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**Computer Program for Calculation of
Real Gas Turbulent Boundary Layers
with Variable Edge Entropy**

(NASA-TM-X-71970) COMPUTER PROGRAM FOR
CALCULATION OF REAL GAS TURBULENT
BOUNDARY LAYERS WITH VARIABLE EDGE
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1 COMPUTER PROGRAM FOR CALCULATION OF
2 REAL GAS TURBULENT BOUNDARY LAYERS WITH
3 VARIABLE EDGE ENTROPY

4 By Lillian R. Boney
5 Langley Research Center
6

7 SUMMARY
8

9 This report describes a computer program developed at NASA-LRC for
10 the calculation of real gas turbulent boundary layers with variable edge
11 entropy on a blunt cone or flat plate at zero angle of attack. The ana-
12 lytical techniques employed and results obtained using the program have
13 been previously reported in (ref. 42) NASA TN D-6217. The details of the
14 coding and operation of the program are discussed in the present report.
15 The digital computer program is described in detail including the flow-
16 charts, program code and instructions for use with sample input and output.
17 The program is written in FORTRAN IV language for use on a CDC 6600 computer.

18 An integral method is used to compute turbulent boundary layer. The
19 method includes the effect of real gas in thermodynamic equilibrium and
20 variable edge entropy. A modified Crocco enthalpy velocity relationship
21 is used for the enthalpy profiles and an empirical correlation of the
22 N-power law profile is used for the velocity profile. The skin friction
23 coefficient expression of Van Driest, corrected for axisymmetric flow by
24 a turbulent Mangler transformation is used in the solution of the momentum
25 equation. The value of the local coefficient of skin friction is also

1 calculated using Spalding-Chi and Eckert's theories. Heat-transfer
2 predictions are obtained by use of various modified forms of Reynolds
3 analogy.

4 The program is written in FORTRAN IV language for use on a CDC
5 6000 series computer.

6 Minimum machine requirements are 77000 octal locations of core storage
7 and three input tapes.

8 The calculation of a typical case with 25 points on the body and
9 four iterations required 260 seconds of CDC 6600 machine time.

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2 INTRODUCTION

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4 This report describes the analytical techniques employed in the cal-
5 culation of the turbulent boundary layer with variable edge entropy on a
6 blunt cone at zero angle of attack or on a flat plate. The description
7 of theory was previously reported in NASA TN D-6217 (ref. 42) and is re-
8 peated here for ready reference.

9 In the section entitled Program Description a description of the
10 function performed by each subroutine in the program is given. Flowcharts
11 are provided for the more complicated subroutines. The descriptions of
12 the subroutines are intended as a guide in relating the analysis and govern-
13 ing equations presented in NASA TND 6217 to the program described in the
14 present report.

15 The section entitled Input Description gives instructions on the
16 preparation of input data for the computer program. Sample turbulent boundary
17 layer flight calculations at an altitude of 60,000 ft. and flight conditions
18 of approximately 19,000 ft./sec. for a 13 ft. long, 5° half angle cone with
19 a nose radius of .4 inch are used to demonstrate the use of the program.
20 In the section entitled Output Description some of the results of this cal-
21 culation are used to describe the form of the output data.

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SYMBOLS

- A area
- A_R, B_R coefficients in equations (10) and (12)
- a speed of sound
- \bar{C}_F average skin-friction coefficient based on conditions at edge of boundary layer
- C_f local skin-friction coefficient based on conditions at edge of boundary layer
- F_c functions given by equations (20), (21), and (22)
- F_{MT} Mangler transformation factor
- g_c a dimensional constant to convert from slug/ft³ to lbm/ft³
- H total enthalpy
- h static enthalpy
- \bar{h} heat-transfer coefficient
- M Mach number
- N exponent in velocity-profile relation
- N_{Pr} Prandtl number
- N_r recovery factor
- $N_{St,e}$ local Stanton number based on conditions at the edge of the boundary layer
- p pressure
- \bar{q} normalized heat-transfer rate

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3	q	heating rate
4	R	unit Reynolds number
5	R_{AF}	Reynolds analogy factor
6	$R_{e,x}$	local Reynolds number based on surface distance x/r_n
7	$R_{e,\theta}$	local Reynolds number based on momentum thickness
8	r_b/r_n	dimensionless body radius
9	r_n	nose radius
10	r_s/r_n	dimensionless radius out to shock (entering stream tube)
11	S	entropy
12	T	temperature
13	u	velocity along x/r_n
14	v	velocity along y/r_n
15	x	surface distance
16	x/r_n	normalized surface distance from stagnation point or sharp-cone apex
17		
18	x_{vo}	distance from virtual origin of turbulent boundary layer
19	y/r_n	normalized coordinate normal to wall
20	z	correlation parameter defined by equation (8)
21	α_R	exponent in equation (10)
22	γ	ratio of specific heats
23	δ/r_n	dimensionless boundary-layer thickness
24		
25		

1		
2		
3	δ^*/r_n	dimensionless displacement thickness
4	θ/r_n	dimensionless momentum thickness
5	θ_c	cone half-angle
6	ρ	density
7	τ	shear stress
8	Subscripts:	
9	aw	adiabatic wall
10	e	edge of boundary layer
11	i	incompressible value
12	max	maximum
13	R	one of three regions in boundary layer, I, II, or III
14	s	shock conditions
15	t	stagnation conditions
16	tr	transition
17	w	wall
18	∞	free-stream value

19 Primes denote evaluation at reference enthalpy condition of
20 equations (13).

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PROBLEM DISCUSSION

Thermodynamic Properties for a Real Gas

The physical problem to be considered is that of a blunt body traveling in a homogeneous gas with known thermodynamic properties. The gas in which the body is traveling can be in any state of molecular excitation provided it is in thermodynamic equilibrium. For use in the present program the calculated values of the thermodynamic properties of several gases have been spline fitted with cubics and the coefficients of the cubics have been stored on magnetic tape (TAPE10) by NASA-Ames Research Center. The subroutine RGAS described in reference 27 reads the tape, searches for the proper coefficients, and evaluates the desired properties.

Inviscid Flow Field and Laminar Boundary Layer

Prior to the turbulent boundary layer calculation, the inviscid flow field is determined by the Lomax and Inouye blunt-body and method of characteristics programs. (See refs. 27 and 34.) The inviscid solution gives the first-order stagnation entropy flow property distribution along the body which is used as the initial estimate of conditions at the edge of the boundary layer. In addition, the shock shape r_s/r_n and entropy distribution along the shock are found from the inviscid solution. The results of the inviscid solution are first used to make a laminar boundary-layer calculation, with variable entropy, over the entire length of the body.

(See ref. 35.)

1

2

3 The initial use of the edge conditions from the variable-entropy
4 solution for laminar flow enables the turbulent calculation to be completed
5 in less time than the initial use of the stagnation entropy edge conditions
6 directly from the inviscid solution. Subroutine CRRD reads the inviscid
7 flow field from tapes generated by the Lomax and Inouye blunt body and
8 method of characteristics programs. The laminar boundary layer program
9 punches on cards tables of r_s/r_n and dimensionless shear as functions of
10 x/r_n which are read as input to the turbulent boundary layer program.

11

Transition Region

12

13 The turbulent boundary layer calculation is initiated at the point
14 where transition has been determined to start (XMIN). The region from
15 the end of the laminar flow solution to the point where the solution is
16 considered to be fully turbulent (X2REX) is defined as the transition
17 region. The velocity profile at the end of the transition region is
18 printed in subroutine FOFX.

18

19

Turbulent Boundary Layer

20

21 The general method of calculation of the turbulent boundary layer is
22 an iterative procedure which requires a calculation from the beginning of
23 transition (XMIN) to the end of the body (XMAXTB(20)) to be repeated until
24 the velocity at the edge of the boundary layer changes less than UERR from
25 one iteration to the next.

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The momentum integral equation (eq. 3) is solved by a variable step size fifth-order Runge Kutta numerical scheme (subroutine INTLA). The calculation of the integrals from the wall to the edge of the boundary layer (eq. 4, 5, 19) is by Gaussian quadrature (subroutine VGAUSS).

Variable-Entropy Momentum Integral Equation

The boundary-layer equations for the conservation of mass and momentum for application to a body of revolution at zero angle of attack are

$$\frac{\partial \rho u \frac{r_b}{r_n}}{\partial \frac{x}{r_n}} + \frac{\partial \rho v \frac{r_b}{r_n}}{\partial \frac{x}{r_n}} = 0 \tag{1}$$

$$\rho u \frac{\partial u}{\partial \frac{x}{r_n}} + \rho v \frac{\partial u}{\partial \frac{y}{r_n}} = - \frac{dp}{d \frac{x}{r_n}} + \frac{\partial \tau}{\partial \frac{y}{r_n}} \tag{2}$$

where $p = p(x)$ and $\frac{\delta}{r_n} \ll \frac{r_b}{r_n}$.

1 Equations (1) and (2) are combined and integrated from the wall to
 2 the edge of the boundary layer. The resulting equations are cast in an
 3 integral form amenable for numerical integration as

4

$$\begin{aligned}
 \frac{d}{d \frac{x}{r_n}} \left[\frac{\theta}{r_n} \right] &= \frac{C_f}{2} - \frac{\theta}{r_n} \left[\left(2.0 + \frac{\delta^*/r_n}{\theta/r_n} \right) \frac{1}{u_e} \frac{du_e}{d \frac{x}{r_n}} + \frac{1}{\rho_e} \frac{d\rho_e}{d \frac{x}{r_n}} + \frac{1}{r_b/r_n} \frac{d}{d \frac{x}{r_n}} \left[\frac{r_b}{r_n} \right] \right] \\
 &+ \frac{\delta/r_n}{u_e} \left(\frac{dp_e}{d \frac{x}{r_n}} \frac{g_c}{\rho_e u_e} + \frac{du_e}{d \frac{x}{r_n}} \right) \quad (3)
 \end{aligned}$$

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11 where δ^*/r_n and θ/r_n are defined by

12

$$\frac{\delta^*}{r_n} \left(1.0 + \frac{\cos \theta_c}{2} \frac{\delta^*}{r_n} \right) = \frac{\delta}{r_n} \int_0^{1.0} \left(1.0 - \frac{\rho u}{\rho_e u_e} \right) \left(1.0 + \frac{\frac{\delta}{r_n} \frac{y/r_n \cos \theta_c}{\delta/r_n}}{r_b/r_n} \right) d \frac{y/r_n}{\delta/r_n} \quad (4)$$

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$$\frac{\theta}{r_n} \left(1.0 + \frac{\cos \theta_c}{2} \frac{\theta}{r_n} \right) = \frac{\delta}{r_n} \int_0^{1.0} \frac{\rho u}{\rho_e u_e} \left(1.0 - \frac{u}{u_e} \right) \left(1.0 + \frac{\frac{\delta}{r_n} \frac{y/r_n \cos \theta_c}{\delta/r_n}}{r_b/r_n} \right) d \frac{y}{\delta} \quad (5)$$

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23 Equation (3) is similar to the well-known momentum integral equation
 24 (eq. (42), Ch. 9 of ref. 10), with the exception of the additional term
 25

$$\frac{\delta/r_n}{u_e} \left[\frac{dp_e}{d \frac{x}{r_n}} \frac{g_c}{\rho_e u_e} + \frac{du_e}{d \frac{x}{r_n}} \right] \quad (6)$$

For configurations with slight nose bluntness, a variable-entropy condition exists along the edge of the boundary layer. Therefore, the Bernoulli equation is not applicable and the previous term (eq. (6)) is added.

Velocity Profile

The velocity profiles used in the integral parameters (eqs. (4) and (5)) were calculated from the N-power law relations:

$$\frac{u}{u_e} = \left(\frac{y/r_n}{\delta/r_n} \right)^{1/N} \quad (7)$$

The value of N was calculated from a correlation of data taken from references 11 to 24 and correlate as

$$N = 6.0 \log z - 7.0$$

where

$$z = \frac{R_{e,\theta}^{1/3} \left(\frac{T_w}{T_e} \right)^{1/2} \left(\frac{x_{vo}/r_n}{\theta/r_n} \right)^{1/3}}{M_e^{1/4}} \quad (8)$$

The x_{vo}/r_n used in equation (8) is the dimensionless distance from the virtual origin of turbulent flow. The expression used to find the virtual origin distance on a cone is

1
$$\frac{x_{vo}}{r_n} = \frac{\theta/r_n}{1.045 \frac{\bar{C}_F}{2}} \quad (9)$$

2

3

4 where $\bar{C}_F/2$ is the Spalding-Chi (ref. 7) average value of skin friction
 5 and θ/r_n is the local value of momentum thickness.

6

7

Density Profiles

8

9 The calculation of a density profile through the boundary layer is
 10 based on the assumption that the total enthalpy through the boundary
 11 layer varies as a function of u/u_e according to a modified form of the
 12 Crocco expression given by

13

14
$$\frac{H - h_w}{H_e - h_w} = A_R + B_R \left(\frac{u}{u_e} \right)^{\alpha_R} \quad (10)$$

15

16 The total enthalpy at any point in the boundary layer is given by

17

18
$$H = h + \frac{u^2}{2} \quad (11)$$

19

20 When equations (10) and (11) are combined, the resulting expression for
 21 static enthalpy is

22

23
$$h = h_w + (H_e - h_w) \left[A_R + B_R \left(\frac{u}{u_e} \right)^{\alpha_R} \right] - \frac{u_e^2}{2} \left(\frac{u}{u_e} \right)^2 \quad (12)$$

24

25 where the coefficients A_R and B_R and the exponent α_R vary with
 three regions of calculation through the boundary layer (denoted by

1 subscripts I, II, and III) which are as follows:

2 Region I (wall) ($0 \leq u/u_e < 0.01$). - The coefficients for the wall
3 region as used in equation (12) are

4

$$\left. \begin{aligned} 5 \quad A_I &= 0 \\ 6 \quad B_I &= \frac{H_{aw} - h_w}{H_e - h_w} \frac{(N_{Pr})_w}{(N'_{Pr})^{2/3}} \\ 8 \quad \alpha_I &= 1.0 \end{aligned} \right\} \quad (13)$$

9

10 where the coefficient B_I is derived from

11

$$\left(\frac{d \frac{H - h_w}{H_e - h_w}}{d \frac{u}{u_e}} \right)_w \quad (14)$$

12

13

14

15 combined with the energy equation, the Fourier conduction law, and the
16 Colburn form of the Reynolds analogy. (See ref. 28.) The prime indicates
17 that the Prandtl number is evaluated at Eckert's reference enthalpy which
18 is

19

$$h' = \frac{1}{2} (h_w + h_e) + 0.22 (h_{aw} - h_e) \quad (15)$$

20

21 where $h_{aw} = h_e + N_r (H_e - h_e)$ and $N_r = 0.89$ were used. The local N'_{Pr}
22 is found from table IV of reference 29 where the Prandtl number is tabulated
23 as a function of temperature and pressures. The temperature used to deter-
24 mine the Prandtl number in reference 29 is found from the real-gas thermo-
25 dynamic tables as a function of h' (eq. (15)) and the local pressure p_e .

1 Region III (outer) ($0.1 < u/u_e \leq 1.0$). - The coefficients for the
 2 outer region (region III) as used in equation (10) are

$$\left. \begin{aligned}
 3 \quad & A_{III} = 0 \\
 4 \quad & \\
 5 \quad & B_{III} = 1.0 \\
 6 \quad & \\
 7 \quad & \alpha_{III} = \text{Constant at a given } x \text{ station}
 \end{aligned} \right\} \quad (16)$$

8 The value of α_{III} varies linearly from an initial value (α_{MIN})
 9 at the start of transition to α_{IX} at the end of the transition region.

10 Region II (intermediate) ($0.01 \leq u/u_e \leq 0.1$). - Regions I and III
 11 are joined by an intermediate linear relationship which matches the
 12 region I (wall) equation at $u/u_e = 0.01$ and the region III (outer) at
 13 $u/u_e = 0.10$, where the coefficients used in equation (10) for the inter-
 14 mediate region are calculated from

$$\left. \begin{aligned}
 15 \quad & \\
 16 \quad & A_{II} = B_{III}(0.1)^{\alpha_{III}} - 0.1B_{II} \\
 17 \quad & \\
 18 \quad & B_{II} = \frac{B_{III}(0.1)^{\alpha_{III}} - B_I(0.01)}{(0.09)} \\
 19 \quad & \\
 20 \quad & \alpha_{II} = 1.0
 \end{aligned} \right\} \quad (17)$$

21 It should be noted that the boundaries of the three regions may be different
 22 from the values assumed herein. (See ref. 8.)

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Mass Flow Into Boundary Layer

The change in entropy at the edge of the boundary layer is determined from the entropy distribution along the shock. The variation in boundary-layer edge conditions due to change in entropy may be calculated by balancing the mass flow in the boundary layer with that entering the stream tube through the shock given by

$$2\pi \left(\frac{r_s}{r_n}\right)^2 \rho_\infty u_\infty = \int_0^\delta \rho u dA \quad (18)$$

The expression for the shock radius is then given by

$$\frac{r_s}{r_n} = \sqrt{2 \frac{r_b}{r_n} \frac{\rho_e u_e}{\rho_\infty u_\infty} \frac{\delta}{r_n} \int_0^{1.0} \frac{\rho u}{\rho_e u_e} \left(1.0 + \frac{\frac{\delta}{r_n} \frac{y/r_n \cos \theta_c}{\delta/r_n}}{r_b/r_n}\right) d \frac{y/r_n}{\delta/r_n}} \quad (19)$$

The value of the entropy at the edge of the boundary layer is found with r_s/r_n (from eq. (19)) from a table of shock radius and shock entropy from the inviscid calculation.

Skin-Friction Calculation

The calculation of the Van Driest II theory in reference 30 (described in detail in ref. 6) uses a Karman-Schoenherr incompressible skin-friction expression. The Karman-Schoenherr equation uses a transformed value of the local Reynolds number based on momentum thickness to obtain skin-friction

1 coefficient for the incompressible plane. The skin-friction coefficient
 2 for the incompressible plane is transformed to the compressible plane by
 3 using an expression which is a function of M_e , and T_w/T_e , and is analogous
 4 to the Spalding-Chi F_c function. (See ref. 7.) This analogous F_c
 5 function is referred to as the "Van Driest II F_c function" and is given
 6 in reference 6 as

$$7 \quad F_c = \frac{0.176M_e^2}{\sin^{-1}\alpha + \sin^{-1}\beta} \quad (20)$$

9 where α and β are functions of Mach number and temperature ratio.
 10 (See ref. 6.)

11 The general expression given in reference 7 for F_c is

$$13 \quad F_c = \left[\int_0^1 \left(\frac{\rho}{\rho_e} \right)^{1/2} d \frac{u}{u_e} \right]^{-2} \quad (21)$$

15 The F_c function given in equation (21) may be integrated by using
 16 a real-gas variation of equation (12); however, the correct values of α_R
 17 must be used. The ideal gas F_c function used in reference 7 to correlate
 18 the skin-friction data is given by

$$19 \quad F_c = \left(\int_0^1 \frac{d \frac{u}{u_e}}{\left\{ \frac{T_w}{T_e} + \left[1 + \frac{N_r}{2}(\gamma - 1)M_e^2 - \frac{T_w}{T_e} \right] \frac{u}{u_e} - \frac{N_r}{2}(\gamma - 1)M_e^2 \left(\frac{u}{u_e} \right)^2 \right\}^{1/2}} \right)^{-2} \quad (22)$$

23 where N_r , as used in reference 7, is equal to 0.89. Equation (22) was
 24 derived from equation (21) with the assumption of a linear Crocco relation-
 25 ship (that is, $\alpha_R = 1.0$). The local skin-friction coefficient obtained

1 from the turbulent-flat-plate theories from either reference 7 or reference
 2 6 must be corrected for application to a cone by the Mangler transformation
 3 factor F_{MT} . (See equations 33, 34.) The local skin friction on a cone
 4 downstream of the end of transition is found from

$$5 \quad \left(\frac{C_f}{2}\right)_{\text{Cone}} = F_{MT} \left(\frac{C_f}{2}\right)_{\text{Flat plate}} \quad (23)$$

6 where for fully turbulent flow

$$7 \quad F_{MT} = 1.176 \quad (24)$$

8 The value of the local coefficient of skin friction needed at each
 9 point of calculation in order to evaluate the right-hand side of equation
 10 (3) is determined from Van Driest II (ref. 6) theory, calculated by use
 11 of a Reynolds number based on momentum thickness. Subroutine CFA also
 12 computes skin friction coefficient by seven additional methods, which are given
 13 in the output for comparison: (1) Van Driest II based on R_{ex} , (2) Spalding-Chi
 14 based on R_{ex} and ideal gas F_c function, (3) Eckert's reference enthalpy based
 15 on R_{ex} , (4) Eckert's reference enthalpy based on $R_{ex_{MIN}}$, (5) Eckert's refer-
 16 ence enthalpy based on $R_{e\theta}$, (6) Spalding-Chi based on $R_{e\theta}$ and ideal gas F_c
 17 function, (7) Spalding-Chi based on $R_{e\theta}$ and real gas F_c function.

21 Transition Region Skin Friction

22 The value of $C_f/2$ in the transition region is assumed to vary as

$$23 \quad \frac{C_f}{2} = \frac{C_f}{2} \Big|_{tr} + \frac{Y}{2 \tanh \psi} \left[\left(\frac{C_f}{2}\right)_{\text{turb}} - \left(\frac{C_f}{2}\right)_{tr} \right] \quad (25)$$

1 where

2

$$Y = \tanh \psi + \tanh X$$

3

4

5

6

$$X = \psi - 2\psi \left[\frac{\left(\frac{x}{r_n}\right)_{\text{turb}} - \frac{x}{r_n}}{\left(\frac{x}{r_n}\right)_{\text{turb}} - \left(\frac{x}{r_n}\right)_{\text{tr}}} \right]$$

7

8 and $\psi = \text{Constant}$.

9

The value of N in the transition region is assumed to vary as

10

11

$$N = N_{\text{tr}} + \frac{Y}{2 \tanh \psi} (N_{\text{turb}} - N_{\text{tr}}) \quad (26)$$

12

13

where Y is the expression used in equation (25) and $\psi = 2.0$. The value

14

of N_{tr} is taken from the theoretical laminar calculation. The value of

15

N at the end of the transition N_{turb} is calculated from equation (8).

16

The value of α_{III} used in equation (12) varies linearly from an

17

initial value (ALMIN) at the start of transition to $\alpha_{\text{III}} = 1.0$ (ALX)

18

at the end of the transition region.

19

20

Heat Transfer

21

22

The local Stanton number is calculated from a modified Reynolds

23

analogy in the form

24

25

$$N_{\text{St,e}} = \frac{C_f}{2} R_{\text{AF}} \quad (27)$$

1 where R_{AF} is the Reynolds analogy factor. The value of the R_{AF} depends
 2 on which local turbulent skin-friction theory is used. If the Van Driest II
 3 (ref. 6) is used for heat transfer, the Reynolds analogy factor is a function
 4 of h_w/H_e as listed in table I and for the Spalding-Chi skin-friction theory
 5 (ref. 7), $R_{AF} = \frac{1}{(N'_{Pr})^{2/3}}$.
 6

7 TABLE I. - VARIATION OF REYNOLDS ANALOGY FACTOR WITH h_w/H_e
 8

h_w/H_e	R_{AF}
$\frac{h_w}{H_e} < 0.2$	1.0
$0.2 \leq \frac{h_w}{H_e} \leq 0.65$	$0.8311 + 0.9675 \frac{h_w}{H_e} - 0.6142 \left(\frac{h_w}{H_e}\right)^2$
$\frac{h_w}{H_e} > 0.65$	1.2

9
 10
 11
 12
 13
 14
 15
 16
 17 The value of N'_{Pr} is taken from tables of Prandtl number given in
 18 reference 29 evaluated at h' (see eq. (15)) and the local static pressure.

19 The local heat-transfer coefficient \bar{h} is calculated from

20
 21
$$\bar{h} = N_{St,e} u_e \rho_e \quad (28)$$

22 The heating rate q is calculated from

23
 24
$$q = \bar{h}(h_{aw} - h_w) \quad (29)$$

25 where $h_{aw} = h_e + N_r(H_e - h_e)$ where $N_r = 0.89$.

1 The variation of the wall shear is calculated from

2

3
$$\tau_w = \frac{C_f}{2} \rho_e u_e^2 \quad (30)$$

4

5

6 Transformation of the Local and Average Turbulent Skin
7 Friction from a Flat-Plate to a Sharp-Cone Value

8

Local Skin Friction

9

10 The general form of the Mangler transformation factor F_{MT} (see ref.
11 41) converting local flat-plate skin friction to a sharp-cone value is

12
$$F_{MT} = \frac{C_f|_{\text{Cone}}}{C_f|_{\text{Flat plate}}} = \left[\frac{\frac{x}{r_n} \left(\frac{r_b}{r_n}\right)^{\frac{n}{n-1}}}{\int_0^{\frac{x}{r_n} \left(\frac{r_b}{r_n}\right)^{\frac{n}{n-1}}} d \frac{x}{r_n}} \right]^{1/n} \quad (31)$$

17 When the Blasius form of the turbulent skin friction for a flat plate

18

19
$$C_f \propto R_{e,x}^{-1/n} \quad (32)$$

20 is used, with $n = 5.0$, along with the assumption of turbulent flow over
21 the entire cone, the resulting Mangler transformation factor is

22

23
$$F_{MT} = 1.176 \quad (33)$$

24

25 In the region of fully turbulent flow, the $F_{MT} = 1.176$ (eq. (33))
was used for the calculations in which the Van Driest II skin-friction

1 theory was used. When the Spalding-Chi skin-friction theory was used,
 2 an alternate variation of the F_{MT} was used which took into account the
 3 transition from a laminar $F_{MT} (\sqrt{3})$ to a turbulent F_{MT} (1.176) in
 4 the form

$$5 \quad F_{MT}^2 - 2\sqrt{3} F_{MT} + 3.0 = \bar{P} \left[\frac{x}{r_n} - \left(\frac{x_{v0}}{r_n} \right)_0 \right] \quad (34)$$

7 where

$$8 \quad \bar{P} = \frac{0.309136}{\left[\left(\frac{x}{r_n} \right)_{\max} - \left(\frac{x_{v0}}{r_n} \right)_0 \right]}$$

10 The $\left(\frac{x_{v0}}{r_n} \right)_0$ term was evaluated at the beginning of fully turbulent
 11 flow from equation (9) and the $\left(\frac{x}{r_n} \right)_{\max}$ was evaluated at the end of
 12 the cone.

17 Average Skin Friction

18 The ratio of the average skin friction on a sharp cone to that on a
 19 flat plate is

$$20 \quad \frac{\bar{C}_F|_{\text{Cone}}}{\bar{C}_F|_{\text{Flat plate}}} = \frac{\int_0^L (C_f)_{\text{Cone}} dA}{\int_0^L dA} \quad (35)$$

$$21 \quad \frac{\bar{C}_F|_{\text{Cone}}}{\bar{C}_F|_{\text{Flat plate}}} = \frac{\int_0^L (C_f)_{\text{Cone}} dA}{\int_0^L (C_f)_{\text{Flat plate}} d \frac{x}{r_n}}$$

$$22 \quad \frac{\bar{C}_F|_{\text{Cone}}}{\bar{C}_F|_{\text{Flat plate}}} = \frac{\int_0^L (C_f)_{\text{Cone}} dA}{\int_0^L d \frac{x}{r_n}}$$

1
2 where L is a constant and is the same for the flat plate and cone. When
3 equations (32) and (33) are substituted into equation (35) and the indicated
4 integration is performed, the resulting ratio of the average skin friction
5 on a cone to that on a flat plate is
6

$$\frac{\bar{C}_F \text{ Cone}}{\bar{C}_F \text{ Flat plate}} = 1.045 \quad (36)$$

7
8
9
10
11 PROGRAM DESCRIPTION

12 The turbulent boundary layer program is written in FORTRAN IV. The
13 various portions of the program, the main program D3340 and subroutines,
14 are given. The function performed by each subroutine is explained.
15 Flow charts are provided for the more complicated subroutines. A FORTRAN
16 listing is given for each subroutine. Library subroutines DIF for
17 differentiation, DISCOT, UNS, DISSER, LAGRAN for interpolation, and INTIA,
18 VGAUSS for integration are used. A description of these subroutines
19 is included in the appendix.

20 An alphabetical listing of Subroutines with the calling programs
21 written in parentheses.

22 D3340.- Program D3340 computes the equilibrium gas compressible turbulent
23 boundary layer over blunt cones or flat plates including the effects of
24 variable entropy.
25

1

2

3 AL3CAL. (D3340, DERSUB)

4 Subroutine AL3CAL computes coefficients α_{III} , B_{II} , A_{II} for use in
5 the calculation of density profiles.

6 CFA. (D3340)

7 Subroutine CFA computes skin friction coefficient by seven methods--
8 Van Driest (R_{ex}), Spalding-Chi I (R_{ex}), Eckert's reference enthalpy (R_{ex}),
9 Eckert's reference enthalpy ($R_{ex_{MIN}}$), Eckert's reference enthalpy ($R_{e\theta}$),
10 Spalding-Chi I ($R_{e\theta}$), Spalding-Chi II ($R_{e\theta}$).

11 CFCAL. (DERSUB)

12 Subroutine CFCAL computes the VanDriest II F_c function to correlate
13 the skin-friction data.

14 CHECK. (D3340)

15 Subroutine to be used by INTIA to allow certain logical control.
16 The control is not desired in this case and a dummy subroutine is
17 inserted.

18 CMT. (CFA)

19 Subroutine CMT computes Mangler transformation factor for VanDriest
20 and Eckert's skin-friction coefficient.

21 CMT1. (CFA)

22 Subroutine CMT1 computes Mangler transformation factor for Spalding-
23 Chi skin-friction coefficient.

24 CRRD. (D3340)

25 Subroutine CRRD reads inviscid flow field from tapes 15, 16, 22 if
CARD = 0 is input. This subroutine computes tables of x/r_n , r_b/r_n ,

1
2
3 s, p, on body and r_s/r_n , s on shock.
4 DELITR. (DERSUB)
5 Subroutine DELITR computes boundary layer thickness for cone or
6 flat plate and displacement thickness for flat plate.
7 DERSUB. (D3340)
8 Subroutine DERSUB evaluates the derivative of the variable entropy
9 momentum integral equation.
10 DIF. (D3340)
11 This is a function subprogram which differentiates the function at
12 any given point in a table of supplied values.
13 DISCOT. (D3340, CFA, DERSUB, EDGE)
14 Single or double interpolation subroutine for continuous or dis-
15 continuous functions.
16 DISSER. (DISCOT)
17 Library subroutine used by DISCOT.
18 EDGE. (D3340, DERSUB)
19 Subroutine EDGE computes the initial conditions at the edge of the
20 boundary layer using the results of the inviscid solution and the
21 laminar boundary layer calculation.
22 FOFX. (DELITR, START)
23 Function subroutine FOFX computes integrals in the boundary layer
24 equations for conservation of mass and momentum.
25

1
2 FOFZ. (CFA, CFCAL)
3 Function subroutine FOFZ computes the ideal gas F_c function to
4 correlate the skin-friction data.
5 FOFZA. (CFA)
6 Function subroutine FOFZA computes the real gas F_c function to
7 correlate the skin-friction data.
8 INPN2. (D3340)
9 Subroutine INPN2 reads NAMELIST \$N2 if CARD = 1. is input. Given
10 cone angle, shock angle, constant pressure and entropy this subroutine
11 computes tables of x/r_n , r_b/r_n , s , p on body and r_s/r_n , s on shock.
12 INTLA. (D3340)
13 INTLA is a closed subroutine for the solution of a set of
14 ordinary differential equations.
15 LAGRAN. (DISCOT)
16 Library subroutine used by DISCOT.
17 RFCAL. (CFA)
18 Subroutine RFCAL computes Reynolds analogy factor for VanDriest
19 skin-friction theory.
20 RFCAL1. (CFA)
21 Subroutine RFCAL1 computes Reynolds analogy factor for Spalding-
22 Chi and Eckert's skin-friction theories.
23 RGAS. (D3340, EDGE, RGASH, RGAST)
24 Subroutine RGAS computes the thermodynamic properties for a real
25 gas.

1 RGASH. (CFA, EDGE, FOFX, FOFZA)
2 Subroutine RGASH computes thermodynamic properties density, speed
3 of sound, temperature and entropy given pressure, enthalpy and an esti-
4 mate of entropy.

5 RGAST. (D3340, EDGE)
6 Subroutine RGAST computes thermodynamic properties density, speed of
7 sound, enthalpy and entropy, given pressure, temperature and an estimate
8 of entropy.

9 ROLL. (RGAS)
10 Subroutine called by RGAS to position TAPE10 to proper file for gas
11 properties.

12 SERCH. (RGAS)
13 Subroutine called by RGAS to locate information for gas properties.

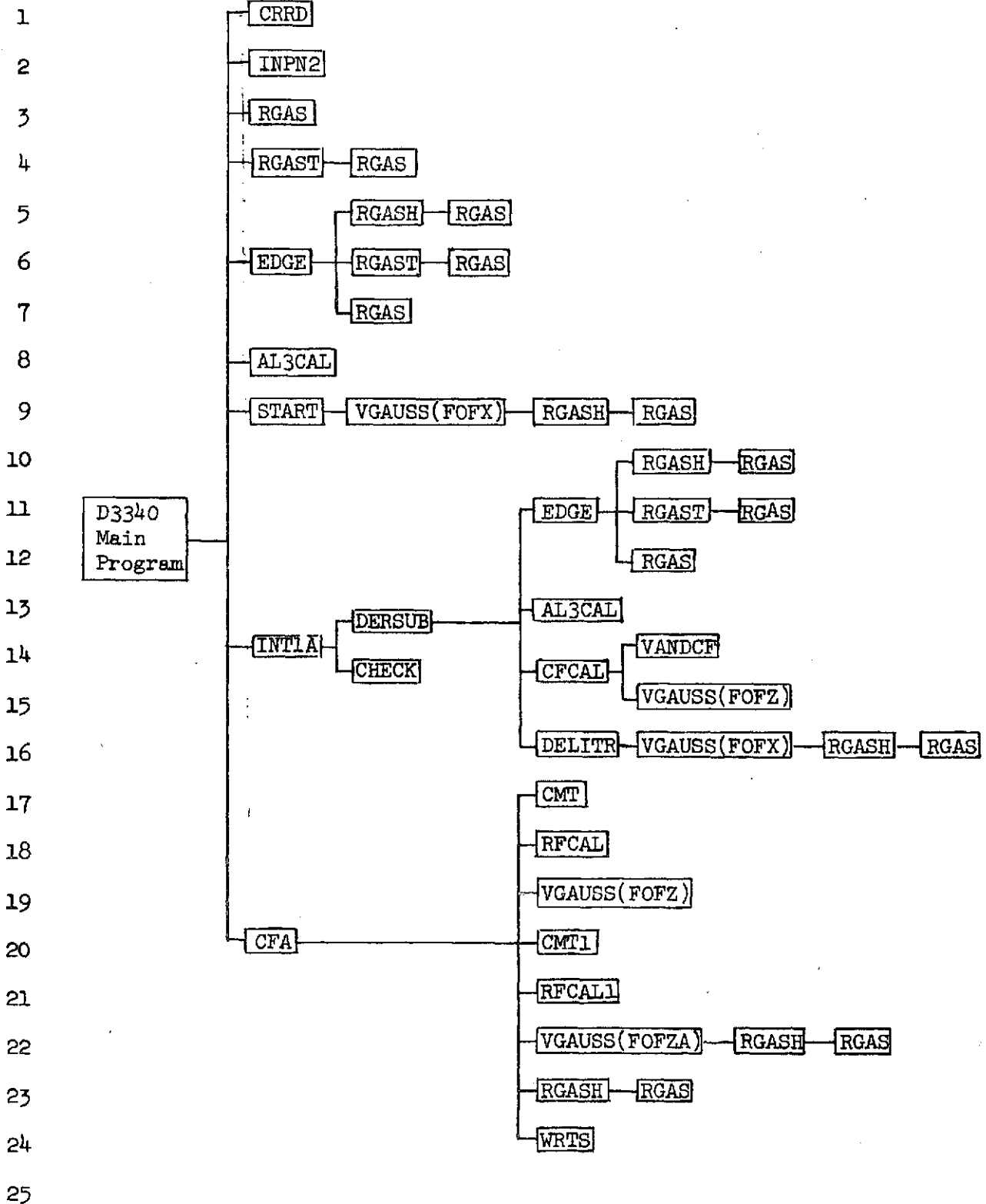
14 START. (D3340)
15 Subroutine START computes initial values of boundary layer thickness,
16 displacement thickness, momentum thickness, skin-friction coefficient.

17 UNS. (DISCOT)
18 Library Subroutine used by DISCOT.

19 VANDCF. (CFCAL)
20 Subroutine VANDCF computes the VanDriest II skin-friction coefficient
21 using Reynolds number based on momentum thickness.

22 VGAUSS. (CFA, CFACAL, DELITR, START)
23 To compute the integrals $\int_a^b F_i(x) dx$ for $i = 1, 2, 3, \dots$, number.

24 WRIS. (CFA)
25 Subroutine WRIS computes heat transfer coefficient and heating rates
based on each skin-friction theory and prints output.



A Flow Diagram of D3340 by Subroutines Called

1

2 Fortran Subroutines and their functions with flow charts

3 D3340.-Program D3340 computes the equilibrium gas compressible turbulent
4 boundary layer over blunt cones or flat plates including the effects of
5 variable entropy. The boundary-layer equations for the conservation of
6 mass and momentum are combined and integrated from the wall to the edge
7 of the boundary layer. Prior to the boundary-layer calculation, the invis-
8 cid flow field must be determined. The Lomax and Inouye blunt-body and
9 method-of-characteristics programs were used to make this determination.
10 (See refs. 27 and 34.) The inviscid solution gives the first-order stag-
11 nation entropy flow property distribution along the body which is used as
12 the initial estimate of conditions at the edge of the boundary layer. In
13 addition, the shock shape r_s/r_n and entropy distribution along the shock
14 are found from the inviscid solution. The results of the inviscid solution
15 are first used to make a laminar boundary-layer calculation, with variable
16 entropy, over the entire length of the body. (See ref. 35.) The turbulent-
17 boundary-layer calculation is initiated at the point where transition has
18 been determined to start (XMIN). The initial edge conditions used in the
19 turbulent-boundary-layer calculation come from the laminar solution.

20 The momentum integral equation (eq. 3) is solved by a variable-step-
21 size fifth-order Runge-Kutta numerical scheme. The iterative procedure

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2 requires a calculation from the beginning of transition to the end of
3 the body to be repeated until the velocity at the edge of the boundary-
4 layer changes less than UERR from one iteration to the next.

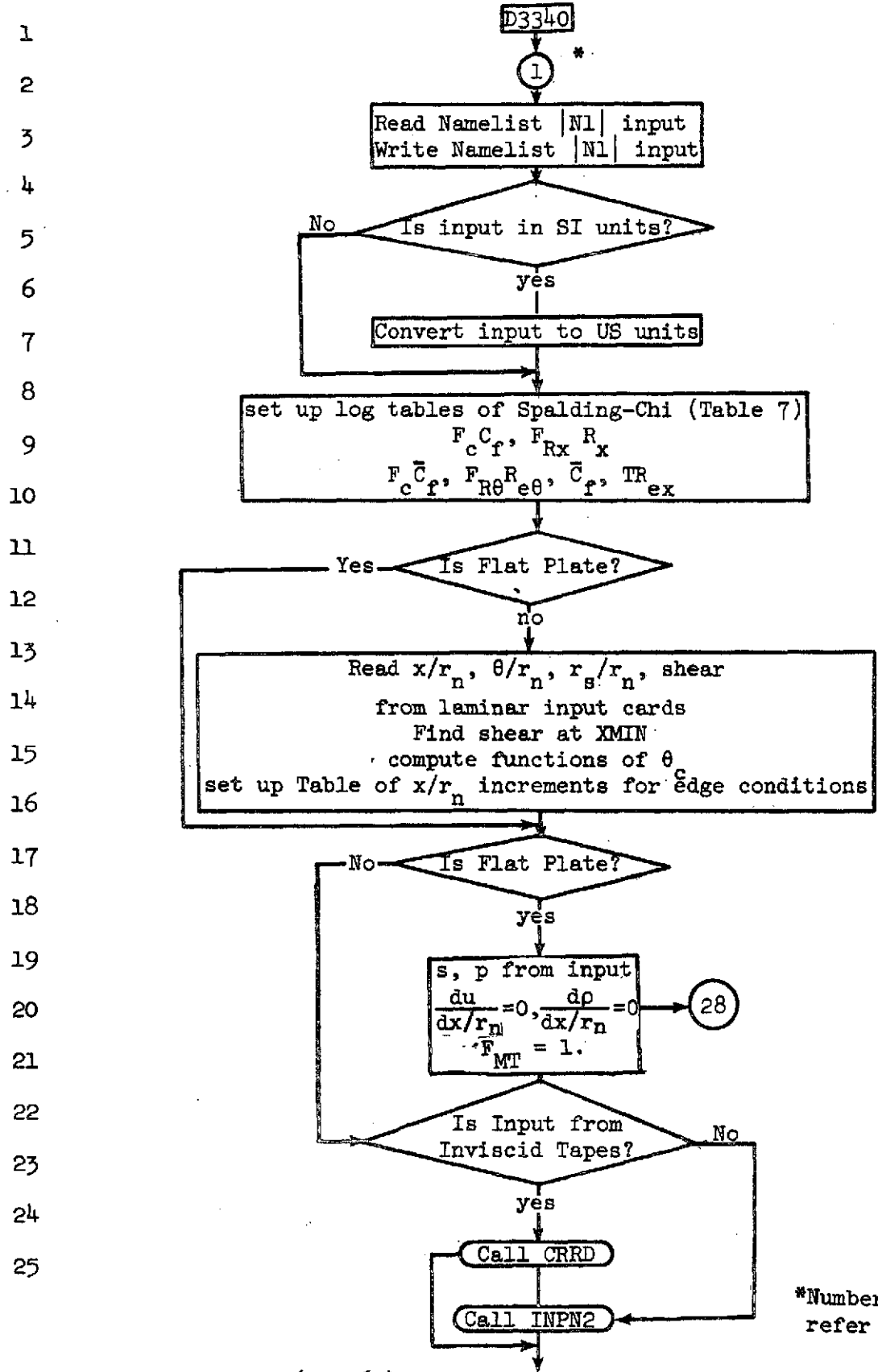
5 Skin friction, heat transfer coefficient and heating rate are
6 calculated by VanDriest II theory with Reynolds number based on momentum
7 thickness. In addition, skin-friction, heat transfer coefficient and
8 heating rate are calculated by Spalding-Chi and Eckerts reference enthalpy
9 theories with Reynolds number based on surface distance or momentum thickness.
10 These additional skin-friction theories are not used in the calculation of
11 the momentum equation but are printed output from the program.

12 The velocity profile through the boundary-layer at the end of tran-
13 sition (X2REX + .01) is printed output from the subroutine FOFX.

14 The thermodynamic properties for a real gas in thermodynamic equili-
15 brium are calculated by the RGAS subroutine described by Lomax and Inouye
16 (ref. 27). The RGAS subroutine requires the use of TAPE10 which contains
17 on file 1 the information for Nitrogen and on file 2 the information for
18 Air, $T < 27000^{\circ}\text{R}$.

19 A maximum of 160 stations along the body may be retained in a block
20 of common storage. This block is replaced in the course of each
21 iteration. Thus, values from the final iteration are available at the
22 end of the program and the user may call his own plotting program for plots
23 of $X, N, R_{e\theta}, C_{f/2}, M, \delta, \delta^*, \theta, h/H, R_{ex}, S/S_T, u/u_{\infty}, \rho/\rho_{\infty}, q/q_t, r_s/r_n$.

Flow Chart of D3340



*Numbers in circles refer to statement numbers

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Write $x_{CL}/r_n, r_b/r_n, s, p, x/r_n$ of body
Write $r_s/r_n, s$ of shock

at desired x/r_n values interpolate for
 $s, p, r_b/r_n, x_{CL}/r_n$

call RGAS for ρ, a, h, T

If x/r_n beyond Table
Compute $x_{CL}/r_n, r_b/r_n$
using θ_c
Write $x/r_n, s, p, r_b/r_n, x_{CL}/r_n,$
 T, h, u, a, M, ρ

Call DIF for derivatives
with 7 point Lagrangian Formula

Write $x/r_n, du/dx/r_n, dp/dx/r_n, dp/dx/r_n, dr_b/r_n/dx/r_n$

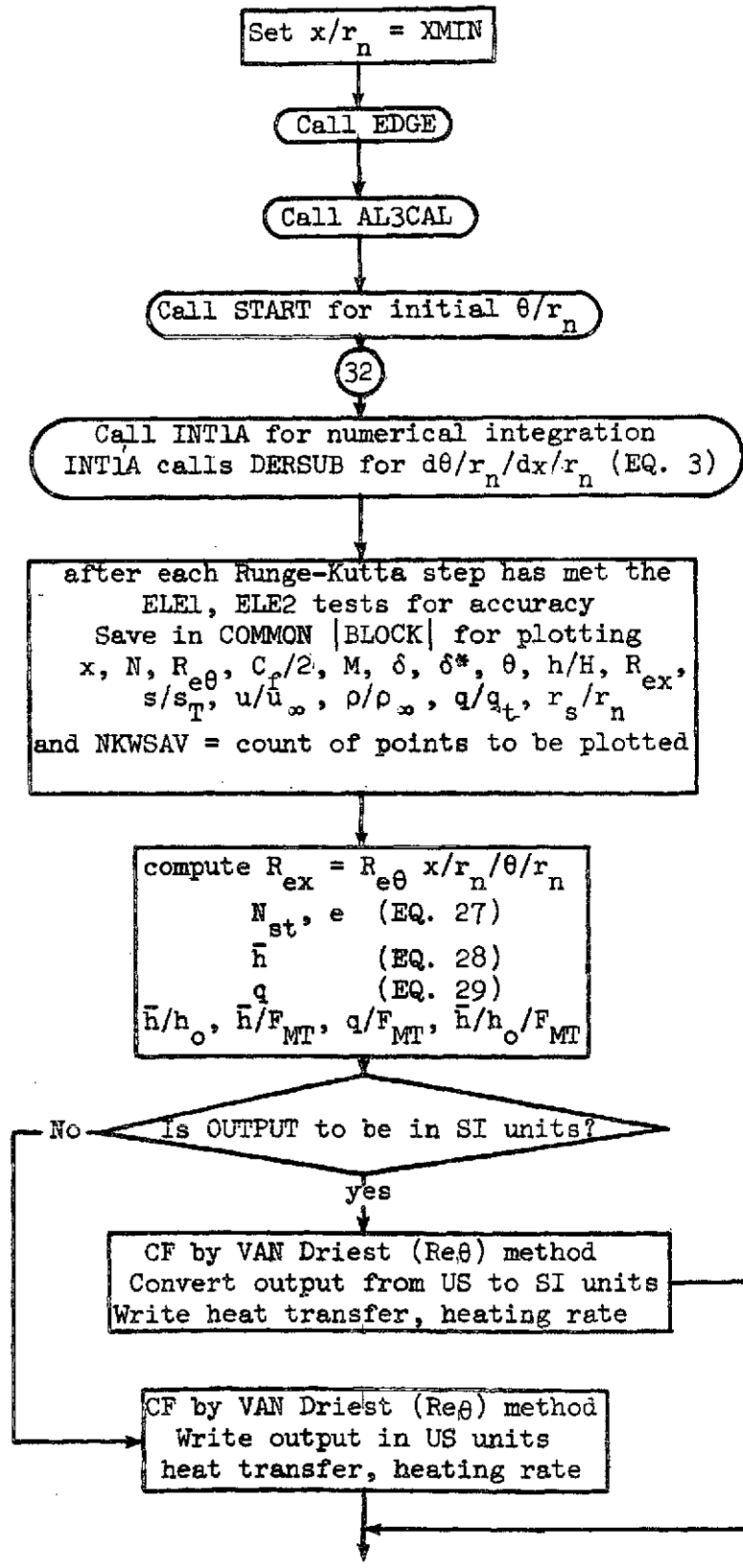
$F_{MT} = 1.045$ (EQ. 36)

28

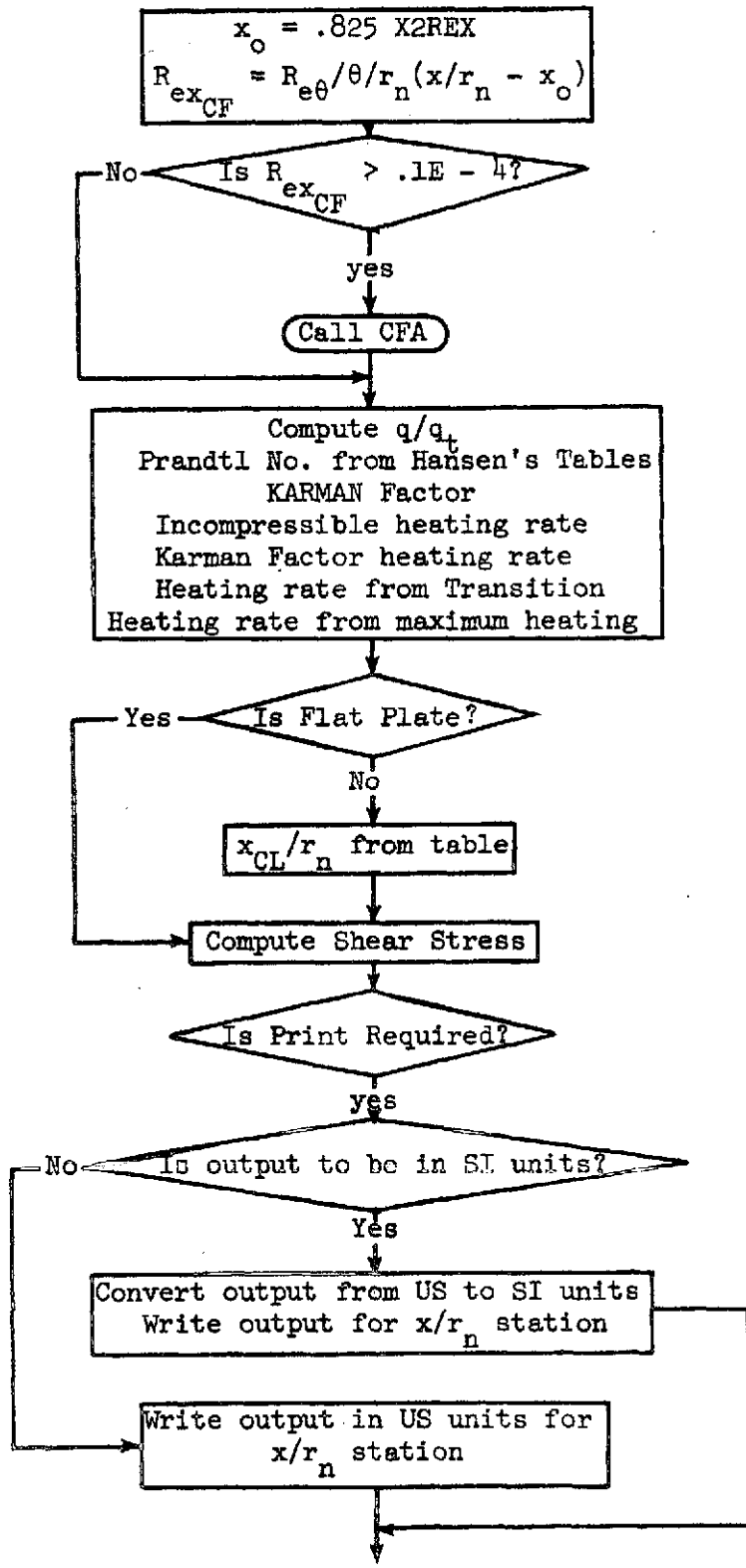
Set Initial Counts
Compute stagnation h, q and print

31

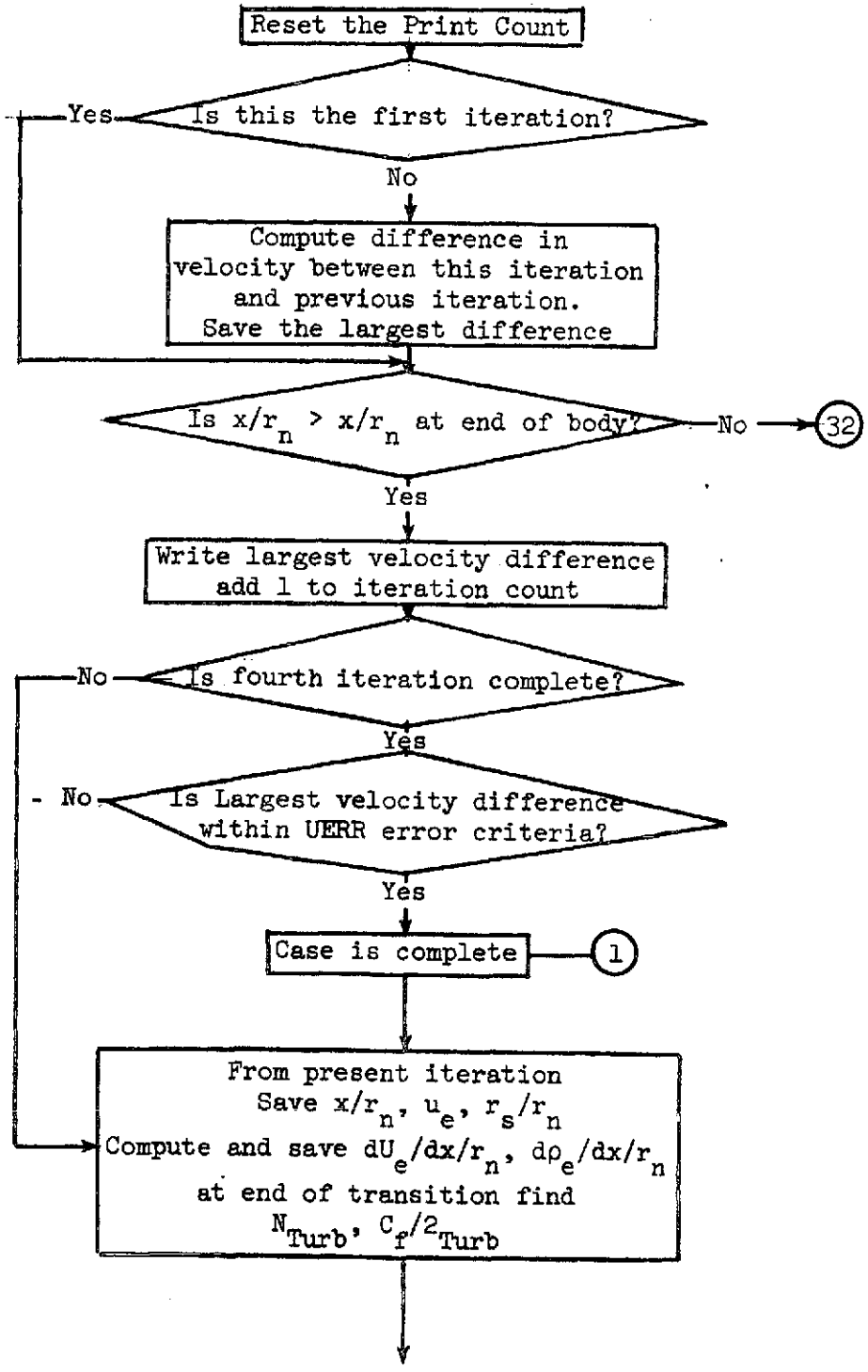
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Compute and print at end of iteration
 $x/r_{n_{Turb}}$, N_{Turb} , $N_{Turb} - N_{Tran}$,
 $2\psi/(x/r_{n_{Turb}} - x/r_{n_{Tran}})$, $C_f/2_{Turb}$,
 $(C_f/2_{Turb} - C_f/2_{Tran})$, $\tanh \psi$, $x/r_{n_{Tran}}$,
 N_{Tran} , $C_f/2_{Tran}$, $R_{ex_{Tran}}$



	PROGRAM D3340(INPUT=1001,OUTPUT=1001,TAPE5=INPUT,TAP E6=OUTPUT,TAPEPRG	1
	110=1001,TAPE15=1001,TAPE16=1001,TAPE17=1001,IAPE18=1 001,TAPE19=100PRG	2
	21,TAPE20=1001,TAPE21=1001,TAPE22=1001)	PRG 3
C		PRG 4
C	MAIN PROGRAM FOR VARIABLE ENTROPY,REAL GAS,TURBULENT BOUNDARY	PRG 5
C	LAYER	PRG 6
C	READS NAMELIST INPUT,LAMINAR INPUT CARDS, AMES TAPES FOR INVISCID	PRG 7
C	SOLUTION	PRG 8
C	READ TAPES AND SET UP TABLES	PRG 9
C	AT START OF TRANSITION COMPUTES MOMENTUM THICKNESS FROM SHOCK	PRG 10
C	RADIUS	PRG 11
C	CALLS INTIA FOR VARIABLE STEP SIZE FIFTH ORDER RUNGE KUTTA TO	PRG 12
C	INTEGRATE	PRG 13
C	VARIABLE ENTROPY MOMENTUM INTEGRAL EQUATION	PRG 14
C	AFTER EACH STEP COMPUTES HEATING RATES,SHEAR STRESS,PRINT IF	PRG 15
C	DESIRED	PRG 16
C	IN COMMON/BLOCK/ SAVES OUTPUT TO BE PLOTTED	PRG 17
C	COMPARES VELOCITIES WITH THOSE FROM PREVIOUS ITERATION	PRG 18
C	SAVES VELOCITY,SHOCK RADIUS,DENSITY,N POWER VELOCITY PROFILE ,SKIN	PRG 19
C	FRICITION	PRG 20
C	VELOCITY DERIVATIVE,DENSITY DERIVATIVE FOR NEXT ITERATION	PRG 21
C	WHEN VELOCITIES FROM TWO SUCCESSIVE ITERATIONS AGREE WITHIN ERROR	PRG 22
C	CRITERIA	PRG 23
C	AND FINAL X/L ON BODY REACHED,CASE IS COMPLETE	PRG 24
C		PRG 25
C	SN1 INPUT (UNIN=1.) (UNIN=2.)	PRG 26
C	XMIN X/RN BEGIN TRANSITION	PRG 27
C	DXLTAB(20) TABLE OF INCREMENTS OF X/RN FOR EDGE CONDITION	PRG 28
C	XMAXTR(20) TABLE OF X/RN VALUES WHERE INCREMENTS CHANGE	PRG 29
C	XMAXTR(20) IS END OF BODY	PRG 30
C	FLT X2REX+.01 FOR PRINT AT END OF TRANSITION	PRG 31
C	XLSH MAXIMUM X/RN ON SHOCK	PRG 32
C	FROM TAPE15 IF BODY ANGLE.NE.SHOCK ANGLE	PRG 33
C	XLSH1 MAXIMUM X/RN ON SHOCK	PRG 34
C	FROM TAPE22 IF BODY ANGLE.NE.SHOCK ANGLE	PRG 35
C	XLSH=XLSH1 IF BODY=SHOCK	PRG 36
C	XMHL X/RN AT MAXIMUM HEATING	PRG 37
C	FL RN NOSE RADIUS (M) (INCH)	PRG 38
C	X2REX X/RN END TRANSITION,PROFILE PRINT AT X2REX+.01	PRG 39
C	RHOUI RHOINF*UINF (KG/M2SEC) (LBM/FT2SEC)	PRG 40
C	SHEAR IF SHEAR=0 INTERPOLATE FROM LAMINAR CARDS	PRG 41
C	RO RHO DENSITY (KG/M3) (LBM/FT3)	PRG 42

C	RHOI	RHOINF DENSITY (KG/M3)	(SLUG/FT3)	PRG	43
C	UI	UINF VELOCITY (M/SEC)	(FT/SEC)	PRG	44
C	HT	TOTAL ENTHALPY (M2/SEC2)	(FT2/SEC2)	PRG	45
C	ST	TOTAL ENTROPY (M2/SEC2 DEGR)	(FT2/SEC2DEGR)	PRG	46
C	TT11	TOTAL TEMPERATURE (DEGR)	(DEGR)	PRG	47
C	DEL	INITIAL DEL/RN BOUNDARY LAYER THICKNESS FROM LAMINAR		PRG	48
C		FLAT PLATE INPUT, OMIT IF CONE		PRG	49
C	THC	CONE HALF ANGLE (RAD), OMIT IF FLAT PLATE (DEGR)		PRG	50
C	PR	PRANDTL NO.=.72		PRG	51
C	GC	DIMENSIONAL CONSTANT TO CONVERT FROM SLUG/FT3 TO		PRG	52
C		LBM/FT3 =32.174		PRG	53
C	TRAN	=0 NO TRANSITION		PRG	54
C		=1 TRANSITION		PRG	55
C	CARD	=0 READ INPUT FROM AMES TAPES		PRG	56
C		=1 READ NAMELIST N2		PRG	57
C	PRINT	PRINT FREQUENCY		PRG	58
C	A(3)	AR COEFFICIENTS FOR ENTHALPY EQ(12) A(1)=0, A(3)=0		PRG	59
C	F(3)	BR COEFFICIENTS FOR ENTHALPY EQ(12) F(3)=1.		PRG	60
C	ALPHE(3)	ALPHA COEFFICIENTS FOR ENTHALPY EQ(12)		PRG	61
C		ALPHE(1)=ALPHE(2)=1.		PRG	62
C	ZMIN	=31.623 EQ(8), SETS N=2		PRG	63
C	ZMAX	=681.33 EQ(8), SETS N=10		PRG	64
C	AN	=1/3 EQ(8), RETH**AN		PRG	65
C	CN	=1/2 EQ(8), (TW/TE)**CN		PRG	66
C	DN	=1/4 EQ(8), ME**DN		PRG	67
C	KN	=1/3 EQ(8), (XVO/THETA)**KN		PRG	68
C	FRXT(20)	FRRX FROM SPALDING CHI TABLE 7		PRG	69
C	FCXT(20)	FCCF FROM SPALDING CHI TABLE 7		PRG	70
C	FRTB(20)	FRTHRETH FROM SPALDING CHI TABLE 7		PRG	71
C	FCTB(20)	FCCBARF FROM SPALDING CHI TABLE 7		PRG	72
C	TKTAB(30)	TEMPERATURE FROM HANSEN TABLE 4 (DEGR) (DEGR)		PRG	73
C	PATAB(7)	PRESSURE FROM HANSEN TABLE 4 (N/M2) (ATM)		PRG	74
C	PRTAB(210)	PRANDTL NO. FROM HANSEN TABLE 4		PRG	75
C		STARTS WITH SMALL PRESSURE AND INCREASING TEMPERATURE		PRG	76
C		----LARGE PRESSURE AND INCREASING TEMPERATURE		PRG	77
C	NXINT	NO. OF VALUES IN WALL TEMPERATURE TABLE		PRG	78
C	XINT(99)	VALUES OF X FOR WALL TEMPERATURE TABLE (M) (INCH)		PRG	79
C	TWT(99)	VALUES OF WALL TEMPERATURE (DEGR) (DEGR)		PRG	80
C	L	=5 NO. OF INTERVALS FOR GAUSSIAN INTEGRATION		PRG	81
C	NN	=4 NO. OF POINTS PER INTERVAL FOR GAUSSIAN INTEGRATION		PRG	82
C	NT	=1 NO. OF VALUES IN ELT BLOCK FOR RUNGE KUTTA		PRG	83
C	CI	INITIAL INTERVAL OF X/RN FOR RUNGE KUTTA		PRG	84
C	SPEC	=0 TO PRINT EVERY INTERVAL IN RUNGE KUTTA		PRG	85

C	CIMAX	MAXIMUM INTERVAL OF X/RN FOR RUNGE KUTTA	PRG 86
C	ELE1	RELATIVE ERROR IN THETA/RN	PRG 87
C		IF ERROR GREATER, RK HALVES COMPUTING INTERVAL	PRG 88
C	ELF2	RELATIVE ZERO IN THETA/RN	PRG 89
C		WILL NOT APPLY RELATIVE ERROR IF THETA/RN BELOW THIS	PRG 90
C	FRR	RELATIVE ERROR IN T OR H WHEN ITERATING IN RGAS	PRG 91
C	UERP	RELATIVE ERROR IN VELOCITY ON SUCCESSIVE ITERATIONS	PRG 92
C	CFERR	RELATIVE ERROR IN SKIN FRICTION, SP I OR SP II	PRG 93
C	XVO	XVO/RN VIRTUAL ORIGIN FOR EQ(34), SP I OR SP II	PRG 94
C	PSI	FACTOR IN CF/2 EQ(25)	PRG 95
C	ENI	N AT BEGIN TRANSITION EQ(26)	PRG 96
C	ALMIN	ALPHA(3) AT BEGIN TRANSITION EQ(10)	PRG 97
C	ALX	ALPHA(3) AT END TRANSITION =1. EQ(10)	PRG 98
C	FPOPT	OPTION =1 FLAT PLATE	PRG 99
C		=0 CONE	PRG 100
C	TP	PRESSURE FLAT PLATE (N/M2) (LBF/FT2)	PRG 101
C		OMIT IF CONE	PRG 102
C	TS	ENTROPY FLAT PLATE (M2/SEC2DEGK) (FT2/SEC2DEGR)	PRG 103
C		OMIT IF CONE	PRG 104
C	ENX	N TURBULENT EQ(26)	PRG 105
C	RHOT2	DENSITY AT STAGNATION POINT (KG/M3) (SLUG/FT3)	PRG 106
C	RNOT	RN NOSE RADIUS (M) (FEET)	PRG 107
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C				PRG 285
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C				PRG 298
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C				PRG 316
C				PRG 317
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C	U/UF	VELOCITY RATIO		PRG 320
C	H	ENTHALPY	(M2/SEC2) (FT2/SEC2)	PRG 321
C	RHO/RHOE	DENSITY RATIO		PRG 322
C	RHOU/RHOEU	DENSITY*VELOCITY RATIO		PRG 323
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C	M	MACH NUMBER		PRG 326
C				PRG 327
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C	CEBP	COEFF CF,N EQNS. (TANH(PSI))		PRG 339
C	XMIN	X BEGIN TRANSITION		PRG 340
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C	ENI	N BEGIN TRANSITION		PRG 342
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C			PRG 344
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C	HG(2)	ENTHALPY TRIAL 2	{FT2/SEC2} PRG 351
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C	HW	DESIRED ENTHALPY	{FT2/SEC2} PRG 353
C			PRG 354
C			PRG 355
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	10),TXL(450),TYLS(450),TSS(450)		PRG 357
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI		PRG 358
	COMMON CMTOPT		PRG 359
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CER,CEBP,CEM,CEMP,CFBMT,CFB2,CFER		PRG 360
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DFERR,DNPRG		PRG 361
	2,DPVAR,DRBVAR,DRVVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,EPRG		PRG 362
	3NGN,FNI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,F DPR,FRRE,FATH,G,GC,GX,H,HPRG		PRG 363
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,PRG		PRG 364
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHQU1,RHOW,RO,ROPPRG		PRG 365
	6,ROVAR,ROW,RRI,RRN,RRTVAR,RRX,RSERR,RSISAV,RSVVAR,RX,SHEAR,SP,SVARPRG		PRG 366
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPPRG		PRG 367
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XI		PRG 368
	9N,XMIN,X2REX,Z,ZMAX,ZMIN		PRG 369
	REAL IN,JN,KN		PRG 370
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNPRG		PRG 371
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)		PRG 372
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),PRG		PRG 373
	1FCTR(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SPRG		PRG 374
	2(160),PI(160),XC(160),RB(160),WF(160),RRT(160),XMAXTB(20),DUDXT(160		PRG 375
	3),DRDXT(160),DPOXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16		PRG 376
	40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(PRG 377
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)		PRG 378
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	COMMON XXI		PRG 380
	COMMON ACFT(22),TREXT(22),ACFLGT(22),TRLGT(22),REXCF,HO,XO		PRG 381
	COMMON HBCF,OXCF,HHCF		PRG 382
	COMMON /BLK/ CV1,CV2,CV3,CV4,CV5,CV6,CV7,CV8,CV9,CV10,CV11,CV12,CVPRG		PRG 383
	113,UNIN,UNIO		PRG 384
	COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PPRG		PRG 385
	1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12		PRG 386

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2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV          PRG 387
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C   LENGTH      INCH      METER      2.54E-2      PRG 389
C   VELOCITY    FT/SEC    M/SEC    3.048E-1    PRG 391
C   ENTHALPY    FT2/SEC2  M2/SEC2  9.290304E-2 PRG 392
C   ENTROPY      FT2/SEC2DEGR  M2/SEC2DEGK  16.7225472E-2 PRG 393
C   HEATTRANSFER LBM/FT2SEC  KG/M2SEC    4.882427522E0 PRG 394
C   DENSITY      LBM/FT3    KG/M3      1.6018463E+1 PRG 395
C   DENSITY      SLUG/FT3   KG/M3      5.15379E+2   PRG 396
C   TEMPERATURE  DEGR      DEGK       .55555555E0  PRG 397
C   ANGLE        DEG        RADIAN     1.745329252E-2 PRG 398
C   PRESSURE     LBF/FT2    NEWTON/M2  4.7880258E+1 PRG 399
C   PRESSURE     ATM        NEWTON/M2  1.01325E+5   PRG 400
C   HEAT         BTU/FT2SEC  WATT/M2    1.1348931E+4 PRG 401
C   VISCOSITY    LBM/FTSEC  NEWTONSEC/M2  1.4881639E0  PRG 402
DATA CV1/2.54E-2/,CV2/3.048E-1/,CV3/9.290304E-2/,CV4/16.7225472E-2PRG 403
1/,CV5/4.882427522/,CV6/16.018463/,CV7/5.15379E2/,CV8/.555555556/,PRG 404
2CV9/1.745329252E-2/,CV10/4.7880258E1/,CV11/1.01325E5/,CV12/1.13489PRG 405
331E4/,CV13/1.4881639/          PRG 406
EXTERNAL DERSUB          PRG 407
EXTERNAL CHECK          PRG 408
NAMELIST /N1/ XMIN,DXLTAB,XMAXTB,ELT,XLSH,XLSHL,XMHL,EL,X2REX,RHOUPRG 409
1I,SHEAR,RO,RHOI,UI,HT,ST,TT11,DEL,THC,PR,GC,TRAN,CARD,PRINT,A,F,ALPRG 410
2PHE,ZMIN,ZMAX,AN,CN,DN,KN,FRXT,FCXT,FRTB,FCTB,TKTAB,PATAB,PRTAB,NXPRG 411
3INT,XINT,TWT,L,NN,NT,CI,SPEC,CIMAX,ELE1,ELE2,ERR,UERR,CFERR,XVO,PSPRG 412
4I,ENI,ALMIN,ALX,FPOPT,TP,TS,ENX,RHOT2,RNOT,PT2,PINF,TWO,IGAS,ACFT,PRG 413
5STREXT,UNIN,UNIO          PRG 414
C   READ NAMELIST /N1/ INPUT          PRG 415
C   READ (5,N1)                      PRG 416
1   IF (ENDFILE 5) 2,3              PRG 417
2   CALL EXIT                        PRG 418
3   WRITE (6,N1)                    PRG 420
4   IF (UNIN-1.) 4,4,7              PRG 421
C   CONVERT INPUT FROM SI TO US UNITS PRG 422
4   EL=EL/CV1                      PRG 423
   RHOI=RHOI/CV5                    PRG 424
   RO=RO/CV6                        PRG 425
   RHOI=RHOI/CV7                    PRG 426
   UI=UI/CV2                        PRG 427
   HT=HT/CV3                        PRG 428
   ST=ST/CV4                        PRG 429

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	THC=THC / CV9	PRG 430
	TP=TP / CV10	PRG 431
	TS=TS / CV4	PRG 432
	RHOT2=RHOT2 / CV7	PRG 433
	RNOT=RNOT / CV2	PRG 434
	PT2=PT2 / CV10	PRG 435
	PINF=PINF / CV10	PRG 436
	TWO=TWO / CV8	PRG 437
	TT11=TT11 / CV8	PRG 438
	DO 5 N=1,NXINT	PRG 439
	XINT(N)=XINT(N) / CV1	PRG 440
5	TWT(N)=TWT(N) / CV8	PRG 441
	DO 6 N=1,7	PRG 442
6	PATAB(N)=PATAB(N) / CV11	PRG 443
7	CUVAR(2)=0	PRG 444
	XX1=0	PRG 445
	HBCF=0	PRG 446
	QXCF=0	PRG 447
	HMCF=0	PRG 448
	RETH=0	PRG 449
	REX=0	PRG 450
	FC=0	PRG 451
	CFMT=0	PRG 452
	ELVO=0	PRG 453
	Z=0	PRG 454
	CFI=0	PRG 455
	TOLL=0	PRG 456
	REX2=0	PRG 457
	RSISAV=0	PRG 458
	REXSAV(1)=0	PRG 459
	CFMT=0	PRG 460
	CFI=0	PRG 461
	FC=0	PRG 462
C		PRG 463
C	SET UP LOG OF SPALDING-CHI TABLES	PRG 464
C		PRG 465
	DO 8 N=1,20	PRG 466
	FRXLGT(N)=ALOG10(FRXT(N))	PRG 467
	FCXLGT(N)=ALOG10(FCXT(N))	PRG 468
	FRLGT(N)=ALOG10(FRTB(N))	PRG 469
8	FCLGT(N)=ALOG10(FCTB(N))	PRG 470
	DO 9 N=1,22	PRG 471
	ACFLGT(N)=ALOG10(ACFT(N))	PRG 472

9	TRLG(TN)=ALOG10(TREXT(N))	PRG 473
C		PRG 474
C	IS FLAT PLATE	PRG 475
C		PRG 476
C	IF (FPOPT) 13,10,13	PRG 477
C		PRG 478
C	READ X/L,TH/L,RS/L FROM LAMINAR INPUT CARDS	PRG 479
C		PRG 480
10	READ (5,65) LLIM	PRG 481
	READ (5,66) (XW(LL),LL=1,LLIM)	PRG 482
	READ (5,66) (FTN6(LL),LL=1,LLIM)	PRG 483
	READ (5,66) (RSLW(LL),LL=1,LLIM)	PRG 484
	IF (SHEAR) 12,11,12	PRG 485
11	READ (5,66) (SHEER(LL),LL=1,LLIM)	PRG 486
	CALL DISCOT (XMIN,XMIN,XW,SHEER,SHEER,011,LLIM,0,SHEAR)	PRG 487
C		PRG 488
C	COMPUTE FUNCTIONS OF THC	PRG 489
C		PRG 490
12	THCR=THC/57.29578	PRG 491
	STHCR=SIN(THCR)	PRG 492
	CTHCR=COS(THCR)	PRG 493
	TTHCR=STHCR/CTHCR	PRG 494
	T1=THCR-1.570796	PRG 495
	T2=1.-STHCR	PRG 496
C		PRG 497
C	WRITE NAMELIST INPUT	PRG 498
C		PRG 499
13	CONTINUE	PRG 500
	WRITE (6,67)	PRG 501
C		PRG 502
C	IS FLAT PLATE	PRG 503
C		PRG 504
C	IF (FPOPT) 14,15,14	PRG 505
C		PRG 506
C	S,P FROM INPUT TS AND TP,DU/DX=DRHO/DX=0,MTF=1.	PRG 507
C		PRG 508
14	SVAR=TS(1)	PRG 509
	PIVAR=TP(1)	PRG 510
	S(1)=SVAR	PRG 511
	PI(1)=PIVAR	PRG 512
	NKW=2	PRG 513
	XKW(1)=XMIN	PRG 514
	DUDXT(1)=DUDXT(2)=0	PRG 515

	DRDXT(1)=DRDXT(2)=0	PRG 516
	XKW(2)=XMAXTB(20)	PRG 517
	CFBMT=1.	PRG 518
	GO TO 26	PRG 519
C		PRG 520
C	IS INPUT FROM AMES BLUNT BODY AND MOC TAPES	PRG 521
C		PRG 522
15	IF (CARD) 17,16,17	PRG 523
C		PRG 524
C	CALL CRRD	PRG 525
C		PRG 526
16	CALL CRRD	PRG 527
	GO TO 18	PRG 528
C		PRG 529
C	CALL INPN2	PRG 530
C		PRG 531
17	CALL INPN2	PRG 532
C		PRG 533
C	WRITE TABLES X/LCL, RB/L, S, P, X/L ON BODY, RS/L, S ON SHOCK	PRG 534
C		PRG 535
18	WRITE (6,71)	PRG 536
	WRITE (6,73) ((TXLCL(J), TYL(J), TS(J), TP(J), TXL(J)), J=1, J LIM)	PRG 537
	WRITE (6,72)	PRG 538
	WRITE (6,74) ((TYLS(K), TSS(K)), K=1, K LIM)	PRG 539
C		PRG 540
C	AT DESIRED X/L STATIONS INTERPOLATE IN TABLES FOR S, P, RB/L, X/LCL	PRG 541
C	CALL RGAS TO FIND RHO, A, H, T	PRG 542
C	FIND U, M	PRG 543
C	IF X/L BEYOND TABLE VALUE USE FINAL S, P, FIND X/LCL, RB/L	PRG 544
C		PRG 545
	J=1	PRG 546
	X(J)=XMIN	PRG 547
	WRITE (6,75)	PRG 548
19	IF (X(J)-TXL(J LIM)) 21,21,20	PRG 549
20	S(J)=TS(J LIM)	PRG 550
	PI(J)=TP(J LIM)	PRG 551
	XC(J)=(X(J)+T1)*CTHCR+T2	PRG 552
	RB(J)=CTHCR*(XC(J)-T2)*TTHCP	PRG 553
	GO TO 22	PRG 554
21	CALL DISCOT (X(J), X(J), TXL, TS, TS, 011, J LIM, 0, S(J))	PRG 555
	CALL DISCOT (X(J), X(J), TXL, TP, TP, 011, J LIM, 0, PI(J))	PRG 556
	CALL DISCOT (X(J), X(J), TXL, TYL, TYL, 011, J LIM, 0, RB(J))	PRG 557
	CALL DISCOT (X(J), X(J), TXL, TXLCL, TXLCL, 011, J LIM, 0, XC(J))	PRG 558

22	GX=1.4	PRG 559
	CALL RGAS (PI(J),RX,AX,HX,TX,S(J),RRX,GX,-1,5,(GAS)	PRG 560
	W(J)=SQRT(2.*(HT-HX))	PRG 561
	RRT(J)=RX*32.174	PRG 562
	EMX=W(J)/AX	PRG 563
C		PRG 564
C	WRITE TABLES X/L,S,P,RB/L,X/LCL,T,H,U,A,M,RHO	PRG 565
C		PRG 566
	WRITE (6,70) X(J),S(J),PI(J),RB(J),XC(J),TX,HX,W(J),AX,EMX,RRT(J)	PRG 567
	IF (X(J)-XMAXTB(20)) 23,24,24	PRG 568
23	CALL DISCOT (X(J),X(J),XMAXTB,DXLTAB,DXLTAB,011,20,0,DXL)	PRG 569
	J=J+1	PRG 570
	X(J)=X(J-1)+DXL	PRG 571
	GO TO 19	PRG 572
24	JJLIM=J	PRG 573
	WRITE (6,69)	PRG 574
C		PRG 575
C	WRITE X/L,DU/DX,DPHO/DX,DP/DX,DRB/DX USING 3 POINT SLOPE SUBR DIF	PRG 576
C		PRG 577
	DO 25 J=1,JJLIM	PRG 578
	XKW(J)=X(J)	PRG 579
	DUDXT(J)=DIF(J,3,JJLIM,X,W)	PRG 580
	DRDXT(J)=DIF(J,3,JJLIM,X,RRT)	PRG 581
	DPDXT(J)=DIF(J,3,JJLIM,X,PI)	PRG 582
	DRBDXT(J)=DIF(J,3,JJLIM,X,RB)	PRG 583
25	WRITE (6,70) X(J),DUDXT(J),DRDXT(J),DPDXT(J),DRBDXT(J)	PRG 584
C		PRG 585
C	MTF=1.045 EQ(36)	PRG 586
C		PRG 587
	CFBMT=1.045	PRG 588
C		PRG 589
C	SET INITIAL COUNTS AND X/L=XMIN	PRG 590
C		PRG 591
	NKW=JJLIM	PRG 592
26	CEBP=TANH(PSI)	PRG 593
	CNT=0	PRG 594
	ICELL=0	PRG 595
	PATM=PT2*.4725E-3	PRG 596
	TK=TWO/1.8	PRG 597
	CALL DISCOT (TK,PATM,TKTAB,PRTAB,PATAB,011,210,7,PRTWO)	PRG 598
	RHOW=RHOT2*TT11/TWO	PRG 599
	EMUW=7.310615E-7*SQRT(TWO)/(1.+201.6/TWO)	PRG 600
	EMUT2=7.310615E-7*SQRT(TT11)/(1.+201.6/TT11)	PRG 601

	DUEDX=SQRT(2.*(PT2-PINF)/RHOT2)/RNOT	PRG 602
	CALL RGAST (PT2,RX,AX,HWO,TWO,S(1),ERR,IGAS)	PRG 603
	HO=.768*SQRT(32.174)*PRTWO**(-.6)*(RHOW*EMUW)**.1*(RHOT2*EMUT2)**.14*DUEDX**.5	PRG 604
	QO=HO*(HT-HWO)/2.5036E4	PRG 605
	IF (UNIO-1.) 27,27,28	PRG 607
27	O87=HO*CV5	PRG 608
	O88=QO*CV12	PRG 609
	WRITE (6,60) O87,O88	PRG 610
	GO TO 29	PRG 611
28	WRITE (6,60) HO,QO	PRG 612
29	TOLL=0	PRG 613
	II=0	PRG 614
	SP=6.9E4	PRG 615
	SW=4.8E4	PRG 616
	EK=.4	PRG 617
	E=12.	PRG 618
	PRCT=0	PRG 619
	CO=CI	PRG 620
	NKWSAV=0	PRG 621
	VAR(1)=XMIN	PRG 622
	CUVAR(1)=XMIN	PRG 623
C		PRG 624
C	CALL EDGE	PRG 625
C		PRG 626
	CALL EDGE	PRG 627
C		PRG 628
C	CALL AL3CAL	PRG 629
C		PRG 630
	CALL AL3CAL	PRG 631
C		PRG 632
C	CALL START TO GET INITIAL TH/L	PRG 633
C		PRG 634
	CALL START	PRG 635
	VAR(2)=CUVAR(2)	PRG 636
	WRITE (6,63)	PRG 637
	WRITE (6,61)	PRG 638
	WRITE (6,62)	PRG 639
	WRITE (6,63)	PRG 640
	WRITE (6,68)	PRG 641
C		PRG 642
C	CALL INTIA VARIABLE STEP SIZE RUNGE KUTTA	PRG 643
C	INTIA CALLS DERSUB TO GET DTH/DX EQ(3)	PRG 644

C		PRG 645
30	CALL INT1A (I1,1,NT,CO,SPEC,CIMAX,IERR,VAR,CUVAR,DER,ELE1,ELE2,ELT	PRG 646
	1,ERRVAL,DESUB,CHECK,0)	PRG 647
	IF (IERR-1) 31,32,31	PRG 648
31	CALL EXIT	PRG 649
C		PRG 650
C	AFTER EACH RK STEP HAS MET THE ELE1,ELE2 TESTS FOR ACCURACY	PRG 651
C	IN COMMON/BLOCK/ SAVE FOR PLOTTING	PRG 652
C	X,N,RETH,CF/2,M,DEL,DELST,THETA,H/HT,REX,S/ST,U/UI,RHO/KHOI,Q,RS/L	PRG 653
C	AND NKWSAV=COUNT OF POINTS TO BE PLOTTED	PRG 654
C		PRG 655
32	NKWSAV=NKWSAV+1	PRG 656
	PLT1(NKWSAV)=VAR(1)*EL	PRG 657
	PLT3(NKWSAV)=RETH	PRG 658
	PLT5(NKWSAV)=EMVAR	PRG 659
	PLT6(NKWSAV)=DEL*EL	PRG 660
	PLT7(NKWSAV)=DELS*EL	PRG 661
	PLT8(NKWSAV)=VAR(2)*EL	PRG 662
	PLT9(NKWSAV)=HVAR/HT	PRG 663
C		PRG 664
C	REYNOLDS NO,STANTON NO(EQ27),HEAT TRANSFER COEFF(EQ28)	PRG 665
C		PRG 666
	REX=RETH*VAR(1)/VAR(2)	PRG 667
	PLT11(NKWSAV)=SVAR/ST	PRG 668
	PLT12(NKWSAV)=WVAR/UI	PRG 669
	PLT13(NKWSAV)=ROVAR/RHOI	PRG 670
	ENST=CF2*RAF	PRG 671
	HBAR=ENST*WVAR*RRTVAR	PRG 672
C		PRG 673
C	HEATING RATE(EQ29),PRANDTL NO.FROM HANSENS TABLE,KARMAN FACTOR	PRG 674
C		PRG 675
	Q=HBAR*(HAW-HW)/2.5036E4	PRG 676
	HH=HBAR/HO	PRG 677
	WRITE (6,63)	PRG 678
	IF (CFMT) 33,34,33	PRG 679
33	HBCF=HBAR/CFMT	PRG 680
	QXCF=Q/CFMT	PRG 681
	HHCF=HH/CFMT	PRG 682
34	IF (UNIO-1.) 35,35,36	PRG 683
35	O81=HBAR*CV5	PRG 684
	O82=Q*CV12	PRG 685
	O85=HBCF*CV5	PRG 686
	O86=QXCF*CV12	PRG 687

	WRITE (6,70) RAF,CFMT,CF2,ENST,081,082,HH,XX1,085,086,HHCF	PRG 688
	GO TO 37	PRG 689
36	WRITE (6,70) RAF,CFMT,CF2,ENST,HBAR,Q,HH,XX1,HBCF,QXCF,HHCF	PRG 690
37	XO=.825*X2REX	PRG 691
	REXCF=(RETH/VAR(2))*IVAR(1)-XO	PRG 692
	IF (ABS(REXCF)-.1E-4) 39,38,38	PRG 693
38	CALL CFA	PRG 694
39	Q=Q/QO	PRG 695
	WRITE (6,63)	PRG 696
	PLT14(NKWSAV)=Q	PRG 697
	WSAV(NKWSAV)=WVAR	PRG 698
	RRTSAV(NKWSAV)=RRTVAR	PRG 699
	XSAV(NKWSAV)=VAR(1)	PRG 700
	RSLSAV(NKWSAV)=PLT15(NKWSAV)=RSLVAR	PRG 701
	REXSAV(NKWSAV)=PLT10(NKWSAV)=REX	PRG 702
	ENSAV(NKWSAV)=PLT2(NKWSAV)=EN	PRG 703
	CFSAV(NKWSAV)=PLT4(NKWSAV)=CF2	PRG 704
	TK=TIVAR/1.8	PRG 705
	CALL DISCOT (TK,PATM,TKTAB,PRTAB,PATAB,011,210,7,PRE)	PRG 706
	EKF=1./(1.+5.*SQRT(CFI))*(PRE-1.-ALOG(15.*PRE+1./6.))	PRG 707
C		PRG 708
C	INCOMPRESSIBLE Q,KARMAN FACTOR Q	PRG 709
C		PRG 710
	QIN=(WVAR*RRTVAR*CF2*(HAW-HW))/2.5036E4	PRG 711
	QKF=EKF*QIN	PRG 712
	VARO=VAR(1)/DELS	PRG 713
	PN3=WVAR/SORT(2.*HT)	PRG 714
	PN7=HAW/HT	PRG 715
	PN8=HW/HT	PRG 716
	FRX=FRTH/FC	PRG 717
C		PRG 718
C	TRANSITION HEATING	PRG 719
C		PRG 720
	RXTR=REX*(1.-XMIN/VAR(1))	PRG 721
	IF (RXTR-1000.) 40,41,41	PRG 722
40	QXTR=1.	PRG 723
	GO TO 42	PRG 724
41	FRRX=ALOG10(FRX*RXTR)	PRG 725
	CALL DISCOT (FRRX,FRRX,FRXLGT,FCXLGT,FCXLGT,011,20,0,FCCXLG)	PRG 726
	FCCX=10.**FCCXLG	PRG 727
	CFP2=CFMT*FCCX/(2.*FC)	PRG 728
	ENSTP=CFP2*RAF	PRG 729
	HBARP=ENSTP*WVAR*RRTVAR	PRG 730

	QXTR=HBARP*(HAW-HW)/2.5036E4	PRG 731
C		PRG 732
C	MAXIMUM HEATING	PRG 733
C		PRG 734
42	PXMH=REX*(1.-XMHL/VAR(1))	PRG 735
	IF (RXMH-1000.) 43,44,44	PRG 736
43	QXMH=1.	PRG 737
	GO TO 45	PRG 738
44	FRRM=ALOG10(FRX*PXMH)	PRG 739
	CALL DISCOT (FRRM,FRRM,FRXLGT,FCXLGT,FCXLGT,011.20.0,FCCMLG)	PRG 740
	FCCM=10.**FCCMLG	PRG 741
	CFPP2=CFMT*FCCM/(2.*FC)	PRG 742
	ENSTPP=CFPP2*RAF	PRG 743
	HBARPP=ENSTPP*WVAR*RRTVAR	PRG 744
	QXMH=HBARPP*(HAW-HW)/2.5036E4	PRG 745
45	IF (FPOPT) 47,46,47	PRG 746
46	CALL DISCOT (VAR(1),VAR(1),X,XC,XC,011,JJLIM,0,XCVAR)	PRG 747
C		PRG 748
C	SHEAR STRESS E0(30)	PRG 749
C		PRG 750
47	RHOUSQ=ROVAR*WVAR*WVAR	PRG 751
	TAU=CF2*RHOUSQ	PRG 752
C		PRG 753
C	WRITE OUTPUT	PRG 754
C		PRG 755
	PRCT=PRCT+1	PRG 756
	IF (PRINT-PRCT) 48,48,52	PRG 757
48	IF (UNIO-1.) 49,49,50	PRG 758
C	CONVERT OUTPUT FROM US TO SI UNITS	PRG 759
49	O2=PLT1(NKWSAV)*CV1	PRG 760
	O4=PLT8(NKWSAV)*CV1	PRG 761
	O5=PIVAR*CV10	PRG 762
	O7=SVAR*CV4	PRG 763
	O9=TIVAR*CV8	PRG 764
	O10=HVAR*CV3	PRG 765
	O12=RRTVAR*CV6	PRG 766
	O14=WVAR*CV2	PRG 767
	O17=AVAR*CV2	PRG 768
	O19=EMU*CV13	PRG 769
	O22=TW*CV8	PRG 770
	O23=HW*CV3	PRG 771
	O25=RHOW*CV6	PRG 772
	O27=TAW*CV8	PRG 773

	035=HAW*CV3	PRG 774
	037=HP*CV3	PRG 775
	038=TPP*CV8	PRG 776
	054=PLT6(NKWSAV)*CV1	PRG 777
	057=PLT7(NKWSAV)*CV1	PRG 778
	060=DUVAR*CV2	PRG 779
	061=DRVAR*CV6	PRG 780
	062=DPVAR*CV10	PRG 781
	066=HBAR*CV5	PRG 782
	070=QIN*CV12	PRG 783
	071=QKF*CV12	PRG 784
	072=QXTR*CV12	PRG 785
	073=QXMH*CV12	PRG 786
	075=RHOUSD*CV10	PRG 787
	076=TAU*CV10	PRG 788
	WRITE (6,70) VAR(1),02,VAR(2),04,05,RBVAR,07,PLT11(NKWSAV),09,010,PRG 789	
	1PLT9(NKWSAV),012,PLT13(NKWSAV),014,PN3,PLT12(NKWSAV),017,PLT5(NKWSAV) 790	
	24V),019,PLT3(NKWSAV),PLT10(NKWSAV),022,023,PN8,025,COE1,027,FRTH,FPRG 791	
	3C,CFMT,ELVD,Z,CFI,PLT4(NKWSAV),035,PN7,037,038,PRP,PRW,F(1),F(2),APRG 792	
	4(2),ALPHE(3),PLT2(NKWSAV),AN2,DEL,054,PLT15(NKWSAV),DELS,057,VARD,PRG 793	
	5DSTH,060,061,062,ORBVAR,DER(2),ENST,066,PLT14(NKWSAV),PRE,EKF,070,PRG 794	
	6071,072,073,XCVAR,075,076	PRG 795
	GO TO 51	PRG 796
50	WRITE (6,70) VAP(1),PLT1(NKWSAV),VAR(2),PLT8(NKWSAV),PIVAR,RBVAR,SPPG 797	
	1VAR,PLT11(NKWSAV),TIVAR,HVAR,PLT9(NKWSAV),RRTVAR,PLT13(NKWSAV),WVAPRG 798	
	2R,PN3,PLT12(NKWSAV),AVAR,PLT5(NKWSAV),EMU,PLT3(NKWSAV),PLT10(NKWSAV)PRG 799	
	3V),TW,HW,PN8,RHOW,COE1,TAW,FRTH,FC,CFMT,ELVD,Z,CFI,PLT4(NKWSAV),HAPRG 800	
	4W,PNT,HP,TPP,PRP,PRW,F(1),F(2),A(2),ALPHE(3),PLT2(NKWSAV),AN2,DEL,PRG 801	
	5PLT6(NKWSAV),PLT15(NKWSAV),DELS,PLT7(NKWSAV),VARD,DS TH,DUVAR,DRVARPRG 802	
	6,DPVAR,ORBVAR,DER(2),ENST,HBAR,PLT14(NKWSAV),PRE,EKF,QIN,QKF,QXTR,PRG 803	
	7QXMH,XCVAR,RHOUSD,TAU	PRG 804
51	PRCT=0	PRG 805
C		PRG 806
C	IS FIRST ITERATION	PRG 807
C		PRG 808
52	IF (ICELL) 53,54,53	PRG 809
C		PRG 810
C	COMPUTE DIFFERENCE IN VELOCITY	PRG 811
C	SAVE LARGEST DIFFERENCE IN VELOCITY	PRG 812
C		PRG 813
53	CALL DISCOT (VAR(1),VAR(1),XKW,WKW,WKW,011,NKW,0,WOLD)	PRG 814
	DIFF=ABS(WOLD-WVAR)/WOLD)	PRG 815
	TOLL=AMAX1(DIFF,TOLL)	PRG 816

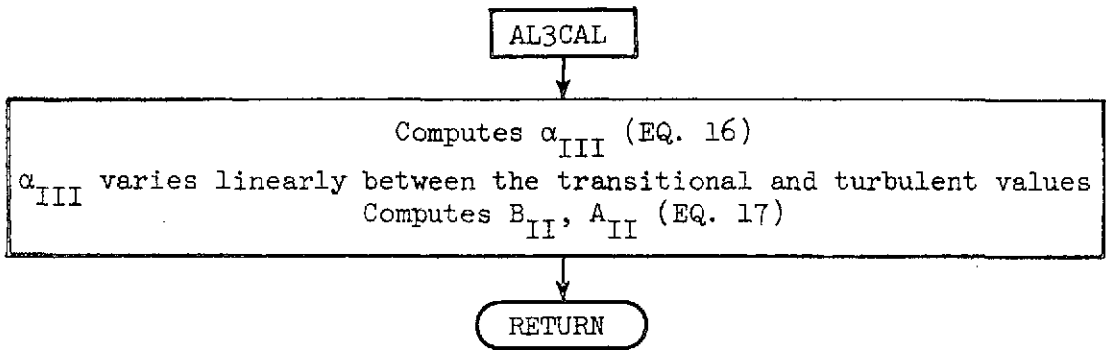
C		PRG 817
C	IS END OF BODY	PRG 818
C		PRG 819
54	IF (VAR(1)-XMAXTB(20)) 30,55,55	PRG 820
55	CONTINUE	PRG 821
	WRITE (6,64) TOLL	PRG 822
C		PRG 823
C	ADD TO ITERATION COUNT	PRG 824
C		PRG 825
	CNT=CNT+1	PRG 826
C		PRG 827
C	IS FOURTH ITERATION COMPLETE	PRG 828
C		PRG 829
	IF (CNT-4) 58,56,56	PRG 830
C		PRG 831
C	IS LARGEST VELOCITY DIFFERENCE WITHIN ERROR CRITERIA	PRG 832
C		PRG 833
56	IF (TOLL-UERR) 57,58,58	PRG 834
C		PRG 835
C	CASE IS COMPLETE	PRG 836
C		PRG 837
57	CONTINUE	PRG 838
	GO TO 1	PRG 839
C		PRG 840
C	FROM PRESENT ITERATION SAVE X/L,U,RS/L,DU/DX,DRHO/DX	PRG 841
C		PRG 842
58	DO 59 NK=1,NKWSAV	PRG 843
	WKW(NK)=WSAV(NK)	PRG 844
	XKW(NK)=XSAV(NK)	PRG 845
	RSLKW(NK)=RSLSAV(NK)	PRG 846
	DUDXT(NK)=DIF(NK,3,NKWSAV,XSAV,WSAV)	PRG 847
59	DRDXT(NK)=DIF(NK,3,NKWSAV,XSAV,RRTSAV)	PRG 848
	NKW=NKWSAV	PRG 849
C		PRG 850
C	FIND AT END OF TRANSITION N(TURB) AND CF/2(TURB)	PRG 851
C		PRG 852
	CALL DISCOT (X2REX,X2REX,XKW,ENSAV,ENSAV,111,NKW,0,EN2REX)	PRG 853
	CALL DISCOT (X2PEX,X2REX,XKW,CFSAV,CFSAV,111,NKW,0,CF2REX)	PRG 854
C		PRG 855
C	FIND TRANSITION REGION COEFF FOR CF/2 AND N (EQ25,26)	PRG 856
C		PRG 857
	CEM=EN2REX-EN1	PRG 858
	CEB=(PSI+PSI)/(X2REX-XMIN)	PRG 859

	CEMP=CF2REX-CF2I	PRG 860
	WRITE (6,76)	PRG 861
	WRITE (6,70) REX2,X2REX,EN2REX,CEM,CEB,CF2REX,CEMP,C EBP,XMIN,RSISAPRG	862
	1V,ENI,CF2I,REXSAV(1)	PRG 863
C		PRG 864
C	START NEXT ITERATION	PRG 865
C		PRG 866
	ICELL=2	PRG 867
	GO TO 29	PPG 868
C		PRG 869
C		PRG 870
C		PRG 871
60	FORMAT (1H 3HMO=,F11.3,4H OO=,F11.3)	PRG 872
61	FORMAT (21H SKIN FRICTION THEORY,/24H (1) VAN DRIEST RETHETA,/54HPRG	873
	1 (2) VAN DRIEST REX OMIT IN TRANS REGION,/54H (3) SPRG	874
	2PALDING CHI REX OMIT IN TRANS REGION,/54H (4) ECKERTS PRG	875
	3REF ENTHALPY REX OMIT IN TRANS REGION,/54H (5) ECKERTS REF ENT	PRG 876
	4HALPY REXMIN OMIT IN TRANS REGION,/21H (6) ECKERTS RETHETA,/37H	PRG 877
	5(7) SPALDING CHI I RETHETA IDEAL FC,/37H (8) SPALDING CHI II RETHPRG	878
	6ETA REAL FC)	PRG 879
62	FORMAT (1H ,7X,3HRAF,7X,4HCFMT,7X,3HCF2,8X,4HENST,7X,4HHBAR,7X,1HOPRG	880
	1,10X,2HHH,9X,3HXX1,8X,4HHBCF,7X,4HQXCF,7X,4HHHCF,7X)	PRG 881
63	FORMAT (1H)	PRG 882
64	FORMAT (1H 5HTOLL=,E11.3)	PRG 883
65	FORMAT (1S)	PRG 884
66	FORMAT (5E15.8)	PRG 885
67	FORMAT (1H 14X,1HX,15X,1HY,15X,1HQ,11X,5HTHETA,15X,1HM,15H BODY+SHPRG	886
	10CK PTS/15X,1HS,15X,1HP,15X,1HH,13X,3HRHO,12X,4H PT)	PRG 887
68	FORMAT (1H 7X,3HX/L,10X,1HX,4X,7HTHETA/L,6X,5HTHETA,10X,1HP,9X,2HRPRG	888
	1B,10X,1HS,7X,4HS/ST,10X,1HT,10X,1HH,7X,4HH/HT,8X,3HRHO/3X,4HRHO/RHPRG	889
	2OI,10X,1HU,2X,9HU/SQRT2HT,7X,4HU/UI,10X,1HA,10X,1HM,9X,2HMU,7X,4HRPRG	890
	3ETH,8X,3HREX,9X,2HTW,9X,2HHW,6X,5HHW/HT/7X,4HRHOW,7X,4HTW/T,8X,3HTPRG	891
	4AW,7X,4HFRTH,9X,2HFC,7X,4HCFMT,8X,3HLVO,10X,1HZ,8X,3HCF1,8X,3HCF2,PRG	892
	58X,3HHAW,5X,6HHAW/HT/9X,2HMP,9X,2HTP,8X,3HPRP,8X,3HPRW,7X,4HF(1),7PRG	893
	6X,4HF(2),7X,4HA(2),4X,7HALPH(3),10X,1HN,7X,4HINT1,7X,4HINT2,7X,4HI	PRG 894
	7NT3/7X,4HINT4,7X,4HINT5,7X,4HINT6,7X,4HINT7,6X,5HDEL/L,8X,3HDEL,8X	PRG 895
	8,3HRSL,5X,6HDELS/L,7X,4HDELS,5X,6HX/DELS,7X,4HDSIH,9X,2HDU/7X,4HDP	PRG 896
	9HO,9X,2HDP,8X,3HDRB,5X,6HDTHETA,8X,3HNST,7X,4HHBAR,10X,1HQ,8X,3HPR	PRG 897
	8E,8X,3HEKF,8X,3HQIN,8X,3HOKF,7X,4HQXTR/7X,4HQXMH,9X,2HXC,5X,6HRHO	PRG 898
	8SQ,8X,3HTAU)	PRG 899
69	FORMAT (1H 9X,1HX,3X,5HOU/DX,5X,7HDRHO/DX,5X,5HOP/OX,5X,6HORA/OX)	PRG 900
70	FORMAT (12E11.3)	PRG 901
71	FORMAT (1H 6X,3HXCL,14X,1HY,15X,1HS,15X,1HP,15X,1HX)	PRG 902

72	FORMAT (1H 6X,2HYS,15X,1HS)	PRG 903
73	FORMAT (5E16.8)	PRG 904
74	FORMAT (2E16.8)	PRG 905
75	FORMAT (1H 5X,1HX,10X,1HS,10X,1HP,9X,2HRB,9X,2HXC,10X,1HT,10X,1HH,	PRG 906
	110X,1HU,10X,1HA,10X,1HM,9X,3HRHO,8X,2HRS)	PRG 907
76	FORMAT (1H 6X,4HREX2,6X,5HX2REX,5X,6HEN2REX,8X,3HCEM,8X,3HCEB,5X,6	PRG 908
	1HCF2REX,7X,4HCEMP,7X,4HCEBP,7X,4HXMIN,5X,6HRSISAV,8X,3HENI,7X,4HCF	PRG 909
	??I/5X,6HREXSAV)	PRG 910
	END	PRG 911-

1 AL3CAL.- Subroutine AL3CAL computes coefficients α_{III} , B_{II} , A_{II} for use in
2 the calculation of density profiles.

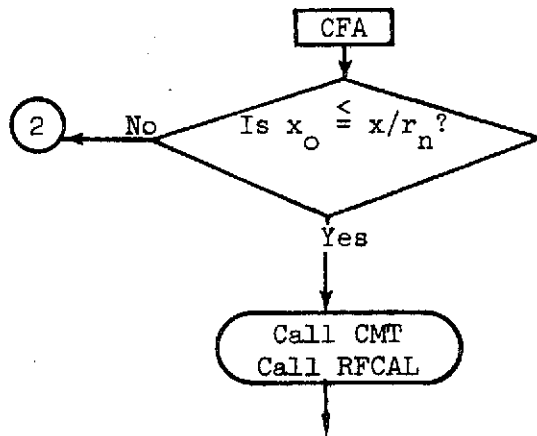
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	SUBROUTINE AL3CAL	ALC	1
C		ALC	2
C	COMPUTE ALPHA(3) EXPONENT IN OUTER BOUNDARY LAYER REGION	ALC	3
C	FOR USE IN STATIC ENTHALPY MODIFIED CROCCO EXPRESSION	ALC	4
C	ALPHA(3)=ALMIN AT START OF TRANSITION	ALC	5
C	ALPHA(3)= LINEAR VARIATION IN TRANSITION REGION	ALC	6
C	ALPHA(3)=ALX AT END OF TRANSITION	ALC	7
C		ALC	8
	COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450),TXL(450),TYLS(450),TSS(450)	ALC	9
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVD,PSI	ALC	10
	COMMON CMTOPT	ALC	11
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERALC	ALC	12
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNALC	ALC	13
	2,DPVAR,DRVAR,DRVAR,OSTH,DUVAR,E,EK,EL,ELT,ELVD,EMU,EMVAR,EMX,EN,EALC	ALC	14
	3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRKE,FRTH,G,GC,GX,H,HALC	ALC	15
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,ALC	ALC	16
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHUI,RHOW,RO,ROPALC	ALC	17
	6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSIVAR,RX,SHEAR,SP,SVARALC	ALC	18
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPALC	ALC	19
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIALC	ALC	20
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	ALC	21
	REAL IN,JN,KN	ALC	22
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNALC	ALC	23
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)	ALC	24
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRKTB(20),FRLGT(20),ALC	ALC	25
	1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SALC	ALC	26
	2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160ALC	ALC	27
	3),DRDXT(160),DPDXT(160),DRBDXT(160),VAR(2),DEK(2),CUVAR(2),WSAV(16ALC	ALC	28
	40),RRTSV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(ALC	ALC	29
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)	ALC	30
	COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PALC	ALC	31
	1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12ALC	ALC	32
	2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV	ALC	33
	IF (CUVAR(1)-XMIN) 2,1,2	ALC	34
		ALC	35
		ALC	36
C	X/L(TRAN),X/L(TURB),ALPHAIII(TRAN),ALPHAIII(TURB),	ALC	37
C	AI=0,ALPHAI=1,ALPHAII=1.,AIII=0,BIII=1. ARE INPUT	ALC	38
C	RI FROM SUBROUTINE EDGE	ALC	39
C		ALC	40
I	ALPHE(3)=ALMIN	ALC	41
	GO TO 5	ALC	42

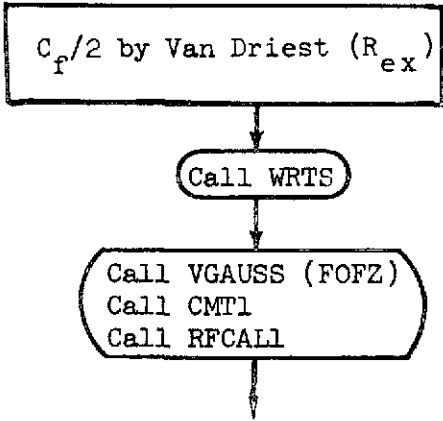
2	IF (CUVAR(1)-X2REX) 3,3,4	ALC	43
C		ALC	44
C	ALPHAIII LINEAR BETWEEN TRANSITION AND TURBUENT (EQ16)	ALC	45
C		ALC	46
3	ALPHE(3)={(CUVAR(1)-XMIN)/(X2REX-XMIN)}*(ALX-ALMIN)+ALMIN	ALC	47
	GO TO 5	ALC	48
4	ALPHE(3)=ALX	ALC	49
C		ALC	50
C	BII (EQ17)	ALC	51
C	API	ALC	52
C		ALC	53
5	TEP=F(3)*.1**ALPHE(3)	ALC	54
	F(2)=(TEP-F(1)*.01)/9.E-2	ALC	55
	A(2)=TEP-.1*F(2)	ALC	56
	RETURN	ALC	57
	END	ALC	58-

1 CFA.- Subroutine CFA computes skin friction coefficient by seven methods--
 2 VanDriest (R_{ex}), Spalding-Chi I (R_{ex}), Eckert's reference enthalpy
 3 (R_{ex}), Eckert's reference enthalpy (R_{ex}^{MIN}), Eckert's reference enthalpy
 4 ($R_{e\theta}$), Spalding-Chi I ($R_{e\theta}$), Spalding-Chi II ($R_{e\theta}$).



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4 $C_f/2$ by Spalding-Chi (R_{ex}), Ideal Gas F_c

5
6 Call WRTS

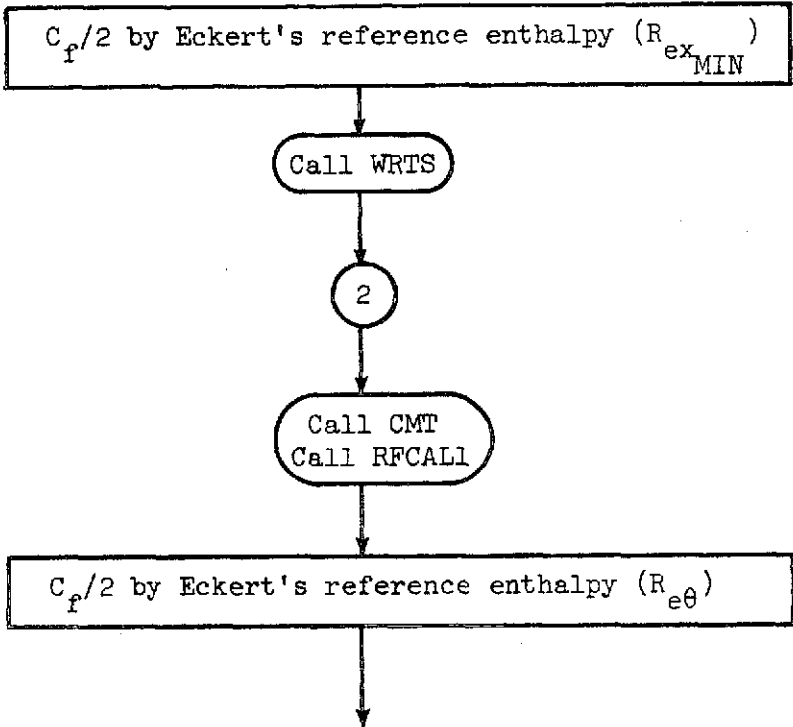
7
8 Call CMT
9 Call RFCALL

10
11 $C_f/2$ by Eckert's reference enthalpy (R_{ex})

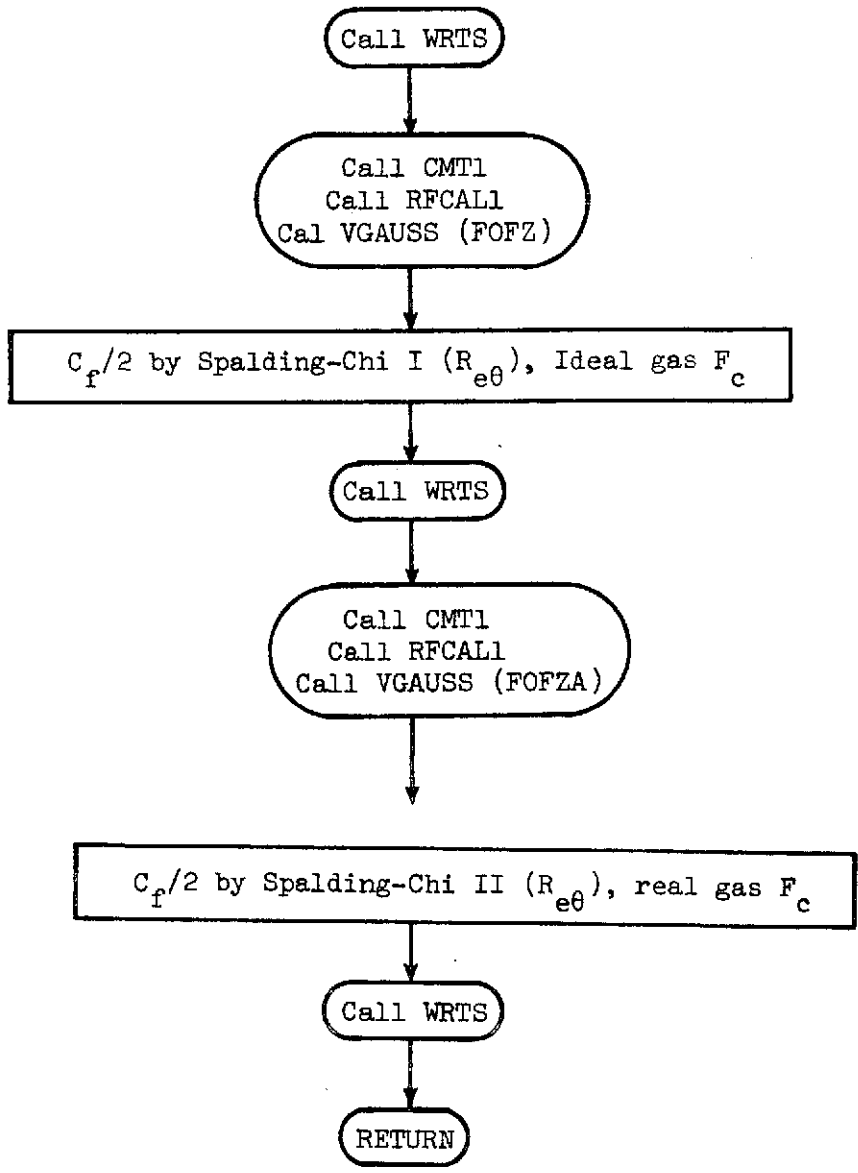
12
13 Call WRTS

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15 Call CMT
16 Call RFCALL

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SUBROUTINE CFA                                CFA 1
C COMPUTES HEATING RATES AND SKIN FRICTION BY CFA 2
C VAN DRIEST (REX) METHOD                      CFA 3
C SPALDING CHI (REX) METHOD                    CFA 4
C ECKERTS REFERENCE ENTHALPY (REX) METHOD     CFA 5
C ECKERTS REFERENCE ENTHALPY (REXMIN) METHOD  CFA 6
C ECKERTS REFERENCE ENTHALPY (RETHETA) METHOD CFA 7
C SPALDING CHI (RETHETA) METHOD (EQ22)       CFA 8
C SPALDING CHI (RETHETA) METHOD (EQ21)       CFA 9
C AND WRITES OUTPUT                          CFA 10
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)
10),TXLI(450),TYLS(450),TSS(450)           CFA 11
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVU,PSI CFA 13
COMMON CMTOPT                                CFA 14
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERCFA 15
1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNCFA 16
2,DPVAR,DRBVAR,DRVVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVU,EMU,EMVAR,EMX,EN,ECFA 17
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRKE,FRTH,G,GC,GX,H,HCFA 18
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,CFA 19
5NN,NO,NXTNT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,KHOU1,RHOW,RO,RDPCFA 20
6,ROVAR,ROW,RI,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARCFA 21
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPCFA 22
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TTTT,TW,TX,WVAR,XICFA 23
9N,XMIN,X2REX,Z,ZMAX,ZMIN                   CFA 24
REAL IN,JN,KN                               CFA 25
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNCFA 26
1(6),DXLTAR(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7) CFA 27
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),CFA 28
1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SCFA 29
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)CFA 30
3),DRDXT(160),DPOXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16)CFA 31
40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(CFA 32
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160),IGCFA 33
6AS                                          CFA 34
COMMON XXI                                  CFA 35
COMMON ACFT(22),TREXT(22),ACFLGT(22),TRLGT(22),KEXCF,HU,XO CFA 36
EXTERNAL FOFZ                               CFA 37
EXTERNAL FOFZA                              CFA 38
IF (XO-VAR(1)) 1,1,2                       CFA 39
CALL CMT (CFMTA)                            CFA 40
CALL RFCAL (RAFA)                           CFA 41
TERM1=.2*EMVAR*EMVAR                       CFA 42

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COE1=TW/TIVAR	CFA	43
AVDSQ1=TERM1/COE1	CFA	44
BVD1=(1.+TERM1-COE1)/COE1	CFA	45
BVDSQ1=BVD1*BVD1	CFA	46
ALVD1=(AVDSQ1+AVDSQ1-BVD1)/SQRT(4.*AVDSQ1+BVDSQ1)	CFA	47
BEVD1=BVD1/SQRT(4.*AVDSQ1+BVDSQ1)	CFA	48
TREX=(2.57*(ASIN(ALVD1)+ASIN(BEVD1)))**2*REXCF)/(TERM1*COE1**.76)	CFA	49
TRLG=ALOG10(TREX)	CFA	50
CALL DISCOT (TRLG,TRLG,TRLGT,ACFLGT,ACFLGT,011,22,0,AVLG)	CFA	51
AVCF=10.**AVLG	CFA	52
CF2FPA=(ASIN(ALVD1)+ASIN(BEVD1)))**2*AVCF/(2.*TERM1)	CFA	53
CF2A=CFMTA*CF2FPA	CFA	54
CALL WRTS (CF2A,RAFA,CFMTA)	CFA	55
CALL VGAUSS (0,1.,L,ANZ,FOFZ,FZ,1,NN)	CFA	56
FCB=1./(ANZ*ANZ)	CFA	57
CALL CMT1 (CFMTB)	CFA	58
CALL RFCAL1 (RAFB)	CFA	59
FRX=FRTH/FCB	CFA	60
FRXRX=REXCF*FRX	CFA	61
FRXG=ALOG10(FRXRX)	CFA	62
CALL DISCOT (FRXG,FRXG,FRXLGT,FCXLGT,FCXLGT,011,20,0,FCLG)	CFA	63
FCFC=10.**FCLG	CFA	64
CF2FPB=FCFC/(2.*FCB)	CFA	65
CF2B=CFMTB*CF2FPB	CFA	66
CALL WRTS (CF2B,RAFB,CFMTB)	CFA	67
CALL CMT (CFMTC)	CFA	68
CALL RFCAL1 (RAFC)	CFA	69
HP=.5*(HW+HVAR)+.22*(HAW-HVAR)	CFA	70
CALL RGASH (PIVAR,ROP,AP,HP,TPP,SP,ERR,IGAS)	CFA	71
EMUT=(TIVAR/TPP)**1.5*(TPP+198.6)/(TIVAR+198.6)	CFA	72
CF2FPC=.370/((ALOG10(REXCF*(ROP/ROVAR)*EMUT))**2.584)*.5	CFA	73
CF2C=CFMTC*CF2FPC	CFA	74
CALL WRTS (CF2C,RAFC,CFMTC)	CFA	75
CALL CMT (CFMTD)	CFA	76
CALL RFCAL1 (RAFD)	CFA	77
REX=RETH*VAR(1)/VAR(2)	CFA	78
REXMIN=REX*(1.-XMIN/VAR(1))	CFA	79
HP=.5*(HW+HVAR)+.22*(HAW-HVAR)	CFA	80
CALL RGASH (PIVAR,ROP,AP,HP,TPP,SP,ERP,IGAS)	CFA	81
EMUT2=(TIVAR/TPP)**1.5*(TPP+198.6)/(TIVAR+198.6)	CFA	82
CF2FPD=.370/((ALOG10(REXMIN*(ROP/ROVAR)*EMUT2))**2.584)*.5	CFA	83
CF2D=CFMTD*CF2FPD	CFA	84
CALL WRTS (CF2D,RAFD,CFMTD)	CFA	85

2	CALL CMT (CFMTE)	CFA 86
	CALL RFCAL1 (RAFE)	CFA 87
	HP=.5*(HW+HVAR)+.22*(HAM-HVAR)	CFA 88
	CALL RGASH (PIVAR,ROP,AP,HP,TPP,SP,ERR,IGAS)	CFA 89
	EMUT3=SQRT(TIVAR/TPP)*((1.+220.*10.**(-9./TPP)/TPP)/(1.+220.*10.**	CFA 90
	1-9./TIVAR)/TIVAR)	CFA 91
	RBARTH=RETH*EMUT3	CFA 92
	RBTLG=ALOG10(RBARTH)	CFA 93
	CFI2E=.5/((17.08*RBTLG+25.11)*RBTLG+6.012)	CFA 94
	CF2FPE=CFI2E/(TPP/TIVAR)	CFA 95
	CF2E=CFMTE*CF2FPE	CFA 96
	CALL WRTS (CF2E,RAFE,CFMTE)	CFA 97
	CALL CMT1 (CFMT1)	CFA 98
	CALL RFCAL1 (RAF1)	CFA 99
C		CFA 100
C	CALL VGAUSS,FOFZ	CFA 101
C		CFA 102
	CALL VGAUSS (0,1.,L,ANZ,FOFZ,FZ,1,NN)	CFA 103
C		CFA 104
C	COMPUTE FC FROM EQ(22)OR (21)	CFA 105
C		CFA 106
	FC1=1./(ANZ*ANZ)	CFA 107
C		CFA 108
C	INITIAL ESTIMATE X	CFA 109
C		CFA 110
	CF21=.9375E-2*(FRTH*RETH)**(-.2148)	CFA 111
C		CFA 112
C	SOLVE FOR X USING NEWTONS METHOD AND CFERR FOR ERROR CRITERIA	CFA 113
C		CFA 114
3	FCF=RETH*FRTH-1./((6.*CF21)-(1./(EK*E))*((1.-2.*CF21**(.5/EK))*EXP(EK	CFA 115
	1*CF21**(-.5))+2.*CF21**(.5/EK+1.-EK**2/(6.*CF21)-EK**3*CF21**(-1.5)	CFA 116
	2/12.-EK**4*CF21**(-2)/40.-EK**5*CF21**(-2.5)/180.)	CFA 117
	FCFPR=1./((6.*CF21*CF21)-(1./(EK*E))*((EXP(EK*CF21**(-.5))*(1./CF21-	CFA 118
	1EK*CF21**(-1.5)/2.-CF21**(-.5)/EK)+CF21**(-.5)/EK+EK*EK/(6.*CF21*CC	CFA 119
	2F21)+EK**3*CF21**(-2.5)/8.+EK**4*CF21**(-3)/20.+EK**5*CF21**(-3.5)	CFA 120
	3/72.)	CFA 121
	H2=-FCF/FCFPR	CFA 122
	IF (ABS(H2/CF21)-CFERR) 5,5,4	CFA 123
4	CF21=CF21+H2	CFA 124
	GO TO 3	CFA 125
C		CFA 126
C	SKIN FRICTION CF/2	CFA 127
C		CFA 128

5	CF21=CF21*CFMT1/FC1	CFA 129
	CALL WRTS (CF21,RAF1,CFMT1)	CFA 130
	CALL CMT1 (CFMT2)	CFA 131
	CALL RFCAL1 (RAF2)	CFA 132
C		CFA 133
C	CALL VGAUSS,FOFZA	CFA 134
C		CFA 135
	CALL VGAUSS (0.1.,L,ANZ,FOFZA,FZ,1,NN)	CFA 136
	FC2=1./(ANZ*ANZ)	CFA 137
	CF22=.9375E-2*(FRTH*RETH)**(-.2148)	CFA 138
6	FCF=RETH*FRTH-1./(6.*CF22)-(1./(EK*E))*((1.-2.*CF22*.5/EK)*EXP(EKCF22	CFA 139
	1*CF22**(-.5))+2.*CF22*.5/EK+1.-EK**2/(6.*CF22)-EK**3*CF22**(-1.5)	CFA 140
	2/12.-EK**4*CF22**(-2)/40.-EK**5*CF22**(-2.5)/180.)	CFA 141
	FCFPR=1./(6.*CF22*CF22)-(1./(EK*E))*(EXP(EK*CF22**(-.5))*(1./CF22-CFA	CFA 142
	1EK*CF22**(-1.5)/2.-CF22**(-.5)/EK)+CF22**(-.5)/EK+EK*EK/(6.*CF22*CF22	CFA 143
	2F22)+EK**3*CF22**(-2.5)/8.+EK**4*CF22**(-3)/20.+EK**5*CF22**(-3.5)	CFA 144
	3/72.)	CFA 145
	H2=-FCF/FCFPR	CFA 146
	IF (ABS(H2/CF22)-CFERR) 9,8,7	CFA 147
7	CF22=CF22+H2	CFA 148
	GO TO 6	CFA 149
8	CF22=CF22*CFMT2/FC2	CFA 150
	CALL WRTS (CF22,RAF2,CFMT2)	CFA 151
	RETURN	CFA 152
	END	CFA 153-

1 CFCAL.- Subroutine CFCAL computes the VanDriest II F_c function to correlate
2 the skin-friction data.

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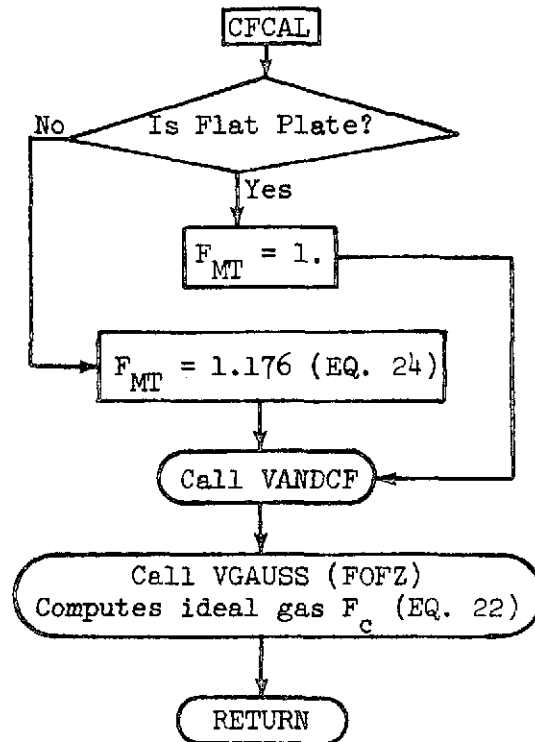
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SUBROUTINE CFCAL                                CFC 1
CFC 2
CFC 3
CALCULATES SKIN FRICTION FOR FIRST ITERATION
OR FOR OTHER ITERATIONS BEYOND TRANSITION REGION
CFC 4
CFC 5
COMPUTES MANGLER TRANSFORMATION FACTOR FOR
CFC 6
VAN DRIEST II (RETHETA) METHOD
CFC 7
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)
CFC 8
10),TXL(450),TYLS(450),TSS(450)
CFC 9
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI
CFC 10
COMMON CMTOPT
CFC 11
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFR2,CFERCFC
CFC 12
1R,CF1,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNCFC
CFC 13
2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,ECFC
CFC 14
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRKE,FRTH,G,GC,GX,H,HCFC
CFC 15
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,CFC
CFC 16
5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOU,RHOW,RO,ROPCFC
CFC 17
6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARCFC
CFC 18
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPCFC
CFC 19
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XICFC
CFC 20
9N,XMIN,X2REX,Z,ZMAX,ZMIN
CFC 21
REAL IN,JN,KN
CFC 22
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNCFC
CFC 23
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)
CFC 24
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),CFC
CFC 25
1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SCFC
CFC 26
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)CFC
CFC 27
31,DRDXT(160),DPDXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(160)CFC
CFC 28
40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(CFC
CFC 29
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)
CFC 30
COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PCFC
CFC 31
1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12CFC
CFC 32
2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV
CFC 33
EXTERNAL FOFZ
CFC 34
EXTERNAL FOFZA
CFC 35
CFC 36
CFC 37
IS FLAT PLATE
CFC 38
CFC 39
IF (FPOPT) 1,2,1
CFC 40
CFC 41
MANGLER TRANSFORMATION =1.
CFC 42

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1	CFMT=1.	CFC 43
	GO TO 3	CFC 44
C		CFC 45
C	MANGLER TRANSFORMATION EQ(24)	CFC 46
C		CFC 47
2	CFMT=1.176	CFC 48
3	CONTINUE	CFC 49
C		CFC 50
C	CALL VANOCF	CFC 51
C		CFC 52
	CALL VANOCF	CFC 53
C		CFC 54
C	INTEGRAL USING GAUSS 5INTERVALS,4PTS PER INTERVAL	CFC 55
C	CALL VGAUSS,FOFZ	CFC 56
C		CFC 57
	CALL VGAUSS (0,1.,L,ANZ,FOFZ,FZ,1,NN)	CFC 58
C		CFC 59
C	COMPUTE FC FROM EQ(22)	CFC 60
C		CFC 61
	FC=1./(ANZ*ANZ)	CFC 62
	RETURN	CFC 63
	END	CFC 64

1 CHECK.- Subroutine to be used by INT1A to allow certain logical control.

2 The control is not desired in this case and a dummy subroutine is
3 inserted.

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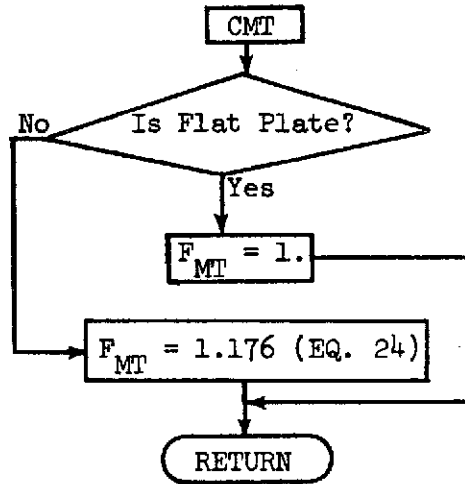
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C	SUBROUTINE CHECK	CHK	1
C	DUMMY SUBROUTINE FOR RUNGE KUTTA	CHK	2
C		CHK	3
	RETURN	CHK	4
	END	CHK	5
		CHK	6-

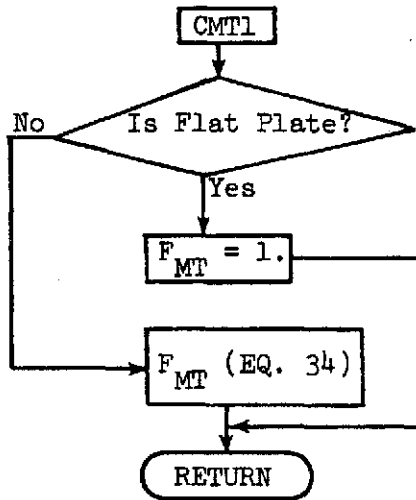
1 CMT.- Subroutine CMT computes Mangler transformation factor for VanDriest
2 and Eckert's skin-friction coefficient.



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	SUBROUTINE CMT (CFMTX)	CMT	1
C	COMPUTES MANGLER TRANSFORMATION FACTOR FOR	CMT	2
C	VAN DRIEST AND ECKERT SKIN FRICTION	CMT	3
	COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)	CMT	4
	10),TXL(450),TYLS(450),TSS(450)	CMT	5
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI	CMT	6
	COMMON CMTOPT	CMT	7
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERCMT	CMT	8
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNCMT	CMT	9
	2,DPVAR,DRBVAR,DRVAR,OSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,FN,ECMT	CMT	10
	3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRKE,FRTH,G,GC,GX,H,HCMT	CMT	11
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,CMT	CMT	12
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOU,RHOW,RO,ROPCMT	CMT	13
	6,ROVAR,ROW,RI,PRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARCMT	CMT	14
	7,SW,SX,TAW,TEMP,TEMPI0,TEMPI1,TEMPI2,TEMP14,TEMP2,TEMP3,TEMP4,TEMPCMT	CMT	15
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TK,WVAR,XICMT	CMT	16
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	CMT	17
	REAL IN,JN,KN	CMT	18
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNCMT	CMT	19
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)	CMT	20
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRIB(20),FRLGT(20),CMT	CMT	21
	1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SCMT	CMT	22
	2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160CMT	CMT	23
	3),DRDXT(160),DPDXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(160CMT	CMT	24
	40),PRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(CMT	CMT	25
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160),IGCMT	CMT	26
	6AS	CMT	27
	COMMON XXI	CMT	28
	COMMON ACFT(22),TREXT(22),ACFLGT(22),TRLGT(22),REXCF,HU,XD	CMT	29
	IF (FPOPT) 1,2,1	CMT	30
1	CFMTX=1.	CMT	31
	GO TO 3	CMT	32
2	CFMTX=1.176	CMT	33
3	RETURN	CMT	34
	END	CMT	35

1 CMTL.- Subroutine CMTL computes Mangler transformation factor for Spalding-
2 Chi skin-friction coefficient.



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SUBROUTINE CMT1 (CFMTX)                                CMI  1
C  COMPUTES MANDLER TRANSFORMATION FACTOR FOR          CMI  2
C  SPALDING CHI SKIN FRICTION                          CMI  3
COMMON XLSH,XLSHI,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450) CMI  4
10),TXL(450),TYLS(450),TSSI(450)                      CMI  5
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI CMI  6
COMMON CMTOPT                                          CMI  7
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERCMI  8
1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELA M,DELS,DERR,DNCMI  9
2,DPVAR,DRBVAR,DRVVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVU,EMU,EMVAR,EMX,EN,FCMI 10
3NGN,FNI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRR,FRTH,G,GC,GX,H,HCM1 11
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,CM1 12
5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHQUI,KHOW,RO,ROPCMI 13
6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSVVAR,RX,SHEAR,SP,SVARCM1 14
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPCM1 15
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TI VAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XICMI 16
9N,XMIN,X2REX,Z,ZMAX,ZMIN                             CMI 17
REAL IN,JN,KN                                         CMI 18
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNCMI 19
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)  CMI 20
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),CM1 21
1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SCMI 22
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)CM1 23
3),DRDXT(160),DPDXT(160),DRBDXT(160),VAR(2),DER(2),CJVAR(2),WSAV(16)CM1 24
40),RPTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(CMI 25
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160),IGCM1 26
6AS                                                    CMI 27
COMMON XXI                                           CMI 28
COMMON ACFT(22),TREXT(22),ACFLGT(22),TRLGT(22),REXCF,HO,XO CMI 29
IF (FPOPT) 1,2,1                                     CMI 30
1  CFMTX=1.                                           CMI 31
GO TO 3                                              CMI 32
2  CC=3.-.309136*(VAR(1)-XVO)/(XMAXTB(20)-XVO)      CMI 33
CFMTX=(3.4641016-SQRT(12.-4.*CC))/2.                CMI 34
3  RETURN                                           CMI 35
END                                                  CMI 36

```

1 CRRD.- Subroutine CRRD reads inviscid flow field from tapes 15, 16, 22 if
 2 CARD = 0 is input. This subroutine computes tables of x/r_n , r_b/r_n ,
 3 s, p, on body and r_s/r_n , s on shock.

4 CRRD

5
 6 Read tape 15 AMES MOC tape
 7 Read body and shock points until XLSH reached
 x_{CL}/r_n , y/r_n , Q, θ , M, s, p, H, ρ , P_T

8
 9 Is XLSH = XLSH1?

Yes

No

10
 11 Read tape 22 AMES MOC tape
 12 Read body and shock points until XLSH1 reached
 13 Save shock points from tape 22
 Save body points from tape 15

14 Read tape 16 AMES blunt body tape
 15 Read body and shock points until EOF
 16 Use tapes 17, 18, 19, 20, 21 for
 intermediate storage of body and shock
 17 From MOC tape save all body points
 18 From MOC tape omit decreasing x/r_n shock points and save others
 From blunt body tape omit shock points with $y/r_n > y/r_n$ at
 first MOC shock point saved.
 19 From blunt body tape omit body points with $x/r_n > x/r_n$ at
 first MOC body point saved.

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Set up table of body points $x_{CL}/r_n, r_b/r_n, s, p, x/r_n$

IF $(x_{CL}/r_n - 1 + \sin \theta_c) \leq 0$, $x/r_n = \cos^{-1}(1 - x_{CL}/r_n)$

IF $(x_{CL}/r_n - 1 + \sin \theta_c) > 0$, $x/r_n = \pi/2 - \theta_c + (x_{CL}/r_n - 1 + \sin \theta_c)/\cos \theta_c$

Set up table of shock points $r_s/r_n, s$

Save count of number of body and shock points in tables

↓

RETURN

	SUBROUTINE CRRD	CRD	1
C		CRD	2
C	READ TAPES FROM AMES BLUNT BODY AND CHARACTERISTICS PROGRAMS	CRD	3
C	SET UP TABLES OF X/L CENTERLINE, X/L BODY, BODY RADIIJS, ENTROPY,	CRD	4
C	PRESSURE	CRD	5
C	SHOCK RADIUS, SHOCK ENTROPY	CRD	6
C	KLIM= COUNTOF SHOCK POINTS, LIMIT OF 450	CRD	7
C	JLIM= COUNTOF BODY POINTS, LIMIT OF 450	CRD	8
C		CRD	9
	COMMON XLSH, XLSH1, THCR, JLIM, KLIM, TXLCL(450), TYL(450), TS(450), TP(450)	CRD	10
	10), TXL(450), TYLS(450), TSS(450)	CRD	11
	DIMENSION CHB(10), CHS(10,2), BLB(10), BLS(10), TSVSH(10), SVBD(10)	CRD	12
	1), SVSH(10)	CRD	13
	REWIND 17	CRD	14
	REWIND 15	CRD	15
	REWIND 18	CRD	16
	J=0	CRD	17
C		CRD	18
C	READ TAPE 15 AMES MOC TAPE	CRD	19
C	X/LCL, Y/L, Q, THETA, M, S, P, H, RHO, PT	CRD	20
C	READ BODY AND SHOCK POINTS UNTIL XLSH REACHED	CRD	21
C	USE TAPES 17, 18, 19, 20, 21 FOR INTERMEDIATE STORAGE OF BODY, SHOCK	CRD	22
C		CRD	23
1	READ (15,37) (CHB(I), I=1,10)	CRD	24
	WRITE (6,37) (CHB(I), I=1,10)	CRD	25
	IF (ENDFILE 15) 2,3	CRD	26
2	JM=J-1	CRD	27
	GO TO 7	CRD	28
3	WRITE (17,37) (CHB(I), I=1,10)	CRD	29
	J=J+1	CRD	30
	READ (15,37) (CHS(I,1), I=1,10)	CRD	31
	WRITE (6,37) (CHS(I,1), I=1,10)	CRD	32
	IF (CHS(I,1)-XLSH) 4,4,5	CRD	33
4	IF (ENDFILE 15) 5,6	CRD	34
5	JM=J-2	CRD	35
	GO TO 7	CRD	36
6	WRITE (18,37) (CHS(I,1), I=1,10)	CRD	37
	GO TO 1	CRD	38
C		CRD	39
C	IS ANGLE BODY=ANGLE SHOCK	CRD	40
C		CRD	41
7	IF (XLSH-XLSH1) 8,15,8	CRD	42

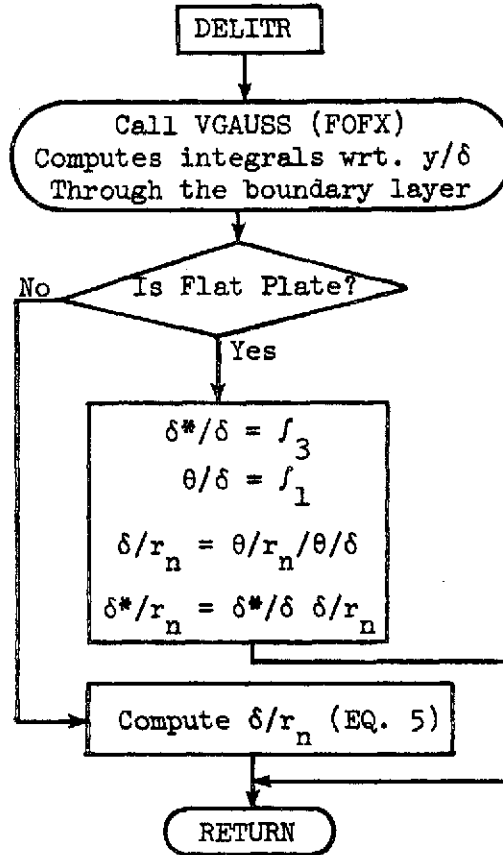
C		CRD 43
C	READ TAPE 22 AMES MOC TAPE	CRD 44
C	READ BODY AND SHOCK POINTS UNTIL XLSH1 REACHED	CRD 45
C	SAVE SHOCK FROM TAPE 22	CRD 46
C	SAVE BODY FROM TAPE 15	CRD 47
C		CRD 48
8	REWIND 22	CRD 49
	REWIND 18	CRD 50
	L=0	CRD 51
9	READ (22,37) (CHB(I),I=1,10)	CRD 52
	WRITE (6,37) (CHB(I),I=1,10)	CRD 53
	IF (ENDFILE 22) 10,11	CRD 54
10	LM=L-1	CRD 55
	GO TO 15	CRD 56
11	CONTINUE	CRD 57
	L=L+1	CRD 58
	READ (22,37) (CHS(I,1),I=1,10)	CRD 59
	WRITE (6,37) (CHS(I,1),I=1,10)	CRD 60
	IF (CHS(1,1)-XLSH1) 12,12,13	CRD 61
12	IF (ENDFILE 22) 13,14	CRD 62
13	LM=L-2	CRD 63
	GO TO 15	CRD 64
14	WRITE (18,37) (CHS(I,1),I=1,10)	CRD 65
	GO TO 9	CRD 66
C		CRD 67
C	READ TAPE 16 AMES BLUNT BODY TAPE	CRD 68
C	READ BODY AND SHOCK POINTS UNTIL EOF	CRD 69
C		CRD 70
15	K=0	CRD 71
	REWIND 16	CRD 72
	REWIND 19	CRD 73
	REWIND 20	CRD 74
16	READ (16,37) (BLB(I),I=1,10)	CRD 75
	WRITE (6,37) (BLB(I),I=1,10)	CRD 76
	IF (ENDFILE 16) 19,17	CRD 77
17	WRITE (19,37) (BLB(I),I=1,10)	CRD 78
	READ (16,37) (BLS(I),I=1,10)	CRD 79
	WRITE (6,37) (BLS(I),I=1,10)	CRD 80
	IF (ENDFILE 16) 19,18	CRD 81
18	WRITE (20,37) (BLS(I),I=1,10)	CRD 82
	K=K+1	CRD 83
	GO TO 16	CRD 84
C		CRD 85

C	FROM MOC TAPE SAVE ALL BODY POINTS	CRD 86
C	FROM MOC TAPE OMIT DECREASING X/L SHOCK PTS AND SAVE OTHERS	CRD 87
C	FROM BLUNT BODY TAPE OMIT SHOCK POINTS WITH Y/L.GT.Y/L AT	CRD 88
C	FIRST MOC SHOCK PT SAVED	CRD 89
C	FROM BLUNT BODY TAPE OMIT BODY PTS WITH X/L.GT.X/L AT	CRD 90
C	FIRST MOC BODY PT SAVED	CRD 91
C		CRD 92
19	REWIND 17	CRD 93
	READ (17,37) (CHB(I),I=1,10)	CRD 94
	REWIND 19	CRD 95
	REWIND 21	CRD 96
	JJ=0	CRD 97
	DO 21 KK=1,K	CRD 98
	READ (19,37) (BLB(I),I=1,10)	CRD 99
	IF (BLB(I)-CHB(I)) 20,20,21	CRD 100
20	JJ=JJ+1	CRD 101
	WRITE (21,37) (BLB(I),I=1,10)	CRD 102
21	CONTINUE	CRD 103
	REWIND 17	CRD 104
	DO 22 KK=1,J	CRD 105
	JJ=JJ+1	CRD 106
	READ (17,37) (CHB(I),I=1,10)	CRD 107
	WRITE (21,37) (CHB(I),I=1,10)	CRD 108
22	CONTINUE	CRD 109
	LL=0	CRD 110
	REWIND 17	CRD 111
	REWIND 18	CRD 112
	READ (18,37) (CHS(I,2),I=1,10)	CRD 113
	IF (XLSH-XLSH1) 24,23,24	CRD 114
23	LM=JM	CRD 115
24	DO 27 KK=1,LM	CRD 116
	DO 25 I=1,10	CRD 117
25	CHS(I,1)=CHS(I,2)	CRD 118
	READ (18,37) (CHS(I,2),I=1,10)	CRD 119
	IF (CHS(I,1)-CHS(I,2)) 26,26,27	CRD 120
26	LL=LL+1	CRD 121
	WRITE (17,37) (CHS(I,1),I=1,10)	CRD 122
27	CONTINUE	CRD 123
	LL=LL+1	CRD 124
	WRITE (17,37) (CHS(I,2),I=1,10)	CRD 125
	REWIND 18	CRD 126
	REWIND 17	CRD 127
	READ (17,37) (TSVSH(I),I=1,10)	CRD 128

	REWIND 20	CRD 129
	ML=0	CRD 130
	DO 29 KK=1,K	CRD 131
	READ (20,37) (BLS(I),I=1,10)	CRD 132
	IF (BLS(2)-TSVSH(2)) 28,28,29	CRD 133
28	ML=ML+1	CRD 134
	WRITE (18,37) (BLS(I),I=1,10)	CRD 135
29	CONTINUE	CRD 136
	REWIND 17	CRD 137
	DO 30 MK=1,LL	CRD 138
	ML=ML+1	CRD 139
	READ (17,37) (TSVSH(I),I=1,10)	CRD 140
	WRITE (18,37) (TSVSH(I),I=1,10)	CRD 141
30	CONTINUE	CRD 142
C		CRD 143
C	SET UP TABLE OF BODY PTS X/LCL,RB/L,S,P,X/L	CRD 144
C	SET UP TABLE OF SHOCK PTS RS/L,S	CRD 145
C	SAVE COUNT OF NO. OF BODY AND SHOCK PTS. IN TABLES	CRD 146
C		CRD 147
	REWIND 21	CRD 148
	STHCR=SIN(THCR)	CRD 149
	CTHCR=COS(THCR)	CRD 150
	PMTH=1.570796-THCR	CRD 151
	J=0	CRD 152
	DO 33 KJ=1,JJ	CRD 153
	J=J+1	CRD 154
	READ (21,37) (SVBD(I),I=1,10)	CRD 155
	TXLCL(J)=SVBD(1)	CRD 156
	TYL(J)=SVBD(2)	CRD 157
	TS(J)=SVBD(6)	CRD 158
	TP(J)=SVBD(7)	CRD 159
	XL=TXLCL(J)-1.+STHCR	CRD 160
	IF (XL) 31,31,32	CRD 161
31	TXL(J)=ACOS(1.-TXLCL(J))	CRD 162
	GO TO 33	CRD 163
32	TXL(J)=PMTH+XL/CTHCR	CRD 164
33	CONTINUE	CRD 165
	JLIM=J	CRD 166
	REWIND 18	CRD 167
	K=0	CRD 168
	DO 36 KJ=1,ML	CRD 169
	K=K+1	CRD 170
	READ (18,37) (SVSH(I),I=1,10)	CRD 171

	TYLS(K)=SVSH(2)	CRD 172
	IF (SVSH(1)-XLSH1) 35,35,34	CRD 173
34	TSS(K)=TSS(K-1)	CRD 174
	GO TO 36	CRD 175
35	TSS(K)=SVSH(6)	CRD 176
36	CONTINUE	CRD 177
	KLIM=K	CRD 178
	CALL EVICT (6LTAPE15)	CRD 179
	CALL EVICT (6LTAPE16)	CRD 180
	CALL EVICT (6LTAPE22)	CRD 181
	RETURN	CRD 182
C		CRD 183
C		CRD 184
C		CRD 185
37	FORMAT (5E16.9)	CRD 186
	END	CRD 187-

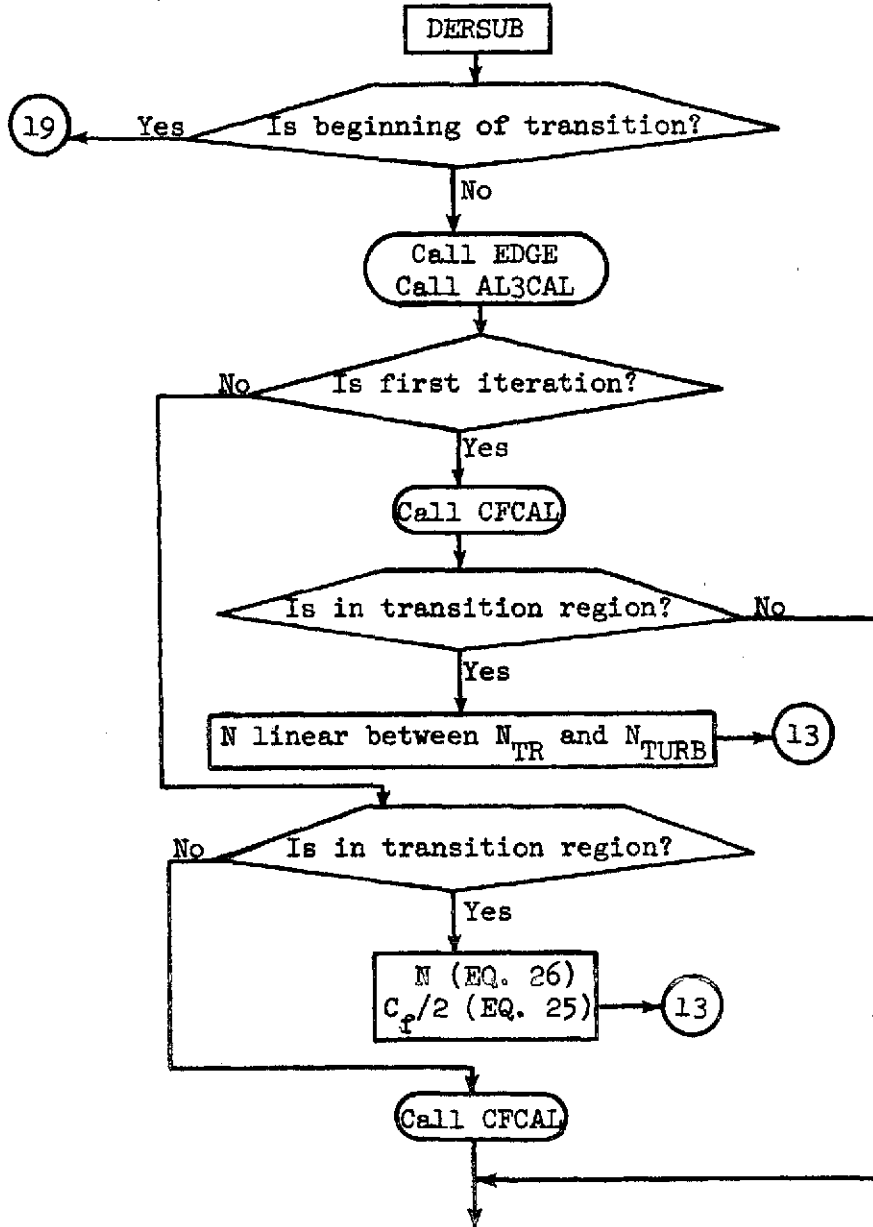
1 DELITR.- Subroutine DELITR computes boundary layer thickness for cone or
2 flat plate and displacement thickness for flat plate.



	SUBROUTINE DELITR	DEL	1
		DEL	2
C	CALLS VGAUSS,FOFX TO GET INTEGRALS WRT. Y/DEL THROUGH BOUNDARY	DEL	3
C		DEL	4
C	COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)	DEL	5
	10),TXL(450),TYLS(450),TSS(450)	DEL	6
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI	DEL	7
	COMMON CMTOPT	DEL	8
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CERP,CEN,CEMP,CFBMT,CFB2,CFERDEL	DEL	9
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNDEL	DEL	10
	2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,EDEL	DEL	11
	3NGN,ENI,ERR,FC,FCCFLG,FCCFLG,FCF,FCFPR,FD,F DPR,FRRE,FRTH,G,GC,GX,H,HDEL	DEL	12
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,DEL	DEL	13
	5NN,NO,NXINT,PATM,PIVAR,PP,PRP,PRW,RBVAR,RET,RETH,RHOU1,RHOW,RO,RODEL	DEL	14
	6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARDEL	DEL	15
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPDEL	DEL	16
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIDEL	DEL	17
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	DEL	18
	REAL IN,JN,KN	DEL	19
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNDEL	DEL	20
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)	DEL	21
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),DEL	DEL	22
	1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SDEL	DEL	23
	2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160DEL	DEL	24
	3),DRDXT(160),DPDXT(160),DRBOXT(160),VAR(2),DER(2),CUVAR(2),WSAV(160DEL	DEL	25
	40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(DEL	DEL	26
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)	DEL	27
	COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PDEL	DEL	28
	1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12DEL	DEL	29
	2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV	DEL	30
	DIMENSION F2(7)	DEL	31
	EXTERNAL FOFX	DEL	32
	SX=SVAR	DEL	33
C		DEL	34
C	CALLS VGAUSS,FOFX TO GET INTEGRALS WRT. Y/DEL THROUGH BOUNDARY	DEL	35
C	CALL VGAUSS (0,1.,L,AN2,FOFX,F2,7,NN)	DEL	36
C		DEL	37
C	IS FLAT PLATE	DEL	38
C		DEL	39
C	IF (FPOPT) 1,2,1	DEL	40
C		DEL	41
C	DEL TASTAR/DELTA = INTEGRAL(3)	DEL	42

C		DEL	43
1	DSOD=AN2(3)	DEL	44
C		DEL	45
C	THETA/DELTA=INTEGRAL(1)	DEL	46
C		DEL	47
	THOD=AN2(1)	DEL	48
C		DEL	49
C	DELTA/L	DEL	50
C	THETA/L FROM SUBROUTINE PERSUR	DEL	51
C		DEL	52
	DEL=CUVAR(2)/THOD	DEL	53
C		DEL	54
C	DELTASTAR/L	DEL	55
C		DEL	56
	DELS=DEL*DSOD	DEL	57
	GO TO 3	DEL	58
C		DEL	59
C	COMPUTE BOUNDARY LAYER THICKNESS	DEL	60
C	IF CONE FIND DELTA/L FROM EQ(5)	DEL	61
C		DEL	62
2	DEL=(-AN2(1))+SQRT(AN2(1)**2+4.*AN2(5)*TEMP1))/(2.*AN2(5))	DEL	63
3	RETURN	DEL	64
C		DEL	65
	FND	DEL	66-

1 DERSUB.- Subroutine DERSUB evaluates the derivative of the variable entropy
 2 momentum integral equation.



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Find $F_c \bar{C}_f$ from $F_{R0} R_{e0}$, $F_c \bar{C}_f$ table
 $\bar{C}_f|_{\text{cone}} / \bar{C}_f|_{\text{FLATPLATE}} = 1.045$ (EQ. 36)
 $\bar{C}_f/2 = F_c \bar{C}_f / 2F_c$
 x_{VO}/r_n (EQ. 9)
 Z (EQ. 8)
computes $N = f(Z)$

13

Is $N < N_{TR}$? No

Yes

$N = N_{TR}$

Is Flat Plate? No

Yes

Call DELITR
 $\delta/r_n, \delta^*/r_n$

Call DELITR
 δ/r_n (EQ. 5)

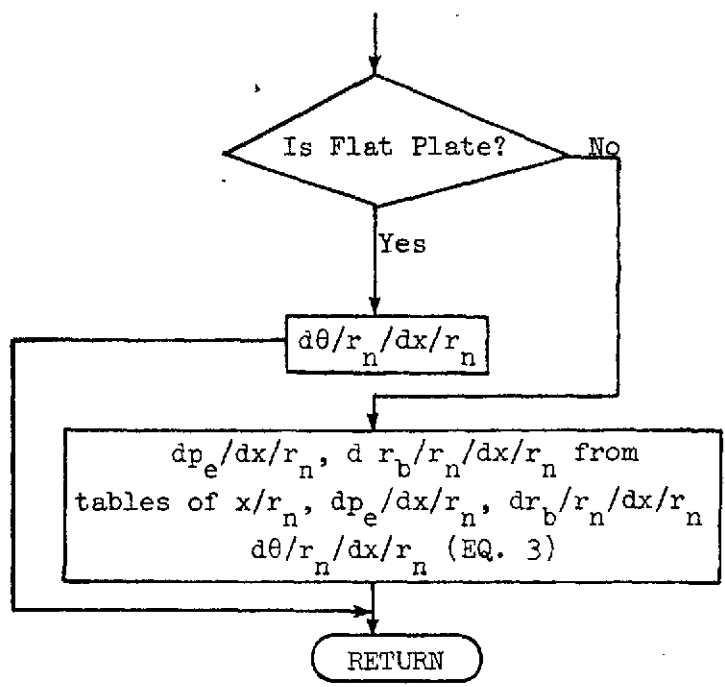
r_s/r_n (EQ. 19)
 δ^*/r_n (EQ. 4)

compute δ^*/θ

19

$dU_e/dx/r_n, d\rho_e/dx/r_n$ from
tables of $x/r_n, dU_e/dx/r_n, d\rho_e/dx/r_n$

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SUBROUTINE DERSUB
C
C X/L=CUVAR(1), MOMENTUM THICKNESS=CUVAR(2)
C AT X/L STATION COMPUTE VARIABLE ENTROPY MOMENTUM INTEGRAL
C EQUATION
C COMPUTES DTHETA/DX AT EACH STEP IN RUNGE-KUTTA INTEGRATION BY EQ3
C
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)
10),TXL(450),TYLS(450),TSS(450)
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI
COMMON CMOPT
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFER
1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DFRR,DNDER
2,DPVAR,DRBVAR,DPVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,EDER
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRRE,FRTH,G,GC,GX,H,HDR
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,DER
5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOUI,RHOW,RO,ROPDER
6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLSVAR,RX,SHEAR,SP,SVARDER
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPDER
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIDER
9N,XMIN,X2REX,Z,ZMAX,ZMIN
REAL IN,JN,KN
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNDER
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRFB(20),FRLGT(20),DER
1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SDER
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)
3),DRDXT(160),OPDXT(160),DRBDXT(160),VAR(2),DEX(2),CUVAR(2),WSAV(160)
40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)
COMMON IGAS,XXI
COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PDER
1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12)
2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV
C
C IS START OF TRANSITION
C
C IF (CUVAR(1)-XMIN) 1,19,1
C
C CALL EDGE
C
C CALL EDGE
I

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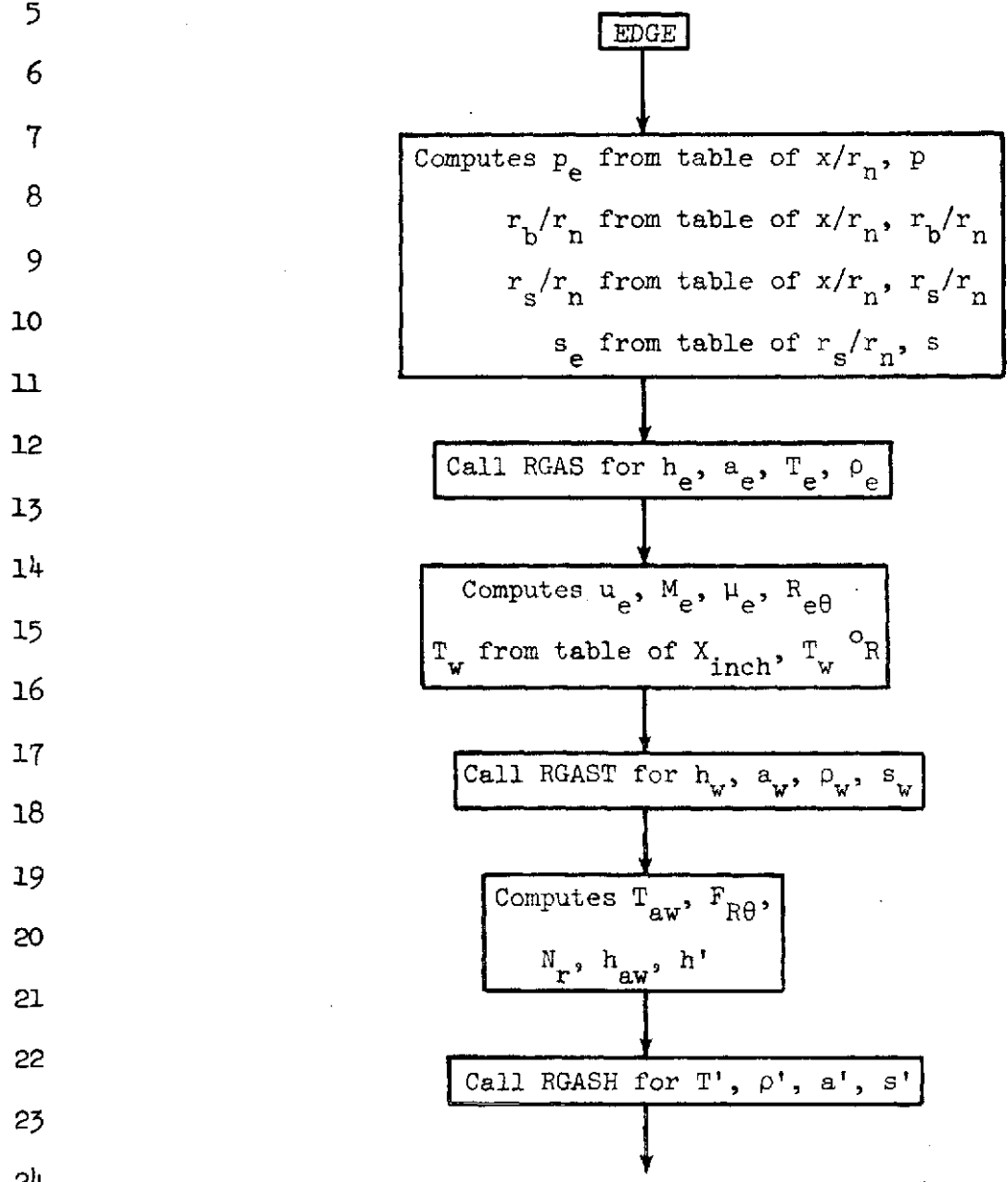
C		DER	43
C	CALL AL3CAL	DER	44
C		DER	45
C	CALL AL3CAL	DER	46
C		DER	47
C	IS FIRST ITERATION	DER	48
C	TEST CODE ICELL	DER	49
C		DER	50
C	IF (ICELL) 4,2,4	DER	51
C		DER	52
C	CALL CFCAL	DER	53
C		DER	54
2	CALL CFCAL	DER	55
C		DER	56
C	IS TRANSITION REGION	DER	57
C		DER	58
C	IF (CUVAR(1)-X2REX) 3,3,8	DER	59
C		DER	60
C	N=LINEAR BETWEEN N(TRANSITION) AND N(TURBULENT)	DER	61
C		DER	62
3	EN=ENI-(XMIN-CUVAR(1))*(ENI-ENX)/(XMIN-X2REX)	DER	63
C	GO TO 13	DER	64
C		DER	65
C	IS TRANSITION REGION	DER	66
C	TEST CODE TRAN	DER	67
C		DER	68
4	IF (TRAN) 5,7,5	DER	69
5	IF (CUVAR(1)-X2REX) 6,6,7	DER	70
C		DER	71
C	ITERATION AFTER FIRST IN TRANSITION REGION THE N VARIATION IS	DER	72
C	NONLINEAR	DER	73
C	WITH PSI CONTROLLING THE DEGREE OF NONLINEARITY	DER	74
C	THE SKIN FRICTION COEFFICIENT ALSO NONLINEAR	DER	75
C	CONTROLLED BY PSI	DER	76
C	N EQ(26)	DER	77
C	CF/2 EQ(25)	DER	78
C		DER	79
6	XX=PSI-CEB*(X2REX-CUVAR(1))	DER	80
	XX1=(CEBP*TANH(XX))/(CEBP+CEBP)	DER	81
	EN=ENI+XX1*CEM	DER	82
	CF2=CF2I+XX1*CEMP	DER	83
	GO TO 13	DER	84
C		DER	85

C	CALL CFCAL	DER	86
C		DER	87
7	CALL CFCAL	DER	88
C		DER	89
C	USING FRTHETA*RETHETA,SPALDING-CHI TABLE GIVES FCCBARF	DER	90
C		DER	91
8	FRRE=ALOG10(FRTH*RETH)	DER	92
	CALL DISCOT (FRRE,FRRE,FRLGT,FCLGT,FCLGT,011,20,0,FCCFLG)	DER	93
	FCCF=10.**FCCFLG	DER	94
	CFB2=FCCF/(2.*FC)	DER	95
C		DER	96
C	CBFMT EQ(36)	DER	97
C	XVO/LO EQ(9)	DER	98
C		DER	99
	ELVO=CUVAR(2)/(CFBMT*CFB2)	DER	100
C		DER	101
C	Z EQ(8)	DER	102
C		DER	103
	Z=(RETH**AN*COE1**CN*(ELVO/CUVAR(2))**KN)/(EMVAR**DN)	DER	104
C		DER	105
C	BEYOND TRANSITION N=6.*LOG(Z)-7. EXCEPT	DER	106
C	N=2 BELOW ZMIN,N=10 ABOVE ZMAX	DER	107
C	WHERE Z COMPUTED USING DISTANCE FROM VIRTUAL ORIGIN.	DER	108
C	Z.LT.ZMIN,N=2	DER	109
C	ZMIN.LE.Z.LE.ZMAX,N(EQ8)	DER	110
C	Z.GT.ZMAX,N=10	DER	111
C		DER	112
	IF (Z-ZMIN) 9,10,10	DER	113
9	EN=2.	DER	114
	GO TO 13	DER	115
10	IF (Z-ZMAX) 12,12,11	DER	116
11	EN=10.	DER	117
	GO TO 13	DER	118
12	EN=6.*ALOG10(Z)-7.	DER	119
C		DER	120
C	IS N.LT.N(TRANSITION)	DER	121
C		DER	122
13	IF (EN-EN) 15,15,14	DER	123
C		DER	124
C	N=N(TRAN)	DER	125
C		DER	126
14	EN=ENI	DER	127
15	TEMP3=1./EN	DER	128

C		DER 129
C	IS FLAT PLATE	DER 130
C		DER 131
	IF (FPOPT) 16,17,16	DER 132
C		DER 133
C	CALL DELITR FOR DEL/L,DELSTAR/L	DER 134
C		DER 135
16	CALL DELITR	DER 136
	GO TO 18	DER 137
C		DER 138
C	GIVEN MOMENTUM THICKNESS COMPUTE BOUNDARY LAYER THICKNESS,SHOCK	DER 139
C	RADIUS	DER 140
C	DISPLACEMENT THICKNESS EXCEPT AT START OF TRANSITION WHEN SHOCK	DER 141
C	RADIUS GIVEN	DER 142
C	FIND VALUE TEMP11 COS(THETAC)/(2R8/L)*(0/L)SQ+(0/L)	DER 143
C	CALL DELITR FOR DEL/L(EQ5)	DER 144
C		DER 145
17	TEMP11=TEMP10*CUVAR(2)*CUVAR(2)+CUVAR(2)	DER 146
	CALL DELITR	DER 147
C		DER 148
C	RS/L(EQ19)	DER 149
C		DER 150
	RSLVAR=SQRT(TEMP12*DEL*AN2(6)+TEMP12*DEL*DEL*AN2(2))	DER 151
C		DER 152
C	DELSTAR/L(EQ4)	DER 153
C		DER 154
	G=-DEL*AN2(3)-DEL*DEL*AN2(4)	DER 155
C		DER 156
C	DELSTAR/THETA	DER 157
C		DER 158
	DELS=(-1.+SQRT(1.-TEMP14*G))/TEMP9	DER 159
18	DSTH=DELS/CUVAR(2)	DER 160
C		DER 161
C	TABLE OF VELOCITY,DENSITY,PRESSURE,BODY RADIUS DERIVATIVES FROM	DER 162
C	PREVIOUS ITERATION	DER 163
C	DU/DX,DRHO/DX FROM TABLES	DER 164
C		DER 165
19	CALL DISCOT (CUVAR(1),CUVAR(1),XKW,DUDXT,DUDXT,011,NKW,0,DUVAR)	DER 166
	CALL DISCOT (CUVAR(1),CUVAR(1),XKW,DRDXT,DRDXT,011,NKW,0,DRVARI)	DER 167
C		DER 168
C	IS FLAT PLATE	DER 169
C		DER 170
	IF (FPOPT) 20,21,20	DER 171

C		DER 172
C	DTHETA/DX	DER 173
C		DER 174
20	DER(2)=CF2-CUVAR(2)*(((2.+DSTH)*DUVAR)/WVAR+DRVAR/RRTVAR)	DER 175
	GO TO 22	DER 176
C		DER 177
C	DP/DX,DRB/DX FROM TABLES	DER 178
C		DER 179
21	CALL DISCOT (CUVAR(1),CUVAR(1),X,DPOXT,DPOXT,011,JJLIM,0,OPVAR)	DER 180
	CALL DISCOT (CUVAR(1),CUVAR(1),X,DRBOXT,DRBOXT,011,JJLIM,0,DRBVAR)	DER 181
C		DER 182
C	DTHETA/DX = DER(2) INCREMENT IN MOMENTUM THICKNESS FOR	DER 183
C	RUNGE KUTTA INTEGRATION	DER 184
C	DTHETA/OX(EQ3)	DER 185
C		DER 186
	DER(2)=CF2-CUVAR(2)*(((2.+DSTH)*DUVAR)/WVAR+DRVAR/RRTVAR+DRBVAR/RB	DER 187
	1VAR)+(DEL/WVAR)*{DPVAR*GC/(RRTVAR*WVAR)+DUVAR}	DER 188
22	RETURN	DER 189
C		DER 190
	END	DER 191-

1 EDGE.- Subroutine EDGE computes the initial conditions at the edge of the
2 boundary layer using the results of the inviscid solution and the
3 laminar boundary layer calculation.
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Computes N'_{pr} from Hansen's Tables
Computes $(N'_{pr})_w$ from Hansen's Tables
Computes R_{AF} from Table I
Computes B_I (EQ. 13)

Is Flat Plate?

Yes
No
Computes $\cos \theta_c / r_b / r_n$
 $\cos \theta_c / 2r_b / r_n$
 $2 \cos \theta_c / r_b / r_n$
 $2 r_b / r_n \rho_e U_e / \rho_\infty U_\infty$

RETURN

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SUBROUTINE EDGE                                EDG  1
                                                EDG  2
C   AT X/L STATION COMPUTE PRESSURE, BODY RADIUS, SHOCK RADIUS, ENTROPY, EDG  3
C   DENSITY                                    EDG  4
C   VELOCITY, MACH NO., ENTHALPY, TEMPERATURE, EDG  5
C   WALL TEMPERATURE, DENSITY, ENTHALPY, PRANDTL NO. EDG  6
C   ADIABATIC WALL ENTHALPY, TEMPERATURE      EDG  7
C   REYNOLDS NO. BASED ON MOMENTUM THICKNESS EDG  8
C   ECKERTS REFERENCE ENTHALPY, TEMPERATURE, PRANDTL NU., EDG  9
C   EDG 10
COMMON XLSH, XLSH1, THCR, JLIM, KLIM, TXLCL(450), TYL(450), TS(450), TP(450) EDG 11
10), TXL(450), TYLS(450), TSS(450)           EDG 12
COMMON ENX, FPOPT, ALX, RAF, ALMIN, COPT, STHCR, T1, T2, L, XVO, PSI EDG 13
COMMON CMTOPT                                EDG 14
COMMON ALGN, AN, ANZ, AP, AVAR, AW, AX, CER, CERP, CEM, CEMP, CFBMT, CFB2, CFER EDG 15
1R, CFI, CFMT, CF2, CF2I, CN, COE1, COE2, COE3, CTHCR, DEL, DELAM, DELS, DERR, ONEDG 16
2, DPVAR, DRBVAR, DRVAR, DSTH, DUVAR, E, EK, EL, ELT, ELVO, EMU, EMVAR, EMX, EN, EEDG 17
3NGN, ENI, ERR, FC, FCCF, FCCFLG, FCF, FCFPR, FD, FDP, FRKE, FRTH, G, GC, GX, H, HEDG 18
4AW, HHAT, HP, HT, HVAR, HW, HZ, ICELL, II, IN, JJ, JLLIM, JN, K, KK, KN, LLIM, NKW, EDG 19
5NN, NO, NXINT, PATM, PIVAR, PR, PRP, PRW, RBVAR, RET, RETH, RHUI, RHOW, RO, ROPEDG 20
6, ROVAR, ROW, RRI, RRN, RRTVAR, RRX, RSERR, RSISAV, RSLVAR, RX, SHEAR, SP, SVARE DG 21
7, SW, SX, TAW, TEMP, TEMP10, TEMP11, TEMP12, TEMP14, TEMP2, TEMP3, TEMP4, TEMP EDG 22
85, TEMP6, TEMP7, TEMP8, TEMP9, TEP, TIVAR, TK, TPP, TRAN, TT11, TW, TX, WVAR, XI EDG 23
9N, XMIN, X2REX, Z, ZMAX, ZMIN              EDG 24
REAL IN, JN, KN                             EDG 25
COMMON F(3), A(3), ALPHE(3), XIINT(99), TWT(99), ZTABL(6), TABIN(6), TABJNE DG 26
1(6), DXLTAB(20), DELK(2), RSLG(2), ALG(2), ENG(2), AN2(7) EDG 27
COMMON FRXT(20), FRXLGT(20), FCXT(20), FCXLGT(20), FKT8(20), FRLGT(20), EDG 28
1FCR(20), FCLGT(20), XW(100), FIN6(100), RSLW(100), SHEER(100), XI(160), SEDG 29
2(160), PI(160), XCI(160), RB(160), W(160), RRT(160), XMAXTB(20), DUDXT(160 EDG 30
3), DRDXT(160), DPDXT(160), DRBDXT(160), VAR(2), DER(2), CUVAR(2), WSAV(16 EDG 31
40), RRTSAV(160), XSAV(160), RSLSAV(160), REXSAV(160), ENSAV(160), CFSAV( EDG 32
5160), TKTAB(30), PRTAB(210), PATAB(7), XKW(160), WKW(160), RSLKW(160) EDG 33
COMMON IGAS                                  EDG 34
COMMON /BLOCK/ PLT1(160), PLT2(160), PLT3(160), PLT4(160), PLT5(160), PEDG 35
1LT6(160), PLT7(160), PLT8(160), PLT9(160), PLT10(160), PLT11(160), PLT12 EDG 36
2(160), PLT13(160), PLT14(160), PLT15(160), NKWSAV EDG 37
IF (FPOPT) 10, 1, 10                       EDG 38
                                                EDG 39
C   FIND PRESSURE          PIVAR          LBS/FT2          BOUNDARY LAYER EDGE AT EDG 40
C   X/L STATION          EDG 41
C   IF X OUTSIDE TABLE USE FINAL PRESSURE FROM TABLE EDG 42

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C	IF X INSIDE TABLE USE INTERPOLATED PRESSURE	EDG	43
C		EDG	44
1	IF (CUVAR(1)-TXL(JLIM)) 3,3,2	EDG	45
2	PIVAR=TP(JLIM)	EDG	46
	GO TO 4	EDG	47
C		EDG	48
C	P FROM TABLE X/L,P	EDG	49
C		EDG	50
3	CALL DISCOT (CUVAR(1),CUVAR(1),TXL,TP,TP,011,JLIM,0,PIVAR)	EDG	51
C		EDG	52
C	INTERPOLATE FOR BODY RADIUS	EDG	53
C	RB/L FROM TABLE X/L,RR/L	EDG	54
C		EDG	55
4	CALL DISCOT (CUVAR(1),CUVAR(1),X,RR,RR,011,JJLIM,0,RBVAR)	EDG	56
C		EDG	57
C	FIRST ITERATION INTERPOLATE FOR SHOCK RADIUS USING LAMINAR TABLE	EDG	58
C	ITERATION AFTER FIRST INTERPOLATE FOR SHOCK RADIUS USING PREVIOUS	EDG	59
C	ITERATION	EDG	60
C		EDG	61
C	IF (ICELL) 6,5,6	EDG	62
C		EDG	63
C	RS/L FROM TABLE X/L,RS/L	EDG	64
C		EDG	65
5	CALL DISCOT (CUVAR(1),CUVAR(1),XW,RSLW,RSLW,011,LLIM,0,RSLVAR)	EDG	66
	GO TO 7	EDG	67
6	CALL DISCOT (CUVAR(1),CUVAR(1),XKW,RSLKW,RSLKW,011,NKW,0,RSLVAR)	EDG	68
C		EDG	69
C	FIND ENTROPY SVAR FT2/SEC2DEGR	EDG	70
C	IF SHOCK RADIUS OUTSIDE TABLE USE FINAL ENTROPY FROM TABLE	EDG	71
C	IF SHOCK RADIUS INSIDE TABLE USE INTERPOLATED ENTROPY	EDG	72
C		EDG	73
7	IF (RSLVAR-TYLS(KLIM)) 9,9,8	EDG	74
8	SVAR=TSS(KLIM)	EDG	75
	GO TO 10	EDG	76
C		EDG	77
C	S FROM TABLE RS/L,S	EDG	78
C		EDG	79
9	CALL DISCOT (RSLVAR,PSLVAR,TYLS,TSS,TSS,011,KLIM,0,SVAR)	EDG	80
10	GX=1.4	EDG	81
C		EDG	82
C	DENSITY,SOUND SPEED,ENTHALPY,TEMPERATURE FROM REAL GAS	EDG	83
C	THERMODYNAMIC TABLES	EDG	84
C	FIND DENSITY ROVAR SLUG/FT3 REAL GAS THERMODYNAMIC	EDG	85

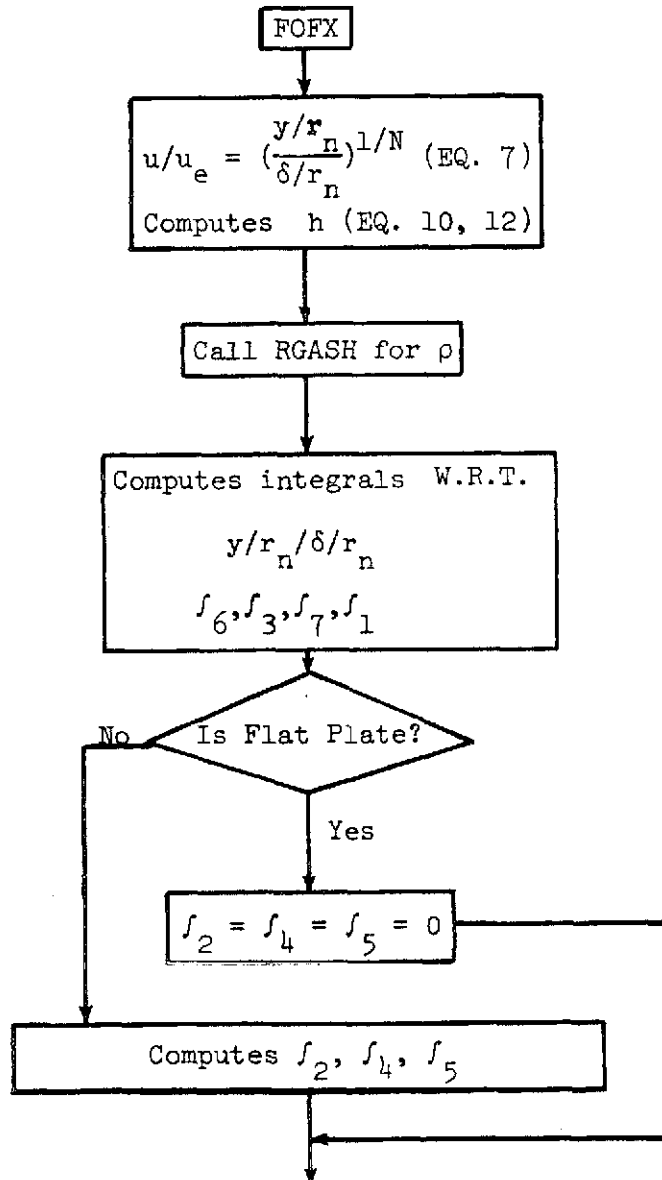
C		TABLES			EDG	86
C	FIND SOUND SPEED	AVAR	FT/SEC		EDG	87
C	FIND ENTHALPY	HVAR	FT2/SEC2		EDG	88
C	FIND TEMPERATURE	TIVAR	DEGR		EDG	89
C	H,A,T,RHO FROM RGAS USING P,S				EDG	90
C					EDG	91
	CALL RGAS (PIVAR,ROVAR,AVAR,HVAR,TIVAR,SVAR,RRX,GX,-1.5,(IGAS)				EDG	92
C					EDG	93
C	FIND PRESSURE ATM	PATM	ATM		EDG	94
C					EDG	95
	PATM=PIVAR*.4725E-3				EDG	96
C					EDG	97
C	FIND DENSITY	RRTVAR	LBM/FT3		EDG	98
C					EDG	99
	RRTVAR=ROVAR*32.174				EDG	100
C					EDG	101
C	FIND VELOCITY	WVAR	FT/SEC		EDG	102
C					EDG	103
	WVAR=SQRT(2.*(HT-HVAR))				EDG	104
C					EDG	105
C	FIND MACH NO	EMVAR			EDG	106
C					EDG	107
	EMVAR=WVAR/AVAR				EDG	108
	IF (IGAS-1) 11,11,12				EDG	109
11	EMU=6.887E-7*SQRT(TIVAR)/(1.+180./TIVAR)				EDG	110
	GO TO 13				EDG	111
12	CONTINUE				EDG	112
C					EDG	113
C	FIND VISCOSITY	EMU			EDG	114
C					EDG	115
	EMU=7.310615E-7*SQRT(TIVAR)/(1.+201.6/TIVAR)				EDG	116
13	CONTINUE				EDG	117
	RET=(RRTVAR*WVAR)/(EMU*12.)				EDG	118
C					EDG	119
C	FIND X INCH	XIN	INCH		EDG	120
C					EDG	121
	XIN=CUVAR(1)*EL				EDG	122
C					EDG	123
C	FIND WALL TEMP	TW	DEGR	INPUT TABLE OF WALL	EDG	124
C	TEMPERATURE				EDG	125
C	TW FROM TABLE XINCH,TWDEGR				EDG	126
C					EDG	127
	CALL DISCOT (XIN,XIN,XINT,TWT,TWT,011,NXINT,0,TW)				EDG	128

C				EDG 129
C				EDG 130
C	WALL DENSITY, SOUND SPEED, ENTHALPY, ENTROPY FROM REAL GAS			EDG 131
C	THERMODYNAMIC TABLES			EDG 132
C	START WITH ESTIMATE FOR WALL ENTROPY			EDG 133
C	FIND DENSITY WALL ROW SLUG/FT3 REAL GAS THERMODYNAMIC			EDG 134
C	TABLES			EDG 135
C	FIND ENTHALPY WALL HW FT2/SEC2			EDG 136
C	HW, AH, RHOH, SW FROM RGAS USING P, TW			EDG 137
C	CALL RGAST (PIVAR, ROW, AH, HW, TW, SW, ERR, (GAS))			EDG 138
C				EDG 139
C	FIND DENSITY WALL RHOH LBM/FT3			EDG 140
C				EDG 141
C	RHOH=ROW*32.174			EDG 142
C				EDG 143
C	COEFFICIENTS FOR FC EQUATION			EDG 144
C	FIND COEFF COE2 WHERE NR=.89 AND GAMMA=1.4			EDG 145
C	FIND COEFF COE1 TW/TE			EDG 146
C	FIND COEFF COE3 COEFF USED IN FC IN SPALDING CHI			EDG 147
C	THEORY			EDG 148
C				EDG 149
C	COE2=.178*EMVAR*EMVAR			EDG 150
C	COE1=TW/TIVAR			EDG 151
C	COE3=1.+COE2-COE1			EDG 152
C				EDG 153
C	FIND REYNOLDS NO RETH REYNOLDS NO BASED ON MOMENTUM			EDG 154
C	THICKNESS			EDG 155
C				EDG 156
C	RETH=RET*CUVAR(2)*EL			EDG 157
C				EDG 158
C	FIND ADR WALL TEMP TAW ADIABATIC WALL TEMP			EDG 159
C				EDG 160
C	TAW=(PR**.33333333)*(TT11-TIVAR)+TIVAR			EDG 161
C				EDG 162
C	FIND FRTHETA FRTH FRTHETA IN SPALDING CHI THEORY EQ 22			EDG 163
C				EDG 164
C	FRTH=COE1**(-1.474)*(TAW/TIVAR)**.772			EDG 165
C				EDG 166
C	FIND VALUE TEMP8 HT-HW			EDG 167
C				EDG 168
C	TEMP8=HT-HW			EDG 169
C				EDG 170
C	FIND VALUE TEMP7 USQ/2.			EDG 171

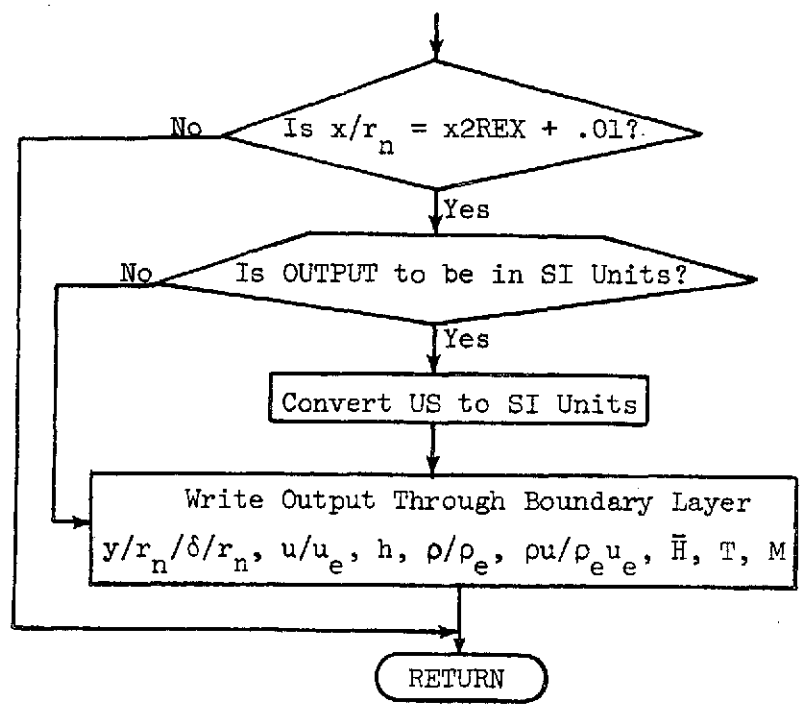
C		EDG 172
	TEMP7=WVAR*WVAR/2.	EDG 173
C		EDG 174
C	FIND ADBWALL ENTH HAW ADIABATIC WALL ENTHALPY	EDG 175
C		EDG 176
	HAW=HVAR+.89*(HT-HVAR)	EDG 177
C		EDG 178
C	ENTHALPY ECKERTS REFERENCE (EQ15)	EDG 179
C		EDG 180
	HP=.5*(HW+HVAR)+.22*(HAW-HVAR)	EDG 181
C		EDG 182
C	REFERENCE DENSITY, SOUND SPEED, TEMPERATURE, ENTROPY FROM REAL GAS	EDG 183
C	THERMODYNAMIC	EDG 184
C	TABLES, START WITH ESTIMATE FOR REFERENCE ENTROPY	EDG 185
C	TP, RHOP, AP, SP FROM RGAS USING P, HP	EDG 186
C	FIND REF TEMP TPP DEGR REAL GAS THERMODYNAMIC	EDG 187
C	TABLES	EDG 188
C		EDG 189
	CALL RGASH (PIVAR, ROP, AP, HP, TPP, SP, ERR, IGAS)	EDG 190
C		EDG 191
C	FIND REF TEMP TK DEGK	EDG 192
C		EDG 193
	TK=TPP/1.8	EDG 194
C		EDG 195
C	FIND REF PRANDTL PRP TABLE IV REF. 30	EDG 196
C	NPRP FROM HANSENS TABLES USING PATM, TPDEGK	EDG 197
C		EDG 198
	CALL DISCOT (TK, PATM, TKTAB, PRTAB, PATAB, 011, 210, 7, PRP)	EDG 199
C		EDG 200
C	FIND WALL TEMP TK DEGK	EDG 201
C		EDG 202
	TK=TW/1.8	EDG 203
C		EDG 204
C	FIND WALL PRANDTL PRW TABLE IV REF. 30	EDG 205
C	NPRW FROM HANSENS TABLES USING PATM, TWDEGK	EDG 206
C		EDG 207
	CALL DISCOT (TK, PATM, TKTAB, PRTAB, PATAB, 011, 210, 7, PRW)	EDG 208
C		EDG 209
C	VANDRIEST II	EDG 210
C	REYNOLDS ANALOGY FACTOR (TABLE I)	EDG 211
C		EDG 212
	HWT=HW/HT	EDG 213
	IF (HWT-.2) 14, 15, 15	EDG 214

14	RAF=1.			EDG 215
	GO TO 18			EDG 216
15	IF (HWT-.65) 16,16,17			EDG 217
16	RAF=.8311+.9675*HWT-.6142*HWT**2			EDG 218
	GO TO 18			EDG 219
17	RAF=1.2			EDG 220
C				EDG 221
C	FIND BI	F(1)	COEFF STATIC ENTH REG I BOUNDARY	EDG 222
C		LAYER		EDG 223
C	BI (EQ13)			EDG 224
C				EDG 225
18	CONTINUE			EDG 226
	F(1)=((HAW-HW)/TEMP8)*PRW/PRP**.		66666667	EDG 227
	IF (FPOPT) 20,19,20			EDG 228
C				EDG 229
C	FIND VALUE	TEMP9	COS(THETAC)/(RB/L)	EDG 230
C				EDG 231
19	TEMP9=CTHCR/RBVAR			EDG 232
C				EDG 233
C	FIND VALUE	TEMP10	COS(THETAC)/(2RB/L)	EDG 234
C				EDG 235
	TEMP10=.5*TEMP9			EDG 236
C				EDG 237
C	FIND VALUE	TEMP14	2COS(THETAC)/(RB/L)	EDG 238
C				EDG 239
	TEMP14=2.*TEMP9			EDG 240
C				EDG 241
C	FIND VALUE	TEMP12	2RB/L*RHO*U/RHO1*UI	EDG 242
C				EDG 243
	TEMP12=2.*RBVAR*RRTVAR*WVAR/RHOUI			EDG 244
20	RETURN			EDG 245
	END			EDG 246-

1
 2 FOFX.- Function subroutine FOFX computes integrals in the boundary layer
 3 equations for conservation of mass and momentum. This subroutine is
 4 called by VGAUSS for integration.



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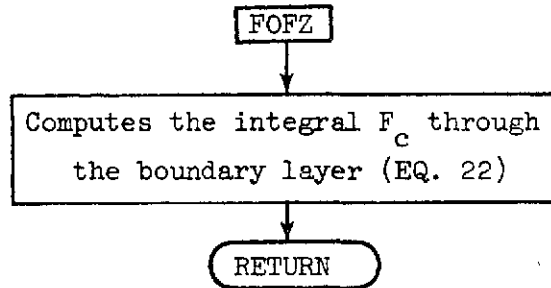


	FUNCTION FOFX (V,F2)	FOX	1
C		FOX	2
C	FUNCTION CALLED BY VGAUSS FOR INTEGRATION THROUGH BOUNDARY LAYER	FOX	3
C	AR,BR,ALPHAR HAVE BEEN INPUT OR CALCULATED	FOX	4
C	IN SUBROUTINES EDGE AND AL3CAL	FOX	5
C	N HAS BEEN INPUT OR CALCULATED IN SUBROUTINE DERSUB	FOX	6
C		FOX	7
	COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450),TXL(450),TYLS(450),TSS(450)	FOX	8
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI	FOX	9
	COMMON CMTOPT	FOX	10
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFER	FOX	11
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DN	FOX	12
	2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,E	FOX	13
	3NGN,ENI,FRR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FOPR,FRKE,FRTH,G,GC,GX,H,H	FOX	14
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,	FOX	15
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOUI,RHOW,RO,ROP	FOX	16
	6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVAR	FOX	17
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMP	FOX	18
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XI	FOX	19
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	FOX	20
	REAL IN,JN,KN	FOX	21
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJN	FOX	22
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),FNG(2),AN2(7)	FOX	23
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FKT8(20),FRLGT(20),	FOX	24
	IFCTR(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),XI(160),S	FOX	25
	2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXIB(20),DUDXT(160)	FOX	26
	3),DRDXT(160),DPOXT(160),DRDXT(160),VAR(2),DER(2),CJVAR(2),WSAV(160)	FOX	27
	40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(FOX	28
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)	FOX	29
	COMMON IGAS	FOX	30
	COMMON /BLK/ CV1,CV2,CV3,CV4,CV5,CV6,CV7,CV8,CV9,CV10,CV11,CV12,CV	FOX	31
	113,UNIN,UNIO	FOX	32
	COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),P	FOX	33
	1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12	FOX	34
	2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV	FOX	35
	DIMENSION F2(7)	FOX	36
		FOX	37
C	COMPUTE INTEGRALS WRT. Y/DELTA FOR BOUNDARY LAYER THICKNESS,	FOX	38
C	DISPLACEMENT	FOX	39
C	THICKNESS,SHOCK RADIUS EQUATIONS,GAUSSIAN QUADRATURE	FOX	40
C	F0(7)	FOX	41
C		FOX	42

C		FOX	43
	CON2=V**TEMP3	FOX	44
	IF (CON2-.01) 2,1,1	FOX	45
1	IF (CON2-.10) 3,4,4	FOX	46
C		FOX	47
C	R=I	FOX	48
C		FOX	49
2	K=1	FOX	50
	GO TO 5	FOX	51
C		FOX	52
C	R=II	FOX	53
C		FOX	54
3	K=2	FOX	55
	GO TO 5	FOX	56
C		FOX	57
C	R=III	FOX	58
C		FOX	59
4	K=3	FOX	60
C		FOX	61
C	FQ(10)	FOX	62
C		FOX	63
5	HHAT=A(K)+F(K)*CON2**ALPHE(K)	FOX	64
C		FOX	65
C	FQ(12)	FOX	66
C		FOX	67
	H=HW+TEMP8*HHAT-TEMP7*CON2*CON2	FOX	68
C		FOX	69
C	RHO FROM REAL GAS USING H AND P	FOX	70
C		FOX	71
	CALL RGASH (PIVAR,RX,AX,H,TX,SX,ERR,IGAS)	FOX	72
	RRI=RX/ROVAR	FOX	73
C		FOX	74
C	INTEGRAL 6,3,7,1	FOX	75
C		FOX	76
	F2(6)=RRI*CON2	FOX	77
	F2(3)=1.-F2(6)	FOX	78
	F2(7)=F2(6)*CON2	FOX	79
	F2(1)=F2(6)-F2(7)	FOX	80
C		FOX	81
C	IS FLAT PLATE	FOX	82
C		FOX	83
	IF (FPOPT) 6,7,6	FOX	84
C		FOX	85

C	INTEGRAL 2,4,5=0	FOX 86
C		FOX 87
6	F2(2)=F2(4)=F2(5)=0	FOX 88
	GO TO 8	FOX 89
C		FOX 90
C	INTEGRAL 2,4,5	FOX 91
C		FOX 92
7	TEMP2=V*TEMP9	FOX 93
	F2(2)=F2(6)*TEMP2	FOX 94
	F2(4)=F2(3)*TEMP2	FOX 95
	F2(5)=F2(1)*TEMP2	FOX 96
C		FOX 97
C	IS X/L=X2REX+.01	FOX 98
C		FOX 99
8	IF (ABS(ELT-CUVAR(1))-0.0001) 9,9,12	FOX 100
C		FOX 101
C	WRITE OUTPUT THROUGH BOUNDARY LAYER	FOX 102
C	Y/DEL,U/UE,H,RHO/RHOE,RHOU/RHOEUE,HHAT,T,M	FOX 103
C		FOX 104
9	EMX=CON2*WVAR/AX	FOX 105
	WRITE (6,14)	FOX 106
	IF (UNIO-1.) 10,10,11	FOX 107
10	O89=H*CV5	FOX 108
	O90=TX*CV8	FOX 109
	WRITE (6,13) V,CON2,O89,RR1,F2(6),HHAT,O90,FMX	FOX 110
	GO TO 12	FOX 111
11	WRITE (6,13) V,CON2,H,RR1,F2(6),HHAT,TX,EMX	FOX 112
12	RETURN	FOX 113
C		FOX 114
C		FOX 115
C		FOX 116
13	FORMAT (8E16.9)	FOX 117
14	FORMAT (1H 5X,3HY/D,13X,4HU/UE,13X,1HH,12X,8HRHD/RHOE,6X,11HRHOU/R	FOX 118
	HOEUE,9X,4HHBAR,13X,1HT,15X,1HM)	FOX 119
	END	FOX 120-

1 FOFZ.- Function subroutine FOFZ computes the ideal gas F_c function to
2 correlate the skin-friction data. This subroutine is called by VGAUSS
3 for integration.



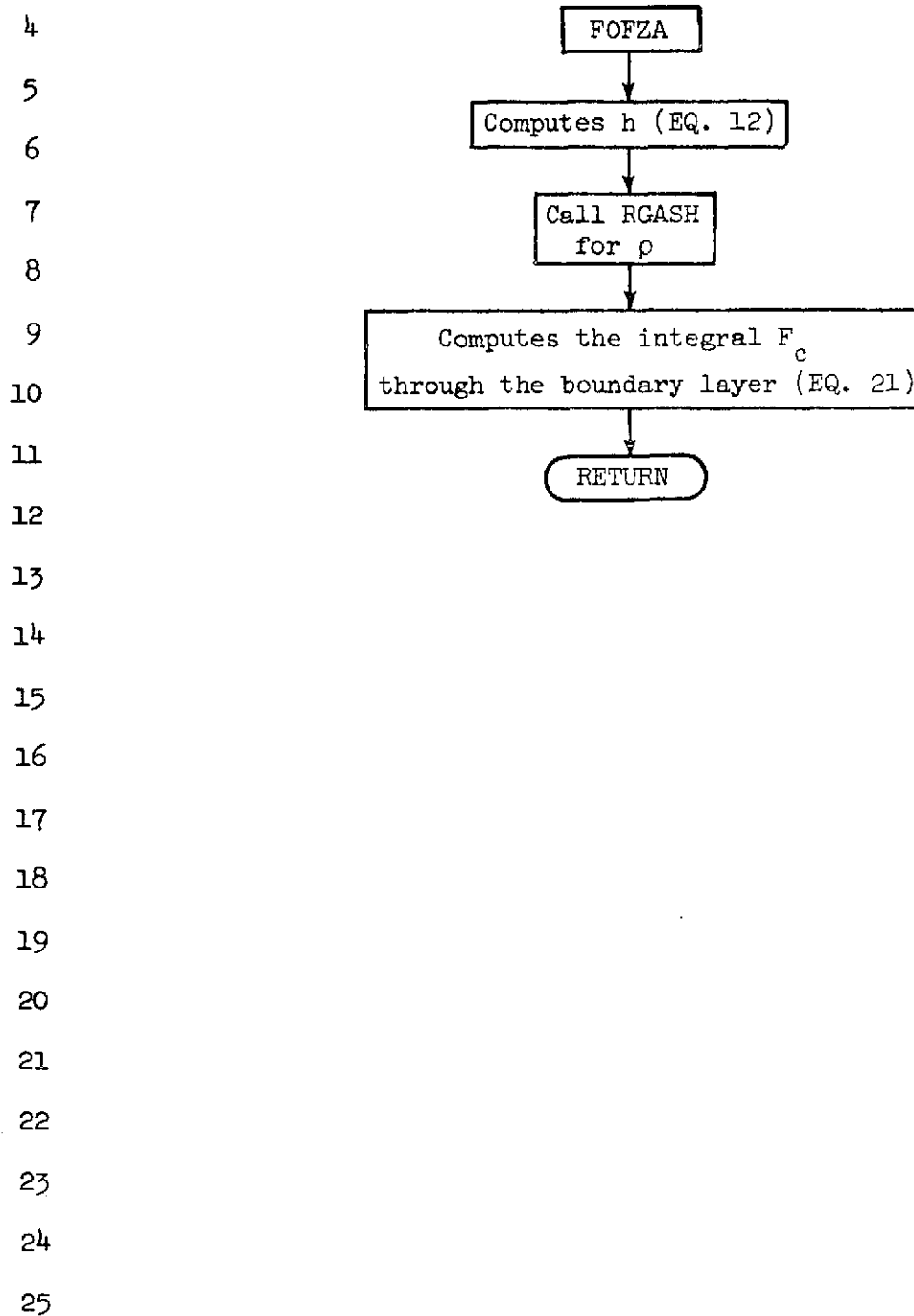
C
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FUNCTION FOFZ (V,FZ)                                F0Z  1
                                                    F0Z  2
FUNCTION CALLED BY VGAUSS FOR INTEGRATION THROUGH BOUNDARY LAYER F0Z  3
FOR SPALDING-CHI I SKIN FRICTION                   F0Z  4
FIND INTEGRAL WRT. U/UE FOR EQ(22)                  F0Z  5
                                                    F0Z  6
COMMON XLSH,XLSH1,THCR,JLIM,KLIM, TXLCL(450),TYL(450),TS(450),TP(450) F0Z  7
10),TXL(450),TYLS(450),TSS(450)                    F0Z  8
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVU,PSI F0Z  9
COMMON CMOPT                                         F0Z 10
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERFOZ 11
1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNFOZ 12
2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,F,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,EFOZ 13
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FOPR,FRRE,FRTH,G,GC,GX,H,HFOZ 14
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,FOZ 15
5NN,ND,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,KHDUI,KHOW,RO,ROFOZ 16
6,ROVAR,ROW,RR1,PRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARFOZ 17
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPFOZ 18
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TJ11,TW,TX,WVAR,XIFOZ 19
9N,XMIN,X2REX,Z,ZMAX,ZMIN                           F0Z 20
REAL IN,JN,KN                                        F0Z 21
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNFOZ 22
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7) F0Z 23
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),FOZ 24
1FCTR(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SFOZ 25
2(160),PI(160),XC(160),RB(160),W(160),PRT(160),XMAXTB(20),DUDXT(160FOZ 26
3),DRDXT(160),DPDXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16FOZ 27
40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(FOZ 28
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160) F0Z 29
COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PFOZ 30
1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12FOZ 31
2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV F0Z 32
RRN=1./((COE1+(COE3-COE2*V)*V) F0Z 33
FZ=SQR(TRRN) F0Z 34
RETURN F0Z 35
END F0Z 36-

```

1 FOFZA.- Function subroutine FOFZA computes the real gas F_c function to
2 correlate the skin-friction data. This subroutine is called by
3 VGAUSS for integration.



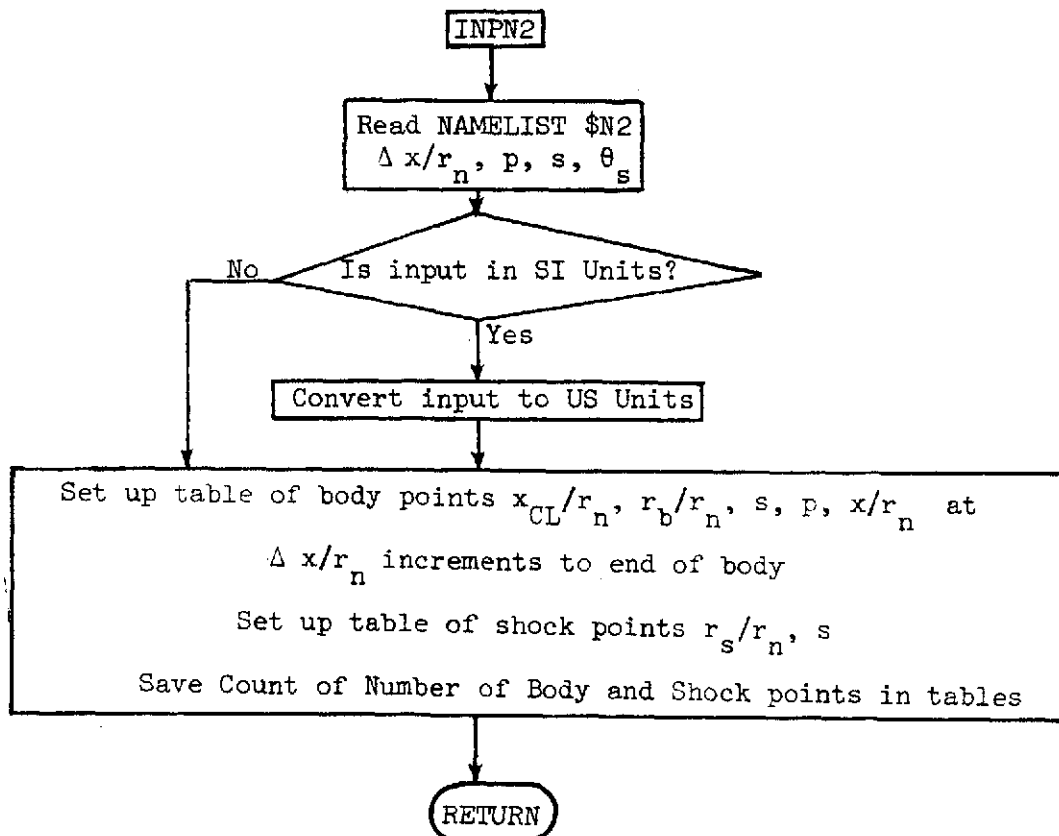
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FUNCTION FOFZA (V,FZ)                                FZA  1
C                                                    FZA  2
C FUNCTION CALLED BY VGAUSS FOR INTEGRATION THROUGH BOUNDARY LAYER FZA  3
C FOR SPALDING-CHI II SKIN FRICTION                FZA  4
C FIND INTEGRAL WRT.U/UE FOR EQ(21)                FZA  5
C                                                    FZA  6
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450) FZA  7
10),TXL(450),TYLS(450),TSS(450)                    FZA  8
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI FZA  9
COMMON CMOPT                                        FZA 10
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFER FZA 11
1R,CFI,CFMT,CF2,CF21,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNFZA 12
2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,EFZA 13
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRRF,FRTH,G,GC,GX,H,HFZA 14
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,FZA 15
5NN,NO,NXINT,PATM,P1VAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOUI,RHOW,RO,ROPFZA 16
6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RS1SAV,RSLVAR,RX,SHEAR,SP,SVARFZA 17
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPFZA 18
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,T1VAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIFZA 19
9N,XMIN,X2REX,Z,ZMAX,ZMIN                          FZA 20
REAL IN,JN,KN                                       FZA 21
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNFZA 22
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7) FZA 23
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),FZA 24
1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SFZA 25
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUOXT(160)FZA 26
3),DRDXT(160),DPDXT(160),DRRDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16)FZA 27
40),RRTS(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFS(16)FZA 28
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160) FZA 29
COMMON IGAS                                         FZA 30
COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PFZA 31
1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12)FZA 32
2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV FZA 33
CON2=V                                              FZA 34
C                                                    FZA 35
C 0.LE.U/UE.LT..01 R=I                             FZA 36
C .01.LE.U/UE.LE..1 R=II                          FZA 37
C U/UE.GT..1 R=III                                FZA 38
C                                                    FZA 39
C IF (CON2=.01) 2,1,1                              FZA 40
1 IF (CON2=.10) 3,4,4                              FZA 41
2 K=1                                              FZA 42

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3	GO TO 5	FZA	43
	K=2	FZA	44
	GO TO 5	FZA	45
4	K=3	FZA	46
C		FZA	47
C	EQ(10)	FZA	48
C		FZA	49
5	HHAT=A(K)+F(K)*CON2**ALPHE(K)	FZA	50
C		FZA	51
C	EQ(12)	FZA	52
C		FZA	53
	H=HW+TEMP8*HHAT-TEMP7*CON2*CON2	FZA	54
C		FZA	55
C	RHO FROM REAL GAS USING H AND P	FZA	56
C		FZA	57
	CALL RGASH (PIVAR,RX,AX,H,TX,SX,ERR,[GAS])	FZA	58
	RRI=RX/ROVAR	FZA	59
	FZ=SQRT(RRI)	FZA	60
	RETURN	FZA	61
	END	FZA	62

1 INPN2.- Subroutine INPN2 reads NAMELIST \$N2 if CARD = 1. is input. Given
2 cone angle, shock angle, constant pressure and entropy this subroutine
3 computes tables of x/r_n , r_b/r_n , s , p on body and r_s/r_n , s on shock.
4



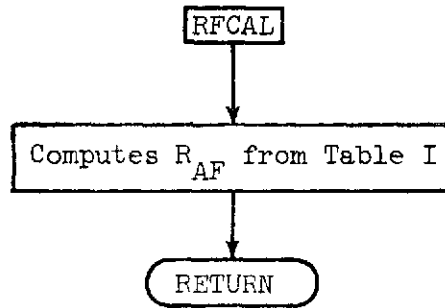
	SUBROUTINE INPN2	INP	1
		INP	2
C	IF INPUT NOT ON TAPE,PRESSURE AND ENTROPY CONSTANT,SHOCK ANGLE	INP	3
C	GIVEN	INP	4
C	SETS UP TABLES AT X CENTERLINE INCREMENT,COMPUTES X CENTERLINE,	INP	5
C	Y CONE, Y SHOCK	INP	6
C		INP	7
	COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(45	INP	8
	10),TXL(450),TYLS(450),TSS(450)	INP	9
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVU,PSI	INP	10
	COMMON CMTOPT	INP	11
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CER,CEBP,CEM,CEMP,CFBMT,CFB2,CFER	INP	12
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DN	INP	13
	2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,E	INP	14
	3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRKE,FRTH,G,GC,GX,H,H	INP	15
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW	INP	16
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHUI,KHOW,RO,ROP	INP	17
	6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVAR	INP	18
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMP	INP	19
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XI	INP	20
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	INP	21
	REAL IN,JN,KN	INP	22
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJN	INP	23
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)	INP	24
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),	INP	25
	1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),S	INP	26
	2(160),PI(160),XC(160),RB(160),W(160),RPT(160),XMAXTB(20),DUDXT(160	INP	27
	3),DRDXT(160),DPDXT(160),DRDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16	INP	28
	40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFS	INP	29
	5(160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)	INP	30
	COMMON /BLK/ CV1,CV2,CV3,CV4,CV5,CV6,CV7,CV8,CV9,CV10,CV11,CV12,CV	INP	31
	13,UNIN,UNIO	INP	32
	COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),P	INP	33
	1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12	INP	34
	2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV	INP	35
	NAMLIST /N2/ DELTX,TP,TS,THSD	INP	36
		INP	37
C	READ NAMLIST/N2/	INP	38
C	DX,P,S,THETAS(DEG)	INP	39
C		INP	40
	READ (5,N2)	INP	41
	IF (ENDFILE 5) 1.2	INP	42

1	CALL EXIT	INP	43
2	WRITE (6,N2)	INP	44
	IF (UNIN-1.) 3,3,4	INP	45
3	TP=TP/CV10	INP	46
	TS=TS/CV4	INP	47
	THSD=THSD/CV9	INP	48
4	TXLCL(1)=0	INP	49
	TSS(1)=TS(1)	INP	50
	THSR=THSD*.01745329	INP	51
	TYL(1)=0	INP	52
	TYLS(1)=0	INP	53
	TXL(1)=0	INP	54
C		INP	55
C	SET UP TABLE OF BODY PTS X/LCL,RB/L,S,P,X/L	INP	56
C	AT DX INCREMENTS TO END OF BODY	INP	57
C	SET UP TABLE OF SHOCK PTS RS/L,S	INP	58
C	SAVE COUNT OF NO. OF BODY AND SHOCK PTS IN TABLES	INP	59
C		INP	60
	DO 8 J=2,450	INP	61
	TXLCL(J)=TXLCL(J-1)+DELTX	INP	62
C		INP	63
C	BODY RADIUS	INP	64
C		INP	65
	TYL(J)=TAN(THCR)*TXLCL(J)	INP	66
C		INP	67
C	SHOCK RADIUS	INP	68
C		INP	69
	TYLS(J)=TAN(THSR)*TXLCL(J)	INP	70
	TP(J)=TP(J-1)	INP	71
	TS(J)=TS(J-1)	INP	72
	TSS(J)=TS(J)	INP	73
C		INP	74
C	X/L	INP	75
C		INP	76
	XL=TXLCL(J)-T2	INP	77
	IF (XL) 5,5,6	INP	78
5	TXL(J)=ACOS(1.-TXLCL(J))	INP	79
	GO TO 7	INP	80
6	TXL(J)=-T1+XL/CTHCR	INP	81
7	IF (TXLCL(J)-XMAXTB(20)) 8,8,9	INP	82
8	CONTINUE	INP	83
9	JLIM=J	INP	84
	KLIM=J	INP	85

RETURN
END

TNP 86
TNP 87-

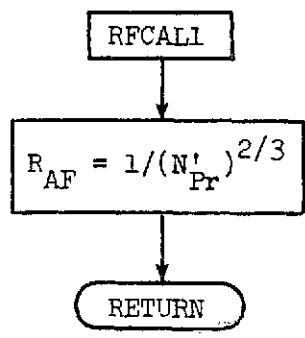
1 RFCAL.- Subroutine RFCAL computes Reynolds analogy factor for VanDriest
2 skin-friction theory.



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	SUBROUTINE RFCAL (RAFX)	RFC	1
C	COMPUTES REYNOLDS ANALOGY FACTOR FOR	RFC	2
C	VAN DRIEST SKIN FRICTION	RFC	3
	COMMON XLSH,XLSHI,THCR,JLIM,KLIM, TXLCL(450),TYL(450),TS(450),TP(450)	RFC	4
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVQ,PSI	RFC	5
	COMMON CMOPT	RFC	6
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERRFC	RFC	7
	1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNRFC	RFC	8
	2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,ERFC	RFC	9
	3NGN,ENI,ERR,FC,FCCFLG,FCF,FCFPR,FD,FOPR,FRRE,FRTH,G,GC,GX,H,HRFC	RFC	10
	4AW,MHAT,HP,HT,HVAR,HW,H2,ICELL,I,I,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,RFC	RFC	11
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOUI,RHOW,RO,ROPRFC	RFC	12
	6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARRFC	RFC	13
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPRFC	RFC	14
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIRFC	RFC	15
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	RFC	16
	REAL IN,JN,KN	RFC	17
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNRFC	RFC	18
	1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),ANZ(7)	RFC	19
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),RFC	RFC	20
	1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SRFC	RFC	21
	2(160),PI(160),XC(160),RB(160),WI(160),RRT(160),XMAXTB(20),DUDXT(160RFC	RFC	22
	3),ORDXT(160),DPDXT(160),DPBDXT(160),VAR(2),DER(2),CJVAR(2),WSAV(160RFC	RFC	23
	40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(RFC	RFC	24
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160),IGRFC	RFC	25
	GAS	RFC	26
	COMMON XXI	RFC	27
	COMMON ACFT(22),TREXT(22),ACFLGT(22),TRLGT(22),REXCF,HO,XO	RFC	28
	HWT=HW/HT	RFC	29
	IF (HWT-.2) 1,2,2	RFC	30
1	RAFX=1.	RFC	31
	GO TO 5	RFC	32
2	IF (HWT-.65) 3,3,4	RFC	33
3	RAFX=.8311+.9675*HWT-.6142*HWT**2	RFC	34
	GO TO 5	RFC	35
4	RAFX=1.2	RFC	36
5	RETURN	RFC	37
	END	RFC	38
		RFC	39-

1 RFCALL.- Subroutine RFCALL computes Reynolds analogy factor for Spalding-
2 Chi and Eckert's skin-friction theories.



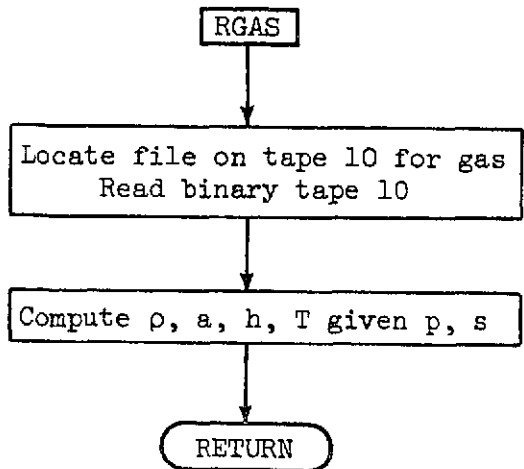
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	SUBROUTINE RFCAL1 (RAFX)	RF1	1
C	COMPUTES REYNOLDS ANALOGY FACTOR FOR	RF1	2
C	SPALDING CHI AND ECKERT SKIN FRICTION	RF1	3
	COMMON XLSH,XLSH1,THCR,JLIM,KLJM,TXLCL(450),TYL(450),TS(450),TP(450)	RF1	4
	10),TXL(450),TYLS(450),TSS(450)	RF1	5
	COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVQ,PSI	RF1	6
	COMMON CMTOPT	RF1	7
	COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBMT,CFB2,CFERRF1	RF1	8
	1R,CF1,CFMT,CF2,CF21,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNRF1	RF1	9
	2,DPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,ERF1	RF1	10
	3NGN,FNI,ERP,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FOPR,FRRE,FRTH,G,GC,GX,H,HRF1	RF1	11
	4AW,HHAT,HP,HT,HVAR,HW,H2,ICFL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,RF1	RF1	12
	5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,KHQUI,KHOW,RO,ROPRF1	RF1	13
	6,ROVAR,ROW,RR1,PPN,RRTVAR,PPX,PSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARRF1	RF1	14
	7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPRF1	RF1	15
	85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TI,VAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIRF1	RF1	16
	9N,XMIN,X2REX,Z,ZMAX,ZMIN	RF1	17
	REAL IN,JN,KN	RF1	18
	COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TARJNRF1	RF1	19
	1(6),DXLTAB(20),DFLK(2),RSLG(2),ALG(2),ENG(2),AN2(7)	RF1	20
	COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRITB(20),FRLGT(20),RF1	RF1	21
	1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SRF1	RF1	22
	2(160),PI(160),XC(160),RR(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)RF1	RF1	23
	3),DPDXT(160),DPDXT(160),DPBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(160)RF1	RF1	24
	40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(RF1	RF1	25
	5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160),IGRF1	RF1	26
	6AS	RF1	27
	COMMON XXI	RF1	28
	COMMON ACFT(22),TREXT(22),ACFLGT(22),TRLGT(22),KEXCF,HO,XO	RF1	29
	RAFX=1./PRP**0.66666667	RF1	30
	RETURN	RF1	31
	END	RF1	32-

1 RGAS.- Subroutine RGAS computes the thermodynamic properties for a real gas.
2 The flow properties p_e , ρ_e , T_e , S_e , h_e , and a_e for a real gas in ther-
3 modynamic equilibrium are calculated by the computer subroutine (RGAS)
4 described by Lomax and Inouye in reference 27. The subroutine RGAS requires
5 use of the Ames real gas TAPE10 containing information for nitrogen on file
6 1 (IGAS=1) and information for air on file 2 (IGAS=2). Subroutine ROLL and
7 SERCH are used by subroutine RGAS to locate the information on TAPE10.
8 During the calculation, thermodynamic data at a point are found by entering
9 the RGAS subroutine with pressure and entropy. For calculation of density
10 profiles through the boundary layer, subroutines RGASH and RGAST are used
11 to allow thermodynamic data to be found for a given enthalpy (or temperature)
12 and pressure. The procedure in this case is to enter the RGAS subroutine
13 with various estimated values of entropy and the local pressure until the
14 value of entropy is found that yields the desired value of enthalpy (or
15 temperature).

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	SUBROUTINE RGAS (PX,RX,AX,HX,TX,SX,RRX,GX,NTEST,NUMX,NGAS)	RGS	1
C		RGS	2
C	AMES PROGRAM FOR REAL GAS EQUILIBRIUM THERMODYNAMIC PROPERTIES	RGS	3
C	AMES TAPE MOUNTED ON UNIT 10	RGS	4
C	PX PRESSURE LBS/FT2	RGS	5
C	RX DENSITY SLUGS/FT3	RGS	6
C	AX SPEED OF SOUND FT/SEC	RGS	7
C	HX ENTHALPY FT2/SEC2	RGS	8
C	TX TEMPERATURE DEGR	RGS	9
C	SX ENTROPY FT2/SEC2 DEGR	RGS	10
C	RRX GAS CONSTANT FT2/SEC2 DEGR	RGS	11
C	GX RATIO OF SPECIFIC HEATS	RGS	12
C	NTEST =1 FOR REAL GAS,=0 FOR PERFECT GAS	RGS	13
C	NUMX =5 FOR PRESSURE AND ENTROPY INPUT	RGS	14
C	NGAS =2 FOR AIR ON FILE 2 OF AMES TAPE 10	RGS	15
C		RGS	16
C	AMES SUBROUTINE TO FIND RHO,A,H,T WHEN P AND S GIVEN	RGS	17
C	CALLS TAPE10 AMES REAL GAS TAPE (FILE2 IS AIR)	RGS	18
C	USES SUBROUTINES ROLL AND SERCH TO LOCATE ON TAPE DESIRED GAS DATA	RGS	19
C	RGASR WALKER TEMP CONVERTED TO RANKINE	RGS	20
	DIMENSION NLL(8), JXX(8), OZZ(8), TZ(3000), NDZ(89)	RGS	21
	DIMENSION TH(5,600), NDL(4,11), NDU(4,11), AN(4), C(7), ANR(17), BRGS	RGS	22
	IN(4)	RGS	23
	EQUIVALENCE (TZ,TH), (NDZ,NDL), (NDZ(45),NDU)	RGS	24
	DATA KEY,NTIMES/0,0/	RGS	25
	DATA WORD1,WORD2/6HNUM HI,6HNUM LO/	RGS	26
	DATA NTAPE/10/	RGS	27
	DATA GTEST/0/	RGS	28
	DATA GTESTR/0/	RGS	29
1	KEY=KEY+1	RGS	30
	P=PX	RGS	31
	S=SX	RGS	32
	R=RX	RGS	33
	NUM=NUMX	RGS	34
	IF (NUM) 6,6,2	RGS	35
2	IF (NUM=8) 7,7,3	RGS	36
3	WORD=WORD1	RGS	37
4	WRITE (6,108) WORD	RGS	38
5	CALL EXIT	RGS	39
6	WORD=WORD2	RGS	40
	GO TO 4	RGS	41
7	IF (NTEST) 8,89,89	RGS	42

8	IF (NFIRST-NGAS) 9,12,9	RGS 43
9	NFIRST=NGAS	RGS 44
	IND=0	RGS 45
	NFILES=NGAS-1	RGS 46
	CALL ROLL (NTAPE,NFILES,IND)	RGS 47
C		RGS 48
C	FOR TAPE WRITTEN BY FORTRAN 2	RGS 49
C		RGS 50
	READ (NTAPE) (NDZ(N),N=1,89)	RGS 51
	DO 10 N=1,89	RGS 52
10	NDZ(N)=NDZ(N)/(2**18)	RGS 53
	NMM=NDZ(89)/(2**18)	RGS 54
C		RGS 55
	READ (NTAPE) (TZ(N),N=1,NMM),WTMIX,(C(N),N=1,7)	RGS 56
	REWIND NTAPE	RGS 57
	CALL EVICT (6LTAPE10)	RGS 58
	DO 11 N=1,88	RGS 59
11	NDZ(N)=5*NDZ(N)	RGS 60
	CONC=WTMIX/28.966	RGS 61
	P0=2116.	RGS 62
	R0=.002498*CONC	RGS 63
	RRR=1716./CONC	RGS 64
	RRX=RRR	RGS 65
	RTO=RRR*493.635	RGS 66
	SQPORO=SQRT(R0/P0)	RGS 67
	B=TZ(NMM-2)	RGS 68
	F=TZ(NMM-1)	RGS 69
	D=TZ(NMM)	RGS 70
	FM=2.1632+.3468*CONC	RGS 71
	AA=D*FM	RGS 72
	BB=E*FM+1.	RGS 73
	CCC=B+FM	RGS 74
12	P=ALOG10(P/P0)	RGS 75
	GO TO (22,22,22,22,13,3,3,3), NUM	RGS 76
13	REAL=S/RRR	RGS 77
	GG=(REAL-C(1)-C(2)*P)/(C(3)+P*(C(4)+P*C(5)))	RGS 78
	R=C(6)*GG+C(7)*P	RGS 79
	RL=P-B	RGS 80
	CC=CCC-P	RGS 81
	RH=-CC*(1.+AA*CC/(BB*BB))/RR+.005	RGS 82
	IF (RH+7.) 14,15,15	RGS 83
14	RH=-7.	RGS 84
15	IF (R-RH) 16,17,17	RGS 85

16	R=RH	RGS 86
17	IF (3.-RL) 18,19,19	RGS 87
18	RL=3.	RGS 88
19	IF (RL-R) 20,21,21	RGS 89
20	R=RL	RGS 90
21	NUMB=0	RGS 91
	NIMX=0	RGS 92
	NUMM=5	RGS 93
	NBOT=9-NUM	RGS 94
	NUP=NBOT	RGS 95
	GO TO 23	RGS 96
22	R=ALOG10(R/RO)	RGS 97
	NUMM=5	RGS 98
	NBOT=1	RGS 99
	NUP=NUM	RGS 100
23	CONTINUE	RGS 101
	IF (R) 24,24,26	RGS 102
24	NR=R-1.	RGS 103
	IF (NR+7) 25,25,28	RGS 104
25	NR=-7	RGS 105
	GO TO 28	RGS 106
26	NR=R	RGS 107
	IF (NR-3) 28,27,27	RGS 108
27	NR=2	RGS 109
28	DX=R-FLOAT(NR)	RGS 110
	NR=NR+8	RGS 111
	F=(P-R-8)/(1.+R*(E+D*R))	RGS 112
	IF (NUMM-9+NUM) 31,29,31	RGS 113
29	IF (F-.000001) 105,30,30	RGS 114
30	IF (FM-F) 83,31,31	RGS 115
31	DO 42 NI=NBOT,NUP	RGS 116
	IF (NI-NUMM) 32,41,32	RGS 117
32	NER1=NI	RGS 118
	NER2=NI+4	RGS 119
	NL=NOL(NI,NR)	RGS 120
	IF (NLL(NER1)-NL) 35,33,35	RGS 121
33	J=JXX(NER1)	RGS 122
	DIFF2=F-TH(S,J)	RGS 123
	IF (DIFF2) 35,34,34	RGS 124
34	IF (DZZ(NER1)-ABS(DIFF2)) 35,35,36	RGS 125
35	NU=NOU(NI,NR)	RGS 126
	CALL SERCH (F,TH,NL,NU,S,J,NER)	RGS 127
	J=J/5	RGS 128

	DZZ(NER1)=ABS(TH(5,J+1)-TH(5,J))	RGS 129
	JXX(NER1)=J	RGS 130
	NLL(NER1)=NL	RGS 131
36	XYZ=XYZ	RGS 132
	NL=NDL(NL,NR+1)	RGS 133
	IF (NLL(NER2)-NL) 39,37,39	RGS 134
37	K=JXX(NER2)	RGS 135
	DIFF2=F-TH(5,K)	RGS 136
	IF (DIFF2) 39,38,38	RGS 137
38	IF (DZZ(NER2)-ABS(DIFF2)) 39,39,40	RGS 138
39	NU=NDU(NL,NR+1)	RGS 139
	CALL SERCH (F,TH,NL,NU,5,K,NER)	RGS 140
	K=K/5	RGS 141
	DZZ(NER2)=ABS(TH(5,K+1)-TH(5,K))	RGS 142
	JXX(NER2)=K	RGS 143
	NLL(NER2)=NL	RGS 144
40	Y1=TH(1,J)+F*(TH(2,J)+F*(TH(3,J)+F*TH(4,J)))	RGS 145
	Y2=TH(1,K)+F*(TH(2,K)+F*(TH(3,K)+F*TH(4,K)))	RGS 146
	AN(N1)=Y1+DX*(Y2-Y1)	RGS 147
	GO TO 42	RGS 148
41	AN(N1)=REAL	RGS 149
42	CONTINUE	RGS 150
	IF (NUM-5) 43,48,48	RGS 151
43	GO TO (47,46,45,44,44,44,44,44), NUM	RGS 152
44	SX=AN(4)*RRR	RGS 153
45	TX=AN(3)*1.8	RGS 154
46	HX=AN(2)*RTO	RGS 155
47	AX=AN(1)/SQPORO	PGS 156
	GO TO 104	RGS 157
48	IF (NUMM-9+NUM) 50,49,50	RGS 158
49	RX=RO*10.##R	RGS 159
	GO TO 43	RGS 160
50	DIFF=ABS((REAL-AN(NUP))/REAL)	RGS 161
	IF (DIFF-.0001) 51,51,52	RGS 162
51	NUMM=9-NUM	RGS 163
	NROT=1	RGS 164
	NUP=4	RGS 165
	GO TO 23	RGS 166
52	NUMB=NUMB+1	RGS 167
	NIMX=NIMX+1	RGS 168
	IF (NIMX-20) 53,53,83	RGS 169
53	IF (NUMB-2) 54,61,80	RGS 170
54	IF (REAL-AN(NUP)) 55,51,58	RGS 171

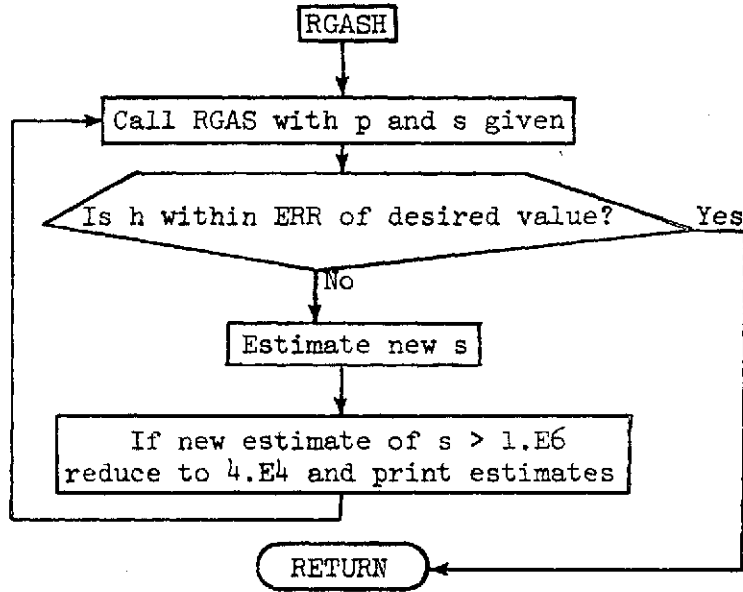
55	R1=R	RGS 172
	S1=AN(NUP)	RGS 173
	R=R+.3	RGS 174
	IF (RL-R) 56,57,57	RGS 175
56	R=RL	RGS 176
57	R2=R	RGS 177
	L=0	RGS 178
	GO TO 23	RGS 179
58	R2=R	RGS 180
	S2=AN(NUP)	RGS 181
	R=R-.3	RGS 182
	IF (R-RH) 59,60,60	RGS 183
59	R=RH	RGS 184
60	R1=R	RGS 185
	L=1	RGS 186
	GO TO 23	RGS 187
61	IF (L) 67,62,67	RGS 188
62	S2=AN(NUP)	RGS 189
	IF (S2-S1) 64,63,64	RGS 190
63	R=R2	RGS 191
	GO TO 65	RGS 192
64	$R=R2-(S2-REAL)/(S2-S1)*(R2-R1)$	RGS 193
65	IF (RL-R) 66,72,72	RGS 194
66	R=RL	RGS 195
	GO TO 72	RGS 196
67	S1=AN(NUP)	RGS 197
	IF (S2-S1) 69,68,69	RGS 198
68	R=R1	RGS 199
	GO TO 70	RGS 200
69	$R=(REAL-S1)/(S2-S1)*(R2-R1)+R1$	RGS 201
70	IF (R-RH) 71,72,72	RGS 202
71	R=RH	RGS 203
72	IF (R2-R) 73,51,76	RGS 204
73	NUMB=1	RGS 205
	R1=R2	RGS 206
	S1=S2	RGS 207
	L=0	RGS 208
	IF (R2+.3-RL) 75,74,74	RGS 209
74	R2=RL	RGS 210
	R=R2	RGS 211
	GO TO 23	RGS 212
75	R2=R2+.3	RGS 213
	R=R2	RGS 214

	GO TO 23	RGS 215
76	IF (R-R1) 77,51,23	RGS 216
77	NUMR=1	RGS 217
	R2=R1	RGS 218
	S2=S1	RGS 219
	L=1	RGS 220
	IF (RH-R1+.3) 79,78,78	RGS 221
78	R1=RH	RGS 222
	R=R1	RGS 223
	GO TO 23	RGS 224
79	R1=R1-.3	RGS 225
	R=R1	RGS 226
	GO TO 23	RGS 227
80	IF (REAL-AN(NUP)) 81,81,82	RGS 228
81	R1=R	RGS 229
	GO TO 67	RGS 230
82	R2=R	RGS 231
	GO TO 62	RGS 232
83	IF (F-.000001) 105,94,84	RGS 233
84	NTIMES=NTIMES+1	RGS 234
	WRITE (6,109)	RGS 235
	WRITE (6,110) PX	RGS 236
	IF (NUM-5) 85,86,86	RGS 237
85	WRITE (6,111) RX	RGS 238
	GO TO 87	RGS 239
86	WRITE (6,112) SX	RGS 240
87	IF (NTIMES-999) 104,88,88	RGS 241
88	WRITE (6,113)	RGS 242
	GO TO 5	RGS 243
89	L=0	RGS 244
	IF (GTEST-GX) 90,92,90	RGS 245
90	GTEST=GX	RGS 246
	L1=2	RGS 247
	ANR(1)=RRX	RGS 248
	ANR(2)=GX	RGS 249
	ANR(3)=ANR(1)/(ANR(2)-1.)	RGS 250
	ANR(4)=ANR(1)+ANR(3)	RGS 251
	ANR(8)=49008.609-ANR(3)*ALOG(171.6/.0001**ANR(2))	RGS 252
91	ANR(L+5)=1./ANR(L+2)	RGS 253
	ANR(L+6)=ANR(L+4)/ANR(L+1)	RGS 254
	ANR(L+7)=ANR(L+6)/ANR(L+2)	RGS 255
92	GO TO (93,93,93,93,98,99,100,102), NUM	RGS 256
93	QUOD=P/R**ANR(L+2)	RGS 257

	QUOT=P/R	RGS 258
	GO TO (97,96,95,94,98,99,100,102), NUM	RGS 259
94	S=ANR(L+8)+ANR(L+3)*ALOG(QUOD)	RGS 260
95	T=QUOT/ANR(L+1)	RGS 261
96	H=QUOT*ANR(L+6)	RGS 262
97	LL=L+1	RGS 263
	A=SQRT(ANR(LL)*QUOT)	RGS 264
	GO TO 103	RGS 265
98	EX=S-ANR(L+8)	RGS 266
	EX=EXP(EX/ANR(L+3))	RGS 267
	R=(P/EX)**ANR(L+5)	RGS 268
	QUOD=P/R**ANR(L+2)	RGS 269
	QUOT=P/R	RGS 270
	GO TO 95	RGS 271
99	R=P/(T*ANR(L+1))	RGS 272
	QUOD=P/R**ANR(L+2)	RGS 273
	QUOT=P/R	RGS 274
	S=ANR(L+8)+ANR(L+3)*ALOG(QUOD)	RGS 275
	GO TO 96	RGS 276
100	ASSIGN 97 TO NJUMP	RGS 277
101	T=H/ANR(L+4)	RGS 278
	P=P/(T*ANR(L+1))	RGS 279
	QUOD=P/R**ANR(L+2)	RGS 280
	QUOT=P/R	RGS 281
	S=ANR(L+8)+ANR(L+3)*ALOG(QUOD)	RGS 282
	GO TO NJUMP, (97,103)	RGS 283
102	ASSIGN 103 TO NJUMP	RGS 284
	H=ANR(L+7)*A**2	RGS 285
	GO TO 101	RGS 286
103	AX=A	RGS 287
	HX=H	RGS 288
	TX=T	RGS 289
	SX=S	RGS 290
	RX=R	RGS 291
104	RETURN	RGS 292
105	L=8	RGS 293
	P=PX	RGS 294
	R=RX	RGS 295
	IF (GTESTR-GX) 106,92,106	RGS 296
106	GTESTR=GX	RGS 297
	L1=9	RGS 298
	Z2=RO/10.**7	RGS 299
	PR=-7.+B	RGS 300

	PR=PO*10.**PR	RGS 301
	Z1=PP	RGS 302
	DO 107 N1=1,4	RGS 303
	NL=NDL(N1,1)	RGS 304
	NU=NDU(N1,1)	RGS 305
	F=0.	RGS 306
	CALL SERCH (F,TH,NL,NU,5,J,NER)	RGS 307
	J=J/5	RGS 308
107	RN(N1)=TH(1,J)	RGS 309
	RN(1)=RN(1)/SQPOPO	RGS 310
	RN(2)=RN(2)*RTO	RGS 311
	RN(3)=RN(3)*1.8	RGS 312
	RN(4)=RN(4)*RRR	RGS 313
	ANR(9)=PR/(Z2*RN(3))	RGS 314
	RRX=ANR(9)	RGS 315
	ANR(12)=RN(2)/RN(3)	RGS 316
	ANR(10)=1.+ANR(9)/(ANR(12)-ANR(9))	RGS 317
	ANR(11)=ANR(12)/ANR(10)	RGS 318
	ANR(17)=RN(1)*RN(1)*Z2/Z1	RGS 319
	ANR(16)=RN(4)-ANR(11)*ALOG(Z1/Z2**ANR(10))	RGS 320
	GO TO 91	RGS 321
C		RGS 322
C		RGS 323
C		RGS 324
108	FORMAT (12H0 ER IN RGAS,3X,A6)	RGS 325
109	FORMAT (1H0,10X,36HOUTSIDE TABLES IN RGAS ENTERING #ITH)	RGS 326
110	FORMAT (11X,2HP=,E13.6)	RGS 327
111	FORMAT (11X,2HR=F14.6)	RGS 328
112	FORMAT (11X,2HS=,E13.6)	RGS 329
113	FORMAT (20X,2BEXIT CALLED ON TENTH FAILURE)	RGS 330
	END	RGS 331-

1 RGASH.- Subroutine RGASH computes thermodynamic properties density, speed
2 of sound, temperature and entropy given pressure, enthalpy and
3 an estimate of entropy.



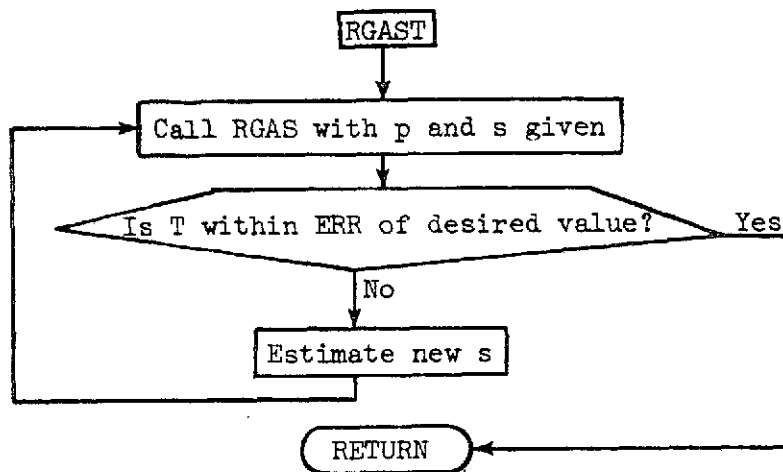
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	SUBROUTINE RGASH (PX,RX,AX,HX, TX, SX, ERR, IGAS)	RGH 1
C		RGH 2
C	GIVEN PRESSURE, ENTHALPY, ESTIMATE ENTROPY	RGH 3
C	VARY S UNTIL H WITHIN ERR OF DESIRED VALUE	RGH 4
C	FIND DENSITY, SPEED OF SOUND, TEMPERATURE, ENTROPY	RGH 5
C	REAL GAS EQUILIBRIUM THERMODYNAMIC PROPERTIES	RGH 6
C		RGH 7
	DIMENSION SG(2), HG(2)	RGH 8
1	HW=HX	RGH 9
	SG(1)=SX	RGH 10
	JJ=1	RGH 11
2	GX=1.4	RGH 12
C		RGH 13
C	RGAS GIVES RHO, A, T, S	RGH 14
C		RGH 15
	CALL RGAS (PX,RX, AX, HG(JJ), TX, SG(JJ), RRX, GX, -1.5, IGAS)	RGH 16
	IF (ABS(HG(JJ)-HW)-ERR*HW) 10,3,3	RGH 17
3	IF (JJ-1) 4,4,5	RGH 18
4	JJ=2	RGH 19
	SG(2)=SG(1)*1.01	RGH 20
	GO TO 2	RGH 21
5	IF (HG(2)-HG(1)) 7,6,7	RGH 22
6	WRITE (6,11) SG(1),SG(2),HG(1),HG(2),SGN,HW	RGH 23
	GO TO 10	RGH 24
7	SGN=((SG(2)-SG(1))/(HG(2)-HG(1)))*(HW-HG(1))+SG(1)	RGH 25
C		RGH 26
C	IF AN S.GT.1.E6 IS ESTIMATED, S WILL BE REDUCED TO 4.E6 AND	RGH 27
C	OUTPUT OF S AND H VALUES GIVEN AND ITERATION CONTINUES	RGH 28
C		RGH 29
	IF (SGN-1.E6) 9,8,9	RGH 30
8	SGN=4.E4	RGH 31
	WRITE (6,11) SG(1),SG(2),HG(1),HG(2),SGN,HW	RGH 32
9	HG(1)=HG(2)	RGH 33
	SG(1)=SG(2)	RGH 34
	SG(2)=SGN	RGH 35
	GO TO 2	RGH 36
10	SX=SG(JJ)	RGH 37
	RETURN	RGH 38
C		RGH 39
C		RGH 40
C		RGH 41
11	FORMAT (6E16.8)	RGH 42

END

RGH 43-

1 RGAST.- Subroutine RGAST computes thermodynamic properties density, speed
2 of sound, enthalpy and entropy, given pressure, temperature and an
3 estimate of entropy.



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	SUBROUTINE RGAST (PX,RX,AX,HX,TX,SX,ERR,IGAS)	RGT 1
C		RGT 2
C	GIVEN PRESSURE,TEMPERATURE,ESTIMATE ENTROPY	RGT 3
C	VARY S UNTIL T WITHIN ERR OF DESIRED VALUE	RGT 4
C	FIND DENSITY,SPEED OF SOUND,ENTHALPY,ENTROPY	RGT 5
C	REAL GAS EQUILIBRIUM THERMODYNAMIC PROPERTIES	RGT 6
C		RGT 7
	DIMENSION SG(2), TG(2)	RGT 8
	TW=TX	RGT 9
	SG(1)=SX	RGT 10
	JJ=1	RGT 11
1	GX=1.4	RGT 12
C		RGT 13
C	RGAS GIVES RHO,A,H,S	RGT 14
	CALL RGAS (PX,RX,AX,HX,TG(JJ),SG(JJ),RRX,GX,-1.5,IGAS)	RGT 15
	IF (ABS(TG(JJ)-TW)-ERR*TW) 5,2,2	RGT 16
2	IF (JJ-1) 3,3,4	RGT 17
3	JJ=2	RGT 18
	SG(2)=SG(1)*1.01	RGT 19
	GO TO 1	RGT 20
4	SGN=((SG(2)-SG(1))/(TG(2)-TG(1)))*(TW-TG(1))+SG(1)	RGT 21
	TG(1)=TG(2)	RGT 22
	SG(1)=SG(2)	RGT 23
	SG(2)=SGN	RGT 24
	GO TO 1	RGT 25
5	SX=SG(JJ)	RGT 26
	RETURN	RGT 27
C		RGT 28
	END	RGT 29-

1 ROLL.- Subroutine called by RGAS to position TAPE10 to proper file for
2 gas properties.

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	SUBROUTINE ROLL (N,NFILES,IND)	ROL	1
C		ROL	2
C	POSITIONS AMES TAPE 10 TO PROPER FILE FOR AIR	ROL	3
C		ROL	4
	REWIND N	ROL	5
	NEOF=0	ROL	6
1	IF (NEOF-NFILES) 2,4,4	ROL	7
2	READ (N) A	ROL	8
	IF (ENDFILE N) 3,2	ROL	9
3	NEOF=NEOF+1	ROL	10
	GO TO 1	ROL	11
4	RETURN	ROL	12
	END	ROL	13-

1 SERCH.- Subroutine called by RGAS to locate information for gas properties.

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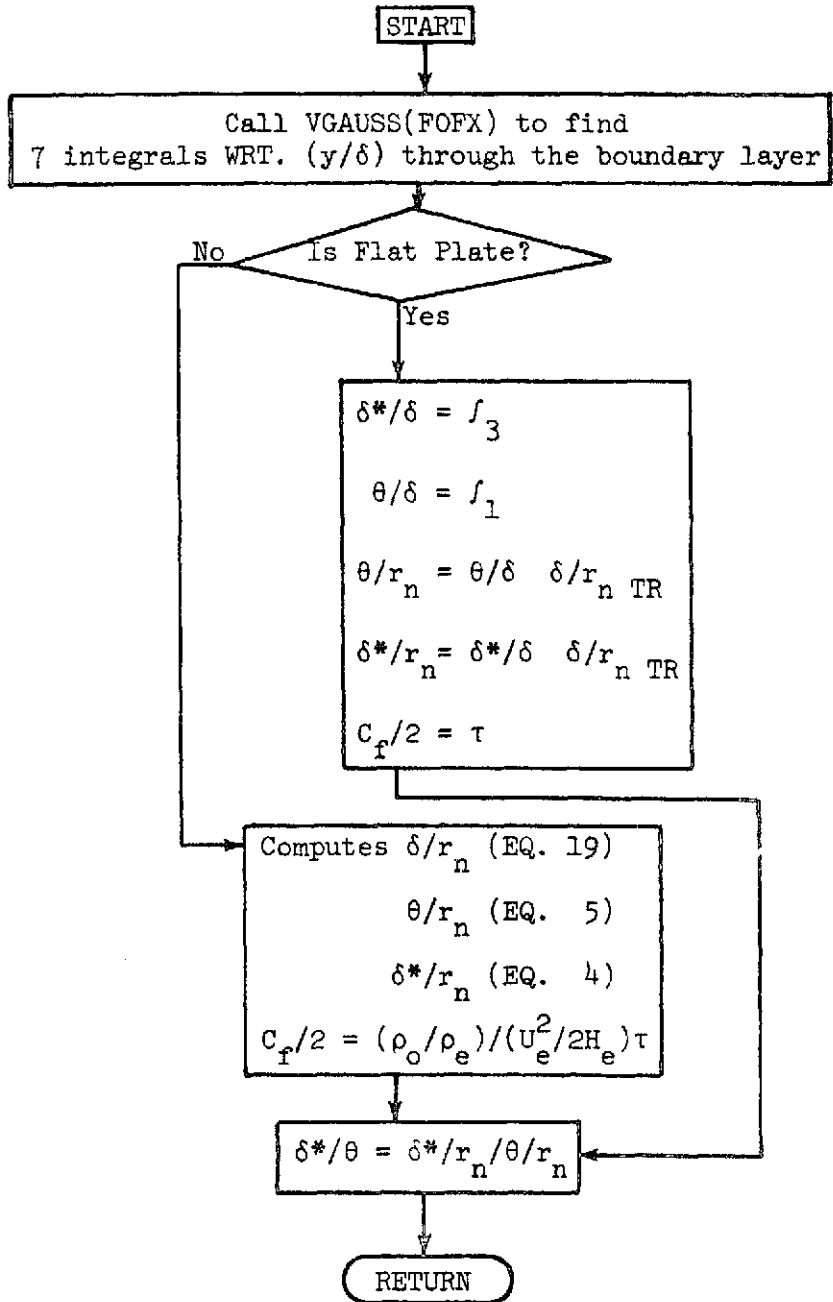
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	SUBROUTINE SERCH (X,Q,NL,NU,NS,NOUT,NERR)	SRH	1
C		SRH	2
C	AMES PROGRAM USED BY PGAS	SRH	3
C		SRH	4
	DIMENSION Q(1,1)	SRH	5
	NERR=0	SRH	6
	K=NL+NS	SRH	7
	IF (Q(NL,1)-Q(K,1)) 1,1,4	SRH	8
1	DO 2 J=NL,NU,NS	SRH	9
	IF (X-Q(J,1)) 3,2,2	SRH	10
2	CONTINUE	SRH	11
3	NOUT=J-NS	SRH	12
	RETURN	SRH	13
4	DO 5 J=NL,NU,NS	SRH	14
	IF (X-Q(J,1)) 5,6,6	SRH	15
5	CONTINUE	SRH	16
6	NOUT=J	SRH	17
	RETURN	SRH	18
	END	SRH	19

1 START.- Subroutine START computes initial values of boundary layer thick-
 2 ness, displacement thickness, momentum thickness, skin-friction
 3 coefficient.

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SUBROUTINE START STR 1
C STR 2
C COMPUTE MOMENTUM THICKNESS,BOUNDARY LAYER THICKNESS,DISPLACEMENT STR 3
C THICKNESS STR 4
C AT START OF TRANSITION GIVEN SHOCK RADIUS STR 5
C STR 6
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)STR 7
10),TXL(450),TYLS(450),TSS(450) STR 8
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVU,PSI STR 9
COMMON CMTOPT STR 10
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CEBP,CEM,CEMP,CFBNT,CFR2,CFER STR 11
1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNSTR 12
2,OPVAR,DRBVAR,DRVAR,OSTH,OUVAR,E,EK,EL,ELT,ELVD,ENU,EMVAR,EMX,EN,ESTR 13
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRRE,FRTH,G,GC,GX,H,HSTR 14
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,I,I,IN,J,J,JLIM,JN,K,K,K,KN,LLIM,NKW,STR 15
5NN,ND,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHQUI,RHOW,RO,ROPSTR 16
6,POVAR,ROW,RTI,RRN,RTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVARSTR 17
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPSTR 18
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TI11,TW,TX,WVAR,XISTR 19
9N,XMIN,X2REX,Z,ZMAX,ZMIN STR 20
REAL IN,JN,KN STR 21
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),7TABL(6),TABIN(6),TABJNSTR 22
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7) STR 23
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRIB(20),FRLGT(20),STR 24
1FCTB(20),FCLGT(20),XW(100),FIN(100),RSLW(100),SHEER(100),XI(160),SSTR 25
2(160),PI(160),XC(160),RR(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)STR 26
3),DRDXT(160),DPOXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(160)STR 27
40),RRTS(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFS(160)STR 28
5(160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160) STR 29
COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PSTR 30
1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12)STR 31
2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV STR 32
EXTERNAL FOFX STR 33
DIMENSION F2(7) STR 34
C STR 35
C N(TRAN) IS INPUT STR 36
C STR 37
EN=FNI STR 38
TEMP3=1./EN STR 39
SX=SVAR STR 40
C STR 41
C CALL VGAUSS,FOFX TO FIND 7 INTEGRALS WRT.(Y/DEL) THROUGH BOUNDARY STR 42

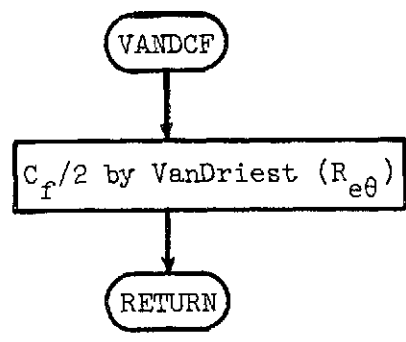
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C	CALL VGAUSS (0,1.,L,AN2,F0FX,F2,7,NN)	STR 43
C		STR 44
C	IS FLAT PLATE	STR 45
C		STR 46
C	IF (FPOPT) 1,5,1	STR 47
C		STR 48
C	DEL/L(TRAN),SHEAR ARE INPUT	STR 49
C	DELST/DEL	STR 50
C		STR 51
C	DSOD=AN2(3)	STR 52
L		STR 53
C	THETA/DEL	STR 54
C		STR 55
C	THOD=AN2(1)	STR 56
	IF (ICELL) 3,2,3	STR 57
2	DELI=DEL	STR 58
	GO TO 4	STR 59
3	DEL=DELI	STR 60
4	CONTINUE	STR 61
C		STR 62
C	THETA/L	STR 63
C		STR 64
C	CUVAR(2)=THOD*DEL	STR 65
C		STR 66
C	DELST/L	STR 67
C		STR 68
C	DELS=DEL*DSOD	STR 69
C		STR 70
C	CF/2	STR 71
C		STR 72
C	CF2=SHEAR	STR 73
	GO TO 6	STR 74
C		STR 75
C	RS/L FROM SUBROUTINE EDGE,SHEAR(LAMINAR) IS INPUT	STR 76
C		STR 77
C	DEL/L (EQL9)	STR 78
C		STR 79
C		STR 80
5	ADEL=TEMP12*AN2(2)	STR 81
	BDEL=TEMP12*AN2(6)	STR 82
	CDEL=-RSLVAR*RSLVAR	STR 83
	DELP=(-BDEL+SORT(BDEL*BDEL-4.*ADEL*CDEL))/(ADEL+ADEL)	STR 84
	DELM=(-BDEL-SORT(BDEL*BDEL-4.*ADEL*CDEL))/(ADEL+ADEL)	STR 85

	DEL=DELP	STR 86
C		STR 87
C	THETA/L (EQ5)	STR 88
C		STR 89
	GA=-DEL*DEL*AN2(5)-DEL*AN2(1)	STR 90
	CUV2P=(-1.+SQRT(1.-TEMP14*GA))/TEMP9	STR 91
	CUV2M=(-1.-SQRT(1.-TEMP14*GA))/TEMP9	STR 92
	CUVAR(2)=CUV2P	STR 93
C		STR 94
C	DELST/L (EQ4)	STR 95
C		STR 96
	G=-DEL*AN2(3)-DEL*DEL*AN2(4)	STR 97
	DELS=(-1.+SQRT(1.-TEMP14*G))/TEMP9	STR 98
C		STR 99
C	CF/2	STR 100
C		STR 101
	CF2=((RO/RRTVAR)/(TEMP7/HT))*SHEAR	STR 102
C		STR 103
C	DELST/THETA	STR 104
C		STR 105
6	DSTH=DELS/CUVAR(2)	STR 106
	CF2I=CF2	STR 107
	RETURN	STR 108
C		STR 109
C		STR 110
	END	STR 111-

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VANDCF.- Subroutine VANDCF computes the VanDriest II skin-friction coefficient using Reynolds number based on momentum thickness.



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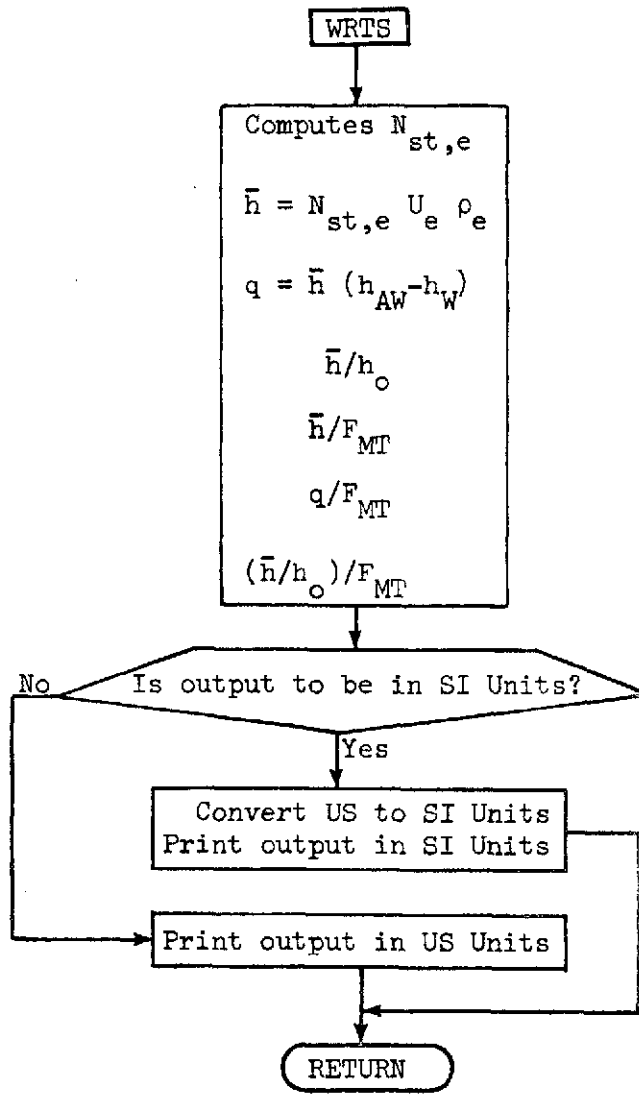
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SUBROUTINE VANDCF                                VAN  1
                                                VAN  2
COMPUTES HEATING RATES AND SKIN FRICTION BY    VAN  3
  VAN DRIEST II (RETHETA) METHOD                 VAN  4
                                                VAN  5
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450)
10),TXL(450),TYLS(450),TSS(450)                VAN  7
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XV0,PSI    VAN  8
COMMON CMTOPT                                    VAN  9
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CERP,CEM,CEMP,CFBMT,CFB2,CFERVAN 10
1R,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,DNVAN 11
2,OPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,FLVO,EMU,EMVAR,EMX,EN,EVAN 12
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRRE,FRTH,G,GC,GX,H,HVAN 13
4AW,HHAT,HP,HT,HVAR,HW,H2,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,VAN 14
5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,RHOUI,RHOW,RO,ROPVAN 15
6,ROVAR,ROW,RR1,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RSX,SHEAR,SP,SVARVAN 16
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPVAN 17
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,WVAR,XIVAN 18
9N,XMIN,X2REX,Z,ZMAX,ZMIN                      VAN 19
REAL IN,JN,KN                                  VAN 20
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNVAN 21
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)    VAN 22
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),VAN 23
1FCTR(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEEK(100),X(160),SVAN 24
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160VAN 25
3),DRDXT(160),DPOXT(160),DRBOXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16VAN 26
40),RPTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(VAN 27
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),WKW(160),RSLKW(160)    VAN 28
COMMON /BLOCK/ PLT1(160),PLT2(160),PLT3(160),PLT4(160),PLT5(160),PVAN 29
1LT6(160),PLT7(160),PLT8(160),PLT9(160),PLT10(160),PLT11(160),PLT12VAN 30
2(160),PLT13(160),PLT14(160),PLT15(160),NKWSAV    VAN 31
TERM=.176*EMVAR*EMVAR                          VAN 32
EMEW=SQRT(TIVAR/TW)*(1.+220.*10.**(-9./TW)/TW)/(1.+220.*10.**(-9./VAN 33
1TIVAR)/TIVAR)                                VAN 34
RBAR=RETH*EMEW                                 VAN 35
RRRLG=ALOG10(RBAR)                             VAN 36
CFI2=.5/1117.08#RRLG+25.11)*RRLG+6.012)      VAN 37
AVDSQ=TERM/COE1                                VAN 38
BVD=(1.+TERM-COE1)/COE1                       VAN 39
BVDSQ=BVD*BVD                                  VAN 40
ALVD=(AVDSQ+AVDSQ-BVD)/SQRT(4.*AVDSQ+BVDSQ)  VAN 41
BEVD=BVD/SQRT(4.*AVDSQ+BVDSQ)                VAN 42

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C		VAN	43
C	EQ(20)	VAN	44
C		VAN	45
	CF2FP=CFI2*((ASIN(ALVD)+ASIN(BEVD))**2)/TERM	VAN	46
C		VAN	47
C	EQ(23)	VAN	48
C		VAN	49
1	CF2=CF2FP*CFMT	VAN	50
	RETURN	VAN	51
C		VAN	52
	END	VAN	53-

1 WRTS.- Subroutine WRTS computes heat transfer coefficient and heating
2 rates based on each skin-friction theory and prints output.



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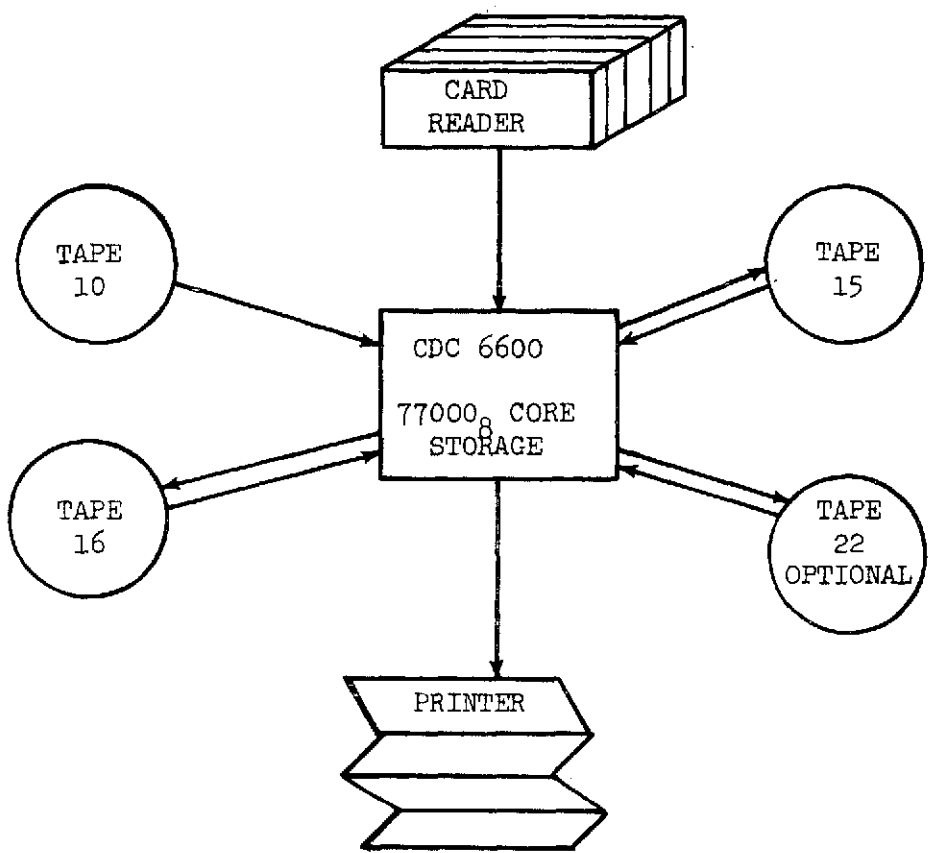
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SUBROUTINE WRTS (CFX,RAFX,CFMTX)                                WRT  1
                                                                WRT  2
      COMPUTES HEAT TRANSFER COEFFICIENT AND HEATING           WRT  3
      RATES BASED ON EACH SKIN FRICTION THEORY                  WRT  4
                                                                WRT  5
COMMON XLSH,XLSH1,THCR,JLIM,KLIM,TXLCL(450),TYL(450),TS(450),TP(450) WRT  6
10),TXL(450),TYLS(450),TSS(450)                                WRT  7
COMMON ENX,FPOPT,ALX,RAF,ALMIN,COPT,STHCR,T1,T2,L,XVO,PSI      WRT  8
COMMON CMTOPT                                                  WRT  9
COMMON ALGN,AN,ANZ,AP,AVAR,AW,AX,CEB,CERP,CEM,CEMP,CFBMT,CFB2,CFER WRT 10
19,CFI,CFMT,CF2,CF2I,CN,COE1,COE2,COE3,CTHCR,DEL,DELAM,DELS,DERR,ONWRT 11
2,OPVAR,DRBVAR,DRVAR,DSTH,DUVAR,E,EK,EL,ELT,ELVO,EMU,EMVAR,EMX,EN,EWRT 12
3NGN,ENI,ERR,FC,FCCF,FCCFLG,FCF,FCFPR,FD,FDPR,FRKE,FRTH,G,GC,GX,H,HWRT 13
4AW,HHAT,HP,HT,HVAR,HW,HZ,ICELL,II,IN,JJ,JJLIM,JN,K,KK,KN,LLIM,NKW,WRT 14
5NN,NO,NXINT,PATM,PIVAR,PR,PRP,PRW,RBVAR,RET,RETH,KHOU1,RHOW,RO,ROPWRT 15
6,ROVAR,PCW,RFI,RRN,RRTVAR,RRX,RSERR,RSISAV,RSLVAR,RX,SHEAR,SP,SVAR,WRT 16
7,SW,SX,TAW,TEMP,TEMP10,TEMP11,TEMP12,TEMP14,TEMP2,TEMP3,TEMP4,TEMPWRT 17
85,TEMP6,TEMP7,TEMP8,TEMP9,TEP,TIVAR,TK,TPP,TRAN,TT11,TW,TX,HVAR,XIWRT 18
9N,XMIN,X2REX,Z,ZMAX,ZMIN                                     WRT 19
REAL IN,JN,KN                                                WRT 20
COMMON F(3),A(3),ALPHE(3),XINT(99),TWT(99),ZTABL(6),TABIN(6),TABJNWRT 21
1(6),DXLTAB(20),DELK(2),RSLG(2),ALG(2),ENG(2),AN2(7)          WRT 22
COMMON FRXT(20),FRXLGT(20),FCXT(20),FCXLGT(20),FRTB(20),FRLGT(20),WRT 23
1FCTB(20),FCLGT(20),XW(100),FIN6(100),RSLW(100),SHEER(100),X(160),SWRT 24
2(160),PI(160),XC(160),RB(160),W(160),RRT(160),XMAXTB(20),DUDXT(160)WRT 25
3),DRDXT(160),DPDXT(160),DRBDXT(160),VAR(2),DER(2),CUVAR(2),WSAV(16)WRT 26
40),RRTSAV(160),XSAV(160),RSLSAV(160),REXSAV(160),ENSAV(160),CFSAV(WRT 27
5160),TKTAB(30),PRTAB(210),PATAB(7),XKW(160),MKW(160),RSLKW(160),IGWRT 28
6AS                                                            WRT 29
COMMON XXI                                                    WRT 30
COMMON ACFT(22),TRFXT(22),ACFLGT(22),TRLGT(22),REXCF,HO,XO    WRT 31
COMMON HBCF,QXCF,HHCF                                         WRT 32
COMMON /BLK/ CV1,CV2,CV3,CV4,CV5,CV6,CV7,CV8,CV9,CV10,CV11,CV12,CVWRT 33
113,UNIN,UNIO                                                WRT 34
FXX=CFX*RAFX                                                 WRT 35
HB=FXX*WVAR*RRTVAR                                           WRT 36
QX=HB*(HAW-HW)/2.5036E4                                       WRT 37
HH=HB/HO                                                       WRT 38
HBCF=HB/CFMTX                                                 WRT 39
QXCF=QX/CFMTX                                                 WRT 40
HHCF=HH/CFMTX                                                 WRT 41
IF (UNIO-1.) 1,1,2                                           WRT 42

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1	O81=HB*CV5	WRT	43
	O82=OX*CV12	WRT	44
	O85=HBCF*CV5	WRT	45
	O86=QXCF*CV12	WRT	46
	WRITE (6,4) RAFX,CFMTX,CFX,EXX,O81,O82,HH,XX1,O85,O86,HHCF	WRT	47
	GO TO 3	WRT	48
2	WRITE (6,4) RAFX,CFMTX,CFX,EXX,HB,OX,HH,XX1,HBCF,QXCF,HHCF	WRT	49
3	RETURN	WRT	50
C		WRT	51
C		WRT	52
C		WRT	53
4	FORMAT (12E11.3)	WRT	54
	END	WRT	55

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Machine Requirements for Turbulent Boundary Layer Program D3340

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USAGE

The turbulent boundary layer program D3340 is run on the Control Data 6000 series computer under the SCOPE 3.0 operating system. Minimum machine requirements are 77000 octal locations of core storage for a minimum of 160 body points.

Computer Calculation Time

The time required for a given variable-entropy calculation for turbulent flow depends on (1) the number of iterative calculations from the start of transition to the end of the body; (2) the number of points on the body per iteration; (3) the number of points in the integration from the wall to the edge of the boundary layer; and (4) the error criterion for various iterative solutions used in the calculation. It usually took four iterations to find a reasonable engineering solution which had a change in velocity of less than 1 percent ($\frac{\Delta u}{u_e} < 0.01$) from one iteration to the next. For the flight calculation, the Runge-Kutta integration was limited to maximum step size of $\frac{\Delta x}{r_n} = 16.0$; however, if calculation time on the computer is extremely critical, the step size could possibly be increased with little effect on the final solution. The number of points required in the Gaussian quadrature for the calculation of δ/r_n and δ^*/r_n from equations (5) and (4), respectively, was determined from a comparison of the values of δ/r_n and δ^*/r_n calculated for various numbers of points used in the quadrature. It was determined that a minimum number of 20 points could be used in the integration

1 through the boundary layer. The momentum integral equation (eq. (3))
2 is solved by a variable-step-size fifth-order Runge-Kutta numerical scheme
3 which uses a maximum relative error criterion of 0.001 for the value of θ
4 for one step of integration. The maximum percent error allowed in the
5 iterative solution for the Spalding-Chi (ref. 7) $C_f/2$ was 0.4. When an
6 iterative procedure had to be used in the determination of thermodynamic
7 properties from the real-gas subroutine (see ref. 27), the maximum allowable
8 relative error was 0.001. For real-gas turbulent-boundary-layer calcula-
9 tions made at altitudes from 18.29 km to 25.91 km (60 000 ft to 85 000 ft)
10 at $M \approx 20$, the time per body station was approximately 2.6 seconds on the
11 Control Data 6600 computer system based on a single iteration from the start
12 of transition to the end of the body and using the relative error criteria.
13

14 Input Description

15 This section describes input procedures for the turbulent boundary
16 layer program. The preparation of input tapes and cards is discussed,
17 including a description of various options available in the program. This
18 is followed by sample input data for the test case.
19

20 Preparation of Input Tapes

21 TAPE 10 - The flow properties p_e , ρ_e , T_e , S_e , h_e and a_e for a
22 real gas in thermodynamic equilibrium are calculated by the computer
23 subroutine (RGAS) described by Lomax and Inouye in reference 27. The
24 subroutine RGAS requires use of TAPE10 containing information for nitrogen
25 on file 1 (IGAS = 1) and information for air on file 2 (IGAS = 2). TAPE 10
was developed by NASA-Ames Research Center and contains information

1 applicable to real equilibrium air ($T < 27000^\circ R$). The information for thermally
2 perfect gas mixtures was taken from NBS Circular 564. Subroutines ROLL and
3 SERCH are used by subroutine RGAS to locate the information on TAPE 10.

4 If CARD = 0, tapes 16, 15, 22 are used for input of the inviscid flow
5 field. If CARD \neq 0, as in the case of cone flow, these tapes are not used and
6 input is taken from NAMELIST \$N2 cards.

7 TAPE 15, 16, 22 - Prior to the turbulent boundary layer calculation the
8 inviscid flow field is determined by the Lomax and Inouye blunt body and method
9 of characteristics programs. (See refs. 27 and 34.) The inviscid solution gives
10 the first-order stagnation entropy flow property distribution along the body
11 which is used as the initial conditions at the edge of the boundary layer. In
12 addition, the shock shape r_s/r_n and entropy distribution along the shock are
13 found from the inviscid solution. Subroutine CRRD reads the body and shock
14 points of the inviscid flow field from tapes 15, 16, and 22.

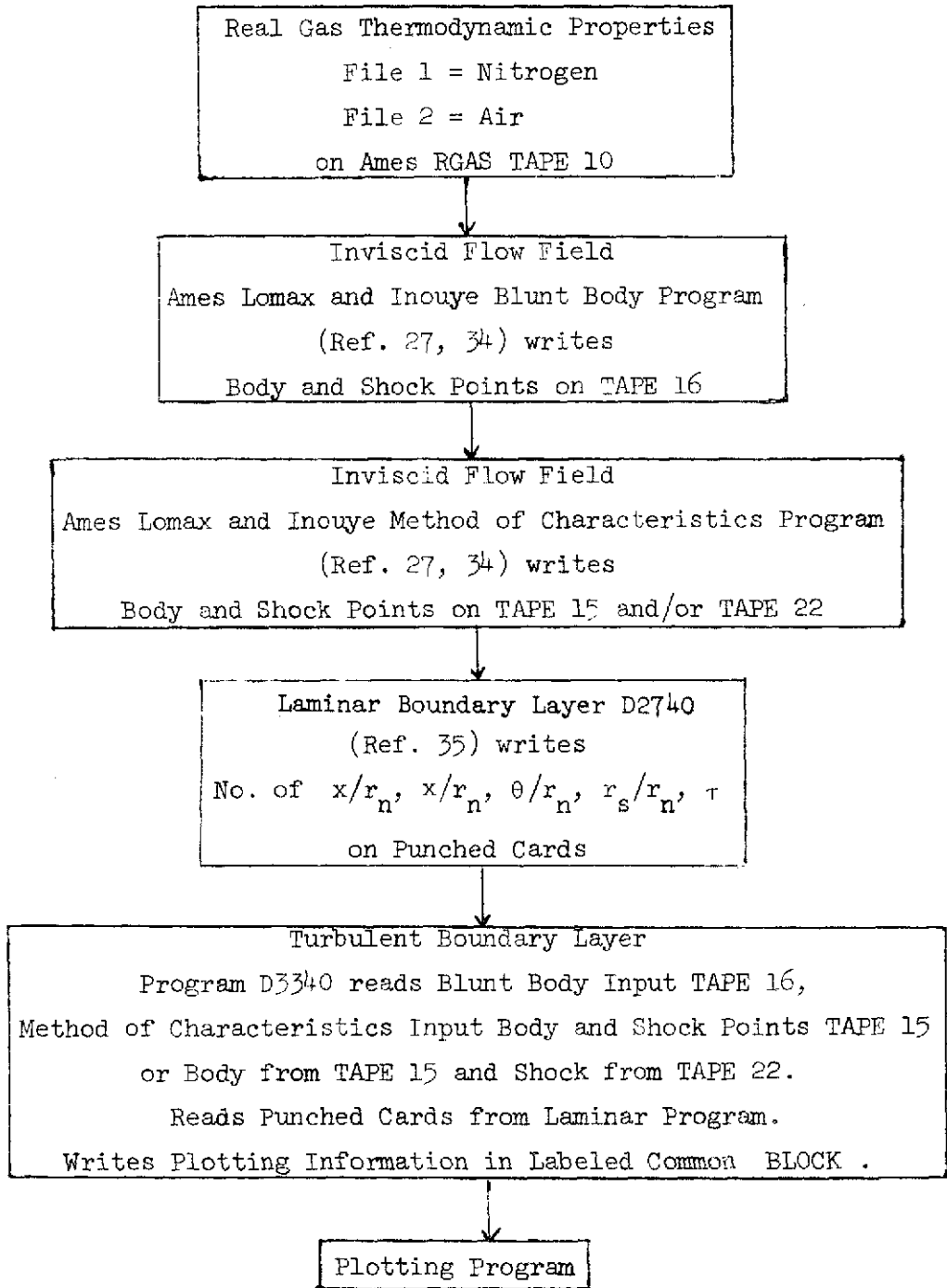
15 TAPE 16 contains the body and shock points from the Lomax and Inouye
16 blunt body program.

17 TAPES 15, 22 contain the body and shock points from the Lomax and Inouye
18 method of characteristics program. TAPE 15 may be used for both body and shock
19 points (XLSH = XLSH1) or TAPE 15 may be used for the body points and TAPE 22
20 for the shock points.

21 TAPES 16, 15, 22 contain x/r_n centerline, y/r_n , stream velocity (ft/sec),
22 stream angle (rad), Mach number, entropy ($\text{ft}^2/\text{sec}^2 \text{ } ^\circ R$), pressure (lb/ft^2),
23 enthalpy (ft^2/sec^2), density (slug/ft^3), total pressure, written in (5E16.9)
24 format with body points on odd numbered records and shock points on even
25 numbered records. A maximum of 450 body points and 450 shock points may
be read.

1 Diagram of Linkage for Input Programs

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Preparation of NAMELIST N1 Input Cards

1
2 The FORTRAN NAMELIST capability is used for data input with \$N1 as
3 the NAMELIST name. The maximum allowable dimension appears following the
4 variable name. Units are SI or US Customary depending on the option
5 chosen for UNIN.

6 \$N1
7 XMIN x/r_n at beginning of transition
8 XVO x/r_n at virtual origin
9 X2REX x/r_n at end of transition
10 ELT X2REX + .01 for print at end of transition
11 XMHL x/r_n at maximum heating
12 XLSH maximum x/r_n on shock (= 0 if flat plate) from tape 15
13 if body points from this MOC case
14 XLSH1 maximum x/r_n on shock (= 0 if flat plate) from tape 22
15 if shock points from this MOC case XLSH1 = XLSH if
16 body and shock both from tape 15
17 DXLTAB(20) table of increments of x/r_n for edge conditions
18 XMAXTB(20) table of x/r_n values where increments change, XMAXTB(20)
19 is end of body. DXLTAB and XMAXTB should be chosen so
20 that no. of x/r_n points on the body will not exceed 160
21 EL r_n nose radius (m) (inch)
22 RNOT r_n nose radius (m) (inch)
23 XINT(99) values of X for wall temperature table (m) (inch)
24 TWT(99) values of wall temperature ($^{\circ}$ K) ($^{\circ}$ R)
25 NXINT no. of values in wall temperature table
THC cone half angle (= 0 if flat plate) (rad) (deg)

	DEL	initial δ/r_n boundary layer thickness from laminar flat plate input (= 0 if cone)
1	R ϕ	density parameter from laminar program (= 0 if flat plate) (kg/m^3) (lbm/ft^3)
2		
3	RH ϕ I	density freestream (kg/m^3) (slug/ft^3)
4	RH ϕ T2	density stagnation point (kg/m^3) (slug/ft^3)
5	UI	velocity freestream (m/sec) (ft/sec)
6	RH ϕ UI	density * velocity freestream ($\text{kg}/\text{m}^2 \text{ sec}$) ($\text{lbm}/\text{ft}^2 \text{ sec}$)
7	PT2	pressure stagnation point (N/m^2) (lbf/ft^2)
8	PINF	pressure freestream (N/m^2) (lbf/ft^2)
9	HT	total enthalpy (m^2/sec^2) (ft^2/sec^2)
10	ST	total entropy ($\text{m}^2/\text{sec}^2 \text{ }^\circ\text{K}$) ($\text{ft}^2/\text{sec}^2 \text{ }^\circ\text{R}$)
11	TT11	total temperature ($^\circ\text{K}$) ($^\circ\text{R}$)
12	TW ϕ	wall temperature stagnation point ($^\circ\text{K}$) ($^\circ\text{R}$)
13	SHEAR	shear stress (if SHEAR = 0, interpolate from laminar cards)
14		
15	A(3)	A_R coefficients for enthalpy, Eq. (12), $A(1) = A(3) = 0$
16	F(3)	P_R coefficients for enthalpy, Eq. (12), $F(3) = 1$
17	ALPHE(3)	α_R coefficients for enthalpy, Eq. (12), $\alpha(1) = \alpha(2) = 1$
18		
19		$A(2)$, $F(1)$, $F(2)$, $ALPHE(3)$ are calculated in program
20	ALMIN	$\alpha(3)$ at beginning of transition, Eq. (12)
21	ALX	$\alpha(3)$ at end of transition, Eq. (12)
22	ENI	N at the beginning of transition, Eq. (26)
23	ENX	N at the end of transition, Eq. (26)
24	PSI	ψ factor in $C_f/2$, Eq. (25)
25	TRAN	= 0, no transition region $\neq 0$, transition region

1	CARD	= 0, read input from TAPE 15, 16, 22	} omit if flat plate
2		≠ 0, read NAMELIST N2	
3	FPØPT	= 0, cone	
4		≠ 0, flat plate	
5	UNIN	≤ 1., input in SI units	
6		> 1., input in US customary units	
7	UNIØ	≤ 1., output in SI units	
8		> 1., output in US customary units	
9	IGAS	= 1, nitrogen file from RGAS TAPE 10	
10		= 2, air file from RGAS TAPE 10	
11	PRINT	print frequency	
12	ERR	relative error in T or H when iterating in RGAS	
13	UERR	relative error in velocity on successive iterations	
14	CFERR	relative error in Spalding-Chi skin friction	
15	L	= 5, no. of intervals in Gaussian integration	
16	NN	= 4, no. of points per interval for Gaussian integration	
17	NT	= 1, no. of values in ELT block for Runge Kutta	
18	CI	initial interval of x/r_n for Runge Kutta	
19	SPEC	= 0, prints every interval in Runge Kutta	
20	CIMAX	maximum interval of x/r_n for Runge Kutta	
21	ELE1	relative error in θ/r_n	
22		if error greater, Runge Kutta halves computing interval	
23	ELE2	relative zero in θ/r_n	
24		will not apply relative error if θ/r_n below this	
25	PR	= .72, Prandtl no. used in T_{AW}	

1 GC = 32.174, dimensional gravitational constant to convert from
2 slug/ft³ to lbm/ft³

3 ZMIN = 31.623, Eq. (8), sets N = 2

4 ZMAX = 681.33, Eq. (8), sets N = 10

5 AN = .33333333, Eq. (8), $R_{e\theta}^{AN}$

6

7 CN = .5, Eq. (8), $(T_w/T_e)^{CN}$

8 DN = .25, Eq. (8), M_e^{DN}

9 KN = .33333333, Eq. (8), $(x_{v0}/r_n/\theta/r_n)^{KN}$

10 FRXT(20) $F_{RX} R_X$ from Spalding-Chi table 7

11 FCXT(20) $F_c C_f$ from Spalding-Chi table 7

12 FRTB(20) $R_{R\theta} R_{e\theta}$ from Spalding-Chi table 7

13 FCTB(20) $F_c \bar{C}_f$ from Spalding-Chi table 7

14 TKTAB(30) temperature °K from Hansen table VI

15 PATAB(7) pressure from Hansen table VI (N/m²) (ATM)

16 PRTAB(210) Prandtl no. from Hansen table VI, starts with Prandtl
17 no.'s for smallest pressure and increasing temperatures
18 up to largest pressure and increasing temperatures.

19 ACFT(22) C_f table to use with Van Driest skin friction

20 TREXT(22) transformed R_{ex} table to use with Van Driest skin
21 friction

22 TP pressure flat plate = PINF (N/m²) (lbf/ft²)
23 (= 0 if cone)

24 TS entropy flat plate = ST (m²/sec² °K) (ft²/sec² °R)
25 (= 0 if cone)

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Preparation of NAMELIST N2 Input Cards

Following the input from the laminar program, data input with \$N2 as the NAMELIST name may be read if CARD \neq 0 in NAMELIST N1 and inviscid flow field tapes are omitted.

\$N2	
DELTX	increment of x/r_n
TP	pressure (N/m^2) (lbf/ft^2)
TS	entropy ($m^2/sec^2 \cdot K$) ($ft^2/sec^2 \cdot R$)
THSD	shock angle (rad) (deg)
\$	

Input for Sample Calculation

The sample case chosen to illustrate the use of the program is the performance of turbulent boundary layer flight calculations at an altitude of 60,000 ft. and flight conditions of approximately 19,000 ft./sec. for a 13 ft. long, 5° half angle cone with a nose radius of .4 inch.

The corresponding input data cards are listed here and sample pages of the output data are shown in the ensuing section to illustrate the printout formats. The input and output for the sample case are in SI units.

Sample Input (S I Units)

\$N1

XMIN=15.,XVO=10.,X2REX=22.,ELT=223.01,XMHL=213.,XLSH=283.,XLSH1=283.,
DXLTAR=.1.,.1.,.2.,.2.,.5.,.5.,.1.,.1.,.5.,.5.,.10.,.10.,.8*25.,
XMAXTB=15.,.16.,.16.,.20.,.20.,.35.,.35.,.65.,.65.,.115.,.115.,.215.,.8*390.,
XINT=.36576.,.747014.,.975868.,1.280922,1.466072,1.81483,2.119884,2.475992,
2.729992,3.035046,3.340608,3.620008,
TWT=635.55556,562.77778,568.88889,577.77778,600.55556,698.88889,748.33333,
788.33333,802.22222,819.44444,838.88889,827.77778,
UNIN=1.,UNIQ=1.,
EL=1.016E-2,RHOU1=710.3932045,RO=2.755175636,RHO1=1.225468186E-1,
UI=.579674736E4,HT=1.701240468E7,ST=11.25026085E3,THC=8.72664626E-2,
RHOT2=1.414612279,RNOT=1.016E-2,PT2=3.944327774E6,PINF=.7369729311E4,
TWO=.1666666667E4,TT11=.0735E5,
NXINT=12,DEL=0,
SHEAR=6.76136E-6,
A=0,0,0,F=0,0,1.,ALPHE=1.,1.,0,
ALMIN=1.26,ALX=1.,ENI=1.54,ENX=7.,PSI=2.,
TRAN=1.,CARD=0,FPOPT=0, [GAS=2,PRINT=1.,
ERR=.001,UERR=.001,CFERR=.004,L=5,NN=4,NT=1,CI=.0125,SPEC=0,CIMAX=16.,
ELE1=.001,ELE2=.001,PR=.72,GC=32.174,ZMIN=31.623,ZMAX=681.33,AN=.33333333,
CN=.5,DN=.25,KN=.33333333,
FRXT =5.826E3,6.883E3,8.253E3,1.006E4,1.251E4,1.592E4,2.078E4,
2.796E4,3.901E4,5.670E4,8.697E4,1.417E5,2.492E5,4.828E5,1.062E6,
2.778E6,9.340E6,4.651E7,4.610E8,5.758E10,
FCXT =.0105,.01,.0095,.009,.0085,.008,.0075,.007,.0065,.006,.0055,
.005,.0045,.004,.0035,.003,.0025,.002,.0015,.001,
FRTB=50.46,55.87,62.55,70.91,92.49,95.62,114.4,140.4,177.6,233.0,319.4,
462.3,716.0,1208,2282,5030,1.386E4,5.425E4,3.955E5,2.878E7,
FCTB=.01732,.01624,.01516,.01409,.01304,.012016,.011014,.010042,.009105,
.008205,.007345,.006526,.005747,.005006,.004299,.003621,.002967,.002333,
.001716,.001117,
TKTAB=500,1000,1500,2000,2500,3000,3500,4000,4500,5000,5500,6000,6500,
7000,7500,8000,8500,9000,9500,10000,10500,11000,11500,12000,12500,13000,
13500,14000,14500,15000,
PATAB=1.01325E1,1.01325E2,1.01325E3,1.01325E4,1.01325E5,1.01325E6,1.01325E7,
PRTAB=.738,.756,.767,.814,.771,.714,.606,.587,.764,.903,.871,.384,.348,
.337,.330,.316,.276,.1987,.1140,.0577,.0312,.0207,.0157,.0132,.0120,
.0115,.0109,.0109,.0109,.0109,.738,.756,.767,.668,.654,.745,.658,.580,
.611,.799,.989,.891,.383,.346,.334,.328,.321,.307,.273,.210,.1427,.0870,
.0503,.0321,.0213,.0166,.0142,.0130,.0119,.0114,.738,.756,.767,.724,
.611,.740,.737,.619,.578,.624,.785,.969,.955,.830,.350,.332,.324,.320,
.316,.313,.284,.246,.1945,.1409,.0949,.0634,.0416,.0293,.0202,.0119,
.738,.756,.767,.766,.645,.636,.744,.759,.610,.581,.617,.736,.906,.986,
.969,.648,.335,.321,.314,.310,.309,.303,.293,.276,.250,.215,.1733,

.1338.,.0903.,.0719.,.738.,.756.,.767.,.773.,.696.,.627.,.660.,.762.,.752.,.611.,
 .583.,.602.,.673.,.796.,.927.,.983.,.943.,.807.,.330.,.308.,.301.,.296.,.295.,.293.,
 .290.,.284.,.276.,.263.,.237.,.220.,.738.,.756.,.767.,.773.,.751.,.680.,.631.,.662.,
 .743.,.767.,.620.,.592.,.592.,.620.,.688.,.788.,.891.,.961.,.966.,.872.,.310.,.294.,
 .284.,.277.,.272.,.272.,.270.,.269.,.265.,.263.,.738.,.756.,.767.,.773.,.762.,.740.,
 .678.,.640.,.654.,.702.,.748.,.763.,.610.,.593.,.595.,.620.,.666.,.730.,.806.,.886.,
 .937.,.955.,.947.,.908.,.728.,.275.,.251.,.245.,.241.,.238.,
 ACFT=.02.,.0175.,.015.,.0125.,.01.,.009.,.008.,.007.,.006.,.0055.,.005.,.0045.,
 .004.,.0035.,.003.,.0025.,.00225.,.002.,.0019.,.0018.,.0017.,.0016.,
 TREXT=2.5714E+3,3.8575E+3,6.307E+3,1.1684E+4,2.6303E+4,3.9506E+4,
 6.3468E+4,1.1152E+5,2.2185E+5,3.3324E+5,5.2895E+5,9.0014E+5,
 1.6761E+6,3.5195E+6,8.7332E+6,2.7673E+7,5.6185E+7,1.2889E+8,
 1.8754E+8,2.8101E+8,4.354E+8,7.0126E+8,

TP=0,TS=0,

\$

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0.	1.00000000E-01	2.00000000E-01	3.00000000E-01	4.00000000E-01
5.00000000E-01	6.00000000E-01	7.00000000E-01	8.00000000E-01	9.00000000E-01
1.00000000E+00	1.10000000E+00	1.20000000E+00	1.30000000E+00	1.40000000E+00
1.50000000E+00	1.60000000E+00	1.70000000E+00	1.80000000E+00	1.90000000E+00
2.00000000E+00	3.00000000E+00	4.00000000E+00	5.00000000E+00	6.00000000E+00
7.00000000E+00	8.00000000E+00	9.00000000E+00	1.00000000E+01	1.50000000E+01
2.00000000E+01	3.00000000E+01	3.73000000E+01	4.00000000E+01	5.00000000E+01
6.00000000E+01	6.78000000E+01	7.00000000E+01	8.00000000E+01	9.04000000E+01
1.00000000E+02	1.20500000E+02	1.38700000E+02	1.73200000E+02	2.03400000E+02
2.38500000E+02	2.63600000E+02	2.93700000E+02	3.00000000E+02	3.23800000E+02
3.51400000E+02	4.00000000E+02			
7.74874187E-04	5.65139131E-04	6.10217578E-04	6.17637067E-04	6.52955756E-04
6.97554929E-04	7.59994135E-04	8.37431679E-04	9.42183903E-04	1.08141354E-03
1.26337507E-03	1.49549067E-03	1.81369757E-03	2.25208282E-03	2.87283048E-03
3.80062763E-03	4.59650658E-03	4.84963409E-03	5.05258637E-03	5.27283967E-03
5.49100524E-03	7.31011937E-03	8.73563712E-03	9.91140259E-03	1.10563112E-02
1.21445645E-02	1.31402231E-02	1.40646459E-02	1.48882199E-02	1.69085027E-02
1.94744337E-02	2.30178717E-02	2.43947375E-02	2.46461261E-02	2.50719485E-02
2.46896983E-02	2.41801884E-02	2.42371613E-02	2.42959237E-02	2.40106092E-02
2.39135594E-02	2.30470534E-02	2.20729627E-02	2.02254653E-02	1.88707917E-02
1.77369142E-02	1.70865639E-02	1.64681056E-02	1.63862858E-02	1.59776292E-02
1.55013646E-02	1.44399776E-02			
0.	2.44281545E-02	4.78320812E-02	7.04198673E-02	9.21476258E-02
1.10728983E-01	1.29227740E-01	1.46239728E-01	1.61342162E-01	1.74350769E-01
1.85500919E-01	1.91767598E-01	1.99401108E-01	2.05451976E-01	2.06631376E-01
2.07587764E-01	2.06965292E-01	2.05167090E-01	2.07415444E-01	2.09306340E-01
2.11040809E-01	2.21331610E-01	2.33851832E-01	2.41151621E-01	2.52215348E-01
2.57139493E-01	2.66479662E-01	2.74888141E-01	2.83022579E-01	3.24824888E-01

3.68180137E-01 4.46402282E-01 4.99952742E-01 5.19899268E-01 5.93882270E-01
6.69018134E-01 7.28881417E-01 7.45840068E-01 8.21595024E-01 8.97335729E-01
9.64180061E-01 1.10351691E+00 1.22138486E+00 1.42816023E+00 1.59729447E+00
1.78499250E+00 1.91500818E+00 2.06595084E+00 2.09697462E+00 2.21468145E+00
2.39837410E+00 2.59003632E+00

Output Description

1
2 In this section the formats for printing the results of the machine
3 computations are described. The results of the sample calculation, for
4 which the input data were described, are used to illustrate the printout
5 procedure.

6 NAMELIST N1 Output

7 For each computational case or run, the program lists the NAMELIST N1
8 input data. The program listing of the input data for the sample calculation
9 is shown in Figure 1. The format for this printout is evident from the
10 figure.

11 Inviscid Solution Output

12
13 If CARD \neq 0, the program lists the NAMELIST N2 input data. If
14 CARD = 0, the program lists the information read from tapes 15, 22, 16.
15 This information is printed on two lines for each body or shock point of
16 the method of characteristics and blunt body solutions as shown in Figure 2.

17 The first line contains

18 X x/r_n measured on centerline

19 Y y/r_n

20 Q stream velocity (ft/sec)

21 THETA stream angle (rad)

22 M mach number

23 The second line contains

24 S entropy (ft²/sec² °R)

25 P pressure (lbf/ft²)

1 H enthalpy (ft^2/sec^2)
2 $\text{RH}\phi$ density (slug/ft^3)
3 PT total pressure (not used in present version of program)

4 Body and shock points of the method of characteristics solution
5 alternate until x/r_n of shock point from TAPE 15 reaches XLSH and if
6 $\text{XLSH} \neq \text{XLSH1}$ x/r_n of shock point from TAPE 22 reaches XLSH1. This is
7 followed by all the body and shock points read from the blunt body solution
8 on TAPE 16. Of these items of information only x/r_n , y/r_n , S, and P of
9 body points and x/r_n , y/r_n , S of shock points will be used in the
10 turbulent program.

11 Tables of body points and shock points are listed as shown in Figure 3.
12 The number of points in these tables may not exceed 450. The information
13 given for body points is

14 XCL x/r_n measured on centerline
15 Y y/r_n
16 S entropy ($\text{ft}^2/\text{sec}^2 \text{ }^\circ\text{R}$)
17 P pressure (lbf/ft^2)
18 X x/r_n measured on surface

19 The information given for shock points is

20 YS y/r_n shock radius
21 S entropy ($\text{ft}^2/\text{sec}^2 \text{ }^\circ\text{R}$)

22 At specified increments of x/r_n on the body (XMAXTB, DXLTAB) linear
23 interpolation in the tables shown in Figure 3 is performed and the results
24 are listed as shown in Figure 4. The number of points in these tables may
25 not exceed 160. The information given is

1	X	x/r_n	
2	S	entropy	(ft ² /sec ² °R)
3	P	pressure	
4	RB	r_b/r_n	
5	XC	x/r_n	measured on centerline
6	T	temperature	(°R)
7	H	enthalpy	(ft ² /sec ²)
8	U	velocity	(ft/sec)
9	A	speed of sound	(ft/sec)
10	M	mach number	
11	RH ϕ	density	(lbm/ft ³)
12	X	x/r_n	
13	DU/DX	$du/d\frac{x}{r_n}$	velocity derivative
14	DRH ϕ /DX	$d\rho/d\frac{x}{r_n}$	density derivative
15			
16	DP/DX	$dp/d\frac{x}{r_n}$	pressure derivative
17	DRB/DX	$\frac{r_b}{r_n} / d\frac{x}{r_n}$	body radius derivative
18			

19 All the output shown in Figs. 2, 3, 4 is in U. S. customary units.

20

21

Stagnation Point Output

22

23 The information for the stagnation point is listed as shown in
 24 Figure 5.

25 H ϕ heat transfer (kg/m² sec) (lbm/ft² sec)

1 $Q\phi$ heating rate (W/m^2) ($Btu/ft^2 \text{ sec}$)

2 These may be output in either SI units ($UNI\phi = 1.$) or U. S. customary
3 units ($UNI\phi = 2.$).

4

5

6 Output Each Iteration

7 The turbulent boundary layer calculation is initiated at the point
8 where transition has been determined to start ($XMIN$) and continues to the
9 end of the body ($XMAXTB(20)$). Integration of the momentum equation is
10 performed by a variable step-size fifth-order Runge Kutta numerical scheme.
11 After each step in the integration the heating rates are calculated. The
12 procedure is repeated until the velocity at the edge of the boundary
13 layer varies from one iteration to the next by less than the allowable
14 difference ($UERR$). The output may be in either SI units ($UNI\phi = 1.$) or
15 U. S. customary units ($UNI\phi = 2.$).

16

17

18 Heating Rates Output

19 Heat transfer has been calculated using several different skin
20 friction theories. There may be one, four, or eight lines of information
21 printed as shown in Figure 6. If one line is printed, the theory used is
22 Van Driest ($R_{e\theta}$). If four lines are printed, the theories used are
23 Van Driest ($R_{e\theta}$), Eckert's ($R_{e\theta}$), Spalding Chi ($R_{e\theta}$, ideal gas), Spalding
24 Chi ($R_{e\theta}$, real gas). If eight lines are printed, the theories used are
25 Van Driest ($R_{e\theta}$), Van Driest (R_{ex}), Spalding Chi (R_{ex} , ideal gas),

1 Eckert's (R_{ex}), Eckert's ($R_{ex_{min}}$), Eckert's ($R_{e\theta}$), Spalding Chi ($R_{e\theta}$, ideal
2 gas), Spalding Chi ($R_{e\theta}$, real gas).

3 The values printed on a line for each skin friction theory are:

4	RAF	Reynolds analogy factor
5	CFMT	Mangler transformation factor
6	CF2	skin friction coefficient/2
7	ENST	Stanton number
8	HBAR	local heat transfer coefficient ($\text{kg/m}^2 \text{ sec}$) ($\text{lbm/ft}^2 \text{ sec}$)
9	Q	heating rate (W/m^2) ($\text{Btu/ft}^2 \text{ sec}$)
10	HH	local heat/stagnation heat
11	XX1	($Y/2 \tanh \psi$) term from Eq. (25)
12	HBCF	local heat transfer coefficient/Mangler transformation
13		($\text{kg/m}^2 \text{ sec}$) ($\text{lbm/ft}^2 \text{ sec}$)
14	QXCF	heating rate/Mangler transformation (W/m^2) ($\text{Btu/ft}^2 \text{ sec}$)
15	HHCF	(local heat/stagnation heat)/Mangler transformation

16

17

Output at Each Integration Step

18

19 In addition to the heating rate information seven lines are printed
20 at each step of the integration as shown in Figure 6. The values printed
21 on line one are:

22	X/L	distance/nose radius
23	X	distance (m) (inch)
24	THETA/L	momentum thickness/nose radius
25	THETA	momentum thickness (m) (inch)

1	P	pressure (N/m ²) (lbf/ft ²)
2	RB	body radius/nose radius
3	S	entropy (m ² /sec ² °K) (ft ² /sec ² °R)
4	S/ST	entropy/total entropy
5	T	temperature (°K) (°R)
6	H	enthalpy (m ² /sec ²) (ft ² /sec ²)
7	H/HT	enthalpy/total enthalpy
8	RHØ	density (kg/m ³) (lbm/ft ³)
9	The values printed on line two are:	
10	RHØ/RHØI	density/freestream density
11	U	velocity (m/sec) (ft/sec)
12	U/SQRT2HT	velocity/(2*total enthalpy) ^{1/2}
13	U/UI	velocity/freestream velocity
14	A	speed of sound (m/sec) (ft/sec)
15	M	mach number
16	MU	viscosity (N sec/m ²) (lbm/ft sec)
17	RETH	Reynolds number based on momentum thickness
18	REX	Reynolds number based on distance
19	TW	wall temperature (°K) (°R)
20	HW	wall enthalpy (m ² /sec ²) (ft ² /sec ²)
21	HW/HT	wall enthalpy/total enthalpy
22	The values printed on line three are	
23	RHØW	wall density (kg/m ³) (lbm/ft ³)
24	TW/T	wall temperature/temperature
25	TAW	adiabatic wall temperature (°K) (°R)

1	FRTH	$F_{R\theta}$
2	FC	F_c , Eq. (22)
3	CFMT	Mangler transformation factor
4	LV ϕ	distance from virtual origin
5	Z	z, Eq. (8)
6	CFI	initial skin friction
7	CF2	skin friction/2
8	HAW	adiabatic wall enthalpy (m^2/sec^2) (ft^2/sec^2)
9	HAW/HT	adiabatic wall enthalpy/total enthalpy
10	The values printed on line four are:	
11	HP	Eckert's reference enthalpy (m^2/sec^2) (ft^2/sec^2)
12	TP	Eckert's reference temperature ($^{\circ}K$) ($^{\circ}R$)
13	PRP	Eckert's reference Prandtl number
14	PRW	wall Prandtl number
15	F(1)	B_I , Eq. (10)
16	F(2)	B_{II} , Eq. (10)
17	A(2)	A_{II} , Eq. (10)
18	ALPH(3)	α_{III} , Eq. (10)
19	N	N exponent in velocity-profile relation
20	INT1	$\int_0^1 \frac{\rho u}{\rho_e u_e} - \frac{\rho u^2}{\rho_e u_e^2} d \frac{y}{\delta}$
21		
22	INT2	$\int_0^1 \frac{\rho u}{\rho_e u_e} \frac{y}{\delta} (\cos \theta_c / r_b / r_n) d \frac{y}{\delta}$
23		
24	INT3	$\int_0^1 1 - \frac{\rho u}{\rho_e u_e} d \frac{y}{\delta}$
25		

1 The values printed on line five are:

2 INT4
$$\int_0^1 \left(1 - \frac{\rho u}{\rho_e u_e}\right) \frac{y}{\delta} \left(\cos \theta_c / r_b / r_n\right) d \frac{y}{\delta}$$

3
4 INT5
$$\int_0^1 \left(\frac{\rho u}{\rho_e u_e} - \frac{\rho u^2}{\rho_e u_e^2}\right) \frac{y}{\delta} \left(\cos \theta_c / r_b / r_n\right) d \frac{y}{\delta}$$

5
6 INT6
$$\int_0^1 \frac{\rho u}{\rho_e u_e} d \frac{y}{\delta}$$

7
8 INT7
$$\int_0^1 \frac{\rho u^2}{\rho_e u_e^2} d \frac{y}{\delta}$$

- 9
- 10 DEL/L boundary layer thickness/nose radius
- 11 DEL boundary layer thickness
- 12 RSL shock radius/nose radius
- 13 DELS/L displacement thickness/nose radius
- 14 DELS displacement thickness
- 15 X/DELS distance/displacement thickness
- 16 DSTH displacement thickness/momentum thickness
- 17 DU $d u_e / d \frac{x}{r_n}$

19 The values printed on line six are:

20 DRHØ $d \rho_e / d \frac{x}{r_n}$ (kg/m³) (lbf/ft³)

21 DP $d P_e / d \frac{x}{r_n}$ (N/m²) (lbf/ft²)

22
23 DRB $d \frac{r_b}{r_n} / d \frac{x}{r_n}$

24
25 DTHETA $d \frac{\theta}{r_n} / d \frac{x}{r_n}$

1 NST Stanton number
 2 HBAR local heat transfer coefficient by Van Driest ($R_{e\theta}$)
 3 (kg/m² sec) (lbm/ft² sec)
 4 Q heating rate/stagnation heating rate (Q/Q0)
 5 PRE Prandtl number
 6 EKF Karman factor
 7 QIN incompressible heating rate (W/m²) (Btu/ft² sec)
 8 QKF Karman factor heating rate (W/m²) (Btu/ft² sec)
 9 QXTR heating rate from transition (W/m²) (Btu/ft² sec)

10 The values printed on line seven are:

11 QXMH heating rate from maximum heating (W/m²) (Btu/ft² sec)
 12 XC distance on centerline/nose radius
 13 RHØUSQ ρu^2 (N/m²) (lbf/ft²)
 14 TAU shear stress (N/m²) (lbf/ft²)

15
 16

Output at End of Transition

17

18 In each iteration, whenever x/r_n is within .0001 of ELT a velocity
 19 profile is printed. The information printed for all points in the
 20 Gaussian integration is:

21 Y/D $y/r_n / \delta/r_n$
 22 U/UE velocity ratio
 23 H enthalpy (m²/sec²) (ft²/sec²)
 24 RHØ/RHØE density ratio
 25 RHØU/RHØEUE density * velocity ratio

1 HBAR $A_R + B_R (u/u_e)^{\alpha R}$
 2 T temperature (°K) (°R)
 3 M Mach number

4
 5

Output at End of Iteration

7 At the end of each iteration the maximum relative error between the
 8 velocities at the edge of the boundary layer of the present iteration and
 9 the previous iteration is printed (TØLL).

10 At the end of each iteration two additional lines of information are
 11 printed as shown in Figure 7. The values printed on line one are:

12 REX2 (omit in present version of program)
 13 X2REX $(x/r_n)_{\text{turb}}$, distance at end of transition
 14 EN2REX N_{turb} , exponent in velocity profile relation at end of
 15 transition
 16 CEM $N_{\text{turb}} - N_{\text{tr}}$
 17 CEB $2\psi / \left[(x/r_n)_{\text{turb}} - (x/r_n)_{\text{tr}} \right]$
 18 CF2REX $(C_f/2)_{\text{turb}}$, skin friction coefficient/2 at end of
 19 transition
 20 CEMP $(C_f/2)_{\text{turb}} - (C_f/2)_{\text{tr}}$
 21 CEBP $\tanh \psi$
 22 XMIN $(x/r_n)_{\text{tr}}$, distance at start of transition
 23 RSISAV (omit in present version of program)
 24 ENI N_{tr} , exponent in velocity profile relation at start of
 25 transition

1 CF2I $(C_f/2)_{tr}$, skin friction coefficient/2 at start of
2 transition

3 The value printed on line two is:

4 REXSAV $R_{e,x}$, local Reynolds number based on surface distance
5 at start of transition

6

7

Final Iteration Plotting Output

8

9 If plotting is desired, the information in labeled common BLOCK may
10 be called for in the user's own plotting routine. This block holds all
11 information from the final iteration. The block contains:

12	PLT1	X	distance (inch)
13	PLT2	N	exponent in velocity profile relation
14	PLT3	RETH	Reynolds no. based on momentum thickness
15	PLT4	CF2	skin friction coefficient/2
16	PLT5	M	mach number
17	PLT6	DEL	boundary layer thickness (inch)
18	PLT7	DELS	displacement thickness (inch)
19	PLT8	THETA	momentum thickness (inch)
20	PLT9	H/HT	enthalpy/total enthalpy
21	PLT10	REX	Reynolds no. based on distance
22	PLT11	S/ST	entropy/total entropy
23	PLT12	U/UI	velocity/velocity freestream
24	PLT13	RH ϕ /RH ϕ I	density/density freestream
25	PLT14	Q/Q ϕ	heating rate

1	PLT15	RSL	shock radius/nose radius
2	NKWSAV		number of X stations (maximum of 160)
3			
4			
5			
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24			
25			

\$N1

Figure 1

XMIN = 0.15E+02,

DXLTAB = 0.1E+00, 0.1E+00, 0.2E+00, 0.2E+00, 0.5E+00, 0.5E+00, 0.1E+01,
0.1E+01, 0.5E+01, 0.5E+01, 0.1E+02, 0.1E+02, 0.25E+02,
0.25E+02, 0.25E+02, 0.25E+02, 0.25E+02, 0.25E+02,
0.25E+02,

XMAXTR = 0.15E+02, 0.16E+02, 0.16E+02, 0.2E+02, 0.2E+02, 0.35E+02,
0.35E+02, 0.65E+02, 0.65E+02, 0.115E+03, 0.115E+03, 0.215E+03,
0.39E+03, 0.39E+03, 0.39E+03, 0.39E+03, 0.39E+03, 0.39E+03,
0.39E+03, 0.39E+03,

ELT = 0.22301E+03,

XLSH = 0.283E+03,

XLSH1 = 0.283E+03,

XMHL = 0.213E+03,

EL = 0.1016E-01,

X2REX = 0.223E+03,

RHOUT = 0.7103932045E+03,

SHEAR = 0.676136E-05,

RO = 0.2755175636E+01,

RHOI = 0.1225468186E+00,

UI = 0.579674736E+04,

HT = 0.1701240468E+08,

ST = 0.1125026085E+05,

TT11 = 0.735E+04,

DEL = 0.0,

THC = 0.872664626E-01,

PR = 0.72E+00,

GC = 0.32174E+02,

TRAN = 0.1E+01.
 CARD = 0.0.
 PRINT = 0.1E+01.
 A = 0.0, 0.0, 0.0,
 F = 0.0, 0.0, 0.1E+01.
 ALPHF = 0.1E+01, 0.1E+01, 0.0,
 7MIN = 0.31623E+02.
 7MAX = 0.68133E+03.
 AN = 0.33333333E+00.
 CN = 0.5E+00.
 DN = 0.25E+00.
 KN = 0.33333333E+00.
 FRXT = 0.5826E+04, 0.6883E+04, 0.8253E+04, 0.1006E+05, 0.1251E+05,
 0.1592E+05, 0.2078E+05, 0.2796E+05, 0.3901E+05, 0.5679E+05,
 0.8697E+05, 0.1417E+06, 0.2492E+06, 0.4828E+06, 0.1062E+07,
 0.2778E+07, 0.934E+07, 0.4651E+08, 0.461E+09, 0.5758E+11,
 FCXT = 0.105E-01, 0.1E-01, 0.95E-02, 0.9E-02, 0.85E-02, 0.8E-02,
 0.75E-02, 0.7E-02, 0.65E-02, 0.6E-02, 0.55E-02, 0.5E-02,
 0.45E-02, 0.4E-02, 0.35E-02, 0.3E-02, 0.25E-02, 0.2E-02,
 0.15E-02, 0.1E-02,
 FRTR = 0.5046E+02, 0.5587E+02, 0.6255E+02, 0.7091E+02, 0.9249E+02,
 0.9562E+02, 0.1144E+03, 0.1404E+03, 0.1776E+03, 0.233E+03,
 0.3194E+03, 0.4623E+03, 0.716E+03, 0.1208E+04, 0.2283E+04,
 0.503E+04, 0.1386E+05, 0.5425E+05, 0.3955E+06, 0.2878E+08,
 FCTR = 0.1732E-01, 0.1624E-01, 0.1516E-01, 0.1409E-01, 0.1304E-01,
 0.12016E-01, 0.11014E-01, 0.10042E-01, 0.9105E-02, 0.8205E-02,
 0.7345E-02, 0.6526E-02, 0.5747E-02, 0.5006E-02, 0.4299E-02,
 0.3621E-02, 0.2967E-02, 0.2333E-02, 0.1716E-02, 0.1117E-02,
 TKTR = 0.5E+03, 0.1E+04, 0.15E+04, 0.2E+04, 0.25E+04, 0.3E+04,
 0.35E+04, 0.4E+04, 0.45E+04, 0.5E+04, 0.55E+04, 0.6E+04,
 0.65E+04, 0.7E+04, 0.75E+04, 0.8E+04, 0.85E+04, 0.9E+04,
 0.95E+04, 0.1E+05, 0.105E+05, 0.11E+05, 0.115E+05, 0.12E+05,
 0.125E+05, 0.13E+05, 0.135E+05, 0.14E+05, 0.145E+05, 0.15E+05,
 PATAR = 0.101325E+02, 0.101325E+03, 0.101325E+04, 0.101325E+05.

0.101325E+06, 0.101325E+07, 0.101325E+08,

PRTAB = 0.738E+00, 0.756E+00, 0.767E+00, 0.614E+00, 0.771E+00,
0.714E+00, 0.606E+00, 0.587E+00, 0.764E+00, 0.993E+00,
0.871E+00, 0.384E+00, 0.348E+00, 0.337E+00, 0.33E+00,
0.316E+00, 0.276E+00, 0.1987E+00, 0.114E+00, 0.577E-01,
0.312E-01, 0.207E-01, 0.157E-01, 0.132E-01, 0.12E-01,
0.115E-01, 0.109E-01, 0.109E-01, 0.109E-01, 0.109E-01,
0.738E+00, 0.756E+00, 0.767E+00, 0.668E+00, 0.654E+00,
0.745E+00, 0.658E+00, 0.58E+00, 0.611E+00, 0.799E+00,
0.989E+00, 0.891E+00, 0.383E+00, 0.346E+00, 0.334E+00,
0.328E+00, 0.321E+00, 0.307E+00, 0.273E+00, 0.21E+00,
0.1427E+00, 0.87E-01, 0.503E-01, 0.321E-01, 0.213E-01,
0.166E-01, 0.142E-01, 0.13E-01, 0.119E-01, 0.114E-01,
0.738E+00, 0.756E+00, 0.767E+00, 0.724E+00, 0.611E+00,
0.74E+00, 0.737E+00, 0.619E+00, 0.578E+00, 0.624E+00,
0.785E+00, 0.969E+00, 0.955E+00, 0.83E+00, 0.35E+00, 0.332E+00,
0.324E+00, 0.32E+00, 0.316E+00, 0.313E+00, 0.284E+00,
0.246E+00, 0.1945E+00, 0.1409E+00, 0.949E-01, 0.634E-01,
0.416E-01, 0.293E-01, 0.202E-01, 0.119E-01, 0.738E+00,
0.756E+00, 0.767E+00, 0.766E+00, 0.645E+00, 0.636E+00,
0.744E+00, 0.759E+00, 0.61E+00, 0.581E+00, 0.617E+00,
0.736E+00, 0.906E+00, 0.986E+00, 0.969E+00, 0.848E+00,
0.335E+00, 0.321E+00, 0.314E+00, 0.31E+00, 0.309E+00,
0.303E+00, 0.293E+00, 0.276E+00, 0.25E+00, 0.215E+00,
0.1733E+00, 0.1338E+00, 0.903E-01, 0.719E-01, 0.738E+00,
0.756E+00, 0.767E+00, 0.773E+00, 0.696E+00, 0.627E+00,
0.66E+00, 0.762E+00, 0.752E+00, 0.611E+00, 0.583E+00,
0.602E+00, 0.673E+00, 0.796E+00, 0.927E+00, 0.983E+00,
0.943E+00, 0.807E+00, 0.33E+00, 0.308E+00, 0.301E+00,
0.296E+00, 0.295E+00, 0.293E+00, 0.29E+00, 0.284E+00,
0.276E+00, 0.263E+00, 0.237E+00, 0.22E+00, 0.738E+00,
0.756E+00, 0.767E+00, 0.773E+00, 0.751E+00, 0.68E+00,
0.631E+00, 0.662E+00, 0.743E+00, 0.767E+00, 0.62E+00,
0.592E+00, 0.592E+00, 0.62E+00, 0.688E+00, 0.788E+00,
0.891E+00, 0.961E+00, 0.966E+00, 0.872E+00, 0.31E+00,
0.294E+00, 0.284E+00, 0.277E+00, 0.272E+00, 0.272E+00,
0.27E+00, 0.269E+00, 0.265E+00, 0.263E+00, 0.738E+00,
0.756E+00, 0.767E+00, 0.773E+00, 0.762E+00, 0.74E+00,
0.678E+00, 0.64E+00, 0.654E+00, 0.702E+00, 0.748E+00,
0.763E+00, 0.61E+00, 0.593E+00, 0.595E+00, 0.62E+00, 0.666E+00,
0.73E+00, 0.806E+00, 0.886E+00, 0.937E+00, 0.955E+00,
0.947E+00, 0.908E+00, 0.728E+00, 0.275E+00, 0.251E+00,
0.245E+00, 0.241E+00, 0.238E+00,

NXINT = 12,

XINT = 0.36576E+00, 0.747014E+00, 0.975868E+00, 0.1280922E+01,
0.1465072E+01, 0.181483E+01, 0.2119884E+01, 0.2475992E+01,
0.2729992E+01, 0.3035046E+01, 0.3340608E+01, 0.3620008E+01,

TWT = 0.63555556E+03, 0.56277778E+03, 0.56888889E+03, 0.57777778E+03,
0.60055556E+03, 0.69888889E+03, 0.74833333E+03, 0.78833333E+03,
0.80222222E+03, 0.81944444E+03, 0.83888889E+03, 0.82777778E+03,

L = 5,
NN = 4,
NT = 1,
CI = 0.125E-01,
SPEC = 0.0,
CIMAX = 0.16E+02,
ELF1 = 0.1E-02,
ELF2 = 0.1E-02,
ERR = 0.1E-02,
UEPR = 0.1E-02,
CFERR = 0.4E-02,
XVO = 0.1E+02,
PSI = 0.2E+01,
FNI = 0.154E+01,
ALMIN = 0.126E+01,
ALX = 0.1E+01,
FPOPT = 0.0,
TP = 0.0,

TS = 0.0,

ENX = 0.7E+01,

RHOT2 = 0.1414612279E+01,

RNOT = 0.1016E-01,

PT2 = 0.3944327774E+07,

PINF = 0.7369729311E+04,

TWO = 0.1666666667E+04,

IGAS = 2,

```

ACFT = 0.2E-01, 0.175E-01, 0.15E-01, 0.125E-01, 0.1E-01, 0.9E-02,
      0.8E-02, 0.7E-02, 0.6E-02, 0.55E-02, 0.5E-02, 0.45E-02,
      0.4E-02, 0.35E-02, 0.3E-02, 0.25E-02, 0.225E-02, 0.2E-02,
      0.19E-02, 0.18E-02, 0.17E-02, 0.16E-02,

TREXT = 0.25714E+04, 0.38575E+04, 0.6307E+04, 0.11684E+05, 0.26303E+05,
        0.39506E+05, 0.63468E+05, 0.11152E+06, 0.22195E+06, 0.33324E+06,
        0.52896E+06, 0.90014E+06, 0.16761E+07, 0.35195E+07, 0.87332E+07,
        0.27673E+08, 0.56185E+08, 0.12889E+09, 0.18754E+09, 0.28101E+09,
        0.4354E+09, 0.70126E+09,

UNIN = 0.1E+01,

UNIO = 0.1E+01,

$END

```

Figure 2

BODY+SHOCK PTS

	X S	Y P	Q H	THETA RHO	M PT
2.350939232E-01	6.441418273E-01	5.954901872E+03	8.767613229E-01	1.049999554E+00	0.
6.642657948E+04	4.437314223E+04	1.662669132E+08	1.619327190E-03	0.	0.
2.279971312E-01	6.500534248E-01	6.332075186E+03	8.679162273E-01	1.120991082E+00	0.
6.620885998E+04	4.489474022E+04	1.639497359E+08	1.653346467E-03	0.	0.
2.373942435E-01	6.468635561E-01	5.954596207E+03	8.673318994E-01	1.052433683E+00	0.
6.642657948E+04	4.307798325E+04	1.653891849E+08	1.579747821E-03	8.009311401E+04	0.
2.214822293E-01	6.554803102E-01	6.686270489E+03	8.611436674E-01	1.188470421E+00	0.
6.599363039E+04	4.540485199E+04	1.616648377E+08	1.687554989E-03	0.	0.
2.404488724E-01	6.504476032E-01	5.976382038E+03	8.626227390E-01	1.056666045E+00	0.
6.642657948E+04	4.287087365E+04	1.652582217E+08	1.573318208E-03	8.009311401E+04	0.
2.154718238E-01	6.604869524E-01	7.020471474E+03	8.558793623E-01	1.252970121E+00	0.
6.577916222E+04	4.590722703E+04	1.593937141E+08	1.722232315E-03	0.	0.
2.439180499E-01	6.544769550E-01	6.003453024E+03	8.573056970E-01	1.061997743E+00	0.
6.642657948E+04	4.250707843E+04	1.650960688E+08	1.561575743E-03	8.009311400E+04	0.
2.098895729E-01	6.651369436E-01	7.337298558E+03	8.516774494E-01	1.314936374E+00	0.
6.556517087E+04	4.640386127E+04	1.571342015E+08	1.757495314E-03	0.	0.
2.477014425E-01	6.588223436E-01	6.048674568E+03	8.515440520E-01	1.070810443E+00	0.
6.642657948E+04	4.207747553E+04	1.648235609E+08	1.548202512E-03	8.009311400E+04	0.
2.046816801E-01	6.694750961E-01	7.638437330E+03	8.482877610E-01	1.374641639E+00	0.
6.535193062E+04	4.689511543E+04	1.548897253E+08	1.793363177E-03	0.	0.
2.517016128E-01	6.633622869E-01	6.097979528E+03	8.454932208E-01	1.080441570E+00	0.
6.642657948E+04	4.160948977E+04	1.645241157E+08	1.533608768E-03	8.009311401E+04	0.
1.999039734E-01	6.735382882E-01	7.925335375E+03	8.455068675E-01	1.432333859E+00	0.
6.513933586E+04	4.738123330E+04	1.526582961E+08	1.829895321E-03	0.	0.
2.558596891E-01	6.680233511E-01	6.149720477E+03	8.392470023E-01	1.090574203E+00	0.
6.642657948E+04	4.111894555E+04	1.642072619E+08	1.518282480E-03	8.009311401E+04	0.
1.952110754E-01	6.773640694E-01	8.199614766E+03	8.431620506E-01	1.488310276E+00	0.
6.492690394E+04	4.786233707E+04	1.504340909E+08	1.867186783E-03	0.	0.
2.601415062E-01	6.727625206E-01	6.202898511E+03	8.328599980E-01	1.101013972E+00	0.
6.642657948E+04	4.061558855E+04	1.638788799E+08	1.502524565E-03	8.009311401E+04	0.
1.908788331E-01	6.809728087E-01	8.462134734E+03	8.411773470E-01	1.542723228E+00	0.
6.471453052E+04	4.833851778E+04	1.482159090E+08	1.905300957E-03	0.	0.
2.645150471E-01	6.775410571E-01	6.257126759E+03	8.263921575E-01	1.111693075E+00	0.

Figure 3

XCL	Y	S	P	X
0.	0.	6.63771505E+04	8.23798913E+04	0.
3.05617151E-04	2.38022945E-02	6.63768433E+04	8.23217647E+04	2.47237829E-02
1.15244400E-03	4.76045890E-02	6.63759072E+04	8.21504048E+04	4.80139611E-02
2.56585963E-03	7.14068835E-02	6.63743315E+04	8.18648376E+04	7.16513455E-02
4.54886810E-03	9.52091780E-02	6.63721301E+04	8.14651309E+04	9.54182476E-02
7.10554445E-03	1.19011472E-01	6.63693186E+04	8.09514154E+04	1.19280973E-01
1.07409998E-02	1.42813767E-01	6.63658954E+04	8.03239180E+04	1.43237756E-01
1.39614534E-02	1.66616062E-01	6.63618328E+04	7.95829928E+04	1.67296515E-01
1.82743294E-02	1.90419356E-01	6.63570640E+04	7.87291525E+04	1.91469375E-01
3.46786637E+02	3.12562876E+01	6.64265795E+04	8.73135277E+02	3.48678504E+02
3.48493199E+02	3.14055925E+01	6.64265795E+04	8.73121593E+02	3.50391584E+02
3.50163579E+02	3.15517319E+01	6.64265795E+04	8.73108332E+02	3.52068345E+02
3.52330323E+02	3.17412976E+01	6.64265795E+04	8.73095413E+02	3.54243366E+02
3.54336586E+02	3.19168229E+01	6.64265795E+04	8.73086819E+02	3.56257292E+02
3.56840722E+02	3.21359066E+01	6.64265795E+04	8.73079509E+02	3.58770994E+02
3.59173091E+02	3.23399624E+01	6.64265795E+04	8.73074999E+02	3.61112272E+02
YS	S			
0.	6.63550253E+04			
4.76045890E-02	6.63365946E+04			
9.52091780E-02	6.62913295E+04			
1.42813767E-01	6.61892724E+04			
1.90418356E-01	6.60605121E+04			
2.38022945E-01	6.58952153E+04			
2.85627534E-01	6.56936475E+04			
3.33232123E-01	6.54561844E+04			
3.80836712E-01	6.51833386E+04			
4.28441301E-01	6.48758421E+04			
4.76045890E-01	6.45327507E+04			
5.23650479E-01	6.41584196E+04			
5.71255069E-01	6.37554612E+04			
6.18859657E-01	6.33284298E+04			
6.66464246E-01	6.29735615E+04			
7.10765960E-01	6.24235728E+04			
7.17789191E-01	6.23499531E+04			
7.24930764E-01	6.22746193E+04			
7.32145333E-01	6.21976852E+04			
7.39455866E-01	6.21190523E+04			
7.46848360E-01	6.20387883E+04			
7.54322201E-01	6.19569352E+04			

Figure 4

X	S	P	RB	XC	T	H	U	A	M	RHO
1.500E+01	6.643E+04	8.373E+02	2.174E+00	1.438E+01	7.110E+03	8.515E+07	1.400E+04	4.185E+03	3.345E+00	1.875E-03
1.510E+01	6.643E+04	8.340E+02	2.183E+00	1.448E+01	7.106E+03	8.509E+07	1.400E+04	4.183E+03	3.347E+00	1.869E-03
1.520E+01	6.643E+04	8.310E+02	2.192E+00	1.458E+01	7.101E+03	8.504E+07	1.401E+04	4.181E+03	3.349E+00	1.863E-03
1.530E+01	6.643E+04	8.280E+02	2.200E+00	1.468E+01	7.097E+03	8.499E+07	1.401E+04	4.180E+03	3.352E+00	1.859E-03
1.540E+01	6.643E+04	8.250E+02	2.209E+00	1.478E+01	7.093E+03	8.494E+07	1.401E+04	4.178E+03	3.354E+00	1.852E-03
1.550E+01	6.643E+04	8.219E+02	2.218E+00	1.488E+01	7.089E+03	8.489E+07	1.402E+04	4.177E+03	3.356E+00	1.847E-03
1.560E+01	6.643E+04	8.189E+02	2.227E+00	1.498E+01	7.085E+03	8.483E+07	1.402E+04	4.175E+03	3.358E+00	1.841E-03

1.951E+02	6.643E+04	8.866E+02	1.787E+01	1.938E+02	7.177E+03	8.598E+07	1.394E+04	4.209E+03	3.311E+00	1.963E-03
2.051E+02	6.643E+04	8.846E+02	1.874E+01	2.038E+02	7.174E+03	8.595E+07	1.394E+04	4.208E+03	3.313E+00	1.961E-03
2.151E+02	6.643E+04	8.825E+02	1.961E+01	2.137E+02	7.171E+03	8.592E+07	1.394E+04	4.207E+03	3.314E+00	1.957E-03
2.251E+02	6.643E+04	8.807E+02	2.049E+01	2.237E+02	7.169E+03	8.588E+07	1.395E+04	4.207E+03	3.315E+00	1.954E-03
2.360E+02	6.643E+04	8.791E+02	2.143E+01	2.345E+02	7.167E+03	8.586E+07	1.395E+04	4.206E+03	3.316E+00	1.951E-03
2.478E+02	6.643E+04	8.777E+02	2.246E+01	2.463E+02	7.165E+03	8.583E+07	1.395E+04	4.205E+03	3.317E+00	1.948E-03
2.606E+02	6.643E+04	8.764E+02	2.358E+01	2.590E+02	7.163E+03	8.581E+07	1.395E+04	4.205E+03	3.318E+00	1.946E-03
2.745E+02	6.643E+04	8.754E+02	2.479E+01	2.729E+02	7.162E+03	8.580E+07	1.395E+04	4.204E+03	3.319E+00	1.944E-03
2.896E+02	6.643E+04	8.747E+02	2.611E+01	2.879E+02	7.161E+03	8.579E+07	1.395E+04	4.204E+03	3.319E+00	1.943E-03
3.060E+02	6.643E+04	8.740E+02	2.753E+01	3.043E+02	7.160E+03	8.577E+07	1.395E+04	4.203E+03	3.320E+00	1.942E-03
3.238E+02	6.643E+04	8.735E+02	2.909E+01	3.220E+02	7.159E+03	8.577E+07	1.395E+04	4.203E+03	3.320E+00	1.941E-03
3.431E+02	6.643E+04	8.732E+02	3.077E+01	3.412E+02	7.159E+03	8.576E+07	1.395E+04	4.203E+03	3.320E+00	1.940E-03
3.641E+02	6.643E+04	8.731E+02	3.260E+01	3.621E+02	7.159E+03	8.576E+07	1.395E+04	4.203E+03	3.320E+00	1.940E-03
3.869E+02	6.643E+04	8.731E+02	3.458E+01	3.848E+02	7.159E+03	8.576E+07	1.395E+04	4.203E+03	3.320E+00	1.940E-03
4.116E+02	6.643E+04	8.731E+02	3.674E+01	4.095E+02	7.159E+03	8.576E+07	1.395E+04	4.203E+03	3.320E+00	1.940E-03

X	NU/DX	DRHO/DX	DP/DX	DRB/DX
1.500E+01	4.644E+01	-6.855E-05	-3.755E+01	9.715E-02
1.510E+01	3.800E+01	-5.603E-05	-3.067E+01	8.716E-02
1.520E+01	3.732E+01	-5.498E-05	-3.007E+01	8.716E-02
1.530E+01	3.758E+01	-5.530E-05	-3.022E+01	8.716E-02
1.540E+01	3.758E+01	-5.524E-05	-3.016E+01	8.716E-02
1.550E+01	3.768E+01	-5.533E-05	-3.019E+01	8.716E-02
1.560E+01	3.781E+01	-5.546E-05	-3.023E+01	8.716E-02
1.570E+01	3.526E+01	-5.167E-05	-2.814E+01	8.716E-02
1.580E+01	3.321E+01	-4.862E-05	-2.646E+01	8.716E-02
1.590E+01	3.374E+01	-4.935E-05	-2.683E+01	8.716E-02
1.600E+01	3.375E+01	-4.930E-05	-2.679E+01	8.716E-02
1.610E+01	3.380E+01	-4.933E-05	-2.678E+01	8.716E-02
1.630E+01	3.194E+01	-4.653E-05	-2.522E+01	8.716E-02
1.650E+01	2.985E+01	-4.340E-05	-2.349E+01	8.716E-02

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Figure 5

H0= 6.131E+00 00= 9.285E+07

Figure 6

SKIN FRICTION THEORY

- (1) VAN DRIEST RETHETA
- (2) VAN DRIEST REX OMIT IN TRANS REGION
- (3) SPALDING CHI REX OMIT IN TRANS REGION
- (4) ECKERTS REF ENTHALPY REX OMIT IN TRANS REGION
- (5) ECKERTS REF ENTHALPY REXMIN OMIT IN TRANS REGION
- (6) ECKERTS RETHETA
- (7) SPALDING CHI I RETHETA IDEAL FC
- (8) SPALDING CHI II RETHETA REAL FC

RAF	CFMT	CF2	ENST	HDAR	Q	NH	XX1	HBCF	QXCF	HHCF		
X/L	X	THETA/L	THETA	P	RB	S	S/ST	T	H	H/HT	RHO	
RHO/RHOI	U	U/SORT2HT	U/UI	A	M	MU	RETH	REX	TW	HW	HW/HT	
RHOW	TW/T	TAW	FRTH	FC	CFMT	LVO	Z	CFI	CF2	HAW	HAW/HT	
HP	TP	PRP	PRW	F(1)	F(2)	A(2)	ALPH(3)	N	INT1	INT2	INT3	
INT4	INT5	INT6	INT7	DEL/L	DEL	RSL	DELS/L	DELS	X/DELS	DSTH	DU	
DRHO	DP	DRB	DTHETA	NST	HBAR	O	PRE	EKF	QIN	OKF	QXTR	
QXMH	KC	RHOUSD	TAU									
1.000E+00	0.	1.017E-03	1.017E-03	1.439E-01	2.194E+06	2.348E-02	0.	0.	0.	0.		
1.500E+01	1.524E-01	3.831E-02	3.853E-04	4.009E+04	2.174E+00	1.095E+04	9.736E-01	3.753E+03	7.316E+06	4.300E-01	3.214E-02	
2.623E-01	4.404E+03	7.550E-01	7.597E-01	1.223E+03	3.601E+00	8.683E-05	0.	0.	6.763E+02	6.944E+05	4.082E-02	
2.046E-01	1.802E-01	6.977E+03	2.018E+01	0.	0.	0.	0.	0.	1.017E-03	1.595E+07	9.373E-01	
5.904E+06	3.380E+03	6.964E-01	7.443E-01	8.855E-01	5.122E-01	3.733E-03	1.260E+00	1.540E+00	2.270E-01	1.868E-01	2.950E-01	
4.227E-02	3.976E-02	7.050E-01	4.780E-01	1.655E-01	1.681E-03	3.248E-01	4.942E-02	5.021E-04	3.035E+02	1.290E+00	1.415E+01	
-1.098E-03	-1.798E+03	8.715E-02	4.395E-04	1.017E-03	1.459E-01	2.363E-02	7.385E-01	1.000E+00	2.194E+06	2.194E+06	1.135E+04	
1.135E+04	1.438E+01	6.233E+05	6.338E+02									
1.000E+00	1.176E+00	2.576E-03	2.576E-03	3.645E-01	5.555E+06	5.945E-02	0.	3.099E-01	4.724E+06	5.055E-02		
1.273E+00	1.176E+00	3.059E-03	3.892E-03	5.507E-01	8.394E+06	8.983E-02	0.	4.683E-01	7.138E+06	7.638E-02		
1.273E+00	1.668E+00	2.441E-03	3.107E-03	4.396E-01	6.700E+06	7.170E-02	0.	2.632E-01	4.016E+06	4.298E-02		
1.273E+00	1.668E+00	3.321E-03	4.227E-03	5.990E-01	9.115E+06	9.754E-02	0.	3.595E-01	5.464E+06	5.847E-02		
1.501E+01	1.525E-01	3.834E-02	3.895E-04	4.007E+04	2.175E+00	1.095E+04	9.736E-01	3.753E+03	7.315E+06	4.300E-01	3.213E-02	
2.622E-01	4.404E+03	7.550E-01	7.597E-01	1.223E+03	3.601E+00	8.682E-05	6.347E+02	2.486E+05	6.763E+02	6.943E+05	4.081E-02	
2.046E-01	1.802E-01	6.977E+03	2.018E+01	9.633E-01	1.176E+00	0.	0.	0.	2.576E-03	1.595E+07	9.373E-01	
5.903E+06	3.380E+03	6.964E-01	7.443E-01	8.855E-01	5.122E-01	3.732E-03	1.260E+00	1.540E+00	2.269E-01	1.868E-01	2.950E-01	
4.220E-02	3.973E-02	7.050E-01	4.780E-01	1.656E-01	1.683E-03	3.250E-01	4.946E-02	5.025E-04	3.035E+02	1.290E+00	1.383E+01	
-1.073E-03	-1.757E+03	8.715E-02	1.978E-03	2.576E-03	3.645E-01	5.983E-02	7.384E-01	1.000E+00	5.555E+06	5.555E+06	1.135E+04	
1.135E+04	1.439E+01	6.231E+05	1.605E+03									
1.000E+00	1.176E+00	2.575E-03	2.575E-03	3.641E-01	5.550E+06	5.939E-02	0.	3.096E-01	4.719E+06	5.050E-02		
1.273E+00	1.176E+00	3.057E-03	3.892E-03	5.532E-01	8.387E+06	8.975E-02	0.	4.679E-01	7.131E+06	7.632E-02		
1.273E+00	1.668E+00	2.440E-03	3.106E-03	4.391E-01	6.693E+06	7.162E-02	0.	2.632E-01	4.012E+06	4.294E-02		
1.273E+00	1.668E+00	3.320E-03	4.225E-03	5.974E-01	9.106E+06	9.744E-02	0.	3.582E-01	5.459E+06	5.842E-02		

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Figure 6 (cont.)

1.894E+02	1.974E+03	1.132E-01	1.150E-03	4.249E+04	1.737E+01	9.006E+03	8.005E-01	1.659E+03	1.849E+06	1.096E-01	8.951E-02
7.223E-01	5.507E+03	9.441E-01	9.500E-01	7.876E+02	6.975E+00	5.568E-05	1.007E+04	1.684E+07	7.166E+02	7.377E+05	4.337E-02
2.347E-01	4.321E-01	6.760E+03	1.019E+01	1.935E+00	1.176E+00	0.	0.	0.	7.349E-04	1.534E+07	9.020E-01
4.262E+06	2.957E+03	6.354E-01	7.458E-01	9.056E-01	9.080E-01	-2.413E-05	1.042E+00	6.110E+00	6.305E-02	2.053E-02	3.966E-01
8.168E-03	1.235E-03	6.034E-01	5.404E-01	1.742E+00	1.770E-02	5.152E+00	7.015E-01	7.127E-03	2.700E+02	6.196E+00	2.321E-02
-1.873E-06	-3.095E+00	8.716E-02	1.708E-04	7.348E-04	3.582E-01	5.631E-02	7.675E-01	1.000E+00	5.228E+06	5.228E+06	4.030E+06
1.135E+04	1.981E+02	2.684E+06	1.972E+03								
1.000E+00	1.176E+00	6.703E-04	6.703E-04	3.578E-01	5.206E+06	5.837E-02	0.	3.043E-01	4.427E+06	4.963E-02	
1.000E+00	1.176E+00	8.862E-04	8.862E-04	4.731E-01	6.883E+06	7.717E-02	0.	4.023E-01	5.853E+06	6.562E-02	
1.352E+00	1.333E+00	7.962E-04	1.076E-03	5.747E-01	9.361E+06	9.373E-02	0.	4.310E-01	6.270E+06	7.030E-02	
1.352E+00	1.176E+00	2.237E-03	3.024E-03	1.615E+00	2.349E+07	2.633E-01	0.	1.373E+00	1.997E+07	2.239E-01	
1.352E+00	1.176E+00	1.520E-03	2.054E-03	1.077E+00	1.596E+07	1.789E-01	0.	9.326E-01	1.357E+07	1.521E-01	
1.352E+00	1.176E+00	8.279E-04	1.119E-03	5.976E-01	8.694E+06	9.747E-02	0.	5.081E-01	7.393E+06	8.288E-02	
1.352E+00	1.333E+00	5.755E-04	7.780E-04	4.153E-01	6.043E+06	6.774E-02	0.	3.115E-01	4.532E+06	5.081E-02	
1.352E+00	1.333E+00	7.112E-04	9.615E-04	5.133E-01	7.468E+06	8.372E-02	0.	3.850E-01	5.601E+06	6.279E-02	
2.054E+02	2.087E+00	1.158E-01	1.176E-03	4.235E+04	1.877E+01	8.894E+03	7.905E-01	1.517E+03	1.673E+06	9.832E-02	9.639E-02
7.865E-01	5.539E+03	9.476E-01	9.555E-01	7.580E+02	7.300E+00	5.295E-05	1.186E+04	2.104E+07	7.430E+02	7.667E+05	4.507E-02
1.967E-01	4.896E-01	6.745E+03	9.063E+00	2.088E+03	1.176E+00	0.	0.	0.	6.703E-04	1.533E+07	3.008E-01
4.223E+06	2.944E+03	6.362E-01	7.467E-01	9.047E-01	9.557E-01	-5.100E-04	1.022E+00	6.530E+00	5.680E-02	1.857E-02	4.145E-01
7.975E-03	1.035E-03	5.855E-01	5.237E-01	1.973E+03	2.305E-02	5.885E+00	8.308E-01	8.441E-03	2.472E+02	7.176E+00	7.691E-02
-6.200E-06	-1.024E+01	8.716E-02	1.459E-04	6.703E-04	3.578E-01	5.607E-02	7.671E-01	1.000E+00	5.206E+06	5.206E+06	4.059E+06
1.135E+04	2.040E+02	2.957E+06	1.982E+03								
1.000E+00	1.176E+00	6.163E-04	6.163E-04	3.573E-01	5.184E+06	5.827E-02	0.	3.039E-01	4.409E+06	4.955E-02	
1.000E+00	1.176E+00	7.544E-04	7.544E-04	4.373E-01	6.345E+06	7.132E-02	0.	3.718E-01	5.396E+06	6.065E-02	
1.351E+00	1.317E+00	6.827E-04	9.223E-04	5.346E-01	7.758E+06	8.720E-02	0.	4.058E-01	5.989E+06	6.619E-02	
1.351E+00	1.176E+00	2.012E-03	2.719E-03	1.576E+00	2.287E+07	2.570E-01	0.	1.340E+00	1.945E+07	2.186E-01	
1.351E+00	1.176E+00	1.498E-03	2.024E-03	1.173E+00	1.702E+07	1.913E-01	0.	9.974E-01	1.447E+07	1.627E-01	
1.351E+00	1.176E+00	7.516E-04	1.015E-03	5.886E-01	8.541E+06	9.600E-02	0.	5.005E-01	7.263E+06	8.164E-02	
1.351E+00	1.317E+00	5.265E-04	7.113E-04	4.123E-01	5.983E+06	6.724E-02	0.	3.130E-01	4.541E+06	5.104E-02	
1.351E+00	1.317E+00	6.395E-04	8.639E-04	5.008E-01	7.267E+06	8.168E-02	0.	3.801E-01	5.516E+06	6.200E-02	
2.214E+02	2.249E+00	1.179E-01	1.198E-03	4.220E+04	2.016E+01	8.793E+03	7.816E-01	1.399E+03	1.520E+06	8.982E-02	1.042E-01
9.500E-01	5.565E+03	9.540E-01	9.600E-01	7.297E+02	7.626E+00	5.055E-05	1.373E+04	2.579E+07	7.629E+02	7.888E+05	4.637E-02
1.908E-01	5.453E-01	6.733E+03	8.222E+00	2.238E+00	1.176E+00	0.	0.	0.	6.163E-04	1.531E+07	8.999E-01
4.190E+06	2.934E+03	6.368E-01	7.475E-01	9.038E-01	1.006E+00	-1.017E-03	1.002E+00	6.958E+00	5.156E-02	1.694E-02	4.302E-01
7.761E-03	8.794E-04	5.698E-01	5.183E-01	2.210E+00	2.245E-02	6.644E+00	9.653E-01	9.809E-03	2.293E+02	8.189E+00	6.397E-02
-5.144E-06	-8.495E+00	8.716E-02	1.183E-04	6.163E-04	3.573E-01	5.583E-02	7.648E-01	1.000E+00	5.184E+06	5.184E+06	4.078E+06
6.379E+06	2.200E+02	3.226E+06	1.988E+03								

Figure 6 (cont.)

Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
6.60318940E-02	6.26710054E-01	2.55947834E+08	4.19331041E-01	2.62799979E-01	6.26710054E-01	3.12916995E+03	3.30731544E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
1.38863688E-02	4.79388116E-01	2.63066796E+08	4.13044031E-01	1.98009400E-01	4.79388116E-01	3.16312940E+03	2.51117634E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
1.33998106E-01	7.07843269E-01	2.36931426E+08	4.38322410E-01	3.10263567E-01	7.07843269E-01	3.02993246E+03	3.81499676E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
1.86113631E-01	7.48971926E-01	2.23196113E+08	4.53241882E-01	3.39465445E-01	7.48971926E-01	2.95259800E+03	4.09952956E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
2.66701894E-01	7.96398322E-01	2.03937095E+08	4.77743294E-01	3.80473959E-01	7.96398322E-01	2.93162413E+03	4.45897654E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
2.13886369E-01	7.67096353E-01	2.16268639E+08	4.61819446E-01	3.54260012E-01	7.67096353E-01	2.90962549E+03	4.23270990E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
3.33998106E-01	8.28181470E-01	1.89980153E+09	4.99916701E-01	4.14021749E-01	8.28181470E-01	2.72671260E+03	4.72447388E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
3.86113631E-01	8.49094770E-01	1.78246239E+08	5.18577720E-01	4.40316444E-01	8.49094770E-01	2.64165892E+03	4.91475862E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
4.66701894E-01	8.76983970E-01	1.62811066E+08	5.50425066E-01	4.82713705E-01	8.76983970E-01	2.50378662E+03	5.19420470E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
4.13886369E-01	8.59284484E-01	1.72750279E+08	5.29337656E-01	4.54851634E-01	8.59284484E-01	2.59393880E+03	5.01371878E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
5.33998106E-01	8.97760712E-01	1.50492614E+09	5.92132951E-01	5.22616003E-01	8.97760712E-01	2.37654097E+03	5.43131813E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
5.86113631E-01	9.12248401E-01	1.41486862E+09	6.09739949E-01	5.56234292E-01	9.12248401E-01	2.27349249E+03	5.61721069E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M

Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
6.66001894E-01	9.32509294E-01	1.28317226E+08	6.59230290E-01	6.14738380E-01	9.32509294E-01	2.10704742E+03	5.92122034E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
6.13886369E-01	9.19537846E-01	1.36824227E+08	6.26165281E-01	5.75782673E-01	9.19537846E-01	2.21574246E+03	5.72058792E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
7.33998106E-01	9.49224643E-01	1.17643539E+08	7.08697521E-01	6.72004455E-01	9.48224643E-01	1.96135507E+03	6.20642508E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
7.86113631E-01	9.59472624E-01	1.09757033E+08	7.52656180E-01	7.22153000E-01	9.59472624E-01	1.84674885E+03	6.44690878E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
8.66001894E-01	9.75570564E-01	9.81114579E+07	8.29528611E-01	8.09263694E-01	9.75570564E-01	1.67453481E+03	6.84873954E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
8.13886369E-01	9.65216564E-01	1.05650187E+08	7.78223223E-01	7.51153946E-01	9.65216564E-01	1.78576716E+03	6.58301608E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
9.33998106E-01	9.89330269E-01	8.95809415E+07	9.08761076E-01	8.98156079E-01	9.88330269E-01	1.52786259E+03	7.23603037E+00
Y/D	U/UE	H	RHO/RHOE	RHOU/RHOEUE	HBAR	T	M
9.86113631E-01	9.97598912E-01	8.14916930E+07	9.79035946E-01	9.76685195E-01	9.97598912E-01	1.41814742E+03	7.56264640E+00

Figure 6 (cont.)

1.000E+00	1.176E+00	6.115E-04	6.115E-04	3.572E-01	5.182E+06	5.826E-02	0.	3.037E-01	4.407E+06	4.954E-02	
1.000E+00	1.176E+00	7.443E-04	7.443E-04	4.348E-01	6.308E+06	7.091E-02	0.	3.697E-01	5.366E+06	6.030E-02	
1.351E+00	1.316E+00	6.737E-04	9.102E-04	5.317E-01	7.714E+06	8.672E-02	0.	4.041E-01	5.863E+06	6.591E-02	
1.351E+00	1.176E+00	1.997E-03	2.628E-03	1.576E+00	2.280E+07	2.570E-01	0.	1.340E+00	1.944E+07	2.186E-01	
1.351E+00	1.176E+00	1.494E-03	2.021E-03	1.190E+00	1.713E+07	1.925E-01	0.	1.004E+00	1.456E+07	1.637E-01	
1.351E+00	1.176E+00	7.446E-04	1.006E-03	5.876E-01	8.526E+06	9.585E-02	0.	4.997E-01	7.250E+06	8.150E-02	
1.351E+00	1.316E+00	5.220E-04	7.052E-04	4.120E-01	5.977E+06	6.719E-02	0.	3.131E-01	4.542E+06	5.107E-02	
1.351E+00	1.316E+00	6.331E-04	8.553E-04	4.996E-01	7.248E+06	8.149E-02	0.	3.797E-01	5.509E+06	6.193E-02	
2.230E+02	2.266E+00	1.181E-01	1.200E-03	4.218E+04	2.030E+01	8.784E+03	7.808E-01	1.388E+03	1.515E+06	8.907E-02	1.049E-01
8.562E-01	5.567E+03	9.544E-01	9.604E-01	7.271E+02	7.657E+00	5.033E-05	1.392E+04	2.630E+07	7.647E+02	7.900E+05	4.644E-02
1.904E-01	5.508E-01	6.732E+03	8.148E+00	2.253E+00	1.176E+00	2.446E+02	1.368E+02	0.	6.115E-04	1.531E+07	8.998E-01
4.187E+06	2.934E+03	6.368E-01	7.475E-01	9.038E-01	1.011E+00	-1.069E-03	1.000E+00	5.817E+00	5.559E-02	1.605E-02	4.632E-01
8.441E-03	9.631E-04	5.368E-01	4.812E-01	2.057E+00	2.090E-02	6.256E+00	9.659E-01	9.814E-03	2.309E+02	8.181E+00	6.245E-02
5.020E+06	-8.290E+00	8.716E-02	1.146E-04	6.115E-04	3.572E-01	5.581E-02	7.645E-01	1.000E+00	5.182E+06	5.182E+06	4.090E+06
6.221E+06	2.216E+02	3.252E+06	1.969E+03								

1.000E+00	1.176E+00	3.459E-04	3.459E-04	3.713E-01	5.338E+06	6.056E-02	0.	3.157E-01	4.539E+06	5.150E-02	
1.346E+00	1.171E+00	2.915E-04	3.922E-04	4.210E-01	6.053E+06	6.808E-02	0.	3.597E-01	5.171E+06	5.866E-02	
1.346E+00	1.176E+00	1.477E-03	1.987E-03	2.133E+00	3.067E+07	3.479E-01	0.	1.814E+00	2.608E+07	2.958E-01	
1.346E+00	1.176E+00	1.345E-03	1.810E-03	1.943E+00	2.794E+07	3.170E-01	0.	1.653E+00	2.376E+07	2.695E-01	
1.346E+00	1.176E+00	3.706E-04	4.987E-04	5.353E-01	7.696E+06	8.731E-02	0.	4.552E-01	6.544E+06	7.425E-02	
1.346E+00	1.171E+00	2.606E-04	3.507E-04	3.764E-01	5.412E+06	6.140E-02	0.	3.215E-01	4.623E+06	5.245E-02	
1.346E+00	1.171E+00	3.059E-04	4.116E-04	4.419E-01	6.353E+06	7.208E-02	0.	3.775E-01	5.427E+06	6.157E-02	
3.974E+02	4.037E+00	1.265E-01	1.265E-03	4.180E+04	3.550E+01	8.100E+03	7.199E-01	7.651E+02	7.910E+05	4.650E-02	1.885E-01
1.538E+00	5.696E+03	9.765E-01	9.826E-01	5.484E+02	1.039E+01	3.522E-05	3.916E+04	1.231E+08	8.112E+02	8.421E+05	4.950E-02
1.777E-01	1.060E+00	6.667E+03	4.860E+00	3.714E+00	1.176E+00	4.681E+02	3.013E+02	0.	3.333E-04	1.523E+07	8.951E-01
3.993E+06	2.870E+03	6.406E-01	7.492E-01	8.969E-01	1.011E+00	-1.145E-03	1.000E+00	7.874E+00	3.136E-02	7.933E-03	5.585E-01
6.098E-03	3.253E-04	4.415E-01	4.101E-01	3.884E+00	3.946E-02	1.403E+01	2.194E+00	2.229E-02	1.812E+02	1.735E+01	1.756E-04
1.405E-08	-2.318E-02	8.715E-02	2.284E-05	3.333E-04	3.577E-01	3.539E-02	7.475E-01	1.000E+00	5.143E+06	5.143E+06	4.209E+06
4.603E+06	3.953E+02	6.114E+06	2.028E+03								

TOLL = 0.

Figure 7

	REX2	X2REX	EN2REX	CEN	CEB	CF2REX	CENP	CERP	XHIN	RSISAV	ENI	CF2I
0.	REFSAV	2.230E+02	5.824E+00	4.284E+00	1.923E-02	6.115E-04	-4.054E-04	9.640E-01	1.500E+01	0.	1.540E+00	1.017E-03
0.												

APPENDIX

LANGLEY LIBRARY SUBROUTINES

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SECTION: D 4.1
INITIALS: VPA
DATE: 8-1-68

COMPUTER PROGRAMING MANUAL

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FUNCTION DIF

LANGUAGE: FORTRAN

PURPOSE: This is a function subprogram which differentiates the function at any given point in a table of supplied values.

USE: R = DIF (L, M, NP, VARI, VARD)

L An integer, the point at which the function is differentiated.

M An integer from 1 - 5 to determine the point formula, N, where $N = 2M + 1$. If M is not in this range, the derivative is set to INDEFINITE.

NP An integer, the number of points in the table.

VARI A one-dimensional array of the independent variable.

VARD A one-dimensional array of the dependent variable.

R The result.

RESTRICTIONS: The maximum N for the formula (see Method below) is 11, that is, M may not exceed 5. The differentiation is indefinite for an invalid M.

The answer will be I, indefinite, for M out of range or $N > NP$.

The two arrays must be dimensioned in the calling program as indicated: VARI(NP), VARD(NP).

METHOD: The Lagrangian N-point formula (N always odd) is used.

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DIF

$$\frac{dY}{dX} = \prod_{j=0}^{j=n} (x_k - x_j)_{j \neq k} \left[\sum_{i=0}^{i=n} \frac{Y_i}{D_{ik}} \right]_{i \neq k} +$$

$$Y_k \sum_{j=0}^{j=n} (x_k - x_j)^{-1}_{j \neq k}$$

where

$$D_{ik} = (x_k - x_i) P_i(x_i) \quad (i \neq k)$$

$$P_i(x_i) = \prod_{j=0}^{j=n} (x_i - x_j) \quad (j \neq i)$$

N points are required to differentiate where N is odd. $N = 2*M + 1$, $M = (N - 1)/2$

The following table shows the value of the discrete point, L, the value of k, and the points used for the differentiation.

NP = last point of the table.

<u>L</u>	<u>K</u>	<u>POINTS FROM TABLE</u>
1, 2, . . . M+1	L	1, 2, . . . N
M+2, M+3, . . . NP-M	M+1	L-M, . . . L+M
NP-M+1, NP-M+2, . . . NP	L-(NP-N)	NP-N+1, NP-N+2, . . . NP

ACCURACY: The accuracy is a function of the chosen M and the number of points in the supplied tables.

REFERENCE: K. L. Neilson, Methods in Numerical Analysis, pp. 150-154

STORAGE: DIF 2178 locations

SOURCE: NASA, LRC, Vivian P. Adair

RESPONSIBLE PERSON: Vivian P. Adair

	FUNCTION DIF (L,M,NP,VARI,VARD)	DIF	1
C		DIF	2
C	THIS FUNCTION SUBPROGRAM FINDS THE DERIVATIVE AT A GIVEN POINT,	DIF	3
C	L. FOR THE DESIRED X AND Y IN A GIVEN TABLE. THE N-POINT	DIF	4
C	LAGRANGIAN FORMULA IS USED WHERE N IS ODD.	DIF	5
C		DIF	6
C	L = INTEGER, THE POINT OF X AND Y AT WHICH DERIVATIVE IS FOUND	DIF	7
C	M = INTEGER, 1-5, TO DETERMINE THE POINT FORMULA, N. N=2*M+1	DIF	8
C	NP= INTEGER, THE NUMBER OF POINTS IN TABLE OF VARIABLES	DIF	9
C	VARI = ARRAY OF INDEPENDENT VARIABLE, X. VARI(NP)	DIF	10
C	VARD = ARRAY OF DEPENDENT VARIABLE, Y. VARD(NP)	DIF	11
C		DIF	12
C	DIMENSION VARI(NP), VARD(NP), X(11), Y(11)	DIF	13
C		DIF	14
	DIF=0177700000000000000000	DIF	15
	IF (M.LT.1) RETURN	DIF	16
	N=2*M+1	DIF	17
	IF (M.GT.5.OR.N.GT.NP) RETURN	DIF	18
	M1=M+1	DIF	19
	M2=NP-M+1	DIF	20
	K=L	DIF	21
	IF (L.LE.M1.OR.N.EQ.NP) GO TO 1	DIF	22
	K=M1	DIF	23
	IF (L.LT.M2) GO TO 1	DIF	24
	K=L-(NP-N)	DIF	25
1	MX=L-K	DIF	26
	DO 2 J=1,N	DIF	27
	MJ=MX+J	DIF	28
	X(J)=VARI(MJ)	DIF	29
2	Y(J)=VARD(MJ)	DIF	30
	A=1.	DIF	31
	B=0.	DIF	32
	C=0.	DIF	33
	DO 4 J=1,N	DIF	34
	IF (J.EQ.K) GO TO 4	DIF	35
	P=1.	DIF	36
	DO 3 I=1,N	DIF	37
	IF (I.EQ.J) GO TO 3	DIF	38
	P=P*(X(J)-X(I))	DIF	39
3	CONTINUE	DIF	40
	T=X(K)-X(J)	DIF	41
	B=B+Y(J)/(P*T)	DIF	42

4
A=A*T
C=C+1./T
CONTINUE
DIF=A*B+Y(K)*C
RETURN
END

DIF 43
DIF 44
DIF 45
DIF 46
DIF 47
DIF 48-



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COMPUTER PROGRAMING MANUAL

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SUBROUTINE DISCOT

LANGUAGE: FORTRAN

PURPOSE: SINGLE OR DOUBLE INTERPOLATION SUBROUTINE FOR
CONTINUOUS OR DISCONTINUOUS FUNCTIONS

Given some function with two independent variables, x and z , this subroutine performs K_x th and K_z th order interpolation to calculate the dependent variable. In this subroutine all single line functions are read in as two separate arrays and all multi-line functions are read in as three separate arrays, i.e.

X_i $i = 1, 2, \dots, L$

Y_j $j = 1, 2, \dots, M$

Z_k $k = 1, 2, \dots, N$

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

XA - The X argument.

ZA - The Z argument (may be the same name as X on single lines).

TABX - A one-dimensional array of X's.

TABY - A one-dimensional array of Y's.

TABZ - A one-dimensional array of Z's.

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

(1) If $NX = NY$, the sign is -. If $NX \neq NY$, NX is computed by DISCOT as $NX = NY/NZ$. The sign is + and may be omitted if desired.

(2) A 1 in the hundreds position of the word indicates that no extrapolation occurs

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DISCOT

above Z max. With a zero in this position extrapolation occurs when $Z > Z_{max}$. The zero may be omitted if desired.

(3) 1-7 in the tens position of the word indicates the order of interpolation in the X direction.

(4) 1-7 in the units position of the word indicates the order of interpolation in the Z direction.

NY - The number of points in the Y array.

NZ - The number of points in the Z array.

ANS - The dependent variable Y.

The following programs will illustrate various ways to use DISCOT.

Case I. Given $Y = f(x)$

NY = 50
NX (number of points in X array) = NY
Extrapolation when $Z > Z_{max}$
Second order interpolation in X direction
No interpolation in Z direction
Control word = -020

```
1.  DIMENSION TABX (50), TABY (50)
    1  FORMAT (8E 9.5)
      READ (5, 1) TABX, TABY
      READ (5, 1) XA
      CALL DISCOT (XA, XA, TABX, TABY, TABY,
        -020, 50, 0, ANS)
```

Case II Given $Y = f(x, z)$

NY = 800
NZ = 10
NX = NY/NZ (computed by DISCOT)
Extrapolation when $Z > Z_{max}$
Linear interpolation in X direction
Linear interpolation in Z direction
Control word = 11



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```
DIMENSION TABX (800), TABY (800), TABZ (10)
1 FORMAT (8E 9.5)
READ (5, 1) TABX, TABY, TABZ
READ (5, 1) XA, ZA
CALL DISCOT ( XA, ZA, TABX, TABY, TABZ,
11, 800, 10, ANS)
```

Case III. Given $Y = f(x, z)$

```
NY = 800
NZ = 10
NX = NY
Extrapolation when  $Z > Z_{max}$ 
Seventh order interpolation in X direction
Third order interpolation in Z direction
Control word = -73
```

```
DIMENSION TABX (800), TABY(800), TABZ (10)
1 FORMAT (8E 9.5)
READ (5, 1) TABX, TABY, TABZ
READ (5, 1) XA, ZA
CALL DISCOT (XA, ZA, TABX, TABY, TABZ,
-73, 800, 10, ANS)
```

Case IV. Same as Case III with no extrapolation above Z_{max} . Control word = -173

```
CALL DISCOT (XA, ZA, TABX, TABY, TABZ, -173,
800, 10, ANS)
```

RESTRICTIONS: See 4c of METHOD for restrictions on tabulating arrays and discontinuous functions. The order of interpolation in the X and Z directions may be from 1-7.

The following subprograms are used by DISCOT:
UNS, DISSER, LAGRAN.

METHOD: Lagrange's interpolation formula is used in both the X and Z direction for interpolation. This method is explained in detail in Methods in Numerical Analysis by Nielsen. The search in both the X and Z direction observe the following rules:

1. $X < X_1$ the routine chooses the following points for extrapolation.

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$X_1, X_2, \dots, X_{k+1} \quad Y_1, Y_2, \dots, Y_{k+1}$

2. $X > X_n$ the routine chooses the following points for extrapolation.

$X_{n-k}, X_{n-k+1}, \dots, X_n \quad Y_{n-k}, Y_{n-k+1}, \dots, Y_n$

3. $X \leq X_n$ the routine chooses the following points for interpolation.

k is odd $X_{\frac{i-k+1}{2}}, X_{\frac{i-k+1+1}{2}}, \dots, X_{\frac{i-k+1+k}{2}}$

$Y_{\frac{i-k+1}{2}}, Y_{\frac{i-k+1+1}{2}}, \dots, Y_{\frac{i-k+1+k}{2}}$

k is even $X_{\frac{i-k}{2}}, X_{\frac{i-k+1}{2}}, \dots, X_{\frac{i-k+k}{2}}$

$Y_{\frac{i-k}{2}}, Y_{\frac{i-k+1}{2}}, \dots, Y_{\frac{i-k+k}{2}}$

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

$k = 2 (X_1, X_2, X_3, X_3, X_4, X_5, Y_1, Y_2, Y_3, Y_4, Y_5, Y_6) .$

The subroutine will automatically examine the points selected before interpolation and if there is a discontinuity, the following rules apply. Let X_d and X_{d+1} be the point of discontinuity.



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- a. $X \leq X_d$ points previously chosen are modified for interpolation as shown

$$X_{d-k}, X_{d-k+1}, \dots, X_d$$

$$Y_{d-k}, Y_{d-k+1}, \dots, Y_d$$

- b. $X > X_d$ points previously chosen are modified for interpolation as shown

$$X_{d+1}, X_{d+2}, \dots, X_{d+k}$$

$$Y_{d+1}, Y_{d+2}, \dots, Y_{d+k}$$

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

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

In some engineering programs with many tables, it is quite desirable to read in one array of x 's that could be used for all lines of a multi-line function or different functions.

The above not only saves much time in preparing tabular data, but can also save many locations previously used when every y coordinate had to have a corresponding x coordinate. Even though the above is not always applicable, the subroutine has been written to handle this situation.

Another additional feature that may be useful is the possibility of a multi-line function with no extrapolation above the top line.

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DISCOT

ACCURACY: A function of the order of interpolation used.

REFERENCE: Nielsen, K.L.; Methods in Numerical Analysis

STORAGE: DISCOT - 555₈ locations

SUBPROGRAMS
USED: UNS 40₈ locations
DISSER 110₈ locations
LAGRAN 55₈ locations

OTHER CODING
INFORMATION: NONE

SOURCE: SHARE Library, General Motors Corp., Allison Div.

RESPONSIBLE
PERSON: Vivian P. Adair

	SUBROUTINE DISCOT (XA,ZA,TABX,TABY,TABZ,NC,NY,NZ,ANS)	DIC	1
C	*** DOCUMENT DATE 08-01-68 SUBROUTINE REVISED 08-01-68 *****	DIC	2
C	THE DIMENSIONS IN THIS SUBROUTINE ARE ONLY DUMMY DIMENSIONS.	DIC	3
	DIMENSION TABX(2),TABY(2),TABZ(2),NPX(8),NPY(8),YY(8)	DIC	4
C	DIMENSION TABX(2),TABY(2),TABZ(2),NPX(8),NPY(8),YY(8)	DIC	5
	CALL UNS (NC,IA,IDX,IDZ,IMS)	DIC	6
	IF (NZ-1) 1,1,2	DIC	7
1	CALL DISSER (XA,TABX(1),1,NY,IDX,NN)	DIC	8
	NNN=IDX+1	DIC	9
	CALL LAGRAN (XA,TABX(NN),TABY(NN),NNN,ANS)	DIC	10
	GO TO 12	DIC	11
2	ZARG=ZA	DIC	12
	IP1X=IDX+1	DIC	13
	IP1Z=IDZ+1	DIC	14
	IF (IA) 3,5,3	DIC	15
3	IF (ZARG-TABZ(NZ)) 5,5,4	DIC	16
4	ZARG=TABZ(NZ)	DIC	17
5	CALL DISSER (ZARG,TABZ(1),1,NZ,IDZ,NPZ)	DIC	18
	NX=NY/NZ	DIC	19
	NPZL=NPZ+IDZ	DIC	20
	I=1	DIC	21
	IF (IMS) 6,6,8	DIC	22
6	CALL DISSER (XA,TABX(1),1,NX,IDX,NPX(1))	DIC	23
	DO 7 JJ=NPZ,NPZL	DIC	24
	NPY(I)=(JJ-1)*NX+NPX(1)	DIC	25
	NPX(I)=NPX(1)	DIC	26
7	I=I+1	DIC	27
	GO TO 10	DIC	28
8	DO 9 JJ=NPZ,NPZL	DIC	29
	IS=(JJ-1)*NX+1	DIC	30
	CALL DISSER (XA,TABX(1),IS,NX,IDX,NPX(I))	DIC	31
	NPY(I)=NPX(I)	DIC	32
9	I=I+1	DIC	33
10	DO 11 LL=1,IP1Z	DIC	34
	NLOC=NPX(LL)	DIC	35
	NLOCY=NPY(LL)	DIC	36
11	CALL LAGRAN (XA,TABX(NLOC),TABY(NLOCY),IP1X,YY(LL))	DIC	37
	CALL LAGRAN (ZARG,TABZ(NPZ),YY(1),IP1Z,ANS)	DIC	38
12	RETURN	DIC	39
	END	DIC	40

1 DISSER.-- Library subroutine used by DISCOT.
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	SUBROUTINE DISSEP (XA,TAB,I,NX,IO,NPX)	DIS	1
	DIMENSION TAB(2)	DIS	2
C	DIMENSION TAB(2)	DIS	3
	NPT=IO+1	DIS	4
	NPB=NPT/2	DIS	5
	NPU=NPT-NPB	DIS	6
	IF (NX-NPT) 2,1,2	DIS	7
1	NPX=I	DIS	8
	RETURN	DIS	9
2	NLOW=I+NPB	DIS	10
	NUPP=I+NX-(NPU+1)	DIS	11
	DO 3 II=NLOW,NUPP	DIS	12
	NLOC=II	DIS	13
	IF (TAB(II)-XA) 3,4,4	DIS	14
3	CONTINUE	DIS	15
	NPX=NUPP-NPB+1	DIS	16
	RETURN	DIS	17
4	NL=NLOC-NPB	DIS	18
	NU=NL+IO	DIS	19
	DO 5 JJ=NL,NU	DIS	20
	NDIS=JJ	DIS	21
	IF (TAB(JJ)-TAB(JJ+1)) 5,6,5	DIS	22
5	CONTINUE	DIS	23
	NPX=NL	DIS	24
	RETURN	DIS	25
6	IF (TAB(NDIS)-XA) 8,7,7	DIS	26
7	NPX=NDIS-IO	DIS	27
	RETURN	DIS	28
8	NPX=NDIS+1	DIS	29
	RETURN	DIS	30
	END	DIS	31-



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SUBROUTINE INT1A

LANGUAGE: FORTRAN

PURPOSE: INT1A is a closed subroutine for the solution of a set of ordinary differential equations.

USE: The calling sequence is identical to INT1 except that the VAR and CUVAR arrays are single precision.

A general guideline for selecting the better subroutine is to use INT1A when the ELE1 values are set to $.1 \times 10^{-8}$ or larger. In those cases the word length of the CDC 6000 series computers affords adequate control of the rounding error without the "partial double precision mode of operation."

RESTRICTIONS: See INT1.

METHOD: This subroutine is identical to INT1 except that the "partial double precision mode of operation" has been eliminated.

ACCURACY: See INT1.

REFERENCES: See INT1.

STORAGE: INT1A 25578 locations

SOURCE: NASA, LRC, Jules J. Lambiotte

RESPONSIBLE
PERSON: Jules J. Lambiotte



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SUBROUTINE INT1

LANGUAGE: FORTRAN

PURPOSE: INT1 is a closed subroutine for the solution of a set of ordinary differential equations.

USE: CALL INT1 (II,N,NT,CI,SPEC,CIMAX,IERR,VAR,CUVAR,DER,ELE1,ELE2,ELT,ERRVAL,DERSUB,CHSUB,ITEXT)

II - INT1 is composed of an initialization section and an integration section. The user is required to enter the initialization section before he starts his first integration step. The above calling sequence is used for both initialization and integration with the value of the code word II determining which of the two sections of INT1 will be entered.

The user must set II = 0 in order to initialize.

During initialization the derivatives will be evaluated using the initial values of the variables but no integration will occur and control will be returned to the calling program. When INT1 is called with II > 0, entry is made to the integration section. Upon each entry to INT1, the subroutine stores a 1 in II so that the users need not supply a value of II > 0 for repetitive integration.

Besides serving as a means for specifying the entry point to INT1 from the calling program, II can also be set to specified values in CHSUB to accomplish the following:

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- 2 The user will store the integer 2 in II if the answers in CHSUB are not acceptable to him and he wishes to recompute the answers using a shorter interval. This shorter interval must be stored by the user in CI. It must be smaller than the computing interval just used.
- 3 The user will store the integer 3 in II if he wishes to return to the calling program. The answers for the interval are considered acceptable to the user and will be transferred to the VAR array (explained below) by INT1.

In DERSUB II may be set to:

- 4 The user will store the integer 4 in II if he wishes to discontinue calculation of the present interval and return to the calling program. On return to the calling program, the answers at the beginning of the interval will still be in the VAR array.

If the user does not set II to a value in either CHSUB or DERSUB, II will always be 1 upon the return to the calling program.

- N - An integer value supplied by the user which is the number of differential equations to be solved. INT1 is compiled to solve a maximum of 20 equations but may be recompiled for larger values of N if necessary.
- NT - An integer value supplied by the user which is the number of values in the ELT block described below. INT1 is compiled with a maximum of 10 values in the ELT block but may be recompiled for more values if necessary.
- CI - A floating point value supplied by the user which is the computing interval INT1 will use initially. CI must be a



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signed value, positive if integrating forward, negative if integrating backwards. Upon entry to CHSUB, CI will contain the computing interval that INT1 will use for the next step unless it has to take a short interval to hit an ELT value or a SPEC value described below. The computing interval used on the present step is available in CHSUB as the algebraic difference between CUVAR (1) and VAR (1). Since the subroutine is used on a binary computer and the interval variation is a halving and doubling process, CI should be a power of 2.

SPEC - A floating point value supplied by the user which specifies how often he wishes INT1 to return control to the calling program so that the user may print his results.

SPEC = 0.0 - Control will be returned after every acceptable integration step.

SPEC > 0.0 - SPEC is the absolute value of the specified increment of the independent variable for which the user desires control returned to the calling program.

The first printout is made at the initial value of the independent variable. The next return is at the nonzero integer multiple of SPEC closest to the initial value of the independent variable. The remaining returns occur at values which have been updated from this point by the increment given in SPEC. The return times generated by the increment given in SPEC are not altered by an intervening return due to an ELT value (explained below).

CIMAX - A floating point value supplied by the user which is the absolute value of the maximum computing interval that will be used. This value will be used if the doubling process would extend the computing interval to a value larger than

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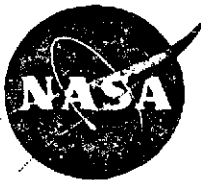
CIMAX. CIMAX should be set to 0.0 if there is no desired maximum.

IERR - An integer value supplied by INT1 as an error code. It must be checked at every return to the calling program. It may have the following values:

- 1 A normal return, no error.
- 2 The ELT block is not monotonic in the direction of integration.
- 3 The variables have failed to meet the local truncation error requirements nine consecutive times. The answers at the beginning of the interval are still in the VAR array.
- 4 The variables have failed to meet the local truncation error requirements at least nine times over the last three intervals. An acceptable answer has been reached, however, and is in the VAR array.

VAR - A double precision one-dimensional array containing the independent variable followed by the N dependent variables. The user must store the N+1 initial values (in the double precision mode) in the array for initialization. INT1 will store the new values of the variables in VAR after each integration step when they are accepted by the user in CHSUB. The elements of the VAR block can be printed out in the calling program in accordance with the user's specification in SPEC.

CUVAR - A double precision one-dimensional array which is given values by INT1 for two purposes. INT1 will store in the same order as the VAR array the values of the



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independent variable and N dependent variables at which it wishes the derivatives to be evaluated in the DERSUB subroutine. Although CUVAR must be in a double precision array in INT1 to maintain the "partial double precision mode" of computation, the evaluation of the derivatives should be in single precision. Two suggested ways of doing this are as follows: (1) Consider CUVAR as a single precision array of $2(N+1)$ elements in the DERSUB subroutine and when using the i th element in a computation subscript it with the value $(2i-1)$. (2) At the beginning of the DERSUB subroutine, transfer from CUVAR to some newly defined single precision array and evaluate the derivatives using the latter.

INT1 will also store the tentative answers after each integration in the CUVAR array before calling CHSUB so that the user can check these values to decide to accept or reject the answers. If accepted, the CUVAR values will then be transferred to the VAR array. The decision as to whether the computation in the CHSUB subroutine should be done in single or double precision is a function of the individual application. In most cases single precision is adequate and can be accomplished by applying the above suggestions to the VAR and CUVAR arrays.

No values need to be initially stored in CUVAR.

DER - An $N+1$ single precision array in which the user will store the derivatives evaluated in DERSUB. The derivatives should be arranged by the user in DERSUB in the same order as the VAR block so that DER (2) will be the derivative of the variable stored in VAR (2), etc. DER (1) will be unused. The derivatives must be computed using values of the variables which have been stored in CUVAR (not VAR)

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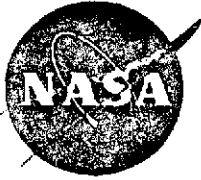
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by INT1. To avoid unnecessary double precision computation the user should apply the suggestion described under CUVAR.

- ELE1 - A one-dimensional array of N values supplied by the user each of which is the upper bound of local relative truncation error for the respective dependent variables. If the error for any variable exceeds its respective ELE1 value, the computing interval is halved and the integration restarted at the beginning of the present interval. If the error for all of the variables is less than 1/128 of their respective ELE1 values, the computing interval is doubled for the next integration step.
- ELE2 - A one-dimensional array of N values supplied by the user which represents a small value or "relative zero" for the respective dependent variables. If the absolute value of any of the variables is less than its respective ELE2 value, the relative error criteria for that variable will not be applied.
- ELT - A one-dimensional array of NT values supplied by the user which are values of the independent variable at which the user specifically desires control returned to his program. The values in the ELT block must be monotonic in the direction of integration or an error return will be given by INT1.
- ERRVAL - A one-dimensional array of N elements in which INT1 stores an estimate of the local truncation error for each of the N dependent variables. The relative errors are computed from these values and compared with the specified ELE1 values.



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DERSUB - The name of a subroutine written by the user which will be called by INT1 to evaluate the derivatives. The derivatives must be stored in the DER array. INT1 will call DERSUB to evaluate the derivatives with the values of the variable it has stored in the CUVAR array.

These evaluations should be done using single precision arithmetic. The name given to the DERSUB subroutine must appear in an EXTERNAL statement in the calling program. The user may return to the calling program by setting II to 4.

CHSUB - The name of a subroutine written by the user to allow certain logical control. After each integration step, INT1 will make available to the user in CHSUB the tentative answers in the CUVAR array. The VAR array will contain the last accepted answer (that is, the value of the variables at the beginning of the interval). Whenever the user specifies the answers are acceptable, the values in the CUVAR block are transferred to the VAR block. In CHSUB the DER block will contain the values of the derivatives evaluated with the present CUVAR block. The user has three options:

1. Not change II. II = 1 is considered by INT1 to denote that the user has accepted the answers in the CUVAR block. II always equals 1 upon entry to CHSUB from INT1.
2. Set II = 2. The user does not accept the answers and wishes to recompute the interval using a new computing interval which he stores in CI. This computing interval must be smaller than the computing interval just used.

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This new value of CI will now be stored by INT1 as the normal computing interval for the subsequent integration steps.

3. Set II = 3. The user accepts the answer but wishes to denote a condition that he can test in the calling program. Control will be returned to the calling program with the answers in the CUVAR array transferred to the VAR array.

The name given to the CHSUB subroutine must appear in an EXTERNAL statement in the calling program.

ITEXT - An integer code word supplied by the user which gives him the option to have INT1 print out a time history of the computing interval and the reasons for its variation. This print out should be requested only for problems which must be rerun due to unsatisfactory results the first time.

ITEXT = 0 No printout requested
ITEXT = 1 A printout requested

RESTRICTIONS: See arguments listed under CALL statement.

METHOD: INT1, written in coordination with the other integration subroutines in the INT(x) common usage series, is a fifth-order integration subroutine. The classical fourth-order Runge-Kutta formula is applied in conjunction with Richardson's Extrapolation to the Limit Theory. INT1 is a variable interval size routine in which the interval is varied to meet a specified local relative truncation error.

ACCURACY: The variable interval size mode of logic is used to make available an estimate of the local relative truncation error which is then controlled as explained in the ELE1 block discussion.



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Roundoff error is controlled by use of the "partial double precision mode of computation" as explained in Reference (1).

REFERENCE: Henrici, Peter (1962): DISCRETE VARIABLE METHODS IN ORDINARY DIFFERENTIAL EQUATIONS, John Wiley and Sons, New York.

STORAGE: INT1 27038 locations

SOURCE: NASA, LRC, Jules J. Lambiotte

RESPONSIBLE
PERSON: Jules J. Lambiotte

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SUBROUTINE INTIA (II,N,NT,CI,SPEC,CIMAX,IERR,VAR,CUVAR,DER,ELE1,ELINT  1
IE2,FLT,ERRVAL,DER SUB,CHSUB,ITEXT) INT 2
C *** DOCUMENT DATE 08-01-68 SUBROUTINE REVISED 08-01-68 *****INT 3
DIMENSION SIVAR(20), SELE1(20), ELE1(20), ELE2(20), DER(21), FDERVINT 4
1(21), SDY(20), SDY1(20), YINCR(20), ERRVAL(20), ERVDVH(20), ELT(10)INT 5
2), SFLT(13), RELMIN(20), STEP(3) INT 6
DIMENSION VAR(21), CUVAR(21) INT 7
INTEGER TEX(15) INT 8
INTEGER CODE,TPSH,SUMHAF,STEP,TEST,DCODE INT 9
REAL K1 INT 10
C BEGIN INITIALIZATION INT 11
IF (II.GT.0) GO TO 19 INT 12
TP=0 INT 13
SSPEC=SIGN(SPEC,CI) INT 14
SCIMAX=SIGN(CIMAX,CI) INT 15
VAR1=VAR(1) INT 16
IF (CI.EQ.0.0) GO TO 18 INT 17
IF (SSPEC.EQ.0.0) GO TO 4 INT 18
IF (ABS(SCIMAX).GT.ABS(SSPEC).OR.SCIMAX.EQ.0.0) SCIMAX=SSPEC INT 19
C TEST TO SEE IF VAR IS ZERO INT 20
IF (ABS(VAR1).GT.1.0E-11) GO TO 1 INT 21
TP=SSPEC INT 22
GO TO 4 INT 23
1 IF ((VAR1/SSPEC).GT.1.E-13) GO TO 2 INT 24
K1=0.0 INT 25
GO TO 3 INT 26
2 K1=1.0 INT 27
3 TP=VAR1-AMOD(VAR1,SSPEC) INT 28
IF (ABS(TP-VAR1).LT.1.E-12) K1=1.0 INT 29
TP=TP+K1*SSPEC INT 30
IF (ABS((TP-VAR1)/VAR1).LT.1.E-11) TP=TP+SPEC INT 31
C TEST FOR DIRECTION OF INTEGRATION INT 32
4 K1=1.0 INT 33
IF (CI.LT.0.0) K1=-1.0 INT 34
CIK=CI*K1 INT 35
CIMAXK=SCIMAX*K1 INT 36
TPK=TP*K1 INT 37
VARK=VAR1*K1 INT 38
C SET UP STORAGE FOR INTERNAL USE INT 39
NPI=N+1 INT 40
NELT=1 INT 41
REMAIN=0.0 INT 42

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	NHAF=0	INT	43
	NTS=NT	INT	44
	SUMHAF=0	INT	45
	LOOP=0	INT	46
	DO 5 I=1,3	INT	47
5	STEP(I)=0	INT	48
	TERR=1	INT	49
	DO 6 I=1,NP1	INT	50
6	CUVAR(I)=VAR(I)	INT	51
	DO 7 I=1,N	INT	52
7	SFLE1(I)=ELE1(I)	INT	53
	IF (NT.EQ.0) GO TO 11	INT	54
	IF (NT.EQ.1) GO TO 9	INT	55
	NTM1=NT-1	INT	56
	ELTK=K1*ELT(I)	INT	57
	DO 8 I=1,NTM1	INT	58
	ELTK2=K1*ELT(I+1)	INT	59
	IF (ELTK.LT.ELTK2) GO TO 8	INT	60
	GO TO 97	INT	61
8	FLTK=ELTK2	INT	62
9	CONTINUE	INT	63
	ELTK=K1*ELT(NELT)	INT	64
	IF (VARK.LT.ELTK) GO TO 10	INT	65
	IF (NELT.EQ.NT) GO TO 11	INT	66
	NFLT=NELT+1	INT	67
	GO TO 9	INT	68
10	NELTL=NT-NELT+1	INT	69
	GO TO 12	INT	70
11	NELTL=0	INT	71
12	DO 13 I=1,N	INT	72
13	RELMIN(I)=SFLE1(I)/128.0	INT	73
	IF (NT.EQ.0) GO TO 15	INT	74
	DO 14 I=1,NT	INT	75
14	SELT(I)=ELT(I)	INT	76
15	CALL DERSUB	INT	77
	IF (II.EQ.4) GO TO 87	INT	78
	DO 16 I=1,N	INT	79
16	FDERV(I)=DER(I+1)	INT	80
	II=1	INT	81
	TEST=0	INT	82
	DO 17 I=1,15	INT	83
17	TEX(I)=0	INT	84
	TEX(I)=1	INT	85

	TEX(2)=1	INT 86
	KK3=1	INT 87
	IF (ITEXT) 93,83,93	INT 88
18	PRINT 100	INT 89
	STOP	INT 90
C	END OF INITIALIZATION	INT 91
19	II=1	INT 92
	TPSH=0	INT 93
	LTSH=0	INT 94
	VARK=VAR(1)*K1	INT 95
	CIK=C1*K1	INT 96
	S1=VARK+CIK	INT 97
	IF (SSPEC.EQ.0.0) GO TO 28	INT 98
	KK=1	INT 99
	IF (NELTL.EQ.0) GO TO 21	INT 100
	IF (ELTK-TPK) 20,20,21	INT 101
20	CV=ELTK	INT 102
	CODE=1	INT 103
	GO TO 22	INT 104
21	CV=TPK	INT 105
	CODE=2	INT 106
22	IF (ABS(CV).LT.1.E-12) GO TO 27	INT 107
	IF (CV-S1) 24,24,23	INT 108
23	IF (ABS((CV-S1)/CV).GE..1E-11) GO TO 36	INT 109
24	IF (NELTL.EQ.0) GO TO 25	INT 110
	IF (ABS((ELTK-TPK)/CV).LT..1E-11) GO TO 26	INT 111
	IF (CODE.EQ.1) GO TO 32	INT 112
25	DX=TP-VAR(1)	INT 113
	TEX(5)=1	INT 114
	TP=TP+SSPEC	INT 115
	TPK=TP*K1	INT 116
	TPSH=1	INT 117
	GO TO 37	INT 118
C	SHORT INTERVAL DUE TO BOTH	INT 119
26	TP=TP+SSPEC	INT 120
	TEX(6)=1	INT 121
	TPK=TP*K1	INT 122
	TPSH=1	INT 123
	GO TO 32	INT 124
C	IF HERE CV IS LIKELY ZERO	INT 125
27	IF (S1.LT.-1.0E-12) GO TO 36	INT 126
	IF (CODE.EQ.1) GO TO 26	INT 127
	IF (NELTL.EQ.0) GO TO 25	INT 128

	IF (ABS(ELTK).LT.1.0E-12) GO TO 26	INT 129
	GO TO 25	INT 130
C	SPEC IS ZERO	INT 131
28	IF (ABS(REMAIN).GT..1E-11) GO TO 34	INT 132
	IF (NELTL.EQ.0) GO TO 33	INT 133
29	IF (ABS(ELTK).GE.1.E-12) GO TO 30	INT 134
	IF (S1.LT.-1.0E-12) GO TO 33	INT 135
	GO TO 32	INT 136
30	S2=ELTK-S1	INT 137
	IF (S2) 32,32,31	INT 138
31	IF (ABS(S2/ELTK).LT.1.0E-12) GO TO 32	INT 139
	GO TO 33	INT 140
C	SHORT INTERVAL IS DUE TO ELT BLOCK	INT 141
32	DELT=SELT(NELT)	INT 142
	TEX(4)=1	INT 143
	DX=DELT-VAR(1)	INT 144
	REMAIN=C I-DX	INT 145
	REMAIK=REMAIN*K1	INT 146
	LTSH=1	INT 147
	NELT=NELT+1	INT 148
	NELTL=NELTL-1	INT 149
	IF (NELTL.EQ.0) GO TO 37	INT 150
	ELTK=K1*SELT(NELT)	INT 151
	GO TO 37	INT 152
33	DX=CI	INT 153
	TEX(3)=1	INT 154
	GO TO 37	INT 155
34	IF (NELTL.EQ.0) GO TO 35	INT 156
	IF (ELTK.LT.(VARK+REMAIK)) GO TO 29	INT 157
35	DX=REMAIN	INT 158
	TEX(7)=1	INT 159
	REMAIN=0.0	INT 160
	GO TO 37	INT 161
36	DX=CI	INT 162
	TEX(3)=1	INT 163
	TEST=1	INT 164
	GO TO 38	INT 165
C		INT 166
C	BEGIN RUNGE-KUTTA	INT 167
C		INT 168
37	TEST=0	INT 169
38	DO 39 I=1,N	INT 170
39	SIVAR(I)=VAR(I+1)	INT 171

40	CUVAR(1)=VAR(1)	INT 172
41	DO 42 I=1,N	INT 173
	SDY(I)=DER(I+1)	INT 174
42	CUVAR(I+1)=S1VAR(I)+(DX*DER(I+1))/2.0	INT 175
	CUVAR(1)=CUVAR(1)+DX/2.0	INT 176
	CALL DERSUB	INT 177
	IF (II.EQ.4) GO TO 87	INT 178
	DO 43 I=1,N	INT 179
	SDY(I)=SDY(I)+2.0*DER(I+1)	INT 180
43	CUVAR(I+1)=S1VAR(I)+(DX*DER(I+1))/2.0	INT 181
	CALL DERSUB	INT 182
	IF (II.EQ.4) GO TO 87	INT 183
	DO 44 I=1,N	INT 184
	SDY(I)=SDY(I)+2.0*DER(I+1)	INT 185
44	CUVAR(I+1)=S1VAR(I)+DX*DER(I+1)	INT 186
	CUVAR(1)=CUVAR(1)+DX/2.0	INT 187
	CALL DERSUB	INT 188
	IF (II.EQ.4) GO TO 87	INT 189
	DO 45 I=1,N	INT 190
	SDY(I)=(SDY(I)+DER(I+1))/6.0	INT 191
45	CONTINUE	INT 192
	IF (LOOP) 46,46,48	INT 193
46	DO 47 I=1,N	INT 194
	SDY1(I)=SDY(I)	INT 195
	YINCR(I)=0.0	INT 196
47	DER(I+1)=FDERV(I)	INT 197
	DX=DX/2.0	INT 198
	LOOP=1	INT 199
	GO TO 40	INT 200
C		INT 201
C	LOOP WAS NOT ZERO	INT 202
C		INT 203
48	DO 49 I=1,N	INT 204
49	YINCR(I)=YINCR(I)+SDY(I)	INT 205
	IF (LOOP.EQ.2) GO TO 51	INT 206
	DO 50 I=1,N	INT 207
	S1VAR(I)=VAR(I+1)+DX*YINCR(I)	INT 208
50	CUVAR(I+1)=S1VAR(I)	INT 209
	CUVAR(1)=VAR(1)+DX	INT 210
	LOOP=2	INT 211
	CALL DERSUB	INT 212
	IF (II.EQ.4) GO TO 87	INT 213
	GO TO 41	INT 214

51	LOOP=0	INT 215
	H=2.0*DX	INT 216
	DO 52 I=1,N	INT 217
	ERVQVH(I)=(YINCR(I))/2.0-SDY1(I)/15.0	INT 218
	ERRVAL(I)=H*ERVQVH(I)	INT 219
52	SIVAR(I)=SIVAR(I)+DX*SDY(I)+ERRVAL(I)	INT 220
C		INT 221
C	SIVAR HOLD THE APPROXIMATE ANSWERS	INT 222
C		INT 223
	IF (SCIMAX) 53,54,53	INT 224
53	IF (ABS(SCIMAX-CI).LT.1.0E-12) GO TO 55	INT 225
54	IF (ABS(H-CI).GT.1.0E-12) GO TO 55	INT 226
	DCODE=0	INT 227
	GO TO 56	INT 228
55	DCODE=1	INT 229
56	CONTINUE	INT 230
	I=0	INT 231
57	I=I+1	INT 232
	IF (I.GT.N) GO TO 58	INT 233
	IF (ABS(SIVAR(I)).LT.ELE2(I)) GO TO 57	INT 234
	RELER=ABS(ERRVAL(I)/SIVAR(I))	INT 235
	IF (RELER.GT.SELE1(I)) GO TO 63	INT 236
	IF (RELER.GT.RELMIN(I)) DCODE=1	INT 237
	GO TO 57	INT 238
58	CONTINUE	INT 239
	IF (DCODE=1) 59,78,59	INT 240
59	CONTINUE	INT 241
	IF (SSPEC) 62,60,62	INT 242
60	IF (SCIMAX) 62,61,62	INT 243
61	CI=2.0*CI	INT 244
	TEX(8)=1	INT 245
	NHAF=NHAF-1	INT 246
	GO TO 78	INT 247
62	IF (2.0*ABS(CI).LE.ABS(SCIMAX)) GO TO 61	INT 248
	CI=SCIMAX	INT 249
	TEX(8)=1	INT 250
	GO TO 78	INT 251
C		INT 252
C	HALF INTERVAL	INT 253
63	NHAF=NHAF+1	INT 254
	TEX(9)=1	INT 255
	NVAR=I+1	INT 256
	IF (NHAF=8) 64,64,98	INT 257

64	IF (LTSH.EQ.0) GO TO 65	INT 258
	TEST=1	INT 259
	LTSH=0	INT 260
	NELT=NELT-1	INT 261
	NELTL=NELTL+1	INT 262
	ELTK=K1*SELT(NELT)	INT 263
	REMAIN=0.0	INT 264
65	IF (TPSH.EQ.0) GO TO 66	INT 265
	TEST=1	INT 266
	TP=TP-SSPEC	INT 267
	TPK=K1*TP	INT 268
	TPSH=0	INT 269
66	IF (SSPEC.NE.0.0) GO TO 67	INT 270
	TEST=0	INT 271
	IF (ABS(CI-2.0*DX).GT.1.E-12) GO TO 71	INT 272
67	CI=DX	INT 273
68	DX=DX/2.0	INT 274
	CIK=K1*CI	INT 275
	DO 69 I=1,N	INT 276
	SIVAR(I)=VAR(I+1)	INT 277
	DER(I+1)=FDERV(I)	INT 278
	SDY1(I)=YINCR(I)-SDY(I)	INT 279
69	YINCR(I)=0.0	INT 280
	KK3=2	INT 281
	IF (ITEXT.EQ.1) GO TO 94	INT 282
70	LOOP=1	INT 283
	GO TO 40	INT 284
71	CONTINUE	INT 285
	IF (NHAF.GT.1) GO TO 68	INT 286
	NTS=NTS+1	INT 287
	IF (NTS.GT.13) GO TO 67	INT 288
	ACV=VAR(1)+CI	INT 289
	ACVK=ACV*K1	INT 290
	IF (NELTL.EQ.0) GO TO 73	INT 291
	NLT=NELT	INT 292
72	ELTK1=SELT(NLT)*K1	INT 293
	IF (ACVK.LT.ELTK1) GO TO 74	INT 294
	NLT=NLT+1	INT 295
	IF (NLT.EQ.NTS) GO TO 76	INT 296
	GO TO 72	INT 297
73	SELT(NELT)=ACV	INT 298
	GO TO 77	INT 299
74	NLTPI=NLT+1	INT 300

	I=NTS	INT 301
75	SELT(I)=SELT(I-1)	INT 302
	IF (I.EQ.NLTP1) GO TO 76	INT 303
	I=I-1	INT 304
	GO TO 75	INT 305
76	SELT(NLT)=ACV	INT 306
77	NELTL=NELTL+1	INT 307
	TEX(9)=0	INT 308
	TEX(10)=1	INT 309
	ELTK=K1*SELT(NELT)	INT 310
	GO TO 68	INT 311
C		INT 312
C	DOUBLE PRECISION UPDATING	INT 313
C		INT 314
78	LOOP=0	INT 315
	DH=H	INT 316
	DO 79 I=1,N	INT 317
	PHI=ERVOVH(I)+YINCR(I)/2.0	INT 318
	DPHI=PHI	INT 319
79	CUVAR(I+1)=VAR(I+1)+DH*DPHI	INT 320
	CUVAR(I)=VAR(I)+DH	INT 321
	CALL DERSUB	INT 322
	IF (II.EQ.4) GO TO 87	INT 323
	CALL CHSUB	INT 324
	IF (II-2) 81,88,80	INT 325
80	TFST=0	INT 326
81	DO 82 I=1,N	INT 327
82	FDERV(I)=DER(I+1)	INT 328
	SUMHAF=SUMHAF+NHAF-STEP(1)	INT 329
	STEP(1)=STEP(2)	INT 330
	STEP(2)=STEP(3)	INT 331
	STEP(3)=NHAF	INT 332
	NHAF=0	INT 333
	IERR=1	INT 334
	IF (SUMHAF-8) 83,83,99	INT 335
83	DO 84 I=1,NP1	INT 336
84	VAR(I)=CUVAR(I)	INT 337
	TEX(12)=1	INT 338
85	KK3=4	INT 339
	IF (ITEXT.EQ.1) GO TO 94	INT 340
86	IF (TFST.EQ.1) GO TO 19	INT 341
87	RETURN	INT 342
C		INT 343

C	RECOMPUTE INTERVAL	INT 344
C		INT 345
88	TEST=0	INT 346
	NHAF=0	INT 347
	II=1	INT 348
	DX=CI	INT 349
	TEX(11)=1	INT 350
	KK3=3	INT 351
	IF (ITEXT.EQ.1) GO TO 92	INT 352
89	CIK=CI*K1	INT 353
	DO 90 I=1,N	INT 354
	DER(I+1)=FDERV(I)	INT 355
90	CUVAR(I)=VAR(I)	INT 356
	CUVAR(N+1)=VAR(N+1)	INT 357
	IF (TPSH.EQ.0) GO TO 91	INT 358
	TP=TP-SPEC	INT 359
	TPK=TP*K1	INT 360
	TPSH=0	INT 361
91	IF (LTSH.EQ.0) GO TO 38	INT 362
	NELT=NELT-1	INT 363
	REMAIN=0.0	INT 364
	NELTL=NELTL+1	INT 365
	ELTK=SELT(NELT)*K1	INT 366
	GO TO 38	INT 367
92	PRINT 113, VAR(1),DX	INT 368
	GO TO 95	INT 369
93	IF (TFX(1).EQ.1) PRINT 101, VAR(1)	INT 370
	IF (TEX(2).EQ.1) PRINT 102, CI,CIMAX,SPEC	INT 371
94	IF (TEX(3).EQ.1) PRINT 103	INT 372
	IF (TEX(4).EQ.1) PRINT 104, H	INT 373
	IF (TEX(5).EQ.1) PRINT 105, H	INT 374
	IF (TEX(6).EQ.1) PRINT 106, H	INT 375
	IF (TEX(7).EQ.1) PRINT 114, H	INT 376
	IF (TEX(8).EQ.1) PRINT 107, CI	INT 377
	IF (TEX(9).EQ.1) PRINT 108, NVAR,CI	INT 378
	IF (TEX(10).EQ.1) PRINT 115, NVAR,DX	INT 379
	IF (TEX(11).EQ.1) PRINT 113, VAR(1),DX	INT 380
	IF (TEX(12).EQ.1) PRINT 109, VAR(1)	INT 381
	IF (TEX(13).EQ.1) PRINT 110	INT 382
	IF (TEX(14).EQ.1) PRINT 111	INT 383
	IF (TEX(15).EQ.1) PRINT 112	INT 384
95	DO 96 I=3,13	INT 385
96	TEX(I)=0	INT 386

	GO TO (87,70,89,86), KK3	INT 387
97	IERR=2	INT 388
	TEX(13)=1	INT 389
	TEST=0	INT 390
	GO TO 83	INT 391
98	IERR=3	INT 392
	TEX(15)=1	INT 393
	TEST=0	INT 394
	GO TO 85	INT 395
99	IERR=4	INT 396
	TEST=0	INT 397
	TEX(14)=1	INT 398
	GO TO 83	INT 399
C		INT 400
C		INT 401
100	FORMAT (//11H CI IS ZERO)	INT 402
101	FORMAT (33H INITIALIZATION STARTS AT VAR(1)=,E16.8/)	INT 403
102	FORMAT (4H CI=,E15.8,9H CIMAX=,E15.8,8H SPEC=,E15.8/)	INT 404
103	FORMAT (37H DX IS THE FULL COMPUTING INTERVAL CI/)	INT 405
104	FORMAT (28H DX IS A SHORTENED INTERVAL ,E15.8,25H DUE TO A CRITIC	INT 406
	IAL VALUE/)	INT 407
105	FORMAT (28H DX IS A SHORTENED INTERVAL ,E15.8,21H DUE TO A SPEC V	INT 408
	IALUE/)	INT 409
106	FORMAT (28H DX IS A SHORTENED INTERVAL ,E15.8,39H DUE TO BOTH A S	INT 410
	IPEC AND CRITICAL VALUE/)	INT 411
107	FORMAT (27H CI HAS BEEN LENGTHENED TO ,E16.8/)	INT 412
108	FORMAT (5H VAR(,12,32H) HAS CAUSED CI TO BE HALVED TO ,E16.8/)	INT 413
109	FORMAT (27H VAR(1) HAS BEEN UPDATED TO,E16.8,/)	INT 414
110	FORMAT (31H ERROR RETURN-ELT NOT MONOTONIC/)	INT 415
111	FORMAT (55H ERROR RETURN-HAVE HALVED 9 TIMES OVER LAST 3 INTERVALS	INT 416
	I/)	INT 417
112	FORMAT (45H ERROR RETURN-HAVE HALVED 9 CONSECUTIVE TIMES/)	INT 418
113	FORMAT (31H INTERVAL RECOMPUTED AT VAR(1)=,E16.8,9H WITH DX=,E16.8	INT 419
	I/)	INT 420
114	FORMAT (25H DX IS SHORTENED INTERVAL,E16.8,28H DUE TO A PREVIOUS E	INT 421
	ILT VALUE/)	INT 422
115	FORMAT (5H VAR(,12,32H) HAS CAUSED DX TO BE HALVED TO ,E16.8,38H B	INT 423
	IUT NOT CI SINCE CI ALREADY SHORTENED/)	INT 424
	END	INT 425-

1 LAGRAN.- Library subroutine used by DISCOT.

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	SUBROUTINE LAGRAN (XA,X,Y,N,ANS)	LAG	1
	DIMENSION X(2), Y(2)	LAG	2
C	DIMENSION X(2),Y(2)	LAG	3
	SUM=0.0	LAG	4
	DO 3 I=1,N	LAG	5
	PROD=Y(I)	LAG	6
	DO 2 J=1,N	LAG	7
	A=X(I)-X(J)	LAG	8
	IF (A) 1,2,1	LAG	9
1	R=(XA-X(J))/A	LAG	10
	PROD=PROD*R	LAG	11
2	CONTINUE	LAG	12
3	SUM=SUM+PROD	LAG	13
	ANS=SUM	LAG	14
	RETURN	LAG	15
	END	LAG	16-

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1 Identification: LF-VGAUSS
2 FORTRAN IV Coded
3 Purpose: To compute the integrals $\int_a^b F_i(x) dx$
4 for $i = 1, 2, 3, \dots$, number.
5 Restrictions: An EXTERNAL statement for the name of the subprogram,
6 FUNC (x, FOFX), must appear in the calling program. If
7 values other than x and FOFX are needed in FUNC, they may
8 be transmitted via COMMON. FOFX (NOFX) and SUM(NOFX) must
9 be dimensioned in the calling program.
10 Usage: Call VGAUSS (A, B, N, SUM, FUNC, FOFX, NOFX, K)
11 where A - Lower Limit of integration
12 B - upper limit of integration
13 N - An integer used to divide the interval (a, b)
14 The interval (a, b) is divided into N equal intervals
15 and a K-point quadrature is performed on each of the
16 intervals.
17 SUM(NOFX) - One dimensional array for answers
18 FUNC(x,FOFX) - Name of subprogram which evaluates $F_i(x)$ -
19 (Only two arguments in list.)
20 FOFX(NOFX) - One-dimensional array for the functions e-
21 valuated in FUNC.
22 NOFX - The number of functions to be evaluated
23 K - An integer which determines the quadrature formula
24 the routine will use. K may equal 3, 4, ---10, 16, 32.
25

1 Accuracy: The routine is at least as accurate as Simpson's rule.
2 The accuracy depends on N and K.
3 Method: Gauss Quadrature Method: This technique gives the most
4 accurate quadrature formula for a given number of ordinates.
5 The interval (a, b) is subdivided into $K * N$ intervals.
6 Thus, if N is 5 and K is 10, the number of points used
7 to calculate the integral is 50.
8 Storage: 364 Octal
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SUBROUTINE VGAUSS (A,B,N,SUM,FUNC,FOFX,NOFX,K)                                VGS 1
C                                                                              VGS 2
C   SUBROUTINE TO USE VARIABLE GAUSSIAN WEIGHTING VALUES                    VGS 3
C   A = LOWER LIMIT OF INTEGRATION                                          VGS 4
C   B = UPPER LIMIT OF INTEGRATION                                          VGS 5
C   N = INTEGER TO GIVE NO. OF INTERVALS, I. I = N * K                     VGS 6
C   SUM(NOFX) = ANSWER ARRAY, ON RETURN = 0. IF A=B.                        VGS 7
C   FUNC = NAME OF ROUTINE, TYPED EXTERNAL, TO SOLVE F(X)                  VGS 8
C   FOFX(NOFX) = ARRAY OF FUNCTIONS EVALUATED AT X IN FUNC                 VGS 9
C   NOFX = THE NUMBER OF FUNCTIONS TO BE INTEGRATED                         VGS 10
C   K = INTEGER TO CHOOSE WEIGHTING TABLE                                  VGS 11
C       = 0,4,5,6,7,8,9,10,16, OR 32                                       VGS 12
C                                                                              VGS 13
DIMENSION U(52), R(52), ITAB(8), FOFX(NOFX), SUM(NOFX)                       VGS 14
C                                                                              VGS 15
DATA (U(I),I=1,52)/0.5,.11270166,.33000947,.06943184,0.5,.2307653VGS 16
14,.046910077,.38069040,.16939530,.033765242,0.5,.29707742,.1292344VGS 17
20,.025446043,.40828267,.23723379,.10166676,.019855071,0.5,.3378732VGS 18
38,.19331428,.081984446,.015919880,.42556283,.28330230,.16029521,.0VGS 19
467468316,.013046735,.45249374,.35919822,.27099161,.19106187,.12229VGS 20
5779,.067184398,.027712488,.0052995325,.47584016,.+2776401,.3803563VGS 21
61,.33406569,.28932436,.24655004,.20614212,.16847786,.13390894,.102VGS 22
775810,.075316193,.051839422,.032546962,.017618872,.0071942442,.001VGS 23
83680690/                                                                    VGS 24
DATA (R(I),I=1,52)/.22222222,.27777777,.32607257,.17392742,.142222VGS 25
122,.23931433,.11846344,.23395696,.18038078,.085662246,.10448979,.1VGS 26
29091502,.13985269,.064742483,.18134189,.15685332,.11119051,.050614VGS 27
3268,.082559838,.15617353,.13030534,.090324080,.040637194,.14776211VGS 28
4,.13463335,.10954318,.074725674,.033335672,.094725305,.091301707,.VGS 29
5084578259,.074797994,.062314485,.047579255,.031126761,.013576229,.VGS 30
6048270044,.047819360,.046922199,.045586939,.043826046,.041655962,.VGS 31
7039096947,.036172897,.032911111,.029342046,.025499029,.021417949,.VGS 32
8017136931,.012696032,.0081371973,.0035093050/,(ITAB(I),I=1,8)/0,2,VGS 33
94,7,10,14,18,23/                                                            VGS 34
C                                                                              VGS 35
DO 1 L=1,NOFX                                                                  VGS 36
SUM(L)=0.0                                                                    VGS 37
IF (A.EQ.B) RETURN                                                            VGS 38
NN=(K+1)/2                                                                    VGS 39
IF (K-16) 2,3,4                                                              VGS 40
J=ITAB(K-2)                                                                    VGS 41
GO TO 5                                                                        VGS 42

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3	J=28	VGS	43
	GO TO 5	VGS	44
4	J=36	VGS	45
5	FINE=N	VGS	46
	DELTA=FINE/(B-A)	VGS	47
	DO 7 KK=1,N	VGS	48
	XI=KK-1	VGS	49
	FINF=A+XI/DELTA	VGS	50
	DO 6 I=1,NN	VGS	51
	LRB=I+J	VGS	52
	UU=U(LRB)/DELTA+FINE	VGS	53
	CALL FUNC (UU,FOFX)	VGS	54
	DO 6 JB=1,NOFX	VGS	55
6	SUM(JB)=R(LRB)*FOFX(JB)+SUM(JB)	VGS	56
	DO 7 JJ=1,NN	VGS	57
	LRB=JJ+J	VGS	58
	UU=(1.0-U(LRB))/DELTA+FINE	VGS	59
	CALL FUNC (UU,FOFX)	VGS	60
	DO 7 JB=1,NOFX	VGS	61
7	SUM(JB)=R(LRB)*FOFX(JB)+SUM(JB)	VGS	62
	DO 8 NX=1,NOFX	VGS	63
8	SUM(NX)=SUM(NX)/DELTA	VGS	64
	RETURN	VGS	65
	END	VGS	66-

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