000  .0000000  .0000000  .0000000  .0000000  .0000000  .0000000
```

CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	0.0000000
CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	0.0000000
CLIL	.0002985	.0004795	.0010124	.0015711	.0017934	.0015860	.0011465
CLIL	.0007049	.0003767	.0001770	.0000734	.0000269	.0000087	.0000025
CLIL	.0000006	.0000001	.0000000	.0000000	.0000000	.0000000	.0000000
CLIL	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	0.0000000
CINF	.2328	.7672	0.0	0.0	0.0	0.0	0.0
CINF	0.0	0.0	0.0	0.0	0.0		
HEAT1	0.0	0.0	1.661 +8	3.619 +8	3.225 +7	3.5341+8	-4.376 +7
HEAT2	-9.621 +7	6.362 +8	3.718 +8	2.426 +8	1.787 +8		
LEWS1	1.4	1.4	1.4	1.4	1.4	1.4	1.4
LEWS2	1.4	1.4	1.4	1.4	1.4		
MOWT1	32.	28.016	16.	14.008	30.008	30.008	28.011
MOWT2	44.011	12.011	24.022	36.033	26.021		
N2-O2	.0435927	.9784219	-8.3354916				
O -O2	.0216586	1.3875747	-9.7389971				
N -O2	.0191055	1.4904448	-10.358828				
NO-O2	.0410864	1.0124720	-8.4455480				
NO+O2	.0410864	1.0124720	-8.4455480				
CO O2	.0179165	1.5005201	-10.718179				
CO2O2	.0179121	1.5005975	-10.880856				
C1 O2	.0205877	1.3928589	-9.701582				
C2-O2	0.0	1.8333333	-10.334				
C3-O2	0.0	1.8333333	-10.583				
CN-O2	0.0	1.8333333	-10.620				
O -N2	.0168907	1.5276702	-10.629306				
N -N2	.0191055	1.4904448	-10.358828				
NO-N2	.0315955	1.2225368	-9.4862934				
NO+N2	.0315955	1.2225368	-9.4862934				
CO N2	.0179097	1.5006422	-10.751745				
CO2N2	.0179116	1.5006011	-10.883928				
C1-N2	.0096732	1.6340559	-10.915004				
C2-N2	0.0	1.8333333	-10.726				
C3-N2	0.0	1.8333333	-10.619				
CN-N2	0.0	1.8333333	-10.679				
N -O	-.0043383	1.9119177	-11.891342				
NO -O	.0183441	1.4750189	-10.265935				
NO+-O	.0183441	1.4750189	-10.265935				
CO O	.0185294	1.4822549	-10.257799				
CO2 O	.0185187	1.4826300	-10.381458				
C1 O	-.0022221	1.8127319	-11.142912				
C2 -O	0.0	1.8333333	-10.364				
C3 -O	0.0	1.8333333	-10.288				
CN -O	0.0	1.8333333	-10.330				
NO -N	.0191055	1.4904448	-10.358828				
NO+-N	.0191055	1.4904448	-10.358828				
CO N	.0151224	1.5510012	-10.528562				
CO2 N	.0151780	1.5499748	-10.639403				
C1 N	.0000066	1.7905907	-11.188052				
C2 -N	0.0	1.8333333	-10.381				
C3 -N	0.0	1.8333333	-10.282				

```
CN -N     0.0     1.8333333     -10.340
NO+NO .0039930 1.5689336 -11.441502
CO NO  .0179125 1.5005908-10.738503
CO2NO  .0179054 1.5007142-10.886634
C1 NO  .0195468 1.4285126- 9.922271
C2-NO     0.0     1.8333333     -10.689
C3-NO     0.0     1.8333333     -10.599
CN-NO     0.0     1.8333333     -10.647
CONO+ -.0000019 1.9000299-13.334293
CO2NP -.0000075 1.9001235-13.438822
C1NO+ -.0000123 1.9002157-13.073044
C2NO+     0.0         0.0          0.0
C3NO+     0.0         0.0          0.0
CNNO+     0.0         0.0          0.0
COCO2  .0179117 1.5006043-10.854986
C1 CO  .0094772 1.6372346-10.878790
C2-CO     0.0     1.8333333     -10.726
C3-CO     0.0     1.8333333     -10.619
CN-CO     0.0     1.8333333     -10.679
C1CO2  .0096961 1.6336592-10.971066
C2CO2     0.0     1.8333333     -10.992
C3CO2     0.0     1.8333333     -10.867
CNCO2     0.0     1.8333333     -10.937
C2-C1     0.0     1.8333333     -10.406
C3-C1     0.0     1.8333333     -10.279
CN-C1     0.0     1.8333333     -10.357
C3-C2     0.0     1.8333333     -10.683
CN-C2     0.0     1.8333333     -10.772
CN-C3     0.0     1.8333333     -10.646
VC O2 .0389680   .0094176     -9.55024
VC N2 .0482203 -.0203515     -9.99159
VC O  .0184896   .455811      -11.6927
VC N  .0083995   .649178      -12.5921
VC NO .0425      -.01887      -9.62
VCNO+ .0425      -.01887      -9.62
VC CO-.03242      1.1434      -14.17
VCCO2-.05772      1.5429      -15.76
VC C1 -.00611      .7385      -12.71
VC C2 -.02729     1.0639      -14.03
VC C3  .0          .8333      -13.516
VC CN -.02572     1.0395      -13.86
      O2  +M1  =O   +O   +M1      3.61+18 59.4 -1.0    3.01+15  .0  -.5
      N2  +M2  =N   +N   +M2      1.92+17113.1 - .5    1.09+16  .0  -.5
      N2  +N   =N   +N   +N       4.15+22113.1 -1.5    2.32+21  .0 -1.5
      NO  +M3  =N   +O   +M3      3.97+20 75.6 -1.5    1.01+20  .0 -1.5
      CO2 +M4  =CO  +O   +M4      1.20+1136.85   .5    1.50+06-26.4 1.25
      CO  +M5  =C1  +O   +M5      8.50+19129.0 -1.0    2.40+18  .0 -1.0
      C2  +M6  =C1  +C1  +M6      4.50+1870.93 -1.0    1.00+16  .0  -.5
      C3  +M7  =C1  +C2  +M7      1.60+1687.48  1.0    1.00+16  .0  -.5
      CN  +M8  =C1  +N   +M8      5.20+1994.14 -1.0    7.40+18 4.12 -1.0
      NO  +O   =O2  +N            3.18+0919.7   1.0    9.63+11 3.6   .5
      N2  +O   =NO  +N            6.75+1337.5    .0    1.50+13  .0   .0
      N2  +C1  =CN  +N            2.00+1031.56  1.0    7.70+09 8.33 1.0
      CO  +N   =CN  +O            2.00+1045.8   1.0    2.70+10 7.1   .75
      CO2 +N   =CN  +O2           3.00+0849.56  1.0    6.70+05 6.96 1.25
```

```
        N2   +CO   =CN   +NO                1.00+0392.01   2.0    3.10+0215.59 1.75
        CO   +NO   =CO2  +N                 1.00+0320.98   2.0    1.80+07 8.75 1.25
        CO2  +O    =CO   +O2                3.00+0818.21   1.0    5.20+0514.30 1.50
        CO   +CO   =CO2  +C1                1.00+0372.39   2.0    2.00+06 6.97 1.25
        CO   +O    =O2   +C1                2.00+1069.5    1.0    1.00+10  .0  1.0
        CO   +N    =C1   +NO                9.00+1653.2   -1.0    1.00+16  .0 -1.0
        CN   +O    =C1   +NO                1.00+1214.5     .0    6.00+11  .0   .0
        CO   +CO   =C2   +O2                9.20+11163.3   .75    3.80+1336.2   .0
        CO   +C1   =C2   +O                 4.10+1059.79   .5     5.00+112.01   .5
        C2   +CO   =C3   +O                 1.20+1343.24   .0     5.00+112.01   .5
        C3   +C1   =C2   +C2                1.70+0919.58   1.5    5.00+113.02   .5
        N    +O    =NO+  +EL                9.03+0932.4    .5     1.80+19 .0   -1.0
Z  EL   0.    0.    0.    0.    0.    1.    0.    0.    0.    0.    0.    0.
Z  M1   9.    2.   25.    1.    1.    0.    2.    5.    1.    1.    1.    1.
Z  M2   1.    2.5   1.    0.    1.    0.    2.    5.    1.    1.    1.    1.
Z  M3   1.    1.   20.   20.   20.    0.    2.    5.    1.    1.    1.    1.
Z  M4   2.    2.    2.    2.    2.    0.    2.    5.    1.    1.    1.    1.
Z  M5   1.    1.    1.    1.    1.    0.    1.    1.    1.    1.    1.    1.
Z  M6   1.    1.    1.    1.    1.    0.    1.    1.    1.    1.    1.    1.
Z  M7   1.    1.    1.    1.    1.    0.    1.    1.    1.    1.    1.    1.
Z  M8   1.    1.    1.    1.    1.    0.    1.    1.    1.    1.    1.    1.
NWT      12
XRN       0.0        .35        .6        1.0        1.4        1.8        2.4
XRN       3.0        5.0       10.0       20.0       55.0
TWT    3000.      3000.      3000.      3000.      3000.      3000.      3000.
TWT    3000.      3000.      3000.      3000.      3000.
RVPT   .001       .00089     .00075     .00056     .000425    .00034     .00026
RVPT   .00021     .000131    .000075    .0000485   .0000368
TETE   15.0       15.0       15.0       15.0       15.0       15.0       15.0
TETE   15.0       15.0       15.0       15.0       15.0
BODSP   10      1   5.0      10.0
STEP1    .0          .01
STEP2    .1          .025
STEP3    .5          .05
STEP4   1.0          .1
STEP5   3.0          .25
STEP6   6.0          .5
STEP7  12.         1.0
STEP8  26.0         2.0
STEP9    50.        5.0
STP10   240.        10.
PTMRO   1.0         1.0         1.0       72
XAEDG0.          1.0000E-022.2667E-023.8000E-025.6000E-027.6667E-021.0000E-01
XAEDG1.2600E-011.5407E-011.8422E-012.1644E-012.5073E-012.8709E-013.2553E-01
XAEDG3.6604E-014.0862E-014.5327E-015.0000E-015.4880E-016.0514E-016.6903E-01
XAEDG7.4046E-018.1943E-019.0594E-011.0000E+001.1016E+001.2150E+001.3403E+00
XAEDG1.4774E+001.6263E+001.7871E+001.9596E+002.1440E+002.3403E+002.5484E+00
XAEDG2.7683E+003.0000E+003.2436E+003.5096E+003.7980E+004.1089E+004.4422E+00
XAEDG4.7980E+005.1762E+005.5769E+006.0000E+006.4455E+006.9795E+007.6020E+00
XAEDG8.3129E+009.1122E+001.0000E+011.0976E+011.2030E+011.3161E+011.4370E+01
XAEDG1.5656E+011.7020E+011.8461E+011.9979E+012.1575E+012.3249E+012.5000E+01
XAEDG2.6829E+012.9027E+013.1597E+013.4537E+013.7847E+014.1527E+014.5579E+01
XAEDG5.0000E+015.4792E+01
PAEDG1.2646E+041.2647E+041.2639E+041.2626E+041.2603E+041.2566E+041.2511E+04
PAEDG1.2433E+041.2328E+041.2196E+041.2034E+041.1841E+041.1616E+041.1361E+04
```

```
PAEDG1.1073E+041.0761E+041.0424E+041.0066E+049.6939E+039.2700E+038.8054E+03
PAEDG8.3114E+037.8021E+037.2732E+036.7579E+036.2507E+035.7588E+035.2818E+03
PAEDG4.8344E+034.4194E+034.0365E+033.6899E+033.3777E+033.0966E+032.8450E+03
PAEDG2.6211E+032.4213E+032.2429E+032.0778E+031.9260E+031.7874E+031.6618E+03
PAEDG1.5482E+031.4459E+031.3537E+031.2710E+031.1963E+031.1203E+031.0462E+03
PAEDG9.7622E+029.1198E+028.5388E+028.0186E+027.5645E+027.1652E+026.8168E+02
PAEDG6.5140E+026.2519E+026.0259E+025.8302E+025.6610E+025.5163E+025.3895E+02
PAEDG5.2790E+025.1701E+025.0675E+024.9757E+024.8514E+024.7464E+024.6567E+02
PAEDG4.5896E+024.5529E+02
VAEDG   0.0       133.07     301.63      505.67      745.19     1020.21     1330.7
VAEDG1.6431E+031.9917E+032.3566E+032.7399E+033.1412E+033.5571E+033.9863E+03
VAEDG4.4246E+034.8673E+035.3144E+035.7626E+036.2082E+036.6963E+037.2141E+03
VAEDG7.7515E+038.2975E+038.8501E+039.3923E+039.9231E+031.0450E+041.0967E+04
VAEDG1.1466E+041.1942E+041.2392E+041.2812E+041.3203E+041.3567E+041.3903E+04
VAEDG1.4212E+041.4510E+041.4778E+041.5038E+041.5291E+041.5530E+041.5758E+04
VAEDG1.5971E+041.6174E+041.6367E+041.6550E+041.6723E+041.6908E+041.7098E+04
VAEDG1.7287E+041.7469E+041.7639E+041.7796E+041.7937E+041.8062E+041.8172E+04
VAEDG1.8269E+041.8350E+041.8438E+041.8519E+041.8594E+041.8662E+041.8726E+04
VAEDG1.8785E+041.8847E+041.8911E+041.8966E+041.9031E+041.9091E+041.9146E+04
VAEDG1.9196E+041.9240E+04
TAEDG1.2632E+041.2626E+041.2612E+041.2589E+041.2568E+041.2548E+041.2530E+04
TAEDG1.2514E+041.2490E+041.2461E+041.2427E+041.2389E+041.2344E+041.2292E+04
TAEDG1.2232E+041.2165E+041.2089E+041.2007E+041.1917E+041.1811E+041.1687E+04
TAEDG1.1548E+041.1393E+041.1214E+041.1037E+041.0839E+041.0629E+041.0401E+04
TAEDG1.0160E+049.9094E+039.6452E+039.3680E+039.0833E+038.7947E+038.5027E+03
TAEDG8.2124E+037.9115E+037.6514E+037.4119E+037.1998E+037.0010E+036.8192E+03
TAEDG6.6564E+036.5059E+036.3691E+036.2487E+036.1438E+036.0481E+035.9644E+03
TAEDG5.8949E+035.8286E+035.7519E+035.6492E+035.5144E+035.3495E+035.1644E+03
TAEDG4.9722E+034.7844E+034.5967E+034.4160E+034.2446E+034.0835E+033.9319E+03
TAEDG3.7896E+033.6373E+033.4807E+033.3311E+033.1717E+033.0214E+032.8814E+03
TAEDG2.7542E+032.6416E+03
O2 EG5.7454E-045.7174E-045.6417E-045.5309E-045.5786E-045.5266E-045.5727E-04
O2 EG5.6167E-045.6060E-045.6130E-045.6275E-045.6701E-045.7232E-045.7927E-04
O2 EG5.8567E-045.9392E-046.0397E-046.1707E-046.3146E-046.5015E-046.7532E-04
O2 EG6.9656E-047.2899E-047.7283E-048.2135E-048.7974E-049.5698E-041.0597E-03
O2 EG1.2068E-031.3850E-031.6541E-032.0769E-032.6853E-033.6112E-035.0681E-03
O2 EG7.3023E-031.0934E-021.5527E-022.1512E-022.8459E-023.6809E-024.6060E-02
O2 EG5.5543E-026.5364E-027.5649E-028.6696E-029.8737E-021.1398E-011.3198E-01
O2 EG1.5206E-011.7239E-011.9087E-012.0588E-012.1662E-012.2354E-012.2763E-01
O2 EG2.2988E-012.3106E-012.3195E-012.3239E-012.3261E-012.3271E-012.3276E-01
O2 EG2.3278E-012.3279E-012.3280E-012.3280E-012.3280E-012.3280E-012.3280E-01
O2 EG2.3280E-012.3280E-01
N2 EG5.8562E-015.8555E-015.8555E-015.8554E-015.8454E-015.8488E-015.8475E-01
N2 EG5.8536E-015.8645E-015.8785E-015.8961E-015.9176E-015.9428E-015.9719E-01
N2 EG6.0055E-016.0428E-016.0837E-016.1283E-016.1771E-016.2329E-016.2927E-01
N2 EG6.3677E-016.4441E-016.5239E-016.6062E-016.6920E-016.7807E-016.8704E-01
N2 EG6.9532E-017.0437E-017.1237E-017.1913E-017.2573E-017.3121E-017.3537E-01
N2 EG7.3813E-017.3962E-017.3994E-017.3954E-017.3860E-017.3719E-017.3551E-01
N2 EG7.3376E-017.3211E-017.3087E-017.3051E-017.3126E-017.3370E-017.3806E-01
N2 EG7.4408E-017.5073E-017.5681E-017.6146E-017.6441E-017.6599E-017.6673E-01
N2 EG7.6703E-017.6715E-017.6718E-017.6720E-017.6720E-017.6720E-017.6720E-01
N2 EG7.6720E-017.6720E-017.6720E-017.6720E-017.6720E-017.6720E-017.6720E-01
N2 EG7.6720E-017.6720E-01
O   EG2.2972E-012.2972E-012.2960E-012.2945E-012.3108E-012.3098E-012.3198E-01
O   EG2.3231E-012.3232E-012.3235E-012.3237E-012.3241E-012.3249E-012.3259E-01
```

```
O   EG2.3265E-012.3273E-012.3286E-012.3299E-012.3316E-012.3338E-012.3415E-01
O   EG2.3375E-012.3394E-012.3406E-012.3447E-012.3455E-012.3462E-012.3448E-01
O   EG2.3479E-012.3342E-012.3249E-012.3165E-012.2928E-012.2599E-012.2157E-01
O   EG2.1581E-012.0797E-011.9946E-011.8954E-011.7896E-011.6696E-011.5415E-01
O   EG1.4147E-011.2879E-011.1640E-011.0435E-019.2839E-028.0155E-026.7056E-02
O   EG5.3859E-024.1206E-022.9779E-022.0168E-021.2852E-027.7811E-034.5546E-03
O   EG2.6678E-031.6326E-038.1653E-043.9504E-041.8549E-048.4721E-053.7640E-05
O   EG1.6302E-056.0488E-061.9399E-067.1471E-071.7528E-073.8865E-087.9339E-09
O   EG1.5331E-092.8899E-10
N   EG1.6723E-011.6736E-011.6761E-011.6799E-011.6734E-011.6722E-011.6631E-01
N   EG1.6533E-011.6428E-011.6288E-011.6111E-011.5891E-011.5628E-011.5323E-01
N   EG1.4980E-011.4595E-011.4170E-011.3703E-011.3189E-011.2600E-011.1911E-01
N   EG1.1195E-011.0398E-019.5663E-028.6782E-027.7875E-026.8598E-025.9293E-02
N   EG5.0004E-024.1531E-023.3254E-022.5514E-021.8907E-021.3471E-029.1913E-03
N   EG6.0847E-033.8002E-032.4651E-031.5949E-031.0717E-037.2474E-045.0034E-04
N   EG3.5791E-042.5857E-041.8759E-041.3655E-049.9042E-056.8101E-054.4053E-05
N   EG2.6580E-051.4723E-057.0693E-063.0847E-061.2236E-064.6112E-071.6976E-07
N   EG5.9988E-082.2359E-086.8970E-091.9617E-095.3535E-101.4122E-103.5994E-11
N   EG8.5539E-121.6662E-122.5347E-134.3449E-144.4023E-153.8604E-163.0511E-17
N   EG2.2005E-181.6419E-19
NO EG1.6190E-021.6136E-021.6006E-021.5801E-021.5817E-021.5709E-021.5742E-02
NO EG1.5783E-021.5742E-021.5722E-021.5711E-021.5735E-021.5765E-021.5810E-02
NO EG1.5837E-021.5879E-021.5932E-021.6011E-021.6097E-021.6205E-021.6341E-02
NO EG1.6415E-021.6559E-021.6765E-021.6983E-021.7203E-021.7500E-021.7903E-02
NO EG1.8501E-021.9142E-022.0112E-022.1535E-022.3322E-022.5666E-022.8759E-02
NO EG3.2642E-023.7652E-024.2585E-024.7798E-025.2894E-025.8314E-026.3768E-02
NO EG6.8871E-027.3476E-027.6890E-027.8299E-027.7060E-027.2098E-026.2857E-02
NO EG4.9969E-023.5656E-022.2528E-021.2484E-026.1194E-032.6914E-031.0843E-03
NO EG4.1790E-041.5914E-045.1327E-051.5627E-054.5225E-061.2498E-063.3011E-07
NO EG8.3653E-081.6467E-082.5565E-093.8361E-103.9034E-113.3823E-122.5718E-13
NO EG1.7970E-141.2127E-15
NO+EG6.7207E-046.7125E-046.6913E-046.6551E-046.6305E-046.5933E-046.5600E-04
NO+EG6.5194E-046.4601E-046.3876E-046.3005E-046.1994E-046.0817E-045.9467E-04
NO+EG5.7917E-045.6213E-045.4352E-045.2367E-045.0213E-044.7756E-044.4947E-04
NO+EG4.1920E-043.8692E-043.5480E-043.1994E-042.8557E-042.5064E-042.1659E-04
NO+EG1.8368E-041.5372E-041.2521E-049.8980E-057.6336E-055.7547E-054.2421E-05
NO+EG3.0941E-052.2030E-051.6338E-051.2338E-059.6243E-067.5793E-066.0139E-06
NO+EG4.7812E-063.7285E-062.8116E-062.0259E-061.3828E-068.3004E-074.3286E-07
NO+EG1.9203E-077.1777E-082.2485E-085.8347E-091.2769E-092.3969E-103.9676E-11
NO+EG6.1615E-129.1814E-131.0266E-131.0328E-149.4562E-167.9420E-176.1308E-18
NO+EG4.4602E-192.9109E-201.0530E-201.0012E-201.0000E-201.0000E-201.0000E-20
NO+EG1.0000E-201.0000E-20
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO EG      0.0         0.0
CO2EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
CO2EG      0.0         0.0         0.0         0.0         0.0         0.0         0.0
```

CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2EG	0.0	0.0					
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1 EG	0.0	0.0					
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2 EG	0.0	0.0	0				
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3 EG	0.0	0.0					
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CN EG	0.0	0.0					

150K BOUNDARY LAYER 20KFPS CARBON OXIDATION

INPUT 07/14/70

```
NMAX = 28     IWC =  6      K = 1.00         RN = .083333333   VINF =  20000.0000  NON-EQUILIBRUM
  NI = 12    IPRT = 20    TOL =   .000200    RS = .083333333   PINF =     23.2719  NON-FROZEN
  NR = 26    IPUN =  1                    DELTA =0.000000000  TKINF =    226.9800  BOUNDARY LAYER
  NJ = 21   IREAD =  1   AMOM = 1.0000      TKW =  3000.0000                       COMPUTE INITIAL PROFILE
             KOPE = 50   AENE = 1.0000      E O =     1.0000                       HYPERBOLOID
             KOPT =  1   ASPE = 1.0000     E O2 =     1.0000                       CON LEWIS NOS.
```

K	INTERACTION	AMD	BMD	CMD
1	N2-O2	4.35927E-02	9.78422E-01	-8.33549E+00
2	O -O2	2.16586E-02	1.38757E+00	-9.73900E+00
3	N -O2	1.91055E-02	1.49044E+00	-1.03588E+01
4	NO-O2	4.10864E-02	1.01247E+00	-8.44555E+00
5	NO+O2	4.10864E-02	1.01247E+00	-8.44555E+00
6	CO O2	1.79165E-02	1.50052E+00	-1.07182E+01
7	CO2O2	1.79121E-02	1.50060E+00	-1.08809E+01
8	C1 O2	2.05877E-02	1.39286E+00	-9.70158E+00
9	C2-O2	0.	1.83333E+00	-1.03340E+01
10	C3-O2	0.	1.83333E+00	-1.05830E+01
11	CN-O2	0.	1.83333E+00	-1.06200E+01
12	O -N2	1.68907E-02	1.52767E+00	-1.06293E+01
13	N -N2	1.91055E-02	1.49044E+00	-1.03588E+01
14	NO-N2	3.15955E-02	1.22254E+00	-9.48629E+00
15	NO+N2	3.15955E-02	1.22254E+00	-9.48629E+00
16	CO N2	1.79097E-02	1.50064E+00	-1.07517E+01
17	CO2N2	1.79116E-02	1.50060E+00	-1.08839E+01
18	C1 N2	9.67320E-03	1.63406E+00	-1.09150E+01
19	C2-N2	0.	1.83333E+00	-1.07260E+01
20	C3-N2	0.	1.83333E+00	-1.06190E+01
21	CN-N2	0.	1.83333E+00	-1.06790E+01
22	N -O	-4.33830E-03	1.91192E+00	-1.18913E+01
23	NO -O	1.83441E-02	1.47502E+00	-1.02659E+01
24	NO+-O	1.83441E-02	1.47502E+00	-1.02659E+01
25	CO O	1.85294E-02	1.48225E+00	-1.02578E+01
26	CO2 O	1.85187E-02	1.48263E+00	-1.03815E+01
27	C1 O	-2.22210E-03	1.81273E+00	-1.11429E+01
28	C2 -O	0.	1.83333E+00	-1.03640E+01
29	C3 -O	0.	1.83333E+00	-1.02880E+01
30	CN -O	0.	1.83333E+00	-1.03300E+01
31	NO -N	1.91055E-02	1.49044E+00	-1.03588E+01
32	NO+-N	1.91055E-02	1.49044E+00	-1.03588E+01
33	CO N	1.51224E-02	1.55100E+00	-1.05286E+01
34	CO2 N	1.51780E-02	1.54997E+00	-1.06394E+01

35	C1 N	6.60000E-06	1.79059E+00	-1.11881E+01
36	C2 -N	0.	1.83333E+00	-1.03810E+01
37	C3 -N	0.	1.83333E+00	-1.02820E+01
38	CN -N	0.	1.83333E+00	-1.03400E+01
39	NO+NO	3.99300E-03	1.56893E+00	-1.14415E+01
40	CO NO	1.79125E-02	1.50059E+00	-1.07385E+01
41	CO2NO	1.79054E-02	1.50071E+00	-1.08866E+01
42	C1 NO	1.95468E-02	1.42851E+00	-9.92227E+00
43	C2-NO	0.	1.83333E+00	-1.06890E+01
44	C3-NO	0.	1.83333E+00	-1.05990E+01
45	CN-NO	0.	1.83333E+00	-1.06470E+01
46	CONO+	-1.90000E-06	1.90003E+00	-1.33343E+01
47	CO2NP	-7.50000E-06	1.90012E+00	-1.34388E+01
48	C1NO+	-1.23000E-05	1.90022E+00	-1.30730E+01
49	C2NO+	0.	0.	0.
50	C3NO+	0.	0.	0.
51	CNNO+	0.	0.	0.
52	COCO2	1.79117E-02	1.50060E+00	-1.08550E+01
53	C1 CO	9.47720E-03	1.63723E+00	-1.08788E+01
54	C2-CO	0.	1.83333E+00	-1.07260E+01
55	C3-CO	0.	1.83333E+00	-1.06190E+01
56	CN-CO	0.	1.83333E+00	-1.06790E+01
57	C1CO2	9.69610E-03	1.63366E+00	-1.09711E+01
58	C2CO2	0.	1.83333E+00	-1.09920E+01
59	C3CO2	0.	1.83333E+00	-1.08670E+01
60	CNCO2	0.	1.83333E+00	-1.09370E+01
61	C2-C1	0.	1.83333E+00	-1.04060E+01
62	C3-C1	0.	1.83333E+00	-1.02790E+01
63	CN-C1	0.	1.83333E+00	-1.03570E+01
64	C3-C2	0.	1.83333E+00	-1.06830E+01
65	CN-C2	0.	1.83333E+00	-1.07720E+01
66	CN-C3	0.	1.83333E+00	-1.06460E+01

GAS MODEL

SPEC	HF	FLEJ	FMOLWT	AMU	BMU	CMU	WFAC .50(FPRIME) .50(THETA)	CINF
O2	0.	1.40000E+00	3.20000E+01	3.89680E-02	9.41760E-03	-9.55024E+00	.50	2.32800E-01
N2	0.	1.40000E+00	2.80160E+01	4.82203E-02	-2.03515E-02	-9.99159E+00	.50	7.67200E-01
O	1.66100E+08	1.40000E+00	1.60000E+01	1.84896E-02	4.55811E-01	-1.16927E+01	.50	0.
N	3.61900E+08	1.40000E+00	1.40080E+01	8.39950E-03	6.49178E-01	-1.25921E+01	.50	0.
NO	3.22500E+07	1.40000E+00	3.00080E+01	4.25000E-02	-1.88700E-02	-9.62000E+00	.50	0.
NO+	3.53410E+08	1.40000E+00	3.00080E+01	4.25000E-02	-1.88700E-02	-9.62000E+00	.50	0.
CO	-4.37600E+07	1.40000E+00	2.80110E+01	-3.24200E-02	1.14340E+00	-1.41700E+01	.50	0.
CO2	-9.62100E+07	1.40000E+00	4.40110E+01	-5.77200E-02	1.54290E+00	-1.57600E+01	.50	0.
C1	6.36200E+08	1.40000E+00	1.20110E+01	-6.11000E-03	7.38500E-01	-1.27100E+01	.50	0.
C2	3.71800E+08	1.40000E+00	2.40220E+01	-2.72900E-02	1.06390E+00	-1.40300E+01	.50	0.
C3	2.42600E+08	1.40000E+00	3.60330E+01	0.	8.33300E-01	-1.35160E+01	.50	0.
CN	1.78700E+08	1.40000E+00	2.60210E+01	-2.57200E-02	1.03950E+00	-1.38600E+01	.50	0.

K	REACTION					C0	C1	C2	D0	D1	D2	CSALPH	CSBETA
1	O2	M1	=O	O	M1	3.610E+18	59.40	-1.00	3.010E+15	0.00	-.50	1.00	2.00
2	N2	M2	=N	N	M2	1.920E+17	113.10	-.50	1.090E+16	0.00	-.50	1.00	2.00
3	N2	N	=N	N	N	4.150E+22	113.10	-1.50	2.320E+21	0.00	-1.50	1.00	2.00
4	NO	M3	=N	O	M3	3.970E+20	75.60	-1.50	1.010E+20	0.00	-1.50	1.00	2.00
5	CO2	M4	=CO	O	M4	1.200E+11	36.85	.50	1.500E+06	-26.40	1.25	1.00	2.00
6	CO	M5	=C1	O	M5	8.500E+19	129.00	-1.00	2.400E+18	0.00	-1.00	1.00	2.00
7	C2	M6	=C1	C1	M6	4.500E+18	70.93	-1.00	1.000E+16	0.00	-.50	1.00	2.00
8	C3	M7	=C1	C2	M7	1.600E+16	87.48	1.00	1.000E+16	0.00	-.50	1.00	2.00
9	CN	M8	=C1	N	M8	5.200E+19	94.14	-1.00	7.400E+18	4.12	-1.00	1.00	2.00
10	NO	O	=O2	N		3.180E+09	19.70	1.00	9.630E+11	3.60	.50	1.00	1.00
11	N2	O	=NO	N		6.750E+13	37.50	0.00	1.500E+13	0.00	0.00	1.00	1.00
12	N2	C1	=CN	N		2.000E+10	31.56	1.00	7.700E+09	8.33	1.00	1.00	1.00
13	CO	N	=CN	O		2.000E+10	45.80	1.00	2.700E+10	7.10	.75	1.00	1.00
14	CO2	N	=CN	O2		3.000E+08	49.56	1.00	6.700E+05	6.96	1.25	1.00	1.00
15	N2	CO	=CN	NO		1.000E+03	92.01	2.00	3.100E+02	15.59	1.75	1.00	1.00
16	CO	NO	=CO2	N		1.000E+03	20.98	2.00	1.800E+07	8.75	1.25	1.00	1.00
17	CO2	O	=CO	O2		3.000E+08	18.21	1.00	5.200E+05	14.30	1.50	1.00	1.00
18	CO	CO	=CO2	C1		1.000E+03	72.39	2.00	2.000E+06	6.97	1.25	1.00	1.00
19	CO	O	=O2	C1		2.000E+10	69.50	1.00	1.000E+10	0.00	1.00	1.00	1.00
20	CO	N	=C1	NO		9.000E+16	53.20	-1.00	1.000E+16	0.00	-1.00	1.00	1.00
21	CN	O	=C1	NO		1.000E+12	14.50	0.00	6.000E+11	0.00	0.00	1.00	1.00
22	CO	CO	=C2	O2		9.200E+11	163.30	.75	3.800E+13	36.20	0.00	1.00	1.00
23	CO	C1	=C2	O		4.100E+10	59.79	.50	5.000E+11	2.01	.50	1.00	1.00
24	C2	CO	=C3	O		1.200E+13	43.24	0.00	5.000E+11	2.01	.50	1.00	1.00
25	C3	C1	=C2	C2		1.700E+09	19.58	1.50	5.000E+11	3.02	.50	1.00	1.00
26	N	O	=NO+	EL		9.030E+09	32.40	.50	1.800E+19	0.00	-1.00	1.00	1.00

STOICHIOMETRIC COEF.

FORWARD - CALPH(NR,NJ)

NJ/NR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
O2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N2	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00
O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
N	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00
NO	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
NO+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
CO2	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
EL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M3	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M4	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M5	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M6	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

NJ/NR	16	17	18	19	20	21	22	23	24	25	26
O2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00
N	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00
NO	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	1.00	0.00	2.00	1.00	1.00	0.00	2.00	1.00	1.00	0.00	0.00
CO2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
C3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
CN	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
EL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

BACKWARD - CBETA(NR,NJ)

NJ/NR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
O2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00
N2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O	2.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
N	0.00	2.00	3.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00
NO+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C1	0.00	0.00	0.00	0.00	0.00	1.00	2.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
EL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M3	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M4	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M5	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M6	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

NJ/NR	16	17	18	19	20	21	22	23	24	25	26
O2	0.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
N2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
N	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
NO+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
CO	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C1	0.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	2.00	0.00
C3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
CN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
M1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

THIRD BODY EFFECIENCIES - Z(NI,NL)

NL/NI	1	2	3	4	5	6	7	8	9	10	11	12
EL	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
M1	9.0000	2.0000	25.0000	1.0000	1.0000	0.0000	2.0000	5.0000	1.0000	1.0000	1.0000	1.0000
M2	1.0000	2.5000	1.0000	0.0000	1.0000	0.0000	2.0000	5.0000	1.0000	1.0000	1.0000	1.0000
M3	1.0000	1.0000	20.0000	20.0000	20.0000	0.0000	2.0000	5.0000	1.0000	1.0000	1.0000	1.0000
M4	2.0000	2.0000	2.0000	2.0000	2.0000	0.0000	2.0000	5.0000	1.0000	1.0000	1.0000	1.0000
M5	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M6	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M7	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M8	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

K	X/RN	T-WALL	RV(PYR)	ETA(EDGE)
1	0.	3.00000E+03	1.00000E-03	1.50000E+01
2	3.50000E-01	3.00000E+03	8.90000E-04	1.50000E+01
3	6.00000E-01	3.00000E+03	7.50000E-04	1.50000E+01
4	1.00000E+00	3.00000E+03	5.60000E-04	1.50000E+01
5	1.40000E+00	3.00000E+03	4.25000E-04	1.50000E+01
6	1.80000E+00	3.00000E+03	3.40000E-04	1.50000E+01
7	2.40000E+00	3.00000E+03	2.60000E-04	1.50000E+01
8	3.00000E+00	3.00000E+03	2.10000E-04	1.50000E+01
9	5.00000E+00	3.00000E+03	1.31000E-04	1.50000E+01
10	1.00000E+01	3.00000E+03	7.50000E-05	1.50000E+01
11	2.00000E+01	3.00000E+03	4.85000E-05	1.50000E+01
12	5.50000E+01	3.00000E+03	3.68000E-05	1.50000E+01

BODY DATA

IPRTB = 1	XMAX = 5.00000	NORM SH PRESS = 1.0000
	CONE ANGLE = 10.00000	NORM SH TEMP = 1.0000
		NORM SH VEL = 1.0000

X =	0.00	.10	.50	1.00	3.00	6.00	12.00	26.00	50.00	240.00
DELT X =	.010	.025	.050	.100	.250	.500	1.000	2.000	5.000	10.000

EDGE TABLES

	XA	PA	VA	TA	CA(SPECIES) O2	N2	O	N	NO	NO+
1	0.	1.2646E+04	0.	1.2632E+04	5.7454E-04	5.8562E-01	2.2972E-01	1.6723E-01	1.6190E-02	6.7207E-04
2	1.0000E-02	1.2647E+04	1.3307E+02	1.2626E+04	5.7174E-04	5.8555E-01	2.2972E-01	1.6736E-01	1.6136E-02	6.7125E-04
3	2.2667E-02	1.2639E+04	3.0163E+02	1.2612E+04	5.6417E-04	5.8555E-01	2.2960E-01	1.6761E-01	1.6006E-02	6.6913E-04
4	3.8000E-02	1.2626E+04	5.0567E+02	1.2589E+04	5.5309E-04	5.8554E-01	2.2945E-01	1.6799E-01	1.5801E-02	6.6551E-04
5	5.6000E-02	1.2603E+04	7.4519E+02	1.2568E+04	5.5786E-04	5.8454E-01	2.3108E-01	1.6734E-01	1.5817E-02	6.6305E-04
6	7.6667E-02	1.2566E+04	1.0202E+03	1.2548E+04	5.5266E-04	5.8488E-01	2.3098E-01	1.6722E-01	1.5709E-02	6.5933E-04
7	1.0000E-01	1.2511E+04	1.3307E+03	1.2530E+04	5.5727E-04	5.8475E-01	2.3198E-01	1.6631E-01	1.5742E-02	6.5600E-04
8	1.2600E-01	1.2433E+04	1.6431E+03	1.2514E+04	5.6167E-04	5.8536E-01	2.3231E-01	1.6533E-01	1.5783E-02	6.5194E-04
9	1.5407E-01	1.2328E+04	1.9917E+03	1.2490E+04	5.6060E-04	5.8645E-01	2.3232E-01	1.6428E-01	1.5742E-02	6.4601E-04
10	1.8422E-01	1.2196E+04	2.3566E+03	1.2461E+04	5.6130E-04	5.8785E-01	2.3235E-01	1.6288E-01	1.5722E-02	6.3876E-04
11	2.1644E-01	1.2034E+04	2.7399E+03	1.2427E+04	5.6275E-04	5.8961E-01	2.3237E-01	1.6111E-01	1.5711E-02	6.3005E-04
12	2.5073E-01	1.1841E+04	3.1412E+03	1.2389E+04	5.6701E-04	5.9176E-01	2.3241E-01	1.5891E-01	1.5735E-02	6.1994E-04
13	2.8709E-01	1.1616E+04	3.5571E+03	1.2344E+04	5.7232E-04	5.9428E-01	2.3249E-01	1.5628E-01	1.5765E-02	6.0817E-04
14	3.2553E-01	1.1361E+04	3.9863E+03	1.2292E+04	5.7927E-04	5.9719E-01	2.3259E-01	1.5323E-01	1.5810E-02	5.9467E-04
15	3.6604E-01	1.1073E+04	4.4246E+03	1.2232E+04	5.8567E-04	6.0055E-01	2.3265E-01	1.4980E-01	1.5837E-02	5.7917E-04
16	4.0862E-01	1.0761E+04	4.8673E+03	1.2165E+04	5.9392E-04	6.0428E-01	2.3273E-01	1.4595E-01	1.5879E-02	5.6213E-04
17	4.5327E-01	1.0424E+04	5.3144E+03	1.2089E+04	6.0397E-04	6.0837E-01	2.3286E-01	1.4170E-01	1.5932E-02	5.4352E-04
18	5.0000E-01	1.0066E+04	5.7626E+03	1.2007E+04	6.1707E-04	6.1283E-01	2.3299E-01	1.3703E-01	1.6011E-02	5.2367E-04
19	5.4880E-01	9.6939E+03	6.2082E+03	1.1917E+04	6.3146E-04	6.1771E-01	2.3316E-01	1.3189E-01	1.6097E-02	5.0213E-04
20	6.0514E-01	9.2700E+03	6.6963E+03	1.1811E+04	6.5015E-04	6.2329E-01	2.3338E-01	1.2600E-01	1.6205E-02	4.7756E-04
21	6.6903E-01	8.8054E+03	7.2141E+03	1.1687E+04	6.7532E-04	6.2927E-01	2.3415E-01	1.1911E-01	1.6341E-02	4.4947E-04
22	7.4046E-01	8.3114E+03	7.7515E+03	1.1548E+04	6.9656E-04	6.3677E-01	2.3375E-01	1.1195E-01	1.6415E-02	4.1920E-04
23	8.1943E-01	7.8021E+03	8.2975E+03	1.1393E+04	7.2899E-04	6.4441E-01	2.3394E-01	1.0398E-01	1.6559E-02	3.8692E-04
24	9.0594E-01	7.2732E+03	8.8501E+03	1.1214E+04	7.7283E-04	6.5239E-01	2.3406E-01	9.5663E-02	1.6765E-02	3.5480E-04
25	1.0000E+00	6.7579E+03	9.3923E+03	1.1037E+04	8.2135E-04	6.6062E-01	2.3447E-01	8.6782E-02	1.6983E-02	3.1994E-04
26	1.1016E+00	6.2507E+03	9.9231E+03	1.0839E+04	8.7974E-04	6.6920E-01	2.3455E-01	7.7875E-02	1.7203E-02	2.8557E-04
27	1.2150E+00	5.7588E+03	1.0450E+04	1.0629E+04	9.5698E-04	6.7807E-01	2.3462E-01	6.8598E-02	1.7500E-02	2.5064E-04
28	1.3403E+00	5.2818E+03	1.0967E+04	1.0401E+04	1.0597E-03	6.8704E-01	2.3448E-01	5.9293E-02	1.7903E-02	2.1659E-04
29	1.4774E+00	4.8344E+03	1.1466E+04	1.0160E+04	1.2068E-03	6.9532E-01	2.3479E-01	5.0004E-02	1.8501E-02	1.8368E-04
30	1.6263E+00	4.4194E+03	1.1942E+04	9.9094E+03	1.3850E-03	7.0437E-01	2.3342E-01	4.1531E-02	1.9142E-02	1.5372E-04
31	1.7871E+00	4.0365E+03	1.2392E+04	9.6452E+03	1.6541E-03	7.1237E-01	2.3249E-01	3.3254E-02	2.0112E-02	1.2521E-04
32	1.9596E+00	3.6899E+03	1.2812E+04	9.3680E+03	2.0769E-03	7.1913E-01	2.3165E-01	2.5514E-02	2.1535E-02	9.8980E-05

33	2.1440E+00	3.3777E+03	1.3203E+04	9.0833E+03	2.6853E-03	7.2573E-01	2.2928E-01	1.8907E-02	2.3322E-02	7.6336E-05
34	2.3403E+00	3.0966E+03	1.3567E+04	8.7947E+03	3.6112E-03	7.3121E-01	2.2599E-01	1.3471E-02	2.5666E-02	5.7547E-05
35	2.5484E+00	2.8450E+03	1.3903E+04	8.5027E+03	5.0681E-03	7.3537E-01	2.2157E-01	9.1913E-03	2.8759E-02	4.2421E-05
36	2.7683E+00	2.6211E+03	1.4212E+04	8.2124E+03	7.3023E-03	7.3813E-01	2.1581E-01	6.0847E-03	3.2642E-02	3.0941E-05
37	3.0000E+00	2.4213E+03	1.4510E+04	7.9115E+03	1.0934E-02	7.3962E-01	2.0797E-01	3.8002E-03	3.7652E-02	2.2030E-05
38	3.2436E+00	2.2429E+03	1.4778E+04	7.6514E+03	1.5527E-02	7.3994E-01	1.9946E-01	2.4651E-03	4.2585E-02	1.6338E-05
39	3.5096E+00	2.0778E+03	1.5038E+04	7.4119E+03	2.1512E-02	7.3954E-01	1.8954E-01	1.5949E-03	4.7798E-02	1.2338E-05
40	3.7980E+00	1.9260E+03	1.5291E+04	7.1998E+03	2.8459E-02	7.3860E-01	1.7896E-01	1.0717E-03	5.2894E-02	9.6243E-06
41	4.1089E+00	1.7874E+03	1.5530E+04	7.0010E+03	3.6809E-02	7.3719E-01	1.6696E-01	7.2474E-04	5.8314E-02	7.5793E-06
42	4.4422E+00	1.6618E+03	1.5758E+04	6.8192E+03	4.6060E-02	7.3551E-01	1.5415E-01	5.0034E-04	6.3768E-02	6.0139E-06
43	4.7980E+00	1.5482E+03	1.5971E+04	6.6564E+03	5.5543E-02	7.3376E-01	1.4147E-01	3.5791E-04	6.8871E-02	4.7812E-06
44	5.1762E+00	1.4459E+03	1.6174E+04	6.5059E+03	6.5364E-02	7.3211E-01	1.2879E-01	2.5857E-04	7.3476E-02	3.7285E-06
45	5.5769E+00	1.3537E+03	1.6367E+04	6.3691E+03	7.5649E-02	7.3087E-01	1.1640E-01	1.8759E-04	7.6890E-02	2.8116E-06
46	6.0000E+00	1.2710E+03	1.6550E+04	6.2487E+03	8.6696E-02	7.3051E-01	1.0435E-01	1.3655E-04	7.8299E-02	2.0259E-06
47	6.4455E+00	1.1963E+03	1.6723E+04	6.1438E+03	9.8737E-02	7.3126E-01	9.2839E-02	9.9042E-05	7.7060E-02	1.3828E-06
48	6.9795E+00	1.1203E+03	1.6908E+04	6.0481E+03	1.1398E-01	7.3370E-01	8.0155E-02	6.8101E-05	7.2098E-02	8.3004E-07
49	7.6020E+00	1.0462E+03	1.7098E+04	5.9644E+03	1.3198E-01	7.3806E-01	6.7056E-02	4.4053E-05	6.2857E-02	4.3286E-07
50	8.3129E+00	9.7622E+02	1.7287E+04	5.8949E+03	1.5206E-01	7.4408E-01	5.3859E-02	2.6580E-05	4.9969E-02	1.9203E-07
51	9.1122E+00	9.1198E+02	1.7469E+04	5.8286E+03	1.7239E-01	7.5073E-01	4.1206E-02	1.4723E-05	3.5656E-02	7.1777E-08
52	1.0000E+01	8.5388E+02	1.7639E+04	5.7519E+03	1.9087E-01	7.5681E-01	2.9779E-02	7.0693E-06	2.2528E-02	2.2485E-08
53	1.0976E+01	8.0186E+02	1.7796E+04	5.6492E+03	2.0588E-01	7.6146E-01	2.0168E-02	3.0847E-06	1.2484E-02	5.8347E-09
54	1.2030E+01	7.5645E+02	1.7937E+04	5.5144E+03	2.1662E-01	7.6441E-01	1.2852E-02	1.2236E-06	6.1194E-03	1.2769E-09
55	1.3161E+01	7.1652E+02	1.8062E+04	5.3495E+03	2.2354E-01	7.6599E-01	7.7811E-03	4.6112E-07	2.6914E-03	2.3969E-10
56	1.4370E+01	6.8168E+02	1.8172E+04	5.1644E+03	2.2763E-01	7.6673E-01	4.5546E-03	1.6976E-07	1.0843E-03	3.9676E-11
57	1.5656E+01	6.5140E+02	1.8269E+04	4.9722E+03	2.2988E-01	7.6703E-01	2.6678E-03	5.9988E-08	4.1790E-04	6.1615E-12
58	1.7020E+01	6.2519E+02	1.8350E+04	4.7844E+03	2.3106E-01	7.6715E-01	1.6326E-03	2.2359E-08	1.5914E-04	9.1814E-13
59	1.8461E+01	6.0259E+02	1.8438E+04	4.5967E+03	2.3195E-01	7.6718E-01	8.1653E-04	6.8970E-09	5.1327E-05	1.0266E-13
60	1.9979E+01	5.8302E+02	1.8519E+04	4.4160E+03	2.3239E-01	7.6720E-01	3.9504E-04	1.9617E-09	1.5627E-05	1.0328E-14
61	2.1575E+01	5.6610E+02	1.8594E+04	4.2446E+03	2.3261E-01	7.6720E-01	1.8549E-04	5.3535E-10	4.5225E-06	9.4562E-16
62	2.3249E+01	5.5163E+02	1.8662E+04	4.0835E+03	2.3271E-01	7.6720E-01	8.4721E-05	1.4122E-10	1.2498E-06	7.9420E-17
63	2.5000E+01	5.3895E+02	1.8726E+04	3.9319E+03	2.3276E-01	7.6720E-01	3.7640E-05	3.5994E-11	3.3011E-07	6.1308E-18
64	2.6829E+01	5.2790E+02	1.8785E+04	3.7896E+03	2.3278E-01	7.6720E-01	1.6302E-05	8.5539E-12	8.3653E-08	4.4602E-19
65	2.9027E+01	5.1701E+02	1.8847E+04	3.6373E+03	2.3279E-01	7.6720E-01	6.0488E-06	1.6662E-12	1.6467E-08	2.9109E-20
66	3.1597E+01	5.0675E+02	1.8911E+04	3.4807E+03	2.3280E-01	7.6720E-01	1.9399E-06	2.5347E-13	2.5565E-09	1.0530E-20
67	3.4537E+01	4.9757E+02	1.8966E+04	3.3311E+03	2.3280E-01	7.6720E-01	7.1471E-07	4.3449E-14	3.8361E-10	1.0012E-20
68	3.7847E+01	4.8514E+02	1.9031E+04	3.1717E+03	2.3280E-01	7.6720E-01	1.7528E-07	4.4023E-15	3.9034E-11	1.0000E-20
69	4.1527E+01	4.7464E+02	1.9091E+04	3.0214E+03	2.3280E-01	7.6720E-01	3.8865E-08	3.8604E-16	3.3823E-12	1.0000E-20
70	4.5579E+01	4.6567E+02	1.9146E+04	2.8814E+03	2.3280E-01	7.6720E-01	7.9339E-09	3.0511E-17	2.5718E-13	1.0000E-20
71	5.0000E+01	4.5896E+02	1.9196E+04	2.7542E+03	2.3280E-01	7.6720E-01	1.5331E-09	2.2005E-18	1.7970E-14	1.0000E-20
72	5.4792E+01	4.5529E+02	1.9240E+04	2.6416E+03	2.3280E-01	7.6720E-01	2.8899E-10	1.6419E-19	1.2127E-15	1.0000E-20

CA(SPECIE)

	CO	CO2	C1	C2	C3	CN
1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	0.	0.
43	0.	0.	0.	0.	0.	0.

44	0.	0.	0.	0.	0.	0.
45	0.	0.	0.	0.	0.	0.
46	0.	0.	0.	0.	0.	0.
47	0.	0.	0.	0.	0.	0.
48	0.	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.
53	0.	0.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.	0.
55	0.	0.	0.	0.	0.	0.
56	0.	0.	0.	0.	0.	0.
57	0.	0.	0.	0.	0.	0.
58	0.	0.	0.	0.	0.	0.
59	0.	0.	0.	0.	0.	0.
60	0.	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.	0.
63	0.	0.	0.	0.	0.	0.
64	0.	0.	0.	0.	0.	0.
65	0.	0.	0.	0.	0.	0.
66	0.	0.	0.	0.	0.	0.
67	0.	0.	0.	0.	0.	0.
68	0.	0.	0.	0.	0.	0.
69	0.	0.	0.	0.	0.	0.
70	0.	0.	0.	0.	0.	0.
71	0.	0.	0.	0.	0.	0.
72	0.	0.	0.	0.	0.	0.

NOTE --- XA, PA, TA AND VA ARE CHANGED IN SUBROUTINE INPBOD

XA(K) = XA(K) * RN
PA(K) = PA(K) * NORM SH PRESS.
VA(K) = VA(K) * NORM SH VEL.
TA(K) = TA(K) * NORM SH TEMP.

END OF INPUT

INITIAL PROFILE

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+	CO	CO2
1	0.0000	0.	4.2749E-01	0.	6.6121E-01	8.8020E-04	6.6438E-02	-0.	3.1900E-05	2.6636E-01	4.4500E-04
2	.0370	1.4455E-01	5.8143E-01	1.8000E-06	6.6973E-01	2.4625E-02	7.0541E-02	2.3800E-04	4.6800E-05	2.2955E-01	4.0770E-04
3	.0741	2.8406E-01	7.1791E-01	1.0900E-05	6.7283E-01	5.0264E-02	8.0590E-02	1.2711E-03	9.0200E-05	1.8934E-01	2.8080E-04
4	.1111	4.0752E-01	8.2851E-01	4.7700E-05	6.7024E-01	7.6195E-02	9.5939E-02	3.7365E-03	1.6880E-04	1.4766E-01	1.6010E-04
5	.1481	5.0699E-01	9.0596E-01	1.1690E-04	6.6232E-01	1.0137E-01	1.1536E-01	6.7900E-03	2.7350E-04	1.0775E-01	8.1800E-05
6	.1852	5.7984E-01	9.5247E-01	1.8850E-04	6.5063E-01	1.2526E-01	1.3591E-01	9.2089E-03	3.8270E-04	7.3140E-02	4.0500E-05
7	.2222	6.2929E-01	9.7748E-01	2.4680E-04	6.3738E-01	1.4743E-01	1.5366E-01	1.0803E-02	4.7800E-04	4.6029E-02	2.0500E-05
8	.2593	6.6212E-01	9.8983E-01	2.9770E-04	6.2450E-01	1.6754E-01	1.6592E-01	1.1924E-02	5.5080E-04	2.6722E-02	1.0500E-05
9	.2963	6.8539E-01	9.9502E-01	3.4750E-04	6.1312E-01	1.8520E-01	1.7229E-01	1.2832E-02	6.0030E-04	1.4193E-02	5.4000E-06
10	.3333	7.0419E-01	9.9620E-01	3.9650E-04	6.0369E-01	1.9999E-01	1.7419E-01	1.3604E-02	6.3010E-04	6.8198E-03	2.6000E-06
11	.3704	7.2130E-01	9.9540E-01	4.4100E-04	5.9629E-01	2.1158E-01	1.7360E-01	1.4229E-02	6.4600E-04	2.9265E-03	1.1000E-06
12	.4074	7.3788E-01	9.9395E-01	4.7670E-04	5.9085E-01	2.1993E-01	1.7219E-01	1.4685E-02	6.5330E-04	1.1063E-03	4.0000E-07
13	.4444	7.5431E-01	9.9259E-01	5.0140E-04	5.8722E-01	2.2534E-01	1.7090E-01	1.4979E-02	6.5630E-04	3.6330E-04	2.0000E-07
14	.4815	7.7071E-01	9.9166E-01	5.1600E-04	5.8509E-01	2.2842E-01	1.7006E-01	1.5141E-02	6.5730E-04	1.0210E-04	0.
15	.5185	7.8711E-01	9.9115E-01	5.2290E-04	5.8404E-01	2.2989E-01	1.6965E-01	1.5214E-02	6.5770E-04	2.4100E-05	0.
16	.5556	8.0350E-01	9.9097E-01	5.2540E-04	5.8366E-01	2.3040E-01	1.6951E-01	1.5240E-02	6.5780E-04	4.7000E-06	0.
17	.5926	8.1989E-01	9.9098E-01	5.2580E-04	5.8360E-01	2.3047E-01	1.6950E-01	1.5245E-02	6.5790E-04	7.0000E-07	0.
18	.6296	8.3628E-01	9.9106E-01	5.2580E-04	5.8365E-01	2.3040E-01	1.6951E-01	1.5247E-02	6.5800E-04	1.0000E-07	0.
19	.6667	8.5267E-01	9.9117E-01	5.2580E-04	5.8372E-01	2.3033E-01	1.6951E-01	1.5251E-02	6.5810E-04	0.	0.
20	.7037	8.6906E-01	9.9131E-01	5.2630E-04	5.8377E-01	2.3029E-01	1.6949E-01	1.5262E-02	6.5830E-04	0.	0.
21	.7407	8.8545E-01	9.9151E-01	5.2720E-04	5.8382E-01	2.3026E-01	1.6945E-01	1.5281E-02	6.5860E-04	0.	0.
22	.7778	9.0183E-01	9.9181E-01	5.2860E-04	5.8389E-01	2.3024E-01	1.6937E-01	1.5310E-02	6.5910E-04	0.	0.
23	.8148	9.1821E-01	9.9225E-01	5.3090E-04	5.8398E-01	2.3022E-01	1.6925E-01	1.5355E-02	6.5980E-04	0.	0.
24	.8519	9.3459E-01	9.9292E-01	5.3420E-04	5.8413E-01	2.3018E-01	1.6908E-01	1.5422E-02	6.6090E-04	0.	0.
25	.8889	9.5096E-01	9.9389E-01	5.3920E-04	5.8433E-01	2.3012E-01	1.6883E-01	1.5521E-02	6.6250E-04	0.	0.
26	.9259	9.6732E-01	9.9529E-01	5.4640E-04	5.8463E-01	2.3003E-01	1.6846E-01	1.5664E-02	6.6480E-04	0.	0.
27	.9630	9.8367E-01	9.9727E-01	5.5700E-04	5.8505E-01	2.2991E-01	1.6794E-01	1.5871E-02	6.6790E-04	0.	0.
28	1.0000	1.0000E+00	1.0000E+00	5.7454E-04	5.8562E-01	2.2972E-01	1.6723E-01	1.6190E-02	6.7207E-04	0.	0.

N	ETA	C1	C2	C3	CN
1	0.0000	4.3427E-03	3.0000E-07	0.	2.9850E-04
2	.0370	4.3718E-03	3.0000E-07	0.	4.7950E-04
3	.0741	4.3115E-03	1.0000E-07	0.	1.0124E-03
4	.1111	4.2812E-03	1.0000E-07	0.	1.5711E-03
5	.1481	4.1536E-03	1.0000E-07	0.	1.7934E-03
6	.1852	3.6660E-03	0.	0.	1.5860E-03
7	.2222	2.8067E-03	0.	0.	1.1465E-03
8	.2593	1.8370E-03	0.	0.	7.0490E-04
9	.2963	1.0304E-03	0.	0.	3.7670E-04
10	.3333	4.9960E-04	0.	0.	1.7700E-04
11	.3704	2.1120E-04	0.	0.	7.3400E-05
12	.4074	7.8300E-05	0.	0.	2.6900E-05
13	.4444	2.5500E-05	0.	0.	8.7000E-06
14	.4815	7.2000E-06	0.	0.	2.5000E-06
15	.5185	1.8000E-06	0.	0.	6.0000E-07
16	.5556	4.0000E-07	0.	0.	1.0000E-07
17	.5926	1.0000E-07	0.	0.	0.
18	.6296	0.	0.	0.	0.
19	.6667	0.	0.	0.	0.
20	.7037	0.	0.	0.	0.
21	.7407	0.	0.	0.	0.
22	.7778	0.	0.	0.	0.
23	.8148	0.	0.	0.	0.
24	.8519	0.	0.	0.	0.
25	.8889	0.	0.	0.	0.
26	.9259	0.	0.	0.	0.
27	.9630	0.	0.	0.	0.
28	1.0000	0.	0.	0.	0.

SMALLE = 3.13118E-06 DUEDX = 1.59684E+05 HO = 2.02460E+08 ETE = 1.50000E+01 CTH = 1.00000E+00

RHOMUREF = 1.62512E-09 REYN NO(S) = 1.43052E+04

ITERATION 1	STANTON NO. = 1.86342E-02	SKIN FRICTION = 1.02571E+00	TIME LEFT =623.723 SEC
ITERATION 2	STANTON NO. = 1.86259E-02	SKIN FRICTION = 1.02535E+00	TIME LEFT =620.002 SEC
ITERATION 3	STANTON NO. = 1.86178E-02	SKIN FRICTION = 1.02497E+00	TIME LEFT =616.272 SEC
ITERATION 4	STANTON NO. = 1.86098E-02	SKIN FRICTION = 1.02457E+00	TIME LEFT =612.511 SEC
ITERATION 5	STANTON NO. = 1.86018E-02	SKIN FRICTION = 1.02417E+00	TIME LEFT =608.775 SEC
ITERATION 6	STANTON NO. = 1.85940E-02	SKIN FRICTION = 1.02376E+00	TIME LEFT =605.031 SEC
ITERATION 7	STANTON NO. = 1.85862E-02	SKIN FRICTION = 1.02335E+00	TIME LEFT =601.281 SEC
ITERATION 8	STANTON NO. = 1.85784E-02	SKIN FRICTION = 1.02294E+00	TIME LEFT =597.538 SEC
ITERATION 9	STANTON NO. = 1.85707E-02	SKIN FRICTION = 1.02254E+00	TIME LEFT =593.787 SEC
ITERATION 10	STANTON NO. = 1.85630E-02	SKIN FRICTION = 1.02213E+00	TIME LEFT =590.055 SEC
ITERATION 11	STANTON NO. = 1.85553E-02	SKIN FRICTION = 1.02172E+00	TIME LEFT =586.313 SEC
ITERATION 12	STANTON NO. = 1.85477E-02	SKIN FRICTION = 1.02131E+00	TIME LEFT =582.571 SEC
ITERATION 13	STANTON NO. = 1.85401E-02	SKIN FRICTION = 1.02091E+00	TIME LEFT =578.820 SEC
ITERATION 14	STANTON NO. = 1.85326E-02	SKIN FRICTION = 1.02050E+00	TIME LEFT =575.058 SEC
ITERATION 15	STANTON NO. = 1.85251E-02	SKIN FRICTION = 1.02010E+00	TIME LEFT =571.309 SEC
ITERATION 16	STANTON NO. = 1.85176E-02	SKIN FRICTION = 1.01969E+00	TIME LEFT =567.563 SEC
ITERATION 17	STANTON NO. = 1.85101E-02	SKIN FRICTION = 1.01929E+00	TIME LEFT =563.790 SEC
ITERATION 18	STANTON NO. = 1.85027E-02	SKIN FRICTION = 1.01889E+00	TIME LEFT =560.027 SEC
ITERATION 19	STANTON NO. = 1.84954E-02	SKIN FRICTION = 1.01849E+00	TIME LEFT =556.259 SEC

PROFILES AFTER 50 ITERATIONS. ....MAXIMUM NUMBER OF ITERATIONS DONE........

X(K)

N	ETA	1	2	3	4	5	6	7	8	9	10
1	0.0000	-6.5196E-03	-1.1646E+02	-4.5028E+02	-8.8906E+00	-4.6512E+00	-2.1723E-01	-2.1780E-01	-5.9094E-06	-1.1490E+01	0.
2	.0370	-3.6749E+00	-5.9742E+01	-1.8347E+02	-1.1582E+02	-8.8937E+00	-2.4876E+00	-1.0388E-01	-2.0999E-06	-7.0648E+00	-4.0351E+00
3	.0741	-1.1797E+01	-4.2891E+01	-1.2338E+02	-1.5644E+02	-2.3384E+00	-2.6149E+00	-5.9258E-02	6.6429E-06	-5.0236E+00	-1.2794E+01
4	.1111	-2.0242E+01	-3.5659E+01	-1.0793E+02	-1.8230E+02	1.9585E-01	-2.3140E+00	-4.0419E-02	2.1178E-05	-3.8343E+00	-1.7799E+01
5	.1481	-2.0529E+01	-2.4721E+01	-8.4103E+01	-1.5797E+02	6.7105E-01	-1.5610E+00	-3.0101E-02	2.7254E-05	-2.2449E+00	-8.4703E+00
6	.1852	-1.1522E+01	-1.0998E+01	-4.1659E+01	-8.4073E+01	4.3690E-01	-7.4387E-01	-2.0389E-02	1.7583E-05	-6.5115E-01	8.3360E+00
7	.2222	-2.4079E+00	-2.0763E+00	-5.7861E+00	-1.9109E+01	1.9697E-01	-3.3448E-01	-1.0985E-02	6.3337E-06	6.7874E-02	1.9331E+01
8	.2593	2.5222E+00	1.2661E+00	1.1007E+01	1.1915E+01	7.3940E-02	-1.9672E-01	-4.4503E-03	1.4192E-06	1.5876E-01	2.1754E+01
9	.2963	4.1956E+00	1.6820E+00	1.4091E+01	1.8526E+01	2.4639E-02	-1.2832E-01	-1.3419E-03	2.1028E-07	8.7401E-02	1.8817E+01
10	.3333	4.2162E+00	1.1140E+00	1.1421E+01	1.4245E+01	7.5162E-03	-7.3290E-02	-3.0332E-04	2.1162E-08	3.2410E-02	1.3935E+01
11	.3704	3.6397E+00	4.3190E-01	7.7317E+00	7.3888E+00	2.1788E-03	-3.4319E-02	-5.1797E-05	1.4547E-09	9.6177E-03	9.2916E+00
12	.4074	3.0403E+00	-7.4215E-02	4.8918E+00	1.7485E+00	6.2735E-04	-1.3180E-02	-6.6794E-06	6.7472E-11	2.5454E-03	5.8789E+00
13	.4444	2.6452E+00	-3.6618E-01	3.2336E+00	-1.6709E+00	1.7965E-04	-4.1958E-03	-6.4186E-07	2.0490E-12	6.4982E-04	3.8334E+00
14	.4815	2.4632E+00	-4.9701E-01	2.4869E+00	-3.2314E+00	4.7975E-05	-1.1123E-03	-4.4706E-08	3.8850E-14	1.6007E-04	2.8434E+00
15	.5185	2.4211E+00	-5.3380E-01	2.2751E+00	-3.6632E+00	1.1006E-05	-2.4383E-04	-2.1614E-09	4.3094E-16	3.5400E-05	2.4865E+00
16	.5556	2.4522E+00	-5.2466E-01	2.3246E+00	-3.5338E+00	2.0320E-06	-4.3264E-05	-6.8173E-11	2.5801E-18	6.4752E-06	2.4301E+00
17	.5926	2.5285E+00	-4.9125E-01	2.5112E+00	-3.1002E+00	2.8514E-07	-5.9795E-06	-1.2810E-12	9.7852E-21	9.1595E-07	2.4915E+00
18	.6296	2.6563E+00	-4.3434E-01	2.8292E+00	-2.3633E+00	2.8191E-08	-6.0006E-07	-1.2350E-14	2.5025E-22	9.2678E-08	2.6102E+00
19	.6667	2.8656E+00	-3.4155E-01	3.3476E+00	-1.1605E+00	1.6989E-09	-3.7693E-08	-4.5363E-17	1.3921E-23	5.8022E-09	2.7954E+00
20	.7037	3.2053E+00	-1.9131E-01	4.1863E+00	7.8765E-01	4.1868E-11	-9.5033E-10	-2.6196E-20	3.0192E-25	1.4531E-10	3.0895E+00
21	.7407	3.7459E+00	4.7611E-02	5.5190E+00	3.8849E+00	0.	0.	0.	0.	0.	3.5555E+00
22	.7778	4.5877E+00	4.1947E-01	7.5903E+00	8.7032E+00	-4.4130E-14	-4.8629E-13	2.0178E-26	1.7104E-28	9.7963E-14	4.2812E+00
23	.8148	5.8729E+00	9.8655E-01	1.0743E+01	1.6046E+01	0.	0.	0.	0.	0.	5.3888E+00
24	.8519	7.8004E+00	1.8357E+00	1.5448E+01	2.7031E+01	-5.2876E-16	-4.1402E-15	1.0078E-29	1.4003E-30	1.2055E-15	7.0488E+00
25	.8889	1.0649E+01	3.0875E+00	2.2353E+01	4.3203E+01	0.	0.	0.	0.	0.	9.4971E+00
26	.9259	1.4812E+01	4.9086E+00	3.2332E+01	6.6701E+01	-1.1687E-17	-8.5727E-17	1.8874E-32	3.0122E-32	4.6435E-17	1.3046E+01
27	.9630	2.0887E+01	7.5286E+00	4.6556E+01	1.0059E+02	0.	0.	0.	0.	0.	1.7860E+01
28	1.0000	3.0362E+01	1.1235E+01	6.6419E+01	1.5011E+02	0.	0.	0.	0.	0.	1.8383E+01

N	ETA	11	12	13	14	15	16	17	18	19	20
1	0.0000	2.2863E-01	-2.8057E+01	5.2070E-02	2.4906E-06	6.7236E-11	-8.9452E-01	1.2702E-03	-1.1668E-02	2.2766E-06	1.7650E-02
2	.0370	-1.7531E+02	-2.2605E+01	-9.0930E+00	1.6218E-04	-6.1359E-07	-1.9419E+00	1.5097E-01	-2.0722E-02	-4.5384E-01	-2.1577E+00
3	.0741	-2.8184E+02	-3.8036E+00	-9.7388E+00	1.2526E-03	-6.6505E-06	-2.3349E+00	4.7937E-01	-2.0125E-02	-1.7487E+00	-3.9832E+00
4	.1111	-2.3772E+02	-2.0883E+01	2.7497E+01	2.9605E-03	-1.1077E-05	-1.8568E+00	6.0724E-01	-1.3053E-02	-4.2581E+00	-4.4562E+00
5	.1481	-9.4940E+01	-6.3248E+01	7.8042E+01	3.1408E-03	1.2506E-05	-1.0127E+00	4.2047E-01	-5.8011E-03	-7.4169E+00	-4.0472E+00
6	.1852	2.5281E+01	-8.1562E+01	9.1009E+01	1.9616E-03	3.1017E-05	-4.0038E-01	1.9397E-01	-1.8317E-03	-9.7011E+00	-3.8394E+00
7	.2222	8.2803E+01	-6.5500E+01	6.7916E+01	8.9220E-04	2.3067E-05	-1.1946E-01	6.8876E-02	-4.5236E-04	-9.7409E+00	-3.5420E+00
8	.2593	9.3480E+01	-3.7694E+01	3.7229E+01	3.3411E-04	8.4647E-06	-2.3978E-02	1.9770E-02	-9.7517E-05	-7.7825E+00	-2.8277E+00
9	.2963	7.8819E+01	-1.6750E+01	1.6037E+01	1.0831E-04	3.5939E-07	1.5908E-04	4.2213E-03	-1.9781E-05	-5.0798E+00	-1.8714E+00
10	.3333	5.4961E+01	-6.1309E+00	5.7960E+00	3.1414E-05	-1.5546E-06	3.1408E-03	3.6885E-04	-3.7340E-06	-2.7411E+00	-1.0177E+00
11	.3704	3.2219E+01	-1.9962E+00	1.9170E+00	8.7272E-06	-1.0976E-06	1.9057E-03	-1.9358E-04	-6.0606E-07	-1.2311E+00	-4.5654E-01
12	.4074	1.5472E+01	-6.1952E-01	6.2141E-01	2.5354E-06	-4.6517E-07	7.7514E-04	-1.2398E-04	-7.8215E-08	-4.6313E-01	-1.7047E-01

13	.4444	5.4535E+00	-1.8481E-01	1.9424E-01	7.6663E-07	-1.4646E-07	2.4705E-04	-4.2781E-05	-7.6124E-09	-1.4650E-01	-5.3390E-02
14	.4815	6.3264E-01	-5.0048E-02	5.4052E-02	2.1586E-07	-3.6992E-08	6.4385E-05	-1.0851E-05	-5.3660E-10	-3.8881E-02	-1.4038E-02
15	.5185	-1.0923E+00	-1.1461E-02	1.2391E-02	5.0803E-08	-7.7950E-09	1.3818E-05	-2.1889E-06	-2.6217E-11	-8.5502E-03	-3.0680E-03
16	.5556	-1.3734E+00	-2.0970E-03	2.1918E-03	9.2960E-09	-1.3959E-09	2.4020E-06	-3.5880E-07	-8.3754E-13	-1.5197E-03	-5.4458E-04
17	.5926	-1.1112E+00	-2.9095E-04	2.7376E-04	1.2293E-09	-2.1253E-10	3.2483E-07	-4.6932E-08	-1.6077E-14	-2.0950E-04	-7.5512E-05
18	.6296	-6.0321E-01	-2.8324E-05	2.0712E-05	1.0541E-10	-2.5717E-11	3.1746E-08	-4.5957E-09	-1.6060E-16	-2.0850E-05	-7.6277E-06
19	.6667	1.8520E-01	-1.6561E-06	6.6251E-07	4.7929E-12	-2.0266E-12	1.9353E-09	-2.9110E-10	-6.2046E-19	-1.2927E-06	-4.8396E-07
20	.7037	1.4371E+00	-3.6656E-08	4.7417E-10	7.6018E-14	-6.1513E-14	4.6946E-11	-7.2086E-12	-3.8743E-22	-3.2208E-08	-1.2358E-08
21	.7407	3.4229E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
22	.7778	6.5139E+00	-1.9040E-11	-2.2097E-11	-2.9995E-16	-4.6879E-17	7.5858E-14	-3.3531E-14	-2.2128E-30	-1.6210E-11	-6.5701E-12
23	.8148	1.1222E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	.8519	1.8247E+01	-1.2590E-13	-3.3821E-13	-3.7653E-18	-5.1166E-19	7.9138E-16	-3.7098E-16	1.6449E-33	-1.4118E-13	-5.9708E-14
25	.8889	2.8505E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	.9259	4.2899E+01	-1.9703E-15	-1.0199E-14	-9.9892E-20	-1.3587E-20	1.9033E-17	-9.1088E-18	1.0651E-36	-3.2364E-15	-1.4032E-15
27	.9630	5.9272E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	1.0000	4.1842E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.

N	ETA	21	22	23	24	25	26
1	0.0000	2.8215E-03	6.4044E-17	-4.2412E-03	-3.8104E-08	-3.1291E-07	-4.0929E+00
2	.0370	-3.9740E-01	-1.2363E-09	-1.0027E-01	-1.9104E-06	-2.5926E-08	-4.0918E+00
3	.0741	-7.7930E-01	5.2174E-08	-6.7959E-02	6.3678E-06	2.7200E-07	-4.9534E+00
4	.1111	-8.1732E-01	2.9699E-06	-4.2764E-02	2.0802E-05	1.3096E-07	-4.0011E+00
5	.1481	-5.0998E-01	1.7907E-05	-3.0382E-02	2.7106E-05	4.7744E-08	-1.5588E+00
6	.1852	-2.7145E-01	2.8676E-05	-2.0719E-02	1.7527E-05	1.1636E-08	5.1974E-01
7	.2222	-2.0300E-01	2.0562E-05	-1.1513E-02	6.3214E-06	1.8443E-09	1.4656E+00
8	.2593	-1.8555E-01	8.9163E-06	-4.8192E-03	1.4179E-06	1.9979E-10	1.6051E+00
9	.2963	-1.4576E-01	2.6997E-06	-1.4993E-03	2.1026E-07	1.4719E-11	1.3414E+00
10	.3333	-8.9669E-02	6.0710E-07	-3.5012E-04	2.1173E-08	7.0145E-13	9.2732E-01
11	.3704	-4.3392E-02	1.0376E-07	-6.2081E-05	1.4557E-09	2.0458E-14	5.3860E-01
12	.4074	-1.6869E-02	1.3483E-08	-8.3912E-06	6.7477E-11	3.4785E-16	2.6523E-01
13	.4444	-5.3707E-03	1.3097E-09	-8.5763E-07	2.0457E-12	3.2770E-18	1.1161E-01
14	.4815	-1.4155E-03	9.2130E-11	-6.4862E-08	3.8660E-14	1.6024E-20	3.9845E-02
15	.5185	-3.0792E-04	4.4833E-12	-3.5032E-09	4.2614E-16	3.7197E-23	1.0544E-02
16	.5556	-5.4182E-05	1.4162E-13	-1.2849E-10	2.5045E-18	3.6942E-26	-1.5074E-03
17	.5926	-7.4012E-06	2.6461E-15	-2.9815E-12	6.8566E-21	2.9786E-29	-8.7855E-03
18	.6296	-7.2990E-07	2.5121E-17	-3.9194E-14	1.4362E-24	1.6749E-31	-1.6889E-02
19	.6667	-4.4942E-08	8.9851E-20	-2.3935E-16	-3.3812E-25	5.8134E-34	-2.8935E-02
20	.7037	-1.1277E-09	4.9768E-23	-4.1443E-19	-7.3683E-27	3.0675E-37	-4.7790E-02
21	.7407	0.	0.	0.	0.	0.	-7.7057E-02
22	.7778	-5.2017E-13	-6.7280E-29	-1.0201E-23	-4.1482E-30	8.2188E-44	-1.2165E-01
23	.8148	0.	0.	0.	0.	0.	-1.8830E-01
24	.8519	-4.5363E-15	-3.0754E-32	-4.0270E-27	-3.3478E-32	5.4684E-48	-2.8601E-01
25	.8889	0.	0.	0.	0.	0.	-4.2598E-01
26	.9259	-1.0413E-16	-5.7646E-35	-7.1728E-30	-6.9855E-34	2.4826E-51	-6.1860E-01
27	.9630	0.	0.	0.	0.	0.	-8.5895E-01
28	1.0000	0.	0.	0.	0.	0.	-1.0886E+00

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+	CO	CO2
1	0.0000	0.	4.2749E-01	0.	6.3145E-01	1.0096E-03	5.9875E-02	0.	3.1010E-05	3.0341E-01	6.6645E-04
2	.0370	1.4167E-01	5.7486E-01	2.8884E-06	6.4162E-01	2.8434E-02	6.3669E-02	2.7714E-04	4.5624E-05	2.6159E-01	6.1303E-04
3	.0741	2.7931E-01	7.0866E-01	1.6479E-05	6.4722E-01	5.8110E-02	7.2699E-02	1.4563E-03	8.8248E-05	2.1583E-01	4.2661E-04
4	.1111	4.0222E-01	8.1885E-01	6.9653E-05	6.4727E-01	8.8121E-02	8.6896E-02	4.3084E-03	1.6636E-04	1.6828E-01	2.4516E-04
5	.1481	5.0222E-01	8.9697E-01	1.6880E-04	6.4181E-01	1.1703E-01	1.0538E-01	7.8736E-03	2.7206E-04	1.2252E-01	1.2477E-04
6	.1852	5.7616E-01	9.4434E-01	2.6721E-04	6.3234E-01	1.4386E-01	1.2548E-01	1.0646E-02	3.8354E-04	8.2655E-02	6.0629E-05
7	.2222	6.2671E-01	9.7006E-01	3.3906E-04	6.2110E-01	1.6762E-01	1.4347E-01	1.2340E-02	4.8086E-04	5.1364E-02	2.9450E-05
8	.2593	6.6036E-01	9.8308E-01	3.9120E-04	6.1016E-01	1.8754E-01	1.5668E-01	1.3360E-02	5.5441E-04	2.9216E-02	1.4354E-05
9	.2963	6.8412E-01	9.8908E-01	4.3290E-04	6.0088E-01	2.0320E-01	1.6461E-01	1.4040E-02	6.0340E-04	1.5087E-02	6.8387E-06
10	.3333	7.0318E-01	9.9130E-01	4.6683E-04	5.9386E-01	2.1458E-01	1.6838E-01	1.4522E-02	6.3216E-04	7.0028E-03	3.0714E-06
11	.3704	7.2042E-01	9.9174E-01	4.9232E-04	5.8911E-01	2.2211E-01	1.6967E-01	1.4850E-02	6.4700E-04	2.8883E-03	1.2572E-06
12	.4074	7.3707E-01	9.9154E-01	5.0904E-04	5.8625E-01	2.2654E-01	1.6987E-01	1.5052E-02	6.5374E-04	1.0451E-03	4.5635E-07
13	.4444	7.5357E-01	9.9127E-01	5.1837E-04	5.8473E-01	2.2883E-01	1.6975E-01	1.5160E-02	6.5644E-04	3.2699E-04	1.4364E-07
14	.4815	7.7002E-01	9.9111E-01	5.2269E-04	5.8405E-01	2.2983E-01	1.6964E-01	1.5209E-02	6.5741E-04	8.6928E-05	3.8392E-08
15	.5185	7.8647E-01	9.9105E-01	5.2432E-04	5.8381E-01	2.3018E-01	1.6958E-01	1.5228E-02	6.5773E-04	1.9196E-05	8.5109E-09
16	.5556	8.0291E-01	9.9105E-01	5.2483E-04	5.8374E-01	2.3028E-01	1.6956E-01	1.5235E-02	6.5784E-04	3.4134E-06	1.5171E-09
17	.5926	8.1935E-01	9.9108E-01	5.2503E-04	5.8373E-01	2.3029E-01	1.6955E-01	1.5238E-02	6.5791E-04	4.6683E-07	2.0775E-10
18	.6296	8.3579E-01	9.9112E-01	5.2524E-04	5.8374E-01	2.3029E-01	1.6954E-01	1.5242E-02	6.5799E-04	4.5538E-08	2.0272E-11
19	.6667	8.5223E-01	9.9120E-01	5.2559E-04	5.8376E-01	2.3028E-01	1.6953E-01	1.5250E-02	6.5811E-04	2.7326E-09	1.2159E-12
20	.7037	8.6867E-01	9.9132E-01	5.2618E-04	5.8379E-01	2.3027E-01	1.6950E-01	1.5261E-02	6.5831E-04	6.5576E-11	2.9194E-14
21	.7407	8.8510E-01	9.9151E-01	5.2713E-04	5.8383E-01	2.3026E-01	1.6945E-01	1.5280E-02	6.5862E-04	0.	0.
22	.7778	9.0154E-01	9.9180E-01	5.2860E-04	5.8389E-01	2.3024E-01	1.6937E-01	1.5310E-02	6.5910E-04	2.9985E-14	1.0642E-17
23	.8148	9.1797E-01	9.9225E-01	5.3084E-04	5.8398E-01	2.3022E-01	1.6926E-01	1.5355E-02	6.5983E-04	0.	0.
24	.8519	9.3439E-01	9.9291E-01	5.3421E-04	5.8412E-01	2.3018E-01	1.6908E-01	1.5422E-02	6.6091E-04	2.3693E-16	7.5646E-20
25	.8889	9.5081E-01	9.9388E-01	5.3917E-04	5.8433E-01	2.3012E-01	1.6883E-01	1.5520E-02	6.6249E-04	0.	0.
26	.9259	9.6722E-01	9.9528E-01	5.4640E-04	5.8463E-01	2.3003E-01	1.6846E-01	1.5663E-02	6.6474E-04	4.9437E-18	1.5118E-21
27	.9630	9.8362E-01	9.9726E-01	5.5698E-04	5.8505E-01	2.2991E-01	1.6794E-01	1.5870E-02	6.6788E-04	0.	0.
28	1.0000	1.0000E+00	1.0000E+00	5.7454E-04	5.8561E-01	2.2972E-01	1.6723E-01	1.6190E-02	6.7207E-04	0.	0.

N	ETA	C1	C2	C3	CN
1	0.0000	3.3297E-03	1.8069E-07	2.4342E-11	2.2873E-04
2	.0370	3.3680E-03	1.5295E-07	2.0919E-11	3.7215E-04
3	.0741	3.3521E-03	6.2630E-08	9.6933E-12	7.9343E-04
4	.1111	3.3736E-03	4.8679E-08	2.7118E-12	1.2686E-03
5	.1481	3.3261E-03	4.6435E-08	9.2133E-13	1.4853E-03
6	.1852	2.9743E-03	3.3570E-08	2.9572E-13	1.3322E-03
7	.2222	2.2919E-03	1.7200E-08	7.5075E-14	9.6598E-04
8	.2593	1.4993E-03	6.4409E-09	1.4194E-14	5.9078E-04
9	.2963	8.3545E-04	1.8167E-09	1.9477E-15	3.1235E-04
10	.3333	4.0002E-04	3.9313E-10	1.9056E-16	1.4449E-04
11	.3704	1.6579E-04	6.5743E-11	1.3028E-17	5.8726E-05
12	.4074	5.9592E-05	8.4562E-12	6.0578E-19	2.0913E-05
13	.4444	1.8478E-05	8.2176E-13	1.8458E-20	6.4627E-06
14	.4815	4.8775E-06	5.8506E-14	3.5068E-22	1.7050E-06
15	.5185	1.0727E-06	2.9224E-15	3.8924E-24	3.7514E-07
16	.5556	1.9058E-07	9.6637E-17	2.3302E-26	6.6686E-08
17	.5926	2.6140E-08	1.9525E-18	8.8181E-29	9.1498E-09
18	.6296	2.5695E-09	2.1316E-20	2.2432E-30	8.9943E-10
19	.6667	1.5614E-10	1.0131E-22	1.2465E-31	5.4639E-11
20	.7037	3.8024E-12	1.2628E-25	2.6992E-33	1.3291E-12
21	.7407	0.	0.	0.	0.
22	.7778	1.8064E-15	2.4968E-30	1.5197E-36	6.3398E-16
23	.8148	0.	0.	0.	0.
24	.8519	1.4829E-17	9.8417E-34	1.2268E-38	5.2160E-18
25	.8889	0.	0.	0.	0.
26	.9259	3.1975E-19	1.7535E-36	2.5613E-40	1.1341E-19
27	.9630	0.	0.	0.	0.
28	1.0000	0.	0.	0.	0.

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	8.9576E-02	0.	1.2400E-03	3.9788E+14	5.0284E+07
2	.0370	4.5575E-04	5.0037E-02	0.	9.0142E-04	4.2555E+14	7.3213E+07
3	.0741	1.0551E-03	-6.7584E-02	0.	7.1079E-04	6.4905E+14	9.7545E+07
4	.1111	1.7907E-03	-2.5796E-01	0.	5.9567E-04	1.0254E+15	1.2183E+08
5	.1481	2.6445E-03	-5.1040E-01	0.	5.2565E-04	1.4798E+15	1.4422E+08
6	.1852	3.5909E-03	-8.1103E-01	0.	4.8330E-04	1.9181E+15	1.6317E+08
7	.2222	4.6040E-03	-1.1459E+00	0.	4.5763E-04	2.2770E+15	1.7784E+08
8	.2593	5.6625E-03	-1.5039E+00	0.	4.4217E-04	2.5366E+15	1.8815E+08
9	.2963	6.7500E-03	-1.8776E+00	0.	4.3324E-04	2.7050E+15	1.9468E+08
10	.3333	7.8543E-03	-2.2630E+00	0.	4.2847E-04	2.8027E+15	1.9836E+08
11	.3704	8.9675E-03	-2.6585E+00	0.	4.2616E-04	2.8531E+15	2.0021E+08
12	.4074	1.0085E-02	-3.0634E+00	0.	4.2518E-04	2.8761E+15	2.0102E+08
13	.4444	1.1204E-02	-3.4775E+00	0.	4.2481E-04	2.8855E+15	2.0134E+08
14	.4815	1.2324E-02	-3.9007E+00	0.	4.2468E-04	2.8889E+15	2.0145E+08
15	.5185	1.3443E-02	-4.3330E+00	0.	4.2464E-04	2.8900E+15	2.0148E+08
16	.5556	1.4563E-02	-4.7745E+00	0.	4.2463E-04	2.8904E+15	2.0149E+08
17	.5926	1.5683E-02	-5.2252E+00	0.	4.2461E-04	2.8906E+15	2.0149E+08
18	.6296	1.6803E-02	-5.6849E+00	0.	4.2460E-04	2.8908E+15	2.0149E+08
19	.6667	1.7923E-02	-6.1538E+00	0.	4.2457E-04	2.8912E+15	2.0149E+08
20	.7037	1.9043E-02	-6.6318E+00	0.	4.2453E-04	2.8918E+15	2.0149E+08
21	.7407	2.0164E-02	-7.1190E+00	0.	4.2447E-04	2.8928E+15	2.0149E+08
22	.7778	2.1284E-02	-7.6153E+00	0.	4.2437E-04	2.8942E+15	2.0150E+08
23	.8148	2.2405E-02	-8.1207E+00	0.	4.2423E-04	2.8964E+15	2.0150E+08
24	.8519	2.3526E-02	-8.6352E+00	0.	4.2401E-04	2.8997E+15	2.0150E+08
25	.8889	2.4648E-02	-9.1589E+00	0.	4.2369E-04	2.9044E+15	2.0150E+08
26	.9259	2.5771E-02	-9.6917E+00	0.	4.2323E-04	2.9111E+15	2.0151E+08
27	.9630	2.6896E-02	-1.0234E+01	0.	4.2259E-04	2.9205E+15	2.0152E+08
28	1.0000	2.8022E-02	-1.0785E+01	-1.8226E-01	4.2171E-04	2.9327E+15	2.0152E+08

TIME LEFT =439.613 SEC
QCOND = -1.15002E+06
QDIFF = -6.91222E+05
QCONV = 1.02844E+05
QTOTAL = -1.73840E+06
QTOTAL(BTU/FT2-SEC) = -2.23400E+03
STANTON NUMBER = 1.82902E-02

RHO V = 2.04528E-03
HEAT TRANSFER = 5.43769E-01
HEAT TRANSFER, BODY = 4.88064E-01
DISPLACEMENT THICKNESS/RN = 5.94924E-03
MOMENTUM THICKNESS = 3.74320E-04
L AT BODY = 1.37681E+00
SKIN FRICTION = 1.00718E+00

SPECIES	WALL MASS FLUX
O2	2.55276E-07
N2	-8.62125E-07
O	-2.72395E-03
N	5.49916E-07
NO	1.80228E-05
NO+	2.84433E-10
CO	4.75122E-03
CO2	6.06793E-09
C1	3.06552E-08
C2	1.67377E-12
C3	2.26254E-16
CN	2.10576E-09

CTH = 1.00000E+00, BODY PROFILES.

1-TH BODY PROFILE.   S = 1.0000E-02

RHOMUREF = 1.62528E-09

INTERPOLATED EDGE CONDITIONS

PE =	1.26470E+04	XO =	0.	LAMBDA =	0.	DELXI =	3.12886E-17
TE =	1.26260E+04	X 1/2 =	4.16667E-04	LAMBDA 1/2 =	1.87729E-14	XIO =	0.
UE =	1.33070E+02	X1 =	8.33333E-04	LAMBDA + 1 =	1.50187E-13	XI 1/2 =	1.56443E-17
DPEO =	0.	RBO =	0.	BETA =	4.99996E-01	XI1 =	3.12886E-17
DPE1 =	-2.67292E+03	RB 1/2 =	4.16665E-04	MU =	3.85228E-06	SMALL E =	3.13116E-06
BEB =	-1.49107E-01	RB1 =	8.33319E-04	RHOE =	4.21900E-04	EBAR =	-6.51601E-04
ETE =	1.50000E+01						

RHOMUREF = 1.62561E-09

X(K)

N	ETA	1	2	3	4	5	6	7	8	9	10
1	0.0000	-6.5383E-03	-1.1549E+02	-4.4454E+02	-8.8470E+00	-4.7015E+00	-2.1607E-01	-2.1488E-01	-5.7572E-06	-1.1362E+01	0.
2	.0370	-3.7053E+00	-5.9473E+01	-1.8212E+02	-1.1602E+02	-9.1100E+00	-2.4875E+00	-1.0291E-01	-2.0651E-06	-7.0088E+00	-4.0860E+00
3	.0741	-1.1930E+01	-4.2767E+01	-1.2273E+02	-1.5718E+02	-2.4426E+00	-2.6219E+00	-5.8825E-02	6.2305E-06	-4.9939E+00	-1.3128E+01
4	.1111	-2.0559E+01	-3.5701E+01	-1.0778E+02	-1.8387E+02	1.4836E-01	-2.3301E+00	-4.0153E-02	2.0238E-05	-3.8275E+00	-1.9135E+01
5	.1481	-2.1019E+01	-2.5103E+01	-8.5199E+01	-1.6083E+02	6.5597E-01	-1.5859E+00	-2.9917E-02	2.6436E-05	-2.2726E+00	-1.0847E+01
6	.1852	-1.1954E+01	-1.1485E+01	-4.3514E+01	-8.7032E+01	4.3361E-01	-7.5287E-01	-2.0283E-02	1.7272E-05	-6.8533E-01	6.3109E+00
7	.2222	-2.5990E+00	-2.3438E+00	-7.0229E+00	-2.0603E+01	1.9523E-01	-3.2048E-01	-1.0950E-02	6.2797E-06	5.0678E-02	1.8520E+01
8	.2593	2.5411E+00	1.2215E+00	1.0733E+01	1.1891E+01	7.1694E-02	-1.7549E-01	-4.4510E-03	1.4153E-06	1.5253E-01	2.1792E+01
9	.2963	4.2699E+00	1.6896E+00	1.4092E+01	1.8829E+01	2.2370E-02	-1.1189E-01	-1.3485E-03	2.1030E-07	8.3494E-02	1.8853E+01
10	.3333	4.1892E+00	1.0315E+00	1.0945E+01	1.3733E+01	5.7883E-03	-6.3826E-02	-3.0660E-04	2.1185E-08	2.9055E-02	1.3325E+01
11	.3704	3.4279E+00	2.0883E-01	6.4784E+00	5.5588E+00	1.1339E-03	-2.9709E-02	-5.2712E-05	1.4564E-09	7.3551E-03	7.8569E+00
12	.4074	2.6472E+00	-4.1959E-01	2.9549E+00	-1.2827E+00	1.1126E-04	-1.1176E-02	-6.8479E-06	6.7533E-11	1.3958E-03	3.7887E+00
13	.4444	2.1250E+00	-7.8964E-01	8.6017E-01	-5.4937E+00	-3.1376E-05	-3.4155E-03	-6.6344E-07	2.0504E-12	1.8834E-04	1.3707E+00
14	.4815	1.8770E+00	-9.5791E-01	-9.5200E-02	-7.4438E+00	-2.3740E-05	-8.4681E-04	-4.6645E-08	3.8873E-14	8.6718E-06	2.3349E-01
15	.5185	1.8107E+00	-1.0067E+00	-3.7338E-01	-8.0065E+00	-9.1381E-06	-1.6743E-04	-2.2813E-09	4.3101E-16	-5.7134E-06	-1.5161E-01
16	.5556	1.8380E+00	-9.9825E-01	-3.2757E-01	-7.8907E+00	-2.5666E-06	-2.5271E-05	-7.3051E-11	2.5608E-18	-2.7003E-06	-1.9756E-01
17	.5926	1.9171E+00	-9.6257E-01	-1.2799E-01	-7.4367E+00	-5.4193E-07	-2.6358E-06	-1.4021E-12	7.2253E-21	-7.2481E-07	-1.2462E-01
18	.6296	2.0491E+00	-9.0339E-01	2.0328E-01	-6.6759E+00	-8.3043E-08	-1.3634E-07	-1.3989E-14	8.1055E-24	-1.3161E-07	-2.8897E-03
19	.6667	2.2631E+00	-8.0868E-01	7.3321E-01	-5.4492E+00	-8.4884E-09	5.8047E-09	-5.5253E-17	4.4715E-27	-1.5794E-08	1.7712E-01
20	.7037	2.6084E+00	-6.5665E-01	1.5834E+00	-3.4749E+00	-4.7403E-10	1.2682E-09	-4.1719E-20	4.0118E-29	-1.1058E-09	4.5773E-01
21	.7407	3.1558E+00	-4.1606E-01	2.9276E+00	-3.4800E-01	-3.1998E-12	4.4349E-12	8.4292E-24	1.9138E-31	-3.7852E-12	8.9906E-01
22	.7778	4.0059E+00	-4.3124E-02	5.0086E+00	4.5011E+00	1.1978E-13	-9.0970E-13	-1.7574E-27	2.3360E-32	9.7890E-13	1.5823E+00
23	.8148	5.2996E+00	5.2331E-01	8.1629E+00	1.1868E+01	-4.3778E-15	1.7933E-14	6.1906E-28	0.	0.	2.6184E+00
24	.8519	7.2337E+00	1.3677E+00	1.2851E+01	2.2850E+01	1.1543E-15	-9.5216E-15	-2.2734E-31	1.9619E-34	5.0100E-15	4.1575E+00
25	.8889	1.0081E+01	2.6053E+00	1.9692E+01	3.8948E+01	0.	0.	2.9301E-31	0.	0.	6.3950E+00
26	.9259	1.4222E+01	4.3931E+00	2.9510E+01	6.2197E+01	1.9060E-17	-1.8956E-16	-1.2367E-34	4.2549E-36	9.9180E-17	9.5369E+00
27	.9630	2.0211E+01	6.9458E+00	4.3401E+01	9.5318E+01	0.	0.	3.5109E-34	0.	0.	1.3457E+01
28	1.0000	2.8805E+01	1.0580E+01	6.2930E+01	1.4156E+02	0.	0.	0.	0.	0.	1.7042E+01

N	ETA	11	12	13	14	15	16	17	18	19	20
1	0.0000	2.2758E-01	-2.7678E+01	5.4510E-02	2.5022E-06	6.7039E-11	-9.0153E-01	1.2864E-03	-1.1732E-02	2.2831E-06	1.7633E-02
2	.0370	-1.7775E+02	-2.2964E+01	-9.1593E+00	1.5998E-04	-6.1178E-07	-1.9505E+00	1.5197E-01	-2.0782E-02	-4.5835E-01	-2.1755E+00
3	.0741	-3.0240E+02	-7.1436E+00	-1.1025E+01	1.2335E-03	-6.9698E-06	-2.3463E+00	4.8279E-01	-2.0205E-02	-1.7857E+00	-4.1045E+00
4	.1111	-2.9505E+02	-2.7327E+01	2.4448E+01	2.9297E-03	-1.4225E-05	-1.8710E+00	6.1374E-01	-1.3158E-02	-4.4163E+00	-4.6957E+00
5	.1481	-1.7323E+02	-6.9382E+01	7.7692E+01	3.1335E-03	7.6341E-06	-1.0237E+00	4.2651E-01	-5.8713E-03	-7.6165E+00	-4.1851E+00
6	.1852	-3.8635E+01	-8.4055E+01	9.7574E+01	1.9779E-03	3.2467E-05	-4.0409E-01	1.9664E-01	-1.8428E-03	-9.6937E+00	-3.7106E+00
7	.2222	4.9514E+01	-6.4649E+01	7.9337E+01	9.1255E-04	3.1182E-05	-1.1811E-01	6.8852E-02	-4.4017E-04	-9.5105E+00	-3.2317E+00
8	.2593	8.3400E+01	-3.5667E+01	4.8740E+01	3.4890E-04	1.7747E-05	-2.0986E-02	1.8656E-02	-8.7556E-05	-7.4904E+00	-2.5055E+00
9	.2963	7.5067E+01	-1.4998E+01	2.4666E+01	1.1686E-04	7.3219E-06	2.8502E-03	3.0352E-03	-1.5582E-05	-4.8468E+00	-1.6344E+00
10	.3333	4.3783E+01	-5.0136E+00	1.1081E+01	3.5714E-05	2.6005E-06	4.9523E-03	-4.9721E-04	-2.5015E-06	-2.5966E+00	-8.7716E-01
11	.3704	7.9692E+00	-1.3916E+00	4.6820E+00	1.0677E-05	1.0267E-06	2.9172E-03	-7.0070E-04	-3.3479E-07	-1.1556E+00	-3.8520E-01
12	.4074	-2.0703E+01	-3.3280E-01	1.8789E+00	3.3442E-06	4.8881E-07	1.2557E-03	-3.7116E-04	-3.2785E-08	-4.2883E-01	-1.3867E-01
13	.4444	-3.8470E+01	-6.6526E-02	6.9053E-01	1.0718E-06	2.2886E-07	4.4143E-04	-1.4390E-04	-1.9055E-09	-1.3293E-01	-4.0959E-02
14	.4815	-4.6964E+01	-8.3962E-03	2.2182E-01	3.1806E-07	9.0167E-08	1.3074E-04	-4.5479E-05	-1.4875E-11	-3.4266E-02	-9.8474E-03
15	.5185	-4.9782E+01	8.0381E-04	6.0014E-02	8.0194E-08	2.8454E-08	3.2658E-05	-1.2013E-05	7.0861E-12	-7.2334E-03	-1.8786E-03
16	.5556	-5.0051E+01	8.5556E-04	1.3260E-02	1.6313E-08	7.0668E-09	6.7543E-06	-2.6236E-06	5.6836E-13	-1.2124E-03	-2.6814E-04
17	.5926	-4.9533E+01	2.7313E-04	2.3094E-03	2.5701E-09	1.3506E-09	1.1167E-06	-4.5803E-07	2.0284E-14	-1.5288E-04	-2.4739E-05
18	.6296	-4.8828E+01	5.3333E-05	3.0172E-04	2.9937E-10	1.9090E-10	1.3947E-07	-6.0388E-08	3.5025E-16	-1.3063E-05	-6.5611E-07
19	.6667	-4.7929E+01	6.6187E-06	2.7202E-05	2.4136E-11	1.8502E-11	1.1929E-08	-5.4527E-09	2.5208E-18	-5.7144E-07	1.6442E-07
20	.7037	-4.6632E+01	4.6653E-07	1.4075E-06	1.1851E-12	1.0300E-12	5.6261E-10	-2.7235E-10	4.7480E-21	3.5353E-09	2.0476E-08
21	.7407	-4.4674E+01	1.6493E-09	5.4349E-09	-1.3724E-15	3.9351E-15	3.3760E-12	-1.7076E-12	1.0187E-25	-6.9519E-12	7.2266E-11
22	.7778	-4.1746E+01	-3.9575E-10	-5.1229E-10	-7.3404E-16	-4.2820E-16	-9.8173E-14	5.4735E-14	-9.3194E-29	-2.0115E-11	-1.2835E-11
23	.8148	-3.7475E+01	0.	8.0190E-12	0.	6.2985E-18	4.1793E-15	-2.2050E-15	7.9503E-32	3.1708E-13	2.5724E-13
24	.8519	-3.1430E+01	-1.8141E-12	-4.0327E-12	-5.0410E-18	-3.4241E-18	-9.1244E-16	5.1578E-16	-1.1737E-32	-2.1744E-13	-1.3552E-13
25	.8889	-2.3187E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	.9259	-1.2358E+01	-2.7275E-14	-7.3842E-14	-1.0998E-19	-6.4869E-20	-1.3154E-17	7.7608E-18	-5.6725E-36	-4.6729E-15	-2.7820E-15
27	.9630	2.5883E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	1.0000	3.9675E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.

N	ETA	21	22	23	24	25	26
1	0.0000	2.7988E-03	6.4169E-17	-4.1622E-03	-3.3851E-08	-3.0059E-07	-4.0742E+00
2	.0370	-4.0063E-01	-1.2156E-09	-9.8486E-02	-1.9042E-06	-2.5506E-08	-4.0978E+00
3	.0741	-8.0102E-01	4.8554E-08	-6.7000E-02	6.0892E-06	2.6277E-07	-5.0715E+00
4	.1111	-8.6766E-01	2.8365E-06	-4.2627E-02	2.0372E-05	1.2798E-07	-4.3995E+00
5	.1481	-5.6767E-01	1.7566E-05	-3.0156E-02	2.6885E-05	4.7088E-08	-2.2330E+00
6	.1852	-3.1441E-01	2.8908E-05	-1.9922E-02	1.7576E-05	1.1598E-08	-1.6896E-01
7	.2222	-2.3101E-01	2.1225E-05	-1.0661E-02	6.4037E-06	1.8596E-09	1.0230E+00
8	.2593	-2.0610E-01	9.3861E-06	-4.3211E-03	1.4506E-06	2.0326E-10	1.4529E+00
9	.2963	-1.6200E-01	2.8909E-06	-1.3060E-03	2.1729E-07	1.5043E-11	1.3226E+00
10	.3333	-1.0128E-01	6.6136E-07	-2.9567E-04	2.2129E-08	7.1832E-13	8.3728E-01
11	.3704	-5.0325E-02	1.1533E-07	-5.0481E-05	1.5416E-09	2.0988E-14	2.5493E-01
12	.4074	-2.0288E-02	1.5374E-08	-6.5045E-06	7.2602E-11	3.5786E-16	-2.2335E-01
13	.4444	-6.7730E-03	1.5437E-09	-6.2689E-07	2.2444E-12	3.3845E-18	-5.2503E-01
14	.4815	-1.8961E-03	1.1336E-10	-4.4306E-08	4.3465E-14	1.6623E-20	-6.7493E-01
15	.5185	-4.4494E-04	5.8331E-12	-2.2281E-09	4.9456E-16	3.8690E-23	-7.3182E-01
16	.5556	-8.6192E-05	1.9847E-13	-7.6663E-11	3.0352E-18	3.7336E-26	-7.4619E-01
17	.5926	-1.3358E-05	4.1128E-15	-1.7202E-12	8.9273E-21	1.2010E-29	-7.4720E-01
18	.6296	-1.5734E-06	4.5685E-17	-2.3602E-14	1.0547E-23	7.9254E-34	-7.4686E-01
19	.6667	-1.2893E-07	2.1616E-19	-1.7775E-16	3.7004E-27	6.9443E-38	-7.4873E-01
20	.7037	-6.1740E-09	2.5357E-22	-5.6682E-19	-7.4972E-31	5.1207E-41	-7.5425E-01
21	.7407	-2.3530E-11	-2.3061E-26	-3.6161E-21	-4.6803E-33	1.0810E-45	-7.6549E-01
22	.7778	3.2401E-12	0.	0.	-5.6956E-34	5.9934E-48	-7.8608E-01
23	.8148	0.	-1.8505E-30	-2.3979E-25	2.0144E-43	-3.5141E-56	-8.2174E-01
24	.8519	1.2280E-14	4.8709E-36	8.8596E-32	-4.7146E-36	5.6741E-52	-8.8050E-01
25	.8889	0.	-8.8522E-34	-1.1192E-28	0.	-7.6635E-63	-9.7137E-01
26	.9259	1.4902E-16	1.8583E-38	1.2695E-34	-9.9185E-38	2.8169E-55	-1.0950E+00
27	.9630	0.	-1.0819E-36	-1.3038E-31	0.	-1.0424E-68	-1.2004E+00
28	1.0000	0.	0.	0.	0.	0.	-1.0002E+00

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+	CO	CO2
1	0.0000	0.	4.2759E-01	0.	6.2955E-01	1.0104E-03	5.9588E-02	0.	3.0926E-05	3.0561E-01	6.7516E-04
2	.0370	1.3391E-01	5.7409E-01	2.9330E-06	6.3983E-01	2.8469E-02	6.3363E-02	2.7841E-04	4.5506E-05	2.6368E-01	6.2122E-04
3	.0741	2.6637E-01	7.0726E-01	1.6696E-05	6.4552E-01	5.8204E-02	7.2337E-02	1.4618E-03	8.8027E-05	2.1782E-01	4.3278E-04
4	.1111	3.8662E-01	8.1727E-01	7.0475E-05	6.4561E-01	8.8328E-02	8.6462E-02	4.3253E-03	1.6601E-04	1.7017E-01	2.4916E-04
5	.1481	4.8571E-01	8.9574E-01	1.7070E-04	6.4022E-01	1.1738E-01	1.0488E-01	7.9057E-03	2.7163E-04	1.2426E-01	1.2706E-04
6	.1852	5.5965E-01	9.4371E-01	2.7000E-04	6.3090E-01	1.4431E-01	1.2496E-01	1.0689E-02	3.8312E-04	8.4142E-02	6.1817E-05
7	.2222	6.1053E-01	9.6995E-01	3.4217E-04	6.1990E-01	1.6812E-01	1.4297E-01	1.2384E-02	4.8052E-04	5.2530E-02	3.0035E-05
8	.2593	6.4459E-01	9.8330E-01	3.9412E-04	6.0922E-01	1.8801E-01	1.5627E-01	1.3399E-02	5.5416E-04	3.0049E-02	1.4633E-05
9	.2963	6.6878E-01	9.8942E-01	4.3532E-04	6.0020E-01	2.0359E-01	1.6431E-01	1.4071E-02	6.0323E-04	1.5626E-02	6.9694E-06
10	.3333	6.8830E-01	9.9162E-01	4.6860E-04	5.9342E-01	2.1487E-01	1.6820E-01	1.4543E-02	6.3206E-04	7.3168E-03	3.1308E-06
11	.3704	7.0601E-01	9.9197E-01	4.9344E-04	5.8885E-01	2.2229E-01	1.6958E-01	1.4863E-02	6.4695E-04	3.0509E-03	1.2830E-06
12	.4074	7.2316E-01	9.9168E-01	5.0965E-04	5.8611E-01	2.2664E-01	1.6983E-01	1.5059E-02	6.5372E-04	1.1191E-03	4.6684E-07
13	.4444	7.4016E-01	9.9134E-01	5.1863E-04	5.8467E-01	2.2887E-01	1.6974E-01	1.5163E-02	6.5643E-04	3.5616E-04	1.4752E-07
14	.4815	7.5713E-01	9.9115E-01	5.2278E-04	5.8403E-01	2.2984E-01	1.6963E-01	1.5210E-02	6.5740E-04	9.6738E-05	3.9654E-08
15	.5185	7.7410E-01	9.9108E-01	5.2434E-04	5.8380E-01	2.3018E-01	1.6958E-01	1.5228E-02	6.5773E-04	2.1959E-05	8.8620E-09
16	.5556	7.9110E-01	9.9108E-01	5.2483E-04	5.8374E-01	2.3028E-01	1.6956E-01	1.5235E-02	6.5784E-04	4.0500E-06	1.5980E-09
17	.5926	8.0812E-01	9.9111E-01	5.2502E-04	5.8373E-01	2.3029E-01	1.6956E-01	1.5238E-02	6.5791E-04	5.8275E-07	2.2261E-10
18	.6296	8.2518E-01	9.9116E-01	5.2523E-04	5.8374E-01	2.3029E-01	1.6955E-01	1.5242E-02	6.5798E-04	6.1386E-08	2.2347E-11
19	.6667	8.4229E-01	9.9124E-01	5.2559E-04	5.8376E-01	2.3028E-01	1.6953E-01	1.5250E-02	6.5811E-04	4.2215E-09	1.4187E-12
20	.7037	8.5946E-01	9.9136E-01	5.2618E-04	5.8378E-01	2.3027E-01	1.6950E-01	1.5261E-02	6.5830E-04	1.4501E-10	4.1000E-14
21	.7407	8.7669E-01	9.9156E-01	5.2713E-04	5.8381E-01	2.3026E-01	1.6946E-01	1.5280E-02	6.5861E-04	6.1037E-13	1.2162E-16
22	.7778	8.9400E-01	9.9186E-01	5.2860E-04	5.8387E-01	2.3024E-01	1.6939E-01	1.5310E-02	6.5909E-04	0.	5.0216E-18
23	.8148	9.1139E-01	9.9231E-01	5.3084E-04	5.8395E-01	2.3022E-01	1.6928E-01	1.5354E-02	6.5982E-04	4.3982E-16	0.
24	.8519	9.2888E-01	9.9298E-01	5.3420E-04	5.8408E-01	2.3018E-01	1.6912E-01	1.5421E-02	6.6089E-04	1.9468E-17	5.6183E-20
25	.8889	9.4648E-01	9.9396E-01	5.3916E-04	5.8428E-01	2.3012E-01	1.6888E-01	1.5520E-02	6.6244E-04	0.	0.
26	.9259	9.6419E-01	9.9535E-01	5.4639E-04	5.8456E-01	2.3003E-01	1.6854E-01	1.5662E-02	6.6463E-04	1.1695E-18	1.2590E-21
27	.9630	9.8202E-01	9.9729E-01	5.5687E-04	5.8496E-01	2.2991E-01	1.6804E-01	1.5864E-02	6.6758E-04	0.	0.
28	1.0000	1.0000E+00	1.0000E+00	5.7174E-04	5.8554E-01	2.2972E-01	1.6736E-01	1.6136E-02	6.7125E-04	0.	0.

N	ETA	C1	C2	C3	CN
1	0.0000	3.3056E-03	1.7714E-07	2.3709E-11	2.2683E-04
2	.0370	3.3440E-03	1.4997E-07	2.0397E-11	3.6920E-04
3	.0741	3.3289E-03	6.1491E-08	9.5268E-12	7.8736E-04
4	.1111	3.3515E-03	4.7977E-08	2.6891E-12	1.2603E-03
5	.1481	3.3074E-03	4.5910E-08	9.1699E-13	1.4774E-03
6	.1852	2.9615E-03	3.3270E-08	2.9492E-13	1.3266E-03
7	.2222	2.2861E-03	1.7082E-08	7.4989E-14	9.6285E-04
8	.2593	1.4987E-03	6.4111E-09	1.4198E-14	5.8948E-04
9	.2963	8.3724E-04	1.8126E-09	1.9510E-15	3.1201E-04
10	.3333	4.0204E-04	3.9319E-10	1.9113E-16	1.4451E-04
11	.3704	1.6716E-04	6.5915E-11	1.3083E-17	5.8799E-05
12	.4074	6.0301E-05	8.4983E-12	6.0893E-19	2.0961E-05
13	.4444	1.8772E-05	8.2776E-13	1.8566E-20	6.4832E-06
14	.4815	4.9779E-06	5.9087E-14	3.5285E-22	1.7116E-06
15	.5185	1.1010E-06	2.9618E-15	3.9157E-24	3.7685E-07
16	.5556	1.9708E-07	9.8494E-17	2.3265E-26	6.7021E-08
17	.5926	2.7317E-08	2.0113E-18	6.5620E-29	9.1968E-09
18	.6296	2.7312E-09	2.2530E-20	7.3566E-32	9.0392E-10
19	.6667	1.7210E-10	1.1611E-22	4.0424E-35	5.5000E-11
20	.7037	4.7992E-12	2.0812E-25	3.6058E-37	1.3634E-12
21	.7407	2.1251E-14	8.8430E-28	1.7158E-39	6.2975E-15
22	.7778	9.6077E-16	0.	2.0863E-40	5.7109E-16
23	.8148	0.	5.8564E-32	0.	0.
24	.8519	1.0942E-17	0.	1.7275E-42	4.8887E-18
25	.8889	0.	2.7345E-35	0.	0.
26	.9259	2.5589E-19	0.	3.6364E-44	1.0621E-19
27	.9630	0.	3.1883E-38	0.	0.
28	1.0000	0.	0.	0.	0.

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	8.9775E-02	0.	1.2408E-03	3.9705E+14	5.0065E+07
2	.0370	4.5507E-04	5.3657E-02	0.	9.0339E-04	4.2538E+14	7.2894E+07
3	.0741	1.0529E-03	-5.4655E-02	0.	7.1281E-04	6.4926E+14	9.7143E+07
4	.1111	1.7864E-03	-2.3208E-01	0.	5.9731E-04	1.0260E+15	1.2139E+08
5	.1481	2.6382E-03	-4.6994E-01	0.	5.2678E-04	1.4806E+15	1.4383E+08
6	.1852	3.5829E-03	-7.5573E-01	0.	4.8398E-04	1.9186E+15	1.6287E+08
7	.2222	4.5950E-03	-1.0762E+00	0.	4.5798E-04	2.2771E+15	1.7763E+08
8	.2593	5.6530E-03	-1.4204E+00	0.	4.4234E-04	2.5364E+15	1.8803E+08
9	.2963	6.7402E-03	-1.7810E+00	0.	4.3333E-04	2.7048E+15	1.9462E+08
10	.3333	7.8443E-03	-2.1537E+00	0.	4.2855E-04	2.8028E+15	1.9834E+08
11	.3704	8.9573E-03	-2.5370E+00	0.	4.2629E-04	2.8537E+15	2.0019E+08
12	.4074	1.0074E-02	-2.9300E+00	0.	4.2534E-04	2.8771E+15	2.0101E+08
13	.4444	1.1193E-02	-3.3327E+00	0.	4.2501E-04	2.8868E+15	2.0132E+08
14	.4815	1.2312E-02	-3.7450E+00	0.	4.2490E-04	2.8903E+15	2.0143E+08
15	.5185	1.3431E-02	-4.1668E+00	0.	4.2486E-04	2.8915E+15	2.0146E+08
16	.5556	1.4551E-02	-4.5982E+00	0.	4.2485E-04	2.8919E+15	2.0147E+08
17	.5926	1.5670E-02	-5.0392E+00	0.	4.2483E-04	2.8921E+15	2.0147E+08
18	.6296	1.6790E-02	-5.4899E+00	0.	4.2482E-04	2.8923E+15	2.0148E+08
19	.6667	1.7909E-02	-5.9502E+00	0.	4.2479E-04	2.8927E+15	2.0148E+08
20	.7037	1.9029E-02	-6.4203E+00	0.	4.2475E-04	2.8933E+15	2.0148E+08
21	.7407	2.0149E-02	-6.9001E+00	0.	4.2468E-04	2.8942E+15	2.0148E+08
22	.7778	2.1269E-02	-7.3898E+00	0.	4.2458E-04	2.8956E+15	2.0149E+08
23	.8148	2.2389E-02	-7.8893E+00	0.	4.2443E-04	2.8977E+15	2.0150E+08
24	.8519	2.3510E-02	-8.3988E+00	0.	4.2420E-04	2.9009E+15	2.0150E+08
25	.8889	2.4631E-02	-8.9184E+00	0.	4.2388E-04	2.9055E+15	2.0151E+08
26	.9259	2.5754E-02	-9.4481E+00	0.	4.2342E-04	2.9119E+15	2.0153E+08
27	.9630	2.6878E-02	-9.9881E+00	0.	4.2278E-04	2.9205E+15	2.0154E+08
28	1.0000	2.8004E-02	-1.0538E+01	-1.4911E-01	4.2190E-04	2.9304E+15	2.0156E+08

TIME LEFT =434.991 SEC
QCOND = -1.14246E+06
QDIFF = -6.92436E+05
QCONV = 1.02396E+05
QTOTAL = -1.73250E+06
QTOTAL(BTU/FT2-SEC) = -2.22642E+03
STANTON NUMBER = 1.81991E-02
RS**(1+J) = 2.56375E-07
REYNOLDS NUMBER = 1.21425E+01
CF-INF = 1.52958E-04

RHO V = 2.04528E-03
HEAT TRANSFER = 5.40967E-01
HEAT TRANSFER, BODY = 4.85605E-01
DISPLACEMENT THICKNESS/RN = 6.29083E+03
MOMENTUM THICKNESS = 3.84054E-04
L AT BODY = 1.37714E+00
SKIN FRICTION = 9.43909E-01
T DRAG COEF = 8.83083E-07
P DRAG COEF = 1.91171E+00
TOTAL DRAG = 1.91172E+00

SPECIES	WALL MASS FLUX	TOTAL MASS FLOW	FLOW(PAR/SEC)
O2	2.57365E-07	2.56398E-10	7.04517E+16
N2	-1.66116E-05	3.18302E-07	9.98988E+19
O	-2.72730E-03	1.14385E-07	6.28604E+19
N	-3.21159E-08	8.65689E-08	5.43392E+19
NO	1.80542E-05	7.67010E-09	2.24746E+18
NO+	-1.66680E-11	3.26357E-10	9.56275E+16
CO	4.77092E-03	9.39648E-09	2.94961E+18
CO2	-3.63889E-10	1.19976E-11	2.39695E+15
C1	-1.78159E-09	2.57613E-10	1.88589E+17
C2	-9.54721E-14	3.14391E-15	1.15077E+12
C3	-1.27784E-17	1.99026E-19	4.85665E+07
CN	-1.22256E-10	9.82280E-11	3.31924E+16

45-TH BODY PROFILE. S = 6.0000E+00

RHOMUREF = 2.23181E-10

INTERPOLATED EDGE CONDITIONS

PE =	1.27100E+03	X0 =	4.64741E-01	LAMBDA =	2.52130E-07	DELXI =	9.10013E-09
TE =	6.24870E+03	X 1/2 =	4.82371E-01	LAMBDA 1/2 =	2.58191E-07	XI0 =	6.43519E-08
UE =	1.65500E+04	X1 =	5.00000E-01	LAMBDA + 1 =	2.63687E-07	XI 1/2 =	6.89020E-08
DPE0 =	-2.55901E+03	RB0 =	2.55110E-01	BETA =	1.75467E-01	XI1 =	7.34520E-08
DPE1 =	-2.18313E+03	RB 1/2 =	2.61196E-01	MU =	2.06757E-06	SMALL E =	3.36626E-05
BEB =	-4.41619E-02	RB1 =	2.67188E-01	RHOE =	1.07944E-04	EBAR =	-2.91567E-01
ETE =	1.50000E+01						

RHOMUREF = 2.24788E-10

X(K)

N	ETA	1	2	3	4	5	6	7	8	9	10
1	0.0000	-8.7826E-05	-3.7940E-01	-7.8911E-01	-4.2980E-02	-7.1441E-02	-2.9148E-04	-2.9763E-05	-1.1903E-11	-7.4350E-03	0.
2	.0370	-1.2186E-01	-2.3159E-01	-4.0815E-01	-1.1437E+00	-3.6904E-01	-5.6875E-03	-1.7481E-05	-5.1161E-12	-5.2520E-03	-1.6779E-01
3	.0741	-5.4616E-01	-1.8009E-01	-2.9706E-01	-2.1557E+00	-2.4121E-01	-7.7017E-03	-1.1349E-05	4.4273E-12	-4.0239E-03	-6.1990E-01
4	.1111	-1.4192E+00	-1.5995E-01	-2.5975E-01	-3.4591E+00	-1.9149E-01	-8.4752E-03	-7.0880E-06	6.0484E-12	-3.1065E-03	-1.4589E+00
5	.1481	-2.8603E+00	-1.4839E-01	-2.3930E-01	-5.0577E+00	-1.7299E-01	-8.0912E-03	-3.8706E-06	1.9259E-12	-2.2495E-03	-2.8849E+00
6	.1852	-4.7718E+00	-1.3651E-01	-2.1543E-01	-6.6492E+00	-1.4770E-01	-6.5978E-03	-1.7437E-06	3.0134E-13	-1.4593E-03	-4.8056E+00
7	.2222	-6.7871E+00	-1.2263E-01	-1.8549E-01	-7.8506E+00	-1.0863E-01	-4.5412E-03	-6.2704E-07	3.1172E-14	-8.3121E-04	-6.7879E+00
8	.2593	-8.5041E+00	-1.0800E-01	-1.5379E-01	-8.4808E+00	-6.7846E-02	-2.6457E-03	-1.7708E-07	2.1122E-15	-4.1359E-04	-8.4188E+00
9	.2963	-9.7145E+00	-9.3904E-02	-1.2418E-01	-8.5881E+00	-3.6194E-02	-1.3134E-03	-3.8757E-08	6.8234E-17	-1.7925E-04	-9.5195E+00
10	.3333	-1.0416E+01	-8.0876E-02	-9.8288E-02	-8.3146E+00	-1.6457E-02	-5.5544E-04	-6.4320E-09	-1.2613E-18	-6.7088E-05	-1.0110E+01
11	.3704	-1.0708E+01	-6.8974E-02	-7.6373E-02	-7.7977E+00	-6.2865E-03	-1.9809E-04	-7.8168E-10	-1.9542E-19	-2.1333E-05	-1.0298E+01
12	.4074	-1.0708E+01	-5.8072E-02	-5.8097E-02	-7.1350E+00	-1.9696E-03	-5.8391E-05	-6.6250E-11	-6.8284E-21	-5.6224E-06	-1.0195E+01
13	.4444	-1.0509E+01	-4.7967E-02	-4.2914E-02	-6.3834E+00	-4.8932E-04	-1.3796E-05	-3.6638E-12	-1.0548E-22	-1.1856E-06	-9.8890E+00
14	.4815	-1.0176E+01	-3.8466E-02	-3.0323E-02	-5.5709E+00	-9.1787E-05	-2.4938E-06	-1.2014E-13	-7.0246E-25	-1.8979E-07	-9.4429E+00
15	.5185	-9.7479E+00	-2.9478E-02	-2.0025E-02	-4.7126E+00	-1.1996E-05	-3.1930E-07	-1.9990E-15	-1.6236E-27	-2.1182E-08	-8.9363E+00
16	.5556	-9.2511E+00	-2.1108E-02	-1.1952E-02	-3.8240E+00	-9.2656E-07	-2.4770E-08	-1.2342E-17	-6.3042E-31	-1.3939E-09	-8.5816E+00
17	.5926	-8.7008E+00	-1.3679E-02	-6.1476E-03	-2.9319E+00	-2.3908E-08	-6.9731E-10	-1.0134E-20	6.5401E-35	-3.1869E-11	-9.0030E+00
18	.6296	-8.1041E+00	-7.6742E-03	-2.5511E-03	-2.0816E+00	0.	0.	0.	0.	0.	-1.1470E+01
19	.6667	-7.4539E+00	-3.5326E-03	-7.8893E-04	-1.3368E+00	-2.6333E-11	-5.8043E-13	-7.7074E-27	3.1062E-39	-1.3927E-14	-1.6778E+01
20	.7037	-6.7185E+00	-1.2906E-03	-1.7335E-04	-7.6514E-01	1.6058E-14	0.	0.	0.	0.	-2.1971E+01
21	.7407	-5.8560E+00	-3.9853E-04	-2.9826E-05	-3.9961E-01	-1.4323E-13	-1.5619E-15	-6.2568E-32	5.1216E-43	-1.3218E-17	-2.1401E+01
22	.7778	-4.8653E+00	-1.2726E-04	-5.4464E-06	-2.0656E-01	1.2715E-16	0.	0.	0.	8.8047E-23	-1.5401E+01
23	.8148	-3.8216E+00	-5.0847E-05	-1.4034E-06	-1.1436E-01	-1.3689E-15	-4.8625E-18	-6.7207E-37	2.3036E-46	-1.6532E-20	-9.2056E+00
24	.8519	-2.8362E+00	-2.6044E-05	-5.2779E-07	-6.8402E-02	5.0315E-19	0.	0.	0.	4.5596E-24	-5.2999E+00
25	.8889	-1.9824E+00	-1.5828E-05	-2.5746E-07	-4.2536E-02	-1.2014E-17	-9.4679E-21	9.0263E-41	2.8958E-49	-2.1843E-23	-3.4556E+00
26	.9259	-1.2764E+00	-1.0480E-05	-1.4344E-07	-2.6084E-02	-1.4345E-18	-5.0248E-24	-1.2934E-48	0.	1.0235E-25	-2.8338E+00
27	.9630	-6.9887E-01	-6.7974E-06	-7.8580E-08	-1.4097E-02	3.7479E-21	0.	2.3063E-43	7.3994E-52	0.	-2.1859E+00
28	1.0000	-2.2196E-01	-1.6076E-06	-1.2163E-08	2.1991E-04	0.	0.	0.	0.	0.	6.3086E+00

N	ETA	11	12	13	14	15	16	17	18	19	20
1	0.0000	2.1798E-02	-2.0398E-01	1.9251E-02	1.4036E-07	5.9483E-12	-5.7332E-02	1.6200E-04	-1.5750E-04	2.6013E-07	1.0586E-03
2	.0370	-2.6381E+00	-7.9455E-02	-6.0733E-03	2.7083E-06	-9.3093E-10	-9.9410E-02	1.6685E-02	-2.3698E-04	-3.9024E-03	-6.5402E-03
3	.0741	-2.9042E+00	8.4126E-02	-1.2556E-01	8.7243E-06	-5.8684E-09	-1.1042E-01	4.5850E-02	-2.2603E-04	-1.5105E-02	-2.6322E-02
4	.1111	-4.1225E+00	2.3065E-01	-4.1005E-01	1.0796E-05	-1.9071E-08	-9.3188E-02	6.2234E-02	-1.5556E-04	-3.7619E-02	-6.0909E-02
5	.1481	-9.1823E+00	2.7657E-01	-5.3871E-01	7.8225E-06	-2.6294E-08	-6.4858E-02	5.7904E-02	-8.2333E-05	-6.1806E-02	-8.2549E-02
6	.1852	-1.5972E+01	2.2822E-01	-4.5413E-01	4.2260E-06	-2.1587E-08	-3.8842E-02	4.2326E-02	-3.4498E-05	-7.0601E-02	-7.8266E-02
7	.2222	-2.1642E+01	1.4880E-01	-2.9544E-01	1.9076E-06	-1.3388E-08	-2.0385E-02	2.5750E-02	-1.1503E-05	-6.0743E-02	-5.7855E-02
8	.2593	-2.5153E+01	8.0559E-02	-1.5896E-01	7.3736E-07	-6.8223E-09	-9.4105E-03	1.3293E-02	-3.0290E-06	-4.1231E-02	-3.4960E-02
9	.2963	-2.6710E+01	3.6662E-02	-7.2005E-02	2.4138E-07	-2.8942E-09	-3.8113E-03	5.8589E-03	-6.2140E-07	-2.2664E-02	-1.7580E-02
10	.3333	-2.6829E+01	1.4039E-02	-2.7503E-02	6.5953E-08	-1.0235E-09	-1.3456E-03	2.2097E-03	-9.7345E-08	-1.0252E-02	-7.4026E-03
11	.3704	-2.5965E+01	4.5053E-03	-8.8232E-03	1.4777E-08	-3.0295E-10	-4.0905E-04	7.1084E-04	-1.1296E-08	-3.8386E-03	-2.6065E-03
12	.4074	-2.4464E+01	1.1982E-03	-2.3533E-03	2.6165E-09	-7.5095E-11	-1.0485E-04	1.9261E-04	-9.2894E-10	-1.1822E-03	-7.5975E-04
13	.4444	-2.2576E+01	2.5828E-04	-5.1125E-04	3.3344E-10	-1.5439E-11	-2.1943E-05	4.2894E-05	-5.0857E-11	-2.9367E-04	-1.7953E-04
14	.4815	-2.0509E+01	4.3359E-05	-8.7222E-05	2.1509E-11	-2.5665E-12	-3.5710E-06	7.5406E-06	-1.6922E-12	-5.6779E-05	-3.3173E-05
15	.5185	-1.8580E+01	5.2721E-06	-1.0942E-05	-1.7170E-12	-3.2775E-13	-4.1852E-07	9.7836E-07	-2.9560E-14	-8.0412E-06	-4.5013E-06
16	.5556	-1.7506E+01	3.9749E-07	-8.8229E-07	-5.7050E-13	-2.8813E-14	-3.0681E-08	8.2369E-08	-2.0364E-16	-7.3969E-07	-3.9330E-07
17	.5926	-1.8763E+01	1.0938E-08	-3.0334E-08	-4.3646E-14	-1.2047E-15	-9.7056E-10	3.1793E-09	-2.3068E-19	-2.8706E-08	-1.3830E-08
18	.6296	-2.4124E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	.6667	-3.2858E+01	1.0026E-11	-1.9854E-11	-1.9258E-16	-1.8709E-18	-3.1212E-14	-5.7435E-13	-5.0466E-26	-9.6340E-11	-2.7965E-11
20	.7037	-3.8934E+01	0.	0.	1.5854E-19	0.	-6.4067E-15	6.5238E-14	0.	0.	0.
21	.7407	-3.7011E+01	2.5514E-14	-4.1949E-14	-2.2615E-18	-1.1461E-20	1.2443E-15	-3.3873E-14	6.4594E-34	-1.3707E-12	-2.2807E-13
22	.7778	-3.0643E+01	-9.0243E-18	-1.1119E-15	-1.1299E-19	-4.5454E-22	-1.8292E-17	5.1307E-16	0.	0.	0.
23	.8148	-2.5327E+01	7.4790E-17	2.1524E-18	0.	5.0189E-25	2.0387E-17	-8.3628E-16	4.0713E-38	-1.2990E-14	-1.5442E-15
24	.8519	-2.2083E+01	-2.7627E-19	-6.3599E-17	-1.5599E-20	-4.6168E-23	-3.6564E-20	1.8567E-18	0.	0.	0.
25	.8889	-2.0048E+01	1.5953E-19	1.1673E-20	7.6230E-26	4.3217E-27	2.6284E-19	-1.3343E-17	-5.4626E-40	-4.8910E-17	-4.7893E-18
26	.9259	-1.8434E+01	-4.7822E-21	-1.4188E-18	-5.9581E-22	-1.4909E-24	3.7160E-20	-2.0371E-18	5.4832E-44	-3.2674E-20	-2.9792E-21
27	.9630	-1.6321E+01	0.	0.	2.7277E-27	0.	-1.5967E-22	1.1067E-20	0.	0.	0.
28	1.0000	-8.2270E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.

N	ETA	21	22	23	24	25	26
1	0.0000	4.4311E-05	6.1160E-18	-6.9632E-07	4.4430E-11	1.4981E-13	-7.1677E-02
2	.0370	-1.1495E-03	2.5716E-15	-2.2815E-05	-1.4627E-10	7.0824E-13	-4.6455E-02
3	.0741	-3.9674E-03	3.3164E-12	-1.6742E-05	-1.6407E-10	7.3638E-13	-1.4797E-02
4	.1111	-9.0412E-03	9.4563E-12	-1.1581E-05	-1.1984E-10	3.3217E-13	7.6632E-03
5	.1481	-1.3298E-02	5.5625E-12	-6.9371E-06	-5.5225E-11	7.0787E-14	-1.5527E-03
6	.1852	-1.3564E-02	1.4892E-12	-3.2455E-06	-1.5567E-11	8.8301E-15	-2.5842E-02
7	.2222	-1.0538E-02	2.4242E-13	-1.1779E-06	-2.9624E-12	7.3464E-16	-4.5747E-02
8	.2593	-6.5709E-03	1.7385E-14	-3.3196E-07	-3.9379E-13	4.0625E-17	-5.6743E-02
9	.2963	-3.3681E-03	-2.7885E-15	-7.1992E-08	-3.5860E-14	1.4049E-18	-6.1012E-02
10	.3333	-1.4341E-03	-1.0187E-15	-1.1807E-08	-2.1705E-15	2.8568E-20	-6.0719E-02
11	.3704	-5.0795E-04	-1.4995E-16	-1.4247E-09	-8.4733E-17	3.2280E-22	-5.7392E-02
12	.4074	-1.4846E-04	-1.3296E-17	-1.2143E-10	-2.0570E-18	1.8992E-24	-5.2395E-02
13	.4444	-3.5115E-05	-7.4863E-19	-6.8939E-12	-2.9519E-20	5.3410E-27	-4.6820E-02
14	.4815	-6.4919E-06	-2.5838E-20	-2.3920E-13	-2.3328E-22	6.3946E-30	-4.1305E-02
15	.5185	-8.8193E-07	-4.9250E-22	-4.4191E-15	-9.1669E-25	2.7605E-33	-3.6100E-02
16	.5556	-7.7262E-08	-4.1367E-24	-3.3248E-17	-1.4752E-27	3.1163E-37	-3.1254E-02
17	.5926	-2.7095E-09	-6.7743E-27	-4.1594E-20	-2.9000E-31	1.6799E-42	-2.6812E-02
18	.6296	0.	0.	0.	0.	0.	-2.2902E-02
19	.6667	-5.8585E-12	-7.9905E-31	-1.3137E-24	-9.4435E-36	4.7534E-50	-1.9571E-02
20	.7037	0.	0.	0.	0.	0.	-1.6498E-02
21	.7407	-4.8198E-14	-6.3093E-34	-2.8628E-28	-2.1654E-39	3.0103E-56	-1.3260E-02
22	.7778	1.1001E-17	0.	0.	0.	0.	-1.0040E-02
23	.8148	-3.2374E-16	-1.3064E-36	-1.6405E-31	-1.3049E-42	6.3396E-62	-7.3302E-03
24	.8519	6.2045E-19	0.	0.	0.	0.	-5.2854E-03
25	.8889	-9.9317E-19	-2.8532E-39	-1.9113E-34	-1.5981E-45	1.9905E-67	-3.7852E-03
26	.9259	1.3180E-20	8.7385E-51	3.5973E-46	0.	0.	-2.6603E-03
27	.9630	0.	-9.5166E-42	-4.0846E-37	-3.5907E-48	-2.6791E-78	-1.7904E-03
28	1.0000	0.	0.	0.	0.	0.	-1.1483E-03

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+	CO	CO2
1	0.0000	0.	2.0061E+00	0.	6.4555E-01	6.2921E-04	9.1365E-03	5.6303E-05	6.3414E-06	3.4410E-01	4.7453E-04
2	.0370	1.7898E-01	2.6095E+00	1.2521E-05	6.6798E-01	3.7714E-02	9.2637E-03	6.5152E-04	7.3208E-06	2.8385E-01	4.7190E-04
3	.0741	3.7368E-01	2.8222E+00	1.0308E-04	6.9396E-01	7.6443E-02	9.1197E-03	2.4339E-03	9.8944E-06	2.1745E-01	4.3669E-04
4	.1111	5.5907E-01	2.7128E+00	6.6453E-04	7.2528E-01	1.1205E-01	6.4632E-03	4.1926E-03	9.0500E-06	1.5091E-01	4.0719E-04
5	.1481	7.0854E-01	2.4300E+00	6.2293E-03	7.5473E-01	1.3569E-01	2.0305E-03	8.4065E-03	5.6153E-06	9.2541E-02	3.6683E-04
6	.1852	8.0951E-01	2.1114E+00	3.3405E-02	7.6528E-01	1.3590E-01	2.1866E-04	1.5779E-02	3.1605E-06	4.9121E-02	2.9302E-04
7	.2222	8.6922E-01	1.8972E+00	7.4723E-02	7.6605E-01	1.1722E-01	3.0335E-05	1.9564E-02	1.8688E-06	2.2210E-02	1.9556E-04
8	.2593	9.0380E-01	1.7747E+00	1.1446E-01	7.6461E-01	9.1331E-02	9.2698E-06	2.1086E-02	1.1589E-06	8.3990E-03	1.0644E-04
9	.2963	9.2564E-01	1.7031E+00	1.4894E-01	7.6286E-01	6.5205E-02	3.8738E-06	2.0353E-02	7.4033E-07	2.5906E-03	4.7630E-05
10	.3333	9.4081E-01	1.6514E+00	1.7682E-01	7.6201E-01	4.3043E-02	1.6990E-06	1.7479E-02	4.7822E-07	6.2925E-04	1.7766E-05
11	.3704	9.5190E-01	1.6030E+00	1.9772E-01	7.6236E-01	2.6486E-02	6.9442E-07	1.3306E-02	3.0671E-07	1.1409E-04	5.5469E-06
12	.4074	9.6021E-01	1.5516E+00	2.1220E-01	7.6351E-01	1.5300E-02	2.5008E-07	8.9718E-03	1.9197E-07	1.4073E-05	1.4385E-06
13	.4444	9.6662E-01	1.4971E+00	2.2147E-01	7.6483E-01	8.3440E-03	7.7897E-08	5.3632E-03	1.1543E-07	9.6185E-07	3.0359E-07
14	.4815	9.7170E-01	1.4419E+00	2.2695E-01	7.6589E-01	4.3121E-03	2.1146E-08	2.8457E-03	6.5782E-08	1.4123E-08	5.0189E-08
15	.5185	9.7586E-01	1.3885E+00	2.2997E-01	7.6657E-01	2.1161E-03	5.1404E-09	1.3405E-03	3.5129E-08	0.	6.0594E-09
16	.5556	9.7936E-01	1.3385E+00	2.3152E-01	7.6694E-01	9.8689E-04	1.1666E-09	5.5937E-04	1.7412E-08	3.2986E-11	4.5898E-10
17	.5926	9.8236E-01	1.2928E+00	2.3225E-01	7.6711E-01	4.3724E-04	2.5913E-10	2.0538E-04	7.9427E-09	0.	1.2502E-11
18	.6296	9.8498E-01	1.2514E+00	2.3258E-01	7.6717E-01	1.8381E-04	5.8486E-11	6.5464E-05	3.3076E-09	3.2949E-13	0.
19	.6667	9.8728E-01	1.2141E+00	2.3272E-01	7.6719E-01	7.3133E-05	1.3573E-11	1.7670E-05	1.2464E-09	0.	8.9082E-15
20	.7037	9.8933E-01	1.1805E+00	2.3277E-01	7.6720E-01	2.7417E-05	3.1945E-12	3.8610E-06	4.2053E-10	6.5365E-15	4.6129E-16
21	.7407	9.9116E-01	1.1501E+00	2.3279E-01	7.6720E-01	9.6181E-06	7.4381E-13	6.2371E-07	1.2529E-10	0.	0.
22	.7778	9.9281E-01	1.1225E+00	2.3280E-01	7.6720E-01	3.1303E-06	1.6738E-13	5.8713E-08	3.2342E-11	2.0244E-16	6.3298E-18
23	.8148	9.9431E-01	1.0973E+00	2.3280E-01	7.6720E-01	9.3771E-07	3.5795E-14	4.4738E-10	7.0332E-12	0.	0.
24	.8519	9.9567E-01	1.0743E+00	2.3280E-01	7.6720E-01	2.5744E-07	7.2099E-15	1.9766E-10	1.2328E-12	8.6198E-18	2.8732E-20
25	.8889	9.9691E-01	1.0533E+00	2.3280E-01	7.6720E-01	6.4282E-08	1.3643E-15	3.3103E-10	1.6125E-13	0.	4.1376E-21
26	.9259	9.9804E-01	1.0340E+00	2.3280E-01	7.6720E-01	1.3893E-08	2.3816E-16	2.5064E-11	1.3369E-14	4.5553E-19	1.5412E-23
27	.9630	9.9907E-01	1.0163E+00	2.3280E-01	7.6720E-01	2.2931E-09	3.4412E-17	0.	4.1335E-16	0.	2.2554E-22
28	1.0000	1.0000E+00	1.0000E+00	2.3280E-01	7.6720E-01	5.4877E-10	1.9973E-18	1.6790E-14	1.0000E-20	0.	0.

N	ETA	C1	C2	C3	CN
1	0.0000	3.2125E-05	6.3744E-12	3.2790E-16	1.5868E-05
2	.0370	2.9893E-05	6.1873E-12	3.0836E-16	1.5691E-05
3	.0741	2.1348E-05	5.2594E-12	2.3088E-16	1.4248E-05
4	.1111	9.4829E-06	8.0461E-13	1.5886E-17	4.7330E-06
5	.1481	1.6565E-06	2.7430E-14	2.1804E-19	6.4382E-07
6	.1852	5.5702E-08	2.2087E-16	1.2997E-21	5.5251E-08
7	.2222	6.3621E-10	1.2710E-18	7.0045E-24	4.7387E-09
8	.2593	4.0040E-12	7.5948E-21	4.0531E-26	4.6349E-10
9	.2963	2.5704E-14	5.1338E-23	2.6471E-28	5.2894E-11
10	.3333	7.5072E-16	4.0462E-25	1.9927E-30	6.7783E-12
11	.3704	4.2712E-17	3.7012E-27	1.7097E-32	9.0122E-13
12	.4074	2.1053E-18	3.6765E-29	1.5496E-34	1.0811E-13
13	.4444	7.3910E-20	3.1374E-31	1.1515E-36	9.0873E-15
14	.4815	1.0512E-21	3.9324E-34	8.6923E-40	2.5384E-16
15	.5185	0.	0.	0.	0.
16	.5556	3.3363E-25	7.2374E-37	9.8465E-43	6.5748E-19
17	.5926	0.	0.	0.	0.
18	.6296	3.8936E-28	8.9044E-39	8.0716E-45	6.6312E-21
19	.6667	0.	0.	0.	0.
20	.7037	8.0001E-31	2.2691E-40	1.5334E-46	1.2026E-22
21	.7407	1.6519E-33	0.	0.	0.
22	.7778	1.3731E-32	8.7472E-42	4.8231E-48	2.8233E-24
23	.8148	1.0718E-34	0.	0.	0.
24	.8519	0.	4.4973E-43	2.1689E-49	3.5387E-26
25	.8889	1.1074E-36	0.	0.	4.2063E-26
26	.9259	0.	2.7665E-44	1.2298E-50	0.
27	.9630	6.3940E-39	0.	0.	8.0532E-27
28	1.0000	0.	0.	0.	0.

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	9.4924E-02	0.	1.2965E-04	1.6952E+13	3.4864E+07
2	.0370	5.0534E-03	5.2556E-02	0.	1.0332E-04	1.6414E+13	5.6972E+07
3	.0741	1.1070E-02	-7.6256E-02	0.	9.0493E-05	2.1329E+13	8.2199E+07
4	.1111	1.7706E-02	-2.9057E-01	0.	8.4380E-05	2.7550E+13	1.0882E+08
5	.1481	2.4680E-02	-5.8089E-01	0.	8.1644E-05	3.2207E+13	1.3412E+08
6	.1852	3.1814E-02	-9.3148E-01	0.	8.0488E-05	3.4520E+13	1.5529E+08
7	.2222	3.9014E-02	-1.3252E+00	0.	8.0116E-05	3.4900E+13	1.7086E+08
8	.2593	4.6221E-02	-1.7483E+00	0.	8.0338E-05	3.3914E+13	1.8112E+08
9	.2963	5.3382E-02	-2.1920E+00	0.	8.1130E-05	3.2015E+13	1.8747E+08
10	.3333	6.0451E-02	-2.6518E+00	0.	8.2400E-05	2.9595E+13	1.9139E+08
11	.3704	6.7399E-02	-3.1253E+00	0.	8.3984E-05	2.6988E+13	1.9394E+08
12	.4074	7.4209E-02	-3.6108E+00	0.	8.5709E-05	2.4434E+13	1.9579E+08
13	.4444	8.0884E-02	-4.1069E+00	0.	8.7439E-05	2.2061E+13	1.9725E+08
14	.4815	8.7430E-02	-4.6120E+00	0.	8.9079E-05	1.9903E+13	1.9852E+08
15	.5185	9.3862E-02	-5.1249E+00	0.	9.0570E-05	1.7934E+13	1.9964E+08
16	.5556	1.0020E-01	-5.6443E+00	0.	9.1879E-05	1.6099E+13	2.0066E+08
17	.5926	1.0645E-01	-6.1691E+00	0.	9.3012E-05	1.4336E+13	2.0157E+08
18	.6296	1.1262E-01	-6.6986E+00	0.	9.4041E-05	1.2604E+13	2.0235E+08
19	.6667	1.1874E-01	-7.2320E+00	0.	9.5144E-05	1.0903E+13	2.0295E+08
20	.7037	1.2477E-01	-7.7686E+00	0.	9.6569E-05	9.2830E+12	2.0329E+08
21	.7407	1.3069E-01	-8.3081E+00	0.	9.8416E-05	7.8229E+12	2.0335E+08
22	.7778	1.3650E-01	-8.8501E+00	0.	1.0043E-04	6.5772E+12	2.0320E+08
23	.8148	1.4221E-01	-9.3945E+00	0.	1.0225E-04	5.5517E+12	2.0302E+08
24	.8519	1.4782E-01	-9.9412E+00	0.	1.0372E-04	4.7137E+12	2.0291E+08
25	.8889	1.5335E-01	-1.0490E+01	0.	1.0495E-04	4.0128E+12	2.0286E+08
26	.9259	1.5883E-01	-1.1041E+01	0.	1.0602E-04	3.3970E+12	2.0286E+08
27	.9630	1.6426E-01	-1.1594E+01	0.	1.0702E-04	2.8232E+12	2.0287E+08
28	1.0000	1.6963E-01	-1.2148E+01	-4.4162E-02	1.0794E-04	2.2628E+12	2.0288E+08

TIME LEFT =246.842 SEC
QCOND = -6.95285E+04
QDIFF = -8.10487E+04
QCONV = 8.77496E+03
QTOTAL = -1.41802E+05
QTOTAL(BTU/FT2-SEC) = -1.82229E+02
STANTON NUMBER = 1.35329E-03
RS**(1+J) = 1.39202E-02
REYNOLDS NUMBER = 4.28927E+05
CF-INF = 1.79040E-03

RHO V = 2.51691E-04
HEAT TRANSFER = 2.50562E-01
HEAT TRANSFER, BODY = 2.49247E-01
DISPLACEMENT THICKNESS/RN = 7.50686E+06
MOMENTUM THICKNESS = 1.36363E-03
L AT BODY = 1.03002E+00
SKIN FRICTION = 5.24722E-01
T DRAG COEF = 5.59086E-03
P DRAG COEF = 4.72727E-01
TOTAL DRAG = 4.78317E-01

SPECIES	WALL MASS FLUX	TOTAL MASS FLOW	FLOW(PAR/SEC)
O2	1.15718E-08	5.23105E-04	1.43736E+23
N2	1.01390E-06	2.13538E-02	6.70187E+24
O	-3.34038E-04	5.69297E-03	3.12857E+24
N	4.09618E-08	3.65374E-04	2.29345E+23
NO	1.62620E-07	6.56448E-04	1.92349E+23
NO+	1.59902E-11	5.22420E-07	1.53077E+20
CO	5.84499E-04	5.70952E-04	1.79225E+23
CO2	9.95320E-10	1.45894E-06	2.91476E+20
C1	4.77037E-10	8.55468E-07	6.26256E+20
C2	3.81763E-16	2.08025E-13	7.61436E+13
C3	1.45765E-20	7.07086E-18	1.72544E+09
CN	4.11679E-11	1.08219E-07	3.65686E+19

N	ETA	11	12	13	14	15	16	17	18	19	20
1	0.0000	-4.5166E-01	-1.1103E-02	1.3342E-03	6.9413E-09	-4.8908E-11	-3.4188E-03	1.8526E-05	-2.8620E-06	3.5251E-08	-3.4550E-04
2	.0370	-2.3759E-01	-3.1298E-03	3.7421E-03	3.2585E-07	-1.8886E-10	-6.9112E-03	4.3093E-03	-4.6144E-06	-2.8125E-04	-8.0230E-05
3	.0741	1.7305E+00	3.6575E-03	-4.2317E-03	6.8261E-07	-3.4138E-11	-6.5849E-03	1.0036E-02	-3.1859E-06	-1.5058E-03	-1.2570E-03
4	.1111	-2.7839E-01	4.2582E-03	-1.6649E-02	8.5959E-08	-2.1153E-09	-3.5069E-03	6.5447E-03	-1.2552E-06	-9.8204E-03	-3.3149E-03
5	.1481	-3.9604E+00	5.0538E-04	-5.0282E-03	-2.1278E-07	-6.9856E-10	-3.5740E-04	-1.5274E-02	-1.6239E-07	-1.7774E-02	-1.9728E-03
6	.1852	-8.9026E-01	4.9576E-06	-4.2486E-04	-7.7392E-08	-6.0111E-11	1.5696E-04	-3.1218E-02	-3.1760E-09	-3.2392E-03	-1.7113E-04
7	.2222	-7.9014E-02	1.2132E-08	-2.5967E-05	-1.1437E-08	-3.4405E-12	4.6719E-05	-1.8913E-02	-1.8295E-11	-8.4244E-05	-3.0599E-06
8	.2593	-3.9923E-02	-1.8921E-10	-1.7297E-06	-1.4502E-09	-2.3994E-13	1.1163E-05	-7.7115E-03	-4.2435E-14	-8.2658E-07	-2.4094E-08
9	.2963	-1.9614E-02	-1.0604E-11	-1.2992E-07	-1.9483E-10	-2.0375E-14	2.3438E-06	-2.4799E-03	2.0894E-16	-6.7144E-09	-1.5371E-10
10	.3333	-5.5359E-03	-5.5543E-13	-1.0336E-08	-2.7480E-11	-1.8371E-15	3.7213E-07	-6.0250E-04	6.7994E-18	-2.2436E-10	-3.7428E-12
11	.3704	2.3446E-04	-2.7650E-14	-7.9175E-10	-3.7717E-12	-1.5185E-16	3.8766E-08	-1.0227E-04	8.4089E-20	-1.4951E-11	-1.7922E-13
12	.4074	1.1426E-03	-1.0738E-15	-5.0572E-11	-4.4089E-13	-9.7160E-18	2.3124E-09	-1.0973E-05	3.0239E-22	-8.3289E-13	-6.8626E-15
13	.4444	6.6746E-04	-2.4763E-17	-2.1009E-12	-3.4498E-14	-3.7254E-19	6.2246E-11	-6.0809E-07	-9.8438E-25	-3.1557E-14	-1.6533E-16
14	.4815	2.5300E-04	-1.6265E-19	-2.7136E-14	-8.6918E-16	-4.1012E-21	1.1011E-13	-6.0198E-09	-3.6772E-27	-4.6686E-16	-1.3974E-18
15	.5185	7.5794E-05	0.	0.	2.7970E-23	0.	-6.1662E-15	5.2032E-11	0.	0.	0.
16	.5556	1.9739E-05	-1.7180E-23	-1.2669E-17	-1.7515E-18	-1.1180E-24	-1.8518E-17	-8.5526E-12	-8.2259E-33	-1.5188E-19	-1.0212E-22
17	.5926	4.7324E-06	0.	0.	4.7750E-28	0.	-4.5847E-19	1.1430E-14	0.	0.	0.
18	.6296	1.0779E-06	-6.4626E-27	-1.8811E-20	-1.3632E-20	-7.2099E-28	3.6795E-20	-5.7604E-14	1.2131E-40	-1.7823E-22	-1.5986E-26
19	.6667	2.3635E-07	0.	0.	3.2569E-33	0.	-1.2481E-23	7.2969E-19	0.	0.	0.
20	.7037	4.9957E-08	-4.8704E-30	-4.0895E-23	-1.9402E-22	-4.4231E-31	2.0254E-23	-6.9442E-16	-7.7835E-45	-3.6658E-25	-2.1756E-30
21	.7407	1.0125E-08	3.9575E-35	0.	0.	0.	0.	0.	0.	-7.5699E-28	-7.6629E-34
22	.7778	1.9501E-09	-4.4899E-33	-8.9727E-26	-3.6514E-24	-9.5279E-35	4.7959E-27	-1.3663E-17	-1.8219E-48	-6.2926E-27	-6.2769E-34
23	.8148	3.5379E-10	1.0407E-36	0.	0.	0.	0.	0.	0.	-4.9121E-29	-3.9177E-38
24	.8519	6.0145E-11	-2.0198E-36	-7.7021E-29	-3.7430E-26	-2.5067E-39	3.6553E-31	-3.8507E-19	1.0438E-52	4.3856E-37	8.3071E-40
25	.8889	9.5024E-12	-4.0385E-37	-2.0988E-29	-4.0517E-26	-4.0870E-39	-2.6479E-34	6.2121E-29	-8.8566E-56	-5.0750E-31	-3.2506E-40
26	.9259	1.3272E-12	0.	2.8365E-41	7.6008E-49	1.7830E-43	1.4407E-33	-1.3989E-20	4.6361E-56	2.2209E-40	4.1694E-43
27	.9630	1.4456E-13	-1.6069E-39	-1.2225E-31	-6.5199E-27	0.	-2.9330E-37	7.8483E-32	-2.3423E-59	-2.9303E-33	0.
28	1.0000	2.3312E-14	0.	0.	0.	0.	0.	0.	0.	0.	0.

N	ETA	21	22	23	24	25	26
1	0.0000	-7.0549E-05	8.6444E-19	-1.0378E-09	2.5839E-13	1.8750E-16	-6.8072E-03
2	.0370	-1.3890E-05	2.0606E-13	-2.2639E-08	6.5428E-14	9.1329E-16	-1.9354E-03
3	.0741	-1.4777E-04	2.9231E-12	-3.9298E-08	-5.9015E-13	7.2923E-16	3.7101E-03
4	.1111	-5.6758E-04	2.3945E-13	-2.3295E-08	-3.2317E-13	1.7664E-17	1.7619E-03
5	.1481	-3.6892E-04	-4.9963E-15	-2.0630E-09	-1.1936E-14	2.2343E-20	-1.9850E-03
6	.1852	-2.8216E-05	-6.3049E-17	-2.3010E-11	-9.2855E-17	1.8316E-24	-1.3662E-03
7	.2222	-3.3446E-07	-2.4523E-19	-1.2061E-13	-4.4455E-19	5.3077E-29	-6.1832E-04
8	.2593	6.4060E-09	-9.9700E-22	-5.6899E-16	-2.0245E-21	1.1669E-33	-2.7854E-04
9	.2963	6.7471E-10	-5.1988E-24	-2.7783E-18	-9.5498E-24	3.5385E-38	-1.2634E-04
10	.3333	5.1210E-11	-3.2441E-26	-1.4596E-20	-4.7923E-26	6.2139E-42	-5.7183E-05
11	.3704	3.6696E-12	-2.2043E-28	-8.2522E-23	-2.5415E-28	2.3907E-45	-2.5338E-05
12	.4074	2.1688E-13	-1.4701E-30	-4.7255E-25	-1.3279E-30	8.0586E-49	-1.0701E-05
13	.4444	8.2321E-15	-7.6383E-33	-2.1814E-27	-5.3374E-33	1.5182E-52	-4.1818E-06
14	.4815	9.6153E-17	-5.4241E-36	-1.3950E-30	-2.0558E-36	1.1397E-57	-1.4695E-06
15	.5185	0.	0.	0.	0.	0.	-4.5285E-07
16	.5556	3.6237E-20	-2.9162E-39	-5.6824E-34	-5.1540E-40	1.9292E-64	-1.1983E-07
17	.5926	0.	0.	0.	0.	0.	-2.6744E-08
18	.6296	4.3502E-23	-1.0638E-41	-1.2546E-36	-7.5818E-43	8.6715E-70	-4.9508E-09
19	.6667	0.	0.	0.	0.	0.	-7.4693E-10
20	.7037	7.7476E-26	-8.7554E-44	-4.5968E-39	-2.0709E-45	3.6348E-75	-8.9941E-11
21	.7407	-7.7243E-35	0.	0.	0.	0.	-8.4122E-12
22	.7778	1.4142E-28	-1.1994E-45	-1.9535E-41	-7.1811E-48	-1.4445E-77	-5.8843E-13
23	.8148	-3.7679E-39	0.	0.	0.	0.	-2.9117E-14
24	.8519	1.0249E-31	-2.3964E-47	-7.9921E-44	-2.5696E-50	-4.8861E-80	-9.3333E-16
25	.8889	2.5796E-32	0.	0.	0.	0.	-1.6612E-17
26	.9259	0.	-6.2256E-49	-2.5727E-46	-7.6238E-53	-1.7483E-82	-1.1848E-19
27	.9630	1.2953E-34	0.	0.	0.	0.	-1.1725E-22
28	1.0000	0.	0.	0.	0.	0.	-5.0505E-32

72-TH BODY PROFILE.   S = 5.5389E+01

WARNING - POLATE CALLED TO INTERPOLATE FOR T= 5.53887037E+01   LARGEST VALUE IN TABLE IS 5.50000000E+01

RHOMUREF = 1.11273E-10

INTERPOLATED EDGE CONDITIONS

PE =	4.55095E+02	X0 =	4.16667E+00	LAMBDA =	2.48706E-06	DELXI =	1.20271E-06
TE =	2.62942E+03	X 1/2 =	4.39120E+00	LAMBDA 1/2 =	2.67744E-06	XI0 =	4.44719E-06
UE =	1.92447E+04	X1 =	4.61573E+00	LAMBDA + 1 =	2.87287E-06	XI 1/2 =	5.04854E-06
DPE0 =	-1.38834E+01	RB0 =	1.07380E+00	BETA =	2.21816E-02	XI1 =	5.64989E-06
DPE1 =	-3.32851E+00	RB 1/2 =	1.11615E+00	MU =	1.10714E-06	SMALL E =	2.04382E-04
PEB =	-9.27780E-04	RB1 =	1.15826E+00	RHOE =	1.00505E-04	EBAR =	-3.89291E-01
ETE =	1.50000E+01						

RHOMUREF = 1.13010E-10

X(K)

N	ETA	1	2	3	4	5	6	7	8	9	10
1	0.0000	-3.8369E-06	-4.3464E-03	-2.5027E-03	-6.1973E-04	-5.2456E-03	-1.9144E-06	-2.9368E-08	-2.8723E-15	-2.3999E-05	2.0552E-05
2	.0370	-1.1782E-02	-2.1787E-03	-9.7731E-04	-2.4063E-02	-2.1015E-02	-4.6895E-05	-1.2821E-08	3.7438E-14	-1.3750E-05	-4.5514E-02
3	.0741	-5.0564E-02	-1.5313E-03	-6.2407E-04	-4.6583E-02	-1.0841E-02	-4.9933E-05	-5.2256E-09	1.6311E-13	-7.5967E-06	-1.9102E-01
4	.1111	-1.3803E-01	-8.3703E-04	-2.5059E-04	-6.7744E-02	-2.2867E-02	-3.7130E-05	-1.1140E-09	4.7389E-15	-2.6307E-06	-2.5283E+00
5	.1481	-2.9666E-01	-1.1042E-04	-1.1567E-05	-4.2667E-02	-5.1530E-02	-1.0958E-05	-4.4276E-11	4.6642E-18	-1.8027E-07	-9.0664E+00
6	.1852	-4.8495E-01	-1.8268E-06	-2.4026E-08	-7.7105E-03	-9.8456E-02	-5.6592E-07	-7.1502E-14	5.8601E-22	-8.4154E-10	-4.2890E+00
7	.2222	-4.7561E-01	-4.6824E-08	-9.6993E-11	-1.2576E-03	-1.1182E-01	-7.8250E-09	-1.2409E-17	1.4705E-25	-1.6070E-12	-8.7337E-01
8	.2593	-3.1361E-01	-5.3292E-09	-3.6727E-12	-3.3246E-04	-6.8422E-02	-4.7963E-11	-5.9355E-22	1.0390E-28	-3.4377E-15	-3.3325E-01
9	.2963	-1.6268E-01	-1.0648E-09	-3.2431E-13	-9.5546E-05	-2.4393E-02	-2.5439E-13	-2.6083E-26	1.6520E-31	-8.5139E-18	-1.8899E-01
10	.3333	-6.8617E-02	-2.2742E-10	-3.1668E-14	-2.4741E-05	-5.6891E-03	-5.4829E-15	-2.0284E-29	4.1384E-34	-6.9429E-20	-1.1204E-01
11	.3704	-2.5335E-02	-4.1786E-11	-2.4670E-15	-5.4544E-06	-9.1698E-04	-2.1302E-16	-6.9160E-32	1.1860E-36	-4.0319E-22	-5.8527E-02
12	.4074	-8.4752E-03	-5.9557E-12	-1.3133E-16	-1.0150E-06	-9.8239E-05	-6.7577E-18	-1.5571E-34	3.1194E-39	3.7743E-23	-2.5109E-02
13	.4444	-2.6037E-03	-6.3467E-13	-4.5262E-18	-1.6174E-07	-5.7789E-06	-1.4497E-19	-6.8707E-38	5.6935E-42	1.2871E-24	-8.7492E-03
14	.4815	-7.3365E-04	-5.1041E-14	-1.0267E-19	-2.2554E-08	-7.1531E-08	-1.1972E-21	2.8947E-41	9.2906E-46	8.7297E-27	-2.5337E-03
15	.5185	-1.8779E-04	-3.2241E-15	-1.6371E-21	-2.8158E-09	2.4760E-11	0.	0.	0.	0.	-6.3597E-04
16	.5556	-4.2993E-05	-1.6728E-16	-1.9970E-23	-3.2293E-10	-1.0643E-10	-1.0905E-25	1.6347E-44	4.2516E-50	1.0532E-30	-1.4572E-04
17	.5926	-8.5535E-06	-6.8407E-18	-1.8677E-25	-3.5057E-11	1.3798E-14	0.	0.	0.	0.	-3.2119E-05
18	.6296	-1.3638E-06	-5.5961E-20	-3.0735E-28	-3.6897E-12	-5.3807E-13	-2.9026E-29	1.8445E-47	1.5495E-53	4.4519E-34	-7.0899E-06
19	.6667	-1.1045E-07	4.7986E-20	7.5613E-29	-3.7738E-13	2.8662E-18	0.	0.	0.	0.	-1.5917E-06
20	.7037	3.8928E-08	1.1827E-20	4.4753E-30	-3.6712E-14	-3.9609E-15	-1.0598E-32	5.1353E-50	1.6613E-56	4.1416E-37	-3.6028E-07
21	.7407	3.0898E-08	2.4211E-21	2.1854E-31	-3.2870E-15	0.	-8.3026E-36	-3.2441E-64	0.	-1.9468E-43	-8.0538E-08
22	.7778	1.5714E-08	4.9608E-22	1.0319E-32	-2.6229E-16	-3.2094E-17	-2.4160E-35	2.6120E-52	3.7959E-59	6.4009E-40	-1.7409E-08
23	.8148	7.4306E-09	1.0664E-22	4.8518E-34	-1.8200E-17	0.	-6.0469E-38	-1.5360E-66	0.	-6.2203E-46	-3.5807E-09
24	.8519	3.5359E-09	2.4390E-23	2.2829E-35	-1.0837E-18	-2.3892E-19	5.5834E-44	2.1109E-54	1.5638E-61	6.6923E-43	-6.9472E-10
25	.8889	1.7289E-09	5.9543E-24	1.0756E-36	-5.4825E-20	5.9885E-26	-4.8426E-41	-1.8163E-70	0.	2.4958E-43	-1.2682E-10
26	.9259	8.7269E-10	1.5517E-24	4.9849E-38	-2.2074E-21	-1.3521E-21	1.2879E-46	2.4023E-56	1.0067E-63	0.	-2.1389E-11
27	.9630	4.5506E-10	4.3154E-25	2.0380E-39	-5.5972E-23	1.3886E-27	-1.1105E-44	-6.6221E-75	0.	5.5233E-45	-2.9904E-12
28	1.0000	2.4514E-10	1.2803E-25	3.5665E-41	-8.2236E-25	0.	0.	0.	0.	0.	-1.6820E-13

N	ETA	FPRIME	THETA	O2	N2	O	N	NO	NO+	CO	CO2
1	0.0000	0.	8.5593E-01	0.	5.8705E-01	1.1170E-03	3.2370E-02	0.	1.2636E-05	3.7826E-01	7.8655E-04
2	.0370	1.4961E-01	1.0430E+00	2.3480E-06	6.0415E-01	4.0790E-02	3.3371E-02	1.4063E-04	1.5353E-05	3.2036E-01	7.6549E-04
3	.0741	2.9968E-01	1.1550E+00	1.2042E-05	6.2184E-01	8.3251E-02	3.4516E-02	5.9975E-04	2.2779E-05	2.5871E-01	6.5719E-04
4	.1111	4.3767E-01	1.2025E+00	3.5597E-05	6.3918E-01	1.2632E-01	3.5305E-02	1.2865E-03	3.1553E-05	1.9698E-01	5.1208E-04
5	.1481	5.5219E-01	1.2101E+00	7.2274E-05	6.5533E-01	1.6720E-01	3.5235E-02	1.9163E-03	3.8123E-05	1.3958E-01	3.6444E-04
6	.1852	6.3756E-01	1.2011E+00	1.1726E-04	6.6947E-01	2.0262E-01	3.4215E-02	2.3937E-03	4.1449E-05	9.0737E-02	2.3525E-04
7	.2222	6.9595E-01	1.1880E+00	1.6537E-04	6.8115E-01	2.2988E-01	3.2468E-02	2.7419E-03	4.2099E-05	5.3319E-02	1.3636E-04
8	.2593	7.3511E-01	1.1738E+00	2.1058E-04	6.9062E-01	2.4787E-01	3.0259E-02	2.9679E-03	4.0796E-05	2.7910E-02	7.0489E-05
9	.2963	7.6348E-01	1.1580E+00	2.4838E-04	6.9866E-01	2.5730E-01	2.7800E-02	3.0683E-03	3.8137E-05	1.2825E-02	3.2324E-05
10	.3333	7.8679E-01	1.1406E+00	2.7809E-04	7.0619E-01	2.6006E-01	2.5256E-02	3.0657E-03	3.4710E-05	5.0951E-03	1.3043E-05
11	.3704	8.0767E-01	1.1226E+00	3.0199E-04	7.1387E-01	2.5833E-01	2.2742E-02	3.0047E-03	3.1056E-05	1.7189E-03	4.5630E-06
12	.4074	8.2698E-01	1.1052E+00	3.2339E-04	7.2200E-01	2.5391E-01	2.0320E-02	2.9303E-03	2.7551E-05	4.8148E-04	1.3532E-06
13	.4444	8.4494E-01	1.0894E+00	3.4569E-04	7.3060E-01	2.4805E-01	1.7995E-02	2.8788E-03	2.4383E-05	1.0855E-04	3.2947E-07
14	.4815	8.6163E-01	1.0757E+00	3.7301E-04	7.3948E-01	2.4150E-01	1.5730E-02	2.8821E-03	2.1593E-05	1.8807E-05	6.2948E-08
15	.5185	8.7710E-01	1.0646E+00	4.1298E-04	7.4845E-01	2.3465E-01	1.3478E-02	2.9839E-03	1.9137E-05	2.3152E-06	8.7998E-09
16	.5556	8.9140E-01	1.0561E+00	4.8624E-04	7.5730E-01	2.2772E-01	1.1195E-02	3.2747E-03	1.6933E-05	1.7214E-07	7.9015E-10
17	.5926	9.0460E-01	1.0500E+00	6.6048E-04	7.6573E-01	2.2075E-01	8.8716E-03	3.9749E-03	1.4896E-05	4.3964E-09	3.1748E-11
18	.6296	9.1676E-01	1.0455E+00	1.1529E-03	7.7307E-01	2.1362E-01	6.5559E-03	5.5911E-03	1.2953E-05	0.	0.
19	.6667	9.2798E-01	1.0408E+00	2.5495E-03	7.7796E-01	2.0602E-01	4.3909E-03	9.0649E-03	1.1074E-05	4.6373E-12	8.1564E-15
20	.7037	9.3833E-01	1.0336E+00	6.0106E-03	7.7843E-01	1.9740E-01	2.6172E-03	1.5539E-02	9.2901E-06	0.	6.9510E-16
21	.7407	9.4790E-01	1.0234E+00	1.2872E-02	7.7321E-01	1.8712E-01	1.4342E-03	2.5356E-02	7.6820E-06	2.3638E-14	0.
22	.7778	9.5679E-01	1.0134E+00	2.3309E-02	7.6367E-01	1.7508E-01	8.0352E-04	3.7129E-02	6.3291E-06	0.	6.6882E-18
23	.8148	9.6511E-01	1.0064E+00	3.5686E-02	7.5319E-01	1.6205E-01	5.0869E-04	4.8561E-02	5.2475E-06	2.2240E-16	0.
24	.8519	9.7292E-01	1.0030E+00	4.7960E-02	7.4450E-01	1.4903E-01	3.6835E-04	5.8138E-02	4.3919E-06	0.	2.9352E-20
25	.8889	9.8028E-01	1.0015E+00	5.9066E-02	7.3841E-01	1.3667E-01	2.9282E-04	6.5559E-02	3.6954E-06	2.1885E-18	4.4148E-21
26	.9259	9.8723E-01	1.0008E+00	6.8961E-02	7.3448E-01	1.2514E-01	2.4472E-04	7.1167E-02	3.0965E-06	2.7943E-19	5.2119E-23
27	.9630	9.9379E-01	1.0003E+00	7.8051E-02	7.3199E-01	1.1439E-01	2.0575E-04	7.5357E-02	2.5494E-06	0.	2.2466E-22
28	1.0000	1.0000E+00	1.0000E+00	8.6696E-02	7.3052E-01	1.0435E-01	1.3655E-04	7.8299E-02	2.0259E-06	0.	0.

N	ETA	C1	C2	C3	CN
1	0.0000	3.7698E-04	3.0169E-10	1.1519E-14	3.2533E-05
2	.0370	3.7536E-04	2.6621E-10	1.0352E-14	3.7108E-05
3	.0741	3.4887E-04	1.4247E-10	6.1911E-15	4.8967E-05
4	.1111	2.9428E-04	8.2489E-11	2.7326E-15	4.4887E-05
5	.1481	2.2212E-04	3.7338E-11	7.6576E-16	3.0839E-05
6	.1852	1.4932E-04	1.3453E-11	1.5098E-16	1.7829E-05
7	.2222	8.9014E-05	4.0109E-12	2.2688E-17	9.2053E-06
8	.2593	4.6813E-05	9.8094E-13	2.5703E-18	4.2801E-06
9	.2963	2.1573E-05	1.9142E-13	2.0866E-19	1.7673E-06
10	.3333	8.6217E-06	2.8972E-14	1.1556E-20	6.3783E-07
11	.3704	2.9419E-06	3.2951E-15	4.1808E-22	1.9828E-07
12	.4074	8.3792E-07	2.6977E-16	9.4208E-24	5.2154E-08
13	.4444	1.9299E-07	1.4949E-17	1.2454E-25	1.1305E-08
14	.4815	3.4298E-08	5.1264E-19	8.9557E-28	1.9376E-09
15	.5185	4.3536E-09	9.4415E-21	3.1849E-30	2.4501E-10
16	.5556	3.3761E-10	7.1148E-23	4.7461E-33	1.9918E-11
17	.5926	9.5736E-12	8.9199E-26	9.1587E-37	6.8724E-13
18	.6296	0.	0.	0.	0.
19	.6667	8.2008E-15	2.9027E-30	3.1278E-41	4.7743E-16
20	.7037	0.	0.	0.	0.
21	.7407	2.2713E-17	6.8499E-34	7.7717E-45	1.1130E-18
22	.7778	0.	0.	0.	3.1169E-20
23	.8148	7.6000E-20	4.4416E-37	5.2992E-48	0.
24	.8519	0.	0.	0.	2.0870E-21
25	.8889	1.6928E-22	6.0094E-40	7.5372E-51	0.
26	.9259	9.7716E-26	0.	0.	5.4622E-23
27	.9630	0.	1.5067E-42	1.9867E-53	0.
28	1.0000	0.	0.	0.	0.

N	ETA	Y/RN	V	BETA/EBB	DENSITY	ELECTRON DENSITY	TOTAL ENTHALPY
1	0.0000	0.	7.0458E-02	0.	4.8188E-05	3.1620E+12	2.7448E+07
2	.0370	2.4702E-02	1.3585E-02	0.	3.6049E-05	2.7308E+12	5.5287E+07
3	.0741	5.4451E-02	-1.6314E-01	0.	3.2431E-05	3.3203E+12	8.9251E+07
4	.1111	8.5379E-02	-4.6183E-01	0.	3.3000E-05	3.0902E+12	1.2689E+08
5	.1481	1.1446E-01	-8.6429E-01	0.	3.6429E-05	2.1167E+12	1.6089E+08
6	.1852	1.4013E-01	-1.3384E+00	0.	4.2136E-05	1.3779E+12	1.8387E+08
7	.2222	1.6251E-01	-1.8527E+00	0.	4.7746E-05	9.2329E+11	1.9583E+08
8	.2593	1.8261E-01	-2.3864E+00	0.	5.2228E-05	6.2627E+11	2.0075E+08
9	.2963	2.0124E-01	-2.9294E+00	0.	5.5684E-05	4.2657E+11	2.0236E+08
10	.3333	2.1884E-01	-3.4769E+00	0.	5.8560E-05	2.8977E+11	2.0270E+08
11	.3704	2.3563E-01	-4.0266E+00	0.	6.1226E-05	1.9431E+11	2.0261E+08
12	.4074	2.5170E-01	-4.5773E+00	0.	6.3891E-05	1.2691E+11	2.0243E+08
13	.4444	2.6711E-01	-5.1285E+00	0.	6.6630E-05	7.9582E+10	2.0229E+08
14	.4815	2.8189E-01	-5.6801E+00	0.	6.9433E-05	4.7261E+10	2.0221E+08
15	.5185	2.9609E-01	-6.2321E+00	0.	7.2248E-05	2.6262E+10	2.0219E+08
16	.5556	3.0974E-01	-6.7846E+00	0.	7.5022E-05	1.3516E+10	2.0222E+08
17	.5926	3.2291E-01	-7.3375E+00	0.	7.7713E-05	6.3870E+09	2.0228E+08
18	.6296	3.3563E-01	-7.8909E+00	0.	8.0300E-05	2.7483E+09	2.0236E+08
19	.6667	3.4796E-01	-8.4448E+00	0.	8.2774E-05	1.0676E+09	2.0243E+08
20	.7037	3.5993E-01	-8.9990E+00	0.	8.5136E-05	3.7046E+08	2.0250E+08
21	.7407	3.7159E-01	-9.5535E+00	0.	8.7389E-05	1.1330E+08	2.0256E+08
22	.7778	3.8295E-01	-1.0108E+01	0.	8.9538E-05	2.9965E+07	2.0261E+08
23	.8148	3.9405E-01	-1.0663E+01	0.	9.1591E-05	6.6656E+06	2.0266E+08
24	.8519	4.0491E-01	-1.1219E+01	0.	9.3550E-05	1.1934E+06	2.0271E+08
25	.8889	4.1555E-01	-1.1774E+01	0.	9.5420E-05	1.5921E+05	2.0275E+08
26	.9259	4.2599E-01	-1.2330E+01	0.	9.7201E-05	1.3446E+04	2.0279E+08
27	.9630	4.3625E-01	-1.2885E+01	0.	9.8896E-05	4.2299E+02	2.0282E+08
28	1.0000	4.4633E-01	-1.3441E+01	-9.2778E-04	1.0051E-04	1.0400E-02	2.0285E+08

TIME LEFT	=135.939 SEC	RHO V =	5.28768E-05
QCOND =	-2.18185E+04	HEAT TRANSFER =	2.41325E-01
QDIFF =	-1.60549E+04	HEAT TRANSFER, BODY =	2.79604E-01
QCONV =	1.45138E+03	DISPLACEMENT THICKNESS/RN =	2.60735E+07
QTOTAL =	-3.64220E+04	MOMENTUM THICKNESS =	1.33399E-03
QTOTAL(BTU/FT2-SEC) =	-4.68055E+01	L AT BODY =	7.56583E-01
STANTON NUMBER =	3.24606E-04	SKIN FRICTION =	5.04926E-01
RS**(1+J) =	1.34603E-01	T DRAG COEF =	3.21057E-03
REYNOLDS NUMBER =	7.93980E+06	P DRAG COEF =	1.04990E-01
CF-INF =	5.04148E-04	TOTAL DRAG =	1.08201E-01

SPECIES	WALL MASS FLUX	TOTAL MASS FLOW	FLOW(PAR/SEC)
O2	4.86977E-08	5.32947E-02	1.46441E+25
N2	-3.83943E-06	2.14740E-01	6.73960E+25
O	-6.66098E-05	7.66187E-03	4.21058E+24
N	1.72413E-10	1.23511E-04	7.75276E+22
NO	1.06248E-12	1.48493E-03	4.35106E+23
NO+	1.19667E-13	2.51141E-07	7.35882E+19
CO	1.23277E-04	4.20328E-03	1.31943E+24
CO2	8.95477E-12	1.55387E-05	3.10442E+21
C1	6.06220E-13	2.39105E-07	1.75039E+20
C2	1.20289E-19	4.27935E-14	1.56638E+13
C3	6.18777E-24	1.82574E-18	4.45518E+08
CN	2.99436E-13	1.35692E-07	4.58518E+19

M	X/RN	RS**(1+J)	REVE	XI	YF(EDGE)
1	0.	0.	-2.3756978E-01	0.	2.8022134E-02
2	1.0000000E-02	2.5637528E-07	-2.4325890E-01	3.1288628E-17	2.8003811E-02
3	2.2666667E-02	1.3339536E-06	-2.4469723E-01	8.2563866E-16	2.7992006E-02
4	3.8000000E-02	3.7796523E-06	-2.4435885E-01	6.5172705E-15	2.7975615E-02
5	5.6000000E-02	8.2010762E-06	-2.4246949E-01	3.0695169E-14	2.7970648E-02
6	7.6666667E-02	1.5330988E-05	-2.4118170E-01	1.0757445E-13	2.7997456E-02
7	1.0000000E-01	2.6060065E-05	-2.3385588E-01	3.1026741E-13	2.8053827E-02
8	1.2600000E-01	4.1308478E-05	-2.2779651E-01	7.7248510E-13	2.8632012E-02
9	1.5407273E-01	6.1580835E-05	-2.2927010E-01	1.6984761E-12	2.8877024E-02
10	1.8421818E-01	8.7603600E-05	-2.2335406E-01	3.4105843E-12	2.9219817E-02
11	2.1643636E-01	1.2010437E-04	-2.1759987E-01	6.3714523E-12	2.9607306E-02
12	2.5072727E-01	1.5975960E-04	-2.1063843E-01	1.1223482E-11	3.0041481E-02
13	2.8709091E-01	2.0719432E-04	-2.0264616E-01	1.8820679E-11	3.0545684E-02
14	3.2552727E-01	2.6300024E-04	-1.9369613E-01	3.0258014E-11	3.1115763E-02
15	3.6603636E-01	3.2771352E-04	-1.8355539E-01	4.6887826E-11	3.1782941E-02
16	4.0861818E-01	4.0170037E-04	-1.7306294E-01	7.0324040E-11	3.2547068E-02
17	4.5327273E-01	4.8521227E-04	-1.6212133E-01	1.0244383E-10	3.3401233E-02
18	5.0000000E-01	5.7843478E-04	-1.5075046E-01	1.4537105E-10	3.4361084E-02
19	5.4880000E-01	6.8139484E-04	-1.3914219E-01	2.0143936E-10	3.5422341E-02
20	6.0514286E-01	8.0631913E-04	-1.2654834E-01	2.8171341E-10	3.6713876E-02
21	6.6902857E-01	9.5464047E-04	-1.1343088E-01	3.9437298E-10	3.8251250E-02
22	7.4045714E-01	1.1273297E-03	-1.0033266E-01	5.4919310E-10	4.0050293E-02
23	8.1942857E-01	1.3249740E-03	-8.7480798E-02	7.5737289E-10	4.2111485E-02
24	9.0594286E-01	1.5476564E-03	-7.4831164E-02	1.0310813E-09	4.4458694E-02
25	1.0000000E+00	1.7949579E-03	-6.3094460E-02	1.3831726E-09	4.7107171E-02
26	1.1016000E+00	2.0659001E-03	-5.3180843E-02	1.8265240E-09	5.0034718E-02
27	1.2150303E+00	2.3709476E-03	-4.4239855E-02	2.3973657E-09	5.3309243E-02
28	1.3402909E+00	2.7090277E-03	-3.6225527E-02	3.1176456E-09	5.6965489E-02
29	1.4773818E+00	3.0786601E-03	-2.9517922E-02	4.0093416E-09	6.0935128E-02
30	1.6263030E+00	3.4784129E-03	-2.3578189E-02	5.0942934E-09	6.5224711E-02
31	1.7870545E+00	3.9069607E-03	-1.8855179E-02	6.3933030E-09	6.9816349E-02
32	1.9596364E+00	4.3628040E-03	-1.5082207E-02	7.9263456E-09	7.4636834E-02
33	2.1440485E+00	4.8445250E-03	-1.1617531E-02	9.7133315E-09	7.9682232E-02
34	2.3402909E+00	5.3508662E-03	-8.5837839E-03	1.1773364E-08	8.4964366E-02
35	2.5483636E+00	5.8808964E-03	-5.9157784E-03	1.4125006E-08	9.0448332E-02
36	2.7682667E+00	6.4328733E-03	-4.4802462E-03	1.6787654E-08	9.6143923E-02

37	3.0000000E+00	7.0051434E-03	-2.3086381E-03	1.9783965E-08	1.0175720E-01
38	3.2435636E+00	7.6000915E-03	6.5568852E-04	2.3136575E-08	1.0789365E-01
39	3.5095697E+00	8.2411138E-03	2.0933355E-03	2.7019073E-08	1.1444616E-01
40	3.7980182E+00	8.9261676E-03	3.2208426E-03	3.1481139E-08	1.2149401E-01
41	4.1089091E+00	9.6542129E-03	3.6404632E-03	3.6572004E-08	1.2885884E-01
42	4.4422424E+00	1.0425404E-02	4.0913088E-03	4.2348188E-08	1.3653396E-01
43	4.7980182E+00	1.1239026E-02	4.2143105E-03	4.8864358E-08	1.4456291E-01
44	5.1762364E+00	1.2093230E-02	3.9556915E-03	5.6177668E-08	1.5274604E-01
45	5.5768970E+00	1.2987025E-02	3.7585911E-03	6.4351916E-08	1.6111291E-01
46	6.0000000E+00	1.3920154E-02	3.4957972E-03	7.3452043E-08	1.6963164E-01
47	6.4455455E+00	1.4892660E-02	3.2279649E-03	8.3544048E-08	1.7830036E-01
48	6.9463712E+00	1.5974849E-02	2.8624475E-03	9.5500430E-08	1.8776181E-01
49	7.5024773E+00	1.7164739E-02	2.3939550E-03	1.0952307E-07	1.9785321E-01
50	8.1138636E+00	1.8461360E-02	1.8310321E-03	1.2583257E-07	2.0856485E-01
51	8.7805303E+00	1.9864213E-02	1.1197061E-03	1.4467235E-07	2.1965687E-01
52	9.5024773E+00	2.1374838E-02	3.9803013E-04	1.6631529E-07	2.3107025E-01
53	1.0279705E+01	2.2995072E-02	-4.0515243E-04	1.9107103E-07	2.4260351E-01
54	1.1112212E+01	2.4727144E-02	-1.2556452E-03	2.1929020E-07	2.5409356E-01
55	1.2000000E+01	2.6574876E-02	-1.9930959E-03	2.5137386E-07	2.6533549E-01
56	1.2943068E+01	2.8543294E-02	-2.5502481E-03	2.8776188E-07	2.7641505E-01
57	1.3987677E+01	3.0732961E-02	-3.0698729E-03	3.3090973E-07	2.8771338E-01
58	1.5133826E+01	3.3150443E-02	-3.4498213E-03	3.8179574E-07	2.9909327E-01
59	1.6381515E+01	3.5805472E-02	-3.8479313E-03	4.4152289E-07	3.1060039E-01
60	1.7730745E+01	3.8691177E-02	-4.4455282E-03	5.1137049E-07	3.2171214E-01
61	1.9181515E+01	4.1810030E-02	-4.9268140E-03	5.9290763E-07	3.3214550E-01
62	2.0733826E+01	4.5188790E-02	-5.2523665E-03	6.8791720E-07	3.4224348E-01
63	2.2387677E+01	4.8842377E-02	-5.6062157E-03	7.9837279E-07	3.5185309E-01
64	2.4143068E+01	5.2785746E-02	-5.8842711E-03	9.2655320E-07	3.6093886E-01
65	2.6000000E+01	5.7033810E-02	-6.1077568E-03	1.0750138E-06	3.6961132E-01
66	2.7958472E+01	6.1604168E-02	-6.3983291E-03	1.2466291E-06	3.7780387E-01
67	3.0406978E+01	6.7441180E-02	-6.7073685E-03	1.4840905E-06	3.8652597E-01
68	3.3345516E+01	7.4653741E-02	-6.5044657E-03	1.8051039E-06	3.9574995E-01
69	3.6774087E+01	8.3322457E-02	-6.0925148E-03	2.2310325E-06	4.0668307E-01
70	4.0692692E+01	9.3516048E-02	-6.1104927E-03	2.7887299E-06	4.1801406E-01
71	4.5101329E+01	1.0536070E-01	-6.3531317E-03	3.5126904E-06	4.2888256E-01
72	5.0000000E+01	1.1899480E-01	-6.8151824E-03	4.4471885E-06	4.3864884E-01

END OF THIS PROBLEM

VIII. RESULTS FROM COMPUTER PROGRAM

The present computer program has been used to solve a large number of problems but this is only a small part of the number possible. One of the original problems solved was the viscous thin shock layer for nonequilibrium air as reported in Reference 4. Additional solutions have been obtained to this problem where the effects of shock slip, multicomponent diffusion and a fully catalytic recombination wall have been taken into account. At low Reynolds numbers, the shock slip effects are important as shown in Fig. 8.1 where the present results have been added to Fig. 9 of Reference 4. The low Reynolds number effects on local skin friction are illustrated in Fig. 8.2. The boundary layer and vorticity interaction results are from Ho and Probstein[41]. The results for electron number density as given in Fig. 8 of Reference 4 are presented in Fig. 8.3 with the latest results included for comparison. There is no difference at the low altitudes and a slight change at the high altitudes.

Additional thin viscous shock layer solutions have been obtained and compared to other theories in Fig. 8.4 and to experimental results in Fig. 8.5. The theory of Lee and Zierten[23] is more approximate than the predictions of Dellinger[42]. In both cases a merged layer approach is employed where the Navier-Stokes equations are solved through the shock layer. The present results are in close agreement with those of Dellinger except near the wall where different boundary conditions have been applied. The present method also is in reasonable agreement with the experimental results of Kaegi and McMenamin[43]. In the present method the details in the shock transition zone are not obtained, but the theory of Cheng[20] can be used for this information. The present studies indicate that the effects of multi-component diffusion for air are small and this is in agreement with results of Adams.[44,45]

Results for the shock layer have been obtained for a body with a 1-inch nose radius at altitudes as low as 100 Kft. At these conditions a boundary layer and a relaxation layer behind the shock wave develop as shown in Fig. 8.6. A variable grid system was used to obtain the results at 100 Kft altitude. At this altitude the temperature in the middle of the shock layer is in agreement with inviscid flow predictions for air in local chemical equilibrium.

The present results are obtained in the transformed boundary layer type coordinate system. The shock layer thickness η_{sh} is correlated in Fig. 8.7 to show the variation with shock Reynolds number. The actual physical thickness only varies slightly with the shock Reynolds number.

Additional results have been obtained for the heat transfer from the thin shock layer theory. These results are compared to theoretical predictions of Tong and Suzuki[46] in Figures 8.8 and 8.9. The present results are for a complete air gas model while Tong and Suzuki use a binary gas model with slightly different wall conditions. The present results for a noncatalytic wall are different from the results of Tong and Suzuki, while the catalytic results are in reasonable agreement. As shown in Figure 8.9 there can be a significant decrease in heat transfer at certain altitudes when the surface is noncatalytic.

In all of the previous solutions, it was assumed that the shock is concentric with the body. The effect of changing this assumption is illustrated in Figures 8.10 and 8.11 where the shock radius has been varied. These results are for a binary gas mixture of oxygen and a freestream velocity of 20 Kfps at an altitude of 100 Kft. When the shock is concentric with the body, the value of $R_N/R_{sh} = 0.95$. In Fig. 8.10 the shock stand-off distance is given for an inviscid air solution of Lomax and Inouye[19] and viscous shock layer solution of Davis[6]. These results indicate R_N/R_{sh} should be approximately 0.86. The effect of varying the shock radius on the skin friction and heat transfer is given in Fig. 8.11. There is a small effect on skin friction but a significant effect on the heat transfer.

Air boundary layer solutions have been obtained previously for flow along a sharp cone and a hyperboloid and these results were presented in Reference 5. The cone results were compared to other theoretical results and reasonable agreement was obtained. The predictions are very sensitive to the reaction rates and transport properties employed. The results for the hyperboloid neglected the swallowing on the inviscid flow. A new boundary layer solution along the hyperboloid has been calculated with the effects of swallowing of the inviscid flow included. These results are presented in Figures 8.12 to 8.16. The variation of the Stanton number and skin friction along the surface are given in Figures 8.12 and 8.13. The heat transfer is slightly changed when swallowing is taken into account while there is a more significant influence on the skin friction. The velocity profile shape is not affected much by swallowing but the magnitude of the velocity is approximately 50% greater. The temperature profile shape has changed and the peak temperature is $6850^{\circ}R$ while previously the value was $8530^{\circ}R$. The profiles of the various species are given in Fig. 8.16 and are significantly different from the results of Reference 5. With swallowing taken into account, the gas at the edge of the boundary layer at $x/R_N = 50$ is only slightly dissociated and ionized. Results for this problem have also been obtained with $\eta_e = 15$ with the results changing only a small amount and this is investigated next for a binary gas mixture.

The boundary layer flow along a hyperboloid for a binary gas mixture has been obtained and some of these results were reported by Davis[6]. These results are for $\eta_e = 5.5$. Additional results have been obtained for $\eta_e = 15.0$ with the effects of swallowing taken into account. Also the effects of the shock shape have been investigated by obtaining the perfect gas inviscid flow solution with two values of γ. The velocity, temperature and atom mass fraction profiles at several distances along the hyperboloid are given in Figures 8.17 to 8.19. The results for two values of η_e are compared to the viscous shock layer results, with the $\eta_e = 15$ results in perhaps better agreement when γ is smaller. The heat transfer and skin friction are given in Figures 8.21 and 8.22. The boundary layer results obtained with the shock shape for the smaller γ and $\eta_e = 15$ are in better agreement with the viscous shock layer results.

Additional boundary layer results have been obtained for a binary gas mixture of oxygen for a flat plate and cone. Boundary layer calculations for air have also been obtained for a sphere-cone. Other gas models have been utilized and some of these results have been presented in Reference 7. This study was concerned with both stagnation point shock layer and boundary layer solutions along carbon bodies. A carbon-air gas model was used and boundary conditions corresponding to oxidation and sublimation of carbon were employed. Also boundary layer solutions for ionized nitrogen and oxygen-hydrogen gas mixtures have been obtained. These results will be published in forthcoming publications.

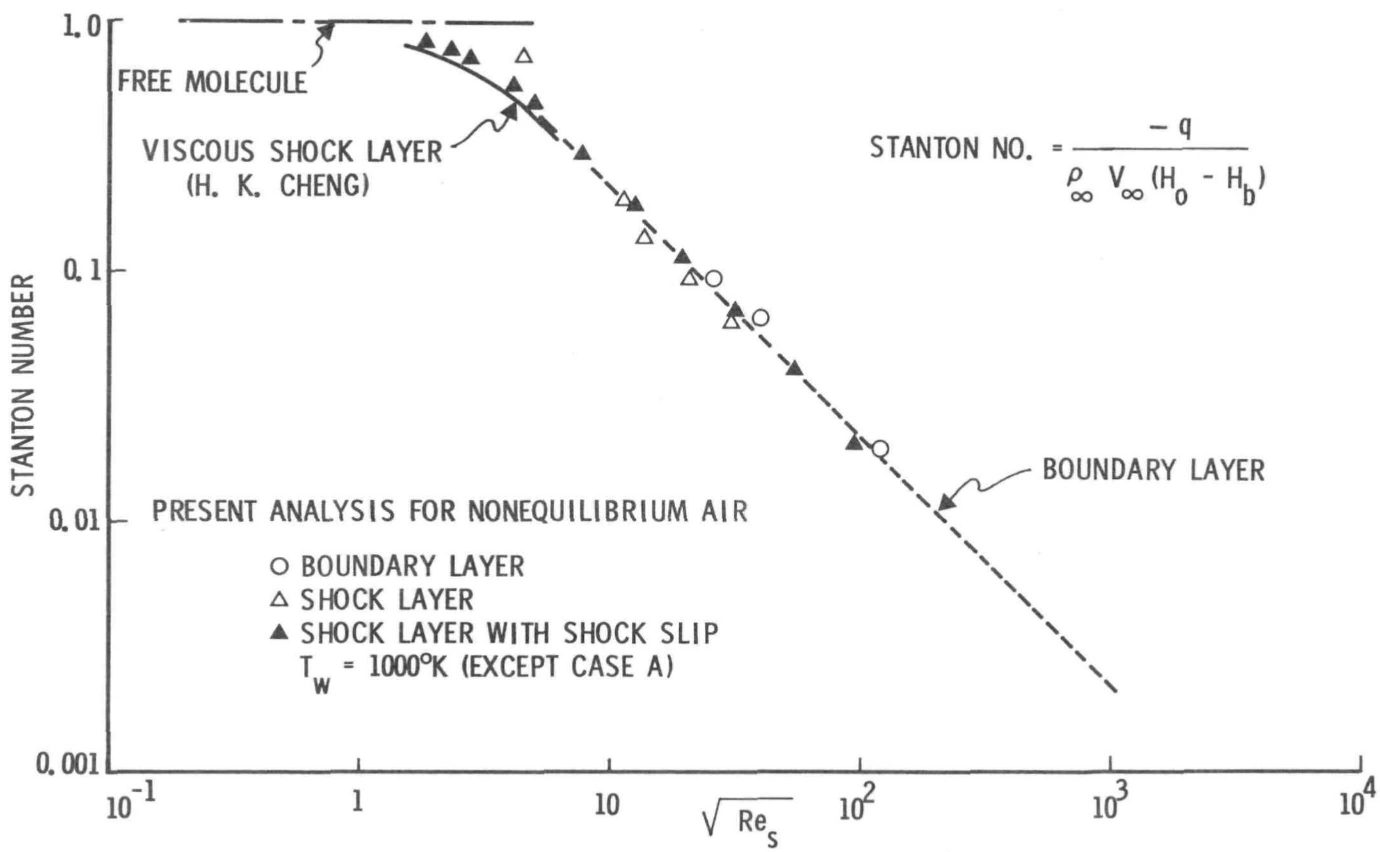


FIG. 8.1 - STANTON NUMBER VARIATION WITH REYNOLDS NUMBER

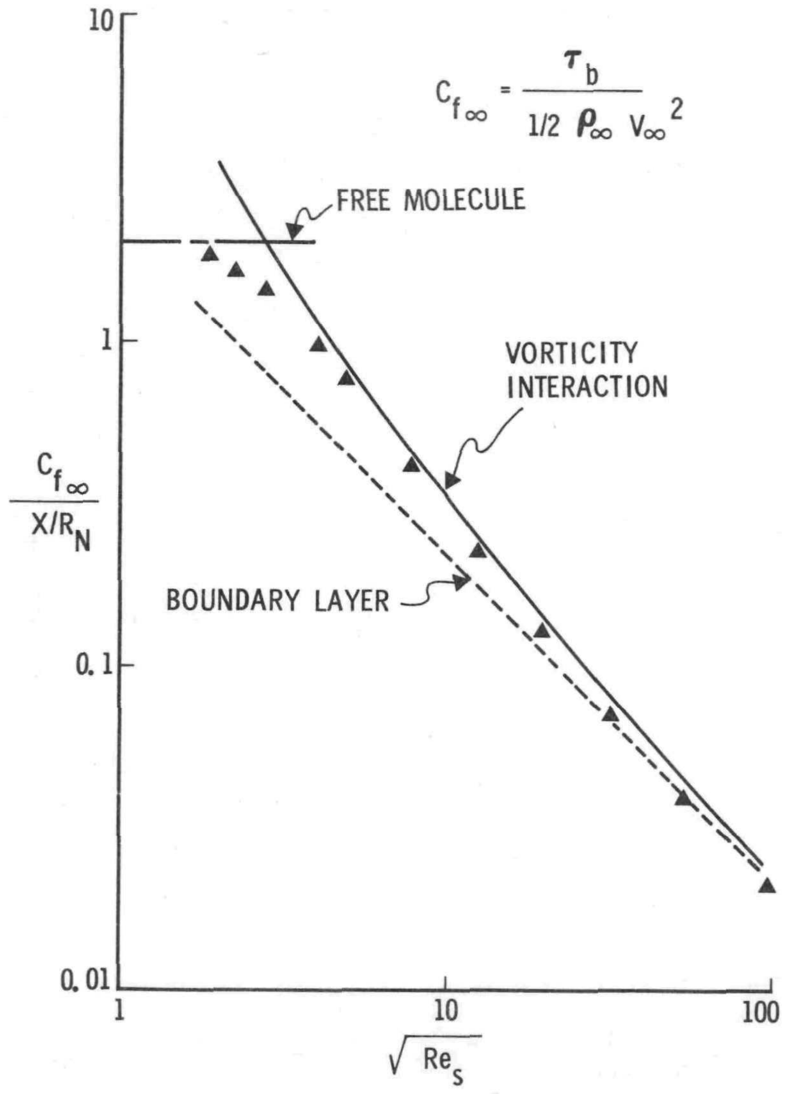


FIG. 8.2 - SKIN FRICTION VARIATION WITH REYNOLDS NUMBER

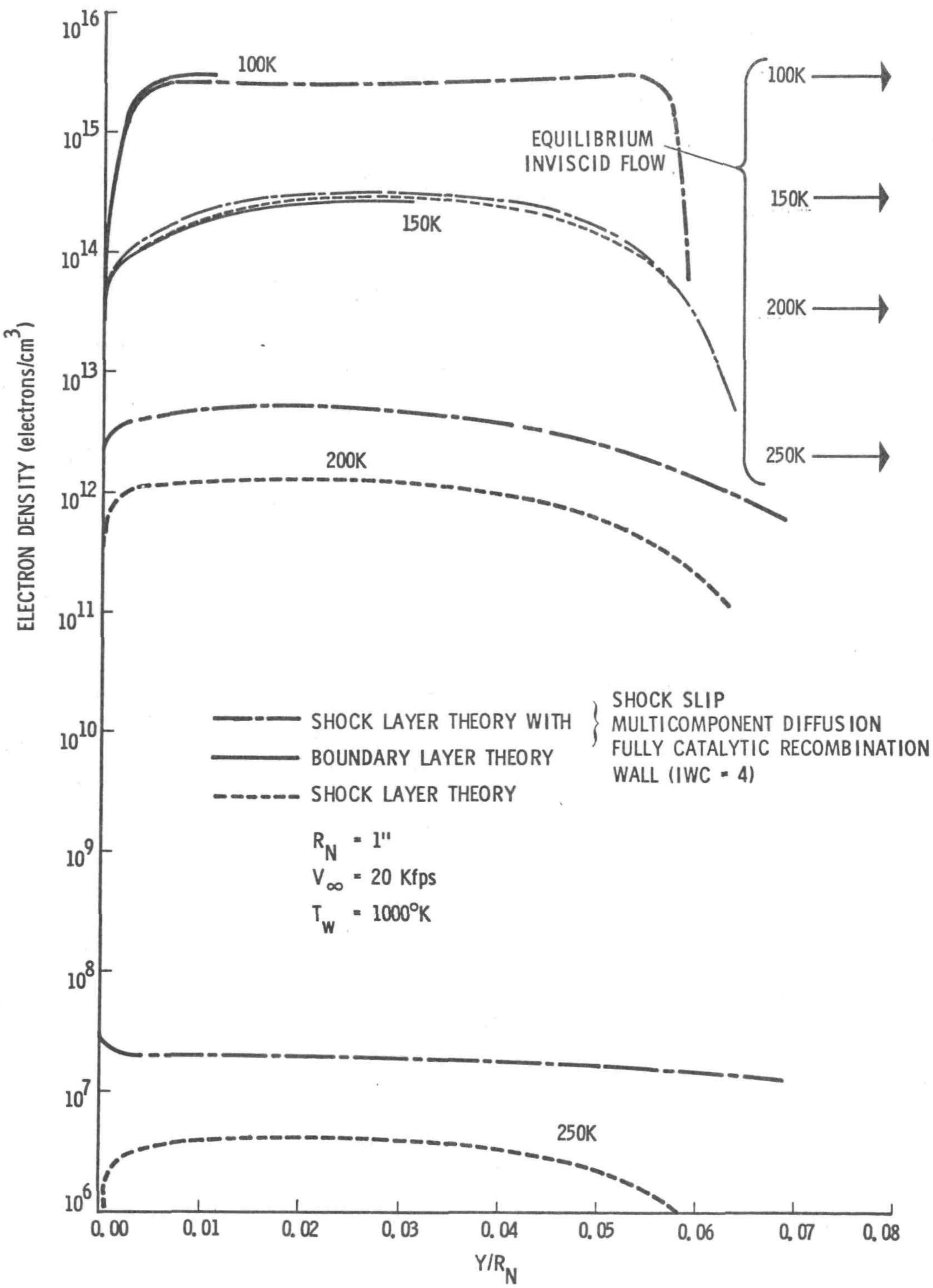


FIG. 8.3 - ELECTRON NUMBER DENSITY ACROSS SHOCK LAYER

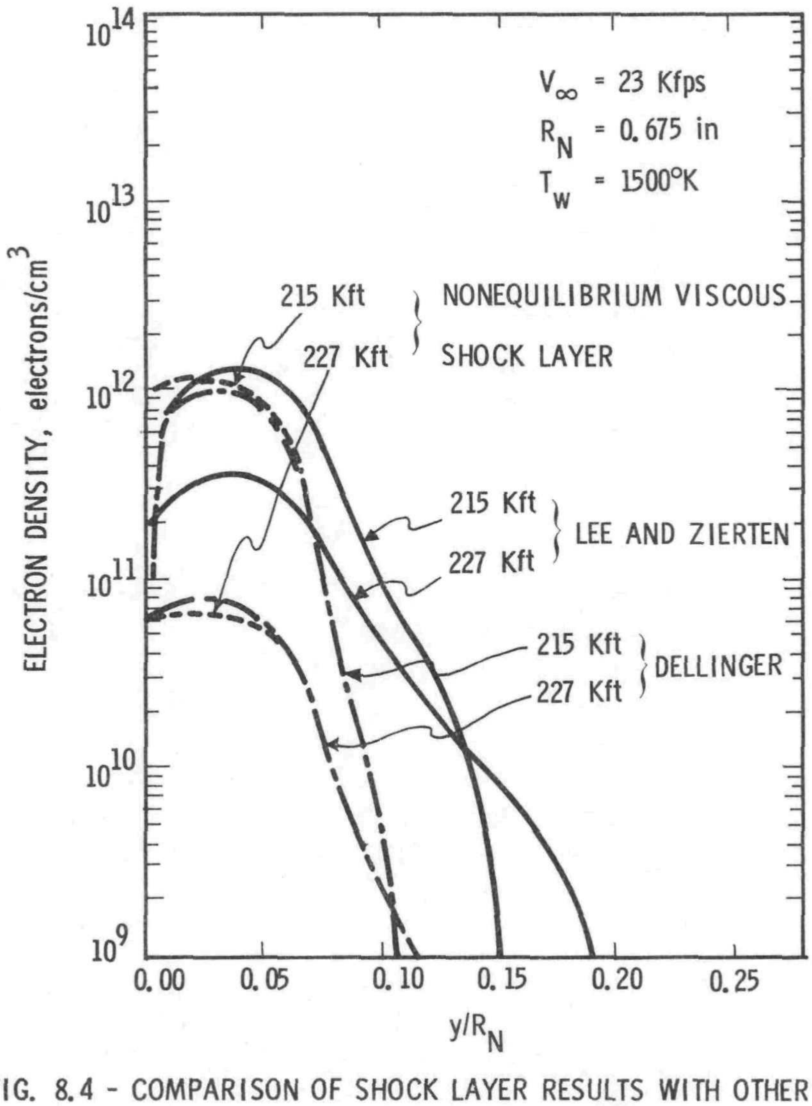


FIG. 8.4 - COMPARISON OF SHOCK LAYER RESULTS WITH OTHER THEORIES

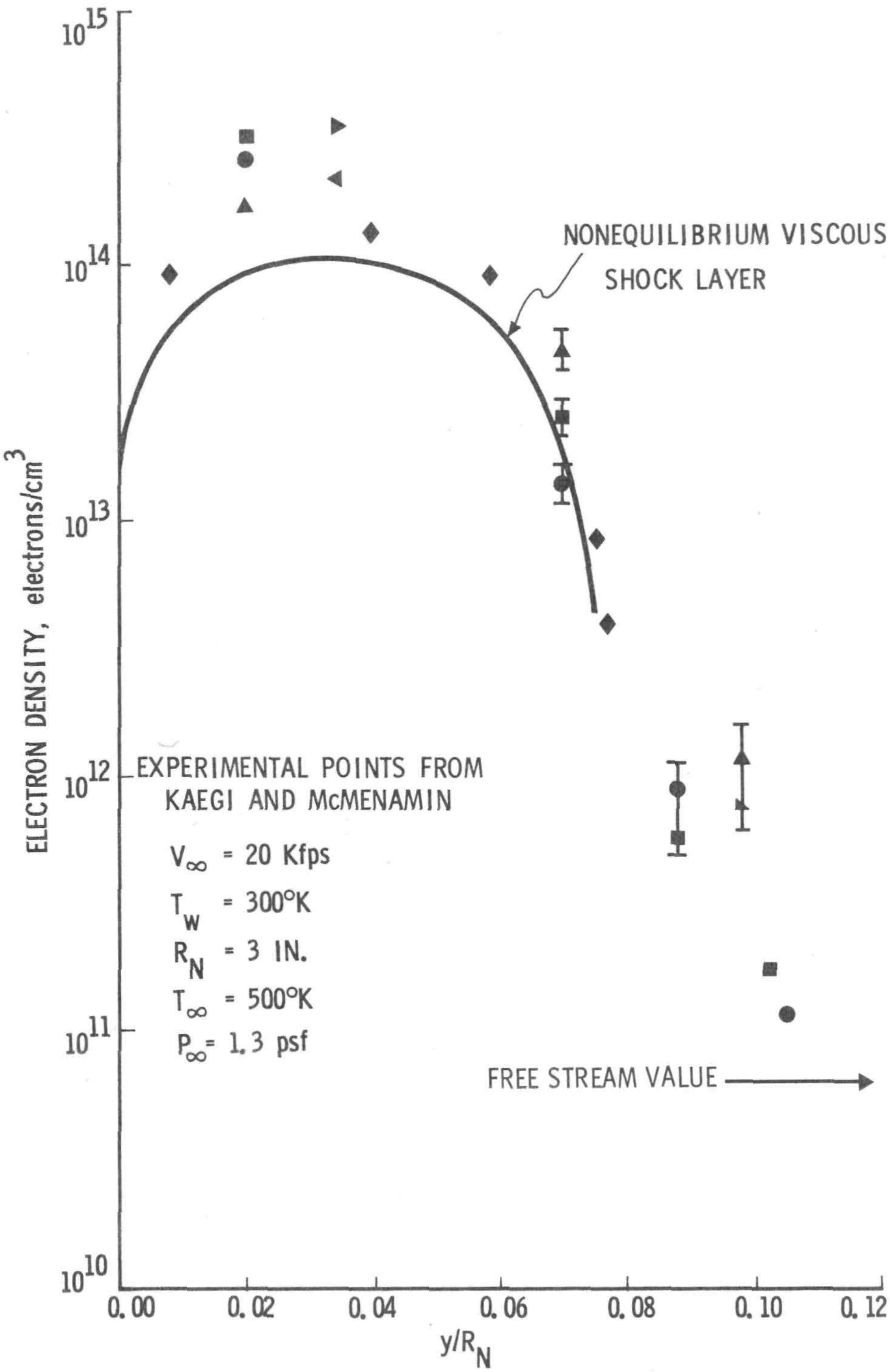
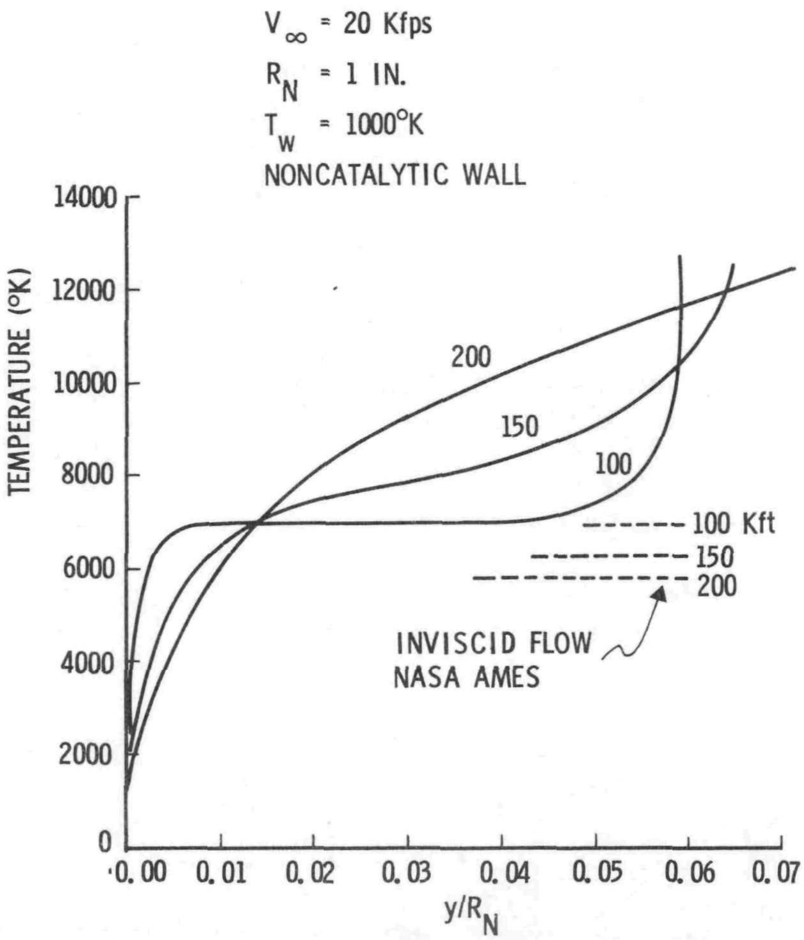


FIG. 8.5 - COMPARISON OF SHOCK LAYER RESULTS WITH EXPERIMENT



VISCOUS SHOCK LAYER

FIG. 8.6 - TEMPERATURE PROFILES ACROSS SHOCK LAYER

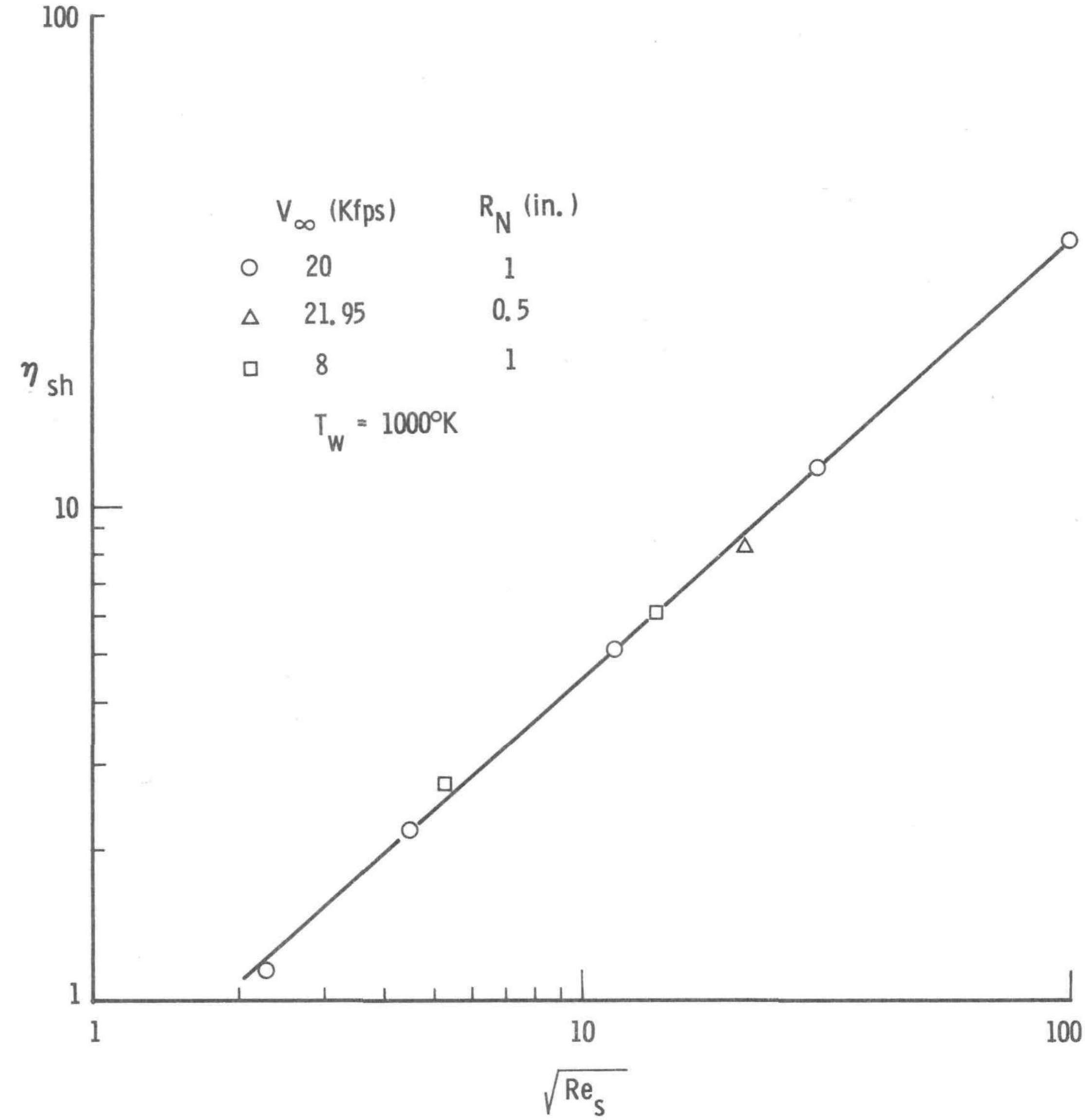


FIG. 8.7 - THICKNESS OF SHOCK LAYER IN TRANSFORMED COORDINATE SYSTEM

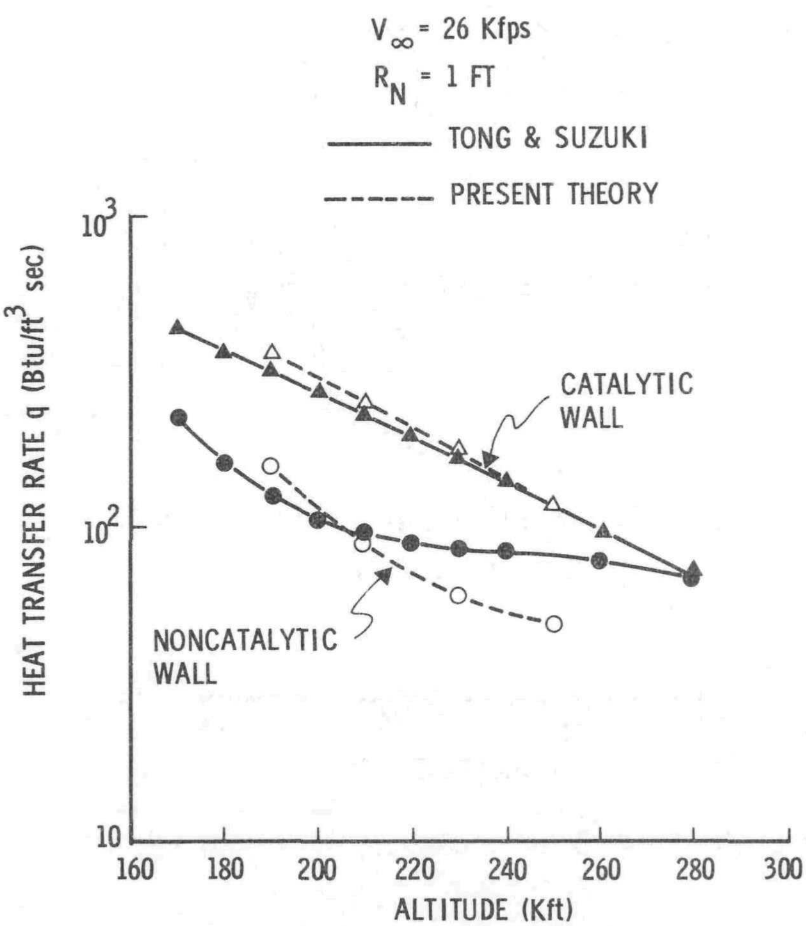


FIG. 8.8 - SHOCK LAYER RESULTS FOR HEAT TRANSFER

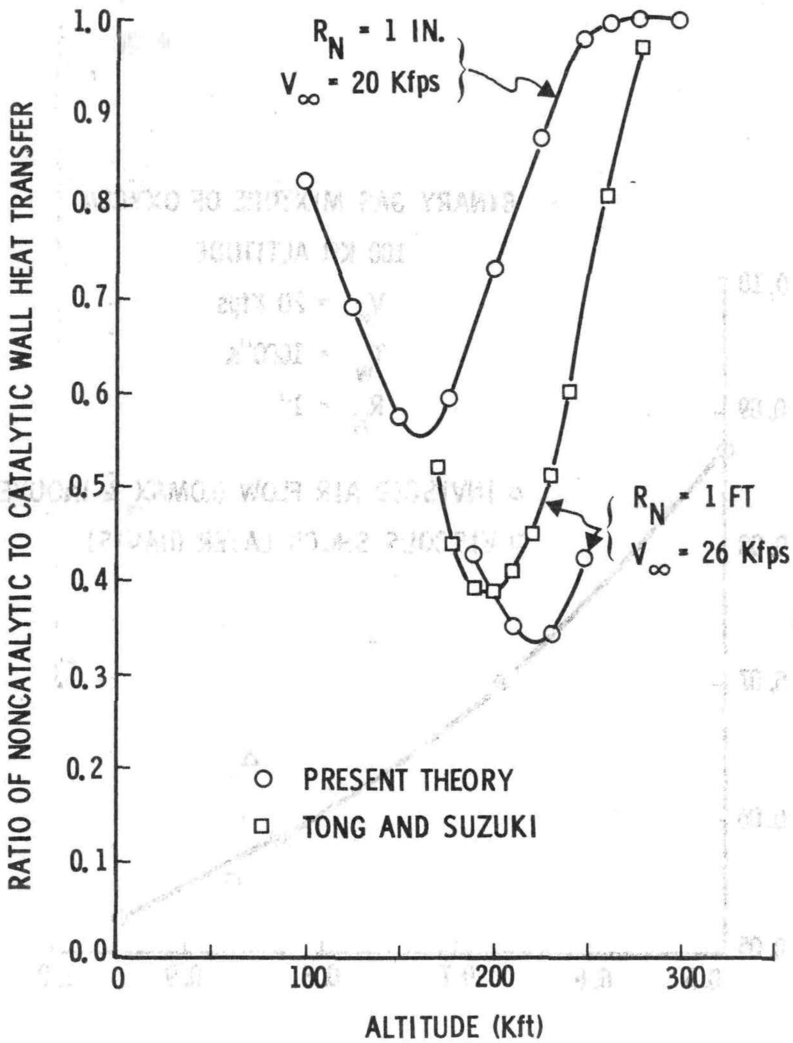


FIG. 8.9 - EFFECT OF WALL CONDITIONS ON HEAT TRANSFER

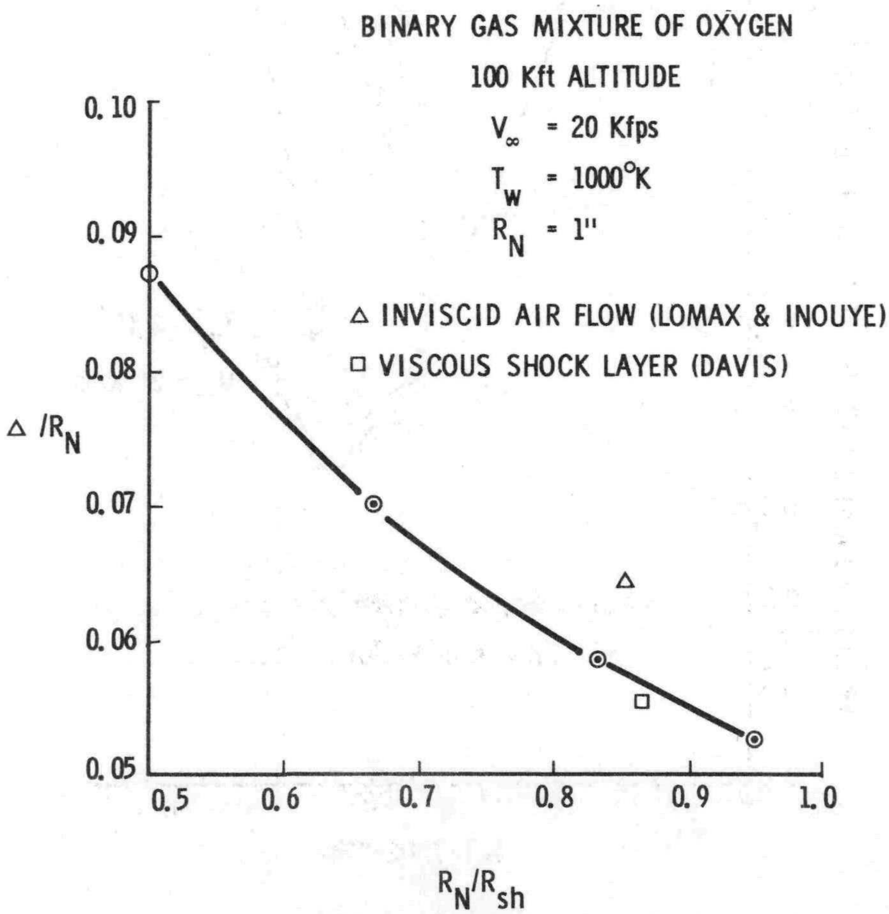


FIG. 8.10 - EFFECT OF SHOCK RADIUS ON THE SHOCK STAND-OFF DISTANCE

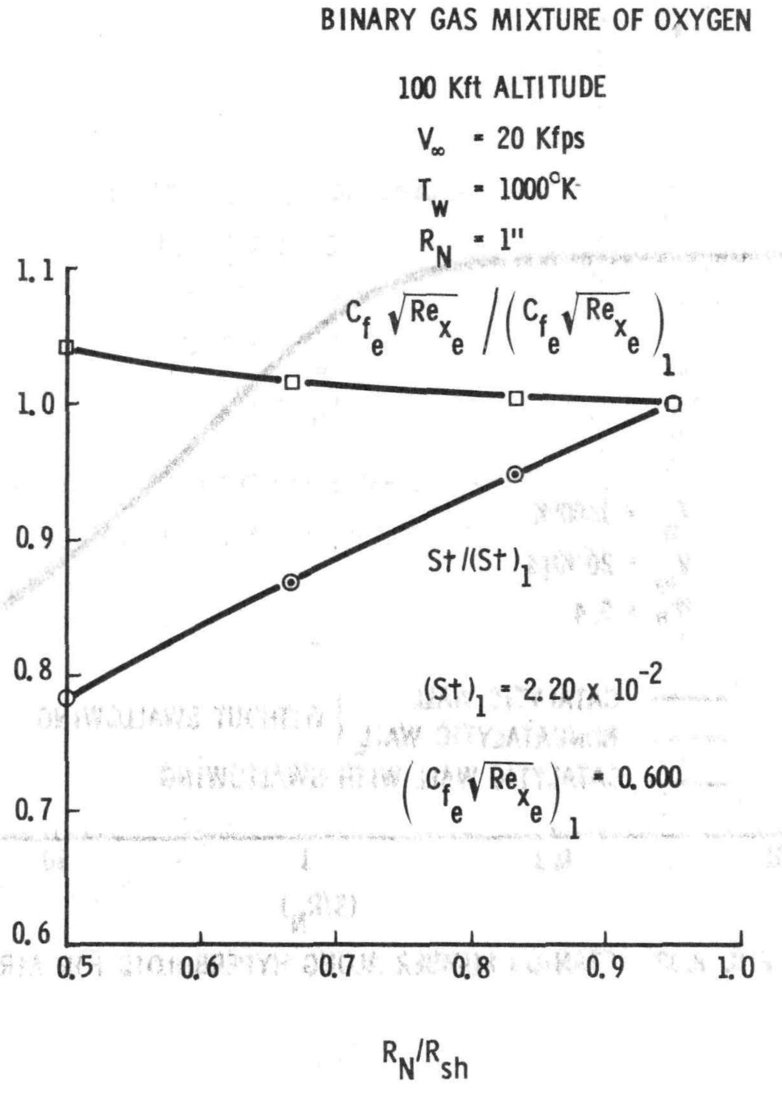


FIG. 8.11 - EFFECT OF SHOCK RADIUS ON SKIN FRICTION AND HEAT TRANSFER

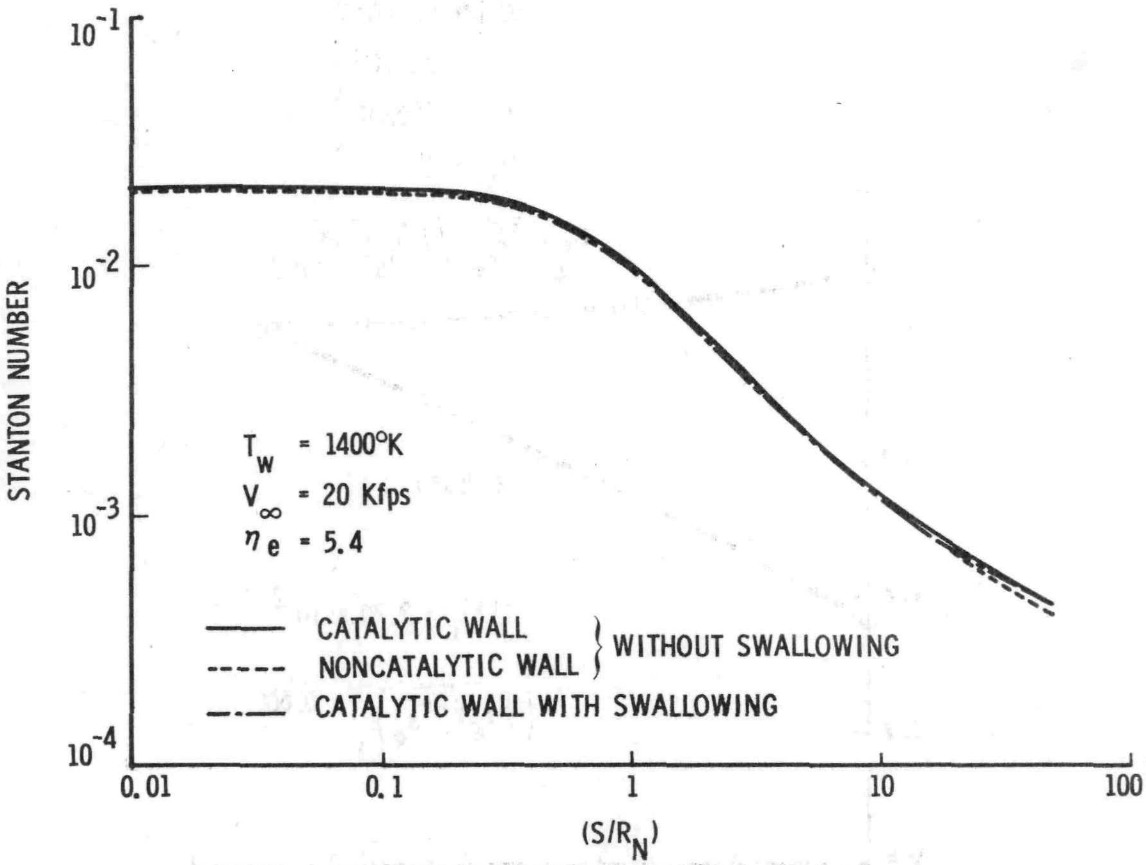


FIG. 8.12 - STANTON NUMBER ALONG HYPERBOLOID FOR AIR

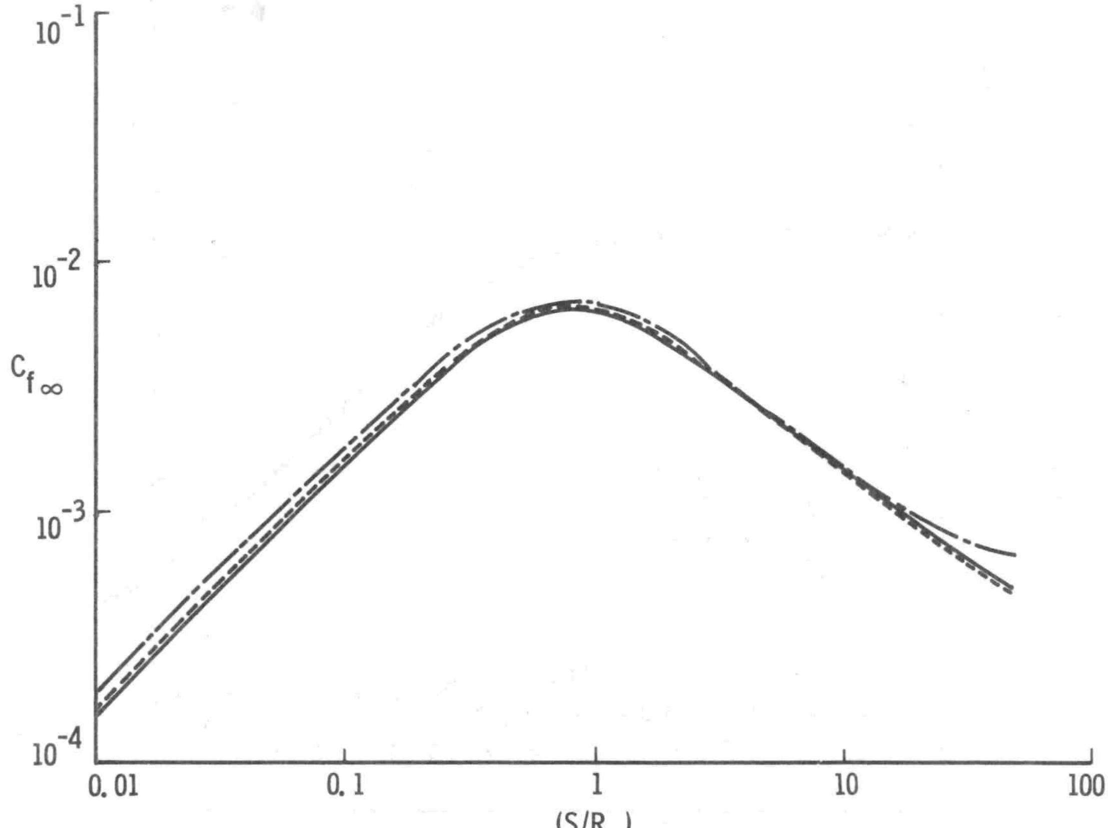


FIG. 8.13 - SKIN FRICTION ALONG HYPERBOLOID FOR AIR

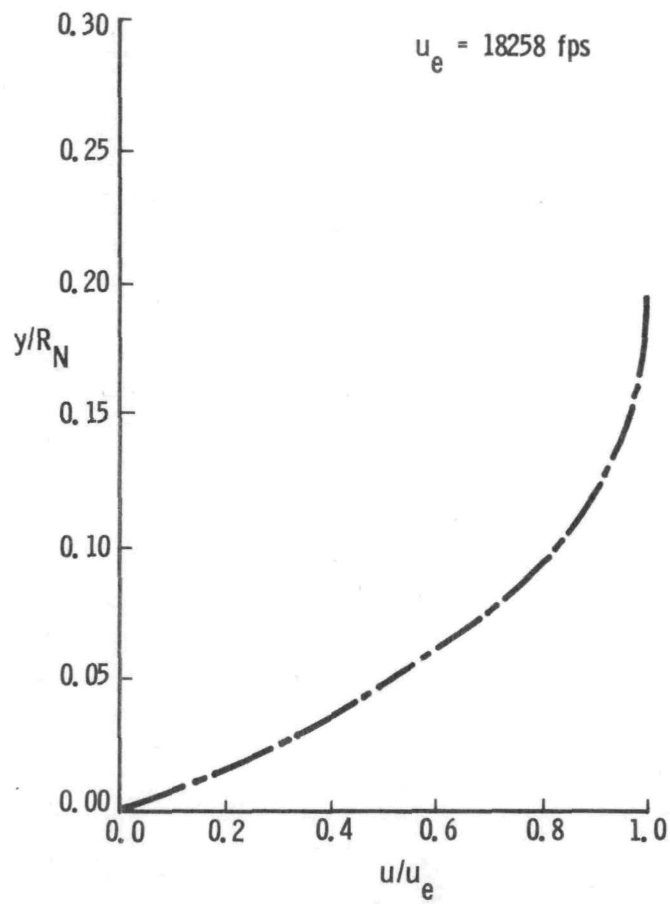


FIG. 8.14 - VELOCITY ACROSS BOUNDARY LAYER AT X/R_N = 50 ON HYPERBOLOID FOR AIR

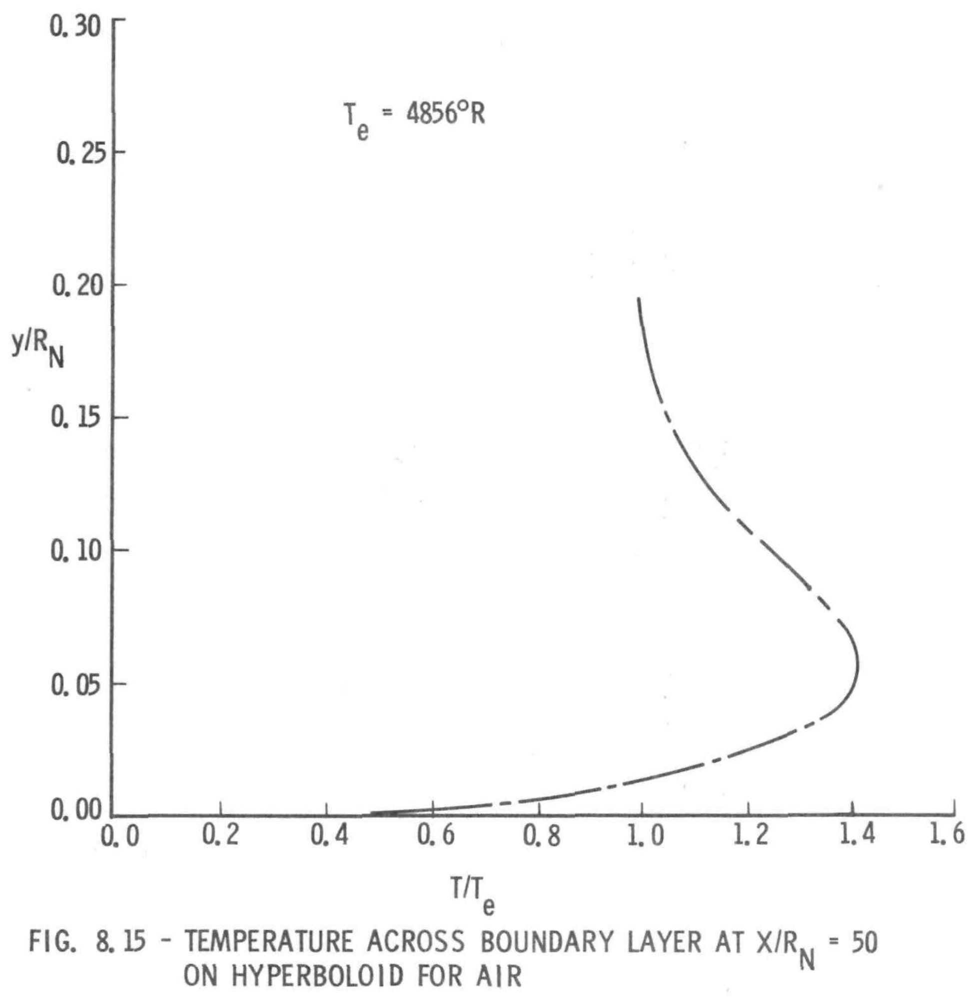


FIG. 8.15 - TEMPERATURE ACROSS BOUNDARY LAYER AT X/R_N = 50 ON HYPERBOLOID FOR AIR

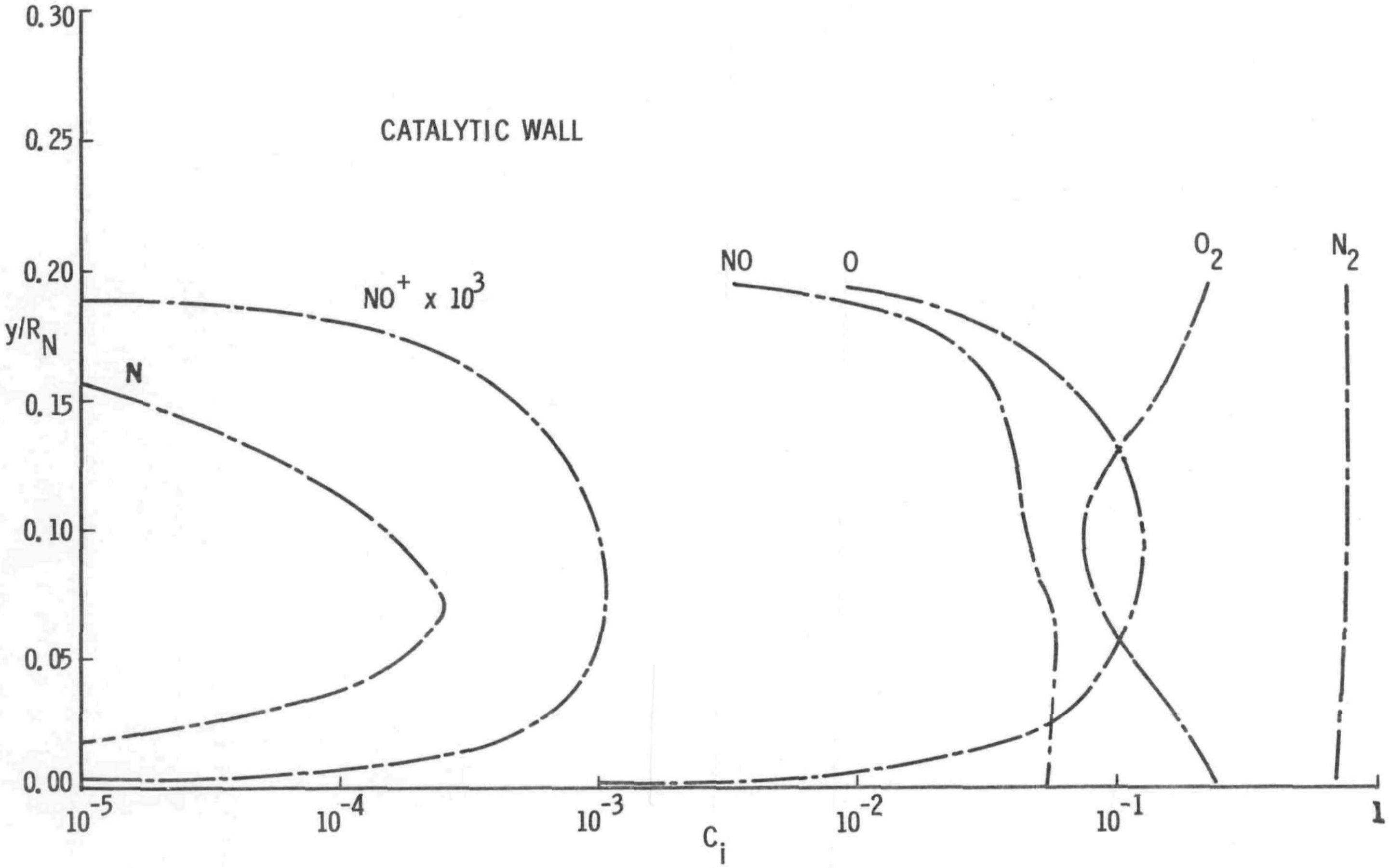


FIG. 8.16 - MASS FRACTION OF CHEMICAL SPECIES ACROSS BOUNDARY LAYER OF X/R_N = 50 ON HYPERBOLOID FOR AIR

X/R_N	u_{sh}	u_e/V_∞	n_{sh}
0	0	0	0.045
1	0.614	0.351	0.093
3	0.843	0.564	0.236
10	0.945	0.735	0.787
25	0.975	0.842	1.462

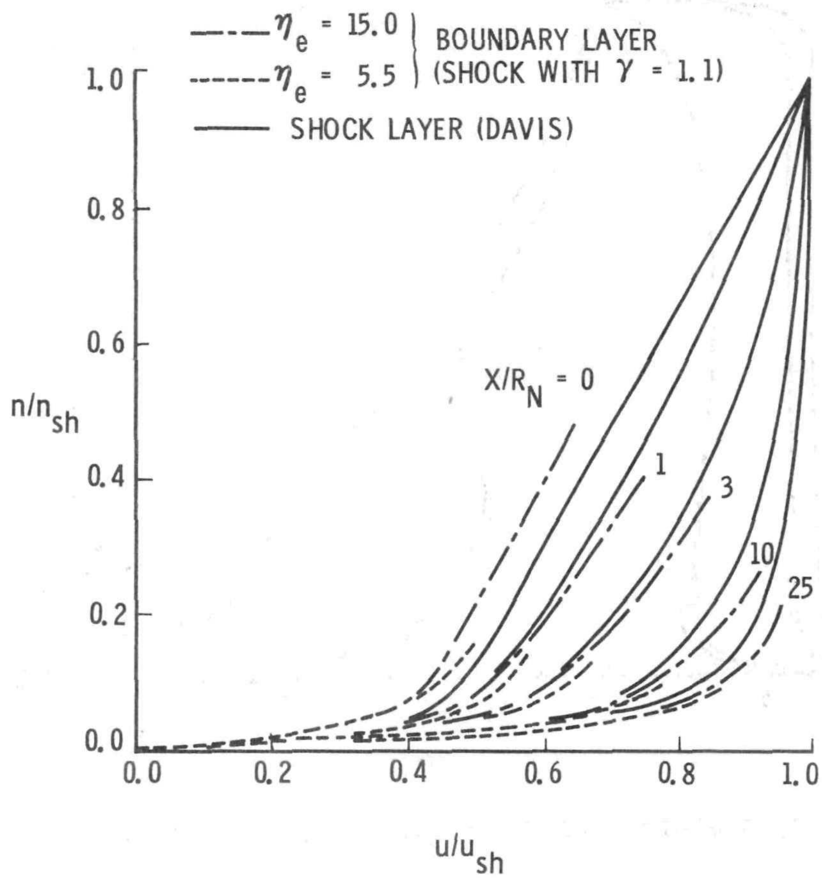


FIG. 8.17 - VELOCITY PROFILES ON HYPERBOLOID FOR BINARY GAS MIXTURE

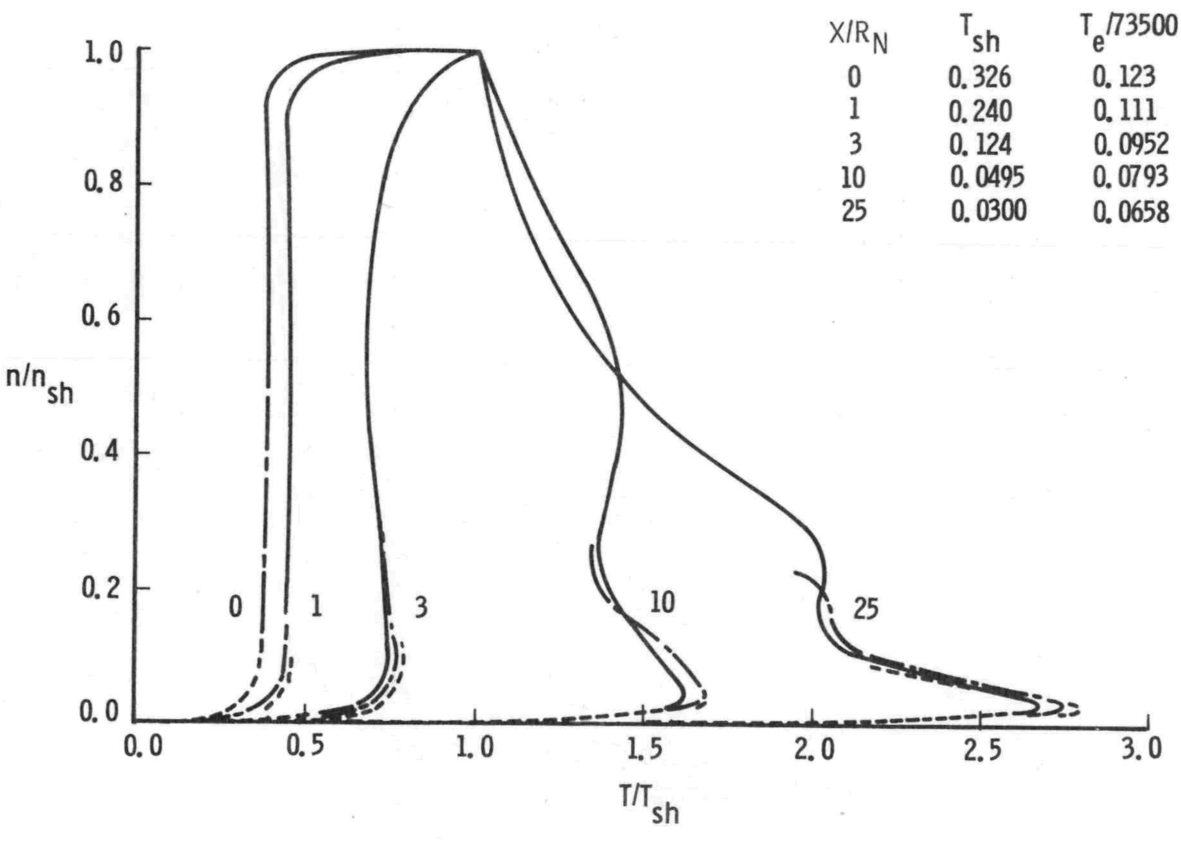


FIG. 8.18 - TEMPERATURE PROFILES ON HYPERBOLOID FOR BINARY GAS MIXTURE

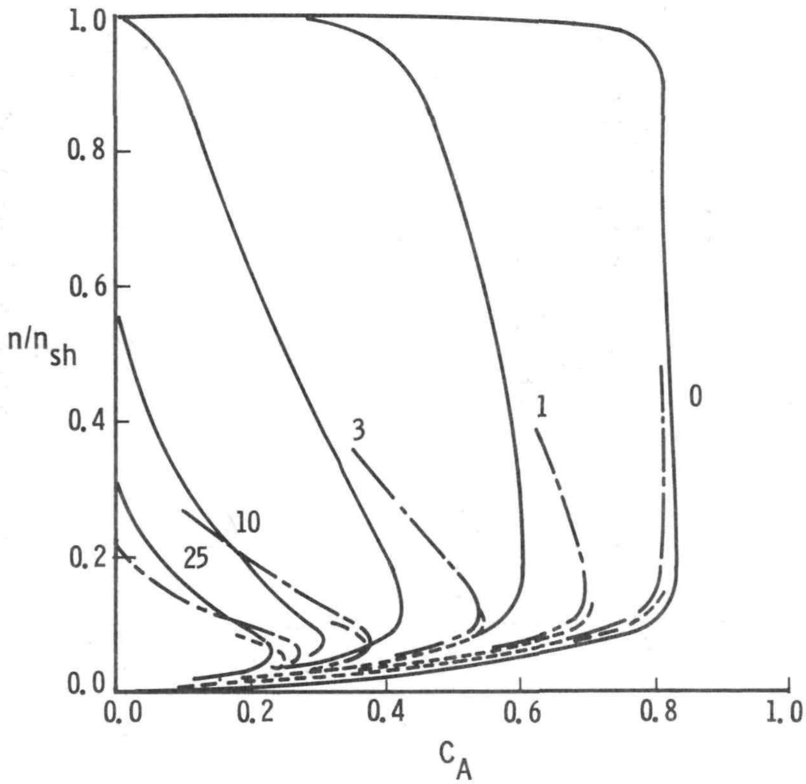


FIG. 8.19 - ATOM MASS FRACTION ON HYPERBOLOID FOR BINARY GAS MIXTURE

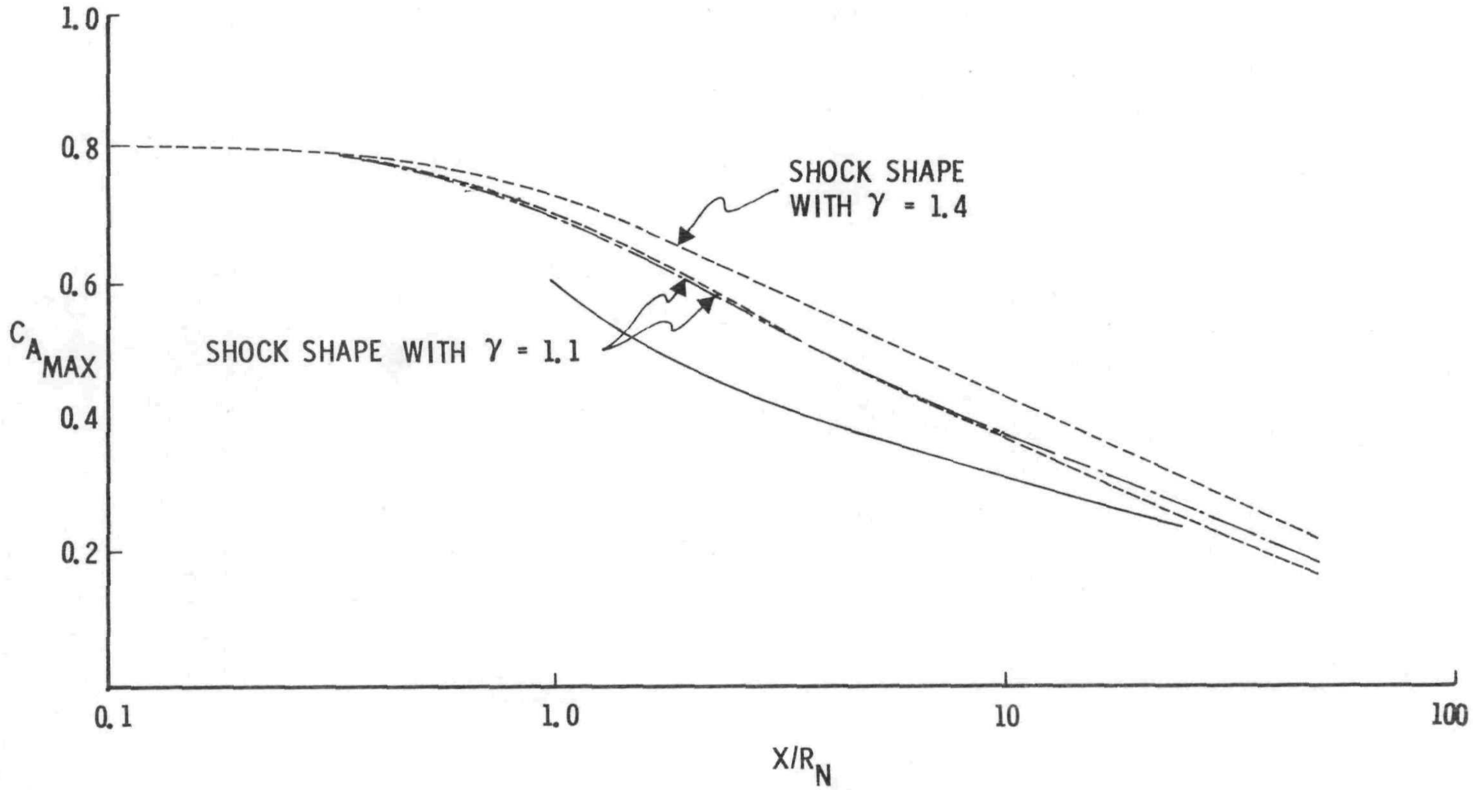


FIG. 8.20 - MAXIMUM ATOM MASS FRACTION ON HYPERBOLOID FOR BINARY GAS MIXTURE

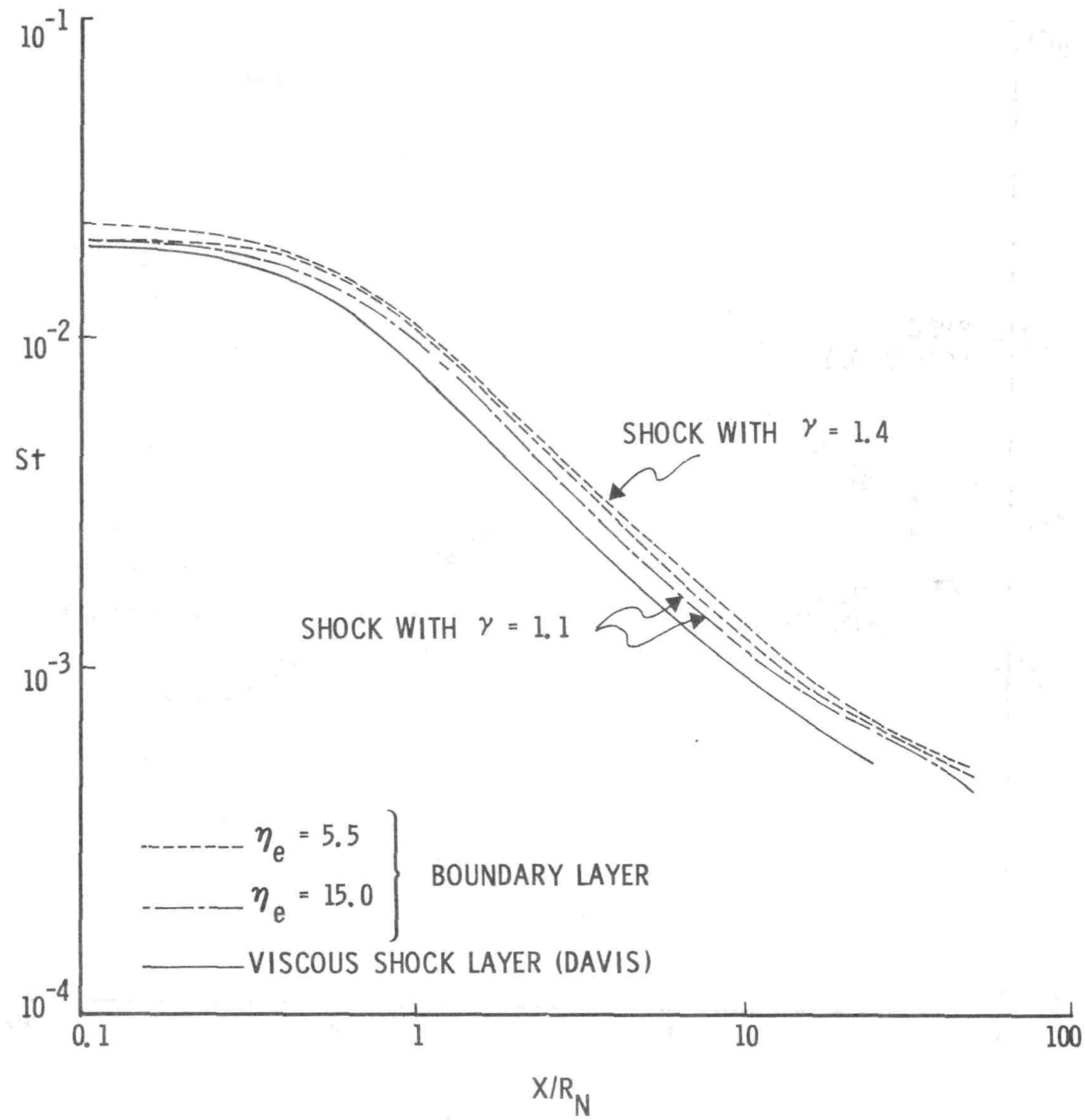


FIG. 8.21 - HEAT TRANSFER ON HYPERBOLOID FOR BINARY GAS MIXTURE

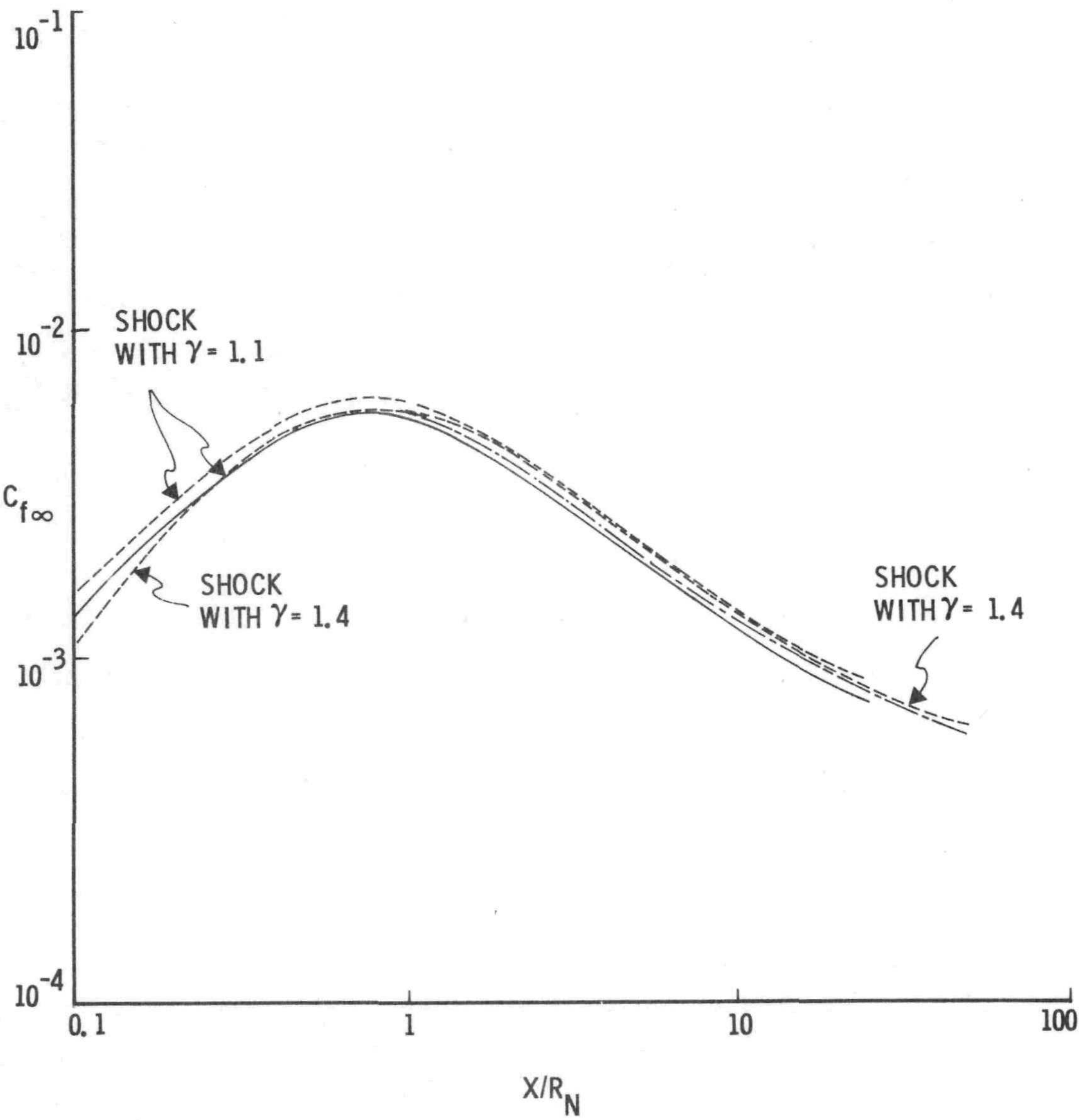


FIG. 8.22 - SKIN FRICTION ON HYPERBOLOID FOR BINARY GAS MIXTURE

REFERENCES

1. Meyer, E. A., Ten Broeck, S. J., and Hearn, K. W., "A Computer Program for Solving the Nonequilibrium Boundary Layer Equations of a Chemically-Reacting Multicomponent Gas," General Electric TIS R64SD89, Nov. 1964.
2. Ten Broeck, S. J. and Blottner, F. G., "A Computer Program for the Numerical Solution of Nonequilibrium Boundary Layer Equations for Chemically Reacting Multi-Component Gaseous Mixtures," General Electric Space Sciences Laboratory Report, April 1966.
3. Blottner, F. G., "Chemically Reacting Boundary Layer with Ablation Products and Nose Bluntness Effects," TIS R67SD14, General Electric Co., April 1967.
4. Blottner, F. G., "Viscous Shock Layer at the Stagnation Point with Nonequilibrium Air Chemistry," AIAA J., Vol. 7, No. 12, pp. 2281-2288, Dec. 1969.
5. Blottner, F. G., "Finite Difference Methods of Solution of the Boundary-Layer Equations," AIAA J., Vol. 8 No. 2, pp. 193-205, Feb. 1970.
6. Davis, R. T., "Hypersonic Flow of a Chemically Reacting Binary Mixture Past a Blunt Body," AIAA 3rd Fluid and Plasma Dynamics Conference, Paper No. 70-805, Los Angeles, California, June 29-July 1, 1970.
7. Blottner, F. G., "Prediction of Electron Density in the Boundary Layer on Entry Vehicles with Ablation," in Proceedings of the Fourth Plasma Sheath Symposium held at Langley Research Center, Oct. 13-15, 1970, NASA SP - 252, 1971.
8. Bird, R. B., Stewart, W. E., and Lightfoot, E. N., Transport Phenomena, John Wiley and Sons, 1960.
9. Richtmyer, R. D., Difference Methods for Initial-Value Problems, Interscience Publishers, Inc., New York, 1957, Chapter 9.
10. Brennan, D., "The Atomization of Diatomic Molecules by Metals," in Advances in Catalysis, Vol. 15, Academic Press, 1964.
11. Rosner, D. E., and Allendorf, H. D., "Primary Products in the Attack of Graphite by Atomic Oxygen and Diatomic Oxygen Above 1100°K," Carbon, Vol. 7, pp. 515-518, 1969.
12. Schrage, R. W., A Theoretical Study of Interphase Mass Transfer, Columbia University Press, New York, 1953.
13. Kucherov, R. Ya and Rikenglaz, L. E., "On Hydrodynamic Boundary Conditions for Evaporation Condensation," Soviet Physics Jetp.,Vol. 37, No. 1, pp. 88-89, January 1960.
14. Kopal, Zdenek, "Tables of Supersonic Flow Around Cones," MIT Technical Report 1, 1947.
15. Sims, J. L., "Tables for Supersonic Flow Around Right Circular Cones at Small Angle of Attack," NASA SP-3007, 1964.
16. Jones, D. J., "Tables of Inviscid Supersonic Flow About Circular Cones at Incidence $\gamma = 1.4$," AGARDograph 137, Nov. 1969.
17. Romig, Mary F., "Conical Flow Parameters for Air in Dissociation Equilibrium," Convair Scientific Research Note 14, January 1958.
18. Hudgins, Henry E., "Supersonic Flow About Right Circular Cones at Zero Yaw in Air at Chemical Equilibrium," Picatinny Aresenal, Dover, New Jersey, TM 1493, Sept. 1964.
19. Lomax, Harvard and Inouye, Mamoru, "Numerical Analysis of Flow Properties About Blunt Bodies Moving at Supersonic Speeds in an Equilibrium Gas," NASA TR R-204, July 1964.
20. Cheng, H. K., "The Blunt-Body Problem in Hypersonic Flow at Low Reynolds Number," IAS Paper 63-92, New York, Jan. 21-23, 1963; Rept. AF-1285-A-10, 1963, Cornell Aeronautical Lab.
21. Cheng, H. K., "Viscous Hypersonic Blunt-Body Problems and the Newtonian Theory," Fundamental Phenomena in Hypersonic Flow, edited by J. G. Hall, Cornell University Press, Ithaca, New York, 1966.
22. Tolstykh, A. I., "On the Structure of a Curvilinear Shock Wave," PMM, Vol. 28, No. 3, pp. 553-556, 1964.
23. Lee, R. H. C. and Zierten, T. A., "Merged Layer Ionization in the Stagnation Region of the Blunt Body," Proceedings of the 1967 Heat Transfer and Fluid Mechanics Institute, edited by P. A. Libby, D. B. Olfe, and C. W. Van Atta, Stanford University Press, Stanford, California, pp. 452-458, 1967.

24. Chung, P. M., Holt, J. F., and Liu, S. W., "Merged Stagnation Shock Layer of Nonequilibrium Dissociating Gas," AIAA J., Vol. 6, No. 12, pp. 2372-2379, Dec. 1968.

25. Brown, W. G., "Thermodynamic Properties of Some Atoms and Atomic Ions," and "Thermodynamic Properties of Some Diatomic and Linear Polyatomic Molecules," MSD Engineering Physics TM2 and 3, General Electric Co., Philadelphia, Pa.

26. Browne, W. G., "Thermodynamic Properties of Some Ablation Products from Plastic Heat Shields in Air," MSD Aerospace Physics Memo 11, March 16, 1964, General Electric Co., Philadelphia, Pa.

27. Browne, W. G., "Thermodynamic Properties of Some Diatoms and Diatomic Ions at High Temperature," and "Thermodynamic Properties of the Species CN, C_2, C_3, C_2N_2, and C^-," MSD Advanced Aerospace Physics TM 8 and 9, May 14, 1962, General Electric Co., Philadelphia, Pa.

28. Brokow, R. S., "Approximate Formulas for Viscosity and Thermal Conductivity of Gas Mixtures," NASA TN D-2502, November 1962.

29. Fay, James A., "Hypersonic Heat Transfer in the Air Laminar Boundary Layer," The High Temperature Aspects of Hypersonic Flow, Edited by Wilbur C. Nelson, the Macmillan Company, 1964.

30. Yos, J. M., "Transport Properties of Nitrogen, Hydrogen, Oxygen, and Air to 30000°K," RAD-TM-63-7, Mar. 1963, Avco Corp., Wilmington, Mass.

31. Yos, J. M., "Revised Transport Properties for High Temperature Air and Its Components," Technical Release, Nov. 28, 1967, Space Systems Division, Avco Corp., Wilmington, Mass.

32. Yun, K. S., and Mason, E. A., "Collision Integrals for the Transport Properties of Dissociating Air at High Temperature," Physics of Fluids, Vol. 5, No. 4, 1962, pp. 380-386.

33. Yun, K. S., Weissman, S., and Mason, E. A., "High-Temperature Transport Properties of Dissociating Nitrogen and Dissociating Oxygen," Physics of Fluids, Vol. 5, No. 6, June 1962, pp. 672-678.

34. Hirschfelder, J. O., Curtiss, C. F., and Bird, R. B., Molecular Theory of Gases and Liquids, John Wiley and Sons, Inc., New York, 1954, p. 486.

35. Moore, J. A., "Chemical Nonequilibrium in Viscous Flows," Ph.D. Dissertation, State University of New York at Buffalo, May 1967.

36. Predroditelev, A. S., et al., "Tables of Thermodynamic Functions of Air," translated and published by Associated Technical Services, Inc., Glen Ridge, N. J., 1962.

37. Hansen, C. F., "Approximations for the Thermodynamic and Transport Properties of High-Temperature Air," NACA TN 4150, March 1958.

38. Bortner, M. H., "Suggested Standard Chemical Kinetics for Flow Field Calculations - A Consensus Opinion," AMRAC Proceedings, Vol. 14, Part 1, 1966.

39. Bortner, M. H., "A Review of Rate Constants of Reactions in Re-Entry Flow Fields," TIS R68SD13, General Electric Co., Philadelphia, Pa., June, 1968.

40. Blottner, F. G. and Larson, D. E., "Approximate Technique for Nonequilibrium Boundary Layer Edge Conditions," Sandia Laboratories Report, to be published.

41. Ho, Hung-Ta and Probstein, Ronald F., "The Compressible Viscous Layer in Rarefied Hypersonic Flow," Rarefied Gas Dynamics, edited by L. Talbot, Academic Press, New York, 1961, pp. 525-552.

42. Dellinger, T. C., "Computation of Nonequilibrium Merged Stagnation Shock Layers by Successive Accelerated Replacement," AIAA Paper No. 69-655, June, 1969.

43. Kaegi, E. M. and McMenamin, D. L., "Measured and Predicted Air Ionization in Blunt Body Shock Layers," Paper No. 69-81, AIAA 7th Aerospace Sciences Meeting, 1969.

44. Adams, John C., "Thin Viscous Shock Layer Analysis of Blunt Stagnation-Point Air Ionization," AIAA J., Vol. 7, No. 7, July 1969, pp. 1396-1398.

45. Adams, John C., "Shock Slip Analysis of Merged Layer Stagnation Point Air Ionization," AIAA J., Vol. 8, No. 5, May 1970, pp. 971-973.

46. Tong, H., and Suzuki, B. H.,"Stagnation Point Heat Transfer to Surfaces of Arbitrary Catalycity," AIAA J., Vol. 2, pp. 2051-2052, 1964.

47. Lieberstein, H. M., A Course in Numerical Analysis, Harper and Row, Publishers, New York, 1968.

48. Fay, James A., and Kemp, Nelson H., "Theory of Stagnation-Point Heat Transfer in a Partially Ionized Diatomic Gas," AIAA J., Vol. 1, No. 12, pp. 2741-2751, Dec. 1963.

49. Pallone, Adrian and Van Tassell, William, "The Effects of Ionization on Stagnation-Point Heat Transfer in Air and Nitrogen," AVCO Corp., RAD TM-62-75, Sept. 1962.

50. Nerem, Robert M. and Strickford, George H., "Radiative and Convective Heating During Hypervelocity Re-Entry," AIAA J., Vol. 2, No. 6, pp. 1156-1157, June 1964.

51. Luikov, A. V., Sergeev, V. L., and Shashkov, A. G., "Experimental Study of Stagnation Point Heat Transfer of a Solid in High-Enthalpy Gas Flow," Int. J. Heat Mass Transfer, Vol. 10, pp. 1361-1371, 1967.

52. Akin, C. M., and Marvin, J. G., "Comparison of Convective Stagnation Heat Transfer in Air, CO_2-N_2, and CO_2-Ar Gas Mixtures," NASA TN D-4255, November 1967.

53. Penner, S. S., Chemistry Problems in Jet Propulsion, Pergamon Press, New York, 1957, p. 153.

54. Warga, J., "A Convergent Procedure for Solving the Thermo-Chemical Equilibrium Problem," Technical Memorandum RAD-TM-62-78, Research and Advanced Development Division, AVCO Corp., September 1962.

55. Vincenti, Walter G., and Kruger, Charles H., Introduction to Physical Gas Dynamics, John Wiley and Sons, Inc., New York, 1965, p. 167.

56. Erickson, Wayne D., Kemper, Jane T., and Allison, Dennis O., "A Method for Computing Chemical-Equilibrium Compositions of Reacting-Gas Mixtures by Reduction to a Single Iteration Equation," NASA TN D-3488, 1966.

57. Smith, G. Louis, Erickson, Wayne D., and Eastwood, Mary R., "Equations for the Rapid Machine Computation of Equilibrium Composition of Air and Derivatives for Flow-Field Calculations," NASA TN D-4103, 1967.

58. Kentzer, Czeslaw P., and Evans, Larry G., "Approximate Closed-Form Expressions for Equilibrium Composition of High-Temperature Air," AIAA J., Vol. 6, No. 3, March 1968, pp. 547-549.

APPENDIX A

Conditions Behind Shock with Slip

The conditions behind a shock wave on a blunt body as illustrated in Fig. 1A are determined in the following analysis. The velocity tangential to the body behind the shock is written as:

$$u_{sh} = v_{2_t} \cos \delta - v_{2_n} \sin \delta \tag{A-1}$$

where $\delta = \theta - \varphi$. The velocities normal and tangential to the shock wave are v_{2_n} and v_{2_t}, respectively and are obtained from the modified Rankine-Hugoniot relations which give

$$v_{2_n} = - \frac{\rho_\infty}{\rho_{sh}} V_\infty \cos \varphi \tag{A-2a}$$

$$v_{2_t} = V_\infty \sin \varphi - \frac{\mu_{sh}}{\rho_\infty V_\infty \cos \varphi} \frac{dv_{2_t}}{d\bar{y}} \tag{A-2b}$$

The velocity u_{sh} becomes

$$u_{sh} = V_\infty \left(\sin \varphi \cos \delta + \frac{\rho_\infty}{\rho_{sh}} \cos \varphi \sin \delta\right) - \frac{\mu_{sh} \cos \delta}{\rho_\infty V_\infty \cos \varphi} \frac{dv_{2_t}}{d\bar{y}} \tag{A-3}$$

Near the stagnation point the above trigonometric functions are expanded, giving

$$\frac{u_{sh}}{V_\infty} = \left(\varphi - \frac{1}{6} \varphi^3 \cdots\right) \left(1 - \frac{1}{2} \delta^2 \cdots\right) + \frac{\rho_\infty}{\rho_{sh}} \left(1 - \frac{1}{2} \varphi^2 \cdots\right) \left(\delta - \frac{1}{6} \delta^3 \cdots\right) - \frac{\mu_{sh} \left(1 - \frac{1}{2} \delta^2 \cdots\right)}{\rho_\infty V_\infty \left(1 - \frac{1}{2} \varphi^2 \cdots\right)} \frac{dv_{2_t}}{d\bar{y}} \tag{A-4}$$

The angles are related to x by the following relations:

$$\theta = \frac{x}{R_N} \tag{A-5a}$$

$$\varphi = \frac{x}{R_N} \left(\frac{R_N + \Delta}{R_{sh}}\right) + 0 \left(x^2\right) \tag{A-5b}$$

$$\delta = \theta - \varphi = \frac{x}{R_N}\left(1 - \frac{R_N + \Delta}{R_{sh}}\right) + 0\ (x^2) \qquad \text{(A-5c)}$$

The density behind the shock, ρ_{sh}, is a function of x and is expressed as

$$\varepsilon = \frac{\rho_\infty}{\rho_{sh}} = \varepsilon_o + \frac{d\varepsilon_o}{dx} x^2 + \cdots$$

since the density is symmetrical about the stagnation point. The velocity becomes

$$u_{sh} = \left(\frac{V_\infty x}{R_N}\right)\{s(1 + \varepsilon) + \varepsilon\} - \frac{\mu_{sh}}{\rho_\infty V_\infty}\left[1 + \frac{1}{2}(2s - 1)\left(\frac{x}{R_N}\right)^2 + \cdots\right]\frac{dv_{2_t}}{d\bar{y}} + 0\ (x^3) \qquad \text{(A-6)}$$

where

$$s = \frac{R_N}{R_{sh}}\left(1 + \frac{\Delta}{R_N}\right) \text{ and } \varepsilon = \rho_\infty / \rho_{sh}.$$

If the shock is concentric with the body, then s = 1. The derivative of the tangential velocity at the shock is

$$\frac{dv_{2_t}}{d\bar{y}} = \frac{\partial u}{\partial \bar{y}} \cos \delta + \frac{\partial v}{\partial \bar{y}} \sin \delta \qquad \text{(A-7)}$$

where

$$\frac{\partial u}{\partial \bar{y}} = \frac{\partial u}{\partial x}\frac{\partial x}{\partial \bar{y}} + \frac{\partial u}{\partial y}\frac{\partial y}{\partial \bar{y}}$$

$$\frac{\partial v}{\partial \bar{y}} = \frac{\partial v}{\partial x}\frac{\partial x}{\partial \bar{y}} + \frac{\partial v}{\partial y}\frac{\partial y}{\partial \bar{y}}$$

The following relations relate the body and shock coordinate systems:

$$(R_{sh} + \bar{y}) \sin \varphi - (y + R_N) \sin \theta = 0$$

$$(R_{sh} + \bar{y}) \cos \varphi - (y + R_N) \cos \theta - R_{sh}(s - 1) = 0$$

The above represent two implicit functions with the four variables $\bar{y}$, φ, y and θ. The total differentials of these functions are zero and are expressed as the following when $d\varphi = 0$:

$$- \sin \varphi\, d\bar{y} + \sin \theta\, dy + (y + R_N) \cos \theta\, d\theta = 0$$

$$- \cos \varphi\, d\bar{y} + \cos \theta\, dy - (y + R_N) \sin \theta\, d\theta = 0.$$

These equations are solved for the desired derivatives which give

$$\left.\frac{dy}{d\bar{y}}\right|_{\varphi} = \sin\theta\sin\varphi + \cos\theta\cos\varphi = \cos\delta \tag{A-8a}$$

$$\left.\frac{dx}{d\bar{y}}\right|_{\varphi} = \frac{(\cos\varphi\sin\theta - \sin\varphi\cos\theta)^2}{\frac{R_{sh}}{R_N}(1 - s)\sin\varphi} = -\sin\delta/(1 + y_{sh}/R_N) \quad . \tag{A-8b}$$

With relations (A-8) employed in (A-7) and the relations (A-5) used to express the angles, the derivative (A-7) becomes

$$\frac{dv_{2_t}}{d\bar{y}} = \frac{\partial u}{\partial x}\left[-\frac{(1 - s)x}{sR_{sh}}\right] + \frac{\partial v}{\partial x}\left[-\frac{x^2(1 - s)^2}{sR_N R_{sh}}\right] + \frac{\partial u}{\partial y}\left[1 + O(x^2)\right] + \frac{\partial v}{\partial y}\left[\frac{x}{R_N}(1 - s)\right] + O(x^3) \tag{A-9}$$

The velocities u and v near the stagnation point are expanded as

$$u = u_1 x + \cdots$$

$$v = v_o + v_2 x^2 + \cdots$$

with the following derivatives becoming

$$\frac{\partial u}{\partial y} = x\frac{du_1}{dy} + \cdots = xu_{1_{sh}}\frac{df'}{dy} + \cdots \tag{A-10a}$$

$$\frac{\partial v}{\partial x} = 2xv_2 + \cdots \tag{A-10b}$$

When the above relations (A-10) are used in (A-9) and this is employed in (A-6), the velocity near the stagnation point becomes

$$u_{sh} = x\left\{\frac{V_\infty}{R_N}[s(1 - \varepsilon) + \varepsilon] + \frac{1}{Re_s}\left[u_{1_{sh}}\frac{(1 - s)R_N}{sR_{sh}} - R_N u_{1_{sh}}\frac{df'}{dy} - (1 - s)\frac{dv_o}{dy}\right]\right\} + O(x^3) \tag{A-11}$$

The velocity gradient behind the shock at the stagnation point becomes

$$\frac{du_{sh}}{dx} = u_{1_{sh}} = \frac{V_\infty}{R_N D}\left[s(1 - \varepsilon) + \varepsilon\right] \tag{A-12}$$

where

$$D = 1 + \frac{1}{Re_x}\left[\frac{1}{\eta_e}\sqrt{(1 + j)\frac{Re_s}{\epsilon}\frac{u_{1_{sh}}}{V_\infty}R_N}\ \frac{df'}{d\bar{\eta}} - \frac{(1 - s)}{s(R_{sh}/R_N)} + \frac{(1 - s)(1 + j)\ \rho_{sh}}{\eta_e}\frac{d}{d\bar{\eta}}\left(\frac{V}{\rho}\right)\right]$$

The pressure behind the shock wave transition zone is

$$p_{sh} = p_\infty + \rho_\infty V_\infty^2 \cos^2\varphi\ (1 - \epsilon)\ .$$

This expression is approximated near the stagnation point as

$$p_{sh} = p_\infty + \rho_\infty V_\infty^2\left(1 - \left(\frac{x}{R_N}\right)^2 s^2 \cdots\right)(1 - \epsilon)$$

The pressure gradient at the stagnation point is

$$\frac{dp_{sh}}{dx} = -\frac{2\rho_\infty V_\infty^2 x}{R_N^2}s^2\ (1 - \epsilon)$$

The value of $\bar{\bar{e}}$ becomes

$$\bar{\bar{e}} = \rho_{sh}u_{sh}\frac{\frac{du_{sh}}{dx}}{\frac{dp_{sh}}{dx}} = -\frac{1}{2\epsilon(1-\epsilon)D^2}\left[1 - \epsilon\left(1 - \frac{1}{s}\right)\right]^2 \qquad \text{(A-13)}$$

The value of V behind the shock is obtained from

$$V = \frac{2\xi}{(\rho\mu)_r u_e r_b^{2j}}\left(f'\frac{\partial\eta}{\partial x} + \frac{\rho v r_b^j}{\sqrt{2\xi}}\right)$$

where at a stagnation point

$$\xi = \int_0^x (\rho\mu)_r u_s r_b^{2j}\ dx = (\rho\mu)_r\frac{\frac{du_{sh}}{dx}}{2(1+j)}x^{2(1+j)}$$

The value of V at the stagnation point becomes

$$V = \frac{\rho v}{\sqrt{(1 + j)\ (\rho\mu)_r\frac{du_{sh}}{dx}}} \qquad \text{(A-14)}$$

When equation (A-12) is employed in (A-14) and the Rankine-Hugoniot relation

$$\rho_{sh}v_{sh} = -\rho_\infty V_\infty$$

is employed, the following is obtained:

$$V_{sh} = - \left\{ \frac{\epsilon \, Re_s D}{(1 + j) \left[s(1 - \epsilon) + \epsilon \right]} \right\}^{\frac{1}{2}} \qquad \text{(A-15)}$$

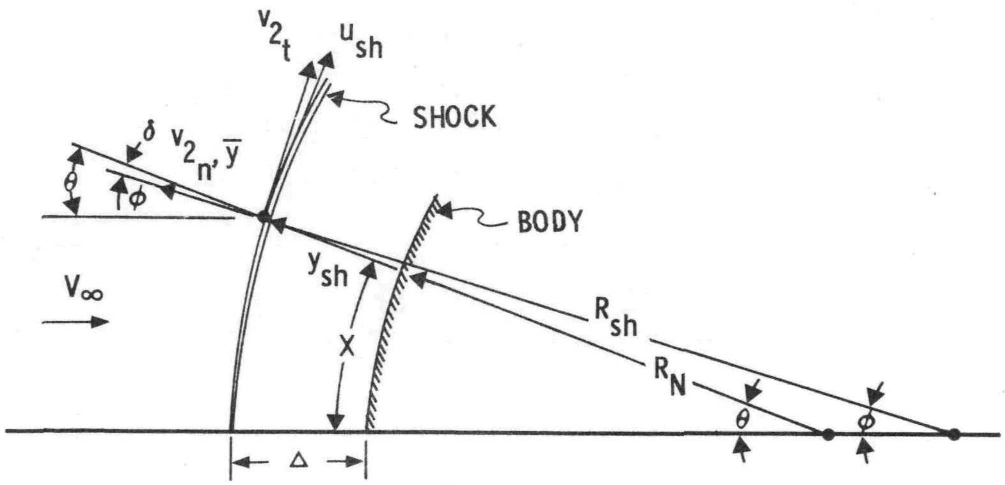


FIG. 1A - FLOW CONFIGURATION

APPENDIX B

Nonlinear Overrelaxation Method

In order to compare the finite difference and nonlinear overrelaxation methods for solving the boundary layer type equations, a binary gas mixture is considered. The two methods are used to solve the boundary layer equations at the stagnation point on a blunt body with a velocity of 20 Kfps and at a 100 Kft altitude. The **rates of convergence of the two methods are compared.** Also, the procedure for applying the nonlinear overrelaxation method to a multicomponent gas mixture is indicated.

The Equations (17) for a multi-component gas are reduced to the following equations when the quantities ℓ, $\bar{c}_p$, Pr, Le_i (all the same), and c_{p_i} (all the same) are constants:

$$\frac{d^2f'}{d\bar{\eta}^2} - \frac{V}{\ell}\frac{df'}{d\bar{\eta}} - \frac{\beta}{\ell}\left[\frac{\bar{M}_e}{\bar{M}}\frac{\theta}{\bar{\bar{e}}} + (f')^2\right] = 0 \qquad \text{(B-1a)}$$

$$\frac{d^2\theta}{d\bar{\eta}^2} - \frac{Pr}{\ell} V \frac{d\theta}{d\bar{\eta}} + \alpha\beta \frac{\bar{M}_e}{\bar{\bar{M}}e} f'\theta \frac{Pr}{\ell} + \alpha\, Pr \left(\frac{\partial f'}{\partial\bar{\eta}}\right)^2 - \frac{Pr\ e}{\ell\ \bar{c}_p T_e}\left(\frac{w_A}{\rho}\right)\left(h_A - h_M\right) = 0 \qquad \text{(B-1b)}$$

$$\frac{d^2c_A}{d\bar{\eta}^2} - \frac{Pr\ V}{\ell\ Le}\frac{dc_A}{d\bar{\eta}} + \frac{Pr\ e}{\ell\ Le}\left(\frac{w_A}{\rho}\right) = 0 \qquad \text{(B-1c)}$$

$$V = V(0) - \int_0^{\bar{\eta}} f'\, d\bar{\eta} \qquad \text{(B-1d)}$$

where

$$\bar{\eta} = \eta\eta_e$$

The equation of state (3) becomes

$$\rho = \left(\frac{2M_A}{1 + c_A}\right)\frac{p}{RT} \qquad \text{(B-2)}$$

The chemical production term for atoms for a diatomic gas is expressed as

$$\frac{w_A}{\rho} = \bar{\rho}\ \gamma_M\left[k_f\ (1 - c_A) - 2k_b\bar{\rho}c_A^2/M_A\right] \qquad \text{(B-3)}$$

where

$$\bar{\rho} = 0.51536\ \rho\ (gm/cm^3)$$

For the case of dissociation of oxygen ($O_2 + M \rightleftarrows 2O + M$) the concentration of the third body, γ_M, is expressed as

$$\gamma_M = \frac{1}{2M_A}\left[9 + 41\, c_A\right] \tag{B-4}$$

and the rate constants are taken as

$$k_f = TK^{-1}\, e^{(\ln 3.61 \times 10^{18} - 59400/TK)} \tag{B-5a}$$

$$k_b = TK^{-.5}\, e^{(\ln 3.01 \times 10^{15})} \tag{B-5b}$$

The derivatives of the production term with respect to θ and c_A for oxygen are

$$\frac{\partial}{\partial\theta}\left(\frac{w_A}{\rho}\right) = \frac{2M_A}{\theta}\left[\left(-2 + 59400/TK\right) L_f + 2.5\, L_b\right] \tag{B-6a}$$

$$\frac{\partial}{\partial c_A}\left(\frac{w_A}{\rho}\right) = 2M_A\left\{L_f\left[-\left(\frac{1}{1 + c_A}\right) - \left(\frac{1}{1 - c_A}\right) + \frac{41}{9 + 41\, c_A}\right] - L_b\left[-\left(\frac{2}{1 + c_A}\right) + \frac{2}{c_A} + \frac{41}{9 + 41\, c_A}\right]\right\} \tag{B-6b}$$

where

$$L_f = \bar{\rho} k_f\, \gamma_M\, (1 - c_A)/(2M_A)$$

$$L_b = \bar{\rho}^2\, k_b \gamma_M c_A^2 / M_A^2$$

The momentum, energy, and species equations are of the following form:

$$f(W) = \frac{d^2W}{d\bar{\eta}^2} - V\, \psi\, \frac{dW}{d\bar{\eta}} + \varphi\,(W) = 0 \tag{B-7}$$

where

Momentum Eq. $(W = f')$

$$\psi = 1/\ell$$

$$\alpha = -\frac{\beta}{\ell}\left[(f')^2 + \frac{\bar{M}_e}{\bar{M}}\,\frac{\theta}{\bar{\bar{e}}}\right]$$

$$\frac{\partial\varphi}{\partial f'} = -\frac{2\beta}{\ell}\, f'$$

Energy Eq. $(W = \theta)$

$$\psi = Pr/\ell$$

$$\varphi = \psi\left[\alpha\beta\,\frac{\bar{M}_e}{\bar{M}}\,\frac{f'\theta}{\bar{\bar{e}}} + \alpha\ell\left(\frac{\partial f'}{\partial\bar{\eta}}\right)^2 - \frac{e}{\bar{c}_p T_e}\left(\frac{w_A}{\rho}\right)\left(h_A - h_M\right)\right]$$

$$\frac{\partial\varphi}{\partial\theta} = \psi \left[\alpha\beta \frac{\bar{M}_e}{\bar{M}} \frac{f'}{\bar{\bar{e}}} - \frac{e}{\bar{c}_p T_e} \left(h_A - h_M\right) \frac{\partial}{\partial\theta} \left(\frac{w_A}{\rho}\right)\right]$$

<u>Species Eq.</u> ($W = c_A$)

$\psi = Pr/(\ell\ Le)$

$\varphi = \psi e\ (w_A/\rho)$

$$\frac{\partial\varphi}{\partial c_A} = \psi e \frac{\partial}{\partial c_A} (w_A/\rho)$$

Before the method of <u>finite differences</u> is applied to Equation (B-7), the nonlinear term φ is linearized and the resulting equation is written as

$$\frac{d^2W}{d\bar{\eta}^2} + \alpha_1 \frac{dW}{d\bar{\eta}} + \alpha_2 W + \alpha_3 = 0 \tag{B-8}$$

where

$\alpha_1 = -V\psi$

$\alpha_2 = \frac{\partial\varphi}{\partial W}$

$\alpha_3 = \varphi - \frac{\partial\varphi}{\partial W} W$

The ordinary differential equation (B-8) is written in finite difference form as

$$\frac{W_{n+1} - 2W_n + W_{n-1}}{\Delta\bar{\eta}^2} + \alpha_1 \frac{W_{n+1} - W_{n-1}}{2\Delta\bar{\eta}} + \alpha_2 W_n + \alpha_3 = 0 \tag{B-9}$$

This gives a system of linear algebraic equations of the form

$$A_n W_{n+1} + B_n W_n + C_n W_{n-1} = D_n \qquad n = 2,3,\cdots(N-1) \tag{B-10}$$

where

$A_n = 1 + \alpha_1\ \Delta\bar{\eta}/2$

$B_n = -2 + \alpha_2\ \Delta\bar{\eta}^2$

$C_n = 1 - \alpha_1\ \Delta\bar{\eta}/2 = 2 - A_n$

$D_n = -\ \Delta\bar{\eta}^2 \alpha_3$

The boundary conditions (34) for the system of equations are written as

$$W_1 = -A_1 W_2 + D_1 \ (B_1 = 1) \tag{B-11a}$$

$$W_N = D_N \ (C_N = 0 \text{ and } B_N = 1) \tag{B-11b}$$

where A_1, D_1, and D_N are determined from the boundary conditions at the wall and outer edge. These parameters have the following values for the various conservation equations:

Tangential Momentum Equation

$$A_1 = 0; \qquad D_1 = 0; \qquad D_N = 1 \tag{B-12a}$$

Energy Equation (wall temperature specified)

$$A_1 = 0; \qquad D_1 = T_b/T_e; \qquad D_N = 1 \tag{B-12b}$$

Species Equation (catalytic wall*)

$$A_1 = 0; \qquad D_1 = 0; \qquad D_N = c_{A_e} \tag{B-12c}$$

The linear algebraic equations (B-10) with boundary conditions (B-11) are a system of the tridiagonal form and are readily solved. If the ordinary differential equation is linear, then α_1, α_2, and α_3 are known quantities and the finite-difference procedure will give the solution directly. Of course, the equations of interest are nonlinear and α_1, α_2, and α_3 are not known as they are a function of W. In order to apply the finite-difference procedure the quantities α_1, α_2, and α_3 must be approximated by assuming an initial distribution for $\overline{W}^{(i)}$. Then the solution can be obtained to give a new value of $W^{(i)}$. This procedure can be repeated until the assumed value of $\overline{W}^{(i)}$ is the same or nearly the same as the calculated value of $W^{(i)}$.

To obtain converged profiles, especially for blunt bodies at low altitudes, the iteration procedure can be very sensitive to the initial approximations of the profiles. Therefore, the estimated distribution of $\overline{W}^{(i-1)}$ and the calculated value of $W^{(i)}$ are weighted to obtain a new estimated value of $\overline{W}^{(i)}$ for the next iteration as follows:

$$\overline{W}^{(i)} = \overline{W}^{(i-1)} + \omega\left(W^{(i)} - \overline{W}^{(i-1)}\right) \tag{B-13}$$

The method of nonlinear overrelaxation as developed by Lieberstein[46] (also called method of accelerated successive replacements) is now applied to Equation (B-7). At a point n in the interval of integration, Equation (B-7) is replaced with difference quotients to give

$$f(W_n) = \frac{W_{n+1} - 2W_n + W_{n-1}}{\Delta\bar{\eta}^2} - V_\psi \frac{W_{n+1} - W_{n-1}}{2\Delta\bar{\eta}} + \varphi(W_n) = 0 \tag{B-14}$$

An initial variation of W across the interval of integration is assumed and W_n is considered the unknown in Equation (B-14). This equation is nonlinear in the unknown W_n and cannot be solved for directly. A Newton-Raphson method is employed to obtain an estimate of W_n and a relaxation factor ω is introduced to give

$$W_n^{(i+1)} = W_n^{(i)} - \omega \frac{f(W_n^{(i)})}{\frac{\partial f}{\partial W_n}} \tag{B-15}$$

*This is not strictly speaking a catalytic wall.

where

$$\frac{\partial f}{\partial W_n} = -\frac{2}{\Delta\bar{\eta}^2} + \frac{\partial\varphi}{\partial W}$$

The values of $\partial\varphi/\partial W$ for the various conservation equations are given in Equation (B-7). There are two ways to apply the iteration relation (B-15) to a system of coupled equations of the form of Equation (B-7). One method is to uncouple the equations and solve one equation at a time. For each equation the iteration relation (B-15) is applied at $n = 2, 3, \cdots$ across the layer from the wall to the outer edge. The second approach is to keep the equations coupled and improve the assumed solution for all of the dependent variables with the iteration relation (B-15) at $n = 2$. Then new values of the dependent variables are found at $n = 3$ with the iteration relation. This procedure is repeated for $n = 4, 5, \ldots$ until the outer edge of the layer is reached. For either of the above methods, the next step is to repeat the solution of the equations until the calculated solution is sufficiently close to the previous solution.

In the iteration relation (B-15), the weighting factor ω should be such that $1 \le \omega < 2$ as indicated by Lieberstein. From this investigation, the optimum value (fastest convergence) of the relaxation factor ω is 1.6 for the binary gas mixture with unstable solutions resulting when ω is 1.7.

The above procedures have been applied to the boundary layer solution at the stagnation point of a blunt body with the following conditions:

Altitude = 100,000 feet

U_∞ = 20,000 fps

T_∞ = 226.98°K = 408.564°R

p_∞ = 23.272 psf = 1.0997×10^{-2} atm.

ρ_∞ = 3.318×10^{-8} slug/ft^3

M_∞ = 20.178

p_o' = 12,772 psf = 6.0352 atm.

T_o' = 12,593°R = 6,996°K

T_W = 1400°K = 2520°R

R_N = 1 inch

The edge conditions for the boundary layer are as follows:

$p_e = p_o'$

$T_e = T_o'$

$u_e = 0$

c_{A_e} = .99293 (equilibrium composition)

The equilibrium composition is obtained from the following relation:

$$c_A = 1\Big/\sqrt{1 + \chi} \qquad \text{(B-16)}$$

where

$$\chi = 4(.51536)\,\frac{k_b}{k_f}\,\frac{p}{R\,T_e\theta}$$

The finite-difference and nonlinear overrelaxation techniques are applied to this problem to obtain the dependent variables f', θ, and c_A across the boundary layer. The interval of integration is taken as $0 \leq \bar{\eta} \leq 5.8$ with $\Delta\bar{\eta} = 0.2$ which gives a total of 28 points at which the dependent variables are unknown. Initially, a linear variation is assumed across the boundary layer connecting the known boundary conditions.

When the conservation equations are uncoupled and the dependent variables are solved for one at a time, the order in which the variables are solved for must be chosen. Before the two orders investigated are described, the production term is put into the following form:

$$\frac{w_i}{\rho} = W^o - W^1\, c_A \qquad \text{(B-17)}$$

where

$$W^o = \bar{\rho}\, k_f\, \gamma_M$$

$$W^1 = \bar{\rho}\, k_f\, \gamma_M + 2k_f\, \bar{\rho}^2\, \gamma_M c_A/M_A$$

In Method I the dependent variables are solved for in the order f', θ, and c_A. In Method II the dependent variables are solved for in the order f', c_A, and θ. After the mass fractions c_A have been determined in Method II, the production term in the energy equation is recalculated using the above expression where W^o and W^1 are based on the dependent variables of the previous iteration. For the nonlinear overrelaxation method with the equations coupled, the production term is evaluated with the newest values of the dependent variables employed.

The number of iterations required for the finite-difference method with various values of the weighting factor and the nonlinear overrelaxation method with various values of the relaxation factor is given in Table B-I. Also shown is the effect of using Methods I and II on the number of iterations required for convergence. Convergence is defined as when the following condition is satisfied:

$$\left|\frac{W^{(i+1)}}{W^{(i)}} - 1\right| < 10^{-6} \quad \text{at} \quad \bar{\eta} = 5 \qquad \text{(B-18)}$$

In this relation $W^{(i)}$ is the value of the dependent variable f', θ, or c_A at the i^{th} iteration. In order to give an indication of the rate of convergence of the methods of solution, the value of T/T_e at $\bar{\eta} = 5$ is shown in Figure B-1 as the iteration proceeds. The nonlinear overrelaxation method jumps around initially and this is more severe when the relaxation factor is large. It appears that the finite-difference procedure generally converges faster as one would expect. For example, for a linear ordinary differential equation, the finite-difference procedure would give the solution directly while the nonlinear overrelaxation method would still require an iteration procedure.

The complete profiles for this problem are given in Figures B-2, B-3, and B-4 where the velocity, temperature and mass fraction of atoms are presented. Also shown is the initial estimate for the various profiles. In Figure B-5, the mass fraction of atoms is given for the solution with a finite-chemical reaction

TABLE B-I

Iterations Required

Scheme	Weight Factor or Relaxation Factor	Number of Iterations Required: Method I	Method II
Nonlinear Overrelaxation (Eqs. Uncoupled)	1.0	377	329
	1.1	327	277
	1.2	284	233
	1.3	246	194
	1.4	213	159
	1.5	174	127
	1.6	NC*	99
	1.7		NC
Finite-Difference	0.5	267	212
	0.6	228	170
	0.7	199	140
	0.8	177	116
	0.9	157	97
	1.0	NC (oscillates)	81
	1.1		68
	1.2		57
	1.3		NC
Nonlinear Overrelaxation (Eqs. Coupled)	1.0		326
	1.1		274
	1.2		229
	1.3		189
	1.4		154
	1.5		122
	1.6		92
	1.7		NC

*NC - No convergence of method

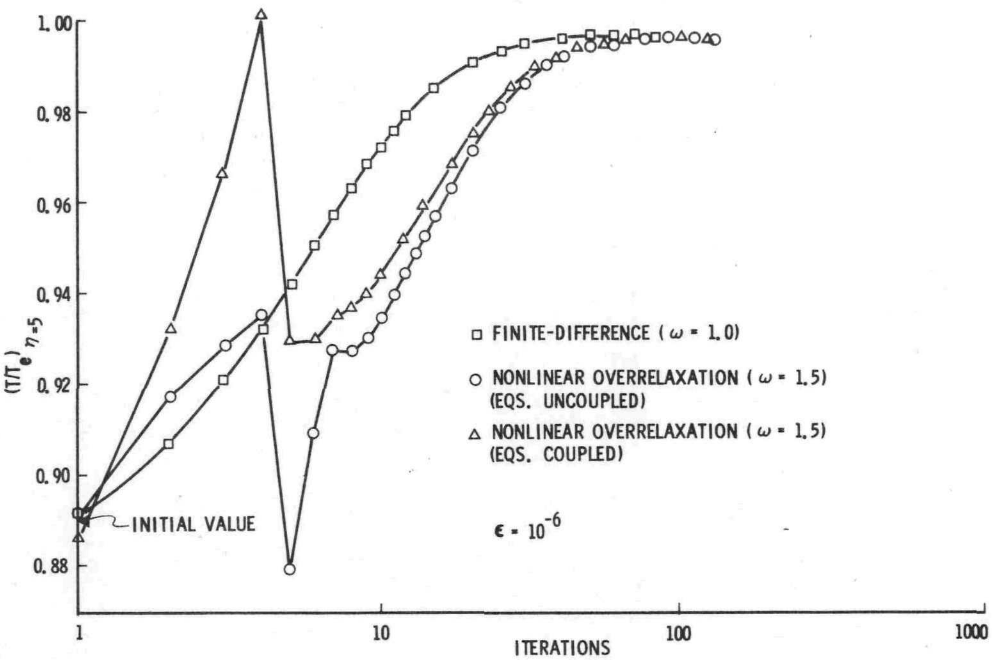


FIG. B1 - CONVERGENCE OF METHODS OF SOLUTION

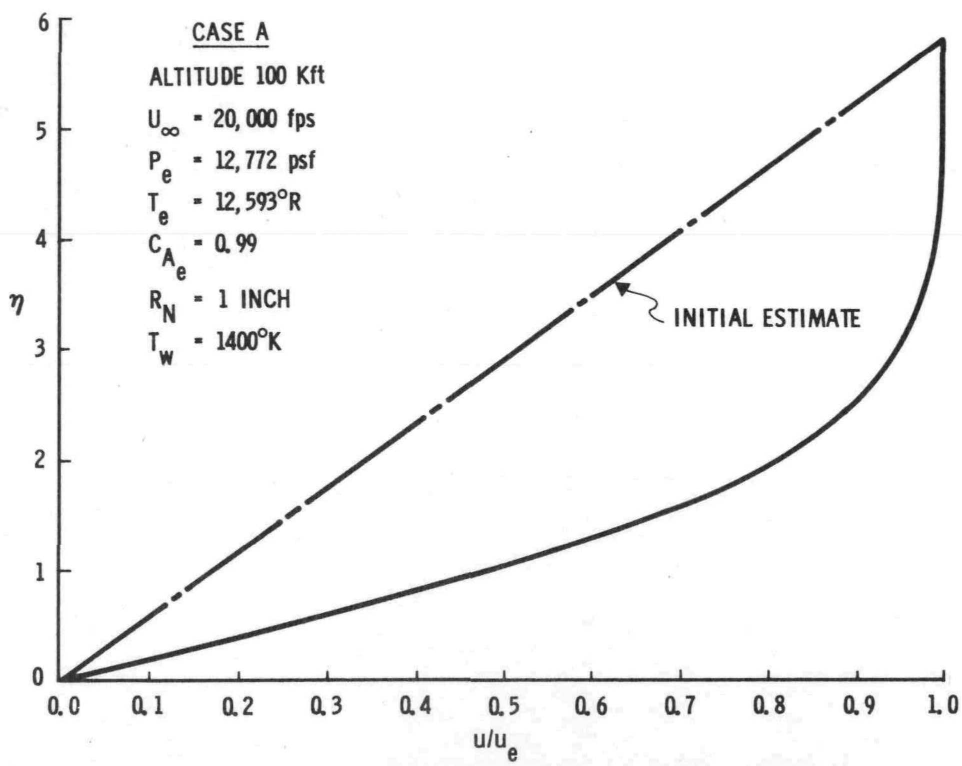


FIG. B2 - BINARY GAS SOLUTION - VELOCITY PROFILE

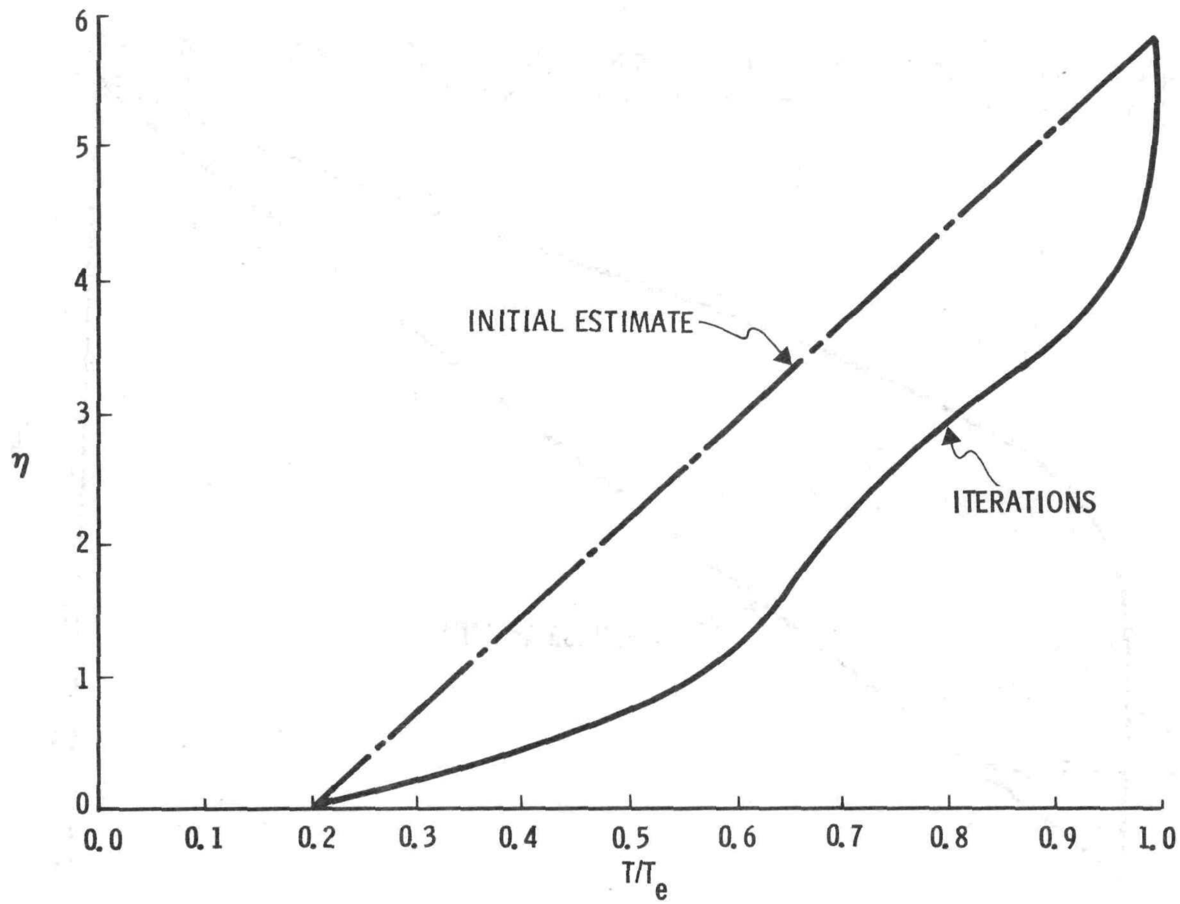


FIG. B3 - BINARY GAS SOLUTION - TEMPERATURE PROFILE

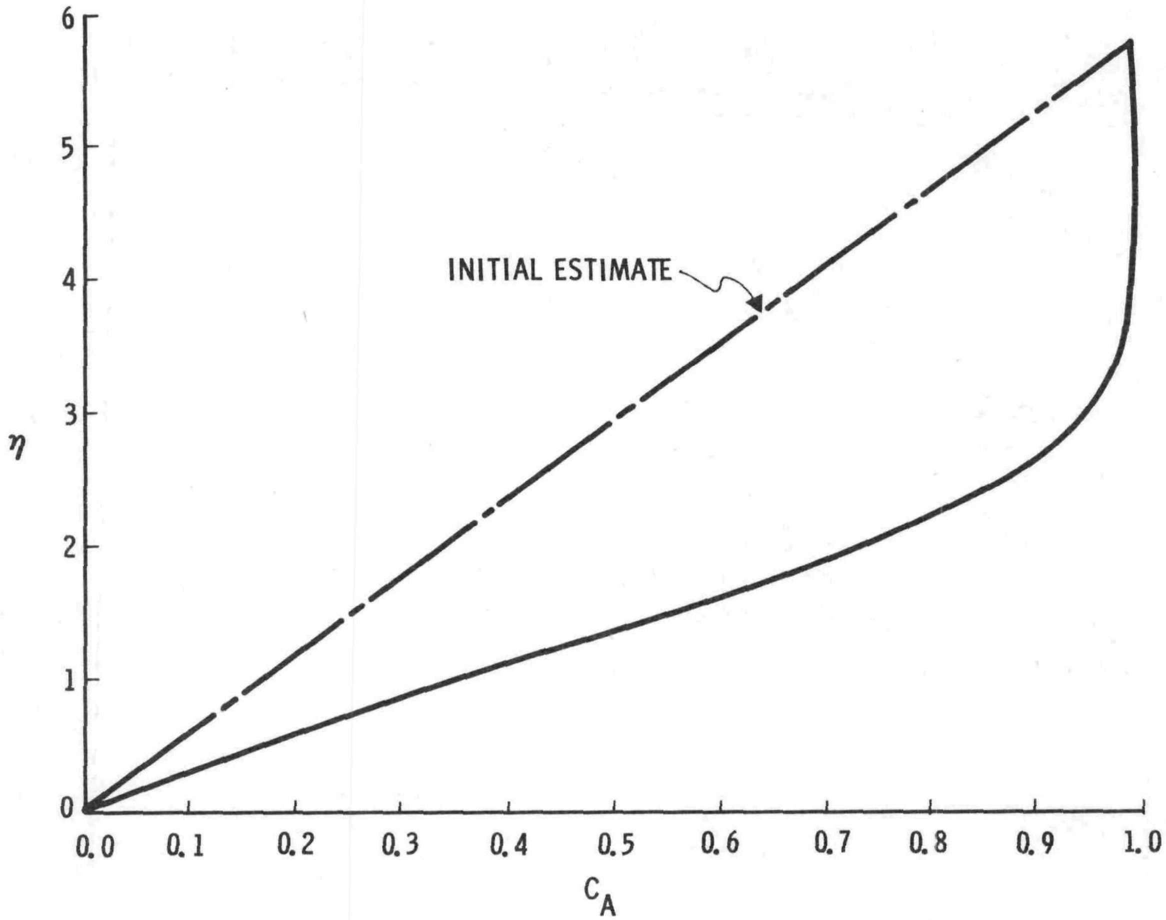


FIG. B4 - BINARY GAS SOLUTION - MASS FRACTION OF ATOMS PROFILE

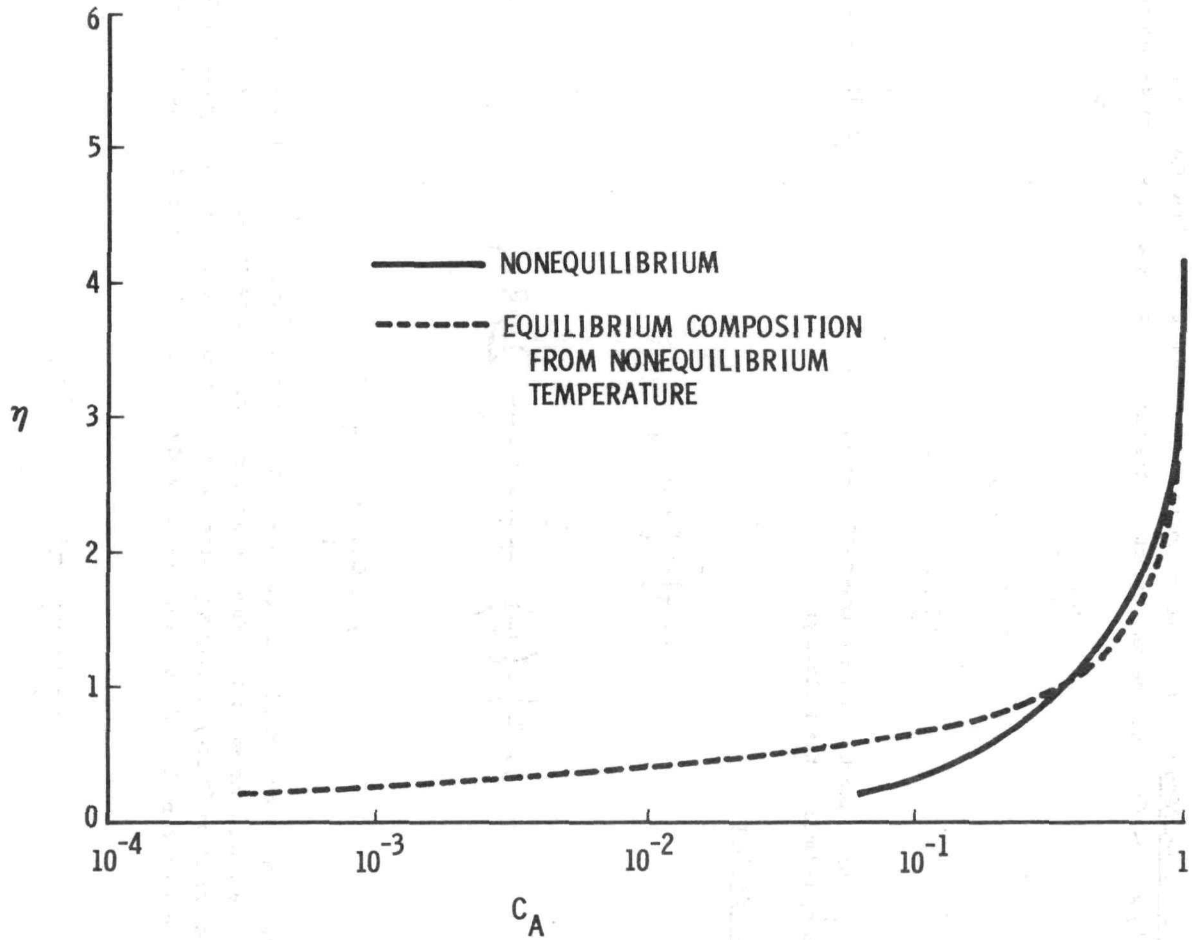


FIG. B5 - CLOSENESS OF SOLUTION TO EQUILIBRIUM rate. The temperature from the previously described nonequilibrium case has been employed to obtain the equilibrium mass fraction of atoms and is given also in this figure. The flow for this problem is still substantially out of chemical equilibrium.

The nonlinear overrelaxation method is readily extended to the case of a multi-component gas mixture. The relations (B-14) and (B-15) remain the same except now the values of the quantities involved become

$$-V\psi = \alpha_1 \tag{B-19a}$$

$$\varphi = \alpha_3 + \alpha_2 W_n \tag{B-19b}$$

$$\frac{\partial\varphi}{\partial W} = \alpha_2 \tag{B-19c}$$

The values of α_1, α_2, and α_3 for the various conservation equations for this case are given in relation (20). The value of φ can be reduced to the following:

Tangential Momentum Equation

$$\varphi = -\frac{\beta}{\ell}\left[\frac{\overline{M}_e}{\overline{M}}\frac{\theta}{\overline{\overline{e}}} + (f')^2\right] \tag{B-20a}$$

Energy Equation

$$\varphi = \frac{Pr}{\ell}\left\{\alpha\ell\left(\frac{\partial f'}{\partial\eta}\right)^2 + \frac{\alpha\beta}{\overline{\overline{e}}}\frac{\overline{M}_e}{\overline{M}} f'\theta - \frac{1}{\bar{c}_p T_e}\sum_{i=1}^{NI} \overline{W}_i h_i\right\} \tag{B-20b}$$

Species Equations

$$\varphi = \frac{Pr}{\ell\, Le_i}\left\{\overline{W}_i + \bar{b}_i'\right\} \tag{B-20c}$$

When the dependent variables are specified as the two-point boundary conditions, the same procedure is followed as the binary case to obtain the solution. When the boundary conditions at the surface involve derivatives and can be expressed as relation (B-11a), a slightly different relation must be employed at the first point away from the surface (called point 2). The value of the derivative in expression (B-15) at this point becomes

$$\frac{\partial f}{\partial W_2} = -\frac{2}{\Delta\bar{\eta}^2} - \frac{A_1}{\Delta\bar{\eta}^2}\left(1 + \frac{1}{2} V\psi\Delta\eta\right) + \frac{\partial\varphi}{\partial W_2} \tag{B-21}$$

with the use of (B-14) and (B-11a). The value of the dependent variable at the surface in the iteration process is determined from relation (B-11a).

APPENDIX C

Locally Similar Boundary Layer Solution for Chemical Equilibrium

An option has been included in the computer program for solving the boundary layer equations with a gas model which assumes local chemical equilibrium. When this option is being used, it is necessary to provide the subroutine EQUIL which will determine the composition. In the present analysis and program, it is assumed that the binary diffusion coefficients are the same for all species involved. The only type of mass transfer that can be considered is the case where the boundary layer gas is injected at the surface. These restrictions are required since the distribution of the elements is assumed constant across the boundary layer.

For this case the appropriate equations that describe the flow are (17a), (17b), (17d), and (3) where the production term in the energy equation is determined from the species equation (17c) which is written as

$$-e\left(\frac{w_i}{\rho}\right) = \frac{b_i}{\eta_e^2}\frac{\partial^2 c_i}{\partial \eta^2} + \frac{(b_i' - V)}{\eta_e}\frac{\partial c_i}{\partial \eta} \qquad \text{(C-1)}$$

The mass fraction of species is determined from the equilibrium composition which can be expressed as

$$c_i = c_{i_{eq}} (T, p, c^j) \qquad \text{(C-2)}$$

The element mass fraction of the j^{th} element is related to the mass fraction of the various species by

$$c^j = \sum_{i=1}^{NI} \alpha_i^j \frac{M^j}{M_i} c_i \qquad \text{(C-3)}$$

where α_i^j = number of atoms of element j in species i. In general, the element distribution across the flow must be obtained from the conservation of element equations. These equations can be obtained from the species equation (1e) by multiplying all of the terms by $(\alpha_i^j M^j/M_i)$ and summing over the species. The chemical production term will not appear in the resulting equation. For the case of no foreign gas mass transfer and all of the binary Lewis-Semenov numbers the same, the elements of the freestream gas are constant across the flow. This is the assumption presently being employed. Therefore, the right side of Equation (C-1) can be evaluated with the relations (C-2). The dependent variables for the equilibrium problem are ρ, T, u, V, and c^j's where the mass fraction of species has been eliminated with the equilibrium composition relations (C-2).

For the present case, the boundary condition (9) is not required but the mass fraction at the body surface is determined from

$$c_{i_b} = c_{i_{eq}} (T_b, p, c_b^j) \qquad \text{(C-4)}$$

and the remaining relations (8) are the appropriate conditions.

The governing equations are solved in the same manner as employed in the solution of the nonequilibrium case. The locally similar boundary layer solution can be used to obtain results far downstream on a sharp cone or at a stagnation point at conditions where the gas is in local chemical equilibrium. The similar solution on a cone for a binary gas mixture of oxygen is given in Figure 1C. These results required 116 iterations with the weight factor ω = 0.1. Stagnation point boundary layer solutions have been obtained at 100 and 150 Kft altitude conditions with the freestream velocity varying from 10 to 30 Kfps. The inviscid flow properties for these various flight conditions were obtained from Lomax and Inouye.[19] The accuracy of these results is evaluated by investigating the predictions of the energy flux normal to the wall as compared to experimental results and other predictions. The present predictions of the Nusselt-Reynolds number heat transfer parameter is compared to results of Fay and Kemp,[48] and Pallone and Van Tassell[49] in Figure 2C. The results of Fay and Kemp are for a Lewis number of 0.6. For the present results, the stagnation pressure at 100 Kft altitude varies between 1.44 to 9.17 atmospheres while at 150 Kft altitude between 0.16 to 1.47. The present results are in reasonable agreement with the methods in Figure 2C but other methods (Cohen, Hoshizak and Scala) are significantly different.

The present prediction of the surface energy flux parameter is compared to experimental results of Nerem and Stickford;[50] Luikov, Sergeev and Shaskov;[51] and Skin and Marvin [52] in Figure 3C. Experimental results for heat transfer have a scatter of ± 20% typically. The present prediction is probably higher than the mean of the experimental data but within the scatter. Also shown in this figure is the surface energy flux for a chemical nonequilibrium solution with a catalytic wall and multi-component diffusion gas model. The surface energy flux for this case is slightly lower than the chemical equilibrium result.

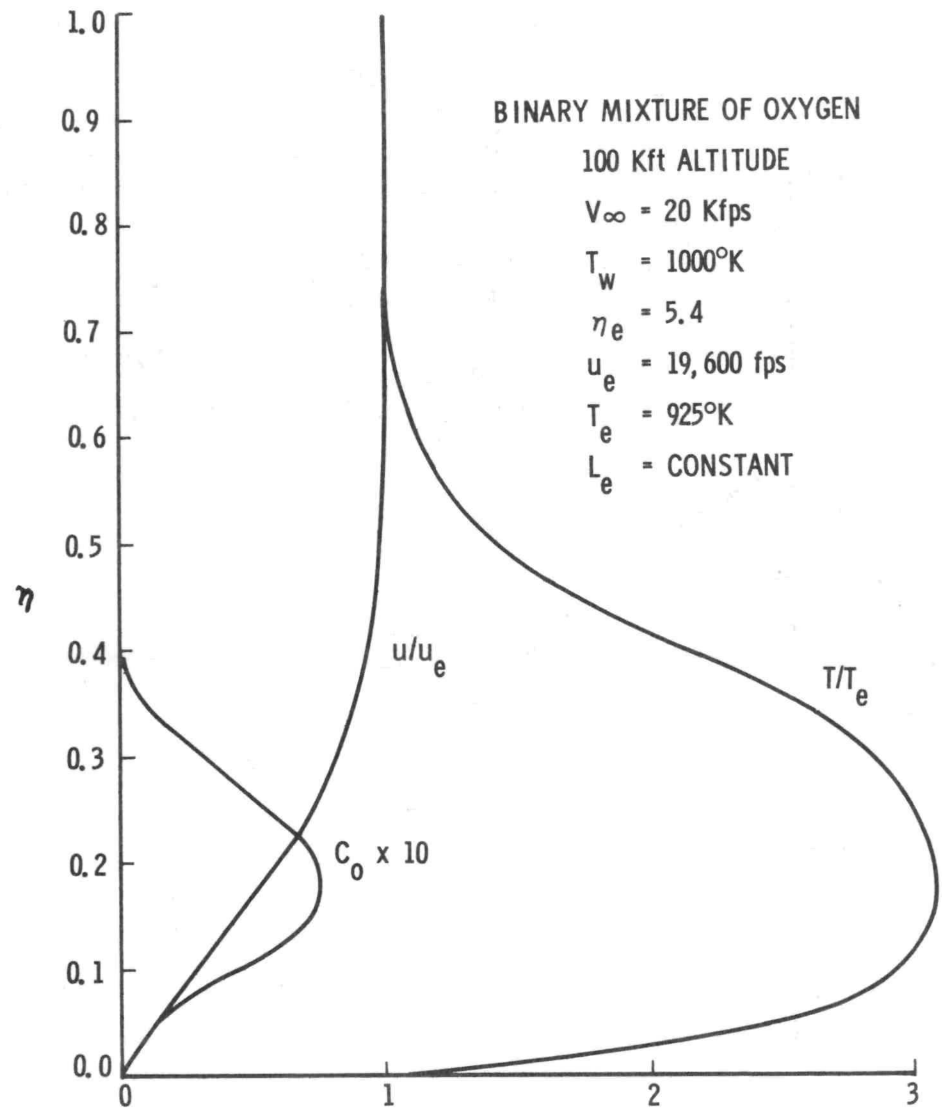


FIG. 1C - PROFILES ACROSS BOUNDARY LAYER FLOW ON A CONE FOR CHEMICAL EQUILIBRIUM

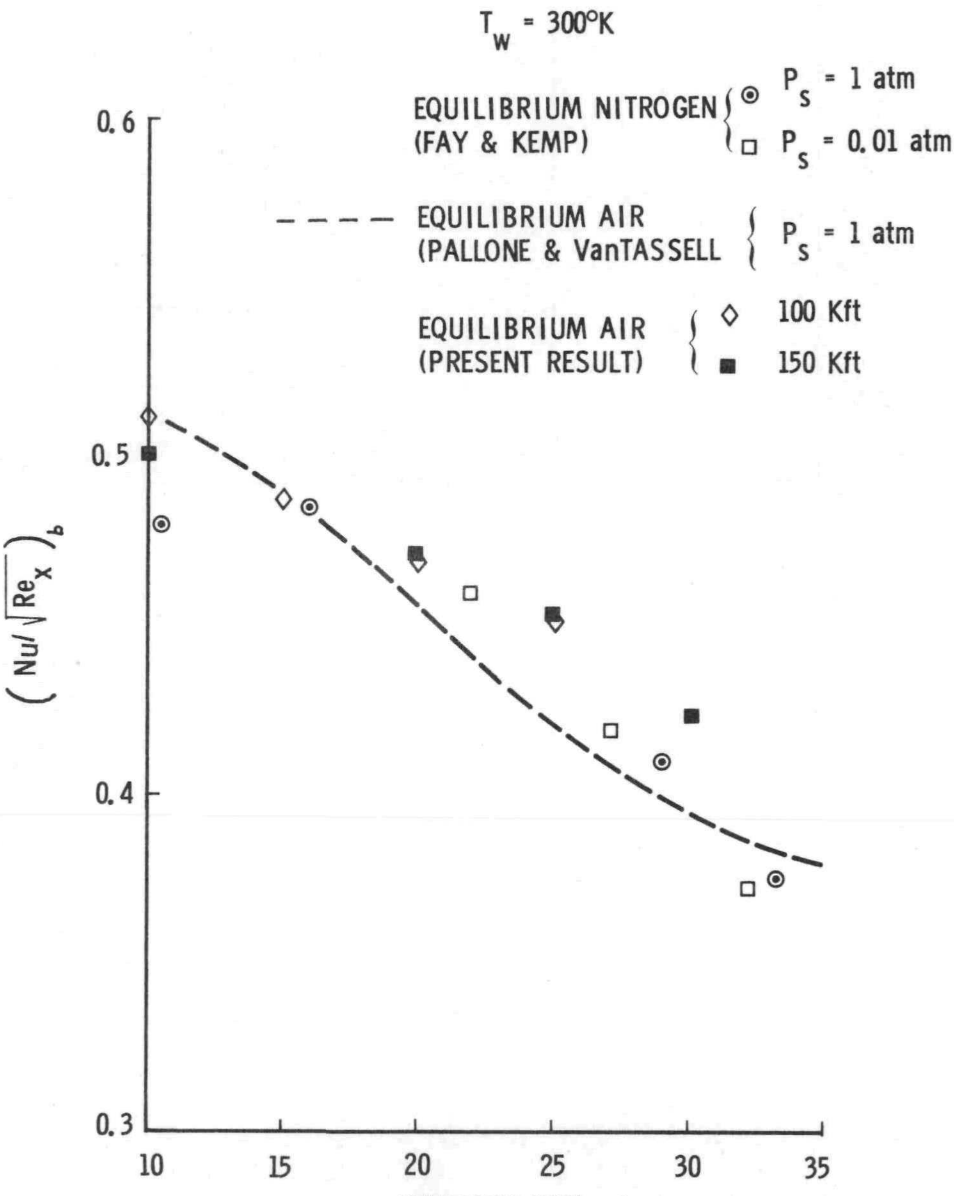


FIG. 2C - COMPARISON OF PREDICTIONS OF THE NUSSELT-REYNOLDS NUMBER PARAMETER

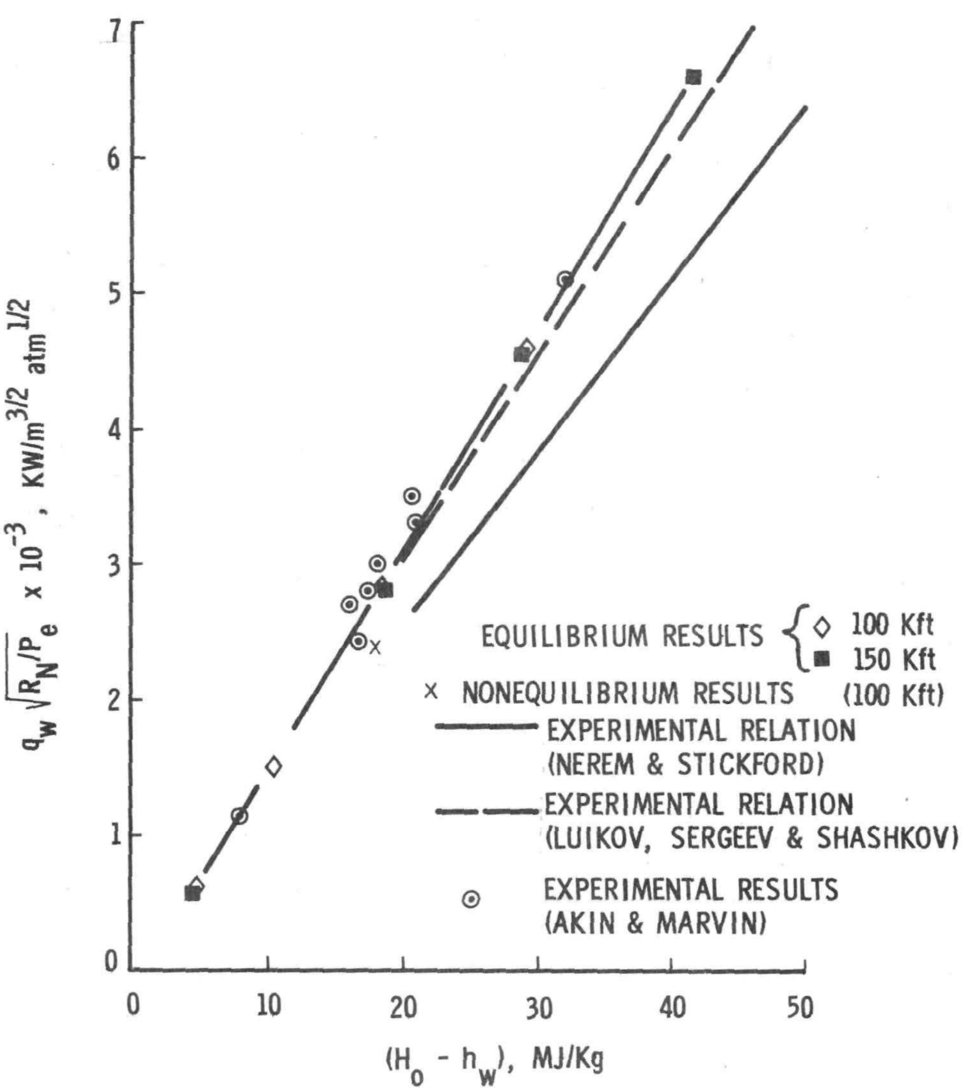


FIG. 3C - COMPARISON OF EXPERIMENTAL HEAT TRANSFER RESULTS WITH PRESENT PREDICTIONS

Appendix D

COMPUTER PROGRAM DESCRIPTION

1. Introduction

The computer program has been written in Fortran IV and run on a CDC 6600. The program has a large number of subroutines and a short main program BLAB which controls the flow. The basic logic of the program is given in Figure D1 which is a flow chart of the main program. A short description of all of the subroutines is given in Section 2 of this Appendix and in Section 3 the order in which the subroutines are used is illustrated. For each COMMON the subroutines in which it is used are given in Section 4, while the list of COMMON is given in Section 5. A list and description of many of the FORTRAN symbols employed in the program is presented in Section 6. The next section, 7, is a description and listing in alphabetical order of all the routines in the program. The list of the block data is given last. There are several subroutines which are standard mathematical type and these are:

DERIV and KUTTAM - Runge-Kutta integration

GAUSS3 - Matrix inversion

POLATE and DPOLATE - interpolation for function and derivative

SIMINT - Simpson's integration

The subroutines CHEMPR, EQUIL and QPR are not general and need to be checked to be sure they are appropriate for the problem being solved. If species are added to the program and their name is required in CHEMPR or QPR, the present list in PRECAL (line 128) of O, N, O_2, N_2, NO, NO^+, e^-, C, CO, CO_2, M, M_2, M_3 and M_4 needs to be extended. Also additional block data needs to be supplied.

The program has a storage requirement of 175 K octile in the present form. If the number of species, number of reactions or number of points across the layer is changed from the present maximum values, then the storage requirements will change. In Section 8, an outline is given to indicate which modifications are necessary if the dimensions of certain parameters are made different.

2. Routines Used

A list of the subroutines in the program is given below along with a brief description. A more complete discussion of the routine is given in Section D-7 and on the page shown.

BLAB	- controls program flow (see flow chart).
BLC	- computes boundary-layer functions, heat transfer, skin thickness, displacement thickness, etc. Controls print of profiles and punch of initial profiles.
BODIM	- computes ξ, λ, and edge conditions for each body profile.
BSETUP	- initializes for body-profile calculation.
CALCV	- computes V, transformed normal velocity.
CALDNS	- computes η and some combinations of $\Delta\eta$'s.
CALEBB	- computes $\bar{\bar{e}}$.
CC1	- function subprogram to interpolate for enthalpy.
CC2	- function subprogram to interpolate for specific heat.
CHEMPR*	- computes density and chemical production terms ρ, W^0, W^1, $\bar{\bar{W}}$.

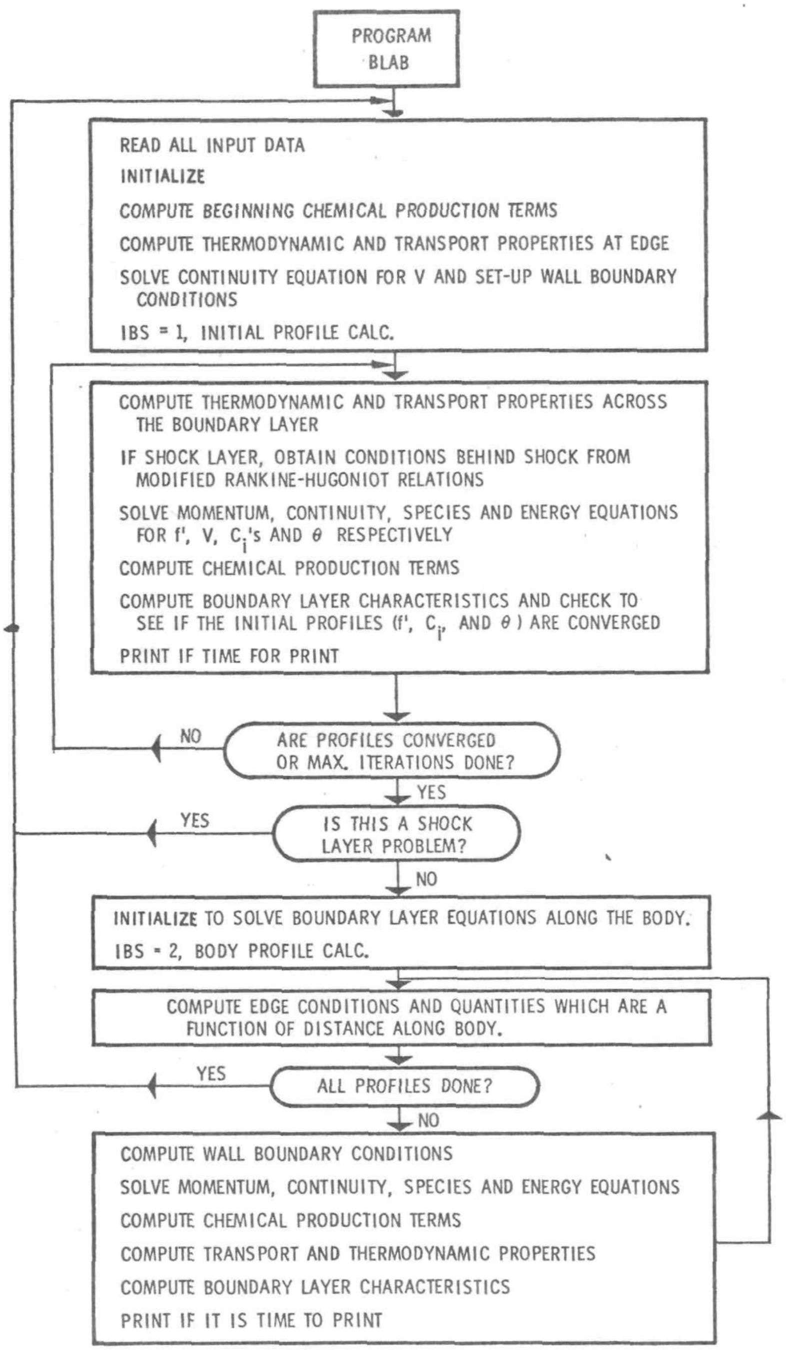


FIG. D1 - PROGRAM FLOW CHART

DPOLATE	- second entry to POLATE: computes slope of interpolated value.
DERIV	- computes derivatives for KUTTAM.
DERVDN	- computes 1st or 2nd derivative with respect to η.
ENEREQ	- solves energy equation for θ values.
EQUIL*	- computes c_i's and ρ for equilibrium. Will only handle air with six species.
EQU2	- computes $\left(c_{i_{eq}}\right)$ pyrolysis.
GAUSS3	- matrix inversion subroutine.
HUGNOT	- computes values of T_e, p_e, ρ_e, and u_e for shock-layer solution.
INPUT	- reads and prints part of input data.
INPBOD	- reads and prints the rest of the input data.
KUTTAM	- Runga-Kutta integration subroutine
MCDIFF	- computes $\bar{\bar{\Lambda}}b_{ik}$ and Lewis numbers for multiple-component diffusion option.
MOMEQ	- computes f' from momentum equation.
PCH	- punches initial profiles and other data, if requested.
POLATE	- Lagrangian interpolation subroutine.
PRECAL	- computes one-time values and initializes.
PRTBL	- prints all output for initial profile.
PRTEDG	- prints edge tables.
PRTPRO	- prints f', θ, c_i for all points across boundary.
PR2DSW	- prints table of stoichiometric coefficients
PRTX	- prints values of X_r
QPR*	- computes Q_i, P_i and $(\rho v)_b$ for wall conditions.
SETOT	- sets switch values from input options
SIMINT	- Simpson integration subroutine
SPBND	- computes boundary values for species equation.
SPECEQ	- computes c_i from species equations.
STOI	- computes forward and backward stoichiometric values.
THERMO	- computes thermal properties
WKHS	- solves difference equations for f', θ, and c_i's.
BLOCK DATA	- contains tables of enthalpy vs. temperature and tables of specific heat vs. temperature at 50 temperature values, and for twenty different species.

*This subroutine is not completely general. If problems other than the type discussed in Chapter VIII are being solved, this subroutine must be checked for consistency with the problem.

HOROLDG - This subroutine is not included with the deck. It is a 6600 system subroutine so will have to be replaced, or the calls (in BLC and INPUT) removed, i.e., CALL HOROLOG (A, J, K) where A = time remaining for job (floating point, milliseconds), J = time of day, K = current date, where J and K are FORMAT A10.

3. Program Flow

The following shows which routines are called by other routines and the order in which the routines are used.

```
BLAB
          INPUT
                    SETOT
                    PR2DSW
                    INPBOD
                              PRTEDG
          PRECAL
                    POLATE
                    CALDNS
                    EQUIL
                    CC1
                              POLATE
                    HUGNOT
                              DERVDN
                              CC1
                                        POLATE
                    PRTPRO
          CHEMPR
                    STOI
          THERMO(-1)
          QPR
                    POLATE
                    EQU2
          CALCV
                    SIMINT
                                                  <--- Initializing to here
          THERMO(0)
                    DERVDN
                    CC1
                              POLATE
                    MCDIFF
                              GAUSS3
                    HUGNOT
                              DERVDN
          MOMEQ
                    CALCV
                              SIMINT
                    CALEBB
                              SIMINT
                    DERVDN
                    WKHS
```

SPECEQ			Initial Profile IBS = 1
	EQUIL		
	SPBND		
	WKHS		
ENEREQ			
	DERVDN		
	WKHS		
CHEMPR			
	STOI		
QPR			
	POLATE		
	EQU2		
BLC			
	SIMINT		
	PCH		
	PRTBL		
		PRTX	
		PRTPRO	
THERMO(1)			
	DERVDN		
	CC1		
		POLATE	
	CC2		
		POLATE	
	MCDIFF		
		GAUSS3	End of Initial Profile Iteration
BSETUP			
BODIM			
	POLATE		
	DPOLATE		
	KUTTAM		
		DERIV	
	THERMO(-1)		
BLC			
	SIMINT		
	PRTBL		
		PRTPRO	
		PRTX	

4. Use of COMMON

In the following a listing of COMMON is given and in which routines they are employed. This information is useful to determine where FORTRAN variables are used in the program.

COMMON	USED IN
(blank)	CHEMPR, ENEREQ, PRECAL, SPECEQ, THERMO
1	BLAB, BLC, BODIM, BSETUP, CALCV, CALDNS, CALEBB, CHEMPR, DERVDN, ENEREQ, HUGNOT, INPBOD, INPUT, MCDIFF, MOMEQ, PCH, PRECAL, PRTBL, PRTEDG, PRTPRO, PR2DSW, PRTX, QPR, SIMINT, SPBND, SPECEQ, STOI, THERMO, WKHS
2	BLAB, BLC, BODIM, CHEMPR, MOMEQ, PRTBL, THERMO

3	BLAB, BLC, BODIM, CHEMPR, ENEREQ, INPUT, PRECAL, PRTBL, SETOT, SPECEQ, THERMO
4	BLAB, BLC, CALCV, CHEMPR, ENEREQ, MOMEQ, PRTBL, SPBND, SPECEQ, THERMO, WKHS
5	BLC, BODIM, BSETUP, CALCV, CALEBB, CHEMPR, ENEREQ, EQUIL, HUGNOT, INPUT, MCDIFF, MOMEQ, PCH, PRECAL, PRTPRO, QPR, SPBND, SPECEQ, THERMO
6	BSETUP, CALCV, ENEREQ, MOMEQ, SPECEQ
7	BLAB, EQUIL, INPBOD, PCH, PRECAL, PRTBL, SETOT
8	BLC, BODIM, BSETUP, CALCV, CHEMPR, ENEREQ, EQUIL, HUGNOT, INPUT, MCDIFF, MOMEQ, PRECAL, PRTBL, QPR, SPECEQ, THERMO
9	BLC, BODIM, CALCV, PRECAL, SETOT, SPBND
10	BLC, BODIM, DERIV, HUGNOT, INPBOD, INPUT, PCH, PRECAL, THERMO
11	BLC, BODIM, BSETUP, CALCV, CALDNS, DERVDN, HUGNOT, PRECAL, SIMINT, SPBND, WKHS
12	BLC, BODIM, CALCV, CHEMPR, HUGNOT, PRECAL, SPECEQ, THERMO
13	BLC, BODIM, CHEMPR, ENEREQ, HUGNOT, INPUT, PCH, PRECAL, QPR, SPECEQ, THERMO
14	BLC, BODIM, POLATE, PRECAL, QPR
15	BLC, BODIM, BSETUP, SPBND
16	BLC, BSETUP
17	BLC, BODIM, BSETUP, CHEMPR, PRECAL
18	BLC, BODIM, CALCV
19	BLC, INPUT, PCH
20	BLC, BODIM, CALCV, HUGNOT, INPBOD, INPUT, PCH, PRECAL, QPR, THERMO
21	BLC, CHEMPR, PRTBL, PRECAL
22	BLC, PRECAL
23	BLC, HUGNOT, SPBND, THERMO
24	BLC, CALCV, CALDNS, DERVDN, INPUT, PCH, PRECAL, SIMINT
25	BLC, CALCV, PRECAL, PRTBL, QPR, SPBND
26	BLC, INPUT, MCDIFF, PRECAL, SPBND, THERMO, QPR
27	BLC, BODIM, ENEREQ, HUGNOT, PRECAL, PRTBL, THERMO
28	BODIM, BSETUP, CALEBB, ENEREQ, MOMEQ, PRECAL, SPECEQ, WKHS
29	BODIM, HUGNOT, PRECAL, SPBND, SPECEQ
30	BODIM, INPBOD, PRECAL, PRTEDG
31	BLC, BODIM, INPBOD, PRECAL, QPR
32	BODIM, ENEREQ, PRECAL, QPR, SPECEQ
33	BODIM, INPBOD
34	BODIM, BSETUP, INPBOD, PCH
35	BODIM, ENEREQ
36	BODIM, CALCV, PRECAL, WKHS
37	BODIM, CHEMPR, INPBOD, PCH, PRECAL, PRTBL, THERMO
38	BODIM, CALEBB, ENEREQ, MOMEQ, PRECAL, PRTBL
39	BODIM, BSETUP, ENEREQ, INPUT, MOMEQ, PCH, PRECAL, SPECEQ
40	BLAB, CALCV, ENEREQ, HUGNOT, MOMEQ, PRECAL, PRTBL, SETOT, SPECEQ, THERMO
41	CALCV, CALDNS, PRECAL, PRTBL, PRTPRO, PRTX, WKHS
42	CALDNS, WKHS
43	BLC, CALDNS, DERVDN
44	BLC, CALDNS, DERVDN, SIMINT, SPBND
45	CALDNS, SPBND
46	CALEBB, HUGNOT, PRECAL, THERMO
47	CHEMPR, PRECAL

48	CHEMPR, EQUIL, HUGNOT, INPUT, PRECAL
49	CHEMPR, INPUT, PRECAL, QPR
50	CHEMPR, INPUT, PCH, PRTBL
51	CHEMPR, STOI
53	CHEMPR, INPUT, MCDIFF
55	ENEREQ, INPUT, MOMEQ, PCH, SPECEQ
56	ENEREQ, THERMO
57	ENEREQ, MOMEQ, SPECEQ, WKHS
58	ENEREQ, MOMEQ, SPBND, WKHS
59	ENEREQ, INPUT, MOMEQ, PCH, SPECEQ
60	CHEMPR, EQU2, PRECAL, SPBND, SPECEQ, QPR
61	INPUT, PCH
62	INPUT, SETOT
63	INPUT, PCH, PRECAL, PRTBL, PRTEDG, PRTPRO, PR2DSW
64	INPUT, THERMO
65	HUGNOT, INPUT, PCH, PRECAL, SETOT
66	INPUT, PCH, QPR, SPBND, SPECEQ, WKHS
67	CHEMPR, PRECAL, QPR
68	MCDIFF, THERMO
69	HUGNOT, PRECAL, THERMO
70	QPR, SPBND
71	SPECEQ, THERMO
72	MOMEQ, THERMO
73	CALCV, THERMO
74	BODIM, CHEMPR
75	HUGNOT, THERMO
76	BLC, HUGNOT
77	HUGNOT, PRECAL
78	CALEBB, HUGNOT
79	PRECAL, QPR
80	CC1, CC2, INPUT, PRECAL
82	INPUT, MCDIFF
83	BODIM, CALCV
84	BODIM, BSETUP
85	CHEMPR, PRTX
86	BLC, BODIM
89	BODIM, INPBOD, INPUT, SETOT
90	BODIM, INPBOD, INPUT, SETOT
AA	BLKDATA, CC1, CC2, INPUT, PRECAL
BB	BLKDATA, INPUT

5. List of COMMON

The following gives the COMMON used in the program and the variables in each.

```
      COMMON       WBAR(50,30), WONE(50,30), WTH(50,30)  , WZERO(50,30)
      COMMON  /1/  NI          , NMAX        , NM2         , NTO          ,
     1             NJ          , NM1         , NR
      COMMON  /2/  M
      COMMON  /3/  IFROZE      , ILE         , MFLAGO       , NEQUIL
      COMMON  /4/  FL(50)      , IBS
      COMMON  /5/  CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON  /6/  CL(50,30)   , FP(50)      , TH(50)
      COMMON  /7/  ICOMPO
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)   , FMBARE      , RHO(50)   , R
      COMMON  /9/  IGEOM       , JBOD
      COMMON /10/  RN          , TANCO
      COMMON /11/  DEN2(50)    , ETE         , VONE
      COMMON /12/  RHOE        , RHOINF      , RMUREF
      COMMON /13/  HINF        , PE          , SMALLE      , TKE       , UE ,
     1             HF(30)      , PINF        , TE          , TINF      , VINF
      COMMON /14/  ICHGSW      , IDYS
      COMMON /15/  FLAPL       , RB1         , TXI1T       , XI1
      COMMON /16/  DRAGP       , DRPL        , RVBINT      ,
     1             DRAGT       , DRTL        , RVBRL
      COMMON /17/  IDX         , RB12        , VE1         ,
     1             DELXN       , TE1         , X1
      COMMON /18/  DELXI       , XI12
      COMMON /19/  IPUN        , KOPE        , TOL
      COMMON /20/  ANGLC       , FJ          , SINCO       , TKINF        ,
     1             DUEDX       , PII         , SINTH       , TKW
      COMMON /21/  CFINF       , FMDOT(30)   , QCOND       , RSUM         ,
     1             DISPTK      , FMOTH       , QCONV       , SKFER        ,
     2             DRAG2       , HE(50)      , QDIFF       , ST           ,
     3             DRAGP2      , HXTFEB      , QTFTLB      , TLEFT        ,
     4             DRAGT2      , HXTFER      , QTOTAL      , YF(50)       ,
     5             EDENS(50)   , PARDOT(30)  , RMFLUX(30)  , REVE
      COMMON /22/  CSAVE(30)   , FPSAVE      , RHVINF       , SQRT2       ,
     1                           HO          , SQRT1       , THSAVE    , TK1
      COMMON /23/  BLBAR(50,30),FMUB         , PR(50)      , PRFL
      COMMON /24/  DN(50)
      COMMON /25/  RVB
      COMMON /26/  DBB(30,30)  , FLEJ(30)    , INOP
```

```
      COMMON /27/  CPBAR(50)  , FFMU       , RES        , UE2TE      ,
     1             ENTAPY(50,30)

      COMMON /28/  BETA       , CTH

      COMMON /29/  CEDG(30)

      COMMON /30/  CA(110,30) , PA(110)    , VA(110)    , XA(110)    ,
     1             NED        , TA(110)

      COMMON /31/  NTP        , SPRT       , TWT(50)    , XRN(50)    ,
     1             RVPT(50)   , TETE(50)

      COMMON /32/  TW

      COMMON /33/  CONPHS     , RNPHIS

      COMMON /34/  DELXT(20)  , NDX        , XDELT(20)  , XMAX

      COMMON /35/  EBAR

      COMMON /36/  ETESQ      , SPFI(50)   , TXIE

      COMMON /37/  IPRTB

      COMMON /38/  BEBB(50)

      COMMON /39/  NKM        , OMW(32)    , WFA(32)

      COMMON /40/  IBRDYO     , V(50)

      COMMON /41/  ETA(50)

      COMMON /42/  DMDN(50)   , DNH(50)    , TDNOM(50)  , TDNOP(50)

      COMMON /43/  DEN1(50)   , DEN3(50)   , DNTR2(50)

      COMMON /44/  DNO6(50)   , DNTR1(50)  , DNTR3(50)  , DPDN(50)

      COMMON /45/  RDN        , RRDN

      COMMON /46/  EDBLT1     , EDBLT2     , EP2

      COMMON /47/  DIFA(30,30), GAMMIN(30,40),GAMPLS(30,40)

      COMMON /48/  C0(30)     , C2(30)     , D1(30)     , CINF(30)   ,
     1             C1(30)     , D0(30)     , D2(30)

      COMMON /49/  CALPH(30,40),CBETA(30,40),CSALPH(30) , CSBETA(30),IO

      COMMON /50/  IPRT

      COMMON /51/  GAMMA(40)  , RHOBAR

      COMMON /53/  AMD(435)   , BMD(435)   , CMD(435)   , Z(30,10)

      COMMON /55/  AENE       , ASPE       , KMOM       , KSPE       ,
     1             AMOM       , KENE

      COMMON /56/  BLIL(50)   , CBAR(50)   , CBARPR(50) , CCC1(50,30),
     1             DLIL(50)

      COMMON /57/  ALPH1(50)  , ALPH4(50)  , ISPC       , OMWF       ,
     1             ALPH2(50)  , CHECK      , MFLAG      , WFAC       ,
     2             ALPH3(50)

      COMMON /58/  A(50)      , B(50)      , C(50)      , D(50)

      COMMON /59/  KOPT
```

```
      COMMON /60/  IN2          , IO2
      COMMON /61/  TITLE(9)
      COMMON /62/  TOT(3,6)
      COMMON /63/  SPN(40)
      COMMON /64/  AMU(30)      , BMU(30)      , CMU(30)
      COMMON /65/  CK           , DELTA        , IREAD        , OPTN(6) , RS
      COMMON /66/   EIO         , EIO2         , IWC
      COMMON /67/  ICO          , ICO2         , IM1          , IM3     , IN  ,
     1             IC1          , IEL          , IM2          , IM4     , INO
      COMMON /68/  CON          , N            , SPB          , TK
      COMMON /69/  CONTH(30,30),FMOLWR(30)  , TMTHA(30,30),EPSI      , TS4
      COMMON /70/  P(30)        , Q(30)
      COMMON /71/  BB(50,30)    , BBPR(50,30), BLBAPR(50,30)
      COMMON /72/  FLPR(50)
      COMMON /73/  VS
      COMMON /74/  PE1
      COMMON /75/  FTER(30)
      COMMON /76/  DUM(50)
      COMMON /77/   FMBARI      , SS
      COMMON /78/  DEB
      COMMON /79/   RSQMWT(30)
      COMMON /80/  JE(30)
      COMMON /81/  ETEH
      COMMON /82/  NIM
      COMMON /83/  XITRM        , XITRP
      COMMON /84/  DXEST(20)    , IXSW         , TRM
      COMMON /85/  X(50,30)
      COMMON /86/  RHOVE(100)   , RSQP(100)    , XIPA(100)    , XORN(100)     ,
     1             YFA(100)
      COMMON /89/  IRB          , XRB(50)
      COMMON /90/  IG
      COMMON /AA/  CCP(50,30)   , ENTHA(50,30),TEMP(50)     , IX
      COMMON /BB/  HNAME(30)
```

6. FORTRAN Symbols

This list gives the FORTRAN symbols that appear in the COMMON's and in which COMMON they occur. Also a brief description is given and the symbol used in the analysis is shown.

FORTRAN SYMBOL	COMMON		SYMBOL
A(50)	58	Coefficient for "W" calculation. See Eq. (25)	A_n
AENE	55	Convergence criterion for energy eq.	
ALPH1 (50)	57	α's for partial differential equation being solved. See eq. (20)	α_1
ALPH2 (50)	57		α_2
ALPH3 (50)	57		α_3
ALPH4 (50)	57		α_4
AMD (435)	53	Coefficient for binary diffusion curve fit (eq. 86)	A_{ik}
AMOM	55	Convergence criterion for momentum eq.	
AMU (30)	64	Coefficient for species viscosity curve fit (eq. 83)	A_{μ_i}
ANCLC	20	cone half angle or hyperboloid asymptotic half angle	θ_c or θ_A
ASPE	55	convergence criterion for species eq.	
B (50)	58	Coefficient for "W" calculation. See Eq. (25)	B_n
BB (50,30)	71	diffusion term (eq. 17)	$b_{n,i}$
BBPR (50,30)	71	diffusion term (eq. 17)	$b'_{n,i}$
BETA	28	pressure gradient parameter	β
BLBAPR (50,30)	71	diffusion term (eq. 17)	$\bar{b}'_{n,i}$
BLBAR (50,30)	23	diffusion term (eq. 17)	$\bar{b}_{n,i}$
BLIL (50)	56	used in energy equation (eq. 17)	b_n
BMD (435)	53	Coefficient for binary diffusion curve fit (eq. 86)	B_{ik}
BMU (30)	64	Coefficient for species viscosity curve fit (eq. 83)	B_{μ_i}
C(50)	58	Coefficient for "W" calculation. See eq. (25)	C_n
C0(30)	48	forward rate coefficients (eq. 88a)	$C0_r$
C1(30)	48		$C1_r$
C2(30)	48		$C2_r$
CA(110,30)	30	species mass fraction at edge of boundary layer	c_{i_e}
CALPH (30,40)	49	forward stoichiometric coefficients	$\alpha_{i,r}$

CBAR (50)	56	terms in energy equation (eq. 17)	$\bar{c}_n$
CBARPR (50)	56	terms in energy equation (eq. 17)	$\bar{c}'_n$
CBETA (30,40)	49	backward stoichiometric coefficients	$\beta_{i,r}$
CCC1 (50,30)	56	enthalpy parameter (eq. 81a)	$C1_{n,i}$
CCP (50,30)*	AA	table of specific heats	$c_{p_{n,i}}$
CEDG (30)	29	mass fraction of species at edge	c_{i_e}
CFINF	21	local skin friction (eq. 95a)	c_{f_∞}
CHECK	57	used to test convergence of initial profile	
CINF (30)	48	mass fraction of species in the free-stream	c_{i_∞}
CK	65	factor for computing $\Delta\eta$	k
CL (50,30)	6	mass fraction of species, previous step	c_{i_m}
CLIL (50,30)	5	mass fraction of species to be calculated	$c_{i_{m+1}}$
CMD (435)	53	Coefficient for binary diffusion curve fit. (eq. 86)	C_{ik}
CMU (30)	64	Coefficient for species viscosity curve fit (eq. 83)	C_{μ_i}
CON	68	$\bar{c}_p P/K$ term for MCDIFF	
CONPHS	33	Constant for BODIM	
CONTH (30,30)	69	Molecular weight term computed for THERMO	
CPBAR (50)	27	Specific heat of mixture	$\bar{c}_{p_n}$
CSALPH (30)	49	Summation of forward stoichiometric coefficients. (eq. 5)	α_r
CSBETA (30)	49	Summation of backward stoichiometric coefficients. (eq. 5)	β_r
CSAVE (30)	22	Value of $(c_i)_m$ at point where convergence is checked.	
CTH	28	Parameter which determines finite-difference scheme being used.	Θ
D(50)	58	Coefficient for "W" calculation See eq. (25)	D_n
DO (30)	48	backward rate coefficients (eq. 88b)	DO_r
D1 (30)	48	backward rate coefficients (eq. 88b)	$D1_r$
D2 (30)	48	backward rate coefficients (eq. 88b)	$D2_r$
DBB (30,30)	26	diffusion term (eq. 2)	$\Delta\bar{\bar{b}}_{ik}$
DEB	78	D term calculated in HUGNOT for CALEBB (eq. 21)	D
DELTA	65	Shock standoff distance	Δ

DELXI	18	Step-size in transformed coordinate	$\Delta\xi$
DELXN	17	Δx being currently used	Δx
DELXT (20)	34	Array of Δx's to be used. Δx_k used from x_k to x_{k+1}	
DEN1(50)	43	}	
DEN2(50)	11	} Combinations of $\Delta\eta$ used several places.	
DEN3(50)	43	}	
DIFA (30,30)	47	Backward stoichiometric coefficients minus the forward stoichiometric coefficients. (eq. 7)	
DISPTK	21	displacement thickness (eq. 99a)	δ^*
DLIL (50)	56	used in energy equation (eq. 17)	d_n
DMDN (50)	42	$\Delta\eta_n - \Delta\eta_{n-1}$	
DN (50)	24	step size across the boundary layer	$\Delta\eta_n$
DNH (50)	42	$\Delta\eta_n/2$	
DNO6 (50)	44	$\Delta\eta_n/6$	
DNTR1 (50)	44	}	
DNTR2 (50)	43	} Combinations of $\Delta\eta$'s used in several places	
DNTR3 (50)	44	}	
DPDN (50)	44	}	
DRAG2	21	Total drag coefficient }	C_D
DRAGP	16	$\int_0^x$ for drag (pressure) }	
DRAGP2	21	Pressure part of drag } (eq. 97)	
DRAGT	16	$\int_0^x$ for drag (shearing stress) }	
DRAGT2	21	Shearing stress part of drag }	
DRPL	16	} Last contribution to drag integrals.	
DRTL	16	}	
DUEDX	20	velocity gradient at edge of boundary layer	$\frac{du_e}{dx}$
DUM (50)	76	Array for temporary storage	
DXEST (20)	84	estimated Δx	
EBAR	35	temperature gradient parameter (eq. 17)	$\bar{e}$
BEBB(50)	38	pressure and velocity gradient parameter (eq. 17)	$\bar{\bar{e}}$
EDBLT1	46	$(1-\epsilon)/[1-\epsilon(1-\frac{1}{s})]^2$ (from eq. 21)	
EDGLT2	46	$\{1 + j)\ Re_s\ \epsilon[s(1-\epsilon) + \epsilon]\}^{\frac{1}{2}}$ (from eq. 21)	

EDENS (50)	21	electron density across boundary layer (eq. 104)	Ne
EIO	66	See equations (54) and (56)	ε_o
EIO2	66		ε_{o_2}
ENTHA (50,30)	AA	Table of enthalpy of species (eq. 81)	c_{1_i}
ENTAPY (50,30)	27	enthalpy (eq. 81a)	h_i
EP2	46	term for CALEBB and HUGNOT	
EPSI	69	density ratio across shock	ε
ETA (50)	41	transformed normal coordinate	η_n
ETE	11		$\eta_{e_{m+1}}$
ETEH	81		$\eta_{e_{m+\frac{1}{2}}}$
ETESQ	36		$(\eta_{e_{m+1}})^2$
FFMU	27	mixture viscosity (eq. 82a)	μ
FJ	20	super script j (floating point)	j
FL (50)	4	density viscosity product	ℓ_n
FLAPL	15		λ_{m+1}
FLEJ (30)	26	Multicomponent Lewis-Semenov numbers (eq. 84)	L_{ij}
FLPR (50)	72		ℓ'_n
FMBAR (50)	8	molecular weight of mixture	$\overline{M}_n$
FMBARE	8	molecular weight of mixture at edge	$\overline{M}_e$
FMBARI	77	molecular weight of mixture in free-stream.	$\overline{M}_\infty$
FMDOT (30)	21	mass flow rate of species (eq. 101b)	$\dot{M}_i$
FMOTH	21	momentum thickness (eq. 100b)	θ_m
FMOLWR (30)	69	M_i/R term for THERMO	
FMOLWT (30)	8	molecular weight of species	M_i
FMUB	23	viscosity at body	μ_b
FP (50)	6	velocity at previous step	$f'_{m,n}$
FPRIME (50)	5	velocity across the boundary layer	$f'_{m+1,n}$
FPSAVE	22	f' at check point, used for initial profile convergence.	
FTER (30)	75	L_{ij} term for HUGNOT	
GAMMA (40)	51	mass concentration	γ_i

GAMMIN (30,40)	47	Eq. 7	Γ_{ri}^{-}
GAMPLS (30,40)	47	Eq. 7	Γ_{ri}^{+}
HE (50)	21	total enthalpy at each point across the boundary layer (eq. 107)	H
HF (30)	13	heats of formation	Δh_i^f
HINF	13	enthalpy at infinity	h_∞
HNAME (30)	BB	hollerith names of species in enthalpy and specific heat tables given in order that species are stored in the tables.	
HO	22	total enthalpy in freestream	H_∞
HXTFEB	21	heat transfer, body (eq. 91b)	$Nu_b/\sqrt{Re_{x_b}}$
HXTFER	21	heat transfer (eq. 91a)	$Nu_e/\sqrt{Re_{x_e}}$
IBRDYO	40	Switch { 1, boundary layer; 2, shock layer	
IBS	4	Switch { 1, initial profile being calculated; 2, body profile being calculated	
IC1	67	Subscript for species C1	
ICHGSW	14	Switch for POLATE	
ICO	67	Subscript for species CO	
ICO2	67	Subscript for species CO2	
ICOMPO	7	Switch { 1, iterate initial profile until converged, then do body profiles. 2, calculate initial profile once, then do body profiles.	
IDX	17	counter for number of times that ΔX has changed.	
IDYS	14	signal for POLATE.	
IEL	67	Subscript for electron	
IFROZE	3	Switch { 1, non frozen flow; 2, frozen flow	
IG	90	Switch { 1, cone; 2, sharp arbitrary axisymmetric body; 3, sphere-cone; 4, blunt arbitrary axisymmetric body; 5, hyperboloid; 6, flat plate; 7, sharp arbitrary 2-D body; 8, blunt wedge; 9, blunt arbitrary 2-D body; 10, hyperbola	

IGEOM	9	Switch { -1, sharp bodies; 0, blunt bodies
ILE	3	Switch { 1, compute Lewis numbers; 2, use constant Lewis numbers
IM1	67	Subscript for M1
IM2	67	Subscript for M2
IM3	67	Subscript for M3
IM4	67	Subscript for M4
IN	67	Subscript for species N
IN2	60	Subscript for species N_2
INO	67	Subscript for species NO
INOP	26	Subscript for species NO^+
IO	49	Subscript for species O
IO2	60	Subscript for species O_2
IPRT	50	Counter for print control, initial profile
IPRTB	37	Counter for print control, body profiles.
IPUN	19	Switch { 0, don't punch initial profiles; 1, punch initial profiles.
IRB	89	Switch { 0, specified body option; 1, arbitrary body option
IREAD	65	Switch { 0, Compute values for initial profile.; 1, Use input values for first estimate of initial profiles.
ISPC	57	Switch for WKHS { 1, not solving species equation; 2, solving species equation.
IWC	66	Wall option switch (see input write-up).
IX	AA	length of enthalpy and specific heat vs. temperature tables. = 50.
IXSW	84	Switch used in Δx calculation.
JBOD	9	Switch { 0, two dimensional body; 1, axisymmetric body
JE(30)	80	Array of subscripts for locating desired species in temperature, enthalpy and specific heat tables.
KENE	55	Number of times to iterate energy equation if KOPT = 1 and IBS = 1.
KMOM	55	Number of times to iterate momentum equation if KOPT = 1 and IBS = 1.
KOPE	19	Maximum number of iterations on initial profile.

KOPT	59	Switch { 1, iterate an integer number of times, i.e. KMOM. / 2, iterate until converged, i.e. AMOM.	
KSPE	55	Number of times to iterate species equations if KOPT = 1 and IBS = 1.	
M	2	Counter for number of steps along the body.	
MFLAG	57	Counter for number of iterations done in any one subroutine.	
MFLAGO	3	Counter for iterations done on initial profile.	
N	68	Point being calculated (for MCDIFF)	n
NDX	34	Number of x and Δx values to read. ≤ 20	
NED	30	Number of values in edge tables. ≤ 110.	
NEQUIL	3	Switch { 1, equilibrium / 2, non-equilibrium	
NI	1	Number of chemical species. ≤ 30.	
NIM	82	NI-1 for MCDIFF	
NJ	1	Number of reactants plus electrons plus catalysts. ≤ 40.	
NKM	39	NI+2, number of weight factors.	
NM1	1	NMAX-1	
NM2	1	NMAX-2	
NMAX	1	Number of points across the boundary layer	N
NR	1	number of reactions. ≤ 30.	
NTO	1	logical number of output file.	
NTP	31	Number of entries in XRN, TWT, RVPT and TETE (input) tables. ≤ 50.	
OMW(32)	39	One minus weight factor for each equation.	$1 - \omega_i$
OMWF	57	One minus weight factor for equation being solved.	$1 - \omega_i$
OPTN(6)	65	Array of options.	
P(30)	70	Coefficient for wall conditions (eq. 43)	P
PA(110)	30	Table of pressure at edge	p_e
PARDOT (30)	21	mass flow rate of species (particles/sec) (eq. 102)	$\dot{M}_i$
PE	13	Pressure at edge	$p_{e_{m+\frac{1}{2}}}$
PE1	74	Pressure at edge	$p_{e_{m+1}}$
PINF	13	Pressure in freestream	p_∞
PII	20	Constant	2π
PR(50)	23	Prandtl number	Pr
PRFL	23		(Pr/ℓ).

Q(30)	70	Coefficient for wall conditions (eq.43)	Q
QCOND	21	energy flux at the surface (conduction)	q_c
QCONV	21	energy flux at the surface (convection)	q_v
QDIFF	21	energy flux at the surface (diffusion)	q_D
QTFTLB	21	total energy flux at surface(eq. 106) (BTU/ft^2/sec)	q
QTOTAL	21	total energy flux at surface (eq. 106) (ft-lb/ft^2-sec)	q
R	8	gas constant, 49686.	R
RB1	15	radius of body	$r_{b_{m+1}}$
RB12	17	radius of body	$r_{b_{m+\frac{1}{2}}}$
RDN	45	constant for SPBND	
RES	27	shock Reynolds number	Re_s
REVE	21	mass flux density at edge	$\rho_e v_e$
RHO(50)	8	density across the boundary layer (lb.sec^2/ft^4)	ρ_n
RHOBAR	51	density in (gm/cm^3)	$\bar{\rho}$
RHOE	12	density at edge	ρ_e
RHOINF	12	density in freestream	ρ_∞
RHOVE(100)	86	mass flux density at edge	$\rho_e v_e$
RHVINF	22	$\rho_\infty v_\infty^2/2$ term for BLC	
RMFLUX(30)	21	mass flux density at surface (eq. 105)	$\dot{m}_i$
RMUREF	12		$(\rho\mu)_r$
RN	10	nose radius	R_N
RNPHIS	33	constant for BODIM	$R_N\varphi$
RRDN	45	constant for SPBND	
RS	65	shock radius	R_{sh}
RSQMWT(30)	79		$1.0/\sqrt{M_i}$
RSQP(100)	86	radial distance to shock where streamline crosses and is being swallowed	r_{sh}^{1+j}
RSUM	21		
RVB	25	mass flux density at body	$(\rho v)_b$
RVBINT	16	$\int_0^x (\rho v)_b \, dx$	
RVBRL	16	previous value of integral for RVBINT	
RVPT(50)	31	table of $(\rho v)_{PYROLYSIS}$ vs. x/R_N	
SINCO	20	sin of cone angle	$\sin \theta_c$

SINTH	20	sin of body angle	$\sin\theta_b$
SKFER	21	skin friction (eq. 96)	$c_{f_e}\sqrt{Re_{x_e}}$
SMALLE	13	coordinate parameter (eq. 17)	e
SPB	68	edge pressure in atmospheres	
SPFI(50)	36	term of P calculated for WKHS(eq. 26)	
SPN(40)	63	species names (hollerith)	
SPRT	31	distance along body in terms of R_N	$(x/R_N)_m$
SQRT1	22	constant for BLC	
SQRT2	22	constant for BLC	
SS	77	shock shape parameter (eq. 21)	s
ST	21	Stanton number	St
TA(110)	30	table of temperature at edge.	T_e
TANCO	10		$\tan^2\theta_c$
TDNOM(50)	42	combination of $\Delta\eta$'s for WKHS	
TDNOP(50)	42	combination of $\Delta\eta$'s for WKHS	
TE	13	temperature at edge ^oR	$T_{e_{m+\frac{1}{2}}}$
TE1	17	temperature at edge	$T_{e_{m+1}}$
TEMP(50)	AA	table of temperature for enthalpy and specific heat tables.	
TETE(50)	31	table of η_e vs x/RN	
TH(50)	6	temperature at previous step	$\theta_{m,n}$
THETA(50)	5	temperature being solved for	$\theta_{m+1,n}$
THSAVE	22	temperature at check point, previous iteration.	
TINF	13	temperature in freestream ^oR	T_∞
TITLE(9)	61	Problem title (to be printed)	
TK	68	temperature ^oK	TK
TK1	22	constant for BLC	
TKE	13	temperature at edge ^oK	T_e
TKINF	20	temperature in freestream ^oK	T_∞
TKW	20	temperature at the wall ^oK	T_W
TLEFT	21	time(sec.) left for computer run.	
TMTHA(30,30)	69	molecular weight term for THERMO (eq. 82)	
TOL	19	convergence criterion for initial profiles.	
TOT(3,6)	62	option descriptions to be printed	

TRM	84	used to save VONE from previous step.	
TS4	69	constant for HUGNOT and THERMO	
TW	32	temperature at the wall ^oR	
TWT(50)	31	table of wall temperatures vs x/RN.	T_W
TXIE	36	ξ term for CALCV and WKHS	
TXI1T	15	ξ_{m+1} term for SPBND	
UE	13	tangential velocity at edge of boundary layer	u_e
UE2TE	27	u_e^2/T_e term for ENERGY	
V(50)	40	transformed normal velocity	V
VA(110)	30	table of velocity at edge	u_e
VE1	17		$u_{e_{m+1}}$
VINF	13	freestream velocity (ft/sec)	V_∞
VONE	11	term of V at wall for CALCV	V_b
VS	73	transformed velocity behind shock	V_{sh}
WBAR(50,30)		production term parameter (eq. 19d)	$\overline{W}_i$
WFA(32)	39	weight factors for f', θ and c_i	W_i
WFAC	57	weight factor to be used in WKHS for current equation.	
WONE(50,30)		production term parameter (eq. 19d)	W^1
WTH(50,30)		derivative of production term (eq. 20)	$\frac{\partial}{\partial\theta}\left(\frac{W_i}{\rho}\right)$
WZERO(50,30)		production term parameter (eq. 19d)	W^0
X(50,30)	85	see equation (108)	X_r
X1	17	distance along the body	x_{m+1}
XA(110)	30	table of x/R_N for edge tables	
XDELT(20)	34	table of x values at which Δx is changed	
XI1	15	transformed coordinate	ξ_{m+1}
XI12	18	transformed coordinate	$\xi_{m+\frac{1}{2}}$
XIPA(100)	86	transformed coordinate	ξ_m

XITRM	83	terms for CALCV computed in BODIM	
XITRP	83		
XMAX	34	distance along the body at which the problem is to be terminated	
XORN	86	distance along surface	x/R_N
XRB(50)	89	table of r_b/RN for body shape	r_b/R_N
XRN(50)	31	table of x/RN for TWT, TETE, RVPT tables	
YF(50)	21	distance normal to surface divided by R_N (eq. 98)	y/R_N
YFA(100)	86	edge value of above	y_e/R_N
Z(30,10)	53	third body efficiencies relative to argon. (eq. 6)	

7. Description of Routines

<u>BLAB</u>

BLAB is the main program and controls the flow, calling subroutines as needed. If calculation of body profiles only is requested, the initial profile (x = 0.) is calculated once before the steps along the body are calculated. If a shock layer is being computed no steps along the body are attempted. When the solution is terminated, a new problem is read.

Program Variables:

IALL - Signal from BODIM. When IALL = 2, all of the requested body profiles have been done.

ICSW - Signal from BLC. When ICSW = 2, iteration of the initial profile is stopped.

```
      PROGRAM BLAB (INPUT,OUTPUT, PUNCH,TAPE60=INPUT,TAPE61=OUTPUT,
     1                                  TAPE62=PUNCH)

      COMMON  /1/  NI         , NMAX       , NM2        , NTO        ,
     1             NJ         , NM1        , NR
      COMMON  /2/  M
      COMMON  /3/  IFROZE     , ILF        , MFLAGO      , NEQUIL
      COMMON  /4/  FL(50)     , IBS
      COMMON  /7/  ICOMPO
      COMMON /40/  IBRDYO     , V(50)

 10   CONTINUE
      IBS    = 1
      CALL INPUT
      CALL PRECAL
      CALL CHEMPR
      CALL THERMO (-1)
      CALL QPR
      CALL CALCV
      MFLAGO = 0
 200  CONTINUE
      MFLAGO = MFLAGO + 1
      CALL THERMO (0)
      CALL MOMEQ
      CALL SPECEQ
      CALL ENEREQ
      CALL CHEMPR
      CALL QPR
```

```
      CALL BLC ( ICSW )
      GO TO (300,400) , ICOMPO
300   CONTINUE
      IF ( ICSW .NE. 2 ) GO TO 200
400   CONTINUE
      IF (IBRDYO .NE. 2) GO TO 404
      WRITE (NTO,401)
401   FORMAT(*0*50X*END OF THIS PROBLEM*)
      GO TO 10
404   CONTINUE
      CALL THERMO (1)
      CALL BSETUP
      MFLAGO = 1
      IBS    = 2
      M      = 0
      IALL = 1
410   CONTINUE
      M      = M + 1
      CALL BODIM (IALL)
      IF (IALL .EQ. 2) GO TO 10
      CALL QPR
      CALL MOMEQ
      CALL SPECEQ
      CALL ENEREQ
      CALL CHEMPR
      CALL THERMO (-1)
      CALL THERMO (1)
      CALL BLC ( 2 )
```

BLC

Subroutine BLC computes the boundary layer characteristics and controls much of the output printing. The test for convergence of the initial profiles is done here and if the profiles are to be punched, PCH is called. BLC has one argument which is computed in BLC and is used in the main program (BLAB).

ICSW
- 1, initial profiles not converged
- 2, initial profiles converged, time about gone, or maximum profiles have been calculated.

The boundary layer characteristics listed below are printed. The equations are in Chapter VI and referenced here by numbers in parentheses.

EDENS,	electron density across the boundary layer. (104)
HXTFER,	heat transfer at the edge of the boundary layer or shock layer. (90a)
HXTFEB,	heat transfer at the body. (90b)
ST,	Stanton number (94)
SKFER,	skin friction. (96a)
DISPTK,	displacement thickness. (99a)
FMOTH,	momentum thickness. (99b) (ft.)
RMFLUX,	mass flux density of each species at the surface. (105)
QTOTAL,	total energy flux at the surface.
QCOND,	energy flux at the surface due to conduction. (106a)
QDIFF,	energy flux at the surface due to diffusion. (106b)
QCONV,	energy flux at the surface due to convection. (106c)
YF,	y/δ_N (98)

For profiles along the body, the following quantities are also computed:

CFINF c_{f_∞} (96b)

DRAGT2 drag from shearing stress.

DRAGP2 drag due to pressure.

DRAG2 total drag.

(DRAGT2, DRAGP2, DRAG2: (97))

RSUM shock radius for streamline being swallowed (62)

FMDOT, mass flow rate of species "i". (101b)

Program variables are:

ABX term for drag $= \frac{(2\pi)^j}{A}$, $A = \begin{cases} r, & j = 0 \\ \pi^2, & j = 1 \\ 1/XI, & \text{flat plate} \end{cases}$

BIKBB $\begin{Bmatrix} L_{e_j}, & j_1 = j_2 \\ \bar{\bar{b}}_{ik}, & j_1 \neq j_2 \end{Bmatrix}$, used in heat transfer calculation.

CAMDOT $\cos \theta_b/(r)_{m+\frac{1}{2}}$

CBDER $\frac{\partial c_{1,j}}{\partial \eta}$

CFMDOT $\begin{cases} 1.0 & j = 0 \\ 1.0 + YF(i)\cdot CAMDOT\cdot T\cdot RN, & j = 1 \end{cases}$

CONFM $\begin{Bmatrix} \sqrt{2\xi_{m+\frac{1}{2}}}, & j = 0 \\ 2\pi\sqrt{2\xi_{m+\frac{1}{2}}}, & j = 1 \end{Bmatrix}$

CONIN2 $\sqrt{2\xi_{m+\frac{1}{2}}}$

COSTH $\cos \theta_b$

DELX Δx, previous step

DELXNH $\frac{\Delta x}{2}$, current step

DRPN contribution to drag (pressure) integral at this step.

DRTN contribution to drag (shearing stress) integral at this step.

DRSDX $\frac{dr_{sh}}{dx}$

DUM temporary storage for values to be integrated

DUMMY temporary storage for values to be integrated.

DXT1 $\frac{\Delta x_{m-1}}{\Delta x_m(\Delta x_{m-1} + \Delta x_m)}$

DXT2 $\frac{\Delta x_m - \Delta x_{m-1}}{\Delta x_m \Delta x_{m-1}}$

DXT3 $\frac{\Delta x_m}{\Delta x_{m-1}(\Delta x_{m-1} + \Delta x_m)}$

DYEDX	$\frac{dy_e}{dx}$
HS	temporary storage, for sum in total enthalpy.
ICHKPT	number of point (across the boundary layer) where convergence is tested. Set to 10 in data statement.
IPSW	$\left\{\begin{array}{l}\text{1, profiles converged, print.}\\ \text{2, time about gone, print.}\\ \text{3, maximum iterations have been done, print.}\\ \text{4, check whether it is time to print.}\end{array}\right\}$
MP	M at previous step
QT	$\bar{c}_p, \cdot TE \cdot \frac{\partial\theta}{\partial\eta}$ (from eq. 91a)
RB	$r^j{}_b$, previous step
RB1J	$\left\{\begin{array}{ll}1 & , j = 0\\ (r_b)_{m+1} & , j = 1\end{array}\right\}$
RHVE	$\rho_e(u_e)_{m+1}$
RM	term in RMFLUX
RSUMO	$\left(r_{sh}^{(1+j)}\right)_{m-1}$
RSUMP	$\left(r_{sh}^{(1+j)}\right)_m$
RVBRN	contribution to r_{sh}^{1+j} integral at this step
S	$\int_0^{\eta_e} f'(1 + y/r_b \cos \theta_b)^j \, d\eta$
S1	$\sum_{j=1}^{NI} h_j \sum_{k=1}^{NI} \bar{\bar{b}}_{jh} \frac{\partial c_k}{\partial\eta}$
S2	$\sum_{k=1}^{NI} \bar{\bar{b}}_{jh} \frac{\partial c_k}{\partial\eta}$
SPRP	x/R_N, previous step
SQRT3	$\left\{\begin{array}{ll}0.0 & \text{, sharp body}\\ \left[(\rho\mu)_r \cdot \frac{du_e}{dx}\right]^{\frac{1}{2}} & \text{, blunt body}\\ \rho_e(u_e)_{m+1}/\sqrt{Re_s} & \text{, body profiles}\end{array}\right.$
SQRT4	$\left\{\begin{array}{ll}0.0 & \text{, sharp body}\\ \left[\frac{(\rho\mu)_r}{\frac{du_e}{dx}}\right]^{\frac{1}{2}} /(\rho_e \cdot SQRT2) & \text{blunt body}\end{array}\right.$
SQRTRE	$[Re_s]^{\frac{1}{2}}$, square root of Reynolds number.

TEM $\begin{cases} T_e & \text{, initial profile} \\ (T_e)_{m+1} & \text{, body profiles} \end{cases}$

TERM part of YF(N) which is constant for one profile.

TJ part of RMFLUX(I) which is constant for one profile.

TWJ $(2)^j$

XI1P ξ at previous step

YFACT $\begin{cases} 0 & \text{sharp body} \\ \dfrac{\sqrt{2\xi}}{u_e\, r_b^j} & \text{blunt body} \end{cases}$ initial profile; $\sqrt{\dfrac{(\rho\mu)_{\bar{}}}{(1+j)\dfrac{du_e}{dx}}}$ body profiles

YFI $(y/R_N)_e$, this step (m+1)

YFO $(y/R_N)_e$, m-1

YFP $(y/R_N)_e$, m

```
      SUBROUTINE BLC (ICSW)                                             BLC
                                                                        BLC
      COMMON  /1/  NI          , NMAX        , NM2         , NTO       ,BLC
     1             NJ          , NM1         , NR                       BLC
      COMMON  /2/  M                                                    BLC
      COMMON  /3/  IFROZE      , ILE         , MFLAGO       , NEQUIL    BLC
      COMMON  /4/  FL(50)      , IBS                                    BLC
      COMMON  /5/  CLIL(50,30) , FPRIME(50)  , THETA(50)                BLC
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)   , FMBARE      , RHO(50)  , RBLC
      COMMON  /9/  IGEOM       , JBOD                                   BLC
      COMMON /10/  RN          , TANCO                                  BLC
      COMMON /11/  DEN2(50)    , ETE         , VONE                     BLC
      COMMON /12/  RHOE        , RHOINF      , RMUREF                   BLC
      COMMON /13/  HINF        , PE          , SMALLE      , TKE    , UE ,BLC
     1             HF(30)      , PINF        , TE          , TINF   , VINFBLC
      COMMON /14/  ICHGSW      , IDYS                                   BLC
      COMMON /15/  FLAPL       , RB1         , TXI1T       , XI1        BLC
      COMMON /16/  DRAGP       , DRPL        , RVBINT      ,            BLC
     1             DRAGT       , DRTL        , RVBRL                    BLC
      COMMON /17/  IDX         , RB12        , VE1         ,            BLC
     1             DELXN       , TF1         , X1                       BLC
      COMMON /18/  DELXI       , XI12                                   BLC
      COMMON /19/  IPUN        , KOPE        , TOL                      BLC
      COMMON /20/  ANGLC       , FJ          , SINCO       , TKINF     ,BLC
     1             DUEDX       , PII         , SINTH       , TKW        BLC
      COMMON /21/  CFINF       , FMDOT(30)   , QCOND       , RSUM      ,BLC
     1             DISPTK      , FMOTH       , QCONV       , SKFER     ,BLC
     2             DRAG2       , HE(50)      , QDIFF       , ST        ,BLC
     3             DRAGP2      , HXTFEB      , QTFTLB      , TLEFT     ,BLC
     4             DRAGT2      , HXTFER      , QTOTAL      , YF(50)    ,BLC
     5             EDENS(50)   , PARDOT(30)  , RMFLUX(30)  , REVE       BLC
      COMMON /22/  CSAVE(30)   , FPSAVE      , RHVINF       , SQRT2    ,BLC
     1                           HO          , SQRT1       , THSAVE , TK1 BLC
      COMMON /23/  BLBAR(50,30),FMUB         , PR(50)      , PRFL       BLC
      COMMON /24/  DN(50)                                               BLC
      COMMON /25/  RVB                                                  BLC
```

```
      COMMON /26/  DBB(30,30) , FLEJ(30)    , INOP
      COMMON /27/  CPBAR(50)  , FFMU        , RES        , UE2TE      ,
     1             ENTAPY(50,30)
      COMMON /31/  NTP        , SPRT        , TWT(50)    , XRN(50)    ,
     1             RVPT(50)   , TETE(50)
      COMMON /43/  DEN1(50)   , DEN3(50)    , DNTR2(50)
      COMMON /44/  DN06(50)   , DNTR1(50)   , DNTR3(50)  , DPDN(50)
      COMMON /76/  DUM(50)
      COMMON /86/  RHOVE(100) , RSQP(100)   , XIPA(100)  , XORN(100)  ,
     1             YFA(100)

      DATA         (IP = 62)  , (ICHKPT = 10)
      DIMENSION    CBDER(30)  , DUMMY(50)
      DO 20 N=1,NMAX
      HS = 0.0
      DO 10 I=1,NI
      HS = HS + CLIL(N,I) * ENTAPY(N,I)
   10 CONTINUE
      HE(N)     = HS + .5 * (FPRIME(N) * VE1)**2
   20 CONTINUE
      ICHGSW = -1
      A3 = -(DN(2)+2.*DN(1)) / DEN3(2)
      B3 =  DPDN(2) / DEN2(2)
      C3 = - DNTR1(2)
      DO 30 I=1,NI
      CBDER(I) = (A3*CLIL(1,I) + B3*CLIL(2,I) + C3*CLIL(3,I)) / ETE
   30 CONTINUE
      HXTFER   = (A3*THETA(1)  + B3*THETA(2)  + C3*THETA(3)) / ETE
      SKFER    = (A3*FPRIME(1) + B3*FPRIME(2) + C3*FPRIME(3)) / ETE
      GO TO (40,60) , IBS
   40 CONTINUE
      TEM    = TE
      IF (IGEOM .GE. 0) GO TO 50
      YFACT = 0.0
      SQRT3 = 0.0
      SQRT4 = 0.0
      TJ = 0.0
      GO TO 82
   50 CONTINUE
      YFACT = SQRT(RMUREF/((1.+FJ) * DUEDX))
      SQRT3 = SQRT(RMUREF * DUEDX)
      SQRT4 = SQRT(RMUREF / DUEDX) / (RHOE * SQRT2)
      GO TO 80
   60 CONTINUE
      TEM      = TE1
      SQRT1    = SQRT(2.*FLAPL*X1/ XI1)
      SQRT2    = .5 * SQRT1
      RHVE     = RHOE * VE1
      RES      = RHVE * X1 / FFMU
      SQRTRE = SQRT(RES)
      SQRT3    = RHVE / SQRTRE
      YFACT     = SQRT(2. * XI1) / VE1
      IF (JBOD .LE. 0) GO TO 70
      YFACT    = YFACT / RB1
   70 CONTINUE
      SQRT4    = YFACT / RHOE
   80 CONTINUE
      TJ       = -(FL(1) * RMUREF) / (PR(1) * YFACT)
   82 CONTINUE
      TK2 = SQRT2 / (HO - HE(1))
      QT     = CPBAR(1) * TEM * HXTFER
      QDIFF = 0.0
      S1     = 0.0
      DO 120 J1=1,NI
      S2     = 0.0
      DO 110 J2=1,NI
      IF (J1 .NE. J2) GO TO 90
      BIKBB = FLFJ(J1)
      GO TO 100
   90 CONTINUE
```

```
      BIKBB = DBB(J1,J2)
  100 CONTINUE
      S2 = S2 + BIKBB * CBDER(J2)
  110 CONTINUE
      RM         = TJ * S2
      QDIFF      = QDIFF + RM * ENTAPY(1,J1)
      S1         = S1 + S2 * ENTAPY(1,J1)
      RMFLUX(J1) = RM + RVB * CLIL(1,J1)
  120 CONTINUE
      IF (IBS .NE. 1) GO TO 130
      IF (IGEOM .LT. 0) GO TO 140
  130 CONTINUE
      QCOND = TJ * QT
      GO TO 150
  140 CONTINUE
      QCOND = 1.0E200
  150 CONTINUE
      QCONV  = RVB * (HE(1) + .5 * (RVB/RHO(1))**2)
      QTOTAL = QCONV + QCOND + QDIFF
      QTFTLB = 1.28509E-3 * QTOTAL
      HXTFER = FL(1) * TK2  * (QT + S1)
      HXTFER = HXTFER * SQRT(RMUPEF/(RHO(1)*FMUB))
      HXTFER = HXTFER * PR(NMAX) / PR(1)
      ST     = HXTFER * SQRT3 / (PR(NMAX) * TK1)
      SKFER  = SKFER * FL(1) * SQRT1
      DO 160 N=1,NMAX
      DUMMY(N) = (FMBARE * THETA(N) / FMBAR(N)) - FPRIME(N)
  160 CONTINUE
      CALL SIMINT (DUMMY, S1, AAA, 1)
      DISPTK = SQRT4 * S1 / RN
      DO 170 N=1,NMAX
      DUMMY(N) = FPRIME(N) * (1.0 - FPRIME(N))
  170 CONTINUE
      CALL SIMINT (DUMMY, S1, AAA, 1)
      FMOTH = SQRT4 * S1
      TERM  = YFACT / RN
      YF(1) = 0.0
      DO 172 N=1,NMAX
      DUMMY(N) = TERM / RHO(N)
  172 CONTINUE
      CALL SIMINT (DUMMY, AAA, YF, 2)
      CALL HOROLOG (TLEFT,DU1, DU2)
      GO TO (180,240) , IBS
  180 CONTINUE
      FPCK = FPRIME(ICHKPT)
      THCK = THETA(ICHKPT)
      IF (ABS(FPCK - FPSAVE) .GT. TOL*FPCK) GO TO 200
      IF (ABS(THCK - THSAVE) .GT. TOL*THCK) GO TO 200
      DO 190 I=1,NI
      CLCK = CLIL(ICHKPT,I)
      IF (ABS(CLCK - CSAVE(I)) .GT. TOL*CLCK) GO TO 200
  190 CONTINUE
      IPSW = 1
      GO TO 230
  200 CONTINUE
      ICSW  = 1
      IF (TLEFT .GE. 10.) GO TO 210
      IPSW = 2
      GO TO 230
  210 CONTINUE
      FPSAVE = FPCK
      THSAVE = THCK
      DO 220 I=1,NI
      CSAVE(I) = CLIL(ICHKPT,I)
  220 CONTINUE
      IF (MFLAGO .GE. KOPE) GO TO 224
      IPSW = 4
      GO TO 232
  224 CONTINUE
      IPSW = 3
  230 CONTINUE
```

```
      ICSW = 2
      IF (IPUN .LE. 0) GO TO 232
      CALL PCH
232   CONTINUE
      YFI = YF(NMAX)
      GO TO 320
C                                GO TO PRINT HERE IF INITIAL PROFILE.
240   CONTINUE
      IF (JBOD .GT. 0) GO TO 250
      RB1J  = 1.0
      TWJ   = 1.0
      CONFM = 1.0
      ABX   = 1.0 / RB1
      IF (SINCO .EQ. 0.) ABX = (1./X1)
      GO TO 260
250   CONTINUE
      RB1J  = RB1
      TWJ   = 2.0
      CONFM = PII
      ABX   = 2.0 / (RB1 * RB1)
260   CONTINUE
      CFINF  = (VE1/VINF)**2 * SKFER * RHOE / (SQRTRE * RHOINF)
      COSTH  = SQRT(1.0 - SINTH * SINTH)
      CAMDOT = COSTH / RB1
      DRTN   = RB1J * COSTH * CFINF
      DRPN   = RB1J * SINTH * PE / RHVINF
      DELXNH = DELXN * .5
      DRAGT  = DRAGT + (DRTL + DRTN) * DELXNH
      DRAGP  = DRAGP + (DRPL + DRPN) * DELXNH
      DRTL   = DRTN
      DRPL   = DRPN
      DRAGT2 = DRAGT * ABX
      DRAGP2 = DRAGP * ABX
      DRAG2  = DRAGT2 + DRAGP2
      RVBRN  = RVB * RB1J
      RVBINT = RVBINT + (RVBRL + RVBRN) * DELXNH
      RVBRL  = RVBRN
      CONIN2 = SQRT(2. * XI1 )
      CONFM  = CONFM * CONIN2
      DISPTK = DISPTK + RVBINT / (RN * RMUREF * RB1J)
      DO 290 N=1,NMAX
      IF (JBOD .GT. 0) GO TO 270
      CFMDOT = 1.0
      GO TO 280
270   CONTINUE
      CFMDOT = (1.0 + YF(N) * CAMDOT * RN)
280   CONTINUE
      DUMMY(N) = FPRIME(N) * CFMDOT
290   CONTINUE
      CALL SIMINT (DUMMY, S, AAA, 1)
      RSUM  = (TWJ / TK1) * (CONIN2 * S - RVBINT)
      DO 310 I=1,NI
      DO 300 N=1,NMAX
      DUM(N) = CLIL(N,I) * DUMMY(N)
300   CONTINUE
      CALL SIMINT (DUM,   S, AAA, 1)
      FMDOT(I) = CONFM * S
      PARDOT(I) = FMDOT(I) * 8.7928E27 / FMOLWT(I)
310   CONTINUE
      JP1 = JBOD + 1
      IF ( M .GT. 1 ) GO TO 3104
      RSUMP = 0.0
      SPRP = 0.0
      XI1P = 0.0
      YFP  = YFI
      DEN  = 1.0
      MP   = 0
      IF (JBOD .NE. 1 ) GO TO 3102
      DEN   = DEN + YF(NMAX)
3102  CONTINUE
      REVE = -TK1 * RSUM / (DEN * X1**JP1)
      GO TO 3106
```

```
3104  CONTINUE
      DEN = 1.0
      IF (JBOD .EQ. 1) DEN = 2.0 * (RB + RN * YFO * COST)
      SDX    = DELXN + DELX
      DXT1   = DELX / (DELXN*SDX)
      DXT2   = (DELXN-DELX) / (DELXN*DELX)
      DXT3   = DELXN / (DELX*SDX)
      DRSDX = RSUM     *DXT1 + RSUMO*DXT2 - RSUMP*DXT3
      DYEDX =(YF(NMAX)*DXT1 + YFO  *DXT2 - YFP  *DXT3) * RN
      REVE   = -TK1 / DEN * DRSDX + RHOE * VE1 * DYEDX
      YFP    = YFO
      RSUMP = RSUMO
3106  CONTINUE
      WRITE (IP,3107) MP,SPRP, RSUMP, REVE, XI1P, YFP
3107  FORMAT(I5,5E15.7)
      MP    = M
      IF (MP .GE. 100) GO TO 311
      XORN(MP)   = SPRP
      RSOP(MP)   = RSUMP
      RHOVE(MP) = REVE
      XIPA(MP)   = XI1P
      YFA(MP)    = YFP
311   CONTINUE
      RSUMO = RSUM
      COST = COSTH
      RB    = RB1
      YFO   = YF(NMAX)
      XI1P = XI1
      SPRP = SPRT
      DELX = DELXN
320   CONTINUE
      CALL PRTBL (IPSW)
      RETURN
      END
```

BODIM

Subroutine BODIM is called once for each of the profiles along the body and calculates variables associated with the distance along the body. The step size Δx is determined using the procedure described in Equations 73 through 78. The interpolated edge conditions are found and printed in BODIM. BODIM has one argument, IALL, which is set to 2 when all body profiles have been done, i.e., X ≥ XMAX.

Common variables, with equations referenced in parentheses are:

BETA	β (66b)
CEDG	c_i at wall
DELXI	$\Delta\xi$ (71b)
DELXN	Δx for this step (see eq. 73-78)
DELXT	Δx from input data (see eq. 73-78)
DUEDX	$\left(\frac{du_e}{dx}\right)_{m+\frac{1}{2}}$
EBAR	$\bar{e}$ (66c)
EBB(NMAX)	$\bar{\bar{e}}$ (66d)
ETE	η_e
ETESQ	η_e^2
FLAPL	λ_{m+1} (71c)
PE	Pressure at edge
RB12	radius of body, $m+\frac{1}{2}$
RB1	radius of body, m+1 (69a, 69b)
RHOE	$(\rho_e)_{m+1}$
SPFI	factor for P in WKHS
SPRT	x/R_N
TE	$(T_e)_{m+\frac{1}{2}}$ °R
TKE	$(T_e)_{m+\frac{1}{2}}$ °K
TKW	T_w, temperature at wall °K
TXI1T	$\left(\frac{\sqrt{2\xi}}{(\rho\mu)_r U_e r_b^j}\right)_{m+1}$ for $\bar{W}$ in SPBND
UE	u_e
UE2TE	$\frac{u_e^2}{T_e}$
VONE	$\left(\frac{\sqrt{2\xi}}{(\rho\mu)_r u_e r_b^j}\right)_{m+\frac{1}{2}}$ for V(1) in CALCV

X1	x_{m+1}	
XI1	ξ_{m+1} (71a)	
XI12	$\xi_{m+\frac{1}{2}}$	
XITRM	$\left(\frac{\xi_{m+\frac{1}{2}}}{\Delta\xi} - \frac{1}{4}\sigma\right)\eta_{e_{m+\frac{1}{2}}}$	Terms for V in CALCV See eq. (36).
XITRP	$\left(\frac{\xi_{m+\frac{1}{2}}}{\Delta\xi} + \frac{1}{4}\sigma\right)\eta_{e_{m+\frac{1}{2}}}$	

```
      SUBROUTINE BODIM (IALL)

      COMMON  /1/  NI           , NMAX        , NM2         , NTO         ,
     1             NJ           , NM1         , NR
      COMMON  /2/  M
      COMMON  /3/  IFROZE       , ILE         , MFLAGO      , NEQUIL
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /8/  FMOLWT(30)   , FMBAR(50)   , FMBARE      , RHO(50)   , R
      COMMON  /9/  IGEOM        , JBOD
      COMMON /10/  RN           , TANCO
      COMMON /11/  DEN2(50)     , FTE         , VONE
      COMMON /12/  RHOE         , RHOINF      , RMUREF
      COMMON /13/  HINF         , PE          , SMALLE      , TKE       , UE ,
     1             HF(30)       , PINF        , TE          , TINF      , VINF
      COMMON /14/  ICHGSW       , IDYS
      COMMON /15/  FLAPL        , RB1         , TXI1T       , XI1
      COMMON /17/  IDX          , RB12        , VE1         ,
     1             DELXN        , TE1         , X1
      COMMON /18/  DELXI        , XI12
      COMMON /20/  ANGLC        , FJ          , SINCO       , TKINF       ,
     1             DUEDX        , PII         , SINTH       , TKW
      COMMON /27/  CPBAR(50)    , FEMU        , RES         , UE2TE       ,
     1             ENTAPY(50,30)
      COMMON /28/  BETA         , CTH
      COMMON /29/  CEDG(30)
      COMMON /30/  CA(110,30)   , PA(110)     , VA(110)     , XA(110)     ,
     1             NED          , TA(110)
      COMMON /31/  NTP          , SPRT        , TWT(50)     , XPN(50)     ,
     1             RVPT(50)     , TETE(50)
      COMMON /32/  TW
      COMMON /33/  CONPHS       , PNPHIS
      COMMON /34/  DELXT(20)    , NDX         , XDELT(20)   , XMAX
      COMMON /35/  EBAR
      COMMON /36/  FTESQ        , SPFI(50)    , TXIE
      COMMON /37/  IPRTR
      COMMON /38/  BEBR(50)
      COMMON /39/  NKM          , OMW(32)     , WFA(32)
      COMMON /74/  PE1
      COMMON /83/  XITRM        , XITRP
      COMMON /84/  DXEST(20)    , IXSW        , TRM
      COMMON /86/  RHOVE(100)   , RSQP(100)   , XIPA(100)   , XORN(100)   ,
     1             YFA(100)
      COMMON /89/  IRB          , XRB(50)
      COMMON /90/  IG
      DIMENSION    CE1(30)

      GO TO (10,20,30) , IXSW
   10 CONTINUE
      IXSW = 2
      GO TO 40
   20 CONTINUE
      IXSW = 3
      BETX = (XDELT(IDX+1) - XDELT(IDX)) / DELXT(IDX)
      XM   = (2. * BETX + 1. + DXEST(IDX)) / (3. + DXEST(IDX))
      MX   = (XM + .5)
      FMX  = MX
```

```
      DXL  = (2. * BETX + 1. - 3. * FMX) / (FMX - 1.0)
      MS   = 1
30    CONTINUE
      FMS  = MS
      DELXN = DELXT(IDX) * (1.0 + (1.0 + DXL) * FMS / FMX)
      IF (MS .GE. MX) GO TO 34
      MS = MS + 1
      GO TO 40
34    CONTINUE
      IF (IDX .GE. NDX) GO TO 180
      IDX         = IDX + 1
      IXSW        = 2
      DELXT(IDX) = (2. + DXL) * DELXT(IDX-1)
40    CONTINUE
      XO = X1
      X1 = XO + DELXN
      IF ( X1 .GT. XMAX ) GO TO 180
      X12    = XO + DELXN / 2.0
      IDYS   = 2
      ICHGSW = -1
C                                  INTERPOLATE FOR EDGE CONDITIONS.
      IF (M .NE. 1) GO TO 44
      PEO  = PE
      DPEO = 0.0
      VEO  = UE
      TEO  = TE
      DTEO = 0.0
      DVEO = 0.0
      IF (IGEOM .GE. 0) DVEO = VA(2) / XA(2)
      DETO = 0.0
      SEO = SMALLE
      GO TO 48
44    CONTINUE
      PEO  = PE1
      DPEO = DPE1
      VEO  = VE1
      DVEO = DVE1
      TEO  = TE1
      DTEO = DTE1
      DETO = DET1
48    CONTINUE
      DO 50 I=1,NI
      CALL POLATE (X1, XA, CA(1,I), CE1(I), NED)
      CEDG(I)        = CE1(I)
      CLIL(NMAX,I) = CE1(I)
50    CONTINUE
      CALL  POLATE (X1, XA, PA,  PE1, NED)
      CALL DPOLATE (X1, XA, PA, DPE1, NED)
      CALL  POLATE (X1, XA, VA,  VE1, NED)
      CALL DPOLATE (X1, XA, VA, DVE1, NED)
      CALL  POLATE (X1, XA, TA,  TE1, NED)
      CALL DPOLATE (X1, XA, TA, DTE1, NED)
      PE  = (PEO + PE1) / 2.0
      UE  = (VEO + VE1) / 2.0
      TE  = (TEO + TE1) / 2.0
      UE2TE = UE * UE / TE
      TKE  = TE / 1.8
      SPRT = X1 / RN
      ETEO = ETE
      IF ( MOD( M ,IPRTB) .NE. 0) GO TO 58
      WRITE (NTO,53)  M, SPRT
53    FORMAT(*1*25X,I4*-TH BODY PROFILE.     S =*E12.4)
58    CONTINUE
      ICHGSW = -1
      CALL  POLATE (SPRT, XRN, TETE,  ETE, NTP)
      CALL DPOLATE (SPRT, XRN, TETE, DET1, NTP)
      IDYS = 0
      ETEH = .5 * (ETE + ETEO)
      ETESQ = ETE * ETE
      DETE = .5 * (DETO + DET1)
      CALL POLATE (SPRT, XRN, TWT, TKW, NTP)
```

```
      TW = TKW * 1.8
      ICHGSW = -1
      IF (IRB .GT. 0) GO TO 115
      GO TO (60,115,70,115,110,60,115,70,115,110) IG
60    CONTINUE
      RBO   = XO  * SINCO
      RB1   = X1  * SINCO
      RB12  = X12 * SINCO
      SINTH = SINCO
      GO TO 130
70    CONTINUE
      RBO   = RB1
      IF ( X1 .GT. RNPHIS ) GO TO 80
      RB1   = RN * SIN(X1/RN)
      GO TO 90
80    CONTINUE
      RB1   = CONPHS + X1 * SINCO
90    CONTINUE
      IF ( X12 .GT. RNPHIS ) GO TO 100
      RB12  = RN * SIN(X12/RN)
      GO TO 120
100   CONTINUE
      RB12  = CONPHS + X12 * SINCO
      GO TO 120
110   CONTINUE
      RBO  = RB1
      RB12 = RBO
      CALL KUTTAM (XO, X12, X12-XO, RB12)
      RB1  = RB12
      CALL KUTTAM (X12, X1, X1-X12, RB1)
      GO TO 120
  115 CONTINUE
      XRO  = XO/RN
      XR1  = X1/RN
      XR12 = X12/RN
      CALL POLATE (XRO  , XRN, XRB, RBO  , NTP)
      CALL POLATE (XR1  , XRN, XRB, RB1  , NTP)
      CALL POLATE (XR12, XRN, XRB, RB12, NTP)
120   CONTINUE
      SINTH = (RB1-RBO) / DELXN
130   CONTINUE
      RMURM = RMUREF
      CSUM  = 0.0
      DO 132 I=1,NI
132   CSUM  = CSUM + CE1(I) / FMOLWT(I)
      RHOEO = RHOE
      RHOE  = PE1 / (R * TE1 * CSUM)
      RHOEH = .5 * (RHOE + RHOEO)
      TKE = TE1 / 1.8
      CALL THERMO (-1)
      TKE = TE / 1.8
      FLAMM = RMURM * VEO
      FLAPL = RMUREF * VE1
      FLAHF = .5 * (RMURM + RMUREF) * UE
      IF ( JBOD .LE. 0 ) GO TO 140
      JB2   = 2 * JBOD
      FLAMM = FLAMM * RBO **JB2
      FLAPL = FLAPL * RB1 **JB2
      FLAHF = FLAHF * RB12**JB2
140   CONTINUE
      ETEPR = DETE / (RN * FLAHF)
      XIO    = XI1
      DELXI  = DELXN * (FLAMM + 4.0 * FLAHF + FLAPL) / 6.0
      XI1    = DELXI + XIO
      XI12   = XIO   + DELXI / 2.0
      SEN = 2.0 * XI1 / (VE1 * FLAPL)
      SMALLE = CTH * SEN + (1.0 - CTH) * SEO
      SEO = SEN
      EBAR   = XI12 * (DTEO + DTE1) / (TE * FLAHF)
      TXIE   = 2.0 * XI12 * ETEPR
      SIG   = 1.0 + TXIE / ETEH
```

```
      XIODI = XI12 / DELXI
      XITRP = (XIODI + .25 * SIG) * ETEH
      XITRM = (XIODI - .25 * SIG) * ETEH
      XIT = CTH * XI1 + (1. - CTH) * XIO
      SPT = DELXI / (2.0 * XIT)
      DO 141 N=2,NM1
      SPEI(N) = SPT / DEN2(N)
141   CONTINUE
      TXI1T = SQRT(2.0 * XI1) / FLAPL
      IF ( JBOD .EQ. 0) GO TO 142
      TXI1T = TXI1T * RB1
142   CONTINUE
      VONE = .5 * (TRM + TXI1T)
      TRM  = TXI1T
      BEBB(NMAX) = SMALLE * (DPEO + DPE1) * .5 / (RHOEH * UE)
      EB = BEBB(NMAX)
      DUEDX = (DVEO + DVE1) / 2.0
      BETA = SMALLE * DUEDX
      IF ( MOD( M ,IPPTR) .NE. 0) GO TO 200
      WRITE (NTO,55)
55    FORMAT(*0*46X*INTERPOLATED EDGE CONDITIONS*)
      WRITE (NTO,155) PE1,XO, FLAMM, DELXI, TE1,X12, FLAHF, XIO,
     1                VE1, X1, FLAPL, XI12, DPEO, RBO, BETA, XI1,
     2                 DPE1, RB12, EEMU, SMALLE, EB, RB1, RHOE, EBAR
155   FORMAT(*0*
     112X*PE =*E13.5,13X*XO =*E13.5,9X*LAMBDA =*E13.5,10X*DELXI =*E13.5/
     213X*TE =*E13.5,10X*X 1/2 =*E13.5,5X*LAMBDA 1/2 =*E13.5,12X*XIO =*E
     313.5/13X*UE =*E13.5,13X*X1 =*E13.5,5X*LAMBDA + 1 =*E13.5,9X*XI 1/2
     4 =*E13.5/11X*DPEO =*E13.5,12X*RBO =*E13.5,11X*BETA =*E13.5,12X*XI1
     5 =*E13.5/11X*DPE1 =*E13.5,9X*RB 1/2 =*E13.5,13X*MU =*E13.5,8X*SMAL
     6L E =*E13.5/12X*BEB =*E13.5,12X*RB1 =*E13.5,11X*RHOE =*E13.5,
     711X*EBAR =*E13.5)
      WRITE (NTO,165) ETE
165   FORMAT(12X*ETE =*E13.5)
      GO TO 200
180   CONTINUE
      IALL = 2
      WRITE (NTO,181)
181   FORMAT(*1  M*7X*X/RN*8X,9HRS**(1+J),9X*REVE*12X*XI*10X*YE(EDGE)*)
      ME = M - 1
      WRITE (NTO,183) (I,XORN(I),RSQR(I),RHOVE(I),XIPA(I),YEA(I),I=1,ME)
183   FORMAT(I5,5E15.7)
      WRITE (NTO,185)
185   FORMAT(*0*50X*END OF THIS PROBLEM*)
200   CONTINUE
      RETURN
      END
```

BSETUP

Subroutine BSETUP is called only once per problem, before the body profile calculation is started, and **initializes** the following variables.

DRAGP DRAGT DRPL DRTL RVBINT RVBRL RBI X1 XI1	}	set = 0.0
IDX IXSW	}	= 1
CTH	= 1.0	= Θ for body profiles.
FP(N) TH(N) CL(N,I)	= FPRIME(N) = THETA(N) = CLIL(N,I)	Profiles from initial profiles **are** stored as previous values.
FMBAR(N)	$\bar{M}$	
WFA(NK)	weight factors all set = 1.0	
DXEST(K)	δ_{est} see eq. (75).	

```
      SUBROUTINE  BSETUP                                                    BSET   1
                                                                            BSET   2
      COMMON  /1/  NI          , NMAX        , NM2        , NTO       ,     BSET   3
     1             NJ          , NM1         , NR                           BSET   4
      COMMON  /5/  CLIL(50,30), FPRIME(50)  , THETA(50)                     BSET   5
      COMMON  /6/  CL(50,30)  , FP(50)      , TH(50)                        BSET   6
      COMMON  /8/  FMOLWT(30) , FMBAR(50)   , FMBARE     , RHO(50)   , R    BSET   7
      COMMON /11/  DEN2(50)   , ETE         , VONE                          BSET   8
      COMMON /15/  FLAPL      , RB1         , TXI1T      , XI1              BSET   9
      COMMON /16/  DRAGP      , DRPL        , RVBINT     ,                  BSET  10
     1             DRAGT      , DRTL        , RVBRL                         BSET  11
      COMMON /17/  IDX        , RB12        , VE1        ,                  BSET  12
     1             DELXN      , TF1         , X1                            BSET  13
      COMMON /28/  BETA       , CTH                                         BSET  14
      COMMON /34/  DELXT(20)  , NDX         , XDELT(20)  , XMAX             BSET  15
      COMMON /39/  NKM        , OMW(32)     , WFA(32)                       BSET  16
      COMMON /84/  DXEST(20)  , IXSW        , TRM                           BSET  17
```

```
      CTH = 1.0
      WRITE (NTO, 5) CTH
5     FORMAT(*0*11X* CTH =*F13.5*, BODY PROFILES.*)
      DRTL   = 0.0
      DRPL   = 0.0
      RVRPL   = 0.0
      RVRINT = 0.0
      X1     = 0.0
      XI1    = 0.0
      PR1    = 0.0
      IDX    = 1
      IXSW   = 1
      DRAGP = 0.0
      TRM = VONE
      DRAGT = 0.0
      DFLXN = DFLXT(1)
      DO 20 N=1,NMAX
      FP(N) = FPRIME(N)
      TH(N) = THETA(N)
      CSUM   = 0.0
      DO 10 I=1,NI
      CL(N,I) = CLIL(N,I)
      CSUM     = CSUM + (CLIL(N,I) / FMOLWT(I) )
10    CONTINUE
      FMBAR(N) = 1.0 / CSUM
20    CONTINUE
      FMBARE   = FMBAR(NMAX)
      DO 30 NK=1,NKM
      WFA(NK) = 1.0
      OMW(NK) = 0.0
30    CONTINUE
      NDX1 = NDX - 1
      DO 40 K=1,NDX1
      DXEST(K) = DFLXT(K+1) / DFLXT(K) - 2.0
40    CONTINUE
      RETURN
      END
```

CALCV

Subroutine CALCV calculates V, the transformed normal velocity, for each point across the boundary layer. See Equations 36, 39 and 48. If a shock layer is being computed, new values of η_e and η_e^2 are calculated in CALCV using V_{sh} (Eq. 80a).

```
      SUBROUTINE CALCV

      COMMON  /1/  NI          , NMAX       , NM2        , NTO        ,
     1             NJ          , NM1        , NR
      COMMON  /4/  FL(50)      , IBS
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /6/  CL(50,30)   , FP(50)     , TH(50)
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)  , FMBARE     , RHO(50)    , R
      COMMON  /9/  IGEOM       , JBOD
      COMMON /11/  DEN2(50)    , ETE        , VONE
      COMMON /12/  RHOE        , RHOINF     , RMUREF
      COMMON /18/  DELXI       , XI12
      COMMON /20/  ANGLC       , FJ         , SINCO      , TKINF      ,
     1             DUEDX       , PII        , SINTH      , TKW
      COMMON /24/  DN(50)
      COMMON /25/  RVB
      COMMON /36/  ETESQ       , SPFI(50)   , TXIE
      COMMON /40/  IBRDYO      , V(50)
      COMMON /41/  ETA(50)
      COMMON /73/  VS
      COMMON /83/  XITRM       , XITRP

      GO TO (10, 20) , IBS
   10 CONTINUE
      DO 12 N=1,NMAX
      FP(N) = -FPRIME(N)
   12 CONTINUE
      IF (IGEOM .GE. 0) GO TO 14
      VONE = 0.0
      GO TO 16
   14 CONTINUE
      VONE = 1.0 / SQRT((1.+FJ)*RMUREF*DUEDX)
   16 CONTINUE
      V(1) = VONE * RVB
      CALL SIMINT (FP, AAA, V, 2)
      IF (IBRDYO .NE. 2) GO TO 40
      ETE   = VS * ETE / V(NMAX)
      ETESQ = ETE * ETE
      WRITE (NTO,17) ETE
   17 FORMAT(12X*ETE =*E13.5)
      GO TO 40
   20 CONTINUE
      V(1) = VONE * RVB
      DO 30 N=2,NMAX
      V(N) = V(N-1) + DN(N-1) * ((FP(N)+FP(N-1)) * XITRM
     1                          - (FPRIME(N) + FPRIME(N-1)) * XITRP)
   30 CONTINUE
   40 CONTINUE
      RETURN
      END
```

CALDNS

Subroutine CALDNS computes η at each point across the boundary layer and combinations of the $\Delta\eta$'s. Common variables computed are:

$$\text{DEN1} = \Delta\eta_n(\Delta\eta_n + \Delta\eta_{n-1})$$

$$\text{DEN2} = \Delta\eta_n \cdot \Delta\eta_{n-1}$$

$$\text{DEN3} = \Delta\eta_{n-1}\,(\Delta\eta_n + \Delta\eta_{n-1})$$

$$\text{DMDN} = \Delta\eta_n - \Delta\eta_{n-1}$$

$$\text{DNH} = \Delta\eta_n/2$$

$$\text{DNO6} = \Delta\eta_n/6$$

$$\text{DNTR1} = \frac{\Delta\eta_{n-1}}{\Delta\eta_n(\Delta\eta_n + \Delta\eta_{n-1})}$$

$$\text{DNTR2} = \frac{\Delta\eta_n - \Delta\eta_{n-1}}{\Delta\eta_n \cdot \Delta\eta_{n-1}}$$

$$\text{DNTR3} = \frac{\Delta\eta_n}{\Delta\eta_{n-1}(\Delta\eta_n + \Delta\eta_{n-1})}$$

$$\text{DPDN} = \Delta\eta_n + \Delta\eta_{n-1}$$

$$\text{TDNOP} = \frac{2\Delta\eta_n}{\Delta\eta_n + \Delta\eta_{n-1}}$$

$$\text{TDNOM} = \frac{2\Delta\eta_{n-1}}{\Delta\eta_n + \Delta\eta_{n-1}}$$

$$\text{RDN} = \frac{\Delta\eta_2}{\Delta\eta_1}$$

$$\text{RRDN} = \left(1.0 + \frac{\Delta\eta_2}{\Delta\eta_1}\right)^2$$

```
      SUBROUTINE CALDNS

      COMMON /1/  NI          , NMAX        , NM2         , NTO         ,
     1            NJ          , NM1         , NR
      COMMON /11/ DEN2(50)    , ETE         , VONE
      COMMON /24/ DN(50)
      COMMON /41/ ETA(50)
      COMMON /42/ DMDN(50)    , DNH(50)     , TDNOM(50)   , TDNOP(50)
      COMMON /43/ DEN1(50)    , DEN3(50)    , DNTR2(50)
      COMMON /44/ DNO6(50)    , DNTR1(50)   , DNTR3(50)   , DPDN(50)
      COMMON /45/ RDN         , RRDN

      ETA(1)   = 0.0
      DO 10 N=1,NM1
      ETA(N+1) = ETA(N) + DN(N)
      DNH(N)   = DN(N) / 2.0
      DNO6(N)  = DN(N) / 6.0
   10 CONTINUE
      DO 20 N=2,NM1
      DPDN(N)  = DN(N) + DN(N-1)
```

```
      DMDN(N)  = DN(N) - DN(N-1)                                        CADN  21
      TDNOP(N) = 2.0 * DN(N)   / DPDN(N)                                CADN  22
      TDNOM(N) = 2.0 * DN(N-1) / DPDN(N)                                CADN  23
      DEN1(N)  = DN(N) * DPDN(N)                                        CADN  24
      DEN2(N)  = DN(N) * DN(N-1)                                        CADN  25
      DEN3(N)  = DN(N-1) * DPDN(N)                                      CADN  26
      DNTR1(N) = DN(N-1) / DEN1(N)                                      CADN  27
      DNTR2(N) = DMDN(N) / DEN2(N)                                      CADN  28
      DNTR3(N) = DN(N)   / DEN3(N)                                      CADN  29
   20 CONTINUE                                                          CADN  30
      RDN  = DN(2) / DN(1)                                              CADN  31
      RRDN = (1.0 + RDN) * (1.0 + RDN)                                  CADN  32
      RETURN                                                            CADN  33
      END                                                               CADN  34
```

CALEBB

Subroutine CALEBB is called to compute $\bar{\bar{e}}$ for the stagnation point shock layer solution. See Equation 21.

```
      SUBROUTINE CALEBB

      COMMON  /1/  NI           , NMAX        , NM2         , NTO         ,
     1             NJ           , NM1         , NR
      COMMON  /5/  CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON /28/  BETA         , CTH
      COMMON /38/  BEBB(50)
      COMMON /46/  EDBLT1       , EDBLT2      , EP2
      COMMON /78/  DEB

      DIMENSION       DUM(50)        , S(50)
      DO 10 N=1,NMAX
      DUM(N) = FPRIME(N)* FPRIME(N)
   10 CONTINUE
      S(1) = 0.0
      CALL SIMINT (DUM, AA, S, 2)
      DEBQ = DEB * DEB
      DEBR = SQRT(DEB)
      DO 20 N=1,NMAX
      EBB    = 1.0 / (EP2*(EDBLT1*DEBQ+(S(NMAX)-S(N))*DEBR/EDBLT2))
      BEBB(N) = BETA / EBB
   20 CONTINUE
      RETURN
      END
```

CC1

CC1 is a function subroutine which calls POLATE to get the interpolated value of enthalpy at TK.

CC2

CC2 is a function subroutine which calls POLATE to get the interpolated value of specific heat at TK.

```
      FUNCTION CC1 ( TK, I)

      COMMON /AA/  CCP(50,30) , ENTHA(50,30),TEMP(50)    , IX
      COMMON /80/  JE(30)

      J1 = JE(I)
      CALL POLATE (TK, TEMP, ENTHA(1,J1), ANS, IX)
      CC1=ANS
      RETURN
      END
```

```
      FUNCTION CC2 ( TK, I)

      COMMON /AA/  CCP(50,30) , ENTHA(50,30),TEMP(50)    , IX
      COMMON /80/  JE(30)

      J1 = JE(I)
      CALL POLATE (TK, TEMP, CCP  (1,J1), ANS, IX)
      CC2=ANS
      RETURN
      END
```

CHEMPR

Subroutine CHEMPR computes the chemical production terms. CHEMPR is not completely generalized so care is recommended when problems other than an air mixture are being run. See Chapter 2 beginning with Equation (28a) for a description of W^0, W^1 and $\bar{W}$. See Chapter 5 for discussion of the chemical reactions and rates which are computed in CHEMPR.

Common variables computed are:

FMBAR	$\bar{M}$, molecular weight of mixture at each point across the boundary layer.
FMBARE	$\bar{M}_e$, molecular weight at edge.
GAMMA	γ, mass concentration of species and catalytic bodies. See Eq. (6).
RHO	ρ, density at each point across the boundary layer.
RHOBAR	$\bar{\rho}$
RHOE	ρ_e, density at the edge.
WBAR	$\bar{W}$
WONE	W^1
WTH	$\frac{w_i}{\rho}$
WZERO	W^0

Program variables are:

BACKK	k_{b_r}, Eq. (88b)
BACL	Backward stoichiometric coefficients, computed in subroutine STOI.
FORK	k_{f_r}, Eq. (88a)
FORL	forward stoichiometric coefficients, computed in subroutine STOI.
T	temperature at current point across boundary layer.
TEM	T_e, for initial profile $(T)_m$, for body profiles
X_k	$FORL_k - BACL_k$, X_k is printed every IPRT or IPRTB iteration.

The term TEMST should be used only for a gas model with oxygen and then the first reaction must be $O_2 + M_1 \rightleftarrows 2O + M_1$. The term TEMP8 should be used only for a gas model with CO_2 as the 8th species and the 8th and 9th reactions are:

$$r = 8 \qquad CO + O + M_4 \rightleftarrows CO_2 + M_4$$

$$= 9 \qquad CO_2 + O \rightleftarrows CO + O_2$$

This subroutine is general except between the lines 100 to 116.

```
      SUBROUTINE CHEMPR
      COMMON         WBAR(50,30), WONE(50,30), WTH(50,30) , WZERO(50,30)
      COMMON   /1/   NI          , NMAX        , NM2         , NTO          ,
     1               NJ          , NM1         , NR
      COMMON   /2/   M
      COMMON   /3/   IFROZE      , ILE         , MFLAGO       , NEQUIL
      COMMON   /4/   FL(50)      , IBS
      COMMON   /5/   CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON   /8/   FMOLWT(30)  , FMBAR(50)   , FMBARE      , RHO(50)    , R
      COMMON  /12/   RHOE        , RHOINF      , RMUREF
      COMMON  /13/   HINF        , PE          , SMALLE      , TKE      , UE ,
     1               HF(30)      , PINF        , TE          , TINF     , VINF
      COMMON  /17/   IDX         , RB12        , VE1         ,
     1               DELXN       , TE1         , X1
      COMMON  /21/   CFINF       , FMDOT(30)   , QCOND       , RSUM         ,
     1               DISPTK      , FMOTH       , QCONV       , SKFER        ,
     2               DRAG2       , HE(50)      , QDIFF       , ST           ,
     3               DRAGP2      , HXTFEB      , QTFTLB      , TLEFT        ,
     4               DRAGT2      , HXTFER      , QTOTAL      , YF(50)       ,
     5               FDENS(50)   , PARDOT(30)  , RMFLUX(30)  , REVE
      COMMON  /37/   IPRTB
      COMMON  /47/   DIFA(30,30), GAMMIN(30,40),GAMPLS(30,40)
      COMMON  /48/   C0(30)      , C2(30)      , D1(30)      , CINF(30)     ,
     1               C1(30)      , D0(30)      , D2(30)
      COMMON  /49/   CALPH(30,40),CBETA(30,40),CSALPH(30) , CSBETA(30),IO
      COMMON  /50/   IPPT
      COMMON  /51/   GAMMA(40)   , RHOBAR
      COMMON  /53/   AMD(435)    , BMD(435)    , CMD(435)    , Z(30,10)
      COMMON  /60/   IN2         , IO2
      COMMON  /67/   ICO         , ICO2        , IM1         , IM3    , IN   ,
     1               IC1         , IFL         , IM2         , IM4    , INO
      COMMON  /74/   PE1
      COMMON  /85/   X(50,30)

      DIMENSION         BACKK(30)        , FORK(30)        ,
     1                  BACL(30)         , FORL(30)
      DO 110 N=1,NMAX
      CSUMI = 0.0
      DO 10 I=1,NI
      GAMMA(I) = CLIL(N,I) / FMOLWT(I)
      CSUMI     = CSUMI + GAMMA(I)
   10 CONTINUE
      FMBAR(N) = 1.0 / CSUMI
      GO TO (12,14) , IBS
12    TEM = TE
      PE1 = PE
      GO TO 16
14    TEM = TE1
16    CONTINUE
      T     = THETA(N) * TEM
      TK    = T / 1.8
      TKLN = ALOG(TK)
      DO 20 KR=1,NR
      FORK(KR)  = EXP (C2(KR)*TKLN+C0(KR)-C1(KR)/TK)
      BACKK(KR) = EXP (D2(KR)*TKLN+D0(KR)-D1(KR)/TK)
   20 CONTINUE
      MMN = NI+1
      DO 40 J=MMN,NJ
      JMNI = J - NI
      GAMMA(J) = 0.0
      DO 40 I=1,NI
      GAMMA(J) = GAMMA(J) + GAMMA(I) * Z(I,JMNI)
   40 CONTINUE
      DO 50 J=1,NJ
      IF (GAMMA(J) .GE. 0.0) GO TO 50
      GAMMA(J) = 0.0
50    CONTINUE
      RHO(N) = PE1 * FMBAR(N) / (R * T)
      RHOBAR = RHO(N) * .51536
      IF (IEL.EQ. 0) GO TO 52
```

```
      EDENS(N) = RHOBAR * 6.025E23 * GAMMA(MMN)
   52 CONTINUE
      CALL STOI (CALPH , CSALPH , FORK ,  FORL )
      CALL STOI (CBETA,  CSBETA , BACKK , BACL )
      DO 54 K=1,NR
      X(N,K) = FORL(K) - BACL(K)
54    CONTINUE
60    CONTINUE
      GO TO ( 64, 110 ) , IFROZE
64    CONTINUE
      DO 80 I=1,NI
      SUM0 = 0.0
      SUM1 = 0.0
      DO 70 KR=1,NR
      GP   = GAMPLS(KR,I)
      GM   = GAMMIN(KR,I)
      SUM0 = SUM0 + (GP * FORL(KR) + GM * BACL(KR))
      SUM1 = SUM1 + (GP * BACL(KR) + GM * FORL(KR))
   70 CONTINUE
      IF (GAMMA(I) .NE. 0.0) GO TO 72
      SUM1 = 0.0
      GO TO 74
   72 CONTINUE
      SUM1 = SUM1 / GAMMA(I)
   74 CONTINUE
      WZERO(N,I) = FMOLWT(I) * SUM0
      WONE(N,I)  = SUM1
      WBAR(N,I)  = SMALLE * (WZERO(N,I)-SUM1*CLIL(N,I))
   80 CONTINUE
      IF (IO .EQ. 0 .OR. IM1 .EQ. 0) GO TO 81
      TEMST = BACKK(8) * RHOBAR * GAMMA(IM4)
      WZERO(N,IO) = WZERO(N,IO) + FMOLWT(IO) * GAMMA(IO) * TEMST
      WONE(N,IO)  = WONE(N,IO)  + TEMST
81    CONTINUE
      IF (ICO .EQ. 0) GO TO 82
C                                THE CONSTANT SUBSCRIPTS IN THE THREE
C                                FOLLOWING STATEMENTS REFER TO REACT-
C                                IONS AND THEY MUST MATCH THE REACTION
C                                INPUT OR VISA VERSA. SEE CHAPTER 2 OF
C                                WRITE UP.
      TEMP8 = RHOBAR * (FORK(8)*RHOBAR*GAMMA(IO)*GAMMA(IM4)+ BACKK(9)
     1           * GAMMA(IO2))
      WZERO(N,8)  = WZERO(N,8) + CLIL(N,8) * TEMP8
      WONE(N,8)   = WONE(N,8)  + TEMP8
82    CONTINUE
      DO 100 J1=1,NI
      GSUM = 0.0
      DO 90  J2=1,NR
      GSUM = GSUM+ DIFA(J2,J1) * (FORL(J2)*(C2(J2)+C1(J2)/TK-CSALPH(J2))
     1                        - BACL(J2)*(D2(J2)+D1(J2)/TK-CSBETA(J2)))
   90 CONTINUE
      WTH(N,J1)   = FMOLWT(J1) * GSUM / THETA(N)
  100 CONTINUE
  110 CONTINUE
      FMBARE      = FMBAR(NMAX)
      RHOE  = RHO(NMAX)
      RETURN
      END
```

DERIV

Subroutine DERIV computes the value of the derivative $\frac{dr_b}{dx}$ which is used in subroutine KUTTAM. The equation for $\frac{dr_b}{dx}$ is given in (70).

```
      SUBROUTINE DERIV (Y, DY)
      COMMON /10/  RN          , TANCO

      FOO=Y/RN
      FOO=FOO*FOO
      DY = SQRT(1.0/(1.0+FOO /(1.0+FOO * TANCO)))
      RETURN
      END
```

DERVDN

Subroutine DERVDN computes the first or second derivative of a function with respect to η. See Equations (23b) and (23c).

The arguments are:

W	function (array)
WP	computed value of the derivative
IORD	1, first derivative desired. 2, second derivative desired.
N	point where derivative is to be calculated.

```
      SUBROUTINE DERVDN (W, WP, IORD, N)

      COMMON  /1/  NI          , NMAX        , NM2         , NTO         ,
     1             NJ          , NM1         , NR
      COMMON /11/  DEN2(50)    , ETE         , VONE
      COMMON /24/  DN(50)
      COMMON /43/  DEN1(50)    , DEN3(50)    , DNTR2(50)
      COMMON /44/  DNO6(50)    , DNTR1(50)   , DNTR3(50)   , DPDN(50)

      DIMENSION      W(1)
      GO TO (10, 40) , IORD
   10 CONTINUE
      IF (N .NE. 1) GO TO 20
      WP = -W(1) * ((DN(2) + 2.*DN(1)) / DEN3(2))
     1     +W(2) * DPDN(2) / DEN2(2) - W(3)*DN(1) /(DN(2)*DPDN(2))
      GO TO 50
   20 CONTINUE
      IF (N .EQ. NMAX) GO TO 30
      WP = W(N+1)*DNTR1(N) + W(N)*DNTR2(N) - W(N-1)*DNTR3(N)
      GO TO 50
   30 CONTINUE
      WP = W(NMAX) * ((DN(NM2)+2.*DN(NM1)) / DEN1(NM1))
     1              -W(NM1) * DPDN(NM1)/DEN2(NM1)
     2              + W(NM2) * DN(NM1) / (DN(NM2) * DPDN(NM1))
      GO TO 50
   40 CONTINUE
      WP = 2.0 * (W(N+1)/DEN1(N) - W(N)/DEN2(N) + W(N-1)/DEN3(N)) / ETE
   50 CONTINUE
      WP = WP / ETE
      RETURN
      END
```

ENEREQ

Subroutine ENEREQ computes the coefficients and sets boundary values for the solution of the energy equation (θ). For the initial profile calculation one may iterate inside this subroutine. The calculation is done KENE times if KOPT = 1, or if KOPT = 2, calculation is repeated until CHECK (computed in WKHS) is $\leq$ AENE. The coefficients are the α's described in Equations (20e) through (20h). The boundary conditions used are:

$$\left.\begin{aligned} A(1) &= 0.0 \\ B(1) &= 1.0 \\ D(1) &= T_b/T_e \end{aligned}\right\} \quad \text{Eq. (47b)}$$

$$\begin{aligned} B(NMAX) &= 1.0 \\ C(NMAX) &= 0.0 \\ D(NMAX) &= 1.0 \end{aligned}$$

The appropriate weight factor is set. If body profiles are being calculated (IBS = 2) the previous value of $THETA(N)_m$ is saved in TH before the new $THETA(N)_{m+1}$ are computed by calling WKHS.

```
      SUBROUTINE ENEREQ

      COMMON      WBAR(50,30), WONE(50,30), WTH(50,30) , WZERO(50,30)
      COMMON /1/  NI          , NMAX       , NM2        , NTO        ,
     1            NJ          , NM1        , NR
      COMMON /3/  IFROZE      , ILE        , MFLAGO      , NEQUIL
      COMMON /4/  FL(50)      , IBS
      COMMON /5/  CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON /6/  CL(50,30)   , FP(50)     , TH(50)
      COMMON /8/  FMOLWT(30)  , FMBAR(50)  , FMBARE     , RHO(50)   , R
      COMMON /13/ HINF        , PE         , SMALLE     , TKE       , UE ,
     1            HF(30)      , PINF       , TE         , TINF      , VINF
      COMMON /27/ CPBAR(50)   , FFMU       , RES        , UE2TE     ,
     1            ENTAPY(50,30)
      COMMON /28/ BETA        , CTH
      COMMON /32/ TW
      COMMON /35/ EBAR
      COMMON /38/ BEBB(50)
      COMMON /39/ NKM         , OMW(32)    , WFA(32)
      COMMON /40/ IBRDYO      , V(50)
      COMMON /55/ AENE        , ASPE       , KMOM       , KSPE      ,
     1            AMOM        , KENE
      COMMON /56/ BLIL(50)    , CBAR(50)   , CBARPR(50) , CCC1(50,30),
     1            DLIL(50)
      COMMON /57/ ALPH1(50)   , ALPH4(50)  , ISPC       , OMWF      ,
     1            ALPH2(50)   , CHECK      , MFLAG      , WFAC      ,
     2            ALPH3(50)
      COMMON /58/ A(50)       , B(50)      , C(50)      , D(50)
      COMMON /59/ KOPT

      ISPC     = 1
      A(1)     = 0.0
      B(1)     = 1.0
      D(1)     = TW / TE
      B(NMAX)  = 1.0
      C(NMAX)  = 0.0
      D(NMAX)  = 1.0
      SETE  = SMALLE / TE
      WFAC  = WFA(2)
      OMWF  = OMW(2)
      UETRM = UE2TE * FMBARE
      GO TO (10,30) , IBS
   10 CONTINUE
```

```
      MFLAG = 0
20    CONTINUE
      MFLAG = MFLAG + 1
30    CONTINUE
      DO 120 N=2,NM1
      TERM  = UETRM * FPRIME(N) / FMBAR(N)
      GO TO (42, 44) , IBRDYO
42    CONTINUE
      TERM  = TERM * BEBB(NMAX)
      GO TO 46
44    CONTINUE
      TERM  = TERM * BEBB(N)
46    CONTINUE
      CALL DERVDN (FPRIME, DFP, 1, N)
      WC1S = 0.0
      WHFS = 0.0
      CBDEN = 1.0 / CBAR(N)
      DO  70 I=1,NI
      WC1S = WC1S + WBAR(N,I) * CCC1(N,I)
      WHFS = WHFS + WBAR(N,I) * HF(I)
      GO TO (40,60) , IBS
40    CONTINUE
      GO TO (70,60) , NEQUIL
50    CONTINUE
      TEMS = ENTAPY(N,I) * WTH(N,I)
      WC1S = WC1S + TEMS * SETE
      WHFS = WHFS - TEMS * SMALLE * THETA(N)
70    CONTINUE
      GO TO (80,100) , IBS
80    CONTINUE
      DFPSQ = DFP * DFP
      GO TO 110
100   CONTINUE
      CALL DERVDN (FP     , DFP2, 1, N)
      DFPSQ = DFP  * DFP2
      FPCP      = FPRIME(N) * CPBAR(N)
      ALPH4(N) = - FPCP * CBDEN
      TERM      = TERM - EBAR * FPCP
110   CONTINUE
      ALPH1(N) = (CBARPR(N) - CPBAR(N) * (V(N)+DLIL(N)+BLIL(N)))*CBDEN
      ALPH2(N) = ( TERM - WC1S)  * CBDEN
      ALPH3(N) = (UE2TE * FL(N) * DFPSQ - WHFS / TE)  * CBDEN
120   CONTINUE
      GO TO (150,130) , IBS
130   DO 140 N=1,NMAX
140   TH(N)  = THETA(N)
150   CONTINUE
      CALL WKHS (THETA)
      GO TO (160,190) , IBS
160   GO TO (170,180) , KOPT
170   IF (MFLAG .LT. KENE) GO TO 20
      GO TO 190
180   IF (CHECK .GT. AENE) GO TO 20
190   CONTINUE
      RETURN
      END
```

EQU2

Subroutine EQU2 is called by QPR when IWC = 5, for mass transfer of ablation products. The value of $\left(c_{i_{eq}}\right)_{pyrolysis}$ is computed. This subroutine may have to be changed for different pyrolysis gases or surface material.

```
      SUBROUTINE EQU2 (C, I)
      COMMON /60/  IN2          , IO2
      IF (I .NE. IO2) GO TO 10
      C = .2328
      GO TO 30
10    CONTINUE
      IF (I .NE. IN2) GO TO 20
      C = .7672
      GO TO 30
20    CONTINUE
      C = 0.0
30    CONTINUE
      RETURN
      END
```

EQUIL

Subroutine EQUIL computes the values of $c_{n,i}$ for the equilibrium option and $c_{\infty,i}$ when it is not given. EQUIL is not a general subroutine and is only good for "air" with the species in the following order:

$$O_2,\ N_2,\ O,\ N,\ NO,\ NO^+$$

There are three arguments to EQUIL:

T	temperature, ^{o}R
P	pressure, psf
N	if N = 0, compute c_∞ for each species; if N > 0, compute c for each species at N^{th} point (across the boundary layer). RHO(N) is also computed.

There is an iteration loop in EQUIL and if more than 20 iterations are attempted an error message is printed. "TOO MANY ITERATIONS IN EQUIL, GCK = GCH = ... " followed by a normal return from the subroutine.

A second version of EQUIL is included which was used for Binary Gas Model problems.

```
      SUBROUTINE EQUIL (T, P, N)

      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /7/  ICOMPO
      COMMON  /8/  FMOLWT(30) , FMBAR(50)  , FMBARE     , RHO(50)  , R
      COMMON /48/  C0(30)     , C2(30)     , D1(30)     , CINF(30)  ,
     1             C1(30)     , D0(30)     , D2(30)

      DIMENSION      FCK(7)        , GL(7)          , JKI(6)      ,
     1               GB(2)         , GP(2)          , KRI(4)
      DATA          (KRI = 1,  2,  4,  7)   ,     ( EPS = .000001) ,
     1              (JKI = 5,  6,  1,  2,  3,  4), (ISP  = 6)      ,
     2              (IRM = 4) ,                    (ISP1 = 7)
      ICT = 0
      TK     = T / 1.8
      TKLN   = ALOG(TK)
      GSUM    = .04
      PART   = .51536 * P / ( R * T )
      RHOBAR = PART / GSUM
      GP(1)  = 2.0 * (.2328 / FMOLWT(1) )
      GP(2)  = 2.0 * (.7672 / FMOLWT(2))
      DO 10 J =1,ISP1
      GL(J) = 0.0
10    CONTINUE
      DO 20  J=1,IRM
      K        = KRI(J)
      FORK     = C2(K) * TKLN + C0(K) - C1(K) / TK
      BACK     = D2(K) * TKLN + D0(K) - D1(K) / TK
      FCK(J)   = EXP (FORK - BACK)
20    CONTINUE
30    CONTINUE
      GL34 = GL(3) + GL(4)
      GCK   = 0.0
      DO 60 J=1,2
      GAMC  = GL(J)
      GB(J) = GP(J) - GL34
      REK    = RHOBAR / ECK(J)
      IF ( 8. * REK * GB(J) .LT. .001) GO TO 40
      GL(J) = .25/REK * (-1.0 + SQRT(1.0 + 8.0 * REK   * GB(J)))
      GO TO 50
40    CONTINUE
      GL(J) = GB(J) * (1.0 - 2.*REK * GB(J) + 8.0 * (REK*GB(J))**2 )
50    CONTINUE
```

```
      GCH = ABS (GAMC - GL(J)) / GL(J)
      GCK = AMAX1(GCK,GCH)
60    CONTINUE
      GL12 = GL(1) * GL(2)
      DO 130 J=3,6
      ISW  = J - 2
      GAMC = GL(J)
      GO TO (80, 90, 100, 100) , ISW
80    CONTINUE
      GL(J) = RHOBAR * GL12 / ECK(J)
      GO TO 110
90    CONTINUE
      GL(J) = SQRT(ECK(J) * GL12)
      GO TO 110
100   CONTINUE
      GL(J) = RHOBAR * GL(J-4)**2 / ECK(J-4)
110   CONTINUE
      GCH = ABS (GAMC - GL(J)) / GL(J)
120   CONTINUE
      GCK = AMAX1(GCK,GCH)
130   CONTINUE
      GSUM  = 0.0
      GL(7) = GL(4)
      DO 140 J=1,ISP1
      GSUM  = GSUM + GL(J)
140   CONTINUE
      RHOBAR = PART / GSUM
      ICT = ICT + 1
      IF (ICT .GT. 20) GO TO 142
      IF ( GCK .GT. EPS ) GO TO 30
      GO TO 148
142   CONTINUE
      PRINT 145, GCK, GCH
145   FORMAT(*0 TOO MANY ITERATIONS IN EQUIL, GCK =*E12.4,* GCH =*E12.4)
148   CONTINUE
      GO TO ( 150, 200) , ICOMPO
150   CONTINUE
      DO 190 K=1,ISP
      JK = JKI(K)
      C  = GL(JK) * FMOLWT(K)
      IF (N .GT. 0) GO TO 180
      CINF(K) = C
      GO TO 190
180   CONTINUE
      CLIL(N,K) = C
190   CONTINUE
      IF (N .LT. 1) GO TO 210
200   CONTINUE
      RHO(N) = RHOBAR / .51536
210   CONTINUE
      RETURN
      END


      SUBROUTINE EQUIL (T, P, N)
C
C                            THIS SUBROUTINE SHOULD ONLY BE USED
C                              FOR BINARY GAS MODEL PROBLEM.
C
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /8/  FMOLWT(30) , FMBAR(50)  , FMBARE     , RHO(50)   , R
      COMMON /48/  C0(30)     , C2(30)     , D1(30)     , CINF(30)  ,
     1             C1(30)     , D0(30)     , D2(30)

      DATA   (EPS = .000001)
      TK = T / 1.8
      TKLN = ALOG (TK)
      PART = .51536 * P / (R * T)
      ICT = 0
      GSO  = 0.0
```

```
      GSUM = .04
      FORK = C2(1) * TKLN + C0(1) - C1(1) / TK
      BACK = D2(1) * TKLN + D0(1) - D1(1) / TK
      ECK  = EXP(FORK - BACK)
   10 CONTINUE
      GCK    = GSO
      RHOBAR = PART / GSUM
      EKR    = ECK  / (4.0 * RHOBAR)
      EKR8   = 1.0 / ( 8.0 * EKR)
      IF (EKR8 .LT.  .001) GO TO 20
      GSO = EKR * (-1.0 + SQRT(1.0 + EKR8))
      GO TO 30
   20 CONTINUE
      GSO = .0625 * (1.0 - ERK8 * (.25 - .125 * ERK8))
   30 CONTINUE
      GCH = ABS(GCK - GSO) / GSO
      GSO2 = RHOBAR * GSO * GSO / ECK
      GSUM = GSO + GSO2
      IF (GCH .LE. EPS) GO TO 40
      IF (ICT .LE. 20) GO TO 10
      ICT = ICT + 1
      PRINT 35, GSO, GSO2
   35 FORMAT(*0  GAMMA O =*E12.5,4X*GAMMA O2 =*E12.5,* TOO MANY ITERATIO
     1NS IN EQUIL.*)
   40 CONTINUE
      CLIL(N,1) = 16.00 * GSO
      CLIL(N,2) = 1.0 - CLIL(N,1)
      RHO(N)  = RHOBAR / .51536
      RETURN
      END
```

GAUSS3

GAUSS3 is a matrix inversion subroutine from the CO-OP library. The arguments are:

- K1 - order of Matrix (integer)
- A1 - The error flag is set when a diagonal element of the triangularized Matrix is ≤ A1.
- A2 - Name of Matrix to be inverted.
- A3 - Name of inverted matrix
- K2 - error flag { 1 - No errors; 2 - Matrix is singular.

GAUSS3 is called by MCDIFF where the error flag (K2) is tested; if it is = 2, the message "ERROR IN MATRIX INVERSION" is printed and the calculation is terminated.

```
      SUBROUTINE GAUSS3 (NN, EP, A, X, KER)
      DIMENSION     A(30,1)   , X(30,1)
      N = NN
       DO 1 I=1,N
       DO 1 J=1,N
    1  X(I,J)=0.0
       DO 2 K=1,N
    2  X(K,K)=1.0
   10  DO 34 L=1,N
       KP=0
       Z=0.0
       DO 12 K=L,N
       IF(Z-ABS (A(K,L)))11,12,12
   11  Z=ABS (A(K,L))
       KP=K
   12  CONTINUE
       IF(L-KP)13,20,20
   13  DO 14 J=L,N
       Z=A(L,J)
       A(L,J)=A(KP,J)
   14  A(KP,J)=Z
       DO 15 J=1,N
       Z=X(L,J)
       X(L,J)=X(KP,J)
   15  X(KP,J)=Z
   20  IF(ABS (A(L,L))-EP)50,50,30
   30  IF(L-N)31,34,34
   31  LP1=L+1
       DO 36 K=LP1,N
       IF(A(K,L))32,36,32
   32  RATIO=A(K,L)/A(L,L)
       DO 33 J=LP1,N
   33  A(K,J)=A(K,J)-RATIO*A(L,J)
       DO 35 J=1,N
       X(K,J)=X(K,J)-RATIO*X(L,J)
   35  CONTINUE
   36  CONTINUE
   34  CONTINUE
   40  DO 43 I=1,N
       II=N+1-I
       DO 43 J=1,N
       S=0.0
       IF(II-N)41,43,43
   41  IIP1=II+1
       DO 42 K=IIP1,N
   42  S=S+A(II,K)*X(K,J)
   43  X(II,J)=(X(II,J)-S)/A(II,II)
       KER=1
       GO TO 75
   50  KER=2
   75  CONTINUE
      RETURN
      END
```

HUGNOT

Subroutine HUGNOT is called to compute the flow at the edge for a shock layer calculation using the modified Rankine-Hugoniot relations as described in Appendix A.

HUGNOT has one argument - IHSW.

> IHSW = 1 when HUGNOT is called by PRECAL and the initial values of PE, UE, TE and RHOE are required.
>
> IHSW = 2 when HUGNOT is called by THERMO and conditions behind the shock with slip are calculated. New values of c_i at the outer edge of the shock layer are also computed.

There is an iteration loop in HUGNOT with a built-in limit of 100. If this limit is exceeded, "TOO MANY ITERATIONS IN HUGNOT", is printed and execution of the job is terminated.

```
      SUBROUTINE HUGNOT (IHSW)

      COMMON  /1/  NI            , NMAX          , NM2           , NTO          ,
     1             NJ            , NM1           , NR
      COMMON  /5/  CLIL(50,30),  FPRIME(50)    , THETA(50)
      COMMON  /8/  FMOLWT(30)    , FMBAR(50)     , FMBARE        , RHO(50)     , R
      COMMON /10/  RN            , TANCO
      COMMON /11/  DEN2(50)      , ETE           , VONE
      COMMON /12/  RHOE          , RHOINF        , RMUREF
      COMMON /13/  HINF          , PE            , SMALLE        , TKE         , UE  ,
     1             HF(30)        , PINF          , TE            , TINF        , VINF
      COMMON /20/  ANGLC         , FJ            , SINCO         , TKINF       ,
     1             DUEDX         , PII           , SINTH         , TKW
      COMMON /23/  BLBAR(50,30),FMUB             , PR(50)        , PRFL
      COMMON /27/  CPBAR(50)     , FFMU          , RES           , UE2TE       ,
     1             ENTAPY(50,30)
      COMMON /29/  CEDG(30)
      COMMON /40/  IBRDYO        , V(50)
      COMMON /46/  EDBLT1        , EDBLT2        , EP2
      COMMON /48/  C0(30)        , C2(30)        , D1(30)        , CINF(30)    ,
     1             C1(30)        , D0(30)        , D2(30)
      COMMON /65/  CK            , DELTA         , IREAD         , OPTN(6)     , RS
      COMMON /69/  CONTH(30,30),FMOLWR(30)       , TMTHA(30,30),EPSI           , TS4
      COMMON /75/  FTER(30)
      COMMON /76/  DUM(50)
      COMMON /77/   FMBARI       , SS
      COMMON /78/  DEB

      ICTR = 0
      GO TO (10,20) , IHSW
   10 CONTINUE
      SRT    = (1.0-SS) / RN
      VRN    =  VINF / RN
      PE     = TE = VSVINF = CHS = SH = UE = 0.0
      CCS    = 7000.
      VINFQ = VINF * VINF
      FMT = FMBARI
      GO TO 50
   20 CONTINUE
      FMT = FMBARE
      CALL DERVDN (FPRIME, DFP, 1, NMAX)
      CALL DERVDN (THETA , DTH, 1, NMAX)
      DO 30 IK=NM2,NMAX
      DUM(IK) = V(IK) / RHO(IK)
```

```
30    CONTINUE
      CALL DERVDN (DUM, DVRE, 1, NMAX)
      EPSI  = VSVINF
      RVNI  = 1.0 / (RHOINF*VINF)
      EP2   = -2.0 * EPSI
      EDBLT1 = (1.0-EPSI) / (1.0-EPSI*(1.0-1.0/SS))**2
      TS1    = SS * (1.0 - EPSI) + EPSI
      OPJ   = 1.0 + FJ
      TS4   = OPJ * TS1
      ATER  = OPJ * RMUREF
      DEB   = 1.0 + 1.0/RES * (SQRT(OPJ*RES*RN*DUEDX/(EPSI*VINF)) * DFP
     1                  + (1.0-SS)*(-RN/(SS*RS)+OPJ*RHOE*DVRE))
      DUEDX = VRN * TS1 / DEB
      TEMP  = ATER * DUEDX
      SQTEM = SQRT(TEMP)
      CTEM  = RVNI * SQTEM / PR(NMAX)
      SUM   = 0.0
      DO 40 I=1,NI
      SUM         = SUM + ENTAPY(NMAX,I) * FTER(I)
      CEDG(I)    = CINF(I) - CTEM * FTER(I)
      IF (CEDG(I) .LT. 0.0) CEDG(I) = 0.0
40    CONTINUE
      SHOLD = SH
      SH = RVNI * SQTEM * ((CPBAR(NMAX)*TE*DTH+SUM) / PR(NMAX)
     1                 + 1.33333333*V(NMAX)*DVRE*TEMP/ RHOE )
      IF (SH .LE. HSP) GO TO 42
      SH = HSP
42    CONTINUE
      SH = .5 * (SH + SHOLD)
50    CONTINUE
      GO TO (60,70) , IHSW
60    CONTINUE
      PET = PE
      PE  = PINF + RHOINF * VINFQ * (1.0-VSVINF)
70    CONTINUE
      TET = TE
      HSP = HINF + .5 * VINFQ * (1.0 - VSVINF * VSVINF)
      HS = HSP - SH
      TE  = (HS - CHS) / CCS
      IF (ABS(TE-TET) .LE. .0001) GO TO 100
      ICTR = ICTR + 1
      IF ( ICTR .LE. 100) GO TO 80
      WRITE (NTO, 75)
75    FORMAT(*0  TOO MANY ITERATIONS IN HUGNOT*)
      STOP
80    CONTINUE
      VSVINF = RHOINF * R * TE / (PE * FMT)
      TKE  = TE / 1.8
      CCS  = 0.0
      CHS  = 0.0
      DO 90 I=1,NI
      GO TO (82,84) , IHSW
82    CTEMP = CINF(I)
      GO TO 86
84    CTEMP = CEDG(I)
86    CONTINUE
      CHS    = CHS + CTEMP * HF(I)
      CCS    = CCS + CTEMP * CC1(TKE, I)
90    CONTINUE
      GO TO 50
100   CONTINUE
      GO TO (110,120) , IHSW
110   CONTINUE
      IF (ABS(PE-PET) .GT. .1) GO TO 80
120   CONTINUE
      RHOE = RHOINF / VSVINF
      WRITE (NTO,233) PE, TE, RHOE, UE
233   FORMAT(   13X*PE =*E13.5,13X*TE =*E13.5,11X*RHOE =*E13.5,13X*UE =*
```

```
      1E13.5)                                                              HUGO 113
      GO TO (240,234) , IHSW                                               HUGO 114
234   CONTINUE                                                             HUGO 115
      WRITE (NTO,235) SH, DUEDX, TS1, EPSI                                 HUGO 116
235   FORMAT(13X*SH =*E13.5,10X*DUEDX =*E13.5,12X*TS1 =*E13.5,             HUGO 117
     1   11X*EPSI =*E13.5)                                                 HUGO 118
240   CONTINUE                                                             HUGO 119
      RETURN                                                               HUGO 120
      END                                                                  HUGO 121
```

INPBOD

Subroutine INPBOD reads and prints the input cards beginning with card named "NWC" through the end (edge tables). The edge tables are a function of X/RN and the first value of X/RN must be 0.0. This is checked in INPBOD and if this is not true an error message, "SUBR. INPBOD FOUND THAT FIRST VALUES IN EDGE TABLE NOT FOR X = 0.0", is printed and execution stopped.

INPBOD calls subroutine PRTEDG to print the edge tables.

Common variables computed are:

SINCO	$\sin \theta_c$
TANCO	$\tan^2 \theta_c$
RNPHIS	$R_N \varphi_s$
CONPHS	$R_N(\sin \varphi_x - \varphi_s \sin \theta_c)$

DELTX(K)	$R_N \cdot$DELTX(K)	K = 1, NDX
XDELT(K)	$R_N \cdot$XDELT(K)	

Edge conditions are adjusted after being printed.

PA(K)	PA(K)·PO	K = 1, NED
TA(K)	TA(K)·TO	
VA(K)	VA(K)·UO	
XA(K)	XA(K)·RN	

```
      SUBROUTINE INPBOD

      COMMON  /1/  NI           , NMAX        , NM2         , NTO         ,
     1             NJ           , NM1         , NR
      COMMON  /7/  ICOMPO
      COMMON /10/  RN           , TANCO
      COMMON /20/  ANGLC        , FJ          , SINCO       , TKINF       ,
     1             DUEDX        , PII         , SINTH       , TKW
      COMMON /30/  CA(110,30)   , PA(110)     , VA(110)     , XA(110)     ,
     1             NED          , TA(110)
      COMMON /31/  NTP          , SPRT        , TWT(50)     , XRN(50)     ,
     1             RVPT(50)     , TETE(50)
      COMMON /33/  CONPHS       , RNPHIS
      COMMON /34/  DELXT(20)    , NDX         , XDELT(20)   , XMAX
      COMMON /37/  IPRTB
      COMMON /89/  IRB          , XRB(50)
      COMMON /90/  IG

      READ 295, NTP
      READ 225, (XRN(K) ,K=1,NTP)
      READ 225, (TWT(K) ,K=1,NTP)
      READ 225, (RVPT(K),K=1,NTP)
      READ 225, (TETE(K),K=1,NTP)
      WRITE (NTO,101)
  101 FORMAT(*0*)
      IF (IRB .EQ. 0) GO TO 104
      READ 225, (XRB(K), K=1,NTP)
      WRITE (NTO, 106) (K,XRN(K),TWT(K),RVPT(K),TETE(K),XRB(K),K=1,NTP)
  106 FORMAT (*0* 3X*K*5X*X/RN*8X*T-WALL*7X*RV(PYR)*6X*ETA(EDGE)*4X,
     1                  *RB*/( 3X,I2,1X5E13.5)
      GO TO 107
  104 CONTINUE
```

```
      WRITE (NTO,105) (K,XRN(K),TWT(K),RVPT(K),TETE(K),K=1,NTP)
  105 FORMAT(*0* 3X*K*5X*X/RN*8X*T-WALL*7X*RV(PYR)*6X*ETA(EDGE)*/
     1( 3X,I2,1X4E13.5)
  107 CONTINUE
      READ 295, NDX, IPRTB, XMAX, ANGLC
  295 FORMAT(5X,2I5,2E10.0)
      READ 297, (XDELT(NS) , DELXT(NS) ,NS=1,NDX)
  297 FORMAT(5X,2E10.0)
      READ 299, PO, TO, UO, NED
  299 FORMAT(5X,3E10.0,I5)
      ARG    = ANGLC / 57.29578
      SINCO = SIN(ARG)
      TANCO = (TAN (ARG))**2
      PHIS   = (90. - ANGLC) / 57.29578
      SINPH = SIN(PHIS)
      RNPHIS = RN * PHIS
      CONPHS = RN * (SINPH - PHIS * SINCO)
      WRITE (NTO,301)
  301 FORMAT(*1*50X*BODY DATA*/)
      WRITE (NTO,303) IPRTB, XMAX, PO, ANGLC, TO, UO
  303 FORMAT(8X*IPRTB =*I3,19X*XMAX =*F10.5,16X*NORM SH PRESS =*F12.4/
     1                    31X*CONE ANGLE =*F10.5,17X*NORM SH TEMP =*
     2F12.4/71X*NORM SH VEL =*F12.4)
      ND = 14
      IF (NDX .LE. ND) ND = NDX
      WRITE (NTO,305) (XDELT(K),K=1,ND)
  305 FORMAT(*0*6X*X =*F6.2,14F8.2)
      WRITE (NTO,307) (DELXT(K),K=1,ND)
  307 FORMAT(2X*DELT X =*2X,14F8.3)
      IF ( ND .EQ. NDX) GO TO 320
      WRITE (NTO,309) (XDELT(K),K=ND,NDX)
  309 FORMAT(*0*6X*X =*F6.2,7F8.2)
      ND = ND + 1
      WRITE (NTO,307) (DELXT(K),K=ND,NDX)
  320 CONTINUE
      DO 322 K=1,NDX
      XDELT(K)= RN * XDELT(K)
      DELXT(K) = RN * DELXT(K)
  322 CONTINUE
      READ 225 , (XA(ND),ND=1,NED)
      READ 225 , (PA(ND),ND=1,NED)
      READ 225 , (VA(ND),ND=1,NED)
      READ 225 , (TA(ND),ND=1,NED)
      DO 330 I=1,NI
      READ 225 , (CA(ND,I), ND=1,NED)
  330 CONTINUE
      CALL PRTEDG
      DO 340 K=1,NED
      XA(K) = XA(K) * RN
      PA(K) = PA(K) * PO
      VA(K) = VA(K) * UO
      TA(K) = TA(K) * TO
  340 CONTINUE
  225 FORMAT(5X,7E10.0)
      IF (XA(1) .LT. 1.0E-10) GO TO 350
      WRITE (NTO,345)
  345 FORMAT(*0 SUBR. INPBOD FOUND THAT THE FIRST VALUES IN THE EDGE TAB
     1LE NOT FOR X=0.0.*)
      STOP
  350 CONTINUE
      RETURN
      END
```

INPUT

Subroutine INPUT is called to read and print the input data. The input cards, through the third body efficiencies relative to argon (Z), are read and printed by this subroutine. Then the other input subroutine INPBOD is called. INPUT prints the message "END OF INPUT".

Tables of enthalpy and specific heat vs. temperature are in the Block Data subprogram and INPUT determines subscripts for the ones needed for each particular problem (by species name). If any are not present, or located, an error message is printed, "SUBR. INPUT CANT LOCATE ENTHALPY TABLES FOR SOME SPECIES", and a core dump is given before termination of the job. INPUT calls SETOT to set option switches and PR2DSW for some of the 2-D array prints.

Common variables computed are:

$$\left.\begin{array}{lll} \text{CSALPH(K)} & \sim & \alpha_r = \sum_{j=1}^{NJ} \alpha_{rj} - 1, \\ \text{CSBETA(K)} & \sim & \beta_r = \sum_{j=1}^{NJ} \beta_{rj} - 1 \end{array}\right\} K = 1, NR$$

JE(I) ~ subscripts needed to locate enthalpy and specific heat in BLOCK DATA, for species in this problem.

$$\left.\begin{array}{lll} \text{KENE} & = & \text{AENE} \\ \text{KMOM} & = & \text{AMOM} \\ \text{KSPE} & = & \text{ASPE} \end{array}\right\} \text{if KOPT} = 1$$

KKM = NI(NI - 1)/2

NL = NJ - NI

```
      SUBROUTINE INPUT

      COMMON  /1/  NI           , NMAX        , NM2         , NTO         ,
     1             NJ           , NM1         , NR
      COMMON  /3/  IFROZE       , ILE         , MFLAGO      , NEQUIL
      COMMON  /5/  CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON  /8/  FMOLWT(30)   , FMBAR(50)   , FMBARE      , RHO(50)   , R
      COMMON /10/  RN           , TANCO
      COMMON /13/  HINF         , PE          , SMALLE      , TKE       , UE ,
     1             HF(30)       , PINF        , TE          , TINF      , VINF
      COMMON /19/  IPUN         , KOPE        , TOL
      COMMON /20/  ANGLC        , FJ          , SINCO       , TKINF       ,
     1             DUEDX        , PII         , SINTH       , TKW
      COMMON /24/  DN(50)
      COMMON /26/  DBB(30,30)   , FLEJ(30)    , INOP
      COMMON /39/  NKM          , OMW(32)     , WFA(32)
      COMMON /48/  CO(30)       , C2(30)      , D1(30)      , CINF(30)    ,
     1             C1(30)       , D0(30)      , D2(30)
      COMMON /49/  CALPH(30,40),CBETA(30,40),CSALPH(30) , CSBETA(30),IO
      COMMON /50/  IPRT
      COMMON /53/  AMD(435)     , BMD(435)    , CMD(435)    , Z(30,10)
      COMMON /55/  AENE         , ASPE        , KMOM        , KSPE        ,
     1             AMOM         , KENE
      COMMON /59/  KOPT
      COMMON /61/  TITLE(9)
      COMMON /62/  TOT(3,6)
      COMMON /63/  SPN(40)
      COMMON /64/  AMU(30)      , BMU(30)     , CMU(30)
```

```
      COMMON /65/  CK          , DELTA        , IREAD       , OPTN(6) , RS
      COMMON /66/   EIO        , EIO2         , IWC
      COMMON /80/  JE(30)
      COMMON /82/  NIM
      COMMON /89/  IRB         , XRB(50)
      COMMON /90/  IG
      COMMON /AA/  CCP(50,30)  , ENTHA(50,30),TEMP(50)    , IX
      COMMON /BB/  HNAME(30)

      DIMENSION    CHK(4)
      DIMENSION    AR(6,30)
      DATA      (CHK  = 8HBLUNT 2D, 8HSHARP 2D, 8HBLUNT AX, 8HSHARP AX)
      DATA      (BLANK = 4H    )
      DATA       (NTO=61)   ,   (PII=6.283185)

      READ  5, TITLE
      IF (EOF,60) 2,10
2     STOP
5     FORMAT(5X,9A8)
10    CONTINUE
      CALL HOROLOG (TM, DU1, DU2)
      WRITE (NTO,15) TITLE  , DU2
15    FORMAT(*1*19X,9A8/*0*52X*INPUT*20X,A10/)
      READ 25,  NMAX,  NI,  NR,  NJ,  TOL,  CK
25    FORMAT(5X,4I5,3F10.0)
      NL = NJ - NI
      KKM = ((NI*NI)-NI) / 2
      READ 35,  (SPN(J),J=1,NJ)
35    FORMAT(5X,15A5)
      NM1    = NMAX - 1
      NM2    = NMAX - 2
      NIM = NI - 1
      IF (CK .NE. 0.0) GO TO 42
40    CONTINUE
      READ 225,  (DN(N), N=1,NM1)
42    CONTINUE
      READ 45, IPRT, IPUN, IREAD, KOPE, KOPT, AMOM, AENE, ASPE, IWC,
     1        EIO, EIO2
45    FORMAT(5X,5I5,3F5.1,I5,2F10.0)
      GO TO (50,60), KOPT
50    CONTINUE
      KMOM = XFIXF(AMOM)
      KENE = XFIXF(AENE)
      KSPE = XFIXF(ASPE)
60    CONTINUE
      READ 63 , (OPTN(L),L=1,6)
63    FORMAT(5X,7(A8,2X))
      IF (OPTN(5) .EQ. CHK(1)) GO TO 64
      IF (OPTN(5) .EQ. CHK(2)) GO TO 64
      IF (OPTN(5) .EQ. CHK(3)) GO TO 64
      IF (OPTN(5) .EQ. CHK(4)) GO TO 64
      IRB = 0
      GO TO 641
   64 CONTINUE
      IRB = 1
  641 CONTINUE
      READ 65 , RN, RS,  DELTA, TKW
65    FORMAT(5X,4F10.0)
      READ 65 , VINF, PINF, TKINF

      CALL SETOT

      IF (NEQUIL .EQ. 1) IWC = 2
      WRITE (NTO,211) NMAX,  IWC,   CK, RN, VINF, (TOT(I,1),I=1,3)
211   FORMAT(2X*NMAX =*I3,5X*   IWC =*I3,8X*K =*F5.2,10X*RN =*F11.9,6X
     1*VINF =*F12.4,2X,3A8)
      WRITE (NTO,213) NI,  IPRT,  TOL,  RS,       PINF,(TOT(I,2),I=1,3)
213   FORMAT(4X*NI =*I3,7X*IPRT =*I3,6X*TOL =*F9.6,6X*RS =*F11.9,6X
     1*PINF =*F12.4,2X,3A8)
      WRITE (NTO,215) NR, IPUN, DELTA, TKINF,(TOT(I,3),I=1,3)
```

```
215   FORMAT(4X*NR =*I3,7X*IPUN =*I3,23X,*DELTA =*F11.9,5X
     1*TKINF =*F12.4,2X,3A8)
      WRITE (NTO,217) NJ, IREAD, AMOM, TKW, (TOT(I,4),I=1,3)
217   FORMAT(4X*NJ =*I3,6X*IREAD =*I3,5X*AMOM =*F7.4,7X*TKW =*F11.4,26X
     13A8)
      WRITE (NTO,219) KOPE, AENE, EIO, (TOT(I,5),I=1,3)
219   FORMAT(18X*KOPE =*I3,5X*AENE =*F7.4,7X*E O =*F11.4,26X,3A8)
      WRITE (NTO,221) KOPT, ASPE, EIO2, (TOT(I,6),I=1,3)
221   FORMAT(18X*KOPT =*I3,5X*ASPE =*F7.4,6X*E O2 =*F11.4,26X,3A8/)
      NKM = NI + 2
      READ 295, (WFA(NK),NK=1,NKM)
      READ 225 , (FPRIME(N),N=1,NMAX)
225   FORMAT(5X,7E10.0)
      READ 225 ,  (THETA(N),N=1,NMAX)
      DO 226 I=1,NI
226   READ 225 , (CLIL(N,I), N=1,NMAX)
      READ 225 , (CINF(I)   , I=1,NI)
      READ 225 , (HF(I)     , I=1,NI)
      READ 225 , (FLEJ(I)   , I=1,NI)
      READ 225 , (FMOLWT(I), I=1,NI)
      WRITE (NTO,2395)
2395  FORMAT(*0*20X*K   INTERACTION*5X*AMD*10X*BMD*10X*CMD*)
      DO 241 KK=1,KKM
      READ 240,  AAC,AMD(KK), BMD(KK), CMD(KK)
240   FORMAT(A5,3E10.0)
      WRITE (NTO,2405) KK, AAC, AMD(KK), BMD(KK), CMD(KK)
2405  FORMAT(19X,I3,6X,A5,3X,3E13.5)
241   CONTINUE
      DO 242 I=1,NI
      READ 225, AMU(I), BMU(I), CMU(I)
242   CONTINUE
      WRITE (NTO,243) WFA(1), WFA(2)
243   FORMAT(*0*85X*WFAC*/41X*GAS MODEL*34XF6.2*(FPRIME)*/
     1 1X*SPEC*6X*HF*10X*FLEJ*8X*FMOLWT*9X*AMU*10X*BMU*10X*CMU*5XF6.2,
     2*(THETA)*,2X*CINF*)
      WRITE (NTO,245) (SPN(I),HF(I),FLEJ(I),FMOLWT(I),AMU(I),BMU(I),
     1                CMU(I),WFA(I+2), CINF(I), I=1,NI)
245   FORMAT(1X,A5,6E13.5,F6.2,7XE13.5)
      DO 246 K=1,NR
      DO 2462 I=1,6
      AR(I,K) = BLANK
2462  CONTINUE
      DO 246 J=1,NJ
      CALPH(K,J) = 0.0
      CBETA(K,J) = 0.0
246   CONTINUE
      DO 260 K=1,NR
      READ 250, (AR(I,K),I=1,6),C0(K),C1(K),C2(K),D0(K),D1(K),D2(K)
250   FORMAT(6(A4,1X),2(E10.0,2F5.0))
      DO 260 J=1,NJ
      DO 260 L=1,3
      LL = L + 3
      IF (SPN(J) .NE. AR(L,K)) GO TO 252
      CALPH(K,J) = CALPH(K,J) + 1.0
252   CONTINUE
      IF (SPN(J) .NE. AR(LL,K)) GO TO 260
      CBETA(K,J) = CBETA(K,J) + 1.0
260   CONTINUE
      DO 264 K=1,NR
      S1 = 0.0
      S2 = 0.0
      DO 262 J=1,NJ
      S1 = S1 + CALPH(K,J)
      S2 = S2 + CBETA(K,J)
262   CONTINUE
      CSALPH(K) = S1 - 1.0
      CSBETA(K) = S2 - 1.0
264   CONTINUE
      WRITE (NTO,275)
275   FORMAT(*0 K*12X*REACTION*16X*C0*11X*C1*8X*C2*6X*D0*11X*D1*8X*D2*
```

```
     16X*CSALPH*4X*CSBETA*)
      WRITE (NTO,277) (K,(AR(I,K),I=1,6),C0(K),C1(K),C2(K),
     1    D0(K),D1(K),D2(K),CSALPH(K),CSBETA(K),K=1,NR)
277   FORMAT(1X,I2,1X,A4* *A4* *A4*=*A4* *A4* *A4,2(E12.3,2F10.2),
     1    2F10.2)
      WRITE (NTO,279)
279   FORMAT(*1*44X*STOICHIOMETRIC COEF.*)
      CALL PR2DSW ( CALPH,  NR,  NJ, 1)
      CALL PR2DSW ( CBETA,  NR,  NJ, 2)
      DO 290 L=1,NL
      READ 295 , (Z(I,L), I=1,NI)
290   CONTINUE
295   FORMAT(5X,15F5.2)
      CALL PR2DSW (     Z ,  NI,  NL, 3)
      DO 330 I=1,NI
      DO 320 K=1,30
      IF (SPN(I) .NE. HNAME(K) ) GO TO 320
      JE(I) = K
      GO TO 330
320   CONTINUE
      WRITE (NTO,325)
325   FORMAT(*0 SUBR. INPUT CANT LOCATE ENTHALPY TABLES FOR SOME SPECIES
     1.*)
      CALL DUMP
330   CONTINUE
      CALL INPBOD
      WRITE (NTO,345)
345   FORMAT(*0*48X*END OF INPUT*//)
      RETURN
      END
```

KUTTAM

Subroutine KUTTAM is the subroutine which does the Runge-Kutta solution of the ordinary differential equation to find the radius of the body when the shape is a hyperboloid. KUTTAM calls DERIV for the value of the derivative.

```
      SUBROUTINE KUTTAM (X1, X2, HO, Y )
      DATA  (TOL=.0001)
      XR  = X1
      H   = HO
    2 CONTINUE
      H   = AMIN1(H,X2-XR)
      HH  = 2.0 * H
      H23 = HH / 3.0
      H13 = H23 / 2.0
      H16 = H13 / 2.0
      H12 = H / 2.0
      H32 = 3.0 * H12
      H18 = H / 8.0
      H38 = 3.0 * H18
      XR1 = XR + H
      CALL DERIV (Y,FOO)
      YT1 = Y + H13 * FOO
      CALL DERIV (YT1, F31)
      YT1 = Y + H16 * FOO + H16 * F31
      CALL DERIV (YT1 , F32)
      YT1 = Y + H18 * FOO + H38 * F32
      CALL DERIV (YT1,F23)
      YT1 = Y + H12*FOO - H32 * F32 + HH * F23
      CALL DERIV (YT1, F14)
      TM = 0.0
      YT2 = Y + H16 * FOO + H23 * F23 + H16 * F14
      TRUNC = ABS(YT2 - YT1) / TOL
      TM    = AMAX1 (TM,TRUNC)
      TM    = AMAX1 (TM, .001)
      H     = H * ((.2/TM)**.2 )
      IF (TM .GT. 1.0) GO TO 2
      Y   = YT2
      XR = XR1
      IF ( XR1 .LT. X2 ) GO TO 2
      RETURN
      END
```

MCDIFF

Subroutine MCDIFF computes the multicomponent Lewis-Semenov numbers and is called by THERMO if the input option requests calculated Lewis numbers. MCDIFF is called for each value of N (each point across the boundary layer). The variable DBB is needed at NI x NI points for each N and since the values at N = 1 are needed by subroutine BLC, the N loop in THERMO is done in reverse order to leave the proper values in core without increasing the storage requirement. MCDIFF calls GAUSS3 to invert the matrix. See equations (2) and (84) through (86).

Common variables computed are:

DBB(J,K) - $\Delta \bar{\bar{b}}_{ik}$, eq. (2)

FLEJ(I) - Le_i , eq. (2)

```
      SUBROUTINE MCDIFF

      COMMON  /1/  NI            , NMAX        , NM2          , NTO         ,
     1             NJ            , NM1         , NR
      COMMON  /5/  CLIL(50,30),  FPRIME(50)  , THETA(50)
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)   , FMBARE       , RHO(50)    , R
      COMMON /26/  DBB(30,30)  , FLEJ(30)    , INOP
      COMMON /53/  AMD(435)    , BMD(435)    , CMD(435)     , Z(30,10)
      COMMON /68/  CON         , N           , SPB          , TK
      COMMON /82/  NIM

      DIMENSION         CLI(30,30)     , FB(30,30)        , FM(30,30)      ,
     1                  DEL(30,30)
      EQUIVALENCE       (CLI,FM    )   , (DEL,FB )
      DO 2 I=1,NI
      DO 2 K=1,NI
    2 DEL(I,K) = 0.0
      JM   = 1
      KK   = 1
      TKLN = ALOG(TK)
      DO 20 K=1,NIM
      JM   = JM + 1
      DO 10 I =JM,NI
      DBAR = EXP((AMD(KK)*TKLN + BMD(KK))*TKLN + CMD(KK))
      DD    = DBAR * 1.0764E-3  / SPB
      DEL(I,K) = CON * DD
      DEL(K,I) = DEL(I,K)
      KK = KK + 1
   10 CONTINUE
   20 CONTINUE
      DO 50  I=1,NI
      SUM  = 0.
      SUM1 = 0.
      DO 40 K=1,NI
      IF (K .EQ. I) GO TO 40
      T1   = CLIL(N,K) / FMOLWT(K)
      SUM  = SUM + T1
      SUM1 = SUM1 + T1 / DEL(I,K)
   40 CONTINUE
      FLEJ(I) = SUM / SUM1
   50 CONTINUE
      DO 100 K=1,NI
      DO 100 I=1,NI
      IF (I .EQ. K) GO TO 80
      SUM = 0.
      DO 70 L=1,NI
      IF (L .EQ. I) GO TO 70
      SUM = SUM + CLIL(N,L) / (FMOLWT(L) * DEL(I,L))
   70 CONTINUE
      FM(I,K) = CLIL(N,I) / DEL(I,K) + FMOLWT(K) * SUM
```

```
      GO TO 100
80    CONTINUE
      FM(I,K) = 0.0
100   CONTINUE
      CALL GAUSS3 (NI, .00001, FM, FB, KER)
      IF (KER .EQ. 2) GO TO 150
      DO 110 I=1,NI
      DO 110 K=1,NI
      CLI(I,K) = FB(I,K) - FMOLWT(I) * FB(I,I) / FMOLWT(K)
110   CONTINUE
      DO 130 K=1,NI
      DO 130 I=1,NI
      SUM = 0.
      DO 120 L=1,NI
      SUM = SUM + CLI(I,L) * CLIL(N,L)
120   CONTINUE
      DBB(I,K) = FLEJ(I) - (FMOLWT(I)*CLI(I,K)/FMBAR(N)
     1                 + (1.0 - FMOLWT(I)/FMOLWT(K)) * SUM)
130   CONTINUE
      GO TO 160
150   CONTINUE
      WRITE (NTO,155)
155   FORMAT(*0 MCDIFF FOUND THAT MATRIX IS SINGULAR.*)
      STOP
160   CONTINUE
      RETURN
      END
```

MOMEQ

Subroutine MOMEQ computes the coefficients and sets boundary values for the solution of the momentum equation (f'). For the initial profile calculation one may iterate inside MOMEQ. The calculation is done KMOM times if KOPT = 1, or if KOPT = 2 the calculation is repeated until CHECK ≤ AMOM. CHECK is computed in WKHS. When a new f' has been found CALCV is called to compute new values of V. The coefficients are the α's described in equations (20a) through (20d). The boundary conditions are:

$$\left.\begin{aligned} A(1) &= 9. \\ B(1) &= 1.0 \\ D(1) &= 0.0 \end{aligned}\right\} \quad \text{eq. (47a)}$$

$$\begin{aligned} B(NMAX) &= 1.0 \\ C(NMAX) &= 0.0 \\ D(NMAX) &= 1.0 \end{aligned}$$

The appropriate weight factor is set. If body profiles are being calculated (IBS = 2), the previous value of $FPRIME(N)_m$ is saved in FP(N) before calling WKHS to calculate the new $FPRIME(N)_{m+1}$.

If a shock layer is being computed CALEBB is called to compute $\bar{\bar{e}}$ at each point across the shock layer.

```
      SUBROUTINE MOMEQ
      COMMON  /1/  NI          , NMAX        , NM2         , NTO        ,
     1             NJ          , NM1         , NR
      COMMON  /2/  M
      COMMON  /4/  FL(50)      , IBS
      COMMON  /5/  CLIL(50,30) , FPRIME(50)  , THETA(50)
      COMMON  /6/  CL(50,30)   , FP(50)      , TH(50)
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)   , FMBARE      , RHO(50)    , R
      COMMON /28/  BETA        , CTH
      COMMON /38/  BEBB(50)
      COMMON /39/  NKM         , OMW(32)     , WFA(32)
      COMMON /40/  IBRDYO      , V(50)
      COMMON /55/  AENE        , ASPE        , KMOM        , KSPE       ,
     1             AMOM        , KENE
      COMMON /57/  ALPH1(50)   , ALPH4(50)   , ISPC        , OMWF       ,
     1             ALPH2(50)   , CHECK       , MFLAG       , WFAC       ,
     2             ALPH3(50)
      COMMON /58/  A(50)       , B(50)       , C(50)       , D(50)
      COMMON /59/  KOPT
      COMMON /72/  FLPR(50)

      ISPC    = 1
      A(1)    = 0.0
      B(1)    = 1.0
      D(1)    = 0.0
      B(NMAX) = 1.0
      C(NMAX) = 0.0
      D(NMAX) = 1.0
      WFAC = WFA(1)
      OMWF = OMW(1)
      GO TO (10,50) , IBS
   10 CONTINUE
      MFLAG = 0
   20 CONTINUE
      MFLAG = MFLAG + 1
      GO TO (50,30) , IBRDYO
   30 CONTINUE
      CALL CALEBB
```

```
50      CONTINUE
        DO 110 N=2,NM1
        OOFL = 1.0 / FL(N)
        FTF  = FMBARE * THETA(N) / FMBAR(N)
        FPSQ = FPRIME(N) * FPRIME(N)
        FPSQB = FPSQ * BETA
        ALPH1(N) = (FLPR(N) - V(N)) * OOFL
        ALPH2(N) = -2.0 * OOFL * BETA * FPRIME(N)
        GO TO (60,70) , IBRDYO
60      CONTINUE
        ALPH3(N) = (FPSQB - BEBB(NMAX) * FTF) * OOFL
        GO TO 80
70      CONTINUE
        ALPH3(N) = (FPSQB - BEBB(N) * FTF) * OOFL
80      CONTINUE
        GO TO (110,90) , IBS
90      CONTINUE
        CALL DERVDN (FPRIME, DFP , 1, N)
        CALL DERVDN (FPRIME, SDRFP, 2, N)
        CF   = SDRFP + ALPH1(N) * DFP - OOFL * (FPSQB + BEBB(NMAX)*FTF)
        ALPH2(N) = ALPH2(N) - CF / FPRIME(N)
        ALPH3(N) = ALPH3(N) + CF
        ALPH4(N) = -FPRIME(N) * OOFL
110     CONTINUE
        GO TO (140,120) , IBS
120     CONTINUE
        DO 130 N=1,NMAX
130     FP(N) = FPRIME(N)
140     CONTINUE
        CALL WKHS (FPRIME)
        CALL CALCV
        GO TO (150,180) , IBS
150     CONTINUE
        GO TO (160,170) , KOPT
160     IF (MFLAG .LT. KMOM) GO TO 20
        GO TO 180
170     IF ( CHECK .GT. AMOM ) GO TO 20
180     CONTINUE
        RETURN
        END
```

PCH

Subroutine PCH writes a tape in BCD for punching. The tape is logical unit 61. Cards punched may be used as input (partial) for a succeeding run. Identified by card name, the cards punched are: TITLE, LIMTS, SPNA, DNS, CONTR, OPTN, SIZE, FRSTR, WFACS, FPRIM, THETA, CLIL and BODSP.

PCH is called by BLC if: 1. The input value IPUN > 0, and, 2. the initial profiles are converged, or time is about gone, or the maximum number of iterations have been done on the initial profiles.

```
      SUBROUTINE  PCH
      COMMON  /1/  NI          , NMAX       , NM2        , NTO        ,
     1             NJ          , NM1        , NR
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /7/  ICOMPO
      COMMON /10/  RN          , TANCO
      COMMON /13/  HINF        , PE         , SMALLE     , TKE        , UE ,
     1             HF(30)      , PINF       , TE         , TINF       , VINF
      COMMON /19/  IPUN        , KOPE       , TOL
      COMMON /20/  ANGLC       , FJ         , SINCO      , TKINF      ,
     1             DUEDX       , PII        , SINTH      , TKW
      COMMON /24/  DN(50)
      COMMON /34/  DELXT(20)   , NDX        , XDELT(20)  , XMAX
      COMMON /37/  IPRTB
      COMMON /39/  NKM         , OMW(32)    , WFA(32)
      COMMON /50/  IPRT
      COMMON /55/  AENE        , ASPE       , KMOM       , KSPE       ,
     1             AMOM        , KENE
      COMMON /59/  KOPT
      COMMON /61/  TITLE(9)
      COMMON /63/  SPN(40)
      COMMON /65/  CK          , DELTA      , IREAD      , OPTN(6) , RS
      COMMON /66/   EIO        , EIO2       , IWC

      DATA     (IP=62)
      WRITE (IP,261)
  261 FORMAT(80(1H,))
      WRITE (IP,263) TITLE
  263 FORMAT(*TITLE*9A8)
      WRITE (IP,265) NMAX, NI,  NR,  NJ,  TOL,  CK
  265 FORMAT(*LIMTS*4I5,3F10.6)
      WRITE (IP,267) (SPN(J),J=1,NJ)
  267 FORMAT(*SPNA *15A5)
      IF (CK .NE. 0.0) GO TO 270
      WRITE (IP,268) (DN(N),N=1,NM1)
  268 FORMAT(*DNS  *,7F10.7)
 270  CONTINUE
      WRITE (IP,269) IPRT, IPUN, IREAD, KOPE, KOPT, AMOM,
     1              AENE,  ASPE, IWC, EIO, EIO2
  269 FORMAT(*CONTR*5I5,3F5.3,I5,2F10.4)
      WRITE (IP,271) (OPTN(I),I=1,6)
  271 FORMAT(*OPTN *6(A8,2X))
      WRITE (IP,273) RN, RS, DELTA, TKW
 273  FORMAT(*SIZE *3F10.8,F10.4)
      WRITE (IP,277) VINF, PINF, TKINF
  277 FORMAT(*FRSTR*F10.3,2F10.4)
      WRITE (IP,276) (WFA(NK),NK=1,NKM)
  276 FORMAT(*WFACS*15F5.2)
      WRITE (IP,2772) (FPRIME(N),N=1,NMAX)
 2772 FORMAT(*FPRIM*,7F10.7)
      WRITE (IP,2774) (THETA(N) ,N=1,NMAX)
 2774 FORMAT(*THETA*,7F10.7)
      DO 278 I=1,NI
      WRITE (IP,2776) (CLIL(N,I),N=1,NMAX)
 2776 FORMAT(*CLIL *,7F10.7)
```

```
 278    CONTINUE                                                    PCH   57
        WRITE (IP,2778) NDX, IPRTB, XMAX, ANGLC                      PCH   58
 2778   FORMAT(*BODSP*2I5,2F10.6)                                   PCH   59
        WRITE (IP,261)                                              PCH   60
        RETURN                                                      PCH   61
        END                                                         PCH   62
```

POLATE
DPOLATE

The POLATE subroutine interpolates using Lagrangian interpolation to find Y as f(T). DPOLATE, second entry to the subroutine, calculates the slope of Y as f(T).

A call to DPOLATE must be preceded by a call to POLATE with the same arguments.

The arguments are:

T	- independent variable.
TTAB	- table of independent variable.
YTAB	- table of dependent variable vs TTAB.
ANS	- value of Y corresponding to T, or for DPOLATE, value of slope of Y.
K	- length of tables.

In addition, two variables from common are used by POLATE:

IDYS	0	- DPOLATE will not be called.
	≠0	- signals POLATE that DPOLATE will be called so values that will be needed are calculated.
ICHGSW	-1	- search for the correct spot in the table to interpolate and set ICHGSW to 0.
	0	- check T and if it is the same as T in previous call, interpolate (no search).
	+1	- search for correct spot in table for interpolation and leave ICHGSW = +1.

The search for the correct location for interpolation is done by dividing the table in half, determining the correct half, then dividing that portion in half and again determining the correct half, etc., until the nearest three points are located. The table should contain at least three points, (K ≥ 3). If K = 2, linear interpolation is done but the slope is not calculated.

```
      SUBROUTINE POLATE (T, TTAB, YTAB, ANS, K)

      COMMON /14/  ICHGSW     , IDYS

      DIMENSION TTAB(1), YTAB(1)
      DATA (A1=8HSMALLEST),(A2=7HLARGEST)
      ITYP=69
      GO TO 2
      ENTRY DPOLATE
      ITYP=0
 2    CONTINUE
      IX = K
      IX1 = IX - 1
      IX2 = IX - 2
      IF ( IX1 ) 54, 8, 4
 4    IF (ICHGSW) 6,46,8
 6    ICHGSW=0
 8    IF (T-TTAB(2)) 10,12,14
 10   IF (T.LT.TTAB) WRITE (61,58) T,A1,TTAB
 12   IM=2
      GO TO 19
 14   IF (T - TTAB(IX1)) 20,18,16
 16   IF (T .GT. TTAB(IX)) WRITE (61,58) T,A2,TTAB(IX)
 18   IM = IX1
 19   IF ( IX2 ) 30,30,34
 20   IL=2
```

```
      IU = IX1
22    IDEL=IU-IL
      IF (IDEL-1) 32,32,24
24    IM=IDEL/2+IL
      IF (T-TTAB(IM)) 26,34,28
26    IU=IM
      GO TO 22
28    IL=IM
      GO TO 22
30    ANS=YTAB+(T-TTAB)*(YTAB(2)-YTAB)/(TTAB(2)-TTAB)
      GO TO 56
32    IM=IU
      IF ((TTAB(IU)-T).GT.(T-TTAB(IL))) IM=IL
34    DM1=TTAB(IM)-TTAB(IM-1)
      DP1=TTAB(IM+1)-TTAB(IM)
      DP2=TTAB(IM+1)-TTAB(IM-1)
      P1=DP2*DM1
      P2=-DM1*DP1
      P3=DP2*DP1
      DO=T-TTAB(IM)
      DM1=T-TTAB(IM-1)
      DP1=T-TTAB(IM+1)
      CM1=DO*DP1/P1
      CO=DM1*DP1/P2
      CP1=DM1*DO/P3
      IF (IDYS) 36,38,36
36    DCM1=(DO+DP1)/P1
      DCO=(DM1+DP1)/P2
      DCP1=(DM1+DO)/P3
38    TO=T
40    IF (ITYP) 42,44,42
42    ANS=CM1*YTAB(IM-1)+CO*YTAB(IM)+CP1*YTAB(IM+1)
      GO TO 56
44    ANS=DCM1*YTAB(IM-1)+DCO*YTAB(IM)+DCP1*YTAB(IM+1)
      GO TO 56
46    IF (T-TO) 48,40,48
48    IF (T-TTAB(IM)) 50,34,52
50    IL=1
      IU=IM
      IF (T-TTAB(2)) 10,12,22
52    IL=IM
      IU = IX1
      IF ( T - TTAB(IX1)) 22,18,16
54    WRITE (61, 60) IX
      ANS=YTAB
56    CONTINUE
C
C
58    FORMAT (*0WARNING  -  POLATE CALLED TO INTERPOLATE FOR T=*E16.8,3X
     1A8,* VALUE IN TABLE IS*E16.8)
60    FORMAT (*0WARNING  -  POLATE CALLED WITH ILLEGAL N*I16)
      RETURN
      END
```

PRECAL

Subroutine PRECAL is the initializing subroutine and is called once per problem. One-time calculations are done here. CALDNS is called to compute η and combinations of $\Delta\eta$ across the boundary layer. CC1 is called to obtain some enthalpy values. EQUIL may be called to compute c_{i_e} and/or c_∞. For a shock layer calculation HUGNOT is called to compute the initial edge conditions, PE, UE, RHOE and TKE. POLATE is called to interpolate for the initial value of η_e. PRTPRO is called to print the initial profile. Other values printed by PRECAL are: SMALLE, DUEDX, HO, ETE and CTH.

Input values changed in PRECAL are:

$$\left.\begin{aligned} CO(J) &= \ln CO(J) \\ C1(J) &= 1000.\ C1(J) \\ DO(J) &= \ln DO(J) \\ D1(J) &= 1000.\ D1(J) \end{aligned}\right\} \quad J = 1,\ NR$$

```
      SUBROUTINE PRECAL

      COMMON       WBAR(50,30), WONE(50,30), WTH(50,30) , WZERO(50,30)
      COMMON  /1/  NI          , NMAX       , NM2        , NTO         ,
     1             NJ          , NM1        , NR
      COMMON  /3/  IFROZE      , ILE        , MFLAGO      , NEQUIL
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /7/  ICOMPO
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)  , FMBARE     , RHO(50)    , R
      COMMON  /9/  IGEOM       , JBOD
      COMMON /10/  RN          , TANCO
      COMMON /11/  DEN2(50)    , ETE        , VONE
      COMMON /12/  RHOE        , RHOINF     , RMUREF
      COMMON /13/  HINF        , PE         , SMALLE     , TKE        , UE ,
     1             HF(30)      , PINF       , TE         , TINF       , VINF
      COMMON /14/  ICHGSW      , IDYS
      COMMON /17/  IDX         , RB12       , VE1        ,
     1             DELXN       , TE1        , X1
      COMMON /20/  ANGLC       , FJ         , SINCO      , TKINF      ,
     1             DUEDX       , PII        , SINTH      , TKW
      COMMON /21/  CFINF       , FMDOT(30)  , QCOND      , RSUM       ,
     1             DISPTK      , FMOTH      , QCONV      , SKFER      ,
     2             DRAG2       , HE(50)     , QDIFF      , ST         ,
     3             DRAGP2      , HXTFEB     , QTFTLB     , TLEFT      ,
     4             DRAGT2      , HXTFER     , QTOTAL     , YF(50)     ,
     5             FDENS(50)   , PARDOT(30) , RMFLUX(30) , REVE
      COMMON /22/  CSAVE(30)   , FPSAVE     , RHVINF     , SQRT2      ,
     1                           HO         , SQRT1      , THSAVE     , TK1
      COMMON /24/  DN(50)
      COMMON /25/  RVB
      COMMON /26/  DBB(30,30)  , FLEJ(30)   , INOP
      COMMON /27/  CPBAR(50)   , FFMU       , RES        , UE2TE      ,
     1             ENTAPY(50,30)
      COMMON /28/  BETA        , CTH
      COMMON /29/  CEDG(30)
      COMMON /30/  CA(110,30)  , PA(110)    , VA(110)    , XA(110)    ,
     1             NED         , TA(110)
      COMMON /31/  NTP         , SPRT       , TWT(50)    , XRN(50)    ,
     1             RVPT(50)    , TETE(50)
      COMMON /32/  TW
      COMMON /36/  ETESQ       , SPFI(50)   , TXIE
      COMMON /37/  IPRTB
      COMMON /38/  BEBB(50)
      COMMON /39/  NKM         , OMW(32)    , WFA(32)
      COMMON /40/  IBRDYO      , V(50)
      COMMON /41/  ETA(50)
      COMMON /46/  EDBLT1      , EDBLT2     , EP2
```

```
      COMMON /47/  DIFA(30,30), GAMMIN(30,40),GAMPLS(30,40)
      COMMON /48/  C0(30)        , C2(30)       , D1(30)        , CINF(30)     ,
     1             C1(30)        , D0(30)       , D2(30)
      COMMON /49/  CALPH(30,40),CBETA(30,40),CSALPH(30) , CSBETA(30),IO
      COMMON /60/  IN2           , IO2
      COMMON /63/  SPN(40)
      COMMON /65/  CK            , DELTA        , IREAD         , OPTN(6)  , RS
      COMMON /67/  ICO           , ICO2         , IM1           , IM3      , IN  ,
     1             IC1           , IEL          , IM2           , IM4      , INO
      COMMON /69/  CONTH(30,30),FMOLWR(30) , THTHA(30,30),EPSI       , TSA
      COMMON /77/   FMBARI       , SS
      COMMON /79/   RSQMWT(30)
      COMMON /80/  JE(30)
      COMMON /AA/  CCP(50,30) , ENTHA(50,30),TEMP(50)     , IX

      DIMENSION    TMTH(30)      , TST(14)      , ISB(14)
      DATA  (TST =6HO       ,6HNO+     ,6HN2      ,6HO2      ,
     1             6HCO     ,6HCO2     ,6HN       ,6HNO      ,6HC1      ,
     2             6HEL     ,6HM1      ,6HM2      ,6HM3      ,6HM4      )
      DATA           (SQRT8 = 2.828427)
      DO 1 NK=1,NKM
      OMW(NK) = 1.0 - WFA(NK)
1     CONTINUE
      CTH     = 1.0
      ICHGSW = -1
      R       = 49686.0
      IF (IBRDYO .EQ. 2) GO TO 1002
      UE   = VA(1)
      PE   = PA(1)
      TE   = TA(1)
      TKE = TE / 1.8
      DO 1001 I=1,NI
      CLIL(NMAX,I) = CA(1,I)
1001  CONTINUE
1002  CONTINUE
      TW       = TKW * 1.8
      TINF     = TKINF * 1.8
      FPSAVE = 0.0
      THSAVE = 0.0
      RVB  = 0.0
      SPRT = 0.0
      IDYS = 0
      CALL POLATE (SPRT, XRN, TETE, ETE, NTP)
      ETESQ = ETE * ETE
      DO 1004 K=1,14
      ISB(K)  = 0
1004  CONTINUE
      IF (CK .EQ. 0.0) GO TO 2008
      IF (CK .NE. 1.0) GO TO 2004
      DNN = 1.0 / FLOAT(NM1)
      DO 2002 N=1,NM1
      DN(N) = DNN
2002  CONTINUE
      GO TO 2008
2004  CONTINUE
      DN(1) = (CK - 1.0) / (CK**NM1 - 1.0)
      DO 2006 N=2,NM1
      DN(N) = DN(N-1) * CK
2006  CONTINUE
2008  CONTINUE
      CALL CALDNS
      ICHGSW = -1
      DO 2 K=1,14
      DO 2 J=1,NJ
      IF (SPN(J) .NE. TST(K)) GO TO 2
      ISB(K) = J
2     CONTINUE
      IO   = ISB(1)
      INOP = ISB(2)
      IN2  = ISB(3)
      IO2  = ISB(4)
```

```
      ICO   = ISB(5)
      ICO2  = ISB(6)
      IN    = ISB(7)
      INO   = ISB(8)
      IC1   = ISB(9)
      IEL   = ISB(10)
      IM1   = ISB(11)
      IM2   = ISB(12)
      IM3   = ISB(13)
      IM4   = ISB(14)
      DO 4 J=1,NR
      CO(J) = ALOG(CO(J))
      DO(J) = ALOG(DO(J))
      C1(J) = C1(J) * 1000.
      D1(J) = D1(J) * 1000.
    4 CONTINUE
      DO 10 K=1,NI
      CSAVE(K) = 0.0
      DO 10 I=1,NI
      DBB(I,K) = 0.0
   10 CONTINUE
      DO 30 I=1,NI
      DO 30 K=1,NR
      GAMPLS(K,I) = 0.0
      GAMMIN(K,I) = 0.0
      GDIF          = CBETA(K,I) - CALPH(K,I)
      IF ( GDIF ) 12,20,14
   12 CONTINUE
      GAMMIN(K,I) = - GDIF
      GO TO 20
   14 CONTINUE
      GAMPLS(K,I) =    GDIF
   20 CONTINUE
      DIFA(K,I)   =    GDIF
   30 CONTINUE
      FJ     = FLOAT (JBOD)
      IF ( CINF(1) + CINF(2) .GT. 0.0 ) GO TO 34
      CALL EQUIL ( TINF, PINF, 0 )
C                                    CINF COMPUTED IN EQUIL
   34 CONTINUE
      GO TO (40,60) , ICOMPO
   40 CONTINUE
      IF (IBRDYO .EQ. 2) GO TO 50
      IF (CLIL(NMAX,1) + CLIL(NMAX,2) .GT. 0.0) GO TO 60
      CALL EQUIL (TE, PE, NMAX)
C                                    CLIL AT EDGE COMPUTED IN EQUIL
      GO TO 60
   50 CONTINUE
      DO 52 I=1,NI
      CLIL(NMAX,I) = CINF(I)
   52 CONTINUE
   60 CONTINUE
      DO 62 I=1,NI
      CEDG(I) = CLIL(NMAX,I)
   62 CONTINUE
      IF (CLIL(1,1) + CLIL(1,2) .GT. 0.0 ) GO TO 70
      CLIL(1,1) = .2328
      CLIL(1,2) = .7672
   70 CONTINUE
      IRNSW = 1
      IF (NEQUIL .EQ. 1 .OR. IREAD .EQ. 1 ) IRNSW = 2
      DO 100 N=1,NMAX
      CSUM = 0.0
      DO  90 I=1,NI
      GO TO ( 75, 80 ) , IRNSW
   75 CONTINUE
      CLIL(N,I) = CLIL(1,I) + (CLIL(NMAX,I) - CLIL(1,I)) * FPRIME(N)
   80 CONTINUE
      CSUM  = CSUM + CLIL(N,I) / FMOLWT(I)
   90 CONTINUE
      FMBAR(N) = 1.0 / CSUM
```

```
100   CONTINUE
      FMBARE = FMBAR(NMAX)
      CSUM    = 0.0
      HINF    = 0.0
      DO 110 I=1,NI
      HJ      = CC1(TKINF,I) * TINF + HF(I)
      HINF    = HINF + CINF(I) * HJ
      ENTAPY(1,I) = CC1(TKW, I) * TW + HF(I)
      CSUM    = CSUM + CINF(I) / FMOLWT(I)
110   CONTINUE
      FMBARI = 1.0 / CSUM
      RHOINF = PINF * FMBARI / TINF / R
      HO      = VINF**2 / 2.0
      RHVINF = RHOINF * HO
      HO      = HO + HINF
      TK1     = RHOINF * VINF
      GO TO ( 130, 140 ) , IBRDYO
130   CONTINUE
      DO 131 N=1,NMAX
      BEBB(N) = 0.0
131   CONTINUE
      RHOE   = PE * FMBARE / TE / R
      IF (IGEOM .LT. 0) GO TO 136
      DUEDX = VA(2) / XA(2)
      IF (PE .EQ. PA(6)) GO TO 134
      EBB = -RHOE * VA(6) * VA(6) * .5 / (PE - PA(6))
      GO TO 136
134   CONTINUE
      EBB = -1.0
136   CONTINUE
      GO TO 150
140   CONTINUE
      SS      = (RN/RS) * ( 1.0 + (DELTA/RN) )
      CALL HUGNOT (1)
C                                       PE,UE,RHOE,TKE COMPUTED FOR SHOCK L.
150   CONTINUE
      EPSI = RHOINF / RHOE
      EP2   = -2.0 * EPSI
      VE1 = UE
      GO TO ( 170, 160 ) , IBRDYO
160   CONTINUE
      TE      = TKE * 1.8
      TS3     = 1.0 - 1.0/SS
      TS2     = 1.0 - EPSI
      TS1     = SS * TS2 + EPSI
      TS4     = (1.0 + FJ ) * TS1
      EDBL    = 1.0 - EPSI * TS3
      EDBLT1 = TS2 / EDBL**2
      EBB =  1.0 / (EP2 * EDBLT1)
      DUEDX  = VINF * TS1 / RN
170   CONTINUE
      IF ( IREAD .EQ. 1 ) GO TO 200
      ETAE     = ETA(NMAX)
      THW     = TKW / TKE
      OMTHW  = 1.0 - THW
      DO 190 N=1,NMAX
      ETAR       = ETA(N) / ETAE
      THETA(N) = THW + OMTHW * ETAR * (2.0 - ETAR)
190   CONTINUE
200   CONTINUE
      WRITE (NTO, 205)
205   FORMAT(*1*49X*INITIAL PROFILE*)
      CALL PRTPRO
      IF ( IGEOM ) 210,220,220
210   CONTINUE
C                                       CONE
      BETA    = 0.0
      SMALLE = 0.0
      DUEDX  = 0.0
      CONS    = 2.0
      GO TO 230
220   CONTINUE
```

```
C                                SPHERE CONE OR HYPERBOLOID                    PREC 262
      DEN    = 1.0 + FJ                                                        PREC 263
      BETA   = 1.0 / DEN                                                       PREC 264
      SMALLE = BETA / DUEDX                                                    PREC 265
      CONS   = 4.0                                                             PREC 266
      BEBB(NMAX) = BETA / EBB                                                  PREC 267
  230 CONTINUE                                                                 PREC 268
      WRITE (NTO,235) SMALLE, DUEDX, HO, ETE, CTH                              PREC 269
  235 FORMAT(*0*8X*SMALLE =*E12.5,6X*DUEDX =*E12.5,9X*HO =*E12.5,              PREC 270
     18X*ETE =*E12.5,6X*CTH =*E12.5)                                           PREC 271
      UE2TE = UE**2 / TE                                                       PREC 272
      SQRT1 = SQRT(4. * FJ + CONS)                                             PREC 273
      SQRT2 = SQRT1 / 2.0                                                      PREC 274
      DO 240 I=1,NI                                                            PREC 275
      FMOLWR(I) = FMOLWT(I) / R                                                PREC 276
      TMTH(I)   = FMOLWT(I)**.25                                               PREC 277
      RSQMWT(I) = 1.0 / SQRT(FMOLWT(I))                                        PREC 278
  240 CONTINUE                                                                 PREC 279
      DO 250 K=1,NI                                                            PREC 280
      DO 250 I=1,NI                                                            PREC 281
      CONTH(I,K) = SQRT8 * SQRT(1.0 + FMOLWT(I) / FMOLWT(K))                   PREC 282
      TMTHA(I,K) = TMTH(I) / TMTH(K)                                           PREC 283
  250 CONTINUE                                                                 PREC 284
      DO 260 N=1,NMAX                                                          PREC 285
      EDENS(N)   = 0.0                                                         PREC 286
      DO 260 I=1,NI                                                            PREC 287
      WBAR(N,I)  = 0.0                                                         PREC 288
      WONE(N,I)  = 0.0                                                         PREC 289
      WTH(N,I)   = 0.0                                                         PREC 290
      WZERO(N,I) = 0.0                                                         PREC 291
  260 CONTINUE                                                                 PREC 292
      RETURN                                                                   PREC 293
      END                                                                      PREC 294
```

PRTBL

Subroutine PRTBL is a print subroutine called by BLC and prints the output for each profile. There is one argument to PRTBL, IPSW. Its value (used for initial profiles only) is determined by BLC and may be:

1 - initial profile converged

2 - time is about gone

3 - maximum iterations done on initial profile

4 - none of the above conditions exist, but have finished one profile.

For an initial profile call and IPSW = 4, the entire profile is printed if MFLAGO is an integer multiple of IPRT; otherwise, only one line is printed giving MFLAGO, Stanton number, skin friction and amount of time left. If IPSW $\neq$ 4, an appropriate message is printed plus the entire profile.

When IBS = 2, body profiles, the profile values are printed if M is an integer multiple of IPRTB.

```
      SUBROUTINE PRTBL (IPSW)

      COMMON  /1/  NI           , NMAX        , NM2         , NTO          ,
     1             NJ           , NM1         , NR
      COMMON  /2/  M
      COMMON  /3/  IFROZE       , ILE         , MFLAGO      , NEQUIL
      COMMON  /4/  FL(50)       , IBS
      COMMON  /7/  ICOMPO
      COMMON  /8/  FMOLWT(30)   , FMBAR(50)   , FMBARE      , RHO(50)    , R
      COMMON /21/  CFINF        , FMDOT(30)   , QCOND       , RSUM         ,
     1             DISPTK       , FMOTH       , QCONV       , SKFER        ,
     2             DRAG2        , HE(50)      , QDIFF       , ST           ,
     3             DRAGP2       , HXTFEB      , QTFTLB      , TLEFT        ,
     4             DRAGT2       , HXTFER      , QTOTAL      , YF(50)       ,
     5             EDENS(50)    , PARDOT(30)  , RMFLUX(30)  , REVE
      COMMON /25/  RVB
      COMMON /27/  CPBAR(50)    , FFMU        , RES         , UE2TE        ,
     1             ENTAPY(50,30)
      COMMON /37/  IPRTB
      COMMON /38/  BEBB(50)
      COMMON /40/  IBRDYO       , V(50)
      COMMON /41/  ETA(50)
      COMMON /50/  IPRT
      COMMON /63/  SPN(40)

      GO TO (10,20) , IBS
10    CONTINUE
      IF ( ICOMPO .EQ. 2 ) GO TO 13
      GO TO (13,13,13,11) , IPSW
11    CONTINUE
      IF ( MOD (MFLAGO,IPRT) .EQ. 0) GO TO 13
      WRITE (NTO,15) MFLAGO, ST, SKFER , TLEFT
15    FORMAT(6X*ITERATION*I4,15X*STANTON NO. =*E13.5*  SKIN FRICTION =*
     1E13.5,6X*TIME LEFT =*F7.3* SEC*)
      RETURN
13    CONTINUE
      WRITE (NTO,185) MFLAGO
185   FORMAT(*1*8X*PROFILES AFTER*I4* ITERATIONS.*)
      IF (ICOMPO .NE. 2) GO TO 14
      WRITE (NTO,187)
187   FORMAT(50X*AT S=0.0*)
      GO TO 30
14    CONTINUE
      GO TO (16,17,18,30) , IPSW
16    CONTINUE
      WRITE (NTO,195)
195   FORMAT(*+*48X,8(*+*),*PROFILES CONVERGED*8(*+*))
```

```
      GO TO 30                                                          PRTB  48
   17 CONTINUE                                                          PRTB  49
      WRITE (NTO,205)                                                   PRTB  50
  205 FORMAT(*+*48X,8(*-*),*TIME ABOUT GONE. THIS IS LAST ITERATION*,   PRTB  51
     18(*-*))                                                           PRTB  52
      GO TO 30                                                          PRTB  53
   18 CONTINUE                                                          PRTB  54
      WRITE (NTO,225)                                                   PRTB  55
  225 FORMAT(*+*48X,8(*.*)*MAXIMUM NUMBER OF ITERATIONS DONE*,8(*.*))   PRTB  56
      GO TO 30                                                          PRTB  57
   20 CONTINUE                                                          PRTB  58
      IF ( MOD ( M ,IPRTB) .NE. 0) RETURN                               PRTB  59
   30 CONTINUE                                                          PRTB  60
      CALL PRTX                                                         PRTB  61
      WRITE (NTO,37)                                                    PRTB  62
      CALL PRTPRO                                                       PRTB  63
      WRITE (NTO,37)                                                    PRTB  64
      WRITE (NTO,33)                                                    PRTB  65
   33 FORMAT(*0*59X*ELECTRON*5X*TOTAL*/*  N*3X*ETA*5X*Y/RN*9X*V*8X      PRTB  66
     1* BETA/EBB*4X*DENSITY*6X*DENSITY*3X*ENTHALPY*)                    PRTB  67
      WRITE (NTO,35) (N, ETA(N), YF(N), V(N),BEBB(N), RHO(N), EDENS(N), PRTB  68
     1                HE(N), N=1,NMAX)                                  PRTB  69
   35 FORMAT(1X,I2,F7.4,6E12.4)                                         PRTB  70
   37 FORMAT(*1*)                                                       PRTB  71
   40 CONTINUE                                                          PRTB  72
      WRITE (NTO,41) TLEFT, RVB, QCOND, HXTFER, QDIFF, HXTFEB, QCONV,   PRTB  73
     1              DISPTK, QTOTAL, FMOTH, QTFTLB, FL(1), ST, SKFER     PRTB  74
   41 FORMAT(*0*21X*TIME LEFT =*F7.3* SEC*34X*RHO V =*E13.5/            PRTB  75
     126X*QCOND =*E13.5,24X*HEAT TRANSFER =*E13.5/26X*QDIFF =*E13.5,    PRTB  76
     218X*HEAT TRANSFER, BODY =*E13.5/26X*QCONV =*E13.5,12X*DISPLACEMENTPRTB  77
     3 THICKNESS/RN =*E13.5/25X*QTOTAL =*E13.5,19X*MOMENTUM THICKNESS =*PRTB  78
     4E13.5/  12X*QTOTAL(BTU/FT2-SEC) =*E13.5,28X*L AT BODY =*E13.5/    PRTB  79
     517X*STANTON NUMBER =*E13.5,24X*SKIN FRICTION =*E13.5)             PRTB  80
      GO TO (60,50) , IBS                                               PRTB  81
   50 CONTINUE                                                          PRTB  82
      WRITE (NTO,55)  RSUM, DRAGT2, RES, DRAGP2, CFINF, DRAG2           PRTB  83
   55 FORMAT(22X,11HRS**(1+J) =,E13.5,26X*T DRAG COEF =*E13.5/          PRTB  84
     116X*REYNOLDS NUMBER =*E13.5,26X*P DRAG COEF =*E13.5/              PRTB  85
     225X*CF-INF =*E13.5,27X*TOTAL DRAG =*E13.5/*0*)                    PRTB  86
      WRITE (NTO,57)                                                    PRTB  87
   57 FORMAT(58X*TOTAL*)                                                PRTB  88
      GO TO 70                                                          PRTB  89
   60 CONTINUE                                                          PRTB  90
      WRITE (NTO,65)                                                    PRTB  91
   65 FORMAT(*0*)                                                       PRTB  92
   70 CONTINUE                                                          PRTB  93
      GO TO (80,90) , IBS                                               PRTB  94
   80 CONTINUE                                                          PRTB  95
      WRITE (NTO,83)                                                    PRTB  96
   83 FORMAT(29X*SPECIES   WALL MASS FLUX*)                             PRTB  97
      WRITE (NTO,85) (SPN(I), RMFLUX(I), I=1,NI)                        PRTB  98
   85 FORMAT(31X,A6,E13.5)                                              PRTB  99
      RETURN                                                            PRTB 100
   90 CONTINUE                                                          PRTB 101
      WRITE (NTO,93)                                                    PRTB 102
   93 FORMAT(29X*SPECIES   WALL MASS FLUX   MASS FLOW   FLOW(PAR/SEC)*)PRTB 103
      WRITE (NTO,95) (SPN(I), RMFLUX(I), FMDOT(I), PARDOT(I),I=1,NI)    PRTB 104
   95 FORMAT(31X,A6,3E15.5)                                             PRTB 105
      RETURN                                                            PRTB 106
      END                                                               PRTB 107
```

PRTEDG

Subroutine PRTEDG is called by INPBOD and prints the edge tables, XA, PA, VA, TA and CA (species).

```
      SUBROUTINE PRTEDG

      COMMON /1/  NI          , NMAX        , NM2         , NTO         ,
     1            NJ          , NM1         , NR
      COMMON /30/ CA(110,30)  , PA(110)     , VA(110)     , XA(110)     ,
     1            NED         , TA(110)
      COMMON /63/ SPN(40)

      IL =  MINO (NI,6)
      WRITE (NTO,5)
    5 FORMAT(*0*50X*EDGE TABLES*)
      WRITE (NTO,15) (SPN(I),I=1,IL)
   15 FORMAT(*0*74X*CA(SPECIES)*/7X*XA*9X*PA*9X*VA*9X*TA*3X,6(6XA5))
      DO 30 ND=1,NED
      WRITE (NTO,25) ND,XA(ND),PA(ND),VA(ND),TA(ND),(CA(ND,I),I=1,IL)
   25 FORMAT(1X,I2,10E11.4)
   30 CONTINUE
   32 CONTINUE
      IF (IL .EQ. NI) GO TO 50
      IS = IL + 1
      IL = IS + 9
      IL =  MINO (NI,IL)
      WRITE (NTO,35) (SPN(I),I=IS,IL)
   35 FORMAT(*0*48X*CA(SPECIE)*/1X,10(6XA5))
      DO 40 ND=1,NED
      WRITE (NTO,25) ND, (CA(ND,I),I=IS,IL)
   40 CONTINUE
      GO TO 32
   50 CONTINUE
      WRITE (NTO,55)
   55 FORMAT(*0*15X*NOTE ---*5X*XA, PA, TA AND VA ARE CHANGED IN SUBROUT
     1INE INPBOD*//39X18HXA(K) = XA(K) * RN/
     2              39X30HPA(K) = PA(K) * NORM SH PRESS./
     3              39X28HVA(K) = VA(K) * NORM SH VEL./
     4              39X29HTA(K) = TA(K) * NORM SH TEMP.)
      RETURN
      END
```

PRTPRO

Subroutine PRTPRO prints the profiles as follows: N, ETA(N), FPRIME(N), THETA(N) and C(N,I) (for each species) for each point across the boundary layer, where N = 1 to NMAX. PRTPRO is called by INPUT, PRECAL and PRTBL.

```
      SUBROUTINE PRTPRO

      COMMON  /1/  NI         , NMAX       , NM2       , NTO        ,
     1             NJ         , NM1        , NR
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON /41/  ETA(50)
      COMMON /63/  SPN(40)

      NE =  MIN0 (NI,8)
      WRITE (NTO,15) (SPN(I),I=1,NE)
   15 FORMAT(*0 N*3X*ETA*5X*FPRIME*6X*THETA  *8(7X,A5))
      DO 30 N=1,NMAX
      WRITE (NTO,25) N, ETA(N), FPRIME(N), THETA(N), (CLIL(N,I),I=1,NE)
   25 FORMAT(1X,I2,F7.4,10E12.4)
   30 CONTINUE
   32 CONTINUE
      IF (NE .EQ. NI) GO TO 50
      NS = NE + 1
      NE = NS + 9
      NE =  MIN0 (NE,NI)
      WRITE (NTO,35) (SPN(I),I=NS,NE)
   35 FORMAT(*0 N*3X*ETA*6X,10(A5,7X))
      DO 40 N=1,NMAX
      WRITE (NTO,25) N, ETA(N), (CLIL(N,I),I=NS,NE)
   40 CONTINUE
      GO TO 32
   50 CONTINUE
      RETURN
      END
```

PR2DSW

Subroutine PR2DSW is a specialized print subroutine used to print the stoichiometric coefficients and third body efficiencies (all 2-dimensional arrays).

PR2DSW has 4 arguments; in order they are:

A	- name of array to be printed	
NCOL	- 1st dimension	
NROW	- 2nd dimension	
ID	- indicates variable being printed	1 - CALPH 2 - CBETA 3 - Z

PR2DSW is called by INPUT.

```
      SUBROUTINE PR2DSW (A,NCOL,NROW,ID)

      COMMON  /1/  NI          , NMAX        , NM2          , NTO          ,
     1             NJ          , NM1         , NR
      COMMON /63/  SPN(40)

      DIMENSION      A(30,1)        , IRP(30)
      DATA           (IRP=1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,
     1         19,20,21,22,23,24,25,26,27,28,29,30)
      GO TO (10,20,30) , ID
   10 CONTINUE
      WRITE (NTO,15)
   15 FORMAT(*0*42X*FORWARD - CALPH(NR,NJ)*)
      GO TO 50
   20 CONTINUE
      WRITE (NTO,25)
   25 FORMAT(*0*42X*BACKWARD - CBETA(NR,NJ)*)
      GO TO 50
   30 CONTINUE
      WRITE (NTO,35)
   35 FORMAT(*0*34X*THIRD BODY EFFECIENCIES - Z(NI,NL)*)
      GO TO 80
   50 CONTINUE
      IRL = 0
   60 CONTINUE
      IRF = IRL + 1
      IRL = IRF + 14
      IRL =  MIN0 (IRL,NCOL)
      WRITE (NTO,65) (IRP(IR),IR=IRF,IRL)
   65 FORMAT(*0 NJ/NR   *15(I2,5X))
      DO 70 NC=1,NROW
      WRITE (NTO,67) SPN(NC), (A(IR,NC), IR=IRF,IRL)
   67 FORMAT(1X,A5,15F7.2)
   70 CONTINUE
      IF (IRL .LT. NCOL) GO TO 60
      GO TO 110
   80 CONTINUE
C                                    PRINT Z TABLE
      IRL = 0
   90 CONTINUE
      IRF = IRL + 1
      IRL = IRF + 11
      IRL =  MIN0 (IRL,NCOL)
      WRITE (NTO,95) (IRP(IR), IR=IRF,IRL)
   95 FORMAT(*0 NL/NI    *12(I2,8X))
      DO 100 NC=1,NROW
      L  = NI + NC
      WRITE (NTO,97) SPN(L), (A(IR,NC), IR=IRF,IRL)
   97 FORMAT(1X,A5,12F10.4)
```

```
100   CONTINUE                                                      PRSW  50
      IF (IRL .LT. NCOL) GO TO 90                                   PRSW  51
110   CONTINUE                                                      PRSW  52
      RETURN                                                        PRSW  53
      END                                                           PRSW  54
```

Subroutine PRTX is called when the values of X_r (see Equation 108) are to be printed.

```
      SUBROUTINE PRTX

      COMMON  /1/   NI          , NMAX        , NM2         , NTO         ,
     1              NJ          , NM1         , NR
      COMMON /41/   ETA(50)
      COMMON /85/   X(50,30)

      WRITE (NTO,5)
5     FORMAT(*0*55X*X(K)*)
      K2 = 0
10    CONTINUE
      K1 = K2 + 1
      K2 = K1 + 9
      K2 = MINO(K2,NR)
      WRITE (NTO,15)  (K,K=K1,K2)
15    FORMAT(*0 N*3X*ETA*6X,10(I2,10X))
      DO 20 N=1,NMAX
      WRITE (NTO,17) N, ETA(N), (X(N,K),K=K1,K2)
17    FORMAT(1X,I2,F7.4,10E12.4)
20    CONTINUE
      IF (K2 .LT. NR) GO TO 10
      RETURN
      END
```

QPR

Subroutine QPR computes the values of Q_i, P_i and RVB where i = 1, NI. These values are used in the calculation of the boundary condition at the wall and are a function of IWC (wall condition switch). IWC may have any value from 1 to 11. If IWC = 2, P_i, Q_i and RVB are all set to 0.0, but this is not necessary because this case is not solved in terms of P_i and Q_i but is handled differently in the program.

IWC = 1, non catalytic wall, see equation (49).

IWC = 3, fully catalytic dissociation wall, see equation (52)

IWC = 4, fully catalytic recombination wall with species NO non-catalytic, see equation (51).

IWC = 5, mass transfer of ablation products, see equation (58).

IWC = 6, oxidation of graphite, see equation (54).

IWC = 7, oxidation of metals, see equation (56).

IWC = 8, vaporization of surface carbon, see equation (60).

IWC = 9, mass transfer of ablation products with oxidation of graphite. IWC = 5 + IWC = 6.

IWC =10, oxidation of graphite with vaporization of surface carbon. IWC = 6. + IWC = 8.

IWC =11, oxidation of metals with vaporization of surface carbon. IWC = 7 + IWC = 8.

Note: For IWC = 6, 7, 9, 10 or 11, two input values are required; EO and EO2. See INPUT write-up. For IWC = 8, 10 or 11, an additional table is required. CCOE(I), condensation coefficient of i is set by a data statement in QPR. CSV(I), mass fraction of i corresponding to the equilibrium vapor pressure, is calculated. Where I for these two arrays is 1, 2, 3 for species C1, C2 and C3, it must be used in this order. RVB is calculated using Equation (43).

```
      SUBROUTINE QPR                                                    QPR
                                                                        QPR
      COMMON   /1/  NI          , NMAX       , NM2        , NTO       , QPR
     1              NJ          , NM1        , NR                       QPR
      COMMON   /5/  CLIL(50,30) , FPRIME(50) , THETA(50)                QPR
      COMMON   /8/  FMOLWT(30)  , FMBAR(50)  , FMBARE     , RHO(50)  , R QPR
      COMMON  /13/  HINF        , PE         , SMALLE     , TKE     , UE ,QPR
     1              HF(30)      , PINF       , TF         , TINF    , VINFQPR
      COMMON  /14/  ICHGSW      , IDYS                                  QPR
      COMMON  /20/  ANGLC       , FJ         , SINCO      , TKINF     , QPR
     1              DUEDX       , PII        , SINTH      , TKW         QPR
      COMMON  /25/  RVB                                                 QPR
      COMMON  /26/  DBB(30,30)  , FLEJ(30)   , INOP                     QPR
      COMMON  /31/  NTP         , SPRT       , TWT(50)    , XRN(50)   , QPR
     1              RVPT(50)    , TETE(50)                              QPR
      COMMON  /32/  TW                                                  QPR
      COMMON  /49/  CALPH(30,40),CBETA(30,40),CSALPH(30)  , CSBETA(30),IO QPR
      COMMON  /60/  IN2         , IO2                                   QPR
      COMMON  /66/   EIO        , EIO2       , IWC                      QPR
      COMMON  /67/  ICO         , ICO2       , IM1        , IM3    , IN , QPR
     1              IC1         , IEL        , IM2        , IM4    , INO  QPR
      COMMON  /70/  P(30)       , Q(30)                                 QPR
      COMMON  /79/   RSQMWT(30)                                         QPR
                                                                        QPR
      DIMENSION      CCOE(3)    , CSV(3)     , PT(30)     , QT(30)      QPR
      DATA          (CCOE =   .24,     .5 ,    .023)                    QPR
      DATA          (CPH  = 1.0) , (RMWC = .08325701)                   QPR
```

```
      RVB = 0.0
      DO 10 I=1,NI
      P(I) = 0.0
      Q(I) = 0.0
 10   CONTINUE
      GO TO (140,140,20,20,50,20,20,80,20,20,20) , IWC
 20   CONTINUE
      QTR = -RHO(1) * SQRT(7907.7725 * TW)
      GO TO (140,140,30,40,50,56,56,80,56,56,56) , IWC
 30   CONTINUE
      Q(IO2) = QTR * RSQMWT(IO2)
      Q(IN2) = QTR * RSQMWT(IN2)
      P(IO)  = -CLIL(1,IO2) * Q(IO2)
      P(IN)  = -CLIL(1,IN2) * Q(IN2)
      GO TO 140
 40   CONTINUE
      Q(IO)    = QTR * RSQMWT(IO)
      Q(IN)    = QTR * RSQMWT(IN)
      Q(INOP) = QTR * RSQMWT(INOP)
      PTR      = CLIL(1,INOP) * Q(INOP)
      P(IO2)   = -CLIL(1,IO) * Q(IO) - PTR
      P(IN2)   = -CLIL(1,IN) * Q(IN) - PTR
      GO TO 140
 50   CONTINUE
      IDYS   = 0
      ICHGSW = 1
      CALL POLATE (SPRT, XRN, RVPT, RVP, NTP)
      DO 52 I=1,NI
      CALL EQU2 (CYPR, I)
      P(I) = CYPR * RVP
 52   CONTINUE
      IF (IWC .EQ. 9) GO TO 92
      GO TO 120
 56   CONTINUE
      IF (EIO .GT. 0.0 .AND. EIO2 .GT. 0.0) GO TO 58
      WRITE (NTO,57)
 57   FORMAT(*0 SUBR. QPR FINDS THAT ONE OR BOTH E-SUB-I INPUTS WERE .LT
     1. OR .EQ. 0, SO CANT DO IWC=6,7,9,10,11.*)
      STOP
 58   CONTINUE
      GO TO (140,140,140,140,140,60,70,80,90,100,110) , IWC
 60   CONTINUE
      Q(IO)   =  FMOLWT(IO) * EIO * QTR * RSQMWT(IO) * RMWC
      Q(IO2)  =  FMOLWT(IO2)*EIO2 * QTR* RSQMWT(IO2) * .5 * RMWC
      P(ICO) = -FMOLWT(ICO)/ FMOLWT(IO) * (Q(IO2) * CLIL(1,IO2)
     1                                  +  Q(IO)  * CLIL(1,IO))
      IF (IWC .EQ. 9) GO TO 96
      IF (IWC .EQ. 10) GO TO 102
      GO TO 120
 70   CONTINUE
      Q(IO)   =  EIO * QTR * RSQMWT(IO)
      Q(IO2)  =  EIO2 * QTR * RSQMWT(IO2)
      IF (IWC .EQ. 11) GO TO 112
      GO TO 120
 80   CONTINUE
      PART1 = 1.0 / SQRT(3.1218633E5 * TW)
      DO 82 I=1,NI
      IF (I .EQ. IC1) GO TO 84
 82   CONTINUE
      WRITE (NTO,83)
 83   FORMAT(*0 SUBR. QPR DIDNT FIND 3 CARBONS IN SPECIES SO CANT DO IWC
     1=8,10,11.*)
      STOP
 84   CONTINUE
      J = I
      CSV(1) = 2.36387 E12 * EXP(-85334. / TKW)
      CSV(2) = 2.94848 E14 * EXP(-99738. / TKW)
      CSV(3) = 3.27891 E20 * EXP(-97597. / TKW) * TKW**-1.5
      DO 86 K=1,3
      PARTI = CCOE(K) * RSQMWT(J) * PART1
      P(J) =   PARTI * CSV(K)
      Q(J) = - PARTI * PE * FMBAR(1) * CPH
```

```
      J = J + 1
86    CONTINUE
      IF (IWC .EQ. 10) GO TO 106
      IF (IWC .EQ. 11) GO TO 116
      GO TO 120
90    CONTINUE
      GO TO 50
92    CONTINUE
      DO 94 I=1,NI
      PT(I) = P(I)
94    CONTINUE
      GO TO 60
96    CONTINUE
      DO 98 I=1,NI
      P(I) = P(I) + PT(I)
98    CONTINUE
      GO TO 120
100   CONTINUE
      GO TO 60
102   CONTINUE
      DO 104 I=1,NI
      PT(I) = P(I)
      QT(I) = Q(I)
104   CONTINUE
      GO TO 80
106   CONTINUE
      DO 108 I=1,NI
      P(I) = P(I) + PT(I)
      Q(I) = Q(I) + QT(I)
108   CONTINUE
      GO TO 120
110   CONTINUE
      GO TO 70
112   CONTINUE
      DO 114 I=1,NI
      QT(I) = Q(I)
114   CONTINUE
      GO TO 80
116   CONTINUE
      DO 118 I=1,NI
      Q(I) = Q(I) + QT(I)
118   CONTINUE
120   CONTINUE
      DO 130 I=1,NI
      RVB = RVB + (P(I) + Q(I) * CLIL(1,I))
130   CONTINUE
140   CONTINUE
      RETURN
      END
```

SETOT

Subroutine SETOT sets the following switches depending on the input options and sets up the Hollerith arrays for printing the options.

NEQUIL	1 equilibrium 2 nonequilibrium	
IFROZE	1 nonfrozen 2 frozen	
IBRDYO	1 boundary layer 2 shock layer	
IG	1 cone 2 sharp arbitrary axisymmetric body 3 sphere cone 4 blunt arbitrary axisymmetric body 5 hyperboloid	JBOD = 1
IG	6 flat plate 7 sharp arbitrary 2-D body 8 blunt wedge 9 blunt arbitrary 2-D body 10 hyperbola	JBOD = 0
IGEOM	-1 when IG = 1, 2, 6 or 7 0 when IG = 3, 4, 5, 8, 9 or 10	
ICOMPO	1 iterate initial profile 2 calculate initial profile once	
ILE	1 compute Lewis numbers 2 use constant Lewis numbers	

```
      SUBROUTINE SETOT                                                  SETO
                                                                        SETO
      COMMON  /1/  IFROZE      , ILE         , MFLAGO      , NEQUIL     SETO
      COMMON  /7/  ICOMPO                                               SETO
      COMMON  /9/  IGEOM       , JBOD                                   SETO
      COMMON /40/  IBRDYO      , V(50)                                  SETO
      COMMON /62/  TOT(3,6)                                             SETO
      COMMON /65/  CK          , DELTA       , IREAD       , OPTN(6) , RS SETO
      COMMON /89/  IRB         , XRB(50)                                SETO
      COMMON /90/  IG                                                   SETO
                                                                        SETO
      DIMENSION    CHK(14)     , HOL(19)                                SETO
      DATA    (BLNK = 1H )                                              SETO
      DATA    (CHK  =8HEQUILIBR, 8HNON-FROZ, 8HBOUNDARY, 8HINITIAL ,    SETO
     1              8HCAL LEWI, 8HCONE    , 8HSPHERE C, 8HHPERBOID,     SETO
     2              8HFLAT PLA, 8HBLUNT WE, 8HBLUNT 2D, 8HSHARP 2D,     SETO
     3              8HBLUNT AX, 8HSHARP AX)                             SETO
```

```fortran
      DATA     (HOL   =8HHYPERBOL, 8HA         , 8HOID      , 8HIUM     ,
     1                 8HLIBRUM  , 8HEN        , 8HTE       , 8HDGE     ,
     2                 8H LAYER  , 8HYER       , 8HCOMPUTE  , 8HPROFILE ,
     3                 8HCULATION, 8HONE       , 8HS NOS.   , 8HARB BODY,
     4                 8H        , 8H          , 8H         )
      DO 10 K=1,3
      DO 10 J=1,6
      TOT(K,J) = BLNK
10    CONTINUE
      TOT(1,1) = OPTN(1)
      IF (OPTN(1) .NE. CHK(1)) GO TO 20
      NEQUIL = 1
      TOT(2,1) = HOL(4)
      GO TO 30
20    CONTINUE
      NEQUIL = 2
      TOT(2,1) = HOL(5)
30    CONTINUE
      TOT(1,2) = OPTN(2)
      IF (OPTN(2) .NE. CHK(2)) GO TO 40
      IFROZE = 1
      TOT(2,2) = HOL(6)
      GO TO 50
40    CONTINUE
      IFROZE = 2
      NEQUIL = 2
      TOT(1,1) = BLNK
      TOT(2,1) = BLNK
      TOT(3,1) = BLNK
50    CONTINUE
      TOT(1,3) = OPTN(3)
      IF (OPTN(3) .NE. CHK(3)) GO TO 60
      IBRDYO = 1
      TOT(2,3) = HOL(9)
      GO TO 70
60    CONTINUE
      IBRDYO = 2
      TOT(2,3) = HOL(10)
70    CONTINUE
      IF (OPTN(4) .NE. CHK(4) ) GO TO 80
      ICOMPO = 1
      TOT(1,4) = HOL(11)
      TOT(2,4) = OPTN(4)
      TOT(3,4) = HOL(12)
      GO TO 90
80    CONTINUE
      ICOMPO = 2
      TOT(1,4) = OPTN(4)
      TOT(2,4) = HOL(13)
90    CONTINUE
      JBOD = 1
      TOT(1,5) = OPTN(5)
      IF (OPTN(5) .NE. CHK(6)) GO TO 100
C***  CONE
      IG = 1
      GO TO 190
  100 CONTINUE
      IF (OPTN(5) .NE. CHK(14)) GO TO 110
C***  SHARP ARBITRARY AXISYMMETRIC BODY
      IG = 2
      TOT(2,5) = HOL(16)
      GO TO 190
  110 CONTINUE
      IF (OPTN(5) .NE. CHK(7)) GO TO 120
C***  SPHERE CONE
      IG = 3
      TOT(2,5) = HOL(14)
      GO TO 200
  120 CONTINUE
      IF (OPTN(5) .NE. CHK(13)) GO TO 130
C***  BLUNT ARBITRARY AXISYMMETRIC BODY
      IG = 4
```

```
      TOT(2,5) = HOL(16)
      GO TO 200
  130 CONTINUE
      IF (OPTN(5) .NE. CHK(8)) GO TO 140
C***  HYPERBOLOID
      IG = 5
      TOT(1,5) = HOL(1)
      TOT(2,5) = HOL(3)
      GO TO 200
  140 CONTINUE
      JBOD = 0
      IF (OPTN(5) .NE. CHK(9)) GO TO 150
C***  FLAT PLATE
      IG = 6
      TOT(2,5) = HOL(7)
      GO TO 190
  150 CONTINUE
      IF (OPTN(5) .NE. CHK(12)) GO TO 160
C***  SHARP ARBITRARY 2-D BODY
      IG = 7
      TOT(2,5) = HOL(16)
      GO TO 190
  160 CONTINUE
      IF (OPTN(5) .NE. CHK(10)) GO TO 170
C***  BLUNT WEDGE
      IG = 8
      TOT(2,5) = HOL(8)
      GO TO 200
  170 CONTINUE
      IF (OPTN(5) .NE. CHK(11)) GO TO 180
C***  BLUNT ARBITRARY 2-D BODY
      IG = 9
      TOT(2,5) = HOL(16)
      GO TO 200
  180 CONTINUE
C***  HYPERBOLA
      TOT(1,5) = HOL(1)
      TOT(2,5) = HOL(2)
      IG = 10
      GO TO 200
  190 CONTINUE
      IGEOM = -1
      GO TO 210
  200 CONTINUE
      IGEOM = 0
  210 CONTINUE
      TOT(1,6) = OPTN(6)
      TOT(2,6) = HOL(15)
      ILE = 2
      IF (NEQUIL .EQ. 1) GO TO 220
      IF (OPTN(6) .EQ. CHK(5)) ILE = 1
  220 CONTINUE
      RETURN
      END
```

SIMINT

Subroutine SIMINT computes the integral, $\int_0^{\eta} F(\eta)d\eta$, where $d\eta$ need not be constant, using Simpson's rule. There are four arguments to SIMINT:

F	- array to be integrated
TI	- total integral, $\eta_e \int_0^{\eta}$
SI	- partial integral at each point across the boundary layer times η_e
IWST	- switch $\begin{cases} 1 \text{ - compute TI} \\ 2 \text{ - compute SI; 1st value of SI should be set by calling routine.} \end{cases}$

For n = 2, NMAX - 1

$$\int_{n-1}^{n} F d\eta = \frac{\Delta\eta_{n-1}}{6}\left\{F_{n-1}\left[\frac{3\Delta\eta_n + 2\Delta\eta_{n-1}}{\Delta\eta_n + \Delta\eta_{n-1}}\right] + F_n\left[3 + \frac{\Delta\eta_{n-1}}{\Delta\eta_n}\right] - F_{n+1}\left[\frac{\Delta\eta_{n-1}\,\Delta\eta_{n-1}}{\Delta\eta_n(\Delta\eta_n + \Delta\eta_{n-1})}\right]\right\}$$

For the last point, N = NMAX

$$\int_{N-1}^{N} F d\eta = \frac{\Delta\eta_{N-1}}{6}\left\{F_{N}\left[\frac{3\Delta\eta_{N-2} + 2\Delta\eta_{N-1}}{\Delta\eta_{N-1} + \Delta\eta_{N-2}}\right] + F_{N-1}\left[3 + \frac{\Delta\eta_{N-1}}{\Delta\eta_{N-2}}\right] - F_{N-2}\left[\frac{\Delta\eta_{N-1}\Delta\eta_{N-1}}{\Delta\eta_{N-2}(\Delta\eta_{N-1} + \Delta\eta_{N-2})}\right]\right\}$$

```
      SUBROUTINE SIMINT (F, TI, SI, ISWT)

      COMMON  /1/  NI           , NMAX        , NM2         , NTO        ,
     1             NJ           , NM1         , NR
      COMMON /11/  DEN2(50)     , ETE         , VONE
      COMMON /24/  DN(50)
      COMMON /44/  DNO6(50)     , DNTR1(50)   , DNTR3(50)   , DPDN(50)

      DIMENSION       F(1)         , SI(1)
      IF (ISWT .EQ. 1) TI = 0.0
      DO 50 N=2,NMAX
      IF (N .EQ. NMAX) GO TO 10
      DELA = DNO6(N-1)*(F(N-1)*((3.0*DN(N)+2.0*DN(N-1)) / DPDN(N))
     1                + F(N)  * (3.0+ DN(N-1) / DN(N) )
     2                - F(N+1)* (DN(N-1) * DNTR1(N)) )
      GO TO 20
   10 CONTINUE
      DELA = DNO6(NM1)*(F(NMAX)*((3.0*DN(NM2)+2.0*DN(NM1)) / DPDN(NM1))
     1                + F(NM1) * (3.0 + DN(NM1) / DN(NM2))
     2                - F(NM2) *  (DN(NM1) * DNTR3(NM1)))
   20 CONTINUE
      GO TO (30, 40) , ISWT
   30 CONTINUE
      TI = TI + DELA
      GO TO 50
   40 CONTINUE
      SI(N) = SI(N-1) + DELA * ETE
   50 CONTINUE
      GO TO (60,70) , ISWT
   60 TI = TI * ETE
   70 CONTINUE
      RETURN
      END
```

SPBND

Subroutine SPBND sets the boundary values for the solution of the species equation. SPBND has one argument, I, current species subscript. See Equation (47c) for boundary conditions at the wall.

```
      SUBROUTINE SPBND (I)

      COMMON  /1/  NI           , NMAX        , NM2         , NTO        ,
     1             NJ           , NM1         , NR
      COMMON  /4/  FL(50)       , IBS
      COMMON  /5/  CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON  /9/  IGEOM        , JBOD
      COMMON /11/  DEN2(50)     , ETE         , VONE
      COMMON /15/  FLAPL        , RB1         , TXI1T       , XI1
      COMMON /23/  BLBAR(50,30),FMUB        , PR(50)      , PRFL
      COMMON /25/  RVB
      COMMON /26/  DBB(30,30) , FLEJ(30)    , INOP
      COMMON /29/  CEDG(30)
      COMMON /44/  DNO6(50)     , DNTR1(50)   , DNTR3(50)   , DPDN(50)
      COMMON /45/  RDN          , RRDN
      COMMON /58/  A(50)        , B(50)       , C(50)       , D(50)
      COMMON /60/  IN2          , IO2
      COMMON /66/   EIO         , EIO2        , IWC
      COMMON /70/  P(30)        , Q(30)

      B(NMAX) = 1.0
      C(NMAX) = 0.0
      D(NMAX) = CEDG(I)
      IF (IWC .NE. 2 ) GO TO 10
      A(1) = 0.0
      B(1) = 1.0
      D(1) = CLIL(1,I)
      GO TO 60
10    CONTINUE
      GO TO (20,40) , IBS
20    CONTINUE
      IF (IGEOM .GE. 0) GO TO 30
      WB = 0.0
      GO TO 50
30    CONTINUE
      WB = PRFL * VONE
      GO TO 50
40    CONTINUE
      WB = PRFL * TXI1T
50    CONTINUE
      DTRM = ETE * DPDN(2) / FLEJ(I)
      A(1) = -RRDN
      B(1) = RDN * (2.0 + RDN + DTRM * WB * (RVB - Q(I)))
      D(1) = RDN * DTRM * (WB * P(I) + PRFL * BLBAR(1,I))
60    CONTINUE
      RETURN
      END
```

SPECEQ

Subroutine SPECEQ computes the coefficients, calls SPBND for the boundary values and calls WKHS for the new values of c_i. For the initial profile calculation one may iterate inside SPECEQ. The calculation is done KSPE times if KOPT = 1 or the calculation is repeated until CHECK ≤ ASPE if KOPT = 2. CHECK is computed in WKHS. The α's computed are described in equations (201) through (201). If a body profile is being calculated, the old c_i's are saved in CL(N,I) before new ones are computed. WBAR(N,I) is recomputed here to make use of the newest c_i's.

```
      SUBROUTINE SPECEQ

      COMMON       WBAR(50,30), WONE(50,30), WTH(50,30) , WZERO(50,30)
      COMMON  /1/  NI          , NMAX       , NM2        , NTO          ,
     1             NJ          , NM1        , NR
      COMMON  /3/  IFROZE      , ILE        , MFLAGO      , NEQUIL
      COMMON  /4/  FL(50)      , IBS
      COMMON  /5/  CLIL(50,30), FPRIME(50) , THETA(50)
      COMMON  /6/  CL(50,30)   , FP(50)     , TH(50)
      COMMON  /8/  FMOLWT(30)  , FMBAR(50)  , FMBARF     , RHO(50)    , R
      COMMON /12/  RHOE        , RHOINF     , RMUREF
      COMMON /13/  HINF        , PE         , SMALLE     , TKE      , UE ,
     1             HF(30)      , PINF       , TE         , TINF     , VINF
      COMMON /28/  BETA        , CTH
      COMMON /29/  CEDG(30)
      COMMON /32/  TW
      COMMON /39/  NKM         , OMW(32)    , WFA(32)
      COMMON /40/  IBRDYO      , V(50)
      COMMON /55/  AENE        , ASPE       , KMOM       , KSPE         ,
     1             AMOM        , KENE
      COMMON /57/  ALPH1(50)   , ALPH4(50)  , ISPC       , OMWF         ,
     1             ALPH2(50)   , CHECK      , MFLAG      , WFAC         ,
     2             ALPH3(50)
      COMMON /59/  KOPT
      COMMON /60/  IN2         , IO2
      COMMON /66/   EIO        , EIO2       , IWC
      COMMON /71/  BB(50,30)   , BBPR(50,30), BLBAPR(50,30)

      ISPC = 2
      GO TO (10,20) , IBS
   10 CONTINUE
      MFLAG = 0
      GO TO 40
   20 CONTINUE
      DO 30 N=1,NMAX
      DO 30 I=1,NI
      CL(N,I) = CLIL(N,I)
   30 CONTINUE
   40 CONTINUE
      GO TO (200,50) , NEQUIL
   50 CONTINUE
      IF ( IWC .NE. 2 ) GO TO 60
      CALL EQUIL (TW, PE, 1)
   60 CONTINUE
      GO TO (70,80) , IBS
   70 CONTINUE
      MFLAG = MFLAG + 1
   80 CONTINUE
      DO 120 I=1,NI
      DO 110 N=2,NM1
      BBDEN = 1.0 / BB(N,I)
      ALPH1(N) = (BBPR(N,I) - V(N)) * BBDEN
      ALPH2(N) = -SMALLE * WONE(N,I) * BBDEN
      IF (CLIL(N,I) .LT. 1.0E-6) BLBAPR(N,I) = 0.0
      ALPH3(N) = (SMALLE * WZERO(N,I) + BLBAPR(N,I)) * BBDEN
      GO TO (110,100) , IBS
```

```
100   CONTINUE
      ALPH2(N) = ALPH2(N) / CTH
      ALPH4(N) = -FPRIME(N) * BBDEN
110   CONTINUE
      WFAC = WFA(I+2)
      OMWF = OMW(I+2)
      CALL SPBND (I)
      CALL WKHS (CLIL(1,I))
120   CONTINUE
      DO 140 N=1,NMAX
      CSUM = 0.0
      DO 130 I=1,NI
      CSUM = CSUM + CLIL(N,I)
130   CONTINUE
      CLIL(N,2) = 1.0 + CLIL(N,2) - CSUM
140   CONTINUE
      GO TO (150,220) , IBS
150   CONTINUE
      GO TO (160,170) , KOPT
160   CONTINUE
      IF (MFLAG .LT. KSPE) GO TO 70
      GO TO 220
170   CONTINUE
      IF ( CHECK .GT. ASPE) GO TO 70
      GO TO 220
200   CONTINUE
      DO 210 N=1,NMAX
      CALL EQUIL (THETA(N) * TE, PE, N)
210   CONTINUE
      RHOE = RHO(NMAX)
      GO TO 240
220   CONTINUE
      DO 230 I=1,NI
      DO 230 N=1,NMAX
      WBAR(N,I) = SMALLE * (WZERO(N,I) - WONE(N,I) * CLIL(N,I))
230   CONTINUE
240   CONTINUE
      RETURN
      END
```

STOI

Subroutine STOI computes the **stoichiometric** relations. STOI is called by CHEMPR and has four arguments, all of which are arrays.

Forward	Backward
CAS - CALPH	CBETA
CSAS - CSALPH	CSBETA
STIN - FORK	BACKK
STOUT - FORL	BACL

The first 3 arguments are input to STOI and the last one is the stoichiometric value being computed.

```
      SUBROUTINE STOI ( CAS, CSAS, STIN, STOUT)

      COMMON  /1/  NI          , NMAX        , NM2         , NTO         ,
     1             NJ          , NM1         , NR
      COMMON /51/  GAMMA(40)   , RHOBAR

      DIMENSION
     1              CAS( 30,1)  ,  CSAS(1),  STIN(1) , STOUT(1)
      DO 50 K=1,NR
      FLP = 1.0
      DO 30 J=1,NJ
      IF (CAS(K,J) .EQ. 0.0 .AND. GAMMA(J) .EQ. 0.0) GO TO 30
      IF (GAMMA(J) .EQ. 0.0) GO TO 40
      FLP = GAMMA(J)**CAS(K,J) * FLP
   30 CONTINUE
      STOUT(K) = STIN(K) * (RHOBAR**CSAS(K)) * FLP
      GO TO 50
   40 CONTINUE
      STOUT(K) = 0.0
   50 CONTINUE
      RETURN
      END
```

THERMO

Subroutine THERMO computes the thermal properties and has one argument:

IBSW
- -1, compute RMUREF only.
- 0, compute values needed for initial profile only.
- 1, compute values needed for body profiles.

MCDIFF is called by THERMO if Lewis numbers are to be computed. HUGNOT is called by THERMO for a shock layer solution.

Variables computed in THERMO are:

b_i	-	BB(N,I)	See equation (17)
b'_i	-	BBPR(N,I)	See equation (17)
$\bar{b}$	-	BLBAR(N,I)	See equation (17)
$\bar{b}'$	-	BLBAPR(N,I)	See equation (17)
b	-	BLIL(N,I)	See equation (17)
d	-	DLIL(N,I)	See equation (17)
$\bar{c}$	-	CBAR(N)	See equation (17)
$\bar{c}'$	-	CBARPR(N)	See equation (17)
$\bar{c}_p$	-	CPBAR(N), see NOMENCLATURE	
μ	-	FFMU, see equation (82a)	
k	-	FFK(N), see equation (82b)	
$(\rho\mu)_r \sim (\rho\mu)_e$		RMUREF	
h_i	-	ENTAPY(N,I), see equation (81a)	
$\bar{W}$	-	WBAR(N,I) = $(v - b_i') C_i' - b_i C_i'' - \bar{b}_i'$	
ℓ	-	FL(N), see NOMENCLATURE	
ℓ'	-	FLPR(N), see equation (17)	
V_{sh}	-	$VS = -\left[\dfrac{Re_s \epsilon}{(1+j)[s(1-\epsilon) + \epsilon]}\right]^{\frac{1}{2}}$ for shock layer.	

The following quantities are computed and used only in THERMO:

X_i	-	XTH(I)	See equation (82)
Φ_{ij}	-	PHI(I,J)	See equation (82)
k_i	-	FK(I)	See equation (82)
μ_i	-	FMU(I)	See equation (83)

```
      SUBROUTINE THERMO ( IBSW )
C                                   IBSW = -1 ,EDGE CONDITIONS, N=NMAX.
C                                   IBSW =  0 ,INITIAL PROFILE
C                                   IBSW =  1 , BODY
C
      COMMON          WBAR(50,30), WONE(50,30), WTH(50,30) , WZERO(50,30)
      COMMON   /1/    NI          , NMAX        , NM2         , NTO         ,
     1                NJ          , NM1         , NR
      COMMON   /2/    M
      COMMON   /3/    IFROZE      , ILF         , MFLAGO      , NEQUIL
      COMMON   /4/    FL(50)      , IBS
      COMMON   /5/    CLIL(50,30), FPRIME(50)  , THETA(50)
      COMMON   /8/    FMOLWT(30)  , FMBAR(50)   , FMBARE      , RHO(50)    , R
      COMMON  /10/    RN          , TANCO
      COMMON  /12/    RHOE        , RHOINF      , RMUREF
      COMMON  /13/    HINF        , PE          , SMALLE      , TKE        , UE ,
     1                HF(30)      , PINF        , TE          , TINF       , VINF
      COMMON  /20/    ANGLC       , FJ          , SINCO       , TKINF      ,
     1                DUEDX       , PII         , SINTH       , TKW
      COMMON  /23/    BLBAR(50,30),FMUB         , PR(50)      , PRFL
      COMMON  /26/    DBB(30,30)  , FLEJ(30)    , INOP
      COMMON  /27/    CPBAR(50)   , FFMU        , RES         , UF2TE      ,
     1                ENTAPY(50,30)
      COMMON  /37/    IPRTB
      COMMON  /40/    IBRDYO      , V(50)
      COMMON  /46/    EDBLT1      , EDBLT2      , EP2
      COMMON  /56/    BLIL(50)    , CBAR(50)    , CBARPR(50)  , CCC1(50,30),
     1                DLIL(50)
      COMMON  /64/    AMU(30)     , BMU(30)     , CMU(30)
      COMMON  /68/    CON         , N           , SPB         , TK
      COMMON  /69/    CONTH(30,30),FMOLWR(30)  , TMTHA(30,30),EPSI      , TS4
      COMMON  /71/    BB(50,30)   , BBPR(50,30), BLBAPR(50,30)
      COMMON  /72/    FLPR(50)
      COMMON  /73/    VS
      COMMON  /75/    FTER(30)

      DIMENSION        CP(50,30)    , FK(30)    , SQRTMU(30)     , XTH(30) ,
     1                 DCDETA(50,30), FMU(30), PHI(30,30)      , FFK(50)
C
      IF (IBSW .GE. 0) GO TO 2
      ISW = 2
      N   = NMAX
      GO TO 4
    2 CONTINUE
      ISW = 1
      N   = 1
      SPB = PE / 2116.2
    4 CONTINUE
      FMB = FMBAR(N)
      GO TO (6,10) , ISW
    6 CONTINUE
      TK  = THETA(N) * TKE
      TLN = ALOG(TK)
      TR  = TK * 1.8
      CPBARD = 0.0
      FFK(N) = 0.0
      GO TO 20
   10 CONTINUE
      TLN = ALOG(TKE)
   20 CONTINUE
      FFMU = 0.0
      DO 70 I=1,NI
      XTH(I)          = CLIL(N,I) * FMB / FMOLWT(I)
      GO TO (30,50) , ISW
   30 CONTINUE
      CPDUM           = CC2( TK, I)
      CP(N,I)         = CPDUM
      CPBARD          = CPBARD + CLIL(N,I) * CPDUM
      CCC1(N,I)       = CC1(TK, I)
      ENTAPY(N,I)     = TR * CCC1(N,I) + HF(I)
   50 CONTINUE
```

```
      FMU(I)         = EXP((AMU(I)*TLN+BMU(I)) * TLN + CMU(I))
      SQRTMU(I)      = SQRT(FMU(I))
      GO TO (60,70) , ISW
   60 CONTINUE
      FK(I) = (CPDUM * FMOLWR(I) + 1.25) * FMU(I) / FMOLWT(I)
   70 CONTINUE
      DO 80 J1=1,NI
      DO 80 J2=1,NI
      TM1 = 1.0 + SQRTMU(J1)/SQRTMU(J2) * TMTHA(J2,J1)
      PHI(J1,J2) = TM1**2 / CONTH(J1,J2)
   80 CONTINUE
      DO 110 J1=1,NI
      S3 = 0.0
      DO 90 J2=1,NI
      S3 = S3 + XTH(J2) * PHI(J1,J2)
   90 CONTINUE
      FFMU = FFMU + XTH(J1) * FMU(J1) / S3
      GO TO (100,110) , ISW
  100 CONTINUE
      FFK(N) = FFK(N) + XTH(J1) * FK(J1) / S3
  110 CONTINUE
      FFMU = FFMU * .00208855
      GO TO (120,140), ISW
  120 CONTINUE
      IF (N .NE. 1) GO TO 122
      FMUB = FFMU
  122 CONTINUE
      FFK(N)    = FFK(N) * 103.873424
      PR(N)     = CPBARD * FFMU / FFK(N)
      CPBAR(N) = CPBARD
      FL(N)     = RHO(N) * FFMU / RMUREF
      CBAR(N)   = FL(N) * CPBARD / PR(N)
      IF (N .GE. NMAX) GO TO 140
      N = N + 1
      GO TO 4
  140 CONTINUE
      IF (IBSW) 142,141,150
141   CONTINUE
      IF (IBRDYO .EQ. 1) GO TO 150
142   CONTINUE
      RMUREF = FFMU * RHOE
      IF (IBS .EQ. 1) GO TO 144
      IF ( MOD ( M ,IPRTB) .NE. 0) GO TO 260
144   CONTINUE
      WRITE (NTO,145) RMUREF
145   FORMAT(*0*6X*RHOMUREF =*E13.5)
      IF (IBS .EQ. 2 ) GO TO 260
      RES = RHOINF * VINF * RN / FFMU
      WRITE (NTO,5) RES
5     FORMAT(*+*34X*REYN NO(S) =*E13.5)
      IF (IBRDYO .EQ. 1) GO TO 260
      EPRES = RES * EPSI
      EDBLT2 = SQRT(EPRES * TS4)
      VS  = - SQRT(EPRES / TS4)
      WRITE (NTO,15) VS
15    FORMAT(*+*72X*VS =*E13.5)
      IF (IBSW) 260,150,150
150   CONTINUE
      DO 160 N=2,NM1
      CALL DERVDN (FL          , FLPR(N)      , 1, N )
      CALL DERVDN (CBAR        , CBARPR(N)    , 1, N )
      DO 160 I=1,NI
      CALL DERVDN (CLIL(1,I) , DCDETA(N,I), 1, N )
  160 CONTINUE
      DO 162 I=1,NI
      CALL DERVDN (CLIL(1,I) , DCDETA(1,I)      , 1, 1)
      CALL DERVDN (CLIL(1,I) , DCDETA(NMAX,I), 1, NMAX)
162   CONTINUE
C                                  ORDER OF 190 LOOP REVERSED SO THAT
C                                    DBB(J,K) FOR N=1 IS SAVED IN CORE
C                                    FOR USE IN BLC
      KI = NMAX + 1
      DO 190 KK=1,NMAX
```

```
      N  = KI  - KK
      GO TO (164,168) , ILE
164   CONTINUE
      TK  = THETA(N) * TKF
      CON = CPBAR(N) * RHO(N) / FFK(N)
      CALL MCDIFF
168   CONTINUE
      IF (IBRDYO .NE. 2) GO TO 174
      IF (N .NE. NMAX) GO TO 174
      DO 172 J1=1,NI
      SUM = 0.0
      DO 170 J2=1,NI
      IF (J2 .EQ. J1) GO TO 170
      SUM = SUM + DBB(J1,J2) * DCDETA(NMAX,J2)
170   CONTINUE
      FTER(J1) = FLEJ(J1) * DCDETA(NMAX,J1) + SUM
172   CONTINUE
      CALL HUGNOT (2)
174   CONTINUE
      FLPRI   = FL(N) / PR(N)
      FLPRCI  = FLPRI / CPBAR(N)
      BLIL(N) = 0.0
      DLIL(N) = 0.0
      DO 190 I=1,NI
      S1 = 0.0
      IF (CLIL(N,I) .LT. 1.0E-4) GO TO 182
      DO 180 IK=1,NI
      IF (IK .EQ. I) GO TO 180
      S1 = S1 + DBB(I,IK) * DCDETA(N,IK)
  180 CONTINUE
182   CONTINUE
      BLBAR(N,I) = S1 * FLPRI
      BB(N,I)      = FLPRI * FLEJ(I)
      IF (I .EQ. INOP) BB(N,I) = 2.0 * BB(N,I)
      BLIL(N) =  BLIL(N) - CP(N,I) * BLBAR(N,I) / CPBAR(N)
      DLIL(N) = DLIL(N) - CP(N,I) * FLPRCI * DCDETA(N,I) * FLEJ(I)
  190 CONTINUE
      PRFL  = PR(1) / FL(1)
      DO 200 N=2,NM1
      DO 200 I=1,NI
      CALL DERVDN (BLBAR(1,I), BLBAPR(N,I), 1, N)
      CALL DERVDN (BB(1,I)    , BBPR(N,I)   , 1, N)
  200 CONTINUE
      GO TO (204,250) , NEQUIL
204   CONTINUE
      DO 210 N=2,NM1
      DO 210 I=1,NI
      CALL DERVDN (CLIL(1,I), DDCDE,  2, N)
      WBAR(N,I) = (V(N) - BBPR(N,I)) * DCDETA(N,I)
     1                  -     BB(N,I)   * DDCDE  - BLBAPR(N,I)
  210 CONTINUE
  250 CONTINUE
  260 CONTINUE
      RETURN
      END
```

WKHS

Subroutine WKHS solves the boundary layer equations in the (finite difference) form of equation (25). The α's, see equation (18), are computed before calling WKHS and the boundary values of A, B, C, and D at edge and wall are also set. WKHS then computes the rest of the coefficients, see equation (26), and the final solution, W is calculated using equations (32), (33), (34), and (35).

WKHS has one argument, W, which is: f' for the momentum equation, θ for the energy equation and c_i for the species equation.

The solution returned from WKHS will be weighted as described in equation (41).

The solution of the species equation must be handled a little differently in WKHS and the switch ISPC is used to signal WKHS which equation is being solved.

When ISPC = 1, not solving species equation. See equations (35a) and (35b).

ISPC = 2, solving species equation, see equations (27), (32a), (32b).

```
      SUBROUTINE WKHS ( W )

      COMMON  /1/  NI          , NMAX       , NM2         , NTO         ,
     1             NJ          , NM1        , NR
      COMMON  /4/  FL(50)      , IBS
      COMMON /11/  DEN2(50)    , ETE        , VONE
      COMMON /28/  BETA        , CTH
      COMMON /36/  ETESQ       , SPFI(50)   , TXIE
      COMMON /41/  ETA(50)
      COMMON /42/  DMDN(50)    , DNH(50)    , TDNOM(50)   , TDNOP(50)
      COMMON /57/  ALPH1(50)   , ALPH4(50)  , ISPC        , OMWF        ,
     1             ALPH2(50)   , CHECK      , MFLAG       , WFAC        ,
     2             ALPH3(50)
      COMMON /58/  A(50)       , B(50)      , C(50)       , D(50)
      COMMON /66/   EIO        , EIO2       , IWC

      DIMENSION    E(50)       , ELIL(50)   , W(1)        , Q(50)
      DATA          (DELB = 1.0)
      CTHMO = CTH - 1.0
      DO 30 N=2,NM1
      ALPH1(N) = ALPH1(N) * ETE
      ALPH2(N) = ALPH2(N) * ETESQ
      ALPH3(N) = ALPH3(N) * ETESQ
      DA  = TDNOM(N) * (1.0 + ALPH1(N) * DNH(N-1) )
      DBB = -2.0 + ALPH1(N) * DMDN(N)
      DBA = ALPH2(N) * DEN2(N)
      DB  = DBA + DBB
      DC  = TDNOP(N) * (1.0 - ALPH1(N) * DNH(N))
      DD  = - ALPH3(N) * DEN2(N)
      GO TO (10,20) , IBS
   10 CONTINUE
      A(N) = DA
      B(N) = DB
      C(N) = DC
      D(N) = DD
      GO TO 30
   20 CONTINUE
      SP  = SPFI(N) / (ALPH4(N) * ETESQ)
      THP = SP * CTH
      A(N) = THP * DA
      B(N) = DELB + THP * DB
      C(N) = THP * DC
      GO TO (24,22) , ISPC
   22 DB = DBB
      B(N) = DELB + THP * (DBA / CTH + DBB)
   24 CONTINUE
      D(N) = CTHMO * SP * (DA*W(N+1) + DB*W(N) + DC*W(N-1))
     1              + DELB * W(N) + SP * DD
```

```fortran
30    CONTINUE
      IF ( IWC .EQ. 2 ) GO TO 40
      GO TO (40,50) , ISPC
40    CONTINUE
C                             ENERGY OR MOMENTUM EQUATION.
      E(1)     = -A(1) / B(1)
      ELIL(1) =  D(1) / B(1)
      GO TO 60
50    CONTINUE
C                             SPECIES EQUATION.
      DTR      = 1.0 / (C(2) - A(2) * B(1))
      E(1)     = -(B(2) - A(2) * A(1)) * DTR
      ELIL(1) =  (D(2) - A(2) * D(1)) * DTR
60    CONTINUE
      DO 70 N=2,NM1
      DTR      = 1.0 / (C(N) * E(N-1) + B(N))
      E(N)     = - A(N) * DTR
      ELIL(N) = (D(N) - C(N) * ELIL(N-1)) * DTR
70    CONTINUE
      Q(NMAX) = (D(NMAX)-C(NMAX)*ELIL(NM1))/(B(NMAX)+C(NMAX)*E(NM1))
      CHECK = 0.0
      DO 80 N=1,NM1
      K = NMAX - N
      CONV1 = W(K)
      Q(K)   = E(K) * Q(K+1) + ELIL(K)
      CONV3 = ABS(Q(K) - CONV1)
      CHECK = AMAX1(CHECK,CONV3)
80    CONTINUE
      DO 90 N=1,NMAX
      IF ( Q(N) .LT. 0.0 ) Q(N) = 0.0
      W(N) = WFAC * Q(N) + OMWF * W(N)
90    CONTINUE
      RETURN
      END
```

BLOCK DATA

Subprogram BLOCK DATA enters the tables of enthalpy and specific heats vs. temperature into core. Two versions are included:

1) The values for 20 species are given for the species listed in HNAME and in that order.
2) The values for 2 species that were used for the Binary Gas Model problems are given. Species names and order are given in HNAME.

```
      BLOCK DATA
      COMMON /AA/  CCP(50,30) , ENTHA(50,30),TEMP(50)    , IX
      COMMON /BB/  HNAME(30)
      DATA   (IX = 50)
      DATA  (HNAME=6HO2    ,6HN2    ,6HO     ,6HN     ,6HNO    ,
     1             6HNO+   ,6HCO    ,6HCO2   ,6HCN    ,6HC1    ,
     2             6HC2    ,6HC3    ,6HN+    ,6HN2+   ,6HH     ,
     3             6HH2    ,6HOH    ,6HH2O   ,6HA     ,6HA2    )
      DATA    (TEMP(N), N=1,50)
     1  /    50.  ,   400.  ,   600.  ,   800.  ,  1000.  ,  1200.  ,
     2     1400.  ,  1600.  ,  1800.  ,  2000.  ,  2200.  ,  2400.  ,
     3     2600.  ,  2800.  ,  3000.  ,  3200.  ,  3400.  ,  3600.  ,
     4     3800.  ,  4000.  ,  4200.  ,  4400.  ,  4600.  ,  4800.  ,
     5     5000.  ,  5200.  ,  5400.  ,  5600.  ,  5800.  ,  6000.  ,
     6     6200.  ,  6400.  ,  6600.  ,  6800.  ,  7000.  ,  7200.  ,
     7     7400.  ,  8000.  ,  9000.  , 10000.  , 11000.  , 12000.  ,
     8    13000.  , 14000.  , 15000.  , 16000.  , 17000.  , 18000.  ,
     9    19000.  , 20000.  /
      DATA    (ENTHA(N),N=  1, 50)
     1  / 5434.655, 5469.135, 5581.590, 5724.916, 5862.467, 5983.822,
     2    6089.019, 6180.965, 6262.793, 6337.042, 6405.563, 6469.639,
     3    6530.090, 6587.455, 6642.077, 6694.152, 6743.828, 6791.200,
     4    6836.337, 6879.317, 6920.219, 6959.121, 6996.109, 7031.300,
     5    7064.795, 7096.712, 7127.168, 7156.287, 7184.188, 7211.003,
     6    7236.849, 7261.828, 7286.065, 7309.661, 7332.702, 7355.290,
     7    7377.511, 7593.319, 7720.237, 7830.317, 7923.451, 8000.254,
     8    8061.276, 8107.686, 8140.501, 8160.816, 8169.879, 8168.785,
     9    8158.862, 8141.048 /
      DATA    (ENTHA(N),N= 51,100)
     1  / 6207.380, 6212.075, 6246.960, 6325.511, 6428.979, 6538.775,
     2    6644.795, 6742.855, 6831.794, 6911.827, 6983.695, 7048.288,
     3    7106.519, 7159.182, 7206.998, 7250.584, 7290.484, 7327.145,
     4    7360.959, 7392.257, 7421.323, 7448.408, 7473.727, 7497.465,
     5    7519.794, 7540.855, 7560.792, 7579.729, 7597.765, 7615.025,
     6    7631.597, 7647.581, 7663.082, 7678.182, 7692.987, 7707.578,
     7    7722.045, 7765.631, 7844.173, 7951.533, 8120.201, 8323.746,
     8    8529.942, 8764.677, 9021.018, 9289.996, 9561.829, 9827.148,
     9   10077.921,10307.899 /
      DATA    (ENTHA(N),N=101,150)
     1  / 7857.617, 8341.035, 8209.055, 8121.797, 8062.057, 8019.022,
     2    7986.675, 7961.548, 7941.499, 7925.248, 7911.950, 7901.089,
     3    7892.370, 7885.603, 7880.665, 7877.478, 7875.962, 7876.071,
     4    7877.696, 7880.790, 7885.213, 7890.870, 7897.667, 7905.465,
     5    7914.153, 7923.622, 7933.780, 7944.484, 7955.672, 7967.220,
     6    7979.065, 7991.129, 8003.333, 8015.615, 8027.913, 8040.196,
     7    8052.400, 8088.231, 8143.986, 8193.803, 8238.432, 8280.280,
     8    8323.143, 8372.022, 8432.778, 8511.676, 8614.888, 8747.963,
     9    8915.337, 9119.809 /
      DATA    (ENTHA(N),N=151,200)
     1  / 8867.431, 8867.431, 8867.431, 8867.431, 8867.431, 8867.431,
     2    8867.431, 8867.431, 8867.467, 8867.556, 8867.824, 8868.449,
     3    8869.698, 8871.947, 8875.588, 8881.085, 8888.867, 8899.345,
     4    8912.909, 8929.848, 8950.374, 8974.665, 9002.777, 9034.708,
     5    9070.405, 9109.743, 9152.526, 9198.540, 9247.534, 9299.224,
     6    9353.323, 9409.510, 9467.482, 9526.918, 9587.514, 9648.948,
     7    9710.972, 9897.846,10199.041,10471.731,10708.225,10910.181,
```

```
     8    11085.757,11247.090,11408.102,11582.697,11783.350,12019.861,    BKDT  57
     9    12298.549,12621.768 /                                           BKDT  58
      DATA    (ENTHA(N),N=201,250)                                        BKDT  59
     1  / 5795.345, 5810.168, 5882.563, 5999.576, 6127.095, 6247.807,     BKDT  60
     2     6356.130, 6451.480, 6535.015, 6608.327, 6672.957, 6730.272,    BKDT  61
     3     6781.413, 6827.330, 6868.806, 6906.474, 6940.877, 6972.446,    BKDT  62
     4     7001.558, 7028.520, 7053.590, 7077.003, 7098.932, 7119.562,    BKDT  63
     5     7139.025, 7157.463, 7174.977, 7191.682, 7207.671, 7223.027,    BKDT  64
     6     7237.833, 7252.163, 7266.086, 7279.684, 7293.006, 7306.121,    BKDT  65
     7     7319.077, 7471.150, 7568.274, 7667.449, 7767.373, 7866.555,    BKDT  66
     8     7963.471, 8056.780, 8145.231, 8227.858, 8303.628, 8371.858,    BKDT  67
     9     8431.847, 8483.421 /                                           BKDT  68
      DATA    (ENTHA(N),N=251,300)                                        BKDT  69
     1  / 5795.320, 5799.544, 5831.297, 5903.568, 5999.409, 6101.541,     BKDT  70
     2     6200.465, 6292.166, 6375.485, 6450.580, 6518.093, 6578.849,    BKDT  71
     3     6633.672, 6683.305, 6728.422, 6769.599, 6807.317, 6842.019,    BKDT  72
     4     6874.072, 6903.800, 6931.478, 6957.374, 6981.711, 7004.699,    BKDT  73
     2     7026.553, 7047.441, 7067.563, 7087.093, 7106.189, 7125.028,    BKDT  74
     6     7143.766, 7162.554, 7181.559, 7200.914, 7220.761, 7241.232,    BKDT  75
     7     7262.462, 7331.774, 7471.591, 7648.044, 7840.285, 8173.551,    BKDT  76
     8     8464.591, 8773.620, 9084.899, 9386.179, 9667.463, 9921.585,    BKDT  77
     9    10144.462,10334.179 /                                           BKDT  78
      DATA    (ENTHA(N),N=301,350)                                        BKDT  79
     1  / 6208.515, 6216.138, 6265.034, 6361.192, 6478.246, 6596.630,     BKDT  80
     2     6707.427, 6807.745, 6897.378, 6977.149, 7048.190, 7111.662,    BKDT  81
     3     7168.591, 7219.888, 7266.347, 7308.602, 7347.224, 7382.678,    BKDT  82
     4     7415.347, 7445.570, 7473.650, 7499.812, 7524.287, 7547.262,    BKDT  83
     5     7568.898, 7589.365, 7608.788, 7627.300, 7645.036, 7662.111,    BKDT  84
     6     7678.660, 7694.780, 7710.615, 7726.279, 7741.900, 7757.600,    BKDT  85
     7     7773.506, 7823.812, 7924.104, 8058.152, 8237.643, 8543.059,    BKDT  86
     8     8839.237, 9179.188, 9544.703, 9916.912,10278.231,10614.379,    BKDT  87
     9    10915.270,11175.192 /                                           BKDT  88
      DATA    (ENTHA(N),N=351,400)                                        BKDT  89
     1  / 3951.307, 4537.736, 5039.139, 5457.311, 5800.040, 6081.416,     BKDT  90
     2     6314.106, 6508.393, 6672.401, 6812.208, 6932.530, 7037.059,    BKDT  91
     3     7128.635, 7209.418, 7281.224, 7345.362, 7403.023, 7455.117,    BKDT  92
     4     7502.439, 7545.500, 7584.983, 7621.227, 7654.631, 7685.535,    BKDT  93
     5     7714.167, 7740.810, 7765.636, 7788.814, 7810.515, 7830.909,    BKDT  94
     6     7850.054, 7868.119, 7885.105, 7901.182, 7916.407, 7930.837,    BKDT  95
     7     7944.528, 7981.681, 8033.150, 8074.791, 8074.791, 8074.791,    BKDT  96
     8     8074.791, 8074.791, 8074.791, 8074.791, 8074.791, 8074.791,    BKDT  97
     9     8074.791, 8074.791 /                                           BKDT  98
      DATA    (ENTHA(N),N=401,450)                                        BKDT  99
     1  / 6683.341, 6694.141, 6756.990, 6871.793, 7005.860, 7138.668,     BKDT 100
     2     7262.945, 7378.381, 7487.255, 7592.276, 7695.557, 7798.340,    BKDT 101
     3     7901.083, 8003.635, 8105.456, 8205.826, 8303.958, 8399.130,    BKDT 102
     4     8490.708, 8578.194, 8661.249, 8739.664, 8813.323, 8882.226,    BKDT 103
     5     8946.458, 9006.166, 9061.520, 9112.733, 9160.046, 9203.687,    BKDT 104
     6     9243.918, 9281.804, 9320.238, 9358.672, 9397.106, 9430.736,    BKDT 105
     7     9464.366, 9555.646, 9689.493, 9776.546, 9845.631, 9898.381,    BKDT 106
     8     9935.566, 9957.666, 9965.353, 9959.780, 9942.004, 9913.755,    BKDT 107
     9     9876.474, 9831.602 /                                           BKDT 108
      DATA    (ENTHA(N),N=451,500)                                        BKDT 109
     1  /12912.603,10768.437,10629.406,10558.693,10515.895,10487.315,     BKDT 110
     2    10467.290,10453.364,10444.579,10440.603,10441.290,10446.453,    BKDT 111
     3    10455.841,10469.080,10485.670,10505.092,10526.865,10550.471,    BKDT 112
     4    10575.429,10601.345,10627.824,10654.572,10681.321,10707.882,    BKDT 113
     5    10734.048,10759.735,10784.819,10809.215,10832.925,10855.885,    BKDT 114
     6    10878.096,10899.557,10920.311,10940.066,10959.716,10978.451,    BKDT 115
     7    10996.602,11048.039,11127.536,11207.490,11299.352,11415.964,    BKDT 116
     8    11570.316,11773.814,12034.807,12357.291,12740.162,13177.363,    BKDT 117
     9    13658.465,14169.939 /                                           BKDT 118
      DATA    (ENTHA(N),N=501,550)                                        BKDT 119
     1  / 7239.550, 9208.548, 9237.129, 9145.819, 9094.569, 9079.134,     BKDT 120
     2     9087.273, 9111.181, 9146.017, 9188.481, 9236.161, 9287.181,    BKDT 121
     3     9340.085, 9393.739, 9447.268, 9500.037, 9551.577, 9601.588,    BKDT 122
     4     9649.829, 9696.197, 9740.629, 9783.115, 9823.655, 9862.321,    BKDT 123
     5     9899.155, 9934.251, 9967.671, 9999.509,10029.849,10058.783,    BKDT 124
     6    10086.396,10112.760,10137.968,10162.083,10185.179,10207.338,    BKDT 125
     7    10228.612,10287.719,10373.450,10447.202,10512.252,10570.433,    BKDT 126
```

```
8     10623.202,10671.288,10715.314,10715.314,10715.314,10715.314,
9     10715.314,10715.314 /
 DATA     (ENTHA(N),N=551,600)
1  / 4826.179, 5874.778, 6489.916, 6978.124, 7371.896, 7692.325,
2     7955.719, 8174.566, 8358.580, 8515.048, 8649.382, 8765.813,
3     8867.674, 8957.391, 9036.978, 9108.100, 9171.936, 9229.527,
4     9281.845, 9329.445, 9373.020, 9413.056, 9449.901, 9483.970,
5     9515.541, 9544.892, 9572.230, 9597.765, 9621.634, 9644.046,
6     9665.140, 9684.984, 9703.719, 9721.343, 9738.135, 9753.955,
7     9769.012, 9809.881, 9866.362, 9912.088, 9912.088, 9912.088,
8     9912.088, 9912.088, 9912.088, 9912.088, 9912.088, 9912.088,
9     9912.088, 9912.088 /
 DATA     (ENTHA(N),N=601,650)
1  /11682.042, 9892.438, 9576.733, 9409.010, 9305.274, 9234.826,
2     9183.886, 9145.351, 9115.276, 9091.252, 9071.851, 9056.216,
3     9043.739, 9034.119, 9027.087, 9022.463, 9020.144, 9019.929,
4     9021.714, 9025.338, 9030.639, 9037.457, 9045.631, 9055.502,
5     9065.443, 9076.777, 9088.878, 9101.604, 9114.848, 9128.502,
6     9142.460, 9156.632, 9170.964, 9185.368, 9199.771, 9214.157,
7     9228.472, 9270.595, 9336.813, 9397.105, 9451.454, 9500.501,
8     9545.052, 9585.961, 9624.050, 9660.050, 9694.641, 9728.392,
9     9761.858, 9795.521/
 DATA     (ENTHA(N),N=651,700)
1  / 6207.398, 6214.404, 6260.649, 6353.863, 6468.996, 6587.100,
2     6700.322, 6807.386, 6909.810, 7009.655, 7108.563, 7207.471,
3     7306.593, 7405.634, 7503.971, 7600.826, 7695.397, 7786.960,
4     7874.909, 7958.770, 8038.214, 8113.053, 8183.198, 8248.684,
5     8309.592, 8366.074, 8418.326, 8466.571, 8511.031, 8551.958,
6     8589.592, 8624.173, 8655.926, 8685.073, 8711.826, 8736.378,
7     8758.903, 8815.992, 8924.279, 9011.023, 9067.335, 9115.794,
8     9156.220, 9188.705, 9213.069, 9229.132, 9237.075, 9236.540,
9     9228.597, 9213.693 /
 DATA     (ENTHA(N),N=701,750)
1  /123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
2    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
3    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
4    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
5    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
6    123229.42,123229.42,123229.91,123230.40,123231.40,123233.14,
7    123236.11,123260.67,123475.47,124493.17,127993.98,137374.30,
8    157689.13,193582.76,244888.75,309378.71,383790.02,470603.63,
9    557417.05,644230.47 /
 DATA     (ENTHA(N),N=751,800)
1  / 86081.33, 86441.86, 86544.55, 86732.81, 87106.48, 87697.42,
2     88471.31, 89370.82, 90341.64, 91342.47, 92344.43, 93328.64,
3     94284.21, 95204.80, 96422.16, 96931.52, 97737.40, 98506.81,
4     99241.26, 99942.96,100613.90,101256.19,101871.95,102463.03,
5    103031.03,103577.83,104104.92,104861.68,105105.50,105581.49,
6    106042.84,106490.42,106925.36,107348.26,107760.13,108158.82,
7    108553.36,109676.23,111402.70,111730.11,112991.51,115915.38,
8    117323.50,118745.63,120220.71,121733.74,123296.39,124908.63,
9    126570.49,128281.96 /
 DATA     (ENTHA(N),N=801,850)
1  /10225.791,10233.891,10243.343,10274.772,10340.056,10435.579,
2    10550.961,10676.384,10804.718,10931.420,11053.888,11170.770,
3    11281.507,11385.997,11484.386,11576.998,11664.215,11746.419,
4    11824.037,11897.450,11967.012,12033.089,12095.977,12155.969,
5    12213.345,12268.324,12321.156,12372.020,12421.104,12468.571,
6    12514.598,12559.287,12602.770,12645.166,12686.576,12727.090,
7    12766.781,12881.605,13061.978,13232.296,13395.013,13551.351,
8    13701.911,13846.974,13986.759,14122.002,14252.834,14379.257,
9    14501.269,14618.872 /
 DATA     (ENTHA(N),N=851,900)
1  /11031.514,11082.959,11275.333,11561.951,11899.918,12263.280,
2    12631.806,12991.213,13332.927,13652.727,13949.282,14222.675,
3    14474.279,14705.484,14918.092,15113.908,15294.319,15460.992,
4    15615.313,15758.250,15891.204,16014.994,16130.457,16238.288,
5    16339.318,16434.104,16523.199,16607.160,16686.264,16760.926,
6    16831.426,16898.317,16961.738,17021.968,17079.283,17133.684,
7    17185.587,17327.696,17526.704,17689.491,17825.216,17939.985,
8    18038.379,18123.589,18197.974,18261.534,18316.491,18362.287,
```

```
9    18400.596,18432.509 /
 DATA    (ENTHA(N),N=901,950)
1  / 3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
2      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
3      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
4      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
5      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
6      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.735,
7      3109.735, 3109.754, 3109.935, 3110.818, 3114.091, 3123.756,
8      3147.566, 3198.311, 3294.210, 3457.610, 3711.363, 4072.601,
9      4545.174, 5113.884 /
 DATA    (ENTHA(N),N=951,1000)
1  / 3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
2      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
3      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
4      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
5      3109.729, 3109.729, 3109.729, 3109.729, 3109.729, 3109.729,
6      3109.735, 3109.735, 3109.741, 3109.751, 3109.772, 3109.804,
7      3109.854, 3110.236, 3113.321, 3127.349, 3175.020, 3304.438,
8      3598.495, 4176.375, 5179.895, 6737.667, 8904.835,11591.589,
9    14518.264,17247.018 /
 DATA     (CCP(N),N=  1, 50)
1  / 5435.163, 5622.336, 5992.768, 6299.773, 6512.175, 6661.157,
2      6775.183, 6872.215, 6961.848, 7048.348, 7132.957, 7215.441,
3      7295.011, 7370.752, 7441.907, 7507.913, 7568.489, 7623.548,
4      7673.240, 7717.846, 7757.795, 7793.595, 7825.786, 7855.085,
5      7881.884, 7906.965, 7930.873, 7954.078, 7977.049, 8000.254,
6      8024.085, 8048.774, 8074.714, 8101.982, 8130.813, 8161.285,
7      8193.475, 8675.472, 8786.966, 8846.268, 8856.972, 8825.329,
8      8757.510, 8659.298, 8535.928, 8392.712, 8234.572, 8066.276,
9      7891.963, 7715.455 /
 DATA     (CCP(N),N= 51,100)
1  / 6207.916, 6238.892, 6422.482, 6704.650, 6973.922, 7192.665,
2      7361.682, 7491.200, 7591.304, 7669.856, 7732.558, 7783.506,
3      7825.611, 7860.978, 7891.133, 7917.210, 7940.065, 7960.332,
4      7978.511, 7995.003, 8010.112, 8024.105, 8037.215, 8049.655,
5      8061.622, 8073.331, 8084.977, 8096.802, 8109.028, 8121.933,
6      8135.783, 8150.874, 8167.518, 8186.045, 8206.794, 8230.095,
7      8256.315, 8355.802, 8648.519, 9191.115, 9852.582,10608.201,
8    11408.798,12221.532,12984.647,13642.367,14152.925,14493.832,
9    14661.698,14668.123 /
 DATA     (CCP(N),N=101,150)
1  / 8201.757, 8023.678, 7889.791, 7837.240, 7811.628, 7797.330,
2      7788.595, 7783.016, 7779.703, 7778.516, 7779.797, 7784.110,
3      7791.986, 7803.846, 7819.879, 7840.084, 7864.242, 7891.979,
4      7922.810, 7956.172, 7991.519, 8028.257, 8065.870, 8103.842,
5      8141.736, 8179.177, 8215.836, 8251.433, 8285.765, 8318.658,
6      8349.989, 8379.648, 8407.604, 8433.825, 8458.311, 8481.079,
7      8502.159, 8555.945, 8619.388, 8663.392, 8708.225, 8779.544,
8      8907.602, 9125.184, 9464.356, 9952.572,10608.943,11440.878,
9    12441.781,13590.103 /
 DATA     (CCP(N),N=151,200)
1  / 8867.431, 8867.431, 8867.431, 8867.431, 8867.431, 8867.431,
2      8867.449, 8867.521, 8867.878, 8869.109, 8872.304, 8879.104,
3      8891.634, 8912.178, 8943.002, 8986.089, 9043.008, 9114.723,
4      9201.717, 9303.864, 9420.612, 9550.924, 9693.498, 9846.728,
5    10008.882,10178.069,10352.378,10529.971,10708.956,10887.638,
6    11064.392,11237.720,11406.317,11569.043,11724.896,11873.075,
7    12012.901,12378.225,12801.325,13021.683,13109.641,13154.137,
8    13246.646,13470.235,13891.497,14554.464,15475.985,16643.495,
9    18015.799,19526.501 /
 DATA     (CCP(N),N=201,250)
1  / 5796.295, 5888.279, 6186.593, 6505.928, 6755.759, 6937.044,
2      7068.204, 7165.012, 7238.399, 7295.597, 7341.373, 7378.924,
3      7410.427, 7437.397, 7460.918, 7481.765, 7500.511, 7517.600,
4      7533.364, 7548.070, 7561.917, 7575.107, 7587.796, 7600.135,
5      7612.267, 7624.348, 7636.512, 7648.919, 7661.708, 7675.039,
6      7689.070, 7703.959, 7719.848, 7736.903, 7755.258, 7775.046,
7      7796.409, 8238.273, 8453.760, 8665.306, 8865.271, 9046.072,
8      9202.795, 9332.022, 9430.838, 9497.076, 9529.237, 9527.321,
9      9492.577, 9427.588 /
```

```
      DATA     (CCP(N),N=251,300)
     1 / 5795.820, 5823.690, 5991.961, 6253.714, 6505.362, 6710.826,
     2   6870.172, 6992.659, 7087.592, 7162.271, 7222.052, 7270.760,
     3   7311.120, 7345.130, 7374.234, 7399.521, 7421.809, 7441.788,
     4   7460.010, 7476.982, 7493.179, 7509.093, 7525.199, 7542.012,
     5   7560.051, 7579.864, 7602.002, 7627.022, 7655.459, 7687.853,
     6   7724.714, 7766.506, 7813.665, 7866.597, 7925.628, 7991.058,
     7   8063.121, 8320.600, 8887.684, 9606.557,10498.150,11511.388,
     8  12408.563,13147.016,13708.251,14069.770,14234.574,14222.993,
     9  14065.854,13797.485 /
      DATA     (CCP(N),N=301,350)
     1 / 6209.122, 6259.348, 6493.956, 6804.951, 7077.949, 7289.135,
     2   7447.623, 7566.890, 7658.086, 7729.252, 7785.949, 7832.060,
     3   7870.281, 7902.530, 7930.200, 7954.309, 7975.597, 7994.645,
     4   8011.898, 8027.706, 8042.362, 8056.135, 8069.265, 8081.984,
     5   8094.552, 8107.245, 8120.357, 8134.236, 8149.250, 8165.825,
     6   8184.418, 8205.518, 8229.645, 8257.351, 8289.207, 8325.795,
     7   8367.675, 8530.849, 8957.470, 9610.933,10523.603,11781.080,
     8  13020.437,14163.752,15124.087,15828.517,16241.874,16371.299,
     9  16254.638,15945.356 /
      DATA     (CCP(N),N=351,400)
     1 / 3723.491, 5609.048, 6419.714, 6969.683, 7348.770, 7612.137,
     2   7798.074, 7932.257, 8031.332, 8106.093, 8163.584, 8208.690,
     3   8244.650, 8273.680, 8297.483, 8317.195, 8333.670, 8347.645,
     4   8359.518, 8369.744, 8378.549, 8386.275, 8392.979, 8398.944,
     5   8404.170, 8408.829, 8413.032, 8416.782, 8420.134, 8423.201,
     6   8425.928, 8428.428, 8430.700, 8432.802, 8434.733, 8436.495,
     7   8438.085, 8442.232, 8447.459, 8451.151, 8451.151, 8451.151,
     8   8451.151, 8451.151, 8451.151, 8451.151, 8451.151, 8451.151,
     9   8451.151, 8451.151 /
      DATA     (CCP(N),N=401,450)
     1 / 6683.572, 6754.069, 7039.624, 7388.874, 7683.489, 7912.604,
     2   8100.065, 8271.884, 8446.048, 8630.963, 8827.400, 9031.292,
     3   9236.327, 9435.819, 9623.867, 9795.859, 9948.922,10081.519,
     4  10193.170,10284.643,10357.187,10412.532,10452.695,10479.503,
     5  10494.973,10501.026,10501.603,10502.083,10505.926,10509.770,
     6  10513.613,10517.457,10520.339,10523.510,10528.026,10530.716,
     7  10533.407,10544.841,10563.962,10554.065,10513.805,10436.937,
     8  10319.714,10164.537, 9978.132, 9769.339, 9546.893, 9318.653,
     9   9090.845, 8868.149 /
      DATA     (CCP(N),N=451,500)
     1 /11299.789,10356.215,10348.138,10345.349,10344.266,10345.078,
     2  10350.220,10363.250,10387.376,10424.304,10473.867,10534.505,
     3  10603.781,10678.906,10757.175,10836.172,10913.900,10988.838,
     4  11059.904,11126.328,11187.736,11243.960,11295.064,11341.234,
     5  11382.721,11419.919,11468.462,11482.909,11509.533,11533.471,
     6  11555.099,11574.812,11593.005,11610.033,11626.269,11642.090,
     7  11657.848,11708.576,11829.414,12046.006,12421.737,13016.579,
     8  13874.183,15010.557,16407.111,18009.808,19734.633,21478.713,
     9  23134.220,24603.839 /
      DATA     (CCP(N),N=501,550)
     1 / 7239.956, 9861.904, 8952.343, 8851.739, 8939.666, 9129.603,
     2   9206.415, 9351.295, 9498.007, 9642.742, 9782.054, 9913.310,
     3  10034.803,10145.722,10245.879,10335.586,10415.457,10486.336,
     4  10548.993,10604.364,10653.178,10696.267,10734.361,10768.083,
     5  10797.954,10824.494,10848.329,10869.665,10888.920,10906.510,
     6  10922.538,10937.422,10951.265,10964.379,10976.764,10988.630,
     7  11000.183,11032.968,11085.425,11136.945,11186.903,11234.052,
     8  11277.037,11315.339,11348.853,11348.853,11348.853,11348.853,
     9  11348.853,11348.853 /
      DATA     (CCP(N),N=551,600)
     1 / 4826.478, 7264.762, 8123.844, 8725.777, 9142.100, 9429.432,
     2   9630.793, 9775.188, 9881.211, 9960.868,10022.067,10069.875,
     3  10107.899,10138.568,10163.686,10184.433,10201.849,10216.490,
     1  10228.979,10239.734,10249.032,10257.081,10264.159,10270.404,
     5  10275.885,10280.812,10285.183,10289.069,10292.607,10295.799,
     6  10298.714,10301.350,10303.709,10305.930,10307.942,10309.746,
     7  10311.411,10315.783,10321.195,10325.081,10325.081,10325.081,
     8  10325.081,10325.081,10325.081,10325.081,10325.081,10325.081,
     9  10325.081,10325.081 /
```

```
 DATA     (CCP(N),N=601,650)
1  /12575.130, 8985.107, 8918.907, 8896.096, 8885.655, 8880.032,
2     8876.730, 8874.892, 8874.499, 8876.052, 8880.372, 8888.368,
3     8900.719, 8917.925, 8940.182, 8967.312, 8998.975, 9034.601,
4     9073.529, 9115.062, 9158.452, 9203.056, 9248.212, 9293.387,
5     9338.080, 9381.916, 9424.538, 9465.733, 9505.285, 9543.071,
6     9575.018, 9613.090, 9645.271, 9675.596, 9704.082, 9730.837,
7     9755.915, 9821.937, 9906.842, 9969.598,10018.735,10060.340,
8    10098.768,10137.178,10177.980,10223.011,10273.862,10331.834,
9    10398.142,10473.980 /
 DATA     (CCP(N),N=651,700)
1  / 6207.996, 6254.340, 6480.115, 6787.369, 7062.621, 7284.666,
2     7470.505, 7642.592, 7817.035, 8001.268, 8195.576, 8395.801,
3     8595.750, 8788.978, 8969.882, 9134.267, 9279.465, 9404.227,
4     9508.284, 9592.707, 9658.658, 9708.009, 9742.725, 9764.857,
5     9776.280, 9778.779, 9773.960, 9763.250, 9756.022, 9754.237,
6     9754.237, 9748.882, 9744.420, 9731.926, 9728.357, 9727.464,
7     9727.464, 9709.616, 9685.520, 9682.843, 9659.640, 9648.930,
8     9630.546, 9587.353, 9516.584, 9419.309, 9299.099, 9160.594,
9     9009.060, 8849.440 /
 DATA     (CCP(N),N=701,750)
1  /11031.680,11328.596,12023.555,12830.994,13672.250,14476.360,
2    15192.734,15803.774,16313.506,16734.840,17082.336,17369.885,
3    17608.861,17808.701,17976.900,18117.564,18241.134,18345.634,
4    18435.839,18514.249,18582.805,18643.035,18696.187,18743.233,
5    18785.144,18822.614,18856.198,18886.452,18913.791,18938.632,
6    18961.114,18981.654,19000.389,19017.597,19033.418,19047.851,
7    19061.312,19095.868,19139.167,19170.253,19193.429,19211.193,
8    19224.932,19235.895,19244.777,19251.577,19256.296,19260.320,
9    19267.263,19264.206 /
 DATA     (CCP(N),N=751,800)
1  /123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
2    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
3    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
4    123229.17,123229.17,123229.17,123229.17,123229.17,123229.17,
5    123229.17,123229.17,123229.41,123229.41,123229.91,123230.90,
6    123232.89,123236.61,123243.80,123256.70,123278.77,123316.23,
7    123377.25,123845.54,127515.27,143033.54,190815.15,304462.10,
8    515994.15,813315.23,1099077.7,1143456.7,1190584.0,1235230.9,
9    1277397.4,1314603.2 /
 DATA     (CCP(N),N=801,850)
1  / 86304.94, 86625.03, 86924.79, 87806.56, 89402.32, 91845.25,
2     94396.94, 96916.76, 99266.68,101394.48,103294.95,104984.46,
3    106487.82,107830.82,109037.53,110128.90,111123.16,112035.32,
4    112878.28,113662.33,114396.27,115087.56,115742.13,116364.95,
5    116960.49,117532.22,118083.24,118616.15,119133.06,119635.84,
6    120126.33,120605.79,121075.45,121536.43,121989.60,122435.82,
7    122875.96,124166.75,126253.99,128332.56,130499.17,132881.58,
8    135636.04,138934.95,142940.77,147281.44,152366.23,157078.96,
9    161791.69,166504.42 /
 DATA     (CCP(N),N=851,900)
1  /10226.95 ,10244.25 ,10294.74 ,10466.17 ,10749.61 ,11079.25 ,
3    11403.84 ,11698.97 ,11957.46 ,12180.40 ,12371.99 ,12537.09 ,
3    12680.28 ,12805.52 ,12916.03 ,13014.53 ,13103.15 ,13183.69 ,
4    13257.59 ,13326.07 ,13390.10 ,13450.54 ,13508.09 ,13563.35 ,
5    13616.83 ,13668.94 ,13720.07 ,13770.49 ,13820.47 ,13870.20 ,
6    13919.84 ,13969.53 ,14019.36 ,14069.39 ,14119.66 ,14170.20 ,
7    14221.02 ,14375.07 ,14635.13 ,14894.63 ,15148.36 ,15391.95 ,
8    15623.03 ,15840.60 ,16044.49 ,16234.13 ,16410.53 ,16573.70 ,
9    16723.65 ,16860.36  /
 DATA     (CCP(N),N=951,1000)
1  / 3109.806, 3128.316, 3177.609, 3227.266, 3263.295, 3285.804,
2     3298.280, 3303.988, 3305.322, 3303.876, 3300.715, 3296.527,
3     3291.757, 3286.670, 3281.542, 3276.396, 3271.351, 3266.456,
4     3261.724, 3257.886, 3252.836, 3248.679, 3244.711, 3240.924,
5     3273.318, 3233.882, 3230.602, 3227.472, 3224.493, 3221.645,
6     3218.922, 3216.324, 3213.839, 3211.454, 3209.176, 3206.998,
7     3204.901, 3199.104, 3190.836, 3183.836, 3178.104, 3173.134,
8     3168.884, 3165.284, 3162.349, 3160.164, 3158.900, 3158.843,
9     3160.364, 3163.932 /
```

```
      DATA   (CCP(N),N=901,950)                                        BKDT 409
     1 / 3109.806, 3204.869, 3338.994, 3401.229, 3409.035, 3387.089,   BKDT 410
     2   3358.621, 3329.545, 3302.868, 3279.457, 3259.296, 3242.076,   BKDT 411
     3   3277.378, 3214.816, 3204.043, 3194.760, 3186.723, 3179.731,   BKDT 412
     4   3173.622, 3168.258, 3163.525, 3159.332, 3155.601, 3152.265,   BKDT 413
     5   3149.279, 3146.593, 3144.165, 3141.968, 3139.971, 3138.156,   BKDT 414
     6   3136.497, 3134.976, 3133.580, 3132.297, 3131.120, 3130.025,   BKDT 415
     7   3129.017, 3126.394, 3123.083, 3120.698, 3119.008, 3118.006,   BKDT 416
     8   3117.950, 3119.459, 3123.596, 3111.971, 3146.756, 3170.711,   BKDT 417
     8   3207.079, 3259.496 /                                          BKDT 418
      END                                                              BKDT 419
```

```
      BLOCK DATA
C
C                             FOR BINARY GAS MODEL ONLY
C
      COMMON /AA/  CCP(50,30) , ENTHA(50,30),TEMP(50),   , IX
      COMMON /BB/   HNAME(30)
      DATA    (IX = 50)
      DATA      (HNAME=6HO      ,6HO2     )
      DATA      (TEMP(N), N=1,50)
     1  /   50.    ,   400.   ,   600.   ,   800.   ,  1000.   ,  1200.   ,
     2    1400.    ,  1600.   ,  1800.   ,  2000.   ,  2200.   ,  2400.   ,
     3    2600.    ,  2800.   ,  3000.   ,  3200.   ,  3400.   ,  3600.   ,
     4    3800.    ,  4000.   ,  4200.   ,  4400.   ,  4600.   ,  4800.   ,
     5    5000.    ,  5200.   ,  5400.   ,  5600.   ,  5800.   ,  6000.   ,
     6    6200.    ,  6400.   ,  6600.   ,  6800.   ,  7000.   ,  7200.   ,
     7    7400.    ,  8000.   ,  9000.   , 10000.   , 11000.   , 12000.   ,
     8   13000.    , 14000.   , 15000.   , 16000.   , 17000.   , 18000.   ,
     9   19000.    , 20000.   /
      DATA      (ENTHA(N),N= . 1, 50)
     1  / 7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     2    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     3    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     4    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     5    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     6    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     7    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     8    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     9    7728.042, 7728.042 /
      DATA      (ENTHA(N),N= 51,100)
     1  / 5409.630, 5442.422, 5552.791, 5692.327, 5824.902, 5940.248,
     2    6038.030, 6120.600, 6190.630, 6250.463, 6302.023, 6346.808,
     3    6386.015, 6420.604, 6451.310, 6478.742, 6503.385, 6525.637,
     4    6545.826, 6564.226, 6581.056, 6596.510, 6610.746, 6623.903,
     5    6636.100, 6647.437, 6658.000, 6667.868, 6677.104, 6685.761,
     6    6693.902, 6701.567, 6708.802, 6715.630, 6722.092, 6728.218,
     7    6734.031, 6749.813, 6771.651, 6789.301, 6803.857, 6816.069,
     8    6826.461, 6835.407, 6843.197, 6850.033, 6856.081, 6861.472,
     9    6866.308, 6870.668 /
      DATA      (CCP(N),N=  1, 50)
     1  / 7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     2    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     3    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     4    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     5    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     6    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     7    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     8    7728.042, 7728.042, 7728.042, 7728.042, 7728.042, 7728.042,
     9    7728.042, 7728.042 /
      DATA      (CCP(N),N= 51,100)
     1  / 5409.630, 5593.154, 5954.960, 6249.346, 6447.262, 6577.860,
     2    6666.071, 6727.585, 6771.846, 6804.592, 6829.430, 6848.682,
     3    6863.870, 6876.067, 6885.997, 6894.178, 6900.999, 6906.749,
     4    6911.633, 6915.820, 6919.430, 6922.571, 6925.321, 6927.736,
     5    6929.869, 6931.767, 6933.455, 6934.971, 6936.338, 6937.565,
     6    6938.682, 6939.698, 6940.620, 6941.463, 6942.229, 6942.940,
     7    6943.596, 6945.268, 6947.355, 6948.847, 6949.956, 6950.800,
     8    6951.456, 6951.972, 6952.394, 6952.738, 6953.027, 6953.261,
     9    6953.464, 6953.636 /
      END
```

8. Dimensions of Variables

There are eight parameters which determine most of the dimensions in the program and have the following maximum values:

NI = 30
NR = 30
N = 50
NTP = 50
NED = 110
NJ = 40
IX = 50
NDX = 20

If any of these quantities need to be increased, then the dimension of certain variables must be changed. Also, if the storage requirements need to be reduced and the above parameters are larger than required, the dimension of some of the variables can be reduced. Since some of the parameters have the same value, the change of dimensions is not straight-forward. The chart below shows the changes required when any of the parameters are changed. All the variables are in COMMON unless a subroutine is given to indicate a DIMENSION statement is used in that subroutine.

To change	Replace	Except
a. Number of species, NI	30 by new NI 435 by $\frac{1}{2}$ NI (NI - 1)	Z(NI,NJ-NI) OMW(2 + NI) WFA (2 + NI) NR Terms
b. Number of reactions, NR	30 by NR in CO(NR) C1(NR) C2(NR) CSALPH(NR) CSBETA(NR) DO(NR) D1(NR) D2(NR) DIFA(NR,NI) GAMMIN (NR,NI) GAMPLS(NR,NI) X(N,NR) AR(6,NR) - INPUT CAS(NR,1) - STOI	
c. Number of points across Layer, N	50 by new N	NTP terms
d. Number of points in wall table, NTP	50 by NTP in RVPT(NTP) TETE(NTP) TWT(NTP) XRN(NTP) XRB(NTP)	
e. Number of entries in edge table, NED	110 by new NED	

f. NJ	40 by NJ in SPN(NJ) CALPH(NI,NJ) CBETA(NI,NJ) Z(NI,NJ-NI) TST(NJ) ISB(NJ)	PRECAL
g. IX	50 by IX in ENTHA (IX,NI) TEMP(IX) CCP(IX,NI)	
h. NDX	20 by NDX in DELXT(NDX) XDELT(NDX)	

In subroutine PR2DSW the following quantities are given in a DIMENSION statement:

A(30,1) and IRP(30)

IF either NI or NR are changed, then the 30 should be changed to the larger of NI and NR.

APPENDIX E

Equilibrium Composition

The composition of a gas in local chemical equilibrium is determined from the temperature, pressure and the mass fraction of the chemical elements involved. The solution requires the solution of a set of simultaneous nonlinear algebraic equations. There have been several methods employed to solve these equations as indicated in references 53-58. The present approach is similar to that employed by Penner[53] and depends upon a knowledge of the importance of the various chemical species in the gas mixture. The present method is simple to apply and has been very successful for the conditions of interest. The original version was presented in reference 3 and as this report has limited availability, the details of the method are described in this appendix. Only the case of pure air (O_2, N_2, O, N, NO, NO^+, e) is described below. In reference 3 the same approach has been used to determine the composition of the systems: (1) Sodium-Air (2) Carbon-Air and (3) Hydrogen-Carbon-Air.

The reactions which occur in a multicomponent gas mixture can be represented as given in equation (4). When the gas is in chemical equilibrium, the production of species i is zero and

$$K_{c_r} = \frac{k_{f_r}}{k_{b_r}} = \bar{\rho}^{\theta_r} \prod_{i=1}^{NI} \gamma_i^{\theta_{ri}} \tag{E-1}$$

where

$$\theta_r = \sum_{i=1}^{NI} \theta_{ri}$$

$$\theta_{ri} = \beta_{ri} - \alpha_{ri} \quad .$$

In addition to the above relations, the equations for conservation of elements and charge are written as

$$\gamma^j = \sum_{i=1}^{NI} \alpha_i^j \gamma_i \tag{E-2}$$

where

α_i^j = number of atoms of element j in species i .

To complete the foregoing equations, the equilibrium constant is approximated by the following type of relation over a limited temperature range

$$K_{c_r} = A_r (TK)^{n_r} e^{-E_r/TK} \quad . \tag{E-3}$$

Accurate values of K_{c_r} can be obtained in terms of partition functions and are a function of temperature. The equilibrium constants K_{p_r} based on partial pressure are given in the JANAF tables and can be used to determine the parameters in equation (E-3). The equilibrium constants are related by

$$K_{c_r} = (\bar{R}\ TK)^{-\theta_r} K_{p_r} \qquad \text{(E-4)}$$

where

$\bar{R} = 82.057$ atm cm^3/gm-mole ^oK .

The above relations (E-3) and (E-4) are written as

$$\ln K_{c_r} = 2.3026 \left[\log K_{p_r} - \theta_r \log (\bar{R}\ TK)\right]$$
$$= \ln A_r + n_r \ln TK - E_r/TK \qquad \text{(E-5)}$$

The equilibrium constants $\bar{K}_p$ given in the JANAF tables correspond to the species being formed from its elements. The air and carbon species equilibrium constants are given in Table E-I. The equilibrium constant for a reaction of the form of equation (4) is expressed in terms of the species equilibrium constants as

$$\log K_{p_r} = \sum_{i=1}^{NI} \theta_{ri} \log p_i = \sum_{i=1}^{NI} \theta_{ri} \log \bar{K}_{p_i} \qquad \text{(E-6)}$$

For the elements (O_2, N_2, C^*, etc.) the log $\bar{K}_{p_i}$ is zero. The parameter E_r is the heat of reaction and is the amount of energy that must be added to reaction (4) for it to proceed from right to left. With the heats of formation or heats of reaction as given in Table E-I, the value of E_r is obtained from

$$E_r = \sum_{i=1}^{NI} \theta_{ri} \bar{E}_i \qquad \text{(E-7)}$$

with the heats of reaction of the elements being zero. The coefficients A_r and n_r in relation (E-3) are determined by finding $\ln K_{c_r}$ from the first part of equation (E-5). Then from the second part of (E-5) the following relation is written:

$$y = a + bx \qquad \text{(E-8)}$$

where

$y = \ln K_{c_r} + E_r/TK$

$a = \ln A_r$

$b = n_r$

$x = \ln TK$.

Then with a plot of equation (E-8), the value of A_r is determined from the y-intercept and n_r from the slope as given in Figure EI. The resulting coefficients for the air reactions defined before are given in Table E-II.

The equilibrium composition is obtained by solving the nonlinear algebraic equations (E-1) with the relations given by (E-2). For the case of air, the following independent chemical reactions are used:

$$
\begin{aligned}
r &= 1 \qquad O_2 \rightleftarrows 2O \\
&= 2 \qquad N_2 \rightleftarrows 2N \\
&= 3 \qquad NO \rightleftarrows N + O \\
&= 4 \qquad N + O \rightleftarrows NO^+ + e^-
\end{aligned}
\tag{E-9}
$$

The equilibrium constants for the above reactions are obtained from (E-1) and are

$$K_{c_1} = \bar{\rho}\, \gamma_O^{\,2}/\gamma_{O_2} \tag{E-10a}$$

$$K_{c_2} = \bar{\rho}\, \gamma_N^{\,2}/\gamma_{N_2} \tag{E-10b}$$

$$K_{c_3} = \bar{\rho}\, \gamma_O \gamma_N/\gamma_{NO} \tag{E-10c}$$

$$K_{c_4} = \gamma_{NO^+}\, \gamma_{e^-}/\gamma_O \gamma_N \tag{E-10d}$$

The equations (E-2) for this system become

$$\gamma^O = \gamma_O + \gamma_{NO} + \gamma_{NO^+} + 2\gamma_{O_2} \tag{E-11a}$$

$$\gamma^N = \gamma_N + \gamma_{NO} + \gamma_{NO^+} + 2\gamma_{N_2} \tag{E-11b}$$

$$0 = \gamma_{NO^+} + \gamma_{e^-} \tag{E-11c}$$

For the present calculation it is assumed that the element composition remains fixed and

$$\gamma^O = 0.01455$$
$$\gamma^N = 0.05477$$

Equations (E-10a) and (E-11a) are used to eliminate γ_{O_2} and the resulting equation is solved for γ_O which gives

$$\gamma_O = \frac{1}{K_1}\left(-1 + \sqrt{1 + 2K_1\Gamma_O}\right) \tag{E-12a}$$

where

$$K_1 = 4\bar{\rho}/K_{c_1}$$

$$\Gamma_O = \gamma^O - \gamma_{NO} - \gamma_{NO^+}$$

When $2K_1\Gamma_O < 10^{-3}$, then

$$\gamma_O = \Gamma_O \left[1 - \frac{1}{2} K_1\Gamma_O + \frac{1}{2} K_1^2 \Gamma_O^2 + \ldots\right] \qquad \text{(E-12b)}$$

In a similar manner

$$\gamma_N = \frac{1}{K_2} \left(- 1 + \sqrt{1 + 2K_2 \Gamma_N}\right) \qquad \text{(E-13a)}$$

where

$$K_2 = 4\bar{\rho}/K_{c_2}$$

$$\Gamma_N = \gamma^N - \gamma_{NO} - \gamma_{NO^+} \quad .$$

When $2K_2 \Gamma_N < 10^{-3}$, then

$$\gamma_N = \Gamma_N \left[1 - \frac{1}{2} K_2\Gamma_N + \frac{1}{2} K_2^2 \Gamma_N^2 + \ldots\right] \qquad \text{(E-13b)}$$

The other species are obtained from (E-10) and (E-11c) which give

$$\gamma_{NO} = \bar{\rho}\, \gamma_O\gamma_N/K_{c_3} \qquad \text{(E-14a)}$$

$$\gamma_{NO^+} = \sqrt{K_{c_4} \gamma_O\gamma_N} \qquad \text{(E-14b)}$$

$$\gamma_{O_2} = \bar{\rho}\, \gamma_O^2/K_{c_1} \qquad \text{(E-14c)}$$

$$\gamma_{N_2} = \bar{\rho}\, \gamma_N^2/K_{c_2} \qquad \text{(E-14d)}$$

$$\gamma_{e^-} = \gamma_{NO^+} \qquad \text{(E-14e)}$$

The density is obtained from

$$\bar{\rho} = 0.51536\, p \Bigg/ \left(RT \sum_{i=1}^{NI} \gamma_i\right) \qquad \text{(E-15)}$$

To obtain an initial estimate of the density, it is assumed that

$$\sum_{i=1}^{NI} \gamma_i = 0.04 \quad .$$

To start the solution of (E-12) to (E-15), it is assumed that $\gamma_{NO} = \gamma_{NO^+} = 0$. Solution of these equations is repeated until the γ_i's have converged. The desired result is the mass fraction of species obtained from $c_i = M_i\gamma_i$ for various temperatures and pressures.

TABLE E-I

EQUILIBRIUM CONSTANTS FOR A SPECIES FORMED FROM ITS ELEMENTS

Species	Reaction	Equilibrium Constant, $\bar{K}_{p_i}$	$\bar{E}_i = \Delta h_f^0/R(^\circ K)$
i = O	$\frac{1}{2} O_2 \rightarrow O$	$\bar{K}_{p_O} = p_O/\sqrt{p_{O_2}}$	29,684
= N	$\frac{1}{2} N_2 \rightarrow N$	$\bar{K}_{p_N} = p_N/\sqrt{p_{N_2}}$	56,622
= NO	$\frac{1}{2} O_2 + \frac{1}{2} N_2 \rightarrow NO$	$\bar{K}_{p_{NO}} = p_{NO}/\sqrt{p_{O_2} p_{N_2}}$	10,797
= C	$C^* \rightarrow C$	$\bar{K}_{p_C} = p_C$	85,334
= CN	$C^* + \frac{1}{2} N_2 \rightarrow CN$	$\bar{K}_{p_{CN}} = p_{CN}/\sqrt{p_{N_2}}$	51,940
= CO	$C^* + \frac{1}{2} O_2 \rightarrow CO$	$\bar{K}_{p_{CO}} = p_{CO}/\sqrt{p_{O_2}}$	-13,688
= CO_2	$C^* + O_2 \rightarrow CO_2$	$\bar{K}_{p_{CO_2}} = p_{CO_2}/p_{O_2}$	-47,285
= C_2	$2C^* \rightarrow C_2$	$\bar{K}_{p_{C_2}} = p_{C_2}$	99,738
= C_3	$3C^* \rightarrow C_3$	$\bar{K}_{p_{C_3}} = p_{C_3}$	97,597
= NO^+	$\frac{1}{2} O_2 + \frac{1}{2} N_2 \rightarrow NO^+ + e^-$	$\bar{K}_{p_{NO^+}} = p_{NO^+}\ p_{e^-}/\sqrt{p_{O_2} p_{N_2}}$	118,347

Elements: O_2, N_2, C^* (graphite)

TABLE E-II

COEFFICIENTS FOR EQUILIBRIUM CONSTANTS FOR AIR REACTIONS

$1000 \leq TK \leq 6000$

r	E_r	A_r	n_r
1	59,368	18.0	0
2	113,244	18.0	0
3	75,509	4.06	0
4	32,041	3.96×10^{-10}	1.5

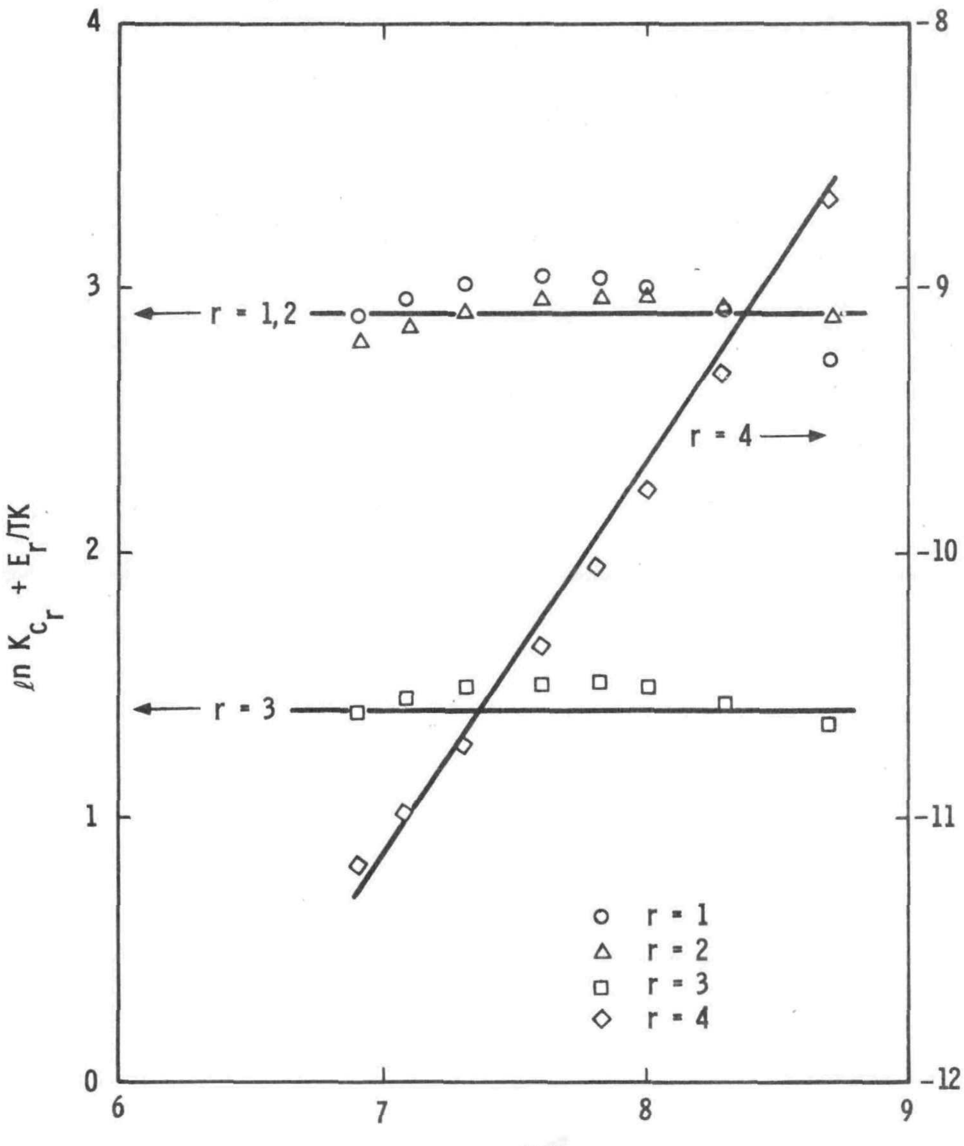


FIG. E1 - COEFFICIENTS FOR EQUILIBRIUM CONSTANTS

Distribution:

Dr. W. W. Hirt - T3
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87544

R. L. Peurifoy, 1220
B. J. Roscoe, 1225
T. B. Lane, 1540
T. M. Burford, 1700
A. M. Clogston, 5000
A. Narath, 50
O. E. Jones, 5100
L. C. Hebel, 5200
J. E. McDonald, 5300
A. M. Clogston (actg), 5400
J. L. Tischhauser, 5420
L. M. Berry, 5500
A. Y. Pope, 5600
R. C. Maydew, 5620
H. R. Vaughn, 5625
S. J. McAlees, 5628
K. J. Touryan, 5640
F. G. Blottner, 5643 (100)
J. W. Weihe, 8320
G. W. Anderson, 8330
A. N. Blackwell, 8350
R. S. Gillespie, 3151
L. C. Baldwin, 3152
Central Files, 3142-1 (15)