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Computer Program for Solving Laminar, Transitional, or Turbulent Compressible Boundary-Layer Equations for Two-Dimensional and Axisymmetric Flow

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SUMMARY

A numerical algorithm and computer program are presented for solving the laminar, transitional, or turbulent two-dimensional or axisymmetric compressible boundary-layer equations for perfect-gas flows. The governing equations are solved by an iterative three-point implicit finite-difference procedure. The software, program VGBLP, is a modification of the approach presented in NASA TR R-368 and NASA TM X-2458, respectively. The major modifications are: (1) replacement of the fourth-order Runge-Kutta integration technique with a finite-difference procedure for numerically solving the equations required to initiate the parabolic marching procedure; (2) introduction of the Blottner variable-grid scheme; (3) implementation of an iteration scheme allowing the coupled system of equations to be converged to a specified accuracy level; and (4) inclusion of an iteration scheme for variable-entropy calculations. These modifications to the approach presented in NASA TR R-368 and NASA TM X-2458 yield a software package with high computational efficiency and flexibility. Turbulence-closure options include either two-layer eddy-viscosity or mixing-length models. Eddy conductivity is modeled as a function of eddy viscosity through a static turbulent Prandtl number formulation. Several options are provided for specifying the static turbulent Prandtl number. The transitional boundary layer is treated through a streamwise intermittency function which modifies the turbulence-closure model. This model is based on the probability distribution of turbulent spots and ranges from zero to unity for laminar and turbulent flow, respectively. Several test cases are presented as guides for potential users of the software.

INTRODUCTION

A number of finite-difference and integral methods are currently available for numerically solving the two-dimensional, or axisymmetric, compressible boundary-layer equations. No attempt is made in the present paper to present a literature review of either solution techniques (ref. 1) or turbulence closure (ref. 2). Reference 2 includes a tabular summary of 34 additional two-dimensional programs available as of 1975. The purpose of the present paper is to present modifications of the algorithm and software presented in references 3 and 4 that render the approach more accurate, more efficient, and easier to implement.

In the present approach, a coupled, iterative implicit finite-difference procedure, similar in many respects to that presented in references 5 and 6 for laminar flows, is used to solve the system of equations for laminar, transitional, or turbulent boundary-layer flows. The major modifications presented in the present approach as compared with references 3 and 4 are as follows: (1) replacement of the fourth-order Runge-Kutta integration technique used in reference 4 with a finite-difference procedure for numerically solving the equations required to initiate the parabolic marching procedure; (2) introduction of the variable-grid scheme proposed by Blottner in reference 7; (3) implementation of an iteration scheme allowing the coupled system of equations to be converged to a specified accuracy level; and (4) implementation of an iteration scheme for variable-entropy calculations. For most applications, because of the quasilinearization technique, the iteration cycle for constant-entropy calculations can be omitted if a sufficiently fine grid distribution is chosen for the coordinate normal to the wall boundary. (See ref. 8.) The present program can be easily applied to any attached, compressible, perfect-gas (two-dimensional or axisymmetric), boundary-layer flow. Transverse-curvature terms are retained in the system of equations with the option of being neglected if the user so desires. The program is also structured to allow the user the option of obtaining locally similar solutions.

Options are provided for either two-layer eddy-viscosity or mixing-length turbulence-closure models. No attempt has been made to generalize the closure models to empirically include the effects of streamwise pressure gradient, wall curvature, wall roughness, wall mass transfer, and low Reynolds number. (See ref. 2.) The models are structured in subroutine TURBLNT such that the user can easily modify the formulation to best represent the specific type of flow under investigation. The static turbulent Prandtl number can be specified in one of three ways: (1) as a constant; (2) as an analytic function of the coordinate normal to the wall boundary; or (3) as tabular input from experimental data.

The transitional region of the boundary layer is modeled through the streamwise intermittency function (ref. 9), which modifies the turbulence-closure model. Boundary-layer transition location and the extent of the transition (length of transition region) can either be specified from experimental data or computed from empirical correlation equations. The laminar boundary-layer equations are recovered by equating the streamwise intermittency function to zero.

Five test cases are presented in the present paper. These cases cover external and internal flows, including flows with wall mass transfer, transverse-curvature, and variable-entropy effects. The cases are designed to serve as guides for assisting potential users as they become familiar with program VGBLP prior to applying the program to their specific problems.

SYMBOLS

A	damping function, $26\nu/u_\tau$
A^+	damping constant, Au_τ/ν
$A1_n,B1_n,C1_n,D1_n$, $E1_n,F1_n,G1_n$	coefficients in difference equation (45a) and defined by equations (B3)
$A2_n,B2_n,C2_n,D2_n$, $E2_n,F2_n,G2_n$	coefficients in difference equation (45b) and defined by equations (B4)
a	speed of sound
a_1,a_2,a_3,a_4	coefficients in molecular viscosity relations (see eqs. (7))
C_f	skin-friction coefficient
c_p	specific heat at constant pressure
D	damping term (eq. (17a))
F	velocity ratio, u/u_e

h	heat-transfer coefficient
i	index used in grid-point notation (see eq. (41))
k	geometric progression constant, $\Delta\eta_{i+1}/\Delta\eta_i$
k_ℓ	thermal conductivity
k_T	eddy conductivity (see eq. (2c))
k_1	constant in eddy-viscosity model (see eq. (16a))
k_2	constant in eddy-viscosity model (see eq. (16b))
k_3	constant in intermittency function (see eq. (17c))
k_4	constant in intermittency function (see eq. (17c))
k_5	constant in mixing-length model (see eq. (20b))
L_r	reference length
l	defined in equation (30)
$\bar{\ell}$	mixing length (see eq. (20a))
M	Mach number
m	grid-point index in S-direction
N	number of grid points normal to wall boundary
N_o	reference number of grid points normal to wall boundary (see eq. (42))
N_{Pr}	Prandtl number, $c_p\mu/k_\ell$
$N_{Pr,t}$	static turbulent Prandtl number (see eqs. (3))
N_{Re}	unit Reynolds number, u_e/ν_e
$N_{Re,r}$	reference Reynolds number, $\rho_r u_r L_r/\mu_r$
$N_{Re,s}$	Reynolds number based on s, $u_e s/\nu_e$
$N_{Re,s_{t,i}}$	Reynolds number at transition, $u_e s_{t,i}/\nu_e$
N_{Re,δ^*}	Reynolds number based on displacement thickness, $u_e\delta^*/\nu_e$
$N_{Re,\theta}$	Reynolds number based on momentum thickness, $u_e\theta/\nu_e$
$N_{Re,\infty}$	free-stream unit Reynolds number, u_∞/ν_∞
N_{St}	Stanton number, $h/(c_p\rho u)$

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n grid-point index in Y-direction (see fig. 1)

$P^{(1)},P^{(2)},P^{(3)}$ defined in equations (50)

p pressure

$Q^{(1)},Q^{(2)},Q^{(3)}$ defined in equations (50)

q heat-transfer rate

R,Z body axis system with origin at stagnation point, where Z is positive downstream and R is positive radially outward (see fig. 2)

R_g gas constant (see eq. (6))

r radial body coordinate measured normal to Z-axis (see fig. 2)

r_o body radius (see fig. 2)

r_s radial coordinate of shock wave (see fig. 2)

S,Y orthogonal boundary-layer coordinate system with origin at stagnation point, where S lies along the body surface and is positive downstream and Y is normal to the body surface and positive outward (see fig. 2)

s boundary-layer coordinate along S-axis (see fig. 2)

$s_{t,f}$ end of transition (see fig. 2)

$s_{t,i}$ beginning of transition (see fig. 2)

T static temperature

t transverse-curvature term (see eqs. (23))

u velocity component in S-direction (fig. 2)

u_τ friction velocity, $\sqrt{\tau_w/\rho}$

V transformed normal-velocity component (see eq. (26))

v velocity component in Y-direction

$\tilde{v}$ velocity component, $v + \dfrac{\overline{\rho' v'}}{\rho}$

v^+ velocity component, $\tilde{v}\sqrt{N_{Re,r}}$

$X_1,X_2,\ldots,X_5$ functions of grid-point distribution (see eqs. (A4) to (A8))

$Y_1,Y_2,\ldots,Y_6$ functions of grid-point distributions (see eqs. (A12) to (A17))

y boundary-layer coordinate along Y-axis (see fig. 2)

$\tilde{y}$ stretched y-coordinate (see eq. (15))

y_m match point for two-layer eddy-viscosity model

z axial body coordinate (see fig. 2)

α defined in equation (30)

β defined in equation (30)

Γ streamwise intermittency distribution (see eq. (38))

γ ratio of specific heats

$\bar{\gamma}$ transverse intermittency distribution (see eq. (17c))

$\Delta s, \Delta y$ grid-point spacing, physical plane

Δs_t transition extent, $s_{t,f} - s_{t,i}$

$\Delta\xi, \Delta\eta$ grid-point spacing, transformed plane (see fig. 1)

Δ^* defined in equation (50g)

δ boundary-layer thickness

δ^* displacement thickness

δ^*_{inc} incompressible displacement thickness, $\int_0^\infty (1 - F)\, dy$

ε eddy viscosity, $-\rho \dfrac{\overline{u'v'}}{\partial u/\partial y}$

$\bar{\varepsilon}$ defined in equation (5a)

$\tilde{\varepsilon}$ defined in equation (5b)

Θ static-temperature ratio, T/T_e

θ momentum thickness

θ_s shock-wave angle (see fig. 2)

λ defined in equation (40)

μ molecular viscosity

ν kinematic viscosity, μ/ρ

ξ, η transformed boundary-layer coordinates (see fig. 1 and eqs. (22))

$\bar{\xi}$ defined in equation (39)

ρ density

τ shear stress

ϕ	local surface angle (see fig. 2)
χ	vorticity Reynolds number, $\frac{y^2}{\nu}\left(\frac{\partial u}{\partial y}\right)$
χ_{max}	maximum value of $(\chi)_{m+1}$
ψ	stream function (see fig. 2)

Subscripts:

aw	adiabatic wall
e	based on boundary-layer edge conditions
i	inner region of turbulent layer
m	mesh point in ξ-direction (see fig. 1)
max	maximum value
n	mesh point in η-direction (see fig. 1)
o	outer region of turbulent layer
r	reference quantity
s	shock
t	total condition
w	wall value
∞	free stream

Superscript:

j	flow index; $j = 0$ for planar flow, $j = 1$ for axisymmetric flow

An asterisk $(\ )^*$ on a symbol denotes a dimensional quantity.

A prime on a symbol denotes a fluctuating component.

A bar over a symbol denotes the time average value.

A coordinate used as a subscript denotes the partial differential with respect to the coordinate. (See eqs. (A1).)

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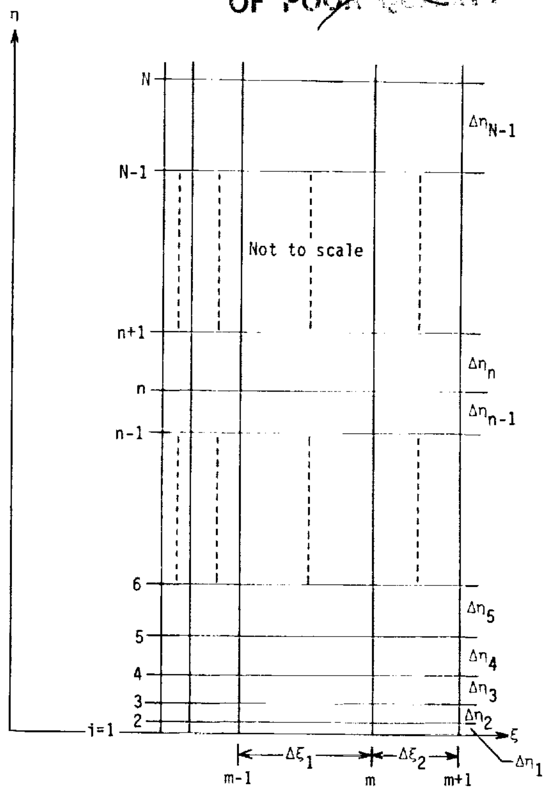

Figure 1.- Finite-difference grid model.

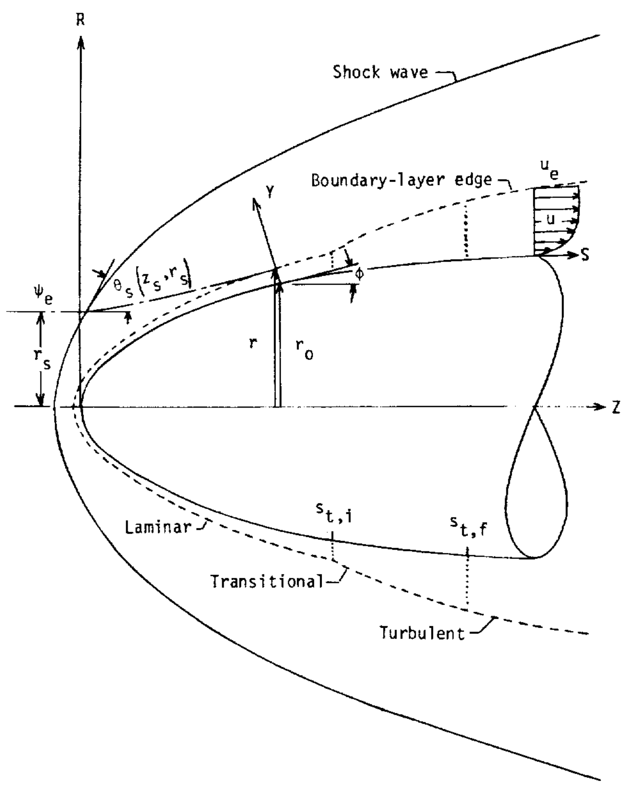

Figure 2.- Coordinate system and notation.

PROBLEM DESCRIPTION

This section presents the governing equations for compressible laminar, transitional, or turbulent boundary-layer flows together with the required boundary conditions. It should be noted that the system of equations can be found in numerous references (e.g., see refs. 2 and 3); however, for completeness, the equation set is presented in order to allow the user to modify the software if required. The algebraic turbulence closure, transition location and extent, and transitional-flow-structure models are presented and briefly discussed; however, the reader interested in a detailed discussion of these models is referred to references 2, 3, and 8.

Basic Partial Differential Equations

Dimensional governing equations.- The mean turbulent boundary-layer equations can be written as follows:

Continuity

$$\frac{\partial}{\partial s^*}\left(r^{*j}\rho^* u^*\right) + \frac{\partial}{\partial y^*}\left[r^{*j}\rho^*\left(v^* + \frac{\overline{\rho^{*\prime} v^{*\prime}}}{\rho^*}\right)\right] = 0 \tag{1a}$$

Momentum

$$\rho^*\left[u^*\frac{\partial u^*}{\partial s^*} + \left(v^* + \frac{\overline{\rho^{*\prime} v^{*\prime}}}{\rho^*}\right)\frac{\partial u^*}{\partial y^*}\right] = -\frac{dp^*}{ds^*} + \frac{1}{r^{*j}}\frac{\partial}{\partial y^*}\left[r^{*j}\left(\mu^*\frac{\partial u^*}{\partial y^*} - \rho^*\overline{u^{*\prime} v^{*\prime}}\right)\right] \tag{1b}$$

Energy

$$\begin{aligned}\rho^*\left[u^*\frac{\partial}{\partial s^*}(c_p^* T^*) + \left(v^* + \frac{\overline{\rho^{*\prime} v^{*\prime}}}{\rho^*}\right)\frac{\partial}{\partial y^*}(c_p^* T^*)\right] &= u^*\frac{dp^*}{ds^*} + \frac{1}{r^{*j}}\frac{\partial}{\partial y^*}\left[r^{*j}\frac{k_\ell^*}{c_p^*}\frac{\partial}{\partial y^*}(c_p^* T^*)\right] \\ &\quad + \mu^*\left(\frac{\partial u^*}{\partial y^*}\right)^2 + \frac{1}{r^{*j}}\frac{\partial}{\partial y^*}\left[r^{*j}\left(-c_p^*\rho^*\overline{v^{*\prime} T^{*\prime}}\right)\right] \\ &\quad - \rho^*\overline{u^{*\prime} v^{*\prime}}\frac{\partial u^*}{\partial y^*}\end{aligned} \tag{1c}$$

The mean turbulent equations are identical to those for laminar flow with the exception of the correlations of turbulent fluctuating quantities. These correlations must be related to the mean flow in order to obtain a closed system of equations. In the present analysis, the apparent mass-flux term $\overline{\rho^{*\prime} v^{*\prime}}$, the apparent stress term $\rho^*\overline{u^{*\prime} v^{*\prime}}$ (Reynolds stress), and the apparent heat-flux term $c_p^*\rho^*\overline{v^{*\prime} T^{*\prime}}$ are modeled or represented by a new velocity component $\tilde{v}^*$, an eddy viscosity ε^*, and an eddy conductivity k_T^*, respectively, as follows:

$$\tilde{v}^* = v^* + \frac{\overline{\rho^{*\prime} v^{*\prime}}}{\rho^*} \tag{2a}$$

$$\varepsilon^* = -\rho^* \frac{\overline{u^{*\prime} v^{*\prime}}}{\partial u^*/\partial y^*} \tag{2b}$$

$$k_T^* = -c_p^* \rho^* \frac{\overline{v^{*\prime} T^{*\prime}}}{\partial T^*/\partial y^*} \tag{2c}$$

The static turbulent Prandtl number is defined as follows:

$$N_{Pr,t} = \frac{\overline{u^{*\prime} v^{*\prime}}}{\overline{v^{*\prime} T^{*\prime}}}\left(\frac{\partial T^*/\partial y^*}{\partial u^*/\partial y^*}\right) \tag{3a}$$

Equation (3a) can then be rewritten in terms of equations (2b) and (2c) as

$$N_{Pr,t} = \frac{c_p^* \varepsilon^*}{k_T^*} \tag{3b}$$

In terms of equations (2) and (3), the governing differential equations can be written as follows:

<u>Continuity</u>

$$\frac{\partial}{\partial s^*}(r^{*j}\rho^* u^*) + \frac{\partial}{\partial y^*}(r^{*j}\rho^*\tilde{v}^*) = 0 \tag{4a}$$

<u>Momentum</u>

$$\rho^*\left(u^* \frac{\partial u^*}{\partial s^*} + \tilde{v}^* \frac{\partial u^*}{\partial y^*}\right) = -\frac{dp^*}{ds^*} + \frac{1}{r^{*j}} \frac{\partial}{\partial y^*}\left(r^{*j}\overline{\varepsilon^*} \frac{\partial u^*}{\partial y^*}\right) \tag{4b}$$

<u>Energy</u>

$$\rho^*\left[u^* \frac{\partial}{\partial s^*}(c_p^* T^*) + \tilde{v}^* \frac{\partial}{\partial y^*}(c_p^* T^*)\right] = u^* \frac{dp^*}{ds^*} + \overline{\varepsilon^*}\left(\frac{\partial u^*}{\partial y^*}\right)^2$$
$$+ \frac{1}{r^{*j}} \frac{\partial}{\partial y^*}\left[r^{*j}\tilde{\varepsilon}^* \frac{\partial}{\partial y^*}(c_p^* T^*)\right] \tag{4c}$$

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The terms $\overline{\varepsilon^*}$ and $\tilde{\varepsilon}^*$ appearing in equations (4) are defined as follows:

$$\overline{\varepsilon^*} = \mu^*\left(1 + \frac{\varepsilon^*}{\mu^*}\,\Gamma\right) \tag{5a}$$

$$\tilde{\varepsilon}^* = \frac{\mu^*}{N_{Pr}}\left(1 + \frac{\varepsilon^*}{\mu^*}\,\frac{N_{Pr}}{N_{Pr,t}}\,\Gamma\right) \tag{5b}$$

The function Γ appearing in equations (5) represents the streamwise intermittency distribution for the transitional-flow region. The Γ distribution assumes a value of zero for laminar flows, a value of unity for fully turbulent flows, and a range of 0 to 1 for the transitional region of flow. The variation of Γ in the transitional region depends upon the statistical growth and distribution of turbulent spots. The model used to represent Γ is discussed in a subsequent section of the present paper.

The system of equations is closed by the addition of the perfect-gas law and a viscosity-temperature relation. The perfect-gas law is written as

$$p^* = \rho^* R_g^* T^* \tag{6}$$

Two viscosity-temperature relations are provided: (1) the Sutherland law

$$\mu^* = \frac{a_1^*(T^*)^{3/2}}{T^* + a_2^*} \tag{7a}$$

and (2) the power law

$$\mu^* = a_3^*(T^*)^{a_4} \tag{7b}$$

The pressure-gradient term in equations (4) is replaced by the Bernoulli relation

$$\frac{dp^*}{ds^*} = -\rho_e^* u_e^* \frac{du_e^*}{ds^*} \tag{8}$$

for constant entropy flows; however, for variable entropy flows the value of dp^*/ds^* is explicitly retained in the equation system.

The equations are rewritten in nondimensional form where the nondimensional variables are as follows:

$$\left.\begin{aligned}
u &= u^*/u_r^* \\
v &= v^*/u_r^* \\
p &= p^*\Big/\left(\rho_r^* u_r^{2*}\right) \\
\rho &= \rho^*/\rho_r^* \\
T &= T^*/T_r^* \\
\mu &= \mu^*/\mu_r^*
\end{aligned}\right\} \tag{9}$$

where all dimensional lengths are nondimensionalized by a reference length L_r^*. The reference values of density and velocity are taken to be those of the free stream, the reference temperature is taken to be $u_r^{2*}\Big/c_p^*$, and the reference viscosity is the viscosity obtained from either equation (7a) or (7b) evaluated at the reference temperature.

Nondimensional governing equations.- The nondimensional equations are as follows:

Continuity

$$\frac{\partial}{\partial s}(r^j \rho u) + \frac{\partial}{\partial \tilde{y}}(r^j \rho v^+) = 0 \tag{10}$$

Momentum

$$\rho\left(u \frac{\partial u}{\partial s} + v^+ \frac{\partial u}{\partial \tilde{y}}\right) = -\frac{dp^*}{ds} + \frac{1}{r^j} \frac{\partial}{\partial \tilde{y}}\left(r^j \bar{\varepsilon} \frac{\partial u}{\partial \tilde{y}}\right) \tag{11}$$

Energy

$$\rho\left(u \frac{\partial T}{\partial s} + v^+ \frac{\partial T}{\partial \tilde{y}}\right) = u \frac{dp}{ds} + \frac{1}{r^j} \frac{\partial}{\partial \tilde{y}}\left(r^j \tilde{\varepsilon} \frac{\partial T}{\partial \tilde{y}}\right) + \bar{\varepsilon}\left(\frac{\partial u}{\partial \tilde{y}}\right)^2 \tag{12}$$

Equation of State

$$p = \left(\frac{\gamma - 1}{\gamma}\right)\rho T \tag{13}$$

Viscosity-Temperature

$$\left.\begin{aligned} \mu &= T^{3/2}\left(\frac{1 + a_2}{T + a_2}\right) \\ &\text{or} \\ \mu &= T^{a_4} \end{aligned}\right\} \tag{14}$$

where

$$\left.\begin{aligned} \tilde{y} &= y\sqrt{N_{Re,r}} \\ v^+ &= \tilde{v}\sqrt{N_{Re,r}} \\ a_2 &= a_2^*/T_r^* \end{aligned}\right\} \tag{15}$$

Turbulence closure.- Algebraic models are used to close the system of equations. Two options are provided: (1) a two-layer eddy-viscosity model (KODVIS = 2), and (2) a mixing-length model (KODVIS = 1).

Two-layer model

The equations describing the two-layer model are as follows (see ref. 8):

$$\left(\frac{\varepsilon}{\mu}\right)_i = \frac{\rho^*}{\mu^*}(k_1 y^* D)^2 \left|\frac{\partial u^*}{\partial y^*}\right| \qquad (0 \le y^* \le y_m^*) \tag{16a}$$

$$\left(\frac{\varepsilon}{\mu}\right)_o = \frac{\rho^*}{\mu^*}\, k_2 u_e^* (\delta_{inc}^*)^* \bar{\gamma} \qquad (y_m^* < y^*) \tag{16b}$$

where

$$D = 1 - \exp(-y^*/A^*) \tag{17a}$$

$$(\delta_{inc}^*)^* = \int_0^\infty \left(1 - \frac{u}{u_e}\right) dy^* \tag{17b}$$

and

$$\bar{\gamma} = \frac{1 - \text{erf}\left[k_3\left(\frac{y}{\delta} - k_4\right)\right]}{2} \tag{17c}$$

The boundary-layer thickness δ in equation (17c) is defined as the distance normal to the wall boundary where $u/u_e = 0.995$. The empirical constants k_1 to k_4 are assigned values of 0.4, 0.0168, 5.0, and 0.78, respectively.

The location of the boundary separating the two layers y_m^* is defined from the continuity of eddy viscosity; that is, where

$$\left(\frac{\varepsilon}{\mu}\right)_i = \left(\frac{\varepsilon}{\mu}\right)_o \tag{18}$$

Mixing-length model

A mixing-length option (KODVIS = 1) is provided for those interested in utilizing experimental mixing-length data. The eddy-viscosity distribution across the boundary layer can be written as follows:

$$\frac{\varepsilon}{\mu} = \frac{\rho^*}{\mu^*}\,\bar{\ell}^{*2}\left|\frac{\partial u^*}{\partial y^*}\right| \tag{19}$$

where the mixing length $\bar{\ell}^*$ can be expressed as

$$\frac{\bar{\ell}}{\delta} = D\bar{\gamma}f\left(\frac{y}{\delta}\right) \tag{20a}$$

An analytic formulation is provided in subroutine TURBLNT for $f\left(\frac{y}{\delta}\right)$ as follows (see ref. 10):

$$f\left(\frac{y}{\delta}\right) = k_5 \tan h\left(\frac{k_1}{k_5}\frac{y}{\delta}\right) \tag{20b}$$

where k_5 is assigned the value of 0.108. It should be noted that the assigned values of $k_1, k_2, \ldots, k_5$ and the definition of δ can be modified through input to program VGBLP.

Eddy conductivity

The eddy conductivity (eq. (2c)) is modeled as a static turbulent Prandtl number (eq. (3a)). Three options are provided in subroutines TURBLNT for $N_{Pr,t}$: (1) a constant, for example $N_{Pr,t} = 0.95$ (KODPRT = 1); (2) the Rotta (ref. 11) distribution (KODPRT = 2)

$$N_{Pr,t} = \frac{(N_{Pr,t})_w}{2}\left[2 - \left(\frac{y}{\delta}\right)^2\right] \tag{21}$$

and (3) a distribution $N_{Pr,t} = g\left(\frac{y}{\delta}\right)$ specified in tabular form from experimental data (KODPRT = 3).

Transformed plane.- The system of governing equations is singular at $s = 0$. The Probstein-Elliott (ref. 12) and Levy-Lees (ref. 13) transformation is used to remove this singularity as well as to reduce the growth of the boundary layer as the solution proceeds downstream. This transformation can be written as follows:

$$\xi(s) = \int_0^s \rho_e u_e \mu_e r_o^{2j}\, ds \tag{22a}$$

$$\eta(s,\tilde{y}) = \frac{\rho_e u_e r_o^j}{\sqrt{2\xi}} \int_0^{\tilde{y}} t^j\left(\frac{\rho}{\rho_e}\right) d\tilde{y} \tag{22b}$$

where the parameter t appearing in equation (22b) is the transverse-curvature term, defined as

$$t = \frac{r}{r_o} \tag{23a}$$

or, in terms of the y-coordinate, as

$$t = 1 + \frac{y}{r_o}\cos\phi \tag{23b}$$

The relation between derivatives in the stretched physical $(s,\tilde{y})$ and transformed (ξ,η) coordinate system is as follows:

$$\left(\frac{\partial}{\partial s}\right)_{\tilde{y}} = \rho_e u_e \mu_e r_o^{2j}\left(\frac{\partial}{\partial \xi}\right)_\eta + \left(\frac{\partial \eta}{\partial s}\right)\left(\frac{\partial}{\partial \eta}\right)_\xi \tag{24a}$$

$$\left(\frac{\partial}{\partial \tilde{y}}\right)_s = \frac{\rho_e u_e r_o^j t^j}{\sqrt{2\xi}}\left(\frac{\rho}{\rho_e}\right)\left(\frac{\partial}{\partial \eta}\right)_\xi \tag{24b}$$

Two parameters F and Θ are introduced and defined as

$$\left.\begin{aligned} F &= \frac{u}{u_e} \\ \Theta &= \frac{T}{T_e} \end{aligned}\right\} \tag{25}$$

together with a transformed normal velocity

$$V = \frac{2\xi}{\rho_e u_e \mu_e r_o^{2j}} \left[F\left(\frac{\partial \eta}{\partial s}\right) + \frac{\rho \tilde{v} r_o^j t^j}{\sqrt{2\xi}} \right] \tag{26}$$

The governing equations in the transformed plane can then be written as follows:

Continuity

$$\frac{\partial V}{\partial \eta} + 2\xi \frac{\partial F}{\partial \xi} + F = 0 \tag{27}$$

Momentum

$$2\xi F \frac{\partial F}{\partial \xi} + V \frac{\partial F}{\partial \eta} - \frac{\partial}{\partial \eta}\left(t^{2j} l \bar{\varepsilon} \frac{\partial F}{\partial \eta}\right) + \beta(F^2 - \Theta) = 0 \tag{28}$$

Energy

$$2\xi F \frac{\partial \Theta}{\partial \xi} + V \frac{\partial \Theta}{\partial \eta} - \frac{\partial}{\partial \eta}\left(t^{2j} l \tilde{\varepsilon} \frac{\partial \Theta}{\partial \eta}\right) - \alpha l t^{2j} \bar{\varepsilon} \left(\frac{\partial F}{\partial \eta}\right)^2 = 0 \tag{29}$$

where

$$\left.\begin{aligned} l &= \frac{\rho\mu}{(\rho\mu)_e} \\ \alpha &= (\gamma - 1) M_e^2 \\ \beta &= \frac{2\xi}{u_e}\left(\frac{du_e}{d\xi}\right) \end{aligned}\right\} \tag{30}$$

By using the viscosity relations (eqs. (14)) and the equation of state (eq. (13)), the parameter l can be written as follows:

Sutherland law

$$l = \sqrt{\Theta}\left(\frac{1 + a_2/T_e}{\Theta + a_2/T_e}\right) \tag{31a}$$

Power law

$$l = (\Theta)^{a_4 - 1} \tag{31b}$$

The transverse-curvature term can be written in terms of the transformed variables as

$$t = \left(1 + \frac{2\sqrt{2\xi}\cos\phi}{\rho_e u_e r_o^{2j}\sqrt{N_{Re,r}}}\int_0^\eta \Theta\, d\eta\right)^{1/2} \tag{32}$$

The physical coordinate normal to the wall is obtained from the inverse transformation; namely,

$$y = \frac{r_o}{\cos\phi}\left[-1 + \left(1 + \frac{2\sqrt{2\xi}\cos\phi}{\rho_e u_e r_o^{2j}\sqrt{N_{Re,r}}}\int_0^\eta \Theta\, d\eta\right)^{1/2}\right] \tag{33}$$

The boundary conditions in the transformed plane are as follows:

Wall boundary

$$\left.\begin{aligned} F(\xi,0) &= 0 \\ V(\xi,0) &= V_w(\xi) \\ \Theta(\xi,0) &= \Theta_w(\xi) \\ &\text{or} \\ \left(\frac{\partial\Theta}{\partial\eta}\right)_{\xi,0} &= \left(\frac{\partial\Theta}{\partial\eta}\right)_w \end{aligned}\right\} \tag{34a}$$

Edge boundary

$$\left.\begin{aligned} F(\xi,\eta_e) &= 1 \\ \Theta(\xi,\eta_e) &= 1 \end{aligned}\right\} \tag{34b}$$

The boundary condition at the wall for the transformed V component can be related to the physical plane as (see eq. (26))

$$V_w = \frac{\sqrt{2\xi}}{\mu_e r_o^j}\left(\frac{\rho_w v_w}{\rho_e u_e}\right) \tag{35}$$

Transition

Transition location.- Because of the large parameter space influencing transition to turbulence (refs. 14 to 17), it is not possible to predict with assurance the location of transition for general flows. However, for certain classes of geometry (e.g., flat plate, cone, etc.), empirical correlations are available. These empirical correlations can be used with confidence provided one realizes that a probable range of transition locations is being predicted. In program VGBLP either the transition location (SST) or the stability index at transition (SMXTR; see ref. 8) must be specified; however, any correlation can be directly incorporated into the program.

Transition extent.- The assumption of a universal intermittency distribution implies that the transition-zone length (transition extent) can be expressed as a function of the Reynolds number at transition $u_e s_{t,i}/\nu_e$. In reference 9 it is shown, for the transition data considered, that the data are represented on the average by the equation

$$N_{Re,\Delta s_t} = 5\left(N_{Re,s_{t,i}}\right)^{0.8} \tag{36}$$

where $N_{Re,\Delta s_t} = \frac{u_e}{\nu_e}(s_{t,f} - s_{t,i})$. The location of the end of transition $s_{t,f}$ can then be obtained directly from equation (36) as follows:

$$s_{t,f} = s_{t,i} + 5N_{Re}^{-1}\left(N_{Re,s_{t,i}}\right)^{0.8} \tag{37}$$

where N_{Re} is the local unit Reynolds number, u_e/ν_e.

In program VGBLP the extent of the transition region $(s_{t,f} - s_{t,i})$ can be specified in one of two ways: (1) from equation (37) (KTCOD = 1); or (2) from the specification of $s_{t,f}/s_{t,i}$ obtained from experimental data (KTCOD = 2). It should be noted that the program can be easily modified to include any desired correlation or equation in place of equation (37).

Transition-flow structure.- The parameter Γ (eqs. (5)) is the streamwise intermittency function which models the turbulent spot distribution in the transitional region. The parameter is a function of the s-coordinate only and is defined (see ref. 9) as follows:

$$\Gamma(\bar{\xi}) = 1 - \exp(-0.412\bar{\xi}^2) \tag{38}$$

where

$$\bar{\xi} = \frac{s - s_{t,i}}{\lambda} \tag{39}$$

and

$$\lambda = (s)_{\Gamma=\frac{3}{4}} - (s)_{\Gamma=\frac{1}{4}} \tag{40}$$

It should be noted that $\Gamma = 0$ for laminar flow, $\Gamma = 1$ for fully turbulent flow, and Γ ranges from 0 to 1 for the transitional-flow region. Equations (27) to (29) reduce to the classical laminar boundary-layer equations when Γ is set to zero.

SOLUTION TECHNIQUE

The system of governing equations (eqs. (27) to (29)) is parabolic and, therefore, can be numerically integrated by a marching procedure in the streamwise direction. In order to cast the equations into a form in which the marching procedure can be implemented, the derivatives with respect to ξ and η are replaced by finite-difference quotients. The method of linearization and solution used in the analysis closely parallels that of references 5 and 6.

Finite-Difference Mesh

Because of the magnitude and variation of the gradients of the dependent variables ($\partial F/\partial y$; $\partial \Theta/\partial y$) near the wall boundary for turbulent flow, it is computationally inefficient to use equally spaced mesh points in the y-coordinate. This problem can be alleviated by selecting a variable mesh-point distribution such that $\Delta\eta_{i+1}/\Delta\eta_i > 1$ where the distribution in the wall region is chosen sufficiently small to resolve all gradients. One approach to grid specification is to use a geometric progression

$$\Delta\eta_i = (k)^{i-1}\,\Delta\eta_1 \qquad (i = 2, 3, 4, \ldots, N) \tag{41}$$

where k is defined as the geometric progression constant $\Delta\eta_{i+1}/\Delta\eta_i$. A schematic of such a grid is presented (not to scale) in figure 1.

Blottner (ref. 7) introduced a variable-grid scheme that is more computationally efficient than the differencing scheme and mesh distribution used in references 3 and 4. The Blottner variable-grid scheme (ref. 7) and the Cebeci-Keller box scheme (ref. 18) appear to be two of the most promising schemes currently available in the literature for solving the boundary-layer equations. The Cebeci-Keller box scheme, although efficient for two-dimensional flow, yields block-tridiagonal matrices and requires greater computational effort than the simple-tridiagonal matrices of the Blottner variable-grid scheme. Blottner has shown (ref. 7) that the variable-grid scheme is as accurate as the box scheme for the two-dimensional boundary-layer equations and, furthermore, that large values of the geometric progression constant can be used for the normal mesh-point distribution, provided the variable grid is interpreted as a coordinate transformation. In reference 8 it was shown that k values on the order of 1.04 could be used for turbulent flows. In reference 19 it was shown that an accuracy requirement on τ_w of 1 percent required approximately 220 mesh points normal to the wall with $k \approx 1.04$. In order to increase the computational efficiency of such schemes one can reduce the number of mesh points while simultaneously increasing the value of k; however, this approach generally results in unacceptable levels of accuracy. Blottner (ref. 7) demonstrated that with the variable-grid scheme satisfactory results could be obtained with approximately 20 mesh points for $k = 1.82$. Vatsa and Goglia (ref. 20), using the method of reference 4, showed that the variable-grid scheme proposed by Blottner (ref. 7) could reduce the number of grid points from approximately 201 to 61 for a specified 1-percent accuracy in wall shear stress. They also showed that for most applications one could obtain reasonably accurate solutions for turbulent boundary layers with as few as 25 to 30 mesh points, as compared to approximately 200 mesh points for the method of reference 3.

Blottner (ref. 7) introduced a modified definition for the geometric progression constant such that

$$\bar{k} = (k)^{\frac{N-1}{N_o-1}} \tag{42}$$

where $\bar{k}$ is now defined as the conventional geometric progression constant for N_o mesh points normal to the wall. Using equation (41), one obtains

$$\eta_i = \eta_e\left(\frac{k^{i-1} - 1}{k^{N-1} - 1}\right) \tag{43}$$

which when combined with equation (42) yields the following for the η-mesh distribution:

$$\eta_i = \eta_e\left[\frac{(\bar{k})^{(i-1)(N_o-1)/(N-1)} - 1}{(\bar{k})^{N_o-1} - 1}\right] \tag{44}$$

Two options are provided in program VGBLP: (1) specify η_{max}, N, and k (IGEOM = 1); or (2) specify η_{max}, N, and $\Delta\eta_1$ (IGEOM = 2). Of these two options, it is recommended that the user select the first option (IGEOM = 1) where the value of k is computed from equation (42) for specified values of $\bar{k}$ and N_o. Typical values for $\bar{k}$ and N_o are 1.5 and 25, respectively, for $N \geq 41$. (See ref. 20.) It is obvious that the larger the selected value of N and the smaller the value of $k - 1$ $(k \geq 1)$, the more accurate the solution. Since program VGBLP is very efficient in terms of computer resources, it is suggested that potential users of the program perform a series of numerical experiments over a range of k and N values in order to gain experience with the procedure. If the second option (IGEOM = 2) is selected (specify η_{max}, N, and $\Delta\eta_1$), the user is cautioned to exercise care in selecting the number of grid points. If transitional or turbulent flow occurs in a given problem, the laminar region of the boundary layer is calculated with the value of k used for the turbulent region; that is, for a given solution, k is invariant.

Difference Equations

Three-point implicit difference relations (see appendices A and B) are used to reduce the transformed momentum and energy equations (eqs. (28) and (29), respectively) to finite-difference form. The difference quotients produce linear difference equations when substituted into the momentum and energy equations provided truncation terms of the order $\Delta\xi_{m-1}\,\Delta\xi_m$ and $\Delta\eta_{n-1}\,\Delta\eta_n$ are neglected. (It should be noted that the truncation term for $\partial^2F/\partial\eta^2$ is of the order $(\Delta\eta_{n-1} - \Delta\eta_n)$.) The resulting difference equations may be written as follows:

Momentum equation

$$A1_nF_{m+1,n-1} + B1_nF_{m+1,n} + C1_nF_{m+1,n+1} + D1_n\Theta_{m+1,n-1} + E1_n\Theta_{m+1,n} + F1_n\Theta_{m+1,n+1} = G1_n \tag{45a}$$

Energy equation

$$A2_nF_{m+1,n-1} + B2_nF_{m+1,n} + C2_nF_{m+1,n+1} + D2_n\Theta_{m+1,n-1} + E2_n\Theta_{m+1,n} + F2_n\Theta_{m+1,n+1} = G2_n \tag{45b}$$

The coefficients $A1_n$, $B1_n$, ..., $G1_n$ and $A2_n$, $B2_n$, ..., $G2_n$ (see appendix B) are functions of known quantities at stations m and $m-1$. It is important to note that equations (45) are coupled through the dependent variables F and Θ; however, the dependent variable V does not appear explicitly as an unknown at station $m+1$. The variable V is uncoupled from the system because of the particular way that the nonlinear terms $V\frac{\partial F}{\partial\eta}$ and $V\frac{\partial\Theta}{\partial\eta}$ are linearized. (See eq. (A23).)

Solution of Difference Equations

The system of difference equations (eqs. (45)) represents a set of $2(N - 1)$ linear algebraic equations for $2(N - 1)$ unknowns. The boundary conditions to be used with the difference equations are specified in equations (34). The $2(N - 1)$ linear algebraic equations may be written in tridiagonal matrix form; consequently, an efficient algorithm (Thomas algorithm) is available for simultaneous solution.

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The simultaneous or coupled-solution technique is presented in appendix B of reference 5; however, because of differences between the present work and that presented in reference 5, the solution technique is discussed here in some detail.

Because of the special form of equations (45), the following relations exist (see ref. 21):

$$F_{m+1,n-1} = P^{(1)}_{m+1,n-1} + P^{(2)}_{m+1,n-1}F_{m+1,n} + P^{(3)}_{m+1,n-1}\Theta_{m+1,n} \tag{46a}$$

$$\Theta_{m+1,n-1} = Q^{(1)}_{m+1,n-1} + Q^{(2)}_{m+1,n-1}F_{m+1,n} + Q^{(3)}_{m+1,n-1}\Theta_{m+1,n} \tag{46b}$$

Next, equations (46) are substituted into equations (45) to obtain the following relations:

$$\begin{aligned} B1^*_{m+1,n}F_{m+1,n} + E1^*_{m+1,n}\Theta_{m+1,n} = G1^*_{m+1,n} &- C1_{m+1,n}F_{m+1,n+1} \\ &- F1_{m+1,n}\Theta_{m+1,n+1} \end{aligned} \tag{47a}$$

$$\begin{aligned} B2^*_{m+1,n}F_{m+1,n} + E2^*_{m+1,n}\Theta_{m+1,n} = G2^*_{m+1,n} &- C2_{m+1,n}F_{m+1,n+1} \\ &- F2_{m+1,n}\Theta_{m+1,n+1} \end{aligned} \tag{47b}$$

where

$$B1^*_{m+1,n} = B1_{m+1,n} + A1_{m+1,n}P^{(2)}_{m+1,n-1} + D1_{m+1,n}Q^{(2)}_{m+1,n-1} \tag{48a}$$

$$E1^*_{m+1,n} = E1_{m+1,n} + A1_{m+1,n}P^{(3)}_{m+1,n-1} + D1_{m+1,n}Q^{(3)}_{m+1,n-1} \tag{48b}$$

$$G1^*_{m+1,n} = G1_{m+1,n} - A1_{m+1,n}P^{(1)}_{m+1,n-1} - D1_{m+1,n}Q^{(1)}_{m+1,n-1} \tag{48c}$$

$$B2^*_{m+1,n} = B2_{m+1,n} + A2_{m+1,n}P^{(2)}_{m+1,n-1} + D2_{m+1,n}Q^{(2)}_{m+1,n-1} \tag{48d}$$

$$E2^*_{m+1,n} = E2_{m+1,n} + A2_{m+1,n}P^{(3)}_{m+1,n-1} + D2_{m+1,n}Q^{(3)}_{m+1,n-1} \tag{48e}$$

and

$$G2^*_{m+1,n} = G2_{m+1,n} - A2_{m+1,n}P^{(1)}_{m+1,n-1} - D2_{m+1,n}Q^{(1)}_{m+1,n-1} \tag{48f}$$

The unknown values of F and Θ at station $m+1,n$ are obtained from equations (47) as follows:

$$F_{m+1,n} = P^{(1)}_{m+1,n} + P^{(2)}_{m+1,n} F_{m+1,n+1} + P^{(3)}_{m+1,n} \Theta_{m+1,n+1} \tag{49a}$$

$$\Theta_{m+1,n} = Q^{(1)}_{m+1,n} + Q^{(2)}_{m+1,n} F_{m+1,n+1} + Q^{(3)}_{m+1,n} \Theta_{m+1,n+1} \tag{49b}$$

where

$$P^{(1)}_{m+1,n} = \left(E2^{*}_{m+1,n} G1^{*}_{m+1,n} - E1^{*}_{m+1,n} G2^{*}_{m+1,n}\right) \Delta^{*}_{m+1,n} \tag{50a}$$

$$P^{(2)}_{m+1,n} = \left(E1^{*}_{m+1,n} C2_{m+1,n} - E2^{*}_{m+1,n} C1_{m+1,n}\right) \Delta^{*}_{m+1,n} \tag{50b}$$

$$P^{(3)}_{m+1,n} = \left(E1^{*}_{m+1,n} F2_{m+1,n} - E2^{*}_{m+1,n} F1_{m+1,n}\right) \Delta^{*}_{m+1,n} \tag{50c}$$

$$Q^{(1)}_{m+1,n} = \left(B1^{*}_{m+1,n} G2^{*}_{m+1,n} - B2^{*}_{m+1,n} G1^{*}_{m+1,n}\right) \Delta^{*}_{m+1,n} \tag{50d}$$

$$Q^{(2)}_{m+1,n} = \left(B2^{*}_{m+1,n} C1_{m+1,n} - B1^{*}_{m+1,n} C2_{m+1,n}\right) \Delta^{*}_{m+1,n} \tag{50e}$$

$$Q^{(3)}_{m+1,n} = \left(B2^{*}_{m+1,n} F1_{m+1,n} - B1^{*}_{m+1,n} F2_{m+1,n}\right) \Delta^{*}_{m+1,n} \tag{50f}$$

and

$$\Delta^{*}_{m+1,n} = \frac{1}{\left(B1^{*}_{m+1,n} E2^{*}_{m+1,n} - B2^{*}_{m+1,n} E1^{*}_{m+1,n}\right)} \tag{50g}$$

Next, equations (46) are rewritten as follows (where $n = n + 1$):

$$F_{m+1,n} = P^{(1)}_{m+1,n} + P^{(2)}_{m+1,n} F_{m+1,n+1} + P^{(3)}_{m+1,n} \Theta_{m+1,n+1} \tag{51a}$$

$$\Theta_{m+1,n} = Q^{(1)}_{m+1,n} + Q^{(2)}_{m+1,n} F_{m+1,n+1} + Q^{(3)}_{m+1,n} \Theta_{m+1,n+1} \tag{51b}$$

The "no-slip" boundary condition ($F_{m+1,1} = 0$) is applied at the wall boundary to obtain the values of $P^{(i)}_{m+1,1}$ where $i = 1, 2, 3$; that is,

$$P^{(1)}_{m+1,1} = P^{(2)}_{m+1,1} = P^{(3)}_{m+1,1} = 0 \tag{52}$$

The thermal condition at the wall boundary can be specified in one of two ways: (1) specified wall-temperature distribution (KODWAL = 1); or (2) specified heat-transfer distribution (KODWAL = 2). For a specified wall-temperature distribution it can be seen directly from equation (51b) that

$$\left.\begin{aligned} Q^{(1)}_{m+1,1} &= \Theta_{m+1,1} \\ Q^{(2)}_{m+1,1} &= Q^{(3)}_{m+1,1} = 0 \end{aligned}\right\} \tag{53}$$

The case in which a heat-transfer distribution is specified presents a somewhat more difficult problem; however, this class of flows is often of interest; for example, adiabatic flows where $q^*_w = 0$.

The heat transfer at the wall boundary can be written in the transformed plane as follows (see ref. 3):

$$q^*_{m+1,1} = -\frac{\mu^*_r u^{*2}_r \sqrt{N_{Re,r}}}{L^*_r}\left(\frac{\rho_e u_e T_e \mu_e r^j_o}{N_{Pr}\sqrt{2\xi}}\right)_{m+1,N} l_{m+1,1}\left(\frac{\partial\Theta}{\partial\eta}\right)_{m+1,1} \tag{54}$$

Then, for a specified value of $q^*_{m+1,1}$, the gradient of Θ can be obtained directly as follows:

$$\left(\frac{\partial\Theta}{\partial\eta}\right)_{m+1,1} = -q^*_{m+1,1}\frac{L^*_r}{\mu^*_r u^{*2}_r \sqrt{N_{Re,r}}}\left(\frac{N_{Pr}\sqrt{2\xi}}{\rho_e u_e T_e \mu_e r^j_o}\right)_{m+1,N}\left(\frac{1}{l}\right)_{m+1,1} \tag{55}$$

For the grid-point spacing used in program VGBLP, the gradient of Θ evaluated at the wall, by using a three-point relation, is as follows:

$$\left(\frac{\partial\Theta}{\partial\eta}\right)_{m+1,1} = \frac{\left[1-(1+k)^2\right]\Theta_{m+1,1} + (1+k)^2\Theta_{m+1,2} - \Theta_{m+1,3}}{k(1+k)\Delta\eta_1} \tag{56}$$

Equations (55) and (56) then yield the following expression for $\Theta_{m+1,1}$:

$$\Theta_{m+1,1} = \frac{k(1+1)\Delta\eta_1}{1-(1+k)^2}\left(\frac{\partial\Theta}{\partial\eta}\right)_{m+1,1} - \frac{(1+k)^2}{1-(1+k)^2}\Theta_{m+1,2} + \frac{1}{1-(1+k)^2}\Theta_{m+1,3} \tag{57}$$

where $\left(\frac{\partial\Theta}{\partial\eta}\right)_{m+1,1}$ is evaluated from equation (55). Equations (45) are next written at the m+1,2 point to obtain two equations in terms of $F_{m+1,n}$ and $\Theta_{m+1,n}$ where

$n = 1, 2, 3$. (Note that $F_{m+1,1} = 0$.) The quantity $F_{m+1,3}$ is then eliminated from these two equations to obtain one equation in terms of $F_{m+1,2}$ and $\Theta_{m+1,n}$ where $n = 1, 2, 3$. The quantity $\Theta_{m+1,3}$ is next eliminated through use of equation (57) to obtain the relation

$$\Theta_{m+1,1} = \bar{Q}^{(1)}_{m+1,1} + \bar{Q}^{(2)}_{m+1,1} F_{m+1,2} + \bar{Q}^{(3)}_{m+1,1} \Theta_{m+1,2} \tag{58}$$

where

$$\bar{Q}^{(1)}_{m+1,1} = \frac{\Big[(C2)(G1) - (C1)(G2)\Big]_{m+1,2} + \Big[(C2)(F1) - (C1)(F2)\Big]_{m+1,2}\Big[k(1 + k)\Delta\eta_1\Big]\left(\frac{\partial\Theta}{\partial\eta}\right)_{m+1,1}}{\Delta_{m+1,2}} \tag{59a}$$

$$\bar{Q}^{(2)}_{m+1,1} = \frac{\Big[(C1)(B2) - (C2)(B1)\Big]_{m+1,2}}{\Delta_{m+1,2}} \tag{59b}$$

$$\bar{Q}^{(3)}_{m+1,1} = \frac{\Big[(C1)(E2) - (C2)(E1)\Big]_{m+1,2} + \Big[(C1)(F2) - (C2)(F1)\Big]_{m+1,2}(1 + k)^2}{\Delta_{m+1,2}} \tag{59c}$$

and

$$\Delta_{m+1,2} = \Big\{\Big[(C2)(D1) - (C1)(D2)\Big] + \Big[(C2)(F1) - (C1)(F2)\Big]\Big[1 - (1 + k)^2\Big]\Big\}_{m+1,2} \tag{59d}$$

By comparing equations (51b) and (58), it is observed that

$$Q^{(i)}_{m+1,1} = \bar{Q}^{(i)}_{m+1,1} \qquad (i = 1, 2, 3) \tag{60}$$

which completes the desired boundary condition for the case of a specified heat-transfer distribution along the wall boundary. The temperature at the wall is obtained from equation (57) once $\Theta_{m+1,2}$ and $\Theta_{m+1,3}$ are known.

The quantities $P^{(i)}_{m+1,n}$ and $Q^{(i)}_{m+1,n}$ where $i = 1, 2, 3$ (see eqs. (51)) must first be determined across the boundary layer at the $m+1$ station where $n = 1, 2, \ldots, N$. These quantities are calculated by the following procedure:

(1) Perform the following steps at the first grid point away from the wall ($n = 2$):

(a) Calculate $A1_2$, $B1_2$, ..., $G1_2$ from equations (B3)

(b) Calculate $A2_2$, $B2_2$, ..., $G2_2$ from equations (B4)

(c) Using the results from steps (a) and (b) and the boundary conditions (eqs. (52) and (53) or (59)), calculate $B1_2^*$, $B2_2^*$, $E1_2^*$, $E2_2^*$, $G1_2^*$, and $G2_2^*$ from equations (48)

(d) Using the results from steps (a) to (c), calculate $P_2^{(i)}$ and $Q_2^{(i)}$ where $i = 1, 2, 3$ from equations (50)

(2) The procedure outlined in step (1) is now repeated at the second grid point off the wall ($n = 3$) by using the results obtained at $n = 2$. This procedure is repeated until the entire boundary layer is traversed ($n = N$) and all values of $P_{m+1,n}^{(i)}$ and $Q_{m+1,n}^{(i)}$ are determined where $i = 1, 2, 3$ and $n = 2, 3, 4, \ldots, N$.

(3) Using the values of $P_{m+1,n}^{(i)}$ and $Q_{m+1,n}^{(i)}$ where $i = 1, 2, 3$ and $n = 2, 3, 4, \ldots, N$, the values of $F_{m+1,n}$ and $\Theta_{m+1,n}$ where $n = N-1, N-2, \ldots, 2$ are calculated from equations (49). It should be noted that $F_{m+1,N}$ and $\Theta_{m+1,N}$ are specified edge boundary conditions (eqs. (34b)). The wall-boundary values of F and Θ are obtained from equations (34a), or from equation (57) for the case of a specified wall-boundary heat-transfer distribution. At this point in the procedure, the values of $F_{m+1,n}$ and $\Theta_{m+1,n}$ are known for $n = 1, 2, \ldots, N$, and it remains only to determine $V_{m+1,n}$ for all values of n to complete the first iteration.

(4) The continuity equation (eq. (27)) is solved numerically for the $N - 1$ unknown values of $V_{m+1,n}$ as follows:

$$V_{m+1,n} = V_{m+1,1} - \int_0^{\eta_n} \left(2\xi \frac{\partial F}{\partial \xi} + F\right)_{m+1} d\eta \tag{61}$$

where $V_{m+1,1}$ represents the wall-boundary condition V_w. (See eq. (35).) The trapezoidal rule of integration is used to numerically solve equation (61).

(5) The solution is now checked for convergence where the convergence criterion is as follows (q is iteration index):

$$\mathrm{DIF} = \left| 1 - \frac{(\partial F/\partial \eta)^q}{(\partial F/\partial \eta)^{q-1}} \right|_{m+1,1} \tag{62}$$

If DIF $\leq$ CONV, station $m+1$ is declared converged and m is incremented by 1. During the development of program VGBLP, a global convergence check was initially applied to each of the three dependent variables over all values of n. Global convergence was declared once all three variables were converged over all values of n; however, it was observed numerically that a local check on the gradient of F at the wall was a sufficiently accurate criterion. Consequently, the logic and storage requirements for the global check were removed from the software.

Initial Profiles

A major change in the present approach compared with that of references 3 and 4 is the technique for numerically generating the initial profiles at $\xi = 0$. These initial values are required to initiate the three-point implicit marching procedure. In references 3 and 4, the equations at the initial station ($\xi = 0$) were numerically solved using a fourth-order Runge-Kutta scheme for an equally spaced grid $\left(\Delta\eta = \eta_{max}/(N - 1)\right)$ in the η-direction. The converged solution on the equally spaced grid was then interpolated onto the variably spaced grid $\left(\Delta\eta_i = k\ \Delta\eta_{i-1}\right)$. This procedure introduced some interpolation error into the initial profiles which, although decaying in ξ, could cause oscillations in the neighborhood of the stagnation point for blunt-body flows. These oscillations, if they occurred, made it difficult to accurately determine parameters such as $\lim_{s\to 0} q_w$ and $\lim_{s\to 0} \tau_w$. Another problem sometimes encountered by users of the approach presented in reference 4 was the sensitivity of the convergence of the initial solution to the selected initial values for $\left.\frac{\partial F}{\partial \eta}\right|_{\eta=0}$ and $\left.\frac{\partial \Theta}{\partial \eta}\right|_{\eta=0}$ required to initiate the Runge-Kutta integration. To ensure convergence, the user would often have to make several trial runs before the initial guesses were sufficiently close to the converged values.

In the present approach these two problems (interpolation and convergence) are completely eliminated. The locally similar form of the momentum and energy equations is numerically solved in finite-difference form for the variable grid used in the marching procedure. Initial value guesses and interpolation procedures are not required. The momentum and energy equations are of tridiagonal form and are easily solved. The continuity equation is uncoupled from the system and solved using the trapezoidal rule of integration. The initial profiles are generated in subroutine SIMILAR.

The marching procedure requires evaluation of the ξ-derivatives at two backward points; consequently, the first solution station SS(1) + SS(2) in the ξ-coordinate requires special attention to assure local accuracy in the neighborhood of the stagnation point. For flows with a stagnation point (IBODY = 1), the profiles at $\xi = \Delta\xi_1$ are reflected about the stagnation point to impose symmetry. For flows without a stagnation point (IBODY = 2), it is assumed that the solution at $\xi = \Delta\xi_1$ is identical to that at $\xi = 0$ $(s = 0)$. As a result of this approach, the solutions are physically correct and merge smoothly with the downstream marching solution $(\xi > \Delta\xi_1)$. The quantity $\Delta\xi_1$ is evaluated using Simpson's rule for stagnation-point flows.

Evaluation of Wall Derivatives

The shear stress and heat transfer at the wall are directly proportional to the gradient of F and Θ evaluated at the wall, respectively. By using G to represent a general quantity, where $G_{m+1,1}$ is the value of G at m+1 evaluated at the wall, the four-point difference scheme used to evaluate derivatives at the wall is given as

$$\left(\frac{\partial G}{\partial \eta}\right)_{m+1,1} = Y_7 G_{m+1,1} + Y_8 G_{m+1,2} + Y_9 G_{m+1,3} + Y_{10} G_{m+1,4} \tag{63}$$

where the coefficients are defined by the following relations:

$$Y_7 = -\frac{(1 + k + k^2)^2\left[k(1 + k) - 1\right] + (1 + k)}{(1 + k)(1 + k + k^2)k^3\ \Delta\eta_1} \tag{64a}$$

$$Y_8 = \frac{(1 + k + k^2)}{k^2\ \Delta\eta_1} \tag{64b}$$

$$Y_9 = -\frac{(1 + k + k^2)}{(1 + k)k^3\ \Delta\eta_1} \tag{64c}$$

and

$$Y_{10} = \frac{1}{(1 + k + k^2)k^3\ \Delta\eta_1} \tag{64d}$$

For the case of equally spaced grid points in the η-direction ($k = 1$), equation (63) reduces to the familiar four-point relation:

$$\left(\frac{\partial G}{\partial \eta}\right)_{m+1,1} = -\frac{1}{6\ \Delta\eta}(11G_{m+1,1} - 18G_{m+1,2} + 9G_{m+1,3} - 2G_{m+1,4}) \tag{65}$$

PROGRAM DESCRIPTION

Program VGBLP is run on the Control Data CYBER 170 series computers under the NOS 1.4 operating system at the Langley Research Center.

Array Dimensions

Program VGBLP and subroutines TABLE, VARENT, TURBLNT, MESH, SIMILAR, and SOLVE use the variable-dimension capability of the preprocessor at the Langley Research Center. This capability allows the user to designate the minimum storage requirements for a given problem. If the preprocessor capability is not available at the user's installation, the dimension statements can be modified by inserting the required dimensions in place of their equivalent designations (UPDATE, MODIFY, etc.) in accordance with the following definitions for program VGBLP and its subroutines.

<u>Program VGBLP</u>

Variable dimension	Assigned value
JI	1 - (KODPRT $\neq$ 3); NUMB1 - (KODPRT = 3)
JK	IE + 2

JL	1 - (constant entropy); IEND1 - (variable entropy)
JM	INTEGER (s_{max}/PRNTINC + IPRNT)
JN	INTEGER (s_{max}/PROINC + IPRO)
JH	IEND1 + 1

Subroutine TABLE

JH	See definition in VGBLP
JJ	NUMBER

Subroutine VARENT

JL	See definition in VGBLP

Subroutine TURBLNT

JI	See definition in VGBLP
JK	See definition in VGBLP

Subroutines MESH, SIMILAR, SOLVE

JK	See definition in VGBLP

Input Description

Standard CDC NAMELIST is used for all data input. Program VGBLP reads input under $NAM1. Subroutine TABLE reads input under $NAM2. For cases where the variable entropy option is required (IENTRO = 2), subroutine VARENT reads input under $NAM3.

Input/output flexibility is provided to the user wherein either the International System of Units (SI, KODUNIT = 1) or the U.S. Customary Units (U.S., KODUNIT = 0) can be used. The required input and resulting output data are listed in the following sections with appropriate dimensional units. The SI Units are listed first, followed by U.S. Units in parentheses. If no units are listed, the quantity is nondimensional.

Input data for $NAM1.-

Variable name	Variable description
CONV	Convergence criterion for boundary-layer solution; DEFAULT = 1×10^{-4}
CONVE	Convergence criterion for variable entropy iteration; DEFAULT = 1×10^{-2}
DETA1	$\Delta\eta_1$ (see fig. 1)

FT — 1.0 - nonsimilar solution; 0.0 - locally similar solution; DEFAULT = 1.0

G — γ; DEFAULT = 1.4

GLAR — y/δ array corresponding to PRTAR array, used only if KODPRT = 3; NUMB1 values

IBODY — 1 - flows with stagnation point; 2 - flows without stagnation point

IE — Number of mesh points in η-coordinate

IEND1 — Number of steps in S-direction

$$S_{max} = \sum_{m=1}^{IEND1} SS(m) \quad \text{where} \quad SS(1) = 0$$

IENTRO — 1 - constant entropy; 2 - variable entropy; DEFAULT = 1

IGAS — 1 - Sutherland's viscosity (see eq. (7a)); 2 - power-law viscosity (see eq. (7b)); DEFAULT = 1

IGEOM — 1 - specify XEND, IE, XK; 2 - specify XEND, IE, DETA1

IPRNT — Number of specified wall-value printouts desired other than those determined by PRNTINC; DEFAULT = 0

IPRO — Number of specified profile printouts desired other than those determined by PROINC; DEFAULT = 0

ITMAX — Maximum number of iteration cycles, $1 \leq m \leq$ IEND1, for variable-entropy calculations; DEFAULT = 3

IYINT — 1 - normal intermittency function, $\bar{\gamma}$ set to 1.0; 2 - normal intermittency function, $\bar{\gamma}$ calculated from equation (17c); DEFAULT = 1

J — j; 0 - two-dimensional; 1 - axisymmetric

KODAMP — 1 - local values used in equation (5b) for damping; 2 - wall values used in equation (5b) for damping; DEFAULT = 2

KODE — 1 - both laminar and turbulent profile prints are desired for diagnostic reasons once flow is turbulent; 0 - otherwise; DEFAULT = 0

KODPRT — 1 - constant $N_{Pr,t}$; 2 - Rotta distribution (see eq. (21)); 3 - tabular, $N_{Pr,t} = f(y/\delta)$; DEFAULT = 1

KODUNIT — 0 - all dimensional input and output in U.S. Units; 1 - all dimensional input and output in SI Units; DEFAULT = 0

KODVIS — 1 - mixing-length model; 2 - two-layer eddy-viscosity model; DEFAULT = 2

KODWAL — 1 - specified wall temperature distribution; 2 - specified wall heat-transfer distribution; DEFAULT = 1

KTCOD — 1 - transition extent calculated from equation (37); 2 - transition extent specified as TLNGTH; DEFAULT = 2.0

NAUXPRO — 1 - auxiliary profile prints are desired (see output description); 2 - otherwise; DEFAULT = 2.0

NITMAX — Maximum number of iterations allowed at any given station; DEFAULT = 1

NUMB1 — Number of values read into PRTAR and GLAR arrays if KODPRT = 3

PHII — Opening angle of body at $s = 0$, $\tan^{-1}\left(\frac{ds}{dz}\right)_{s=0}$, deg

PR — N_{Pr}; DEFAULT = 0.72

PRNTINC — Incremental s^*-value for which wall-value printouts will be made, m (ft); DEFAULT = 0.1

PRNTVAL — Array of IPRNT specified s^*-values for which wall-value printouts are desired, m (ft)

PROINC — Incremental s^*-value for which profile printouts will be made, m (ft); DEFAULT = 1.0

PROVAL — Array of IPRO specified s^*-values for which profile printouts are desired, m (ft)

PRT — $N_{Pr,t}$; DEFAULT = 0.95

PRTAR — $N_{Pr,t}$ array, used only if KODPRT = 3; NUMB1 values

PT1 — $p^*_{t,\infty}$, Pa (lb/ft^2)

R — R^*_g, gas constant (eq. (6)), m^2/(s^2-K) (ft^2/(s^2-$^\circ$R)); DEFAULT = 1716 ft^2/(s^2-$^\circ$R)

SMXTR — Critical-vorticity Reynolds number; DEFAULT = 1×10^8

SST	S^*-location of transition, $s_{t,i}$, m (ft); DEFAULT = 1×10^8
TLNGTH	$s_{t,f}/s_{t,i}$, transition extent (see fig. 2); DEFAULT = 2.0
TT1	$T^*_{t,\infty}$, K ($^\circ$R)
VELEDG	Value of F to be used in defining edge of boundary layer; DEFAULT = 0.995
VIS1C1	a_1^* (see eq. (7a)), Pa-s (lb-s/ft^2); DEFAULT = 2.27×10^{-8} lb-s/ft^2
VIS1C2	a_2^* (see eq. (7a)), K ($^\circ$R); DEFAULT = 198.6 $^\circ$R
VIS2C1	a_3^* (see eq. (7b)), Pa-s (lb-s/ft^2)
VIS2C2	a_4 (see eq. (7b))
W	0 - neglect transverse curvature; 1 - include transverse curvature; DEFAULT = 0
WAVE	$\Theta_s^*\Big\|_{s=0}$, shock-wave angle at $s = 0$ (see fig. 2), deg
XEND	η_{max} (see fig. 1)
XK	k, constant in geometric progression (see eq. (42))
XMA	M_∞
XT1	k_1 (see eq. (16a)); DEFAULT = 0.4
XT2	k_2 (see eq. (16b)); DEFAULT = 0.0168
XT3	k_3 (see eq. (17c)); DEFAULT = 5.0
XT4	k_4 (see eq. (17c)); DEFAULT = 0.78
XT5	k_5 (see eq. (20b)); DEFAULT = 0.108
XT6	A^+, damping function; DEFAULT = 26.0

Input data for $NAM2.-

Variable name	Variable description
L	Order of interpolation to be used for $NAM2 tables; DEFAULT = 1
NUMBER	Number of values read into $NAM2 tables

PE — Edge pressure-distribution array (NUMBER values), Pa (lb/ft^2)

QW — Wall heat-transfer-distribution array (NUMBER values); KODWAL = 2, W/m^2 (Btu/ft^2-s)

RMI — Body radial-coordinate array r_o (NUMBER values), m (ft)

RVWALD — Wall mass-flux array V_w (NUMBER values); DEFAULT = 0, Pa-s/m ($lb\text{-}s/ft^3$)

S — S-station array (NUMBER values); independent variable for tabular input, m (ft)

SS — Array of incremental values between adjacent solution stations (s_1^*, s_2^*, ..., s_{IEND1}^*); step size can be arbitrary and not directly associated with the S-station array other than $\sum_{m=1}^{IEND1} SS(I) = s_{max}^*$; the first two members of the array must be equal (SS(2) = SS(1))

TW — Wall-temperature-distribution array (NUMBER values); KODWAL = 1, K (°R)

Z — Axial-coordinate array (NUMBER values), m (ft)

Input data for $NAM3.-

Variable name	Variable description
NUMBER	Number of values read into $NAM3 tables
RRS	Array of radial coordinates of shock wave (NUMBER values), m (ft)
ZZS	Array of axial coordinates of shock wave (NUMBER values), m (ft)

A unique relationship exists between the print control parameters (PROINC; PRNTINC; IPRO; IPRNT; PROVAL; PRNTVAL) and IEND1 in $NAM1 and the SS array in $NAM2. The potential user of program VGBLP should note that there are exactly IEND1 values in the SS array and that these values specify the solution-station locations along the s-coordinate. Also, a solution station must be located at the s-coordinate locations designated as print (profile or wall) stations. A failure to understand this relationship generally results in a computer run with no output. Consider the following input where the program user wishes to march the solution to $s_{max} = 1.0$:

SS = 10*.001, 99*.01

IEND1 = 75

PRNTINC = 0.201, PROINC = 0.501

IPRO = 1, IPRNT = 1

PROVAL = 0.751, PRNTVAL = 0.751

Two errors have been made in the preceding input that will result in the program stopping at $s = 0.66$ (instead of $s = 1.0$) without any output (wall print or profile print). The two errors are as follows: (1) IEND1 is not equal to the number of values in the SS array; (2) the designated print locations do not agree with the solution stations designated by the SS array. An example of correct input is as follows:

SS = 10*.001, 99*.01

IEND = 109

PRNTINC = 0.2, PROINC = 0.5,

IPRO = 1, IPRNT = 1,

PROVAL = 0.75, PRNTVAL = 0.75

The program would now have a normal STOP at $s = 1.0$ with wall prints at $s = 0.2$, 0.4, 0.6, 0.75, 0.8, and 1.0 and profile prints at $s = 0.5$, 0.75, and 1.0. Finally, it should be noted that the SS array can be composed of completely arbitrary Δs values with the restriction SS(1) = SS(2), but to obtain output the user must specify print-control input corresponding to the location of the solution stations.

Intermediate Data Storage

The output (S, PE, RMI, TW, Z, DPEDS, RVWALD, DRDZ, QW) required at station $m+1$ generated in subroutine TABLE is written on TAPE 4. Program VGBLP reads this output just prior to obtaining the boundary-layer solution at station $m+1$. For cases where variable entropy is included (IENTRO = 2), TAPE 4 is rewound at the end of the last computed station s_{max} to enable restart for the next variable-entropy iteration.

Output Description

Program VGBLP first prints namelist data for $NAM1. Next, subroutine TABLE prints $NAM2. If the case includes the effect of variable entropy (IENTRO = 2), subroutine VARENT then prints $NAM3 input. It should be noted that for many cases the user can take advantage of many of the DEFAULT values for $NAM1 and $NAM2.

Following the input data prints, the similar-solution profiles at the initial station ($\xi = 0$) are printed as follows:

Variable name	Variable (see "Symbols")
ETA	η
FZ	$\partial F/\partial \eta$
T/TE	Θ
TZ	$\partial \Theta/\partial \eta$
U/UE	F
V	V
XL	$(\rho\mu)/(\rho\mu)_e$

The initial station parameters are then printed.

MUE	μ_e^*, Pa-s (lb-s/ft^2)
PE	p_e^*, Pa (lb/ft^2)
QSD	q_w^*, W/m^2 (Btu/ft^2-s)
TE	T_e^*, K (^{o}R)
UE	u_e^*, m/s (ft/s)

The units used in input and expected as output for dimensional quantities are next declared as either SI or U.S. Customary.

Free-stream and reference variables are then printed.

AA1	a_∞^*, m/s (ft/s)
PREF	$\rho_r^* u_r^{*2}$, Pa (lb/ft^2)
PTR	$p_{t,\infty}/\left(\rho_\infty u_\infty^2\right)$
PTI	$p_{t,\infty}^*$, Pa (lb/ft^2)
P1	p_∞^*, Pa (lb/ft^2)
REY	$N_{Re,\infty}$, m^{-1} (ft^{-1})
RREF	ρ_r^*, kg/m^3 (lb-s^2/ft^4)
RT1	$\rho_{t,\infty}^*$, kg/m^3 (lb-s^2/ft^4)
R1	ρ_∞^*, kg/m^3 (lb-s^2/ft^4)
TREF	u_r^{*2}/c_p^*, K (^{o}R)
TT1	$T_{t,\infty}^*$, K (^{o}R)

T1	T_∞^*, K ($^{\circ}$R)
UREF	u_r^*, m/s (ft/s)
U1	u_∞^*, m/s (ft/s)
VISREF	μ_r^*, Pa-s (lb-s/ft^2)
XMA	M_∞

The profile-print and wall-print stations are next printed in accordance with input specified in $NAM1.

Laminar-profile

CROCCO	$\dfrac{T_t - T_w}{T_{t,e} - T_w}$
ETA	η
FZ	$\left(\dfrac{\partial F}{\partial \eta}\right)_{m+1,n}$
M/ME	M/M_e, Mach number ratio
PT/PTR	$p_t/p_{t,r}$, total pressure ratio
T/TE	Θ
TT/TTE	$T_t/T_{t,e}$
TZ	$\left(\dfrac{\partial \Theta}{\partial \eta}\right)_{m+1,n}$
U/UE	F
VORTREY	$\chi_{m+1,n} = \left[\dfrac{y^2}{\nu}\left(\dfrac{\partial \mu}{\partial y}\right)\right]_{m+1,n}$, vorticity Reynolds number
XLM11	$\dfrac{(\rho\mu)_{m+1,n}}{(\rho\mu)_e}$
Y/YE	y/y_e

Additional values for transitional and turbulent profiles

UDEF	$\dfrac{u_e - u}{u_\tau}$
UPLUS	$\dfrac{u}{u_\tau}$
VISEFF	$1 + \dfrac{\varepsilon}{\mu}\Gamma$, effective viscosity parameter
YPLUS	$\dfrac{y u_\tau}{\nu}$

Auxiliary-profile values (NAUXPRO = 1)

DAMP	$\left[1 - \exp\left(-\frac{y}{A}\right)\right]_{m+1,n}$
EP	$\left(\frac{\varepsilon}{\mu}\right)_{m+1,n}$
EP1	$\left[\left(\frac{\varepsilon}{\mu}\right)_i\right]_{m+1,n}$ (see eq. (16a))
EP2	$\left[\left(\frac{\varepsilon}{\mu}\right)_o\right]_{m+1,n}$ (see eq. (16b))
FC1	$\left(\frac{\rho}{\mu}\left\lvert\frac{\partial u}{\partial y}\right\rvert\right)_{m+1,n}$
GRAD(U/UE)	$\frac{\partial F}{\partial \eta}$
GRAD(T/TE)	$\frac{\partial \Theta}{\partial \eta}$
MIXDEL	$\left(\frac{l}{\delta}\right)_{m+1,n}$
V	V (see eq. (26))

Wall print

BETA	β, pressure-gradient parameter (see eqs. (30))
CFE	$\frac{\tau_w}{\frac{1}{2}\rho_e u_e^2}$, skin-friction coefficient based on edge condition
CFW	$\frac{\tau_w}{\frac{1}{2}\rho_w u_e^2}$, skin-friction coefficient based on wall density
DLTAST	δ^*, displacement thickness, m (ft)
DPEDS	$\frac{dp_e}{ds}$, pressure gradient
DSMXO	$\left(\frac{\partial \chi_{max}}{\partial s}\right)_{m+1}$
DTEDS	$\frac{dT_e}{ds}$, temperature gradient

DUEDS	$\frac{du_e}{ds}$, velocity gradient
ERROR	value of DIF at convergence (see eq. (62))
FORM	$\frac{\delta^*}{\theta}$
HD	$\frac{q_w}{T_w - T_{aw}}$, heat-transfer coefficient, W/m^2-K (Btu/ft^2-s-^oR)
ITRO	number of iterations performed for variable entropy
ME	M_e, edge Mach number
MUE	μ_e, Pa-s ($lb\text{-}s/ft^2$)
NOITER	number of iterations required for convergence
NSTE	$\frac{h}{c_p(\rho u)_e}$, Stanton number based on edge condition
NSTW	$\frac{h}{c_p\rho_w u_e}$, Stanton number based on wall condition
NUE	Nusselt number based on edge condition
NUW	Nusselt number based on wall condition
OMEGA	$\left(\frac{\rho_r u_r L_r}{\mu_r}\right)^{-1/2}$
PE	p_e, edge pressure, Pa (lb/ft^2)
P20	$\frac{p_{t,e}}{\rho_r u_r^2}$
QSD	q_w, heat transfer, W/m^2 (Btu/ft^2-s)
RE	ρ_e, edge density, kg/m^3 ($lb\text{-}s^2/ft^4$)
REDELT	$\frac{\rho_e u_e \delta^*}{\mu_e}$, Reynolds number based on local displacement thickness
RES	$\frac{\rho_e u_e s}{\mu_e}$, local Reynolds number

RETHET	$\frac{\rho_e u_e \theta}{\mu_e}$, Reynolds number based on local momentum thickness
RFTRUE	$\frac{T_{aw} - T_e}{T_t - T_e}$, recovery factor
RMI	r_o, body radius (see fig. 2), m (ft)
ROUSE	$\chi_{max} = \left[\left(\frac{y^2}{\nu} \frac{\partial u}{\partial y}\right)_{m+1,n}\right]_{max}$
RSHK	local radius of shock wave, m (ft)
RVWAL	$(\rho v)_w/(\rho u)_e$
RVWALD	$(\rho v)_w$, dimensional mass flux at wall, Pa-s/m (lb-s/ft^3)
S	s, boundary-layer coordinate (see fig. 2), m (ft)
SWANG	local shock-wave angle, deg
TAUD	τ_w, wall shear stress, Pa (lb/ft^2)
TE	T_e, edge temperature, K (^{o}R)
THETA	θ, momentum thickness, m (ft)
TRFCT	Γ, intermittency distribution (see eq. (38))
TW/TT1	$\frac{T_w}{T_{t,\infty}}$
UE	u_e, edge velocity, m/s (ft/s)
UTAU	$u_\tau = \sqrt{\frac{\tau_w}{\rho}}$, m/s (ft/s)
VW	$V_{m+1,1}$
XAL	$(\gamma - 1)M_e^2$
XI	ξ
YE	δ_e, boundary-layer thickness, m (ft)
YMP	n-value at y_m
Z	z, axial coordinate of body (see fig. 2), m (ft)
ZSHK	axial coordinate of shock wave, m (ft)

Flow charts and listings for program VGBLP and its subroutines are presented in appendix C.

SAMPLE CASES

A range of test cases is presented as guides for assisting users of program VGBLP in their own specific applications. Five major test cases are presented that include external and internal flows, flows with wall-mass transfer, flows where transverse-curvature effects are important, and flows where variable-entropy effects must be included. For each test case presented, the following information is given: (1) schematic of geometry; (2) boundary conditions; (3) all input data including variable dimension specification; (4) samples of output (see appendix D); and (5) plots of selected results. It is suggested that users compute two or more of the test cases prior to applying program VGBLP to their own particular problem. This approach is beneficial in that it (1) confirms that the software has been correctly implemented on the user's computer system and (2) provides experience in using the program and specifying the correct input data; however, the user need not understand the algorithm in order to successfully apply program VGBLP. The first test case, flat-plate flows, is especially useful in developing experience with the grid specification and control.

Test Case No. 1

This case represents the simplest class of flow that is usually encountered. The flat-plate boundary layer need not be similar; for example, turbulent flow, arbitrarily distributed wall-mass transfer, arbitrary heat transfer, or externally imposed pressure gradients result in nonsimilar boundary-layer development.

For the present case, the test conditions of reference 22 are selected. A schematic of the model, including flow conditions and numerical results, is presented in figure 3. The input and sample output are presented in appendix D. Comparisons

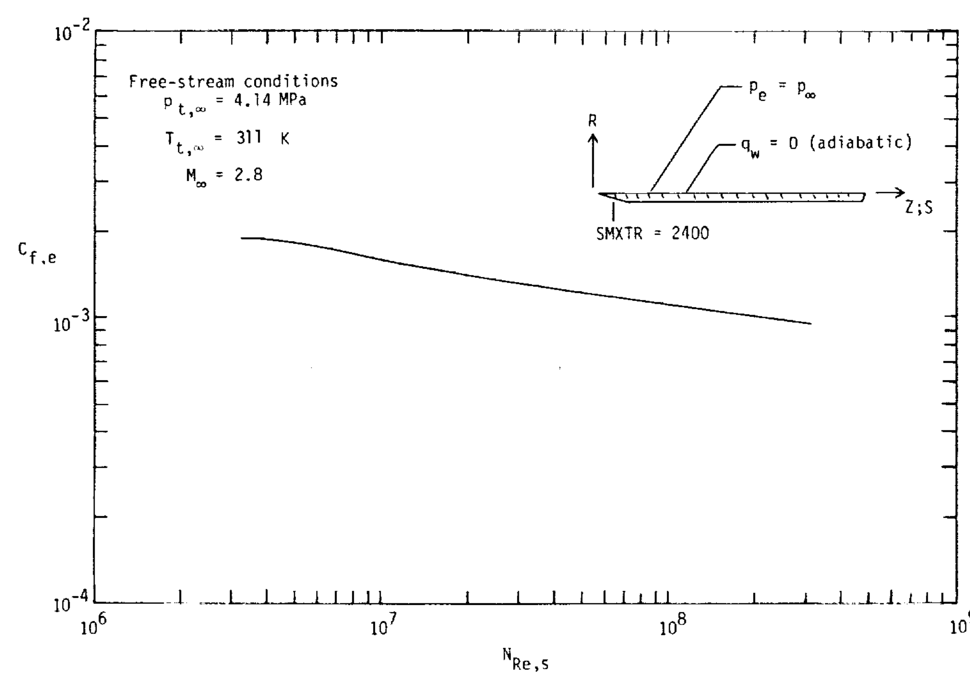


Figure 3.- Test case no. 1.

of numerical results with the experimental data of reference 22 are presented in reference 3. A grid refinement study showing the order of accuracy of the numerical approach is presented in reference 20.

Test Case No. 2

This test case is for the flow past a waisted-afterbody configuration (ref. 23). Transverse-curvature terms must be included; also, the flow is supersonic with an attached shock wave. A schematic of the model, flow conditions, and typical numerical results are presented in figure 4. The input and sample output are presented in appendix D. Comparisons of the numerical results with experimental data are presented in reference 3.

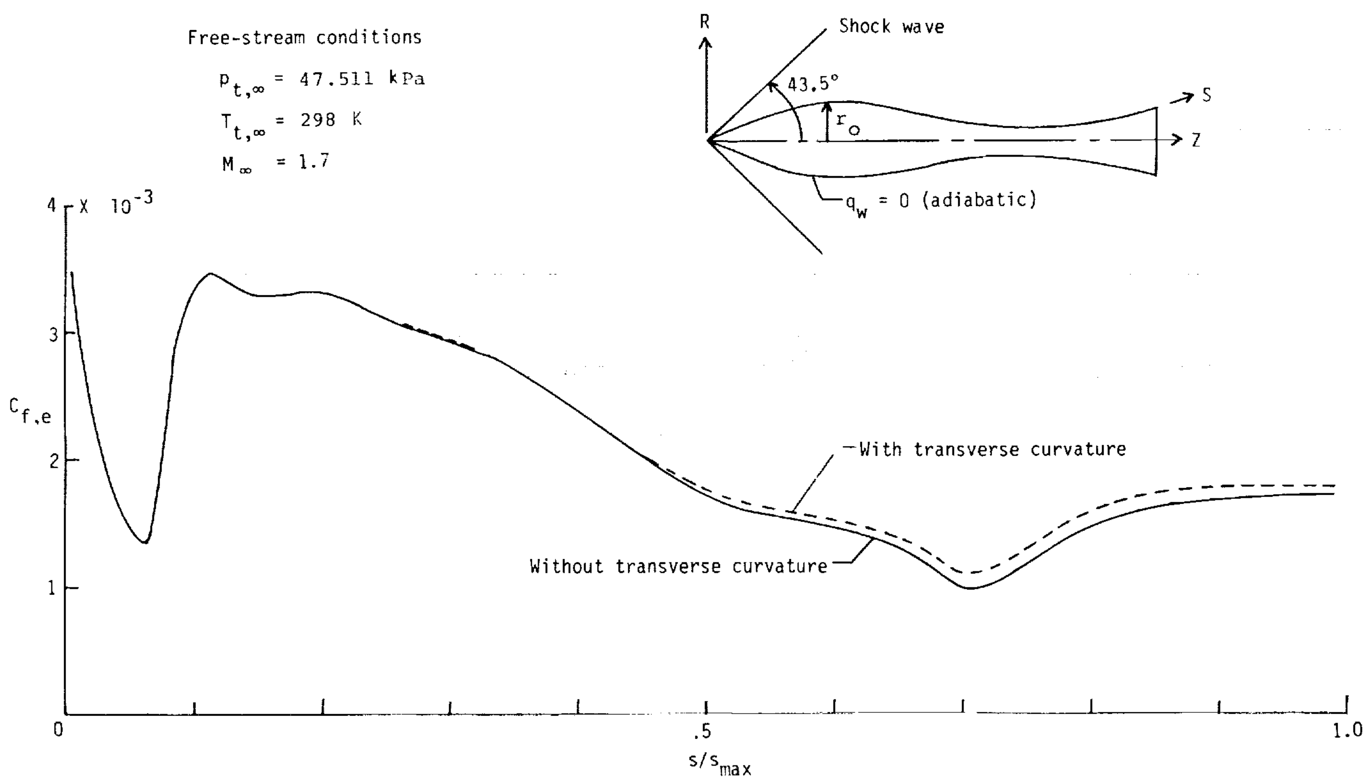


Figure 4.- Test case no. 2; skin-friction coefficient.

The pressure distribution was taken directly from the experimental data (ref. 23). Results for two calculations are presented: (1) without transverse-curvature (TVC) terms; (2) with TVC terms. This particular configuration is an example of a body where the boundary-layer coordinate s cannot be expressed as an explicit function of the body-coordinate system R,Z, and as such must be obtained by numerical integration. In the previous example for flat-plate flow, this presented no difficulty since S and Z were congruent. It is suggested that the user of program VGBLP develop software to numerically generate the s-coordinate from a specified body-coordinate system and to interpolate edge-pressure and wall-boundary data, often specified as a function of the body-coordinate system, to the S,R-coordinate system.

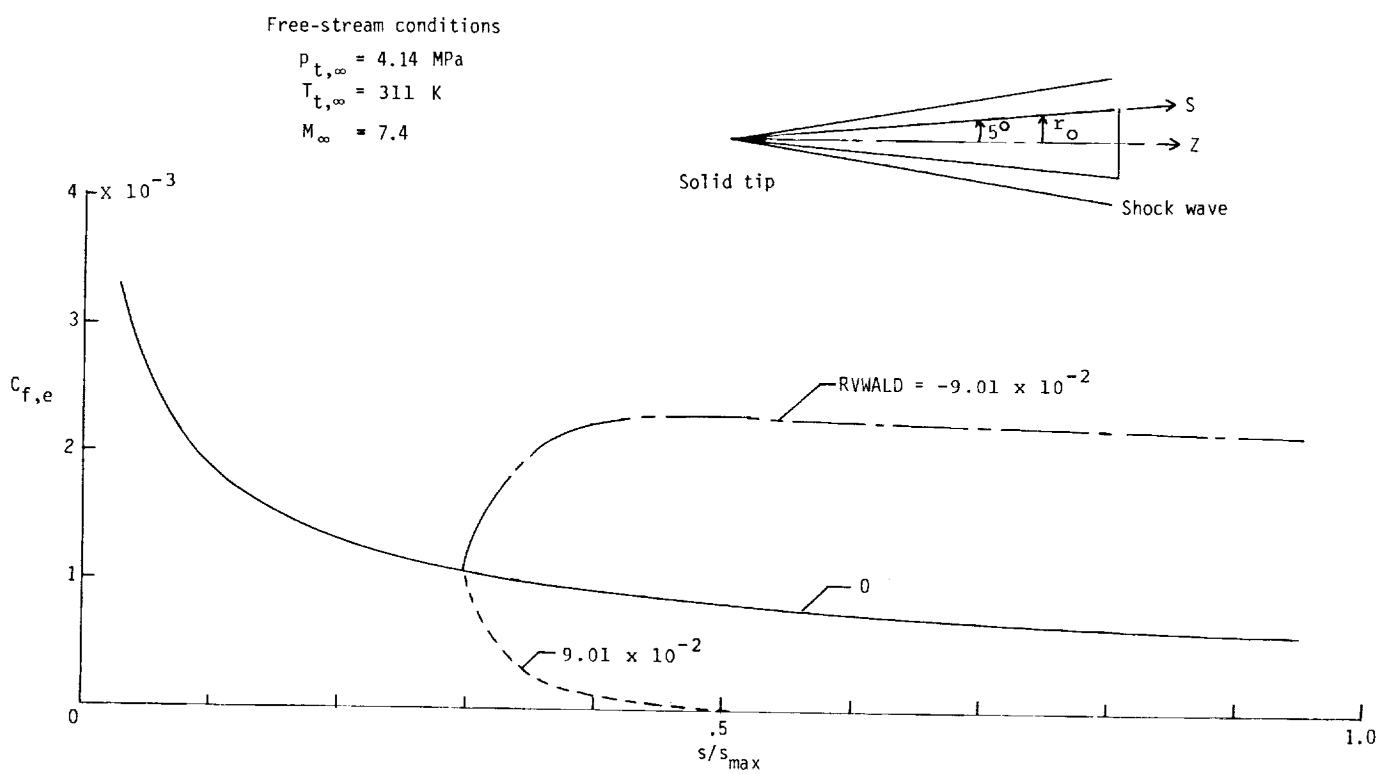
The trapezoidal rule is sufficiently accurate and can be easily implemented to integrate the following relationship:

$$s = s_0 + \int_0^z \sqrt{1 + \left(\frac{dr_o}{dz}\right)^2}\, dz \tag{66}$$

Test Case No. 3

Flows with wall-mass transfer are often encountered and can be efficiently solved by program VGBLP. The sample case selected is that of reference 24 for laminar boundary-layer flow. A schematic of the model, including flow conditions and numerical results, is presented in figure 5. The required input and sample output are presented in appendix D. It should be noted that program VGBLP can be applied to turbulent flow with wall-mass transfer if the user modifies the A^+ definition in subroutine TURBLNT. (See ref. 2.)

The numerical results for three wall-mass transfer boundary conditions are presented in figure 5: (1) $(\rho v)_w < 0$ (suction); (2) $(\rho v)_w = 0$ (solid wall); and (3) $(\rho v)_w > 0$ (transpiration). The input and sample output are presented in appendix D. Comparisons of the numerical results with experimental data are presented in reference 3. It should be noted that program VGBLP is not limited to fixed values of $(\rho v)_w^*$; that is, $(\rho v)_w^* = g(s)$ can be input in $NAM2 if required.



(a) Skin-friction coefficient.

Figure 5.- Test case no. 3.

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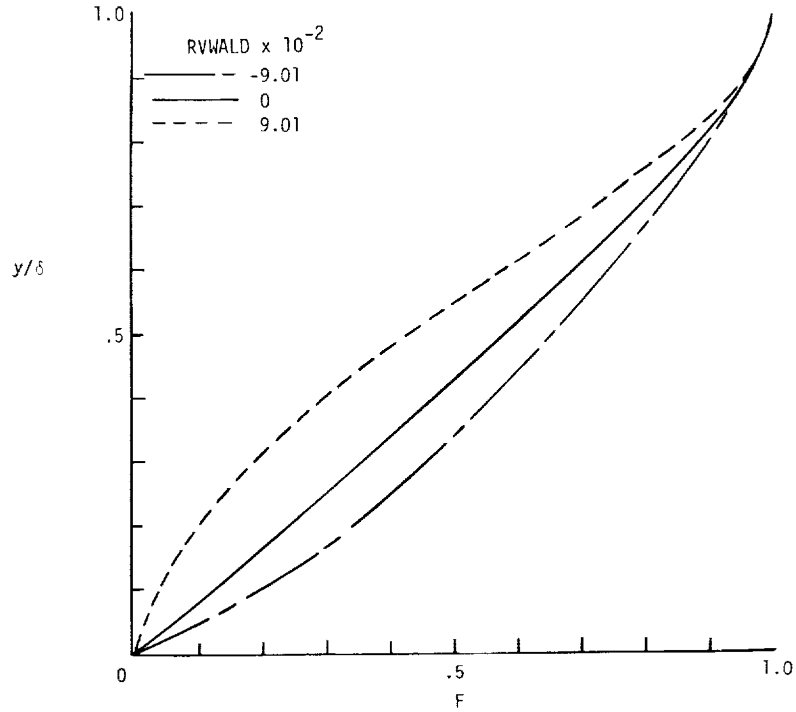


(b) Velocity profiles; s = 0.100 m.

Figure 5.- Concluded.

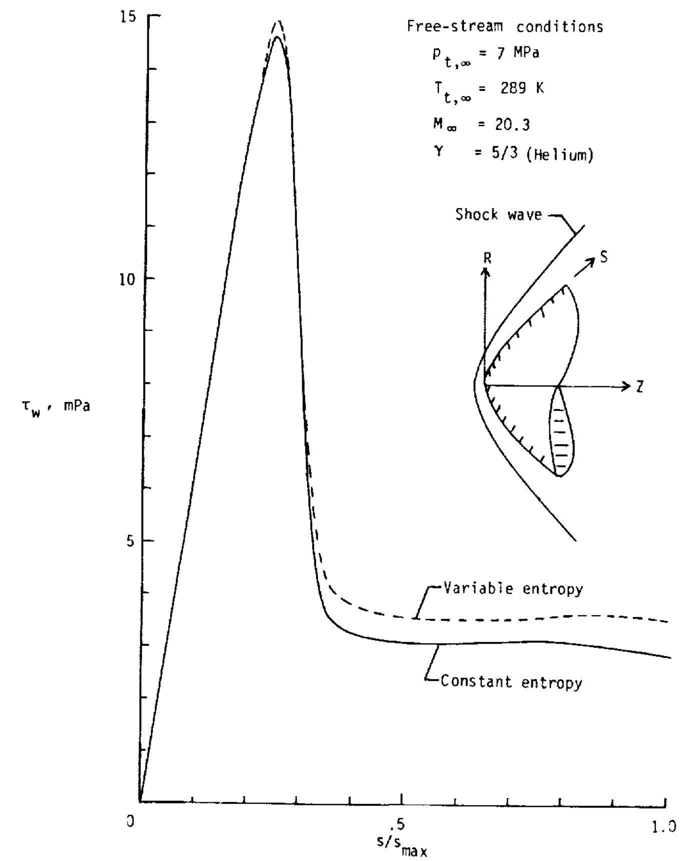
Test Case No. 4

For hypersonic, blunt-body flows, the effect of variable entropy introduced by the bow shock wave can significantly affect the boundary-layer development. As an example, the flow over a 45° spherically blunted cone in helium flow is considered. (See ref. 25.) A schematic of the model, including flow conditions and numerical results, is presented in figure 6. Experimental pressure data, supplied by the authors of reference 25, were used as input. The shock-wave data were obtained from figure 7(d) of reference 25. The input and sample output are presented in appendix D.

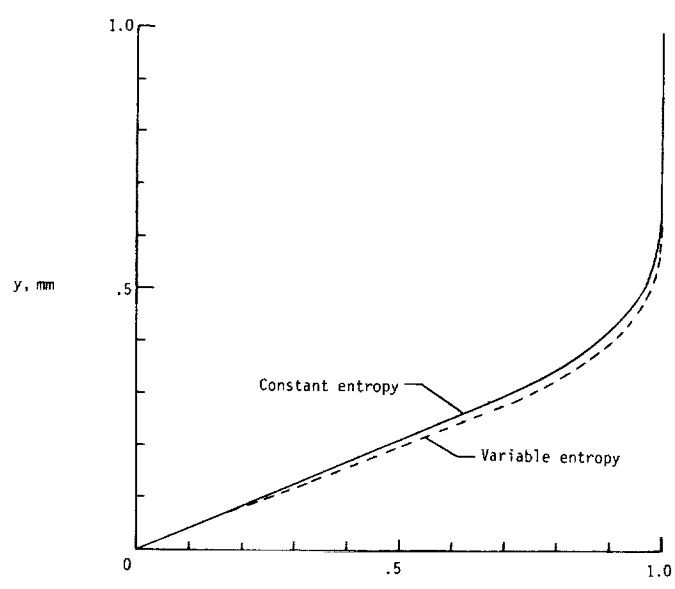
Test Case No. 5

Boundary-layer solutions are usually required for the design and analysis of nozzle flows. A typical wind-tunnel design case (see ref. 26) is presented in figure 7. It should be noted that the solution for this case is initiated in the stagnation chamber and marched downstream to the nozzle exit. The input and sample output are presented in appendix D. Extensive comparisons of the numerical results with experimental data are presented in reference 26.

Nozzle flows are typical of the more difficult applications of boundary-layer theory because of the large variation of pressure gradient dp_e/ds as the solution proceeds from the settling chamber through the sonic throat and into the supersonic region of the nozzle. The thinning effect of the pressure gradient on the boundary-layer thickness in the throat region of the nozzle necessitates care in selecting the grid distribution in the normal-coordinate as well as the marching-coordinate direction.



(a) Shear stress.



(b) Velocity profiles; s = 0.0495 m.

Figure 6.- Test case no. 4.

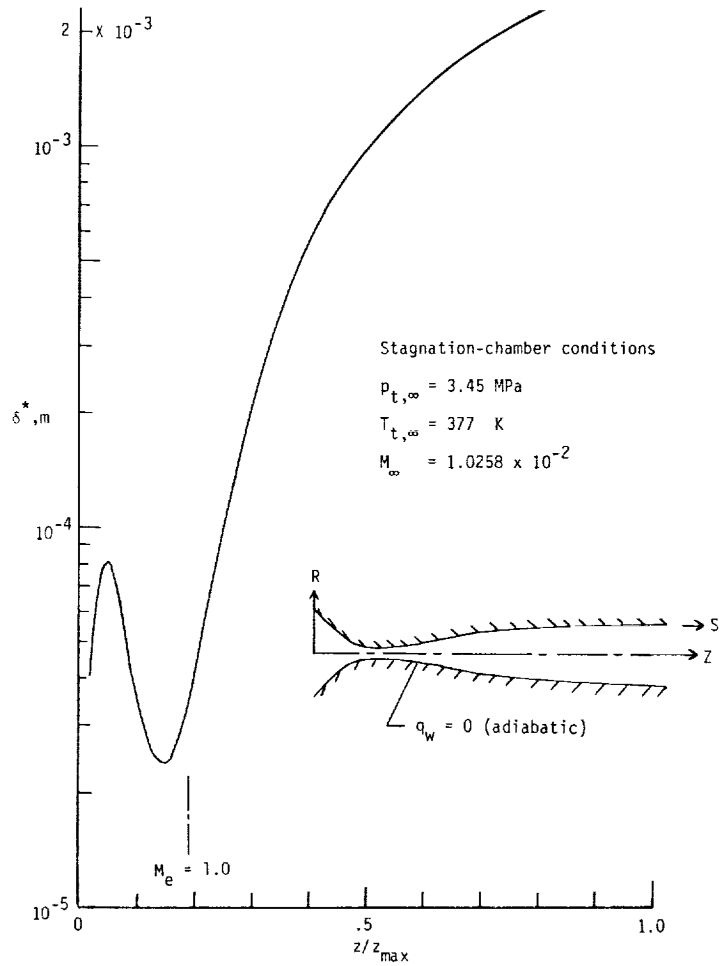


Figure 7.- Test case no. 5; displacement thickness.

A common problem often encountered in large pressure-gradient flows is oscillations in δ^* caused by the specification of $p_e = g(s)$ and/or step size in the s-coordinate. For many applications (e.g., rocket nozzle design), these oscillations may be acceptable, but for facility design, where the design goal is usually to achieve a shock-free flow that meets the design test-section flow conditions, caution and judgment must be exercised in specifying the inviscid pressure distribution and step-size distribution in the s-coordinate. For example, if a relatively course distribution of $p_e = g(s)$ and a fine distribution of Δs were specified, the resulting pressure-gradient distribution $\frac{dp_e}{ds} = \frac{d[g(s)]}{ds}$ would be a series of step functions for linear interpolation. Spline functions or higher-order interpolation could be used to obtain p_e and dp_e/ds at the solution stations from the specified input values; however, care must be exercised since higher-order interpolation can introduce oscillations resulting in changes in the sign of the pressure gradient. Splines with tension represent the optimum technique for generating p_e and dp_e/ds at the solution stations from the input data; however, experience has indicated that it is more efficient to input a sufficiently dense distribution of $p_e = g(s)$ and use linear interpolation. It is suggested that the user of program VGBLP work several problems with large pressure variations in order to gain experience in specifying pressure input and step-size distributions.

CONCLUDING REMARKS

A computer program, VGBLP, has been presented for solving the compressible laminar, transitional, or turbulent boundary-layer equations for planar or axisymmetric perfect-gas attached flows. A three-point implicit, variable-grid finite-difference procedure is used to solve the governing equations. The algorithm and software are modifications of the procedures presented in NASA TR R-368 and NASA TM X-2458, respectively. The modifications render the approach easier to implement while increasing the efficiency (computer resources) and accuracy as compared with the original approach presented in NASA TR R-368.

Test cases have been presented and should serve as guides for potential users of the software. These cases cover external and internal flows including flows with wall-mass transfer effects, transverse-curvature effects, and variable-entropy effects.

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APPENDIX A

DIFFERENCE RELATIONS

Three-point implicit difference relations are used in references 3 and 4 to reduce the transformed momentum and energy equations (eqs. (28) and (29)) to finite-difference form. The differencing scheme proposed by Blottner (ref. 7) is used in program VGBLP. For completeness, both differencing techniques are presented.

It is assumed that all data are known at the solution stations $m-1$ and m. (See fig. 1.) Then, it is possible to obtain the unknown quantities at the grid points for the $m+1$ station. In the subsequent development the notations G and H are utilized to represent any typical variable.

Taylor-series expansions are first written about the unknown grid point $(m+1,n)$ in the ξ-direction as follows:

$$G_{m,n} = G_{m+1,n} - \Delta\xi_2 (G_\xi)_{m+1,n} + \frac{\Delta\xi_2^2}{2}(G_{\xi\xi})_{m+1,n} - \frac{\Delta\xi_2^3}{6}(G_{\xi\xi\xi})_{m+1,n} + \cdots \tag{A1a}$$

and

$$G_{m-1,n} = G_{m+1,n} - (\Delta\xi_1 + \Delta\xi_2)(G_\xi)_{m+1,n} + \frac{(\Delta\xi_1 + \Delta\xi_2)^2}{2}(G_{\xi\xi})_{m+1,n} - \frac{(\Delta\xi_1 + \Delta\xi_2)^3}{6}(G_{\xi\xi\xi})_{m+1,n} + \cdots \tag{A1b}$$

where subscript notation has been utilized to denote differentiation; for example, $G_\xi \equiv \partial G/\partial \xi$.

Equations (A1a) and (A1b) can be solved to yield

$$\left(\frac{\partial G}{\partial \xi}\right)_{m+1,n} = \frac{X_1 G_{m+1,n} - X_2 G_{m,n} + X_3 G_{m-1,n}}{2\,\Delta\xi_2} + \frac{\Delta\xi_2(\Delta\xi_1 + \Delta\xi_2)}{6} G_{\xi\xi\xi} + \cdots \tag{A2}$$

and

$$G_{m+1,n} = X_4 G_{m,n} - X_5 G_{m-1,n} + \frac{\Delta\xi_1\,\Delta\xi_2}{2}\left(1 + \frac{\Delta\xi_2}{\Delta\xi_1}\right) G_{\xi\xi} + \cdots \tag{A3}$$

Terms of the order of $\Delta\xi_1\,\Delta\xi_2$, or smaller, are neglected. This produces truncation errors of the order of $\Delta\xi_1\,\Delta\xi_2$ instead of $\Delta\xi_2$ as in reference 5 where two-point difference relations are used. The $X_1, X_2, \ldots, X_5$ coefficients appearing in equations (A2) and (A3) are defined as follows:

$$X_1 = 2\,\frac{\Delta\xi_1 + 2\,\Delta\xi_2}{\Delta\xi_1 + \Delta\xi_2} \tag{A4}$$

$$X_2 = 2\,\frac{\Delta\xi_1 + \Delta\xi_2}{\Delta\xi_1} \tag{A5}$$

$$X_3 = 2\,\frac{\Delta\xi_2^2}{\Delta\xi_1(\Delta\xi_1 + \Delta\xi_2)} \tag{A6}$$

$$X_4 = \frac{\Delta\xi_1 + \Delta\xi_2}{\Delta\xi_1} \tag{A7}$$

and

$$X_5 = \frac{\Delta\xi_2}{\Delta\xi_1} \tag{A8}$$

Taylor-series expansions are next written about the unknown grid point (m+1,n) in the η-direction as follows:

$$G_{m+1,n+1} = G_{m+1,n} + \Delta\eta_n (G_\eta)_{m+1,n} + \frac{\Delta\eta_n^2}{2}(G_{\eta\eta})_{m+1,n} + \frac{\Delta\eta_n^3}{6}(G_{\eta\eta\eta})_{m+1,n} + \cdot\cdot\cdot \tag{A9a}$$

and

$$G_{m+1,n-1} = G_{m+1,n} - \Delta\eta_{n-1} (G_\eta)_{m+1,n} + \frac{\Delta\eta_{n-1}^2}{2}(G_{\eta\eta})_{m+1,n} - \frac{\Delta\eta_{n-1}^3}{6}(G_{\eta\eta\eta})_{m+1,n} + \cdot\cdot\cdot \tag{A9b}$$

Equations (A9a) and (A9b) can be solved to yield

$$\left(\frac{\partial^2 G}{\partial\eta^2}\right)_{m+1,n} = Y_1 G_{m+1,n+1} - Y_2 G_{m+1,n} + Y_3 G_{m+1,n-1} + \frac{(\Delta\eta_{n-1} - \Delta\eta_n)}{3} G_{\eta\eta\eta} + \cdot\cdot\cdot \tag{A10}$$

and

$$\left(\frac{\partial G}{\partial \eta}\right)_{m+1,n} = Y_4 G_{m+1,n+1} - Y_5 G_{m+1,n} - Y_6 G_{m+1,n-1} - \frac{\Delta\eta_n \, \Delta\eta_{n-1}}{6} G_{\eta\eta\eta} + \ldots \tag{A11}$$

The Y_1, Y_2, ..., Y_6 coefficients appearing in equations (A10) and (A11) are defined as follows:

$$Y_1 = \frac{2}{\Delta\eta_n(\Delta\eta_n + \Delta\eta_{n-1})} \tag{A12}$$

$$Y_2 = \frac{2}{\Delta\eta_n \, \Delta\eta_{n-1}} \tag{A13}$$

$$Y_3 = \frac{2}{\Delta\eta_{n-1}(\Delta\eta_n + \Delta\eta_{n-1})} \tag{A14}$$

$$Y_4 = \frac{\Delta\eta_{n-1}}{\Delta\eta_n(\Delta\eta_n + \Delta\eta_{n-1})} \tag{A15}$$

$$Y_5 = \frac{\Delta\eta_{n-1} - \Delta\eta_n}{\Delta\eta_n \, \Delta\eta_{n-1}} \tag{A16}$$

and

$$Y_6 = \frac{\Delta\eta_n}{\Delta\eta_{n-1}(\Delta\eta_n + \Delta\eta_{n-1})} \tag{A17}$$

For the case of equally spaced grid points in the ξ- and η-coordinates, equations (A4) to (A8) and (A12) to (A17) reduce to the following relations:

$$\left.\begin{aligned} X_1 &= 3 \\ X_2 &= 4 \\ X_3 &= 1 \\ X_4 &= 2 \\ X_5 &= 1 \end{aligned}\right\} \tag{A18a}$$

and

$$\left.\begin{aligned} Y_1 &= \frac{1}{\Delta\eta^2} \\ Y_2 &= 2Y_1 \\ Y_3 &= Y_1 \\ Y_4 &= \frac{1}{2\ \Delta\eta} \\ Y_5 &= 0 \\ Y_6 &= Y_4 \end{aligned}\right\} \tag{A18b}$$

where $\Delta\xi$ and $\Delta\eta$ represent the spacing between the grid points in the ξ- and η-coordinates, respectively.

Equations (A2), (A3), (A10), and (A11) can then be written for constant grid-point spacing as follows:

$$\left(\frac{\partial G}{\partial \xi}\right)_{m+1,n} = \frac{3G_{m+1,n} - 4G_{m,n} + G_{m-1,n}}{2\ \Delta\xi} + \frac{\Delta\xi^2}{3} G_{\xi\xi\xi} + \ldots \tag{A19}$$

$$G_{m+1,n} = 2G_{m,n} - G_{m-1,n} + \Delta\xi^2 G_{\xi\xi} + \ldots \tag{A20}$$

$$\left(\frac{\partial^2 G}{\partial \eta^2}\right)_{m+1,n} = \frac{G_{m+1,n+1} - 2G_{m+1,n} + G_{m+1,n-1}}{\Delta\eta^2} - \frac{\Delta\eta^2}{12} G_{\eta\eta\eta\eta} + \ldots \tag{A21}$$

and

$$\left(\frac{\partial G}{\partial \eta}\right)_{m+1,n} = \frac{G_{m+1,n+1} - G_{m+1,n-1}}{2\ \Delta\eta} - \frac{\Delta\eta^2}{6} G_{\eta\eta\eta} + \ldots \tag{A22}$$

Quantities of the form $\left(G\ \frac{\partial H}{\partial \xi}\right)$ that appear in the governing equations must be linearized in order to obtain a system of linear-difference equations. Quantities of this type are obtained from equations (A2) and (A3).

APPENDIX A

The procedure used to linearize nonlinear products such as $\left(\frac{\partial G}{\partial \eta}\right)\left(\frac{\partial H}{\partial \eta}\right)$ is the same as that used by Flügge-Lotz and Blottner (ref. 5) and is as follows:

$$\left[\left(\frac{\partial G}{\partial \eta}\right)\left(\frac{\partial H}{\partial \eta}\right)\right]_{m+1,n} = \left(\frac{\partial G}{\partial \eta}\right)_{m,n}\left(\frac{\partial H}{\partial \eta}\right)_{m+1,n} - \left(\frac{\partial G}{\partial \eta}\right)_{m,n}\left(\frac{\partial H}{\partial \eta}\right)_{m,n} + \left(\frac{\partial H}{\partial \eta}\right)_{m,n}\left(\frac{\partial G}{\partial \eta}\right)_{m+1,n} + O(\Delta\xi_2)^2 \tag{A23}$$

where the terms $\left(\frac{\partial G}{\partial \eta}\right)_{m,n}$ and $\left(\frac{\partial H}{\partial \eta}\right)_{m,n}$ are evaluated from equation (A11), but at the known station m. By equating G to H in equation (A23), the linearized form for quantities of the type $\left(\frac{\partial G}{\partial \eta}\right)^2$ is obtained; that is,

$$\left(\frac{\partial G}{\partial \eta}\right)^2_{m+1,n} = \left(\frac{\partial G}{\partial \eta}\right)_{m,n}\left[2\left(\frac{\partial G}{\partial \eta}\right)_{m+1,n} - \left(\frac{\partial G}{\partial \eta}\right)_{m,n}\right] + O(\Delta\xi_2)^2 \tag{A24}$$

where $\left(\frac{\partial G}{\partial \eta}\right)_{m+1,n}$ is obtained from equation (A11).

The preceding relations for the difference quotients produce linear-difference equations when substituted into the governing differential equations (eqs. (45)). In references 3 and 4 it is noted that in practice the nonlinearities do not require iteration provided a sufficiently fine mesh-point distribution is chosen. However, if one wishes to increase the computational speed by reducing the number of grid points to a minimum, then iteration may become necessary.

Blottner (ref. 7) proposed a variable grid scheme that in principle is only first-order accurate in the normal step size $\Delta\eta_n$, but approaches second-order accuracy when the grid defined by equations (42) to (43) is used. In the variable grid scheme, the following difference relations are used:

$$\left(\frac{\partial G}{\partial \eta}\right)_{m+1,n} = \frac{G_{m+1,n+1} - G_{m+1,n-1}}{\Delta\eta_{n-1} + \Delta\eta_n} - \frac{(\Delta\eta_n - \Delta\eta_{n-1})}{2} G_{\eta\eta} + \ldots \tag{A25}$$

$$\left(\frac{\partial^2 G}{\partial \eta^2}\right)_{m+1,n} = \text{Equation (A10)}$$

The nonlinear term is evaluated as follows:

$$\left[\frac{\partial}{\partial\eta}\left(l\,\frac{\partial G}{\partial\eta}\right)\right]_{m+1,n} = \frac{2}{\Delta\eta_n + \Delta\eta_{n-1}}\left[l_{m+1,n+\frac{1}{2}}\left(\frac{G_{m+1,n+1} - G_{m+1,n}}{\Delta\eta_n}\right) - l_{m+1,n-\frac{1}{2}}\left(\frac{G_{m+1,n} - G_{m+1,n-1}}{\Delta\eta_{n-1}}\right)\right] - \frac{1}{12}\left[lG_{\eta\eta\eta} + 3(lG_\eta)_{\eta\eta}\right]_{m+1,n}(\Delta\eta_n - \Delta\eta_{n-1}) \tag{A26}$$

where

$$l_{m+1,n+\frac{1}{2}} = \frac{l_{m+1,n+1} + l_{m+1,n}}{2} \tag{A27}$$

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APPENDIX B

COEFFICIENTS FOR DIFFERENCE EQUATIONS

Equations (45) are the difference equations used to represent the partial differential equations for the conservation of momentum and energy, respectively. These equations are repeated for convenience as follows:

Momentum equation

$$A1_n F_{m+1,n-1} + B1_n F_{m+1,n} + C1_n F_{m+1,n+1} + D1_n \Theta_{m+1,n-1} + E1_n \Theta_{m+1,n} + F1_n \Theta_{m+1,n+1} = G1_n \tag{B1}$$

Energy equation

$$A2_n F_{m+1,n-1} + B2_n F_{m+1,n} + C2_n F_{m+1,n+1} + D2_n \Theta_{m+1,n-1} + E2_n \Theta_{m+1,n} + F2_n \Theta_{m+1,n+1} = G2_n \tag{B2}$$

These equations are obtained from equations (28) and (29) and the difference quotients presented in appendix A. The coefficients $A1_n$, $B1_n$, and so forth, in equations (B1) and (B2) are functions of known quantities evaluated at stations m and m-1. (See fig. 1.) Therefore, equations (B1) and (B2) can be solved simultaneously. In references 3 and 4, equations (B1) and (B2) were solved simultaneously without iteration. The reader interested in the coefficients for the noniterative simultaneous solution is referred to appendix B of reference 4. In the present approach, using the Blottner variable grid scheme (ref. 7), the coefficients are written as follows:

Momentum equation

$$A1_n = -\frac{(v_{m+1,n})_g}{\Delta\eta_{n-1} + \Delta\eta_n} - \left[\frac{(t^{2j} l\bar{\varepsilon})_{m+1,n} + (t^{2j} l\bar{\varepsilon})_{m+1,n-1}}{2}\right] Y3_n \tag{B3a}$$

$$B1_n = \left[\frac{\xi (F_{m+1,n})_g}{\Delta\xi_2}\right] X1 + \left[\frac{(t^{2j} l\bar{\varepsilon})_{m+1,n} + (t^{2j} l\bar{\varepsilon})_{m+1,n+1}}{2}\right] Y1_n + \left[\frac{(t^{2j} l\bar{\varepsilon})_{m+1,n} + (t^{2j} l\bar{\varepsilon})_{m+1,n-1}}{2}\right] Y3_n + 2\beta (F_{m+1,n})_g \tag{B3b}$$

$$C1_n = \frac{(v_{m+1,n})_g}{\Delta\eta_{n-1} + \Delta\eta_n} - \left[\frac{(t^{2j} l\bar{\varepsilon})_{m+1,n} + (t^{2j} l\bar{\varepsilon})_{m+1,n+1}}{2}\right] Y1_n \tag{B3c}$$

$$D1_n = 0 \tag{B3d}$$

$$E1_n = -\beta \tag{B3e}$$

$$F1_n = 0 \tag{B3f}$$

$$G1_n = \frac{\xi(F_{m+1,n})_g}{\Delta\xi_2}\left[(X2)F_{m,n} - (X3)F_{m-1,n}\right] - \beta(F_{m+1,n})_g^2 \tag{B3g}$$

<u>Energy equation</u>

$$A2_n = \frac{2(\alpha l t^{2j}\bar{\varepsilon})_{m+1,n}\left[\left(\frac{\partial F}{\partial \eta}\right)_{m+1,n}\right]_g}{\Delta\eta_{n-1} + \Delta\eta_n} \tag{B4a}$$

$$B2_n = 0 \tag{B4b}$$

$$C2_n = -\frac{2(\alpha l t^{2j}\bar{\varepsilon})_{m+1,n}\left[\left(\frac{\partial F}{\partial \eta}\right)_{m+1,n}\right]_g}{\Delta\eta_{n-1} + \Delta\eta_n} \tag{B4c}$$

$$D2_n = -\frac{(v_{m+1,n})_g}{\Delta\eta_{n-1} + \Delta\eta_n} - \left[\frac{(t^{2j}l\tilde{\varepsilon})_{m+1,n} + (t^{2j}l\tilde{\varepsilon})_{m+1,n-1}}{2}\right]Y3_n \tag{B4d}$$

$$E2_n = \left[\frac{\xi(F_{m+1,n})}{\Delta\xi_2}\right]X1 + \left[\frac{(t^{2j}l\tilde{\varepsilon})_{m+1,n} + (t^{2j}l\tilde{\varepsilon})_{m+1,n-1}}{2}\right]Y1_n$$
$$+ \left[\frac{(t^{2j}l\tilde{\varepsilon})_{m+1,n} + (t^{2j}l\tilde{\varepsilon})_{m+1,n-1}}{2}\right]Y3_n \tag{B4e}$$

$$F2_n = \frac{(v_{m+1,n})_g}{\Delta\eta_{n-1} + \Delta\eta_n} - \left[\frac{(t^{2j}l\tilde{\varepsilon})_{m+1,n} + (t^{2j}l\tilde{\varepsilon})_{m+1,n+1}}{2}\right]Y1_n \tag{B4f}$$

$$G2_n = \frac{\xi(F_{m+1,n})_g}{\Delta\xi_2}\left[(X2)\Theta_{m,n} - (X3)\Theta_{m-1,n}\right] - (\alpha l t^{2j}\bar{\varepsilon})_{m+1,n}\left[\left(\frac{\partial F}{\partial \eta}\right)^2_{m+1,n}\right]_g \tag{B4g}$$

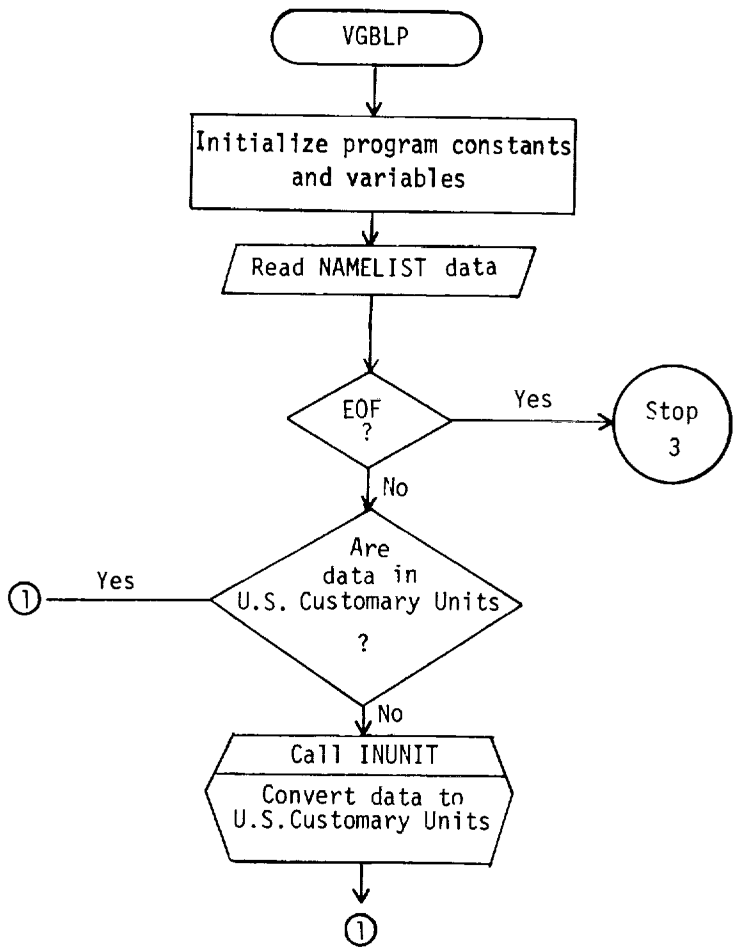
These equations are solved using the coupled solution technique presented in references 3 and 4. A major difference between the present approach (program VGBLP) and that of reference 4 is that the system of equations can be iterated in the present approach as opposed to no iteration in reference 4. The iteration cycle is as follows: (1) the g subscripted quantities are first obtained from known values at stations $m-1$ and m using equation (A3) for the initial solution of the system at station $m+1$ (note that the continuity equation is integrated using the trapezoidal rule of integration); (2) for the remaining iterations the g subscripted quantities assume their value at the previous iteration at station $m+1$. The eddy viscosity is updated after each iteration.

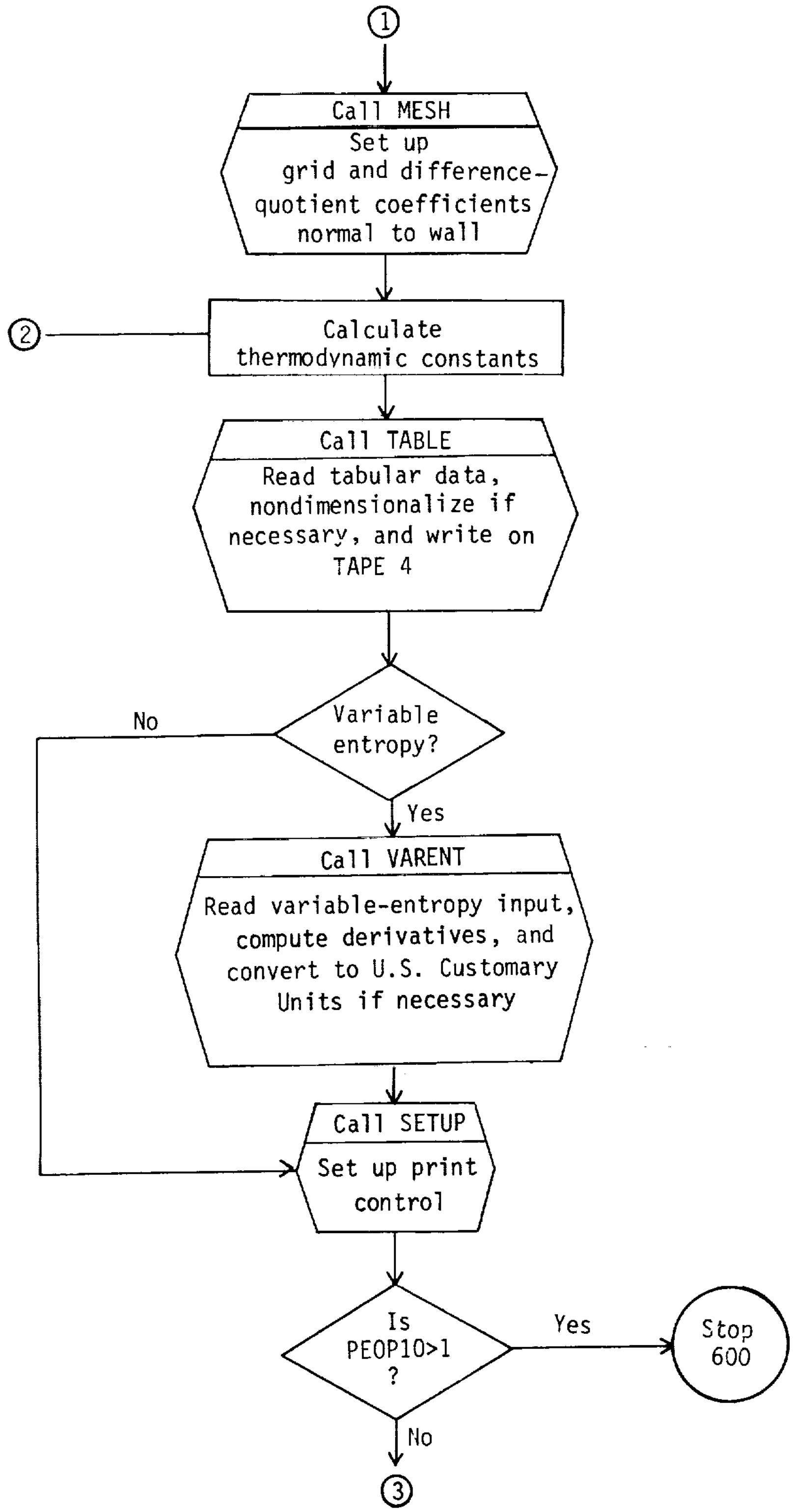
APPENDIX C

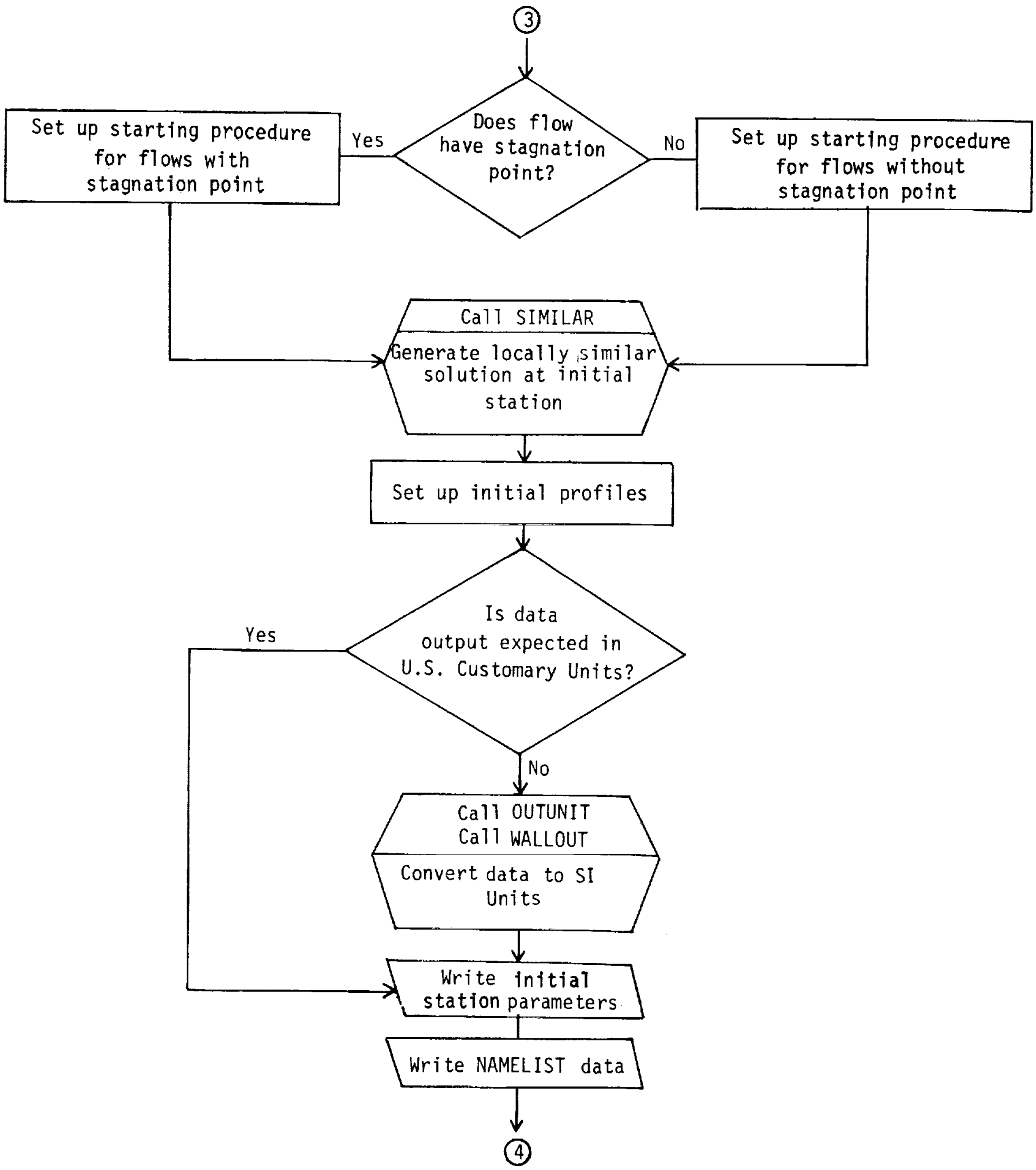
FLOW CHARTS AND PROGRAM LISTING

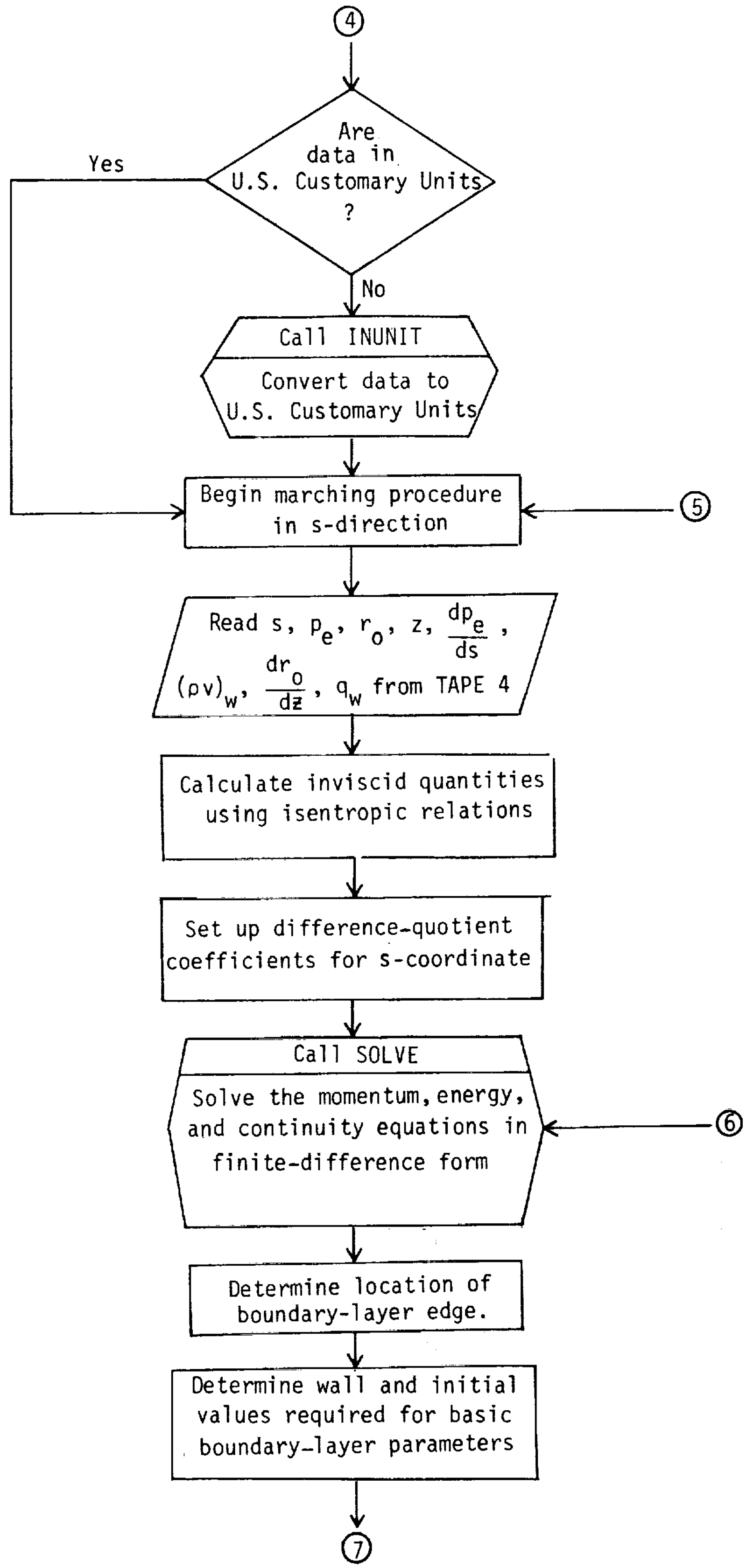
Main Program VGBLP

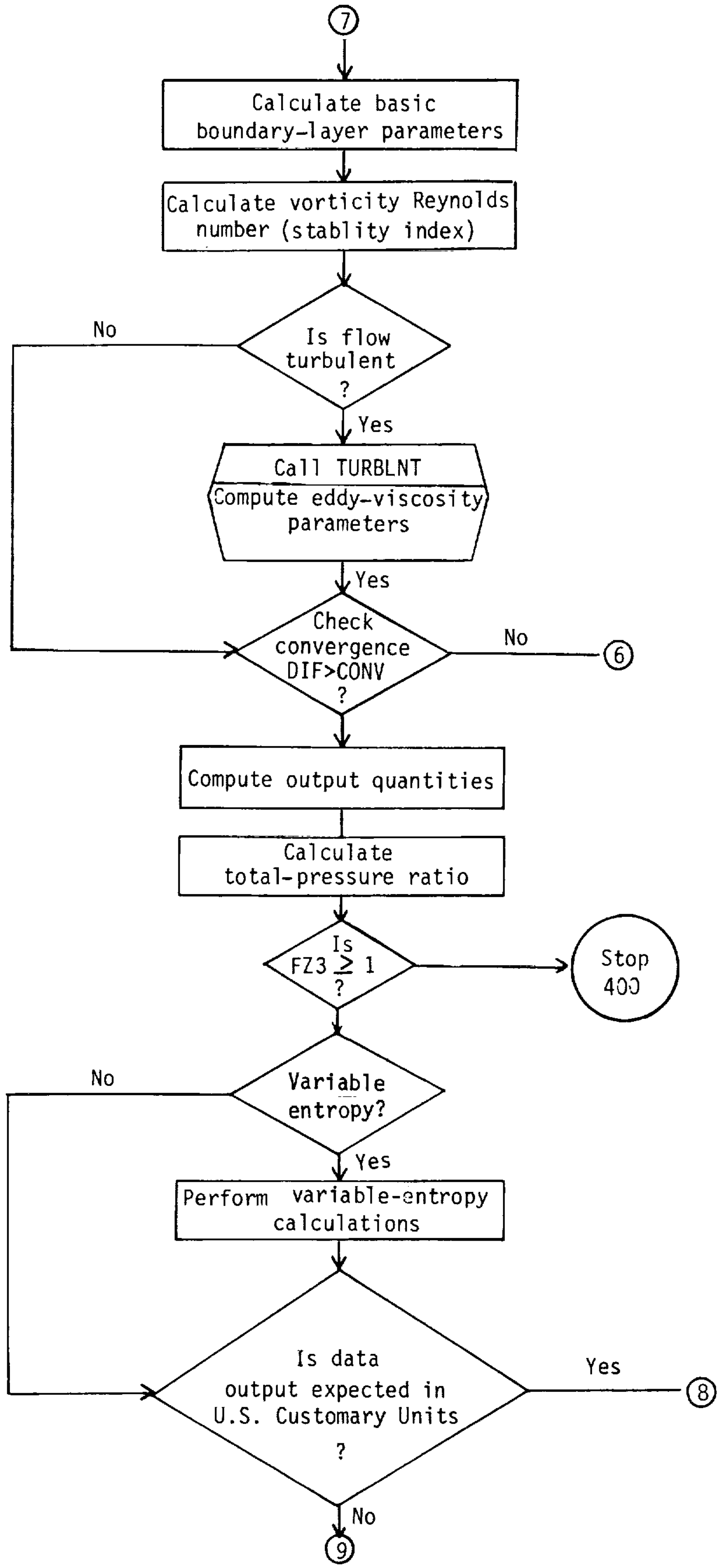
Program VGBLP controls the sequence of finite-difference solutions for the boundary-layer equations. It reads the input and, through its subroutines, sets up the computational grid, generates the initial solution, controls the parabolic marching procedure wherein the nonsimilar solutions are obtained, calculates all boundary-layer parameters, and prints the output at specified locations. The flow chart for the main program is as follows:

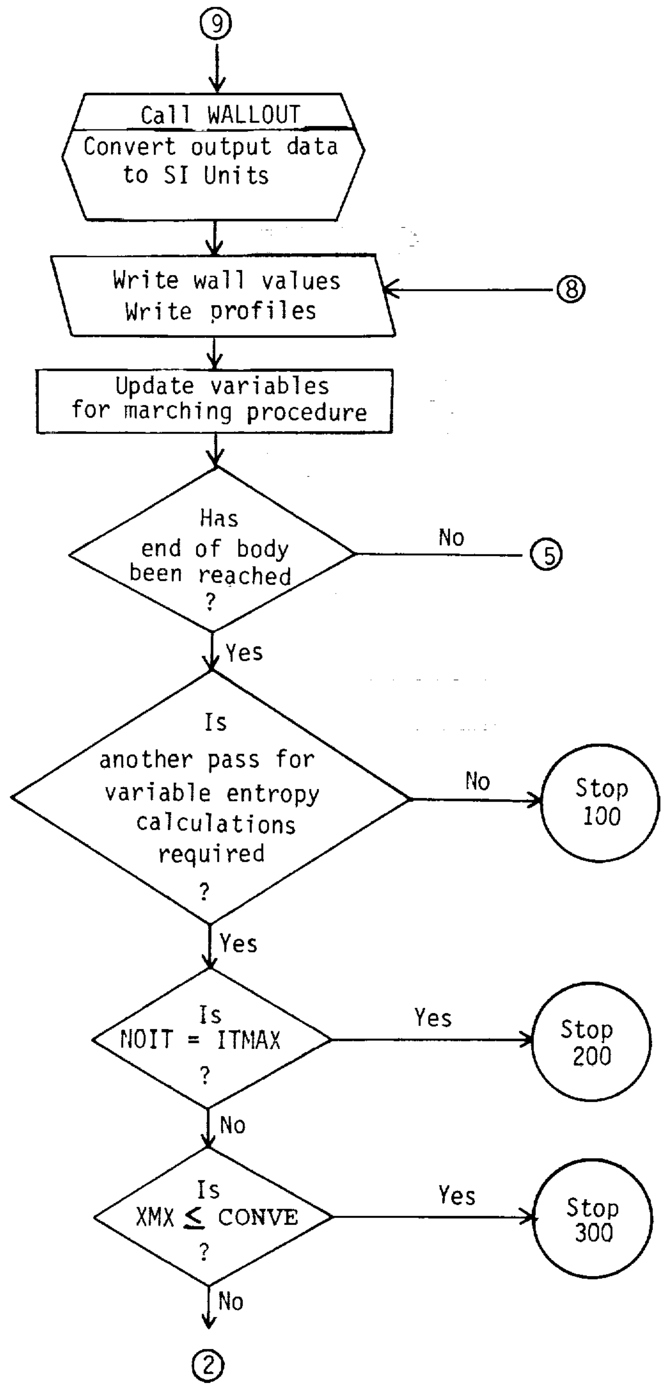



1
Call MESH
Set up grid and difference-quotient coefficients normal to wall
2
Calculate thermodynamic constants
Call TABLE
Read tabular data, nondimensionalize if necessary, and write on TAPE 4
Variable entropy?
No
Yes
Call VARENT
Read variable-entropy input, compute derivatives, and convert to U.S. Customary Units if necessary
Call SETUP
Set up print control
Is PEOP10>1 ?
Yes
Stop 600
No
3


3
Does flow have stagnation point?
Yes
Set up starting procedure for flows with stagnation point
No
Set up starting procedure for flows without stagnation point
Call SIMILAR
Generate locally similar solution at initial station
Set up initial profiles
Is data output expected in U.S. Customary Units?
Yes
No
Call OUTUNIT
Call WALLOUT
Convert data to SI Units
Write initial station parameters
Write NAMELIST data
4


4
Are data in U.S. Customary Units ?
Yes
No
Call INUNIT
Convert data to U.S. Customary Units
Begin marching procedure in s-direction
5
Read s, p_e, r_o, z, $\frac{dp_e}{ds}$, $(\rho v)_w$, $\frac{dr_o}{dz}$, q_w from TAPE 4
Calculate inviscid quantities using isentropic relations
Set up difference-quotient coefficients for s-coordinate
Call SOLVE
Solve the momentum, energy, and continuity equations in finite-difference form
6
Determine location of boundary-layer edge.
Determine wall and initial values required for basic boundary-layer parameters
7


7
Calculate basic boundary-layer parameters
Calculate vorticity Reynolds number (stablity index)
Is flow turbulent ?
No
Yes
Call TURBLNT
Compute eddy-viscosity parameters
Yes
Check convergence DIF>CONV ?
No
6
Compute output quantities
Calculate total-pressure ratio
Is FZ3 ≥ 1 ?
Stop 400
Variable entropy?
No
Yes
Perform variable-entropy calculations
Is data output expected in U.S. Customary Units ?
Yes
8
No
9


9
Call WALLOUT
Convert output data to SI Units
Write wall values
Write profiles
8
Update variables for marching procedure
Has end of body been reached ?
No
5
Yes
Is another pass for variable entropy calculations required ?
No
Stop 100
Yes
Is NOIT = ITMAX ?
Yes
Stop 200
No
Is XMX ≤ CONVE ?
Yes
Stop 300
No
2

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The program listing for program VGBLP is as follows:

```
      PROGRAM VGBLP(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE4)
      DIMENSION PTOPT(JK), STAB2(JK), MOME(JK), TTOTT(JK), CROCCO(JK), U
     1OUPL(JK), TCORD(JK), UDEF(JK), NONDEL(JK), UEE(JH), PROVAL(JN), PR
     2NTVAL(JM), TAUP(JK), RRS(JL), ZZS(JL), DRSDZS(JL), DVT(JL,2), ANS(
     32), PRTAR(JI)
      COMMON /MESH1/ XN(JK),DN(JK),Y1(JK),Y2(JK),Y3(JK),Y4(JK),Y5(JK),Y6
     1(JK)
      COMMON /SOLV1/ F1(JK),F2(JK),F3(JK),T1(JK),T2(JK),T3(JK),V1(JK),V2
     1(JK),V3(JK),EP2(JK),EP3(JK),FZ2(JK),FZ3(JK),TZ2(JK),TZ3(JK),XL2(JK
     2),XL3(JK),XLP2(JK),XLP3(JK),RAT01(JK),RAT02(JK),RAT03(JK),EH2(JK),
     3EH3(JK),DRAT01(JK),DRAT02(JK),DRAT03(JK),VARA(JK),VARB(JK),VARC(JK
     4),VARD(JK),VARE(JK),Y(JK),EP1(JK),EH1(JK),XL1(JK),XLP1(JK)
      COMMON /SOLV2/ Z1,Z2,Z3,Z4,Z5,TE,FAA,FAB,FAC,FAD,BEX1,BEX2,BEX3,BE
     1X4
      EQUIVALENCE (ZZS,DVT(1,1)), (DRSDZS,DVT(1,2))
      COMMON /TRBULNT/ S,KSTR,TLNGTH,TRFACT,DISINC,XT1,XT2,XT6,XT3,XT4,X
     1T5,PRTW,RE,UE,XNJE,J,RMI,EPS,JPOINT,IE,WW1,WW2,WW3,WW4,WW5,  NEDGE
     2,KODVIS,A,XBE,X,PR,KODPRT,PRT,PRTAR,GLAR,NUMB1,XK
      COMMON /UNIT/ VIS1C1,VIS1C2,VIS2C1,VIS2C2,PT1,TT1,WAVE,R,PHIO,DS,S
     1ST,RT1,P1,T1,R1,U1,AA1,TREF,VISREF,PESTAR,TESTAR,RESTAR,UESTAR,MUE
     2STAR,YESTAR,THETA,TAUD,QSD,HD,UPLUS,DISP,PE,Z,TW,QW,RVWALD,PROINC,
     3PRNTINC,ZS,RS
      INTEGER W
      REAL MOME,NUE,NUW,KWD,KED,INTEGT,INTEGL,NONDEL,MUESTAR
      EXTERNAL INTEGT
      NAMELIST /NAM1/IGEOM,XEND,IE,XK,DETA1,XMA,PT1,TT1,IGAS,VIS1C1,VIS1
     1C2,VIS2C1,VIS2C2,G,R,PR,IBODY,WAVE,PHI1,J,W,IENTRO,SST,SMXTR,KODVI
     2S,KTCOD,TLNGTH,IYINT,KODAMP,XT1,XT2,XT3,XT4,XT5,XT6,PRT,KODPRT,NUM
     3B1,GLAR,PRTAR,IEND1,PROINC,PRNTINC,IPRO,IPRNT,NAUXPRO,PROVAL,PRNTV
     4AL,FT,KODE,KODWAL,VELEDG,CONV,NITMAX,KODUNIT,ITMAX,CONVE
C
C        INITIALIZE DATA TO STANDARD INPUT
C
      DATA G/1.4/,R/1716./,PR/.72/,PRT/.95/,W/0/,KODE/0/,KODWAL/1/,IENTR
     1O/1/,A/1./,KODVIS/2/,SST/1.E8/,FT/1./,SMXTR/1.E8/,TLNGTH/2./,XT1 /
     2.4/,XT2/.0168/,XT3/5./,XT4/.78/,XT5/.108/,XT6/26./,PROINC/1./,PRNT
     3INC/.1/,NAUXPRO/0/,NPUTYPE/1/,IPRO/0/,IPRNT/0/,CONV/.0001/,NUMB1/0
     4/
      DATA THATS/0./,RS/0./,P20/0./,NITMAX/1/,SIGN/1./,ST2MAX/1000001/,T
     1RFACT/0./,KSTR/0/,ITMAX/3/,NOIT/0/,DPEDS/0./,Z/0./,KODPRT/1/,KTCOD
     2/2/,KTCD/0/,IGAS/1/,KODAMP/2/,VELEDG/.995/,IYINT/1/,SMXN/0./,SMXO/
     30./,SMXP/0./,PRTW/.95/,KODUNIT/0/,ANRAD/1.745329E-2/,VIS1C1/2.27E-
     48/,VIS1C2/198.6/,XVAL1/0./,CONVE/.01/
      Y(1)=0.
      NONDEL(1)=0.
      DO 1 I=1,JN
    1 PROVAL(I)=0.
      DO 2 I=1,JM
    2 PRNTVAL(I)=0.
      DO 3 I=1,JL
      DRSDZS(I)=0.
```

```
    3 UEE(I)=0.
      DO 4 I=1,JK
      EP2(I)=EP3(I)=XL2(I)=XL3(I)=RATO1(I)=RATO2(I)=RATO3(I)=T1(I)=T2(I)
     1=T3(I)=F1(I)=F2(I)=F3(I)=EF1(I)=1.0
      TAUP(I)=1.
      STAB2(I)=FZ2(I)=TZ2(I)=XLP2(I)=XLP3(I)=FZ3(I)=TZ3(I)=DRATO1(I)=DRA
     1TO2(I)=DRATO3(I)=0.
    4 CONTINUE
C
C           READ NAMELIST INPUT
C
      READ (5,NAM1)
      IF (EOF(5)) 5,6
    5 STOP 3
    6 WRITE(6,82) IGEOM,XEND,IE,XK,DETA1,XMA,PT1,TT1,IGAS,VIS1C1,VIS1C2,
     1VIS2C1,VIS2C2,G,R,PR,IBODY,WAVE,PHII,J,W,IENTRO,SST,SMXTR,KODVIS,K
     2TCOD,TLNGTH,IYINT,KODAMP,XT1,XT2,XT3,XT4,XT5,XT6,PRT,KODPRT,NUMB1,
     3GLAR,PRTAR
      WRITE(6,83)IEND1,PROINC,PRNTINC,IPRO,IPRNT,NAUXPRO,FT,KODE,KODWAL,
     1VELEDG,CONV,NITMAX,KODUNIT,ITMAX,CONVE
      IF (KODUNIT.NE.1) GO TO 8
      AT1=TT1
      AT2=TT1/2.
      IF (IGAS.EQ.2) GO TO 7
      AX1=VIS1C1*(AT1**1.5)/(AT1+VIS1C2)
      AX2=VIS1C1*(AT2**1.5)/(AT2+VIS1C2)
      AC1=SQRT(5./9.)/47.878258
      VIS1C1=AC1*SQRT(AX1*AX2*(AT1+VIS1C2)*(AT2+VIS1C2)/((AT1*AT2)**1.5)
     1)
      VIS1C2=VIS1C2*9./5.
      GO TO 8
    7 CONTINUE
      AX1=VIS2C1*(AT1**VIS2C2)
      AX2=VIS2C1*(AT2**VIS2C2)
      AC1=((5./9.)**VIS2C2)/47.860258
      VIS2C1=AC1*SQRT(AX1*AX2/((AT1*AT2)**VIS2C2))
    8 CONTINUE
      PHIO=PHII
      IF (KODUNIT.EQ.1) CALL INUNIT (PROVAL,PRNTVAL,JM,JN)
C
C          SET UP GRID NORMAL TO WALL
C
      W1=XK
      W2=1+W1
      W3=1+W1+W1*W1
      WW1=W3*W3*(W1*W2-1.)+W2
      WW2=W1*W2*W3*W3
      WW3=W3*W3
      WW4=1.+W1
      WW5=W1*W1*W1*W2*W3
      CALL MESH (XK,XEND,IE,IGEOM,DETA1)
      RPR=1./PR
      DO 9 N=1,JK
      EH2(N)=RPR
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      EH3(N)=RPR
      EH1(N)=RPR
    9 CONTINUE
C
C        PROGRAM CONSTANTS
C
   10 CONTINUE
      XMAC=1.+.5*(G-1.)*XMA**2
      RT1=PT1/(R*TT1)
      P1=PT1/(XMAC)**(G/(G-1.))
      R1=RT1/(XMAC)**(1./(G-1.))
      TI=TT1/XMAC
      AA1=SQRT(G*P1/R1)
      U1=XMA*AA1
      TREF=U1**2/((G/(G-1.))*R)
      GP1=G+1.
      GM1=G-1.
      GM1OG=GM1/G
      XWAVE=ANRAD*WAVE
      IF (KODWAL.EQ.1) GO TO 12
      IF (XWAVE.EQ.0.) GO TO 11
      XAF=(XMA*SIN(XWAVE))**2
      T2OT1=(2.*G*XAF-GM1)*(GM1*XAF+2.)/(GP1*GP1*XAF)
      XM2=(GP1*GP1*XMA*XMA*XAF-4.*(XAF-1.)*(G*XAF+1.))/((2.*G*XAF-GM1)*(
     1GM1*XAF+2.))
      AWT=TI*T2OT1*(1.+SQRT(PR)*GM1*XM2*0.5)
      GO TO 12
   11 AWT=TI*(1.+SQRT(PR)*GM1*XMA*XMA*0.5)
   12 CONTINUE
      IF (IGAS.EQ.2) GO TO 13
      VIS1=VIS1C1*(TI**1.5)/(TI+VIS1C2)
      VISREF=VIS1C1*(TREF**1.5)/(TREF+VIS1C2)
      GO TO 14
   13 VIS1=VIS2C1*(TI**VIS2C2)
      VISREF=VIS2C1*(TREF**VIS2C2)
   14 CONTINUE
      REY=R1*U1*A/VIS1
      REYREF=REY*VIS1/VISREF
      XCONE=ANRAD*PHIO
      EPS=1./SQRT(REYREF)
      ABC=(XMA*SIN(XWAVE))**2
      P10=PT1/(R1*U1*U1)
      IF (XWAVE.GT..0000001.OR.XWAVE.LT.-.0000001) P10=(1./(G*XMA*XMA))*
     1((XMAC*ABC*(G+1.))/(ABC*(G-1.)+2.))**(G/(G-1.))*((G+1.)/(2.*G*ABC-
     2(G-1.)))**(1./(G-1.))
      T10=0.5+1.0/(XMA*XMA*(G-1.0))
      R10=G*P10/(T10*(G-1.0))
      TC=VIS1C2/(TI*XMAC)
      RFL=SQRT(PR)
      RFT=PR**0.33333
C
C        READ TABULAR DATA
C
      IF (NOIT.GT.0) GO TO 20
      NABC=NPUTYPE+1
```

```
      GO TO (19,15,16), NABC
   15 CALL TABLE (IEND1,SD,R1,U1,A,TREF,KODWAL,VISREF,KODUNIT,AWT)
      GO TO 17
   16 CALL TABLE1 (IEND1,SD,R1,U1,A,TREF,KODWAL,VISREF,KODUNIT,AWT)
   17 GO TO (19,18), IENTRO
   18 CALL VARENT (RRS,ZZS,DRSDZS,NNN,KODUNIT,A)
   19 CONTINUE
C
C       SET UP PRINT CONTROL
C
      SD=SD*A
      CALL SETUP (PROINC,PROVAL,SD,JN,IPRO)
      CALL SETUP (PRNTINC,PRNTVAL,SD,JM,IPRNT)
      WRIT E(6,97)
      IF(KODUNIT.EQ.1) WRITE(6,84) (PROVAL(I)*.3048,I=1,JN)
      IF(KODUNIT.EQ.1) WRITE(6,85) (PRNTVAL(I)*.3048,I=1,JM)
      IF(KODUNIT.NE.1) WRITE(6,84) PROVAL
      IF(KODUNIT.NE.1) WRITE(6,85) PRNTVAL
   20 CONTINUE
      READ (4) TW,RVWALD,QSD,PE,DS
      SI=DS
      UE=0.
      PEOP10=PE/P10
      IF (PEOP10.GT.1.) GO TO 21
      GO TO 22
   21 CONTINUE
      ABYZ=ABS(1.-PEOP10)
      WRITE (6,81) ABYZ
      STOP 600
   22 CONTINUE
      IF (IBODY.NE.1) UE=SQRT(2.*T10*(1.-(PEOP10)**GM1OG))
      TE=T10-.5*UE*UE
      RE=G*PE/((G-1.)*TE)
      TR=T10*TC/TE
      TW=TW/TE
      SUT=VIS1C2/TREF
      IF (IGAS.EQ.1) XNUE=(TE**1.5)*((1.+SUT)/(TE+SUT))
      IF (IGAS.EQ.2) XNUE=TE**VIS2C2
      GO TO (23,25), IBODY
C
C        STARTING PROCEDURE FOR FLOWS WITH STAGNATION POINT
C
   23 SUT=T10*TC
      IF (IGAS.EQ.1) VIS10=(T10**1.5)*(1.+SUT)/(T10+SUT)
      IF (IGAS.EQ.2) VIS10=T10**VIS2C2
      P1PT2=P1/PT1
      IF (XMA.LE.1.) GO TO 24
      P1PT2=((((G+1.)*XMA**2)/2.)**(-G/(G-1.)))*((G+1.)/((2.*G*XMA**2)-(
     1G-1.)))**(-1./(G-1.))
   24 CONTINUE
      DUEDS=SQRT(2.*((G-1.)/G)*T10*(1.-P1PT2))
      BELA=R10*VIS10*DUEDS
      RMI=SI
      DX1DS=BELA*(SI-DS)**(2*J+1)
```

```
      DXDS=BELA*SI**(2*J+1)
      DX1=(BELA*SI**(2*J+2))/(2*J+2)
      X=DX1
      ARGM=-778.26*EPS*A*PR/(VISREF*U1*U1*T10*SQRT((J+1)*R10*VIS10*DUEDS
     1))
      XAL=0.
      XBE=1./(FLOAT(J)+1.)
      GO TO 28
C
C        STARTING PROCEDURE FOR FLOWS WITHOUT STAGNATION POINT
C
   25 CONTINUE
      IF (J.EQ.0) GO TO 26
      RMI=SI*SIN(XCONE)
      BELEX=RE*UE*XNUE*(SIN(XCONE)**(2*J))
      IF (J.NE.0.AND.PHIO.EQ.0.) BELEX=RE*UE*XNUE
      DX1DS=BELEX*((SI-DS)**(2*J))
      GO TO 27
   26 CONTINUE
      RMI=1.
      BELEX=RE*UE*XNUE
      DX1DS=BELEX
   27 DXDS=BELEX*SI**(2*J)
      DX1=(BELEX*(SI**(2*J+1)))/(2*J+1)
      X=DX1
      QS=DISP=0.
      XAL=UE**2/TE
      XBE=0.
      ARGM=0.
      DUEDS=0.
   28 CONTINUE
C
C       GENERATE SELF SIMILAR SOLUTION
C
      CALL SIMILAR (IE,IGAS,XAL,XBE,PR,KODWAL,TW,DTDZW,XK,TR,VIS2C2,F3,F
     12,T3,T2,V3,V2,FZ3,TZ3,XL3,EP3,ARGM,QSD)
      IF (KODWAL.EQ.1.AND.IBODY.EQ.1) QSD=TZ3(1)*XL3(1)/ARGM
      MUESTAR=XNUE*VISREF
      UESTAR=UE*U1
      TESTAR=TE*TREF
      PESTAR=PE*R1*U1*U1
      RESTAR=RE*R1
      X=0.
      DX2=DX1
C
C        SET UP INITIAL PROFILES
C
      DO 29 N=1,IE
      V2(N)=V3(N)
      V1(N)=V3(N)
      T2(N)=T3(N)
      T1(N)=T3(N)
      F2(N)=F3(N)
      F1(N)=F3(N)
```

```
      XL2(N)=XL3(N)
      XL1(N)=XL3(N)
      XLP2(N)=XLP3(N)
      XLP1(N)=XLP3(N)
      TZ2(N)=TZ3(N)
      FZ2(N)=FZ3(N)
   29 CONTINUE
      IF (KODUNIT.EQ.1) CALL OUTUNIT (PROVAL,PRNTVAL,JM,JN)
      IF (KODUNIT.EQ.1) CALL WALLOUT (PROVAL,PRNTVAL,JM,JN)
C
C        WRITE INITIAL STATION PARAMETERS
C
      WRITE (6,72) MUESTAR,UESTAR,TESTAR,PESTAR,QSD,XAL,XBE,RESTAR
      IF (KODUNIT.NE.1) WRITE (6,69)
      IF (KODUNIT.EQ.1) WRITE (6,70)
      PTREF=PT1/(R1*U1*U1)
      WRITE (6,71) PT1,TT1,RT1,P1,T1,R1,U1,AA1,XMA,REY,R1*U1*U1,TREF,R1,
     1U1,VISREF,PTREF,P10,T10,R10
      IF (KODUNIT.EQ.1) CALL INUNIT (PROVAL,PRNTVAL,JM,JN)
      ZS=0.
       IF((IENTRO.EQ.2) .AND. (NOIT.EQ.0)) WRITE(6,88)
C
C         BEGIN MARCHING PROCEDURE ALONG SURFACE
      SM1=-DS
      S=0.
      DXDS=DX1DS
      IENDP1=IEND1+1
      DO 68 M=2,IENDP1
      SM2=SM1
      SM1=S
      READ (4) S,PE,RMI,TW,Z,DPEDS,RVWALD,DRDZ,QW
      PHI=ATAN(DRDZ)
      COSTH=COS(PHI)
      PP=DPEDS
      UE=SQRT(2.0*T10*(1.0-(PE/P10)**((G-1.0)/G)))
      IF (NOIT.GT.0) UE=UEE(M)
      TE=T10-0.5*UE*UE
      XAL=UE*UE/TE
      RE=G*PE/((G-1.0)*TE)
      IF (IGAS.EQ.1) XNUE=(TE**1.5)*(1.0+T10*TC)/(TE+T10*TC)
      IF (IGAS.EQ.2) XNUE=TE**VIS2C2
      DX2DS=DX1DS
      DX1DS=DXDS
      DXDS=RE*UE*XNUE*(RMI**(2*J))
      DX2=(DXDS+DX1DS)*.5*DS
      IF (IBODY.EQ.1) DX2=DX2*.5
      IF (M.EQ.2) DX1=DX2
      IF (M.EQ.2) GO TO 31
C
C         CHECK FOR CHANGE IN STEP INCREMENT
C
      CKK=(S-SM1)/(SM1-SM2)
      IF (CKK.LT..999999999) GO TO 30
      IF (CKK.GT.1.00000001) GO TO 30
```

```
      DX2=(S-SM1)*(DXDS+4.*DX1DS+DX2DS)/3.-DX1
      GO TO 31
   30 DX2=(S-SM1)*(DX1DS+DXDS)/2.
   31 X=X+DX2
      OY=2.*X
      OZ=SQRT(OY)
      DUEDS=-PP/(RE*UE*DXDS)
      DTEDS=-UE*DUEDS
      XAL=UE*UE/TE
      XBE=OY*DUEDS/UE
      TR=T10*TC/TE
C
C        SET UP DIFFERENCE-QUOTIENT COEFFICIENTS FOR X-COORDINATE
C
      Z1=2.*((DX1+2.*DX2)/(DX1+DX2))
      Z2=2.*(DX1+DX2)/DX1
      Z3=2.*((DX2*DX2)/(DX1*(DX1+DX2)))
      Z4=(DX1+DX2)/DX1
      Z5=DX2/DX1
      FAA=OZ/(RE*UE*(RMI**J))
      FAB=2.*EPS*W*FAA*COSTH/(RMI**J)
      FAC=2.*EPS*OZ*COSTH/(RE*UE*RMI*RMI)
      FAD=RMI/(EPS*COSTH)
      BEX1=(RMI**J)/(EPS*COSTH)
      IF (J.EQ.0) SIGN=ABS(SIGN)
      BEX2=SIGN**J
      BEX3=(2.**J)*EPS*COSTH*SQRT(2.*X)/(RE*UE*(RMI**(2.*J)))
      BEX4=1./(J+1)
      DFDZW=1.
      NIT=0
   32 CONTINUE
      NIT=NIT+1
      IF (KODWAL.NE.1) ARGM=-QW*778.26*(EPS*A/(VISREF*U1**2))*(PR*OZ/(RE
     1*UE*TE*XNUE*RMI**J))
      CALL SOLVE (KODWAL,ARGM,TR,VIS2C2,XAL,XBE,X,DX2,TW,IGAS,IE,J,NIT,R
     1VWALD,R1,U1,WW1,WW2,WW3,WW4,WW5,XNUE,XK,EPS,M,IBODY,FT)
      CO=0.
      DISINC=0.
      DISP=0.
      TPK=0.
      THETA=0.
      KON=IE+2
      DO 33 N=2,KON
      TPK=TPK+.5*(T3(N-1)+T3(N))*DN(N-1)
      RATO3(N)=SIGN*SQRT(1.+FAB*TPK)
      DRATO3(N)=FAB*T3(N)
      Y(N)=BEX1*(-1.+BEX2*(1.+BEX3*TPK)**BEX4)
      DISP=DISP+.5*((T3(N-1)-F3(N-1))+(T3(N)-F3(N)))*DN(N-1)
      C=1./(RATO3(N)**J)
      C=C*(F3(N)*(1.-F3(N)))
      THETA=THETA+.5*(CO+C)*DN(N-1)
      CO=C
      DISINC=DISINC+.5*((T3(N-1)*(1.-F3(N-1))/RATO3(N-1))+(T3(N)*(1.-F3(
     1N))/RATO3(N)))*DN(N-1)
```

```
   33 CONTINUE
      DISINC=DISINC*EPS*FAA*A
      THETA=THETA*EPS*FAA*A
      DISP=DISP*EPS*FAA*A
C
C
      DETERMINE THE LOCATION OF THE BOUNDARY-LAYER EDGE
C     SEE INPUT DESCRIPTION FOR DEFINITION FOR VELEDG
C
      NCOUNT=0
      DO 34 N=1,IE
      NCOUNT=NCOUNT+1
      IF (F3(N).GE.VELEDG) GO TO 35
   34 CONTINUE
   35 NEDGE=NCOUNT
      YEDGE=Y(NEDGE-1)+(VELEDG-F3(NEDGE-1))*(Y(NEDGE)-Y(NEDGE-1))/(F3(NE
     1DGE)-F3(NEDGE-1))
C
C     CHECK THE CONVERGENCE
C
      DIF=ABS(1.-FZ3(1)/DFDZW)
      DFDZW=FZ3(1)
      DIF1=DIF
      IF (NIT.GT.NITMAX) DIF=0.
C
C       CALCULATE WALL AND INITIAL VALUES REQUIRED FOR BASIC BOUNDARY
C       LAYER PARAMETERS
C
      MOME(1)=F3(1)/SQRT(T3(1))
      XMF1=2.+XAL
      XMF2=T3(1)*TE/T10
      XMF3=1.-XMF2
      TTOTT(1)=(2.*T3(1)+XAL*F3(1)*F3(1))/XMF1
      CROCCO(1)=(TTOTT(1)-XMF2)/XMF3
      UOUPL(1)=0.
      TCORD(1)=0.
      UDEF(1)=0.
      NONDEL(1)=0.
      XMF4=EPS*XNUE*UE*UE*(RMI**J)*XL3(1)*FZ3(1)/DZ
C
C       CALCULATE BASIC BOUNDARY LAYER PARAMETERS
C
      KON=IE+2
      DO 37 N=2,KON
      IF (TRFACT.EQ.0.0) GO TO 36
      UPLUS=SQRT(XMF4*T3(1))
      UOUPL(N)=UE*F3(N)/UPLUS
      TCORD(N)=(Y(N)*UPLUS*RE)/(EPS*XNUE*((T3(N)*XL3(N))**2))
      UDEF(N)=UE*(1.-F3(N))/UPLUS
   36 CONTINUE
      TTOTT(N)=(2.*T3(N)+XAL*F3(N)*F3(N))/XMF1
      CROCCO(N)=(TTOTT(N)-XMF2)/XMF3
      MOME(N)=F3(N)/SQRT(T3(N))
   37 CONTINUE
```

```
C
C        CALCULATE VORTICITY REYNOLDS NUMBER
C        AND DETERMINE STABILITY INDEX
C
      IF (TRFACT.GT.0.0.AND.TRFACT.LT.0.9999) GO TO 40
      DO 38 I=1,NEDGE
      TERMB=RE*RE*UE*UE*Y(I)*Y(I)*(RMI*RATO3(I))**J/(SQRT(2.*X)*XNUE*EPS
     1)
   38 STAB2(I)=TERMB*FZ3(I)/(XL3(I)*T3(I)**3)
      ST2MAX=STAB2(1)
      DO 39 IX=2,IE
      IF (ST2MAX.GT.STAB2(IX)) GO TO 39
      ST2MAX=STAB2(IX)
   39 CONTINUE
      SMXP=ST2MAX
   40 CONTINUE
      DSMXO=(SMXP-SMXN)/(S-SM1)
      SMXN=SMXO
      SMXO=SMXP
      IF (KTCOD.EQ.2.OR.KTCD.EQ.1) GO TO 41
      KTCD=1
      RRRR=RE*UE*R1*U1/(XNUE*VISREF)
      TLNGTH=1.+(5.*RRRR**(-1)*(RRRR*A*SST)**.8)/SST
   41 CONTINUE
      IF (SMXTR.LE.ST2MAX) CALL TURBLNT (T3,XL3,FZ3,RATO3,Y,EP3,F3,EH3,V
     1ARA,VARB,VARC,VARD,VARE,KODAMP,IYINT,YEDGE,TAUP)
      IF (SST.LE.S*A) CALL TURBLNT (T3,XL3,FZ3,RATO3,Y,EP3,F3,EH3,VARA,V
     1ARB,VARC,VARD,VARE,KODAMP,IYINT,YEDGE,TAUP)
      IF (DIF.GT.CONV) GO TO 32
C
C     OUTPUT QUANTITIES
C
      DO 42 N=2,KON
      NONDEL(N)=Y(N)/YEDGE
   42 CONTINUE
      IF (J.NE.1) GO TO 44
      TIBURON=2.*DISP/RMI
      IF(TIBURON.LT.-1.)GO TO 43
      DISP=RMI*(-1.+SQRT(1.+TIBURON))
      GO TO 44
   43 WRITE(6,93)
   44 CONTINUE
      THADIS=DISP/THETA
      REDELT=(RE*UE*DISP/(XNUE*A))*REYREF
      RETHET=REDELT/THADIS
      RES=(RE*UE*S/XNUE)*REYREF
      XMAE=UE/SQRT(TE*(G-1.))
      TWOTT1=T3(1)*TE*TREF/TT1
      RFCTOR=(T3(1)-1.)/((TT1/(TE*TREF))-1.)
      TAUD=VISREF*U1*(XL3(1)*RE*XNUE*UE*UE*(RMI**J)*FZ3(1)/OZ)/(EPS*A)
      CFE=TAUD/(.5*R1*U1*U1*RE*UE*UE)
      CFW=CFE*TW/TE
      IF (KODWAL.NE.1) GO TO 45
      QS=-XL3(1)*RE*UE*TE*XNUE*(RMI**J)*TZ3(1)/(PR*OZ*EPS)
```

```
      QSD=QS*VISREF*U1*U1/(778.26*A)
      GO TO 46
   45 QSD=QW
   46 CONTINUE
      IF(FZ3(1).GE.0.) GO TO 92
      WRITE(6,91)S,TAUD,QSD
      STOP 400
   92 CONTINUE
      TWD=TREF*TW
      TAWD=(RFL+(RFT-RFL)*TRFACT)*(TT1-TE*TREF)+TE*TREF
      HD=QSD/(TWD-TAWD)
      CHE=778.26*HD*(G-1.)/(G*R*R1*U1*RE*UE)
      CHW=CHE*TW/TE
      HSD=HD*A*S
      KED=R*VISREF*XNUE*G/(778.26*PR*(G-1.))
      KWD=KED*XL3(1)*T3(1)
      NUE=HSD/KED
      NUW=HSD/KWD
C
C              TOTAL PRESSURE RATIO, (PT2)BL/(PT2)REF
C
      DO 49 I=1,IE
      ZEB=(MOME(I)*XMAE)**2
      IF (SQRT(ZEB)-1.) 47,47,48
   47 PT2=PE*((1.+(G-1.)*ZEB/2.)**(G/(G-1.)))
      GO TO 49
   48 BBA=(ZEB*(G+1.)/2.)**(G/(G-1.))
      BBB=((G+1.)/((2.*G*ZEB)-(G-1.)))**(1./(G-1.))
      PT2=PE*BBA*BBB
   49 PTOPT(I)=PT2/PTREF
C
C          VARIABLE ENTROPY CALCULATIONS
C
      GO TO (51,50), IENTRO
   50 INTEGL=INTEGT(F3,NEDGE,DN)
      XXJ=J
      RS=((J+1)*EPS*DZ*INTEGL)**((2.-XXJ)/2.)
      IPT=-1
      CALL IUNI (JL,NNN,KRS,2,DVT,2,RS,ANS,IPT,IERR)
      ZS=ANS(1)
      TANTHTS=ANS(2)
      THATS=ATAN(TANTHTS)
      SWANG=THATS/.0174533
      PTTWO=(G+1.)*XMA**2*SIN(THATS)**2
      PTTWO=PTTWO/((G-1.)*(XMA)**2*SIN(THATS)**2+2.)
      PTTWO=PTTWO**(G/(G-1.))*PT1
      PTTWO=PTTWO*((G+1.)/(2.*G*XMA**2*SIN(THATS)**2-(G-1.)))**(1./(G-1.
     1))
      P20=PTTWO/(R1*J1*U1)
      UEE(M)=SQRT(2.*T10*(1.-(PE/P20)**((G-1.)/G)))
      XVAL2=ABS((UEE(M)-UE)/UE)
      IF(XVAL2.GE.XVAL1) XMX=XVAL2
      XVAL1=XVAL2
      NN=IE+2
```

```
   51 CONTINUE
      NN=IE+2
      IF (IENTRO.EQ.1) P20=P10
C
C        PRINT PROFILES AND WALL VALUES
C
      KPRNT=0
      IF (ABS(A-1.).LE.0.0000001) GO TO 52
      S=S*A
      Z=Z*A
      RMI=RMI*A
      ZS=ZS*A
      RS=RS*A
   52 CONTINUE
      DO 53 NUMBR=1,JN
      IF (S.GT.PROVAL(NUMBR)-.000001.AND.S.LT.PROVAL(NUMBR)+.000001) GO
     1TO 54
   53 CONTINUE
      GO TO 63
   54 CONTINUE
      IF (KODUNIT.EQ.1) S=S*.3048
      WRITE (6,73) S
      IF (KODUNIT.EQ.1) S=S/.3048
      IEDGEX=NEDGE+10
      IF (IEDGEX.GT.IE) IEDGEX=IE
      IF (NAUXPRO.NE.1) GO TO 56
      WRITE (6,74)
      DO 55 I=1,IEDGEX
   55 WRITE (6,75) (XN(I),TAUP(I),V3(I),FZ3(I),TZ3(I),VARA(I),VARB(I),VA
     1RC(I),VARD(I),EP3(I),VARE(I))
   56 CONTINUE
      IF (KODE.EQ.1) GO TO 58
      IF (TRFACT.GT.0.9999) GO TO 61
      IF (TRFACT.GT.0.0.AND.TRFACT.LT.0.9999) GO TO 58
      WRITE (6,76)
      DO 57 I=1,IEDGEX
   57 WRITE (6,77) XN(I),NONDEL(I),F3(I),T3(I),TTOTT(I),CROCCO(I),PTOPT(
     1I),MOME(I),FZ3(I),TZ3(I),STAB2(I),XL3(I)
      GO TO 63
   58 WRITE (6,76)
      DO 59 I=1,IEDGEX
   59 WRITE (6,77) XN(I),NONDEL(I),F3(I),T3(I),TTOTT(I),CROCCO(I),PTOPT(
     1I),MOME(I),FZ3(I),TZ3(I),STAB2(I),XL3(I)
      WRITE (6,78)
      DO 60 I=1,IEDGEX
   60 WRITE (6,77) XN(I),NONDEL(I),F3(I),T3(I),TTOTT(I),CROCCO(I),PTOPT(
     1I),MOME(I),TCORD(I),UOUPL(I),UDEF(I),EP3(I)
      GO TO 63
   61 WRITE (6,78)
      DO 62 I=1,IEDGEX
   62 WRITE (6,77) XN(I),NONDEL(I),F3(I),T3(I),TTOTT(I),CROCCO(I),PTOPT(
     1I),MOME(I),TCORD(I),UOUPL(I),UDEF(I),EP3(I)
```

```
   63 CONTINUE
      DO 64 NUMBER=1,JM
      IF (S.GT.PRNTVAL(NUMBER)-.000001.AND.S.LT.PRNTVAL(NUMBER)+.000001)
     1 GO TO 65
   64 CONTINUE
      GO TO 66
   65 CONTINUE
      PESTAR=PE*R1*U1*U1
      TESTAR=TE*TREF
      RESTAR=RE*R1
      UESTAR=UE*U1
      MUESTAR=XNUE*VISREF
      YESTAR=YEDGE*EPS*A
      RVWAL=RVWALD/(RESTAR*UESTAR)
      GANDOG=RVWALD
      IF(KODUNIT.EQ.1)GANDOG=GANDOG/.0063658804
      IF (KODUNIT.EQ.1) CALL WALLOUT (PROVAL,PRNTVAL,JM,JN)
      WRITE (6,79) S,RETHET,PP,CFW,ZS,YESTAR,X,RES,DTEDS,QSD,RS,UPLUS,RM
     1I,PESTAR,DUEDS,HD,NOIT,TRFACT,Z,TESTAR,DISP,CHE,TWOTT1,JPOINT,XBE,
     2RESTAR,THETA,CHW,RFCTOR,P20
      WRITE (6,80) XAL,UESTAR,THADIS,NUE,ST2MAX,EPS,GANDOG,XMAE,TAUD,NUW
     1,DSMXD,REDELT,MUESTAR,CFE,SWANG,V3(1),RVWAL,NIT,DIF1
      KPRNT=1
   66 CONTINUE
      AINV=1./A
      IF (KODUNIT.EQ.1.AND.KPRNT.EQ.1) AINV=AINV*3.280839895
      S=S*AINV
      Z=Z*AINV
      RMI=RMI*AINV
      ZS=ZS*AINV
      RS=RS*AINV
C
C        UPDATE VARIABLES FOR MARCHING PROCEDURE
C
      DO 67 N=1,NN
      F1(N)=F2(N)
      T1(N)=T2(N)
      V1(N)=V2(N)
      RATO1(N)=RATO2(N)
      DRATO1(N)=DRATO2(N)
      XL1(N)=XL2(N)
      XLP1(N)=XLP2(N)
      F2(N)=F3(N)
      T2(N)=T3(N)
      V2(N)=V3(N)
      RATO2(N)=RATO3(N)
      DRATO2(N)=DRATO3(N)
      XL2(N)=XL3(N)
      XLP2(N)=XLP3(N)
      TZ2(N)=TZ3(N)
      EP1(N)=EP2(N)
      EP2(N)=EP3(N)
      EP3M=EP3(N)
      IF (N.GT.1.AND.N.LT.IE) EP3M=(EP3(N-1)+EP3(N)+EP3(N+1))/3.
```

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```
      TAUP(N)=1./(XL3(1)*FZ3(1))*XL3(N)*ABS(FZ3(N))*EP3M
      EH1(N)=EH2(N)
      EH2(N)=EH3(N)
      FZ2(N)=FZ3(N)


   67 CONTINUE
   68 DX1=DX2
      IF (IENTRO.EQ.1) STOP 100
      IF(NOIT.EQ.ITMAX) WRITE(6,69)
      IF (NOIT.EQ.ITMAX) STOP 200
      IF(XMX.LE.CONVE) WRITE(6,90)
      IF (XMX.LE.CONVE) STOP 300
      NOIT=NOIT+1
      WRITE(6,86) ITMAX,NOIT
      REWIND 4
      GO TO 10
C
C
C
   69 FORMAT (1H1,20X,64H****DIMENSIONAL OUTPUT QUANTITIES ARE IN U.S. S
     1TANDARD UNITS****,/)
   70 FORMAT (1H1,20X,55H****DIMENSIONAL OUTPUT QUANTITIES ARE IN S.I. U
     1NITS****,/)
   71 FORMAT (2X,30HFREE STREAM VALUES-DIMENSIONAL,/,5X,5HPT1 =,E14.6,2X
     1,5HTT1 =,E14.6,2X,5HRT1 =,E14.6,2X,5H P1 =,E14.6,2X,7H     T1=,E14.
     26,2X,5H R1 =,E14.6,/,5X,5H U1 =,E14.6,2X,5HAA1 =,E14.6,2X,5HXMA =,
     3E14.6,2X,5HREY =,E14.6,//,2X,28HREFERENCE VALUES-DIMENSIONAL,/,5X,
     55HPREF=,E14.6,2X,5HTREF=,E14.6,2X,5HRREF=,E14.6,2X,5HUREF=,E14.6,2
     6X,7HVISREF=,E14.6,2X,5HPTR =,E14.6,//2X,25HPARAMETERS-NONDIMENSION
     7AL,/,5X,5HP10 =,E14.6,2X,5HT10 =,E14.6,2X,5HR10 =,E14.6,/)
   72 FORMAT (2X,5HMUE =,E12.6,2X,5HUE   =,E12.6,2X,5HTE   =,E12.6,2X,5HPE
     1   =,E12.6,2X,5HQSD =,E12.6,/,2X,5HXAL =,E12.6,2X,5HXBE =,E12.6,2X,
     25HRE  =,E12.6)
   73 FORMAT (//1X,2HS=F14.4,9H  PROFILE/)
   74 FORMAT (130H           ETA           TAUP              V     GRAD(U/UE)  GRAD
     1(T/TE)          FC1           DAMP           EPI          EPO           EP
     2     MIXDEL/)
   75 FORMAT (11E12.3)
   76 FORMAT (//4X,3HETA,8X,4HY/YE,7X,4HU/UE,7X,4HT/TE,6X,6HTT/TTE,5X,6H
     1CROCCO,5X,6HPT/PTR,6X,4HM/ME,8X,2HFZ,9X,2HTZ,6X,7HVORTREY,6X,5HXLM
     211/)
   77 FORMAT (12E11.3)
   78 FORMAT (//4X,3HETA,8X,4HY/YE,7X,4HU/UE,7X,4HT/TE,6X,6HTT/TTE,5X,6H
     1CROCCO,5X,6HPT/PTR,6X,4HM/ME,7X,5HYPLUS,6X,5HUPLUS,6X,4HUDEF,6X,6H
     2VISEFF/)
   79 FORMAT (/2X,7HS      =,E12.5,2X,7HRETHET=,E12.5,2X,7HDPEDS =,E12.5,
     12X,7HCFW    =,E12.5,2X,7HZSHK   =,E12.5,2X,7HYE     =,E12.5,/2X,7HXI
     2    =,E12.5,2X,7HRES    =,E12.5,2X,7HDTEDS =,E12.5,2X,7HQSD    =,E12.
     35,2X,7HRSHK   =,E12.5,2X,7HUTAU   =,E12.5,/2X,7HRMI    =,E12.5,2X,7HP
     4E     =,E12.5,2X,7HDUEDS =,E12.5,2X,7HHD     =,E12.5,2X,7HITRO   =,I1
     52,2X,7HTRFCT =,E12.5,/2X,7HZ      =,E12.5,2X,7HTE     =,E12.5,2X,7HD
     6LTAST=,E12.5,2X,7HNSTE   =,E12.5,2X,7HTW/TT1=,E12.5,2X,7HYMP    =,I1
     72,/2X,7HBETA   =,E12.5,2X,7HRE     =,E12.5,2X,7HTHETA =,E12.5,2X,7HN
     8STW   =,E12.5,2X,7HRFTRUE=,E12.5,2X,7HP20    =,E12.5)
```

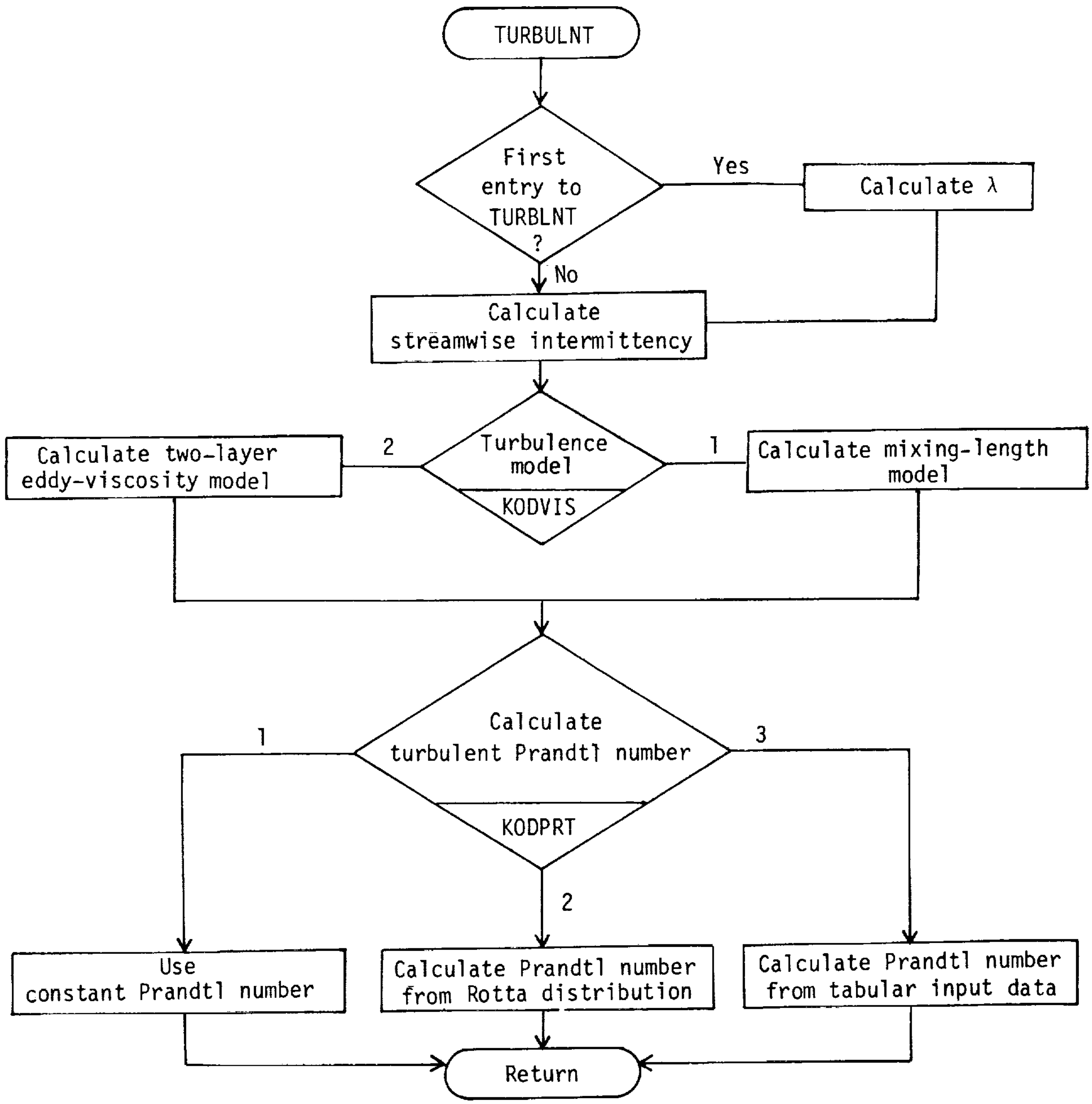
```
80 FORMAT (2X,7HXAL    =,E12.5,2X,7HUE     =,E12.5,2X,7HFORM   =,E12.5,2
  1X,7HNUE    =,E12.5,2X,7HROUSE =,E12.5,2X,7HOMEGA =,E12.5,/2X,7HRVWA
  2LD=,E12.5,2X,7HME     =,E12.5,2X,7HTAUD   =,E12.5,2X,7HNUW    =,E12.5
  3,2X,7HDSMXO =,E12.5/2X,7HREDELT=,E12.5,2X,7HMUE     =,E12.5,2X,7HCFE
  4     =,E12.5,2X,7HSWANG =,E12.5,2X,7HVW     =,E12.5,2X,7HRVWAL =,E12.
  55/2X,7HNOITER=,I12,2X,7HERROR =,E12.5)
81 FORMAT (/2X,8HMISTAKE=,E12.5,37H  MISTAKE=ABSOLUTE VALUE OF 1.-PE/
  1P10/10X,106HYOU HAVE MADE AN ERROR IN YOUR INPUT SUCH THAT THE RAT
  2IO OF STATIC TO TOTAL PRESSURE IS GREATER THAN UNITY/11X,66HERROR
  3COULD INVOLVE EITHER OR ALL OF THE FOLLOWING:XMA,PT1,PE,WAVE//12X,
  497HTHE PROBABILITY IS VERY HIGH THAT YOUR SPECIFIED VALUE OF PE(1)
  5 IN $NAM3 IS NOT CORRECT FOR YOUR /,12X,40HSELETED VALUES OF XMA,P
  6T1,WAVE IN $NAM2.//,12X,27HPE/P10 CANNOT EXCEED UNITY./)
82 FORMAT(1H1,2X,5H$NAM1,//,2X,8HIGEOM   =,I12,2X,8HXEND    =,E12.5,2X,
  18HIE      =,I12,2X,8HXK      =,E12.5,2X,8HDETA1   =,E12.5,2X,8HXMA
  2 =,E12.5,/,2X,8HPT1     =,E12.5,2X,8HTT1     =,E12.5,2X,8HIGAS    =,I
  312,2X,8HVIS1C1 =,E12.5,2X,8HVIS1C2 =,E12.5,2X,8HVIS2C1 =,E12.5,/,2
  4X,8HVIS2C2 =,E12.5,2X,8HG       =,E12.5,2X,8HR       =,E12.5,2X,8HPR
  5      =,E12.5,//,2X,8HIBODY   =,I12,2X,8HWAVE    =,E12.5,2X,8HPHII

  6=,E12.5,2X,8HJ       =,I12,2X,8HW       =,I12,2X,8HIENTRO =,I12,//,2
  7X,8HSST     =,E12.5,2X,8HSMXTR   =,E12.5,2X,8HKODVIS =,I12,2X,8HKTCO
  8D   =,I12,2X,8HTLNGTH =,E12.5,2X,8HIYINT   =,I12,/,2X,8HKODAMP =,I12
  9,2X,8HXT1     =,E12.5,2X,8HXT2     =,E12.5,2X,8HXT3     =,E12.5,2X,8H
  1XT4     =,E12.5,2X,8HXT5     =,E12.5,/,2X,8HXT6     =,E12.5,2X,8HPRT
  2     =,E12.5,2X,8HKODPRT =,I12,2X,8HNUMB1   =,I12,2X,8HGLAR    =,E12.5
  4,/,2X,8HPRTAR    ,/,(10E12.5))
83 FORMAT(/,2X,8HIEND1   =,I12,2X,8HPROINC =,E12.5,2X,8HPRNTINC=,E12.5
  1,2X,8HIPRO    =,I12,2X,8HIPRNT   =,I12,2X,8HNAUXPRO=,I12,/,2X,8HFT
  1    =,E12.5,2X,8HKODE    =,I12,2X,8HKODWAL =,I12,2X,8HVELEDG =,E12.5
  1,2X,8HCONV    =,E12.5,2X,8HNITMAX =,I12,/,2X,8HKODUNIT=,I12,2X,8HIT
  2MAX  =,I12,2X,8HCONVE   =,E12.5,//,2X,119HTHIS COMPLETES THE OUTPUT
  3 OF $NAM1 WITH THE EXCEPTION OF PROVAL AND PRNTVAL. THESE VALUES A
  4RE PRINTED JUST PRIOR TO THE,/,2X,22HINITIAL STATION PRINT.)
84 FORMAT(2X,6HPROVAL,/,(10E12.5))
85 FORMAT(2X,8HPRNTVAL ,/,(10E12.5))
86 FORMAT(//,35X,50H*********************************************
  1*,/35X,1H*,10X,28HVARIBLE ENTROPY CALCULATIONS,10X,1H*,/,35X,1H*,1
  21X,6HITMAX=,I8,2X,5HNOIT=,I8,8X,1H*,/,35X,1H*,48X,1H*,/,35X,50H***
  3***********************************************)
87 FORMAT(/,2X,63HPRINT STATIONS DESIGNATED IN $NAM1 INPUT AND GENERA
  1TED IN SETUP,/)
88 FORMAT(/,2X,125HFOR YOUR VARIBLE ENTROPY CASE (IENTRO=2) THE FIRST
  1 PASS OVER THE BODY IS EQUIVALENT TO A CONVERGED CONSTANT ENTROPY(
  2IENTRO=1)/,2X,92HSOLUTION. VARIBLE ENTROPY EFFECTS ARE TREATED IN
  3SUBSEQUENT PASSES; THAT IS FOR NOIT=1,2,...)
89 FORMAT(/,2X,117HYOUR VARIBLE ENTROPY CASE HAS NOT CONVERGED FOR YO
  1UR INPUT VALUES OF CONVE AND ITMAX.  YOU MUST EITHER INCREASE ITMA
  2X,/,2X,66HOR REDUCE YOUR CONVERGENCE LEVEL BY INCREASING THE VALUE
  3 OF CONVE.)
90 FORMAT(/,2X,77HYOUR VARIBLE CASE ENTROPY IS CONVERGED TO YOUR SELE
  1CTED INPUT VALUE OF CONVE.)
91 FORMAT(2X,47HBOUNDARY-LAYER SEPARATION INDICATED BY SOLUTION,/,2X,
  12HS=,E12.5,2X,5HTAUD=,E12.5,2X,4HQSD=,E12.5)
```

```
93 FORMAT(1H1,2X,61HFOR J=1 DISP IS DEFINED AS(SEE AIAA PAPER NO. 69-
  1687) FOLLOWS,//,4X,41HDISP=RMI*(-1.+SQRT(1.+2.*DISP(J=0)/RMI))),//
  2,2X,109HFOR YOUR CURRENT S-STATION DISP(J=0) IS NEGATIVE(ALLOWED)
  3AND 2.*DISP(J=0)/RMI IS LESS THAN -1.(NOT ALLOWED);,/,2X,112HCONSE
  4QUENTLY,THE VALUE PRINTED ABOVE IS DISP(J=0) WHERE DISP(J=0) IS TH
  5E TWO DIMENSIONAL DEFINITION. THE PROBLEM,/,2X,111HNORMALLY OCCURS
  6 FOR (1)EXTREMELY FINE DS NEAR S=0. FOR BLUNT BODIES WHERE RMI IS
  7VERY SMALL; (2) FLOW OVER VERY,/,2X,110HSLENDER BODY OF REVOLUTION
  8(NEEDLE). THE PROBLEM IS EASILY SOLVED BY REFINED GRID DISTRIBUTIO
  9N. HOWEVER, IF YOU,/,2X,100HARE NOT INTERESTED IN THE TWO ABOVE ME
  1NTIONED CASES,IGNORE THIS MESSAGE AND PROBLEM WILL CURE ITSELF,/,2
  2X,50HAS S INCREASES FOR ALL PHYSICALLY REALISTIC FLOWS.)
   END
```

APPENDIX C

Subroutine TURBLNT

Subroutine TURBLNT calculates either the eddy viscosity or mixing-length parameters required for the transitional and/or turbulent boundary-layer equations. The flow chart for subroutine TURBLNT is as follows:



APPENDIX C

The program listing for subroutine TURBLNT is as follows:

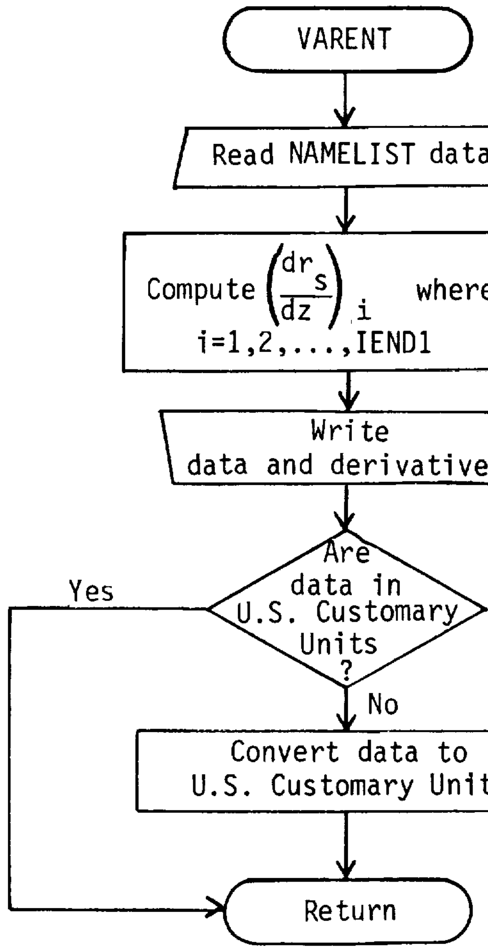
```
      SUBROUTINE TURBLNT (T3,XL3,FZ3,RATO3,Y,EP3,F3,EH3,VARA,VARB,VARC,V
     1ARD,VARE,KODAMP,IYINT,YEDGE,TAUP)
      DIMENSION VARA(JK), VARB(JK), VARC(JK), VARD(JK), VARE(JK), Y(JK),
     1 T3(JK), XL3(JK), FZ3(JK), RATO3(JK), EP3(JK), F3(JK), EH3(JK), TA
     2UP(JK)
      DIMENSION PRTAR(JI), GLAR(JI), DVT(JI,1)
      EQUIVALENCE (PRTAR,DVT(1,1))
      COMMON /TRBULNT/ S,KSTR,TLNGTH,TRFACT,DISINC,XT1,XT2,XT6,XT3,XT4,X
     1T5,PRTW,RE,UE,XNUE,J,RMI,EPS,JPOINT,IE,WW1,WW2,WW3,WW4,WW5,  NEDGE
     2,KODVIS,A,XBE,X,PR,KODPRT,PRT,PRTAR,GLAR,NUMB1,XK
      COMMON /UNIT/ VIS1C1,VIS1C2,VIS2C1,VIS2C2,PT1,TT1,WAVE,R,PHIO,DS,S
     1ST,RT1,P1,T1,R1,U1,AA1,TREF,VISREF,PESTAR,TESTAR,RESTAR,UESTAR,MUE
     2STAR,YESTAR,THETA,TAUD,QSD,HD,UPLUS,DISP,PE,Z,TW,QW,RVWALD,PROINC,
     3PRNTINC,ZS,RS
      GO TO (1,2), KSTR+1
    1 KSTR=1
      PRTW=PRT
      STR=S
      XLAMDA=STR*(TLNGTH-1.)/(SQRT((ALOG(50.))/.412))
    2 CONTINUE
C
C        CALCULATE STREAMWISE INTERMITANCY
C
      SNORM=.412*(((S-STR)/XLAMDA)**2)
      TRFACT=1.
      IF (SNORM.LT.20.) TRFACT=1.-EXP(-SNORM)
C
C        CALCULATE EDDY-VISCOSITY
C             2 LAYER MODEL
C
C
      IFC=0
      A2=RE*RE*UE*UE*(RMI**J)*XL3(1)*FZ3(1)/(SQRT(2.*X)*XNUE*EPS)
      A3=RE*RE*UE*UE*(RMI**J)/(A*A*EPS*EPS*EPS*XNUE*SQRT(2.*X))
      A4=RE*UE*XT2*DISINC/(EPS*EPS*XNUE*A)
      A5=SQRT(A2/(XL3(1)*XL3(1)*T3(1)**3))
      NDAMP=0
      DO 8 N=2,IE
      ERA=XT3*((Y(N)/YEDGE)-XT4)
      CALL ERF (ERA,ERB)
      YINTER=.5*(1.-ERB)
      IF (IYINT.EQ.1) YINTER=1.
      IF (IFC.EQ.1) GO TO 3
      YPLUS=Y(N)*SQRT(A2/(XL3(N)*XL3(N)*T3(N)**3))
      IF (KODAMP.EQ.2) YPLUS=Y(N)*A5
      DAMP=1.
      B2=-YPLUS/XT6
      IF (NDAMP.EQ.0) DAMP=1.-EXP(B2)
      IF (DAMP.GT.0.9999.AND.NDAMP.EQ.0) NDAMP=1
      VARA(N)=A3*(RATO3(N)**J)*ABS(FZ3(N))/(XL3(N)*T3(N)**3)
      VARB(N)=DAMP
      IF (KODVIS.EQ.1) GO TO 4
```

```
      XMIXL=XT1*A*Y(N)*DAMP*EPS
      EP1=1.+TRFACT*VARA(N)*XMIXL*XMIXL
      VARC(N)=EP1
    3 CONTINUE
C
C
C     OUTER EDDY VISCOSITY LAW
C
C
      EP2=1.+TRFACT*A4*YINTER/(XL3(N)*T3(N)*T3(N))
      VARD(N)=EP2
      IF (IFC.EQ.1) GO TO 6
      IF (EP1.LE.EP2.AND.IFC.EQ.0) GO TO 5
      IFC=1
      JPOINT=N
      GO TO 6
C
C     MIXING LENGTH MODEL
C
    4 CONTINUE
      YRAT=1.
      IF (Y(N).LE.YEDGE) YRAT=Y(N)/YEDGE
      XMIXL=XT5*TANH(XT1*YRAT/XT5)*EPS*A*YEDGE*DAMP
      EP3(N)=1.+TRFACT*YINTER*VARA(N)*XMIXL*XMIXL
      GO TO 7
    5 EP3(N)=EP1
      GO TO 7
    6 EP3(N)=EP2
    7 CONTINUE
      VARE(N)=XMIXL/YEDGE
    8 CONTINUE
C
C      CALCULATE TURBULENT PRANDTL NUMBER
C
      DO 12 N=2,IE
      GO TO (11,9,10), KODPRT
    9 PRT=PRTW-PRTW*.5*((Y(N)/YEDGE)**2)
      IF (Y(N).GE.YEDGE) PRT=PRTW*.5
      GO TO 11
   10 GL=Y(N)/YEDGE
      IF (GL.GT.1) GL=1.
      CALL IUNI (JI,NUMB1,GLAR,1,DVT,2,GL,PRT,IPT,IERR)
 11   EH3(N)=(PRT+(EP3(N)-1.)*PR)/(PR*PRT)
   12 CONTINUE
      DO 13 N=2,IE
      IF (EP3(N).LT.1.) EP3(N)=1.
   13 CONTINUE
      VARA(1)=VARA(2)
      VARB(1)=0.
      VARC(1)=1.
      VARD(1)=VARD(2)
      VARE(1)=0.
      RETURN
      END
```

APPENDIX C

Subroutine VARENT

Subroutine VARENT reads the variable-entropy input (coordinates for shock wave; see fig. 2), computes the derivatives dR_s/dz, and writes the input and derivatives. The flow chart for subroutine VARENT is as follows:



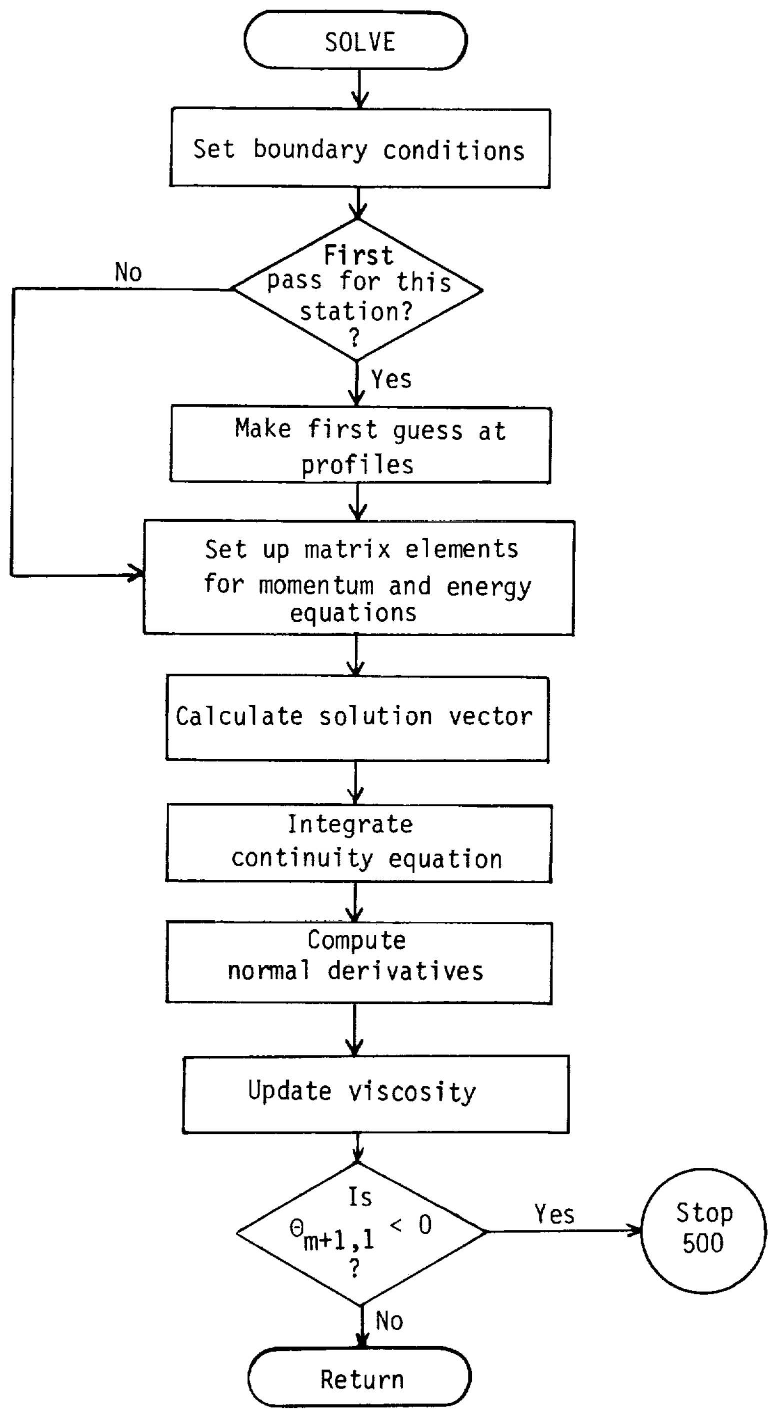
The program listing for subroutine VARENT is as follows:

```
      SUBROUTINE VARENT (RRS,ZZS,DRSDZS,NUMBER,KODUNIT,A)
      DIMENSION RRS(JL), ZZS(JL), DRSDZS(JL)
      NAMELIST /NAM3/ NUMBER,RRS,ZZS,DRSDZS
      READ (5,NAM3)
      NUMM1=NUMBER-1
      DO 1 I=2,NUMM1
    1 DRSDZS(I)=(RRS(I+1)-RRS(I-1))/(ZZS(I+1)-ZZS(I-1))
      DRSDZS(1)=(RRS(2)-RRS(1))/(ZZS(2)-ZZS(1))
      DRSDZS(NUMBER)=(RRS(NUMBER)-RRS(NUMBER-1))/(ZZS(NUMBER)-ZZS(NUMBER
     1-1))
      WRITE(6,3) NUMBER,RRS
      WRITE(6,4) ZZS
      WRITE(6,5) DRSDZS
      C5=1.
      IF (KODUNIT.EQ.1) C5=3.28083985
      C6=C5/A
      DO 2 I=1,NUMBER
      RRS(I)=RRS(I)*C6
      ZZS(I)=ZZS(I)*C6
    2 CONTINUE
    3 FORMAT(2X,5H$NAM3,//,2X,8HNUMBER =,I12,/,2X,3HRRS,/,(10E12.5))
    4 FORMAT(2X,3HZZS,/,(10E12.5))
    5 FORMAT(2X,6HDRSDZS,/,(10E12.5))
      RETURN
      END
```

APPENDIX C

Subroutine SOLVE

Subroutine SOLVE is the main subroutine of program VGBLP wherein the nonsimilar laminar, transitional, and/or turbulent boundary-layer equations are solved using a coupled algorithm for the energy and momentum equations. The continuity equation is solved using the trapezoidal rule. An iterative loop is provided to assure convergence of the system of equations to a preselected value. The flow chart for subroutine SOLVE is as follows:



The program listing for subroutine SOLVE is as follows:

```
      SUBROUTINE SOLVE (KODWAL,ARGM,TR,VIS2C2,XAL,XBE,X3,DX2,TW,IGAS,IE,
     1J,NIT,RVWALD,R1,U1,WW1,WW2,WW3,WW4,WW5,XNUE,XK,EPS,M,IBODY,FT)
      COMMON /SOLV1/ F1(JK),F2(JK),F3(JK),T1(JK),T2(JK),T3(JK),V1(JK),V2
     1(JK),V3(JK),EP2(JK),EP3(JK),FZ2(JK),FZ3(JK),TZ2(JK),TZ3(JK),XL2(JK
     2),XL3(JK),XLP2(JK),XLP3(JK),RATO1(JK),RATO2(JK),RATO3(JK),EH2(JK),
     3EH3(JK),DRATO1(JK),DRATO2(JK),DRATO3(JK),VARA(JK),VARB(JK),VARC(JK
     4),VARD(JK),VARE(JK),Y(JK),EP1(JK),EH1(JK),XL1(JK),XLP1(JK)
      COMMON /SOLV2/ Z1,Z2,Z3,Z4,Z5,TE,FAA,FAB,FAC,FAD,BEX1,BEX2,BEX3,BE
     1X4
      COMMON /MESH1/ XN(JK),DN(JK),Y1(JK),Y2(JK),Y3(JK),Y4(JK),Y5(JK),Y6
     1(JK)
      DIMENSION XK1(JK), XK2(JK), XK3(JK), XM1(JK), XM2(JK), XM3(JK)
C
C     THIS SUBROUTINE SOLVES THE COMPLETE B.L. EQUATIONS
C
C     SET UP THE BOUNDARY-CONDITIONS
      XK1(1)=XK2(1)=XK3(1)=XM2(1)=XM3(1)=0.
      IF (KODWAL.EQ.1) GO TO 1
      TZ3(1)=ARGM/XL3(1)
      GO TO 2
    1 CONTINUE
      XM1(1)=TW/TE
      T3(1)=XM1(1)
    2 CONTINUE
      F3(1)=0.
      IF (NIT.GT.1) GO TO 6
C
C      MAKE FIRST GUESS AT THE CURRENT STATION PROFILES
C
      DO 5 N=2,IE
      T3(N)=Z4*T2(N)-Z5*T1(N)
      F3(N)=Z4*F2(N)-Z5*F1(N)
      IF (T3(N).LT.0.) WRITE (6,18) T3(N),N,M
      IF (T3(N).LT.0.) T3(N)=.5*(T2(N)+T1(N))
      RATO3(N)=Z4*RATO2(N)-Z5*RATO1(N)
      IF (IGAS.EQ.2) GO TO 3
      XL3(N)=((1.+TR)*SQRT(T3(N))/(T3(N)+TR))
      XLP3(N)=XL3(N)*(TR-T3(N))/(2.*T3(N)*(T3(N)+TR))
      GO TO 4
    3 CONTINUE
      XL3(N)=T3(N)**(VIS2C2-1.)
      XLP3(N)=(VIS2C2-1.)*(T3(N)**(VIS2C2-2.))
    4 CONTINUE
      TZ3(N)=TZ2(N)
      FZ3(N)=FZ2(N)
      EP3(N)=EP2(N)
      V3(N)=Z4*V2(N)-Z5*V1(N)
      EH3(N)=EH2(N)
    5 CONTINUE
    6 CONTINUE
      IM=IE-1
```

```
C
C     SET UP MATRIX ELEMENTS
C
      DO 8 N=2,IM
C
C     MOMENTUM  EQUATION
C
      A11=X3*F3(N)/DX2*FT
      A12=V3(N)/(DN(N)+DN(N-1))
      CLEBP=.5*RATO3(N+1)**(2*J)*XL3(N+1)*EP3(N+1)+.5*RATO3(N)**(2*J)*XL
     13(N)*EP3(N)
      CLEBM=.5*RATO3(N-1)**(2*J)*XL3(N-1)*EP3(N-1)+.5*RATO3(N)**(2*J)*XL
     13(N)*EP3(N)
      A13=XBE
      A14=-XBE*F3(N)**2
      A1=-A12-Y3(N)*CLEBM
      B1=A11*Z1+Y1(N)*CLEBP+Y3(N)*CLEBM+2.*A13*F3(N)
      C1=A12-Y1(N)*CLEBP
      D1=0.
      E1=-A13
      H1=0.
      G1=A11*(Z2*F2(N)-Z3*F1(N))-A14
C
C     ENERGY EQUATION
C
      CLEHP=.5*RATO3(N+1)**(2*J)*XL3(N+1)*EH3(N+1)+.5*RATO3(N)**(2*J)*XL
     13(N)*EH3(N)
      CLEHM=.5*RATO3(N-1)**(2*J)*XL3(N-1)*EH3(N-1)+.5*RATO3(N)**(2*J)*XL
     13(N)*EH3(N)
      A15=XAL*XL3(N)*EP3(N)*RATO3(N)**(2*J)
      A16=-A15*FZ3(N)**2
      A17=FZ3(N)/(DN(N-1)+DN(N))
      A2=2.*A15*A17
      B2=0.
      C2=-A2
      D2=-A12-Y3(N)*CLEHM
      E2=A11*Z1+Y1(N)*CLEHP+Y3(N)*CLEHM
      H2=A12-Y1(N)*CLEHP
      G2=A11*(Z2*T2(N)-Z3*T1(N))+A16
      IF (KODWAL.EQ.1) GO TO 7
      IF (N.GT.2) GO TO 7
      DID=(C2*D1-C1*D2)-((C2*H1-C1*H2)*(((1.+XK)**2)-1.))
      XM1(1)=((C2*G1-C1*G2)+(C2*H1-C1*H2)*(XK*(1.+XK)*DN(1))*TZ3(1))/DID
      XM2(1)=-(C2*B1-C1*B2)/DID
      XM3(1)=-((C2*E1-C1*E2)+((C2*H1-C1*H2)*((1.+XK)**2)))/DID
    7 CONTINUE
C
C     SET UP MATRIX ARRAYS
C
      B1S=B1+A1*XK2(N-1)+D1*XM2(N-1)
      B2S=B2+A2*XK2(N-1)+D2*XM2(N-1)
      E1S=E1+A1*XK3(N-1)+D1*XM3(N-1)
      E2S=E2+A2*XK3(N-1)+D2*XM3(N-1)
      G1S=G1-A1*XK1(N-1)-D1*XM1(N-1)
```

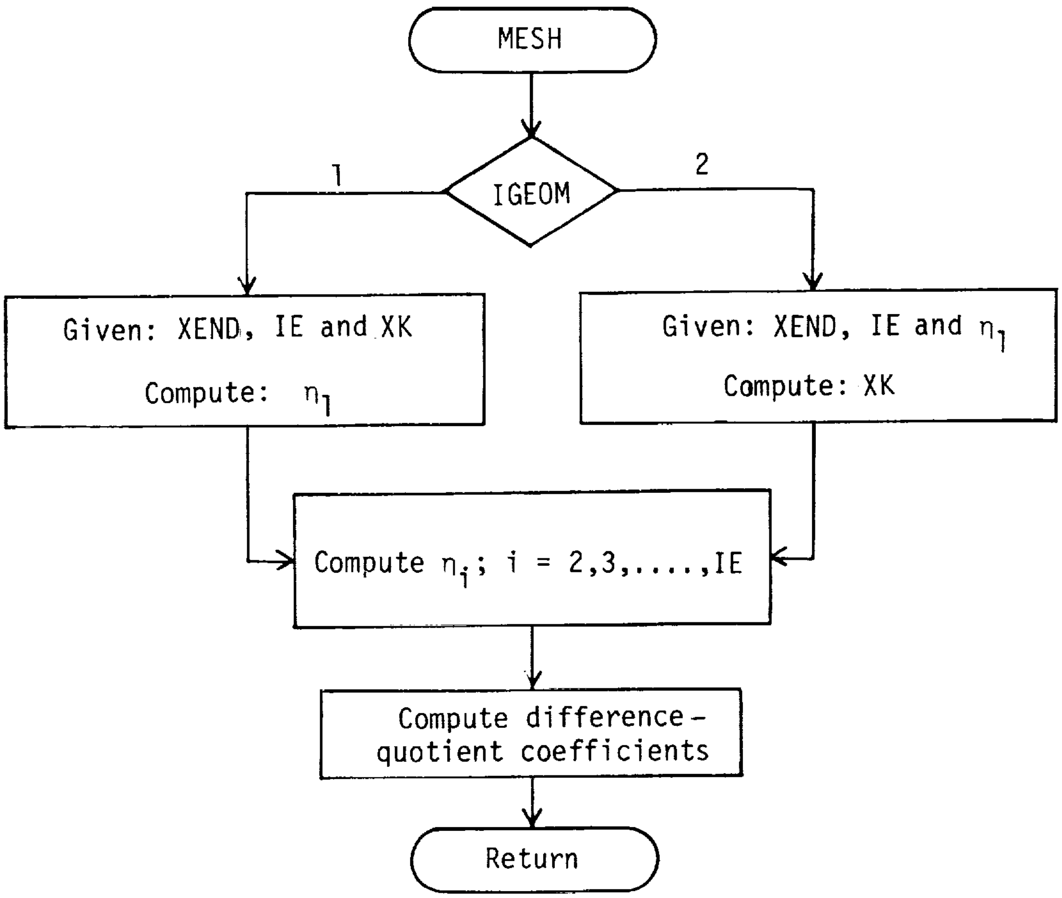
```
      G2S=G2-A2*XK1(N-1)-D2*XM1(N-1)
      D=1./(B1S*E2S-E1S*B2S)
      XK1(N)=D*(G1S*E2S-G2S*E1S)
      XK2(N)=D*(E1S*C2-C1*E2S)
      XK3(N)=D*(E1S*H2-H1*E2S)
      XM1(N)=D*(B1S*G2S-B2S*G1S)
      XM2(N)=D*(C1*B2S-B1S*C2)
      XM3(N)=D*(H1*B2S-B1S*H2)
    8 CONTINUE
      KON=IM
C
C     CALCULATE THE SOLUTION VECTOR
C
      DO 9 N=2,IM
      F3(KON)=XK1(KON)+XK2(KON)*F3(KON+1)+XK3(KON)*T3(KON+1)
      T3(KON)=XM1(KON)+XM2(KON)*F3(KON+1)+XM3(KON)*T3(KON+1)
      KON=KON-1
    9 CONTINUE
      IF (KODWAL.EQ.1) GO TO 10
      T3(1)=(XK*(1.+XK)*DN(1)*TZ3(1)-(1.+XK)**2*T3(2)+T3(3))/(1.-(1.+XK)
     1**2)
      TW=T3(1)*TE
   10 CONTINUE
C
C     INTEGRATE CONTINUITY EQUATION
C
      V3(1)=(RVWALD*FAA)/(R1*U1*EPS*XNUE)
      BO=0.
      A28=.5*X3/DX2*FT
      DO 11 N=2,IE
      B=A28*(Z1*F3(N)-Z2*F2(N)+Z3*F1(N))+F3(N)*.5
      V3(N)=V3(N-1)-(B+BO)*DN(N-1)
      BO=B
   11 CONTINUE
C
C     COMPUTE NORMAL DERIVATIVES
C
      DO 12 N=2,IM
      RDN=1./(DN(N-1)+DN(N))
      TZ3(N)=(T3(N+1)-T3(N-1))*RDN
      FZ3(N)=(F3(N+1)-F3(N-1))*RDN
   12 CONTINUE
      FZ3(IE)=0.
      TZ3(IE)=0.
      IF (KODWAL.EQ.1) TZ3(1)=(-WW1*T3(1)+WW2*T3(2)-WW3*T3(3)+WW4*T3(4))
     1/(WW5*DN(1))
      FZ3(1)=(-WW1*F3(1)+WW2*F3(2)-WW3*F3(3)+WW4*F3(4))/(WW5*DN(1))
C
C     UPDATE VISCOSITY
C
      KON=IE+2
      DO 17 N=1,KON
      IF (T3(N).LT.0.) GO TO 13
       GO TO 14
```

```
   13 WRITE(6,19) T3(N),N,M
      STOP 500
   14 CONTINUE
      IF (IGAS.EQ.2) GO TO 15
      XL3(N)=((1.+TR)*SQRT(T3(N))/(T3(N)+TR))
      XLP3(N)=XL3(N)*(TR-T3(N))/(2.*T3(N)*(T3(N)+TR))
      GO TO 16
   15 CONTINUE
      XL3(N)=T3(N)**(VIS2C2-1.)
      XLP3(N)=(VIS2C2-1.)*(T3(N)**(VIS2C2-2.))
   16 CONTINUE
      IF (IBODY.NE.1) GO TO 17
      IF (M.NE.2) GO TO 17
      T1(N)=T3(N)
      F1(N)=F3(N)
      RATO1(N)=RATO3(N)
      DRATO1(N)=DRATO3(N)
      XL1(N)=XL3(N)
      XLP1(N)=XLP3(N)
      V1(N)=V3(N)
   17 CONTINUE
      RETURN
C
C
C
   18 FORMAT (2X,12HNEGATIVE T3=,F15.7,2X,27H REPLACE WITH MEAN OF T1,T2
     1,2X,7HAT N = ,I5,2X,20H AND AT STATION M = ,I5)
   19 FORMAT(//,2X,125HSOLUTION HAS RESULTED IN GENERATION OF NEGATIVE T
     1EMPERATURE WHICH CANNOT BE PHYSICALLY ACCEPTED. THIS GENERALLY OCC
     2URS IN THE,/,2X,125HREGION OF ADVERSE PRESSURE GRADIENT AND/OR MAS
     3S INJECTION AT WALL BOUNDARY AND IS AN INDICATION OF BOUNDARY LAYE
     4R SEPARATION.,//,2X,118HIF DPEDS IS NEGATIVE AND THERE IS NO MASS
     5INJECTION AT THE WALL BOUNDARY, THE PROBLEM IS PROBABLY CAUSED BY
     6TOO COURSE,/,2X,32HA STEP SIZE IN THE S-COORDINATE.,//,2X,6HT3(N)=
     7,F15.7,2HN=,I5,2X,2HM=,I5)
      END
```

APPENDIX C

Subroutine MESH

Subroutine MESH generates the grid in the y-coordinate and obtains the difference quotient coefficients descriptive of the grid. The flow chart for subroutine MESH is as follows:



The program listing for subroutine MESH is as follows:

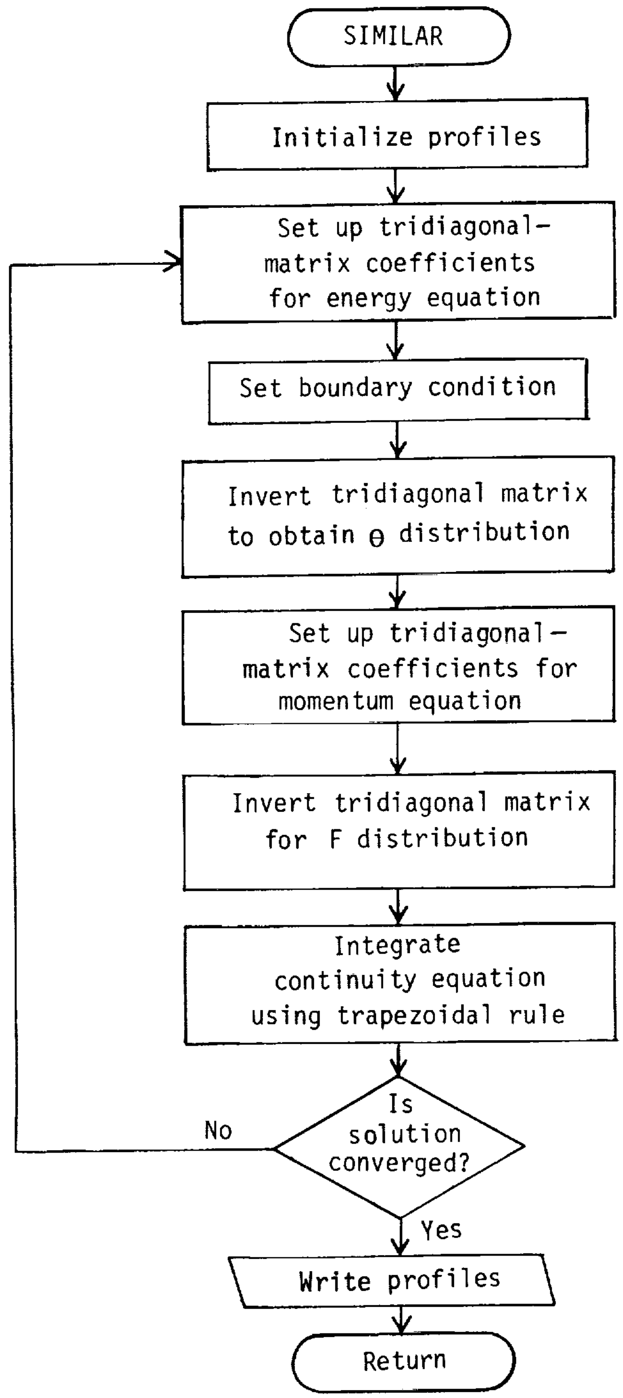
```
      SUBROUTINE MESH (K,ETAMAX,IE,IGEOM,DETA1)
      REAL K
      COMMON /MESH1/ XN(JK),DN(JK),Y1(JK),Y2(JK),Y3(JK),Y4(JK),Y5(JK),Y6
     1(JK)
      XN(1)=0.
      JKP1=JK
C
C     IGEOM=1 SPECIFY ETAMAX,IE,K ,=2 SPECIFY ETAMAX,IE,DETA(1)
C
      IF (K.EQ.1.) GO TO 5
      IF (IGEOM.EQ.2) GO TO 1
      GO TO 4
```

```
    1 CONTINUE
      XKO=1.0001
      DIF=1.
      RATIO=ETAMAX/DETA1
      NIT=0
    2 CONTINUE
      A11=1.+(XKO-1.)*RATIO
      A12=1./FLOAT(IE-1)
      XKN=A11**A12
      NIT=NIT+1
      DIF=ABS(1.-XKN/XKO)
      XKO=XKN
      IF (NIT.GT.20) DIF=0.
      IF (DIF.GT.0.0005) GO TO 2
      NIT2=0
      DIF2=1.0
    3 CONTINUE
      AN1=FLOAT(IE-1)
      AN2=AN1-1.
      FK=(XKO)**AN1-1.-(XKO-1.)*RATIO
      DFK=AN1*XKO**AN2-RATIO
      XKN=XKO-FK/DFK
      NIT2=NIT2+1
      DIF2=ABS(1.-XKN/XKO)
      XKO=XKN
      IF (NIT.GT.100) DIF2=0.
      IF (DIF2.GT.0.00000001) GO TO 3
      WRITE (6,9) NIT,NIT2,DIF,DIF2,XKN
      K=XKN
    4 CONTINUE
      DN(1)=((1-K)/(1-K**(IE-1)))*ETAMAX
      GO TO 6
    5 DN(1)=ETAMAX/(IE-1)
    6 XN(2)=DN(1)
      DN(2)=K*DN(1)
      DO 7 N=3,JKP1
      DN(N)=(K**(N-1))*DN(1)
    7 XN(N)=XN(N-1)+DN(N-1)
      DO 8 N=2,JKP1
      D1=DN(N-1)
      D2=DN(N)
      Y1(N)=2./(D2*(D1+D2))
      Y2(N)=2./(D1*D2)
      Y3(N)=2./(D1*(D1+D2))
      Y4(N)=D1/(D2*(D1+D2))
      Y5(N)=(D1-D2)/(D1*D2)
      Y6(N)=D2/(D1*(D1+D2))
    8 CONTINUE
      RETURN
C
C
C
9     FORMAT (2X,2I5,3E16.8)
      END
```

APPENDIX C

Subroutine SIMILAR

Subroutine SIMILAR generates the similar solutions for the boundary-layer equations at the initial station ($\xi = 0$). The flow chart for subroutine SIMILAR is as follows:



The program listing for subroutine SIMILAR is as follows:

```
      SUBROUTINE SIMILAR (IE,IGAS,XAL,XBE,PR,KODWAL,TW,DTDZW,XK,TR,VIS2C
     12,F3,F2,T3,T2,V3,V2,DFDZ,DTDZ,VIS,EP,ARGM,QW)
      DIMENSION F3(JK), F2(JK), T3(JK), T2(JK), V3(JK), V2(JK), DFDZ(JK)
     1, DTDZ(JK), VIS(JK), EP(JK), E(JK), F(JK)
      COMMON /MESH1/ XN(JK),DN(JK),Y1(JK),Y2(JK),Y3(JK),Y4(JK),Y5(JK),Y6
     1(JK)
C     THIS SUBROUTINE GENERATES THE SELF-SIMILAR SOLUTIONS TO THE
C     BOUNDARY-LAYER EQUATIONS
      NITMAX=30
      CONV=.0001
C     INITIALIZE THE PROFILES
      DO 1 N=1,JK
      F3(N)=F2(N)=T3(N)=T2(N)=VIS(N)=EP(N)=1.0
      DFDZ(N)=DTDZ(N)=0.0
      V3(N)=V2(N)=-XN(N)
    1 CONTINUE
      DFDZW=1.
      NIT=1
    2 CONTINUE
      IF (KODWAL.NE.1) DTDZW=QW*ARGM/VIS(1)
C
C     SET UP FOR ENERGY EQUATION
C
      E(IE)=0.
      F(IE)=1.0
      IM=IE-1
      N=IM
      DO 3 I=2,IM
      RDN=1./(DN(N-1)+DN(N))
      VISM1=.5*VIS(N-1)+.5*VIS(N)
      VISP1=.5*VIS(N+1)+.5*VIS(N)
      A=-V3(N)*RDN-VISM1/PR*Y3(N)
      B=VISP1/PR*Y1(N)+VISM1/PR*Y3(N)
      C=V3(N)*RDN-VISP1/PR*Y1(N)
      D=XAL*VIS(N)*DFDZ(N)**2
      E(N)=-A/(B+C*E(N+1))
      F(N)=(D-C*F(N+1))/(B+C*E(N+1))
      N=N-1
    3 CONTINUE
      T3(1)=TW
      IF (KODWAL.EQ.1) GO TO 4
C
C     HEAT TRANSFER BOUNDARY CONDITION
C
      ANMR=XK*(1.+XK)*DN(1)*DTDZW-(1.+XK)*(1.+XK)*F(2)+E(3)*F(2)+F(3)
      DNMR=1.-(1.+XK)*(1.+XK)+E(2)*(1.+XK)*(1.+XK)-E(3)*E(2)
      T3(1)=ANMR/DNMR
    4 CONTINUE
      DO 5 N=2,IE
      T2(N)=T3(N)
      T3(N)=E(N)*T3(N-1)+F(N)
```

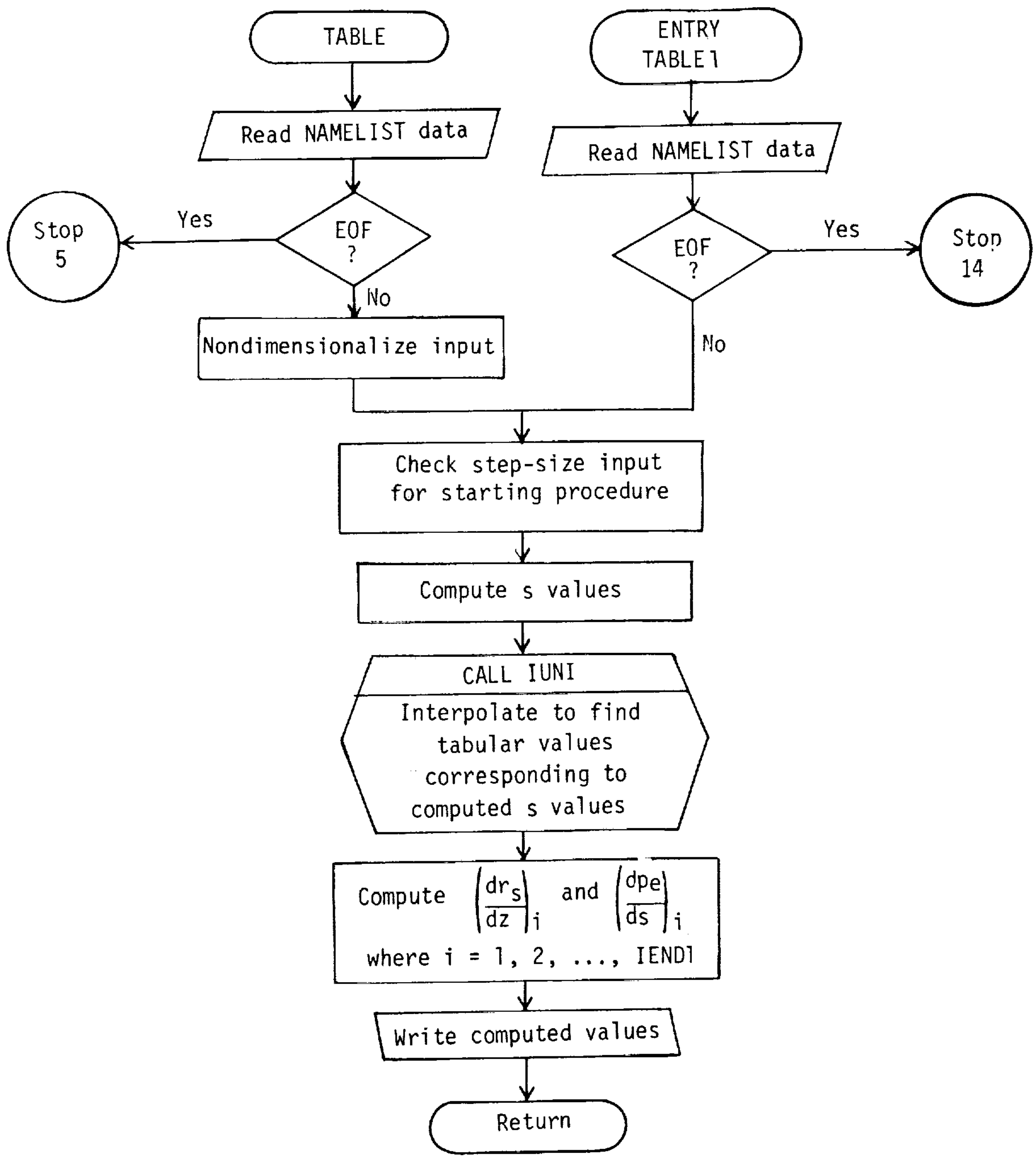
```
    5 CONTINUE
      DO 7 N=1,IE
      IF (T3(N).LT.0.) T3(N)=1.
      IF (IGAS.EQ.2) GO TO 6
      VIS(N)=((1.+TR)*SQRT(T3(N))/(T3(N)+TR))
      GO TO 7
    6 CONTINUE
      VIS(N)=T3(N)**(VIS2C2-1.)
    7 CONTINUE
C
C     SET UP FOR SOLVING MOMENTUM EQUATION
C
      E(IE)=0.
      F(IE)=1.
      IM=IE-1
      N=IM
      DO 8 I=2,IM
      RDN=1./(DN(N-1)+DN(N))
      VISM1=.5*VIS(N-1)+.5*VIS(N)
      VISP1=.5*VIS(N+1)+.5*VIS(N)
      A=-V3(N)*RDN-VISM1*Y3(N)
      B=VISP1*Y1(N)+VISM1*Y3(N)+2.*XBE*F3(N)
      C=V3(N)*RDN-VISP1*Y1(N)
      D=XBE*(F3(N)**2+T3(N))
      E(N)=-A/(B+C*E(N+1))
      F(N)=(D-C*F(N+1))/(B+C*E(N+1))
      N=N-1
    8 CONTINUE
      F3(1)=0.
      DO 9 N=2,IE
      F2(N)=F3(N)
      F3(N)=E(N)*F3(N-1)+F(N)
    9 CONTINUE
      IF (NIT.LT.5) GO TO 11
      DO 10 N=2,IE
      F3(N)=.5*(F3(N)+F2(N))
      T3(N)=.5*(T3(N)+T2(N))
   10 CONTINUE
   11 CONTINUE
      DO 12 N=2,IM
      RDN=1./(DN(N-1)+DN(N))
      DTDZ(N)=(T3(N+1)-T3(N-1))*RDN
      DFDZ(N)=(F3(N+1)-F3(N-1))*RDN
   12 CONTINUE
      XK1=XK+1.
      XK2=XK1**2
      DTDZ(1)=DTDZW
      IF (KODWAL.EQ.1) DTDZ(1)=((1.-XK2)*T3(1)+XK2*T3(2)-T3(3))/(XK*XK1*
     1DN(1))
      DFDZ(1)=((1.-XK2)*F3(1)+XK2*F3(2)-F3(3))/(XK*XK1*DN(1))
      DTDZ(IE)=0.
      DFDZ(IE)=0.
```

```
C
C     SOLVE THE CONTINUITY EQUATION
C
      V3(1)=0.
      DO 13 N=2,IE
      V3(N)=V3(N-1)-DN(N-1)*.5*(F3(N)+F3(N-1))
   13 CONTINUE
      DIF=ABS(1.-DFDZW/DFDZ(1))
      DFDZW=DFDZ(1)
      NIT=NIT+1
      IF (NIT.GT.NITMAX) WRITE (6,15) DIF,NIT
      IF (NIT.GT.NITMAX) DIF=0.
      IF (DIF.GT.CONV) GO TO 2
C     ASSIGN PROFILES AT THE PREVIOUS STATION
C     AND PRINT THE SIMILAR SOLUTION
      WRITE (6,18)
      WRITE (6,19)
      DO 14 N=1,IE
      WRITE (6,20) XN(N),F3(N),T3(N),V3(N),DFDZ(N),DTDZ(N),VIS(N)
      F2(N)=F3(N)
      T2(N)=T3(N)
      V2(N)=V3(N)
   14 CONTINUE
      WRITE (6,17) NIT
      WRITE (6,16)
      RETURN
C
C
C
   15 FORMAT (2X,27HTHE ERROR IN WALL SHEAR IS=,E15.7,5HAFTER,I5,12HITER
     1ATIONS= /)
   16 FORMAT (1H0,20X,26HINITIAL STATION PARAMETERS,/)
   17 FORMAT (9X,40HCONVERGED SELF-SIMILAR SOLUTION REQUIRED,I5,11HITERA
     1TIONS.,/)
   18 FORMAT (1H1,20X,46HSIMILAR SOLUTION REQUIRED TO INITIATE MARCHING,
     110H PROCEDURE,///,20X,14HPROFILE VALUES,/)
   19 FORMAT (15X,3HETA,11X,4HU/UE,10X,4HT/TE,10X,1HV,13X,2HFZ,12X,2HTZ,
     112X,2HXL,//)
   20 FORMAT (10X,7E14.6)
      END
```

APPENDIX C

Subroutine TABLE

Subroutine TABLE reads tabular input data for body geometry, pressure distribution, and wall-boundary conditions. These inputs are nondimensionalized and distributed to the solution stations designated in the SS array. The flow diagram for subroutine TABLE is as follows:



The program listing for subroutine TABLE is as follows:

```
      SUBROUTINE TABLE (IEND1,SD,R1,U1,A,TREF,KODWAL,VISREF,KODUNIT,AWT)
      DIMENSION PE(JJ), Z(JJ), RMI(JJ), TW(JJ), S(JJ), RVWALD(JJ), QW(JJ
     1), PD(JH), ZED(JH), RMIDD(JH), SS(JH)
      DIMENSION DVT1(JJ,3), ANS1(3)
      EQUIVALENCE (Z,DVT1(1,1)), (RMI,DVT1(1,2)), (PE,DVT1(1,3))
      NAMELIST /NAM2/ NUMBER,L,PE,Z,RMI,TW,RVWALD,QW,S,SS
      DATA C1/.0208854346/,C2/1.8/,C5/3.280839895/,C15/.0063658804/,C16/
     1.0000881/,SS(2)/0./,L/1/
      DO 1 I=1,JJ
      QW(I)=RVWALD(I)=0.0
      RMI(I)=1.
      TW(I)=AWT
    1 CONTINUE
      READ (5,NAM2)
      IF (EOF(5)) 2,3
    2 STOP 5
    3 CONTINUE
      WRITE(6,23) NUMBER,L,S
      WRITE(6,24) Z
      WRITE(6,25) RMI
      IF(KODWAL.EQ.1) WRITE(6,26) TW
      WRITE(6,27) QW
      WRITE(6,28) RVWALD
      WRITE(6,29) PE
      WRITE(6,30) SS
C
C
      IF (KODUNIT.NE.1) GO TO 7
C
C          CONVERT $NAM2  INPUT DATA TO U.S.STANDARD UNITS
C
      DO 4 I=1,IEND1
    4 SS(I)=SS(I)*C5
      DO 6 I=1,NUMBER
      S(I)=S(I)*C5
      Z(I)=Z(I)*C5
      RMI(I)=RMI(I)*C5
      PE(I)=PE(I)*C1
      RVWALD(I)=RVWALD(I)*C15
      IF (KODWAL.NE.1) GO TO 5
      TW(I)=TW(I)*C2
      GO TO 6
    5 QW(I)=QW(I)*C16
    6 CONTINUE
    7 DO 9 I=1,NUMBER
      PE(I)=PE(I)/(R1*U1*U1)
      S(I)=S(I)/A
      RMI(I)=RMI(I)/A
      IF (KODWAL.NE.1) GO TO 8
      TW(I)=TW(I)/TREF
      GO TO 9
```

```
  8 CONTINUE
  9 Z(I)=Z(I)/A
    DO 10 I=1,IEND1
 10 SS(I)=SS(I)/A
    GO TO 12
    ENTRY TABLE1
    READ (5,NAM2)
    IF (EOF(5)) 11,12
 11 STOP 14
 12 CONTINUE
    DS=SS(1)
    IF (SS(1).GT.DS+.000001.OR.SS(1).LT.DS-.000001) GO TO 13
    IF (SS(2).GT.DS+.000001.OR.SS(2).LT.DS-.000001) GO TO 13
    IF (SS(3).GT.DS+.000001.OR.SS(3).LT.DS-.000001) GO TO 13
    GO TO 14
 13 WRITE (6,22) SS(1),SS(2),SS(3),DS
    STOP 77
 14 CONTINUE
    TEMP=0.
    DO 15 I=1,IEND1
    SS(I)=TEMP+SS(I)
 15 TEMP=SS(I)
    WRITE(6,31) SS
    TEMP1=0.
    TEMP2=SS(1)
    DO 16 I=1,IEND1
    SS(I)=TEMP1
    TEMP1=TEMP2
    IF (I.LT.IEND1) TEMP2=SS(I+1)
    IPT=-1
    SD=DS*(I-1)
    IF (SS(2).NE.0.) SD=SS(I)
    CALL IUNI (JJ,NUMBER,S,3,DVT1,L,SD,ANS1,IPT,IERR)
    ZED(I)=ANS1(1)
    RMIDD(I)=ANS1(2)
    PD(I)=ANS1(3)
 16 CONTINUE
    SD=TEMP1
    IENDP1=IEND1+1
    IPT=-1
    CALL IUNI(JJ,NUMBER,S,3,DVT1,L,SD,ANS1,IPT,IERR)
    ZED(IENDP1)=ANS1(1)
    RMIDD(IENDP1)=ANS1(2)
    PD(IENDP1)=ANS1(3)
    SS(IENDP1)=TEMP1
    WRITE (4) TW(1),RVWALD(1),QW(1),PE(1),DS
    TWODS=2.*DS
    DO 21 I=2,IENDP1
    IPT=-1
    SD=DS*(I-1)
    IF (SS(2).NE.0.) SD=SS(I)
    IF (KODWAL.EQ.1) GO TO 17
    CALL IUNI (JJ,NUMBER,S,1,QW,L,SD,QWD,IPT,IERR)
    GO TO 18
```

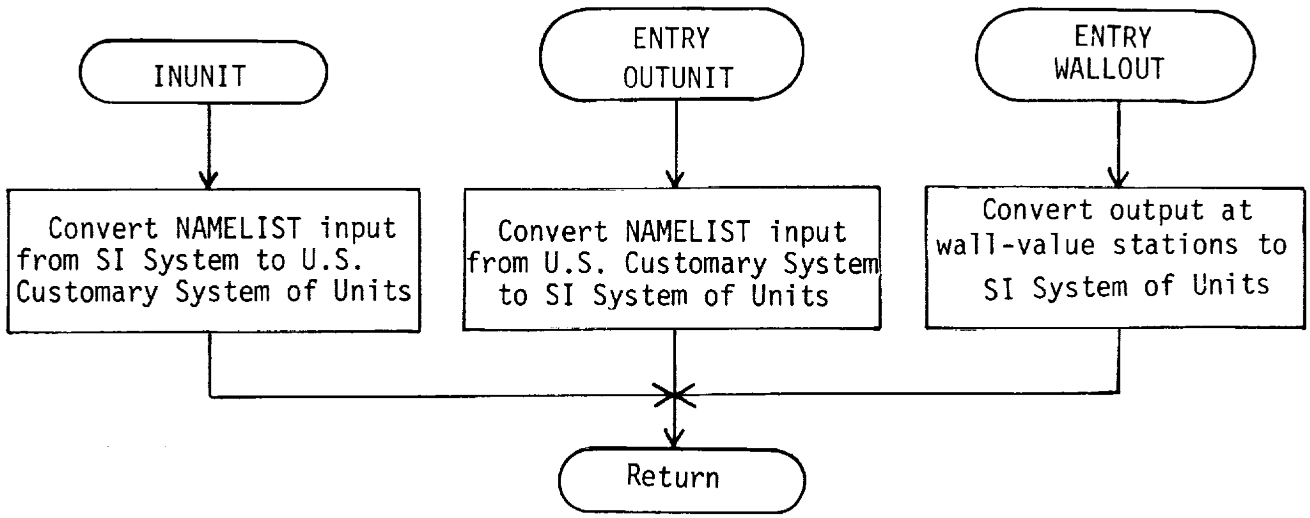

C-2.

```
   17 CONTINUE
      CALL IUNI (JJ,NUMBER,S,1,TW,L,SD,TWD,IPT,IERR)
   18 CONTINUE
      CALL IUNI (JJ,NUMBER,S,1,RVWALD,L,SD,RVWALDD,IPT,IERR)
      IF (I.EQ.IENDP1) GO TO 19
      DRDZ=(RMIDD(I+1)-RMIDD(I-1))/(ZED(I+1)-ZED(I-1))
      IF (SS(2).NE.0.) TWODS=SS(I+1)-SS(I-1)
      DPEDSD=(PD(I+1)-PD(I-1))/TWODS
      GO TO 20
   19 IF (SS(2).NE.0.) DDS=SS(I)-SS(I-1)
      DPEDSD=(PD(I)-PD(I-1))/DDS
      DRDZ=(RMIDD(I)-RMIDD(I-1))/(ZED(I)-ZED(I-1))
   20 WRITE (4) SD,PD(I),RMIDD(I),TWD,ZED(I),DPEDSD,RVWALDD,DRDZ,QWD
   21 CONTINUE
      REWIND 4
      RETURN
C
C
C
   22 FORMAT (1X,7HSS(1) =,F9.4,/1X,7HSS(2) =,F9.4,/1X,7HSS(3) =,F9.4,/1
     1X,7HDS    =,F9.4,/1X,53HTHESE VALUES MUST BE EQUAL FOR THE STARTIN
     2G PROCEDURE)
   23 FORMAT(/,2X,5H$NAM2,//,2X,8HNUMBER =,I12,/,2X,8HL       =,I12,/,2X,
     11HS,/,(10E12.5))
   24 FORMAT(2X,1HZ,/,(10E12.5))
   25 FORMAT(2X,3HRMI,/,(10E12.5))
   26 FORMAT(2X,2HTW,/,(10E12.5))
   27 FORMAT(2X,2HQW,/,(10E12.5))
   28 FORMAT(2X,6HRVWALD,/,(10E12.5))
   29 FORMAT(2X,2HPE,/,(10E12.5))
   30 FORMAT(2X,2HSS,/,(10E12.5))
   31 FORMAT(//,2X,117HTHE FOLLOWING SPOINT VALUES DESIGNATE THE S-COORD
     1INATE LOCATIONS WHERE THE SOLUTIONS ARE OBTAINED DURING THE S-MARC
     2H.,/,2X,116HYOUR PRINT STATION MUST AGREE WITH ONE OR MORE OF THE
     3SPOINT LOCATIONS; IE, YOU CAN PRINT ONLY AT SOLUTION STATIONS.,/,2
     4X,113HIF THE CASE COMPLETES WITH A NORMAL STOP AND NO OUTPUT IS PR
     5INTED, YOUR PRINT INPUT IS IN ERROR. THE ERROR CAN BE,/,2X,50HNOTE
     6D BY COMPARING PROVAL AND PRNTVAL WITH SPOINT.,///,2X,6HSPOINT,/,(
     710E12.5))
      END
```

APPENDIX C

Subroutine INUNIT

Subroutine INUNIT converts the International System (SI) of dimensional input data to the U.S. Customary System of Units for calculations in the program. The subroutine then converts the output data back to the SI System of Units before output. The flow diagram for subroutine INUNIT is as follows:



The program listing for subroutine INUNIT is as follows:

```
      SUBROUTINE INUNIT (PROVAL,PRNTVAL,JM,JN)
      COMMON /TRBULNT/ S,KSTR,TLNGTH,TRFACT,DISINC,XT1,XT2,XT6,XT3,XT4,X
     1T5,PRTW,RE,UE,XNUE,J,RMI,EPS,JPOINT,IE,WW1,WW2,WW3,WW4,WW5,   NEDGE
     2,KODVIS,A,XBE,X,PR,KODPRT,PRT,PRTAR,GLAR,NUMB1,XK
      COMMON /UNIT/ VIS1C1,VIS1C2,VIS2C1,VIS2C2,PT1,TT1,WAVE,R,PHIO,DS,S
     1ST,RT1,P1,T1,R1,U1,AA1,TREF,VISREF,PESTAR,TESTAR,RESTAR,UESTAR,MUE
     2STAR,YESTAR,THETA,TAUD,QSD,HD,UPLUS,DISP,PE,Z,TW,QW,RVWALD,PROINC,
     3PRNTINC,ZS,RS
      DIMENSION PROVAL(JN), PRNTVAL(JM)
      REAL MUESTAR
      DATA RT1,P1,T1,R1,U1,AA1,TREF,VISREF/8*1.0/,UPLUS/0.0/
      DATA TAUD,S,RMI,Z,ZS,RS,YESTAR,DISP,THETA,QSD,HD/11*0./
      DATA CC1/.0208854346/,CC2/1.8/,CC4/5.97995/,CC5/3.280839895/,CC6/.
     10019403196/,CC7/47.880258/,CC8/.55555555/,CC10/.167225478/,CC11/.3
     22048/,CC12/515.379/,CC13/11348.93/,CC14/20428.0758/
C
C
C          CONVERT $NAM1 VALUES TO U.S. STANDARD UNITS
C
      PROINC=PROINC*CC5
      PRNTINC=PRNTINC*CC5
      DO 1 I=1,JN
    1 PROVAL(I)=PROVAL(I)*CC5
      DO 2 I=1,JM
```

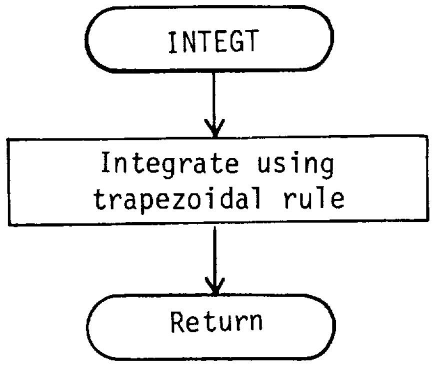
```
    2 PRNTVAL(I)=PRNTVAL(I)*CC5
      A=A*CC5
      U1=U1*CC5
      AA1=AA1*CC5
      SST=SST*CC5
      PT1=PT1*CC1
      P1=P1*CC1
      VISREF=VISREF*CC1
      TREF=TREF*CC2
      T1=T1*CC2
      TT1=TT1*CC2
      R=R*CC4
      RT1=RT1*CC6
      R1=R1*CC6
      GO TO 5
C
C          CONVERT $NAM1 VALUES TO INTERNATIONAL STANDARD UNITS
C
      ENTRY OUTUNIT
      PROINC=PROINC*CC11
      PRNTINC=PRNTINC*CC11
      DO 3 I=1,JN
    3 PROVAL(I)=PROVAL(I)*CC11
      DO 4 I=1,JM
    4 PRNTVAL(I)=PRNTVAL(I)*CC11
      A=A*CC11
      SST=SST*CC11
      U1=U1*CC11
      AA1=AA1*CC11
      PT1=PT1*CC7
      P1=P1*CC7
      VISREF=VISREF*CC7
      TREF=TREF*CC8
      T1=T1*CC8
      TT1=TT1*CC8
      R=R*CC10
      RT1=RT1*CC12
      R1=R1*CC12
      GO TO 5
C
C          CONVERT WALL VALUES TO  INTERNATIONAL STANDARD UNITS
C
      ENTRY WALLOUT
      PESTAR=PESTAR*CC7
      MUESTAR=MUESTAR*CC7
      TAUD=TAUD*CC7
      TESTAR=TESTAR*CC8
      S=S*CC11
      RMI=RMI*CC11
      Z=Z*CC11
      ZS=ZS*CC11
      RS=RS*CC11
```

```
      UPLUS=UPLUS*CC11
      DISP=DISP*CC11
      UESTAR=UESTAR*CC11
      YESTAR=YESTAR*CC11
      THETA=THETA*CC11
      RESTAR=RESTAR*CC12
      QSD=QSD*CC13
      HD=HD*CC14
    5 RETURN
      END
```

APPENDIX C

Function INTEGT

Function subroutine INTEGT integrates the continuity equation by the trapezoidal rule. The flow diagram for function INTEGT is as follows:



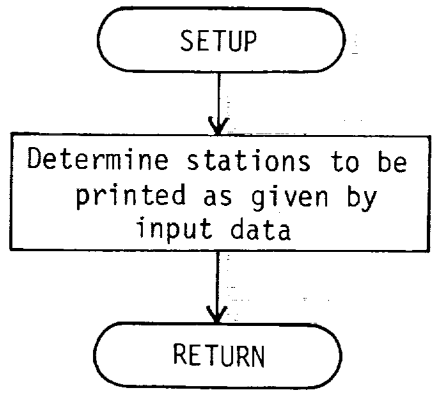
The program listing for function subroutine INTEGT is as follows:

```
      REAL FUNCTIONINTEGT(YY,NOPTS,DX)
      DIMENSION YY(NOPTS), DX(NOPTS)
      INTEGT=0.
      IF (NOPTS.LT.2) GO TO 2
      DO 1 N=2,NOPTS
    1 INTEGT=INTEGT+(DX(N-1)/2.)*(YY(N-1)+YY(N))
    2 RETURN
      END
```

APPENDIX C

Subroutine SETUP

Subroutine SETUP determines from input where profiles and wall values are to be printed. The flow diagram for subroutine SETUP is as follows:



The program listing for subroutine SETUP is as follows:

```
      SUBROUTINE SETUP (A,B,C,J,K)
      DIMENSION B(J)
      IF (A.EQ.0) RETURN
      KPLUS2=K+2
      B(K+1)=A
      IF(KPLUS2.GT.J) RETURN
      DO 1 I=KPLUS2,J
      B(I)=B(I-1)+A
      IF (B(I).GE.C) RETURN
    1 CONTINUE
      RETURN
      END
```

APPENDIX D

RESULTS FROM TEST CASES - INPUT/OUTPUT

The input and selected output from each of the test cases is presented in the following order: (1) VARDIM data; (2) input data for $NAM1, $NAM2, and $NAM3 (note that $NAM3 data are required only for test case number 4); (3) initial profile ($\xi = 0$); (4) free-stream and reference values; (5) selected wall-print locations; (6) selected profile-print locations. It should be noted that (5) and (6) are selected locations and not all the print locations obtained for the input data. The selected print values allow users to verify that the software has been correctly implemented on their computer system.

```
                               TEST CASE NO. 1

    THE LISTING FOR TEST CASE NO. 1 INCLUDES THE FOLLOWING:  (1) VARDIM DATA;  (2) $NAM1 AND $NAM2 INPUT;
          (3) INITIAL STATION SOLUTION;  (4)  REFEFENCE VALUES;  (5)  PROFILE AND WALL PRINTS AT S=1.0 M.

*VARDIM/VGBLP(JK=103,JL=1,JM= 11,JN= 2,JI=1,JH=217)
*VARDIM/TABLE(JJ=2,JH=217)
*VARDIM/VARENT(JL=1)
*VARDIM/TURBLNT(JI=1,JK=103)
*VARDIM/MESH(JK=103)
*VARDIM/SIMILAR(JK=103)
*VARDIM/SOLVE(JK=103)

 $NAM1

IGEOM  =          1  XEND   =  .12000E+03  IE     =         101  XK     =  .12754E+01  DETA1  =           I  XMA    =  .28000E+01
PT1    = .41400E+07  TT1    =  .31100E+03  IGAS   =           1  VIS1C1 =  .14582E-05  VIS1C2 =  .11033E+03  VIS2C1 =           I
VIS2C2 =          I  G      =  .14000E+01  R      =  .28696E+03  PR     =  .72000E+00

IBODY  =          2  WAVE   = 0.           PHII   = 0.           J      =           0  W      =           0  IENTRO =           1

SST    = .10000E+09  SMXTR  =  .24000E+04  KODVIS =           2  KTCOD  =           2  TLNGTH =  .20000E+01  IYINT  =           2
KODAMP =          2  XT1    =  .40000E+00  XT2    =  .16800E-01  XT3    =  .50000E+01  XT4    =  .78000E+00  XT5    =  .10800E+00
XT6    = .26000E+02  PRT    =  .95000E+00  KODPRT =           1  NUMB1  =           0  GLAR   =           I
PRTAR
      I

IEND1  =        216  PROINC =  .10000E+01  PRNTINC=  .10000E+00  IPRO   =           1  IPRNT  =           1  NAUXPRO=           0
FT     = .10000E+01  KODE   =           0  KODWAL =           2  VELEDG =  .99500E+00  CONV   =  .10000E-03  NITMAX =           5
KODUNIT=          1  ITMAX  =           3  CONVE  =  .10000E-01

THIS COMPLETES THE OUTPUT OF $NAM1 WITH THE EXCEPTION OF PROVAL AND PRNTVAL. THESE VALUES ARE PRINTED JUST PRIOR TO THE
INITIAL STATION PRINT.

$NAM2

NUMBER =          2
L      =          1
```

```
 S
0.           .10000E+01
 Z
0.           .10000E+01
 RMI
 .10000E+01  .10000E+01
 QW
0.          0.
 RVWALD
0.          0.
 PE
 .15255E+06  .15255E+06
 SS
 .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02
 .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02       I
```

```
THE FOLLOWING SPOINT VALUES DESIGNATE THE S-COORDINATE LOCATIONS WHERE THE SOLUTIONS ARE OBTAINED DURING THE S-MARCH.
YOUR PRINT STATION MUST AGREE WITH ONE OR MORE OF THE SPOINT LOCATIONS; IE, YOU CAN PRINT ONLY AT SOLUTION STATIONS.
IF THE CASE COMPLETES WITH A NORMAL STOP AND NO OUTPUT IS PRINTED, YOUR PRINT INPUT IS IN ERROR. THE ERROR CAN BE
NOTED BY COMPARING PROVAL AND PRNTVAL WITH SPOINT.

SPOINT
.10000E-02  .20000E-02  .30000E-02  .40000E-02  .50000E-02  .60000E-02  .70000E-02  .80000E-02  .90000E-02  .10000E-01
.11000E-01  .12000E-01  .13000E-01  .14000E-01  .15000E-01  .16000E-01  .17000E-01  .18000E-01  .19000E-01  .20000E-01
.25000E-01  .30000E-01  .35000E-01  .40000E-01  .45000E-01  .50000E-01  .55000E-01  .60000E-01  .65000E-01  .70000E-01
.75000E-01  .80000E-01  .85000E-01  .90000E-01  .95000E-01  .10000E+00  .10500E+00  .11000E+00  .11500E+00  .12000E+00
.12500E+00  .13000E+00  .13500E+00  .14000E+00  .14500E+00  .15000E+00  .15500E+00  .16000E+00  .16500E+00  .17000E+00
.17500E+00  .18000E+00  .18500E+00  .19000E+00  .19500E+00  .20000E+00  .20500E+00  .21000E+00  .21500E+00  .22000E+00
.22500E+00  .23000E+00  .23500E+00  .24000E+00  .24500E+00  .25000E+00  .25500E+00  .26000E+00  .26500E+00  .27000E+00
.27500E+00  .28000E+00  .28500E+00  .29000E+00  .29500E+00  .30000E+00  .30500E+00  .31000E+00  .31500E+00  .32000E+00
.32500E+00  .33000E+00  .33500E+00  .34000E+00  .34500E+00  .35000E+00  .35500E+00  .36000E+00  .36500E+00  .37000E+00
.37500E+00  .38000E+00  .38500E+00  .39000E+00  .39500E+00  .40000E+00  .40500E+00  .41000E+00  .41500E+00  .42000E+00
.42500E+00  .43000E+00  .43500E+00  .44000E+00  .44500E+00  .45000E+00  .45500E+00  .46000E+00  .46500E+00  .47000E+00
.47500E+00  .48000E+00  .48500E+00  .49000E+00  .49500E+00  .50000E+00  .50500E+00  .51000E+00  .51500E+00  .52000E+00
.52500E+00  .53000E+00  .53500E+00  .54000E+00  .54500E+00  .55000E+00  .55500E+00  .56000E+00  .56500E+00  .57000E+00
.57500E+00  .58000E+00  .58500E+00  .59000E+00  .59500E+00  .60000E+00  .60500E+00  .61000E+00  .61500E+00  .62000E+00
.62500E+00  .63000E+00  .63500E+00  .64000E+00  .64500E+00  .65000E+00  .65500E+00  .66000E+00  .66500E+00  .67000E+00
.67500E+00  .68000E+00  .68500E+00  .69000E+00  .69500E+00  .70000E+00  .70500E+00  .71000E+00  .71500E+00  .72000E+00
.72500E+00  .73000E+00  .73500E+00  .74000E+00  .74500E+00  .75000E+00  .75500E+00  .76000E+00  .76500E+00  .77000E+00
.77500E+00  .78000E+00  .78500E+00  .79000E+00  .79500E+00  .80000E+00  .80500E+00  .81000E+00  .81500E+00  .82000E+00
.82500E+00  .83000E+00  .83500E+00  .84000E+00  .84500E+00  .85000E+00  .85500E+00  .86000E+00  .86500E+00  .87000E+00
.87500E+00  .88000E+00  .88500E+00  .89000E+00  .89500E+00  .90000E+00  .90500E+00  .91000E+00  .91500E+00  .92000E+00
.92500E+00  .93000E+00  .93500E+00  .94000E+00  .94500E+00  .95000E+00  .95500E+00  .96000E+00  .96500E+00  .97000E+00
.97500E+00  .98000E+00  .98500E+00  .99000E+00  .99500E+00  .10000E+01        I

PRINT STATIONS DESIGNATED IN $NAM1 INPUT AND GENERATED IN SETUP

PROVAL
.70000E-02  .10000E+01
PRNTVAL
.70000E-02  .10000E+00  .20000E+00  .30000E+00  .40000E+00  .50000E+00  .60000E+00  .70000E+00  .80000E+00  .90000E+00
.10000E+01
```

SIMILAR SOLUTION REQUIRED TO INITIATE MARCHING PROCEDURE

PROFILE VALUES

ETA	U/UE	T/TE	V	FZ	TZ	XL
0.	0.	.232179E+01	0.	.502786E+00	0.	.900739E+00
.900542E-09	.452780E-09	.232203E+01	-.203874E-18	.502786E+00	.115652E+06	.900739E+00
.204909E-08	.103026E-08	.232203E+01	-.105554E-17	.502786E+00	-.163130E-04	.900739E+00
.351396E-08	.176677E-08	.232203E+01	-.310417E-17	.502786E+00	-.426349E-05	.900739E+00
.538224E-08	.270612E-08	.232203E+01	-.728248E-17	.502786E+00	.668574E-05	.900739E+00
.776505E-08	.390416E-08	.232203E+01	-.151580E-16	.502786E+00	.131052E-04	.900739E+00
.108041E-07	.543214E-08	.232203E+01	-.293447E-16	.502786E+00	.143855E-04	.900739E+00
.146801E-07	.738094E-08	.232203E+01	-.541764E-16	.502786E+00	.193358E-04	.900739E+00
.196235E-07	.986643E-08	.232203E+01	-.968070E-16	.502786E+00	.240042E-04	.900739E+00
.259284E-07	.130364E-07	.232203E+01	-.169007E-15	.502786E+00	.237738E-04	.900739E+00
.339696E-07	.170794E-07	.232203E+01	-.290091E-15	.502786E+00	.256304E-04	.900739E+00
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.134389E+02	.999814E+00	.999709E+00	-.122815E+02	-.315453E-05	-.713927E-05	.100001E+01
.171400E+02	.100001E+01	.100002E+01	-.159823E+02	.137030E-05	.299940E-05	.999999E+00
.218603E+02	.999825E+00	.999734E+00	-.207022E+02	-.618434E-06	-.132710E-05	.100001E+01
.278806E+02	.100000E+01	.100001E+01	-.267220E+02	.285730E-06	.605893E-06	.100000E+01
.355590E+02	.999829E+00	.999743E+00	-.343997E+02	-.133960E-06	-.282025E-06	.100001E+01
.453519E+02	.100000E+01	.100000E+01	-.441918E+02	.633907E-07	.132873E-06	.100000E+01
.578418E+02	.999831E+00	.999746E+00	-.566807E+02	-.301764E-07	-.630844E-07	.100001E+01
.737715E+02	.100000E+01	.100000E+01	-.726090E+02	.144213E-07	.300990E-07	.100000E+01
.940881E+02	.999831E+00	.999747E+00	-.929239E+02	-.690972E-08	-.144071E-07	.100001E+01
.120000E+03	.100000E+01	.100000E+01	-.118834E+03	0.	0.	.100000E+01

CONVERGED SELF-SIMILAR SOLUTION REQUIRED 16ITERATIONS.

INITIAL STATION PARAMETERS

MUE = .839745E-05 UE = .617610E+03 TE = .121106E+03 PE = .152552E+06 QSD =0.
XAL = .313600E+01 XBE =0. RE = .438968E+01

****DIMENSIONAL OUTPUT QUANTITIES ARE IN S.I. UNITS****

FREE STREAM VALUES-DIMENSIONAL
PT1 = .414000E+07 TT1 = .311000E+03 RT1 = .463896E+02 P1 = .152552E+06 T1= .121106E+03 R1 = .438968E+01
U1 = .617610E+03 AA1 = .220575E+03 XMA = .280000E+01 REY = .322849E+09

REFERENCE VALUES-DIMENSIONAL
PREF= .167441E+07 TREF= .379788E+03 RREF= .438968E+01 UREF= .617610E+03 VISREF= .220214E-04 PTR = .247251E+01

S= 1.0000 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	YPLUS	UPLUS	UDEF	VISEFF
0.	0.	0.	.244E+01	.952E+00	.147E-12	.368E-01	0.	0.	0.	0.	.100E+01
.901E-09	.225E-10	.122E-07	.244E+01	.952E+00	.221E-12	.368E-01	.779E-08	.396E-06	.358E-06	.294E+02	.100E+01
.205E-08	.515E-10	.277E-07	.244E+01	.952E+00	.221E-12	.368E-01	.177E-07	.907E-06	.814E-06	.294E+02	.100E+01
.351E-08	.889E-10	.475E-07	.244E+01	.952E+00	.368E-12	.368E-01	.304E-07	.157E-05	.140E-05	.294E+02	.100E+01
.538E-08	.136E-09	.728E-07	.244E+01	.952E+00	.441E-12	.368E-01	.466E-07	.239E-05	.214E-05	.294E+02	.100E+01
.777E-08	.197E-09	.105E-06	.244E+01	.952E+00	.882E-12	.368E-01	.672E-07	.346E-05	.309E-05	.294E+02	.100E+01
.108E-07	.273E-09	.146E-06	.244E+01	.952E+00	.147E-11	.368E-01	.934E-07	.481E-05	.429E-05	.294E+02	.100E+01
.147E-07	.372E-09	.198E-06	.244E+01	.952E+00	.250E-11	.368E-01	.127E-06	.654E-05	.583E-05	.294E+02	.100E+01
.196E-07	.497E-09	.265E-06	.244E+01	.952E+00	.412E-11	.368E-01	.170E-06	.875E-05	.780E-05	.294E+02	.100E+01
.259E-07	.656E-09	.351E-06	.244E+01	.952E+00	.640E-11	.368E-01	.224E-06	.116E-04	.103E-04	.294E+02	.100E+01
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
.134E+02	.230E+00	.817E+00	.151E+01	.994E+00	.880E+00	.183E+00	.665E+00	.896E+04	.240E+02	.539E+01	.239E+04
.171E+02	.287E+00	.834E+00	.147E+01	.995E+00	.902E+00	.195E+00	.689E+00	.118E+05	.245E+02	.488E+01	.252E+04
.219E+02	.357E+00	.854E+00	.142E+01	.996E+00	.927E+00	.209E+00	.717E+00	.156E+05	.251E+02	.430E+01	.268E+04
.279E+02	.444E+00	.876E+00	.136E+01	.998E+00	.955E+00	.228E+00	.751E+00	.208E+05	.257E+02	.365E+01	.287E+04
.356E+02	.550E+00	.900E+00	.130E+01	.999E+00	.983E+00	.250E+00	.790E+00	.281E+05	.264E+02	.295E+01	.301E+04
.454E+02	.678E+00	.926E+00	.123E+01	.100E+01	.101E+01	.278E+00	.836E+00	.384E+05	.272E+02	.218E+01	.271E+04
.578E+02	.830E+00	.958E+00	.113E+01	.100E+01	.103E+01	.319E+00	.900E+00	.545E+05	.281E+02	.124E+01	.149E+04
.738E+02	.101E+01	.997E+00	.101E+01	.100E+01	.101E+01	.383E+00	.991E+00	.821E+05	.293E+02	.984E-01	.277E+03
.941E+02	.122E+01	.100E+01	.999E+00	.100E+01	.995E+00	.390E+00	.100E+01	.102E+06	.294E+02	.287E-03	.598E+01
.120E+03	.149E+01	.100E+01	.100E+01	.100E+01	.100E+01	.389E+00	.100E+01	.124E+06	.294E+02	.926E-08	.100E+01

S =	.10000E+01	RETHET=	.17548E+06	DPEDS =	0.	CFW =	.23161E-02	ZSHK =	0.	YE =	.75919E-02
XI =	.38133E+00	RFS =	.32285E+09	DTEDS =	0.	OSD =	0.	RSHK =	0.	UTAU =	.10372E-01
RMI =	.10000E+01	PE =	.15255E+06	DUEDS =	0.	HD =	0.	ITRO =	0	TRFCT =	.10000E+01
Z =	.10000E+01	TE =	.12111E+03	DLTAST=	.25105E-02	NSTE =	0.	TW/TT1=	.95169E+00	YMP =	92
BETA =	0.	RE =	.43897E+01	THETA =	.54354E-03	NSTW =	0.	RFTRUE=	.92088E+00	P2O =	.24725E+01
XAL =	.31360E+01	UE =	.61761E+03	FORM =	.46189E+01	NUE =	0.	ROUSE =	.28124E+06	OMEGA =	.90126E-04
RVWALD=	0.	ME =	.28000E+01	TAUD =	.79342E+03	NUW =	0.	DSMXO =	-.11551E+03		
REDELT=	.81052E+06	MUF =	.83975E-05	CFE =	.94770E-03	SWANG =	I	VW =	0.	RVWAL =	0.
NOITER=	4	ERROR =	.47339E-04								

```
                         TEST CASE NO. 2

  THE LISTING FOR TEST CASE NO. 2 INCLUDES THE FOLLOWING:  (1) VARDIM DATA;  (2) $NAM1 AND $NAM2 INPUT;
       (3) INITIAL STATION SOLUTION;  (4)  REFEFENCE VALUES;  (5)  PROFILE AND WALL PRINTS AT S=1.07 M.
  NOTE:  TWO RUNS ARE INCLUDED IN THIS TEST CASE: W=1; W=0 .

             TEST CASE NO. 2;  W = 1.

*VARDIM/VGBLP(JK= 63,JL=1,JM= 17,JN=2,JI=1,JH=165)
*VARDIM/TABLE(JJ=41,JH=165)
*VARDIM/VAPENT(JL=1)
*VARDIM/TURBLNT(JI=1,JK= 63)
*VARDIM/MESH(JK= 63)
*VARDIM/SIMILAR(JK= 63)
*VARDIM/SOLVE(JK= 63)

 $NAM1

 IGEOM  =           1  XFEND  =  .60000E+02  IE      =          61  XK      =  .12754E+01  DETA1   =           I  XMA     =  .17000E+01
 PT1    =  .47511E+05  TT1    =  .29780E+03  IGAS    =           1  VISIC1  =  .14582F-05  VISIC2  =  .11033E+03  VIS2C1  =           I
 VIS2C2 =           I  G      =  .14000E+01  R       =  .28696E+03  PP      =  .72000E+00

 IBODY  =           2  WAVE   =  .43523E+02  PHII    =  .20000E+02  J       =           1  W       =           1  IENTRO  =           1

 SST    =  .90000E-01  SMXTR  =  .10000E+09  KODVIS  =           2  KTCOD   =           2  TLNGTH  =  .20000E+01  IYINT   =           2
 KODAMP =           2  XT1    =  .40000E+00  XT2     =  .16800E-01  XT3     =  .50000E+01  XT4     =  .78000E+00  XT5     =  .10800E+00
 XT6    =  .26000E+02  PPT    =  .95000E+00  KODPRT  =           1  NUMB1   =           0  GLAR    =           I
 PRTAR
     I

 IEND1  =         164  PROINC = 0.              PRNTINC=  .10000E+00  IPRO    =           1  IPRNT   =           2  NAUXPRO=           0
 FT     =  .10000E+01  KODE   =           0  KODWAL  =           2  VELEDG  =  .99500E+00  CONV    =  .10000E-03  NITMAX  =           5
 KODUNIT=           1  ITMAX  =           3  CONVE   =  .10000F-01

 THIS COMPLETES THE OUTPUT OF $NAM1 WITH THE EXCEPTION OF PROVAL AND PRNTVAL. THESE VALUES ARE PRINTED JUST PRIOR TO THE
 INITIAL STATION PRINT.
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
$NAM2

NUMBER =        41
L      =         1
S
0.          .40545E-01  .81090E-01  .12164E+00  .16218E+00  .20273E+00  .24324E+00  .28334E+00  .32288E+00  .36190E+00
.40049E+00  .43877E+00  .47690E+00  .51501E+00  .55324E+00  .59164E+00  .63023E+00  .66897E+00  .70777E+00  .74652E+00
.78518E+00  .82376E+00  .86227E+00  .90072E+00  .93913E+00  .97749E+00  .10158E+01  .10541E+01  .10922E+01  .11303E+01
.11685E+01  .12068E+01  .12452E+01  .12836E+01  .13220E+01  .13605E+01  .13991E+01  .14377E+01  .14764E+01  .15152E+01
.15542E+01
Z
0.          .38100E-01  .76200E-01  .11430E+00  .15240E+00  .19050E+00  .22860E+00  .26670E+00  .30480E+00  .34290E+00
.38100E+00  .41910E+00  .45720E+00  .49530E+00  .53340E+00  .57150E+00  .60960E+00  .64770E+00  .68580E+00  .72390E+00
.76200E+00  .80010E+00  .83820E+00  .87630E+00  .91440E+00  .95250E+00  .99060E+00  .10287E+01  .10668E+01  .11049E+01
.11430E+01  .11811E+01  .12192E+01  .12573E+01  .12954E+01  .13335E+01  .13716E+01  .14097E+01  .14478E+01  .14859E+01
.15240E+01
RMI
0.          .13867E-01  .27735E-01  .41602E-01  .55469E-01  .69336E-01  .83118E-01  .95612E-01  .10618E+00  .11457E+00
.12063E+00  .12430E+00  .12559E+00  .12463E+00  .12161E+00  .11684E+00  .11070E+00  .10368E+00  .96332E-01  .89279E-01
.82739E-01  .76681E-01  .71071E-01  .65875E-01  .61061E-01  .56593E-01  .52443E-01  .49042E-01  .47498E-01  .48314E-01
.51229E-01  .55247E-01  .59612E-01  .64313E-01  .69384E-01  .74859E-01  .80772E-01  .87156E-01  .94046E-01  .10147E+00
.10948E+00
OW
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.
RVWALD
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.

PE
.16545E+05  .16605E+05  .16665E+05  .16726E+05  .16817E+05  .16847E+05  .16545E+05  .15291E+05  .12882E+05  .11293E+05
.98360E+04  .85489E+04  .74028E+04  .64416E+04  .57289E+04  .53851E+04  .53078E+04  .54409E+04  .57882E+04  .63758E+04
.70202E+04  .76013E+04  .81278E+04  .86529E+04  .90624E+04  .95845E+04  .10174E+05  .10923E+05  .12019E+05  .12759E+05
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.12981E+05  .12956E+05  .12833E+05  .12686E+05  .12661E+05  .12710E+05  .12833E+05  .13006E+05  .13231E+05  .13511E+05
.13848E+05
SS
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .50000E-02
.50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
.50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01  .10000E-01
.10000E-01  .10000E-01  .10000E-01  .10000E-01 0.

THE FOLLOWING SPOINT VALUES DESIGNATE THE S-COORDINATE LOCATIONS WHERE THE SOLUTIONS ARE OBTAINED DURING THE S-MARCH.
YOUR PRINT STATION MUST AGREE WITH ONE OR MORE OF THE SPOINT LOCATIONS; IE, YOU CAN PRINT ONLY AT SOLUTION STATIONS.
IF THE CASE COMPLETES WITH A NORMAL STOP AND NO OUTPUT IS PRINTED, YOUR PRINT INPUT IS IN ERROR. THE ERROR CAN BE
NOTED BY COMPARING PROVAL AND PRNTVAL WITH SPOINT.

SPOINT
.10000E-01  .20000E-01  .30000E-01  .40000E-01  .50000E-01  .60000E-01  .70000E-01  .80000E-01  .90000E-01  .95000E-01
.10000E+00  .10500E+00  .11000E+00  .11500E+00  .12000E+00  .12500E+00  .13000E+00  .13500E+00  .14000E+00  .14500E+00
.15000E+00  .15500E+00  .16000E+00  .16500E+00  .17000E+00  .17500E+00  .18000E+00  .19000E+00  .20000E+00  .21000E+00
.22000E+00  .23000E+00  .24000E+00  .25000E+00  .26000E+00  .27000E+00  .28000E+00  .29000E+00  .30000E+00  .31000E+00
.32000E+00  .33000E+00  .34000E+00  .35000E+00  .36000E+00  .37000E+00  .38000E+00  .39000E+00  .40000E+00  .41000E+00
.42000E+00  .43000E+00  .44000E+00  .45000E+00  .46000E+00  .47000E+00  .48000E+00  .49000E+00  .50000E+00  .51000E+00
.52000E+00  .53000E+00  .54000E+00  .55000E+00  .56000E+00  .57000E+00  .58000E+00  .59000E+00  .60000E+00  .61000E+00
.62000E+00  .63000E+00  .64000E+00  .65000E+00  .66000E+00  .67000E+00  .68000E+00  .69000E+00  .70000E+00  .71000E+00
.72000E+00  .73000E+00  .74000E+00  .75000E+00  .76000E+00  .77000E+00  .78000E+00  .79000E+00  .80000E+00  .81000E+00
```

```
.82000E+00  .83000E+00  .84000E+00  .85000E+00  .86000E+00  .87000E+00  .88000E+00  .89000E+00  .90000E+00  .91000E+00
.92000E+00  .93000E+00  .94000E+00  .95000E+00  .96000E+00  .97000E+00  .98000E+00  .99000E+00  .10000E+01  .10100E+01
.10200E+01  .10300E+01  .10400E+01  .10500E+01  .10600E+01  .10700E+01  .10800E+01  .10900E+01  .11000E+01  .11100E+01
.11200E+01  .11300E+01  .11400E+01  .11500E+01  .11600E+01  .11700E+01  .11800E+01  .11900E+01  .12000E+01  .12100E+01
.12200E+01  .12300E+01  .12400E+01  .12500E+01  .12600E+01  .12700E+01  .12800E+01  .12900E+01  .13000E+01  .13100E+01
.13200E+01  .13300E+01  .13400E+01  .13500E+01  .13600E+01  .13700E+01  .13800E+01  .13900E+01  .14000E+01  .14100E+01
.14200E+01  .14300E+01  .14400E+01  .14500E+01  .14600E+01  .14700E+01  .14800E+01  .14900E+01  .15000E+01  .15100E+01
.15200E+01  .15300E+01  .15400E+01  .15500E+01 0.

PRINT STATIONS DESIGNATED IN $NAM1 INPUT AND GENERATED IN SETUP

PROVAL
.10700E+01 0.
PRNTVAL
.10700E+01  .15500E+01  .10000E+00  .20000E+00  .30000E+00  .40000E+00  .50000E+00  .60000E+00  .70000E+00  .80000E+00
.90000E+00  .10000E+01  .11000E+01  .12000E+01  .13000E+01  .14000E+01  .15000E+01
```

SIMILAR SOLUTION REQUIRED TO INITIATE MARCHING PROCEDURE

PROFILE VALUES

ETA	U/UE	T/TE	V	FZ	TZ	XL
0.	0.	.129560E+01	0.	.484458E+00	0.	.950876E+00
.757409E-05	.366933E-05	.129568E+01	-.138959E-10	.484458E+00	.461521E+01	.950876E+00
.172341E-04	.834919E-05	.129568E+01	-.719454E-10	.484458E+00	-.219528E-05	.950876E+00
.295545E-04	.143179E-04	.129568E+01	-.211579E-09	.484458E+00	-.369595E-05	.950876E+00
.452678E-04	.219304E-04	.129568E+01	-.496370E-09	.484458E+00	-.561053E-05	.950876E+00
.653087E-04	.316393E-04	.129568E+01	-.103316E-08	.484458E+00	-.805249E-05	.950876E+00
.908688E-04	.440221E-04	.129568E+01	-.200012E-08	.484458E+00	-.111673E-04	.950876E+00
.123468E-03	.598151E-04	.129568E+01	-.369263E-08	.484458E+00	-.151403E-04	.950876E+00
.165045E-03	.799576E-04	.129568E+01	-.659831E-08	.484458E+00	-.202075E-04	.950876E+00
.218073E-03	.105647E-03	.129568E+01	-.115194E-07	.484458E+00	-.266703E-04	.950876E+00
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.671942E+01	.100034E+01	.100005E+01	-.553421E+01	.730311E-04	.192905E-04	.999991E+00
.856996E+01	.999935E+00	.999987E+00	-.738501E+01	-.226654E-04	-.501431E-05	.100000E+01
.109301E+02	.100025E+01	.100003E+01	-.974540E+01	.843866E-05	.170021E-05	.999994E+00
.139403E+02	.999981E+00	.999996E+00	-.127559E+02	-.347684E-05	-.664433E-06	.100000E+01
.177795E+02	.100022E+01	.100003E+01	-.165955E+02	.151994E-05	.281627E-06	.999995E+00
.226759E+02	.999994E+00	.999999E+00	-.214925E+02	-.688598E-06	-.125266E-06	.100000E+01
.289209E+02	.100022E+01	.100003E+01	-.277381E+02	.318888E-06	.573730E-07	.999995E+00
.368857E+02	.999998E+00	.100000E+01	-.357038E+02	-.149719E-06	-.267574E-07	.100000E+01
.470441E+02	.100021E+01	.100003E+01	-.458632E+02	.709106E-07	.126216E-07	.999995E+00
.600000E+02	.100000E+01	.100000E+01	-.588205E+02	0.	0.	.100000E+01

CONVERGED SELF-SIMILAR SOLUTION REQUIRED 15ITERATIONS.

INITIAL STATION PARAMETERS

MUE = .144383E-04 UE = .393777E+03 TE = .220606E+03 PE = .165451E+05 QSD =0.
XAL = .699833E+00 XBE =0. RE = .261356E+00

****DIMENSIONAL OUTPUT QUANTITIES ARE IN S.I. UNITS****

FREE STREAM VALUES-DIMENSIONAL
PT1 = .475108E+05 TT1 = .297800E+03 RT1 = .555966E+00 P1 = .962539E+04 T1= .188720E+03 R1 = .177738E+00
U1 = .468092E+03 AA1 = .275348E+03 XMA = .170000E+01 REY = .658109E+07

REFERENCE VALUES-DIMENSIONAL
PREF= .389443E+05 TREF= .218160E+03 RREF= .177738E+00 UREF= .468092E+03 VISREF= .143045E-04 PTR = .121997E+01

S= 1.0700 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	YPLUS	UPLUS	UDEF	VISEFF
0.	0.	0.	.147E+01	.977E+00	.310E-08	.240E+00	0.	0.	0.	0.	.100E+01
.757E-05	.532E-06	.289E-04	.147E+01	.977E+00	.342E-08	.240E-00	.239E-04	.107E-02	.100E-02	.346E+02	.100E+01
.172E-04	.121E-05	.658E-04	.147E+01	.977E+00	.177E-07	.240E+00	.543E-04	.245E-02	.228E-02	.346E+02	.100E+01
.296E-04	.208E-05	.113E-03	.147E+01	.977E+00	.521E-07	.240E+00	.932E-04	.419E-02	.391E-02	.346E+02	.100E+01
.453E-04	.318E-05	.173E-03	.147E+01	.977E+00	.122E-06	.240E+00	.143E-03	.642E-02	.598E-02	.346E+02	.100E+01
.653E-04	.459E-05	.249E-03	.147E+01	.977E+00	.254E-06	.240E+00	.206E-03	.927E-02	.863E-02	.346E+02	.100E+01
.909E-04	.638E-05	.347E-03	.147E+01	.977E+00	.492E-06	.240E+00	.287E-03	.129E-01	.120E-01	.346E+02	.100E+01
.123E-03	.867E-05	.472E-03	.147E+01	.977E+00	.909E-06	.240E+00	.389E-03	.175E-01	.163E-01	.346E+02	.100E+01
.165E-03	.116E-04	.631E-03	.147E+01	.977E+00	.162E-05	.240E+00	.520E-03	.234E-01	.218E-01	.346E+02	.100E+01
.218E-03	.153E-04	.833E-03	.147E+01	.977E+00	.284E-05	.240E+00	.688E-03	.309E-01	.288E-01	.346E+02	.100E+01
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.672E+01	.384E+00	.753E+00	.121E+01	.997E+00	.878E+00	.501E+00	.684E+00	.105E+04	.261E+02	.855E+01	.320E+03
.857E+01	.475E+00	.801E+00	.118E+01	.999E+00	.939E+00	.556E+00	.738E+00	.136E+04	.277E+02	.688E+01	.333E+03
.109E+02	.583E+00	.855E+00	.113E+01	.100E+01	.999E+00	.629E+00	.803E+00	.178E+04	.296E+02	.501E+01	.333E+03
.139E+02	.710E+00	.917E+00	.108E+01	.100E+01	.105E+01	.727E+00	.881E+00	.234E+04	.317E+02	.289E+01	.273E+03
.178E+02	.857E+00	.981E+00	.102E+01	.100E+01	.104E+01	.854E+00	.972E+00	.313E+04	.340E+02	.649E+00	.130E+03
.227E+02	.103E+01	.998E+00	.100E+01	.100E+01	.996E+00	.892E+00	.997E+00	.387E+04	.345E+02	.753E-01	.187E+02
.289E+02	.124E+01	.100E+01	.100E+01	.100E+01	.101E+01	.898E+00	.100E+01	.467E+04	.346E+02	-.255E-01	.129E+01
.369E+02	.148E+01	.100E+01	.100E+01	.100E+01	.100E+01	.896E+00	.100E+01	.560E+04	.346E+02	.980E-02	.100E+01
.470E+02	.178E+01	.100E+01	.100E+01	.100E+01	.101E+01	.897E+00	.100E+01	.671E+04	.346E+02	-.107E-01	.100E+01
.600E+02	.213E+01	.100E+01	.100E+01	.100E+01	.100E+01	.897E+00	.100E+01	.803E+04	.346E+02	.163E-07	.100E+01

ORIGINAL PAGE IS
OF POOR QUALITY

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S      =  .10700E+01  RETHET=  .14735E+05  DPEDS =  .73790E+00  CFW    =  .16699E-02  ZSHK   = 0.               YE     =  .19267E-01
XI     =  .66998E-02  RES    =  .72574E+07  DTEDS =  .28226E+03  QSD    = 0.           RSHK   = 0.               UTAU   =  .84142E-02
RMI    =  .48397E-01  PE     =  .11381E+05  DUEDS = -.29544E+03  HD     = 0.           ITRO   =               0  TRFCT  =  .10000E+01
Z      =  .10446E+01  TE     =  .19824E+03  DLTAST=  .55260E-02  NSTE   = 0.           TW/TT1=  .97708E+00  YMP    =           50
BETA   = -.41437E+01  RE     =  .20006E+00  THETA =  .21724E-02  NSTW   = 0.           RFTRUE=  .93145E+00  P20    =  .12142E+01
XAL    =  .10045E+01  UE     =  .44720E+03  FORM  =  .25437E+01  NUE    = 0.           ROUSE =  .25906E+05  OMEGA  =  .41465E-03
RVWALD= 0.            ME     =  .15847E+01  TAUD  =  .22759E+02  NUW    = 0.           DSMXO = -.43617E+04
REDELT=  .37481E+05  MUE    =  .13191E-04  CFE   =  .11377E-02  SWANG  = 0.           VW     = 0.               RVWAL  = 0.
NOITER=           3  ERROR  =  .98881E-05
```

TEST CASE NO. 2 ; W = 0
NOTE : ALL INPUT WITH THE EXCEPTION OF W = 0 IN $NAM1 IS IDENTICAL TO CASE FOR W = 1 ; CONSEQUENTLY, ONLY
THE PROFILE AND WALL PRINT AT S = 1.07 M ARE PRESENTED.

S= 1.0700 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	YPLUS	UPLUS	UDEF	VISEFF
0.	0.	0.	.147E+01	.978E+00	.484E-12	.240E+00	0.	0.	0.	0.	.100E+01
.757E-05	.557E-06	.261E-04	.147E+01	.978E+00	.289E-08	.240E+00	.215E-04	.102E-02	.950E-03	.364E+02	.100E+01
.172E-04	.127E-05	.593E-04	.147E+01	.978E+00	.150E-07	.240E+00	.489E-04	.232E-02	.216E-02	.364E+02	.100E+01
.296E-04	.217E-05	.102E-03	.147E+01	.978E+00	.440E-07	.240E+00	.839E-04	.398E-02	.371E-02	.364E+02	.100E+01
.453E-04	.333E-05	.156E-03	.147E+01	.978E+00	.103E-06	.240E+00	.129E-03	.610E-02	.568E-02	.364E+02	.100E+01
.653E-04	.480E-05	.225E-03	.147E+01	.978E+00	.215E-06	.240E+00	.185E-03	.880E-02	.819E-02	.364E+02	.100E+01
.909E-04	.668E-05	.313E-03	.147E+01	.978E+00	.416E-06	.240E+00	.258E-03	.122E-01	.114E-01	.364E+02	.100E+01
.123E-03	.908E-05	.425E-03	.147E+01	.978E+00	.768E-06	.240E+00	.351E-03	.166E-01	.155E-01	.364E+02	.100E+01
.165E-03	.121E-04	.568E-03	.147E+01	.978E+00	.137E-05	.240E+00	.469E-03	.222E-01	.207E-01	.364E+02	.100E+01
.218E-03	.160E-04	.751E-03	.147E+01	.978F+00	.240E-05	.240E+00	.619E-03	.294E-01	.274E-01	.364E+02	.100E+01
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.672E+01	.405E+00	.739E+00	.122E+01	.997E+00	.877E+00	.486E+00	.668E+00	.991E+03	.269E+02	.950E+01	.360E+03
.857E+01	.500E+00	.791E+00	.119E+01	.999E+00	.944E+00	.543E+00	.726E+00	.129E+04	.288E+02	.762E+01	.373E+03
.109E+02	.613E+00	.852E+00	.114E+01	.100E+01	.101E+01	.624E+00	.799E+00	.169E+04	.310E+02	.540E+01	.363E+03
.139E+02	.746E+00	.926E+00	.107E+01	.100E+01	.105E+01	.745E+00	.894E+00	.227E+04	.338E+02	.269E+01	.274E+03
.178E+02	.898E+00	.991E+00	.101E+01	.100E+01	.103E+01	.875E+00	.986E+00	.303E+04	.361E+02	.340E+00	.104E+03
.227E+02	.108E+01	.998E+00	.100E+01	.100E+01	.995E+00	.893E+00	.998E+00	.368E+04	.364E+02	.618E-01	.102E+02
.289E+02	.129E+01	.100E+01	.999E+00	.100E+01	.101E+01	.898E+00	.100E+01	.444E+04	.365E+02	-.294E-01	.107E+01
.369E+02	.155E+01	.100E+01	.100E+01	.100E+01	.100E+01	.896E+00	.100E+01	.532E+04	.364E+02	.938E-02	.100E+01
.470E+02	.186E+01	.100E+01	.100E+01	.100E+01	.101E+01	.897E+00	.100E+01	.638E+04	.365E+02	-.973E-02	.100E+01
.600E+02	.223E+01	.100E+01	.100E+01	.100E+01	.100E+01	.897E+00	.100E+01	.763E+04	.364E+02	.172E-07	.100E+01

S = .10700E+01	RETHET= .16626E+05	DPEDS = .73790E+00	CFW = .15055E-02	ZSHK = 0.	YE = .18425E-01
XI = .66998E-02	RES = .72574E+07	DTEDS = .28226E+03	QSD = 0.	RSHK = 0.	UTAU = .79895E-02
RMI = .48397E-01	PE = .11381E+05	DUEDS = -.29544E+03	HD = 0.	ITRO = 0	TRFCT = .10000E+01
Z = .10446E+01	TE = .19824E+03	DLTAST= .55991E-02	NSTE = 0.	TW/TT1= .97800E+00	YMP = 50
BETA = -.41437E+01	RE = .20006E+00	THETA = .24513E-02	NSTW = 0.	RFTRUE= .93420E+00	P20 = .12142E+01
XAL = .10045E+01	UE = .44720E+03	FORM = .22842E+01	NUE = 0.	ROUSE = .23024E+05	OMEGA = .41465E-03
RVWALD= 0.	ME = .15847E+01	TAUD = .20500E+02	NUW = 0.	DSMXO = -.91544E+02	
REDELT= .37977E+05	MUE = .13191E-04	CFF = .10247E-02	SWANG = 0.	VW = 0.	RVWAL = 0.
REDELT= .37977E+05	MUE = .13191E-04	CFE = .10247E-02	SWANG = 0.	VW = 0.	RVWAL = 0.
NOITER= 5	ERROR = .27836E-04				

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                  TEST CASE NO. 3

     THE LISTING FOR TEST CASE 3 INCLUDES THE FOLLOWING:  (1) VARDIM DATA;;  (2)  $NAM1 AND $NAM2 INPUT;
           (3)  INITIAL STATION SOLUTION VALUES;  (4)  REFERENCE VALUES; (5)  PROFILE AND WALL PRINTS.
     NOTE:  THREE RUNS ARE INCLUDED IN THIS TEST CASE:  RVWALD = 0 ; RVWALD < 0  ; RVWALD > 0 .

               TEST CASE NO. 3 ;  RVWALD = 0.

 PREPROCESSOR CONTROL CARDS

*VARDIM/VGBLP(JK= 43,JL=1,JM= 30,JN= 3,JI=1,JH=85)
*VARDIM/TABLE(JJ=11,JH=85)
*VARDIM/VARENT(JL=1)
*VARDIM/TURBLNT(JI=1,JK= 43)
*VARDIM/MESH(JK= 43)
*VARDIM/SIMILAR(JK= 43)
*VARDIM/SOLVE(JK= 43)

 $NAM1
 IGEOM  =            1  XEND   =  .10000E+02  IE     =            41  XK     =  .12754E+01  DETA1  = 0.           XMA    =  .74000E+01
 PT1    =  .41400E+07  TT1    =  .83300E+03  IGAS   =             1  VISIC1 =  .14582E-05  VISIC2 =  .11033E+03  VIS2C1 = 0.
 VIS2C2 = 0.            G      =  .14000E+01  R      =  .28696E+03  PR     =  .72000E+00
 IBODY  =            2  WAVE   =  .92140E+01  PHII   =  .50000E+01  J      =            1  W      =            0  IENTRO =            1
 SST    =  .10000E+09  SMXTR  =  .10000E+09  KODVIS =             2  KTCOD  =            2  TLNGTH =  .20000E+01  IYINT  =            1
 KODAMP =            2  XT1    =  .40000E+00  XT2    =  .16800E-01  XT3    =  .50000E+01  XT4    =  .78000E+00  XT5    =  .10800E+00
 XT6    =  .26000E+02  PRT    =  .95000E+00  KODPRT =             1  NUMB1  =            0  GLAR   = 0.
 PRTAR
0.
 IEND1  =           84  PROINC =  .10000E+00  PRNTINC=  .10000E-01  IPRO   =            0  IPRNT  =            0  NAUXPRO=            0
 FT     =  .10000E+01  KODE   =            0  KODWAL =             1  VELEDG =  .99500E+00  CONV   =  .10000E-03  NITMAX =            5
 KODUNIT=            1  ITMAX  =            3  CONVE  =  .10000E-01

 THIS COMPLETES THE OUTPUT OF $NAM1 WITH THE EXCEPTION OF PROVAL AND PRNTVAL. THESE VALUES ARE PRINTED JUST PRIOR TO THE
 INITIAL STATION PRINT.
```

```
$NAM2

NUMBER =          11
L      =           1
S
0.          .94488E-01  .96012E-01  .12009E+00  .14417E+00  .16794E+00  .19202E+00  .24018E+00  .26426E+00  .28804E+00
 .30480E+00
Z
0.          .94122E-01  .95646E-01  .11963E+00  .14362E+00  .16730E+00  .19129E+00  .23927E+00  .26326E+00  .28694E+00
 .30364E+00
RMI
0.          .82296E-02  .83668E-02  .10467E-01  .12565E-01  .14637E-01  .16736E-01  .20933E-01  .23032E-01  .25104E-01
 .26565E-01
TW
 .31665E+03  .31665E+03  .31665E+03  .31665E+03  .31665E+03  .31665E+03  .31665E+03  .31665E+03  .31665E+03  .31665E+03
 .31665E+03
QW
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.
RVWALD
0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
0.
PE
 .12465E+04  .12465E+04  .12465E+04  .12465E+04  .12465E+04  .12465E+04  .12465E+04  .12465E+04  .12465E+04  .12465E+04
 .12465E+04
SS
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .10000E-02  .10000E-02
 .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02
 .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02
 .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .10000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02  .50000E-02
 .50000E-02  .50000E-02  .50000E-02  .50000E-02 0.
```

```
THE FOLLOWING SPOINT VALUES DESIGNATE THE S-COORDINATE LOCATIONS WHERE THE SOLUTIONS ARE OBTAINED DURING THE S-MARCH.
YOUR PRINT STATION MUST AGREE WITH ONE OR MORE OF THE SPOINT LOCATIONS; IE, YOU CAN PRINT ONLY AT SOLUTION STATIONS.
IF THE CASE COMPLETES WITH A NORMAL STOP AND NO OUTPUT IS PRINTED, YOUR PRINT INPUT IS IN ERROR. THE ERROR CAN BE
NOTED BY COMPARING PROVAL AND PRNTVAL WITH SPOINT.

SPOINT
.50000E-02  .10000E-01  .15000E-01  .20000E-01  .25000E-01  .30000E-01  .35000E-01  .40000E-01  .45000E-01  .50000E-01
.55000E-01  .60000E-01  .65000E-01  .70000E-01  .75000E-01  .80000E-01  .85000E-01  .90000E-01  .91000E-01  .92000E-01
.93000E-01  .94000E-01  .95000E-01  .96000E-01  .97000E-01  .98000E-01  .99000E-01  .10000E+00  .10100E+00  .10200E+00
.10300E+00  .10400E+00  .10500E+00  .10600E+00  .10700E+00  .10800E+00  .10900E+00  .11000E+00  .11100E+00  .11200E+00
.11300E+00  .11400E+00  .11500E+00  .11600E+00  .11700E+00  .11800E+00  .11900E+00  .12000E+00  .12500E+00  .13000E+00
.13500E+00  .14000E+00  .14500E+00  .15000E+00  .15500E+00  .16000E+00  .16500E+00  .17000E+00  .17500E+00  .18000E+00
.18500E+00  .19000E+00  .19500E+00  .20000E+00  .20500E+00  .21000E+00  .21500E+00  .22000E+00  .22500E+00  .23000E+00
.23500E+00  .24000E+00  .24500E+00  .25000E+00  .25500E+00  .26000E+00  .26500E+00  .27000E+00  .27500E+00  .28000E+00
.28500E+00  .29000E+00  .29500E+00  .30000E+00 0.

PRINT STATIONS DESIGNATED IN $NAM1 INPUT AND GENERATED IN SETUP

PROVAL
.10000E+00  .20000E+00  .30000E+00
PRNTVAL
.10000E-01  .20000E-01  .30000E-01  .40000E-01  .50000E-01  .60000E-01  .70000E-01  .80000E-01  .90000E-01  .10000E+00
.11000E+00  .12000E+00  .13000F+00  .14000E+00  .15000E+00  .16000E+00  .17000E+00  .18000E+00  .19000E+00  .20000E+00
.21000E+00  .22000E+00  .23000E+00  .24000E+00  .25000E+00  .26000E+00  .27000E+00  .28000E+00  .29000E+00  .30000E+00
```

SIMILAR SOLUTION REQUIRED TO INITIATE MARCHING PROCEDURE

PROFILE VALUES

ETA	U/UE	T/TE	V	FZ	TZ	XL
0.	0.	.384858E+01	0.	.497793E+00	.214623E+01	.884947E+00
.163732E-03	.815055E-04	.384893E+01	-.667252E-08	.497806E+00	.214568E+01	.884928E+00
.372556E-03	.185460E-03	.384938E+01	-.345469E-07	.497820E+00	.214504E+01	.884903E+00
.638889E-03	.318046E-03	.384995E+01	-.101598E-06	.497838E+00	.214422E+01	.884871E+00
.978571E-03	.487158E-03	.385068E+01	-.238355E-06	.497862E+00	.214318E+01	.884831E+00
.141180E-02	.702852E-03	.385161E+01	-.496129E-06	.497892E+00	.214186E+01	.884779E+00
.196434E-02	.977966E-03	.385279E+01	-.960490E-06	.497930E+00	.214017E+01	.884714E+00
.266906E-02	.132888E-02	.385430E+01	-.177332E-05	.497978E+00	.213801E+01	.884630E+00
.356785E-02	.177648E-02	.385622E+01	-.316865E-05	.498040E+00	.213526E+01	.884523E+00
.471416E-02	.234742E-02	.385867E+01	-.553249E-05	.498119E+00	.213174E+01	.884388E+00
⋮	⋮	⋮	⋮	⋮	⋮	⋮
.111938E+01	.556841E+00	.421333E+01	-.316420E+00	.436282E+00	-.136939E+01	.865131E+00
.142782E+01	.684086E+00	.371567E+01	-.507796E+00	.363826E+00	-.177287E+01	.892380E+00
.182121E+01	.812184E+00	.296909E+01	-.802102E+00	.261914E+00	-.179556E+01	.935873E+00
.232293E+01	.918527E+00	.210844E+01	-.123627E+01	.148601E+00	-.137770E+01	.985428E+00
.296283E+01	.981830E+00	.139627E+01	-.184429E+01	.563286E-01	-.731029E+00	.101057E+01
.377896E+01	.100054E+01	.104405E+01	-.265322E+01	.966652E-02	-.217523E+00	.100292E+01
.481984E+01	.999781E+00	.992329E+00	-.369428E+01	-.212271E-03	-.179766E-01	.999432E+00
.614739E+01	.100004E+01	.100147E+01	-.502171E+01	.372291E-04	.169536E-02	.100011E+01
.784055E+01	.999893E+00	.997450E+00	-.671481E+01	-.105317E-04	-.381710E-03	.999813E+00
.100000E+02	.100000E+01	.100000E+01	-.887415E+01	0.	0.	.100000E+01

CONVERGED SELF-SIMILAR SOLUTION REQUIRED 15ITERATIONS.

INITIAL STATION PARAMETERS

MUE = .565042E-05 UE = .122800E+04 TE = .822781E+02 PE = .124651E+04 QSD =0.
XAL = .182484E+02 XBE =0. RE = .527947E-01

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****DIMENSIONAL OUTPUT QUANTITIES ARE IN S.I. UNITS****

FREE STREAM VALUES-DIMENSIONAL
PT1 = .414000E+07 TT1 = .833000E+03 RT1 = .173195E+02 P1 = .701388E+03 T1= .696954E+02 R1 = .350699E-01
U1 = .123825E+04 AA1 = .167331E+03 XMA = .740000E+01 REY = .921384E+07

REFERENCE VALUES-DIMENSIONAL
PREF= .537712E+05 TPEF= .152661E+04 KREF= .350699E-01 UREF= .123825E+04 VISREF= .531367E-04 PTR = .769929E+02

S= .1000 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	FZ	TZ	VORTREY	XLM11
0.	0.	0.	.385E+01	.380E+00	.573E-14	.301E-03	0.	.498E+00	.214E+01	0.	.885E+00
.164E-03	.625E-04	.815E-04	.385E+01	.380E+00	.560E-04	.301E-03	.415E-04	.498E+00	.214E+01	.342E-05	.885E+00
.373E-03	.142E-03	.195E-03	.385E+01	.380E+00	.127E-03	.301E-03	.945E-04	.498E+00	.214E+01	.177E-04	.885E+00
.639E-03	.244E-03	.318E-03	.385E+01	.380E+00	.218E-03	.301E-03	.162E-03	.498E+00	.214E+01	.521E-04	.885E+00
.979E-03	.374E-03	.487E-03	.385E+01	.380E+00	.334E-03	.301E-03	.248E-03	.498E+00	.214E+01	.122E-03	.885E+00
.141E-02	.539E-03	.703E-03	.385E+01	.380E+00	.483E-03	.301E-03	.358E-03	.498E+00	.214E+01	.254E-03	.885E+00
.196E-02	.751E-03	.978E-03	.385E+01	.381E+00	.672E-03	.301E-03	.498E-03	.498E+00	.214E+01	.492E-03	.885E+00
.267E-02	.102E-02	.133E-02	.385E+01	.381E+00	.913E-03	.301E-03	.677E-03	.498E+00	.214E+01	.908E-03	.885E+00
.357E-02	.136E-02	.178E-02	.386E+01	.381E+00	.122E-02	.301E-03	.905E-03	.498E+00	.213E+01	.162E-02	.885E+00
.471E-02	.180E-02	.235E-02	.386E+01	.381E+00	.161E-02	.301E-03	.119E-02	.498E+00	.213E+01	.283E-02	.884E+00
.618E-02	.236E-02	.308E-02	.386E+01	.381E+00	.212E-02	.301E-03	.156E-02	.498E+00	.213E+01	.485E-02	.884E+00
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
.112E+01	.475E+00	.557E+00	.421E+01	.696E+00	.509E+00	.145E-02	.271E+00	.436E+00	-.137E+01	.135E+03	.865E+00
.143E+01	.591E+00	.684E+00	.372E+01	.789E+00	.659E+00	.237E-02	.355E+00	.364E+00	-.177E+01	.246E+03	.892E+00
.182E+01	.714E+00	.812E+00	.297E+01	.888E+00	.819E+00	.407E-02	.471E+00	.262E+00	-.180E+01	.484E+03	.936E+00
.232E+01	.833E+00	.918E+00	.211E+01	.969E+00	.949E+00	.721E-02	.632E+00	.149E+00	-.138E+01	.989E+03	.985E+00
.296E+01	.936E+00	.982E+00	.140E+01	.101E+01	.101E+01	.123E-01	.831E+00	.564E-01	-.731E+00	.159E+04	.101E+01
.378E+01	.103E+01	.100E+01	.104E+01	.101E+01	.101E+01	.171E-01	.979E+00	.968E-02	-.218E+00	.793E+03	.100E+01
.482E+01	.112E+01	.100E+01	.992E+00	.999E+00	.998E+00	.180E-01	.100E+01	-.212E-03	-.180E-01	0.	.999E+00
.615E+01	.124E+01	.100E+01	.100E+01	.100E+01	.100E+01	.178E-01	.999E+00	.370E-04	.170E-02	0.	.100E+01
.784E+01	.139E+01	.100E+01	.997E+00	.100E+01	.999E+00	.179E-01	.100E+01	-.105E-04	-.382E-03	0.	.100E+01
.100E+02	.158E+01	.100E+01	.100E+01	.100E+01	.100E+01	.178E-01	.100E+01	0.	0.	0.	.100E+01

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```
S      =  .10000E+00  RETHET=  .37964E+03  DPEDS = 0.            CFW    =  .38783E-02  ZSHK   = 0.
XI     =  .40149E-06  RES   =  .11474E+07  DTEDS = 0.            QSD    = -.16140E+05  RSHK   = 0.            YE    =  .76769E-03
RMI    =  .87146E-02  PE    =  .12465E+04  DUEDS = 0.            HD     =  .40086E+02  ITRO   =            0  UTAU  = 0.
Z      =  .99619E-01  TE    =  .82278E+02  DLTAST=  .56296E-03   NSTE   =  .61611E-03  TW/TT1=  .38014E+00  TRFCT = 0.
BETA   = 0.           RE    =  .52795E-01  THETA =  .33088E-04   NSTW   =  .23712E-02  RFTRUE=  .31220E+00  YMP   =            0
XAL    =  .18248E+02  UE    =  .12280E+04  FORM  =  .17014E+02   NUE    =  .50898E+03  ROUSE =  .15917E+04  P20   =  .76543E+02
RVWALD= 0.            ME    =  .67543E+01  TAUD  =  .40114E+02   NUW    =  .14945E+03  DSMXO =  .85922E+04  OMEGA =  .11062E-02
REDELT=  .64593E+04   MUE   =  .56504E-05  CFE   =  .10077E-02   SWANG  = 0.           VW     = 0.
NOITER=            2  ERROR =  .36984E-10                                                                   RVWAL = 0.

S      =  .11000E+00  RETHET=  .39819E+03  DPEDS = 0.            CFW    =  .36976E-02  ZSHK   = 0.
XI     =  .53453E-06  RES   =  .12621E+07  DTEDS = 0.            QSD    = -.15388E+05  RSHK   = 0.            YE    =  .80673E-03
RMI    =  .95867E-02  PE    =  .12465E+04  DUEDS = 0.            HD     =  .38219E+02  ITRO   =            0  UTAU  = 0.
Z      =  .10958E+00  TE    =  .82278E+02  DLTAST=  .59289E-03   NSTE   =  .58741E-03  TW/TT1=  .38014E+00  TRFCT = 0.
BETA   = 0.           RE    =  .52795E-01  THETA =  .34705E-04   NSTW   =  .22607E-02  RFTRUE=  .31220E+00  YMP   =            0
XAL    =  .18248E+02  UE    =  .12280E+04  FORM  =  .17084E+02   NUE    =  .53379E+03  ROUSE =  .16754E+04  P20   =  .76543E+02
RVWALD= 0.            ME    =  .67543E+01  TAUD  =  .38245E+02   NUW    =  .15673E+03  DSMXO =  .81947E+04  OMEGA =  .11062E-02
REDELT=  .68028E+04   MUE   =  .56504E-05  CFE   =  .96077E-03   SWANG  = 0.           VW     = 0.
NOITER=            2  ERROR =  .26056E-10                                                                   RVWAL = 0.
```

TEST CASE NO. 3 ; RVWALD < 0.
NOTE : ALL INPUT WITH THE EXCEPTION OF RVWALD IN $NAME IS IDENTICAL TO THE CASE FOR RVWALD = 0 ;
CONSEQUENTLY ONLY RVWALD INPUT AND THE PROFILE AND WALL PRINTS ARE PRESENTED.

RVWALD
0. 0. -.90117E-01 -.90117E-01 -.90117E-01 -.90117E-01 -.90117E-01 -.90117E-01 -.90117E-01 -.90117E-01
-.90117E-01

S= .1000 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	FZ	TZ	VORTREY	XLM11
0.	0.	0.	.385E+01	.380E+00	.573E-14	.301E-03	0.	.111E+01	.453E+01	0.	.885E+00
.164E-03	.752E-04	.182E-03	.385E+01	.380E+00	.118E-03	.301E-03	.930E-04	.111E+01	.453E+01	.766E-05	.885E+00
.373E-03	.171E-03	.415E-03	.385E+01	.380E+00	.269E-03	.301E-03	.211E-03	.111E+01	.453E+01	.396E-04	.885E+00
.639E-03	.294E-03	.712E-03	.385E+01	.380E+00	.462E-03	.301E-03	.363E-03	.111E+01	.452E+01	.116E-03	.885E+00
.979E-03	.450E-03	.109E-02	.385E+01	.381E+00	.707E-03	.301E-03	.555E-03	.111E+01	.451E+01	.273E-03	.885E+00
.141E-02	.649E-03	.157E-02	.385E+01	.381E+00	.102E-02	.301E-03	.800E-03	.111E+01	.451E+01	.567E-03	.885E+00
.196E-02	.903E-03	.219E-02	.386E+01	.381E+00	.142E-02	.301E-03	.111E-02	.111E+01	.449E+01	.110E-02	.884E+00
.267E-02	.123E-02	.297E-02	.386E+01	.381E+00	.193E-02	.301E-03	.151E-02	.111E+01	.448E+01	.202E-02	.884E+00
.357E-02	.164E-02	.397E-02	.386E+01	.382E+00	.258E-02	.301E-03	.202E-02	.111E+01	.446E+01	.360E-02	.884E+00
.471E-02	.217E-02	.524E-02	.387E+01	.382E+00	.341E-02	.301E-03	.266E-02	.111E+01	.444E+01	.626E-02	.884E+00
.618E-02	.285E-02	.686E-02	.388E+01	.383E+00	.447E-02	.301E-03	.348E-02	.111E+01	.441E+01	.107E-01	.883E+00
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.112E+01	.553E+00	.703E+00	.361E+01	.803E+00	.682E+00	.257E-02	.370E+00	.352E+00	-.181E+01	.156E+03	.898E+00
.143E+01	.671E+00	.802E+00	.304E+01	.880E+00	.806E+00	.389E-02	.460E+00	.271E+00	-.181E+01	.286E+03	.932E+00
.182E+01	.790E+00	.893E+00	.234E+01	.951E+00	.921E+00	.616E-02	.584E+00	.179E+00	-.153E+01	.547E+03	.973E+00
.232E+01	.903E+00	.962E+00	.166E+01	.998E+00	.997E+00	.998E-02	.746E+00	.905E-01	-.102E+01	.979E+03	.100E+01
.296E+01	.100E+01	.997E+00	.118E+01	.101E+01	.102E+01	.151E-01	.918E+00	.276E-01	-.463E+00	.104E+04	.101E+01
.378E+01	.110E+01	.100E+01	.989E+00	.100E+01	.100E+01	.181E-01	.101E+01	.151E-02	-.100E+00	.261E+03	.999E+00
.482E+01	.122E+01	.999E+00	.992E+00	.998E+00	.997E+00	.179E-01	.100E+01	-.871E-03	.554E-02	0.	.999E+00
.615E+01	.136E+01	.100E+01	.100E+01	.100E+01	.100E+01	.178E-01	.999E+00	.138E-03	.167E-02	0.	.100E+01
.784E+01	.154E+01	.100E+01	.997E+00	.100E+01	.999E+00	.179E-01	.100E+01	-.221E-04	-.584E-03	0.	.100E+01
.100E+02	.177E+01	.100E+01	.100E+01	.100E+01	.100E+01	.178E-01	.100E+01	0.	0.	0.	.100E+01

```
S     =  .10000E+00  RETHET=  .33251E+03  DPEDS = 0.            CFW    =  .86813E-02  ZSHK   = 0.              YE    =  .63846E-03
XI    =  .40149E-06  PES   =  .11474E+07  DTEDS = 0.            QSD    = -.34131E+05  RSHK   = 0.              UTAU  = 0.
RMI   =  .87146E-02  PE    =  .12465E+04  DUEDS = 0.            HD     =  .84770E+02  ITRO   =             0   TRFCT = 0.
Z     =  .99619E-01  TE    =  .82278E+02  DLTAST=  .46610E-03   NSTE   =  .13029E-02  TW/TT1=  .38014E+00   YMP   =             0
BETA  = 0.           RE    =  .52795E-01  THETA =  .28980E-04   NSTW   =  .50142E-02  RFTRUE=  .31220E+00   P20   =  .76543E+02
XAL   =  .18248E+02  UE    =  .12280E+04  FORM  =  .16084E+02   NUE    =  .10763E+04  ROUSE =  .10359E+04   OMEGA =  .11062E-02
RVWALD= -.90117E-01  ME    =  .67543E+01  TAUD  =  .89792E+02   NUW    =  .31603E+03  DSMXO = -.89739E+03
REDELT=  .53480E+04  MUE   =  .56504E-05  CFE   =  .22557E-02   SWANG  = 0.           VW     = -.12151E+01   RVWAL = -.13900E-02
NOITER=           4  ERROR =  .90073E-04

S     =  .11000E+00  RETHET=  .28837E+03  DPEDS = 0.            CFW    =  .10460E-01  ZSHK   = 0.              YE    =  .58139E-03
XI    =  .53453E-06  RES   =  .12621E+07  DTEDS = 0.            QSD    = -.42263E+05  RSHK   = 0.              UTAU  = 0.
RMI   =  .95867E-02  PE    =  .12465E+04  DUEDS = 0.            HD     =  .10497E+03  ITRO   =             0   TRFCT = 0.
Z     =  .10958E+00  TE    =  .82278E+02  DLTAST=  .41139E-03   NSTE   =  .16133E-02  TW/TT1=  .38014E+00   YMP   =             0
BETA  = 0.           RE    =  .52795E-01  THETA =  .25133E-04   NSTW   =  .62089E-02  RFTRUE=  .31220E+00   P20   =  .76543E+02
XAL   =  .18248E+02  UE    =  .12280E+04  FORM  =  .16369E+02   NUE    =  .14661E+04  ROUSE =  .85055E+03   OMEGA =  .11062E-02
RVWALD= -.90117E-01  ME    =  .67543E+01  TAUD  =  .10819E+03   NUW    =  .43046E+03  DSMXO = -.15633E+05
REDELT=  .47202E+04  MUE   =  .56504E-05  CFE   =  .27179E-02   SWANG  = 0.           VW     = -.12745E+01   RVWAL = -.13900E-02
NOITER=           2  ERROR =  .19737E-04
```

TEST CASE NO. 3 ; RVWALD > 0.
NOTE : ALL INPUT WITH THE EXCEPTION OF RVWALD IN $NAME IS IDENTICAL TO THE CASE FOR RVWALD = 0 ;
CONSEQUENTLY ONLY RVWALD INPUT AND THE PROFILE AND WALL PRINTS ARE PRESENTED.

RVWALD
0. 0. .90117E-01 .90117E-01 .90117E-01 .90117E-01 .90117E-01 .90117E-01 .90117E-01 .90117E-01
.90117E-01

S= .1000 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	FZ	TZ	VORTREY	XLM11
0.	0.	0.	.385E+01	.380E+00	.573E-14	.301E-03	0.	.901E-01	.511E+00	0.	.885E+00
.164E-03	.471E-04	.148E-04	.385E+01	.380E+00	.133E-04	.301E-03	.752E-05	.902E-01	.511E+00	.620E-06	.885E+00
.373E-03	.107E-03	.336E-04	.385E+01	.380E+00	.303E-04	.301E-03	.171E-04	.902E-01	.511E+00	.321E-05	.885E+00
.639E-03	.184E-03	.574E-04	.385E+01	.380E+00	.520E-04	.301E-03	.294E-04	.902E-01	.511E+00	.945E-05	.885E+00
.979E-03	.281E-03	.883E-04	.385E+01	.380E+00	.797E-04	.301E-03	.450E-04	.903E-01	.511E+00	.222E-04	.885E+00
.141E-02	.406E-03	.127E-03	.385E+01	.380E+00	.115E-03	.301E-03	.649E-04	.903E-01	.511E+00	.462E-04	.885E+00
.196E-02	.565E-03	.177E-03	.385E+01	.380E+00	.160E-03	.301E-03	.904E-04	.904E-01	.512E+00	.895E-04	.885E+00
.267E-02	.767E-03	.241E-03	.385E+01	.380E+00	.218E-03	.301E-03	.123E-03	.905E-01	.512E+00	.165E-03	.885E+00
.357E-02	.103E-02	.322E-03	.385E+01	.380E+00	.291E-03	.301E-03	.164E-03	.906E-01	.512E+00	.296E-03	.885E+00
.471E-02	.136E-02	.426E-03	.385E+01	.380E+00	.385E-03	.301E-03	.217E-03	.908E-01	.513E+00	.517E-03	.885E+00
.618E-02	.178E-02	.559E-03	.385E+01	.380E+00	.504E-03	.301E-03	.285E-03	.909E-01	.513E+00	.889E-03	.885E+00
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.112E+01	.344E+00	.232E+00	.457E+01	.499E+00	.192E+00	.430E-03	.108E+00	.372E+00	.321E+00	.858E+02	.847E+00
.143E+01	.445E+00	.357E+00	.460E+01	.570E+00	.306E+00	.662E-03	.167E+00	.434E+00	-.404E+00	.164E+03	.845E+00
.182E+01	.569E+00	.536E+00	.428E+01	.682E+00	.487E+00	.134E-02	.259E+00	.424E+00	-.134E+01	.318E+03	.862E+00
.232E+01	.703E+00	.737E+00	.340E+01	.825E+00	.718E+00	.297E-02	.400E+00	.317E+00	-.179E+01	.684E+03	.910E+00
.296E+01	.826E+00	.898E+00	.224E+01	.948E+00	.915E+00	.651E-02	.600E+00	.166E+00	-.139E+01	.162E+04	.979E+00
.378E+01	.926E+00	.978E+00	.137E+01	.998E+00	.997E+00	.125E-01	.836E+00	.536E-01	-.640E+00	.277E+04	.101E+01
.482E+01	.101E+01	.997E+00	.105E+01	.100E+01	.100E+01	.169E-01	.974E+00	.910E-02	-.154E+00	.126E+04	.100E+01
.615E+01	.110E+01	.100E+01	.100E+01	.100E+01	.100E+01	.177E-01	.998E+00	.825E-03	-.171E-01	0.	.100E+01
.784E+01	.121E+01	.100E+01	.998E+00	.100E+01	.999E+00	.179E-01	.100E+01	.327E-04	-.115E-02	0.	.100E+01
.100E+02	.135E+01	.100E+01	.100E+01	.100E+01	.100E+01	.178E-01	.100E+01	0.	0.	0.	.100E+01

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S      =  .10000E+00  RETHET=  .44266E+03  DPEDS  = 0.                CFW    =  .70232E-03  ZSHK   = 0.                YE     =  .10200E-02
XI     =  .40149E-06  RES    =  .11474E+07  DTEDS  = 0.                QSD    = -.38437E+04  RSHK   = 0.                UTAU   = 0.
RMI    =  .87146E-02  PE     =  .12465E+04  DUEDS  = 0.                HD     =  .95464E+01  ITRO   =              0   TRFCT  = 0.
Z      =  .99619E-01  TE     =  .82278E+02  DLTAST=  .75760E-03        NSTE   =  .14672E-03  TW/TT1=  .38014E+00      YMP    =************
BETA   = 0.           RE     =  .52795E-01  THETA  =  .38580E-04       NSTW   =  .56468E-03  RFTRUE=  .31220E+00      P20    =  .76543E+02
XAL    =  .18248E+02  UE     =  .12280E+04  FORM   =  .19637E+02       NUE    =  .12121E+03  ROUSE  =  .27699E+04     OMEGA  =  .11062E-02
RVWALD=  .90117E-01   ME     =  .67543E+01  TAUD   =  .72642E+01       NUW    =  .35590E+02  DSMXO  =  .58418E+04
REDELT=  .86926E+04   MUE    =  .56504E-05  CFE    =  .18249E-03       SWANG  =            I  VW     =  .12151E+01     RVWAL  =  .13900E-02
NOITER=            6  ERROR  =  .15178E-02

S      =  .11000E+00  RETHET=  .58659E+03  DPEDS  = 0.                CFW    =  .78597E-04  ZSHK   = 0.                YE     =  .15302E-02
XI     =  .53453E-06  RES    =  .12621E+07  DTEDS  = 0.                QSD    = -.52038E+03  RSHK   = 0.                UTAU   = 0.
RMI    =  .95667E-02  PE     =  .12465E+04  DUEDS  = 0.                HD     =  .12924E+01  ITRO   =              0   TRFCT  = 0.
Z      =  .10958E+00  TE     =  .82278E+02  DLTAST=  .11162E-02        NSTE   =  .19864E-04  TW/TT1=  .38014E+00      YMP    =************
BETA   = 0.           RE     =  .52795E-01  THETA  =  .51124E-04       NSTW   =  .76450E-04  RFTRUE=  .31220E+00      P20    =  .76543E+02
XAL    =  .18248E+02  UE     =  .12280E+04  FORM   =  .21834E+02       NUE    =  .18051E+02  ROUSE  =  .51653E+04     OMEGA  =  .11062E-02
RVWALD=  .90117E-01   ME     =  .67543E+01  TAUD   =  .81295E+00       NUW    =  .53002E+01  DSMXO  =  .13475E+06
REDELT=  .12808E+05   MUE    =  .56504E-05  CFE    =  .20422E-04       SWANG  =            I  VW     =  .12745E+01     RVWAL  =  .13900E-02
NOITER=            6  ERROR  =  .10152E-01

SOLUTION HAS RESULTED IN GENERATION OF NEGATIVE TEMPERATURE WHICH CANNOT BE PHYSICALLY ACCEPTED. THIS GENERALLY OCCURS IN THE
REGION OF ADVERSE PRESSURE GRADIENT AND/OR MASS INJECTION AT WALL BOUNDARY AND IS AN INDICATION OF BOUNDARY LAYER SEPARATION.

IF DPEDS IS NEGATIVE AND THERE IS NO MASS INJECTION AT THE WALL BOUNDARY, THE PROBLEM IS PROBABLY CAUSED BY TOO COURSE
A STEP SIZE IN THE S-COORDINATE.

T3(N)=     -5.8932609N=   36  M=   46
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                               TEST CASE NO. 4

 THE LISTING FOR TEST CASE NO. 4 INCLUDES THE FOLLOWING:  (1) VARDIM DATA;  (2) $NAM1 AND $NAM2 INPUT;
     (3) INITIAL STATION SOLUTION;  (4)  REFEFENCE VALUES;  (5)  PROFILE AND WALL PRINTS AT S=.0495 M.
 NOTE:  TWO OUTPUT LISTINGS OF RESULTS FOLLOW:  (1) THE FIRST PASS OVER THE BODY CORRESPONDS TO CONSTANT
     ENTROPY CONDITIONS;  (2)  THE FINAL PASS OVER THE BODY FOR THE CONVERGED VARIBLE ENTROPY SOLUTION.

*VARDIM/VGBLP(JK= 43,JL= 33,JM= 33,JN=2,JI=1,JH= 34)
*VARDIM/TABLE(JJ=150,JH= 34)
*VARDIM/VARENT(JL= 33)
*VARDIM/TURBLNT(JI=1,JK= 43)
*VARDIM/MESH(JK= 43)
*VARDIM/SIMILAR(JK= 43)
*VARDIM/SOLVE(JK= 43)

 $NAM1
                                                                   DETA1  =              I  XMA    =  .20300E+02
IGEOM  =           1  XEND   =  .10000E+02  IE     =          41  XK     =  .10000E+01
PT1    =  .70000E+07  TT1    =  .28900E+03  IGAS   =           2  VISIC1 =  .22700E-07  VISIC2 =  .19860E+03  VIS2C1 =  .50231E-06
VIS2C2 =  .64700E+00  G      =  .16667E+01  R      =  .20790E+04  PR     =  .68800E+00

IBODY  =           1  WAVE   =  .90000E+02  PHII   =  .90000E+02  J      =           1  W      =           0  IENTRO =           2

SST    =  .10000E+09  SMXTR  =  .10000E+09  KODVIS =           2  KTCOD  =           2  TLNGTH =  .20000E+01  IYINT  =           1
KODAMP =           2  XT1    =  .40000E+00  XT2    =  .16800E-01  XT3    =  .50000E+01  XT4    =  .78000E+00  XT5    =  .10800E+00
XT6    =  .26000E+02  PRT    =  .95000E+00  KODPRT =           1  NUMB1  =           0  GLAR   =           I
PRTAR
    I
IEND1  =          33  PROINC =  .30000E-01  PRNTINC=  .15000E-02  IPRO   =           1  IPRNT  =           0  NAUXPRO=           0
FT     =  .10000E+01  KODE   =           0  KODWAL =           1  VELEDG =  .99500E+00  CONV   =  .10000E-03  NITMAX =           5
KODUNIT=           1  ITMAX  =           5  CONVE  =  .10000E-03

THIS COMPLETES THE OUTPUT OF $NAM1 WITH THE EXCEPTION OF PROVAL AND PRNTVAL. THESE VALUES ARE PRINTED JUST PRIOR TO THE
INITIAL STATION PRINT.
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$NAM2

NUMBER = 150
L = 1
S

0.	.33248E-03	.66498E-03	.99746E-03	.13299E-02	.16624E-02	.19949E-02	.23274E-02	.26599E-02	.29924E-02
.33248E-02	.36573E-02	.39898E-02	.43224E-02	.46549E-02	.49871E-02	.53197E-02	.56522E-02	.59847E-02	.63173E-02
.66498E-02	.69821E-02	.73146E-02	.76471E-02	.79797E-02	.83122E-02	.86447E-02	.89770E-02	.93095E-02	.96420E-02
.99746E-02	.10307E-01	.10640E-01	.10972E-01	.11304E-01	.11637E-01	.11969E-01	.12302E-01	.12635E-01	.12967E-01
.13299E-01	.13632E-01	.13964E-01	.14297E-01	.14630E-01	.14962E-01	.15294E-01	.15627E-01	.15959E-01	.16292E-01
.16624E-01	.16957E-01	.17289E-01	.17622E-01	.17954E-01	.18287E-01	.18619E-01	.18952E-01	.19284E-01	.19617E-01
.19949E-01	.20282E-01	.20614E-01	.20946E-01	.21279E-01	.21612E-01	.21944E-01	.22277E-01	.22609E-01	.22941E-01
.23274E-01	.23606E-01	.23939E-01	.24272E-01	.24604E-01	.24936E-01	.25269E-01	.25601E-01	.25934E-01	.26266E-01
.26599E-01	.26931E-01	.27264E-01	.27596E-01	.27929E-01	.28261E-01	.28594E-01	.28926E-01	.29259E-01	.29591E-01
.29924E-01	.30256E-01	.30590E-01	.30922E-01	.31254E-01	.31586E-01	.31919E-01	.32251E-01	.32583E-01	.32915E-01
.33248E-01	.33580E-01	.33912E-01	.34247E-01	.34580E-01	.34912E-01	.35244E-01	.35576E-01	.35908E-01	.36241E-01
.36573E-01	.36905E-01	.37237E-01	.37570E-01	.37902E-01	.38237E-01	.38569E-01	.38902E-01	.39234E-01	.39566E-01
.39898E-01	.40231E-01	.40563E-01	.40895E-01	.41227E-01	.41559E-01	.41892E-01	.42227E-01	.42559E-01	.42892E-01
.43224E-01	.43556E-01	.43888E-01	.44220E-01	.44553E-01	.44885E-01	.45217E-01	.45549E-01	.45882E-01	.46217E-01
.46549E-01	.46881E-01	.47214E-01	.47546E-01	.47878E-01	.48210E-01	.48542E-01	.48875E-01	.49207E-01	.49539E-01

Z

0.	.29014E-05	.11605E-04	.26107E-04	.46406E-04	.72491E-04	.10436E-03	.14200E-03	.18539E-03	.23454E-03
.28941E-03	.35000E-03	.41630E-03	.48826E-03	.56586E-03	.64910E-03	.73795E-03	.83241E-03	.93238E-03	.10379E-02
.11489E-02	.12653E-02	.13871E-02	.15144E-02	.16470E-02	.17848E-02	.19280E-02	.20763E-02	.22299E-02	.23885E-02
.25522E-02	.27209E-02	.28947E-02	.30733E-02	.32568E-02	.34452E-02	.36381E-02	.38359E-02	.40383E-02	.42453E-02
.44568E-02	.46729E-02	.48930E-02	.51176E-02	.53465E-02	.55797E-02	.58147E-02	.60497E-02	.62850E-02	.65200E-02
.67550E-02	.69903E-02	.72253E-02	.74603E-02	.76956E-02	.79306E-02	.81656E-02	.84009E-02	.86359E-02	.88709E-02
.91062E-02	.93412E-02	.95762E-02	.98115E-02	.10047E-01	.10282E-01	.10517E-01	.10752E-01	.10987E-01	.11222E-01
.11457E-01	.11692E-01	.11927E-01	.12162E-01	.12398E-01	.12633E-01	.12868E-01	.13103E-01	.13338E-01	.13573E-01
.13808E-01	.14043E-01	.14278E-01	.14514E-01	.14749E-01	.14984E-01	.15219E-01	.15454E-01	.15689E-01	.15924E-01
.16159E-01	.16394E-01	.16630E-01	.16865E-01	.17100E-01	.17335E-01	.17570E-01	.17805E-01	.18040E-01	.18275E-01
.18510E-01	.18746E-01	.18981E-01	.19216E-01	.19451E-01	.19686E-01	.19921E-01	.20156E-01	.20391E-01	.20626E-01
.20861E-01	.21096E-01	.21331E-01	.21567E-01	.21802E-01	.22037E-01	.22272E-01	.22507E-01	.22742E-01	.22977E-01
.23212E-01	.23447E-01	.23683E-01	.23918E-01	.24153E-01	.24388E-01	.24623E-01	.24858E-01	.25093E-01	.25328E-01
.25563E-01	.25799E-01	.26034E-01	.26269E-01	.26504E-01	.26739E-01	.26974E-01	.27209E-01	.27444E-01	.27679E-01
.27914E-01	.28149E-01	.28385E-01	.28620E-01	.28855E-01	.29090E-01	.29325E-01	.29560E-01	.29795E-01	.30030E-01

RMI

0.	.33248E-03	.66483E-03	.99700E-03	.13289E-02	.16603E-02	.19913E-02	.23216E-02	.26512E-02	.29801E-02
.33080E-02	.36350E-02	.39606E-02	.42852E-02	.46086E-02	.49304E-02	.52508E-02	.55696E-02	.58869E-02	.62021E-02
.65154E-02	.68269E-02	.71363E-02	.74435E-02	.77483E-02	.80510E-02	.83509E-02	.86484E-02	.89434E-02	.92357E-02
.95250E-02	.98115E-02	.10095E-01	.10375E-01	.10653E-01	.10927E-01	.11197E-01	.11464E-01	.11728E-01	.11989E-01
.12245E-01	.12498E-01	.12747E-01	.12992E-01	.13233E-01	.13470E-01	.13706E-01	.13941E-01	.14176E-01	.14411E-01
.14646E-01	.14881E-01	.15116E-01	.15351E-01	.15586E-01	.15822E-01	.16057E-01	.16292E-01	.16527E-01	.16762E-01
.16997E-01	.17232E-01	.17467E-01	.17702E-01	.17938E-01	.18172E-01	.18407E-01	.18643E-01	.18878E-01	.19113E-01
.19348E-01	.19583E-01	.19818E-01	.20053E-01	.20288E-01	.20523E-01	.20759E-01	.20994E-01	.21229E-01	.21464E-01
.21699E-01	.21934E-01	.22169E-01	.22404E-01	.22639E-01	.22875E-01	.23110E-01	.23345E-01	.23580E-01	.23815E-01
.24050E-01	.24285E-01	.24520E-01	.24755E-01	.24991E-01	.25226E-01	.25461E-01	.25696E-01	.25931E-01	.26166E-01
.26401E-01	.26636E-01	.26871E-01	.27106E-01	.27342E-01	.27576E-01	.27812E-01	.28047E-01	.28282E-01	.28517E-01
.28752E-01	.28987E-01	.29222E-01	.29457E-01	.29692E-01	.29928E-01	.30163E-01	.30398E-01	.30632E-01	.30867E-01
.31102E-01	.31340E-01	.31574E-01	.31809E-01	.32044E-01	.32278E-01	.32513E-01	.32748E-01	.32982E-01	.33220E-01
.33455E-01	.33690E-01	.33924E-01	.34159E-01	.34394E-01	.34628E-01	.34866E-01	.35101E-01	.35335E-01	.35570E-01
.35805E-01	.36040E-01	.36274E-01	.36509E-01	.36747E-01	.36981E-01	.37216E-01	.37451E-01	.37685E-01	.37920E-01

TW

.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03
.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03	.28889E+03

QW

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

RVWALD

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

PE

.18802E+05	.18796E+05	.18781E+05	.18754E+05	.18716E+05	.18669E+05	.18610E+05	.18541E+05	.18461E+05	.18371E+05
.18270E+05	.18159E+05	.18037E+05	.17905E+05	.17762E+05	.17609E+05	.17446E+05	.17272E+05	.17088E+05	.16895E+05
.16691E+05	.16477E+05	.16253E+05	.16019E+05	.15776E+05	.15522E+05	.15259E+05	.14987E+05	.14705E+05	.14413E+05
.14114E+05	.13831E+05	.13539E+05	.13239E+05	.12931E+05	.12614E+05	.12290E+05	.11957E+05	.11611E+05	.11259E+05
.10898E+05	.10529E+05	.10310E+05	.10446E+05	.10557E+05	.10669E+05	.10776E+05	.10875E+05	.10974E+05	.11047E+05
.11112E+05	.11176E+05	.11240E+05	.11304E+05	.11361E+05	.11400E+05	.11440E+05	.11479E+05	.11519E+05	.11558E+05
.11591E+05	.11623E+05	.11655E+05	.11687E+05	.11719E+05	.11746E+05	.11768E+05	.11791E+05	.11813E+05	.11835E+05
.11857E+05	.11874E+05	.11891E+05	.11908E+05	.11926E+05	.11943E+05	.11957E+05	.11969E+05	.11982E+05	.11994E+05
.12006E+05	.12018E+05	.12031E+05	.12043E+05	.12055E+05	.12068E+05	.12080E+05	.12087E+05	.12093E+05	.12099E+05
.12105E+05	.12111E+05	.12118E+05	.12124E+05	.12130E+05	.12136E+05	.12142E+05	.12148E+05	.12151E+05	.12153E+05
.12155E+05	.12158E+05	.12161E+05	.12163E+05	.12165E+05	.12168E+05	.12170E+05	.12173E+05	.12175E+05	.12175E+05
.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05
.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05
.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05
.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05	.12175E+05

```
SS
.15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02
.15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02
.15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02  .15000E-02
.15000E-02  .15000E-02  .15000E-02  .15000E-02

THE FOLLOWING SPOINT VALUES DESIGNATE THE S-COORDINATE LOCATIONS WHERE THE SOLUTIONS ARE OBTAINED DURING THE S-MARCH.
YOUR PRINT STATION MUST AGREE WITH ONE OR MORE OF THE SPOINT LOCATIONS; IE, YOU CAN PRINT ONLY AT SOLUTION STATIONS.
IF THE CASE COMPLETES WITH A NORMAL STOP AND NO OUTPUT IS PRINTED, YOUR PRINT INPUT IS IN ERROR. THE ERROR CAN BE
NOTED BY COMPARING PROVAL AND PRNTVAL WITH SPOINT.

SPOINT
.15000E-02  .30000E-02  .45000E-02  .60000E-02  .75000E-02  .90000E-02  .10500E-01  .12000E-01  .13500E-01  .15000E-01
.16500E-01  .18000E-01  .19500E-01  .21000E-01  .22500E-01  .24000E-01  .25500E-01  .27000E-01  .28500E-01  .30000E-01
.31500E-01  .33000E-01  .34500E-01  .36000E-01  .37500E-01  .39000E-01  .40500E-01  .42000E-01  .43500E-01  .45000E-01
.46500E-01  .48000E-01  .49500E-01  .15000E-02
```

```
$NAM3

NUMBER =         30
RRS
0.           .76200E-03  .15240E-02  .22860E-02  .30480E-02  .38100E-02  .45720E-02  .53340E-02  .60960E-02  .68580E-02
 .76200E-02  .83820E-02  .91440E-02  .99060E-02  .10668E-01  .11430E-01  .12192E-01  .12954E-01  .13716E-01  .14478E-01
 .15240E-01  .16002E-01  .16764E-01  .17526E-01  .18288E-01  .19050E-01  .19812E-01  .22860E-01  .34290E-01  .49530E-01
0.          0.          0.
ZZS
-.41910E-02 -.41605E-02 -.41453E-02 -.40843E-02 -.39624E-02 -.38100E-02 -.36576E-02 -.34900E-02 -.33223E-02 -.31090E-02
-.28575E-02 -.26213E-02 -.23470E-02 -.20726E-02 -.17678E-02 -.14630E-02 -.10973E-02 -.76200E-03 -.41148E-03 -.60960E-04
 .38100E-03  .82296E-03  .12954E-02  .17678E-02  .22860E-02  .28575E-02  .33833E-02  .57150E-02  .14288E-01  .24765E-01
0.          0.          0.
DRSDZS
 .24984E+02  .33348E+02  .20000E+02  .83324E+01  .55560E+01  .50000E+01  .47625E+01  .45452E+01  .39996E+01  .32788E+01
 .31251E+01  .29853E+01  .27775E+01  .26314E+01  .25000E+01  .22728E+01  .21740E+01  .22222E+01  .21739E+01  .19231E+01
 .17241E+01  .16667E+01  .16130E+01  .15385E+01  .13986E+01  .13889E+01  .13333E+01  .13277E+01  .14000E+01  .14546E+01
0.          0.          0.

PRINT STATIONS DESIGNATED IN $NAM1 INPUT AND GENERATED IN SETUP

PROVAL
 .49500E-01  .30000E-01
PRNTVAL
 .15000E-02  .30000E-02  .45000E-02  .60000E-02  .75000E-02  .90000E-02  .10500E-01  .12000E-01  .13500E-01  .15000E-01
 .16500E-01  .18000E-01  .19500E-01  .21000E-01  .22500E-01  .24000E-01  .25500E-01  .27000E-01  .28500E-01  .30000E-01
 .31500E-01  .33000E-01  .34500E-01  .36000E-01  .37500E-01  .39000E-01  .40500E-01  .42000E-01  .43500E-01  .45000E-01
 .46500E-01  .48000E-01  .49500E-01
```

SIMILAR SOLUTION REQUIRED TO INITIATE MARCHING PROCEDURE

PROFILE VALUES

ETA	U/UE	T/TE	V	FZ	TZ	XL
0.	0.	.999615E+00	0.	.928175E+00	.180125E-03	.100014E+01
.250000E+00	.216480E+00	.999660E+00	-.270599E-01	.803662E+00	.179292E-03	.100012E+01
.500000E+00	.401831E+00	.999705E+00	-.104349E+00	.680148E+00	.177286E-03	.100010E+01
.750000E+00	.556554E+00	.999749E+00	-.224147E+00	.560071E+00	.172371E-03	.100009E+01
.100000E+01	.681867E+00	.999791E+00	-.378949E+00	.446656E+00	.163709E-03	.100007E+01
.125000E+01	.779882E+00	.999831E+00	-.561668E+00	.343457E+00	.151070E-03	.100006E+01
.150000E+01	.853595E+00	.999867E+00	-.765852E+00	.253608E+00	.134879E-03	.100005E+01
.175000E+01	.906686E+00	.999898E+00	-.985888E+00	.179157E+00	.116137E-03	.100004E+01
.200000E+01	.943173E+00	.999925E+00	-.121712E+01	.120683E+00	.962084E-04	.100003E+01
.225000E+01	.967027E+00	.999946E+00	-.145590E+01	.772904E-01	.765431E-04	.100002E+01
⋮	⋮	⋮	⋮	⋮	⋮	⋮
.775000E+01	.100000E+01	.100000E+01	-.694273E+01	.163425E-12	.381561E-11	.100000E+01
.800000E+01	.100000E+01	.100000E+01	-.719273E+01	.284217E-13	.966338E-12	.100000E+01
.825000E+01	.100000E+01	.100000E+01	-.744273E+01	.142109E-13	.234479E-12	.100000E+01
.850000E+01	.100000E+01	.100000E+01	-.769273E+01	.710543E-14	.710543E-13	.100000E+01
.875000E+01	.100000E+01	.100000E+01	-.794273E+01	.710543E-14	.284217E-13	.100000E+01
.900000E+01	.100000E+01	.100000E+01	-.819273E+01	.213163E-13	.213163E-13	.100000E+01
.925000E+01	.100000E+01	.100000E+01	-.844273E+01	.142109E-13	.284217E-13	.100000E+01
.950000E+01	.100000E+01	.100000E+01	-.869273E+01	.284217E-13	.284217E-13	.100000E+01
.975000E+01	.100000E+01	.100000E+01	-.894273E+01	.284217E-13	.284217E-13	.100000E+01
.100000E+02	.100000E+01	.100000E+01	-.919273E+01	0.	0.	.100000E+01

CONVERGED SELF-SIMILAR SOLUTION REQUIRED 7ITERATIONS.

INITIAL STATION PARAMETERS

MUE = .196497E-04 UE =0. TE = .289000E+03 PE = .188020E+05 QSD =-.144357E+02
XAL =0. XBE = .500000E+00 RE = .312933E-01

****DIMENSIONAL OUTPUT QUANTITIES ARE IN S.I. UNITS****

FREE STREAM VALUES-DIMENSIONAL

PT1 =	.700000E+07	TT1 =	.289000E+03	RT1 =	.116505E+02	P1 =	.310923E+02	T1=	.208860E+01	R1 =	.716049E-02
U1 =	.172695E+04	AA1 =	.850714E+02	XMA =	.203000E+02	REY =	.152799E+08				

REFERENCE VALUES-DIMENSIONAL

PREF=	.213551E+05	TPEF=	.573823E+03	RREF=	.716049E-02	UREF=	.172695E+04	VISREF=	.306256E-04	PTR =	.327790E+03

S= .0495 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	FZ	TZ	VORTREY	XLM11
0.	0.	0.	.119E+01	.100E+01	.185E-10	.174E-02	0.	.482E+00	-.133E-01	0.	.940E+00
.250E+00	.745E-01	.121E+00	.118E+01	.998E+00	-.546E+01	.175E-02	.111E+00	.481E+00	-.286E-01	.496E+01	.942E+00
.500E+00	.148E+00	.240E+00	.118E+01	.997E+00	-.717E+01	.178E-02	.222E+00	.475E+00	-.432E-01	.199E+02	.944E+00
.750E+00	.222E+00	.358E+00	.116E+01	.998E+00	-.533E+01	.183E-02	.332E+00	.461E+00	-.565E-01	.443E+02	.948E+00
.100E+01	.294E+00	.471E+00	.115E+01	.999E+00	-.501E+00	.190E-02	.440E+00	.438E+00	-.674E-01	.767E+02	.953E+00
.125E+01	.365E+00	.577E+00	.113E+01	.100E+01	.635E+01	.199E-02	.543E+00	.404E+00	-.749E-01	.114E+03	.958E+00
.150E+01	.435E+00	.673E+00	.111E+01	.100E+01	.139E+02	.210E-02	.639E+00	.359E+00	-.781E-01	.150E+03	.964E+00
.175E+01	.503E+00	.757E+00	.109E+01	.101E+01	.208E+02	.221E-02	.724E+00	.306E+00	-.768E-01	.180E+03	.970E+00
.200E+01	.571E+00	.826E+00	.107E+01	.101E+01	.257E+02	.232E-02	.798E+00	.250E+00	-.714E-01	.197E+03	.976E+00
.225E+01	.637E+00	.881E+00	.105E+01	.101E+01	.280E+02	.242E-02	.858E+00	.193E+00	-.628E-01	.199E+03	.981E+00
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.400E+01	.108E+01	.998E+00	.100E+01	.100E+01	.574E+01	.268E-02	.997E+00	.623E-02	-.662E-02	.212E+02	.999E+00
.425E+01	.114E+01	.999E+00	.100E+01	.100E+01	.383E+01	.269E-02	.998E+00	.293E-02	-.400E-02	0.	.999E+00
.450E+01	.120E+01	.100E+01	.100E+01	.100E+01	.259E+01	.269E-02	.999E+00	.128E-02	-.230E-02	0.	.100E+01
.475E+01	.126E+01	.100E+01	.100E+01	.100E+01	.185E+01	.269E-02	.100E+01	.520E-03	-.127E-02	0.	.100E+01
.500E+01	.133E+01	.100E+01	.100E+01	.100E+01	.143E+01	.269E-02	.100E+01	.195E-03	-.665E-03	0.	.100E+01
.525E+01	.139E+01	.100E+01	.100E+01	.100E+01	.120E+01	.269E-02	.100E+01	.676E-04	-.333E-03	0.	.100E+01
.550E+01	.145E+01	.100E+01	.100E+01	.100E+01	.109E+01	.269E-02	.100E+01	.216E-04	-.158E-03	0.	.100E+01
.575E+01	.151E+01	.100E+01	.100E+01	.100E+01	.104E+01	.269E-02	.100E+01	.630E-05	-.717E-04	0.	.100E+01
.600E+01	.157E+01	.100E+01	.100E+01	.100E+01	.102E+01	.269E-02	.100E+01	.168E-05	-.308E-04	0.	.100E+01
.625E+01	.163E+01	.100E+01	.100E+01	.100E+01	.101E+01	.269E-02	.100E+01	.407E-06	-.126E-04	0.	.100E+01

```
S      =  .49500E-01  RETHET=  .84412E+02  DPEDS = -.38981E-02  CFW    =  .58682E-02  ZSHK   = -.30304E-02  YE     =  .76811E-03
XI     =  .19720E-04  RES    =  .47197E+05  DTEDS = -.10389E+01  QSD    =  .20878E+04  RSHK   =  .71088E-02  UTAU   = 0.
RMI    =  .37893E-01  PE     =  .12175E+05  DUEDS =  .25865E+01  HD     =  .26827E+03  ITRO   =            0  TRFCT  = 0.
Z      =  .30003E-01  TE     =  .24272E+03  DLTAST=  .29136E-03  NSTE   =  .30868E-02  TW/TT1=  .99962E+00  YMP    =            0
BETA   =  .25399E-03  RE     =  .24127E-01  THETA =  .88531E-04  NSTW   =  .36741E-02  RFTRUE=  .99760E+00  P2O    =  .10154E+01
XAL    =  .38139E+00  UE     =  .69362E+03  FORM  =  .32911E+01  NUE    =  .10023E+03  ROUSE =  .19874E+03  OMEGA  =  .15737E-02
RVWALD= 0.            ME     =  .75634E+00  TAUD  =  .28615E+02  NUW    =  .89554E+02  DSMXO =  .15627E+04
REDELT=  .27781E+03   MUE    =  .17551E-04  CFE   =  .49302E-02  SWANG  =  .72469E+02  VW     = 0.           RVWAL  = 0.
NOITER=            2  ERROR  =  .30815E-04

*************************************************
*        VARIBLE ENTROPY CALCULATIONS           *
*         ITMAX=       5  NOIT=       1         *
*                                               *
*************************************************
```

S= .0495 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	FZ	TZ	VORTREY	XLM11
0.	0.	0.	.126E+01	.100E+01	.185E-10	.174E-02	0.	.489E+00	-.284E-01	0.	.922E+00
.250E+00	.771E-01	.122E+00	.125E+01	.995E+00	-.127E+02	.175E-02	.109E+00	.487E+00	-.507E-01	.532E+01	.925E+00
.500E+00	.153E+00	.244E+00	.123E+01	.992E+00	-.207E+02	.179E-02	.219E+00	.480E+00	-.710E-01	.214E+02	.929E+00
.750E+00	.228E+00	.362E+00	.121E+01	.990E+00	-.237E+02	.186E-02	.329E+00	.465E+00	-.879E-01	.482E+02	.934E+00
.100E+01	.302E+00	.476E+00	.119E+01	.991E+00	-.218E+02	.196E-02	.437E+00	.440E+00	-.998E-01	.840E+02	.941E+00
.125E+01	.374E+00	.583E+00	.116E+01	.994E+00	-.156E+02	.209E-02	.540E+00	.404E+00	-.106E+00	.125E+03	.948E+00
.150E+01	.444E+00	.678E+00	.114E+01	.997E+00	-.643E+01	.223E-02	.637E+00	.358E+00	-.106E+00	.167E+03	.956E+00
.175E+01	.513E+00	.762E+00	.111E+01	.100E+01	.355E+01	.239E-02	.723E+00	.304E+00	-.100E+00	.201E+03	.964E+00
.200E+01	.580E+00	.830E+00	.109E+01	.100E+01	.123E+02	.254E-02	.797E+00	.246E+00	-.905E-01	.221E+03	.971E+00
.225E+01	.646E+00	.885E+00	.106E+01	.101E+01	.184E+02	.269E-02	.857E+00	.190E+00	-.777E-01	.222E+03	.978E+00
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.400E+01	.108E+01	.998E+00	.100E+01	.100E+01	.569E+01	.308E-02	.997E+00	.593E-02	-.740E-02	.109E+02	.999E+00
.425E+01	.114E+01	.999E+00	.100E+01	.100E+01	.383E+01	.309E-02	.998E+00	.278E-02	-.443E-02	.792E+01	.999E+00
.450E+01	.120E+01	.100E+01	.100E+01	.100E+01	.260E+01	.309E-02	.999E+00	.121E-02	-.254E-02	.553E+01	.100E+01
.475E+01	.126E+01	.100E+01	.100E+01	.100E+01	.185E+01	.309E-02	.100E+01	.489E-03	-.139E-02	.371E+01	.100E+01
.500E+01	.132E+01	.100E+01	.100E+01	.100E+01	.143E+01	.309E-02	.100E+01	.183E-03	-.724E-03	0.	.100E+01
.525E+01	.139E+01	.100E+01	.100E+01	.100E+01	.120E+01	.309E-02	.100E+01	.631E-04	-.360E-03	0.	.100E+01
.550E+01	.145E+01	.100E+01	.100E+01	.100E+01	.109E+01	.309E-02	.100E+01	.201E-04	-.170E-03	0.	.100E+01
.575E+01	.151E+01	.100E+01	.100E+01	.100E+01	.104E+01	.309E-02	.100E+01	.584E-05	-.767E-04	0.	.100E+01
.600E+01	.157E+01	.100E+01	.100E+01	.100E+01	.102E+01	.309E-02	.100E+01	.155E-05	-.329E-04	0.	.100E+01
.625E+01	.163E+01	.100E+01	.100E+01	.100E+01	.101E+01	.309E-02	.100E+01	.374E-06	-.134E-04	0.	.100E+01

S =	.49500E-01	RETHET=	.91401E+02	DPEDS =	-.38981E-02	CFW =	.56633E-02	ZSHK =	-.29594E-02	YE =	.68738E-03
XI =	.21807E-04	RES =	.58614E+05	DTEDS =	-.85032E+00	QSD =	.45493E+04	RSHK =	.73057E-02	UTAU =	0.
RMI =	.37893E-01	PE =	.12175E+05	DUEDS =	.18684E+01	HD =	.45387E+03	ITRO =	3	TRFCT =	0.
Z =	.30003E-01	TE =	.22957E+03	DLTAST=	.26938E-03	NSTE =	.43593E-02	TW/TT1=	.99962E+00	YMP =	0
BETA =	.17905E-03	RE =	.25508E-01	THETA =	.77189E-04	NSTW =	.54857E-02	RFTRUE=	.99813E+00	P20 =	.10136E+01
XAL =	.51770E+00	UE =	.78595E+03	FORM =	.34898E+01	NUE =	.17580E+03	ROUSE =	.22197E+03	OMEGA =	.15737E-02
RVWALD=	0.	ME =	.88120E+00	TAUD =	.35457E+02	NUW =	.15151E+03	DSMXO =	.20241E+04		
REDELT=	.31897E+03	MUE =	.16931E-04	CFE =	.45005E-02	SWANG =	.72579E+02	VW =	0.		
NOITER=	2	ERROR =	.18193E-04							RVWAL =	0.

YOUR VARIBLE CASE ENTROPY IS CONVERGED TO YOUR SELECTED INPUT VALUE OF CONVE.

TEST CASE NO. 5

THE LISTING FOR TEST CASE NO. 5 INCLUDES THE FOLLOWING: (1) VARDIM DATA; (2) $NAM1 AND $NAM2 INPUT; (3) INITIAL STATION SOLUTION; (4) REFEFENCE VALUES; (5) PROFILE AND WALL PRINTS AT S=.6385 M.

```
*VARDIM/VGBLP(JK=103,JL=1,JM= 99,JN= 2,JI=1,JH=101)
*VARDIM/TABLE(JJ=100,JH=101)
*VARDIM/VARENT(JL=1)
*VARDIM/TURBLNT(JI=1,JK=103)
*VARDIM/MESH(JK=103)
*VARDIM/SIMILAR(JK=103)
*VARDIM/SOLVE(JK=103)

 $NAM1

IGEOM  =           1  XEND   =  .60000E+02  IF     =          101  XK     =  .12754E+01  DETA1  =           I  XMA    =  .12058E-01
PT1    =  .34500E+07  TT1    =  .37700E+03  IGAS   =            1  VISIC1 =  .14582E-05  VISIC2 =  .11033E+03  VIS2C1 =           I
VIS2C2 =           I  G      =  .14000E+01  R      =  .28696E+03  PR     =  .72000E+00

IBODY  =           2  WAVE   = 0.           PHII   = 0.           J      =           1  W      =           0  IENTRO =           1

SST    =  .30000E-03  SMXTR  =  .10000E+09  KODVIS =            2  KTCOD  =           2  TLNGTH =  .20000E+01  IYINT  =           1
KODAMP =           2  XT1    =  .40000E+00  XT2    =  .16800E-01  XT3    =  .50000E+01  XT4    =  .78000E+00  XT5    =  .10800E+00
XT6    =  .26000E+02  PRT    =  .95000E+00  KODPRT =            1  NUMB1  =           0  GLAR   =           I
PRTAR
    I

IEND1  =         100  PROINC = 0.           PRNTINC= 0.           IPRO   =           2  IPRNT  =          99  NAUXPRO=           0
FT     =  .10000E+01  KODE   =           0  KODWAL =            2  VELEDG =  .99500E+00  CONV   =  .10000E-03  NITMAX =           5
KODUNIT=           1  ITMAX  =           3  CONVE  =  .10000E-01
```

THIS COMPLETES THE OUTPUT OF $NAM1 WITH THE EXCEPTION OF PROVAL AND PRNTVAL. THESE VALUES ARE PRINTED JUST PRIOR TO THE INITIAL STATION PRINT.

```
$NAM2

NUMBER =        100
L      =          1
S
0.          .43266E-02  .13029E-01  .23303E-01  .36585E-01  .50368E-01  .62798E-01  .72764E-01  .82604E-01  .92552E-01
 .10107E+00 .10986E+00  .11861E+00  .12723E+00  .13579E+00  .13604E+00  .13683E+00  .13843E+00  .14001E+00  .14161E+00
 .14318E+00 .14636E+00  .15272E+00  .15906E+00  .16538E+00  .17175E+00  .17808E+00  .18444E+00  .19079E+00  .19713E+00
 .20350E+00 .20984E+00  .21619E+00  .22256E+00  .22891E+00  .23526E+00  .24161E+00  .24799E+00  .25434E+00  .26069E+00
 .26706E+00 .27342E+00  .27978E+00  .28613E+00  .29248E+00  .29885E+00  .30521E+00  .31157E+00  .31793E+00  .32427E+00
 .33062E+00 .33697E+00  .34335E+00  .34971E+00  .35604E+00  .36240E+00  .36876E+00  .37511E+00  .38146E+00  .38784E+00
 .39419E+00 .40053E+00  .40690E+00  .41324E+00  .41958E+00  .42595E+00  .43231E+00  .43865E+00  .44501E+00  .45137E+00
 .45771E+00 .46407E+00  .47042E+00  .47577E+00  .48311E+00  .48947E+00  .49582E+00  .50218E+00  .50853E+00  .51489E+00
 .51948E+00 .52124E+00  .52759E+00  .53394E+00  .54029E+00  .54665E+00  .55300E+00  .55935E+00  .56570E+00  .57205E+00
 .57840E+00 .58473E+00  .59108E+00  .59743E+00  .60454E+00  .61013E+00  .61648E+00  .62918E+00  .63553E+00  .63853E+00
Z
0.          .43190E-02  .12701E-01  .21336E-01  .29971E-01  .38481E-01  .47497E-01  .55498E-01  .64008E-01  .73152E-01
 .81205E-01 .89663E-01  .98246E-01  .10678E+00  .11531E+00  .11557E+00  .11636E+00  .11796E+00  .11953E+00  .12113E+00
 .12271E+00 .12588E+00  .13223E+00  .13856E+00  .14486E+00  .15118E+00  .15745E+00  .16375E+00  .17003E+00  .17627E+00
 .18255E+00 .18880E+00  .19505E+00  .20132E+00  .20757E+00  .21382E+00  .22007E+00  .22634E+00  .23259E+00  .23884E+00
 .24511E+00 .25138E+00  .25766E+00  .26393E+00  .27021E+00  .27651E+00  .28280E+00  .28910E+00  .29540E+00  .30170E+00
 .30800E+00 .31430E+00  .32063E+00  .32695E+00  .33325E+00  .33957E+00  .34590E+00  .35222E+00  .35855E+00  .36490E+00
 .37122E+00 .37755E+00  .38390E+00  .39022E+00  .39654E+00  .40289E+00  .40925E+00  .41557E+00  .42192E+00  .42827E+00
 .43459E+00 .44095E+00  .44729E+00  .45263E+00  .45997E+00  .46632E+00  .47267E+00  .47902E+00  .48537E+00  .49172E+00
 .49631E+00 .49807E+00  .50442E+00  .51077E+00  .51712E+00  .52347E+00  .52982E+00  .53617E+00  .54252E+00  .54887E+00
 .55522E+00 .56154E+00  .56789E+00  .57424E+00  .58135E+00  .58694E+00  .59329E+00  .60599E+00  .61234E+00  .61534E+00
RMI
 .69851E-01 .69595E-01  .66294E-01  .59055E-01  .46430E-01  .37286E-01  .29947E-01  .24613E-01  .20498E-01  .17145E-01
 .14527E-01 .12625E-01  .11101E-01  .10311E-01  .10083E-01  .10083E-01  .10083E-01  .10083E-01  .10110E-01  .10135E-01
 .10186E-01 .10235E-01  .10363E-01  .10744E-01  .11253E-01  .11912E-01  .12674E-01  .13564E-01  .14530E-01  .15545E-01
 .16612E-01 .17703E-01  .18821E-01  .19937E-01  .21056E-01  .22199E-01  .23342E-01  .24485E-01  .25628E-01  .26746E-01
 .27865E-01 .28932E-01  .29971E-01  .30989E-01  .31980E-01  .32918E-01  .33857E-01  .34747E-01  .35610E-01  .36424E-01
 .37085E-01 .37999E-01  .38761E-01  .39472E-01  .40182E-01  .40843E-01  .41477E-01  .42114E-01  .42696E-01  .43282E-01
 .43815E-01 .44348E-01  .44882E-01  .45339E-01  .45821E-01  .46278E-01  .46659E-01  .47092E-01  .47497E-01  .47829E-01
 .48210E-01 .48564E-01  .48844E-01  .49173E-01  .49478E-01  .49734E-01  .50012E-01  .50268E-01  .50469E-01  .50697E-01
 .50926E-01 .51030E-01  .51078E-01  .51283E-01  .51435E-01  .51612E-01  .51740E-01  .51993E-01  .52145E-01  .52221E-01
 .52349E-01 .52401E-01  .52502E-01  .52554E-01  .52630E-01  .52654E-01  .52679E-01  .52782E-01  .52858E-01  .52858E-01
```

OW

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

RVWALD

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

PE

.34470E+07	.34470E+07	.34469E+07	.34467E+07	.34456E+07	.34431E+07	.34368E+07	.34245E+07	.33993E+07	.33476E+07
.32474E+07	.30757E+07	.27434E+07	.23008E+07	.18218E+07	.18099E+07	.17823E+07	.16823E+07	.16306E+07	.15410E+07
.14479E+07	.13100E+07	.10756E+07	.85150E+06	.75842E+06	.54813E+06	.43092E+06	.34129E+06	.27786E+06	.22408E+06
.19822E+06	.14824E+06	.12169E+06	.10066E+06	.84461E+05	.71361E+05	.61019E+05	.56192E+05	.47574E+05	.43092E+05
.38611E+05	.35336E+05	.31647E+05	.28820E+05	.26717E+05	.24752E+05	.23097E+05	.21650E+05	.20305E+05	.19133E+05
.18133E+05	.17168E+05	.16203E+05	.15444E+05	.14755E+05	.14134E+05	.13514E+05	.13031E+05	.12514E+05	.12066E+05
.11721E+05	.11376E+05	.10997E+05	.10687E+05	.10342E+05	.10066E+05	.98250E+04	.95837E+04	.92734E+04	.90321E+04
.88598E+04	.86184E+04	.84461E+04	.83082E+04	.82048E+04	.79979E+04	.79290E+04	.78600E+04	.76877E+04	.76187E+04
.75498E+04	.75153E+04	.74463E+04	.73429E+04	.72740E+04	.72395E+04	.71629E+04	.71016E+04	.70327E+04	.69637E+04
.69223E+04	.68948E+04	.68603E+04	.68913E+04	.68086E+04	.67569E+04	.67224E+04	.66534E+04	.66190E+04	.65845E+04

SS

.43431E-02	.43431E-02	.43431E-02	.10274E-01	.13282E-01	.13783E-01	.12430E-01	.99664E-02	.98402E-02	.99481E-02
.85225E-02	.87819E-02	.87572E-02	.86194E-02	.85542E-02	.25603E-03	.78638E-03	.16002E-02	.15761E-02	.16008E-02
.15734E-02	.31781E-02	.63572E-02	.63408E-02	.63273E-02	.63648E-02	.63267E-02	.63688E-02	.63502E-02	.63340E-02
.63685E-02	.63450E-02	.63475E-02	.63718E-02	.63493E-02	.63523E-02	.63520E-02	.63764E-02	.63496E-02	.63478E-02
.63706E-02	.63606E-02	.63566E-02	.63557E-02	.63465E-02	.63700E-02	.63627E-02	.63612E-02	.63551E-02	.63429E-02
.63490E-02	.63551E-02	.63703E-02	.63642E-02	.63337E-02	.63581E-02	.63551E-02	.63551E-02	.63520E-02	.63764E-02

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 .63459E-02  .63459E-02  .63703E-02  .63398E-02  .63429E-02  .63642E-02  .63642E-02  .63398E-02  .63581E-02  .63581E-02
 .63368E-02  .63612E-02  .63551E-02  .53431E-02  .73457E-02  .63581E-02  .63551E-02  .63520E-02  .63551E-02  .63551E-02
 .45964E-02  .17556E-02  .63520E-02  .63520E-02  .63520E-02  .63551E-02  .63490E-02  .63520E-02  .63520E-02  .63490E-02
 .63520E-02  .63246E-02  .63520E-02  .63490E-02  .71110E-02  .55900E-02  .63490E-02  .12704E-01  .63490E-02  .29962E-02
0.

THE FOLLOWING SPOINT VALUES DESIGNATE THE S-COORDINATE LOCATIONS WHERE THE SOLUTIONS ARE OBTAINED DURING THE S-MARCH.
YOUR PRINT STATION MUST AGREE WITH ONE OR MORE OF THE SPOINT LOCATIONS; IE, YOU CAN PRINT ONLY AT SOLUTION STATIONS.
IF THE CASE COMPLETES WITH A NORMAL STOP AND NO OUTPUT IS PRINTED, YOUR PRINT INPUT IS IN ERROR. THE ERROR CAN BE
NOTED BY COMPARING PROVAL AND PRNTVAL WITH SPOINT.

SPOINT
 .43431E-02  .86862E-02  .13029E-01  .23303E-01  .36585E-01  .50368E-01  .62798E-01  .72764E-01  .82604E-01  .92552E-01
 .10107E+00  .10986E+00  .11861E+00  .12723E+00  .13579E+00  .13604E+00  .13683E+00  .13843E+00  .14001E+00  .14161E+00
 .14318E+00  .14636E+00  .15272E+00  .15906E+00  .16538E+00  .17175E+00  .17808E+00  .18444E+00  .19079E+00  .19713E+00
 .20350E+00  .20984E+00  .21619E+00  .22256E+00  .22891E+00  .23526E+00  .24161E+00  .24799E+00  .25434E+00  .26069E+00
 .26706E+00  .27342E+00  .27978E+00  .28613E+00  .29248E+00  .29885E+00  .30521E+00  .31157E+00  .31793E+00  .32427E+00
 .33062E+00  .33697E+00  .34335E+00  .34971E+00  .35604E+00  .36240E+00  .36876E+00  .37511E+00  .38146E+00  .38784E+00
 .39419E+00  .40053E+00  .40690E+00  .41324E+00  .41958E+00  .42595E+00  .43231E+00  .43865E+00  .44501E+00  .45137E+00
 .45771E+00  .46407E+00  .47042E+00  .47577E+00  .48311E+00  .48947E+00  .49582E+00  .50218E+00  .50853E+00  .51489E+00
 .51948E+00  .52124E+00  .52759E+00  .53394E+00  .54029E+00  .54665E+00  .55300E+00  .55935E+00  .56570E+00  .57205E+00
 .57840E+00  .58473E+00  .59108E+00  .59743E+00  .60454E+00  .61013E+00  .61648E+00  .62918E+00  .63553E+00  .63853E+00
0.

PRINT STATIONS DESIGNATED IN $NAM1 INPUT AND GENERATED IN SETUP

PROVAL
 .13604E+00  .63853E+00
PRNTVAL
 .43266E-02  .13029E-01  .23303E-01  .36585E-01  .50368E-01  .62798E-01  .72764E-01  .82604E-01  .92552E-01  .10107E+00
 .10986E+00  .11861E+00  .12723E+00  .13579E+00  .13604E+00  .13683E+00  .13843E+00  .14001E+00  .14161E+00  .14318E+00
 .14636E+00  .15272E+00  .15906E+00  .16538E+00  .17175E+00  .17808E+00  .18444E+00  .19079E+00  .19713E+00  .20350E+00
 .20984E+00  .21619E+00  .22256E+00  .22891E+00  .23526E+00  .24161E+00  .24799E+00  .25434E+00  .26069E+00  .26706E+00
 .27342E+00  .27978E+00  .28613E+00  .29248E+00  .29885E+00  .30521E+00  .31157E+00  .31793E+00  .32427E+00  .33062E+00
 .33697E+00  .34335E+00  .34971E+00  .35604E+00  .36240E+00  .36876E+00  .37511E+00  .38146E+00  .38784E+00  .39419E+00
 .40053E+00  .40690E+00  .41324E+00  .41958E+00  .42595E+00  .43231E+00  .43865E+00  .44501E+00  .45137E+00  .45771E+00
 .46407E+00  .47042E+00  .47577E+00  .48311E+00  .48947E+00  .49582E+00  .50218E+00  .50853E+00  .51489E+00  .51948E+00
 .52124E+00  .52759E+00  .53394E+00  .54029E+00  .54665E+00  .55300E+00  .55935E+00  .56570E+00  .57205E+00  .57840E+00
 .58473E+00  .59108E+00  .59743E+00  .60454E+00  .61013E+00  .61648E+00  .62918E+00  .63553E+00  .63853E+00
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SIMILAR SOLUTION REQUIRED TO INITIATE MARCHING PROCEDURE

PROFILE VALUES

ETA	U/UE	T/TE	V	FZ	TZ	XL
0.	0.	.100013E+01	0.	.468918E+00	0.	.999963E+00
.450271E-09	.211140E-09	.100011E+01	-.475351E-19	.468918E+00	-.269108E+05	.999963E+00
.102455E-08	.480428E-09	.100011E+01	-.246111E-18	.468918E+00	.108753E-04	.999963E+00
.175698E-08	.823879E-09	.100011E+01	-.723768E-18	.468918E+00	.170540E-04	.999963E+00
.269112E-08	.126191E-08	.100011E+01	-.169798E-17	.468918E+00	.200572E-04	.999963E+00
.388253E-08	.182059E-08	.100011E+01	-.353424E-17	.468918E+00	.235893E-04	.999963E+00
.540204E-08	.253312E-08	.100011E+01	-.684200E-17	.468918E+00	.308260E-04	.999963E+00
.734004E-08	.344188E-08	.100011E+01	-.126318E-16	.468918E+00	.338376E-04	.999963E+00
.981176E-08	.460091E-08	.100011E+01	-.225715E-16	.468918E+00	.353746E-04	.999963E+00
.129642E-07	.607914E-08	.100011E+01	-.394055E-16	.468918E+00	.356607E-04	.999963E+00
⋮	⋮	⋮	⋮	⋮	⋮	⋮
.671945E+01	.100038E+01	.100000E+01	-.550546E+01	.810735E-04	.128846E-07	.100000E+01
.856998E+01	.999929E+00	.100000E+01	-.735627E+01	-.250747E-04	-.333380E-08	.100000E+01
.109302E+02	.100027E+01	.100000E+01	-.971668E+01	.931878E-05	.112791E-08	.100000E+01
.139403E+02	.999979E+00	.100000E+01	-.127272E+02	-.383535E-05	-.440228E-09	.100000E+01
.177795E+02	.100025E+01	.100000E+01	-.165668E+02	.167551E-05	.186459E-09	.100000E+01
.226760E+02	.999993E+00	.100000E+01	-.214639E+02	-.758719E-06	-.828869E-10	.100000E+01
.289209E+02	.100024E+01	.100000E+01	-.277096E+02	.351242E-06	.379526E-10	.100000E+01
.368857E+02	.999998E+00	.100000E+01	-.356753E+02	-.164868E-06	-.176691E-10	.100000E+01
.470441E+02	.100023E+01	.100000E+01	-.458348E+02	.780711E-07	.834572E-11	.100000E+01
.600000E+02	.100000E+01	.100000E+01	-.587923E+02	0.	0.	.100000E+01

CONVERGED SELF-SIMILAR SOLUTION REQUIRED 15ITERATIONS.

INITIAL STATION PARAMETERS

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MUE = .219000E-04  UE  = .136191E+02  TE  = .376908E+03  PE  = .344704E+07  QSD =0.
XAL = .489974E-03  XBE =0.            RE  = .318707E+02
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****DIMENSIONAL OUTPUT QUANTITIES ARE IN S.I. UNITS****

FREE STREAM VALUES-DIMENSIONAL

PT1 =	.345000E+07	TT1 =	.377000E+03	RT1 =	.318903E+02	P1 =	.344965E+07	T1=	.376989E+03	R1 =	.318880E+02
U1 =	.469260E+01	AA1 =	.389169E+03	XMA =	.120580E-01	REY =	.683167E+07				

REFERENCE VALUES-DIMENSIONAL

PREF=	.702188E+03	TREF=	.219250E-01	RREF=	.318880E+02	UREF=	.469260E+01	VISREF=	.428995E-10	PTR =	.491321E+04

S= .6385 PROFILE

ETA	Y/YE	U/UE	T/TE	TT/TTE	CROCCO	PT/PTR	M/ME	YPLUS	UPLUS	UDEF	VISEFF
0.	0.	0.	.545E+01	.911E+00	.397E-13	.191E-02	0.	0.	0.	0.	.100E+01
.450E-09	.731E-10	.342E-08	.545E+01	.911E+00	.795E-13	.191E-02	.146E-08	.773E-07	.690E-07	.202E+02	.100E+01
.102E-08	.166E-09	.777E-08	.545E+01	.911E+00	.199E-12	.191E-02	.333E-08	.176E-06	.157E-06	.202E+02	.100E+01
.176E-08	.285E-09	.133E-07	.545E+01	.911E+00	.238E-12	.191E-02	.571E-08	.302E-06	.269E-06	.202E+02	.100E+01
.269E-08	.437E-09	.204E-07	.545E+01	.911E+00	.318E-12	.191E-02	.875E-08	.462E-06	.412E-06	.202E+02	.100E+01
.388E-08	.630E-09	.295E-07	.545E+01	.911E+00	.358E-12	.191E-02	.126E-07	.667E-06	.595E-06	.202E+02	.100E+01
.540E-08	.877E-09	.410E-07	.545E+01	.911E+00	.397E-12	.191E-02	.176E-07	.928E-06	.828E-06	.202E+02	.100E+01
.734E-08	.119E-08	.557E-07	.545E+01	.911E+00	.517E-12	.191E-02	.239E-07	.126E-05	.112E-05	.202E+02	.100E+01
.981E-08	.159E-08	.744E-07	.545E+01	.911E+00	.715E-12	.191E-02	.319E-07	.169E-05	.150E-05	.202E+02	.100E+01
.130E-07	.211E-08	.984E-07	.545E+01	.911E+00	.111E-11	.191E-02	.421E-07	.223E-05	.199E-05	.202E+02	.100E+01
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.672E+01	.451E+00	.934E+00	.163E+01	.998E+00	.981E+00	.337E-01	.732E+00	.395E+04	.189E+02	.133E+01	.316E+03
.857E+01	.531E+00	.952E+00	.147E+01	.100E+01	.995E+00	.387E-01	.786E+00	.577E+04	.192E+02	.971E+00	.390E+03
.109E+02	.622E+00	.967E+00	.133E+01	.100E+01	.101E+01	.441E-01	.840E+00	.835E+04	.195E+02	.664E+00	.479E+03
.139E+02	.726E+00	.979E+00	.121E+01	.100E+01	.101E+01	.494E-01	.890E+00	.119E+05	.198E+02	.416E+00	.579E+03
.178E+02	.846E+00	.989E+00	.112E+01	.100E+01	.101E+01	.543E-01	.934E+00	.164E+05	.200E+02	.231E+00	.681E+03
.227E+02	.987E+00	.995E+00	.106E+01	.100E+01	.101E+01	.582E-01	.967E+00	.217E+05	.201E+02	.106E+00	.768E+03
.289E+02	.116E+01	.998E+00	.102E+01	.100E+01	.101E+01	.606E-01	.988E+00	.275E+05	.202E+02	.364E-01	.828E+03
.369E+02	.136E+01	.100E+01	.101E+01	.100E+01	.100E+01	.618E-01	.997E+00	.336E+05	.202E+02	.794E-02	.856E+03

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.470E+02  .161E+01  .100E+01  .100E+01  .100E+01  .100E+01  .621E-01  .100E+01  .402E+05  .202E+02  .902E-03  .865E+03
.600E+02  .192E+01  .100E+01  .100E+01  .100E+01  .100E+01  .621E-01  .100E+01  .480E+05  .202E+02  .934E-09  .866E+03

S      =  .63853E+00  RETHET=  .18342E+05  DPEDS = -.16386E+02  CFW   =  .49052E-02  ZSHK  = 0.               YE    =  .73393E-02
XI     =  .87087E+03  RES    =  .43890E+08  DTEDS = -.27090E+01  QSD   = 0.           RSHK  = 0.               UTAU  =  .25547E+01
RMI    =  .52858E-01  PE     =  .65845E+04  DUEDS =  .16007E-01  HD    = 0.           ITRO  =              0  TRFCT =  .10000E+01
Z      =  .61534E+00  TE     =  .63009E+02  DLTAST=  .29232E-02  NSTE  = 0.           TW/TT1=  .91061E+00  YMP   =          86
BETA   =  .16473E+00  RE     =  .36417E+00  THETA =  .26684E-03  NSTW  = 0.           RFTRUE=  .89267E+00  P20   =  .49132E+04
XAL    =  .99666E+01  UE     =  .79418E+03  FORM  =  .10955E+02  NUE   = 0.           ROUSE =  .15444E+05  OMEGA =  .53543E-06
RVWALD= 0.            ME     =  .49917E+01  TAUD  =  .10339E+03  NUW   = 0.           DSMXO = -.14305E+03
REDELT=  .20093E+06   MUE    =  .42076E-05  CFE   =  .90030E-03  SWANG = 0.           VW    = 0.               RVWAL = 0.
NOITER=          4    ERROR  =  .62741E-04
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