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A Computer Program for Two-Dimensional and Axisymmetric Nonreacting Perfect Gas and Equilibrium Chemically Reacting Laminar, Transitional and-or Turbulent Boundary Layer Flows

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A COMPUTER PROGRAM FOR TWO-DIMENSIONAL AND AXISYMMETRIC NONREACTING PERFECT GAS AND EQUILIBRIUM CHEMICALLY REACTING LAMINAR, TRANSITIONAL AND/OR TURBULENT BOUNDARY LAYER FLOWS

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ABSTRACT

A computer program is described in detail for laminar, transitional and/or turbulent boundary-layer flows of non-reacting (perfect gas) and reacting gas mixtures in chemical equilibrium. An implicit finite-difference scheme is developed for both two-dimensional and axisymmetric flows over bodies and in rocket nozzles and hypervelocity wind tunnel nozzles.

This report provides those interested in the computer program with a description of the program, description of the program subroutines, and variables, and description of input and output data. Also included in the report is the output from a sample calculation of fully developed turbulent, perfect gas flow over a flat plate. Input data coding forms and a Fortran source listing of the program are included. Further, the report includes a description of the method for obtaining thermodynamic and transport property data which are required to perform boundary-layer calculations for reacting gases in chemical equilibrium.

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INTRODUCTION

The purpose of this report is to provide the user of Computer Program LTBLCEQL with the necessary information to utilize the program as a research tool in boundary layer flow problems. The section "Description of Program LTBLCEQL" is basic to any use of the program as the various capabilities of the program are described in that section. Further, the sections "Description of Input Data" and "Description of Output" provide the user with necessary information.

For applications in which only the perfect gas model is required, the three sections mentioned above should provide the information that the user would require if no modifications need to be made to the program for the particular application. In order to utilize the capabilities provided by the equilibrium gas model, the appendices provide an explanation of the data required on the gas property and expansion tapes as well as a description of a method of obtaining the required data for the tapes.

The user who is interested in making modifications to the program should find the sections "Description of Variables in Common" and "Description of Subroutines and Variables not in Common" particularly beneficial.

For all users and prospective users, a Fortran source listing of the program is included.

The program was developed under contract NAS 1-9337 with NASA Langley Research Center. The name of the program is an acronym derived from "Laminar and/or Turbulent Boundary Layers in Chemical Equilibrium".

In this report many details in the derivation of equations have been omitted. For the details of the theory and derivations, the user is referred to the contractor report by Anderson and Lewis [1971].

DESCRIPTION OF PROGRAM LTBLCEQL

Program LTBLCEQL has been developed to provide solutions to a large number of boundary-layer flows. The program can predict laminar and/or turbulent boundary-layer flows and in addition transition models are included and described herein. The geometries included in the program are those for either 2-D or axisymmetric blunt bodies, axisymmetric nozzles, and wedges or flat plates. Modifications may be easily made for other geometries. For example, sharp cones could be included with the principal changes being the addition of two geometry subroutines comparable to subroutines BLUNT1 and BLUNT2. The geometry is specified by the variables NOSE (values of 1 for a blunt body, 2 for a wedge or a flat plate, and 3 for a nozzle) and XJFAC (0.0 for 2-D flow and 1.0 for axisymmetric flow).

Basic Equations

The program uses the basic compressible boundary-layer equations which are valid for turbulent flow of either a perfect gas or a gas in chemical equilibrium. The energy equation is written in terms of the stagnation enthalpy and the Reynold's shear and conductivity terms are given by an eddy viscosity ε and the turbulent Prandtl Number Pr_t. The boundary-layer equations are transformed by the Levy-Lees transformation equations,

$$d\xi \equiv \rho_e \mu_e u_e r_w^{2j} \, dx$$

and

$$d\eta \equiv \frac{\rho_e u_e r_w^{j}}{(2\xi)^{1/2}} \frac{\rho}{\rho_e} \, dy$$

where

$j = 0$ for 2-D flow

$= 1$ for axially symmetric flow.

With the definition $f' = u/u_e$ and $f = \int f' \, d\eta$, the continuity equation may be written as

$$V_\eta = 2\xi f'_\xi - f'$$

where

$$V = \frac{2\xi}{\rho_e \mu_e u_e r_w^{2j}} \left[f' \eta_x + \frac{(\rho v + \overline{\rho' v'}) r_w^{j}}{(2\xi)^{\frac{1}{2}}} \right]$$

With the further definitions $F \equiv f'$, $g = H/H_e$, $C \equiv \rho\mu/\rho_e\mu_e$, $\varepsilon^+ = \varepsilon/\nu$,

and

$$\beta \equiv \frac{2\xi}{u_e} \frac{du_e}{d\xi}$$

the energy and momentum equations can be written in the following "standard" form;

$$\Phi'' + A_1 \Phi' + A_2 \Phi + A_3 + A_4 \Phi_\xi = 0$$

where the prime denotes differentiation with respect to η and the subscript ξ denotes differentiation with respect to ξ.

For the momentum equation, $\Phi = F$, and the coefficients are given by the following equations:

$$A_1 = \frac{C_\eta}{C} + \frac{(\overline{A}_o)_\eta}{\overline{A}_o} - \frac{V}{A_o}$$

$$A_2 = -\beta F/A_o$$

$$A_3 = \frac{\beta}{A_o} \frac{\rho_e}{\rho}$$

and

$$A_4 = -2\xi F/A_o$$

where

$$A_o = C(1 + \varepsilon^+)$$

and

$$\overline{A}_o = A_o/C.$$

For the energy equation, $\Phi = g = H/H_e$, and the coefficients are given by the following equations:

$$A_1 = \frac{C_\eta}{C} + \frac{(\overline{A}_o)_\eta}{\overline{A}_o} - \frac{V}{A_o}$$

$$A_2 = 0$$

$$A_3 = \frac{u_e^{\,2}}{H_e} \left(1 - \frac{1}{Pr}\right) \left[\frac{C_\eta}{C\overline{A}_o} FF_\eta + \frac{F_\eta^{\,2}}{\overline{A}_o} + \frac{FF_{\eta\eta}}{\overline{A}_o} \right]$$

$$A_4 = -\frac{2\xi F}{A_o}$$

where

$$A_o = \frac{C}{Pr} \left(1 + \varepsilon^+ \frac{Pr}{Pr_t}\right)$$

and

$$\overline{A}_o = A_o/C.$$

With the equations written in the "standard" form, solutions are obtained from subroutine SOLVE which uses a three-point, finite-difference method. The solution procedure may be fully implicit, fully explicit, or intermediate (such as Crank-Nicolson). The most satisfactory results have been obtained with the fully implicit procedure and it is recommended.

Eddy Viscosity Laws

For turbulent (and transition) flows, the Reynolds shear term is given by an eddy viscosity. Two different equations are used for the eddy viscosity. One equation (referred to as the inner law) is used in the region of the boundary layer near the wall, the other equation (the outer law) is used in the outer region of the boundary layer. The values given by the inner law increase from zero at the wall and, when they exceed the values given by the outer law, they are replaced by the values from the outer law. The outer law, which follows Clauser's work using Klebanoff's intermittency factor, gives values which tend to zero at the outer edge of the boundary layer. The program provides the user with two choices for the inner eddy viscosity law. One follows the work of Van Driest, the other is the eddy viscosity law derived by Reichardt. In general, the results obtained from the program using both laws have been equivalent, although the calculations using the Reichardt law required less computer time. Therefore, the Reichardt law is preferable for most applications.

Transition Models

The user interested in utilizing either of the transition models is advised that even though quite satisfactory results have been obtained for transition problems, caution must be exercised.

Satisfactory agreement has been obtained with experimental results for several cases involving transition, but only by selecting appropriate values of the transition parameters CHICRT and XBAR. Calculations involving transition are most satisfactory when done ex post facto, that is, when the parameters can be appropriately adjusted to obtain agreement with the experimental results.

The first transition model changes the flow instantaneously from laminar to turbulent at the specified value of x, and the x step size is reduced to 0.01. Heat transfer results obtained with this model show a much steeper rise than occurs in experimental data and on this basis the instantaneous transition model is not completely satisfactory.

The second transition model provides a regime of transition from laminar to turbulent flow. The calculation is started with the flow laminar ($\varepsilon^+ = 0$) and at the beginning of transition the flow is changed to turbulent with the eddy viscosity attenuated by the transition intermittency factor. As the intermittency factor increases from zero to unity as x increases, the eddy viscosity reaches its fully turbulent value at some distance downstream of the point where transition begins.

The procedure which is used to indicate the beginning of transition utilizes the vorticity Reynolds number χ which is given by the following expression:

$$\chi = \frac{y^2}{\nu} \frac{\partial u}{\partial y} .$$

Transition is initiated when the maximum value of χ, χ_{max}, exceeds a critical value, χ_{crit} (= CHICRT), which is generally in the range of 2000 to 4000.

The transition intermittency factor is given by the expression

$$\Gamma = 1 - \exp(-A\bar{\xi}^2)$$

where

$$A = 0.412$$

and

$$\bar{\xi} = \frac{x-x_o}{\lambda}$$

The value of x at the beginning of transition is x_o and λ is a measure of the length of the transition region which is given by Owen [1970] as

$$\lambda = x|_{\Gamma=\frac{3}{4}} - x|_{\Gamma=\frac{1}{4}} .$$

The values of x needed to calculate λ can not be predetermined and an equivalent expression for λ is used instead, with λ given by the expression

$$\lambda = \frac{x_o}{4} (\bar{x} - 1)$$

where $\bar{x}$ (=XBAR) is another measure of the length of transition which is such that

$$x_{\text{end of transition}} \simeq \bar{x}\, x_{\text{beginning of transition}} \cdot$$

When the Van Driest inner eddy viscosity law is used, the above expression is quite close to an exact equality. For calculations with the Reichardt inner eddy viscosity law equivalent results are obtained when $\bar{x}$ is increased by about 65%. Then, however, the above expression misses equality by 65%. With the Van Driest inner eddy viscosity law, 2.0 has been found to be an appropriate value for XBAR for some cases and larger values of XBAR have been required to obtain reasonable agreement with experimental results in other cases. The values of CHICRT and XBAR cited above should provide the user with reasonable initial estimates of appropriate values of these parameters.

Normal Injection Model

The program contains provisions for calculating boundary-layer flows with normal mass transfer through a porous wall. For no mass transfer, the transformed normal velocity component, V, is zero at the wall. With mass transfer the value of V at the wall (VW) is given by

$$VW = \frac{\sqrt{2\xi}\ \ \rho_w v_w}{\rho_e \mu_e u_e r_w{}^j}$$

At the stagnation point of a blunt body (where $r_w{}^j = 0$) the equation for VW is

$$VW = \rho_w v_w \,/\, \sqrt{\rho_e \mu_e u'_e\,(j+1)} \quad .$$

In the equations above, VW is calculated using the injection rate $\rho_w v_w$ or equivalently CQ.

An alternative method of obtaining the value of V at the wall is from the value of the stream function at the wall. Also, V may be given by the equation

$$V = -\ 2\xi\frac{\partial f}{\partial \xi} - f\,.$$

With f_w = constant, VW = - f_w since $\partial f/\partial \xi = 0$ along the body streamline. If the value of f_w (FINJ) in the program is zero, VW is calculated from the injection rate CQ; if both CQ and FINJ are non-zero, VW is set equal to -FINJ.

The beginning and end of injection are specified by the variables KINJ and KNOINJ which are subscripts for the array XSTA. Injection begins immediately after XSTA(KINJ). For X less than or equal to XSTA(KINJ), CQ1 is set equal to CQ and CQ is set equal to zero. After a solution has been obtained at X = XSTA(KINJ), DX is reduced to 0.01 and CQ is set equal to CQ1, and the message "INJECTION BEGINS" is written. After a solution has been obtained at X = XSTA(KNOINJ), CQ is set to zero and the message "INJECTION ENDS" is written. If the input values of KINJ and KNOINJ are greater than IIMAX, they are set equal to IIMAX.

The value of CQ may be either constant or variable. If the value of the variable KCQ is zero, CQ has a constant value and the values of CQZ(J), J = KINJ, KNOINJ, are set equal to CQ, the other values of CQZ(J) being set equal to zero. If KCQ is non-zero, the value of CQ is obtained by interpolation in the array CQZ if X is greater than XSTA (KINJ) and less than or equal to XSTA(KNOINJ).

For turbulent flow, the Van Driest inner eddy viscosity law includes the required corrections for mass transfer whereas the Reichardt inner eddy viscosity law does not.

The normal injection model has been used for calculations of boundary-layer flows over a flat plate (the conditions corresponding to the Danberg [1967] experimental data) for fully laminar, fully turbulent and transitional cases. The agreement with the experimental data was reasonably good (see Anderson and Lewis [1971]).

Flow Diagrams

The flow of logic in the program is controlled by MAIN (see description of MAIN). To assist the user in following the flow of logic in the program, two flow diagrams of MAIN are included. Fig. 1 gives a flow diagram of MAIN by the logical functions involved, while Fig. 2 gives a flow diagram of MAIN by the subroutines called. As the major subroutines have particular logical functions, there is a close correspondence between the two flow diagrams.

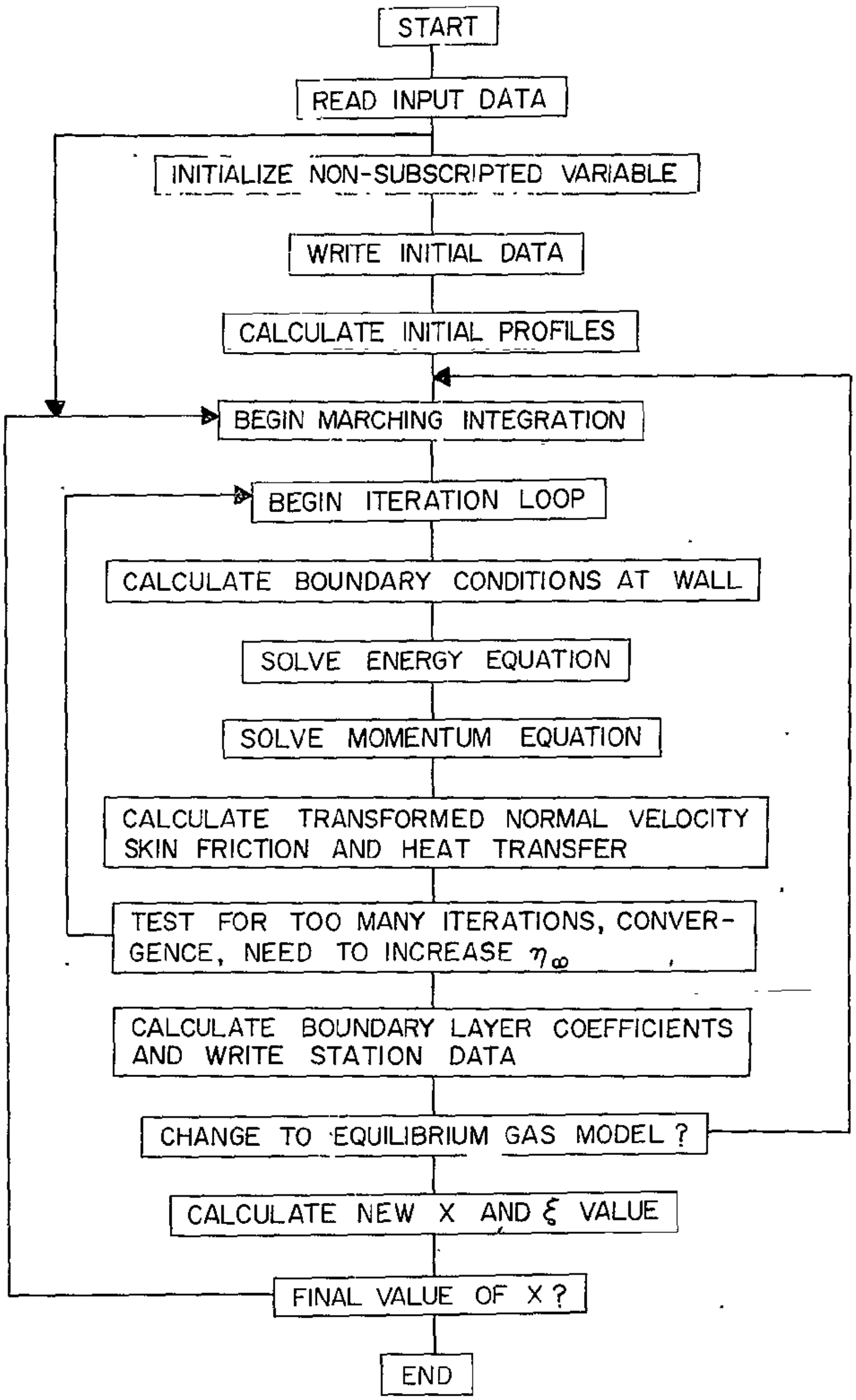

Fig. 1 FLOW DIAGRAM OF MAIN ROUTINE BY FUNCTION

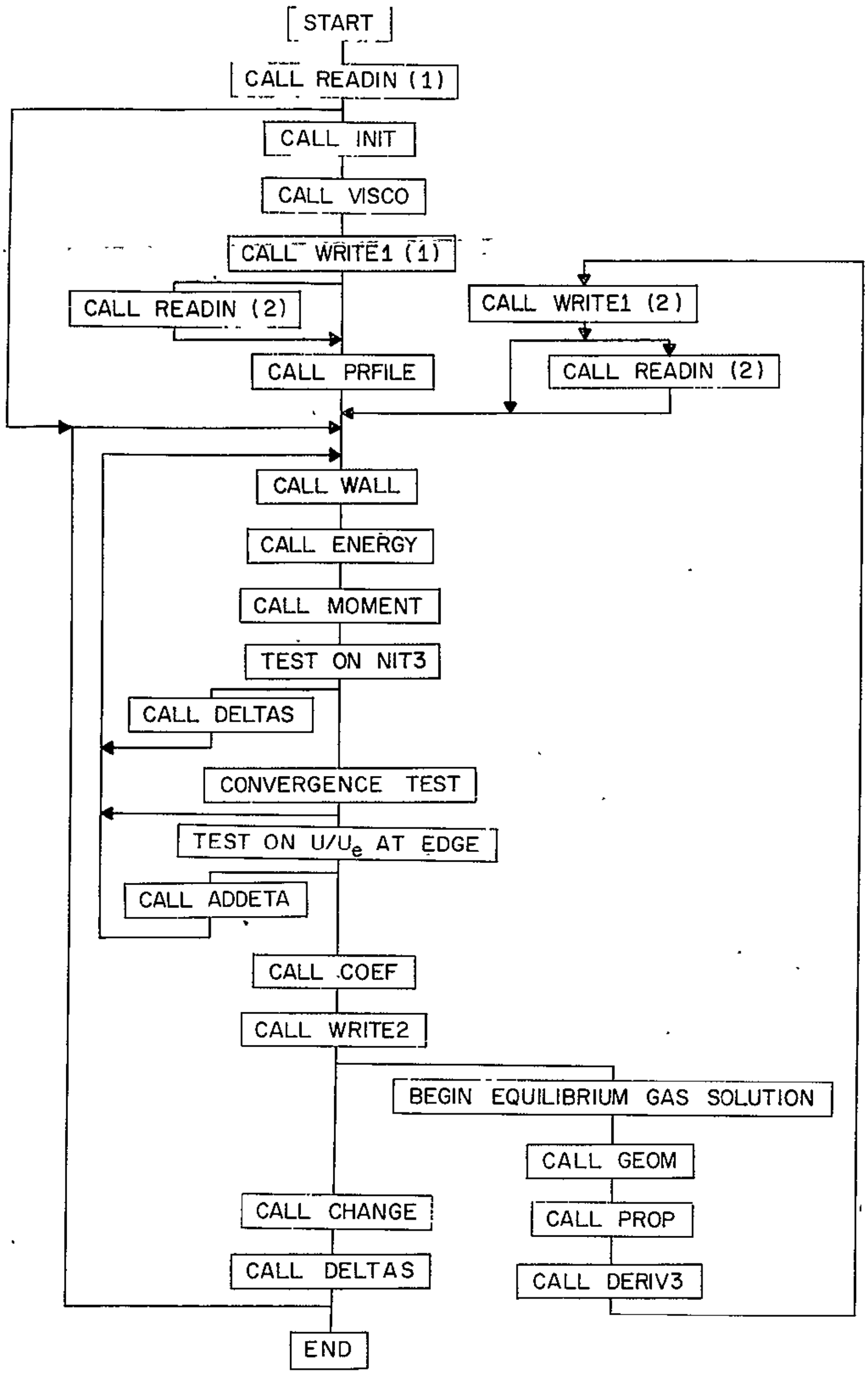

Fig. 2 FLOW DIAGRAM OF MAIN ROUTINE BY SUBROUTINES CALLED

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Other Features of the Program

In the development of the program, generous use has been made of comment cards. Most major transfers of control are marked by comments, and each subroutine is preceded by comments giving the subroutines called and the subroutines by which it is called. In addition, brief comments are included describing the subroutine function.

The common blocks have been structured so that most free-stream quantities are in the labeled common block FRSTRM, edge properties are in EDGPRP, transition regime related quantities are in TRANS, etc. With certain exceptions all subscripted variables in the program are in common blocks ARRAY1 or ARRAY2. The variables in ARRAY1 are those which depend on the number of grid points (note that DN, DN2, XN, and XN2 must have dimensions of at least IE+1, the other variables dimensions of at least IE), while the variables in ARRAY2 are functions of x (e.g. ZA, RZ, PZ, etc.). The array CQZ occurs in common block INJECT instead of in ARRAY2. In subroutines where arrays are in the subroutine argument, the arrays are dimensioned by 1 (as is permissible on the IBM 360). There are three arrays (not in common) in the program which depend on the number of grid points; XMU in subroutine PROP and E and F in subroutine SOLVE. If the variables in ARRAY1 are redimensioned, these three variables must be also (unless the dimensions in ARRAY1 are reduced). All other subscripted variables, such as ZZ, have dimensions suitable to their function.

The program as listed is in single precision. This precision is quite adequate on computers such as the CDC 6600. The six significant figures used in the IBM 360 single precision is adequate for only the very simplest cases. Thus for use on computers such as the IBM 360, a 029 punch, double precision version of the program is available.

DESCRIPTION OF VARIABLES IN COMMON

In this section, each variable which is included in a labeled common block is given a brief description. The name of the labeled common block in which the variable occurs is given to the left of the variable name.

Common Block	Variable Name		Description of Variable
NMLCRD	ADTEST	,	Criterion for Increasing ETAINF, (F(IE) - F(IE-4) is compared with ADTEST)
EDGPRP	ALP	=	UE**2/TE or UE**2/HESTAT
EDGPRP	ALP1	=	1 + ALP/2
FRSTRM	AMUINF	=	μ_∞, lbf-sec/ft^2
REF	AMUREF	,	Reference Viscosity Corresponding to TREF1, lbf-sec/ft^2
GEOME	ANGLE	,	Wedge Half Angle, in Degrees (Converted to Radians)
TRANS	ATR	,	Transition Constant (=0.412)
ARRAY1	A0	=	$A_o = C(1 + \varepsilon^+)$, Momentum Equation $= \frac{C}{Pr}(1 + \varepsilon^+ \frac{Pr}{Pr_t})$, Energy Equation
ARRAY1	A0B	=	$\overline{A}_o = A_o/C$, where $C = \rho\mu/\rho_e\mu_e$
ARRAY1	A0BP	=	$\frac{\partial \overline{A}_o}{\partial \eta}$
ARRAY1	A1	,	Partial Differential Equation Coefficient
COMWLL	A1B	,	Derivative of U/U_e at Wall
ARRAY1	A2	,	Partial Differential Equation Coefficient
ARRAY1	A3	,	Partial Differential Equation Coefficient
ARRAY1	A4	,	Partial Differential Equation Coefficient

Common Block	Variable Name		Description of Variable
EDGPRP	BETA	=	$\beta = 2\xi/U_e(dU_e/d\xi)$
COMWLL	B0	=	H_w/H_o
ARRAY1	C	=	$\rho\mu/\rho_e \mu_e$
CNVERG	CCRNI	=	1 - CRNI
CFPR	CF	,	Skin Friction in Transformed Coordinates $(= C_{f_\infty}/\varepsilon_{VD})$
COEFF	CFBAR	=	$\overline{C}_f = \frac{1}{x}\int_o^x C_{f_\infty}\,dt$
COEFF	CFBREX	=	$\overline{C}_f \sqrt{REX}$
COEFF	CFE	=	$C_{f_e} = 2\tau_w/\rho_e U_e^2$
COEFF	CFINF	=	$C_{f_\infty} = 2\tau_w/\rho_\infty U_\infty^2$
COEFF	CFRES	=	CFREY
COEFF	CFREY	=	$C_{f_\infty} \sqrt{REX}$
COEFF3	CF1	,	Term Used in Computing CFBREX
COEFF	CH	=	$C_{h_\infty} = \frac{q}{\rho_\infty U_\infty (H_w - H_{aw})}$, Where H_{aw} is the Adiabatic Wall Enthalpy
COEFF	CHEDGE	=	$C_{h_e} = \frac{q}{\rho_e U_e (H_w - H_{aw})}$
ARRAY1	CHI	=	$\chi = \frac{y^2}{\nu}\frac{\partial u}{\partial y}$, Vorticity Reynolds Number
TRANS	CHICRT	,	Value of CHIMAX at which Transition Regime Calculations are Begun

Common Block	Variable Name		Description of Variable
TRANS	CHIMAX	,	Maximum Value in CHI Array
COEFF	CHOCF	=	$2\ C_{h_e}/C_{f_e}$
COEFF	CHREY	=	$C_{h_\infty}\ \sqrt{REX}$
REF	CMSTD	,	Standard Molecular Weight of Given Gas
CNVERG	CONVRG	,	Convergence Criterion
ARRAY1	CP	=	$\frac{\partial C}{\partial \eta}$
SUTH	CPRIM	=	C^*/T_{ref}, where $C^* = 198.6°R$
INJECT	CQ	=	$\rho_w v_w/\rho_\infty u_\infty$
INJECT	CQ1	,	Storage Value of CQ
INJECT	CQZ	,	Array of Injection Rate Values
CNVERG	CRNI	,	Selector for Finite Difference Scheme; 1.0 for Fully Implicit, 0.5 for Crank-Nicolson, and 0.0 for Fully Explicit
VSCSTY	CSTAR	=	$C^* = 198.6°R$
FRSTRM	CX	=	C_p, Specific Heat, $ft^2/(sec^2\text{-}°R)$
ARRAY1	C1	=	1 - 1/PREQ
ARRAY1	C1N	=	$\frac{\partial C1}{\partial \eta}$
COEFF	DEL	=	δ, Boundary Layer Thickness (Value of y where $U/U_e = 0.995$)
COEFF2	DELORF	=	δ/reference length
COEFF2	DELOX	=	δ/x
COEFF	DELST	=	δ^*, Compressible Boundary Layer Displacement Thickness

Common Block	Variable Name		Description of Variable
COEFF	DELTA	=	δ/ε_{VD}
CNVERG	DIF	,	Maximum Difference in G or F (or their Derivative at the Wall) between Iterations (Compared with CONVRG in Convergence Test)
CNVERG	DIFF	,	Local Difference in G or F between Iterations
CNVERG	DIF1	,	Difference in G (or its Derivative) at the Wall Between Iterations
CNVERG	DIF2	,	Difference in the Derivative of F at the Wall Between Iterations
ARRAY1	DN	,	Array of $\Delta\eta$ Values
ARRAY1	DN2	,	Array of $\Delta\eta$ Values (Used only when ETAINF is Increased)
GEOME	DS	=	$\Delta\xi$ Corresponding to Δx
COEFF2	DSAXOR	=	δ^*_{axi}/reference length
COEFF	DSTARK	=	δ^*_k, Incompressible Boundary Layer Displacement Thickness
COEFF2	DSTODL	=	δ^*/δ
COEFF2	DSTORF	=	δ^*/reference length
COEFF2	DSTOTH	=	δ^*/θ
COEFF2	DSTOX	=	δ^*/x
COEFF	DSTRAX	=	$\delta^*_{axi} = r\ \{\sqrt{1+2\delta^*/r} - 1\}$ (Zero for 2-D Flow)
EDGPRP	DUEDS	=	dUE/ds
GEOME	DX	=	Δx, Step Size in x Direction

Common Block	Variable Name		Description of Variable
GEOME	DXMAX	,	Maximum Value of Δx Permitted in the Calculations
GEOME	DXOLD	,	Previous Value of Δx
GEOME	DX1	,	Storage Value of Δx at the First Station
ARRAY1	EPSO	=	ε_o^+, the Outer Eddy Viscosity
ARRAY1	EPSPL	=	ε_i^+, or ε^+, the Inner Eddy Viscosity or the Combined Inner and Outer Eddy Viscosities
VSCSTY	EPSVD	=	$\varepsilon_{VD} = \{\mu_{ref}/(\rho_\infty U_\infty L)\}^{1/2}$, Where L is the Unit Length in REINF
NMLCRD	ETAINF	,	Maximum Value of η
COMWLL	E1	,	Matrix Inversion Coefficient Evaluated at the Wall
ARRAY1	FC	=	CRNI(F2-F1) + F1
ARRAY1	FCN	=	CRNI(F2N-F1N) + F1N
ARRAY1	FCP	=	(F2-F1)/DS
COMWLL	FF	,	Wall Boundary Condition on F
COMWLL	FINJ	=	f_w, Value of Stream Function at Wall
ARRAY1	F1	,	Value of F (U/U_e) from Previous Iteration or Station
ARRAY1	F1N	=	$\frac{\partial F1}{\partial \eta}$
ARRAY1	F1NN	=	$\frac{\partial^2 F1}{\partial \eta^2}$
ARRAY1	F2	,	Value of F from Solution of Momentum Equation

Common Block	Variable Name		Description of Variable.
ARRAY1	F2N	=	$\frac{\partial F2}{\partial \eta}$
ARRAY1	F2NN	=	$\frac{\partial^2 F2}{\partial \eta^2}$
COMWLL	F2N1	,	Value of F2N at Wall from Previous Iteration
EDGPRP	G	=	$\gamma = C_p/C_v$
EDGPRP	GAMEFF	,	Effective γ Behind Normal Shock (for Blunt Body) (Same as G for a Nozzle)
TRANS	GAMMA	,	Transition Intermittency Factor, Γ, $\Gamma = 1 - \exp(-A\bar{\xi}^2)$, where A = ATR and $\bar{\xi}$ = XIBAR
COEFF	HAFCF	=	$C_{f_\infty}/2$
EDGPRP	HALP	=	ALP/2
EDGPRP	HE	=	H_o/H_{ref}, where $H_{ref} = U_{ref}^2$
EDGPRP	HESTAT	=	Static Enthalpy at Edge Divided by H_{ref}
FRSTRM	HEXIT	=	Log_{10} (H*/RGAS) at Nozzle Exit
FRSTRM	HFS	=	H_∞, ft^2/sec^2
COEFF	HG	=	QW*EPSVD
COEFF3	HGFAC1	,	Term Used in Computing HG1
COEFF3	HGFAC2	,	Term Used in Computing HG2
COEFF	HG1	,	Heat Transfer Coefficient in BTU/(in^2-sec-°R)
COEFF	HG2	,	Heat Transfer Coefficient in lbm/(in^2-sec)
REF	HREF	=	$H_{ref} = U_\infty^2$, ft^2/sec^2
STAG	HSTAG	=	H_o, ft^2/sec^2
COMWLL	HW	=	H_w/H_{ref}
COMWLL	IADW	,	Indicator, 1 for Adiabatic Wall, 0 for Non-adiabatic Wall

Common Block	Variable Name		Description of Variable
INTGR	IE	,	Number of Grid Points in η Direction
NTEGER	II	,	Subscript for Array IPR
INTGR	IIMAX	,	Maximum Number of Values in Geometry Arrays (i.e. ZA, XSTA, etc.)
INTGR	IM	=	IE - 1
NTEGER	IPFL	,	Number of Values in Array IPRFL
ARRAY2	IPR	,	Array of Subscripts for Array XSTA Giving Values of x at which a Solution is to be Obtained.
ARRAY2	IPRFL	,	Array of Subscripts for Array XSTA Giving Values of x at which Complete Solutions (with Profiles) are to be Printed
NTEGER	IPRINT	,	Number of Values in Array IPR
INTGR	IPRNT	,	Subscript for Array IPRFL
INTGR	ISTOP	,	Number of Iterations Since Last Converged Solution
INTGR	ITH	,	Subscript in the Geometry Arrays of the Throat Location
NTEGER	JJ	,	Integer Used in Computing DX
NTEGER	K	,	Station Counter
NTEGER	KADETA	,	Indicator, if Zero, ETAINF is Held Constant, if Non-zero, ETAINF can be Increased
INJECT	KCQ	,	Indicator, Zero for Constant Injection Rate, Non-zero for Injection Rate Distribution Input

Common Block	Variable Name		Description of Variable
NTEGER	KEND	,	Maximum Value Allowed for K
NTEGER	KEP	,	Subscript in EPSPL Array Where the Inner and Outer Eddy Viscosities are Matched
NTEGER	KFS	,	Indicator, Non-zero for Computing in the Program Dimensional Free-stream, Stagnation and Reference Values and Dimensional Heat Transfer and Heat Transfer Coefficients, Zero to Bypass Computing Dimensional Quantities
INJECT	KINJ	,	Subscript in XSTA Array Giving Location of Beginning of Injection
INTGR	KL	,	Index for Profile Output DO Loop, 1 Gives Output for Each Grid Point, 2 for Every Second Grid Point
INJECT	KNOINJ	,	Subscript in XSTA Array Giving Location of End of Injection
INTGR	KPD	,	Indicator, 0 for Pressure Computed by Program Based on Nozzle Area Ratio, Non-zero for Pressure Distribution Input
INJECT	KPGRAD	,	Indicator for Expression for A^+ in Van Driest Inner Eddy Viscosity Law; 0 for $A^+ = 26$, 1 for A^+ Corrected for Mass Transfer, 2 for A^+ Corrected for Pressure Gradient, 3 for A^+ Corrected for Both Mass Transfer and Pressure Gradient
STRT	KRSTRT	,	Restart Indicator; Zero for Starting New Solution; Greater than Zero Restarts Solution, Next Solution obtained at K = KRSTRT + 1, Solution at K = KRSTRT used as Initial Values

Common Block	Variable Name		Description of Variable
NTEGER	KSTOP	,	Indicator, Normally Zero, Set to One when Solution is Completed (X = XSTA(IIMAX))
NTEGER	KSTRT	=	KRSTRT + 1
NTEGER	KTPW	,	Next Value of K at which the Restart Tape will be Written
TRANS	KTRANS	,	Indicator for Transition Regime, Zero for No Transition or Instantaneous Transition, One for Transition Regime (Set to Two at "End of Transition")
NTEGER	KTRNSN	,	Subscript in XSTA Array at Which Instantaneous Transition Occurs
COMWLL	KTW	,	Indicator, Zero for Constant Wall Temperature, Non-zero for Wall Temperature Distribution Input
INTGR	KVSLAW	,	Indicator for Inner Eddy Viscosity Law, Zero for Reichardt Law, Non-zero for Van Driest Law
NTEGER	LAMTRB	,	Indicator, 1 for Laminar Flow, 2 for Turbulent Flow
CNVERG	NC	,	Specifies Convergence Test, Zero for Test on Derivatives at Wall, One for Test on Functions at all Points in Profile
INTGR	NEQIL	,	Indicator for Gas Model, Zero for Perfect Gas Model, Non-zero for Equilibrium Gas Model
INTGR	NEQL	,	Storage Value of NEQIL
INTGR	NIT	,	Number of Iterations at Current Value of x
NTEGER	NITTOT	,	Cumulative Total Number of Iterations in x Direction

Common Block	Variable Name		Description of Variable
INTGR	NIT1	,	If, after a converged solution is obtained, NIT is less than or equal to NIT1, Δx is doubled.
INTGR	NIT2	,	If, after a converged solution is obtained, NIT is greater than or equal to NIT2, Δx is halved.
INTGR	NIT3	,	If NIT = NIT3 before a converged solution is obtained, Δx is halved, X and XI are recomputed and the iteration loop is restarted with the smaller values of X and XI.
INTGR	NOSE	,	Indicator for Geometry, 1 for a Blunt Nose, 2 for a Wedge or a Flat Plate, 3 for a Nozzle
STRT	NRSTRT	,	Increment in K for which the Restart Tape is Written
TAPENV	NT1	,	Tape Unit Number for Expansion Tape
TAPENV	NT2	,	Tape Unit Number for Gas Table Tape
TAPENV	NT3	,	Tape Unit Number for Restart Tape
TAPENV	NT4	,	Unit Number for Scratch Tape
TAPENV	NV	,	Number of Variables Written on the Gas Property Tape
VSCSTY	OMEGA	,	ω, Exponent for Power Viscosity Law (If ω=o, Sutherland's law is used.)
EDGPRP	PE	=	P_e/P_{ref}, where $P_{ref} = \rho_{ref} U_{ref}^2$
EDGPRP	PESO	=	$P_e P_{ref}$, at s = 0
FRSTRM	PEXIT	=	Log_{10} P at Nozzle Exit, P in Atmospheres
FRSTRM	PFS	,	Free-stream Static Pressure, PSIA

Common Block	Variable Name		Description of Variable
GEOME	PNG	=	$\frac{\sqrt{2\xi}}{u_e \rho_e r_w^j}$, Term in Transformation of Normal Co-ordinate
EDGPRP	PP	=	dPE/dS
CFPR	PR	=	Pr, Laminar Prandtl Number
REF	PREF	=	$P_{ref} = \rho_{ref} U_{ref}^2$
ARRAY1	PREQ	=	Pr for Equilibrium Gas Model
CFPR	PRL	=	PR
CFPR	PRT	=	Pr_t, Turbulent Prandtl Number
STAG	PSTAG	,	Free-stream Stagnation Pressure, PSIA
ARRAY2	PZ	,	Local Pressure Array, P/P_o in Input, P/P_{ref} for Ideal Gas, P in PSIA for Equilibrium Gas
REF	POPRIM	,	Local Stagnation Pressure for Ideal or Equilibrium Gas, PSIA (Corresponds to Stagnation Pressure on Expansion Tape)
STAG	P10	=	P_o/P_{ref}
COEFF	QDOT	,	Wall Heat Transfer, BTU/(ft^2-sec)
COEFF3	QW	,	Heat Transfer Coefficient in Transformed Coordinates
GEOME	R	,	Gas Constant for Specified Gas
GEOME	REFLEN	,	reference length (May be any value appropriate to user's needs.)
FRSTRM	REINF	,	Free-stream Reynolds Number per Unit Length
COEFF	RETHET	=	Re_θ, Edge Unit Reynolds Number Times θ

Common Block	Variable Name		Description of Variable
COEFF	REX	,	Local Reynolds Number Based on Edge Conditions
EDGPRP	RGAS	=	R, Specific Gas Constant, $ft^2/(sec^2 - °R)$
FRSTRM	RHOFS	=	ρ_∞, slugs/ft^3
REF	RHOREF	=	$\rho_{ref} = \rho_\infty$, slugs/ft^3
REF	RHOSTD	,	Density of Gas at Standard Atmospheric Conditions, slugs/ft^3
STAG	RHOSTG	=	ρ_o, Reservoir or Local Stagnation Density, slugs/ft^3
EDGPRP	ROESO	=	ρ_e/ρ_{ref} at s=o
COEFF2	ROREFL	=	r/reference length
ARRAY1	ROROE	=	ρ/ρ_e
EDGPRP	ROWE	=	ρ_e/ρ_{ref}
EDGPRP	ROWEP	=	ρ_e/ρ_{ref} at Previous Value of x
ARRAY2	RZ	=	r, Array of Radius Values
GEOME	R0	=	r, Local Radius
GEOME	SCF	,	Scale Factor used to Convert Unit Length for REINF (REINF is Computed per Foot if SCF=1; per inch if SCF=1; per inch if SCF=12.)
COEFF	STE	=	$\dfrac{q}{\rho_e u_e (H_w - H_o)}$
COEFF	STINF	=	$\dfrac{q}{\rho_\infty u_\infty (H_w - H_o)}$
COEFF3	SUM	,	Term used in Computing CFBREX
COMWLL	TB	=	H_w/H_e

Common Block	Variable Name		Description of Variable
ARRAY1	TC	=	CRNI (T2 - T1) + T1
ARRAY1	TCN	=	CRNI (T2N-T1N) + T1N
EDGPRP	TE	=	T_e/T_{ref}, where $T_{ref} = U_\infty{}^2/C_p$
EDGPRP	TES0	=	T_e/T_{ref} at s = 0
FRSTRM	TFS	=	T_∞, °R
ARRAY1	TH	=	T/T_e
COEFF	THET	=	θ, Boundary Layer Momentum Thickness
COMWLL	THN1	,	Value of THP at Wall
COEFF2	THODEL	=	θ/δ
COEFF2	THOREF	=	θ/reference length
ARRAY1	THP	=	$\frac{dTH}{d\eta}$
GEOME	THSHOK	,	Shock Angle, in Degrees (Converted to Radians)
COMWLL	TH1	,	Value of TH at Wall
FRSTRM	TIN	=	T_∞/T_{ref}
REF	TREF	=	$T_{ref} = U_\infty{}^2/C_p$
REF	TREF1	,	Reference Temperature, °R (Used in Computing REINF if Input Value of REINF is Zero)
STAG	TSTAG	,	T_o, °R
COMWLL	TW	=	T_w, °R or T_w/T_{ref}
ARRAY2	TWZ	,	Array of Wall Temperature Values, °R
ARRAY1	T1	,	Value of G (H/H_e) from Previous Iteration or Station

Common Block	Variable Name		Description of Variable
ARRAY1	T1N	=	$\frac{\partial T1}{\partial \eta}$
ARRAY1	T1NN	=	$\frac{\partial^2 T1}{\partial \eta^2}$
STAG	T10	=	T_o/T_{ref}
ARRAY1	T2	,	Value of G from Solution of Energy Equation
ARRAY1	T2N	=	$\frac{\partial T2}{\partial \eta}$
ARRAY1	T2NN	=	$\frac{\partial^2 T2}{\partial \eta^2}$
COMWLL	T2N1	,	Value of T2N at Wall from Previous Iteration
COMWLL	T21	,	Value of T2 at Wall from Previous Iteration
EDGPRP	UE	=	U_e/U_{ref}
EDGPRP	UERO2	=	$(U_e/U_{ref})r^{2j}$
EDGPRP	UESO	=	U_e/U_{ref} at $s = 0$
ARRAY2	UEZ	=	U_e/U_∞, Array
FRSTRM	UFS	=	U_∞, ft/sec
REF	UREF	=	$U_{ref} = U_\infty$, ft/sec
ARRAY1	VC	=	$V = \int_0^\eta (-2\xi \frac{\partial F}{\partial \xi} - F)d\eta$, Transformed Normal Velocity Component
VSCSTY	VK	=	CPRIM/TE
COMWLL	VW	,	Value of VC at Wall
GEOME	X	,	Local Surface Distance, x

Common Block	Variable Name		Description of Variable
TRANS	XBAR	,	Measure of Relative Length of Transition (i.e. $X_{\text{End of Transition}} \simeq$ XBAR* $X_{\text{Beginning of Transition}}$)
GEOME	XI	=	ξ, Transformed Surface Distance
TRANS	XIBAR	=	$\overline{\xi}$, Transition Intermittency Factor Coordinate $\overline{\xi}$ = (X-XZERO)/XLAMDA, where XLAMDA = (XBAR-1)* XZERO/4 and XZERO is the value of x at the start of transition.
GEOME	XIOLD	,	Previous Value of XI
GEOME	X12	=	2*XI
GEOME	XJAY	=	XJFAC
GEOME	XJFAC	,	Indicator, Zero for 2-D Flow, One for Axially Symmetric Flow
NMLCRD	XKETA	,	Parameter Which Controls the Grid Spacing in the η Direction (1.0 Gives an Equally Spaced Grid, a Value Greater than 1.0 Gives a Grid with a Smaller Spacing at the Wall than at the Outer Edge.)
VSCSTY	XK1	,	Constant for Van Driest Inner Eddy Viscosity Law
VSCSTY	XK2	,	Constant for Outer Eddy Viscosity Law
EDGPRP	XM	,	M_e, Local Edge Mach Number
FRSTRM	XMA	,	M_∞, Free-stream Mach Number
EDGPRP	XMUE	=	μ_e/μ_{ref}
EDGPRP	XMUEP	=	μ_e/μ_{ref} at Previous Value of x
FRSTRM	XMUFS	=	μ_∞, lbf-sec/ft^2

Common Block	Variable Name		Description of Variable
VSCSTY	XMUINF	=	μ_∞/μ_{ref}
REF	XMUREF	=	μ_{ref}, lbf-sec/ft^2
EDGPRP	XMUS0	=	μ_e/μ_{ref} at $s = o$
ARRAY1	XN	,	Array of η Values
ARRAY1	XN2	,	Array of η Values (Used only when ETAINF is Increased)
GEOME	XOLD	,	Previous Value of X
COEFF2	XOREFL	=	x/reference length
ARRAY2	XSTA	=	x, Array of Surface Distance Values used to Specify Geometry
ARRAY1	Y	=	y/ε_{VD}, Stretched Normal Co-ordinate
ARRAY1	YOVDEL	=	y/δ
ARRAY1	YOVTHT	=	y/θ
ARRAY1	YY	=	y, Normal Coordinate
GEOME	Z	=	z, Local Axial Coordinate
ARRAY2	ZA	=	z, Array of Axial Coordinate Values used to Specify Geometry
GEOME	ZOL	=	z/body length
COEFF2	ZOREFL	=	z/reference length

DESCRIPTION OF SUBROUTINES AND VARIABLES NOT IN COMMON

Following the subroutine index, each subroutine is given a brief description. Included in the subroutine description is a description of the variables used in the subroutine which do not appear in common and a listing of the variables used in the subroutine which appear in common and thus are described in the preceding section "Description of Variables in Common".

Subroutine Index

Subroutine	Subroutine Label+	Listing on Page	Description on Page
VISCO	AB	145	64
WALL	AC	146	65
WDGFP1	AD	148	66
WDGFP2	AE	150	67
WRITE1	AF	150	68
WRITE2	AG	152	69
ZRO	AH	154	70

+See section "Fortran Source Listing of Program LTBLCEQL".

MAIN

The principal function of MAIN is to control the flow of logic in the program. Also, some calculations are made in MAIN. In general, the calculations in MAIN are such that they cannot conveniently be performed in the subroutines or they are not sufficiently similar to the calculations made in particular subroutines.

Subroutine READIN is called first. If the input data is from the restart tape, the calculations which normally occur at the end of MAIN after subroutine WRITE2 is called are made, the next section of the program is skipped, and the marching integration is resumed. Otherwise, the initial data and profiles are calculated and written by subroutine WRITE1 and the integration is begun, with the statement DO 210 K = KSTRT,KEND. The boundary conditions at the wall are calculated and the energy and momentum equations are solved. The transformed normal velocity component, V, is calculated as are the skin friction and heat transfer in the transformed co-ordinates (CF and QW). The iteration counters are incremented and NIT and ISTOP are checked. If ISTOP is greater than 100 the program is stopped. If NIT equals (or exceeds) NIT3 the step size is halved, x and ξ are recalculated, and control is returned to the beginning of the iteration loop. Otherwise, the next test is the convergence test. If the convergence criterion is not satisfied, control is returned to the beginning of the iteration loop.

When convergence has been obtained, the velocity profile is checked to see if η_∞ needs to be increased. If so, subroutine ADDETA is called and control is returned to the beginning of the iteration loop. If not, subroutines COEF and WRITE2 are called. For equilibrium gas calculations a perfect gas solution is obtained for the first station, control is then transferred to a point before the marching integration is begun, and the perfect gas solution provides starting values for the equilibrium gas calculations.

New values of x and ξ are obtained and the present values of velocity and enthalpy are assigned to the arrays which contain the values for the previous station, and the iteration counters NIT and ISTOP are reset. If a solution has been obtained for the final value of x, (or for K = KEND) the program stops, otherwise, the program returns to the beginning of the marching integration loop to obtain a solution at the new value of x.

Description of Variables

ABST	=	$\|F2(IE) - F2(IE-4)\|$. If ABST is greater than or equal to ADTEST, η_∞ is increased.
CW	,	$\rho_w\mu_w/\rho_e\mu_e$
IPRIIM	=	IPR(II-1)
KREADN	,	Indicator for Subroutine READIN, 1 for Input Data, 2 for Initial Data Written on Restart Tape, 3 for Station Data Written on Restart Tape
KRITE1	,	Indicator for Subroutine WRITE1, 1 for Initialized Data, 2 for Recomputed Data for Equilibrium Gas
N	,	Array Subscript

The following variables which are used in MAIN are described in the section "Description of Variables in Common"; ADTEST, ALP, ALP1, A1B, C, CCRNI, CF, CF1, CONVRG, CQ, CQ1, CRNI, CSTAR, CX, DIF, DN, DUEDS, DX, EPSVD, FC, FCN, FCP, FINJ, F1, F1N, F2, F2N, F2NN, F2N1, G, HALP, HE, HGFAC1, HGFAC2, IADW, IE, II, IIMAX, IPR, IPRNT, ISTOP, K, KADETA, KEND, KINJ, KNOINJ, KSTOP, KSTRT, LAMTRB, NEQIL, NEQL, NIT, NITTOT, NIT3, NOSE, NT3, OMEGA, PNC, PR, QW, REINF, RHOFS, RHOREF, ROROE, ROWE, RO, SCF, SUM, TC, TCN, TE, TH, THP, TIN, T1, T1N, T1NN, T2, T2N, T2NN, T2N1, UE, UFS, UREF, VC, VK, VW, X, XI, XIOLD, XI2, XJFAC, XMA, XMUE, XMUFS, XMUINF, XMUREF, XN, XOLD, XSTA, Y, YY.

Subroutine ADDETA

Subroutine ADDETA is used to increase ETAINF when the value of F at the outermost grid point and the value of F four points inward differ by more than the quantity ADTEST. A new array of η values is generated with the maximum value increased by five. Three point interpolation is used to obtain the values of velocity and enthalpy (F and G) at the new grid points, whereas, at the grid points lying between the new and old values of η_∞, F and G are set equal to unity. First and second derivatives of F and G are then calculated. The storage arrays for F and G and their derivatives are updated and V is recalculated using the new values of F and η. The arrays for y, T/T_e, ρ/ρ_e, etc. are not updated in this subroutine but are recalculated at the normal points in the solution procedure.

The subroutine provides the output of the intermediate profiles following the message that η_∞ has been increased. DX, XKETA, ETAINF, and ADTEST are also included in the output.

USAGE:

CALL ADDETA

Description of Variable

DETA1	,	$\Delta\eta$ at Wall
ETA1N2	,	New Value of η_∞
JC	,	Array Subscript
N	,	Array Subscript

The following variables which are used in subroutine ADDETA are described in the section "Description of Variables in Common": AOBP, C, CHI, CP, DN, DN2, DX, EPSPL, ETAINF, FC, FCN, FCP, F1, F1N, F1NN, F2, F2N, F2NN, IE, IM, ISTOP, KL, ROROE, TC, TCN, TH, T1, T1N, T1NN, T2, T2N, T2NN, VC, VK, XKETA, XN, XN2, YOVDEL, YOVTHT, YY.

Subroutine BLUNT1

This subroutine calculates the edge and reference conditions at the stagnation point for a blunt body. For a perfect gas, the properties are obtained from perfect gas relations. For an equilibrium gas, the properties are calculated using the data on the expansion and gas property tapes. The derivative of u_e with respect to s is obtained using the five-point differentiation formula with two points reflected about the stagnation point.

USAGE:

CALL BLUNT1

Description of Variables

DUM	,	Dummy Variable
DUM1	,	Dummy Variable
DUM2	,	Dummy Variable
DUM3	,	Dummy Variable
HESTJ	,	Array of Log_{10} (H*/RGAS) Values
J	,	Array Subscript
NERR	,	Dummy Variable
PATMS	,	Pressure in Atmospheres
PEJ	,	Array of PL Values
PL	=	Log_{10} P, P in Atmospheres
TE1	,	Dummy Variable
UEJ	,	Array of U Values
XS2	,	X Coordinate Used to Obtain Stagnation DUEDS
XS3	,	X Coordinate Used to Obtain Stagnation DUEDS
ZZ	,	Dummy Array for Thermodynamic and Transport Properties

The following variables which are used in Subroutine BLUNT1 are described in the section "Description of Variables in Common": ALP, BETA, CPRIM, CSTAR, CX, DUEDS, G, HE, HESTAT, HFS, HREF, HSTAG, IIMAX, NEQIL, NT1, NT2, NV, OMEGA, PE, PESO, PFS, PNC, PP, PREF, PSTAG, PZ, POPRIM, P10, REINF, RGAS, RHOFS, RHOREF, RHOSTD, RHOSTG, ROESO, ROWE, ROWEP, RO, SCF, TE, TESO, TFS, TREF, TSTAG, T10, UE, UERO2, UEZ, UFS, UREF, X, XJFAC, XM, XMA, XMUE, XMUEP, XMUFS, XMUINF, XMUREF, XMUSO, XSTA, Z, ZA.

Subroutine BLUNT2

For a blunt body, the edge properties required by subroutine DELTAS to calculate $\Delta\xi$ are provided by subroutine BLUNT2. For a perfect gas, the properties are calculated from perfect gas relations, whereas, for an equilibrium gas the properties are obtained from subroutine EDGE. In the immediate vicinity of the stagnation point, z and r (for both gas models) and P_e and du_e/ds (for the perfect gas) are calculated using five point interpolation with two points reflected about the stagnation point.

USAGE:

CALL BLUNT2

Description of Variable

DUM , Dummy Variable

DUM1 , Dummy Variable

DUM3 , Dummy Variable

J , Array Subscript

The following variables which are used in subroutine BLUNT2 are described in the section "Description of Variables in Common": DUEDS, G, IIMAX, NEQIL, OMEGA, PE, PP, PZ, P10, ROWE, RZ, RO, TE, T10, UE, UEZ, X, XMUE, XSTA, Z, ZA.

Subroutine CHANGE

Subroutine CHANGE adjusts the x step size when necessary to obtain a solution at the specified values of x. For calculations of flows with normal injection, this subroutine starts and stops injection at the appropriate values of x, and writes corresponding messages.

Subroutine CHANGE is also used when calculations are made with the instantaneous transition model. In this case LAMTRB is set to two, the step size is reduced and a message is printed.

USAGE:

CALL CHANGE

Description of Variables

IPRII = IPR(II)

IPRIIM = IPR(II-1)

The following variables which are used in subroutine CHANGE are described in the section "Description of Variables in Common": CQ, CQ1, DX, DXMAX, DXOLD, DX1, EPSVD, II, IIMAX, IPR, JJ, KINJ, KNOINJ, KSTOP, KTRNSN, LAMTRB, NIT, NIT1, NIT2, X, XOLD, XSTA.

Subroutine COEF

Subroutine COEF calculates the skin friction and heat transfer coefficients for the flow. It calculates the Reynolds number, displacement thickness, momentum thickness, and other dimensionless parameters. If x is zero the calculations of this subroutine are omitted except for z/L.

USAGE:

CALL COEF

Description of Variables

CF2	,	Term Used in Computing CFBREX
DSUM	,	Term Used in Computing CFBREX
FAC1	,	Dummy Variables
FAC2	,	Dummy Variables
HAW	,	Adiabatic Wall Enthalpy
I	,	Array Subscript
N	,	Array Subscript
RECFAC	,	Recovery Factor
RESE	=	REX* EPSVD**2
SQREX	,	Square Root of REX
STRES	=	CHREY
XMAE	,	Perfect Gas Edge Mach Number

The following variables which are used in subroutine COEF are described in the section "Description of Variables in Common": A1B, BO, C, CF, CFBAR, CFBREX, CFE, CFINF, CFRES, CFREY, CF1, CH, CHEDGE, CHOCF, CHREY, DEL, DELORF, DELOX, DELST, DELTA, DN, DSAXOR, DSTODL, DSTORF, DSTOTH, DSTOX, DSTRAX, DX, EPSVD, FC, G, GAMMA, HAFCF, HE, HESTAT, HG, HGFAC1, HGFAC2, HG1, HG2, HW, IE, IIMAX, K, KFS, LAMTRB, NEQIL, PNC, PRL, QDOT, QW, REFLEN, REINF, RETHET, REX, RHOFS, ROREFL, ROROE, ROWE, RO, STE, STINF, SUM, TE, THET, THODEL, THOREF, UE, UFS, X, XJFAC, XMUE, XMUINF, XOREFL, Y, YOVDEL, YOVTHT, YY, Z, ZA, ZOL, ZOREFL.

Subroutine DELTAS

Subroutine DELTAS calculates the transformed surface distance ξ using integration by Simpson's rule. A value of $\Delta\xi$ is obtained for each increment Δx from the equation

$$d\xi = \rho_e \mu_e u_e r_w{}^{2j}\ dx.$$

The transformation factor, PNC,

$$PNC = \frac{\sqrt{2\xi}}{u_e \rho_e r_w{}^j}$$

and the pressure gradient term, β,

$$\beta = \frac{2\xi}{u_e} \frac{du_e}{d\xi}$$

are also calculated.

USAGE:

CALL DELTAS

Description of Variables

HA = X - DX/2

ROWEHA = ROWE at HA

RP = RO at X

ROHA = RO at HA

UEHA = UE at HA

XMUEHA = XMUE at HA

X1 , Storage Value of X

The following variables which are used in Subroutine DELTAS are described in the section "Description of Variables in Common": ALP, BETA, DS, DUEDS, DX, HESTAT, NEQIL, PNC, ROWE, ROWEP, RO, TE, UE, UERO2, X, XI, XIOLD, X12, XJFAC, XMUE, XMUEP.

Subroutine DENSIT

Subroutine DENSIT calculates the density ratio ρ/ρ_e corresponding to the pressure ratio P/2q and the temperature ratio T/T_{ref}. The formula for the density is

$$\frac{\rho}{\rho_e} = \gamma \frac{P/2q}{(\gamma-1)T/T_{ref}}$$

USAGE:

CALL DENSIT (RHO, P, T)

Description of Variables

G = γ, Ratio of Specific Heats (from common)

GM1 = γ-1

P = P/2q

T = T/T_{ref}, where $T_{ref} = (\gamma - 1)\, M_\infty^2\, T_\infty = U_\infty^2/C_p$

RHO = ρ/ρ_e

Subroutine DERIV3

Subroutine DERIV3 uses subroutine FD3 to generate the first derivative of a function which is given by the array F. The array of abscissa values is given by X and the derivative of F with respect to X is returned in the array FP.

USAGE:

```
CALL DERIV3 (F, X, IMAX, IMIN, FP)
```

where F and X are the arrays of ordinate and abscissa values, and where IMAX and IMIN are the upper and lower subscripts for the array FP.

Subroutine EDGE

The purpose of this subroutine is to define the boundary-layer edge conditions for nozzles and blunt bodies with the pressure distribution given or for nozzles in which the pressure distribution is assumed to be that for an isentropic expansion of the gas. The subroutine is called for all equilibrium gas solutions having non-constant edge conditions.

Nozzle - Isentropic Expansion

In this case, the indicator IJK is undefined for the first call of the subroutine and subroutine EQLDTA is called. Subroutine EQLDTA defines the stagnation, nozzle exit, and reference conditions and calls subroutine EDGE1 which reads the expansion data on unit NT1 and writes the edge conditions for the specified geometry on unit NT4. Unit NT4 is a scratch unit and is recreated if the problem is restarted. After return from subroutine EQLDTA the indicator IJK is defined. Counter JK and indicator JJ are initialized as 0. JK indicates the number of records read on unit NT4 and JJ is an indicator to prevent reading the end of the data set on unit NT4.

At the start of the solution, the first five records on unit NT4 are used for the interpolation of edge conditions for Z $\leq$ZJ(4) and at the end of the nozzle the last five records are used for Z$\geq$ZJ(3). Edge temperature, density, and viscosity are determined from interpolation in subroutine SLOW.

Pressure Distribution Given

In this case, the pressure is a known function of Z and the expansion data are read directly from unit NT1 (See Appendix A). When creating the data set on unit NT1, it is necessary to have two records with values of PL less than the minimum value specified in the input data.

Near the nose of a blunt body, the interpolation for the edge conditions is obtained by reflection. With this exception the subroutine is the same for both blunt bodies and nozzles. It is noted that P in this section of the subroutine represents pressure in PSIA. This should be accounted for in the appropriate geometry subroutine if additional body shapes are to be considered.

It is noted that the computer program may be easily modified to solve two-dimensional nozzle flows. The changes which need to be made are the expressions for area ratio in subroutines EQLDTA, EDGE1 and MACH.

USAGE:

CALL EDGE

Description of Variables

DUM	,	Dummy Variable
H	=	Log_{10} (H*/RGAS)
HEI	,	Dummy Variable
HESTJ	,	Array of H Values
HI	,	Dummy Variable
I	,	Array Subscript
IJK	,	Indicator (see text)

J	,	Counter, or Index
JJ	,	Indicator (see text)
JK	,	Counter (see text)
K	,	Counter
M	,	Do Loop Index
NERR	,	Dummy Variable
P	=	Log_{10} (P), P in Atmospheres or
	=	P in PSIA
PATMS	,	Pressure in Atmospheres
PEI	,	Dummy Variable
PEJ	,	Array of P or PL
PI	,	Dummy Variable
PL	=	Log_{10} P
ROWEJ	=	Log_{10} (ρ), ρ in Amagats
TEJ	,	Array of Temperature Values
U	,	Velocity, ft/sec
UEI	,	Dummy Variable
UEJ	,	Array of U Values
UI	,	Dummy Variable
XJ	,	Array of X Values
XMI	,	Dummy Variable
XMJ	,	Array of Mach Numbers
XMUEJ	,	Dummy Array (Not Used)
XS	,	Dummy Variable
ZI	,	Dummy Variable

ZJ , Array of Z Values

ZZ , Dummy Array for Thermodynamic and Transport Properties

The following variables which are used in subroutine EDGE are described in the section "Description of Variables in Common": DUEDS, HESTAT, HREF, IIMAX, KPD, NOSE, NT1, NT2, NT4, NV, PE, PP, PREF, PZ, RGAS, RHOREF, RHOSTD, ROWE, TE, TREF, UE, UREF, X, XM, XMA, XMUE, XMUREF, XSTA, Z.

Subroutine EDGE1

The purpose of this subroutine is to match the expansion data obtained from the Cornell Aeronautics Laboratory (CAL) computer program developed by Lordi, Mates, and Moselle [1965] to the nozzle geometry specified. The modifications which were made to their computer program are described in Appendix A. The subroutine is called only when solutions corresponding to isentropic expansion of the gas are desired.

The expansion data obtained from the CAL computer program provides the flow properties as a function of area ratio. Since the flow is assumed to be isentropic, the same expansion data are used for all nozzles having the same reservoir conditions. Thus, to perform parametric studies of nozzles with the same reservoir conditions it is necessary to change only the nozzle geometry input data.

The solution obtained from the modified CAL computer program are written as unformatted records on unit NT1. The first record written on NT1 is the stagnation or reservoir conditions, and it is necessary for the last two records to have area ratios greater than that of the exit area ratio of the specified nozzle.

To determine the edge conditions as a function of the axial coordinate Z and surface distance X, five-point Lagrange interpolation is used. In cases where the area ratio corresponding to the second record on unit NT1 is less than the area ratio at Z = Z(K) of the given nozzle, the flow properties are assumed to be linear functions of area ratio up to Z = Z(K). Nozzle exit conditions are determined in Subroutine EQLDTA. The resulting edge conditions are written on unit NT4.

USAGE:

CALL EDGE1

Description of Variables

A	,	Area Ratio Read from Unit NT1
AOASTR	,	Area Ratio at Z = Z(K)
ASTROA	,	Inverse of the Area Ratio at Z = Z(K)
A11	,	Array of Area Ratios
H	=	Log_{10} (H*/RGAS)
HSTG1	=	H at Stagnation Conditions
HZ	=	H at Z = Z(K)
H1	,	Array of H Values
IMAX	=	ITH if $XM \geq 1$, = IIMAX if $XM > 1$.
IMIN	=	1 if $XM \leq 1$, = ITH if $XM > 1$
I1	=	-1 if A is Monotone Decreasing, = 1 if A is Monotone Increasing
J	,	Array Subscript
K	,	Array Subscript and DO Loop Index
KKK	,	Indicator for Return
MMM	,	Indicator for Reading Stagnation Conditions
ONEOA	,	Inverse of A
P	=	Log_{10} P, P in Atmospheres
PSTG1	=	P at Stagnation Conditions
PZ1	=	P at Z = Z(K)
P1	,	Array of P Values
RX	,	Radius Corresponding to A
R1	,	Array of RZ Values

U	,	Velocity, ft/sec
UZ	=	U at Z = Z(K)
U1	,	Array of U Values
XMZ	,	Mach Number at Z = Z(k)
XM1	,	Array of Mach Numbers
XSTA1	,	Subarray of Array XSTA
X1	=	X Corresponding to A
ZZ	,	Dummy Array of Thermodynamic and Transport Properties
Z1	=	Z Corresponding to A

The following variables which are used in subroutine EDGE1 are described in the section "Description of Variables in Common": HEXIT, IIMAX, ITH, KRSTRT, NT1, NT4, PEXIT, RZ, UE, UREF, XM, XMA, XSTA, ZA.

Subroutine EFFMU

Subroutine EFFMU calculates the terms in the coefficients of the differential equations which contain the eddy viscosity. These terms are A_o, $\bar{A}_o$ and $\frac{\partial \bar{A}_o}{\partial \eta}$ (or $\bar{A}_o{}'$) where

$$A_o = C\ (1 + \varepsilon^+)$$

for the momentum equation, or

$$A_o = \frac{C}{Pr}\ (1 + \varepsilon^+ \frac{Pr}{Pr_t})$$

for the energy equation, and

$$\bar{A}_o = A_o/C$$

and where

$$C = \rho\mu/\rho_e\mu_e \; .$$

For the laminar case $\varepsilon^+ = 0$ and the terms reduce to

$$A_o = C \text{ or } C/Pr$$

$$\bar{A}_o = 1 \text{ or } 1/Pr$$

and

$$\bar{A}_o' = 0 \text{ or } \frac{\partial}{\partial\eta}\left(\frac{1}{Pr}\right).$$

The first portion of the subroutine calculates the terms for the laminar case. For a perfect gas C is calculated by Subroutine RHOMU and Pr is a constant. For an equilibrium gas, C and Pr are calculated previously in Subroutine PROP.

The next portion of the subroutine calculates the vorticity Reynolds number

$$\chi = \frac{y^2}{\nu}\frac{\partial u}{\partial y}$$

and for calculations with a transition regime initiates transition and calculates the transition intermittency factor Γ where

$$\Gamma = 1 - \exp\left(-0.412\bar{\xi}^2\right),$$

$$\bar{\xi} = 4\,\frac{x - x_o}{(\bar{x} - 1)\quad x_o},$$

and x_o is the location of the beginning of transition and $\bar{x}$ is a measure of the relative length of transition.

In the third portion of the subroutine the eddy viscosity is computed for turbulent flow calculations and the terms A_o, $\bar{A}_o$, and $\bar{A}_o'$ are then computed.

USAGE:

CALL EFFMU (LAMTRB, MOMEGY, II, DSTARK)

Description of Variables

APLUS	=	$A^+ = 26$ if KPGRAD = 0
		$= 26 \exp(-5.9\, v_w^{\,+})$ if KPGRAD = 1
		$= 26\, [1 - 11.8\, p^+]^{-1/2}$ if KPGRAD = 2
		$= 26\, \{ - \frac{p^+}{v_w^{\,+}} [\exp(11.8\, v_w^{\,+}) - 1] + \exp(11.8\, v_w^{\,+})\}^{-1/2}$ if KPGRAD = 3
ARG	,	Dummy Variable
DCDTH	=	$\frac{\partial C}{\partial \theta}$, where $\theta = T/T_e$
DELTA	=	δ/ε_{VD}, Boundary Layer Thickness in Stretched Coordinates
DSTARK	=	δ_k^*, Incompressible Displacement Thickness
FAC FAC1 FAC2 FAC3 FAC4	,	Dummy Variables
GAMF	=	γ, Outer Eddy Viscosity Intermittency Factor
I	,	Array Subscript
II	,	The Subscript in the EPSPL Array Where the Inner and Outer Eddy Viscosities are Matched
LAMTRB	,	Indicator for Laminar or Turbulent Flow; 1 for Laminar, 2 for Turbulent

MOMEGY	,	Indicator for Momentum or Energy Equations; 1 for Momentum, 2 for Energy
N	;	Array Subscript
PPLUS	=	$p^+ = -\frac{dp}{dx} \frac{\nu}{\rho} \frac{1}{u^{+3}}$ (dimensional quantities)
RHO	=	ρ/ρ_∞
RHOWL	=	ρ_w/ρ_∞
UPLUS	=	u^+/u_∞ where $u^+ = \sqrt{\tau_w/\rho}$ (dimensional quantities)
VPLUS	=	$v_w{}^+ = v_w/u^+$ (dimensional quantities)
XLAMDA	=	$\lambda = (\overline{x} - 1)\ x_o/4$ (See XIBAR)
XMU	=	μ/μ_{ref}
XZERO	=	x_o, Location of Start of Transition
YPLUS	=	$y^+ = \frac{yu^+}{\nu}$ (dimensional quantities)

The following variables which are used in subroutine EFFMU are described in the section "Description of Variables in Common": ATR, AO, AOB, AOBP, C, CF, CHI, CHICRT, CHIMAX, CP, CQ, DN, DX, DXOLD, EPSO, EPSPL, EPSVD, FC, FCN, GAMMA, IE, IM, KPGRAD, KTRANS, KVSLAW, NEQIL, OMEGA, PNC, PP, PREQ, PRL, PRT, ROROE, ROWE, RO, TH, THP, UE, VK, X, XBAR, XIBAR, XI2, XJFAC, XK1, XK2, XMUE, XN, Y.

Subroutine EGPROP

Subroutine EGPROP obtains the edge properties used in subroutine DELTAS to calculate $\Delta\xi$. The edge properties are obtained from subroutines BLUNT2, WDGFP2, or NOZLE2 depending on the geometry specified by the variable NOSE which is passed through common. For a blunt nosed body, NOSE = 1; for a wedge or flat plate, NOSE = 2; and for a nozzle, NOSE = 3.

USAGE:

```
CALL EGPROP
```

Subroutine ENERGY

Subroutine ENERGY calculates the coefficients for the energy equation. After the coefficients are calculated, subroutine SOLVE is called and the new values of $G = H/H_e$ and its first and second derivatives with respect to η are returned. The difference between the new and the former values is obtained for either the wall or the all points convergence test. New values of T/T_e and ρ/ρ_e are calculated as are new values of the normal coordinates y/L and $y/L\varepsilon_{VD}$.

USAGE:

CALL ENERGY

Description of Variables

FAC	=	U_e^2/H_e
GFAC	=	$(U_e^2/H_e)\ (1 - 1/Pr)$
J	,	Array Subscript
MOMEGY	,	Indicator, 1 for Momentum Equation, 2 for Energy Equation
N	,	Array Subscript

The following variables which are used in subroutine ENERGY are described in the section "Description of Variables in Common": ALP, ALP1, AO, AOB, AOBP, A1, A2, A3, A4, C, CCRNI, CP, CRNI, C1, C1N, DIF, DIFF, DIF1, DN, DSTARK, EPSVD, E1, FC, FCN, F2NN, HALP, HE, IADW, IE, IM, KEP, LAMTRB, NC, NEQIL, PNC, PREQ, PRL, ROROE, TB, TC, TCN, TH, THP, T1, T1N, T1NN, T2, T2N, T2NN, T2N1, T21, UE, VC, X, XI, XN, Y, YY.

Subroutine EQLDTA

In this subroutine, the stagnation, nozzle exit, and reference conditions are defined. The subroutine is called only when solutions corresponding to isentropic expansion of the gas are desired.

The expansion data are obtained as described in Appendix A. The data from this program are written as unformatted records on unit NT1. To provide the necessary data for five-point interpolation, the area ratios of the last two records on unit NT1 must exceed the exit area ratio of the given nozzle geometry. The first record on unit NT1 is the stagnation or reservoir condition.

USAGE:

CALL EQLDTA

Description of Variables

A	,	Area Ratio Read from Unit NT1
AEXIT	,	Exit Area Ratio of Given Geometry
A11	,	Array of A Values
H	=	Log_{10} (H*/RGAS)
H1	,	Array of H Values
J	,	Array Subscript
NERR	,	Dummy Variable
P	,	Log_{10} (P), P in Atmospheres
P1	,	Array of P Values
U	,	Velocity, ft/sec
U1	,	Array of U Values
XM1	,	Array of Mach Numbers
ZZ	,	Dummy Array of Thermodynamic and Transport Properties

The following variables which are used in subroutine EQLDTA are described in the section "Description of Variables in Common": CX, HE, HEXIT, HFS, HREF, HSTAG, IIMAX, ITH, NT1, NT2, NV, PEXIT, PFS, PREF, PSTAG, P10, RGAS, RHOFS, RHOREF, RHOSTD, RHOSTG, RZ, TFS, TREF, TSTAG, T10, UFS, UREF, XM, XMA, XMUFS, XMUINF, XMUREF.

Subroutines FD3 and FD5

Subroutines FD3 and FD5 use the first derivative of the Lagrangian interpolating polynomial of second and fourth order respectively to provide the first derivative of the function F at point X. The returned value is denoted by FX. The interpolating polynomials are described in the descriptions of subroutines INTER3 and INTER5.

USAGE:

```
CALL FD3 (X, X1, X2, X3, F1, F2, F3, FX)
```

or

```
CALL FD5 (X, X1, X2, X3, X4, X5, F1, F2, F3, F4, F5, FX)
```

where X1, X2, etc. are the abscissa values, and where F1, F2, etc. are the ordinate values.

Subroutine GEOM

This subroutine obtains the edge properties at the initial value of x for the geometry specified by the variable NOSE which is passed through common. The edge properties are obtained from subroutine BLUNT1 for a blunt nosed body (NOSE = 1), from subroutine WDGFP1 for a wedge or flat plate (NOSE = 2), and from subroutine NOZLE1 for a nozzle (NOSE = 3).

USAGE:

```
CALL GEOM
```

Subroutine INIT

Many variables are given fixed initial values in the program before the marching integration procedure is begun. The non-subscripted variables are given the initial values in subroutine INIT.

USAGE:

```
CALL INIT
```

Description of Variables

JT Array Subscript

The following variables which are used in subroutine INIT are described in the section "Description of Variables in Common": BO, CCRNI, CF, CHIMAX, CMSTD, CRNI, CSTAR, CX, DS, DX, DXOLD, DX1, E1, FF, G, GAMEFF, GAMMA, HGFAC1, HGFAC2, IE, IIMAX, IM, IPRNT, ISTOP, JJ, KEP, KFS, KSTOP, KTPW, KTW, LAMTRB, NEQIL, NEQL, NIT, NITTOT, NOSE, NRSTRT, PR, PRL, QW, R, RGAS, RHOFS, RHOSTD, SUM, TFS, TSTAG, TW, TWZ, UFS, VW, X, XI, XIBAR, XIOLD, XI2, XJAY, XJFAC, XM, XMA, XOLD, XSTA, Z.

Subroutine INTER3

Subroutine INTER3 uses a second-order Lagrangian interpolating polynomial interpolating on the points x_1, x_2, and x_3, with the corresponding function values f_1, f_2, and f_3 to provide a value F corresponding to x.

The general form of the polynomial is

$$F(x) = \sum_{k=1}^{3} f_k \, L_k(x)$$

where

$L_k(x)$ is given by

$$L_k(x) = \prod_{\substack{m=1 \\ m \neq k}}^{3} \frac{x - x_m}{x_k - x_m}$$

USAGE:

```
CALL INTER3 (X, X1, X2, X3, F1, F2, F3, F)
```

where X1, X2, and X3 are the abscissa values and F1, F2, and F3 are the function values.

Subroutine INTER5

Subroutine INTER5 uses a fourth-order Lagrangian interpolating polynomial interpolating on the points x_1, x_2, x_3, x_4, and x_5 with the corresponding function values f_1, f_2, f_3, f_4 and f_5 to provide a value F corresponding to x.

The general form of the polynomial is

$$F(x) = \sum_{k=1}^{5} f_k \, L_k \, (x)$$

where

L_k (x) is given by

$$L_k \, (x) = \prod_{\substack{m=1 \\ m \neq k}}^{5} \frac{x - x_m}{x_k - x_m} \quad .$$

USAGE:

CALL INTER5 (X, X1, X2, X3, X4, X5, F1, F2, F3, F4, F5, F)

where X1, X2, etc. are the absissa values and F1, F2, etc. are the function values.

Subroutine INTERP

Subroutine INTERP uses function TLU to linearly interpolate in the array F2 for the value FF corresponding to the value XX in the array XN. If XX is not within the range of XN, a message is printed and FF is set equal to F2(IE) where IE is the size of the arrays. XN must be a strictly increasing array.

USAGE:

CALL INTERP (XX, XN, F2, IE, FF)

Subroutine INTRP5

Subroutine INTRP5 uses five-point interpolation to obtain a value F0 in the array FI corresponding to the value X0 in the array X1. The array X1 can be either monotone increasing or monotone decreasing.

USAGE:

CALL INTRP5 (X0, X1, F1, IMAX, IMIN, I1, F0) where X1 and F1 are the arrays of coordinate values, IMAX and IMIN are the maximum and minimum values allowed for the subscripts of the arrays, and I1 is an indicator ($I1<0$, X1 is monotone decreasing; $I1\geq 0$, X1 is monotone increasing).

Subroutine MACH

The first time subroutine MACH is called, a table of MACH numbers is generated. If a pressure distribution is not part of the input data (KPD = 0) the MACH numbers are calculated from the area ratios. In the range M = 0 to M = 2 the MACH number increment is 0.01. For $M \geq 2$ the MACH number increment is 0.05. If $KPD \neq 0$, the table of MACH numbers is generated from the pressure distribution table.

After the MACH number table has been generated, five-point interpolation is used to calculate the MACH number which corresponds to the values of z and r passed through the argument list.

USAGE:

CALL MACH (X,R,RT, ZTH)

Description of Variables

A	=	$\gamma + 1$
AR	,	Area Ratio
AR1	,	Area Ratio Array
B	=	$\gamma - 1$

C	=	A/2B
DXM1	,	Mach Number Increment
FAC	,	Dummy Variable
FAC1	,	Dummy Variable
J	,	Array Subscript
JKL	,	Indicator, Undefined for First Call, Then Set to 235
N	,	Array Subscript
R	,	Local Radius
RT	,	Throat Radius
X	,	Local Axial Coordinate
XM1	,	Mach Number Array
XTH	,	Axial Coordinate of Throat

The following variables which are used in subroutine MACH are described in the section "Description of Variables in Common": G, IIMAX, KPD, PZ, XM, ZA.

Subroutine MOMENT

The solution of the momentum equation is obtained in subroutine MOMENT. The coefficients of the partial differential equation are calculated and new values of $F = u/u_e$ and the first and second derivatives of F with respect to η are obtained from subroutine SOLVE. The difference between the new and the former values is obtained for either the wall or the all points convergence test. The derivative of F with respect to x is also calculated.

USAGE:

CALL MOMENT

Description of Variables

MOMEGY	,	Indicator, 1 for Momentum Equation, 2 for Energy Equation
N	,	Array Subscript

The following variables which are used in subroutine MOMENT are described in the section "Description of Variables in Common": AO, AOB, AOBP, A1, A2, A3, A4, BETA, C, CCRNI, CP, CRNI, DIF, DIFF, DIF1, DIF2, DS, DSTARK, E1, FC, FCN, FCP, FF, F1, F1N, F1NN, F2, F2N, F2NN, F2N1, IE, IM, KEP, LAMTRB, NC, TH, VC, X, XI.

Subroutine NOZLE1

This subroutine calculates the edge and reference conditions at the initial value of x for a nozzle. For a perfect gas, the properties are obtained from perfect gas relations. For an equilibrium gas, the properties are calculated using the data on the expansion and gas property tapes.

USAGE:

CALL NOZLE1

Description of Variables

CPRIME	=	CPRIM
DUM	,	Dummy Variable
DUM1	,	Dummy Variable
DUM2	,	Dummy Variable
HESTJ	,	Array of HORL Values
HFSL	,	Free-stream Value of HORL
HI	,	Dummy Variable
HORL	=	Log_{10} (H*/RGAS)

IJK	,	Indicator, Undefined for First Call, then Set to 231
J	,	Array Subscript
NERR	,	Dummy Variable
PATMS	,	Pressure in Atmospheres
PE1	,	Dummy Variable
PI	,	Dummy Variable
PJ	,	Array of PL Values
PL	=	$\text{Log}_{10}P$, P in Atmospheres
TE1	,	Dummy Variable
UI	,	Dummy Variable
XMACHS	=	M_{∞}^2
XMI	,	Dummy Variable
XMJ	,	Array of Mach Numbers
ZZ	,	Dummy Array for Thermodynamic and Transport Properties

The following variables which are used in subroutine NOZLE1 are described in the section "Description of Variables in Common": ALP, BETA, CPRIM, CSTAR, CX, DUEDS, G, HE, HESTAT, HFS, HREF, HSTAG, IIMAX, ITH, KPD, NEQIL, NT1, NT2, NV, OMEGA, PE, PESO, PFS, PNC, PP, PREF, PSTAG, PZ, P10, REINF, RGAS, RHOFS, RHOREF, RHOSTD, RHOSTG, ROWE, ROWEP, RZ, RO, SCF, TE, TESO, TFS, TREF, TSTAG, T10, UE, UERO2, UEZ, UFS, UREF, X, XM, XMA, XMUE, XMUEP, XMUFS, XMUINF, XMUREF, XMUSO, XSTA, Z, ZA.

Subroutine NOZLE2

For a nozzle, the edge properties required by subroutine DELTAS to calculate $\Delta\xi$ are provided by subroutine NOZLE2. For a perfect gas, the properties are calculated from perfect gas relations. For an equilibrium gas, the properties are obtained from subroutine EDGE.

USAGE:

CALL NOZLE2

Description of Variables

J , Array Subscript

The following variables which are used in subroutine NOZLE2 are described in the section "Description of Variables in Common": DUEDS, G, IIMAX, ITH, NEQIL, OMEGA, PE, PP, P10, ROWE, RZ, RO, TE, T10, UE, UEZ, X, XM, XMUE, XSTA, Z, ZA.

Subroutine PRFILE

Subroutine PRFILE calculates the array of η values, XN, which corresponds to the values of IE, ETAINF, and XKETA. The grid spacing is given by $\Delta\eta_i = K\,\Delta\eta_{i-1}$ where K corresponds to XKETA and thus at the i-th grid point

$$\eta_i = \Delta\eta_1 \frac{K^i - 1}{K-1} \quad i = 0, 1, 2, 3, \ldots N \quad (N=IE-1)$$

where $\Delta\eta_1$ is given by

$$\Delta\eta_1 = \eta_\infty \frac{K-1}{K^N - 1}$$

The initial profiles of velocity and enthalpy (F and G) are calculated from the formulas

$$F = 1 - \exp(-\eta)$$

and

$$G = H_w/H_o + (1 - H_w/H_o)F.$$

The derivatives of F and G are also calculated as are initial profiles for C, CP, ε^+, y/δ, and y/θ. Further, the boundary conditions at the outer edge of the boundary layer are set in this subroutine.

USAGE:

CALL PRFILE

Description of Variables

DETA1	=	$\Delta\eta$ at wall
N	,	Array Subscript

The following variables which are used in subroutine PRFILE are described in the section "Description of Variables in Common": BO, C, CP, DN, EPSPL, ETAINF, FC, FCN, FCP, F1, F1N, F1NN, F2, F2NN, IE, IM, PNC, TC, TCN, T1, T1N, T1NN, T2, VC, VW, XKETA, XN, Y, YOVDEL, YOVTHT.

Subroutine PROP

This subroutine is called by subroutines ENERGY and MAIN for all equilibrium gas solutions. The subroutine uses the correct values of F and T to call subroutine SLOW. Subroutine SLOW returns the corresponding current values of density, temperature, viscosity, and Prandtl number.

USAGE:

CALL PROP

Description of Variables

HL	,	Log_{10}(HOR)
HOR	,	Local Static Enthalpy/RGAS, Degrees Kelvin
HSTAT	,	Locat Static Enthalpy, ft^2/sec^2
HSTGL	,	Local Stagnation Enthalpy, ft^2/sec^2
J	,	Array Subscript
NERR	,	Dummy Variable

P	,	Pressure in Atmospheres
PL	,	$Log_{10}(P)$
RHOIE	,	Density at Edge of Boundary Layer In Amagats
THIE	,	Temperature at Edge of Boundary Layer in Degrees Kelvin
ULOC	,	Local Velocity, ft/sec
XMU	,	Viscosity, lb-sec/ft^2
XMUIE	,	Viscosity at Edge of Boundary Layer, lb-sec/ft^2
ZZ	,	Dummy Array for Thermodynamic and Transport Properties

The following variables which are used in subroutine PROP are described in the section "Description of Variables in Common": C, FC, HE, HREF, IE, NT2, NV, PE, PR, PREF, PREQ, RGAS, ROROE, TC, TH, UE, UREF.

Subroutine READIN

Subroutine READIN provides the input of data for the program. The input data may come either from cards or from a restart tape. The first card gives the restart station number and the second card gives the tape unit numbers. If the restart station number is zero, the input data is from cards and is as described in the section "Description of Input Data". If a restart station number greater than zero is used, the input data comes from the restart tape, and only the two cards described above are read. With the exception of the two variables on the first card and some of the arrays (which are not needed for a restart), all variables which are in COMMON in the program are written on the restart tape. The order in which the variables are written on the restart tape is as they appear in the COMMON statements.

The restart tape is also written by subroutine READIN. The array LABEL and the variables in ARRAY2 are written at the beginning of the tape; the other variables are written every NRSTRT-th station. The variable KREADN controls which part of the subroutine is used: for a value of one, the input data are read; for a value of two, the initial data are written on the restart tape, and for a value of three the station data are written on the restart tape.

If the input data is from the restart tape, subroutine WRITE1 and WRITE2 are called to print the data which has been read from the tape. Subroutine WRITE2 prints the data from the last converged solution written on the tape (corresponding to K-KRSTRT). When the restart tape is written, a message is printed giving the current value of K and the next value of K for which the restart tape will be written.

USAGE:

CALL READIN (KREADN)

Description of Variables

J	,	Array Subscript
KREADN	,	Indicator for Part of Subroutine Used
KRITE1	,	Indicator for Part of Subroutine WRITE1 to be Used
LST	,	Alphmeric Variable, Assigned Value of 'LAST' in a DATA Statement

All other variables are described in the section "Description of Variables in Common", except for LABEL and LSTC which are described in the section "Description of Input Data".

Subroutine REFSUB

Subroutine REFSUB computes the free stream Reynolds number for nozzle flow calculations and for other calculations for which the input value of Re_∞ is zero. It also calculates the dimensional quanties needed for the heat transfer calculation. Values of ρ_∞, u_∞, and μ_∞ are needed to calculate Re_∞. The value of μ_∞ is obtained from T_∞ and reference values of viscosity and temperature using Sutherland's law. The value of u_∞ is obtained from T_∞ and M_∞, and ρ_∞ is obtained from P_∞ and T_∞. If the value

ρ_∞ or T_∞ is not specified in the input data, it can be calculated from M_∞ and ρ_0 or from M_∞ and T_0 respectively.

For a nozzle, M_∞ is taken to be the exit MACH number and is calculated from the nozzle geometry in subroutine MACH. For other geometries, M_∞ needs to be part of the input data. If the indicator KFS is zero this subroutine is bypassed as are the other calculations in the program using dimensional quantities (one exception is that subroutine INIT will calculate u_∞ from M_∞ and T_∞ if u_∞ is zero).

USAGE:

CALL REFSUB

Description of Variables

The following variables occur in this subroutine and are described in the section "Description of Variables in Common". AMUINF, AMUREF, G, PFS, PSTAG, R, REINF, RHOFS, SCF, TFS, TREF1, TSTAG, UFS, XMA.

Subroutine RHOMU

Subroutine RHOMU calculates the density-viscosity product C where

$$C = \frac{\rho\mu}{\rho_e\mu_e}$$

If $\omega \neq 0$, the power law is used, i.e.

$$C = \theta^{\omega-1} \quad \text{where } \theta = T/T_e.$$

If $\omega = 0$, Sutherlands law is used, i.e.

$$C = \theta^{0.5} \quad \frac{1 + VK}{\theta + VK}$$

where $VK = C^*/T_e$ and $C^* = 198.6°K$. Also: $dC/d\theta$ is calculated.

USAGE:

CALL RHOMU (OMEGA, TH, C, DCDTH, VK)

where OMEGA = ω, TH = T/T_e, and DCDTH = $dC/d\theta$

Subroutine SLOW

The purpose of this subroutine is to determine the thermodynamic and transport properties by interpolation in tables written on unit IT. The data on unit IT are obtained as described in Appendix B.

The solution obtained for the thermodynamic and transport properties at a given pressure are written on unit IT as unformatted records. For each pressure, two records are written. The first record contains the pressure and the number of steps in the table of thermodynamic and transport properties at the given pressure. The second record contains the arrays of temperature, enthalpy, density, viscosity, specific heat, and Prandtl number in that order. These arrays are dimensioned by 100 in the generating program. The records are written with P decreasing and the corresponding table of thermodynamic and transport properties is written with temperature decreasing. Five sets of these records are read in this subroutine and stored as the array X and the three dimensional array Y.

A table of thermodynamic and transport properties at the desired pressure is obtained by five point interpolation in the array Y and stored in the two dimensional array Y2. Local values of the thermodynamic and transport properties are obtained by five-point interpolation in the array Y2 for a given temperature or enthalpy.

USAGE:

CALL SLOW (XX, Z, I1, S1, IT, NV, NERR)

Description of Variables

I	,	Array Subscript
IJK	,	Indicator for Initial or Subsequent Call to Subroutine, Undefined for First Call, Then Set to 301

IT	,	Tape Unit Number (NT2)
I1	,	Index of Array Z Indicating the Point in Array Y2 at which Interpolations are to be Made
JJ	,	Indicator For Number of Steps in Property Table
J1	,	Index of Array Z Indicating the Property Value which is to be Returned by the Subroutine
K	,	Array Subscript
L	,	Array Subscript
MM	,	Array Subscript
NERR	,	Dummy Variable
NV	,	Index which Indicates the Number of Arrays Written on Unit IT
X	,	Array of Log_{10} (P), P in Atmospheres
XX	,	Local Value of X at which Interpolations are made for Array Y2
XX1	,	Value of XX for the Previous Call of the Subroutine
X1	,	Dummy Variable
Y	,	Three Dimensional Array of Thermodynamic and Transport Properties
Y2	,	Two Dimensional Array of Thermodynamic and Transport Properties at XX
Z	,	Array of the Calling and Returned Argument where:

Z(1), Temperature, °K
Z(2), Log_{10} (H*/RGAS), H*/RGAS has units of °K
Z(3), Log_{10} (Density), Density in Amagats
Z(4), Viscosity, lb-sec/ft^2
Z(5), Specific Heat/RGAS
Z(6), Prandtl Number

Subroutine SOLVE

Subroutine SOLVE calculates the solution for a general parabolic partial differential equation when the equation is written in the "standard" form

$$\phi_{\eta\eta} + A_1 \phi_\eta + A_2 \phi + A_3 + A_4 \phi_\xi = 0.$$

In order to obtain a solution for the above equation, values of ϕ and the first and second derivatives of ϕ with respect to η from a previous iteration or from a previous x station are required. These are passed through the argument list as the arrays W1, W1N, and W1NN. The new values of ϕ and the first and second derivatives are returned through the argument list as the arrays W2, W2N, and W2NN.

USAGE:

CALL SOLVE (W1NN, W1N, W1, W2NN, W2N, W2, E1, F11, CRNI)

Description of Variables

A	,	Matrix Inversion Coefficient
B	,	Matrix Inversion Coefficient
CC	,	Matrix Inversion Coefficient
D	,	Matrix Inversion Coefficient
E	,	Array of Matrix Inversion Coefficients
E1	,	Value of E at Wall
F	,	Array of Matrix Inversion Coefficients
F11	,	Value of F at Wall
KON	,	Array Subscript, Descending Order
N	,	Array Subscript
W1	,	Value of ϕ at Previous Station
W1N	=	$\partial\phi/\partial\eta$ at Previous Station

W1NN = $\partial^2\phi/\partial\eta^2$ at Previous Station

W2 , New Value of ϕ

W2N , New Value of $\partial\phi/\partial\eta$

W2NN , New Value of $\partial^2\phi/\partial\eta$

The following variables which are used in subroutine SOLVE are described in the section "Description of Variables in Common": A1, A2, A3, A4, CRNI, DN, DS, IE, IM, XN.

Function TLU

Function TLU searches in the array X for the two values which bracket XSTAR and linearly interpolates for the corresponding value in the array Z. The returned value is TLU. If XSTAR is not within the range of the array X, TLU is set equal to zero and the error flag is set equal to one. The array X must be strictly increasing.

USAGE:

TLU (NTABLE, Z, X, XSTAR, NFLAG)

where NTABLE is the dimension of the arrays Z and X and NFLAG is the error flag.

Subroutine VISCO

Subroutine VISCO calculates the viscosity ratio μ/μ_{ref} corresponding to the temperature ratio T/T_{ref}. If $\omega = 0$ the power law is used, i.e.

$$\frac{\mu}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{\omega} .$$

If $\omega = 0$, Sutherlands law is used, i.e.

$$\frac{\mu}{\mu_{ref}} = \frac{1+C'}{T/T_{ref}+C'} \left(\frac{T}{T_{ref}}\right)^{1.5}$$

USAGE:

CALL VISCO (OMEGA, T. XMU)

where OMEGA = ω, $\dot{T}$ and XMU are the temperature and viscosity ratios, and $C' = C^*/T_{ref}$ is provided through common as CPRIM. $C^* = 198.6°R$ and $T_{ref} = (\gamma-1)M_\infty^2\ T_\infty = U_\infty^2/Cp$.

Subroutine WALL

This subroutine calculates the temperature and enthalpy boundary conditions at the wall. If a wall temperature distribution is part of the input data, five point interpolation is used to obtain the value of T_W corresponding to the local value of x. If KCQ is non-zero, five-point interpolation is used to obtain the local value of CQ. For an adiabatic wall, a value of the wall enthalpy is calculated such that the enthalpy gradient is zero at the wall. For a non-adiabatic wall, the wall enthalpy is specified by the wall temperature.

USAGE:

CALL WALL

Description of Variables

C11	,	Intermediate Variable used in computing GW
GW	=	H_w/H_e
H	=	H_w^*, ft^2/sec^2
HOR	=	H_w^*/RGAS), °K
HORL	=	Log_{10} HOR
HORLOG	=	Log_{10} (H_w/RGAS)
JT	=	Array Subscript
NERR	,	Dummy Variable
PATMS	,	Pressure in Atmospheres

PLOG	=	Log_{10} P
PSTR	,	Pressure, lb/ft^2
TSTR	,	Wall Temperature, °K
ZZ	,	Dummy Array for Thermodynamic and Transport Properties

The following variables which are used in subroutine WALL are described in the section "Description of Variables in Common": ALP1, BO, CONVRG, CQ, CQZ, DIF, DN, DUEDS, EPSVD, FINJ, HE, HREF, HW, IADW, IIMAX, KCQ, KINJ, KNOINJ, KTW, NEQIL, NT2, NV, PE, PREF, R, ROWE, RO, TB, TC, TE, TH, TREF, TSTAG, TW, TWZ, T10, T2, T21, UE, VW, X, XJFAC, XMUE, XSTA.

Subroutine WDGFP1

This subroutine calculates the edge and reference conditions at the initial value of x for a wedge or a flat plate. For a perfect gas the properties are obtained from perfect gas relations. For an equilibrium gas, the properties are calculated using the data on the gas property tape.

USAGE:

CALL WDGFP1

Description of Variables

CPRIME	=	CPRIM
HOR	=	H*/RGAS, °K
HORL	=	Log_{10}(HOR)
J	,	Array Subscript
NERR	,	Dummy Variable
PATMS	,	Pressure in Atmospheres
SINTH	,	Sin (ANGLE)

TDGRK	,	Temperature, °K
XMACHS	,	$M_\infty^{\ 2}$
XMTHSK	,	M_∞ Sin (THSHOK)
XMTHSQ	,	Square of XMTHSK
ZZ	,	Dummy Array for Thermodynamic and Transport Properties

The following variables which are used in subroutine WDGFP1 are described in the section "Description of Variables in Common": ALP, ANGLE, BETA, CPRIM, CSTAR, CX, DUEDS, G, HE, HESTAT, HFS, HREF, HSTAG, NEQIL, NT2, NV, OMEGA, PE, PESO, PFS, PNC, PP, PREF, PSTAG, P10, R, RGAS, RHOFS, RHOREF, RHOSTD, RHOSTG, ROESO, ROWE, ROWEP, RO, TE, TESO, TFS, THSHOK, TREF, TSTAG, T10, UE, UERO2, USEO, UFS, UREF, XMA, XMUE, XMUEP, XMUFS, XMUINF, XMUREF, XMUSO.

Subroutine WDGFP2

For a wedge or for a flat plate the edge properties required by subroutine DELTAS to calculate $\Delta\xi$ are provided by subroutine WDGFP2. The properties are constant and have been computed in subroutine WDGFP1. A value is calculated for the variable Z; to the other variables are assigned the values computed in subroutine WDGFP1.

USAGE:

CALL WDGFP2

Description of Variables

The following variables which are used in subroutine WDGFP2 are described in the section "Description of Variables in Common": ANGLE, DUEDS, ROESO, ROWE, RO, TE, TESO, UE, UESO, X, XMUE, XMUSO, Z.

Subroutine WRITE1

Subroutine WRITE1 provides two sections of output. The first section is the input data and other data initialized by the program. The integer quantities are written first in the same order as they appear in the input followed by the injection parameters CQ and FINJ. The next data written are the free-stream quantities. If the indicator KFS is zero, the free-stream pressure and density and the stagnation pressure and temperature are not written. If the reference temperature, TREF1, is zero, the reference temperature, the reference viscosity, and the free stream viscosity are not written. The transition parameters are then written and are followed by a group of variables, most of which are from the program input and appear in approximately the same order. Next are written the integer arrays which control the values of x at which a solution is obtained and at which full profile data is to be written. Finally, the values of axial distance, radius, surface distance, surface pressure, non-dimensional edge velocity, surface temperature, and injection rate distribution are written.

The second section of the subroutine is used when calculations are made using the equilibrium gas model. The stagnation, free-stream and reference conditions which have been recomputed for the equilibrium gas are written following the message "BEGIN EQUILIBRIUM GAS SOLUTION".

USAGE:

CALL WRITE1 (KRITE1)

Description of Variables

J	,	Array Subscript
KRITE1	,	Indicator for Section of Subroutine to be Used, 1 for First Section, 2 for Second Section

The other variables which appear in this subroutine are described in the sections "Description of Output" and Description of Variables in Common".

Subroutine WRITE2

Subroutine WRITE2 provides the output of computed results after a converged solution is obtained. The output is in two sections. The first section is written at every station at which a solution is obtained. The second section is written for specified values of x. The first line of output contains the values of geometry related variables (such as x, z, and ξ), the pressure gradient term, β, the number of iterations, and the station counter, K. The second line contains the non-dimensionalized edge conditions (such as T_e, M_e, and μ_e). The third line contains the skin friction and heat transfer in the transformed coordinates, the subscript in the eddy viscosity array where the inner and outer eddy viscosities are matched, and the cumulative total of the number of iterations. The fourth line gives the first and second derivatives of the velocity at the wall and at the second grid point from the wall. The remainder of the first section is omitted if x = o. The next line gives transition parameters and the following line contains the Reynolds number or the Reynolds number, the heat transfer rate, and two dimensional heat transfer coefficients. In the remaining lines in the first section are skin friction coefficients, Stanton numbers, the boundary layer thicknesses, and quotients of boundary layer parameters.

In the second section of the output, some of the variables which are functions of the normal coordinate are written. The output of this section contains η, y, y/θ y/δ, $F(=u/u_e)$, $\partial F/\partial\eta$, $\partial^2F/\partial\eta^2$, ε^+, $\partial\bar{A}_o/\partial\eta$, $G(=H/H_e)$, $\partial G/\partial\eta$, V, T/T_e, ρ/ρ_e, $C(=\rho\mu/\rho_e\mu_e)$, $\partial C/\partial\eta$, and χ.

After the second section of output is written, subroutine READIN is called with KREADN=3 to write the station data on the restart tape if NT3≠0 and if K=KTPW. The first derivative of F at the wall is then tested for a negative value and if $\partial F/\partial\eta$ at the wall is negative, it is assumed that the flow has separated, a message is written, and the program is stopped.

USAGE:

CALL WRITE2

Description of Variables

II	Counter or Subscript for Array IPR

IPRNT	,	Counter or Subscript for Array IPRFL
KL	,	The values of η and the functions of η are written at every KL - th grid point.
KREADIN	,	Specifies READIN is Called to Write the Station Data on the Restart Tape
XOLD	,	Previous Value of x.

The above variables except for KREADIN are in common and thus are also described in the section "Description of Variables in Common". The other variables which appear in this subroutine (except for N, an array subscript) are described in the sections "Description of Output" and "Description of Variables in Common".

Subroutine ZRO

Subroutine ZRO uses subroutine INTER5 to interpolate in the arrays ZA and RZ for the values Z and RO corresponding to the value X2 in the array XSTA. The arrays RZ, XSTA, and ZA contain values of radius, surface distance, and axial distance respectively for axially symmetric geometry.

USAGE:

```
CALL ZRO (JJ, X2, Z, RO)
```

where JJ is the dimension of the arrays, Z and RO are the returned values, and the arrays RZ, XSTA, and ZA are provided through common.

DESCRIPTION OF INPUT DATA

In the description of the input data, a card number is given first, followed by the list of variables on that card and the format under which the card is read. Then each variable in the list is described. At the end of this section are coding forms which may be used for coding the input data.

Card 1. KRSTRT, NRSTRT (4(7X,I3))

KRSTRT,	Restart Indicator; Zero for Starting New Solution; Greater Than Zero Restarts Solution, Next Solution Obtained at K = KRSTRT + 1
NRSTRT	Increment in K for Which Restart Tape is Written

Card 2. NT1, NT2, NT3, NT4 (4(8X,I2))

NT1,	Tape Unit Number for Expansion Tape
NT2,	Tape Unit Number for Gas Table Tape
NT3,	Tape Unit Number for Restart Tape
NT4,	Unit Number for Scratch Tape

For a perfect gas case, NT1, NT2, and NT3 are zero. If NT3 = 0, the restart tape is bypassed.

Card 3. LABEL (18A4)

Alphameric Data for Identification of the Case. Printed on the First Page of Output.

Card 4. NOSE, LAMTRB, KTRANS, KTRNSN (4(8X,I2)

NOSE,	Indicator for Geometry, 1 for a Blunt Nose, 2 for a Wedge or a Flat Plate, 3 for a Nozzle A value of 0 is reset to 1.
LABTRB,	Indicator, 1 for Laminar Flow, 2 for Turbulent Flow A value of 0 is reset to 1.

KTRANS, Indicator for Transition Regime, 0 for No Transition or Instantaneous Transition, 1 for Transition Regime (LAMTRB Must be 1.)

KTRNSN, Subscript for XSTA Array Giving Value of x at Which Instantaneous Transition Occurs

A value of 0 is reset equal to IIMAX and a value greater than IIMAX is reset equal to IIMAX.

Card 5. IADW, KTW, KPD, KFS (4(8X,I2))

IADW, Indicator, 1 for Adiabatic Wall, 0 for Non-adiabatic Wall

If IADW $\neq$ 0, BO is set equal to 1.0.

KTW, Indicator, 0 for Constant Wall Temperature, Non-zero for Wall Temperature Distribution Input

KPD, Indicator, 0 for Pressure Computed by Program Based on Nozzle Area Ratio, Non-zero for Pressure Distribution Input

KFS, Indicator, Non-zero for Computing in the Program Dimensional Free-stream, Stagnation and Reference Values and Dimensional Heat Transfer and Heat Transfer Coefficients, 0 to Bypass Computing Dimensional Quantities

Card 6. NIT1, NIT2, NIT3, NC (4(8X,I2))

NIT1, NIT2, and NIT3 are used in conjunction with NIT (the number of iterations) to control the variation in the x step size.

NIT1, After solution converges, Δx is doubled if NIT is less than or equal to NIT1.

A value of 0 is reset equal to 3. A value less than zero is reset equal to 0.

NIT2, After solution converges, Δx is halved if NIT is greater than or equal to NIT2.

A value of 0 is reset to 6.

NIT3, If NIT = NIT3, Δx is halved, X and XI are recomputed and the iteration loop is restarted with the smaller values of X and XI.

A value of 0 is reset to 9.

NC, Specifies Convergence Test, 0 for Test on Derivatives at Wall, 1 for Test on Functions at all Points in Profile Recommended Value 1.

Card 7. IE, KEND, IIMAX, ITH (4(7X,I3))

IE, Number of Grid Points in η Direction (Program Dimensioned for IE = 101 Which is the Recommended Value)

KEND, Upper Index on K (the Station Counter)

Recommended Value, 300-600

IIMAX, Number of Values in Geometry, Pressure and Temperature Distribution Arrays; Arrays Dimensioned for 500 Values (IIMAX is also obtained from the number of cards read.)

ITH, Subscript in the Geometry Arrays of the Throat Location (For NOSE $\neq$ 3, the value is arbitrary.)

Card 8. KADETA, KL, IPFL, IPRINT (4(8X,I2))

KADETA, Indicator; if Zero, ETAINF is Held Constant, if Non-zero, ETAINF can be Increased

KL, Index for Profile Output DO Loop, 1 Gives Output for Each Grid Point, 2 for Every Second Grid Point.

A value of 0 is reset equal to 2.

IPFL, Number of Values in IPRFL Array (Maximum 100)

IPRINT, Number of Values in IPR Array (Maximum 100)

Card 9. KVSLAW, KPGRAD, NV, NEQIL (4(8X,I2))

KVSLAW, Indicator for Eddy Viscosity Law, 0 for Reichardt Law, Non-zero for Van Driest Law

KPGRAD, Indicator for Expression for A^+ in Van Driest Inner Eddy Viscosity Law; 0 for $A^+ = 26$, 1 for A^+ Corrected for Mass Transfer, 2 for A^+ Corrected for Pressure Gradient, 3 for A^+ Corrected for Both Mass Transfer and Pressure Gradient

NV, Number of Variables Written on the Gas Property Tape

NEQIL, Indicator for Gas Model, 0 for Perfect Gas Model, Non-zero for Equilibrium Gas Model

Card 10 KCQ, KINJ, KNOINJ (4(7X,I3))

KCQ, Indicator, Zero for Constant Injection Rate, Non-zero for Injection Rate Distribution Input.

KINJ, Subscript in XSTA Array Giving the Location of the Beginning of Injection

A value greater than IIMAX is set equal to IIMAX.

KNOINJ, Subscript in XSTA Array Giving the Location of the End of Injection

A value greater than IIMAX is set equal to IIMAX

Card 11 CHICRT, XBAR, ATR, CQ, FINJ (6F12.6)

CHICRT, Value of CHIMAX at which Transition Regime Calculations Begin (arbitrary if KTRANS = 0)

Appropriate values have been found to be between 2000 and 4000.

XBAR, Measure of Relative Length of Transition Region (i.e. $X_{\text{End of Transition}}$ = XBAR * $X_{\text{Beginning of Transition}}$)

For Reichardt Law, XBAR should be about 65% greater than value used with Van Driest Law.

Recommended values are approximately 3.3 and 2.0, respectively.

ATR, Transition Constant = 0.412

CQ= $\rho_w v_w/\rho_\infty u_\infty$, Injection Rate

FINJ= f_w, Value of Stream Function at Wall
If FINJ is zero, VW is calculated from CQ.

Card 12. TFS, UFS, XMA, REINF (6F12.6)

TFS, Free-stream temperature, °R

UFS, Free-stream Velocity, ft/sec

If input value is zero, UFS is computed from TFS and XMA

XMA, Free-stream Mach Number

For a nozzle, TFS, UFS and XMA correspond to exit conditions and are computed by the program.

REINF, Free-stream Reynolds Number per Unit Length

If input value is zero, REINF is computed in Subroutine REFSUB and KFS must be non-zero

Card 13. B0, PRL, PRT, OMEGA (6F12.6)

B0= H_w/H_o

PRL= Pr, Laminar Prandtl Number

A value of 0.0 is reset to 0.7.

PRT= Pr_t, Turbulent Prandtl Number

OMEGA= ω, Exponent for Power Viscosity Law (If $\omega = 0$, Sutherland's law is used.)

Card 14. XK1, XK2, CONVRG, ADTEST (6F12.6)

XK1, Constant for Van Driest Inner Eddy Viscosity Law

A value of 0.0 is reset to 0.4, the normal value.

XK2, Constant for Outer Eddy Viscosity Law.

A value of 0.0 is reset to 0.0168, the normal value.

CONVRG, Convergence Criterion

A value of 0.0 is reset to 0.001.

ADTEST, Criterion for Increasing ETAINF (F(IE) - F(IE-4) is compared with ADTEST.)

A value of 0.0 is reset to 0.001, the recommended value.

Card 15. DX, CRNI, XKETA, ETAINF, REFLEN (6F12.6)

DX, Initial x Step Size

CRNI, Selector for Finite Difference Scheme; 1.0 for Fully Implicit (Recommended), 0.5 for Crank-Nicolson, and 0.0 for Fully Explicit

XKETA, Parameter Which Controls the Grid Spacing in the η Direction (1.0 Gives an Equally Spaced Grid, a Value Greater than 1.0 Gives a Finer Grid at the Wall than at the Outer Edge.) A value of 0.0 is reset to 1.09, the value recommended for IE = 101.

ETAINF, Maximum value of η

A value of 0.0 is reset to 100 which is the recommended value.*

REFLEN, An arbitrary Reference Length (See "Description of Output")

Card 16. XJFAC, ANGLE, THSHOK, G (6F12.6)

XJFAC, Indicator, 0.0 for 2-D Flow, 1.0 for Axially Symmetric Flow

ANGLE, Wedge Half Angle, in Degrees

THSHOK, Shock Angle, in Degrees

G= $\gamma = C_p/C_v$

---

*Note: ETAINF may be considerably larger than the value of η corresponding to δ; particularly for laminar flow. The recommended values of IE, XKETA, and ETAINF are appropriate for laminar, transition, and turbulent flows.

Card 17. TSTAG, TREF1, PSTAG, PFS, AMUREF, SCF (6F12.6)

TSTAG, Stagnation Temperature, °R

TREF1, Reference Temperature, °R (Used in Computing REINF if Input Value of REINF is Zero)

PSTAG, Free-stream Stagnation Pressure for Ideal Gas, PSIA

PFS, Free-stream Pressure, PSIA

AMUREF, Reference Viscosity Corresponding to TREF1, lbf-sec/ft^2

SCF, Scale Factor used to Convert Unit Length for REINF (REINF as Computed is per Foot if SCF = 1.0; REINF is per Inch if SCF = 12.0)

Card 18. POPRIM, CMSTD, GAMEFF, DXMAX (6F12.6)

POPRIM, Local Stagnation Pressure for Ideal or Equilibrium Gas, PSIA (Corresponds to Stagnation Pressure on Expansion Tape)

CMSTD, Standard Molecular Weight of Given Gas)

GAMEFF, Effective γ (C_p/C_v) Behind Normal Shock (for Blunt Body) (Same as G for a Nozzle)

DXMAX Maximum x Step Size Permitted in the Calculation

Cards 19 a, b, c, . . . (IPR(J), J = 1, IPRINT) (14I5)

IPR, Array of Subscripts for Array XSTA Giving Values of x at which a Solution is to be Obtained (Array Dimensioned for 100 Values)

Cards 20 a, b, c, . . . (IPRFL(J), J-1, IPFL) (14I5)

IPRFL, Array of Subscripts for Array XSTA Giving Values of x at which Complete Solutions (with Profiles) are Printed (Array Dimensioned for 100 Values)

Each value of IPRFL must also be a value of IPR.

Cards 21. ZA(J), XSTA(J), RZ(J), PZ(J), TWZ(J), CQZ(J), LSTC (6E12.6, A4)

The six arrays are dimensioned for 500 values.

ZA, Array of Coordinate Values Along the Body Axis

XSTA, Array of Coordinate Values Along the Body Surface (Same as ZA for a Flat Plate)

RZ, Array of Radius Values for a Nozzle or a Blunt Body

PZ, Array of Pressure Ratio Values - P/P_o (P_o, Local Stagnation Pressure)

TWZ, Array of Surface Temperature Values, °R

CQZ, Array of Injection Rate Values, $\rho_w v_w / \rho_\infty u_\infty$

LSTC, Alphameric Variable Used to Determine the Last Card in Data Deck ('LAST' is Coded on Final Card.)

For a flat plate, ZA and XSTA are both used and must be part of the input and the array RZ should be zero. If KPD is zero, the array PZ should be zero and if KTW is zero, the array TWZ should be zero.

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Coding Form for Input Data

PROGRAM LTBLCEQL

PROGRAMMER DATE

PUNCHING INSTRUCTIONS GRAPHIC PUNCH

PAGE 1 OF

CARD ELECTRO NUMBER*

```
KRSTRT=    NRSTRT=                                   (4(7X,I3))         CARD 1
    NT1=       NT2=       NT3=       NT4=            (4(8X,I2))              2
                                        LABEL   (18A4)
                                                                             3
   NOSE=   LAMTRB=    KTRANS=    KTRNSN=             (4(8X,I2))              4
   IADW=       KTW=       KPD=       KFS=            (4(8X,I2))              5
   NIT1=      NIT2=      NIT3=        NC=            (4(8X,I2))              6
     IE=      KEND=     IIMAX=       ITH=            (4(7X,I3))              7
 KADETA=        KL=      IPFL=    IPRINT=            (4(8X,I2))              8
 KVSLAW=    KPGRAD=        NV=     NEQIL=            (4(8X,I2))              9
    KCQ=      KINJ=    KNOINJ=                       (4(7X,I3))             10
   CHICRT      XBAR        ATR         CQ          FINJ      (6F12.6)
                                                                            11
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Coding Form for Input Data

PROGRAM LTBLCEQL | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE 2 OF

PROGRAMMER | DATE | CARD ELECTRO NUMBER*

COMM. | STATEMENT NUMBER | CONT. | FORTRAN STATEMENT | IDENTIFICATION SEQUENCE

```
    TFS         UFS         XMA        REINF                (6F12.6)
                                                                              12
     BO         PRL         PRT        OMEGA                (6F12.6)
                                                                              13
    XK1         XK2        CONVRG      ADTEST               (6F12.6)
                                                                              14
     DX         CRNI       XKETA       ETAINF      REFLEN   (6F12.6)
                                                                              15
   XJFAC       ANGLE       THSHOK        G                  (6F12.6)
                                                                              16
   TSTAG       TREFI       PSTAG        PFS        AMUREF       SCF   (6F12.6)
                                                                              17
   POPRIM      CMSTD       GAMEFF      DXMAX                (6F12.6)
                                                                              18
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Coding Form for Input Data

PROGRAM LTBLCEQL | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE 3 OF | CARD ELECTRO NUMBER*

PROGRAMMER | DATE

COMM	STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION SEQUENCE
			(IPR(J),J=1,IPRINT) (14I5)	
				19
			(IPRFL(J),J=1,IPFL) (14I5)	

Coding Form for Input Data

PROGRAM LTBLCEQL		PUNCHING INSTRUCTIONS	GRAPHIC						PAGE 4 OF
PROGRAMMER	DATE		PUNCH						CARD ELECTRO NUMBER*

COMM	STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION SEQUENCE
			ZA(J) XSTA(J) RZ(J) PZ(J) TWZ(J) CQZ(J)	LSTG
			(6E12.6,A4)	

Coding Form for Input Data

PROGRAM LTBLCEQL		PUNCHING INSTRUCTIONS	GRAPHIC	PAGE 5 OF
PROGRAMMER	DATE		PUNCH	CARD ELECTRO NUMBER*

COMM	STATEMENT NUMBER	CONT	FORTRAN STATEMENT						IDENTIFICATION SEQUENCE
		ZA	XSTA	RZ	PZ	TWZ	CQZ		LSTC

Coding Form for Input Data

PROGRAM LTBLCEQL		PUNCHING INSTRUCTIONS	GRAPHIC	PAGE 6 OF
PROGRAMMER	DATE		PUNCH	CARD ELECTRO NUMBER*

COMM	STATEMENT NUMBER	CONT.	FORTRAN STATEMENT						IDENTIFICATION SEQUENCE
		ZA	XSTA	RZ	PZ	TWZ	CQZ		LSTC
									LAST
					must be on	final card →			

DESCRIPTION OF OUTPUT

This section contains three subsections. The first subsection describes the first section of the output which is the input and initialized data. The second subsection describes the data which is written for each station at which solutions are obtained. The third subsection describes the miscellaneous messages and data written by the program. The output from a sample calculation of turbulent flow over a flat plate is included at the end of this section.

Input and Initialized Data

LABEL	,	Alphameric Data for Identification of the Case (Written by Subroutine READIN)
T10	=	T_o/T_{ref} where $T_{ref} = U_\infty^2/C_p$
P10	=	P_o/P_{ref} where $P_{ref} = \rho_\infty U_\infty{}^2$
UES0	=	U_e/U_∞ at $s = 0$
TES0	=	T_e/T_{ref} at $s = 0$
PES0	=	P_e/P_{ref} at $s = 0$

The five variables above are written by subroutine BLUNT1, NOZZLE1, or WDGFP1, depending upon the body geometry. The data in the remainder of the first block is written by subroutine WRITE1 and corresponds to the input data with the following exceptions:

Line 5

TIN	=	T_∞/T_{ref}
XMUINF	=	μ_∞/μ_{ref}

Line 6

RHOFS	=	ρ_∞, slugs/ft^3

Line 7

AMUINF = μ_∞, lbf-sec/ft^2

Note: Line 5 is written only if KFS$\neq$0. Line 6 is written if TREF1>1.0.

Line 11

EPSVD = $\varepsilon_{VD} = \{\mu_{ref}/(\rho_\infty U_\infty L)\}^{1/2}$, Where L is the Unit Length in REINF

Line 13

RHOSTD , Density of Gas at Standard Atmospheric Conditions, slugs/ft^3

Line 14

CP = C_p, Specific Heat

R = Gas Constant for Specified Gas

Next in the program output are the arrays IPR and IPRFL (which are described in the section "Description of Input"). Following the arrays IPR and IPRFL are the arrays ZA, RZ, XSTA, PZ, UEZ, TWZ, and CQZ with the array subscripts. PZ in the output differs from the values of PZ in the input in that for input PZ is P/P_o and is changed by the program to P/P_{ref}. UEZ is the array of non-dimensional edge velocities calculated by the program (U_e/U_∞). For a flat plate, the values of UEZ are unity.

When the restart procedure is used, the input and initialized data described above (except for T10, P10, UES0, TES0, and PES0) are written preceded by the message "PROGRAM RESTARTED. KRSTRT = #". For equilibrium gas solutions, free stream and reference conditions are recalculated after a converged solution is obtained for K = 1 using the perfect gas model. Thus for a restart, these quantities as printed in this data group will correspond to the values used in the equilibrium gas model and not the input values. A particular example is PZ which is recalculated for the equilibrium gas model and is the dimensional pressure in lbf/in^2.

Station Data

The station data are divided into two groups. The first group of data is written for each value of x at which a solution is obtained. The second group--the function profiles--is written only for the values of x corresponding to XSTA (IPRFL). In the first group, lines 5-13 are not written if x = 0. In the sixth line, REX alone is written if KFS = 0. If KFS ≠ 0, REX is written followed by the wall heat transfer (BTU/ft^2/sec) and two heat transfer coefficients; one in BTU/in^2-sec-°R, the other in lbm/in^2-sec.

GROUP ONE

Line 1

S	,	Surface Distance, x
XI	=	ξ, Transformed Surface Distance
Z	,	Axial Distance, z
Z/L	,	Axial Distance/Body Length (Z/ZA(IIMAX))
R0	,	Local Radius, r, (Set Equal to One for a Wedge or a Flat Plate)
BETA	=	$\beta = 2\xi/U_e(dU_e/d\xi)$
PP	=	dPE/ds
NIT	,	Number of Iterations at Current Value of x
K	,	Station Counter

Line 2

TE	=	T_e/T_{ref}
UE	=	U_e/U_∞
MACHE	,	Edge Mach Number
RHOE	=	ρ_e/ρ_∞
MUE	=	μ_e/μ_{ref}
PE	=	P_e/P_{ref}
DUEDS	=	dUE/ds

Line 3

CF	,	Skin Friction in Transformed Coordinates $= C_{f_\infty}/\varepsilon_{VD}$
QW	,	Heat Transfer Coefficient in Transformed Coordinates
HG	=	QW * EPSVD
EPSVD	=	$\varepsilon_{VD} = \{\mu_{ref}/(\rho_\infty U_\infty L)\}^{\frac{1}{2}}$, Where L is the Unit Length in REINF
CQ	=	$\rho_w v_w/\rho_\infty U_\infty$
KEP	,	Subscript in EPSPL Array Where the Inner and Outer Eddy Viscosities are Matched (Zero for Laminar Flow)
NITTOT	,	Cumulative Total Number of Iterations in x Direction

Line 4 (F = U/U_e; Prime Denotes $\partial/\partial\eta$)

F2N(1)	=	F'_w
F2N(3)	=	F' at Two Points from the Wall
F2NN(1)	=	F''_w
F2NN(3)	=	F'' at Two Points from the Wall

Line 5

CHIMAX	,	Maximum Value of Vorticity Reynolds Number - χ
GAMMA	,	Transition Intermittency Factor (Set to Zero for Laminar Flow, Set to One for Turbulent Flow)
XIBAR	=	$\bar{\xi}$, Transition Intermittency Factor Coordinate Initialized as Zero, Calculated after Transition Regime is Entered

Line 6

REX , Local Reynolds Number Based on Edge Conditions

WALL HEAT TRANSFER AND HEAT TRANSFER COEFFICIENTS (If KFS≠0)

Line 7

STE = $\frac{q}{\rho_e U_e (H_w - H_o)}$

STINF = $\frac{q}{\rho_\infty U_\infty (H_w - H_o)}$

CHEDGE = $C_{h_e} = \frac{q}{\rho_e U_e (H_w - H_{aw})}$, Where H_{aw} is the Adiabatic Wall Enthalpy

CHINF = $C_{h_\infty} = \frac{q}{\rho_\infty U_\infty (H_w - H_{aw})}$

CHINF*SQRT(REX) = $C_{h_\infty} \sqrt{REX}$

Line 8

CFE = $C_{f_e} = 2\tau_w / \rho_e U_e^2$

CFINF = $C_{f_\infty} = 2\tau_w / \rho_\infty U_\infty^2$

CF(TOTAL) = $\overline{C}_f = \frac{1}{x} \int_o^x C_{f_\infty} \, dt$

CFBAR*SQRT(REX) = $\overline{C}_f \sqrt{REX}$

CFINF*SQRT(REX) = $C_{f_\infty} \sqrt{REX}$

Line 9

CFINF/2 = $C_{f_\infty}/2$

CHINF/(CFINF/2) = $2C_{h_\infty}/C_{f_\infty}$

CHEDGE/(CFE/2) = $2C_{h_e}/C_{f_e}$

Line 10

X/REFLEN	=	x/reference length
Z/REFLEN	=	z/reference length
RO/REFLEN	=	r/reference length
DELTA/X	=	δ/x
DELSTR/X	=	δ^*/x

Line 11

THETA/REFLEN	=	θ/reference length
DELSTR/REFLEN	=	δ^*/reference length
DELTA/REFLEN	=	δ/reference length
DELSTRAXI/REFLEN	=	δ^*_{axi}/reference length

Line 12

THETA/DELTA	=	θ/δ
DELSTR/DELTA	=	δ^*/δ
DELSTR/THETA	=	δ^*/θ
DELSTRAXI	=	$\delta^*_{axi} = r\,\{\sqrt{1+2\delta^*/r}\ -1\}$ (Zero for 2-D Flow)

Line 13

DELSTRK	=	δ^*_k, Incompressible Boundary Layer Displacement Thickness
DELSTR	=	δ^*, Compressible Boundary Layer Displacement Thickness
DELTA	=	δ, Boundary Layer Thickness (Value of y where $U/U_e = 0.995$)
THETA	=	θ, Boundary Layer Momentum Thickness

RETHETA	=	Re_θ, Edge Unit Reynolds Number Times θ
GROUP TWO	-	PROFILES
Block 1		
ETA	,	η, Transformed Normal Coordinate
Y	,	y, Corresponding Physical Coordinate
Y/THETA	,	y/θ (Zero for x = o)
Y/DELTA	,	y/δ (Zero for x = o)
F=U/UE	,	Nondimensional Velocity
FP(N)	=	$\frac{\partial F}{\partial \eta}$
FPP	=	$\frac{\partial^2 F}{\partial \eta^2}$
EPS+	=	ε^+, Eddy Viscosity (Zero for Laminar Flow)
AOBP	=	$\frac{\partial \overline{A}_o}{\partial \eta}$ (= $\frac{\partial \varepsilon^+}{\partial \eta}$ for a Constant Prandtl Number)
N	,	Grid Point Number
Block 2		
ETA	,	(As Above)
G=H/HE	,	Nondimensional Stagnation Enthalpy
GP(N)	=	$\frac{\partial G}{\partial \eta}$
V	=	$\int_o^\eta (-2\xi \frac{\partial F}{\partial \xi} - F) \, d\eta$
T/TE	=	T/T_e
RHO/RHOE	=	ρ/ρ_e (=T_e/T for Ideal Gas)

RHOMU/RHOEMUE	=	$\rho\mu/\rho_e\mu_e$ (=C)
CP	=	$\frac{\partial C}{\partial \eta}$
CHI	=	χ, Vorticity Reynolds Number (Zero for x = o)
N	,	(As above)

Miscellaneous Messages and Data

For an equilibrium gas solution several messages and sets of data are written. For a nozzle, if the pressure distribution is calculated by the program (KPD=0), subroutine EDGE1 writes the message "EDGE CONDITIONS FOR EQUILIBRIUM NOZZLE" and the values for the arrays Z, XSTA, LOG10P, LOG10H, UE, and MACH. When the equilibrium gas solution is begun, the appropriate geometry subroutine (BLUNT1, NOZZLE1, or WDGFP1) is called and the new values of T10, P10, UESO, TESO, and PESO are written. Subroutine WRITE1 is called to write the message "BEGIN EQUILIBRIUM GAS SOLUTION" and the new reservoir, free-stream and reference conditions.

Subroutine READIN writes the message "RESTART TAPE WRITTEN. K = # KTPW = #" after the station data has been written on the restart tape. K is the current value of K and KTPW is the next value of K at which the restart tape will be written.

For transition regime calculations, subroutine EFFMU writes the message "TRANSITION BEGINS" at the beginning of transition and the message "TRANSITION ENDS" when XIBAR first exceeds 2.0 with the Reichardt eddy viscosity law or when XIBAR first exceeds 4.0 with the Van Driest eddy viscosity law. The message "TRANSITION ENDS" was found to be useful when the Van Driest eddy viscosity law was used in calculations but less useful with the Reichardt eddy viscosity law. At best, the message indicates only approximately where transition ends.

For the instantaneous transition model, subroutine CHANGE writes the message "TRANSITION BEGINS INSTANTANEOUSLY" and the values of X and DX when transition is initiated.

For the normal injection model, subroutine CHANGE writes the message "INJECTION BEGINS" and the values of X, DX, and CQ at the beginning of injection and the message "INJECTION ENDS" and the value of X at the end of injection.

If the iteration counter NIT reaches the value of NIT3, the step size is halved, new values of X and XI and new edge properties are calculated and the program attempts to obtain a converged solution for the smaller value of X. In this case, MAIN writes the values of NIT, DX, X, F2N(1), F2N1, and DIF.

When ETAINF is increased, subroutine ADDETA writes the message "INTERMEDIATE PROFILE DATA--ETAINF INCREASED ISTOP = #", the values of DX, XKETA, ETAINF, and ADTEST, and the function profiles. The function profiles are as described above in the subsection "Station Data; GROUP TWO". ISTOP is the number of iterations since the last converged solution was obtained.

If ISTOP exceeds 100, the message "STOP *** ISTOP.GT.100" is written by MAIN and the program is stopped. If after a converged solution is obtained, the derivative of F at the wall is negative, subroutine WRITE2 writes the message "PROBLEM TERMINATED. NEGATIVE DF/DETA INDICATES THAT THE BOUNDARY LAYER HAS SEPARATED" and stops the program.

Normal termination of the program is indicated by the message "THE END X = XSTA(IIMAX)" or the message "THE END K = KEND" which is written twice by MAIN.

In the above descriptions, all quantities which have the apparent dimension of length have been non-dimensionalized by the per unit length in REINF.

PROGRAM LTBLCEQL (LAMINAR AND/OR TURBULENT BOUNDARY LAYERS IN CHEMICAL EQUILIBRIUM)
A PROGRAM FOR
2-D AND AXISYMMETRIC NONREACTING PERFECT GAS AND EQUILIBRIUM CHEMICALLY REACTING LAMINAR, TRANSITIONAL AND/OR TURBULENT BOUNDARY-LAYER FLOW
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SAMPLE OUTPUT CASE, FULLY TURBULENT FLAT PLAT, WITH KEND=8

```
T10=  0.5493151D 00  P10=  0.9261968D 00

UESO=   0.1000000D 01  TESO=   0.4931511D-01  PESO=    0.1409003D-01

KRSTRT =   0, NRSTRT =  2, NT1 =  0, NT2 =  0, NT3 =  0, NT4 =  0

NOSE = 2, LAMTRB = 2, KTRANS = 0, KTRNSN =  17, IADW = 0, KTW = 0, KPD = 0, KFS = 1

NIT1 =  3, NIT2 =  6, NIT3 =  9, NC =  1, IE = 101, KEND =   8, IIMAX =  17, ITH =   0

KADETA = 1, KL = 2, IPFL =  17, IPRINT =  17, KVSLAW = 1, KPGRAD = 0, NV =  0, NEQIL = 0

KCQ = 0, KINJ =  17, KNOINJ =  17, CQ =     0.0     , FINJ =     0.0

TFS =   546.000000, UFS =  8157.279981, MINF =   7.12000, REINF =  4.1017223D 05, TIN =   0.049315, XMUINF =   0.165760

PFS =   1.528000, RHOFS =  2.346838D-04, PSTAG =    7048.0454, TSTAG =  6081.828480

CHICRIT =     2000.000, XBAR =     2.000000, ATR =     0.412000

BO =  0.087767, PRL =  0.7100, PRT =  0.9000, OMEGA =  0.0    , XK1 =  0.4000, XK2 =  0.016800

CONVRG =  0.0100, ADTEST =  0.0010, CRNI =  1.0000, XKETA =  1.0900, ETAINF =  100.00

CP/CV =     1.400000, EPSVD =     0.003835, SCALE FACTOR =  12.00000, REFERENCE LENGTH =    1.0000

XJFAC =  0.0    , ANGLE =  0.0     , THSHOK =  0.0     , DX =  0.0100, DXMAX = 20.0000

POPRIM =       1.5280, CMSTD =  28.967000, GAMEFF =  1.400000, RHOSTD =  0.002506559

CP= 6010.05 FT2/(SEC2-DEGREE RANKINE)   R= 1717.16 FT2/(SEC2-DEGREE RANKINE)   FREE STREAM MACH NUMBER=  7.1200
```

7-2

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

AXIAL POSITION	ZA	RZ	XSTA	PZ	UEZ	TWZ	CQZ
1	0.0	0.0	0.0	0.0	1.000000	0.0	0.0
2	3.130000	0.0	3.130000	0.0	1.000000	0.0	0.0
3	4.380000	0.0	4.380000	0.0	1.000000	0.0	0.0
4	5.630000	0.0	5.630000	0.0	1.000000	0.0	0.0
5	6.880000	0.0	6.880000	0.0	1.000000	0.0	0.0
6	8.130000	0.0	8.130000	0.0	1.000000	0.0	0.0
7	9.380000	0.0	9.380000	0.0	1.000000	0.0	0.0
8	10.630000	0.0	10.630000	0.0	1.000000	0.0	0.0
9	11.880000	0.0	11.880000	0.0	1.000000	0.0	0.0
10	13.130000	0.0	13.130000	0.0	1.000000	0.0	0.0
11	14.380000	0.0	14.380000	0.0	1.000000	0.0	0.0
12	15.630000	0.0	15.630000	0.0	1.000000	0.0	0.0
13	17.380000	0.0	17.380000	0.0	1.000000	0.0	0.0
14	19.130000	0.0	19.130000	0.0	1.000000	0.0	0.0
15	20.880000	0.0	20.880000	0.0	1.000000	0.0	0.0
16	22.630000	0.0	22.630000	0.0	1.000000	0.0	0.0
17	24.380000	0.0	24.380000	0.0	1.000000	0.0	0.0

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```
S =    0.00010,
                 XI =    0.00002, Z =   0.00010, Z/L = 0.00000, RO = 1.00000, BETA = 0.0     , PP =      0.0     , NIT =    8, K =  1

TE = 0.04932, UE = 1.00000, MACHE =  7.1200000, RHOE =    1.00000, MUE = 0.16576, PE =    0.01409, DUEDS =    0.0

CF =   23.96969, QW =   -6.30086, HG = -0.241644D-01, EPSVD = 0.383510D-02, CQ = 0.0          , KEP = 58, NITTOT =    8

F2N(1) =    0.414130, F2N(3) =    0.415164, F2NN(1) =    0.303937, F2NN(3) =    0.304071

CHIMAX = 8.673126D 00, GAMMA = 1.000000D 00, XIBAR = 0.0

REX = 4.10172D 01          WALL HEAT TRANSFER                          HEAT TRANSFER COEFFICIENTS
                            3.956546D 03                          5.549817D-03                  2.311454D-02
                           BTU/(FT**2*SEC)                  BTU/(IN**2*SEC*DEGREE R)          LBM/(IN**2*SEC)

STE = 4.822245D-02, STINF = 4.822245D-02, CHEDGE = 5.403985D-02, CHINF = 5.403985D-02, CHINF*SQRT(REX) = 3.460965D-01

CFE = 9.192613D-02, CFINF = 9.192613D-02, CF(TOTAL) = 1.838522D-01, CFBAR*SQRT(REX) = 1.177476D 00, CFINF*SQRT(REX) = 5.887380D-01

CFINF/2 = 4.596306D-02, CHINF/(CFINF/2) = 1.175723D 00, CHEDGE/(CFE/2) = 1.175723D 00

X/REFLEN = 9.999999D-05, Z/REFLEN = 9.999999D-05, RO/REFLEN = 1.000000D 00, DELTA/X = 1.499149D 00, DELSTR/X = 9.966523D-01

THETA/REFLEN = 8.850004D-06, DELSTR/REFLEN = 9.966522D-05, DELTA/REFLEN = 1.499149D-04, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.903352D-02, DELSTR/DELTA = 6.648120D-01, DELSTR/THETA = 1.126160D 01, DELSTRAXI = 0.0

DELSTRK = 5.30060D-05, DELSTR = 9.96652D-05, DELTA = 1.49915D-04, THETA = 8.85000D-06, RETHETA = 3.63003D 00
```

ETA	Y	Y/THETA	Y/DELTA	F=U/UE	FP(N)	FPP	EPS+	AOBP	N
0.0	0.0	0.0	0.0	0.0	0.414130	0.303937	0.0	-0.000000	1
0.003403	0.000000	0.008345	0.000493	0.001411	0.415164	0.304071	0.000000	0.000000	3
0.007445	0.000000	0.018378	0.001085	0.003092	0.416394	0.304278	0.000000	0.000000	5
0.012248	0.000000	0.030464	0.001798	0.005095	0.417856	0.304449	0.000000	0.000000	7
0.017955	0.000000	0.045058	0.002660	0.007485	0.419593	0.304550	0.000000	0.000000	9
0.024735	0.000001	0.062727	0.003703	0.010337	0.421658	0.304534	0.000000	0.000000	11
0.032790	0.000001	0.084186	0.004970	0.013743	0.424111	0.304338	0.000000	0.000000	13
0.042361	0.000001	0.110340	0.006514	0.017816	0.427022	0.303872	0.000000	0.000001	15
0.053732	0.000001	0.142340	0.008403	0.022691	0.430472	0.303018	0.000000	0.000001	17
0.067241	0.000002	0.181666	0.010724	0.028534	0.434557	0.301619	0.000000	0.000002	19
0.083292	0.000002	0.230229	0.013591	0.035548	0.439382	0.299470	0.000000	0.000004	21
0.102362	0.000003	0.290516	0.017150	0.043981	0.445064	0.296307	0.000000	0.000006	23
0.125019	0.000003	0.365779	0.021593	0.054141	0.451729	0.291787	0.000000	0.000009	25
0.151937	0.000004	0.460296	0.027173	0.066406	0.459502	0.285467	0.000001	0.000014	27
0.183919	0.000005	0.579717	0.034223	0.081247	0.468497	0.276772	0.000001	0.000020	29
0.221917	0.000006	0.731516	0.043184	0.099246	0.478797	0.264945	0.000002	0.000030	31
0.267063	0.000008	0.925576	0.054640	0.121128	0.490409	0.248978	0.000004	0.000045	33
0.320700	0.000010	1.174911	0.069359	0.147783	0.503205	0.227517	0.000007	0.000067	35
0.384426	0.000013	1.496486	0.088343	0.180299	0.516814	0.198737	0.000012	0.000102	37
0.460139	0.000017	1.912016	0.112873	0.219972	0.530446	0.160234	0.000022	0.000158	39
0.550094	0.000022	2.448427	0.144539	0.268288	0.542619	0.109024	0.000040	0.000256	41
0.656969	0.000028	3.137313	0.185207	0.326812	0.550763	0.041936	0.000076	0.000435	43
0.783948	0.000036	4.012252	0.236857	0.396918	0.550745	-0.043036	0.000151	0.000793	45
0.934811	0.000045	5.102313	0.301207	0.479224	0.536564	-0.143617	0.000320	0.001572	47
1.114052	0.000057	6.420444	0.379021	0.572628	0.500906	-0.248233	0.000738	0.003435	49
1.327008	0.000070	7.948236	0.469212	0.673057	0.437729	-0.332287	0.001881	0.008271	51
1.580020	0.000085	9.625292	0.568215	0.772628	0.347355	-0.364129	0.005290	0.021233	53
1.880625	0.000101	11.358129	0.670510	0.860644	0.241332	-0.325447	0.015663	0.052219	55
2.237773	0.000116	13.057173	0.770811	0.927363	0.141073	-0.229879	0.043012	0.097854	57
2.662101	0.000130	14.684270	0.866864	0.969335	0.068289	-0.124970	0.062021	-0.014921	59
3.166245	0.000144	16.270725	0.960518	0.990810	0.025337	-0.056397	0.052526	-0.021866	61
3.765218	0.000159	17.909913	1.057285	0.998448	0.005878	-0.017378	0.038493	-0.022735	63
4.476858	0.000175	19.728474	1.164641	0.999911	0.000601	-0.002759	0.024285	-0.016420	65
5.322358	0.000193	21.844915	1.289582	1.000000	0.000011	-0.000131	0.013779	-0.009212	67
6.326896	0.000216	24.351685	1.437566	1.000000	0.000000	-0.000000	0.007319	-0.004526	69
7.520387	0.000242	27.329570	1.613361	1.000000	0.000000	-0.000000	0.003700	-0.002069	71
8.938375	0.000273	30.867594	1.822223	1.000000	0.000000	-0.000000	0.001792	-0.000896	73
10.623086	0.000310	35.071121	2.070372	1.000000	0.000000	-0.000000	0.000835	-0.000370	75
12.624691	0.000355	40.065330	2.365197	1.000000	0.000000	0.000000	0.000376	-0.000146	77
15.002798	0.000407	45.998951	2.715480	1.000000	0.000000	0.000000	0.000164	-0.000056	79
17.828227	0.000469	53.048686	3.131651	1.000000	0.000000	0.000000	0.000070	-0.000021	81
21.185119	0.000544	61.424476	3.626103	1.000000	0.000000	0.000000	0.000029	-0.000007	83
25.173443	0.000632	71.375752	4.213562	1.000000	0.000000	0.000000	0.000012	-0.000003	85
29.911970	0.000736	83.198863	4.911522	1.000000	0.000000	0.000000	0.000005	-0.000001	87
35.541814	0.000861	97.245901	5.740768	1.000000	0.000000	0.000000	0.000002	-0.000000	89
42.230632	0.001008	113.935187	6.725995	1.000000	0.000000	0.000000	0.000001	-0.000000	91
50.177617	0.001184	133.763728	7.896543	1.000000	0.000000	-0.000000	0.000000	-0.000000	93
59.619429	0.001392	157.322017	9.287272	1.000000	0.000000	-0.000000	0.000000	-0.000000	95
70.837247	0.001640	185.311621	10.939597	1.000000	0.000000	-0.000000	0.000000	-0.000000	97
84.165135	0.001934	218.566069	12.902724	1.000000	0.000000	-0.000000	0.000000	-0.000000	99
100.000000	0.002284	258.075678	15.235115	1.000000	-0.000000	-0.000000	0.000000	-0.000000	101

ORIGINAL PAGE IS OF POOR QUALITY

ETA	G=H/HE	GP(N)	V	T/TE	RHO/RHOE	RHOMU/RHOEMUE	CP	CHI	N
0.0	0.087767	0.281411	0.0	0.977626	1.022886	1.005242	-0.737555	0.0	1
0.003403	0.088726	0.282433	-0.000002	0.988291	1.011848	1.002738	-0.734427	0.000044	3
0.007445	0.089871	0.283651	-0.000011	1.000959	0.999042	0.999776	-0.730606	0.000206	5
0.012248	0.091236	0.285103	-0.000031	1.016005	0.984248	0.996278	-0.725933	0.000544	7
0.017955	0.092868	0.286834	-0.000067	1.033873	0.967237	0.992152	-0.720213	0.001139	9
0.024735	0.094820	0.288900	-0.000127	1.055090	0.947786	0.987293	-0.713209	0.002097	11
0.032790	0.097157	0.291367	-0.000224	1.080280	0.925686	0.981582	-0.704637	0.003560	13
0.042361	0.099960	0.294313	-0.000375	1.110175	0.900759	0.974888	-0.694166	0.005713	15
0.053732	0.103326	0.297834	-0.000606	1.145644	0.872872	0.967067	-0.681414	0.008793	17
0.067241	0.107378	0.302041	-0.000952	1.187699	0.841964	0.957966	-0.665956	0.013101	19
0.083292	0.112267	0.307071	-0.001466	1.237525	0.808065	0.947426	-0.647335	0.019020	21
0.102362	0.118180	0.313083	-0.002224	1.296488	0.771314	0.935293	-0.625084	0.027029	23
0.125019	0.125354	0.320266	-0.003335	1.366148	0.731985	0.921430	-0.598758	0.037736	25
0.151937	0.134091	0.328841	-0.004958	1.448244	0.690491	0.905728	-0.567970	0.051919	27
0.183919	0.144771	0.339058	-0.007318	1.544653	0.647395	0.888135	-0.532444	0.070589	29
0.221917	0.157885	0.351199	-0.010746	1.657281	0.603398	0.868677	-0.492052	0.095105	31
0.267063	0.174065	0.365555	-0.015719	1.787848	0.559332	0.847495	-0.446851	0.127341	33
0.320700	0.194126	0.382398	-0.022929	1.937485	0.516133	0.824881	-0.397096	0.169980	35
0.384426	0.219122	0.401904	-0.033379	2.106039	0.474825	0.801320	-0.343223	0.226988	37
0.460139	0.250401	0.423997	-0.048527	2.290913	0.436507	0.777549	-0.285793	0.304431	39
0.550094	0.289655	0.448053	-0.070482	2.485283	0.402369	0.754611	-0.225418	0.411890	41
0.656969	0.338911	0.472363	-0.102276	2.675605	0.373747	0.733942	-0.162681	0.564998	43
0.783948	0.400373	0.493265	-0.148225	2.838783	0.352264	0.717472	-0.098123	0.790037	45
0.934811	0.475914	0.504047	-0.214334	2.940536	0.340074	0.707730	-0.032440	1.132288	47
1.114052	0.565953	0.494387	-0.308672	2.938594	0.340299	0.707913	0.032910	1.670331	49
1.327008	0.667570	0.452360	-0.441490	2.796086	0.357643	0.721677	0.094388	2.535272	51
1.580020	0.772543	0.371400	-0.624743	2.506345	0.398987	0.752240	0.144424	3.910056	53
1.880625	0.867493	0.260383	-0.870833	2.115015	0.472810	0.800118	0.170467	5.891217	55
2.237773	0.938652	0.146886	-1.190933	1.711608	0.584246	0.859691	0.160129	7.968090	57
2.662101	0.980398	0.063505	-1.594152	1.381423	0.723891	0.918457	0.118777	8.673126	59
3.166245	0.998153	0.017341	-2.088923	1.160384	0.861784	0.963856	0.066249	6.334193	61
3.765218	1.001521	0.000420	-2.685096	1.047534	0.954623	0.989018	0.025432	2.348178	63
4.476858	1.000564	-0.001226	-3.396295	1.008070	0.991994	0.998120	0.005931	0.323759	65
5.322358	1.000042	-0.000219	-4.241773	1.000475	0.999525	0.999889	0.000622	0.007837	67
6.326896	1.000000	-0.000004	-5.246311	1.000000	1.000000	1.000000	0.000011	0.000081	69
7.520387	1.000000	-0.000000	-6.439803	1.000000	1.000000	1.000000	0.000000	0.000006	71
8.938375	1.000000	-0.000000	-7.857791	1.000000	1.000000	1.000000	0.000000	0.000000	73
10.623086	1.000000	-0.000000	-9.542502	1.000000	1.000000	1.000000	0.000000	0.000000	75
12.624691	1.000000	-0.000000	-11.544107	1.000000	1.000000	1.000000	0.000000	0.000000	77
15.002798	1.000000	-0.000000	-13.922214	1.000000	1.000000	1.000000	0.000000	-0.000000	79
17.828227	1.000000	-0.000000	-16.747643	1.000000	1.000000	1.000000	0.000000	-0.000000	81
21.185119	1.000000	-0.000000	-20.104535	1.000000	1.000000	1.000000	0.000000	-0.000000	83
25.173443	1.000000	-0.000000	-24.092858	1.000000	1.000000	1.000000	0.000000	-0.000000	85
29.911970	1.000000	-0.000000	-28.831386	1.000000	1.000000	1.000000	0.000000	-0.000000	87
35.541814	1.000000	-0.000000	-34.461230	1.000000	1.000000	1.000000	0.000000	-0.000000	89
42.230632	1.000000	-0.000000	-41.150048	1.000000	1.000000	1.000000	0.000000	-0.000000	91
50.177617	1.000000	-0.000000	-49.097032	1.000000	1.000000	1.000000	0.000000	-0.000000	93
59.619429	1.000000	-0.000000	-58.538845	1.000000	1.000000	1.000000	0.000000	-0.000000	95
70.837247	1.000000	-0.000000	-69.756662	1.000000	1.000000	1.000000	0.000000	-0.000000	97
84.165135	1.000000	-0.000000	-83.084551	1.000000	1.000000	1.000000	0.000000	-0.000000	99
100.000000	1.000000	-0.000000	-98.919416	1.000000	1.000000	1.000000	-0.000000	-0.000000	101

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S =   0.01010,
              XI =    0.00167, Z =  0.01010, Z/L = 0.00041, RO = 1.00000, BETA = 0.0    , PP =     0.0    , NIT =   5, K =  2

TE = 0.04932, UE = 1.00000, MACHE =  7.1200000, RHOE =    1.00000, MUE = 0.16576, PE =    0.01409, DUEDS =    0.0

CF =    2.53603, QW =   -0.67314, HG = -0.258156D-02, EPSVD = 0.383510D-02, CQ = 0.0          , KEP = 54, NITTOT =   13

F2N(1) =    0.440340, F2N(3) =    0.441521, F2NN(1) =    0.346997, F2NN(3) =    0.347182

CHIMAX = 9.020401D 01, GAMMA = 1.0000000 00, XIBAR = 0.0

REX = 4.14274D 03          WALL HEAT TRANSFER                                HEAT TRANSFER COEFFICIENTS
                              4.226893D 02                          5.929031D-04                 2.469393D-03
                            BTU/(FT**2*SEC)                     BTU/(IN**2*SEC*DEGREE R)           LBM/(IN**2*SEC)

STE = 5.151744D-03, STINF = 5.151744D-03, CHEDGE = 5.773234D-03, CHINF = 5.773234D-03, CHINF*SQRT(REX) = 3.715891D-01

CFE = 9.725905D-03, CFINF = 9.725905D-03, CF(TOTAL) = 1.116334D-02, CFBAR*SQRT(REX) = 7.185183D-01, CFINF*SQRT(REX) = 6.259993D-01

CFINF/2 = 4.862952D-03, CHINF/(CFINF/2) = 1.187187D 00, CHEDGE/(CFE/2) = 1.187187D 00

X/REFLEN = 1.010000D-02, Z/REFLEN = 1.010000D-02, RO/REFLEN = 1.000000D 00, DELTA/X = 1.604908D-01, DELSTR/X = 1.032528D-01

THETA/REFLEN = 9.179497D-05, DELSTR/REFLEN = 1.042853D-03, DELTA/REFLEN = 1.620957D-03, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.663011D-02, DELSTR/DELTA = 6.433563D-01, DELSTR/THETA = 1.136068D 01, DELSTRAXI = 0.0

DELSTRK = 5.30933D-04, DELSTR = 1.04285D-03, DELTA = 1.62096D-03, THETA = 9.17950D-05, RETHETA = 3.76517D 01
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ETA	Y	Y/THETA	Y/DELTA	F=U/UE	FP(N)	FPP	EPS+	AOBP	N
0.0	0.0	0.0	0.0	0.0	0.440340	0.346997	0.0	-0.000000	1
0.003403	0.000001	0.008089	0.000458	0.001500	0.441521	0.347182	0.000000	0.000000	3
0.007445	0.000002	0.017822	0.001009	0.003288	0.442925	0.347473	0.000000	0.000001	5
0.012248	0.000003	0.029559	0.001674	0.005420	0.444595	0.347720	0.000000	0.000002	7
0.017955	0.000004	0.043747	0.002477	0.007962	0.446580	0.347884	0.000000	0.000007	9
0.024735	0.000006	0.060948	0.003451	0.010998	0.448939	0.347905	0.000000	0.000017	11
0.032790	0.000008	0.081870	0.004636	0.014626	0.451740	0.347702	0.000000	0.000035	13
0.042361	0.000010	0.107412	0.006083	0.018965	0.455066	0.347166	0.000001	0.000068	15
0.053732	0.000013	0.138724	0.007856	0.024162	0.459008	0.346150	0.000002	0.000123	17
0.067241	0.000016	0.177287	0.010040	0.030394	0.463674	0.344460	0.000004	0.000212	19
0.083292	0.000021	0.225020	0.012743	0.037881	0.469183	0.341846	0.000008	0.000348	21
0.102362	0.000026	0.284428	0.016107	0.046890	0.475667	0.337986	0.000017	0.000554	23
0.125019	0.000033	0.358799	0.020319	0.057754	0.483265	0.332467	0.000033	0.000855	25
0.151937	0.000042	0.452470	0.025623	0.070883	0.492115	0.324759	0.000061	0.001293	27
0.183919	0.000052	0.571181	0.032346	0.086786	0.502338	0.314173	0.000112	0.001924	29
0.221917	0.000066	0.722542	0.040918	0.106098	0.514012	0.299807	0.000202	0.002840	31
0.267063	0.000084	0.916627	0.051909	0.129605	0.527123	0.280450	0.000359	0.004191	33
0.320700	0.000107	1.166701	0.066070	0.158273	0.541490	0.254457	0.000635	0.006237	35
0.384426	0.000137	1.490023	0.084380	0.193280	0.556628	0.219565	0.001127	0.009453	37
0.460139	0.000175	1.908585	0.108083	0.236022	0.571531	0.172674	0.002026	0.014760	39
0.550094	0.000225	2.449398	0.138710	0.288072	0.584316	0.109641	0.003728	0.024053	41
0.656969	0.000289	3.143578	0.178021	0.351034	0.591655	0.025271	0.007118	0.041540	43
0.783948	0.000369	4.022927	0.227819	0.426152	0.587960	-0.086077	0.014334	0.077334	45
0.934811	0.000469	5.112263	0.289508	0.513481	0.564374	-0.228170	0.031047	0.157783	47
1.114052	0.000589	6.416603	0.363373	0.610286	0.508236	-0.393810	0.073690	0.354470	49
1.327008	0.000726	7.907598	0.447808	0.708552	0.406964	-0.530150	0.192052	0.841566	51
1.580020	0.000874	9.525703	0.539442	0.793842	0.272863	-0.439846	0.521053	1.464851	53
1.880625	0.001029	11.210504	0.634852	0.859631	0.185650	-0.197918	0.736256	0.082045	55
2.237773	0.001185	12.904546	0.730786	0.915067	0.127545	-0.145855	0.741234	-0.044369	57
2.662101	0.001336	14.559552	0.824509	0.957032	0.074992	-0.102199	0.700290	-0.137119	59
3.166245	0.001485	16.177901	0.916156	0.983433	0.035280	-0.058758	0.610972	-0.209068	61
3.765218	0.001636	17.824633	1.009411	0.995953	0.011541	-0.025247	0.471601	-0.237841	63
4.476858	0.001800	19.613444	1.110711	0.999582	0.001942	-0.006396	0.313139	-0.193298	65
5.322358	0.001989	21.670658	1.227212	0.999995	0.000085	-0.000592	0.183597	-0.117069	67
6.326896	0.002212	24.100103	1.364791	1.000000	-0.000000	-0.000005	0.099619	-0.059731	69
7.520387	0.002477	26.985420	1.528187	1.000000	-0.000000	-0.000000	0.051233	-0.027961	71
8.938375	0.002792	30.413462	1.722318	1.000000	-0.000000	-0.000000	0.025180	-0.012335	73
10.623086	0.003166	34.486318	1.952964	1.000000	-0.000000	-0.000000	0.011889	-0.005175	75
12.624691	0.003610	39.325279	2.226995	1.000000	-0.000000	-0.000000	0.005417	-0.002079	77
15.002798	0.004138	45.074448	2.552571	1.000000	-0.000000	-0.000000	0.002391	-0.000804	79
17.828227	0.004765	51.905036	2.939388	1.000000	-0.000000	-0.000000	0.001026	-0.000300	81
21.185119	0.005510	60.020458	3.398965	1.000000	-0.000000	-0.000000	0.000429	-0.000109	83
25.173443	0.006395	69.662390	3.944989	1.000000	-0.000000	-0.000000	0.000176	-0.000039	85
29.911970	0.007446	81.117970	4.593719	1.000000	-0.000000	-0.000000	0.000070	-0.000013	87
35.541814	0.008696	94.728345	5.364476	1.000000	-0.000000	-0.000000	0.000028	-0.000004	89
42.230632	0.010180	110.898830	6.280213	1.000000	-0.000000	-0.000000	0.000011	-0.000001	91
50.177617	0.011944	130.110985	7.368199	1.000000	-0.000000	-0.000000	0.000004	-0.000000	93
59.619429	0.014039	152.936945	8.660836	1.000000	-0.000000	-0.000000	0.000002	-0.000000	95
70.837247	0.016528	180.056469	10.196617	1.000000	-0.000000	-0.000000	0.000001	-0.000000	97
84.165135	0.019486	212.277175	12.021280	1.000000	-0.000000	-0.000000	0.000000	-0.000000	99
100.000000	0.023000	250.558596	14.189161	1.000000	-0.000000	-0.000000	0.000000	-0.000000	101

ORIGINAL PAGE IS
OF POOR QUALITY

ETA	G=H/HE	GP(N)	V	T/TE	RHO/RHOE	RHOMU/RHOEMUE	CP	CHI	N
0.0	0.087767	0.302139	0.0	0.977626	1.022886	1.005242	-0.791882	0.0	1
0.003403	0.088797	0.303303	-0.000003	0.989077	1.011044	1.002554	-0.788352	0.000463	3
0.007445	0.090026	0.304690	-0.000014	1.002680	0.997327	0.999375	-0.784029	0.002172	5
0.012248	0.091493	0.306344	-0.000037	1.018838	0.981511	0.995622	-0.778731	0.005737	7
0.017955	0.093247	0.308317	-0.000080	1.038029	0.963364	0.991197	-0.772230	0.011989	9
0.024735	0.095346	0.310672	-0.000152	1.060821	0.942666	0.985988	-0.764255	0.022034	11
0.032790	0.097859	0.313483	-0.000268	1.087883	0.919217	0.979871	-0.754482	0.037329	13
0.042361	0.100876	0.316842	-0.000448	1.120007	0.892851	0.972707	-0.742533	0.059757	15
0.053732	0.104501	0.320856	-0.000723	1.158126	0.863464	0.964346	-0.727979	0.091730	17
0.067241	0.108868	0.325655	-0.001137	1.203332	0.831026	0.954630	-0.710347	0.136301	19
0.083292	0.114141	0.331391	-0.001753	1.256899	0.795609	0.943399	-0.689139	0.197311	21
0.102362	0.120526	0.338247	-0.002662	1.320297	0.757405	0.930498	-0.663859	0.279590	23
0.125019	0.128282	0.346438	-0.003997	1.395199	0.716744	0.915796	-0.634048	0.389249	25
0.151937	0.137739	0.356213	-0.005947	1.483462	0.674099	0.899197	-0.599337	0.534130	27
0.183919	0.149318	0.367857	-0.008791	1.587076	0.630090	0.880671	-0.559491	0.724530	29
0.221917	0.163559	0.381684	-0.012930	1.708026	0.585471	0.860276	-0.514460	0.974372	31
0.267063	0.181159	0.398020	-0.018948	1.848041	0.541113	0.838194	-0.464404	1.303112	33
0.320700	0.203024	0.417158	-0.027692	2.008111	0.497981	0.814775	-0.409696	1.738911	35
0.384426	0.230319	0.439261	-0.040400	2.187662	0.457109	0.790574	-0.350883	2.323954	37
0.460139	0.264536	0.464163	-0.058865	2.383205	0.419603	0.766411	-0.288606	3.123598	39
0.550094	0.307535	0.490967	-0.085686	2.586253	0.386660	0.743439	-0.223489	4.242427	41
0.656969	0.361507	0.517263	-0.124585	2.780463	0.359652	0.723234	-0.156027	5.852707	43
0.783948	0.428700	0.537707	-0.180794	2.938528	0.340306	0.707919	-0.086585	8.243053	45
0.934811	0.510591	0.541684	-0.261405	3.020957	0.331021	0.700299	-0.015821	11.885163	47
1.114052	0.605837	0.510659	-0.375330	2.982359	0.335305	0.703837	0.053425	17.419902	49
1.327008	0.706500	0.422569	-0.532000	2.795509	0.357717	0.721735	0.110826	25.074756	51
1.580020	0.796148	0.288588	-0.737532	2.491990	0.401286	0.753853	0.137765	33.544577	53
1.880625	0.865404	0.194156	-0.992337	2.148537	0.465433	0.795674	0.145338	46.806357	55
2.237773	0.923141	0.131736	-1.304232	1.784312	0.560440	0.848051	0.144405	69.723220	57
2.662101	0.965601	0.073435	-1.691043	1.457619	0.686050	0.903978	0.118130	88.736690	59
3.166245	0.998045	0.030200	-2.170701	1.215670	0.822592	0.952016	0.075064	82.895443	61
3.765218	0.999397	0.006889	-2.758273	1.073927	0.931162	0.983016	0.034204	45.917732	63
4.476858	1.000592	-0.000241	-3.466866	1.015086	0.985138	0.996491	0.009660	11.053678	65
5.322358	1.000101	-0.000341	-4.312059	1.001231	0.998770	0.999713	0.001295	0.632257	67
6.326896	1.000000	-0.000016	-5.316594	1.000005	0.999995	0.999999	0.000041	-0.001488	69
7.520387	1.000000	0.000000	-6.510085	1.000000	1.000000	1.000000	-0.000000	-0.000045	71
8.938375	1.000000	0.000000	-7.928073	1.000000	1.000000	1.000000	-0.000000	-0.000006	73
10.623086	1.000000	0.000000	-9.612784	1.000000	1.000000	1.000000	-0.000000	-0.000001	75
12.624691	1.000000	0.000000	-11.614389	1.000000	1.000000	1.000000	-0.000000	-0.000001	77
15.002798	1.000000	0.000000	-13.992496	1.000000	1.000000	1.000000	-0.000000	-0.000000	79
17.828227	1.000000	0.000000	-16.817925	1.000000	1.000000	1.000000	-0.000000	-0.000000	81
21.185119	1.000000	0.000000	-20.174817	1.000000	1.000000	1.000000	-0.000000	-0.000000	83
25.173443	1.000000	0.000000	-24.163141	1.000000	1.000000	1.000000	-0.000000	-0.000000	85
29.911970	1.000000	0.000000	-28.901668	1.000000	1.000000	1.000000	-0.000000	-0.000000	87
35.541814	1.000000	0.000000	-34.531512	1.000000	1.000000	1.000000	-0.000000	-0.000000	89
42.230632	1.000000	0.000000	-41.220330	1.000000	1.000000	1.000000	-0.000000	-0.000000	91
50.177617	1.000000	0.000000	-49.167315	1.000000	1.000000	1.000000	-0.000000	-0.000000	93
59.619429	1.000000	0.000000	-58.609127	1.000000	1.000000	1.000000	-0.000000	-0.000000	95
70.837247	1.000000	-0.000000	-69.826945	1.000000	1.000000	1.000000	-0.000000	-0.000000	97
84.165135	1.000000	-0.000000	-83.154833	1.000000	1.000000	1.000000	-0.000000	-0.000000	99
100.000000	1.000000	-0.000000	-98.989698	1.000000	1.000000	1.000000	-0.000000	-0.000007	101

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S = 0.02010, XI = 0.00333, Z = 0.02010, Z/L = 0.00082, RO = 1.00000, BETA = 0.0 , PP = 0.0 , NIT = 3, K = 3

TE = 0.04932, UE = 1.00000, MACHE = 7.1200000, RHOE = 1.00000, MUE = 0.16576, PE = 0.01409, DUEDS = 0.0

CF = 1.87774, QW = -0.50068, HG = -0.192015D-02, EPSVD = 0.383510D-02, CQ = 0.0 , KEP = 54, NITTOT = 16

F2N(1) = 0.459947, F2N(3) = 0.461242, F2NN(1) = 0.380316, F2NN(3) = 0.380529

CHIMAX = 1.272545D 02, GAMMA = 1.0000000D 00, XIBAR = 0.0

REX = 8.24446D 03 WALL HEAT TRANSFER 3.143950D 02 BTU/(FT**2*SEC) HEAT TRANSFER COEFFICIENTS 4.409996D-04 BTU/(IN**2*SEC*DEGREE R) 1.836727D-03 LBM/(IN**2*SEC)

STE = 3.831852D-03, STINF = 3.831852D-03, CHEDGE = 4.294115D-03, CHINF = 4.294115D-03, CHINF*SQRT(REX) = 3.899014D-01

CFE = 7.201327D-03, CFINF = 7.201327D-03, CF(TOTAL) = 9.115823D-03, CFBAR*SQRT(REX) = 8.277077D-01, CFINF*SQRT(REX) = 6.538734D-01

CFINF/2 = 3.600663D-03, CHINF/(CFINF/2) = 1.192590D 00, CHEDGE/(CFE/2) = 1.192590D 00

X/REFLEN = 2.010000D-02, Z/REFLEN = 2.010000D-02, RO/REFLEN = 1.000000D 00, DELTA/X = 1.180934D-01, DELSTR/X = 7.460366D-02

THETA/REFLEN = 1.324257D-04, DELSTR/REFLEN = 1.499534D-03, DELTA/REFLEN = 2.373677D-03, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.578925D-02, DELSTR/DELTA = 6.317344D-01, DELSTR/THETA = 1.132359D 01, DELSTRAXI = 0.0

DELSTRK = 7.43856D-04, DELSTR = 1.49953D-03, DELTA = 2.37368D-03, THETA = 1.32426D-04, RETHETA = 5.43173D 01

S = 0.04010, XI = 0.00665, Z = 0.04010, Z/L = 0.00164, RO = 1.00000, BETA = 0.0 , PP = 0.0 , NIT = 3, K = 4

TE = 0.04932, UE = 1.00000, MACHE = 7.1200000, RHOE = 1.00000, MUE = 0.16576, PE = 0.01409, DUEDS = 0.0

CF = 1.41259, QW = -0.37824, HG = -0.145058D-02, EPSVD = 0.383510D-02, CQ = 0.0 , KEP = 53, NITTOT = 19

F2N(1) = 0.488721, F2N(3) = 0.490189, F2NN(1) = 0.431215, F2NN(3) = 0.431480

CHIMAX = 1.855149D 02, GAMMA = 1.0000000D 00, XIBAR = 0.0

REX = 1.64479D 04 WALL HEAT TRANSFER 2.375100D 02 BTU/(FT**2*SEC) HEAT TRANSFER COEFFICIENTS 3.331535D-04 BTU/(IN**2*SEC*DEGREE R) 1.387557D-03 LBM/(IN**2*SEC)

STE = 2.894776D-03, STINF = 2.894776D-03, CHEDGE = 3.243993D-03, CHINF = 3.243993D-03, CHINF*SQRT(REX) = 4.160401D-01

CFE = 5.417405D-03, CFINF = 5.417405D-03, CF(TOTAL) = 7.191686D-03, CFBAR*SQRT(REX) = 9.223294D-01, CFINF*SQRT(REX) = 6.947789D-01

CFINF/2 = 2.708703D-03, CHINF/(CFINF/2) = 1.197619D 00, CHEDGE/(CFE/2) = 1.197619D 00

X/REFLEN = 4.010000D-02, Z/REFLEN = 4.010000D-02, RO/REFLEN = 1.000000D 00, DELTA/X = 8.736284D-02, DELSTR/X = 5.415920D-02

THETA/REFLEN = 1.931181D-04, DELSTR/REFLEN = 2.171784D-03, DELTA/REFLEN = 3.503250D-03, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.512543D-02, DELSTR/DELTA = 6.199341D-01, DELSTR/THETA = 1.124588D 01, DELSTRAXI = 0.0

DELSTRK = 1.04341D-03, DELSTR = 2.17178D-03, DELTA = 3.50325D-03, THETA = 1.93118D-04, RETHETA = 7.92117D 01

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S =    0.08010,
                  XI =    0.01328, Z =  0.08010, Z/L = 0.00329, RO = 1.00000, BETA = 0.0     , PP =     0.0     , NIT =   3, K =  5

TE = 0.04932, UE = 1.00000, MACHE =  7.1200000, RHOE =    1.00000, MUE = 0.16576, PE =    0.01409, DUEDS =    0.0

CF =    1.08445, QW =   -0.29192, HG = -0.111953D-02, EPSVD = 0.383510D-02, CQ = 0.0          , KEP = 53, NITTOT =   22

F2N(1) =    0.530272, F2N(3) =    0.532009, F2NN(1) =    0.510378, F2NN(3) =    0.510728

CHIMAX = 2.711108D 02, GAMMA = 1.000000D 00, XIBAR = 0.0

REX = 3.28548D 04            WALL HEAT TRANSFER                              HEAT TRANSFER COEFFICIENTS
                               1.833056D 02                           2.571214D-04                1.070890D-03
                             BTU/(FT**2*SEC)                      BTU/(IN**2*SEC*DEGREE R)          LBM/(IN**2*SEC)

STE = 2.234132D-03, STINF = 2.234132D-03, CHEDGE = 2.503651D-03, CHINF = 2.503651D-03, CHINF*SQRT(REX) = 4.538090D-01

CFE = 4.158964D-03, CFINF = 4.158964D-03, CF(TOTAL) = 5.595847D-03, CFBAR*SQRT(REX) = 1.014297D 00, CFINF*SQRT(REX) = 7.538492D-01

CFINF/2 = 2.079482D-03, CHINF/(CFINF/2) = 1.203978D 00, CHEDGE/(CFE/2) = 1.203978D 00

X/REFLEN = 8.010000D-02, Z/REFLEN = 8.010000D-02, RO/REFLEN = 1.000000D 00, DELTA/X = 6.574365D-02, DELSTR/X = 3.970486D-02

THETA/REFLEN = 2.853395D-04, DELSTR/REFLEN = 3.180359D-03, DELTA/REFLEN = 5.266067D-03, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.418457D-02, DELSTR/DELTA = 6.039345D-01, DELSTR/THETA = 1.114588D 01, DELSTRAXI = 0.0

DELSTRK = 1.46813D-03, DELSTR = 3.18036D-03, DELTA = 5.26607D-03, THETA = 2.85340D-04, RETHETA = 1.17038D 02


S =    0.16010,
                  XI =    0.02654, Z =  0.16010, Z/L = 0.00657, RO = 1.00000, BETA = 0.0     , PP =     0.0     , NIT =   5, K =  6

TE = 0.04932, UE = 1.00000, MACHE =  7.1200000, RHOE =    1.00000, MUE = 0.16576, PE =    0.01409, DUEDS =    0.0

CF =    0.85488, QW =   -0.23310, HG = -0.893977D-03, EPSVD = 0.383510D-02, CQ = 0.0          , KEP = 52, NITTOT =   27

F2N(1) =    0.590979, F2N(3) =    0.593165, F2NN(1) =    0.642201, F2NN(3) =    0.642719

CHIMAX = 4.023174D 02, GAMMA = 1.000000D 00, XIBAR = 0.0

REX = 6.56686D 04            WALL HEAT TRANSFER                              HEAT TRANSFER COEFFICIENTS
                               1.463747D 02                           2.053187D-04                8.551354D-04
                             BTU/(FT**2*SEC)                      BTU/(IN**2*SEC*DEGREE R)          LBM/(IN**2*SEC)

STE = 1.784017D-03, STINF = 1.784017D-03, CHEDGE = 1.999235D-03, CHINF = 1.999235D-03, CHINF*SQRT(REX) = 5.123216D-01

CFE = 3.278531D-03, CFINF = 3.278531D-03, CF(TOTAL) = 4.353770D-03, CFBAR*SQRT(REX) = 1.115692D 00, CFINF*SQRT(REX) = 8.401523D-01

CFINF/2 = 1.639265D-03, CHINF/(CFINF/2) = 1.219592D 00, CHEDGE/(CFE/2) = 1.219592D 00

X/REFLEN = 1.601000D-01, Z/REFLEN = 1.601000D-01, RO/REFLEN = 1.000000D 00, DELTA/X = 5.006776D-02, DELSTR/X = 2.940175D-02

THETA/REFLEN = 4.272234D-04, DELSTR/REFLEN = 4.707220D-03, DELTA/REFLEN = 8.015848D-03, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.329734D-02, DELSTR/DELTA = 5.872392D-01, DELSTR/THETA = 1.101817D 01, DELSTRAXI = 0.0

DELSTRK = 2.06483D-03, DELSTR = 4.70722D-03, DELTA = 8.01585D-03, THETA = 4.27223D-04, RETHETA = 1.75235D 02
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S =   0.24010,
              XI =    0.03980, Z =  0.24010, Z/L = 0.00985, RO = 1.00000, BETA = 0.0     , PP =     0.0    , NIT =   4, K =  7

TE = 0.04932, UE = 1.00000, MACHE =  7.1200000, RHOE =     1.00000, MUE = 0.16576, PE =    0.01409, DUEDS =    0.0

CF =    0.74717, QW =   -0.20513, HG = -0.786708D-03, EPSVD = 0.383510D-02, CQ = 0.0          , KEP = 52, NITTOT =   31

F2N(1) =    0.632542, F2N(3) =    0.635063, F2NN(1) =    0.740800, F2NN(3) =    0.741458

CHIMAX = 5.103432D 02, GAMMA = 1.000000D 00, XIBAR = 0.0

REX = 9.84824D 04          WALL HEAT TRANSFER                                  HEAT TRANSFER COEFFICIENTS
                             1.288110D 02                          1.806822D-04                7.525267D-04
                           BTU/(FT**2*SEC)                  BTU/(IN**2*SEC*DEGREE R)          LBM/(IN**2*SEC)

STE = 1.569951D-03, STINF = 1.569951D-03, CHEDGE = 1.759345D-03, CHINF = 1.759345D-03, CHINF*SQRT(REX) = 5.521157D-01

CFE = 2.865467D-03, CFINF = 2.865467D-03, CF(TOTAL) = 3.826509D-03, CFBAR*SQRT(REX) = 1.200831D 00, CFINF*SQRT(REX) = 8.992381D-01

CFINF/2 = 1.432734D-03, CHINF/(CFINF/2) = 1.227963D 00, CHEDGE/(CFE/2) = 1.227963D 00

X/REFLEN = 2.401000D-01, Z/REFLEN = 2.401000D-01, RO/REFLEN = 1.000000D 00, DELTA/X = 4.311801D-02, DELSTR/X = 2.484595D-02

THETA/REFLEN = 5.457521D-04, DELSTR/REFLEN = 5.965514D-03, DELTA/REFLEN = 1.035263D-02, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.271626D-02, DELSTR/DELTA = 5.762315D-01, DELSTR/THETA = 1.093081D 01, DELSTRAXI = 0.0

DELSTRK = 2.54132D-03, DELSTR = 5.96551D-03, DELTA = 1.03526D-02, THETA = 5.45752D-04, RETHETA = 2.23852D 02


S =   0.32010,
              XI =    0.05306, Z =  0.32010, Z/L = 0.01313, RO = 1.00000, BETA = 0.0     , PP =     0.0    , NIT =   4, K =  8

TE = 0.04932, UE = 1.00000, MACHE =  7.1200000, RHOE =     1.00000, MUE = 0.16576, PE =    0.01409, DUEDS =    0.0

CF =    0.68322, QW =   -0.18817, HG = -0.721657D-03, EPSVD = 0.383510D-02, CQ = 0.0          , KEP = 51, NITTOT =   35

F2N(1) =    0.667848, F2N(3) =    0.670668, F2NN(1) =    0.828464, F2NN(3) =    0.829249

CHIMAX = 6.090532D 02, GAMMA = 1.000000D 00, XIBAR = 0.0

REX = 1.31296D 05          WALL HEAT TRANSFER                                  HEAT TRANSFER COEFFICIENTS
                             1.181600D 02                          1.657422D-04                6.903025D-04
                           BTU/(FT**2*SEC)                  BTU/(IN**2*SEC*DEGREE R)          LBM/(IN**2*SEC)

STE = 1.440136D-03, STINF = 1.440136D-03, CHEDGE = 1.613870D-03, CHINF = 1.613870D-03, CHINF*SQRT(REX) = 5.847825D-01

CFE = 2.620217D-03, CFINF = 2.620217D-03, CF(TOTAL) = 3.507721D-03, CFBAR*SQRT(REX) = 1.271016D 00, CFINF*SQRT(REX) = 9.494306D-01

CFINF/2 = 1.310109D-03, CHINF/(CFINF/2) = 1.231859D 00, CHEDGE/(CFE/2) = 1.231859D 00

X/REFLEN = 3.201000D-01, Z/REFLEN = 3.201000D-01, RO/REFLEN = 1.000000D 00, DELTA/X = 3.875620D-02, DELSTR/X = 2.211976D-02

THETA/REFLEN = 6.522566D-04, DELSTR/REFLEN = 7.080535D-03, DELTA/REFLEN = 1.240586D-02, DELSTRAXI/REFLEN = 0.0

THETA/DELTA = 5.257650D-02, DELSTR/DELTA = 5.707413D-01, DELSTR/THETA = 1.085544D 01, DELSTRAXI = 0.0

DELSTRK = 2.94768D-03, DELSTR = 7.08054D-03, DELTA = 1.24059D-02, THETA = 6.52257D-04, RETHETA = 2.67538D 02

                                        THE END  K=KEND
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FORTRAN SOURCE LISTING OF PROGRAM LTBLCEQL

In the following source listing, the subroutines in the program are listed alphabetically, except for MAIN which is at the beginning of the list, and except for the interpolation and differentiation subroutines which are at the end of the list.

In each subroutine, the statement numbers are in ascending order with an increment of 10. The cards in each subroutine are sequence numbered in columns 77 through 79. Further, the subroutines are sequenced by an alphabetic label in columns 74 and 75. The first subroutine, MAIN, is labeled A, the second subroutine, BLUNT1, is labeled B, and the forty-second (and last) subroutine is labeled AP. The interpolation and differentiation subroutines with their alphabetic labels are listed below.

Subroutine	Alphabetic Label
DERIV3	AI
FD3	AO
FD5	AP
INTERP	AJ
INTER3	AL
INTER5	AM
INTRP5	AN
TLU	AK

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C      PROGRAM LTBLCEQL
C      (LAMINAR AND/OR TURBULENT BOUNDARY LAYERS IN CHEMICAL EQUILIBRIUM)
C
C
C                               A PROGRAM FOR
C         2-D AND AXISYMMETRIC NONREACTING PERFECT GAS AND EQUILIBRIUM
C         CHEMICALLY REACTING LAMINAR, TRANSITIONAL AND/OR TURBULENT
C         BOUNDARY-LAYER FLOW
C
C                                    BY
C
C         E. C. ANDERSON,  E. W. MINER  AND  C. H. LEWIS
C         AEROSPACE ENGINEERING DEPT.
C         VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
C         BLACKSBURG, VA. 24061
C         PHONE - (703)-552-6126
C         PROGRAM DEVELOPED UNDER CONTRACT NAS1-9337 WITH NASA
C         LANGLEY RESEARCH CENTER
C
C
C      MAIN ROUTINE
C
C      MAIN CALLS SUBROUTINES ACDETA, CHANGE, COEF, DELTAS, DERIV3,
C      ENERGY, GEOM, INIT, MOMENT, PRFILE, PROP, READIN, VISCO, WALL,
C      WRITE1, AND WRITE2.
C
C      MAIN PROVIDES CONTROL OF THE FLOW OF LOGIC IN THE PROGRAM AND
C      SOME CALCULATIONS.
C
C          STAGNATION ENTHALPY ENERGY EQUATION IN LEVY-LEES VARIABLES
C
       COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
      1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
      2,EPS0(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
      3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
      41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
      501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
      61),YY(101)
       COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
      1),IPR(101),IPRFL(101)
       COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
       COMMON /COEFF3/ CF1,HGFAC1,HGFAC2,QW,SUM
       COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
      1DW,KTW
       COMMON /CFPR/ CF,PR,PRL,PRT
       COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
      10,PP,RGAS,ROES0,ROWE,ROWEP,TE,TES0,UE,UERO2,UES0,XM,XMUE,XMUEP,XMU
      2S0
       COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
      1UFS,XMA,XMUFS
       COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,R0,REFLEN,SCF,THS
      1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
       COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
       COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
      1L,NIT,NIT1,NIT2,NIT3,NOSE
       COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
      1T,KTPW,KTRNSN,LAMTRB,NITTOT
       COMMON /NMLCRD/ ADTEST,ETAINF,XKETA
       COMMON /REF/ AMUREF,CMSTD,HREF,P0PRIM,PREF,RHOREF,RHOSTD,TREF,TREF
      11,UREF,XMUREF
       COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
       COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
       KREADN=1
       CALL READIN (KREADN)
       IF (KSTRT.EQ.1) GO TO 20
C
C         UPDATE PROPERTIES FOR RESTART
C
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```
      XOLD=X
      XIOLD=XI
      CALL CHANGE
      DO 10 N=1,IE
      F1(N)=F2(N)
      F1N(N)=F2N(N)
      F1NN(N)=F2NN(N)
      T1(N)=T2(N)
      T1N(N)=T2N(N)
      T1NN(N)=T2NN(N)
10    CONTINUE
      NIT=0
      ISTOP=0
      CALL DELTAS
      CF1=2.0*XMUE*UE*C(1)*A1B/PNC*EPSVD
C
C        RESUME MARCHING INTEGRATION WITH K=KSTRT
C
      GO TO 90
20    CONTINUE
      CALL INIT
      TIN=1.0/((G-1.0)*XMA**2)
      CALL VISCO (OMEGA,TIN,XMUINF)
      EPSVD=1.0/(XMUINF*REINF)**0.50
      KRITE1=1
      CALL WRITE1 (KRITE1)
      IF (NT3.EQ.0) GO TO 30
C
C        WRITE INITIAL DATA ON RESTART TAPE
C
      KREADN=2
      CALL READIN (KREADN)
30    CONTINUE
      II=2
      CQ1=CQ
      IF ((II-KINJ).LE.0) CQ=0.0
      IF (RO.EQ.0.0) VW=CQ/(EPSVD*SQRT(ROWE*XMUE*DUEDS*(XJFAC+1.0)))
      IF (RO.NE.0.0) VW=CQ*SQRT(2.0*XI)/(XMUE*RO**XJFAC*ROWE*UE*EPSVD)
      IF (CQ.NE.0.0.AND.FINJ.NE.0.0) VW=-FINJ
      CALL PRFILE
      XIOLD=XI
      XOLD=X
      ALP1=1.0+0.50*ALP
      HALP=0.50*ALP
      DO 40 N=1,IE
      THP(N)=ALP1*TCN(N)-ALP*FC(N)*FCN(N)
40    CONTINUE
      DO 50 N=1,IE
      TH(N)=ALP1*TC(N)-HALP*FC(N)**2
      ROROE(N)=1.0/TH(N)
50    CONTINUE
      GO TO 70
60    CONTINUE
C
C     NORMAL COORDINATE EVALUATED FOR EQUILIBRIUM REF CONDITIONS
C
      REINF=RHOFS*UFS/XMUFS/SCF
      EPSVD=SQRT(XMUREF*SCF/(RHOREF*UREF))
      KRITE1=2
      CALL WRITE1 (KRITE1)
      IF (NT3.EQ.0) GO TO 70
      REWIND NT3
      KREADN=2
      CALL READIN (KREADN)
70    CONTINUE
      Y(1)=0.0
      YY(1)=0.0
      DO 80 N=2,IE
      Y(N)=Y(N-1)+PNC*(1.0/ROROE(N)+1.0/ROROE(N-1))*DN(N-1)/2.0
      YY(N)=Y(N)*EPSVD
```

```
80    CONTINUE
90    CONTINUE
C
C        BEGIN MARCHING INTEGRATION
C
      DO 210 K=KSTRT,KEND
      ALP1=1.0+0.50*ALP
      HALP=0.50*ALP
      VK=CSTAR*CX/(TE*UFS**2)
      F1(1)=0.00
      F2(1)=0.00
      FC(1)=0.00
      F2N(1)=1.00
      T2N(1)=TCN(1)
      IF (IADW.EQ.0) GO TO 100
      T2(1)=TC(1)
C
C        BEGIN ITERATION LOOP
C
100   F2N1=F2N(1)
      T2N1=T2N(1)
      CALL WALL
      CALL ENERGY
      CALL MOMENT
      VC(1)=VW
      DO 110 N=2,IE
110   VC(N)=VC(N-1)-(XI2*(FCP(N)+FCP(N-1))+FC(N)+FC(N-1))*DN(N-1)*.50
      A1B=CRNI*F2N(1)+CCRNI*F1N(1)
      CW=C(1)
      IF (PNC.LT.1.0E-8) GO TO 120
      CF=2.0*XMUE*UE*CW*A1B/PNC
      QW=-XMUE*HE*CW*TCN(1)/(PNC*PR)
120   CONTINUE
      NIT=NIT+1
      NITTOT=NITTOT+1
      ISTOP=ISTOP+1
      IF (ISTOP.GT.100) GO TO 230
      IF (K.EQ.1) GO TO 130
      IF (NIT.LT.NIT3) GO TO 130
      WRITE (6,240) NIT,DX,X
      WRITE (6,250) F2N(1),F2N1,DIF
      IPRIIM=IPR(II-1)
      IF (ABS(1.-X/XSTA(IPRIIM)).LE.1.E-6) II=II-1
      X=XOLD+DX/2.0
      DX=DX/2.0
      NIT=0
      CALL DELTAS
      GO TO 100
130   CONTINUE
      IF (NIT.LT.3) GO TO 100
      IF (DIF.GT.CONVRG) GO TO 100
      ABST=ABS(F2(IE)-F2(IE-4))
      IF (KADETA.EQ.0) GO TO 140
      IF (ABST.LT.ADTEST) GO TO 140
      CALL ADDETA
      GO TO 100
140   IF (KINJ.EQ.0.OR.KINJ.EQ.IIMAX) GO TO 150
      IF (NIT.EQ.1.AND.ABS(1.0-XOLD/XSTA(KINJ)).LE.1.E-6) GO TO 100
150   IF (KNOINJ.EQ.0.OR.KNOINJ.EQ.IIMAX) GO TO 160
      IF (NIT.EQ.1.AND.ABS(1.0-XOLD/XSTA(KNOINJ)).LE.1.E-6) GO TO 100
160   CONTINUE
      CALL COEF
      CALL WRITE2
      IF (NEQIL.EQ.1) GO TO 180
      IF (NEQIL.EQ.0.AND.NEQL.EQ.0) GO TO 180
C
C        BEGIN EQUILIBRIUM GAS SOLUTION
C
      NEQIL=NEQL
      XI=0.0
```

```
      XIOLD=0.0
      X=0.0
      CALL GEOM
      X=XOLD
      IF (NOSE.EQ.1) GO TO 170
      IF (LAMTRB.EQ.2) CALL DELTAS
170   CONTINUE
      HGFAC1=(RHOFS*UFS*CX)/(778.0*SCF**2)
      HGFAC2=RHOFS*UFS*32.1740/144.0
      CALL PROP
      CALL DERIV3 (TH,XN,IE,1,THP)
      SUM=0.0
      IPRNT=1
C
C        RETURN AND OBTAIN EQUILIBRIUM GAS SOLUTION FOR FIRST STATION
C
      GO TO 60
180   CONTINUE
      XOLD=X
      XIOLD=XI
      CALL CHANGE
      DO 190 N=1,IE
      F1(N)=F2(N)
      F1N(N)=F2N(N)
      F1NN(N)=F2NN(N)
      T1(N)=T2(N)
      T1N(N)=T2N(N)
      T1NN(N)=T2NN(N)
190   CONTINUE
      NIT=0
      ISTOP=0
      IF (KSTOP.EQ.1) GO TO 200
      CALL DELTAS
      UERO2=UE*RO**(2.0*XJFAC)
      XMUEP=XMUE
      ROWEP=ROWE
      CF1=2.0*XMUE*UE*C(1)*A1B/PNC*EPSVD
200   CONTINUE
      IF (KSTOP.EQ.0) GO TO 210
      WRITE (6,260)
      WRITE (6,260)
      GO TO 220
210   CONTINUE
      WRITE (6,270)
      WRITE (6,270)
220   STOP
230   WRITE (6,280)
      GO TO 220
C
C
C
240   FORMAT (1H0,///6H  NIT=,I5,5H  DX=,E14.6,4H  X=,E14.6/)
250   FORMAT (9H  F2N(1)=,1PE14.6,7H  F2N1=,E14.6,6H  DIF=,E14.6///)
260   FORMAT (1H1,/////50X,9H THE END ,14H X=XSTA(IIMAX))
270   FORMAT (1H1,/////50X,9H THE END ,7H K=KEND)
280   FORMAT (25H  STOP *** ISTOP.GT.100//)
      END
```

```
      SUBROUTINE ADDETA
C
C     SUBROUTINE ADDETA CALLS SUBROUTINES INTER3 AND DERIV3.
C
C     SUBROUTINE ADDETA IS CALLED BY MAIN.
C
C     SUBROUTINE ADDETA INCREASES ETAINF IF F(IE) AND F(IE-4) DIFFER BY
C     MORE THAN ADTEST.
C     GENERATES NEW ETA SPACING AND INTERPOLATES FOR NEW VELOCITY AND
C     ENTHALPY PROFILES.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /COMWLL/ A1B,BD,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NMLCRD/ ADTEST,ETAINF,XKETA
C
C
      WRITE (6,80) ISTOP
      ETAIN2=ETAINF+5.0
      IF (XKETA.EQ.1.0) DETA1=ETAIN2/FLOAT(IE-1)
      IF (XKETA.NE.1.0) DETA1=ETAIN2*(XKETA-1.0)/(XKETA**IM-1.0)
      DN2(1)=DETA1
      XN2(1)=0.0
      DO 10 N=1,IE
      DN2(N+1)=DN2(N)*XKETA
      XN2(N+1)=XN2(N)+DN2(N)
10    CONTINUE
      DO 40 N=2,IE
      IF (XN2(N).GE.ETAINF) GO TO 30
      JC=0
20    JC=JC+1
      IF (XN2(N).GT.XN(JC)) GO TO 20
      IF (JC.LT.2) JC=2
      IF (JC.GT.(IE-1)) JC=IE-1
      CALL INTER3 (XN2(N),XN(JC-1),XN(JC),XN(JC+1),F1(JC-1),F1(JC),F1(JC
     1+1),F2(N))
      CALL INTER3 (XN2(N),XN(JC-1),XN(JC),XN(JC+1),T1(JC-1),T1(JC),T1(JC
     1+1),T2(N))
      GO TO 40
30    F2(N)=1.0
      T2(N)=1.0
40    CONTINUE
      CALL DERIV3 (F2,XN2,IE,1,F2N)
      CALL DERIV3 (F2N,XN2,IE,1,F2NN)
      CALL DERIV3 (T2,XN2,IE,1,T2N)
      CALL DERIV3 (T2N,XN2,IE,1,T2NN)
      VC(1)=VW
      DO 50 N=1,IE
      DN(N)=DN2(N)
      XN(N)=XN2(N)
      F1(N)=F2(N)
      F1N(N)=F2N(N)
      F1NN(N)=F2NN(N)
      T1(N)=T2(N)
      T1N(N)=T2N(N)
      T1NN(N)=T2NN(N)
      FC(N)=F1(N)
      FCN(N)=F1N(N)
      TC(N)=T1(N)
      TCN(N)=T1N(N)
      FCP(N)=0.0
      IF (N.EQ.1) GO TO 50
```

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      VC(N)=VC(N-1)-(F2(N)+F2(N-1))*DN(N-1)*0.50
50    CONTINUE
      ETAINF=ETAIN2
      WRITE (6,90) DX,XKETA,ETAINF,ADTEST
      WRITE (6,100)
      DO 60 N=1,IE,KL
60    WRITE (6,110) XN(N),YY(N),YOVTHT(N),YOVDEL(N),FC(N),FCN(N),F2NN(N)
     1,EPSPL(N),AOBP(N),N
      WRITE (6,120)
      DO 70 N=1,IE,KL
      WRITE (6,110) XN(N),TC(N),TCN(N),VC(N),TH(N),ROROE(N),C(N),CP(N),C
     1HI(N),N
70    CONTINUE
      RETURN
C
C
C
80    FORMAT (1H0,9X,42HINTERMEDIATE PROFILE DATA-ETAINF INCREASED,2X,6H
     1ISTOP=,I3)
90    FORMAT (1H0,2X,3HDX=,F12.6,1X,6HXKETA=,F12.6,1X,7HETAINF=,F12.6,1X
     1,7HADTEST=,F12.6)
100   FORMAT (1H0,/124H          ETA         Y(N)/L       Y/THETA       Y
     1/DELTA       F=U/UE        FP(N)          FPP           EPS+
     2   AOBP   ,4X,2H N/)
110   FORMAT (9F14.6,I5)
120   FORMAT (1H0,/123H          ETA         G=H/HE        GP(N)
     1  V            T/TE        RHO/RHOE   RHOMU/RHOEMUE       CP
     2    CHI   ,5X,2H N/)
      END


      SUBROUTINE BLUNT1
C
C     SUBROUTINE BLUNT1 CALLS SUBROUTINES DENSIT, FD5, INTER5, MACH,
C     SLOW, AND VISCO.
C
C     SUBROUTINE BLUNT1 IS CALLED BY SUBROUTINE GEOM.
C
C     SUBROUTINE BLUNT1 CALCULATES THE EDGE AND REFERENCE PROPERTIES
C     FOR THE STAGNATION POINT OF A BLUNT BODY.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /SUTH/ CPRIM
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
      DIMENSION ZZ(9), UEJ(3), PEJ(3), HESTJ(3)
C
C
      IF (NEQIL.EQ.1) GO TO 20
C
C     ****************************************************************
C     --------------PERFECT GAS STARTING AND REFERENCE CONDITIONS-------
C     ****************************************************************
```

```
C
      CPRIM=CSTAR/((G-1.0)*XMA**2*TFS)
      T10=0.50+1.0/((G-1.0)*XMA**2)
      P10=((((G+1.0)*XMA*XMA)/2.0)**(G/(G-1.00)))*(((G+1.00)/(2.00*G*XMA
     1*XMA-(G-1.00)))**(1.00/(G-1.00)))/(G*XMA*XMA)
      DO 10 J=1,IIMAX
      CALL MACH (ZA(J),DUM2,DUM2,DUM3)
      PZ(J)=PZ(J)*P10
      TE1=T10/(1.0+(G-1.0)/2.0*XM**2)
      UEZ(J)=SQRT(2.0*(T10-TE1))
10    CONTINUE
      Z=0.0
      R0=0.0
      XM=0.0
      PE=P10
      TE=T10
      UE=0.0
      CALL DENSIT (ROWE,PE,TE)
      CALL VISCO (OMEGA,TE,XMUE)
      PP=0.0
      CALL FD5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),-UEZ(3),-UEZ
     1(2),UEZ(1),UEZ(2),UEZ(3),DUEDS)
      UERO2=0.0
      HE=T10
      PNC=0.0
      PNC=SQRT(XMUE/((XJFAC+1.0)*DUEDS*ROWE))
      BETA=1.0/(1.0+XJFAC)
      ALP=0.0
      XMUS0=XMUE
      XMUEP=XMUE
      ROES0=ROWE
      ROWEP=ROWE
      TES0=TE
      PES0=PE
      WRITE (6,100) T10,P10
      WRITE (6,110) UE,TE,PE
      RETURN
20    CONTINUE
C
C     ******************************************************************
C     -----------EQUILIBRIUM GAS STARTING AND REFERENCE CONDITIONS------
C     ******************************************************************
C
      REWIND NT1
      DO 30 J=1,3
      READ (NT1) DUM,DUM1,UEJ(J),PEJ(J),HESTJ(J)
30    CONTINUE
      POPRIM=10.0**PEJ(1)*2116.2240/144.0
      PSTAG=POPRIM
      HSTAG=10.0**HESTJ(1)*RGAS*1.80
      PL=PEJ(1)
      ZZ(2)=HESTJ(1)
      DO 40 J=1,4
      IF (J.EQ.2) GO TO 40
      CALL SLOW (PL,ZZ,2,J,NT2,NV,NERR)
40    CONTINUE
      TSTAG=ZZ(1)*1.80
      RHOSTG=10.0**ZZ(3)*RHOSTD
      XMUSTG=ZZ(4)
      DO 50 J=1,IIMAX
      PZ(J)=PZ(J)*POPRIM/P10
50    CONTINUE
C
C     ------FREESTREAM CONDITIONS
C
      PATMS=PFS*144.0/2116.2240
      PL=ALOG10(PATMS)
      ZZ(1)=TFS/1.80
      DO 60 J=2,5
      CALL SLOW (PL,ZZ,1,J,NT2,NV,NERR)
60    CONTINUE
      HFS=10.0**ZZ(2)*RGAS*1.80
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```
      RHOFS=10.0**ZZ(3)*RHOSTD
      XMUFS=ZZ(4)
      CX=ZZ(5)*RGAS
C
C     ---------REFERENCE CONDITIONS-------------------------------------
C
      UREF=UFS
      RHOREF=RHOFS
      PREF=RHOFS*UFS**2
      HREF=UFS**2
      TREF=UFS**2/CX
      XMUREF=(518.60+198.60)/(TREF+198.60)*(TREF/518.60)**1.50*3.719E-07
C
C     XMUREF EVALUATED USING SUTHERLAND VISCOSITY LAW.XMUREF MAY BE CHOS
C     ARBITRARILY
C
      XMUINF=XMUFS/XMUREF
      REINF=RHOFS*UFS/XMUFS/SCF
      Z=0.0
      RO=0.0
      X=0.0
      P10=POPRIM*144.0/PREF
      T10=TSTAG/TREF
      HE=HSTAG/HREF
      HESTAT=HE
      TE=T10
      PE=P10
      ROWE=RHOSTG/RHOREF
      XMUE=XMUSTG/XMUREF
      UE=0.0
      PNC=0.0
      PP=0.0
      ALP=0.0
      DO 70 J=1,3
      UEJ(J)=UEJ(J)/UREF
      PEJ(J)=10.0**PEJ(J)*2116.2240/144.0
70    CONTINUE
      REWIND NT1
      J=1
80    J=J+1
      IF (PEJ(2).LT.PZ(J)) GO TO 80
      IF (J.LT.3) J=3
      CALL INTER5 (PEJ(2),PZ(J-2),PZ(J-1),PZ(J),PZ(J+1),PZ(J+2),XSTA(J-2
     1),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),XS2)
      J=1
90    J=J+1
      IF (PEJ(3).LT.PZ(J)) GO TO 90
      IF (J.LT.3) J=3
      CALL INTER5 (PEJ(3),PZ(J-2),PZ(J-1),PZ(J),PZ(J+1),PZ(J+2),XSTA(J-2
     1),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),XS3)
      CALL FD5 (0.0,-XS3,-XS2,0.0,XS2,XS3,-UEJ(3),-UEJ(2),0.0,UEJ(2),UEJ
     1(3),DUEDS)
      PNC=SQRT(XMUE/((XJFAC+1.0)*DUEDS*ROWE))
      BETA=1.0/(1.0+XJFAC)
      XMUSO=XMUE
      XMUEP=XMUE
      ROESO=ROWE
      ROWEP=ROWE
      PESO=PE
      TESO=TE
      WRITE (6,100) T10,P10
      WRITE (6,110) UE,TE,PE
      RETURN
C
C
C
100   FORMAT (1H ,2X,4HT10=,E15.7,2X,4HP10=,E15.7/)
110   FORMAT (9H   UESO= ,E15.7,8H  TESO= ,E15.7,9H  PESO=  ,E15.7)
      END
```

```
      SUBROUTINE BLUNT2
C
C     SUBROUTINE BLUNT2 CALLS SUBROUTINES DENSIT, EDGE, FD5, INTER5,
C     MACH, VISCO, AND ZRO.
C
C     SUBROUTINE BLUNT2 IS CALLED BY SUBROUTINE EGPROP.
C
C     SUBROUTINE BLUNT2 CALCULATES THE EDGE PROPERTIES FOR A BLUNT BODY
C     AT THE VALUES OF X AFTER THE INITIAL VALUE OF X.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
      IF (NEQIL.EQ.1) GO TO 40
C
C     ****************************************************************
C     -----EDGE CONDITIONS FOR PERFECT GAS SOLUTION-------------------
C     ****************************************************************
C
      IF (X.LT.XSTA(3)) GO TO 30
      CALL ZRO (IIMAX,X,Z,RO)
      J=0
10    J=J+1
      IF (X.GT.XSTA(J)) GO TO 10
      IF (J.LT.3) J=3
      IF (J.GT.(IIMAX-2)) J=IIMAX-2
      CALL INTER5 (X,XSTA(J-2),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),PZ(
     1J-2),PZ(J-1),PZ(J),PZ(J+1),PZ(J+2),PE)
      UE=SQRT(2.0*T10*(1.0-(PE/P10)**((G-1.0)/G)))
      CALL FD5 (X,XSTA(J-2),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),UEZ(J-
     12),UEZ(J-1),UEZ(J),UEZ(J+1),UEZ(J+2),DUEDS)
20    CONTINUE
      TE=T10-0.50*UE**2
      CALL VISCO (OMEGA,TE,XMUE)
      CALL DENSIT (ROWE,PE,TE)
      PP=-ROWE*UE*DUEDS
      CALL MACH (Z,DUM,DUM1,DUM3)
      RETURN
30    CONTINUE
      CALL INTER5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),ZA(3),ZA(
     12),ZA(1),ZA(2),ZA(3),Z)
      CALL INTER5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),RZ(3),RZ(
     12),RZ(1),RZ(2),RZ(3),RO)
      CALL INTER5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),PZ(3),PZ(
     12),PZ(1),PZ(2),PZ(3),PE)
      CALL FD5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),-UEZ(3),-UEZ
     1(2),UEZ(1),UEZ(2),UEZ(3),DUEDS)
      UE=SQRT(2.0*T10*(1.0-(PE/P10)**((G-1.0)/G)))
      GO TO 20
C
C     ****************************************************************
C     -----EDGE CONDITIONS FOR EQUILIBRIUM GAS SOLUTION---------------
C     ****************************************************************
C
40    CONTINUE
      IF (X.LT.XSTA(3)) GO TO 60
      CALL ZRO (IIMAX,X,Z,RO)
50    CONTINUE
      CALL EDGE
      RETURN
60    CONTINUE
```

```
      CALL INTER5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),ZA(3),ZA(
     12),ZA(1),ZA(2),ZA(3),Z)
      CALL INTER5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),RZ(3),RZ(
     12),RZ(1),RZ(2),RZ(3),RO)
      GO TO 50
      END
```

```
      SUBROUTINE CHANGE
C
C     SUBROUTINE CHANGE IS CALLED BY MAIN.
C
C     SUBROUTINE CHANGE ADJUSTS THE X STEP SIZE IF NECESSARY TO OBTAIN
C     A SOLUTION AT A SPECIFIED VALUE OF X.
C     IF INJECTION WERE CONSIDERED, SUBROUTINE CHANGE WOULD INITIATE OR
C     TERMINATE INJECTION AT THE SPECIFIED VALUES OF X.
C     WHEN INSTANTANEOUS TRANSITION IS TO BE CALCULATED, THIS SUBROUTINE
C     CHANGES THE SOLUTION PROCEDURE FROM LAMINAR TO TURBULENT AND
C     RESETS DELTA X.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
      IF (X.EQ.0.00010) DX=DX1
      IF (X.LE.0.00010) GO TO 20
      IF (NIT.GT.NIT1) GO TO 10
      DX=2.0*DX
      IF (DX.GT.DXMAX) DX=DXMAX
      GO TO 20
10    IF (NIT.LT.NIT2) GO TO 20
      DX=0.50*DX
20    X=X+DX
      IF (JJ.EQ.2) DX=DXOLD
      IF (JJ.EQ.2) X=XOLD+DX
      IPRII=IPR(II)
      IF (XSTA(IPRII).LT.0.0) KSTOP=1
      IF (KSTOP.EQ.1) GO TO 60
      IF (X.LE.XSTA(IPRII)) JJ=1
      IF (ABS(1.0-X/XSTA(IPRII)).LE.1.E-6) II=II+1
      IPRII=IPR(II)
      IF (XSTA(IPRII).LT.0.0) GO TO 30
      IF ((X-XSTA(IPRII)).GT.1.E-6) JJ=2
      IF (JJ.EQ.2) DXOLD=DX
      IF (JJ.EQ.2) DX=XSTA(IPRII)-XOLD
      IF (JJ.EQ.2) II=II+1
30    X=XOLD+DX
      IPRIIM=IPR(II-1)
      IPRII=IPR(II)
      IF (JJ.EQ.2.AND.(XSTA(IPRIIM)+DXOLD).GT.XSTA(IPRII)) DXOLD=XSTA(IP
     1RII)-XSTA(IPRIIM)
      IF (KINJ.EQ.0.OR.KINJ.EQ.IIMAX) GO TO 40
      IF (ABS(1.0-XOLD/XSTA(KINJ)).GT.1.E-6) GO TO 40
      CQ=CQ1
      DX=0.010
      DXOLD=DX
      X=XOLD+DX
C
      WRITE (6,70) X,DX,CQ
      WRITE (6,80)
40    IF (KNOINJ.EQ.0.OR.KNOINJ.EQ.IIMAX) GO TO 50
```

```
      IF (ABS(1.0-XOLD/XSTA(KNOINJ)).GT.1.E-6) GO TO 50
      CQ=0.
      WRITE (6,90) XOLD
      WRITE (6,80)
50    CONTINUE
      IF (KTRNSN.EQ.0.OR.KTRNSN.EQ.IIMAX) GO TO 60
      IF (ABS(1.0-XOLD/XSTA(KTRNSN)).GT.1.E-6) GO.TO 60
      GAMMA=1.0
      LAMTRB=2
      DX=0.010
      DXOLD=DX
      X=XOLD+DX
      WRITE (6,100) X,DX
      WRITE (6,80)
60    CONTINUE
      RETURN
C
C
C
70    FORMAT (1H1,20X,19H  INJECTION BEGINS ,//1X,4H X =,F12.6,5H DX =,F
     112.6,4H CQ=,F12.6)
80    FORMAT (1H1)
90    FORMAT (1H1,20X,17H  INJECTION ENDS ,//3X,3HX =,F12.6)
100   FORMAT (1H1,20X,35HTRANSITION BEGINS - INSTANTANEOUSLY,//1X,3HX =,
     1F12.6,7H   DX =,F12.6)
      END
```

```
      SUBROUTINE COEF
C
C     SUBROUTINE COEF CALLS SUBROUTINE INTERP.
C
C     SUBROUTINE COEF IS CALLED BY MAIN.
C
C     SUBROUTINE COEF COMPUTES FLOW COEFFICIENTS SUCH AS HEAT TRANSFER
C     COEFFICIENT, SKIN FRICTION COEFFICIENT, ETC.
C     ALSO COMPUTES DELTA, THETA, AND DELTA*.
C
      COMMON /ARRAY1/ A0(101),A08(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPS0(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /COEFF/ CFBAR,CFBREX,CFE,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,
     1CHREY,DEL,DELST,DELTA,DSTARK,DSTRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,R
     2EX,STE,STINF,THET
      COMMON /COEFF2/ DELORF,DELOX,DSAXOR,DSTODL,DSTORF,DSTOTH,DSTOX,ROR
     1EFL,THODEL,THOREF,XOREFL,ZOREFL
      COMMON /COEFF3/ CF1,HGFAC1,HGFAC2,QW,SUM
      COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROES0,ROWE,ROWEP,TE,TES0,UE,UERO2,UES0,XM,XMUE,XMUEP,XMU
     2S0
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,R0,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
```

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```
C
      ZOL=Z/ZA(IIMAX)
C
      IF (X.EQ.0.0) RETURN
C
      RESE=ROWE*UE*X/XMUE
      CFRES=CF*RESE**0.50
      REX=REINF*XMUINF*RESE
      SQREX=SQRT(REX)
      RECFAC=PRL**0.5+GAMMA*(PRL**(1.0/3.0)-PRL**0.5)
      IF (NEQIL.EQ.0) XMAE=UE/((G-1.0)*TE)**0.50
      IF (NEQIL.EQ.0) HAW=TE*(1.0+RECFAC*(G-1.0)*XMAE**2/2.0)
      IF (NEQIL.NE.0) HAW=HESTAT+RECFAC*UE**2/2.0
      HG=QW*EPSVD
C
C     HG=DIMENSIONLESS HEAT TRANSFER
C
      IF (KFS.NE.0) QDOT=-HG*RHOFS*UFS**3/778.0
C
C     QDOT-HEATING RATE BTU/FOOT SQUARE-SECOND
C
      HG1=HG/(HW-HAW)*HGFAC1
      HG2=HG/(HW-HAW)*HGFAC2
C
C     HG1-HEAT TRANSFER COEFFICEINT BTU/INCH SQUARE-SECOND-DEGREE R
C     HG2-HEAT TRANSFER COEFFICEINT LBM/INCH SQUARE-SECOND
C
      STRES=-QW/(HAW-HW)*RESE**0.50
      CHEDGE=-QW*EPSVD/(ROWE*UE*(HAW-HW))
      CFE=CF/(ROWE*UE**2)*EPSVD
      CHOCF=CHEDGE/CFE*2.0
      CFINF=CF*EPSVD
      CHREY=STRES
      CFREY=CFRES
      IF (BO.NE.1.0) STINF=-QW*EPSVD/(HE-HW)
      IF (BO.EQ.1.0) STINF=0.0
      IF (BO.NE.1.0) STE=-QW*EPSVD/(ROWE*UE*(HE-HW))
      IF (BO.EQ.1.0) STE=0.0
      IF (X.EQ.0.0) GO TO 20
      CALL INTERP (0.9950,FC,Y,IE,DELTA)
      DO 10 I=1,IE
      YOVDEL(I)=Y(I)/DELTA
10    CONTINUE
20    CONTINUE
C
C        AVG. CF*SQRT(REX)
C
      CFBREX=2.0*2.0**0.50*C(1)*A1B
      IF (K.EQ.1) GO TO 30
      IF (LAMTRB.EQ.1) GO TO 30
      CF2=CFINF
      DSUM=0.50*DX*(CF2+CF1)
      SUM=SUM+DSUM
      CFBREX=SUM/X*SQREX
30    CONTINUE
      SUM=CFBREX*X/SQREX
      HAFCF=CF*EPSVD/2.0
      IF (X.EQ.0.0) GO TO 40
      CFBAR=CFBREX/SQREX
      CH=CHREY/SQREX
40    CONTINUE
      THET=0.0
      DO 50 I=2,IE
      FAC1=FC(I)*(1.0-FC(I))
      FAC2=FC(I-1)*(1.0-FC(I-1))
      THET=THET+0.50*(FAC1+FAC2)*DN(I-1)*PNC*EPSVD
50    CONTINUE
      DELST=0.0
      DO 60 I=2,IE
      FAC1=1.0/ROROE(I)-FC(I)
      FAC2=1.0/ROROE(I-1)-FC(I-1)
      DELST=DELST+0.50*(FAC1+FAC2)*DN(I-1)*PNC*EPSVD
60    CONTINUE
```

```
      RETHET=ROWE*UE*THET/(XMUE*EPSVD**2)
      DEL=DELTA*EPSVD
      ROREFL=RO/REFLEN
      XOREFL=X/REFLEN
      THOREF=THET/REFLEN
      DSTORF=DELST/REFLEN
      DSTOX=DELST/X
      DELOX=DEL/X
      DELORF=DEL/REFLEN
      IF (XJFAC.NE.0.0) DSTRAX=RO*(SQRT(1.0+2.0*DELST/RO)-1.0)
      IF (XJFAC.EQ.0.0) DSTRAX=0.0
      ZOREFL=Z/REFLEN
      THODEL=THET/DEL
      DSTODL=DELST/DEL
      DSTOTH=DELST/THET
      DSAXOR=DSTRAX/REFLEN
      DO 70 N=1,IE
70    YOVTHT(N)=YY(N)/THET
      RETURN
      END
```

```
      SUBROUTINE DELTAS
C
C     SUBROUTINE DELTAS CALLS SUBROUTINE EGPROP.
C
C     SUBROUTINE DELTAS IS CALLED BY MAIN AND SUBROUTINE INIT.
C
C     SUBROUTINE DELTAS CALCULATES DS - DELTA XI, THE TRANSFORMATION
C     FACTOR - PNC, AND THE PRESSURE GRADIENT TERM - BETA.
C     INTEGRATION BY SIMPSONS RULE IS USED FOR CALCULATING DS.
C
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1Q,PP,RGAS,ROESQ,ROWE,ROWEP,TE,TESQ,UE,UERO2,UESQ,XM,XMUE,XMUEP,XMU
     2SQ
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
C
C
10    CONTINUE
      HA=X-DX*0.50
      X1=X
      X=HA
      CALL EGPROP
      UEHA=UE
      ROHA=RO
      ROWEHA=ROWE
      XMUEHA=XMUE
      X=X1
      CALL EGPROP
      RP=RO
      ALP=UE**2/TE
      IF (NEQIL.NE.0) ALP=UE**2/HESTAT
      IF (XJFAC.LT.0.0010) GO TO 20
      GO TO 30
20    CONTINUE
      RP=1.00
      ROHA=1.00
30    CONTINUE
      DS=(UERO2*ROWEP*XMUEP+4.00*UEHA*(ROHA**2)*ROWEHA*XMUEHA+UE*(RP**2)
     1*ROWE*XMUE)*DX/6.00
      XI=XIOLD+DS
      XI2=2.00*XI
      PNC=SQRT(XI2)/(UE*RP*ROWE)
      BETA=XI2*DUEDS/(ROWE*XMUE*(UE*RP)**2)
      RETURN
      END
```

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```
      SUBROUTINE DENSIT (RHO,P,T)
C
C     SUBROUTINE DENSIT IS CALLED BY SUBROUTINES BLUNT1, BLUNT2, NOZLE1,
C     NOZLE2, AND WDGFP1.
C
C     SUBROUTINE DENSIT CALCULATES RHO/RHOINF CORRESPONDING
C     TO P/2Q AND T/TREF.
C
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
C
C
      GM1=G-1.00
      RHO=G*P/((GM1)*T)
      RETURN
      END
```

```
      SUBROUTINE EDGE
C
C     SUBROUTINE EDGE CALLS SUBROUTINES EQLDTA, FD5, INTER5, INTRP5,
C     AND SLOW.
C
C     SUBROUTINE EDGE IS CALLED BY SUBROUTINES BLUNT2, NOZLE1, AND
C     NOZLE2.
C
C     SUBROUTINE EDGE CALCULATES THE EDGE PROPERTIES FOR EQUILIBRIUM
C     GAS SOLUTIONS OF EITHER NOZZLE OR BLUNT BODY FLOWS.  FOR A BLUNT
C     BODY, THE PRESSURE IS SPECIFIED.  FOR A NOZZLE, THE EDGE PRESSURE
C     MAY BE SPECIFIED OR IT MAY BE CALCULATED BY THE PROGRAM FROM AN
C     ISENTROPIC GAS EXPANSION.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     1I,UREF,XMUREF
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
C
      DIMENSION ZJ(5), PEJ(5), TEJ(5), HESTJ(5), ROWEJ(5), XMUEJ(5), UEJ
     1(5), XMJ(5), XJ(5), ZZ(9)
C
C
      IF (KPD.NE.0) GO TO 130
      IF (IJK.NE.61) GO TO 10
      IF (Z.LT.ZJ(2).AND.JK.LT.6) GO TO 70
      IF (Z.LT.ZJ(2)) J=6
      IF (Z.LT.ZJ(2)) GO TO 30
      IF (Z.GE.ZJ(2).AND.Z.LE.ZJ(4)) GO TO 70
      IF (ABS(XMJ(5)-XMA).LE.0.00010) GO TO 70
      IF (Z.GT.ZJ(5)) GO TO 110
      GO TO 90
10    CALL EQLDTA
      REWIND NT4
      IJK=61
      JK=0
      JJ=0
      J=0
20    J=J+1
```

```
      READ (NT4) ZI,XS,PEI,HEI,UEI,XMI
      JK=JK+1
      IF (ZI.LT.Z) GO TO 20
      IF (J.GT.3) J=3
30    CONTINUE
      DO 40 K=1,J
      BACKSPACE NT4
      JK=JK-1
40    CONTINUE
      M=1
50    CONTINUE
      DO 60 J=M,5
      READ (NT4) ZJ(J),XJ(J),PEJ(J),HESTJ(J),UEJ(J),XMJ(J)
      JK=JK+1
      IF (ABS(XMJ(5)-XMA).LT.0.00010) GO TO 70
      IF (ABS(XMJ(J)-XMA).LT.0.00010) JJ=5
      IF (JJ.EQ.5) J=5
      IF (JJ.EQ.5) GO TO 30
60    CONTINUE
70    CONTINUE
      CALL INTRP5 (Z,ZJ,PEJ,5,1,1,P)
      CALL INTRP5 (Z,ZJ,HESTJ,5,1,1,H)
      CALL INTRP5 (Z,ZJ,UEJ,5,1,1,UE)
      CALL FD5 (X,XJ(1),XJ(2),XJ(3),XJ(4),XJ(5),UEJ(1),UEJ(2),UEJ(3),UEJ
     1(4),UEJ(5),DUEDS)
      CALL INTRP5 (Z,ZJ,XMJ,5,1,1,XM)
      ZZ(2)=H
      DO 80 J=1,4
      IF (J.EQ.2) GO TO 80
      CALL SLOW (P,ZZ,2,J,NT2,NV,NERR)
80    CONTINUE
      PE=10.0**P*2116.2240/PREF
      TE=ZZ(1)*1.80/TREF
      HESTAT=10.0**H*RGAS*1.8/HREF
      ROWE=10.0**ZZ(3)*RHOSTD/RHOREF
      XMUE=ZZ(4)/XMUREF
      PP=-ROWE*UE*DUEDS
      RETURN
90    CONTINUE
      DO 100 I=1,3
      ZJ(I)=ZJ(I+2)
      XJ(I)=XJ(I+2)
      PEJ(I)=PEJ(I+2)
      TEJ(I)=TEJ(I+2)
      HESTJ(I)=HESTJ(I+2)
      ROWEJ(I)=ROWEJ(I+2)
      XMUEJ(I)=XMUEJ(I+2)
      UEJ(I)=UEJ(I+2)
      XMJ(I)=XMJ(I+2)
100   CONTINUE
      M=4
      GO TO 50
110   CONTINUE
120   READ (NT4) ZI,XS,PEI,HEI,UEI,XMI
      JK=JK+1
      IF (Z.GT.ZI) GO TO 120
      J=3
      GO TO 30
C
C     EQUILIBRIUM GAS SOLUTION WITH SPECIFIED PRESSURE DISTRIBUTION
C
130   CONTINUE
      CALL INTRP5 (X,XSTA,PZ,IIMAX,1,1,P)
      IF (X.GE.XSTA(2).OR.NOSE.NE.1) GO TO 140
      CALL INTER5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),PZ(3),PZ(
     12),PZ(1),PZ(2),PZ(3),P)
140   CONTINUE
      PE=P*144.0/PREF
      PATMS=P*144.0/2116.2240
      PL=ALOG10(PATMS)
      IF (IJK.NE.61) GO TO 150
      IF (PL.GT.PEJ(2).AND.JK.LT.6) GO TO 210
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      IF (PL.GT.PEJ(2)) J=6
      IF (J.EQ.6) GO TO 170
      IF (PL.LE.PEJ(2).AND.PL.GE.PEJ(4)) GO TO 210
      IF (PL.LT.PEJ(5)) GO TO 270
      GO TO 250
  150 REWIND NT1
      IJK=61
      JK=0
      J=0
  160 J=J+1
      READ (NT1) DUM,XMI,UI,PI,HI
      JK=JK+1
      IF (PI.GT.PL) GO TO 160
      IF (J.GT.3) J=3
  170 CONTINUE
      DO 180 K=1,J
      BACKSPACE NT1
      JK=JK-1
  180 CONTINUE
      M=1
  190 CONTINUE
      DO 200 K=M,5
      READ (NT1) DUM,XMJ(K),UEJ(K),PEJ(K),HESTJ(K)
      IF (PL.GT.PEJ(2).AND.JK.GE.6) GO TO 150
  200 CONTINUE
  210 CONTINUE
      CALL INTRP5 (PL,PEJ,XMJ,5,1,1,XM)
      CALL INTRP5 (PL,PEJ,UEJ,5,1,1,U)
      CALL INTRP5 (PL,PEJ,HESTJ,5,1,1,H)
      ZZ(2)=H
      DO 220 J=1,5
      IF (J.EQ.2) GO TO 220
      CALL SLOW (PL,ZZ,2,J,NT2,NV,NERR)
  220 CONTINUE
      TE=ZZ(1)*1.80/TREF
      HESTAT=10.0**H*RGAS*1.8/HREF
      UE=U/UREF
      ROWE=10.0**ZZ(3)*RHOSTD/RHOREF
      XMUE=ZZ(4)/XMUREF
      K=0
  230 K=K+1
      IF (XSTA(K).LT.X) GO TO 230
      IF (K.LT.3) K=3
      IF (K.GT.(IIMAX-2)) K=IIMAX-2
      CALL FD5 (X,XSTA(K-2),XSTA(K-1),XSTA(K),XSTA(K+1),XSTA(K+2),PZ(K-2
     1),PZ(K-1),PZ(K),PZ(K+1),PZ(K+2),PP)
      IF (X.GE.XSTA(2).OR.NOSE.NE.1) GO TO 240
      CALL FD5 (X,-XSTA(3),-XSTA(2),XSTA(1),XSTA(2),XSTA(3),PZ(3),PZ(2),
     1PZ(1),PZ(2),PZ(3),PP)
  240 CONTINUE
      PP=PP*144.0/PREF
      DUEDS=-PP/(ROWE*UE)
      RETURN
  250 CONTINUE
      DO 260 I=1,3
      XMJ(I)=XMJ(I+2)
      UEJ(I)=UEJ(I+2)
      PEJ(I)=PEJ(I+2)
      HESTJ(I)=HESTJ(I+2)
  260 CONTINUE
      M=4
      GO TO 190
  270 CONTINUE
  280 READ (NT1) DUM,XMI,UI,PI,HI
      JK=JK+1
      IF (PI.GT.PL) GO TO 280
      J=3
      GO TO 170
C
C
C
      END
```

```
      SUBROUTINE EDGE1
C
C     SUBROUTINE EDGE1 CALLS SUBROUTINE INTRP5.
C
C     SUBROUTINE EDGE1 IS CALLED BY SUBROUTINE EQLDTA.
C
C     SUBROUTINE EDGE1 MATCHES THE EXPANSION DATA ON UNIT NT1 TO THE
C     NOZZLE GEOMETRY.  THIS SUBROUTINE IS USED ONLY FOR EQUILIBRIUM
C     GAS SOLUTIONS IF THE PRESSURE DISTRIBUTION IS CALCULATED BY THE
C     PROGRAM FROM AN ISENTROPIC GAS EXPANSION.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STRT/ KRSTRT,NRSTRT
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
C
      DIMENSION A11(5), XM1(5), U1(5), P1(5), H1(5), R1(5), ZZ(9), XSTA1
     1(5)
C
C
      IF (KRSTRT.EQ.0) WRITE (6,150)
      IF (KRSTRT.EQ.0) WRITE (6,160)
      REWIND NT4
      READ (NT1) A,XM,U,P,H
      PSTG1=P
      HSTG1=H
      KKK=0
      MMM=0
      READ (NT1) A,XM,U,P,H
      RX=RZ(ITH)*SQRT(A)
      IF (RX.GT.RZ(1).AND.XM.LT.1.0) GO TO 80
      K=0
10    K=K+1
      IF (RX.LT.RZ(K)) GO TO 10
      K=K-1
      ONEOA=1.0/A
      DO 20 J=1,K
      AOASTR=(RZ(J)/RZ(ITH))**2
      ASTROA=1.0/AOASTR
      PZ1=P-(P-PSTG1)/ONEOA*(ONEOA-ASTROA)
      HZ=H-(H-HSTG1)/ONEOA*(ONEOA-ASTROA)
      UZ=U-U/ONEOA*(ONEOA-ASTROA)
      XMZ=XM-XM/ONEOA*(ONEOA-ASTROA)
      UE=UZ/UREF
      Z1=ZA(J)
      X1=XSTA(J)
      IF (KRSTRT.EQ.0) WRITE (6,170) Z1,X1,PZ1,HZ,UE,XMZ
      WRITE (NT4) Z1,X1,PZ1,HZ,UE,XMZ
20    CONTINUE
30    CONTINUE
      IF (RX.GT.RZ(IIMAX).AND.XM.GT.1.0) GO TO 140
      IF (XM.GT.1.0) GO TO 40
      IMAX=ITH
      IMIN=1
      I1=-1
      GO TO 50
```

```
40    CONTINUE
      IMAX=IIMAX
      IMIN=ITH
      I1=1
50    CONTINUE
      CALL INTRP5 (RX,RZ,XSTA,IMAX,IMIN,I1,X1)
      CALL INTRP5 (RX,RZ,ZA,IMAX,IMIN,I1,Z1)
60    CONTINUE
      UE=U/UREF
      IF (KRSTRT.EQ.0) WRITE (6,170) Z1,X1,P,H,UE,XM
      WRITE (NT4) Z1,X1,P,H,UE,XM
      IF (KKK.EQ.1) RETURN
70    READ (NT1) A,XM,U,P,H
      RX=RZ(ITH)*SQRT(A)
      IF (RX.GT.RZ(1).AND.XM.LT.1.0) GO TO 70
      GO TO 30
80    REWIND NT1
      READ (NT1) A,XM,U,P,H
      K=0
90    K=K+1
      READ (NT1) A,XM,U,P,H
      AOASTR=(RZ(1)/RZ(ITH))**2
      IF (A.GT.AOASTR) GO TO 90
      IF (K.LT.3) REWIND NT1
      IF (K.LT.3) MMM=1
      IF (K.LT.3) GO TO 110
      DO 100 J=1,3
      BACKSPACE NT1
100   CONTINUE
110   CONTINUE
      IF (MMM.EQ.1) READ (NT1) A,XM,U,P,H
      DO 120 J=1,5
      READ (NT1) A11(J),XM1(J),U1(J),P1(J),H1(J)
120   CONTINUE
      CALL INTRP5 (AOASTR,A11,XM1,5,1,1,XM)
      CALL INTRP5 (AOASTR,A11,U1,5,1,1,U)
      CALL INTRP5 (AOASTR,A11,P1,5,1,1,P)
      CALL INTRP5 (AOASTR,A11,H1,5,1,1,H)
      Z1=ZA(1)
      X1=XSTA(1)
      DO 130 J=1,5
      BACKSPACE NT1
130   CONTINUE
      GO TO 60
140   KKK=1
      P=PEXIT
      U=UREF
      H=HEXIT
      XM=XMA
      Z1=ZA(IIMAX)
      X1=XSTA(IIMAX)
      GO TO 60
C
C
C
150   FORMAT (1H0,40X,38HEDGE CONDITIONS FOR EQUILIBRIUM NOZZLE)
160   FORMAT (1H0,5X,1HZ,12X,4HXSTA,8X,6HLOG10P,6X,6HLOG10H,6X,2HUE,10X,
     14HMACH)
170   FORMAT (1H0,2X,1P9E12.4)
      END
```

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```
      SUBROUTINE EFFMU (LAMTRB,MOMEGY,II,DSTARK)
C
C     SUBROUTINE EFFMU CALLS SUBROUTINES DERIV3, INTERP, AND RHOMU.
C
C     SUBROUTINE EFFMU IS CALLED BY SUBROUTINES ENERGY AND MOMENT.
C
C     SUBROUTINE EFFMU CALCULATES THE RHOMU PRODUCT AND ITS DERIVATIVE
C     WITH RESPECT TO ETA.
C     CALCULATES THE TERMS AO, AOB, AND AOBP WHICH, FOR THE TURBULENT
C     CASE, INCLUDE THE EDDY VISCOSITY - EPSPL.
C     FOR THE TRANSITION REGIME, THE EDDY VISCOSITY IS REDUCED BY THE
C     TRANSITION INTERMITTENCY FACTOR - GAMMA.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
C         LAMTRB = 1 LAMINAR B.L. ,=2 TURBULENT B.L.
C
C         MOMEGY = 1 MOMENTUM EQ.,= 2 ENERGY EQ.
C
      IF (NEQIL.EQ.0) GO TO 10
      GO TO (30,140), LAMTRB
10    GO TO (20,140), LAMTRB
20    GO TO (40,80), MOMEGY
30    GO TO (60,100), MOMEGY
C
C        LAMINAR
C
40    CONTINUE
C
C         C =RHOMU/RHOEMUE, CP = DCDT *DTDETA
C
C        COEFFICIENTS FOR MOMMENTUM EQUATION
C
      DO 50 I=1,IE
C
C        PERFECT GAS
C
      CALL RHOMU (OMEGA,TH(I),C(I),DCDTH,VK)
      CP(I)=DCDTH*THP(I)
      A0(I)=C(I)
      A0B(I)=1.0
      A0BP(I)=0.0
50    CONTINUE
      GO TO 120
60    CONTINUE
C
C        EQUILIBRIUM GAS
C
      CALL DERIV3 (C,XN,IE,1,CP)
      DO 70 I=1,IE
      A0(I)=C(I)
      A0B(I)=1.0
      A0BP(I)=0.0
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```
70    CONTINUE
      GO TO 120
C
C        COEFFICIENTS FOR ENERGY EQUATION
C
80    DO 90 I=1,IE
C
C        PERFECT GAS
C
      CALL RHOMU (OMEGA,TH(I),C(I),DCDTH,VK)
      CP(I)=DCDTH*THP(I)
      A0(I)=C(I)/PRL
      A0B(I)=1.0/PRL
      A0BP(I)=0.0
90    CONTINUE
      GO TO 120
100   CONTINUE
C
C        EQUILIBRIUM GAS
C
      CALL DERIV3 (C,XN,IE,1,CP)
      DO 110 I=1,IE
      A0(I)=C(I)/PREQ(I)
      A0B(I)=A0(I)/C(I)
110   CONTINUE
      CALL DERIV3 (A0B,XN,IE,1,A0BP)
120   CONTINUE
      IF (X.LT.1.E-7) RETURN
      CHIMAX=0.
C
C        CALCULATES VORTICITY REYNOLDS NUMBER
C
      DO 130 N=1,IE
      RHO=ROROE(N)*ROWE
      XMU=ROWE*XMUE*C(N)/RHO
      CHI(N)=RHO*Y(N)**2*FCN(N)/(EPSVD*PNC*XMU/ROROE(N))*UE
      IF (CHI(N).GT.CHIMAX) CHIMAX=CHI(N)
130   CONTINUE
      IF (KTRANS.EQ.0) RETURN
      IF (CHIMAX.LT.CHICRT) RETURN
C
C        INITIATES TRANSITION
C
      LAMTRB=2
      DX=DX/10.
      DXOLD=DXOLD/10.
      WRITE (6,360)
      WRITE (6,370)
      XZERO=X
      XLAMDA=(XBAR-1.)*XZERO/4.
C
C     WHEN USING THIS TRANSITION MODEL,THE VALUE OF XBAR SHOULD BE
C     SIXTY-FIVE PERCENT GREATER WHEN THE REICHARDT EDDY VISCOSITY LAW
C     IS USED THAN THE VALUE OF XBAR USED WITH THE VAN DRIEST EDDY
C     VISCOSITY LAW.  THE USER IS ADVISED THAT THE TRANSITION MODEL IS
C     TENTATIVE ONLY AND THAT DUE CARE MUST BE EXERCISED IN INTERPRETING
C     THE RESULTS OBTAINED WITH THIS TRANSITION MODEL.
C
140   CONTINUE
      IF (KTRANS.EQ.0) GO TO 150
      XIBAR=(X-XZERO)/XLAMDA
      GAMMA=1.-EXP(-ATR*XIBAR**2)
      IF (KTRANS.EQ.2) GO TO 150
      IF (KVSLAW.EQ.0.AND.XIBAR.LT.2.0) GO TO 150
      IF (KVSLAW.NE.0.AND.XIBAR.LT.4.0) GO TO 150
C
C        KTRANS IS SET EQUAL TO 2 AT THE END OF THE TRANSITION REGIME
C
      KTRANS=2
      WRITE (6,380)
      WRITE (6,370)
```

```
150   CONTINUE
C
C        TURBULENT
C
      FAC1=0.0
      IF (KVSLAW.NE.0) GO TO 170
      DO 160 I=1,IM
C
C        INNER EDDY VISCOSITY LAW, REICHARDT EQUATION
C
      RHO=ROROE(I)*ROWE
      XMU=ROWE*XMUE*C(I)/RHO
      FAC=CF*RHO/(2.0*EPSVD)
      FAC1=SQRT(FAC)
      EPSPL(I)=0.40*Y(I)/XMU*FAC1-4.40*TANH(Y(I)*FAC1/(11.0*XMU))*GAMMA
160   CONTINUE
      GO TO 200
170   CONTINUE
      FAC4=0.0
      RHOWL=ROROE(1)*ROWE
      DO 190 I=1,IM
C
C        INNER EDDY VISCOSITY LAW, VAN DRIEST EQUATION
C
      RHO=ROROE(I)*ROWE
      XMU=ROWE*XMUE*C(I)/RHO
      UPLUS=(CF*EPSVD/(2.0*RHO))**0.5
      YPLUS=Y(I)*RHO/(EPSVD*XMU)*UPLUS
      PPLUS=-EPSVD**2*PP*XMU/(RHO**2*UPLUS**3)
      VPLUS=CQ/(RHOWL*UPLUS)
      IF (KPGRAD.EQ.0) APLUS=26.0
      IF (KPGRAD.EQ.1) APLUS=26.0*EXP(-5.9*VPLUS)
      IF (KPGRAD.EQ.2) APLUS=26.0/(1.0-11.8*PPLUS)**0.5
      IF (KPGRAD.EQ.3) APLUS=26.0/(-PPLUS/VPLUS*(EXP(11.8*VPLUS)-1.0)+EX
     1P(11.8*VPLUS))**0.5
      ARG=-YPLUS/APLUS
      FAC3=(1.0-EXP(ARG))**2
      IF (Y(I).EQ.0.0) GO TO 180
      FAC4=(XK1*Y(I)*RHO*UE)**2*RO**XJFAC/(XMU*XI2**0.50)
180   CONTINUE
      EPSPL(I)=FAC4*FAC3*FIN(I)/EPSVD*GAMMA
190   CONTINUE
200   CONTINUE
      DSTARK=0.0
      DO 210 I=2,IE
      FAC1=(1.0-FC(I))/ROROE(I)
      FAC2=(1.0-FC(I-1))/ROROE(I-1)
      DSTARK=DSTARK+0.50*DN(I-1)*(FAC1+FAC2)*PNC*EPSVD
210   CONTINUE
C
C        INTERPOLATE FOR DELTA WITH INTERP AND TLU
C
      CALL INTERP (0.9950,FC,Y,IE,DELTA)
      CHIMAX=0.
      DO 220 I=1,IE
      RHO=ROROE(I)*ROWE
      XMU=ROWE*XMUE*C(I)/RHO
      CHI(I)=RHO*Y(I)**2*FCN(I)/(EPSVD*PNC*XMU/ROROE(I))*UE
      IF (CHI(I).GT.CHIMAX) CHIMAX=CHI(I)
      GAMF=1.0/(1.0+5.50*(Y(I)/DELTA)**6)
C
C        OUTER EDDY VISCOSITY LAW
C
220   EPSO(I)=XK2*UE*DSTARK*RHO/XMU*GAMF/EPSVD**2*GAMMA
      II=IE
      DO 230 I=1,IE
      IF (EPSPL(I).LT.EPSO(I)) GO TO 230
      II=I
      GO TO 240
230   CONTINUE
240   DO 250 I=II,IE
```

```
250   EPSPL(I)=EPSO(I)
      GO TO (260,310), MOMEGY
260   CONTINUE
C
C        COEFFICIENTS FOR MOMMENTUM EQUATION
C
      IF (NEQIL.NE.0) GO TO 280
      DO 270 I=1,IE
C
C        PERFECT GAS
C
      CALL RHOMU (OMEGA,TH(I),C(I),DCDTH,VK)
      CP(I)=DCDTH*THP(I)
      AO(I)=C(I)*(1.0+EPSPL(I))
      AOB(I)=AO(I)/C(I)
270   CONTINUE
      GO TO 300
280   CONTINUE
C
C        EQUILIBRIUM GAS
C
      CALL DERIV3 (C,XN,IE,1,CP)
      DO 290 I=1,IE
      AO(I)=C(I)*(1.0+EPSPL(I))
      AOB(I)=AO(I)/C(I)
290   CONTINUE
300   CONTINUE
      CALL DERIV3 (AOB,XN,IE,1,AOBP)
      RETURN
310   CONTINUE
C
C        COEFFICIENTS FOR ENERGY EQUATION
C
      IF (NEQIL.NE.0) GO TO 330
      DO 320 I=1,IE
C
C        PERFECT GAS
C
      CALL RHOMU (OMEGA,TH(I),C(I),DCDTH,VK)
      CP(I)=DCDTH*THP(I)
      AO(I)=C(I)/PRL*(1.0+EPSPL(I)*PRL/PRT)
      AOB(I)=AO(I)/C(I)
320   CONTINUE
      GO TO 350
330   CONTINUE
C
C        EQUILIBRIUM GAS
C
      CALL DERIV3 (C,XN,IE,1,CP)
      DO 340 I=1,IE
      AO(I)=C(I)/PREQ(I)*(1.0+EPSPL(I)*PREQ(I)/PRT)
      AOB(I)=AO(I)/C(I)
340   CONTINUE
350   CONTINUE
      CALL DERIV3 (AOB,XN,IE,1,AOBP)
      RETURN
C
C
C
360   FORMAT (28H1           TRANSITION BEGINS/)
370   FORMAT (1H1)
380   FORMAT (26H1           TRANSITION ENDS/)
      END
```

```
      SUBROUTINE EGPROP
C
C     SUBROUTINE EGPROP CALLS SUBROUTINES BLUNT2, NOZLE2, AND WDGFP2.
C
C     SUBROUTINE EGPROP IS CALLED BY SUBROUTINE DELTAS.
C
C     SUBROUTINE EGPROP OBTAINS EDGE PROPERTIES FOR SPECIFIED GEOMETRY
C     FOR VALUES OF X AFTER THE INITIAL VALUE OF X.
C
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
C
C
      GO TO (10,20,30), NOSE
10    CONTINUE
      CALL BLUNT2
      RETURN
20    CALL WDGFP2
      RETURN
30    CONTINUE
      CALL NOZLE2
      RETURN
      END
```

```
      SUBROUTINE ENERGY
C
C     SUBROUTINE ENERGY CALLS SUBROUTINES DERIV3, EFFMU, PROP, AND
C     SOLVE.
C
C     SUBROUTINE ENERGY IS CALLED BY MAIN.
C
C     THIS SUBROUTINE PROVIDES THE SOLUTION FOR THE ENERGY EQUATION.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
      COMMON /COEFF/ CFBAR,CFBREX,CFE,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,
     1CHREY,DEL,DELST,DELTA,DSTARK,DSTRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,R
     2EX,STE,STINF,THET
      COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,R0,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /VSCSTY/ CSTAR,EPSVO,OMEGA,VK,XK1,XK2,XMUINF
C
C
      IF (NEQIL.NE.0) GO TO 10
      GFAC=(UE**2/HE)*(1.0-1.0/PRL)
      GO TO 30
10    CONTINUE
      FAC=UE**2/HE
      DO 20 J=1,IE
      C1(J)=1.0-1.0/PREQ(J)
```

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```
20    CONTINUE
      CALL DERIV3 (C1,XN,IE,1,C1N)
30    CONTINUE
      MOMEGY=2
      CALL EFFMU (LAMTRB,MOMEGY,KEP,DSTARK)
C
C          ENERGY EQUATION SOLUTION
C
      DO 60 N=2,IM
      A1(N)=CP(N)/C(N)+AOBP(N)/AOB(N)-VC(N)/AO(N)
      A2(N)=0.0
      IF (NEQIL.NE.0) GO TO 40
      A3(N)=GFAC*(CP(N)/(C(N)*AOB(N))*FC(N)*FCN(N)+FCN(N)**2/AOB(N)+FC(N
     1)*F2NN(N)/AOB(N))
      GO TO 50
40    A3(N)=FAC*C1(N)*((CP(N)/C(N)+C1N(N)/C1(N))*FC(N)*FCN(N)+FCN(N)**2+
     1FC(N)*F2NN(N))/AOB(N)
50    A4(N)=-2.0*XI*FC(N)/AO(N)
60    CONTINUE
      CALL SOLVE (T1NN,T1N,T1,T2NN,T2N,T2,E1,TB,CRNI)
      IF (NC.NE.0) GO TO 70
C
C        DERIVATIVE CONVERGENCE TEST AT WALL
C
      DIF1=ABS(1.0-T2N1/T2N(1))
      IF (IADW.NE.0) DIF1=ABS(1.0-T21/T2(1))
70    CONTINUE
      IF (X.GT.0.00010) GO TO 90
      DO 80 N=1,IE
      T1(N)=T2(N)
      T1N(N)=T2N(N)
80    T1NN(N)=T2NN(N)
90    CONTINUE
      DO 110 N=1,IE
      IF (NC.EQ.0) GO TO 100
C
C        ALL POINTS CONVERGENCE TEST
C
      DIFF=ABS(1.0-TC(N)/T2(N))
      IF (DIFF.GT.DIF) DIF=DIFF
100   CONTINUE
      TC(N)=T2(N)*CRNI+T1(N)*CCRNI
      TCN(N)=T2N(N)*CRNI+T1N(N)*CCRNI
      IF (NEQIL.NE.0) GO TO 110
C
C        PERFECT GAS
C
      TH(N)=ALP1*TC(N)-HALP*FC(N)**2
      ROROE(N)=1.0/TH(N)
      THP(N)=ALP1*TCN(N)-ALP*FC(N)*FCN(N)
110   CONTINUE
      IF (NEQIL.EQ.0) GO TO 120
C
C        EQUILIBRIUM GAS
C
      CALL PROP
      CALL DERIV3 (TH,XN,IE,1,THP)
120   CONTINUE
      Y(1)=0.0
      YY(1)=0.0
      DO 130 N=2,IE
      Y(N)=Y(N-1)+PNC*(1.0/ROROE(N)+1.0/ROROE(N-1))*DN(N-1)/2.0
      YY(N)=Y(N)*EPSVD
130   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EQLDTA
C
C     SUBROUTINE EQLDTA CALLS SUBROUTINES EDGE1, INTRP5, AND SLOW.
C
C     SUBROUTINE EQLDTA IS CALLED BY SUBROUTINE EDGE.
C
C     SUBROUTINE EQLDTA CALCULATES THE STAGNATION, EXIT, AND REFERENCE
C     CONDITIONS FOR A NOZZLE.  THIS SUBROUTINE IS CALLED ONLY FOR
C     EQUILIBRIUM GAS SOLUTIONS WHEN THE PRESSURE DISTRIBUTION IS
C     OBTAINED BY THE PROGRAM FROM AN ISENTROPIC GAS EXPANSION.
C
C
C      NT1----EXPANSION DATA *****
C      NT2----GAS TABLE ****
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
      DIMENSION A11(5), XM1(5), U1(5), P1(5), H1(5), ZZ(9)
C
C
      NERR=0
      READ (NT1) A,XM,U,P,H
      PSTAG=2116.2240*10.0**P/144.0
      HSTAG=10.0**H*RGAS*1.8
      ZZ(2)=H
      DO 10 J=1,3
      IF (J.EQ.2) GO TO 10
      CALL SLOW (P,ZZ,2,J,NT2,NV,NERR)
   10 CONTINUE
      TSTAG=ZZ(1)*1.80
      RHOSTG=10.0**ZZ(3)*RHOSTD
C
C     NOZZLE EXIT CONDITIONS
C
      AEXIT=(RZ(IIMAX)/RZ(ITH))**2
   20 READ (NT1) A,XM,U,P,H
      IF (XM.LE.1.0) GO TO 20
      IF (A.LT.AEXIT) GO TO 20
      DO 30 J=1,3
      BACKSPACE NT1
   30 CONTINUE
      DO 40 J=1,5
      READ (NT1) A11(J),XM1(J),U1(J),P1(J),H1(J)
   40 CONTINUE
      CALL INTRP5 (AEXIT,A11,XM1,5,1,1,XMA)
      CALL INTRP5 (AEXIT,A11,U1,5,1,1,UFS)
      CALL INTRP5 (AEXIT,A11,P1,5,1,1,P)
      CALL INTRP5 (AEXIT,A11,H1,5,1,1,H)
      ZZ(2)=H
      DO 50 J=1,5
      IF (J.EQ.2) GO TO 50
      CALL SLOW (P,ZZ,2,J,NT2,NV,NERR)
   50 CONTINUE
```

```
      PEXIT=P
      HEXIT=H
      PFS=2116.2240*10.0**P/144.0
      HFS=10.0**H*RGAS*1.8
      TFS=ZZ(1)*1.80
      RHOFS=10.0**ZZ(3)*RHOSTD
      XMUFS=ZZ(4)
      CX=ZZ(5)*RGAS
C
C     REFERENCE CONDITIONS
C
      UREF=UFS
      RHOREF=RHOFS
      PREF=RHOFS*UFS**2
      TREF=UFS**2/CX
      HREF=UFS**2
      XMUREF=(518.60+198.60)/(TREF+198.60)*(TREF/518.60)**1.50*3.719D-07
      XMUINF=XMUFS/XMUREF
      T10=TSTAG/TREF
      HE=HSTAG/HREF
      REWIND NT1
      CALL EDGE1
      RETURN
C
C
C
      END
```

```
      SUBROUTINE GEOM
C
C     SUBROUTINE GEOM CALLS SUBROUTINES BLUNT1, NOZLE1, AND WDGFP1.
C
C     SUBROUTINE GEOM IS CALLED BY MAIN AND SUBROUTINE INIT.
C
C     SUBROUTINE GEOM OBTAINS EDGE PROPERTIES FOR SPECIFIED GEOMETRY
C     FOR THE INITIAL VALUE OF X.
C
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
C
C
C     NOSE=1 BLUNT BODY
C     NOSE=2 FLAT PLATE OR WEDGE
C     NOSE=3 NOZZLE
C
      GO TO (10,20,30), NOSE
10    CALL BLUNT1
      RETURN
20    CALL WDGFP1
      RETURN
30    CALL NOZLE1
      RETURN
      END
```

```
      SUBROUTINE INIT
C
C     SUBROUTINE INIT CALLS SUBROUTINES DELTAS, GEOM, INTER5, AND
C     REFSUB.
C
C     SUBROUTINE INIT IS CALLED BY MAIN.
C
C     THIS SUBROUTINE PROVIDES INITIALIZATION OF DATA FOR THE PROGRAM.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
      COMMON /COEFF3/ CF1,HGFAC1,HGFAC2,QW,SUM
      COMMON /COMWLL/ A1B,BO,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /STRT/ KRSTRT,NRSTRT
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
      R=1.98674*778.158*32.174/CMSTD
      RGAS=R
      RHOSTD=2116.2240/(RGAS*491.670)
      XM=XMA
      XSTA(IIMAX+1)=-1.0
C     NEGATIVE XSTA TERMINATES SOLUTION
      KTPW=NRSTRT
      NEQL=NEQIL
      KEP=0
      NEQIL=0
      XJAY=XJFAC
      CSTAR=198.60
      IF (NOSE.EQ.3) CALL GEOM
      IF (KFS.NE.0) CALL REFSUB
      CF=1.00
      G=GAMEFF
      CX=R*(G/(G-1.0))
      IF (UFS.EQ.0.0) UFS=XMA*(G*TFS*R)**0.50
      IF (KTW.NE.0) BO=TWZ(1)/TSTAG
      VW=0.0
      KSTOP=0
      IPRNT=1
      PR=PRL
      QW=0.0
      HGFAC1=0.0
      HGFAC2=0.0
      IF (KFS.NE.0) HGFAC1=(RHOFS*UFS*CX)/(778.0*144.0)
      IF (KFS.NE.0) HGFAC2=RHOFS*UFS*32.1740/144.0
      SUM=0.0
      Z=0.00
      X=0.00
      XI=0.00
      XI2=2.00*XI
      XIOLD=XI
      XOLD=X
      DXOLD=0.0
      DS=1.00
```

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      CCRNI=1.00-CRNI
      E1=0.00
      FF=0.00
      NIT=0
      NITTOT=0
      ISTOP=0
      CHIMAX=0.0
      GAMMA=1.
      IF (LAMTRB.EQ.1) GAMMA=0.0
      XIBAR=0.
      IM=IE-1
      JJ=1
      CALL GEOM
      DX1=DX
      IF (NOSE.EQ.1) GO TO 20
      IF (LAMTRB.NE.2) GO TO 20
      X=.00010
      DX=X
      XOLD=X
      IF (KTW.EQ.0) GO TO 10
      JT=3
      CALL INTER5 (X,XSTA(JT-2),XSTA(JT-1),XSTA(JT),XSTA(JT+1),XSTA(JT+2
     1),TWZ(JT-2),TWZ(JT-1),TWZ(JT),TWZ(JT+1),TWZ(JT+2),TW)
      BO=TW/TSTAG
   10 CONTINUE
      CALL DELTAS
      UERO2=UE*RO**(2.0*XJFAC)
      XMUEP=XMUE
      ROWEP=ROWE
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MACH (X,R,RT,ZTH)
C
C     SUBROUTINE MACH CALLS SUBROUTINE INTER5.
C
C     SUBROUTINE MACH IS CALLEC BY SUBROUTINES BLUNT1, BLUNT2, NOZLE1,
C     AND NOZLE2.
C
C     SUBROUTINE MACH GENERATES A TABLE OF MACH NUMBERS AS A FUNCTION
C     OF AREA RATIOS FOR A SPECIFIED VALUE OF THE RATIO OF SPECIFIC
C     HEATS.  THE SUBROUTINE ALSO INTERPOLATES IN THIS TABLE FOR THE
C     MACH NUMBER WHICH CORRESPONDS TO THE LOCAL RADIUS AND AREA RATIO.
C
C     IF A PRESSURE DISTRIBUTION IS INPUT, THE TABLE OF MACH NUMBERS
C     IS GENERATED FROM THE INPUT VALUES OF PRESSURE.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
C
      DIMENSION AR1(765), XM1(765)
C
C
      IF (KPD.NE.0) GO TO 70
      IF (JKL.EQ.235) GO TO 40
C
```

```
C          MACH NUMBER FROM AREA RATIO
C
      N=1
      XM1(1)=0.0
      DXM1=0.010
      A=G+1.0
      B=G-1.0
      C=A/(2.0*B)
      N=2
   10 XM1(N)=XM1(N-1)+DXM1
      FAC=(2.0+B*XM1(N)**2)/A
      FAC1=FAC**C
      AR1(N)=FAC1/XM1(N)
      AR1(N)=1.0/AR1(N)
      IF (XM1(N).GE.2.0) DXM1=0.050
      N=N+1
      IF (N.NE.100) GO TO 30
      DO 20 J=1,10
      XM1(N)=1.0
      AR1(N)=1.0
      N=N+1
   20 CONTINUE
   30 CONTINUE
      IF (N.GT.765) JKL=235
      IF (N.GT.765) GO TO 40
      GO TO 10
   40 AR=(R/RT)**2
      AR=1.0/AR
C
C     THE IF STATEMENT BELOW SPECIFIES THAT THE AREA RATIO CORRESPONDS
C     TO A SUBSONIC OR A SUPERSONIC MACH NUMBER
C
      IF (X.EQ.ZTH) XM=1.0
      IF (X.EQ.ZTH) GO TO 60
      IF (X.LE.ZTH) J=1
      IF (X.GT.ZTH) J=111
   50 J=J+1
      IF (X.LE.ZTH.AND.AR.GT.AR1(J)) GO TO 50
      IF (X.GT.ZTH.AND.AR.LT.AR1(J)) GO TO 50
      IF (J.LT.3) J=3
      IF (J.GT.763) J=763
      IF (X.LT.ZTH.AND.J.GT.98) J=98
      CALL INTER5 (AR,AR1(J-2),AR1(J-1),AR1(J),AR1(J+1),AR1(J+2),XM1(J-2
     1),XM1(J-1),XM1(J),XM1(J+1),XM1(J+2),XM)
   60 CONTINUE
      RETURN
   70 CONTINUE
C
C          MACH NUMBER FROM P/PSTAG
C
      IF (JKL.EQ.235) GO TO 90
      FAC=1.0
      IF (KSTRT.NE.1) FAC=1.0/P10
      DO 80 J=1,IIMAX
      XM1(J)=(2.0/(G-1.0)*((PZ(J)*FAC)**(-(G-1.0)/G)-1.0))**0.5
   80 CONTINUE
      JKL=235
   90 CONTINUE
      J=0
  100 J=J+1
      IF (ZA(J).LT.X) GO TO 100
      IF (J.LT.3) J=3
      IF (J.GT.(IIMAX-2)) J=IIMAX-2
      CALL INTER5 (X,ZA(J-2),ZA(J-1),ZA(J),ZA(J+1),ZA(J+2),XM1(J-2),XM1(
     1J-1),XM1(J),XM1(J+1),XM1(J+2),XM)
      RETURN
      END
```

```
      SUBROUTINE MOMENT
C
C     SUBROUTINE MOMENT CALLS SUBROUTINES EFFMU AND SOLVE.
C
C     SUBROUTINE MOMENT IS CALLED BY MAIN.
C
C     THIS SUBROUTINE PROVIDES THE SOLUTION FOR THE MOMENTUM EQUATION.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
      COMMON /COEFF/ CFBAR,CFBREX,CFE,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,
     1CHREY,DEL,DELST,DELTA,DSTARK,DSTRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,R
     2EX,STE,STINF,THET
      COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
C
C
      MOMEGY=1
      CALL EFFMU (LAMTRB,MOMEGY,KEP,DSTARK)
C
C         MOMENTUM EQUATION SOLUTION
C
      DO 10 N=2,IM
      A1(N)=CP(N)/C(N)+A0BP(N)/A0B(N)-VC(N)/A0(N)
      A2(N)=-BETA*FC(N)/A0(N)
      A3(N)=BETA/(A0(N)*ROROE(N))
      A4(N)=-2.0*XI*FC(N)/A0(N)
10    CONTINUE
      CALL SOLVE (F1NN,F1N,F1,F2NN,F2N,F2,E1,FF,CRNI)
      IF (NC.NE.0) GO TO 20
C
C        DERIVATIVE CONVERGENCE TEST AT WALL
C
      DIF=ABS(F2N(1)-F2N1)
      DIF2=DIF/F2N(1)
      DIF=AMAX1(DIF1,DIF2)
20    CONTINUE
      IF (X.GT.0.00010) GO TO 40
      DO 30 N=1,IE
      F1(N)=F2(N)
      F1N(N)=F2N(N)
30    F1NN(N)=F2NN(N)
40    CONTINUE
      IF (NC.EQ.0) GO TO 60
      DO 50 N=2,IE
C
C        ALL POINTS CONVERGENCE TEST
C
      DIFF=ABS(1.0-FC(N)/F2(N))
      IF (DIFF.GT.DIF) DIF=DIFF
50    CONTINUE
60    CONTINUE
      DO 70 N=1,IE
      FCP(N)=(F2(N)-F1(N))/DS
      FCN(N)=F2N(N)*CRNI+F1N(N)*CCRNI
70    FC(N)=F2(N)*CRNI+F1(N)*CCRNI
      RETURN
      END
```

```
      SUBROUTINE NOZLE1
C
C     SUBROUTINE NOZLE1 CALLS SUBROUTINES DENSIT, EDGE, FD5, INTRP5,
C     MACH, SLOW, VISCO, AND ZRO.
C
C     SUBROUTINE NOZLE1 IS CALLED BY SUBROUTINE GEOM.
C
C     SUBROUTINE NOZLE1 CALCULATES THE EDGE AND REFERENCE PROPERTIES
C     FOR A NOZZLE AT THE INITIAL VALUE OF X.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /SUTH/ CPRIM
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
      DIMENSION ZZ(9), XMJ(5), UJ(5), PJ(5), HESTJ(5)
C
C
C     FIRST CALL OF GEOM AND NOZLE1 SPECIFIES THE NOZZLE GEOMETRY AND -
C.    COMPUTES THE TABLE OF EDGE PROPERTIES FOR EITHER A SPECIFIED-
C     PRESSURE DISTRIBUTION ALONG THE NOZZLE AXIS OR AN IDEAL EXPANSION
C
      IF (NEQIL.EQ.1) GO TO 40
C
C        PERFECT GAS
C
      IF (IJK.EQ.231) GO TO 20
      CALL MACH (ZA(IIMAX),RZ(IIMAX),RZ(ITH),ZA(ITH))
      XMA=XM
      XMACHS=XMA**2
      TFS=TSTAG/(1.0+(G-1.0)/2.0*XMACHS)
      CPRIME=CSTAR/((G-1.00)*XMACHS*TFS)
      CPRIM=CPRIME
      T10=0.50+1.00/(XMA*XMA*(G-1.00))
      P10=(1.0+(G-1.0)/2.0*XMA**2)**(G/(G-1.0))/(G*XMA**2)
      DO 10 J=1,IIMAX
      CALL MACH (ZA(J),RZ(J),RZ(ITH),ZA(ITH))
      PE1=P10/((1.0+(G-1.0)/2.0*XM**2)**(G/(G-1.0)))
      PZ(J)=PE1
      TE1=T10/(1.0+(G-1.0)/2.0*XM**2)
      UEZ(J)=SQRT(2.0*(T10-TE1))
 10   CONTINUE
      IJK=231
      RETURN
 20   CONTINUE
      CALL ZRO (IIMAX,X,Z,RO)
      CALL MACH (Z,RO,RZ(ITH),ZA(ITH)).
      PE=P10/((1.0+(G-1.0)/2.0*XM**2)**(G/(G-1.0)))
      TE=T10/(1.0+(G-1.0)/2.0*XM**2)
      CALL DENSIT (ROWE,PE,TE)
      CALL VISCO (OMEGA,TE,XMUE)
      UE=SQRT(2.0*(T10-TE))
      WRITE (6,130) T10,P10
      WRITE (6,140) UE,TE,PE
      XMUSO=XMUE
      XMUEP=XMUE
      ROWEP=ROWE
      PESO=PE
      TESO=TE
      PNC=0.0
      BETA=0.0
```

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```
      UERO2=UE*RO**(2.0*XJFAC)
      J=0
   30 J=J+1
      IF (UE.GT.UEZ(J)) GO TO 30
      IF (J.LT.3) J=3
      IF (J.GT.(IIMAX-2)) J=IIMAX-2
      CALL FD5 (X,XSTA(J-2),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),UEZ(J-
     12),UEZ(J-1),UEZ(J),UEZ(J+1),UEZ(J+2),DUEDS)
      PP=-ROWE*UE*DUEDS
      ALP=UE**2/TE
      HE=T10
      RETURN
   40 CONTINUE
C
C        EQUILIBRIUM GAS
C
      IF (KPD.NE.0) GO TO 60
   50 CONTINUE
      CALL ZRO (IIMAX,X,Z,RO)
      CALL EDGE
      P10=PSTAG/PREF*144.0
      T10=TSTAG/TREF
      HE=HSTAG/HREF
      PNC=0.0
      BETA=0.0
      XMUSO=XMUE
      XMUEP=XMUE
      ROWEP=ROWE
      PESO=PE
      TESO=TE
      UERO2=UE*RO**(2.0*XJFAC)
      ALP=UE**2/HESTAT
      WRITE (6,130) T10,P10
      WRITE (6,140) UE,TE,PE
      RETURN
   60 CONTINUE
      DO 70 J=1,IIMAX
      PZ(J)=PZ(J)*G*XMA**2*PFS
   70 CONTINUE
      PATMS=PZ(IIMAX)*144.0/2116.2240
      PL=ALOG10(PATMS)
      J=0
   80 J=J+1
      READ (NT1) DUM,XMI,UI,PI,HI
      IF (PI.GT.PL) GO TO 80
      DO 90 J=1,3
      BACKSPACE NT1
   90 CONTINUE
      DO 100 J=1,5
      READ (NT1) DUM,XMJ(J),UJ(J),PJ(J),HESTJ(J)
  100 CONTINUE
      CALL INTRP5 (PL,PJ,XMJ,5,1,1,XMA)
      CALL INTRP5 (PL,PJ,UJ,5,1,1,UFS)
      CALL INTRP5 (PL,PJ,HESTJ,5,1,1,HFSL)
      ZZ(2)=HFSL
      DO 110 J=1,6
      IF (J.EQ.2) GO TO 110
      CALL SLOW (PL,ZZ,2,J,NT2,NV,NERR)
  110 CONTINUE
      PFS=PZ(IIMAX)
      HFS=10.0**ZZ(2)*RGAS*1.8
      TFS=ZZ(1)*1.80
      RHOFS=10.0**ZZ(3)*RHOSTD
      XMUFS=ZZ(4)
      CX=ZZ(5)*RGAS
      PREF=RHOFS*UFS**2
      REINF=RHOFS*UFS/XMUFS/SCF
      TREF=UFS**2/CX
      RHOREF=RHOFS
      UREF=UFS
      HREF=UFS**2
      REWIND NT1
      XMUREF=(518.60+198.60)/(TREF+198.60)*(TREF/518.60)**1.50*3.719E-07
C
```

```
C     XMUREF EVALUATED USING SUTHERLAND VISCOSITY LAW.XMUREF MAY BE CHOS
C     ARBITRARILY
C
      XMUINF=XMUFS/XMUREF
      READ (NT1) DUM,DUM1,DUM2,PL,HORL
      PSTAG=10.0**PL*2116.2240/144.0
      HSTAG=10.0**HORL*RGAS*1.80
      ZZ(2)=HORL
      DO 120 J=1,3
      IF (J.EQ.2) GO TO 120
      CALL SLOW (PL,ZZ,2,J,NT2,NV,NERR)
120   CONTINUE
      TSTAG=ZZ(1)*1.80
      RHOSTG=10.0**ZZ(3)*RHOSTD
      REWIND NT1
      GO TO 50
C
C
C
130   FORMAT (1H ,2X,4HT10=,E15.7,2X,4HP10=,E15.7/)
140   FORMAT (9H   UESO= ,E15.7,8H  TESO= ,E15.7,9H  PESO=   ,E15.7)
      END
```

```
      SUBROUTINE NOZLE2
C
C     SUBROUTINE NOZLE2 CALLS SUBROUTINES DENSIT, EDGE, FD5, MACH,
C     VISCO, AND ZRO.
C
C     SUBROUTINE NOZLE2 IS CALLED BY SUBROUTINE EGPROP.
C
C     SUBROUTINE NOZLE2 CALCULATES THE EDGE PROPERTIES FOR A NOZZLE AT
C     THE VALUES OF X AFTER THE INITIAL VALUE OF X.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),THZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
      IF (NEQIL.EQ.1) GO TO 20
C
C        PERFECT GAS
C
      CALL ZRO (IIMAX,X,Z,RO)
      CALL MACH (Z,RO,RZ(ITH),ZA(ITH))
      PE=P10/((1.0+(G-1.0)/2.0*XM**2)**(G/(G-1.0)))
      TE=T10/(1.0+(G-1.0)/2.0*XM**2)
      CALL VISCO (OMEGA,TE,XMUE)
      CALL DENSIT (ROWE,PE,TE)
      UE=SQRT(2.0*(T10-TE))
      J=0
10    J=J+1
      IF (UE.GT.UEZ(J)) GO TO 10
      IF (J.LT.3) J=3
      IF (J.GT.(IIMAX-2)) J=IIMAX-2
      CALL FD5 (X,XSTA(J-2),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),UEZ(J-
     12),UEZ(J-1),UEZ(J),UEZ(J+1),UEZ(J+2),DUEDS)
      PP=-ROWE*UE*DUEDS
      RETURN
20    CONTINUE
C
```

```
C        EQUILIBRIUM GAS
C
      CALL ZRO (IIMAX,X,Z,RO)
      CALL EDGE
      RETURN
      END
```

```
      SUBROUTINE PRFILE
C
C     SUBROUTINE PRFILE IS CALLED BY MAIN.
C
C     SUBROUTINE PRFILE GENERATES THE INITIAL VELOCITY AND ENTHALPY
C     PROFILES.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),RORDE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /COMWLL/ A1B,BO,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NMLCRD/ ADTEST,ETAINF,XKETA
C
C
      IF (XKETA.EQ.1.0) DETA1=ETAINF/FLOAT(IE-1)
      IF (XKETA.NE.1.0) DETA1=ETAINF*(XKETA-1.0)/(XKETA**IM-1.0)
      DN(1)=DETA1
      XN(1)=0.00
      Y(1)=0.0
      XN(IE)=ETAINF
      DO 10 N=1,IE
      DN(N+1)=XKETA*DN(N)
      XN(N+1)=XN(N)+DN(N)
      Y(N)=PNC*XN(N)
      F1(N)=1.0-EXP(-XN(N))
      F1N(N)=EXP(-XN(N))
      IF (F1N(N).LE.1.D-25) F1N(N)=0.0
      F1NN(N)=-F1N(N)
      F2NN(N)=F1NN(N)
      FC(N)=F1(N)
      FCN(N)=F1N(N)
      FCP(N)=0.0
      T1(N)=BO+(1.0-BO)*F1(N)
      T1N(N)=(1.0-BO)*F1N(N)
      T1NN(N)=(1.0-BO)*F1NN(N)
      TC(N)=T1(N)
      TCN(N)=T1N(N)
      VC(N)=VW-XN(N)
      C(N)=1.0
      CP(N)=0.0
      EPSPL(N)=0.0
      F2(N)=F1(N)
      YOVDEL(N)=0.0
      YOVTHT(N)=0.0
      CHI(N)=0.0
10    CONTINUE
      F1(IE)=1.0
      T1(IE)=1.0
      F2(IE)=1.0
      T2(IE)=1.0
      FC(IE)=1.0
      TC(IE)=1.0
```

```
      F1N(IE)=0.0
      F1NN(IE)=0.0
      T1N(IE)=0.0
      T1NN(IE)=0.0
      RETURN
      END
```

```
      SUBROUTINE PROP
C
C     SUBROUTINE PROP CALLS SUBROUTINE SLOW.
C
C     SUBROUTINE PROP IS CALLED BY MAIN AND SUBROUTINE ENERGY.
C
C     SUBROUTINE PROP CALCULATES THE THERMODYNAMIC AND TRANSPORT
C     PROPERTIES FOR EQUILIBRIUM GAS SOLUTIONS.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     1I,UREF,XMUREF
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
C
      DIMENSION ZZ(9), XMU(201)
C
C
      P=PE*PREF/2116.2240
      PL=ALOG10(P)
      DO 10 J=1,IE
      HSTGL=TC(J)*HE*HREF
      ULOC=FC(J)*UE*UREF
      HSTAT=HSTGL-ULOC**2/2.0
      HOR=HSTAT/(RGAS*1.8)
      IF (HOR.LT.35.0) HOR=(TC(IE)*HE*HREF-(FC(IE)*UE*UREF)**2/2.0)/(RGA
     1S*1.80)
      HL=ALOG10(HOR)
      ZZ(2)=HL
      CALL SLOW (PL,ZZ,2,1,NT2,NV,NERR)
      CALL SLOW (PL,ZZ,2,3,NT2,NV,NERR)
      CALL SLOW (PL,ZZ,2,4,NT2,NV,NERR)
      CALL SLOW (PL,ZZ,2,6,NT2,NV,NERR)
      ROROE(J)=10.0**ZZ(3)
      XMU(J)=ZZ(4)
      PREQ(J)=ZZ(6)
      TH(J)=ZZ(1)
10    CONTINUE
      THIE=TH(IE)
      RHOIE=ROROE(IE)
      XMUIE=XMU(IE)
      DO 20 J=1,IE
      TH(J)=TH(J)/THIE
      ROROE(J)=ROROE(J)/RHOIE
      XMU(J)=XMU(J)/XMUIE
      C(J)=ROROE(J)*XMU(J)
20    CONTINUE
      PR=PREQ(1)
      RETURN
      END
```

```
      SUBROUTINE READIN (KREADN)
C
C     SUBROUTINE READIN CALLS SUBROUTINES WRITE1 AND WRITE2.
C
C     SUBROUTINE READIN IS CALLED BY MAIN AND SUBROUTINE WRITE2.
C
C     SUBROUTINE READIN PROVIDES THE INPUT OF DATA FOR THE PROGRAM,
C     EITHER FROM CARDS OR FROM THE RESTART TAPE.  ALSO, THE RESTART
C     TAPE IS WRITTEN BY THIS SUBROUTINE.
C
C     WHEN THE INPUT DATA IS FROM THE RESTART TAPE, SUBROUTINES WRITE1
C     AND WRITE2 ARE CALLED TO WRITE THE DATA FROM THE LAST STATION
C     ( K = KRSTRT ).
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
      COMMON /COEFF/ CFBAR,CFBREX,CFE,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,
     1CHREY,DEL,DELST,DELTA,DSTARK,DSTRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,R
     2EX,STE,STINF,THET
      COMMON /COEFF2/ DELORF,DELOX,DSAXOR,DSTODL,DSTORF,DSTOTH,DSTOX,ROR
     1EFL,THODEL,THOREF,XOREFL,ZOREFL
      COMMON /COEFF3/ CF1,HGFAC1,HGFAC2,QW,SUM
      COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /NMLCRD/ ADTEST,ETAINF,XKETA
      COMMON /REF/ AMUREF,CMSTD,HREF,PDPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /STRT/ KRSTRT,NRSTRT
      COMMON /SUTH/ CPRIM
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
      DIMENSION LABEL(18)
C
      DATA LST/4HLAST/
C
C
      IF (KREADN.EQ.3) GO TO 60
      IF (KREADN.EQ.2) GO TO 50
C
      WRITE (6,70)
C
      READ (5,80) KRSTRT,NRSTRT
      IF (NRSTRT.EQ.0) NRSTRT=2
      READ (5,90) NT1,NT2,NT3,NT4
      KSTRT=KRSTRT+1
      IF (KSTRT.EQ.1) GO TO 20
      WRITE (6,100) KRSTRT
C
```

```
C          READ RESTART TAPE
C
      READ (NT3) LABEL
      READ (NT3) CQZ,PZ,RZ,TWZ,UEZ,XSTA,ZA,IPR,IPRFL
      WRITE (6,120) LABEL
10    READ (NT3) K,KTPW
      READ (NT3)
      READ (NT3)
      IF (K.NE.(KRSTRT-(KTPW-K))) GO TO 10
      READ (NT3) K,KTPW
      READ (NT3) AO,AOB,AOBP,C,CP,CHI,DN,EPSPL,F2,F2N,F2NN,FC,FCN,FCP,PR
     1EQ,ROROE,T2,T2N,T2NN,TC,TCN,TH,THP,VC,XN,Y,YOVDEL,YOVTHT,YY
      READ (NT3) CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC,CFBAR,CFBREX,CF
     1E,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,CHREY,DEL,DELST,DELTA,DSTARK,D
     2STRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,REX,STE,STINF,THET,DELORF,DELOX
     3,DSAXOR,DSTODL,DSTORF,DSTOTH,DSTOX,ROREFL,THODEL,THOREF,XOREFL,ZOR
     4EFL,CF1,HGFAC1,HGFAC2,QW,SUM,A1B,BO,E1,FF,F2N1,HW,T8,THN1,TH1,TW,T
     52N1,T21,VW,IADW,KTW,CF,PR,PRL,PRT,ALP,ALP1,BETA,DUEDS,G,GAMEFF,HAL
     6P,HE,HESTAT,PE,PESO,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO
     7,XM,XMUE,XMUEP,XMUSO,AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS
     8,TIN,UFS,XMA,XMUFS,ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF
     9,THSHOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL,CQ,CQ1,FINJ,KCQ,KINJ,
     $KNOINJ,KPGRAD,IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQL
     $,NIT,NIT1,NIT2,NIT3,NOSE,II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,K
     $STOP,KDUM,KTPW,KTRNSN,LAMTRB,NITTOT,ADTEST,ETAINF,XKETA,AMUREF,CMS
     $TD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF1,UREF,XMUREF,HSTAG,P10
     $,PSTAG,RHOSTG,T10,TSTAG,CPRIM,NT1,NT2,NT3,NT4,NV,ATR,CHICRT,CHIMAX
     $,GAMMA,XBAR,XIBAR,KTRANS,CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
      KRITE1=1
      CALL WRITE1 (KRITE1)
      CALL WRITE2
      RETURN
20    CONTINUE
C
C
      READ (5,110) LABEL
C
C          TITLE CARD
C
      WRITE (6,120) LABEL
      READ (5,90) NOSE,LAMTRB,KTRANS,KTRNSN
      READ (5,90) IADW,KTW,KPD,KFS
      READ (5,90) NIT1,NIT2,NIT3,NC
      READ (5,80) IE,KEND,IIMAX,ITH
      READ (5,90) KADETA,KL,IPFL,IPRINT
      READ (5,90) KVSLAW,KPGRAD,NV,NEQIL
      READ (5,80) KCQ,KINJ,KNOINJ
      READ (5,130) CHICRT,XBAR,ATR,CQ,FINJ
      READ (5,130) TFS,UFS,XMA,REINF
      READ (5,130) BO,PRL,PRT,OMEGA
      READ (5,130) XK1,XK2,CONVRG,ADTEST
      READ (5,130) DX,CRNI,XKETA,ETAINF,REFLEN
      READ (5,130) XJFAC,ANGLE,THSHOK,G
      READ (5,130) TSTAG,TREF1,PSTAG,PFS,AMUREF,SCF
      READ (5,130) POPRIM,CMSTD,GAMEFF,DXMAX
      READ (5,140) (IPR(J),J=1,IPRINT)
      READ (5,140) (IPRFL(J),J=1,IPFL)
      J=0
30    J=J+1
      READ (5,150) ZA(J),XSTA(J),RZ(J),PZ(J),TWZ(J),CQZ(J),LSTC
      IF (LSTC.EQ.LST) GO TO 40
      GO TO 30
40    IIMAX=J
      IPR(IPRINT+1)=IIMAX+1
      IF (NIT1.EQ.0) NIT1=3
      IF (NIT1.LT.0) NIT1=0
      IF (NIT2.EQ.0) NIT2=6
      IF (NIT3.EQ.0) NIT3=9
      IF (KL.EQ.0) KL=2
      IF (ADTEST.EQ.0.0) ADTEST=0.0010
      IF (CONVRG.EQ.0.0) CONVRG=0.0010
      IF (PRL.EQ.0.0) PRL=0.70
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      IF (ETAINF.EQ.0.0) ETAINF=100.0
      IF (XKETA.EQ.0.0) XKETA=1.09
      IF (IADW.NE.0) BO=1.0
      IF (LAMTRB.EQ.0) LAMTRB=1
      IF (NOSE.EQ.0) NOSE=1
      IF (XK1.EQ.0.0) XK1=0.40
      IF (XK2.EQ.0.0) XK2=0.01680
      IF (KINJ.GT.IIMAX) KINJ=IIMAX
      IF (KNOINJ.GT.IIMAX) KNOINJ=IIMAX
      IF (KTRNSN.GT.IIMAX) KTRNSN=IIMAX
      IF (KTRNSN.EQ.0) KTRNSN=IIMAX
C
C
      RETURN
50    CONTINUE
C
C        WRITE INITIAL DATA ON RESTART TAPE
C
      WRITE (NT3) LABEL
      WRITE (NT3) CQZ,PZ,RZ,TWZ,UEZ,XSTA,ZA,IPR,IPRFL
      RETURN
60    CONTINUE
      KTPW=KTPW+NRSTRT
C
C        WRITE STATION DATA ON RESTART TAPE
C
      WRITE (NT3) K,KTPW
      WRITE (NT3) AO,AOB,AOBP,C,CP,CHI,DN,EPSPL,F2,F2N,F2NN,FC,FCN,FCP,P
     1REQ,ROROE,T2,T2N,T2NN,TC,TCN,TH,THP,VC,XN,Y,YOVDEL,YOVTHT,YY
      WRITE (NT3) CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC,CFBAR,CFBREX,C
     1FE,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,CHREY,DEL,DELST,DELTA,DSTARK,
     2DSTRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,REX,STE,STINF,THET,DELORF,DELO
     3X,DSAXOR,DSTODL,DSTORF,DSTOTH,DSTOX,ROREFL,THODEL,THOREF,XOREFL,ZO
     4REFL,CF1,HGFAC1,HGFAC2,QW,SUM,A1B,BO,E1,FF,F2N1,HW,TB,THN1,TH1,TW,
     5T2N1,T21,VW,IADW,KTW,CF,PR,PRL,PRT,ALP,ALP1,BETA,DUEDS,G,GAMEFF,HA
     6LP,HE,HESTAT,PE,PESO,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UES
     7O,XM,XMUE,XMUEP,XMUSO,AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TF
     8S,TIN,UFS,XMA,XMUFS,ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SC
     9F,THSHOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL,CQ,CQ1,FINJ,KCQ,KINJ
     $,KNOINJ,KPGRAD,IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     $L,NIT,NIT1,NIT2,NIT3,NOSE,II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,
     $KSTOP,KSTRT,KTPW,KTRNSN,LAMTRB,NITTOT,ADTEST,ETAINF,XKETA,AMUREF,C
     $MSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF1,UREF,XMUREF,HSTAG,P
     $10,PSTAG,RHOSTG,T10,TSTAG,CPRIM,NT1,NT2,NT3,NT4,NV,ATR,CHICRT,CHIM
     $AX,GAMMA,XBAR,XIBAR,KTRANS,CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
      WRITE (6,160) K,KTPW
      RETURN
C
C
C
70    FORMAT (24X,83HPROGRAM LTBLCEQL (LAMINAR AND/OR TURBULENT BOUNDARY
     1 LAYERS IN CHEMICAL EQUILIBRIUM)/60X,13HA PROGRAM FOR/22X,89H2-D A
     2ND AXISYMMETRIC NONREACTING PERFECT GAS AND EQUILIBRIUM CHEMICALLY
     3 REACTING LAMINAR,/42X,49HTRANSITIONAL AND/OR TURBULENT BOUNDARY-L
     4AYER FLOW/66X,2HBY/44X,46HE. C. ANDERSON,  E. W. MINER  AND  C. H.
     5 LEWIS/53X,27HAEROSPACE ENGINEERING DEPT./41X,51HVIRGINIA POLYTECH
     6NIC INSTITUTE AND STATE UNIVERSITY/56X,21HBLACKSBURG, VA. 24061/56
     7X,22HPHONE - (703)-552-6126/29X,76HPROGRAM DEVELOPED UNDER CONTRAC
     8T NAS1-9337 WITH NASA LANGLEY RESEARCH CENTER)
80    FORMAT (4(7X,I3))
90    FORMAT (4(8X,I2))
100   FORMAT (1HO,2X,28HPROGRAM RESTARTED.  KRSTRT =,I4)
110   FORMAT (18A4)
120   FORMAT (1HO,38X,18A4////)
130   FORMAT (6F12.6)
140   FORMAT (14I5)
150   FORMAT (6E12.6,A4)
160   FORMAT (1HO,26HRESTART TAPE WRITTEN.  K =,I4,2X,6HKTPW =,I4////)
      END
```

```
      SUBROUTINE REFSUB
C
C     SUBROUTINE REFSUB IS CALLED BY SUBROUTINE INIT.
C
C     CALCULATES  TSTAG FROM TFS AND XMA
C              OR TFS FROM TSTAG AND XMA
C
C                 UFS FROM TFS AND XMA
C
C                 PSTAG FROM PFS AND XMA
C              OR PFS FROM PSTAG AND XMA
C
C                 RHOFS FROM PFS AND TFS
C
C                 TREF1 AND AMUREF ARE USED TO CALCULATE REINF IF THE
C                 INPUT VALUE OF REINF IS 0.0
C
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
C
C
      IF (TSTAG.EQ.0.0.AND.TFS.NE.0.0) TSTAG=TFS*(1.0+(G-1.0)/2.0*XMA**2
     1)
      IF (TFS.NE.0.0) GO TO 10
      IF (TSTAG.NE.0.0) TFS=TSTAG/(1.0+(G-1.0)/2.0*XMA**2)
10    IF (XMA.NE.0.0) UFS=XMA*(G*TFS*R)**0.50
      IF (PFS.NE.0.0) PSTAG=PFS*(1.0+(G-1.0)/2.0*XMA**2)**(G/(G-1.0))
      IF (PFS.NE.0.0) GO TO 20
      IF (PFS.EQ.0.0.AND.PSTAG.NE.0.0) PFS=PSTAG/((1.0+(G-1.0)/2.0*XMA**
     12)**(G/(G-1.0)))
20    IF (PFS.NE.0.0) RHOFS=PFS*144.0/(R*TFS)
      IF (TREF1.NE.0.0.AND.AMUREF.NE.0.0) AMUINF=(TREF1+198.60)/(TFS+198
     1.60)*(TFS/TREF1)**1.50*AMUREF
      IF (TREF1.EQ.0.0) AMUINF=0.0
      IF (REINF.EQ.0.0) REINF=RHOFS*UFS/AMUINF/SCF
      RETURN
      END
```

```
      SUBROUTINE RHOMU (OMEGA,TH,C,DCDTH,VK)
C
C     SUBROUTINE RHOMU IS CALLED BY SUBROUTINE EFFMU.
C
C     SUBROUTINE RHOMU CALCULATES (RHO*MU)/(RHOE*MUE) CORRESPONDING TO
C     T/TE.
C     IF (OMEGA .EQ. 0) USES SUTHERLAND LAW
C     IF (OMEGA .NE. 0) USES POWER LAW
C
      IF (TH.LE.0.) TH=1.E-6
      IF (OMEGA.NE.0.) GO TO 10
C
C        SUTHERLAND LAW
C
      C=TH**0.5*(1.+VK)/(TH+VK)
      DCDTH=C*(VK-TH)/(2.*TH*(TH+VK))
      RETURN
C
C        POWER LAW
C
10    C=TH**(OMEGA-1.)
      DCDTH=(OMEGA-1.)*TH**(OMEGA-2.)
      RETURN
      END
```

```
      SUBROUTINE SLOW (XX,Z,I1,J1,IT,NV,NERR)
C
C     SUBROUTINE SLOW CALLS SUBROUTINE INTER5.
C
C     SUBROUTINE SLOW IS CALLED BY SUBROUTINES BLUNT1, EDGE, EQLDTA,
C     NOZLE1, PROP, WALL, AND WDGFP1.
C
C     EACH CALL TO THE SUBROUTINE SLOW RETURNS A THERMODYNAMIC OR
C     TRANSPORT PROPERTY VALUE.  THE VALUE IS OBTAINED BY INTERPOLATION
C     FROM THE DATA READ FROM THE GAS PROPERTY TAPE.  SUBROUTINE SLOW
C     IS USED ONLY FOR EQUILIBRIUM GAS SOLUTIONS.
C
C
      DIMENSION X(5), Y(5,6,100), Z(9), Y2(6,100)
C
C
      NERR=0
      IF (IJK.NE.301) XX1=10.0**20
      IF (IJK.NE.301) GO TO 10
      IF (XX.GT.X(2)) GO TO 10
      IF (XX.GE.X(4)) GO TO 50
      BACKSPACE IT
      BACKSPACE IT
      GO TO 20
10    REWIND IT
      IJK=301
20    READ (IT) X1,JJ
      READ (IT)
      IF (X1.GT.XX) GO TO 20
      DO 30 K=1,6
      BACKSPACE IT
30    CONTINUE
      DO 40 K=1,5
      READ (IT) X(K),JJ
      READ (IT) ((Y(K,I,L),L=1,100),I=1,NV)
40    CONTINUE
50    CONTINUE
      IF (XX.EQ.XX1) GO TO 80
      DO 70 I=1,NV
      DO 60 L=1,JJ
      CALL INTER5 (XX,X(1),X(2),X(3),X(4),X(5),Y(1,I,L),Y(2,I,L),Y(3,I,L
     1),Y(4,I,L),Y(5,I,L),Y2(I,L))
60    CONTINUE
70    CONTINUE
80    CONTINUE
      MM=0
90    MM=MM+1
      IF (Z(I1).LT.Y2(I1,MM)) GO TO 90
      IF (Y2(1,MM).LT.600.0) GO TO 100
      IF (MM.LT.3) MM=3
      IF (MM.GT.(JJ-2)) MM=JJ-2
      CALL INTER5 (Z(I1),Y2(I1,MM-2),Y2(I1,MM-1),Y2(I1,MM),Y2(I1,MM+1),Y
     12(I1,MM+2),Y2(J1,MM-2),Y2(J1,MM-1),Y2(J1,MM),Y2(J1,MM+1),Y2(J1,MM+
     22),Z(J1))
      XX1=XX
      RETURN
100   CONTINUE
      Z(J1)=Y2(J1,MM)-(Y2(J1,MM)-Y2(J1,MM-1))/(Y2(I1,MM)-Y2(I1,MM-1))*(Y
     12(I1,MM)-Z(I1))
      XX1=XX
      RETURN
      END
```

```
      SUBROUTINE SOLVE (W1NN,W1N,W1,W2NN,W2N,W2,E1,F11,CRNI)
C
C     SUBROUTINE SOLVE CALLS SUBROUTINE DERIV3.
C
C     SUBROUTINE SOLVE IS CALLED BY SUBROUTINES ENERGY AND MOMENT.
C
C     SUBROUTINE SOLVE CALCULATES THE SOLUTION FOR A GENERAL PARABOLIC
C     PARTIAL DIFFERENTIAL EQUATION WHEN THE P.D.E. IS REPRESENTED BY A
C     SYSTEM OF IMPLICIT, THREE POINT FINITE DIFFERENCE EQUATIONS.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
C
      DIMENSION E(201), F(201)
C
      DIMENSION W2NN(1), W2N(1), W2(1), W1NN(1), W1N(1), W1(1)
C
C
      E(1)=E1
      F(1)=F11
      DO 10 N=2,IM
      A=(2.00-A1(N)*DN(N))/(DN(N-1)*(DN(N)+DN(N-1)))*CRNI
      B=((-2.0+A1(N)*(DN(N)-DN(N-1)))/(DN(N)*DN(N-1))+A2(N))*CRNI+A4(N)/
     1DS
      CC=(2.00+A1(N)*DN(N-1))/(DN(N)*(DN(N)+DN(N-1)))*CRNI
      D=-(W1NN(N)+A1(N)*W1N(N)+A2(N)*W1(N))*(1.00-CRNI)-A3(N)+A4(N)*W1(N
     1)/DS
      E(N)=-CC/(B+A*E(N-1))
10    F(N)=(D-A*F(N-1))/(B+A*E(N-1))
      W2(IE)=1.00
      KON=IM
      DO 20 N=2,IE
      W2(KON)=E(KON)*W2(KON+1)+F(KON)
20    KON=KON-1
      CALL DERIV3 (W2,XN,IE,1,W2N)
      CALL DERIV3 (W2N,XN,IE,1,W2NN)
      RETURN
      END
```

```
      SUBROUTINE VISCO (OMEGA,T,XMU)
C
C     SUBROUTINE VISCO IS CALLED BY MAIN AND SUBROUTINES BLUNT1, BLUNT2,
C     NOZLE1, NOZLE2, AND WDGFP1.
C
C     SUBROUTINE VISCO CALCULATES MU/MUREF CORRESPONDING TO T/TREF.
C
C     IF (OMEGA .EQ. 0) USES SUTHERLAND LAW
C     IF (OMEGA .NE. 0) USES POWER LAW
C
      COMMON /SUTH/ CPRIM
C
      IF (OMEGA.NE.0.) GO TO 10
C
C        SUTHERLAND LAW
C
      XMU=(1.+CPRIM)/(T+CPRIM)*(T**1.5)
      RETURN
C
C        POWER LAW
C
10    XMU=T**OMEGA
      RETURN
      END
```

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```
      SUBROUTINE WALL
C
C     SUBROUTINE WALL CALLS SUBROUTINES INTER5 AND SLOW.
C
C     SUBROUTINE WALL IS CALLED BY MAIN.
C
C     THIS SUBROUTINE CALCULATES THE WALL BOUNDARY CONDITIONS.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
      COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     1O,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,R0,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
      DIMENSION ZZ(9)
C
C
      IF (KTW.EQ.0) GO TO 20
C
C        CALCULATE TW
C
      JT=0
10    JT=JT+1
      IF (X.GT.XSTA(JT)) GO TO 10
      IF (JT.LT.3) JT=3
      IF (JT.GT.(IIMAX-2)) JT=IIMAX-2
      CALL INTER5 (X,XSTA(JT-2),XSTA(JT-1),XSTA(JT),XSTA(JT+1),XSTA(JT+2
     1),TWZ(JT-2),TWZ(JT-1),TWZ(JT),TWZ(JT+1),TWZ(JT+2),TW)
      B0=TW/TSTAG
      IF (NEQIL.NE.0) TW=TW/TREF
20    CONTINUE
      IF (KCQ.EQ.0) GO TO 40
C
C        CALCULATE CQ
C
      IF (X.LE.XSTA(KINJ)) GO TO 40
      IF (X.GT.XSTA(KNOINJ)) GO TO 40
      JT=KINJ
30    JT=JT+1
      IF (X.GT.XSTA(JT)) GO TO 30
      IF (JT.LT.(KINJ+2)) JT=KINJ+2
      IF (JT.GT.(KNOINJ-2)) JT=KNOINJ-2
      CALL INTER5 (X,XSTA(JT-2),XSTA(JT-1),XSTA(JT),XSTA(JT+1),XSTA(JT+2
     1),CQZ(JT-2),CQZ(JT-1),CQZ(JT),CQZ(JT+1),CQZ(JT+2),CQ)
40    CONTINUE
      IF (R0.EQ.0.0) VW=CQ/(EPSVD*SQRT(ROWE*XMUE*DUEDS*(XJFAC+1.0)))
      IF (R0.NE.0.0) VW=CQ*SQRT(2.0*XI)/(XMUE*R0**XJFAC*ROWE*UE*EPSVD)
      IF (CQ.NE.0.0.AND.FINJ.NE.0.0) VW=-FINJ
      DIF=CONVRG
      IF (IADW.EQ.0) GO TO 60
C
C        ADIABATIC WALL
```

```
C
      T21=T2(1)
      C11=(DN(2)+2.0*DN(1))/(DN(1)*(DN(2)+DN(1)))
      GW=TC(2)*(DN(2)+DN(1))/(DN(2)*DN(1))-TC(3)*DN(1)/(DN(2)*(DN(1)+DN(
     12)))
      GW=GW/C11
      IF (NEQIL.NE.0) GO TO 50
C
C        PERFECT GAS
C
      TH(1)=GW*ALP1
      HW=TH(1)*HE
      T2(1)=GW
      TB=GW
      GO TO 80
50    CONTINUE
C
C        EQUILIBRIUM GAS
C
      PATMS=PE*PREF/2116.2240
      PLOG=ALOG10(PATMS)
      HW=GW
      HOR=HW*HREF/(R*1.8)
      HORL=ALOG10(HOR)
      ZZ(2)=HORL
      CALL SLOW (PLOG,ZZ,2,1,NT2,NV,NERR)
      TW=ZZ(1)/TREF*1.80
      TH(1)=TW/TE
      TB=HW
      GO TO 80
60    CONTINUE
C
C        NON-ADIABATIC WALL
C
      TW=B0*T10
      IF (NEQIL.NE.0) GO TO 70
C
C        PERFECT GAS
C
      HW=B0*HE
      TH(1)=TW/TE
      T2(1)=B0
      TB=B0
      GO TO 80
C
C        EQUILIBRIUM GAS
C
70    TSTR=TW*TREF/1.80
      ZZ(1)=TSTR
      PSTR=PE*PREF
      PATMS=PSTR/2116.2240
      PLOG=ALOG10(PATMS)
      CALL SLOW (PLOG,ZZ,1,2,NT2,NV,NERR)
      HORLOG=ZZ(2)
      H=10.0**HORLOG*R*1.8
      TH(1)=TW/TE
      HW=H/HREF
      T2(1)=HW/HE
      TB=T2(1)
80    CONTINUE
      TC(1)=TB
      RETURN
      END
```

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```
      SUBROUTINE WDGFP1
C
C     SUBROUTINE WDGFP1 CALLS SUBROUTINES DENSIT, SLOW, AND VISCO.
C
C     SUBROUTINE WDGFP1 IS CALLED BY SUBROUTINE GEOM.
C
C     SUBROUTINE WDGFP1 CALCULATES THE EDGE AND REFERENCE PROPERTIES
C     FOR A WEDGE OR A FLAT PLATE AT THE INITIAL VALUE OF X.
C
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /SUTH/ CPRIM
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
      DIMENSION ZZ(9)
C
C
      IF (NEQIL.EQ.1) GO TO 10
C
C        PERFECT GAS SOLUTION FOR A FLAT PLATE
C
      T10=0.50+1.00/(XMA*XMA*(G-1.00))
      P10=((((G+1.)*XMA*XMA)/2.)**(G/(G-1.0)))*(((G+1.0)/(2.0*G*XMA*XMA-
     1(G-1.0)))**(1.0/(G-1.0)))/(G*XMA*XMA)
      XMACHS=XMA**2
      UFS=XMA*(SQRT(G*TFS*R))
      CPRIME=CSTAR/((G-1.00)*XMACHS*TFS)
      CPRIM=CPRIME
      THSHOK=THSHOK*3.1415930/180.0
      XMTHSK=XMA*SIN(THSHOK)
      IF (THSHOK.EQ.0.0) XMTHSK=1.0
      XMTHSQ=XMTHSK**2
      SINTH=SIN(ANGLE*3.141590/180.0)
      ANGLE=ANGLE*3.141590/180.0
      UESO=(1.0-4.0*((XMTHSQ-1.0)*(G*XMTHSQ+1.0))/((G+1.0)**2*XMA**2*XMT
     1HSQ))**0.50
      TESO=(2.0*G*XMTHSQ-(G-1.0))*((G-1.0)*XMTHSQ+2.0)/((G-1.0)*XMA**2*(
     1G+1.0)**2*XMTHSQ)
      PESO=(2.0*G*XMTHSQ-(G-1.0))/((G+1.0)*G*XMA**2)
      TE=TESO
      PE=PESO
      UE=UESO
      WRITE (6,40) T10,P10
      WRITE (6,50) UESO,TESO,PESO
      CALL DENSIT (ROWE,PE,TE)
      CALL VISCO (OMEGA,TE,XMUE)
      ROESO=ROWE
      XMUSO=XMUE
      DUEDS=0.0
      PNC=0.0
      BETA=0.0
      PP=0.0
      RO=1.0
      ALP=UE**2/TE
      UERO2=UE
      XMUEP=XMUE
      ROWEP=ROWE
      HE=T10
      RETURN
   10 CONTINUE
C
```

```
C          EQUILIBRIUM GAS SOLUTION FOR A FLAT PLATE
C
      PATMS=PFS*144.0/2116.2240
      PL=ALOG10(PATMS)
      TDGRK=TFS/1.80
      ZZ(1)=TDGRK
      DO 20 J=2,6
      CALL SLOW (PL,ZZ,1,J,NT2,NV,NERR)
20    CONTINUE
      HFS=10.0**ZZ(2)*RGAS*1.8
      RHOFS=10.0**ZZ(3)*RHOSTD
      XMUFS=ZZ(4)
      CX=ZZ(5)*RGAS
      HSTAG=HFS+UFS**2/2.0
      PSTAG=PFS*144.0+RHOFS*UFS**2/2.0
      PATMS=PSTAG/2116.2240
      PL=ALOG10(PATMS)
      HOR=HSTAG/(RGAS*1.8)
      HORL=ALOG10(HOR)
      ZZ(2)=HORL
      DO 30 J=1,3
      IF (J.EQ.2) GO TO 30
      CALL SLOW (PL,ZZ,2,J,NT2,NV,NERR)
30    CONTINUE
      TSTAG=ZZ(1)*1.80
      RHOSTG=10.0**ZZ(3)*RHOSTD
      HREF=UFS**2
      UREF=UFS
      RHOREF=RHOFS
      TREF=UFS**2/CX
      PREF=RHOFS*UFS**2
      PATMS=PREF/2116.2240
      PL=ALOG10(PATMS)
      HOR=HREF/(RGAS*1.8)
      HORL=ALOG10(HOR)
      ZZ(2)=HORL
      CALL SLOW (PL,ZZ,2,4,NT2,NV,NERR)
      XMUREF=ZZ(4)
      XMUINF=XMUFS/XMUREF
      HE=HSTAG/HREF
      HESTAT=HFS/HREF
      P10=PSTAG/PREF
      T10=TSTAG/TREF
      PE=PFS/PREF*144.0
      TE=TFS/TREF
      ROWE=RHOFS/RHOREF
      XMUE=XMUFS/XMUREF
      TESO=TE
      PESO=PE
      UESO=UE
      ROESO=ROWE
      XMUSO=XMUE
      UERO2=UE
      XMUEP=XMUE
      ROWEP=ROWE
      DUEDS=0.0
      PNC=0.0
      BETA=0.0
      PP=0.0
      ALP=UE**2/HESTAT
      WRITE (6,40) T10,P10
      WRITE (6,50) UESO,TESO,PESO
      RETURN
C
C
C
40    FORMAT (1H ,2X,4HT10=,E15.7,2X,4HP10=,E15.7/)
50    FORMAT (9H   UESO= ,E15.7,8H  TESO= ,E15.7,9H   PESO=  ,E15.7)
      END
```

```
      SUBROUTINE WDGFP2
C
C     SUBROUTINE WDGFP2 IS CALLED BY SUBROUTINE EGPROP.
C
C     SUBROUTINE WDGFP2 PROVIDES THE EDGE PROPERTIES FOR A WEDGE OR A
C     FLAT PLATE AT THE VALUES OF X AFTER THE INITIAL VALUE OF X.
C
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
C
C
C         EDGE CONDITIONS CONSTANT AND COMPUTED IN WDGFP1
C
      TE=TESO
      UE=UESO
      ROWE=ROESO
      XMUE=XMUSO
      DUEDS=0.0
      RO=1.0
      Z=X*COS(ANGLE)
      RETURN
      END
```

```
      SUBROUTINE WRITE1 (KRITE1)
C
C     SUBROUTINE WRITE1 IS CALLED BY MAIN AND SUBROUTINE READIN.
C
C     THIS SUBROUTINE PROVIDES THE OUTPUT OF THE INPUT DATA AND THE
C     INITIALIZED DATA.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /CNVERG/ CONVRG,CCRNI,CRNI,DIF,DIFF,DIF1,DIF2,NC
      COMMON /COMWLL/ A1B,BO,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /FRSTRM/ AMUINF,CX,HFS,HEXIT,PEXIT,PFS,REINF,RHOFS,TFS,TIN,
     1UFS,XMA,XMUFS
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /NMLCRD/ ADTEST,ETAINF,XKETA
      COMMON /REF/ AMUREF,CMSTD,HREF,POPRIM,PREF,RHOREF,RHOSTD,TREF,TREF
     11,UREF,XMUREF
      COMMON /STAG/ HSTAG,P10,PSTAG,RHOSTG,T10,TSTAG
      COMMON /STRT/ KRSTRT,NRSTRT
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
      IF (KRITE1.EQ.2) GO TO 50
      WRITE (6,60) KRSTRT,NRSTRT,NT1,NT2,NT3,NT4
      WRITE (6,70) NOSE,LAMTRB,KTRANS,KTRNSN,IADW,KTW,KPD,KFS
      WRITE (6,80) NIT1,NIT2,NIT3,NC,IE,KEND,IIMAX,ITH
      WRITE (6,90) KADETA,KL,IPFL,IPRINT,KVSLAW,KPGRAD,NV,NEQL
      WRITE (6,100) KCQ,KINJ,KNOINJ,CQ,FINJ
      WRITE (6,110) TFS,UFS,XMA,REINF,TIN,XMUINF
```

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      IF (KFS.NE.0) WRITE (6,120) PFS,RHOFS,PSTAG,TSTAG
      IF (TREF1.GT.1.0) WRITE (6,130) TREF1,AMUREF,AMUINF
      WRITE (6,140) CHICRT,XBAR,ATR
      WRITE (6,150) BO,PRL,PRT,OMEGA,XK1,XK2
      WRITE (6,160) CONVRG,ADTEST,CRNI,XKETA,ETAINF
      WRITE (6,170) G,EPSVD,SCF,REFLEN
      WRITE (6,180) XJFAC,ANGLE,THSHOK,DX1,DXMAX
      WRITE (6,190) POPRIM,CMSTD,GAMEFF,RHOSTD
      WRITE (6,200) CX,R,XMA
      WRITE (6,210) (IPR(J),J=1,IPRINT)
      WRITE (6,220) (IPRFL(J),J=1,IPFL)
      WRITE (6,230)
      IF (KCQ.NE.0) GO TO 30
      DO 10 J=1,IIMAX
10    CQZ(J)=0.0
      DO 20 J=KINJ,KNOINJ
20    CQZ(J)=CQ
30    CONTINUE
      DO 40 J=1,IIMAX
C
      IF (NOSE.EQ.2) UEZ(J)=1.0
C
C     ********* FOR FLAT PLATE ****************************
C
      WRITE (6,240) J,ZA(J),RZ(J),XSTA(J),PZ(J),UEZ(J),TWZ(J),CQZ(J)
40    CONTINUE
      WRITE (6,250)
      RETURN
50    CONTINUE
      WRITE (6,260)
      WRITE (6,270)
      WRITE (6,280) PSTAG,TSTAG,HSTAG,RHOSTG
      WRITE (6,290) PFS,TFS,HFS,RHOFS
      WRITE (6,300) UFS,XMUFS,CX,REINF,XMA
      WRITE (6,310) PREF,TREF,HREF
      WRITE (6,320) RHOREF,XMUREF,UREF
      RETURN
C
C
C
60    FORMAT (1H0,2X,9HKRSTRT = ,I3,11H, NRSTRT = ,I2,8H, NT1 = ,I2,8H,
     1NT2 = ,I2,8H, NT3 = ,I2,8H, NT4 = ,I2)
70    FORMAT (1H0,2X,7HNOSE = ,I1,11H, LAMTRB = ,I1,11H, KTRANS = ,I1,11
     1H, KTRNSN = ,I3,9H, IADW = ,I1,8H, KTW = ,I1,8H, KPD = ,I1,8H, KFS
     2 = ,I1)
80    FORMAT (1H0,2X,7HNIT1 = ,I2,9H, NIT2 = ,I2,9H, NIT3 = ,I2,7H, NC =
     1 ,I2,7H, IE = ,I3,9H, KEND = ,I3,10H, IIMAX = ,I3,8H, ITH = ,I3)
90    FORMAT (1H0,2X,9HKADETA = ,I1,7H, KL = ,I1,9H, IPFL = ,I3,11H, IPR
     1INT = ,I3,11H, KVSLAW = ,I1,11H, KPGRAD = ,I1,7H, NV = ,I2,10H, NE
     2QIL = ,I1)
100   FORMAT (1H0,2X,6HKCQ = ,I1,9H, KINJ = ,I3,11H, KNOINJ = ,I3,7H, CQ
     1 = ,F12.6,9H, FINJ = ,F12.6)
110   FORMAT (1H0,2X,6HTFS = ,F12.6,8H, UFS = ,F12.6,9H, MINF = ,F9.5,10
     1H, REINF = ,1PE14.7,8H, TIN = ,0PF10.6,11H, XMUINF = ,F10.6)
120   FORMAT (1H0,2X,6HPFS = ,F10.6,10H, RHOFS = ,1PE13.6,10H, PSTAG = ,
     10PF12.4,10H, TSTAG = ,F12.6)
130   FORMAT (1H0,2X,8HTREF1 = ,F12.6,11H, AMUREF = ,1PE13.6,11H, AMUINF
     1 = ,E13.6)
140   FORMAT (1H0,2X,10HCHICRIT = ,F12.3,9H, XBAR = ,F12.6,8H, ATR = ,F1
     12.6)
150   FORMAT (1H0,2X,5HBO = ,F9.6,8H, PRL = ,F7.4,8H, PRT = ,F7.4,10H, O
     1MEGA = ,F7.4,8H, XK1 = ,F7.4,8H, XK2 = ,F9.6)
160   FORMAT (1H0,2X,9HCONVRG = ,F7.4,11H, ADTEST = ,F7.4,9H, CRNI = ,F7
     1.4,10H, XKETA = ,F7.4,11H, ETAINF = ,F7.2)
170   FORMAT (1H0,2X,8HCP/CV = ,F12.6,10H, EPSVD = ,F12.6,17H, SCALE FAC
     1TOR = ,F9.5,21H, REFERENCE LENGTH = ,F9.4)
180   FORMAT (1H0,2X,8HXJFAC = ,F7.4,10H, ANGLE = ,F9.6,11H, THSHOK = ,F
     19.6,7H, DX = ,F7.4,10H, DXMAX = ,F7.4)
190   FORMAT (1H0,2X,9HPOPRIM = ,F12.4,10H, CMSTD = ,F10.6,11H, GAMEFF =
     1 ,F9.6,11H, RHOSTD = ,F12.9)
200   FORMAT (1H0,2X,3HCP=,F8.2,1X,25HFT2/(SEC2-DEGREE RANKINE),3X,2HR=,
     1F8.2,1X,25HFT2/(SEC2-DEGREE RANKINE),3X,24HFREE STREAM MACH NUMBER
     2=,F8.4//////)
210   FORMAT (1H0,3X,3HIPR,4X,20I5,//(11X,20I5/))
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220   FORMAT (1H0,3X,5HIPRFL,2X,20I5,//(11X,20I5/))
230   FORMAT (1H0,3X,14HAXIAL POSITION,14X,2HZA,13X,2HRZ,12X,4HXSTA,10X,
     12HPZ,13X,3HUEZ,12X,3HTWZ,12X,3HCQZ/)
240   FORMAT (9X,I3,10X,7F15.6)
250   FORMAT (1H0)
260   FORMAT (1H1)
270   FORMAT (1H0,50X,30HBEGIN EQUILIBRIUM GAS SOLUTION)
280   FORMAT (1H0,2X,20HRESERVOIR CONDITIONS,5X,6HPSTAG=1PE12.6,1X,6HTST
     1AG=E12.6,1X,6HHSTAG=E12.6,1X,7HRHOSTG=E12.6)
290   FORMAT (1H0,2X,22HFREE STREAM CONDITIONS,5X,4HPFS=1PE12.6,1X,4HTFS
     1=E12.6,1X,4HHFS=E12.6,1X,6HRHOFS=E12.6)
300   FORMAT (1H0,2X,4HUFS=1PE12.6,1X,6HXMUFS=E12.6,1X,3HCP=E12.6,1X,6HR
     1EINF=1PE12.6,1X,4HXMA=E12.6)
310   FORMAT (1H0,2X,20HREFERENCE CONDITIONS5X,5HPREF=1PE12.6,1X,5HTREF=
     1E12.6,1X,5HHREF=E12.6)
320   FORMAT (1H0,2X,7HRHOREF=1PE12.6,1X,7HXMUREF=E12.6,1X,5HUREF=E12.6,
     1/////)
      END
```

```
      SUBROUTINE WRITE2
C
C     SUBROUTINE WRITE2 CALLS SUBROUTINE READIN.
C
C
C     SUBROUTINE WRITE2 IS CALLED BY MAIN AND SUBROUTINE READIN.
C
C     THIS SUBROUTINE CONTROLS THE OUTPUT AFTER A CONVERGED SOLUTION IS
C     OBTAINED.
C     COMPLETE SOLUTIONS ARE WRITTEN ONLY AT SELECTED VALUES OF X,
C     I. E.  AT X=XSTA(IPRFL).
C     ALL OTHER COMPUTED RESULTS ARE WRITTEN FOR EVERY VALUE OF X AT
C     WHICH A SOLUTION IS OBTAINED.
C     SUBROUTINE READIN IS CALLED TO WRITE THE RESTART TAPE WHEN
C     APPROPRIATE.
C
      COMMON /ARRAY1/ A0(101),A0B(101),A0BP(101),A1(101),A2(101),A3(101)
     1,A4(101),C1(101),C1N(101),C(101),CP(101),CHI(101),DN(102),DN2(102)
     2,EPSO(101),EPSPL(101),F1(101),F1N(101),F1NN(101),F2(101),F2N(101),
     3F2NN(101),FC(101),FCN(101),FCP(101),PREQ(101),ROROE(101),T1(101),T
     41N(101),T1NN(101),T2(101),T2N(101),T2NN(101),TC(101),TCN(101),TH(1
     501),THP(101),VC(101),XN(102),XN2(102),Y(101),YOVDEL(101),YOVTHT(10
     61),YY(101)
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
      COMMON /COEFF/ CFBAR,CFBREX,CFE,CFINF,CFRES,CFREY,CH,CHEDGE,CHOCF,
     1CHREY,DEL,DELST,DELTA,DSTARK,DSTRAX,HAFCF,HG,HG1,HG2,QDOT,RETHET,R
     2EX,STE,STINF,THET
      COMMON /COEFF2/ DELORF,DELOX,DSAXOR,DSTODL,DSTORF,DSTOTH,DSTOX,ROR
     1EFL,THODEL,THOREF,XOREFL,ZOREFL
      COMMON /COEFF3/ CF1,HGFAC1,HGFAC2,QW,SUM
      COMMON /COMWLL/ A1B,B0,E1,FF,F2N1,HW,TB,THN1,TH1,TW,T2N1,T21,VW,IA
     1DW,KTW
      COMMON /CFPR/ CF,PR,PRL,PRT
      COMMON /EDGPRP/ ALP,ALP1,BETA,DUEDS,G,GAMEFF,HALP,HE,HESTAT,PE,PES
     10,PP,RGAS,ROESO,ROWE,ROWEP,TE,TESO,UE,UERO2,UESO,XM,XMUE,XMUEP,XMU
     2SO
      COMMON /GEOME/ ANGLE,DS,DX,DX1,DXMAX,DXOLD,PNC,R,RO,REFLEN,SCF,THS
     1HOK,X,XI,XI2,XIOLD,XOLD,XJAY,XJFAC,Z,ZOL
      COMMON /INJECT/ CQZ(501),CQ,CQ1,FINJ,KCQ,KINJ,KNOINJ,KPGRAD
      COMMON /INTGR/ IE,IIMAX,IM,IPRNT,ISTOP,ITH,KL,KPD,KVSLAW,NEQIL,NEQ
     1L,NIT,NIT1,NIT2,NIT3,NOSE
      COMMON /NTEGER/ II,IPFL,IPRINT,JJ,K,KADETA,KEND,KEP,KFS,KSTOP,KSTR
     1T,KTPW,KTRNSN,LAMTRB,NITTOT
      COMMON /TAPENV/ NT1,NT2,NT3,NT4,NV
      COMMON /TRANS/ ATR,CHICRT,CHIMAX,GAMMA,XBAR,XIBAR,KTRANS
      COMMON /VSCSTY/ CSTAR,EPSVD,OMEGA,VK,XK1,XK2,XMUINF
C
C
```

```
      WRITE (6,70) X,XI,Z,ZOL,RO,BETA,PP,NIT,K
      WRITE (6,80) TE,UE,XM,ROWE,XMUE,PE,DUEDS
      WRITE (6,90) CF,QW,HG,EPSVD,CQ,KEP,NITTOT
      WRITE (6,100) F2N(1),F2N(3),F2NN(1),F2NN(3)
      IF (X.EQ.0.0) GO TO 10
      WRITE (6,110) CHIMAX,GAMMA,XIBAR
      IF (KFS.EQ.0) WRITE (6,120) REX
      IF (KFS.NE.0) WRITE (6,130) REX,QDOT,HG1,HG2
      WRITE (6,140) STE,STINF,CHEDGE,CH,CHREY
      WRITE (6,150) CFE,CFINF,CFBAR,CFBREX,CFREY
      ANALGY=CH/HAFCF
      WRITE (6,160) HAFCF,ANALGY,CHOCF
      WRITE (6,170) XOREFL,ZOREFL,ROREFL,DELOX,DSTOX
      WRITE (6,180) THOREF,DSTORF,DELORF,DSAXOR
      WRITE (6,190) THODEL,DSTODL,DSTOTH,DSTRAX
      WRITE (6,200) DSTARK,DELST,DEL,THET,RETHET
10    CONTINUE
      IF (K.EQ.1) GO TO 20
      IF (IPRFL(IPRNT).EQ.IPR(II-1)) GO TO 20
      IF (ABS(1.0-XOLD/XSTA(KTRNSN)).LE.1.E-6) GO TO 20
      GO TO 50
20    WRITE (6,210)
      DO 30 N=1,IE,KL
30    WRITE (6,220) XN(N),YY(N),YOVTHT(N),YOVDEL(N),FC(N),FCN(N),F2NN(N)
     1,EPSPL(N),AOBP(N),N
      WRITE (6,230)
      DO 40 N=1,IE,KL
      WRITE (6,220) XN(N),TC(N),TCN(N),VC(N),TH(N),ROROE(N),C(N),CP(N),C
     1HI(N),N
40    CONTINUE
      IF (K.NE.1) IPRNT=IPRNT+1
      WRITE (6,240)
50    CONTINUE
      IF (NT3.EQ.0) GO TO 60
      IF (KTPW.NE.K) GO TO 60
C
C        WRITE STATION DATA ON RESTART TAPE
C
      KREADN=3
      CALL READIN (KREADN)
60    CONTINUE
      IF (A1B.LT.0.0) WRITE (6,250)
      IF (A1B.LT.0.0) STOP
      RETURN
C
C
C
70    FORMAT (1H0,2X,3HS =,F10.5,1H,/16X,6H   XI =,F10.5,5H, Z =,F9.5,7H,
     1 Z/L =,F8.5,6H, RO =,F8.5,8H, BETA =,F8.5,6H, PP =,F12.5,8H, NIT =
     2 ,I3,5H, K =,I3)
80    FORMAT (1H0,2X,4HTE =,F8.5,6H, UE =,F8.5,9H, MACHE =,F11.7,8H, RHO
     1E =,F11.5,7H, MUE =,F8.5,6H, PE =,F11.5,9H, DUEDS =,F11.5)
90    FORMAT (1H0,2X,4HCF =,F11.5,6H, QW =,F11.5,6H, HG =,E14.6,9H, EPSV
     1D =,E13.6,6H, CQ =,E13.6,7H, KEP =,I3,10H, NITTOT =,I5)
100   FORMAT (1H0,2X,8HF2N(1) =,F12.6,10H, F2N(3) =,F12.6,11H, F2NN(1) =
     1,F12.6,11H, F2NN(3) =,F12.6)
110   FORMAT (1H0,2X,8HCHIMAX =,1PE13.6,9H, GAMMA =,E13.6,9H, XIBAR =,E1
     13.6)
120   FORMAT (1H0,2X,5HREX =,1PE12.5)
130   FORMAT (1H0,2X,5HREX =,1PE12.5,11X,18HWALL HEAT TRANSFER,33X,26HHE
     1AT TRANSFER COEFFICIENTS/33X,E13.6,27X,E13.6,17X,E13.6/32X,15HBTU/
     2(FT**2*SEC),21X,24HBTU/(IN**2*SEC*DEGREE R),11X,15HLBM/(IN**2*SEC)
     3)
140   FORMAT (1H0,2X,5HSTE =,1PE13.6,9H, STINF =,E13.6,10H, CHEDGE =,E13
     1.6,9H, CHINF =,E13.6,19H, CHINF*SQRT(REX) =,E13.6)
150   FORMAT (1H0,2X,5HCFE =,1PE13.6,9H, CFINF =,E13.6,13H, CF(TOTAL) =,
     1E13.6,19H, CFBAR*SQRT(REX) =,E13.6,19H, CFINF*SQRT(REX) =,E13.6)
160   FORMAT (1H0,2X,9HCFINF/2 =,1PE13.6,19H, CHINF/(CFINF/2) =,E13.6,18
     1H, CHEDGE/(CFE/2) =,E13.6)
170   FORMAT (1H0,2X,10HX/REFLEN =,1PE13.6,12H, Z/REFLEN =,E13.6,13H, RO
     1/REFLEN =,E13.6,11H, DELTA/X =,E13.6,12H, DELSTR/X =,E13.6)
180   FORMAT (1H0,2X,14HTHETA/REFLEN =,1PE13.6,17H, DELSTR/REFLEN =,E13.
     16,16H, DELTA/REFLEN =,E13.6,20H, DELSTRAXI/REFLEN =,E13.6)
190   FORMAT (1H0,2X,13HTHETA/DELTA =,1PE13.6,16H, DELSTR/DELTA =,E13.6,
```

```
     116H, DELSTR/THETA =,E13.6,13H, DELSTRAXI =,E13.6)
200   FORMAT (1H0,2X,9HDELSTRK =,1PE12.5,10H, DELSTR =,E12.5,9H, DELTA =
     1,E12.5,9H, THETA =,E12.5,11H, RETHETA =,E12.5///)
210   FORMAT (1H0,/124H         ETA              Y           Y/THETA      Y
     1/DELTA        F=U/UE         FP(N)           FPP            EPS+
     2   AOBP   ,4X,2H N/)
220   FORMAT (9F14.6,I5)
230   FORMAT (1H0,/123H          ETA          G=H/HE          GP(N)
     1  V              T/TE         RHO/RHOE   RHCMU/RHOEMUE        CP
     2   CHI   ,5X,2H N/)
240   FORMAT (1X,//)
250   FORMAT (1H1,10X,83HPROBLEM TERMINATED.NEGATIVE DF/DETA INDICATES T
     1HAT THE BOUNDARY LAYER HAS SEPARATED)
      END
```

```
      SUBROUTINE ZRO (JJ,X2,Z,RO)
C
C     SUBROUTINE ZRO CALLS SUBROUTINE INTER5.
C
C     SUBROUTINE ZRO IS CALLED BY SUBROUTINES BLUNT2, NOZLE1 AND NOZLE2.
C
C     SUBROUTINE ZRO CALCULATES FOR AXI-SYMMETRIC FLOW AN AXIAL DISTANCE
C     Z AND A RADIUS RO CORRESPONDING TO A SURFACE DISTANCE X2.
C
      COMMON /ARRAY2/ PZ(501),RZ(501),TWZ(501),UEZ(501),XSTA(501),ZA(501
     1),IPR(101),IPRFL(101)
C
C
      J=0
10    J=J+1
      IF (X2.GT.XSTA(J)) GO TO 10
      IF (J.LT.3) J=3
      IF (J.GT.(JJ-2)) J=JJ-2
      CALL INTER5 (X2,XSTA(J-2),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),RZ
     1(J-2),RZ(J-1),RZ(J),RZ(J+1),RZ(J+2),RO)
      CALL INTER5 (X2,XSTA(J-2),XSTA(J-1),XSTA(J),XSTA(J+1),XSTA(J+2),ZA
     1(J-2),ZA(J-1),ZA(J),ZA(J+1),ZA(J+2),Z)
      RETURN
      END
```

```
      SUBROUTINE DERIV3 (F,X,IMAX,IMIN,FP)
C
C     SUBROUTINE DERIV3 CALLS SUBROUTINE FD3.
C
C     SUBROUTINE DERIV3 IS CALLED BY MAIN AND SUBROUTINES ADDETA, EFFMU,
C     ENERGY, AND SOLVE.
C
C       SUBROUTINE DERIV3 CALCULATES THE FIRST DERIVATIVES OF F WITH
C     RESPECT TO X AND RETURNS THE ARRAY FP.
C
      DIMENSION F(1), X(1), FP(1)
C
C
      DO 10 J=IMIN,IMAX
      K=J
      IF (K.LT.(IMIN+1)) K=IMIN+1
      IF (K.GT.(IMAX-1)) K=IMAX-1
      CALL FD3 (X(J),X(K-1),X(K),X(K+1),F(K-1),F(K),F(K+1),FP(J))
10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INTERP (XX,XN,F2,IE,FF)
C
C     SUBROUTINE INTERP CALLS FUNCTION TLU.
C
C     SUBROUTINE INTERP IS CALLED BY SUBROUTINES COEF AND EFFMU.
C
C     SUBROUTINE INTERP USES FUNCTION TLU TO INTERPOLATE IN ARRAY F2
C     FOR THE VALUE FF CORRESPONDING TO THE VALUE XX IN ARRAY XN.
C     IF XX .LT. XN(1) .OR. XX .GT. XN(IE), FF IS SET EQUAL TO F2(IE)
C     AND A MESSAGE IS PRINTED.
C
      DIMENSION XN(1), F2(1)
C
C
      FF=TLU(IE,F2,XN,XX,NFLAG)
      IF (NFLAG.NE.1) RETURN
      WRITE (6,10)
      FF=F2(IE)
      RETURN
C
C
C
10    FORMAT (1H0,10X,38HINADAQUATE TABLE FOR SUBROUTINE INTERP,//11X,43
     1HSTANDARD FIXUP TAKEN - EXECUTION CONTINUING)
      END
```

```
      FUNCTION TLU (NTABLE,Z,X,XSTAR,NFLAG)
C
C     FUNCTION TLU IS CALLED BY SUBROUTINE INTERP.
C
C        FUNCTION TLU IS A ONE-DIMENSIONAL TABLE LOOK-UP PROGRAM.
C        CORRESPONDING VALUES OF X (ALWAYS INCREASING) AND Z ARE STORED
C        IN THE ARRAYS X(1)...X(NTABLE) AND Z(1)...Z(NTABLE).  USING
C        LINEAR INTERPOLATION, THIS FUNCTION WILL GENERATE A VALUE OF Z
C        CORRESPONDING TO A SPECIFIED VALUE OF X = XSTAR.
C
      DIMENSION X(1), Z(1)
C
C
C     ..... CHECK TO SEE IF XSTAR LIES WITHIN THE SCOPE OF THE
C           TABULATED VALUES X(1)...X(NTABLE) .....
C
      NFLAG=0
      IF (XSTAR.LT.X(1)) GO TO 10
      IF (XSTAR.LE.X(NTABLE)) GO TO 20
10    NFLAG=1
      TLU=0.0
      RETURN
C
C     ..... SEARCH TO FIND TWO SUCCESSIVE ENTRIES,
C        X(I-1) AND X(I), BETWEEN WHICH XSTAR LIES .....
C
20    I=1
30    IF (X(I).GT.XSTAR) GO TO 40
      IF (I.GE.NTABLE) GO TO 40
      I=I+1
      GO TO 30
C
C     ..... LINEARLY INTERPOLATE TO FIND CORRESPONDING VALUE OF Z .....
C
40    TLU=Z(I-1)+(XSTAR-X(I-1))*(Z(I)-Z(I-1))/(X(I)-X(I-1))
      RETURN
C
      END
```

```
      SUBROUTINE INTER3 (X,X1,X2,X3,F1,F2,F3,F)
C
C     SUBROUTINE INTER3 IS CALLED BY SUBROUTINE ADDETA.
C
C     SUBROUTINE INTER3 INTERPOLATES FOR THE VALUE F CORRESPONDING TO
C     POINT X USING 3 POINT LAGRANGIAN INTERPOLATION.
C
C     ASSUMES X1 .LE. X .LE. X3.
C
      A1=(X-X2)*(X-X3)
      A2=(X-X1)*(X-X3)
      A3=(X-X1)*(X-X2)
      D1=(X1-X2)*(X1-X3)
      D2=(X2-X1)*(X2-X3)
      D3=(X3-X1)*(X3-X2)
      C1=A1/D1
      C2=A2/D2
      C3=A3/D3
      F=C1*F1+C2*F2+C3*F3
      RETURN
      END
```

```
      SUBROUTINE INTER5 (X,X1,X2,X3,X4,X5,F1,F2,F3,F4,F5,F)
C
C     SUBROUTINE INTER5 IS CALLED BY SUBROUTINES BLUNT1, BLUNT2, EDGE,
C     INIT, MACH, SLOW, WALL, ZRO, AND INTRP5.
C
C     SUBROUTINE INTER5 INTERPOLATES FOR THE VALUE F CORRESPONDING TO
C     POINT X USING 5 POINT LAGRANGIAN INTERPOLATION FORMULA.
C
C     ASSUMES X1 .LE. X .LE. X5.
C
      A1=(X-X2)*(X-X3)*(X-X4)*(X-X5)
      A2=(X-X1)*(X-X3)*(X-X4)*(X-X5)
      A3=(X-X1)*(X-X2)*(X-X4)*(X-X5)
      A4=(X-X1)*(X-X2)*(X-X3)*(X-X5)
      A5=(X-X1)*(X-X2)*(X-X3)*(X-X4)
      D1=(X1-X2)*(X1-X3)*(X1-X4)*(X1-X5)
      D2=(X2-X1)*(X2-X3)*(X2-X4)*(X2-X5)
      D3=(X3-X1)*(X3-X2)*(X3-X4)*(X3-X5)
      D4=(X4-X1)*(X4-X2)*(X4-X3)*(X4-X5)
      D5=(X5-X1)*(X5-X2)*(X5-X3)*(X5-X4)
      C1=A1/D1
      C2=A2/D2
      C3=A3/D3
      C4=A4/D4
      C5=A5/D5
      F=C1*F1+C2*F2+C3*F3+C4*F4+C5*F5
      RETURN
      END
```

```
      SUBROUTINE INTRP5 (X0,X1,F1,IMAX,IMIN,I1,F0)
C
C     SUBROUTINE INTRP5 CALLS SUBROUTINE INTER5.
C
C     SUBROUTINE INTRP5 IS CALLED BY SUBROUTINES EDGE, EDGE1, EQLDTA,
C     AND NOZLE1.
C
C     SUBROUTINE INTRP5 INTERPOLATES IN ARRAY F1 FOR THE VALUE F0
C     CORRESPONDING TO THE VALUE X0 IN ARRAY X1.  X1 MUST BE EITHER
C     MONOTONE INCREASING OR DECREASING.
C
C
C     I1.LT.0, X1 MONOTONE DECREASING
C     I1.GE.0, X1 MONOTONE INCREASING
C
      DIMENSION X1(1), F1(1)
C
      IF (IMAX.EQ.5) J=3
      IF (IMAX.EQ.5) GO TO 40
      IF (I1.GE.0) GO TO 20
      J=IMIN-1
10    J=J+1
      IF (X1(J).GT.X0) GO TO 10
      IF (J.LT.(IMIN+2)) J=IMIN+2
      IF (J.GT.(IMAX-2)) J=IMAX-2
      GO TO 40
20    J=IMIN-1
30    J=J+1
      IF (X1(J).LT.X0) GO TO 30
      IF (J.LT.(IMIN+2)) J=IMIN+2
      IF (J.GT.(IMAX-2)) J=IMAX-2
40    CALL INTER5 (X0,X1(J-2),X1(J-1),X1(J),X1(J+1),X1(J+2),F1(J-2),F1(J
     1-1),F1(J),F1(J+1),F1(J+2),F0)
      RETURN
      END
```

```
      SUBROUTINE FD3 (X,X1,X2,X3,F1,F2,F3,FX)
C
C     SUBROUTINE FD3 IS CALLED BY SUBROUTINE DERIV3.
C
C     SUBROUTINE FD3 CALCULATES THE FIRST DERIVATIVE-FX-CORRESPONDING
C     TO POINT X USING 3 POINT LAGRANGIAN DIFFERENTIATION FORMULA.
C
C     ASSUMES X1 .LE. X .LE. X3.
C
      A1=2.0*X-X2-X3
      A2=2.0*X-X1-X3
      A3=2.0*X-X1-X2
      D1=(X1-X2)*(X1-X3)
      D2=(X2-X1)*(X2-X3)
      D3=(X3-X1)*(X3-X2)
      C1=A1/D1
      C2=A2/D2
      C3=A3/D3
      FX=C1*F1+C2*F2+C3*F3
      RETURN
      END
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      SUBROUTINE FD5 (X,X1,X2,X3,X4,X5,F1,F2,F3,F4,F5,FX)
C
C     SUBROUTINE FD5 IS CALLED BY SUBROUTINES BLUNT1, BLUNT2, EDGE,
C     NOZLE1, AND NOZLE2.
C
C     SUBROUTINE FD5 CALCULATES THE FIRST DERIVATIVE-FX-CORRESPONDING
C     TO POINT X USING 5 POINT LAGRANGIAN DIFFERENTIATION FORMULA
C
C     ASSUMES X1 .LE. X .LE. X5.
C
      A1=(X-X4)*(X-X5)*(2.0*X-X2-X3)+(X-X2)*(X-X3)*(2.0*X-X4-X5)
      A2=(X-X4)*(X-X5)*(2.0*X-X1-X3)+(X-X1)*(X-X3)*(2.0*X-X4-X5)
      A3=(X-X4)*(X-X5)*(2.0*X-X1-X2)+(X-X1)*(X-X2)*(2.0*X-X4-X5)
      A4=(X-X3)*(X-X5)*(2.0*X-X1-X2)+(X-X1)*(X-X2)*(2.0*X-X3-X5)
      A5=(X-X3)*(X-X4)*(2.0*X-X1-X2)+(X-X1)*(X-X2)*(2.0*X-X3-X4)
      D1=(X1-X2)*(X1-X3)*(X1-X4)*(X1-X5)
      D2=(X2-X1)*(X2-X3)*(X2-X4)*(X2-X5)
      D3=(X3-X1)*(X3-X2)*(X3-X4)*(X3-X5)
      D4=(X4-X1)*(X4-X2)*(X4-X3)*(X4-X5)
      D5=(X5-X1)*(X5-X2)*(X5-X3)*(X5-X4)
      C1=A1/D1
      C2=A2/D2
      C3=A3/D3
      C4=A4/D4
      C5=A5/D5
      FX=C1*F1+C2*F2+C3*F3+C4*F4+C5*F5
      RETURN
      END
```

APPENDIX A

Boundary Layer Edge Conditions for a Reacting Gas in Chemical Equilibrium

The boundary-layer edge conditions are determined from the solution of the inviscid governing equations using the computer program developed by Lordi, Mates, and Moselle [1965]. Minor modifications have been made to this computer program to present the data in the form required by the boundary-layer program. These modifications and a listing of the modified subroutines are given at the end of this appendix.

Boundary-layer flows in nozzles may be solved with either a specified pressure distribution or a specified area ratio distribution. In the latter case, it is assumed that the edge conditions correspond to a quasi-one-dimensional expansion of the gas. The solution for a blunt body requires that the pressure distribution along the surface be given. For either case, the expansion data are obtained for a quasi-one-dimensional flow through a nozzle of arbitrary shape and the necessary geometry is supplied by the boundary-layer program; it is not necessary to obtain new expansion data when the body geometry is changed if the reservoir or stagnation conditions are held constant. This feature is useful when parametric studies of different body shapes are being made for a fixed reservoir or stagnation condition.

The edge conditions which must be specified by the solution of the inviscid equations of motion are area ratio, Mach number, velocity, pressure, and enthalpy. The correct geometry is obtained by interpolation with the area ratio as the independent variable for nozzles having a specified area ratio distribution (quasi-one-dimensional). For blunt bodies or nozzles with the pressure distribution specified, interpolations are made with the pressure as the independent variable.

Modifications have been made to the MAIN program, subroutines REED, and EQUIL in the computer program of Lordi, Mates and Moselle. Listings of subroutine EQUIL and the MAIN program with the modifications are included. In subroutine REED, a read statement was added for the molecular weight of the gas mixture at standard atmospheric pressure and temperature. (FORTRAN symbol-STDMLN) was added.

It is assumed that a listing of this computer program and the report by Lordi, Mates and Moselle are available.

The velocity, enthalpy, and pressure are converted to the form required by the boundary layer program as follows:

U'	=	$U\,(Ro * 778.158 * 1.8 \times To' \times 32.1759/M)^{1/2}$
PL	=	$\mathrm{Log}_{10}\,(P \times Po)$
HL	=	$\mathrm{Log}_{10}\,(H \times To' \times Ms/M)$

Fortran variables not included in the Lordi, Mates and Moselle program are given below.

MAIN Program

AFNX1	,	Area Ratio at Throat
AMACH1	,	Mach Number at Throat
HOR	=	H'/RGAS, °K
HORL	=	Log_{10}(HOR)
PL	=	Log_{10}(P)
UUU	,	Velocity in ft/sec

Subroutine EQUIL

HOR	=	H'/RGAS, °K
HORL	=	Log_{10}(H°K)
PL	=	Log_{10}(P)
R1	,	Ratio of Successive Temperature Steps
UUU	,	Velocity, ft/sec

List of Symbols for Appendix A

H	=	H'M/RoTo'
H'	,	Enthalpy, ft^2/sec^2
HL	=	Log_{10}(H'/RGAS)

M	,	Molecular Weight at Reservoir Stagnation Conditions
Ms	,	Molecular Weight at Standard Atmospheric Conditions
P	,	P/Po
P	,	Pressure in Atmospheres
Po	,	Reservoir or Stagnation Pressure in Atmospheres
Ro	,	Universal Gas Constant
RGAS	,	Gas constant at Standard Atmospheric Conditions, ft^2/sec^2 - °K
To'	,	Stagnation or Reservoir Temperatures, °K
U	,	Dimensionless Velocity
U'	,	Velocity,ft/sec

```
C     CAL STREAMTUBE  VERSION M
C  MAIN PROGRAM FOR NOZZLE FLOW SOLUTION
      IMPLICIT  REAL*8(A-H,O-Z)
      COMMON A, AA(22,24), ACCM(20), AFNTS, AFNX, ALPIJ(20,10), AMACH,
     1AR, ARBA, ARBB, ASUB(10), ATP(5), B(64,20), BCHI(64), BE(64),
     2BET(20), BETA(64,20), BLBK(31), BSUB(31), BZERO, C, CAI(64),
     3CAPX(20), CAPXTH(20), CARB, CCPJ(20), CDIJ(20,10), CEACT(64),
     4CECHII(64),CGI(20), CGMU(20), CH, CHA, CHI(64), CHII(20),
     5CLNIMC(64), CLNPI(64), CLNT, CM, CMA, CMW(20), CRA, CRP, CRRB,CRS,
     6CSTA, CT, CTAP, CTB, CTC, CTMAX, CTMXX, CTP, CTPL, CTT, CX, CXB,
     7CXMAX, DATEST, DBTEST, DELT1, DELT2, DELT3, DELTAX, DLOGA, DLOGR,
     8DT, ELJ(10,20), ELMENT(20), ENT, ETAI(64), ETAJ(20), FLUX,
     9GELJ(10,20), GJA(20), GJB(20), GJC(20), GTEST, HDELX, HP(20)
C
      COMMON  PCT, PCTEST, PERTGJ(20), PGJ(20), PI(64), PICHI(64),
     1PRES, PRESA, PRESB, PRESTH, PRHO, QM(20), QQ(64), RHAP, RHO, RHOB,
     2RHCBAR, RHCC, RHCP, RHPL, RHTH, ROBARA, ROBARP, SAJ(20), SCPG,
     3SDCHI(64), SDELTX, SDT, SEN, SENT(20), SHDELX, SHJ(20), SHJA(20),
     4SHPG, SKIL(20), SC, SL, SL64, SM, SS(20), SU, SU2, SUMG, TB(30),
     5TEMP1, TEST, TESTB, TFA(20), TFB(20), TFC(20), TFD(20), TFE(20),
     6TFK(20), THEV(20), TPRINT, TSTOP, TTEST, UP, XMJAT(20), XNUI(64),
     7XNUIJ(64,20), XNUIJP(64,20), ZP, ZPA
C
      COMMON  IC, IGJ(20), IGM(20), IM, INEQ, INEQV, IP, IRCBAR, IRUN,
     1ISC, ISCP1, ISMC, ISMCNR, ISR, ISS, ISSNR,ISSP1,ISSP2,ISSP3,ISSP4
C
      COMMON  ISW1A, ISW1B, ISW2A, ISW2B, ISW3A, ISW3B, ISW4A, ISW4B,
     1ISW5A, ISW5B, ISW6A, ISW6B, IZERO, ITB(5), IUPD, JJK, KHO, KKUR,
     2KUR(64,20), LC, M1, NAFIT, NFIT, NIT, NNN, NNS, NQS, NOT, NTEST
C
      COMMCN IK
C
      DIMENSION  AAA(22,24), BTA(64,20), CAPQ(31), CCI(20), DGJ(20),
     1GJ(20), SBJ(20), SDGJ(20), SHJAP(20), THEVP(20)
C
      DIMENSION IGJB(30)
      COMMON/STDMLW/CMSTD
C
      EQUIVALENCE ( AA(  1),AAA(  1)), (BETA(  1),BTA(  1)),
     1(BLBK(1),CAPQ(1)),(CAPXTH(1),CCI(1)), (GJA(1),DGJ(1)),(CAPX(1),
     2 GJ(1)), (SAJ(1),SBJ(1)),(SS(1),SDGJ(1)), (SHJA(1),SHJAP(1)),
     3(THEV(1),THEVP(1))
      EXP(X)=DEXP(X)
      SQRT(X)=DSQRT(X)
      ABS(X)=DABS(X)
      SIGN(X1,X2)=DSIGN(X1,X2)
      CALL ERRSET(262,256,-1,1,0,262)
      CALL ERRSET(207,256,-1,1,0,209)
C
      DO 20 I=1,8330
   20 ACOM(I)=0.0
      ZP=0
      ZPA=0
  100 FORMAT(12H1 RESERVOIR-,I4//13H TEMPERATURE=,F9.2,9H DENSITY=,F11.8
     1,10H PRESSURE=,F9.3//10H ENTHALPY=,F8.4,9H ENTROPY=,F9.4,18H MOLEC
     2ULAR WEIGHT=,F7.4//(1X,A6,1PE11.3))
  101 FORMAT(16H1 FROZEN THROAT-,I4//13H TEMPERATURE=,F9.6,11H MASS FLOW
     1=,F8.4,9H DENSITY=,F9.6,10H PRESSURE=,F9.6)
  102 FORMAT(9H1 THROAT-,I4/13H TEMPERATURE=,F9.6,11H MASS FLCW=,F8.4,9H
     1 DENSITY=,F9.6,10H PRESSURE=,F9.6/10H ENTHALPY=,F8.4,10H VELOCITY=
     2,1PE12.4//(1X,A6,E11.3))
  103 FORMAT(38H DISCRIMINANT NEGATIVE IN MAIN PROGRAM)
  104 FORMAT(39H1 STARTING VALUES FCR DOWNSTREAM RUN - ,I4//)
  105 FORMAT(13H TEMPERATURE=,F9.6,9H DENSITY=F9.6,10H PRESSURE=,F9.6,/
     1/10H ENTHALPY=,F8.4,10H VELOCITY=,1PE12.4,6H AREA=,E11.3,3H X=,E11
     2.3//(1X,A6,E11.3))
  106 FORMAT(20H1 DENSITY FIT-ALPHA=,1PE15.7,10H CONSTANT=,E15.7)
 1000 FORMAT(1H0,9X,8HA/ASTAR=F10.5,1X,9HMACH NO.=F10.5,1X,
     *17HVELOCITY(FT/SEC)=F12.5,1X,14HLOG10(P/PSTD)=F10.5,1X,
     *11HLOG10(H/R)=F10.5)
    1 CALL REED
      DO 2 J=1,ISS
```

```
    2 IGJB(J)=IGJ(J)
      CALL INIT
      WRITE(6,100) IRUN,CTAP,RHAP,PRESA,CHA,SEN,CMA,(HP(I),GJA(I),I=1,
     * ISS  )
C     BEGIN PROGRAM MODIFICATIONS
      PL=DLOG10(PRESA)
      HOR=CH*CTAP/CMA*CMSTD
      HORL=DLOG10(HOR)
      UUU=SU*DSQRT(1546.D0*CTAP*1.8D0*32.1759D0/CMA)
      WRITE(6,1000) AFNX,AMACH,UUU,PL,HORL
      WRITE(20)     AFNX,AMACH,UUU,PL,HORL
C     END PROGRAM MODIFICATIONS
      IF(ISW6A-IZERO) 17, 120, 17
  120 IF(ISW1A-IZERO) 121,  4, 121
  121 CALL FROZEN
      WRITE(6,101) IRUN,CTMAX,SM,RHTH,PRESTH
      DO 3 J=1,ISS
    3 IGJ(J)=IGJB(J)
    4 CALL NRMAX
      WRITE(6,102) IRUN,CTMAX,SM,RHTH,PRES,CH,SU,(HP(I),GJ(I),I=1,ISS)
C     BEGIN PROGRAM MODIFICATIONS
      PL=DLOG10(PRES*PRESA)
      HOR=CH*CTAP/CMA*CMSTD
      HORL=DLOG10(HOR)
      UUU=SU*DSQRT(1546.D0*CTAP*1.8D0*32.1759DC/CMA)
      AFNX1=1.0
      AMACH1=1.0
      WRITE(6,1000) AFNX1,AMACH1,UUU,PL,HORL
C     END PROGRAM MODIFICATIONS
      IF(ISW3A-IZERO) 39,  6, 39
   39 DO 40 J=1,ISS
   40 IGJ(J)=IGJB(J)
      CALL EQUIL
      IM=1
      JJK=0
      ISMCNR=ISMC
      ISSNR=ISS
      DO 5 J=1,ISS
    5 IGJ(J)=IGJB(J)
    6 IF(ISW2A-IZERO) 160,  17, 160
  160 IF(IUPD-IZERO) 10,161, 10
  161 CT=CTMAX*(1.-DELT2)
      PRES=PRESTH
      DO 7 I=1,ISS
    7 CAPX(I)=CAPXTH(I)
      CALL NEWRAP
      AFNTS=SM/FLUX
      TEMP1=BSUB(2)*BSUB(2)-4.*BSUB(3)*(BSUB(1)-AFNTS)
      IF(TEMP1)8,9,9
    8 WRITE(6,103)
      CALL PDUMP
      STOP
    9 CX=-(BSUB(2)-SQRT(TEMP1))/(2.*BSUB(3))
      WRITE(6,104)IRUN
      WRITE(6,105) CT,RHO,PRES,CH,SU,AFNTS,CX,(HP(I),GJ(I),I=1,ISS)
      GO TO 16
   10 DO 11 I=1,ISS
   11 CAPX(I)=GJA(I)*CMA
      PRES=1.0
      N=C
      SUM1=DLOG(RHTH)
      A=4.+8.*SUM1
   12 N=N+1
      IF(N-50)13,14,14
   13 SUM2=A+2.
      SUM3=RHTH**A
      D=SUM3*SUM2-2.
      D1=SUM3*(SUM2*SUM1+1.)
      ATEST=A
      A=A-D/D1
      IF(ABS (D)-.00001) 130,130,12
  130 IF(ABS (ATEST-A)-.00001) 14, 14, 12
```

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```
 14 C=(RHTH**2)*(1.-RHTH**A)
    CT=1.0-DELT1
    CALL NEWRAP
    AFNTS=SM/FLUX
    TEMP1=ASUB(2)*ASUB(2)-4.*ASUB(3)*(ASUB(1)-AFNTS)
    IF(TEMP1)8,15,15
 15 CX=-(ASUB(2)+SQRT(TEMP1))/(2.*ASUB(3))
    WRITE(6,106)A,C
    IK=0
 16 CALL NONEQ
    REWIND 9
    DO 800   K=1,IK
    READ (9,111) IRUN,CT
111 FORMAT (I6,F10.6)
    WRITE (6,111) IRUN,CT
    READ (9,112) ((B(I,J), J=1,4), I=1,ISR)
112 FORMAT (1P12E10.1)
    WRITE (6,112) ((B(I,J), J=1,4), I=1,ISR)
800 CONTINUE
 17 IF(ISW4A)1,18,1
 18 CALL EXIT
    STOP
    END
```

```
C
      SUBROUTINE REED
      IMPLICIT  REAL*8(A-H,O-Z)
      COMMON A, AA(22,24), ACOM(20), AFNTS, AFNX, ALPIJ(20,10), AMACH,
     1AR, ARBA, ARBB, ASUB(10), ATP(5), B(64,20), BCHI(64), BE(64),
     2BET(20), BETA(64,20), BLBK(31), BSUB(31), BZERO, C, CAI(64),
     3CAPX(20), CAPXTH(20), CARB, CCPJ(20), CDIJ(20,10), CEACT(64),
     4CECHII(64),CGI(20), CGMU(20), CH, CHA, CHI(64), CHII(20),
     5CLN1MC(64), CLNPI(64), CLNT, CM, CMA, CMW(20), CRA, CRP, CRRB,CRS,
     6CSTA, CT, CTAP, CTB, CTC, CTMAX, CTMXX, CTP, CTPL, CTT, CX, CXB,
     7CXMAX, DATEST, DBTEST, DELT1, DELT2, DELT3, DELTAX, DLOGA, DLOGR,
     8DT, ELJ(10,20), ELMENT(20), ENT, ETAI(64), ETAJ(20), FLUX,
     9GELJ(10,20), GJA(20), GJB(20), GJC(20), GTEST, HDELX, HP(20)
C
      COMMON  PCT, PCTEST, PERTGJ(20), PGJ(20), PI(64), PICHI(64),
     1PRES, PRESA, PRESB, PRESTH, PRHO, QM(20), QQ(64), RHAP, RHO, RHOB,
     2RHOBAR, RHOC, RHOP, RHPL, RHTH, ROBARA, ROBARP, SAJ(20), SCPG,
     3SDCHI(64), SDELTX, SDT, SEN, SENT(20), SHDELX, SHJ(20), SHJA(20),
     4SHPG, SKIL(20), SC, SL, SL64, SM, SS(20), SU, SU2, SUMG, TB(30),
     5TEMP1, TEST, TESTB, TFA(20), TFB(20), TFC(20), TFD(20), TFE(20),
     6TFK(20), THEV(20), TPRINT, TSTOP, TTEST, UP, XMJAT(20), XNUI(64),
     7XNUIJ(64,20), XNUIJP(64,20), ZP, ZPA
C
      COMMON  IC, IGJ(20), IGM(20), IM, INEQ, INEQV, IP, IROBAR, IRUN,
     1ISC, ISCP1, ISMC, ISMCNR, ISR, ISS, ISSNR,ISSP1,ISSP2,ISSP3,ISSP4
C
      COMMON  ISW1A, ISW1B, ISW2A, ISW2B, ISW3A, ISW3B, ISW4A, ISW4B,
     1ISW5A, ISW5B, ISW6A, ISW6B, IZERO, ITB(5), IUPD, JJK, KHO, KKUR,
     2KUR(64,20), LC, M1, NAFIT, NFIT, NIT, NNN, NNS, NQS, NOT, NTEST
      COMMON/STDMLW/CMSTD
C
      DIMENSION  AAA(22,24), BTA(64,20), CAPQ(31), CCI(20), DGJ(20),
     1GJ(20), SBJ(20), SDGJ(20), SHJAP(20), THEVP(20)
C
      EQUIVALENCE ( AA(  1),AAA(  1)), (BETA(  1),BTA(  1)),
     1(BLBK(1),CAPQ(1)),(CAPXTH(1),CCI(1)), (GJA(1),DGJ(1)),(CAPX(1),
     2 GJ(1)), (SAJ(1),SBJ(1)),(SS(1),SDGJ(1)), (SHJA(1),SHJAP(1)),
     3(THEV(1),THEVP(1))
C
      EXP(X)=DEXP(X)
      SQRT(X)=DSQRT(X)
      ABS(X)=DABS(X)
```

```
      SIGN(X1,X2)=DSIGN(X1,X2)
C
    1 FCRMAT(16I4)
    2 FORMAT(7F10.0)
    3 FORMAT(A6,2F10.0)
    4 FORMAT(4E14.8)
    5 FORMAT(24F3.0)
    6 FORMAT(30I1)
    7 FORMAT(5E14.8)
    8 FORMAT(A6,4E14.8,I2)
    9 FORMAT(4(F3.0,E15.8))
   10 FORMAT(4E15.7/3E15.7,9X,A6)
   11 FORMAT(12A6)
   12 FORMAT(1H1,20A6///)
      READ(5,1) ISW1A,ISW2A,ISW3A,ISW4A,ISW5A,ISW6A,
     1          ISW1B,ISW2B,ISW3B,ISW4B,ISW5B,ISW6B
      READ(5,11) (ACOM(I),I=1,20)
      READ(5,1) IRUN,ISC,ISS,ISR,IC,NQS,IUPD,NFIT,
     1          KHO,KKUR,NAFIT,INEQV,IROBAR
      READ(5,2) CTAP,PRESA,CTMXX,CXMAX,SL,BZERC,TSTOP,
     1          TPRINT,DELTAX,DELT2,DELT3,TTEST,GTEST
      READ(5,2) (CECHII(I),I=1,ISR)
      READ(5,3) (ELMENT(I),CAPQ(I),CMW(I),I=1,ISC)
      READ(5,4) (CAI(I),ETAI(I),CEACT(I),QQ(I),I=1,ISR)
      DO 13 I=1,ISS
   13 READ(5,5) (ALPIJ(I,J),J=1,ISC)
      DO 14 I=1,ISR
   14 READ(5,5) (XNUIJP(I,J),J=1,ISS)
      DO 15 I=1,ISR
   15 READ(5,5) (XNUIJ(I,J),J=1,ISS)
      IF(KKUR)16,118,16
   16 DO 18 I=1,ISR
      IF(QQ(I))17,18,17
   17 READ(5,6) (KUR(I,J),J=1,ISS)
   18 CONTINUE
  118 IF(NAFIT)19,20,19
   19 READ(5,7) (ASUB(I),I=1,10)
      READ(5,7) (BSUB(I),I=1,31)
      READ(5,7) (ATP(I),I=1,5)
      GO TO 21
   20 READ(5,7) (ASUB(I),I=1,3)
      READ(5,7) (BSUB(I),I=1,3)
   21 IF(NFIT)24,22,24
   22 DO 23 J=1,ISS
   23 IGJ(J)=0
      GO TO 25
   24 READ(5,6) (IGJ(J),J=1,ISS)
   25 DO 28 J=1,ISS
      IF(IGJ(J))26,27,26
   26 READ(5,10) TFA(J),TFB(J),TFC(J),TFD(J),
     1           TFE(J),TFK(J),SHJAP(J),HP(J)
      IF(CTMXX)27,28,27
   27 READ(5,8) HP(J),ETAJ(J),SBJ(J),THEVP(J),SHJAP(J),IGM(J)
      K=IGM(J)
      READ(5,9) (GELJ(I,J),ELJ(I,J),I=1,K)
   28 CONTINUE
      IZERO=0
      WRITE(6,12) (ACOM(I),I=1,20)
      READ(5,6000) CMSTD
 6000 FORMAT(6F12.6)
      WRITE(6,6001) CMSTD
 6001 FORMAT(1H0,6HCMSTD=F14.6)
      CALL LIST
      RETURN
      END
```

```
C
      SUBROUTINE EQUIL
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON A, AA(22,24), ACOM(20), AFNTS, AFNX, ALPIJ(20,10), AMACH,
     1AR, ARBA, ARBB, ASUB(10), ATP(5), B(64,20), BCHI(64), BE(64),
     2BET(20), BETA(64,20), BLBK(31), BSUB(31), BZERO, C, CAI(64),
     3CAPX(20), CAPXTH(20), CARB, CCPJ(20), CDIJ(20,10), CEACT(64),
     4CECHII(64),CGI(20), CGMU(20), CH, CHA, CHI(64), CHII(20),
     5CLN1MC(64), CLNPI(64), CLNT, CM, CMA, CMW(20), CRA, CRP, CRRB,CRS,
     6CSTA, CT, CTAP, CTB, CTC, CTMAX, CTMXX, CTP, CTPL, CTT, CX, CXB,
     7CXMAX, DATEST, DBTEST, DELT1, DELT2, DELT3, DELTAX, DLOGA, DLOGR,
     8DT, ELJ(10,20), ELMENT(20), ENT, ETAI(64), ETAJ(20), FLUX,
     9GELJ(10,20), GJA(20), GJB(20), GJC(20), GTEST, HDELX, HP(20)
C
      COMMON  PCT, PCTEST, PERTGJ(20), PGJ(20), PI(64), PICHI(64),
     1PRES, PRESA, PRESB, PRESTH, PRHO, QM(20), QQ(64), RHAP, RHO, RHOB,
     2RHOBAR, RHOC, RHOP, RHPL, RHTH, ROBARA, ROBARP, SAJ(20), SCPG,
     3SDCHI(64), SDELTX, SDT, SEN, SENT(20), SHDELX, SHJ(20), SHJA(20),
     4SHPG, SKIL(20), SC, SL, SL64, SM, SS(20), SU, SU2, SUMG, TB(30),
     5TEMP1, TEST, TESTB, TFA(20), TFB(20), TFC(20), TFD(20), TFE(20),
     6TFK(20), THEV(20), TPRINT, TSTOP, TTEST, UP, XMJAT(20), XNUI(64),
     7XNUIJ(64,20), XNUIJP(64,20), ZP, ZPA
C
      COMMON  IC, IGJ(20), IGM(20), IM, INEQ, INEQV, IP, IROBAR, IRUN,
     1ISC, ISCP1, ISMC, ISMCNR, ISR, ISS, ISSNR,ISSP1,ISSP2,ISSP3,ISSP4
C
      COMMON  ISW1A, ISW1B, ISW2A, ISW2B, ISW3A, ISW3B, ISW4A, ISW4B,
     1ISW5A, ISW5B, ISW6A, ISW6B, IZERO, ITB(5), IUPD, JJK, KHO, KKUR,
     2KUR(64,20), LC, M1, NAFIT, NFIT, NIT, NNN, NNS, NQS, NOT, NTEST
      COMMON/STDMLW/CMSTD
C
      DIMENSION  AAA(22,24), BTA(64,20), CAPQ(31), CCI(20), DGJ(20),
     1GJ(20), SBJ(20), SDGJ(20), SHJAP(20), THEVP(20)
C
      EQUIVALENCE ( AA(  1),AAA(  1)), (BETA(  1),BTA(  1)),
     1(BLBK(1),CAPQ(1)),(CAPXTH(1),CCI(1)), (GJA(1),DGJ(1)),(CAPX(1),
     2 GJ(1)), (SAJ(1),SBJ(1)),(SS(1),SDGJ(1)), (SHJA(1),SHJAP(1)),
     3(THEV(1),THEVP(1))
C
      SQRT(X)=DSQRT(X)
      ABS(X)=DABS(X)
      SIGN(X1,X2)=DSIGN(X1,X2)
C
  100 FORMAT(21H1EQUILIBRIUM SOLUTION//)
  101 FORMAT(1P4E14.5,E16.7,2E14.5,E16.7)
  102 FORMAT(1P4E14.5,E16.7,2E14.5)
  103 FORMAT(1P10E12.3)
  104 FORMAT(1H    )
      DO 1 J=1,ISS
    1 GJ(J)=GJA(J)
      PRES=1.0
      CT=1.0
      RHOBAR=ROBARA
      DELT1=0.0025
      TSTOP=0.0001
      RHO=1.0
      SU=0.0
      AMACH=0.0
      AFNX=0.0
      RHOB=1.0
      PRESB=1.0
      R=1.0
      IP=3
      IF(ISS-10)106,106,105
  106 WRITE(6,100)
  105 IP=IP+1
    2 IF(IROBAR)3,4,3
    3 WRITE(6,101)CT,PRES,RHO,SU,AMACH,SEN,AFNX,RHOBAR
      GO TO 5
    4 WRITE(6,102)CT,PRES,RHO,SU,AMACH,SEN,AFNX
    5 DO 6 N=1,ISS,10
      IQR=N
```

```
      IQQ=MIN0(N+9,ISS)
      WRITE(6,103) (GJ(J),J=IQR,IQQ)
    6 CONTINUE
C     BEGIN PROGRAM MODIFICATIONS
      IF(AFNX.EQ.0.0) GO TO 1001
      PL=DLOG10(PRES*PRESA)
      HOR=CH*CTAP/CMA*CMSTD
      HORL=DLOG10(HOR)
      UUU=SU*DSQRT(1546.D0*CTAP*1.8D0*32.1759D0/CMA)
      WRITE(6,1000) AFNX,AMACH,UUU,PL,HORL
      WRITE(20)     AFNX,AMACH,UUU,PL,HORL
1000  FORMAT(1H0,9X,8HA/ASTAR=F12.5,1X,9HMACH NO.=F10.5,1X,
     *17HVELOCITY(FT/SEC)=F12.5,1X,14HLOG10(P/PSTD)=F10.5,1X,
     *11HLOG10(H/R)=F10.5)
1001  CONTINUE
C     END PROGRAM MODIFICATIONS
      WRITE(6,104)
      IF(KKK.NE.22) R1=0.01
      KKK=22
      CT=CT-R1*DELT1
      R1=R1*1.05
      IF(R1.GT.1.0) R1=1.0
      IF(CT-TSTOP)8,60,60
60    CONTINUE
      CALL NEWRAP
      AMACH=SU*SQRT(RHO*ABS(DLOG(RHO/RHOB)/DLOG(PRES/PRESB))/PRES)
      AFNX=SM/FLUX
      PRESB=PRES
      RHCB=RHO
      IF(IP-50)61,61,7
   61 IP=IP+3
      IF(ISS-10)611,611,610
  610 IP=IP+1
  611 GO TO 2
    7 WRITE(6,100)
      IP=3
      IF(ISS-10)72,72,71
   71 IP=IP+1
   72 GO TO 2
    8 RETURN
      END
```

APPENDIX B

Thermodynamic and Transport Properties for a Reacting Gas Mixture in Chemical Equilibrium

To solve the boundary layer equations for a reacting gas mixture in chemical equilibrium, it is necessary to provide a suitable method for determining the thermodynamic and transport properties of the gas for a wide range of pressure and temperature. These data may be given in curve fit form or a table look-up procedure using an interpolation polynomial may be used.

In the present solution of the boundary-layer equations, the primary emphasis has been to obtain solutions to problems where the ratio of the wall enthalpy to the stagnation or reservoir enthalpy is small and for high Mach number flows. In these cases, the coefficients of the polynomial curve fit data may be inaccurate for part of the range in pressure and/or temperature (see Lewis and Burgess [1963]). Thus, a table look-up procedure is used in the solution of the boundary-layer equations. The tables of thermodynamic and transport properties have been generated using a modification of the Cornell Aeronautics Laboratory (CAL) computer program for arbitrary gas mixtures developed by Lordi, Mates, and Moselle [1965]. The table look-up procedure has an additional advantage in that the tables of properties are used directly without the necessity of curve fitting the data. Thus, different gas mixtures may be considered with a minimum of difficulty.

The modifications made to the CAL computer program are described below, and a listing of the modified subroutines are given at the end of the appendix. In the discussion which follows, it is assumed that the CAL program is available.

Thermodynamic and Transport Properties

The properties which must be specified are pressure, temperature, enthalpy, density, specific heat, viscosity, and Prandtl number. For a given pressure and temperature, the enthalpy, density and specific heat are determined using the reservoir calculation described in Section 2.1 of Lordi, Mates and Moselle [1965]. Subroutines have been added to compute viscosity, and to obtain the Prandtl number by interpolation.

To conform with the boundary-layer program, each set of data is tabulated at a constant pressure with temperature decreasing, the dependent variables are H, ρ, μ, CP, and PR. The data sets are generated with decreasing pressure. The specific heat, CP, is determined by numerical differentiation of H in each data set. To provide the necessary data for five-point interpolation in the boundary-layer program, at least two data sets are required both above and below the maximum and minimum pressures of the given problem, and similarly for the temperature in each data set.

The viscosity of the gas mixture is computed using Wilke's semi-empirical formula

$$\mu = \sum_{i=1}^{ISS} \left(\frac{C_i \ \mu_i / M_i}{\sum_{j=1}^{ISS} C_j \phi_{ij} / M_j} \right) \tag{B-1}$$

where

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

The viscosity of the species, μ_i, is approximated by curve fit data of the form

$$\mu_i = e^{c_i} \ T^{(A_i \ \ln T + B_i)} \ \text{gm/cm-sec} \tag{B-3}$$

The curve fit constants are determined by the fitting the μ_i data obtained using the method of Yun and Mason [1962]. The constants used in the computer program were obtained from Blottner [1964].

The Prandtl number for air and nitrogen have been obtained by interpolation of the data given by Hansen [1958] and Ahyte and Peng [1962], respectively.

Description of Computer Program

The computer program used to generate the tables of thermodynamic and transport properties of the gas mixture retains subroutines REED, LIST, INIT, INTA, THERM, MATIN, and SIMSOL of the CAL computer program. Listings of the modified or added subroutines are included at the end of this appendix. It is noted that the common block data in the modified program are not the same as that for the CAL program. However, their common block data may be used without change. A description of the Fortran variables used in the added subroutines which are not included in the Lordi, Mates and Moselle program are given below.

MAIN Program

Description of Variables

AMU	,	Viscosity, lb-sec/ft^2
APR	,	Prandtl Number (frozen)
CJ	,	Mass Fraction of the j<u>th</u> Species
CMLW	,	Molecular Weight of Gas Mixture
CMSTD	,	Molecular Weight of Gas Mixture at Standard Atmospheric Pressure and Temperature
COND	,	Thermal Conductivity (frozen) lb/sec-°R
CP	,	Specific Heat of Gas Mixture at Standard Atmospheric Conditions, ft^2/sec^2-°R
CTAPI	,	Dummy Variable for CTAP
CTINIT	,	Maximum Temperature, °K
CTMIN	,	Minimum Temperature, °K
DELCT	,	Temperature Increment, Value is Negative

DELTPL	,	Pressure Increment, Value is Negative
GAMMA	,	Ratio of Specific Heats
HOR	=	H'/RGAS, °K
HORL	=	Log_{10} (HOR)
I	,	Array Index
IS	,	Array Index
J	,	Array Index
JPL	,	Number of Tables to be Generated
K	,	Array Index
JCT	,	Number of Temperature Steps in Each Table
JCTZ	,	Dummy Variable
PL	=	Log_{10} P, P in Atmospheres
PR	,	Array of Prandtl Numbers
RGAS	,	Gas Constant at Standard Atmospheric Pressure and Temperature, ft^2/sec^2-°K or ft^2/sec^2-°R
RHOLOC	,	Density, $Slugs/ft^3$
RHOLOS	,	Density, Amagats
RHOL	,	$Log_{10}\rho$, ρ in Amagats
SPHTR	,	C_p/R_o, °K
SPHTRF	,	Array of C_p/R_o
SPHTOR	,	Specific Heat of Mixture C_p/RGAS, °K
TEMP	,	Array of Temperature, °K

Subroutine XMUPR

The purpose of this subroutine is to compute the viscosity of the gas mixture using Wilke's semi-empirical equation. The frozen values of thermal conductivity and Prandtl number are also computed but are not used.

Usage:

CALL XMUPR (T, CP, R, CCPS, CGI, GJA, ISS, HP, CMA, YMU, PR, CON)

Where

T	,	Temperature, °K
CP	=	C_p/R_o
R	=	1.98726 gm-cal/gm-mole-°K or BTU/lb-mole-°R
CCPJ	,	Specific Heat of j<u>th</u> Species
CGI	,	Molecular Weight of i<u>th</u> Species
GJA	,	Species Concentration moles/gm
ISS	,	Number of Species in Mixture
HP	,	Chemical Symbol for Species in Mixture
CMA	,	Molecular Weight of Gas Mixture at Given Pressure and Temperature
XMU	,	Viscosity, $lb\text{-}sec/ft^2$ (returned)
PR	,	Frozen Prandtl Number (returned)
CON	,	Frozen Thermal Conductivity, lb/sec-°R (returned)

Description of Variables

A_i	,	Coefficient in Curve Fit Expression for Viscosity
B_i	,	Coefficient in Curve Fit Expression for Viscosity
C_i	,	Coefficient in Curve Fit Expression for Viscosity
CAPK	,	Intermediate Variable in Calculation of Thermal Conductivity
EMU	,	Species Viscosity
FACI	,	Dummy Variable
FACZ	,	Dummy Variable

PHI		Defined by Equation (B-2)

Subroutine PRANDTL

This subroutine interpolates in tables of Prandtl numbers input to the program as functions of pressure and temperature. Five point interpolation is used to determine the Prandtl number at the given pressure and temperature.

Usage:

CALL PRANDTL (PL, TEMP, PR, NTMP)

Where

PL	=	$\log_{10}$ P, P in Atmospheres
TEMP	,	Array of Temperature Values
PR	,	Array of Prandtl Number Values at Pressure P
NTMP	,	Number of Values in Temperature Array

Description of Variables

IJK	,	Undefined for First Call of Subroutine, and is Used to Read Prandtl Number Tables
J	,	Array Subscript
K	,	Array Subscript
NPL	,	Number of Tables to be Read
NTEMP	,	Number of Temperature Values in Each Step
PL1	,	Array of Pressures at which the Prandtl Numbers are Tabulated
PRPLT	,	Interpolated Values of Prandtl Number at Pressure PL
TI	,	Array of Temperature Values at Which Prandtl Number Values are Tabulated

Subroutine DERIV5

This subroutine determines the first derivative of a function F with respect to the independent Variable X. The derivative of F is returned as FP.

Usage:

CALL DERIV5 (X, IE, F, FP)

Where X and F are the ordinate arrays, IE the number of values in the arrays, and FP is the returned array.

The description of subroutines INTER5 and FD5 are given with the boundary layer program.

Input Data Preparation

The card input data given below is to follow (in the order listed) the data cards required by the computer program described in (2).

<u>Card 1</u> FORMAT (7F10.5,I5)

PLMAX	Maximum Value of Log_{10} P, P in Atmospheres
DELTPL	Increment in Log_{10} P, Value is Negative
CTINT	Maximum Temperature, °K
DELCT	Increment in Temperature, Value is Negative
CTMIN	Minimum Value of Temperature, °K
RHOSTD	Density of Gas mixture at Standard Atmospheric Pressure, slugs/ft^3
CMSTD	Molecular Weight at Standard Atmospheric Pressure and Temperature
JPL	Number of Tables to be Generated

<u>Card 2</u>		FORMAT (7F10.5,I5)
GAMMA	Ratio of Specific Heats at Standard Atmospheric Conditions	
<u>Card 3</u>		FORMAT (7F10.5,I5)
A (J)	Coefficients of Viscosity	
B (J)	Curve Fits, One Card for	
C (J)	Each Species Considered	
<u>Card 4</u>		FORMAT (5I5)
NPL	Number of Tables to be Read	
NTEMP	Number of Temperature Values to be Read in T1 Array	
<u>Card 5</u>		FORMAT (8F10.5)
TL (K)	Array of Temperatures, Input in Increasing Increments. Use as many cards as necessary.	
<u>Card 6</u>		FORMAT (8F10.5)
PL1	$\text{Log}_{10}P$, P in Atmospheres	
<u>Card 7</u>		FORMAT (8F10.5)
PR1	Array of Prandtl Numbers Corresponding to PL1 and the Temperatures Input in Array T1. The number of cards is the same as card type 5.	

List of Symbols for Appendix B

A_i	,	Coefficient in Viscosity Curve Fit
B_i	,	Coefficient in Viscosity Curve Fit
C_i	,	Coefficient in Viscosity Curve Fit
c_i	,	Mass Fraction of the ith Specie
CP	=	C_p/RGAS
C_p	,	Specific Heat
H'	,	Enthalpy, ft^2/sec^2
H	,	H'/RGAS, °K
$\tilde{H}$	=	$\text{Log}_{10} H$
M_i	,	Molecular Weight of the ith Specie
P	,	Pressure in Atmospheres
PR	,	Prandtl Number
RGAS	=	Gas Constant
ρ	=	$\text{Log}_{10}\ \rho'$
ρ'	,	Density in Amagats
μ_i	,	Species Viscosity, gm/(cm-sec)
μ	,	Viscosity of Mixture, lb-sec/ft^2

```
C     EQUILIBRIUM THERMODYNAMIC AND TRANSPORT PROPERTIES
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON A, AA(22,24), ACGM(20), AFNTS, AFNX, ALPIJ(20,10), AMACH,
     1AR, ARBA, ARBB, ASUB(10), ATP(5), B(64,20), BCHI(64), BE(64),
     2BET(20), BETA(64,20), BLBK(31), BSUB(31), BZERO, C, CAI(64),
     3CAPX(20), CAPXTH(20), CARB, CCPJ(20), CDIJ(20,10), CEACT(64),
     4CECHII(64),CGI(20), CGMU(20), CH, CHA, CHI(64), CHII(20),
     5CLNIMC(64), CLNPI(64), CLNT, CM, CMA, CMW(20), CRA, CRP, CRRB,CRS,
     6CSTA, CT, CTAP, CTB, CTC, CTMAX, CTMXX, CTP, CTPL, CTT, CX, CXB,
     7CXMAX, DATEST, DBTEST, DELT1, DELT2, DELT3, DELTAX, DLOGA, DLOGR,
     8DT, ELJ(10,20), ELMENT(20), ENT, ETAI(64), ETAJ(20), FLUX,
     9GELJ(10,20), GJA(20), GJB(20), GJC(20), GTEST, HDELX, HP(20)
      COMMON  PCT, PCTEST, PERTGJ(20), PGJ(20), PI(64), PICHI(64),
     1PRES, PRESA, PRESB, PRESTH, PRHO, QM(20), QQ(64), RHAP, RHO, RHOB,
     2RHOBAR, RHOC, RHOP, RHPL, RHTH, ROBARA, ROBARP, SAJ(20), SCPG,
     3SDCHI(64), SDELTX, SDT, SEN, SENT(20), SHDELX, SHJ(20), SHJA(20),
     4SHPG, SKIL(20), SC, SL, SL64, SM, SS(20), SU, SU2, SUMG, TB(30),
     5TEMP1, TEST, TESTB, TFA(20), TFB(20), TFC(20), TFD(20), TFE(20),
     6TFK(20), THEV(20), TPRINT, TSTOP, TTEST, UP, XMJAT(20), XNUI(64),
     7XNUIJ(64,20), XNUIJP(64,20), ZP, ZPA
C
C
      COMMON  IC, IGJ(20), IGM(20), IM, INEQ, INEQV, IP, IROBAR, IRUN,
     1ISC, ISCP1, ISMC, ISMCNR, ISR, ISS, ISSNR,ISSP1,ISSP2,ISSP3,ISSP4
C
      COMMON  IKKK,NDUMMY
      COMMON  DELT4
      COMMON  ISW1A, ISW1B, ISW2A, ISW2B, ISW3A, ISW3B, ISW4A, ISW4B,
     1ISW5A, ISW5B, ISW6A, ISW6B, IZERO, ITB(5), IUPD, JJK, KHO, KKUR,
     2KUR(64,20), LC, M1, NAFIT, NFIT, NIT, NNN, NNS, NQS, NOT, NTEST
C
      DIMENSION  AAA(22,24), BTA(64,20), CAPQ(31), CCI(20), DGJ(20),
     1GJ(20), SBJ(20), SDGJ(20), SHJAP(20), THEVP(20)
C
      DIMENSION TEMP(100),HORL(100),RHOL(100),SPHTOR(100),XMU(100),
     *PR(100),CMLW(100),ZCOMP(100),CJ(20),IGJB(30),HOR(100),CONC(100),
     *SPHTRF(100)
C
      EQUIVALENCE ( AA(  1),AAA(  1)), (BETA(  1),BTA(  1)),
     1(BLBK(1),CAPQ(1)),(CAPXTH(1),CCI(1)), (GJA(1),DGJ(1)),(CAPX(1),
     2 GJ(1)), (SAJ(1),SBJ(1)),(SS(1),SDGJ(1)), (SHJA(1),SHJAP(1)),
     3(THEV(1),THEVP(1))
C
      ABS(X)=DABS(X)
      SQRT(X)=DSQRT(X)
      EXP(X)=DEXP(X)
C
101   FORMAT(12H0 RESERVOIR-,I4//13H TEMPERATURE=,F9.2,9H DENSITY=,F11.8
     1,10H PRESSURE=,F9.3//10H ENTHALPY=,F8.4,9H ENTROPY=,F9.4,18H MOLEC
     2ULAR WEIGHT=,F7.4//(1X,A6,  E11.3))
      CALL REED
      READ(5,100) PLMAX,DELTPL,CTINIT,DELCT,CTMIN,RHOSTD,CMSTD,JPL
      READ(5,100) GAMMA
      WRITE(6,200)PLMAX,DELTPL,CTINIT,DELCT,CTMIN,RHOSTD,CMSTD,JPL
200    FORMAT(1H0,1X,6HPLMAX=F10.3,1X,7HDELTPL=F10.3,1X,
     17HCTINIT=F10.3,1X,6HDELCT=F10.3,1X,6HCTMIN=F10.3,
     27HRHOSTD=F10.7,1X,6HCMSTD=F10.5,1X,4HJPL=I3)
100   FORMAT(7F10.5,I5)
      DO 10 J=1,ISS
      IGJB(J)=IGJ(J)
10    CONTINUE
      RGAS=1.98674*778.158*32.174/CMSTD
      CP=RGAS*(GAMMA/(GAMMA-1.))
      WRITE(6,300) RGAS,CP,GAMMA
300   FORMAT(1H0,5HRGAS=F10.5,1X,3HCP=F10.5,1X,6HGAMMA=F10.5)
      REWIND 20
      PL=PLMAX
      CTAP=CTINIT
       J=1
      DO 30 K=1,JPL
11     CONTINUE
      PRESA=10.D0**PL
```

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```
      CALL INIT
      HOR(J)=CHA*CTAP/CMA*CMSTD
      RHOLOC=RHAP*2.205D-3/(3.531D-5*32.1759D0)
      RHOLOS=RHOLOC/RHOSTD
      TEMP(J)=CTAP
      HORL(J)=DLOG10(HOR(J))
      RHOL(J)=DLOG10(RHOLOS)
      ZCOMP(J)=PRESA*2116.224D0/(RHOLOC*TEMP(J)*RGAS   )/1.8D0
      SUM=0.D0
      DO 15 IJ=1,ISS
      SUM=SUM+CAPX(IJ)
15    CONTINUE
      CAPX(2)=1.D0-SUM+CAPX(2)
      SUM=0.D0
      DO 40 I=1,ISS
      CJ(I)=CAPX(I)*CGI(I)/CMA
      SUM=SUM+CJ(I)*CCPJ(I)
40    CONTINUE
      SPHTR=SUM
      CALL XMUPR(CTAP,SPHTR ,CRA,CCPJ,CGI,GJA,ISS,HP,CMA,AMU,APR,COND(J)
     *)
C     CONDF(J)=COND(J)
      SPHTRF(J)=SPHTR
      XMU(J)=AMU
      PR(J)=APR
      CMLW(J)=CMA
      CTAP1=CTAP
      IF(CTAP1.LE. 600.D0) GO TO 20
      CTAP=CTAP1+DELCT
      IF(CTAP.LT.CTMIN) GO TO 20
      J=J+1
      GO TO 11
20    CONTINUE
      CTAP=CTAP1+DELCT
      JCT=J
      JCT2=J
      I=J
25    CONTINUE
      IF(CTAP.LT.CTMIN) GO TO 2000
      I=I+1
      JCT2=I
      PRESA=10.D0**PL
      SPHTOR(I)=CP/RGAS
      SPHTRF(I)=SPHTOR(I)
      HOR(I)=SPHTOR(I)*CTAP
      HORL(I)=DLOG10(SPHTOR(I)*CTAP)
      RHOLOC=PRESA*2116.224D0/(RGAS    *CTAP*1.8D0)
      RHOL(I)=DLOG10(RHOLOC/RHOSTD)
      TEMP(I)=CTAP
      ZCOMP(I)=1.D0
      CMLW(I)=CMSTD
      XMU(I)=(518.6D0+198.6D0)/(CTAP*1.8D0+198.6D0)*
     1(CTAP*1.8D0/518.6D0)**1.5D0*3.719D-7
      CTAP1=CTAP
      CTAP=CTAP+DELCT
      IF(CTAP.LT.200.D0) CTAP=CTAP1-50.D0
      IF(CTAP.LT.50.D0) CTAP=CTAP1-5.D0
      GO TO 25
2000  CONTINUE
      CALL DERIV5(TEMP,JCT,HORL,SPHTOR)
      DO 50 I=1,JCT
      SPHTOR(I)=SPHTOR(I)*HOR(I)/DLOG10(2.718281828459045D0)
50    CONTINUE
      JCT=JCT2
      CALL PRNDTL(PL,TEMP,PR,JCT)
      WRITE(6,150)PL,JCT
      WRITE(6,152)
      WRITE(6,155) (TEMP(J),HORL(J),RHOL(J),XMU(J),SPHTOR(J),PR(J),
     *CMLW(J),ZCOMP(J),SPHTRF(J),J=1,JCT)
      WRITE(20) PL,JCT
      WRITE(20) TEMP,HORL,RHOL,XMU,SPHTOR,PR
      PL=PL+DELTPL
```

```
      CTAP=CTINIT
      IF(DELTPL.EQ.0.D0) STOP
      J=1
30    CONTINUE
150   FORMAT(1H0,8X,29HLOG10 PRESSURE IN ATMOSPHERES,12X,3HPL=1PD16.8,
     *5X,21HNO.TEMPERATURE STEPS=I3)
152   FORMAT(1H0,/115H      TEMP            H/R            RHO            XMU
     *        CP/R          PRL             MOLW           Z              CP/RF)
155   FORMAT(1X,1P9D13.6)
      STOP
      END




      SUBROUTINE INIT                                                   03350
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON A, AA(22,24), ACOM(20), AFNTS, AFNX, ALPIJ(20,10), AMACH,
     1AR, ARBA, ARBB, ASUB(10), ATP(5), B(64,20), BCHI(64), BE(64),
     2BET(20), BETA(64,20), BLBK(31), BSUB(31), BZERO, C, CAI(64),
     3CAPX(20), CAPXTH(20), CARB, CCPJ(20), CDIJ(20,10), CEACT(64),
     4CECHII(64),CGI(20), CGMU(20), CH, CHA, CHI(64), CHII(20),
     5CLN1MC(64), CLNPI(64), CLNT, CM, CMA, CMW(20), CRA, CRP, CRRB,CRS,
     6CSTA, CT, CTAP, CTB, CTC, CTMAX, CTMXX, CTP, CTPL, CTT, CX, CXB,
     7CXMAX, DATEST, DBTEST, DELT1, DELT2, DELT3, DELTAX, DLOGA, DLOGR,
     8DT, ELJ(10,20), ELMENT(20), ENT, ETAI(64), ETAJ(20), FLUX,
     9GELJ(10,20), GJA(20), GJB(20), GJC(20), GTEST, HDELX, HP(20)
      COMMON  PCT, PCTEST, PERTGJ(20), PGJ(20), PI(64), PICHI(64),
     1PRES, PRESA, PRESB, PRESTH, PRHO, QM(20), QQ(64), RHAP, RHO, RHOB,
     2RHOBAR, RHOC, RHOP, RHPL, RHTH, ROBARA, ROBARP, SAJ(20), SCPG,
     3SDCHI(64), SDELTX, SDT, SEN, SENT(20), SHDELX, SHJ(20), SHJA(20),
     4SHPG, SKIL(20), SC, SL, SL64, SM, SS(20), SU, SU2, SUMG, TB(30),
     5TEMP1, TEST, TESTB, TFA(20), TFB(20), TFC(20), TFD(20), TFE(20),
     6TFK(20), THEV(20), TPRINT, TSTOP, TTEST, UP, XMJAT(20), XNUI(64),
     7XNUIJ(64,20), XNUIJP(64,20), ZP, ZPA
C
C
      COMMON  IC, IGJ(20), IGM(20), IM, INEQ, INEQV, IP, IROBAR, IRUN,
     1ISC, ISCP1, ISMC, ISMCNR, ISR, ISS, ISSNR,ISSP1,ISSP2,ISSP3,ISSP4
C
      COMMON  IKKK,NDUMMY
      COMMON  DELT4
      COMMON  ISW1A, ISW1B, ISW2A, ISW2B, ISW3A, ISW3B, ISW4A, ISW4B,
     1ISW5A, ISW5B, ISW6A, ISW6B, IZERO, ITB(5), IUPD, JJK, KHO, KKUR,
     2KUR(64,20), LC, M1, NAFIT, NFIT, NIT, NNN, NNS, NQS, NOT, NTEST
C
      DIMENSION  AAA(22,24), BTA(64,20), CAPQ(31), CCI(20), DGJ(20),
     1GJ(20), SBJ(20), SDGJ(20), SHJAP(20), THEVP(20)
C
      EQUIVALENCE ( AA(  1),AAA(  1)), (BETA(  1),BTA(  1)),
     1(BLBK(1),CAPQ(1)),(CAPXTH(1),CCI(1)), (GJA(1),DGJ(1)),(CAPX(1),
     2 GJ(1)), (SAJ(1),SBJ(1)),(SS(1),SDGJ(1)), (SHJA(1),SHJAP(1)),
     3(THEV(1),THEVP(1))
C
      DIMENSION TFB1(20),TFC1(20),TFD1(20),TFE1(20),ELJ1(10,20)
      DIMENSION THEVP1(20),SBJ1(20),SHJAP1(20)
      ABS(X)=DABS(X)
      SQRT(X)=DSQRT(X)
      EXP(X)=DEXP(X)
      ALOG(X)=DLOG(X)
      IF(IJK.EQ.34) GO TO 50
      CTMXX1=CTMXX
      TSTOP1=TSTOP
      DO 500 K=1,ISS
      TFB1(K)=TFB(K)
      TFC1(K)=TFC(K)
      TFD1(K)=TFD(K)
      TFE1(K)=TFE(K)
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      SHJAP1(K)=SHJAP(K)
      THEVP1(K)=THEVP(K)
      SBJ1(K)=SBJ(K)
 500   CONTINUE
      DO 501 I=1,ISS
      K=IGM(I)
      DO 501 L=1,K
501   ELJ1(L,I)=ELJ(L,I)
      IJK=34
50    CONTINUE
C
      CTMXX=CTMXX1/CTAP
      TSTOP=TSTOP1/CTAP
      IF(TSTOP-.01)8,9,9
    8 TSTOP=.01
    9 ARBA=5.0
      ARBB=0.0
      JJK=0
      CT=1.0
      IKKK=0.0
      IM=1
      CRA=1.98647
      CRP=CRA*CTAP
      CTPL=ALOG(CTAP)
      ISMC=ISS-ISC
      IF(NFIT)1,3,1
    1 T1=CTAP
      T2=T1*T1
      T3=T1*T2
      T4=T1*T3
      DO 2 I=1,ISS
      TFB(I)=TFB1(I)*T1
      TFC(I)=TFC1(I)*T2
      TFD(I)=TFD1(I)*T3
      TFE(I)=TFE1(I)*T4
    2 CONTINUE
    3 IF(KHO)4,6,4
    4 DO 5 I=1,ISS
      SAJ(I)=SBJ1(I)+(1.5+ETAJ(I))*CTPL
      THEV(I)=THEVP1(I)/CTAP
      K=IGM(I)
      DO 5 L=1,K
    5 ELJ(L,I)=ELJ1(L,I)/CRP
    6 DO 7 I=1,ISS
    7 SHJA(I)=SHJAP1(I)/CRP
      ISMCNR=ISMC
      ISSNR=ISS
      CALL INTA
      RETURN
      END


      SUBROUTINE INTA
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON A, AA(22,24), ACCM(20), AFNTS, AFNX, ALPIJ(20,10), AMACH,
     1AR, ARBA, ARBB, ASUB(10), ATP(5), B(64,20), BCHI(64), BE(64),
     2BET(20), BETA(64,20), BLBK(31), BSUB(31), BZERO, C, CAI(64),
     3CAPX(20), CAPXTH(20), CARB, CCPJ(20), CDIJ(20,10), CEACT(64),
     4CECHII(64),CGI(20), CGMU(20), CH, CHA, CHI(64), CHII(20),
     5CLN1MC(64), CLNPI(64), CLNT, CM, CMA, CMW(20), CRA, CRP, CRRB,CRS,
     6CSTA, CT, CTAP, CTB, CTC, CTMAX, CTMXX, CTP, CTPL, CTT, CX, CXB,
     7CXMAX, DATEST, DBTEST, DELT1, DELT2, DELT3, DELTAX, DLOGA, DLOGR,
     8DT, ELJ(10,20), ELMENT(20), ENT, ETAI(64), ETAJ(20), FLUX,
     9GELJ(10,20), GJA(20), GJB(20), GJC(20), GTEST, HDELX, HP(20)
C
```

```
      COMMON  PCT, PCTEST, PERTGJ(20), PGJ(20), PI(64), PICHI(64),
     1PRES, PRESA, PRESB, PRESTH, PRHO, QM(20), QQ(64), RHAP, RHO, RHOB,
     2RHOBAR, RHOC, RHOP, RHPL, RHTH, ROBARA, ROBARP, SAJ(20), SCPG,
     3SDCHI(64), SDELTX, SDT, SEN, SENT(20), SHDELX, SHJ(20), SHJA(20),
     4SHPG, SKIL(20), SC, SL, SL64, SM, SS(20), SU, SU2, SUMG, TB(30),
     5TEMP1, TEST, TESTB, TFA(20), TFB(20), TFC(20), TFD(20), TFE(20),
     6TFK(20), THEV(20), TPRINT, TSTOP, TTEST, UP, XMJAT(20), XNUI(64),
     7XNUIJ(64,20), XNUIJP(64,20), ZP, ZPA
C
      COMMON  IC, IGJ(20), IGM(20), IM, INEQ, INEQV, IP, IROBAR, IRUN,
     1ISC, ISCP1, ISMC, ISMCNR, ISR, ISS, ISSNR,ISSP1,ISSP2,ISSP3,ISSP4
C
      COMMON  IKKK,NDUMMY
      COMMON  DELT4
      COMMON  ISW1A, ISW1B, ISW2A, ISW2B, ISW3A, ISW3B, ISW4A, ISW4B,
     1ISW5A, ISW5B, ISW6A, ISW6B, IZERO, ITB(5), IUPD, JJK, KHO, KKUR,
     2KUR(64,20), LC, M1, NAFIT, NFIT, NIT, NNN, NNS, NQS, NCT, NTEST
C
      DIMENSION  AAA(22,24), BTA(64,20), CAPQ(31), CCI(20), DGJ(20),
     1GJ(20), SBJ(20), SDGJ(20), SHJAP(20), THEVP(20)
C
      EQUIVALENCE ( AA(  1),AAA(  1)), (BETA(  1),BTA(  1)),
     1(BLBK(1),CAPQ(1)),(CAPXTH(1),CCI(1)), (GJA(1),DGJ(1)),(CAPX(1),
     2 GJ(1)), (SAJ(1),SBJ(1)),(SS(1),SDGJ(1)), (SHJA(1),SHJAP(1)),
     3(THEV(1),THEVP(1))
C
      ABS(X)=DABS(X)
      SQRT(X)=DSQRT(X)
      EXP(X)=DEXP(X)
      ALOG(X)=DLOG(X)
C
      DO 1 I=1,ISC
      DO 1 J=1,ISC
    1 BTA(I,J)=ALPIJ(I,J)
      CALL MATIN (BTA,ISC,64)
      DO 3 I=1,ISMC
      L=I+ISC
      DO 3 J=1,ISC
      CDIJ(I,J)=0.0
      DO 2 K=1,ISC
    2 CDIJ(I,J)=CDIJ(I,J)+BTA(K,J)*ALPIJ(L,K)
    3 CONTINUE
      DO 5 I=1,ISMC
      BET(I)=-1.0
      DO 4 K=1,ISC
    4 BET(I)=BET(I)+CDIJ(I,K)
    5 CONTINUE
      SUM=0.0
      DO 7 I=1,ISC
      QM(I)=0.0
      DO 6 K=1,ISC
    6 QM(I)=QM(I)+BTA(K,I)*CAPQ(K)
      SUM=SUM+QM(I)
    7 CONTINUE
      DO 8 I=1,ISC
      QM(I)=QM(I)/SUM
      CCI(I)=0.0
      DO 8 J=1,ISC
    8 CCI(I)=CCI(I)+ALPIJ(I,J)*CMW(J)
      IF(IC-IZERO)80,81,80
   80 CAPX(1)=.001
      GO TO 82
   81 CAPX(1)=QM(1)
   82 CONTINUE
      DO 9 I=2,ISC
      CAPX(I)=QM(I)
      CGMU(I)=ALOG(CAPX(I))
    9 CGI(I)=CCI(I)
      CGMU(1)=ALOG(CAPX(1))
      CGI(1)=CCI(1)
      DO 11 I=1,ISMC
      SUM=0.0
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      DO 10 K=1,ISC
   10 SUM=SUM+CDIJ(I,K)*CGI(K)
      IL=I+ISC
      CGI(IL)=SUM
   11 CONTINUE
      ZPA=ALOG(PRESA)
      CLGT=ALOG(CT)
      CTP=CT*CTAP
      CLNT=ALOG(CTP)
      DO 70 J=1,ISS
   56 XMJAT(J)=TFA(J)*(1.-CLNT)      -TFK(J)-CT*(TFB(J)+CT*(TFC(J)/2.+
     XCT*(TFD(J)/3.+CT*TFE(J)/4.)))+SHJA(J)/CT
      SHJ(J)=SHJA(J)+CT*(TFA(J)+CT*(TFB(J)+CT*(TFC(J)+CT*(TFD(J)+
     XCT*TFE(J)))))
      CCPJ(J)=TFA(J)+CT*(2.0*TFB(J)+CT*(3.0*TFC(J)+CT*(4.0*TFD(J)+CT*
     X(5.0*TFE(J)))))
  172 SENT(J)=SHJ(J)/CT-XMJAT(J)
   70  CONTINUE
      DO 13 I=1,ISMC
      IL=I+ISC
      CHII(I)=-XMJAT(IL)+ZPA*BET(I)
      DO 12 J=1,ISC
   12 CHII(I)=CHII(I)+XMJAT(J)*CDIJ(I,J)
   13 CONTINUE
      DO 15 I=1,ISMC
      SKIL(I)=CHII(I)
      DO 14 J=1,ISC
   14 SKIL(I)=SKIL(I)+CDIJ(I,J)*CGMU(J)
      L=I+ISC
      CGMU(L)=SKIL(I)
      SKIL(I)=EXP(SKIL(I))
   15 CAPX(L)=SKIL(I)
      M1=ISC+1
      N=0
   16 N=N+1
      DO 18 J=1,ISC
      AA(J,M1)=QM(J)-CAPX(J)
      DO 17 I=1,ISMC
   17 AA(J,M1)=-(CDIJ(I,J)-QM(J)*BET(I))*SKIL(I)+AA(J,M1)
   18 CONTINUE
      DO 23 J=1,ISC
      DO 23 K=1,ISC
      IF(J-K)20,19,20
   19 AA(J,K)=CAPX(J)
      GO TO 21
   20 AA(J,K)=0.0
   21 DO 22 I=1,ISMC
   22 AA(J,K)=AA(J,K)+(CDIJ(I,K)*(CDIJ(I,J)-QM(J)*BET(I))*SKIL(I))
   23 CONTINUE
      CALL SIMSOL(AA,ISC,22)
      DO 26 K=1,ISC
      ZA=1.+AA(K,M1)
      IF(ZA)24,24,25
   24 CAPX(K)=CAPX(K)/2.11
      CGMU(K)=ALOG(CAPX(K))
      GO TO 26
   25 CAPX(K)=CAPX(K)*ZA
      CGMU(K)=ALOG(CAPX(K))
   26 CONTINUE
      DO 28 I=1,ISMC
      SKIL(I)=CHII(I)
      DO 27 L=1,ISC
   27 SKIL(I)=SKIL(I)+CDIJ(I,L)*CGMU(L)
      J=I+ISC
      CGMU(J)=SKIL(I)
      SKIL(I)=EXP(SKIL(I))
      CAPX(J)=SKIL(I)
   28 CONTINUE
      DO 29 K=1,ISC
      IF(ABS(AA(K,M1))-TEST)29,29,280
  280 IF(N-NTEST)16,16,32
   29 CONTINUE
```

```
      CHA=0.0
      SEN=-ZPA
      CM=0.0
      DO 30 I=1,ISS
      SEN=SEN+CAPX(I)*(SENT(I)-CGMU(I))
      CHA=CHA+CAPX(I)*SHJ(I)
   30 CM=CM+CAPX(I)*CGI(I)
      CMA=CM
      CRRB=SEN/CMA
      SEN=CRRB*CRA
      CH=CHA
      DO 31 I=1,ISS
   31 GJA(I)=CAPX(I)/CMA
      ROBARP=PRESA*CMA/(CTAP*41.30558*CRA)
      RHAP=ROBARP/(1.+ROBARP*BZERO)
      ROBARA=ROBARP/RHAP
      CHA=CHA+(ROBARP/RHAP-1.)
      RETURN
   32 WRITE(6,33)
   33 FORMAT(35H TOO MANY NEWTON-RAPHSON ITERATIONS)
      STOP
      END
```

```
      SUBROUTINE XMUPR(T,CP,R,CCPJ,CGI,GJA,ISS,HP,CMA,XMU,PR,CON)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(20),B(20),C(20),EMU(20),CCPJ(1),CGI(1),GJA(1),HP(1)
      IF(IJK.EQ.552) GO TO 1
      READ(5,100) (A(I),B(I),C(I),I=1,ISS)
      WRITE(6,110)
      WRITE(6,111)
      WRITE(6,115) (HP(I),A(I),B(I),C(I),I=1,ISS)
100   FORMAT(3F20.10)
110   FORMAT(1H0,13X,29HVISCOSITY CURVE FIT CONSTANTS)
111   FORMAT(1H0,5X,10HSPECIES(I),8X,4HA(I),14X,4HB(I),15X,4HC(I))
115   FORMAT(1H0,4X,A8,1P3D20.6)
      IJK=552
    1 TL=DLOG(T)
      XMU=0.D0
      CON=0.D0
      DO 10 I=2,ISS
      EMU(I)=DEXP(C(I))*T**(A(I)*TL+B(I))
      EMU(I)=EMU(I)*5.6D-3*12.D0/32.174D0
10    CONTINUE
      DO 30 I=2,ISS
      CAPK=EMU(I)*(CCPJ(I)+1.25D0)/CGI(I)*R*778.158D0*32.174D0
      FAC1=0.D0
      DO 20 J=2,ISS
      PHI=(1.D0+(EMU(I)/EMU(J))**0.5D0*(CGI(J)/CGI(I))**0.25D0)**2/
     *(8.D0*(1.D0+CGI(I)/CGI(J)))**0.5D0
      FAC1=FAC1+GJA(J)*PHI
20    CONTINUE
      FAC2=GJA(I)/FAC1
      XMU=XMU+EMU(I)*FAC2
      CON=CON+CAPK*FAC2
30    CONTINUE
      PR=CP*XMU/CON*R*778.158D0*32.174D0/CMA
C     UNITS OF VISCOSITY(XMU) LB.-SEC./FT.**2
C     CONDUCTIVITY(CON) LB./(SEC-DEG.RANKINE)
      RETURN
      END
```

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```
      SUBROUTINE PRNDTL(PL,TEMP,PR,NTMP)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION TEMP(1),PR(1),PL1(11),T1(50),PR1(11,50),PRPLT(50)
      IF(IJK.EQ.3) GO TO 40
      IJK=3
      READ(5,5) NPL,NTEMP
      READ(5,10) (T1(K),K=1,NTEMP)
      DO 30 J=1,NPL
      READ(5,10) PL1(J)
      READ(5,10) (PR1(J,K),K=1,NTEMP)
30    CONTINUE
40    CONTINUE
      J=0
50    J=J+1
      IF(PL.LT.PL1(J)) GO TO 50
      IF(J.LT.3) J=3
      IF(J.GT.(NPL-2)) J=NPL-2
      DO 60 K=1,NTEMP
      CALL INTER5(PL,PL1(J-2),PL1(J-1),PL1(J),PL1(J+1),PL1(J+2),
     1PR1(J-2,K),PR1(J-1,K),PR1(J,K),PR1(J+1,K),PR1(J+2,K),PRPLT(K))
60    CONTINUE
      DO 80 K=1,NTMP
      J=0
70    J=J+1
      IF(TEMP(K).GT.T1(J)) GO TO 70
      IF(J.LT.3) J=3
      IF(J.GT.(NTEMP-2)) J=NTEMP-2
      CALL INTER5(TEMP(K),T1(J-2),T1(J-1),T1(J),T1(J+1),T1(J+2),
     1PRPLT(J-2),PRPLT(J-1),PRPLT(J),PRPLT(J+1),PRPLT(J+2),PR(K))
80    CONTINUE
      RETURN
5     FORMAT(5I5)
10    FORMAT(8F10.6)
      END
```

```
C
      SUBROUTINE INTER5(X,X1,X2,X3,X4,X5,F1,F2,F3,F4,F5,F)
      IMPLICIT REAL*8(A-H,O-Z)
C X1.LE.XLE.X5
      A1=(X-X2)*(X-X3)*(X-X4)*(X-X5)
      A2=(X-X1)*(X-X3)*(X-X4)*(X-X5)
      A3=(X-X1)*(X-X2)*(X-X4)*(X-X5)
      A4=(X-X1)*(X-X2)*(X-X3)*(X-X5)
      A5=(X-X1)*(X-X2)*(X-X3)*(X-X4)
      D1=(X1-X2)*(X1-X3)*(X1-X4)*(X1-X5)
      D2=(X2-X1)*(X2-X3)*(X2-X4)*(X2-X5)
      D3=(X3-X1)*(X3-X2)*(X3-X4)*(X3-X5)
      D4=(X4-X1)*(X4-X2)*(X4-X3)*(X4-X5)
      D5=(X5-X1)*(X5-X2)*(X5-X3)*(X5-X4)
      C1=A1/D1
      C2=A2/D2
      C3=A3/D3
      C4=A4/D4
      C5=A5/D5
      F=C1*F1+C2*F2+C3*F3+C4*F4+C5*F5
      RETURN
      END
```

```
SUBROUTINE FD5(X,X1,X2,X3,X4,X5,F1,F2,F3,F4,F5,FX)
IMPLICIT REAL*8(A-H,O-Z)
A1=(X-X4)*(X-X5)*(2.D0*X-X2-X3)+(X-X2)*(X-X3)*(2.D0*X-X4-X5)
A2=(X-X4)*(X-X5)*(2.D0*X-X1-X3)+(X-X1)*(X-X3)*(2.D0*X-X4-X5)
A3=(X-X4)*(X-X5)*(2.D0*X-X1-X2)+(X-X1)*(X-X2)*(2.D0*X-X4-X5)
A4=(X-X3)*(X-X5)*(2.D0*X-X1-X2)+(X-X1)*(X-X2)*(2.D0*X-X3-X5)
A5=(X-X3)*(X-X4)*(2.D0*X-X1-X2)+(X-X1)*(X-X2)*(2.D0*X-X3-X4)
D1=(X1-X2)*(X1-X3)*(X1-X4)*(X1-X5)
D2=(X2-X1)*(X2-X3)*(X2-X4)*(X2-X5)
D3=(X3-X1)*(X3-X2)*(X3-X4)*(X3-X5)
D4=(X4-X1)*(X4-X2)*(X4-X3)*(X4-X5)
D5=(X5-X1)*(X5-X2)*(X5-X3)*(X5-X4)
C1=A1/D1
C2=A2/D2
C3=A3/D3
C4=A4/D4
C5=A5/D5
FX=C1*F1+C2*F2+C3*F3+C4*F4+C5*F5
RETURN
END
```

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