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VNAP: A Computer Program for Computation of Two-Dimensional, Time-Dependent Compressible, Viscous, Internal Flow

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COMPRESSIBLE, VISCOUS, INTERNAL FLOW

by

Michael C. Cline

ABSTRACT

A computer program, VNAP, for calculating viscous, as well as inviscid, steady and unsteady, internal flow is presented. The Navier-Stokes equations for two-dimensional, time-dependent, compressible flow are solved using the second-order accurate, MacCormack finite-difference scheme. The boundary mesh points, except no-slip wall points, are calculated using a characteristic scheme with the viscous terms treated as source functions. The no-slip wall points are computed using the MacCormack scheme with the derivatives normal to the wall approximated by one-sided differences. An explicit artificial viscosity is included for shock calculations, and a mixing-length model is included for turbulent flows. The fluid is assumed to be a perfect gas. The steady-state solution is obtained as the asymptotic solution for large time. The flow boundaries may be arbitrary curved solid walls or free jet envelopes. Typical problems that can be solved are flow in pipes and ducts; converging, converging-diverging, and plug nozzles; subsonic and supersonic inlets; and free jet expansions. The accuracy and efficiency of the program are shown by calculations of several inviscid, viscous, and turbulent flows. The program and its use are described completely, and five sample cases and a code listing are included.

I. THE BASIC METHOD

A. Introduction

A computer program, VNAP, for calculating viscous, as well as inviscid, steady and unsteady, internal flow is presented. This program solves the two-dimensional, time-dependent, compressible, Navier-Stokes equations by a second-order accurate finite-difference procedure. Typical problems that can be solved are flow in pipes and ducts; in converging, converging-diverging, and plug nozzles; and in subsonic and supersonic inlets; and free jet expansions. Part I of this report describes the basic method, and Part II describes the VNAP program and its use, and presents five sample cases and a code listing.

This program is intended to replace as well as improve upon the NAP program.[1,2] VNAP solves the Navier-Stokes equations rather than the inviscid Navier-Stokes or Euler equations solved by NAP. Therefore, VNAP can solve all the flows that NAP can handle, as well as fully viscous, separated flows such as those presented in Ref. 3. Also, several "bugs" discovered in NAP have been corrected in VNAP. Finally, VNAP includes options for a sharp expansion corner, mixed sub- and supersonic outflow, velocity and density inflow boundary conditions, and a mixing-length model of turbulence.

Since VNAP, like NAP, has no variable grid spacing option, high Reynolds number flows including the boundary layer will be very costly. The practical Reynolds number limit for most flows is around 10^4 based on the diameter. Higher Reynolds number flows can be solved using VNAP along with a boundary layer program. However, in special cases, such as the transonic region of a supersonic nozzle, where the fact that few axial mesh points are required allows more radial points, higher Reynolds number flows may be calculated at a reasonable cost.

B. Choice of a Method

The long computation times associated with time-dependent calculations are usually required because inefficient numerical schemes or poor treatment of boundaries demands excessively fine computational meshes. Since the interior mesh points are most numerous, a very efficient, reasonably accurate scheme should be used. One such is the second-order accurate MacCormack scheme.[4] The governing equations are left in nonconservation form because the results of Ref. 5, as well as my unpublished results, show that conservation form improves shock calculations only slightly while significantly increasing computational time for all flows.

On the other hand, the boundary mesh points are the fewest and probably the most important.[6,7] Therefore, they should be calculated using a very accurate, reasonably efficient scheme. One such is a second-order, reference plane characteristic scheme. The viscous terms can be treated as source functions. This characteristic scheme is used for free-slip walls and subsonic inflow and outflow boundaries. For supersonic inflow and outflow boundaries, the variables can be fixed and extrapolated, respectively. For no-slip walls, three (u,v,T) of the five variables are known, so the conservation of mass equation and the equation of state can be solved for the remaining two variables (ρ,P).

C. Governing Equations

The two-dimensional, time-dependent, compressible Navier-Stokes equations for flow of a perfect gas can be written

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\varepsilon \rho v}{y} = 0 \ , \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{1}{\rho}\frac{\partial}{\partial x}\left[(\lambda+2\mu)\frac{\partial u}{\partial x} + \lambda\frac{\partial v}{\partial y}\right] + \frac{1}{\rho}\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\varepsilon}{\rho y}\left[(\lambda+\mu)\frac{\partial v}{\partial x} + \mu\frac{\partial u}{\partial y}\right] \ , \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{1}{\rho}\frac{\partial p}{\partial y} = \frac{1}{\rho}\frac{\partial}{\partial y}\left[(\lambda+2\mu)\frac{\partial v}{\partial y} + \lambda\frac{\partial u}{\partial x}\right] + \frac{1}{\rho}\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\varepsilon(\lambda+2\mu)}{\rho y}\left(\frac{\partial v}{\partial y} - \frac{v}{y}\right) \ , \tag{3}$$

$$\frac{\partial p}{\partial t} + u\frac{\partial p}{\partial x} + v\frac{\partial p}{\partial y} - a^2\left(\frac{\partial \rho}{\partial t} + u\frac{\partial \rho}{\partial x} + v\frac{\partial \rho}{\partial y}\right) = (\gamma-1)\left\{(\lambda+2\mu)\left(\frac{\partial u}{\partial x}\right)^2 + (\lambda+2\mu)\left(\frac{\partial v}{\partial y}\right)^2 + \mu\left(\frac{\partial v}{\partial x}\right)^2 + \mu\left(\frac{\partial u}{\partial y}\right)^2 + 2\lambda\frac{\partial u}{\partial x}\frac{\partial v}{\partial y} + 2\mu\frac{\partial u}{\partial y}\frac{\partial v}{\partial x} + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \varepsilon\left[(\lambda+2\mu)\left(\frac{v}{y}\right)^2 + \frac{2\lambda v}{y}\left(\frac{\partial v}{\partial y} + \frac{\partial u}{\partial x}\right) + \frac{k}{y}\frac{\partial T}{\partial y}\right]\right\} \ , \tag{4}$$

$$p = \rho RT \ , \quad a^2 = \gamma P/\rho \ , \tag{5}$$

where ρ is the density, p is the pressure, T is the temperature, u and v are the velocity components, a is the speed of sound, R is the gas constant, μ and λ are the first and second coefficients of viscosity, respectively, γ is the ratio of specific heats, k is the thermal conductivity, x and y are the space coordinates, t is the time, and ε is zero for planar flow and one for axisymmetric flow. Equation (1) is the conservation of mass or continuity equation, Eqs. (2) and (3) are the x and y momentum equations, respectively, and Eq. (4) is the internal energy equation written in terms of pressure by use of the equation of state for a perfect gas, Eq. (5). Thus we have a system of five equations for the five unknowns u, v, p, ρ, and T.

To stabilize the calculations for shocks, we add an artificial viscosity (μ_A, λ_A) and thermal conductivity (k_A) to the laminar values. These quantities are calculated by

$$\lambda_A = C\, C_\lambda\, \Delta x \Delta y \rho \left| \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \varepsilon \frac{v}{y} \right| , \tag{6}$$

$$\mu_A = C_\mu\, \lambda_A / C_\lambda , \tag{7}$$

$$k_A = \gamma R \mu_A / C_k (\gamma - 1) , \tag{8}$$

where C, C_λ, C_μ, and C_k are constants, and Δx and Δy are the mesh spacing. The following artificial density smoothing term also is added to the right-hand side of Eq. (1).

$$\text{Equation (1)} = \frac{C_\rho}{\rho} \left[\frac{\partial}{\partial x} \left(\mu_A \frac{\partial \rho}{\partial x} \right) + \frac{\partial}{\partial y} \left(\mu_A \frac{\partial \rho}{\partial y} \right) + \frac{\varepsilon \mu_A}{y} \frac{\partial \rho}{\partial y} \right] , \tag{9}$$

where C_ρ is a constant. When the divergence of the velocity is greater than zero (expansions), these artificial quantities are set equal to zero.

For turbulent flows, the Prandtl mixing-length model for free shear layers has been included. In this model a turbulent eddy viscosity (μ_T, λ_T) and thermal conductivity (k_T) are added to the laminar values. These quantities are calculated by

$$\mu_T = \rho \ell^2 \left| \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right| , \tag{10}$$

$$\mu_{T,CL} = \rho \ell^3 \left| \frac{\partial^2 u}{\partial y^2} \right| , \tag{11}$$

$$\lambda_T = \lambda \frac{\mu_T}{\mu} , \tag{12}$$

and

$$k_T = k \frac{\mu_T}{\mu} , \tag{13}$$

where $\mu_{T,CL}$ is the turbulent viscosity on the centerline or midplane and ℓ is the mixing length. The mixing length is calculated by

$$\ell = (0.125 - 0.015\varepsilon)(y_2 - y_1) , \tag{14}$$

where

$$y_1 = y \text{ for } \frac{u-u_L}{u_U-u_L} = 0.1 , \tag{15}$$

$$y_2 = y \text{ for } \frac{u-u_L}{u_U-u_L} = 0.9 , \tag{16}$$

and u_L and u_U are the lower and upper velocities of a monotonically increasing or decreasing velocity profile.

The physical (x,y,t) plane is mapped into a rectangular computational plane (ζ,η,τ) as shown in Fig. 1, at the end of this report, by the coordinate transformation

$$\zeta = x; \ \eta = \frac{y-y_c(x)}{y_w(x,t) - y_c(x)} \ ; \quad \tau = t , \tag{17}$$

where $y_w(x,t)$ denotes the nozzle wall and free jet boundary radius as functions of x and t and $y_c(x)$ denotes the nozzle centerbody radius as a function of x. When the lower boundary is an axis of symmetry, $y_c(x)$ equals zero. These mapping functions must be single-valued functions of the x coordinate. In Fig. 1, the flow is assumed to enter from the left and leave at the right.

In the (ζ,η,τ) coordinate system, Eqs. (1) - (4) become

$$\frac{\partial\rho}{\partial\tau} + u\frac{\partial\rho}{\partial\zeta} + \bar{v}\frac{\partial\rho}{\partial\eta} + \rho\frac{\partial u}{\partial\zeta} + \rho\alpha\frac{\partial u}{\partial\eta} + \rho\beta\frac{\partial v}{\partial\eta} + \frac{\varepsilon\rho v}{\bar{\eta}} = 0 \quad , \tag{18}$$

$$\begin{aligned}\frac{\partial u}{\partial\tau} + u\frac{\partial u}{\partial\zeta} + \bar{v}\frac{\partial u}{\partial\eta} + \frac{1}{\rho}\frac{\partial p}{\partial\zeta} + \frac{\alpha}{\rho}\frac{\partial p}{\partial\eta} &= \frac{1}{\rho}\left(\frac{\partial}{\partial\zeta} + \alpha\frac{\partial}{\partial\eta}\right)\left[(\lambda+2\mu)\left(\frac{\partial u}{\partial\zeta} + \alpha\frac{\partial u}{\partial\eta}\right) + \lambda\beta\frac{\partial v}{\partial\eta}\right] \\ &+ \frac{\beta}{\rho}\frac{\partial}{\partial\eta}\left[\mu\left(\frac{\partial v}{\partial\zeta} + \alpha\frac{\partial v}{\partial\eta} + \beta\frac{\partial u}{\partial\eta}\right)\right] + \frac{\varepsilon}{\rho\bar{\eta}}\left[(\lambda+\mu)\left(\frac{\partial v}{\partial\zeta} + \alpha\frac{\partial v}{\partial\eta}\right) + \mu\beta\frac{\partial u}{\partial\eta}\right] ,\end{aligned} \tag{19}$$

$$\begin{aligned}\frac{\partial v}{\partial\tau} + u\frac{\partial v}{\partial\zeta} + \bar{v}\frac{\partial v}{\partial\eta} + \frac{\beta}{\rho}\frac{\partial p}{\partial\eta} &= \frac{\beta}{\rho}\frac{\partial}{\partial\eta}\left[(\lambda+2\mu)\,\beta\frac{\partial v}{\partial\eta} + \lambda\left(\frac{\partial u}{\partial\zeta} + \alpha\frac{\partial u}{\partial\eta}\right)\right] \\ &+ \frac{1}{\rho}\left(\frac{\partial}{\partial\zeta} + \alpha\frac{\partial}{\partial\eta}\right)\left[\mu\left(\frac{\partial v}{\partial\zeta} + \alpha\frac{\partial v}{\partial\eta} + \beta\frac{\partial u}{\partial\eta}\right)\right] + \frac{\varepsilon(\lambda+2\mu)}{\rho\bar{\eta}}\left(\beta\frac{\partial v}{\partial\eta} - \frac{v}{\bar{\eta}}\right) ,\end{aligned} \tag{20}$$

$$\begin{aligned}\frac{\partial p}{\partial\tau} + u\frac{\partial p}{\partial\zeta} + \bar{v}\frac{\partial p}{\partial\eta} - a^2\left(\frac{\partial\rho}{\partial\tau} + u\frac{\partial\rho}{\partial\zeta} + \bar{v}\frac{\partial\rho}{\partial\eta}\right) &= (\gamma-1)\left\{(\lambda+2\mu)\left(\frac{\partial u}{\partial\zeta} + \alpha\frac{\partial u}{\partial\eta}\right)^2\right. \\ &+ (\lambda+2\mu)\left(\beta\frac{\partial v}{\partial\eta}\right)^2 + \mu\left(\frac{\partial v}{\partial\zeta} + \alpha\frac{\partial v}{\partial\eta}\right)^2 + \mu\left(\beta\frac{\partial u}{\partial\eta}\right)^2 + 2\lambda\left(\frac{\partial u}{\partial\zeta} + \alpha\frac{\partial u}{\partial\eta}\right)\beta\frac{\partial v}{\partial\eta} \\ &+ 2\mu\beta\frac{\partial u}{\partial\eta}\left(\frac{\partial v}{\partial\zeta} + \alpha\frac{\partial v}{\partial\eta}\right) + \left(\frac{\partial}{\partial\zeta} + \alpha\frac{\partial}{\partial\eta}\right)\left(k\frac{\partial T}{\partial\zeta} + k\alpha\frac{\partial T}{\partial\eta}\right) + \beta\frac{\partial}{\partial\eta}\left(k\beta\frac{\partial T}{\partial\eta}\right) \\ &+ \left.\varepsilon\left[(\lambda+2\mu)\left(\frac{v}{\bar{\eta}}\right)^2 + \frac{2\lambda v}{\bar{\eta}}\left(\beta\frac{\partial v}{\partial\eta} + \frac{\partial u}{\partial\zeta} + \alpha\frac{\partial u}{\partial\eta}\right) + \frac{k}{\bar{\eta}}\beta\frac{\partial T}{\partial\eta}\right]\right\} ,\end{aligned} \tag{21}$$

where

$$\beta = \frac{1}{y_w - y_c} \quad , \tag{22}$$

$$\alpha = \beta \left[(\eta - 1) \frac{\partial y_c}{\partial x} - \eta \frac{\partial y_w}{\partial x} \right] , \tag{23}$$

$$\delta = -\beta\eta \frac{\partial y_w}{\partial t} , \tag{24}$$

$$\bar{v} = \alpha u + \beta v + \delta , \tag{25}$$

$$\bar{\eta} = y = y_c + \eta/\beta . \tag{26}$$

Equations (6) and (9) of the artificial viscosity model become

$$\lambda_A = \frac{CC_\lambda \Delta\zeta\Delta\eta\rho}{\beta} \left| \frac{\partial u}{\partial \zeta} + \alpha \frac{\partial u}{\partial \eta} + \beta \frac{\partial v}{\partial \eta} + \varepsilon \frac{v}{\bar{\eta}} \right| , \tag{27}$$

$$\text{Equation (18)} = \frac{C_\rho}{\rho} \left[\left(\frac{\partial}{\partial \zeta} + \alpha \frac{\partial}{\partial \eta} \right) \left(\mu_A \frac{\partial \rho}{\partial \zeta} + \mu_A \alpha \frac{\partial \rho}{\partial \eta} \right) + \beta \frac{\partial}{\partial \eta} \left(\mu_A \beta \frac{\partial \rho}{\partial \eta} \right) + \frac{\varepsilon \mu_A}{\bar{\eta}} \beta \frac{\partial \rho}{\partial \eta} \right] . \tag{28}$$

Equations (10) and (11) of the turbulence model become

$$\mu_T = \rho \ell^2 \left| \beta \frac{\partial u}{\partial \eta} + \frac{\partial v}{\partial \zeta} + \alpha \frac{\partial v}{\partial \eta} \right| , \tag{29}$$

$$\mu_{T,CL} = \rho \ell^3 \left| \beta^2 \frac{\partial^2 u}{\partial \eta^2} \right| , \tag{30}$$

and the y in Eqs. (15) and (16) is replaced by $\bar{\eta}$.

D. Numerical Method

The computational plane grid, shown in Fig. 1, is rectangular and has equal spacing in the ζ and η directions, although $\Delta\zeta$ and $\Delta\eta$ are not generally equal. Therefore, the physical space grid shown in Fig. 1 has equal spacing in the x direction, whereas that in the y direction is equal only for x equal to a constant. In other words, Δy is a function of x. For flows with a free jet boundary, Δy is a function of x and t.

The computational plane is divided into five sets of mesh points: interior, inlet, exit, wall and centerbody, and free-jet boundary.

1. Interior Mesh Points. The interior mesh points are computed using the MacCormack second-order, noncentered, two-step, finite-difference scheme. Backward differences are used on the first step; forward differences, on the second. The governing equations are left in nonconservation form. For flows without a centerbody, the centerline or midplane mesh points are computed by enforcing flow symmetry. As an example of the basic scheme, the finite-difference equations for Eq. (2) for planar flow ($\varepsilon = 0$) are

$$
\begin{aligned}
\bar{u}^{N+1}_{L,M} = u^{N}_{L,M} &- \left[u^{N}_{L,M}\left(\frac{u^{N}_{L,M}-u^{N}_{L-1,M}}{\Delta x}\right) + v^{N}_{L,M}\left(\frac{u^{N}_{L,M}-u^{N}_{L,M-1}}{\Delta y}\right) + \frac{1}{\rho^{N}_{L,M}}\left(\frac{p^{N}_{L,M}-p^{N}_{L-1,M}}{\Delta x}\right)\right]\Delta t \\
&+ \frac{\Delta t}{\rho^{N}_{L,M}\Delta x}\left[(\lambda+2\mu)_{L,M}\left(\frac{u^{N}_{L+1,M}-u^{N}_{L,M}}{\Delta x}\right) + \frac{\lambda_{L,M}}{2}\left(\frac{v^{N}_{L+1,M+1}-v^{N}_{L+1,M-1}}{2\Delta y}\right)\right. \\
&\left. - (\lambda+2\mu)_{L,M}\left(\frac{u^{N}_{L,M}-u^{N}_{L-1,M}}{\Delta x}\right) - \frac{\lambda_{L,M}}{2}\left(\frac{v^{N}_{L-1,M+1}-v^{N}_{L-1,M-1}}{2\Delta y}\right)\right] \\
&+ \frac{\Delta t}{\rho^{N}_{L,M}\Delta y}\left[\frac{\mu_{L,M}}{2}\left(\frac{v^{N}_{L+1,M+1}-v^{N}_{L-1,M+1}}{2\Delta x}\right) + \mu_{L,M}\left(\frac{u^{N}_{L,M+1}-u^{N}_{L,M}}{\Delta y}\right)\right. \\
&\left. - \frac{\mu_{L,M}}{2}\left(\frac{v^{N}_{L+1,M-1}-v^{N}_{L-1,M-1}}{2\Delta x}\right) - \mu_{L,M}\left(\frac{u^{N}_{L,M}-u^{N}_{L,M-1}}{\Delta y}\right)\right] ,
\end{aligned}
\tag{31}
$$

for the first step and

$$
\begin{aligned}
u^{N+1}_{L,M} = 0.5 \Bigg\{ u^{N}_{L,M} + \bar{u}^{N+1}_{L,M} &- \left[\bar{u}^{N+1}_{L,M}\left(\frac{\bar{u}^{N+1}_{L+1,M}-\bar{u}^{N+1}_{L,M}}{\Delta x}\right) + \bar{v}^{N+1}_{L,M}\left(\frac{\bar{u}^{N+1}_{L,M+1}-\bar{u}^{N+1}_{L,M}}{\Delta y}\right)\right. \\
&\left. + \frac{1}{\bar{\rho}^{N+1}_{L,M}}\left(\frac{\bar{p}^{N+1}_{L+1,M}-\bar{p}^{N+1}_{L,M}}{\Delta x}\right)\right]\Delta t + Q \Bigg\} ,
\end{aligned}
\tag{32}
$$

for the second step, where the subscripts L and M denote axial and radial mesh points, respectively, the superscript N denotes the time step, the bar denotes values calculated on the first step, and Q denotes the terms in the last two brackets on the right-hand side of Eq. (31), that is, the viscous terms. From Eqs. (31) and (32), we see that all viscous terms are calculated using center differences in the initial-value plane, only. Because the viscous terms are calculated only in the initial-value plane, they are second-order accurate in space but first-order accurate in time. Raising them to second-order accuracy in time requires evaluating them again using the $\bar{u}^{N+1}$ values from the first step. For most problems this greater accuracy does not seem worth the increased effort. Also, the viscosity coefficients are assumed to be locally constant, which significantly reduces the run time. Where this effect is important, the VNAP program can be modified easily. Reference 4 gives complete description of the MacCormack scheme.

2. Inlet Mesh Points. The inlet flow is assumed to be either all subsonic or all supersonic, not mixed.

a. Subsonic Flow. For subsonic flow, the inlet mesh points are computed using a second-order, reference-plane characteristic scheme. In this scheme, the partial derivatives with respect to η in the convective terms are computed in the initial-value and solution surfaces using noncentered differencing as in the MacCormack scheme. These approximations to the convective term derivatives with respect to η are then treated as source terms, and the resulting system of equations is solved in the η = constant reference planes using a two-step, two-independent variable, characteristic scheme. All the viscous terms are set equal to zero. The characteristic relations that relate the interior flow to the inlet flow are derived in Appendix A as Eq. (A-43) which is

$$dp - \rho a du = \left(\psi_4 + a^2\psi_1 - \rho a\psi_2\right)d\tau \quad \text{for } d\zeta = (u-a)d\tau \ , \tag{33}$$

where the first equation is called the compatibility equation and the second is called the characteristic curve equation. The ψ terms (see Appendix A) represent the derivatives in the η direction. Equation (33) may be written in finite-difference form by first replacing the differentials by differences along the characteristic curve. Next, the coefficients are either evaluated in the initial-value plane (first step) or considered to be the average of the coefficients evaluated in both the initial-value and solution planes (second step). The convective terms in the ψ terms are treated as follows: On the first step, the coefficients and derivatives, using backward differences, are evaluated in the initial-value plane; on the second and final step, the coefficients and derivatives, now using forward differences, are evaluated in the solution plane and then averaged with the ψ terms from the first step.

The boundary conditions are specification of either (1) the two velocity components and the density or (2) the stagnation pressure, stagnation temperature, and flow angle. In the first case, the only unspecified variable is the pressure, which can be calculated from Eq. (33). In the second case, the following equations which relate the stagnation or total conditions to the static conditions are required.

$$p_T/p = [1 + (\gamma - 1)\ M^2/2]^{\gamma/(\gamma-1)}\ , \tag{34}$$

$$T_T/T = 1 + (\gamma - 1)\ M^2/2\ , \tag{35}$$

where γ is the ratio of specific heats, M is the Mach number, T is the temperature, and the subscript T denotes the stagnation or total conditions. The solution procedure for case 2 is as follows: M is assumed, P and T are calculated from Eqs. (34) and (35), ρ is calculated from the equation of state, u is calculated from Eq. (33), v is calculated from the specified flow angle, a new M is calculated from u, v, p and ρ, and the process is continued until the change in M has converged to 10^{-3}.

The unit processes of this scheme are described briefly below. The intersection of the characteristic curve through the solution point with the initial-value line in the η = constant plane is determined by solving the characteristic curve equation. The coefficient u-a is evaluated in the initial-value plane. The dependent variables and derivatives in the ψ terms are calculated at the intersection point using linear interpolation. Next, the dependent variables at the solution point are determined as described above. This completes the first step which is applied to all inlet mesh points before the second step is begun. On the second step, the characteristic curve equation is solved again. Now the coefficient u-a is the average of the values in the initial-value plane and the first-step solution plane. Again, linear interpolation is used to obtain the variables and derivatives at the intersection point. Finally, the dependent variables at the solution point are determined as described above using averaged coefficients and derivatives in the compatibility equation.

b. Supersonic Flow. For supersonic flow, the inlet mesh point dependent variables are specified for all time.

3. Exit Mesh Points. The exit flow, unlike the inlet flow, may be both subsonic and supersonic, that is, mixed. The code tests on the Mach number at each mesh point and then uses the appropriate boundary condition.

a. Subsonic Flow. For subsonic flow, a reference-plane characteristic scheme similar to the inlet scheme is used. However, the η derivatives in the viscous terms are calculated using centered differences in the initial-value plane only. The ζ derivatives as well as all of the viscous terms at the exit mesh point on the wall and centerbody are set equal to zero. The characteristic relations that relate the interior flow to the nozzle exit flow are Eqs. (A-41), (A-42), and (A-44). They can be written as

$$\left.\begin{aligned} dp - a^2 d\rho &= \psi_4 \, d\tau \qquad (36) \\ dv &= \psi_3 d\tau \qquad (37) \end{aligned}\right\} \text{ for } d\zeta = u d\tau \ ,$$

$$dp + \rho a du = \left(\psi_4 + a^2\psi_1 + \rho a \psi_2\right) d\tau \quad \text{for } d\zeta = (u+a)\, d\tau \ . \qquad (38)$$

These equations are written in finite-difference form in the same manner as those for the inlet scheme.

The boundary condition is the specification of the static pressure. The u velocity component is then calculated from Eq. (38); the density, from Eq. (36); and the v velocity component, from Eq. (37). If subsonic reverse flow occurs at the exit, inflow boundary conditions must be specified. This is accomplished by leaving p equal to the specified exit pressure, setting ρ equal to the average of the wall and centerbody values, and setting v equal to zero. The ρ and v boundary conditions used here are arbitrary and can be changed by modifying subroutine EXITT.

The unit processes are the same as those of the inlet scheme.

b. Supersonic Flow. For supersonic flow, the exit points are computed using either zeroth-order or linear extrapolation.

4. Wall and Centerbody Mesh Points.

a. Free-Slip Walls. For free-slip walls a reference-plane characteristic scheme is used. Partial derivatives with respect to ζ in the convective terms are computed in the initial-value and solution surfaces using noncentered differencing as in the MacCormack scheme. All derivatives in the viscous terms are computed in the initial-value surface only using centered differencing. The η derivatives in the viscous terms are calculated by either reflecting or extrapolating a row of fictitious mesh points outside the flow boundary. These approximations to the convective term derivatives with respect to ζ and the viscous term derivatives are then treated as source terms, and the resulting system of equations is solved in the ζ = constant reference planes using a two-step, two-independent variable, characteristic scheme.

The characteristic relations that relate the interior flow to the wall are derived in Appendix B as Eqs. (B-15), (B-16), and (B-18) which are

$$\left.\begin{aligned} \beta du - \alpha dv &= (\beta\psi_2 - \alpha\psi_3)d\tau \qquad (39) \\ dp - a^2 d\rho &= \psi_4 d\tau \qquad (40) \end{aligned}\right\} \text{for } d\eta = \bar{v}d\tau \ ,$$

$$dp + \rho\alpha a\ du/\alpha^* + \rho\beta a dv/\alpha^* = \left(\psi_4 + a^2\psi_1 + \rho\alpha a\psi_2/\alpha^* + \rho\beta a\psi_3/\alpha^*\right)d\tau$$

$$\text{for } d\eta = (\bar{v} + \alpha^* a)d\tau \ . \qquad (41)$$

The characteristic relations for the centerbody are Eqs. (B-15), (B-16), and (B-17) in Appendix B. These equations are written in finite-difference form in the same manner as those for the inlet scheme.

The boundary condition is that the flow is tangent to the wall and centerbody. This can be written as

$$v = u \tan\theta + \partial y_w/\partial t \ , \qquad (42)$$

where θ is the local wall or centerbody angle. For the centerbody case, $\partial y_w/\partial t$ is always zero. Equation (42) is substituted into Eq. (39) and the resulting equation is solved for the velocity component u. Then the v velocity component is obtained from Eq. (42). Next, the pressure is obtained from Eq. (41), and finally the density is determined from Eq. (40).

b. No-slip Walls. For no-slip walls, the characteristic scheme is not used. Instead, the conservation of mass and internal energy equations, Eqs. (18) or (28) and (21), respectively, are solved using the MacCormack scheme. The derivatives, except in the viscous terms, that are normal to the wall (centerbody) are calculated using backward (forward) differences on both steps. The viscous terms are calculated by the same procedure as in the free-slip case, except that the velocity components in the fictitious row are always set equal to minus their values in the row of mesh points just inside the flow boundary.

The boundary conditions are that the velocity components vanish and that the static temperature be specified or the temperature gradient normal to the flow boundary be set equal to zero. The density is calculated from the conservation of mass equation. If the static temperature is specified, the pressure is determined from the equation of state, Eq. (5). However, if the vanishing temperature gradient is specified, the internal energy equation, with the normal temperature gradient set equal to zero, is used to calculate the pressure.

c. Supersonic Sharp Expansion Corner. This program allows one supersonic sharp expansion corner on the wall or upper flow boundary. The mesh point at this corner is treated by a special procedure. First, an upstream solution is computed at the corner mesh point, using the upstream flow tangency condition as the boundary condition and backward ζ differences in both the initial-value and solution planes. Next, a downstream solution is calculated, using the Prandtl-Meyer exact solution and the stagnation conditions from the upstream mesh point. The upstream solution is used when computing wall mesh points upstream of the corner mesh point as well as the adjacent interior mesh point; the downstream solution is used when computing downstream wall mesh points.

Only the wall or upper flow boundary may have a sharp expansion corner. Further, the wall cannot have both a sharp expansion corner and a free jet boundary. Finally the sharp expansion corner option must be used with the free-slip wall boundary condition.

5. Free-Jet Boundary Mesh Points. The free-jet boundary mesh points are computed by the wall routine so that the static pressure boundary condition

$$p = p_{ambient} \tag{43}$$

is satisfied. This is accomplished by first assuming the shape of the jet boundary and then using the wall routine to calculate the pressure. Next, the jet boundary location is changed slightly and a second pressure is computed. By use of the secant method, a new jet boundary location is determined. This procedure is then repeated at each point in sequence from the nozzle exit until the jet boundary pressure and the ambient pressure agree within some specified tolerance.

When a free-jet calculation is made, the wall exit lip mesh point becomes a singularity, so it is treated by a special procedure. First, an upstream solution is computed at the exit mesh point, using the flow tangency condition as the boundary condition and backward ζ differences in both the initial-value and solution planes. Next, a downstream solution is calculated, using Eq. (43) as the boundary condition and the stagnation conditions calculated from the upstream mesh point. The upstream solution is used in computing wall mesh points upstream of the exit mesh point; the downstream solution, in computing downstream free-jet mesh points. A third exit mesh point solution to be used for interior mesh point calculation is determined as follows. When the upstream solution is subsonic, the two solution Mach numbers are averaged to be less than or equal to one. This Mach number, along with the upstream stagnation temperature and pressure, is then used to calculate the exit mesh point solution to be used in computing the interior mesh points. When the upstream solution is supersonic, it is used to calculate the interior mesh points.

Only the wall or uppper flow boundary may consist of a solid boundary followed by a free jet. The centerbody or lower flow boundary is always assumed to be solid. In addition, the wall cannot have both a free-jet boundary and a sharp expansion corner. Finally, the free-jet boundary must be used with the free-slip wall boundary condition.

6. Step Size. The step size Δt is determined by

$$\Delta t = A/\left(|u|/\Delta x + |v|/\Delta y + a\sqrt{1/\Delta x^2 + 1/\Delta y^2}\right) \quad , \tag{44}$$

where the coefficient A was determined from actual calculations. For inviscid, shock-free flows, A should be approximately 1.0. Both viscous flows and flows with shocks usually require A to be less than 1.0. In the (ζ,η,τ) coordinate system, Eq. (44) becomes

$$\Delta\tau = A/\left(|u|/\Delta\zeta + |v|\beta/\Delta\eta + a\sqrt{1/\Delta\zeta^2 + \beta^2/\Delta\eta^2}\right) \quad . \tag{45}$$

The condition is checked at each mesh point in the flow field at each time step.

E. Overall Program

The inlet flow may be either sub- or supersonic and may contain variations in the stagnation conditions from streamline to streamline. The exit flow may be subsonic, supersonic, or both. The wall or upper flow boundary may be a solid boundary or a solid boundary followed by a free jet. The upper boundary may contain one sharp expansion corner. The centerbody or lower flow boundary may be either a solid boundary or a plane (axis) of symmetry. The wall and centerbody geometries may be either of two analytical contours or a completely general tabular contour. The initial data may be read in or calculated internally by the program. The internally computed data are calculated assuming one-dimensional, steady, isentropic flow with area change. The flow may be inviscid, viscous-laminar, or viscous-turbulent (mixing-length model) and it may contain shocks. The solid boundaries may be either free-slip or no-slip walls. The program allows input and output in English, metric, and nondimensional units. The program output includes printed coordinates, velocities, pressure, density, Mach number, temperature, mass flow, and axial momentum thrust; films of velocity vector plots and contour plots of density, pressure, temperature, and Mach number; and punched cards for restarting a calculation.

F. Results and Discussion

1. Inviscid Flow Cases. The results presented here have been published in Refs. 1 and 2. The CDC 6600 computational times represent the central processor time, not including compilation. So that these results can be compared with those of other investigators, the following table of relative machine speeds is given.

Computer	Relative Machine Speed
IBM 7094	0.1
IBM 360/50	0.1
IBM 360/65	0.3
IBM 360/75	0.5
Univac 1108	0.5
CDC 6600	1.0
CDC 7600	5.0

These relative speeds, obtained from Refs. 8 and 9, are only rough estimates because values may vary considerably depending on the compiler and machine configuration. In each case, the one-dimensional values that the program computed internally were the initial data. When the relative change in axial velocity in the throat and downstream regions was less than a prescribed convergence tolerance, the flow was assumed to have reached steady state. The convergence tolerance was found to be a function of the mesh spacing, flow speed, and nozzle geometry. For the results presented here, convergence tolerances of 0.003% for flows without free-jet calculations and 0.005% for flows with free-jet calculations were used. Although the code works with English and metric units, the English units in the original publications of the experimental data have been used here.

The present method was used to compute the steady-state solution for flow in the 45-15° conical, converging-diverging nozzle shown in Fig. 2a. The Mach number contours and wall pressure ratio are shown in Fig. 3. The experimental data are those of Cuffel et al.[10] The computed discharge coefficient is 0.983, compared with the experimental value of 0.985. The 21 by 8 computational mesh requires 299 time planes and a computational time of 35 s. There is good agreement with the experimental data. Prozan,[10] Migdal et al.,[11] Laval,[12] and Serra[13] also solved this case. Cuffel et al. did not report the details of Prozan's computation, but Saunders,[14] using Prozan's method, reported a time of 45 min on a CDC 3200 (23 by 11 mesh) for computing the flow in a nozzle with a large radius of curvature. Migdal et al. reported a computational time of less than 5 min on an IBM 350/75; Laval reported a computational time of about 2 h on an IBM 360/50 (61 by 21 mesh); and Serra reported 80 min on a Univac 1108 (3000 mesh points). Prozan and Kooker,[15] also solved this case using a relaxation scheme to solve the steady, irrotational equations of motion. Their computational time was 5 to 10 min on an IBM 7094 (21 by 11 mesh).

The present method was also used to compute the steady-state flow in a 15° conical, converging nozzle whose geometry is shown in Fig. 2b. The Mach number contours and wall pressure ratio for a nozzle pressure ratio of 2.0 are shown in Fig. 4. The experimental data are Thornock's.[16] The computed discharge coefficient is 0.957, compared with the experimental value of 0.960. The 23 by 7 computational mesh required 250 time planes and a computational time of 29 s. There is good agreement with the experimental data. Wehofer and Moger[17] and Brown and Ozcan[18] also solved this case. Wehofer and Moger's solution for a pressure ratio of 2 required over 2 h on an IBM 360/50 (47 by 11 mesh); Brown and Ozcan's results required 17 min on an IBM 360/65 (20 by 6 mesh).

Finally, the present method was used to calculate the flow in a 10° conical, plug nozzle whose geometry is shown in Fig. 2c. Figure 5 shows Mach number contours and plug pressure ratio for a nozzle pressure ratio of 3.29. The experimental data are those of Bresnahan and Johns.[19] The 31 by 6 computational mesh required 316 time planes and a computational time of 52 s. Again, there is good agreement with the experimental data. I am unware of any other time-dependent analayses of plug nozzles.

2. Viscous Flow Case. The results presented here were published in Ref. 3. The nozzle geometry, shown in Fig. 6, is Configuration 1 (5-x size) of Ref. 20. Figure 7 gives the computer-plotted steady-state lines of constant Mach number for a throat Reynolds number of 1200 based on the throat gap. The bottom line of the frame is the nozzle midplane, and the flow is from left to right. The lowest and highest contour lines are labeled L and H, respectively. The static wall temperature was set to the stagnation temperature. The first coefficients of viscosity μ and thermal conductivity k were assumed to vary as the square root of the temperature. The second coefficient of viscosity λ was set equal to $-0.67\ \mu$. As Fig. 7 shows, the boundary layer grows very rapidly in the supersonic part of the nozzle. Figure 8 gives the velocity profile at x = 1.65 cm (0.65 in.). The quantity M^* is the velocity magnitude divided by the speed of sound at the nozzle throat, assuming one-dimensional, isentropic flow, and Y_w is the height of the nozzle wall at x = 1.65 cm. The experimental data are those of Ref. 20. As Fig. 8 shows, the present theory agrees well with the experimental data, as does the inviscid-core, boundary-layer theory of Ref. 20 (not shown). However, the pressure in the boundary layer just downstream of the throat varied as much as 20% radially, making the constant radial pressure assumpution of a boundary-layer technique somewhat questionable. This calculation used an 80 by 21 mesh and required approximately 1000 time steps to reach steady state. The flow was assumed to have reached steady state when there was no visible change in the computer film plots produced every 50 time steps. The computational time was 7 min on a CDC-7600 computer. Figure 9 shows the discharge coefficient for throat Reynolds numbers of 600 to 3600. As Fig. 9 shows, the present solution is superior to the inviscid-core, boundary-layer solution of Ref. 20, whose authors had reservations about the accuracy of the $Re^* = 600$ experimental data point and theoretical solution.

For these calculations, values for the exit column of mesh points were extrapolated from the interior mesh points. For $Re^* = 1200$, this gave a wall pressure of 60.8 Pa (0.0088 psia) at the nozzle exit. To determine the sensitivity of this flow to the downstream plenum pressure, a different nozzle exit boundary condition was applied. The static pressure for all exit mesh points in the subsonic region was specified; i.e., the characteristic scheme for subsonic outflow was used. Figure 10 shows the wall pressure for downstream plenum pressures of 27.6 Pa (0.004 psia) and 269.0 Pa (0.039 psia). Figure 10 shows that the 27.6-Pa plenum pressure did not change the nozzle flow significantly compared with the extrapolated case. In fact, the expansion from the higher wall pressure to the specified exit pressure occurred over only four mesh lengths in the x-direction and two in the y-direction. Reference 20 did not contain any theoretical wall pressure results. On the other hand, the 269.0-Pa plenum pressure caused the boundary layer to separate from the nozzle wall. As Fig. 10 shows, there is reasonably good agreement with the experimental data of Ref. 20. The inviscid-core, boundary-layer technique of Ref. 20 cannot calculate separated flows. Figure 11 shows the computer-plotted, steady-state lines of constant Mach number for the separated case.

3. Turbulent Flow Case. The present method was used to calculate the steady-state solution for a plane jet in a uniform stream. The turbulence was modeled using the mixing-length model option. The jet and external stream had initial Mach numbers of 0.14 and 0.02, respectively. The jet height was 0.9525 cm (0.375 in.), and the Reynolds number based on the jet height was 3×10^4. The inlet flow profile was assumed to have free-slip walls. The midplane velocity decay, along with the laminar value, is shown in Fig. 12. The experimental data are from Ref. 21. Although the mixing-length model does not produce excellent results, it is a significant improvement over the laminar solution. In addition, the assumption of a free-slip inlet velocity profile is most likely a major source of error. The calculation used a 41 by 21 mesh and required approximately 1000 time steps to reach steady state. The flow was assumed to have reached steady state when there was no visible change in the computer film plots produced every 50 time steps. The computational time was 4 min on a CDC 7600 computer.

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II. THE VNAP PROGRAM AND ITS USE

A. The Subroutines

The computer program consists of 1 program, 1 function, and 15 subroutines.

1. Program VNAP. VNAP initiates a run by reading in the input data. Next, the program title, abstract, and input data descriptions are printed. The input data are then converted to the internal units, velocity in feet per second, pressure in pounds-force per square foot, density in pounds-force-second squared per foot to the fourth power, length in inches, $\Delta\tau$ in inch-second per foot, μ and λ in pounds-force-second-inch per cubic foot, k in pounds-force-inch per foot-second-degree Rankine, and R in foot-pounds-force per pound-mass-degree Rankine. If requested, VNAP calls subroutine ØNEDIM to calculate the one-dimensional, initial-value surface. VNAP then prints the initial-value surface, which includes a mass flow and momentum thrust calculation made by subroutine MASFLØ. Next, subroutine PLØT is called to plot the data on film. The final part of VNAP is the time-step loop, which calculates the next time-step size; calls subroutines VISCØUS to calculate the artificial, molecular, and turbulent viscosity-heat conduction terms, INTER to compute the interior mesh points, WALL to compute the wall and centerbody mesh points, INLET to compute the inlet mesh points for subsonic flow, EXITT to compute the exit mesh points, and MASFLØ to compute the mass flow and momentum thrust; prints the solution surface; calls subroutine PLØT to plot the data on film; checks the solution for its convergence to the steady-state solution; and punches the last solution plane on cards for restart. VNAP calls subroutine ADV (LASL system routine) to advance the film 10 frames (if NPLØT $\geqslant$ 0) at the end of the run for handling purposes.

2. Subroutine GEØM. VNAP calls subroutine GEØM to calculate the wall coordinates and slopes for four different wall geometries: a constant area duct; a circular-arc, conical wall; and two tabular input walls. For the first tabular wall, a completely general set of wall coordinates is input. Subroutine GEØM then calls subroutine MTLUP, which interpolates for equally spaced coordinates. Next, subroutine GEØM calls function DIF, which calculates the slopes of the equally spaced coordinates. For the second tabular wall, equally spaced coordinates and slopes are read in.

3. Subroutine GEØMCB. VNAP calls GEØMCB to calculate the centerbody coordinates and slopes for four different centerbody geometries. It is the same as subroutine GEØM.

4. Subroutine MTLUP. Subroutine MTLUP, dated 9-12-69, was taken from the NASA Langley program library. Subroutines GEØM and GEØMCB call it to interpolate the wall and centerbody coordinates for equally spaced coordinates.

5. Function DIF. Function DIF, dated 8-1-68, also was taken from the NASA Langley program library. Subroutines GEØM and GEØMCB call it to calculate the slopes of the wall and centerbody coordinates.

6. Subroutine ØNEDIM. VNAP calls ØNEDIM to compute the one-dimensional, isentropic initial value surface. A Newton-Raphson scheme is used to calculate the Mach number for the area ratios, which are determined from the geometry.

7. Subroutine EØS. Subroutine EØS calculates the equation of state quantities. These calculations have been combined in one subroutine to facilitate modfying the VNAP program for variable ratios of specific heats and gas constants.

8. Subroutine MAP. Subroutine MAP calculates the mapping functions that map the physical plane to a rectangular computational plane. Therefore, it is called before each mesh point is calculated.

9. Subroutine MASFLØ. VNAP calls MASFLØ to calculate the mass flow and axial momentum thrust for the initial-value and solution surfaces. This subroutine uses the trapezoidal rule to evaluate the mass flow and axial momentum thrust integrals.

10. Subroutine PLØT. VNAP calls PLØT to produce velocity vector plots and contours plots of density, pressure, temperature, and Mach number using the SC-4020 microfilm recorder. The SC-4020 recorder uses a 1022 by 1022 array of plotting points or coordinates on each film frame. The origin is at the upper left corner of the array. The coordinates to be plotted by the SC-4020 recorder are assumed to be integer constants. The first section sets up the plot size by setting the maximum left (XL), right (XR), top (YT), and bottom (YB) coordinates in the physical space. Then the film frame coordinates and scaling factors are determined with the plot beginning at 900, instead of 1022, to allow for labeling.

The next section generates the velocity vector plot. First, the maximum velocity is determined to scale the plot. LASL subroutine ADV advances the film one frame. Then the velocity vector is calculated in fixed point film frame coordinates. LASL subroutine DRV draws a line between the points (IX1,IY1) and (IX2,IY2) after which LASL subroutine PLT plots a plus sign at the point (IX1, IY1). LASL subroutine LINCNT skips down 58 lines (each printed line height equals 16 film frame points). The routine then returns to set up the plot size for the next velocity vector plot if IVPTS > 1 or goes on to the next section if IVPTS ≤ 1.

The next section resets the plot size for the contour plots in case the different scaled velocity vector plots were requested (IVPTS > 1).

The next section fills the plotting array called CQ with the variables density (pounds-mass per cubic foot or kilograms per cubic meter), pressure (pounds-force per square inch or kilopascals), temperature (degrees Rankine or kelvins), and Mach number.

The next section determines the plotting line quantities using

$$CQ_K = CQ_{MIN} + 0.1K(CQ_{MAX} - CQ_{MIN}) ,$$

where K goes from 1 to 9. This section also labels the frames.

The next section determines the location of each contour line segment and plots it. Subroutine DRV draws the contour line segment defined by the film frame coordinates (IX1, IY1) and (IX2, IY2). Subroutine PLT plots an L on the low contour (K = 1) and an H on the high contour (K = 9).

The last section draws the geometry boundaries for the contour plots. The upper boundary is specified by YW; the lower, by YCB. Next, the routine returns to the section that fills the plotting array CQ for the next contour plot.

11. Subroutine VISCØUS. VNAP calls VISCØUS to calculate the artificial viscosity terms for shock computations using a velocity gradient viscosity coefficient. VISCØUS also calculates the molecular viscosity terms in the Navier-Stokes equations and calculates the eddy viscosity using the mixing-length turbulence model. The mixing length is calculated in subroutine MIXLEN. Finally, if requested, VISCØUS prints out the various viscous quantities.

12. Subroutine SMØØTH. VNAP calls SMØØTH to add numerical smoothing to stabilize the calculations for very nonuniform initial data surfaces or to accelerate the convergence to steady state. The physically correct molecular viscous terms (with a large viscosity coefficient) also could be used, but they are much slower and cannot be reduced or turned off during a run.

13. Subroutine MIXLEN. VISCØUS calls MIXLEN to calculate the mixing length used to calculate the eddy viscosity in the mixing-length model of turbulence.

14. Subroutine INTER. VNAP calls INTER to calculate the interior mesh points. INTER uses the MacCormack, second-order, finite-difference scheme.

15. Subroutine WALL. VNAP calls WALL to compute the wall, centerbody, free-jet boundary, and sharp expansion corner mesh points. WALL uses a second-order, reference-plane characteristic scheme and controls the interpolation-extrapolation process for locating the free-jet boundary.

16. Subroutine INLET. VNAP calls INLET to compute the inlet mesh points for subsonic flow. INLET uses a second-order, reference-plane characteristic scheme.

17. Subroutine EXITT. VNAP calls EXITT to calculate the exit mesh points. EXITT uses a second-order, reference-plane characteristic scheme when the flow is subsonic and extrapolation when it is supersonic. It also checks the Mach number to determine which boundary condition should be used at each mesh point.

B. The Computational Grid

The computational plane grid is shown in Fig. 13. It is rectangular with equal spacing in the ζ and η directions, although $\Delta\zeta$ and $\Delta\eta$ are not generally equal.

C. The Input Data

The program input data are entered by a title card and seven namelists, CNTRL, IVS, GEMTRY, GCBL, BC, AVL, and RVL, all discussed below. The program continues reading in data decks and executing them until a file mark is encountered. After each data deck is executed, the default values for the input data are restored before the next data deck is read in.

1. Title Card. The first card of each data deck is a title card consisting of 80 alphanumeric characters that identify the job. This must always be the first card of the data deck, even if no information is specified on it. The seven namelists must appear in the following order.

2. Namelist CNTRL. CNTRL inputs the parameters that control the overall logic of the program.

LMAX — An integer that specifies the number of mesh points in the x or ζ direction (81 maximum). No default value is specified.

MMAX — An integer that specifies the number of mesh points in the y or η direction (21 maximum). No default value is specified.

NMAX — An integer that specifies the maximum number of time steps. For NMAX = 0, only the initial data surface is computed and printed (provided NPRINT > 0). The default value is 0.

NPRINT — An integer that specifies the amount of output desired. For NPRINT = N, every Nth solution plane, plus the initial data and final solution planes, is printed. For NPRINT = -N, every Nth solution plane, plus the final solution plane, is printed. For NPRINT = 0, only the final solution plane is printed. The default value is 0.

TCØNV Specifies the axial velocity steady-state convergence tolerance in per cent. If TCØNV is less than or equal to zero, the convergence is not checked. The default is 0.0.

FDT A parameter that premultiplies the allowable time step and is denoted by A in Eq. (45). In general it is desirable to use as large a value of FDT as possible without making the computation unstable. However, sometimes an FDT slightly less than the maximum stable value may increase the convergence to steady state. The default value is 1.0 which should be adequate for most inviscid flows whereas a smaller value may be required for viscous flows and flows that contain shocks (see Sec. II-F).

GAMMA The ratio of specific heats. The default value is 1.4.

RGAS The gas constant in foot-pounds-force per pound-mass-degree Rankine if English units are used, or joules per kilogram-kelvin in metric units. The default value is 53.35.

TSTØP Specifies the physical time, in seconds, at which the computations will be stopped. The default value is 1.0.

IUI An integer that specifies the type of units to be used for the input quantities. If IUI equals 1, English units are assumed; if it equals 2, metric units are assumed. In using any default values, make sure that they correspond to the proper units. The default value is 1.

IUØ Same as IUI, but for output quantities. If IUØ equals 3, both English and metric units are printed. The default value is 1.

IPUNCH An integer that if nonzero punches the last solution plane on cards for restart. The default value is 0.

NPLØT An integer that if greater than or equal to zero plots both velocity vectors and contours of density, pressure, temperature, and Mach number on a SC-4020 microfilm recorder. For NPLØT = N every Nth solution plane, plus the initial-data and final solution planes, is plotted. For NPLOT = 0, only the final solution plane is plotted. The default value is -1.

The remaining parameters in namelist CNTRL are less important. For most flows, these remaining parameters can be left at their default values.

NASM An integer that specifies which part of the flowfield is tested for steady-state convergence. When NASM = 0, the entire flowfield is tested. When NASM = 1, the throat or minimum area region to the exit is tested. The default value is 1.

NAME An integer that when nonzero causes the seven namelists to be printed in addition to the regular output. The default value is 0.

NCØNVI An integer that specifies how many times the convergence tolerance TCØNV must be satisfied on consecutive time steps before the solution is considered to have converged. The default value is 1.

IUNIT An integer that when zero causes the program to use either English or metric units (see IUI and IUØ). When IUNIT = 1, a nondimensional set of units is used. The default value is 0.

PLØW If the pressure becomes negative during a calculation, it is set equal to PLØW in pounds-force per square inch or kilopascals. The default value is 0.01.

RØLØW If the density becomes negative during a calculation, it is set equal to RØLØW in pounds-mass per cubic foot or kilograms per cubic meter. The default value is 0.0001.

IVPTS An integer that controls the scaling of the velocity vector plots. IVPTS = 1 produces one plot with the maximum vector equal to 0.9 $\Delta\zeta$. IVPTS = 2 produces the above plot and a second plot where the maximum vector is 1.9 $\Delta\zeta$, and so on. The default value is 1.

3. Namelist IVS. This namelist specifies the flow variables for the initial data surface.

N1D An integer that specifies the type of initial data surface desired. When N1D = 0, a two-dimensional, initial data surface is read in. Values of U, V, P, and RØ (discussed below) must be read in for all L = 1 to LMAX and M = 1 to MMAX mesh points. For cases with reflected viscous boundary conditions (IVBC = 0 in namelist BC), an initial value of 0.0 for U at grid points next to solid boundaries will cause a division by zero. Therefore, if a value of 0.0 is desired, set U equal to some small but nonzero value. When N1D $\neq$ 0, a one-dimensional data surface is computed internally. The following combinations are possible:

N1D = -2 subsonic } see RSTAR and RSTARS
N1D = -1 supersonic

N1D = 1 subsonic-sonic-supersonic
N1D = 2 subsonic-sonic-subsonic
N1D = 3 supersonic-sonic-supersonic
N1D = 4 supersonic-sonic-subsonic } No additional data are needed.

The default value is 1.

U(L,M,1) The array that denotes the x or ζ direction velocity component in feet or meters per second. When N1D = 0, U(L,M,1) must be input for L = 1 to LMAX and M = 1 to MMAX. When N1D $\neq$ 0, U(L,M,1) is not input. No default values are specified.

V(L,M,1) An array that denotes the y or η direction velocity component in feet or meters per second. See U(L,M,1) for additional information. No default values are specified.

P(L,M,1) An array that denotes the pressure in pounds-force per square inch or kilopascals. See U(L,M,1) for additional information. No default values are specified.

RØ(L,M,1) An array that denotes the density in pounds-mass per cubic foot or kilograms per cubic meter. See U(L,M,1) for additional information. No default values are specified.

RSTAR, RSTARS If N1D = -1 or -2, either RSTAR for planar or RSTARS for axisymmetric flow must be input. RSTAR is the area per unit depth, in inches or centimeters, where the Mach number is unity. RSTARS is the area divided by π, that is, the radius squared, in square inches or centimeters, where the Mach number is unity. The default values are 0.0.

If the restart option is to be used, the initial run must have been made with IPUNCH $\neq$ 0 in CNTRL, thereby causing a new IVS namelist deck to be punched. The new IVS namelist replaces the one used in the initial run and includes two additional parameters, NSTART and TSTART, which denote, respectively, the time step and physical time at which the solution was restarted.

When N1D $\neq$ 0, the initial data are calculated using one-dimensional, isentropic theory. However, the x and y velcoity components are adjusted while the magnitude is kept constant and the flow angle is satisfied. The flow angles are linearly interpolated between the slopes of the wall and centerbody.

4. Namelist GEMTRY. This namelist specifies the parameters that define the wall contour.

NDIM An integer that denotes the flow geometry. When NDIM = 0, two-dimensional planar flow is assumed; when NDIM = 1, axisymmetric flow is assumed. The default value is 1.

NGEØM An integer that specifies one of four different wall geometries. (A discussion of these four cases follows the definitions of the additional parameters in this namelist.) No default value is specified.

XI The x coordinate, in inches or centimeters, of the wall as well as the flow region inlet. No default value is specified.

RI The y coordinate, in inches or centimeters, of the wall inlet. No default value is specified.

RT The y coordinate, in inches or centimeters, of the wall throat. No default value is specified.

XE The x coordinate, in inches or centimeters, of the wall or free jet as well as the flow region exit. No default value is specified.

RCI The radius of curvature, in inches or centimeters, of the wall inlet. No default value is specified.

RCT The radius of curvature, in inches or centimeters, of the wall throat. No default value is specified.

ANGI The angle, in degrees, of the converging section. No default value is is specified.

ANGE The angle, in degrees, of the diverging section. No default value is specified.

XWI A one-dimensional array of unequally spaced x coordinates in inches or centimeters (81 maximum). No default values are specified.

YWI A one-dimensional array of y coordinates, in inches or centimeters, which corresponds to the x coordinates in array XWI (81 maximum). No default values are specified.

NWPTS An integer that specifies the number of entries in arrays XWI and YWI. The maximum value is 81. No default value is specified.

IINT An integer that specifies the order of interpolation used. The maximum value is 2. The default value is 2.

IDIF An integer that specifies the order of differentiation used. The maximum value is 5. The default value is 2.

YW A one-dimensional array of y coordinates, in inches or centimeters, which corresponds to LMAX equally spaced x coordinates. No default values are specified.

NXNY A one-dimensional array (floating point) of the negative of the wall slopes that correspond to the elements of YW. No default values are specified.

JFLAG An integer that when equal to 1 denotes that a free jet calculation is to be carried out and when equal to -1 denotes that there is a supersonic sharp expansion corner on the wall. These two options are allowed only for the free-slip wall boundary condition. Many free jet flows contain shocks and therefore require artificial viscosity (see namelist AVL). The default value is 0 (no free jet and no sharp expansion corner).

LJET An integer that when JFLAG = 1 denotes the first mesh point of the free jet boundary (the last wall mesh point is LJET-1). However, when JFLAG = -1, LJET is the first mesh point downstream of the sharp expansion corner (the corner mesh point is LJET-1). The program assumes that either the wall ends exactly at LJET-1 (JFLAG = 1) or the sharp expansion corner is located exactly at LJET-1 (JFLAG = -1). Also, for the sharp expansion corner case (JFLAG = -1), the slope of the wall at the corner (LJET-1) should be the upstream value. The program does not allow both a sharp expansion corner and a free-jet calculation. No default value is given.

The following are the four different wall geometries that this program considers.

a. Constant Area Duct (NGEØM = 1). The parameter XI, RI (duct radius), and XE must be specified.

b. Circular-Arc Conical Wall (NGEØM = 2). The geometry for this case is shown in Fig. 14. The parameters XI, RI, RT, XE, RCI, RCT, ANGI, and ANGE are specified. The x coordinate of the throat and the exit radius are computed internally.

c. General Wall (NGEØM = 3). An arbitrary wall contour is specified by tabular input. The y coordinates must be single-valued functions of x. NWPTS x and y coordinate pairs are specified by the arrays XWI and YWI, respectively. The tabular data need not be equally spaced. The first element of the XWI array, XWI(1), is assumed to be the flow region inlet, and the last element, XWI(NWPTS), is assumed to be the flow region exit. Therefore, XI and XE are not input. From the specified values of NWPTS, XWI, YWI, IINT, and IDIF, the program uses IINT-order interpolation to obtain LMAX equally spaced contour points. Next, IDIF-order differentiation is used to obtain the wall slope at these LMAX points.

d. General Wall (NGEØM = 4). An arbitary wall contour is specified by tabular input. The y coordinates must be single-valued functions of x. LMAX y coordinates and the negative of their slopes are specified by the arrays YW and NXNY, respectively. These y coordinates correspond to the LMAX equally spaced, x mesh points. Therefore, XI and XE are input instead of each x coordinate.

5. Namelist GCBL. This namelist specifies the parameters that define the centerbody geometry. If there is no centerbody, this namelist is left blank but it still must be present in the data deck.

NGCB — An integer that when nonzero specifies one of four different centerbody geometries. A discussion of these four cases follows the definitions of the additional parameters in this namelist. The default value is 0.

RICB — The y coordinate, in inches or centimeters, of the centerbody inlet. No default value is specified.

RTCB — The y coordinate, in inches or centimeters, of the centerbody maximum radius. No default value is specified.

RCICB — The radius of curvature, in inches or centimeters, of the centerbody inlet. No default value is specified.

RCTCB — The radius of curvature, in inches or centimeters, of the centerbody maximum radius. No default value is specified.

ANGICB — The angle, in degrees, of the converging section. No default value is specified.

ANGECB — The angle, in degrees, of the diverging section. No default value is specified.

XCBI — A one-dimensional array of unequally spaced x coordinates in inches or centimeters (81 maximum). No default values are specified.

YCBI — A one-dimensional array of y coordinates, in inches or centimeters, which corresponds to the x coordinates in array XCBI (81 maximum). No default values are specified.

NCBPTS — An integer that specifies the number of entries in arrays XCBI and YCBI. The maximum value is 81. No default value is specified.

IINTCB — An integer that specifies the order of interpolation. The maximum value is 2. The default value is 2.

IDIFCB — An integer that specifies the order of differentiation. The maximum value is 5. The default value is 2.

YCB — A one-dimensional array of y coordinates, in inches or centimeters, which corresponds to LMAX equally spaced x coordinates. No default values are specified.

NXNYCB — A one-dimensional array (floating point) of the negative of the centerbody slopes that correspond to the elements of YCB. No default values are specified.

The following four different centerbody geometries are considered.

a. Cylindrical Centerbody (NGCB = 1). The parameter RICB (radius of the centerbody) must be specified.

b. Circular-Arc Conical Centerbody (NGCB = 2). The geometry for this case is shown in Fig. 15. The parameters RICB, RTCB, RCICB, RCTCB, ANGICB, and ANGECB are specified. The x coordinate of the maximum radius and the radius of the exit are computed internally.

c. General Centerbody (NGCB = 3). An arbitrary centerbody contour is specified by tabular input. The y coordinates must be single-valued functions of x. NCBPTS x and y coordinate pairs are specified by the arrays XCBI and YCBI, respectively. The tabular data need not be equally spaced. The flow region is assumed to begin and end at either XI or XWI(1) and XE or XWI(NWPTS), respectively (see namelist GEMTRY). From the specified values of NCBPTS, XCBI, YCBI, IINTCB, and IDIFCB, the program uses IINTCB-order interpolation to obtain LMAX equally spaced centerbody points. Next, IDIFCB-order differentiation is used to obtain the centerbody slope at these LMAX points.

d. General Centerbody (NGCB = 4). An arbitrary centerbody contour is specified by tabular input. The y coordinates must be single-valued functions of x. LMAX y coordinates and the negative of their slopes are specified by the arrays YCB and NXNYCB, respectively. These coordinates correspond to the LMAX equally spaced, x mesh points. The flow region is assumed to begin and end at either XI or XWI(1) and XE or XWI(NWPTS), respectively (see namelist GEMTRY).

6. Namelist BC. This namelist specifies the flow variables for the inlet and exit computational boundaries.

NSTAG	An integer that when nonzero denotes that variable total pressure PT, variable total temperature TT, and variable flow angle THETA (all discussed below) across the inlet have been specified. If NSTAG $\neq$ 0, values of PT, TT, and THETA must be specified at the M = 1 to MMAX points even if one or two of the variables are constant. If NSTAG = 0, only the first value for each of the three arrays need be specified. The default value is 0.
PT(M)	A one-dimensional array that denotes the stagnation pressure, in pounds -force per square inch or kilopascals, across the inlet. The default value is PT(1) = 0.0.
TT(M)	A one-dimensional array that denotes the stagnation temperature, in degrees Rankine or kelvins, across the inlet. The default value is TT(1) = 0.0.
THETA(M)	A one-dimensional array that denotes the flow angle, in degrees, across the inlet. The default value is THETA(1) = 0.0, which is meaningful only when NSTAG = 0.
PE(M)	A one-dimensional array that denotes the pressure, in pounds-force per square inch or kilopascals, to which the flow is exiting. This pressure is used to compute the flow exit conditions when the flow is subsonic and the free jet boundary location when a free jet calculation is requested. The free jet boundary pressure is assumed to be constant and equal to PE(MMAX). This array starts with the centerline or centerbody value and ends with the wall value. If PE is constant across the exit, only the first value need be specified. The default value is PE(1) = 14.7.
UI(M)	A one-dimensional array that denotes the x velocity, in feet or meters per second, across the inlet. This array, as well as the arrays VI, PI, and RØI below, starts with the centerline or centerbody value and ends with the wall value. No default values are specified.
VI(M)	Same as UI, but for y velocity.
PI(M)	Same as UI, but for pressure in pounds-force per square inch or kilopascals.
RØI(M)	Same as UI, but for density in pounds-mass per cubic foot or kilograms per cubic meter.

TW A one-dimensional array that denotes the wall temperature in degrees Rankine or kelvins which corresponds to the x mesh points. If TW is not specified, the wall is assumed to be adiabatic.

TCB Same as TW, but for centerbody temperature.

ISUPER An integer that specifies whether the inlet flow is sub- or supersonic. ISUPER may have the following values.

ISUPER = 0 Subsonic inflow. Specify PT, TT, and THETA.

ISUPER = -1 Subsonic inflow. Specify UI, VI, PI, and RØI. (PI is only an initial guess).

ISUPER = 1 Supersonic inflow. Specify UI, VI, PI, and RØI. The default value is 0.

IEXTRA An integer that when not 0 forces either extrapolation (IEXTRA = 1) or specified pressure (IEXTRA = 2) as the outflow boundary condition, regardless of Mach number. The default value is 0.

IEX An integer that denotes the type of extrapolation to be used for supersonic outflow. IEX = 0 denotes zeroth order extrapolation; IEX = 1, linear extrapolation. The default value is 1.

IVBC An integer that specifies whether extrapolation or reflection is used to determine the viscous terms at boundaries. IVBC = 0 specifies reflection; IVBC = 1, linear extrapolation. Reflection is always used at the centerline or midplane. The default value is 0.

NØSLIP An integer that when zero specifies free-slip walls. NØSLIP = 1 specifies no slip ($u = v = 0$) walls for all solid boundaries. No free-jet calculation is allowed for NØSLIP = 1. The default value is 0.

DYW A parameter that specifies the maximum allowable change in the free-jet boundary location on each time step. The default value is 0.001, that is, 0.1% maximum change per time step.

7. Namelist AVL. This namelist specifies the parameters that determine the artificial viscosity used to stabilize the calculations against shocks. Given no shocks or very uniform initial data surfaces, this namelist is left blank. See Sec. II-F on use of the artificial viscosity model.

CAV Denotes the artificial viscosity premultiplier C in Eq. (6) or (27) in the artificial viscosity model. A nondimensional value is used (see Sec. II-F.) The default value is 0.0.

XMU Denotes the coefficient C_μ in Eq. (7) in the artificial viscosity model. A nondimensional value is used. The default value is 0.4.

XLA — Denotes the coefficient C_λ in Eq. (6) or (27) in the artificial viscosity model. A nondimensional value is used. The default value is 1.0.

RKMU — Denotes the coefficient C_k in Eq. (8) in the artificial viscosity model. A nondimensional value is used. The default value is 0.7.

XRØ — Denotes the coefficient C_ρ in Eq. (9) or (28) for the density smoothing in the artificial viscosity model. A nondimensional value is used. The default value is 0.6.

LSS — An integer that specifies the x mesh point at which addition of the artificial viscosity will begin. The default value is 2.

NST — An integer that denotes the time step at which a small amount of numerical smoothing is stopped. This smoothing may be required to stabilize the calculations for very nonuniform or impulsively started initial data surfaces. Some initial smoothing caused subsonic flows to reach steady state faster, but this was not true for trans- and supersonic flows. The default value is 0 (no smoothing). When using the restart option, make sure that NST is equal to zero.

SMP — A parameter that controls the amount of smoothing (provided NST ≠ 0). The dependent variables are smoothed by

$$u_{L,M} = SMP*u_{L,M} + (1.0-SMP)*(u_{L+1,M} + u_{L,M+1} + u_{L-1,M} + u_{L,M-1})/4.0 \ .$$

The physically correct, molecular viscous terms (with a large viscosity coefficient) also could be used, but their computation is much slower and cannot be reduced or turned off during a run. The default value is 0.95.

IAV — An integer that when equal to 0 causes the viscous-turbulence terms to be printed at the solution planes specified by NPRINT in namelist CNTRL. IAV = 1 bypasses this option. The default value is 1.

SMACH — Denotes the Mach number below which no artificial viscosity for shock calculations is added to the solution. The default value is 0.0.

8. Namelist RVL. This namelist specifies the real or molecular viscosity parameters and flags the mixing-length model of turbulence. For inviscid flows, RVL is left blank.

CMU, EMU — These parameters specify the molecular visocisty, μ, by $\mu = CMU \cdot T^{EMU}$, where T is the temperature in degrees Rankine or kelvins. The units of μ are pounds-force-second per square foot or pascal-second. The units of CMU (CLA and CK) that the program prints are the units of μ (λ and k). The default values are 0.0.

CLA, ELA — These parameters specify the second coefficient of viscosity, λ, by

$$\lambda = CLA \cdot T^{ELA} \quad ,$$

where T is the temperature in degrees Rankine or kelvins. The units of λ are pounds-force-second per square foot or pascal-second. The default values are 0.0.

CK, EK — These parameters specify the thermal conductivity, k, by $k = CK \cdot T^{EK}$, where T is the temperature in degrees Rankine or kelvins. The units of k are pounds-force per second-degree Rankine or watts per meter-kelvin. The default values are 0.0.

ITM — An integer that when nonzero specifies the mixing-length model of turbulence. The default value is 0.

D. The Output

Program output consists of printed output, film plots, and punched cards for restart. The program has no options to output any results on magnetic tapes. In all computer-printed figures, the number zero has a slash through it; the typed text has a slash through the letter O.

The first two pages (or first three pages in tabular input geometry) of output include the program title, abstract, list of control parameters, fluid model, flow geometry, duct geometry, boundary conditions, artificial viscosity, molecular viscosity, and turbulence model.

Following the title pages is the initial data surface. These data are either data that have been input or a one-dimensional solution computed by the program. All units are given. At the bottom of the initial data surface are the mass flow at the minimum cross section (MASS), the axial thrust (THRUST) due to the exit momentum only, the inlet mass flow (MASSI), and the exit mass flow (MASSE). For planar flow, the mass flow units are pounds-mass per inch-second or kilograms per centimeter-second and the thrust units are pounds-force per inch or newtons per centimeter. When the initial data surface is the one-dimensional solution calculated by the program, the mass flow and thrust values also are the one-dimensional values, although the velocity components are not.

After the initial data surface has been printed, the solution surfaces are printed in the same format. Each surface gives the flowfield at a certain time.

As many solution planes as desired are printed by varying the input data. If requested (IAV = 0) artificial viscosity, molecular viscosity, and turbulence parameters for grid points at which they are nonzero are printed before each solution plane. QUT and QVT, respectively, denote the ζ and η momentum equation right-hand side terms in feet or meters per second, QPT denotes the internal energy equation right-hand side terms in pounds-force per square inch or kilopascals, and QRØT denotes the continuity equation right-hand side terms in pounds-mass per cubic foot or kilograms per cubic meter. TLMUR is the ratio of turbulent to laminar viscosity. Film plots with the same units as the printed output also are made for each requested time step. When the computation is stopped because the flow has met the convergence tolerance, the physical time equals TSTØP, or the maximum number of time steps has been reached, the final solution plane is always printed and plotted (NPLØT $\neq$ -1). As they are for the initial data surface, the mass flow and thrust are printed below the soltuion surface. The thrust calculation includes only the axial exit momentum. For the free jet case, the thrust is calculated at the nozzle exit upstream of the jet.

E. Computing System Compatibility

1. Deck Setup. The deck begins with the common deck called MCC, followed by the main program called VNAP and the remaining function and subroutines. The common deck is preceeded by the card *CØMDECK, MCC beginning in column 1. This common deck is separated from the main program VNAP by the card *DECK,VNAP also beginning in column 1. Each subroutine and function also begins with a *DECK card. Any routine that uses the common deck MCC has the card *CALL,MCC, beginning in column 1, at the location where the common deck should be. The CDC routine UPDATE, which is similar to the CDC routine MØDIFY, places the common deck in each routine that contains a *CALL,MCC card. This simplifies changing the common statements as well as array sizes (see below). The *DECK cards allow one to compile individual subroutines without compiling the entire deck. For computing systems without an UPDATE or MØDIFY routine, remove all *DECK cards and replace all *CALL,MCC with the common deck, MCC.

2. Array Sizes. This version of the program allows for a maximum of 81 ζ and 21 η mesh points. These values are set by use of a parameter statement that is the first card in the common deck MCC. By using the routine UPDATE or MØDIFY, discussed above, one can change the array sizes by changing the one parameter statement card. When using computing systems that do not allow parameter statements, remove the parameter statement and replace the integers LI and MI in the

common block (as well as the two cards following the NAMELIST statements in program VNAP) with the desired values.

3. Film Plotting. The subroutine PLØT discussion in Sec. II-A describes the LASL system routines that this codes uses. For other computing systems, subroutine PLØT may have to be modified or replaced by a dummy subroutine.

4. Single-Subscripted Arrays. Most Fortran compilers generate a more efficient code when single-subscripted arrays are used. Therefore, in the routines that do most of the work, the triple-subscript solution arrays are used as single-subscripted arrays although they are dimensioned as triple subscripts. This mixing of subscripts is allowed on CDC compilers. If a particular compiler does not allow this, change the names of the single-subscripted arrays to dummy names and make them equivalent to the triple-subscripted arrays by use of an EQUIVALENCE statement. The affected routines are VNAP, VISCØUS, SMØØTH, INTER, WALL, and INLET.

F. Artificial Viscosity

The artificial viscosity model contains many parameters, but usually one needs to be concerned with only two, CAV and FDT, leaving the others at their default values. CAV controls the overall amount of smoothing and FDT controls the time step. If the space oscillations, those from point to point in the same time plane, are too large, increase CAV. If the shock is too smeared, decrease CAV. However, if the time oscillations, those at the same space point in different time planes, are too large, decrease FDT. Increases in CAV often require decreases in FDT, whereas decreases in CAV often allow increases in FDT. For computation efficiency, use large FDT values and, therefore, small CAV values. When FDT is too large, the solution usually "blows up" in less than 10 time steps. When CAV is too small, the solution usually takes a lot longer to "blow up." If FDT is smaller than necessary and CAV is larger, the solutions do not "blow up," but they are inaccurate and inefficient. However, for a given value of CAV there is a lower limit of FDT below which space oscillations appear.

For example, an oblique shock produced by supersonic flow (Mach number = 3.2) over a 30° wedge (pressure ratio = 6.84) required a CAV of 1.0 and an FDT of 0.4. Stronger shocks generally require larger CAV values and smaller FDT values. The opposite is true of weaker shocks.

G. Sample Calculations

1. Case No. 1 - Converging-Diverging, Inviscid Nozzle. The nozzle geometry for this case is shown in Fig. 2a, and results are shown in Fig. 3. The data deck and printed output are presented in Figs. 16 and 17, respectively.

a. Namelist CNTRL. This case uses a 21 by 8 mesh, so LMAX = 21 and MMAX = 8. The maximum number of time steps NMAX is set equal to 400. The convergence tolerance TCØNV is set equal to 0.003. The step-size premultiplier FDT is set equal to 1.34. The additional parameters are left equal to their default values.

b. Namelist IVS. The program computes a one-dimensional, subsonic-sonic-supersonic, initial data surface, so no input is required.

c. Namelist GEMTRY. The nozzle wall is a conical converging-diverging nozzle, so NGEØM = 2. The axial location of the inlet XI equals 0.31 in., the radius of the inlet RI is 2.5 in., the radius of the throat RT is 0.8 in., and the axial location of the exit XE equals 4.05 in. The radius of curvature of the inlet RCI is 0.8 in. and that of the throat RCT is 0.5 in. The angle of the converging section ANGI is 44.88°; that of the diverging section is 15°. No other input is required.

d. Namelist GCBL. Since this nozzle has no centerbody, no input is required.

e. Namelist BC. The stagnation pressure PT is 70.0 psia and the stagnation temperature TT is 540.0°R. No other input is required.

f. Namelist AVL. Since there are no strong shocks and the initial data are smooth, no input is required.

g. Namelist RVL. Since the flow is inviscid, no input is required.

2. Case No. 2 - Converging, Inviscid Nozzle. The nozzle geometry is shown in Fig. 2b, and results are shown in Fig. 4. The data deck and printed output are presented in Figs. 18 and 19, respectively.

a. Namelist CNTRL. This case uses a 23 by 7 mesh, so LMAX = 23 and MMAX = 7. The maximum number of time steps NMAX is set equal to 400. The convergence tolerance TCØNV is set equal to 0.005. The step-size premultiplier FDT is set equal to 1.15. The additional parameters are left equal to their default values.

b. Namelist IVS. No input is required because the program computes a one-dimensional, subsonic-sonic-supersonic, initial data surface.

c. Namelist GEMTRY. The nozzle is a conical converging nozzle, and either the NGEØM = 3 or 4 option could be used. The NGEØM = 4 option was chosen so the YW and NXNY arrays must be input. The axial location of the inlet XI equals -3.6 in. and that of the exit XE equals 0.8 in. Since a free-jet calculation is required for convergent sonic nozzles, JFLAG is set equal to 1. The nozzle ends at the 19th axial mesh point, so LJET is set equal to 20. The values of YW and NXNY for L = 20 to 23 are an initial guess of the shape of the jet boundary. No other input is required.

d. Namelist GCBL. Since this nozzle has no centerbody, no input is required.

e. Namelist BC. The stagnation pressure PT is 25.0 psia, the stagnation temperature TT is 640.0°R, and the ambient pressure to which the jet is exiting PE is 12.5 psia. No other input is required.

f. Namelist AVL. Since there are no strong shocks and the initial data are smooth, no input is required.

g. Namelist RVL. Since the flow is inviscid, no input is required.

3. Case No. 3 - Converging-Diverging, Plug, Inviscid Nozzle. The nozzle geometry is shown in Fig. 2c and the results are shown in Fig. 5. The data deck and printed output are presented in Figs. 20 and 21, respectively.

a. Namelist CNTRL. This case uses a 31 by 6 mesh so LMAX = 31 and MMAX = 6. The maximum number of time steps NMAX is set equal to 400. The convergence tolerance TCØNV is set equal to 0.005. The step-size premultiplier FDT is set equal to 1.25. The additional parameters are left equal to their default values.

b. Namelist IVS. The program computes a one-dimensional subsonic-sonic-supersonic, initial data surface, so no input is required.

c. Namelist GEMTRY. The nozzle wall is a constant-area duct, so NGEØM is set equal to 1. The axial locations of the inlet XI and exit XE are -4.44 and 2.96 in., respectively. The duct radius RI is 4.0 in. Since a free-jet calculation is required for plug nozzles, JFLAG is set equal to 1. The duct ends at the 22nd mesh point, so LJET is set equal to 23. The NGEØM = 1 option specifies a constant radius as the initial guess of the shape of the jet boundary. No other input is required.

d. Namelist GCBL. The nozzle centerbody is a conical, converging-diverging nozzle, so NGCB = 2. The radii of the inlet RICB and throat RTCB sections are 1.3 and 3.365 in., respectively. The radii of curvature of the inlet

RCICB and throat RCTCB sections are 0.75 and 4.95 in., respectively. The angles of the inlet ANGICB and exit ANGECB sections are 45.0° and 10.0°, respectively. No other input is required.

e. Namelist BC. The stagnation pressure PT is 100.0 psia, the stagnation temperature TT is 530.0°R, and the amibient pressure to which the nozzle is exiting PE is 30.4 psia. No other input is required.

f. Namelist AVL. Since there are no strong shocks and the initial data are smooth, no input is required.

g. Namelist RVL. Since the flow is inviscid, no input is required.

4. Case No. 4 - Converging-Diverging, Viscous Nozzle. The nozzle geometry for this case is shown in Fig. 6 and the results are shown in Figs. 7-11. The data deck and partial printed output are presented in Figs. 22 and 23, respectively.

a. Namelist CNTRL. This case uses a 80 by 21 mesh, so LMAX = 80 and MMAX = 21. The maximum number of time steps NMAX is set equal to 1000. The gas constant R is 287.0 J/kg-K. Since metric units are used, IUI = IUØ = 2. Film is requested every 50 time steps, so NPLØT = 50. No other input is required.

b. Namelist IVS. The program computes a one-dimensional, subsonic-sonic, supersonic, initial data surface, so no input is required.

c. Namelist GEMTRY. This is two-dimensional planar flow, so NDIM = 0. The nozzle wall is a general tabular contour, so either NGEØM = 3 or 4 could be used. The NGEØM = 3 option is used. Thirty seven coordinate pairs (XWI, YWI) are read in, so NWPTS = 37. The first coordinate pair (XWI(1), YWI(1)) is assumed to be the nozzle entrance, and the last pair (XWI(NWPTS), YWI(NWPTS)) is assumed to be the exit. No other input is required.

d. Namelist GCBL. Since the nozzle has no centerbody, no input is required.

e. Namelist BC. Since the inlet flow angle THETA is not constant, NSTAG = 1 and MMAX values of THETA, stagnation pressure PT, and stagnation temperature TT must be read in although PT and TT are constant. The stagnation pressure is 6.895 kPa and the stagnation temperature is 289.0 K. Since the exit flow is to be extrapolated regardless of the Mach number, IEXTRA = 1. The nozzle wall is a no-slip boundary, so NØSLIP = 1. No other input is required.

f. Namelist AVL. For this case, the exit boundary conditions do not produce any significant shocks. However, the initial data surface has free-slip walls and on the first time step the no-slip wall conditions are enforced. Therefore, some initial smoothing is used to aid the transition from free-slip to no-slip walls (NST = 50 and SMP = 0.5). No other input is required.

g. Namelist RVL. The viscosity and thermal conductivity coefficients are specified by CMU = 9.643×10^{-7} Pa-s/$K^{1/2}$, CLA = -6.429×10^{-7} Pa-s/$K^{1/2}$, and CK = 1.217×10^{-3} W/m-$K^{3/2}$. Recall that the units of CMU, CLA, and CK which the program prints are the units of μ, λ, and k, respectively. The viscosity is assumed to be a function of the square root of the temperature, so EMU = ELA = EK = 0.5. No other input is required.

5. Case No. 5 - Turbulent Plane Jet in a Uniform Stream. The results are shown in Fig. 12. The data deck and partial printed output are presented in Figs. 24 and 25, respectively.

a. Namelist CNTRL. This case uses a 41 by 21 mesh, so LMAX = 41 and MMAX = 21. The maximum number of time steps NMAX is set equal to 1000. The gas constant R is 287.0 J/kg-K. Since metric units are used, IUI = IUØ = 2. Film is requested every 50 time steps, so NPLØT = 50. No other input is required.

b. Namelist IVS. To speed up the calculation, an initial data surface that approximates the experimental data is input, so N1D = 0. The initial data surface is input by the arrays, U, V, P, and RØ.

c. Namelist GEMTRY. This is two-dimensional planar flow, so NDIM = 0. The upper flow boundary is assumed to be a straight horizontal wall, so NGEØM = 1. The wall height RI is 4.7625 cm, the inlet x location XI equals 0.0, and the exit x location XE equals 38.1 cm. No other input is required.

d. Namelist GCBL. Since this case has no centerbody, no input is required.

e. Namelist BC. Since the inlet flow is subsonic and u, v, and ρ are specified, ISUPER = -1. The values of u, v, and ρ at the inlet are input by the arrays UI, VI, and RØI. In addition, p must be input by PI although it is used only as an initial guess. The exit pressure PE is set at 101.35 kPa. No other input is required.

f. Namelist AVL. The viscous terms for this case are printed by settine IAV = 0. No other input is required.

g. Namelist RVL. The viscosity coefficients are specified by CMU = 1.813×10^{-5} Pa-s and CLA = $- 1.208 \times 10^{-5}$ Pa-s. The thermal conductivity is left at its default value of 0.0. The viscosity is assumed to be constant, so EMU and ELA are left at their default values of 0.0. The mixing-length model of turbulence is specified by setting ITM equal to 1. No other input is required.

APPENDIX A

CONSTANT ETA REFERENCE PLANE CHARACTERISTIC RELATIONS

I. GOVERNING EQUATIONS

The governing equations, (28) and (19)-(21), can be written as

$$\rho_\tau + u\rho_\zeta + \rho u_\zeta = -\bar{v}\rho_\eta - \rho\alpha u_\eta - \rho\beta v_\eta - \varepsilon\rho v/\bar{\eta} + \frac{C_\rho}{\rho}\Big[(\mu_A\rho_\zeta + \mu_A\alpha\rho_\eta)_\zeta$$

$$+ \alpha(\mu_A\rho_\zeta + \mu_A\alpha\rho_\eta)_\eta + \beta(\mu_A\beta\rho_\eta)_\eta + \varepsilon\mu_A\beta\rho_\eta/\bar{\eta}\Big] , \qquad \text{(A-1)}$$

$$u_\tau + uu_\zeta + p_\zeta/\rho = -\bar{v}u_\eta - \alpha p_\eta/\rho + \Big[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta\Big]_\zeta/\rho$$

$$+ \alpha\Big[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta\Big]_\eta/\rho + \beta\Big[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta)\Big]_\eta/\rho$$

$$+ \varepsilon\Big[(\lambda + \mu)(v_\zeta + \alpha v_\eta) + \mu\beta u_\eta\Big]/\rho\bar{\eta} , \qquad \text{(A-2)}$$

$$v_\tau + uv_\zeta = -\bar{v}v_\eta - \beta p_\eta/\rho + \beta\Big[(\lambda + 2\mu)\beta v_\eta + \lambda(u_\zeta + \alpha u_\eta)\Big]_\eta/\rho$$

$$+ \Big[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta)\Big]_\zeta/\rho + \alpha\Big[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta)\Big]_\eta/\rho$$

$$+ \varepsilon(\lambda + 2\mu)(\beta v_\eta - v/\bar{\eta})/\rho\bar{\eta} , \qquad \text{(A-3)}$$

$$p_\tau + up_\zeta - a^2(\rho_\tau + u\rho_\zeta) = -\bar{v}p_\eta + a^2\bar{v}\rho_\eta + (\gamma-1)\Big\{(\lambda + 2\mu)(u_\zeta + \alpha u_\eta)^2$$

$$+ (\lambda + 2\mu)(\beta v_\eta)^2 + \mu(v_\zeta + \alpha v_\eta)^2 + \mu(\beta u_\eta)^2 + 2\lambda(u_\zeta + \alpha u_\eta)\beta v_\eta$$

$$+ 2\mu\beta u_\eta(v_\zeta + \alpha v_\eta) + \Big[k(T_\zeta + \alpha T_\eta)\Big]_\zeta + \alpha\Big[k(T_\zeta + \alpha T_\eta)\Big]_\eta + \beta(k\beta T_\eta)_\eta$$

$$+ \varepsilon\Big[(\lambda + 2\mu)(v/\bar{\eta})^2 + 2\lambda v(\beta v_\eta + u_\zeta + \alpha u_\eta)/\bar{\eta} + k\beta T_\eta/\bar{\eta}\Big]\Big\} , \qquad \text{(A-4)}$$

where the ζ and η subscripts denote partial derivatives with respect to those variables. Letting

$$\psi_1 = \text{right-hand side of Eq. (A-1)} \ , \tag{A-5}$$

$$\psi_2 = \text{right-hand side of Eq. (A-2)} \ , \tag{A-6}$$

$$\psi_3 = \text{right-hand side of Eq. (A-3)} \ , \tag{A-7}$$

$$\psi_4 = \text{right-hand side of Eq. (A-4)} \ , \tag{A-8}$$

makes Eqs. (A-1) - (A-4) become

$$\rho_\tau + u\rho_\zeta + \rho u_\zeta = \psi_1 \ , \tag{A-9}$$

$$u_\tau + uu_\zeta + p_\zeta/\rho = \psi_2 \ , \tag{A-10}$$

$$v_\tau + uv_\zeta = \psi_3 \ , \tag{A-11}$$

$$p_\tau + up_\zeta - a^2\rho_\tau - a^2u\rho_\zeta = \psi_4 \ . \tag{A-12}$$

II. CHARACTERISTIC CURVES

A linear combination of the equations of motion can be formed by multiplying Eqs. (A-9)-(A-12) by ℓ_i, i = 1, 2, 3, 4, respectively, and then summing them. This linear combination can be written as

$$\ell_1(\rho_\tau + u\rho_\zeta + \rho u_\zeta - \psi_1) + \ell_2(u_\tau + uu_\zeta + p_\zeta/\rho - \psi_2) + \ell_3(v_\tau + uv_\zeta - \psi_3)$$

$$+ \ell_4\left(p_\tau + up_\zeta - a^2\rho_\tau - a^2u\rho_\zeta - \psi_4\right) = 0. \tag{A-13}$$

Rearrangement of Eq. (A-13) yields

$$\left(u\ell_1 - a^2u\ell_4\right)\rho_\zeta + \left(\ell_1 - a^2\ell_4\right)\rho_\tau + (\rho\ell_1 + u\ell_2)u_\zeta + \ell_2u_\tau + u\ell_3v_\zeta + \ell_3v_\tau$$

$$+ (\ell_2/\rho + u\ell_4)p_\zeta + \ell_4p_\tau = \ell_1\psi_1 + \ell_2\psi_2 + \ell_3\psi_3 + \ell_4\psi_4 \ . \tag{A-14}$$

The following set of vectors can be defined, where the components are the coefficients of the partial derivatives in Eq. (A-14).

$$W_1 = \left(u\ell_1 - a^2 u\ell_4,\ \ell_1 - a^2\ell_4\right), \tag{A-15}$$

$$W_2 = (\rho\ell_1 + u\ell_2,\ \ell_2) , \tag{A-16}$$

$$W_3 = (u\ell_3,\ \ell_3) , \tag{A-17}$$

$$W_4 = (\ell_2/\rho + u\ell_4,\ \ell_4). \tag{A-18}$$

Therefore, Eq. (A-14) can be written as

$$d_{W_1}\rho + d_{W_2}u + d_{W_3}v + d_{W_4}p = \ell_1\psi_1 + \ell_2\psi_2 + \ell_3\psi_3 + \ell_4\psi_4 , \tag{A-19}$$

where $d_{W_1}\rho$ is defined as the derivative of ρ in the direction of the vector W_1, etc.

A question is now posed: Can the ℓ_i, i = 1, 2, 3, 4, be chosen so that the vectors W_j, j = 1, 2, 3, 4, are linearly dependent or, in other words, lie in one direction. If such ℓ_i do exist, the curve that contains the vectors W_j is called the characteristic curve, its normal N is called the characteristic normal, and Eq. (A-19) is called the compatibility equation. Therefore, if $N = (N_\zeta, N_\tau)$ is the characteristic normal in the ζ-τ plane, N and W_j are related by

$$N \cdot W_j = 0 \ (j = 1, 2, 3, 4). \tag{A-20}$$

When Eq. (A-20) is expanded,

$$\left(u\ell_1 - a^2 u\ell_4\right) N_\zeta + \left(\ell_1 - a^2\ell_4\right) N_\tau = 0 , \tag{A-21}$$

$$(\rho\ell_1 + u\ell_2) N_\zeta + \ell_2 N_\tau = 0 , \tag{A-22}$$

$$u\ell_3 N_\zeta + \ell_3 N_\tau = 0 \ , \tag{A-23}$$

$$(\ell_2/\rho + u\ell_4)\ N_\zeta + \ell_4 N_\tau = 0 \ . \tag{A-24}$$

In matrix form, Eqs. (A-21)-(A-24) become

$$\begin{vmatrix} uN_\zeta+N_\tau & 0 & 0 & -a^2(uN_\zeta+N_\tau) \\ \rho N_\zeta & uN_\zeta+N_\tau & 0 & 0 \\ 0 & 0 & uN_\zeta+N_\tau & 0 \\ 0 & N_\zeta/\rho & 0 & uN_\zeta+N_\tau \end{vmatrix} \begin{vmatrix} \ell_1 \\ \ell_2 \\ \ell_3 \\ \ell_4 \end{vmatrix} = 0. \tag{A-25}$$

Equation (A-25) is a system of homogeneous equations. For Eq. (A-25) to have a nontrivial solution, the coefficient matrix must be singular; in other words, its determinant must equal zero. Setting the determinant equal to zero yields

$$(uN_\zeta + N_\tau)^2 \left[(uN_\zeta + N_\tau)^2 - a^2\ N_\zeta^2\right] = 0 \ . \tag{A-26}$$

Setting the first factor of Eq. (A-26) equal to zero yields

$$uN_\zeta + N_\tau = 0. \tag{A-27}$$

Setting the second factor of Eq. (A-26) equal to zero yields

$$uN_\zeta + N_\tau = \pm\ aN_\zeta. \tag{A-28}$$

Noting that $d\zeta/d\tau = -N_\tau/N_\zeta$, one can write Eqs. (A-27) and (A-28) as

$$d\zeta/d\tau = u \ , \tag{A-29}$$

$$d\zeta/d\tau = u \mp a. \tag{A-30}$$

Equation (A-29) represents the projection of the flow pathlines on the η = constant planes. Equation (A-30) represents the projection of the Mach cones on the η constant planes.

III. SOLUTION FOR THE ℓ_i

If the compatibility equation (A-19) is to be used, the arbitrary parameters ℓ_i must be evaluated as follows. Consider first the characteristic curve given by Eq. (A-27). Substituting Eq. (A-27) into Eq. (A-25) yields

$$\begin{vmatrix} 0 & 0 & 0 & 0 \\ \rho N_\zeta & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & N_\zeta/\rho & 0 & 0 \end{vmatrix} \begin{vmatrix} \ell_1 \\ \ell_2 \\ \ell_3 \\ \ell_4 \end{vmatrix} = 0 \ . \tag{A-31}$$

Since the rank of the coefficient matrix of Eq. (A-31) is two, there are two independent solutions for ℓ_i. From Eq. (31),

$$\ell_1 = \ell_2 = 0,\ \ell_3 \text{ and } \ell_4 \text{ are arbitrary.} \tag{A-32}$$

Therefore, two possible solutions are

$$\ell_1 = \ell_2 = \ell_3 = 0,\ \ell_4 = 1\ , \tag{A-33}$$

and

$$\ell_1 = \ell_2 = \ell_4 = 0,\ \ell_3 = 1\ . \tag{A-34}$$

Consider next the characteristic curve given by Eq. (A-28). Substituting Eq. (A-28) into (A-25) yields

$$\begin{vmatrix} \pm aN_\zeta & 0 & 0 & \mp a^3N_\zeta \\ \rho N_\zeta & \pm aN_\zeta & 0 & 0 \\ 0 & 0 & \pm aN_\zeta & 0 \\ 0 & N_\zeta/\rho & 0 & \pm aN_\zeta \end{vmatrix} \begin{vmatrix} \ell_1 \\ \ell_2 \\ \ell_3 \\ \ell_4 \end{vmatrix} = 0 \ . \tag{A-35}$$

Since the rank of the coefficient matrix of Eq. (A-35) is three, there is only one independent solution for ℓ_i. From Eq. (A-35),

$$\ell_3 = 0, \ \ell_1 = a^2\ell_4, \ \ell_2 = \mp \rho a\ell_4 \ . \tag{A-36}$$

Therefore, one possible solution is

$$\ell_1 = a^2, \ \ell_2 = \mp \rho a, \ \ell_3 = 0, \ \ell_4 = 1 \ . \tag{A-37}$$

IV. COMPATIBILITY EQUATIONS

Substituting Eqs. (A-33) and (A-34) into Eq. (A-14) yields

$$p_\tau + up_\zeta - a^2(\rho_\tau + u\rho_\zeta) = \psi_4 \ , \tag{A-38}$$

$$v_\tau + uv_\zeta = \psi_3 \ . \tag{A-39}$$

Substituting Eq. (A-37) into Eq. (A-14) yields

$$a^2(\rho_\tau + u\rho_\zeta + \rho u_\zeta - \psi_1) \mp \rho a(u_\tau + uu_\zeta + p_\zeta/\rho - \psi_2) + p_\tau + up_\zeta$$
$$- a^2(\rho_\tau + u\rho_\zeta) - \psi_4 = 0 \ . \tag{A-40}$$

Equations (A-38) through (A-40) can be written as

$$\left.\begin{aligned} dp - a^2 d\rho &= \psi_4 d\tau \qquad (A\text{-}41) \\ dv &= \psi_3 d\tau \qquad (A\text{-}42) \end{aligned}\right\} \text{for } d\zeta = u d\tau \ ,$$

$$dp - \rho a du = \left(\psi_4 + a^2\psi_1 - \rho a \psi_2\right) d\tau \quad \text{for } d\zeta = (u-a) d\tau \ , \tag{A-43}$$

$$dp + \rho a du = \left(\psi_4 + a^2\psi_1 + \rho a \psi_2\right) d\tau \quad \text{for } d\zeta = (u+a) d\tau \ . \tag{A-44}$$

APPENDIX B

CONSTANT ZETA REFERENCE PLANE CHARACTERISTIC RELATIONS

I. GOVERNING EQUATIONS

The governing equations, (28) and (19)-(21), can be written as

$$\rho_\tau + \bar{v}\rho_\eta + \rho\alpha u_\eta + \rho\beta v_\eta = - u\rho_\zeta - \rho u_\zeta - \varepsilon\rho v/\bar{\eta} + \frac{C_\rho}{\rho}\Big[\left(\mu_A\rho_\zeta + \mu_A\alpha\rho_\eta\right)_\zeta + \alpha(\mu_A\rho_\zeta$$

$$+ \mu_A\alpha\rho_\eta)_\eta + \beta(\mu_A\beta\rho_\eta)_\eta + \varepsilon\mu_A\beta\rho_\eta/\bar{\eta}\Big] , \qquad \text{(B-1)}$$

$$u_\tau + \bar{v}u_\eta + \alpha p_\eta/\rho = -uu_\zeta - p_\zeta/\rho + \Big[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta\Big]_\zeta/\rho$$

$$+ \alpha\Big[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta\Big]_\eta/\rho + \beta\Big[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta)\Big]_\eta/\rho$$

$$+ \varepsilon\Big[(\lambda + u)(v_\zeta + \alpha v_\eta) + \mu\beta u_\eta\Big]/\rho\bar{\eta} , \qquad \text{(B-2)}$$

$$v_\tau + \bar{v}v_\eta + \beta p_\eta/\rho = - uv_\zeta + \beta\Big[(\lambda + 2\mu)\beta v_\mu + \lambda(u_\zeta + \alpha u_\eta)\Big]_\eta/\rho$$

$$+ \Big[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta)\Big]_\zeta/\rho + \alpha\Big[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta)\Big]_\eta/\rho$$

$$+ \varepsilon(\lambda + 2\mu)(\beta v_\eta - v/\bar{\eta})/\rho\bar{\eta} , \qquad \text{(B-3)}$$

$$p_\tau + \bar{v}p_\eta - a^2(\rho_\tau + \bar{v}\rho_\eta) = - up_\zeta + a^2u\rho_\zeta + (\gamma-1)\Big\{(\lambda + 2\mu)(u_\zeta + \alpha u_\eta)^2$$

$$+ (\lambda + 2\mu)(\beta v_\eta)^2 + \mu(v_\zeta + \alpha v_\eta)^2 + \mu(\beta u_\eta)^2 + 2\lambda(u_\zeta + \alpha u_\eta)\beta v_\eta$$

$$+ 2\mu\beta u_\eta(v_\zeta + \alpha v_\eta) + \Big[k(T_\zeta + \alpha T_\eta)\Big]_\zeta + \alpha\Big[k(T_\zeta + \alpha T_\eta)\Big]_\eta + \beta(k\beta T_\eta)_\eta$$

$$+ \varepsilon\Big[(\lambda + 2\mu)(v/\bar{\eta})^2 + 2\lambda v(\beta v_\eta + u_\zeta + \alpha u_\eta)/\bar{\eta} + k\beta T_\eta/\bar{\eta}\Big]\Big\} , \qquad \text{(B-4)}$$

where the ζ and η subscripts denote partial derivatives with respect to ζ and η, respectively. Letting

$$\psi_1 = \text{right-hand side of Eq. (B-1)}, \tag{B-5}$$

$$\psi_2 = \text{right-hand side of Eq. (B-2)}, \tag{B-6}$$

$$\psi_3 = \text{right-hand side of Eq. (B-3)}, \tag{B-7}$$

$$\psi_4 = \text{right-hand side of Eq. (B-4)}, \tag{B-8}$$

makes Eqs. (B-1) through (B-4) become

$$\rho_\tau + \bar{v}\rho_\eta + \rho\alpha u_\eta + \rho\beta v_\eta = \psi_1, \tag{B-9}$$

$$u_\tau + \bar{v}u_\eta + \alpha p_\eta/\rho = \psi_2, \tag{B-10}$$

$$v_\tau + \bar{v}v_\eta + \beta p_\eta/\rho = \psi_3, \tag{B-11}$$

$$p_\tau + \bar{v}p_\eta - a^2(\rho_\tau + \bar{v}\rho_\eta) = \psi_4 \ . \tag{B-12}$$

II. CHARACTERISTIC CURVES

Following the development of Appendix A, one can show the characteristic curves to be

$$d\eta/d\tau = \bar{v} \ , \tag{B-13}$$

$$d\eta/d\tau = \bar{v} \mp \alpha^* a \ , \tag{B-14}$$

where $\alpha^* = (\alpha^2 + \beta^2)^{1/2}$.

III. COMPATIBILITY EQUATIONS

Again, following the development of Appendix A, one can show the compatibility equations to be

$$\left.\begin{aligned} \beta du - \alpha dv &= (\beta\psi_2 - \alpha\psi_3)d\tau \\ dp - a^2 d\rho &= \psi_4 d\tau \end{aligned}\right\} \text{for } d\eta = \bar{v}d\tau, \qquad \begin{aligned} &(B\text{-}15) \\ &(B\text{-}16) \end{aligned}$$

$$dp - \rho\alpha a du/\alpha^* - \rho\beta a dv/\alpha^* = \left(\psi_4 + a^2\psi_1 - \rho\alpha a\psi_2/\alpha^* - \rho\beta a\psi_3/\alpha^*\right)d\tau$$

$$\text{for } d\eta = (\bar{v} - \alpha^* a)d\tau \ , \tag{B-17}$$

and

$$dp + \rho\alpha a du/\alpha^* + \rho\beta a dv/\alpha^* = \left(\psi_4 + a^2\psi_1 + \rho\alpha a\psi_2/\alpha^* + \rho\beta a\psi_3/\alpha^*\right)d\tau$$

$$\text{for } d\eta = (\bar{v} + \alpha^* a)d\tau \ . \tag{B-18}$$

APPENDIX C

FORTRAN IV LISTING OF THE VNAP PROGRAM

LASL IDENTIFICATION: LP-686

```
*COMDECK,MCC
      PARAMETER (LI=81, MI=21)
      COMMON /ONESID/ UD(4), VD(4), PD(4), ROD(4)
      COMMON /SOLUTN/ U(LI,MI,2), V(LI,MI,2), P(LI,MI,2), RO(LI,MI,2)
      COMMON /CNTRLC/ LMAX, MMAX, NMAX, NPRINT, TCONV, FDT, GAMMA, RGAS,
     1 GAM1, GAM2, GAM3, L1, L2, L3, M1, M2, DX, DY, DT, N, N1, N3, NASM
     2 , ICHAR, N1D, LJET, JFLAG, IERR, IUI, IUO, DXR, DYR, LD, MD, LMD1
     3 , LMD3, IB, RSTAR, RSTARS, NPLOT, G, PC, TC, LC, PLOW, ROLOW, CQ
     4 (LI,MI), RG
      COMMON /GEMTRC/ NGEOM, XI, RI, XT, RT, XE, RE, RCI, RCT, ANGI,
     1 ANGE, XW(LI), YW(LI), XWI(LI), YWI(LI), NXNY(LI), NWPTS, IINT,
     2 IDIF, LT, NDIM
      COMMON /GCB/ NGCB, XICB, RICB, XTCB, RTCB, XECB, RECB, RCICB,
     1 RCTCB, ANGICB, ANGECB, XCB(LI), YCB(LI), XCBI(LI), YCBI(LI),
     2 NXNYCB(LI), NCBPTS, IINTCB, IDIFCB
      COMMON /BCC/ PT(MI), TT(MI), THETA(MI), PE(MI), MASSE, MASSI,
     1 MASST, THRUST, NSTAG, NOSLIP, IEXTRA, TW(LI), TCB(LI), ISUPER,
     2 DYW, IVBC, UI(MI), VI(MI), PI(MI), ROI(MI), IEX
      COMMON /AV/ IAV, CAV, NST, SMP, LSS, XMU, XLA, RKMU, XRO, QUT(LI
     1 ,MI), QVT(LI,MI), QPT(LI,MI), QROT(LI,MI), SMACH
      COMMON /RV/ CMU, CLA, CK, EMU, ELA, EK, CHECK, ITM, TML
      REAL MN3, NXNY, NXNYCB, MASSI, MASST, MASSE, LC, LC2
*DECK,VNAP
      PROGRAM VNAP (ITAPE,OTAPE1,PUN1,TAPE5=ITAPE,TAPE6=OTAPE1,TAPE8
     1 =PUN1)
C
C     ******************************************************************
C
C     VNAP, A COMPUTER PROGRAM FOR THE COMPUTATION OF TWO-DIMENSIONAL,
C            TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERNAL FLOW
C
C                         BY MICHAEL C. CLINE, T-3
C                    LOS ALAMOS SCIENTIFIC LABORATORY
C
C     ******************************************************************
C
C                            PROGRAM ABSTRACT
C
C          THE NAVIER-STOKES EQUATIONS FOR TWO-DIMENSIONAL, TIME-
C     DEPENDENT FLOW ARE SOLVED USING THE SECOND-ORDER, MACCORMACK
C     FINITE-DIFFERENCE SCHEME.  ALL BOUNDARY CONDITIONS ARE COMPUTED
C     USING A SECOND-ORDER, REFERENCE PLANE CHARACTERISTIC SCHEME
C     WITH THE VISCOUS TERMS TREATED AS SOURCE FUNCTIONS.  THE FLUID
C     IS ASSUMED TO BE A PERFECT GAS.  THE STEADY-STATE SOLUTION IS
C     OBTAINED AS THE ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW
C     BOUNDARIES MAY BE ARBITRARY CURVED SOLID WALLS AS WELL AS FREE
C     JET ENVELOPES.  PROBLEMS THAT CAN BE SOLVED ARE FLOW IN PIPES
C     AND DUCTS, CONVERGING, CONVERGING-DIVERGING, AND PLUG NOZZLES,
C     SUBSONIC AND SUPERSONIC INLETS, AND FREE JET EXPANSIONS.
C
      DIMENSION TITLE(8)
*CALL,MCC
      NAMELIST /CNTRL/ LMAX,MMAX,NMAX,NPRINT,TCONV,FDT,TSTOP,GAMMA,RGAS
     1 ,NASM,NAME,NCONVI,IUI,IUO,IPUNCH,IVPTS,NPLOT,IUNIT,PLOW,ROLOW
      NAMELIST /IVS/ U,V,P,RO,N1D,NSTART,TSTART,RSTAR,RSTARS
      NAMELIST /GEMTRY/ NDIM,XI,RI,RT,XE,RCI,RCT,ANGI,ANGE,NGEOM,XWI,YWI
     1 ,NWPTS,IINT,IDIF,LJET,JFLAG,NXNY,YW
      NAMELIST /GCBL/ NGCB,RICB,RTCB,RCICB,RCTCB,ANGICB,ANGECB,YCB
     1 ,NXNYCB,XCBI,YCBI,NCBPTS,IINTCB,IDIFCB
      NAMELIST /BC/ PT,TT,THETA,PE,NSTAG,ISUPER,UI,VI,PI,ROI,TW,NOSLIP
     1 ,IEXTRA,IEX,TCB,DYW,IVBC
      NAMELIST /AVL/ CAV,XMU,XLA,RKMU,XRO,NST,SMP,LSS,SMACH,IAV
      NAMELIST /RVL/ CMU,CLA,CK,EMU,ELA,EK,ITM
C
C     SET ARRAY SIZE FOR COMMONS SOLUTN AND AV
C
      LD=LI
      MD=MI
      LMD=LD*MD
```

```
C
C     SET DEFAULT VALUES
C
   10 TCONV=TSTART=THETA(1)=CAV=TC=CMU=CLA=CK=EMU=ELA=EK=RSTAR=0.0
      RSTARS=SMACH=PT(1)=TT(1)=0.0
      FDT=TSTOP=1.0
      NASM=N1D=NDIM=IEX=NCONVI=IUI=IUO=IAV=IVPTS=1
      NSTAG=NAME=IPUNCH=NGCB=NMAX=NPRINT=NST=N=IERR=JFLAG=ISUPER=0
      IUNIT=NOSLIP=IEXTRA=NSTART=ITM=IVBC=0
      IINT=IDIF=IINTCB=IDIFCB=LSS=2
      GAMMA=1.4
      RGAS=53.35
      PE(1)=14.7
      SMP=0.95
      NPLOT=-1
      G=32.174
      PC=144.0
      LC=12.0
      XMU=0.4
      XLA=1.0
      RKMU=0.7
      XRO=0.6
      PLOW=0.01
      ROLOW=0.0001
      TW(1)=TCB(1)=PE(2)=-1.0
      DYW=0.001
C
C     READ IN INPUT DATA
C
      READ (5,730) TITLE
      IF (EOF(5)) 20,30
   20 CALL EXIT
   30 READ (5,CNTRL)
      READ (5,IVS)
      READ (5,GEMTRY)
      READ (5,GCBL)
      READ (5,BC)
      READ (5,AVL)
      READ (5,RVL)
      IF (NAME.EQ.0) GO TO 40
      WRITE (6,CNTRL)
      WRITE (6,IVS)
      WRITE (6,GEMTRY)
      WRITE (6,GCBL)
      WRITE (6,BC)
      WRITE (6,AVL)
      WRITE (6,RVL)
C
C     PRINT INPUT DATA
C
   40 WRITE (6,740)
      WRITE (6,770)
      WRITE (6,760)
      WRITE (6,780)
      WRITE (6,790)
      WRITE (6,750)
      WRITE (6,800) TITLE
      WRITE (6,750)
      WRITE (6,810)
      NPRIND=ABS(FLOAT(NPRINT))
      WRITE (6,820) LMAX,MMAX,NMAX,NPRIND,TCONV,FDT,NSTAG,NASM,IUNIT,IUI
     1 ,IUO,IVPTS,NCONVI,TSTOP,N1D,NPLOT,IPUNCH,RSTAR,RSTARS,PLOW,ROLOW
      WRITE (6,750)
      IF (IUI.EQ.1) WRITE (6,830) GAMMA,RGAS
      IF (IUI.EQ.2) WRITE (6,840) GAMMA,RGAS
      WRITE (6,750)
      WRITE (6,850)
      IF (NDIM.EQ.0) WRITE (6,860)
      IF (NDIM.EQ.1) WRITE (6,870)
```

```
C
C     CALCULATE THE DUCT RADIUS AND SLOPE
C
      WRITE (6,750)
      CALL GEOM
      IF (IERR.NE.0) GO TO 10
      DY=1.0/FLOAT(MMAX-1)
      XICB=XI
      XECB=XE
      IF (NGCB.NE.0) GO TO 60
      RICB=0.0
      RTCB=0.0
      DO 50 L=1,LMAX
      YCB(L)=0.0
      NXNYCB(L)=0.0
   50 CONTINUE
      GO TO 90
   60 CALL GEOMCB
      LT=1
      YO=YW(1)-YCB(1)
      DO 80 L=1,LMAX
      IF (NDIM.EQ.0) Y=YW(L)-YCB(L)
      IF (NDIM.EQ.1) Y=YW(L)**2-YCB(L)**2
      IF (Y.GT.0.0) GO TO 70
      WRITE (6,990)
      GO TO 10
   70 IF (Y.LT.YO) LT=L
      IF (LT.EQ.L) YO=Y
   80 CONTINUE
C
C     CONTINUE SET UP AND PRINTING OF INPUT DATA
C
   90 IF (PE(2).NE.-1.0) GO TO 110
      DO 100 M=2,MMAX
      PE(M)=PE(1)
  100 CONTINUE
  110 IF (NSTAG.NE.0) GO TO 130
      DO 120 M=2,MMAX
      PT(M)=PT(1)
      TT(M)=TT(1)
      THETA(M)=THETA(1)
  120 CONTINUE
  130 WRITE (6,740)
      IF (IUI.EQ.1) WRITE (6,960)
      IF (IUI.EQ.2) WRITE (6,970)
      DO 140 M=1,MMAX
      WRITE (6,980) M,PT(M),TT(M),THETA(M),PE(M)
  140 CONTINUE
      WRITE (6,1240) IEXTRA,IEX,ISUPER,DYW,IVBC
      IF (NOSLIP.EQ.0) WRITE (6,1130)
      IF (NOSLIP.NE.0) WRITE (6,1140)
      WRITE (6,750)
      IF (TW(1).LT.0.0) WRITE (6,1200)
      IF (TW(1).GE.0.0) WRITE (6,1210)
      WRITE (6,750)
      IF (TCB(1).LT.0.0.AND.NGCB.NE.0) WRITE (6,1220)
      IF (TCB(1).GE.0.0) WRITE (6,1230)
      WRITE (6,750)
      WRITE (6,1120) CAV,XMU,XLA,RKMU,XRO,NST,SMP,LSS,SMACH,IAV
      WRITE (6,750)
      IF (IUI.EQ.1) WRITE (6,1150) CMU,CLA,CK,EMU,ELA,EK
      IF (IUI.EQ.2) WRITE (6,1160) CMU,CLA,CK,EMU,ELA,EK
      WRITE (6,750)
      IF (ITM.EQ.0) WRITE (6,1170)
      IF (ITM.EQ.1) WRITE (6,1180)
C
C     CONVERT METRIC UNITS TO ENGLISH UNITS
C
      IF (IUI.EQ.1) GO TO 240
      RSTAR=RSTAR/2.54
```

```
      RSTARS=RSTARS/6.4516
      PLOW=PLOW/6.8948
      ROLOW=ROLOW/16.02
      CMU=CMU/47.88
      CLA=CLA/47.88
      CK=CK*0.125
      RGAS=RGAS/5.38032
      XI=XI/2.54
      XE=XE/2.54
      XT=XT/2.54
      RT=RT/2.54
      XICB=XICB/2.54
      XECB=XECB/2.54
      DX=DX/2.54
      DO 150 L=1,LMAX
      YW(L)=YW(L)/2.54
      YCB(L)=YCB(L)/2.54
  150 CONTINUE
      DO 160 M=1,MMAX
      PT(M)=PT(M)/6.8948
      PE(M)=PE(M)/6.8948
      TT(M)=TT(M)*1.8
  160 CONTINUE
      IF (TCB(1).LT.0.0) GO TO 180
      DO 170 L=1,LMAX
      TCB(L)=TCB(L)*1.8
  170 CONTINUE
  180 IF (TW(1).LT.0.0) GO TO 200
      DO 190 L=1,LMAX
      TW(L)=TW(L)*1.8
  190 CONTINUE
  200 IF (ISUPER.EQ.0) GO TO 220
      DO 210 M=1,MMAX
      UI(M)=UI(M)/0.3048
      VI(M)=VI(M)/0.3048
      PI(M)=PI(M)/6.8948
      ROI(M)=ROI(M)/16.02
  210 CONTINUE
  220 IF (N1D.NE.0) GO TO 240
      IF (NSTART.NE.0) GO TO 240
      DO 230 L=1,LMAX
      DO 230 M=1,MMAX
      U(L,M,1)=U(L,M,1)/0.3048
      V(L,M,1)=V(L,M,1)/0.3048
      P(L,M,1)=P(L,M,1)/6.8948
      RO(L,M,1)=RO(L,M,1)/16.02
  230 CONTINUE
C
C     CONVERT INPUT DATA UNITS TO INTERNAL UNITS - THE INTERNAL UNITS
C     ARE P=LBF/FT2, RO=LBF-S2/FT4, X=YCB=YW=INCHES, Y=DIMENSIONLESS,
C     DT=IN-S/FT, MU=LA=LBF-S-IN/FT3, K=LBF-IN/S-R-FT, U=V=FT/S,
C     AND RGAS=LBF-FT/LBM-R.
C
  240 IF (IUNIT.EQ.0) GO TO 250
      PC=LC=G=1.0
  250 TCONV=TCONV/100.0
      T=TSTART*LC
      TSTOP=TSTOP*LC
      CMU=CMU*LC
      CLA=CLA*LC
      CK=CK*LC
      DO 260 L=1,LMAX
      XWI(L)=0.0
  260 CONTINUE
      DO 270 M=1,MMAX
      PT(M)=PT(M)*PC
      PE(M)=PE(M)*PC
      THETA(M)=THETA(M)*0.0174533
  270 CONTINUE
      IF (N1D.NE.0) GO TO 290
```

```
      DO 280 L=1,LMAX
      DO 280 M=1,MMAX
      P(L,M,1)=P(L,M,1)*PC
      RO(L,M,1)=RO(L,M,1)/G
  280 CONTINUE
  290 GAM1=GAMMA/(GAMMA-1.0)
      GAM2=(GAMMA-1.0)/2.0
      GAM3=(GAMMA+1.0)/(GAMMA-1.0)
      RG=RGAS*G
      IF (ISUPER.EQ.0) GO TO 310
      DO 300 M=1,MMAX
      U(1,M,1)=UI(M)
      V(1,M,1)=VI(M)
      P(1,M,1)=PI(M)*PC
      RO(1,M,1)=ROI(M)/G
      U(1,M,2)=U(1,M,1)
      V(1,M,2)=V(1,M,1)
      P(1,M,2)=P(1,M,1)
      RO(1,M,2)=RO(1,M,1)
  300 CONTINUE
C
C     SET INDICIES AND ZERO VISCOUS TERM ARRAYS
C
  310 L1=LMAX-1
      L2=LMAX-2
      L3=LMAX-3
      M1=MMAX-1
      M2=MMAX-2
      CHECK=ABS(CMU)+ABS(CLA)+ABS(CK)
      DO 320 L=1,LMAX
      DO 320 M=1,MMAX
      QUT(L,M)=0.0
      QVT(L,M)=0.0
      QPT(L,M)=0.0
      QROT(L,M)=0.0
  320 CONTINUE
      IF (N1D.EQ.0) GO TO 330
C
C     COMPUTE THE 1-D INITIAL-DATA SURFACE
C
      CALL ONEDIM
      IF (IERR.NE.0) GO TO 10
C
C     COMPUTE THE INITIAL-DATA SURFACE MASS FLOW AND THRUST
C
  330 IF (NPRINT.GT.0) GO TO 340
      NPRINT=-NPRINT
      GO TO 420
  340 CALL MASFLO (0)
C
C     CALCULATE AND PRINT THE INITIAL-VALUE SURFACE
C
      DO 410 IU=1,2
      IF (IUO.EQ.1.AND.IU.EQ.2) GO TO 410
      IF (IUO.EQ.2.AND.IU.EQ.1) GO TO 410
      NLINE=0
      WRITE (6,740)
      WRITE (6,880) TSTART,NSTART
      WRITE (6,890)
      IF (IU.EQ.1) WRITE (6,900)
      IF (IU.EQ.2) WRITE (6,910)
      WRITE (6,750)
      X=XI-DX
      DO 370 L=1,LMAX
      X=X+DX
      CALL MAP (0,L,1,AL,BE,DE,LD1,AL1,BE1,DE1)
      DYIO=DY/BE
      Y=YCB(L)-DYIO
      IF (L.NE.1) WRITE (6,1190)
      NLINE=NLINE+1
```

```
      DO 370 M=1,MMAX
      Y=Y+DYIO
      VELMAG=SQRT(U(L,M,1)**2+V(L,M,1)**2)
      CALL EOS (5,P(L,M,1),RO(L,M,1),TEMP,AS,D2,D3)
      XMACH=VELMAG/SQRT(AS)
      PRES=P(L,M,1)/PC
      RHO=RO(L,M,1)*G
      XP=X
      YP=Y
      UP=U(L,M,1)
      VP=V(L,M,1)
      IF (IU.EQ.1) GO TO 350
      XP=XP*2.54
      YP=YP*2.54
      UP=UP*0.3048
      VP=VP*0.3048
      PRES=PRES*6.8948
      RHO=RHO*16.02
      VELMAG=VELMAG*0.3048
      TEMP=TEMP*5.0/9.0
  350 NLINE=NLINE+1
      IF (NLINE.LT.54) GO TO 360
      WRITE (6,740)
      WRITE (6,880) TSTART,NSTART
      WRITE (6,890)
      IF (IU.EQ.1) WRITE (6,900)
      IF (IU.EQ.2) WRITE (6,910)
      WRITE (6,750)
      NLINE=1
  360 WRITE (6,920) L,M,XP,YP,UP,VP,PRES,RHO,VELMAG,XMACH,TEMP
  370 CONTINUE
      IF (IU.EQ.2) GO TO 380
      WRITE (6,940) MASST,THRUST,MASSI,MASSE
      GO TO 400
  380 MASST=MASST*0.4536
      MASSI=MASSI*0.4536
      MASSE=MASSE*0.4536
      THRUST=THRUST*4.4477
      IF (NDIM.NE.0) GO TO 390
      MASST=MASST/2.54
      MASSI=MASSI/2.54
      MASSE=MASSE/2.54
      THRUST=THRUST/2.54
  390 WRITE (6,950) MASST,THRUST,MASSI,MASSE
  400 IF (IUO.NE.3) GO TO 420
  410 CONTINUE
  420 IF (NPLOT.LE.0) GO TO 430
      CALL PLOT (TITLE,TSTART,NSTART,IVPTS)
      WRITE (6,1100) NSTART
  430 IF (NMAX.EQ.0) GO TO 10
C
C     INITIALIZE THE TIME STEP INTEGRATION LOOP PARAMETERS
C
      N1=1
      N3=2
      DQM=0.0
      NCONV=NC=NPC=NPD=0
      LDUM=1
      DXR=1.0/DX
      DYR=1.0/DY
      DXRS=DXR*DXR
      DYRS=DYR*DYR
      IF (NASM.NE.0.AND.LT.NE.1) LDUM=LT-1
      WRITE (6,760)
      IF (JFLAG.EQ.0) GO TO 440
      UD(1)=U(LJET-1,MMAX,N1)
      VD(1)=V(LJET-1,MMAX,N1)
      PD(1)=P(LJET-1,MMAX,N1)
      ROD(1)=RO(LJET-1,MMAX,N1)
      UD(2)=UD(1)
```

```
      VD(2)=VD(1)
      PD(2)=PD(1)
      ROD(2)=ROD(1)
C
C     ENTER THE TIME STEP INTEGRATION LOOP
C
  440 DO 660 N=1,NMAX
      LMD1=LMD*(N1-1)
      LMD3=LMD*(N3-1)
C
C     CALCULATE DELTA T (SINGLE SUBSCRIPT LMN1=L,M,N1)
C
      DO 450 L=1,LMAX
      CALL MAP (0,L,MD,AL,BE,DE,LD1,AL1,BE1,DE1)
      DXDY=DXRS+BE*BE*DYRS
      DO 450 M=1,MMAX
      LMN1=L+LD*(M-1)+LMD1
      CALL EOS (1,P(LMN1),RO(LMN1),TEMP,AS,D2,D3)
      UPA=ABS(U(LMN1))*DXR+ABS(V(LMN1))*BE*DYR+SQRT(AS*DXDY)
      IF (L.EQ.1.AND.M.EQ.1) UPAM=UPA
      IF (UPA.GT.UPAM) UPAM=UPA
  450 CONTINUE
      DT=FDT/UPAM
      T=T+DT
      IF (T.LE.TSTOP) GO TO 460
      T=T-DT
      DT=TSTOP-T
      T=TSTOP
C
C     PRINT N,T AND DT
C
  460 NPD=NPD+1
      IF (NPD.NE.10) GO TO 470
      NP=N+NSTART
      TIME=T/LC
      DTIME=DT/LC
      WRITE (6,1110) NP,TIME,DTIME
      NPD=0
C
C     CALCULATE THE PREDICTOR SOLUTION
C
  470 IF (CAV.NE.0.0.OR.CHECK.NE.0.0) CALL VISCOUS
      ICHAR=1
      IB=1
      CALL INTER
      CALL WALL
      IF (IERR.NE.0) GO TO 10
      IF (NGCB.EQ.0) GO TO 480
      IB=2
      CALL WALL
      IF (IERR.NE.0) GO TO 10
  480 IF (ISUPER.LE.0) CALL INLET
      CALL EXITT
C
C     CALCULATE THE CORRECTOR SOLUTION
C
      ICHAR=2
      IB=1
      CALL INTER
      CALL WALL
      IF (IERR.NE.0) GO TO 10
      IF (NGCB.EQ.0) GO TO 490
      IB=2
      CALL WALL
      IF (IERR.NE.0) GO TO 10
  490 IF (ISUPER.LE.0) CALL INLET
      CALL EXITT
      IF (N.LE.NST) CALL SMOOTH
```

```
C
C     DETERMINE THE MAXIMUM (DELTA U)/U
C
      IF (TCONV.LE.0.0) GO TO 510
      DQM=0.0
      DO 500 L=LDUM,LMAX
      DO 500 M=1,MMAX
      IF (U(L,M,N1).EQ.0.0) GO TO 500
      DQ=ABS((U(L,M,N3)-U(L,M,N1))/U(L,M,N1))
      IF (DQ.GT.DQM) DQM=DQ
  500 CONTINUE
  510 NC=NC+1
      NPC=NPC+1
      IF (DQM.GE.TCONV) GO TO 520
      NCONV=NCONV+1
      IF (NCONV.EQ.1) NCHECK=N-1
      IF (NCONV.GE.NCONVI) NC=NPRINT
  520 IF (N.EQ.NMAX) NC=NPRINT
      IF (N.EQ.NMAX) NPC=NPLOT
      IF (T.EQ.TSTOP) NPC=NPLOT
      IF (NCONV.GE.NCONVI) NPC=NPLOT
      IF (N.GE.NCHECK+NCONVI) NCONV=0
      IF (T.EQ.TSTOP) NC=NPRINT
      IF (NC.EQ.NPRINT) GO TO 530
      IF (NPC.EQ.NPLOT) GO TO 630
      GO TO 650
C
C     COMPUTE THE SOLUTION SURFACE MASS FLOW AND THRUST
C
  530 ICN=0
      IF (JFLAG.EQ.0) GO TO 540
      IF (LT.NE.LJET-1) GO TO 540
      UDUM=U(LT,MMAX,N3)
      RODUM=RO(LT,MMAX,N3)
      U(LT,MMAX,N3)=UD(3)
      RO(LT,MMAX,N3)=ROD(3)
      ICN=1
  540 CALL MASFLO (1)
      IF (ICN.EQ.0) GO TO 550
      U(LT,MMAX,N3)=UDUM
      RO(LT,MMAX,N3)=RODUM
C
C     CALCULATE AND PRINT THE SOLUTION SURFACE
C
  550 DO 620 IU=1,2
      IF (IUO.EQ.1.AND.IU.EQ.2) GO TO 620
      IF (IUO.EQ.2.AND.IU.EQ.1) GO TO 620
      NLINE=0
      WRITE (6,740)
      TIME=T/LC
      DTIME=DT/LC
      NP=N+NSTART
      WRITE (6,930) NP,TIME,DTIME
      WRITE (6,890)
      IF (IU.EQ.1) WRITE (6,900)
      IF (IU.EQ.2) WRITE (6,910)
      WRITE (6,750)
      X=XI-DX
      DO 580 L=1,LMAX
      X=X+DX
      CALL MAP (0,L,1,AL,BE,DE,LD1,AL1,BE1,DE1)
      DYIO=DY/BE
      Y=YCB(L)-DYIO
      IF (L.NE.1) WRITE (6,1190)
      NLINE=NLINE+1
      DO 580 M=1,MMAX
      Y=Y+DYIO
      VELMAG=SQRT(U(L,M,N3)**2+V(L,M,N3)**2)
      CALL EOS (5,P(L,M,N3),RO(L,M,N3),TEMP,AS,D2,D3)
      XMACH=VELMAG/SQRT(AS)
```

```
      PRES=P(L,M,N3)/PC
      RHO=RO(L,M,N3)*G
      XP=X
      YP=Y
      UP=U(L,M,N3)
      VP=V(L,M,N3)
      IF (IU.EQ.1) GO TO 560
      XP=XP*2.54
      YP=YP*2.54
      UP=UP*0.3048
      VP=VP*0.3048
      PRES=PRES*6.8948
      RHO=RHO*16.02
      VELMAG=VELMAG*0.3048
      TEMP=TEMP*5.0/9.0
  560 NLINE=NLINE+1
      IF (NLINE.LT.54) GO TO 570
      WRITE (6,740)
      WRITE (6,930) NP,TIME,DTIME
      WRITE (6,890)
      IF (IU.EQ.1) WRITE (6,900)
      IF (IU.EQ.2) WRITE (6,910)
      WRITE (6,750)
      NLINE=1
  570 WRITE (6,920) L,M,XP,YP,UP,VP,PRES,RHO,VELMAG,XMACH,TEMP
  580 CONTINUE
      IF (IU.EQ.2) GO TO 590
      WRITE (6,940) MASST,THRUST,MASSI,MASSE
      GO TO 610
  590 MASST=MASST*0.4536
      MASSI=MASSI*0.4536
      MASSE=MASSE*0.4536
      THRUST=THRUST*4.4477
      IF (NDIM.NE.0) GO TO 600
      MASSI=MASSI/2.54
      MASST=MASST/2.54
      MASSE=MASSE/2.54
      THRUST=THRUST/2.54
  600 WRITE (6,950) MASST,THRUST,MASSI,MASSE
  610 IF (IUO.NE.3) GO TO 630
  620 CONTINUE
C
C     GENERATE THE FILM PLOTS
C
  630 IF (NPLOT.LT.0) GO TO 640
      IF (NPC.NE.NPLOT) GO TO 640
      TIME=T/LC
      NP=N+NSTART
      CALL PLOT (TITLE,TIME,NP,IVPTS)
      WRITE (6,1100) NP
C
C     CHECK FOR CONVERGENCE OF THE STEADY STATE SOLUTION
C
  640 IF (DQM.LT.TCONV) GO TO 670
      IF (T.EQ.TSTOP) GO TO 670
      IF (N.EQ.NMAX) GO TO 670
      IF (NC.EQ.NPRINT) NC=0
      IF (NPC.EQ.NPLOT) NPC=0
  650 CONTINUE
      NNN=N1
      N1=N3
      N3=NNN
  660 CONTINUE
C
C     PUNCH A SIVS NAMELIST FOR RESTART
C
  670 IF (NPLOT.GE.0) CALL ADV (10)
      IF (IPUNCH.EQ.0) GO TO 10
      DO 680 L=1,LMAX
      DO 680 M=1,MMAX
```

```
      P(L,M,N3)=P(L,M,N3)/PC
      RO(L,M,N3)=RO(L,M,N3)*G
  680 CONTINUE
      WRITE (8,1000) NP,TIME
      DO 690 M=1,MMAX
      WRITE (8,1010) M,U(1,M,N3)
      WRITE (8,1020) (U(L,M,N3),L=2,LMAX)
  690 CONTINUE
      DO 700 M=1,MMAX
      WRITE (8,1030) M,V(1,M,N3)
      WRITE (8,1020) (V(L,M,N3),L=2,LMAX)
  700 CONTINUE
      DO 710 M=1,MMAX
      WRITE (8,1040) M,P(1,M,N3)
      WRITE (8,1050) (P(L,M,N3),L=2,LMAX)
  710 CONTINUE
      DO 720 M=1,MMAX
      WRITE (8,1060) M,RO(1,M,N3)
      WRITE (8,1070) (RO(L,M,N3),L=2,LMAX)
  720 CONTINUE
      WRITE (8,1080)
      NCARDS=(LMAX/7+2)*MMAX*4+2
      WRITE (6,1090) NCARDS
      GO TO 10
C
C     FORMAT STATEMENTS
C
  730 FORMAT (8A10)
  740 FORMAT (1H1)
  750 FORMAT (1H )
  760 FORMAT (1H0)
  770 FORMAT (1H0,10X,46HVNAP, A COMPUTER PROGRAM FOR THE COMPUTATION O,
     1 62HF TWO-DIMENSIONAL, TIMF-DEPENDENT, COMPRESSIBLE, VISCOUS INTER
     2 ,8HNAL FLOW,//,37X,59HBY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIEN
     3TIFIC LABORATORY)
  780 FORMAT (1H0,10X,18HPROGRAM ABSTRACT -,//,26X,17HTHE NAVIER-STOKES,
     1 62H EQUATIONS FOR TWO-DIMFNSIONAL, TIME-DEPENDENT FLOW ARE SOLVED
     2 ,10H USING THE,/,21X,62HSFCOND-ORDER, MACCORMACK FINITE-DIFFERENC
     3E SCHEME. ALL BOUNDAR,31HY CONDITIONS ARE COMPUTED USING,/,21X,13H
     4A SECOND-ORDE,62HR, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THE
     5 VISCOUS TERM,19HS TREATED AS SOURCE)
  790 FORMAT (1H ,20X,41HFUNCTIONS.  THE FLUID IS ASSUMED TO BE A ,54HPE
     1RFECT GAS.  THE STEADY-STATE SOLUTION IS OBTAINED AS,/,21X,62HTHE 
     2ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW BOUNDARIES M,34HAY B
     3E ARBITRARY CURVED SOLID WALLS,/,21X,62HAS WELL AS JET ENVELOPES. 
     4 PROBLEMS THAT CAN BE SOLVED ARE FLO,33HW IN PIPES AND DUCTS, CONV
     5ERGING,,/,21X,55HCONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC 
     6AND SU,41HPERSONIC INLETS, AND FREE JET EXPANSIONS.)
  800 FORMAT (1H0,10X,11HJOB TITLE -//21X,8A10)
  810 FORMAT (1H0,10X,20HCONTROL PARAMETERS -)
  820 FORMAT (1H0,20X,5HLMAX=,I2,2X,5HMMAX=,I2,3X,5HNMAX=,I4,2X,7HNPRINT
     1=,I4,2X,6HTCONV=,F6.3,3X,4HFDT=,F4.2,2X,6HNSTAG=,I1,5X,5HNASM=,I1,
     2 4X,6HIUNIT=,I1,/,21X,4HIUI=,I1,4X,4HIUO=,I1,5X,6HIVPTS=,I1,4X,7HN
     3CONVI=,I2,4X,6HTSTOP=,F7.5,2X,4HN1D=,I2,4X,6HNPLOT=,I4,2X,7HIPUNCH
     4=,I1,2X,/,21X,6HRSTAR=,F11.6,2X,7HRSTARS=,F13.7,4X,5HPLOW=,F6.4,4X
     5 ,6HROLOW=,F11.6)
  830 FORMAT (1H0,10X,13HFLUID MODEL -,//,21X,36HTHE RATIO OF SPECIFIC H
     1EATS, GAMMA =,F6.4,26H AND THE GAS CONSTANT, R =,F9.4,15H (FT-LBF/
     2LBM-R))
  840 FORMAT (1H0,10X,13HFLUID MODEL -,//,21X,36HTHE RATIO OF SPECIFIC H
     1EATS, GAMMA =,F6.4,26H AND THE GAS CONSTANT, R =,F9.4,9H (J/KG-K))
  850 FORMAT (1H0,10X,15HFLOW GEOMETRY -)
  860 FORMAT (1H0,20X,47HTWO-DIMENSIONAL, PLANAR FLOW HAS BEEN SPECIFIED
     1 )
  870 FORMAT (1H0,20X,36HAXISYMMETRIC FLOW HAS BEEN SPECIFIED)
  880 FORMAT (1H ,30HINITIAL-DATA SURFACE - TIME = ,F10.8,8H SECONDS,4H 
     1(N=,I6,1H))
  890 FORMAT (1H0,11X,1HL,4X,1HM,9X,1HX,10X,1HY,10X,1HU,11X,1HV,12X,1HP,
     1 11X,3HRHO,7X,4HVMAG,10X,4HMACH,8X,1HT)
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  900 FORMAT (1H ,25X,4H(IN),7X,4H(IN),6X,5H(F/S),7X,5H(F/S),7X,6H(PSIA)VNP 6740
     1 ,6X,9H(LBM/FT3),4X,5H(F/S),10X,2HNO,8X,3H(R))                   VNP 6750
  910 FORMAT (1H ,25X,4H(CM),7X,4H(CM),6X,5H(M/S),7X,5H(M/S),7X,6H (KPA)VNP 6760
     1 ,7X,7H(KG/M3),5X,5H(M/S),10X,2HNO,8X,3H(K))                     VNP 6770
  920 FORMAT (1H ,7X,2I5,4F12.4,F13.5,F12.6,3F12.4)                      VNP 6780
  930 FORMAT (1H ,20HSOLUTION SURFACE NO.,I6,3H = ,7HTIME = ,F10.8,20H SVNP 6790
     1ECONDS (DELTA T = ,F10.8,1H))                                     VNP 6800
  940 FORMAT (1H0,10X,5HMASS=,F10.6,10H (LBM/SEC),5X,7HTHRUST=,F11.4,6H VNP 6810
     1(LBF),5X,6HMASSI=,F10.6,5X,6HMASSE=,F10.6)                        VNP 6820
  950 FORMAT (1H0,10X,5HMASS=,F10.6,9H (KG/SEC),5X,7HTHRUST=,F11.4,10H (VNP 6830
     1NEWTONS),5X,6HMASSI=,F10.6,5X,6HMASSE=,F10.6)                     VNP 6840
  960 FORMAT (1H0,10X,21HBOUNDARY CONDITIONS =,//,22X,1HM,11X,8HPT(PSIA)VNP 6850
     1 ,10X,5HTT(R),10X,10HTHETA(DEG),10X,8HPE(PSIA),/)                 VNP 6860
  970 FORMAT (1H0,10X,21HBOUNDARY CONDITIONS =,//,22X,1HM,10X,7HPT(KPA),VNP 6870
     1 12X,5HTT(K),10X,10HTHETA(DEG),10X,7HPE(KPA),/)                   VNP 6880
  980 FORMAT (1H ,20X,I2,7X,F10.4,10X,F7.2,10X,F7.2,11X,F9.5)           VNP 6890
  990 FORMAT (1H0,51H***** THE RADIUS OF THE CENTERBODY IS LARGER THAN TVNP 6900
     1 ,20HHE WALL RADIUS *****)                                        VNP 6910
 1000 FORMAT (1X,18H$IVS N1D=0,NSTART=,I6,8H,TSTART=,F14.10,1H,)        VNP 6920
 1010 FORMAT (1X,4HU(1,,I2,5H,1) =,F10.3,1H,)                           VNP 6930
 1020 FORMAT (1X,7(F10.3,1H,))                                          VNP 6940
 1030 FORMAT (1X,4HV(1,,I2,5H,1) =,F10.3,1H,)                           VNP 6950
 1040 FORMAT (1X,4HP(1,,I2,5H,1) =,F10.4,1H,)                           VNP 6960
 1050 FORMAT (1X,7(F10.4,1H,))                                          VNP 6970
 1060 FORMAT (1X,5HRO(1,,I2,5H,1) =,F10.6,1H,)                          VNP 6980
 1070 FORMAT (1X,7(F10.6,1H,))                                          VNP 6990
 1080 FORMAT (1X,1H$)                                                   VNP 7000
 1090 FORMAT (1H0,27H***** EXPECT APPROXIMATELY ,I4,20H PUNCHED CARDS **VNP 7010
     1***)                                                              VNP 7020
 1100 FORMAT (1H0,31H***** EXPECT FILM OUTPUT FOR N=,I6,6H *****)       VNP 7030
 1110 FORMAT (1H ,10X,2HN=,I6,5H,  T=,F10.8,14H SECONDS,  DT=,F10.8,8H SVNP 7040
     1ECONDS)                                                           VNP 7050
 1120 FORMAT (1H0,10X,21HARTIFICAL VISCOSITY =,//,21X,4HCAV=,F4.2,3X,4HXVNP 7060
     1MU=,F4.2,3X,4HXLA=,F4.2,3X,5HRKMU=,F4.2,3X,4HXRO=,F4.2,3X,4HNST=  VNP 7070
     2 ,I4,3X,4HSMP=,F4.2,3X,4HLSS=,I2,3X,6HSMACH=,F4.2,3X,4HIAV=,I1)   VNP 7080
 1130 FORMAT (1H0,20X,29HFREE-SLIP WALLS ARE SPECIFIED)                 VNP 7090
 1140 FORMAT (1H0,20X,27HNO-SLIP WALLS ARE SPECIFIED)                   VNP 7100
 1150 FORMAT (1H0,10X,21HMOLECULAR VISCOSITY =,//,21X,4HCMU=,E10.4,19H (VNP 7110
     1LBF-S/FT2),  CLA=,E11.4,18H (LBF-S/FT2),  CK=,E10.4,17H (LBF/S-R),VNP 7120
     2  EMU=,F4.2,7H,  ELA=,F4.2,1H,,/,21X,7HAND EK=,F4.2)              VNP 7130
 1160 FORMAT (1H0,10X,21HMOLECULAR VISCOSITY =,//,21X,4HCMU=,E10.4,14H (VNP 7140
     1PA-S),  CLA=,E11.4,13H (PA-S),  CK=,E10.4,15H (W/M-K),  EMU=,F4.2,VNP 7150
     2 7H,  ELA=,F4.2,10H,  AND EK=,F4.2)                               VNP 7160
 1170 FORMAT (1H0,10X,18HTURBULENCE MODEL =,//,21X,21HNO MODEL IS SPECIFVNP 7170
     1IED)                                                              VNP 7180
 1180 FORMAT (1H0,10X,18HTURBULENCE MODEL =,//,21X,32HMIXING-LENGTH MODEVNP 7190
     1L IS SPECIFIED)                                                   VNP 7200
 1190 FORMAT (1H ,10X,48H-----------------------------------------------VNP 7210
     1-,61H-------------------------------------------------------------VNP 7220
     2 ,7H-------)                                                      VNP 7230
 1200 FORMAT (1H ,20X,33HADIABATIC UPPER WALL IS SPECIFIED)             VNP 7240
 1210 FORMAT (1H ,20X,15HTW IS SPECIFIED)                               VNP 7250
 1220 FORMAT (1H ,20X,39HADIABATIC LOWER CENTERBODY IS SPECIFIED)       VNP 7260
 1230 FORMAT (1H ,20X,16HTCB IS SPECIFIED)                              VNP 7270
 1240 FORMAT (1H0,20X,7HIEXTRA=,I1,3X,4HIEX=,I1,3X,7HISUPER=,I2,3X,4HDYWVNP 7280
     1=,F6.4,3X,5HIVBC=,I1)                                             VNP 7290
      END                                                               VNP 7300
```

```
*DECK,GEOM
      SUBROUTINE GEOM
C
C     ****************************************************************
C
C     THIS SUBROUTINE CALCULATES THE WALL RADIUS AND SLOPE
C
C     ****************************************************************
C
*CALL,MCC
      GO TO (10,30,120,170), NGEOM
C
C     CONSTANT AREA DUCT CASE
C
   10 WRITE (6,230)
      IF (IUI.EQ.1) WRITE (6,250) XI,RI,XE
      IF (IUI.EQ.2) WRITE (6,260) XI,RI,XE
      LT=LMAX
      DX=(XE-XI)/FLOAT(LMAX-1)
      XT=XE
      RT=RI
      RE=RI
      DO 20 L=1,LMAX
      YW(L)=RI
      NXNY(L)=0.0
   20 CONTINUE
      GO TO 210
C
C     CIRCULAR-ARC, CONICAL NOZZLE CASE
C
   30 WRITE (6,230)
      IF (RCI.EQ.0.0.OR.RCT.EQ.0.0) GO TO 200
      ANI=ANGI*3.141593/180.0
      ANE=ANGE*3.141593/180.0
      XTAN=XI+RCI*SIN(ANI)
      RTAN=RI+RCI*(COS(ANI)-1.0)
      RT1=RT-RCT*(COS(ANI)-1.0)
      XT1=XTAN+(RTAN-RT1)/TAN(ANI)
      IF (XT1.GE.XTAN) GO TO 40
      XT1=XTAN
      RT1=RTAN
   40 XT=XT1+RCT*SIN(ANI)
      XT2=XT+RCT*SIN(ANE)
      RT2=RT+RCT*(1.0-COS(ANE))
      RE=RT2+(XE-XT2)*TAN(ANE)
      LT=1
      DX=(XE-XI)/FLOAT(LMAX-1)
      IF (IUI.EQ.1) WRITE (6,270) XI,RI,RT,XE,RCI,RCT,ANGI,ANGE,XT,RE
      IF (IUI.EQ.2) WRITE (6,280) XI,RI,RT,XE,RCI,RCT,ANGI,ANGE,XT,RE
      DO 110 L=1,LMAX
      X=XI+FLOAT(L-1)*DX
      IF (X.LE.XTAN) GO TO 50
      IF (X.GT.XTAN.AND.X.LE.XT1) GO TO 60
      IF (X.GT.XT1.AND.X.LE.XT) GO TO 70
      IF (X.GT.XT.AND.X.LE.XT2) GO TO 80
      GO TO 90
C
   50 YW(L)=RI+RCI*(COS(ASIN((X-XI)/RCI))-1.0)
      NXNY(L)=(X-XI)/(YW(L)-RI+RCI)
      GO TO 100
C
   60 YW(L)=RT1+(XT1-X)*TAN(ANI)
      NXNY(L)=TAN(ANI)
      GO TO 100
C
   70 YW(L)=RT+RCT*(1.0-COS(ASIN((XT-X)/RCT)))
      NXNY(L)=(XT-X)/(RCT+RT-YW(L))
      GO TO 100
C
```

```
   80 YW(L)=RT+RCT*(1.0-COS(ASIN((X-XT)/RCT)))
      NXNY(L)=(XT-X)/(RCT+RT-YW(L))
      GO TO 100
C
   90 YW(L)=RT2+(X-XT2)*TAN(ANE)
      NXNY(L)=-TAN(ANE)
C
  100 IF (L.EQ.1) GO TO 110
      IF (YW(L).LT.YW(LT)) LT=L
  110 CONTINUE
      GO TO 210
C
C     GENERAL WALL CASE - INPUT WALL COORDINATES
C
  120 WRITE (6,240)
      WRITE (6,230)
      XI=XWI(1)
      XE=XWI(NWPTS)
      DX=(XE-XI)/FLOAT(LMAX-1)
      XW(1)=XI
      XW(LMAX)=XE
      YW(1)=YWI(1)
      YW(LMAX)=YWI(NWPTS)
      RI=YW(1)
      RE=YW(LMAX)
      LT=1
      DO 130 L=2,NWPTS
      IF (YWI(L).LE.YWI(LT)) LT=L
  130 CONTINUE
      XT=XWI(LT)
      RT=YWI(LT)
      IF (IUI.EQ.1) WRITE (6,290) XT,RT,IINT,IDIF
      IF (IUI.EQ.2) WRITE (6,300) XT,RT,IINT,IDIF
      LT=1
      L1=LMAX-1
      IP=1
      DO 140 L=2,L1
      XW(L)=XI+DX*FLOAT(L-1)
      CALL MTLUP (XW(L),YW(L),IINT,NWPTS,NWPTS,1,IP,XWI,YWI)
      IF (L.EQ.1) GO TO 140
      IF (YW(L).LE.YW(LT)) LT=L
  140 CONTINUE
      LDUM=NWPTS
      IF (LMAX.GT.NWPTS) LDUM=LMAX
      DO 160 L=1,LDUM
      IF (L.GT.LMAX) GO TO 150
      SLOPE=DIF(L,IDIF,LMAX,XW,YW)
      NXNY(L)=-SLOPE
  150 IF (L.LE.NWPTS.AND.L.LE.LMAX) WRITE (6,330) L,XWI(L),YWI(L),XW(L)
     1 ,YW(L),SLOPE
      IF (L.GT.NWPTS.AND.L.LE.LMAX) WRITE (6,340) L,XW(L),YW(L),SLOPE
      IF (L.LE.NWPTS.AND.L.GT.LMAX) WRITE (6,350) L,XWI(L),YWI(L)
  160 CONTINUE
      GO TO 210
C
C     GENERAL WALL CASE - INPUT WALL RADIUS AND SLOPE
C
  170 WRITE (6,240)
      WRITE (6,230)
      DX=(XE-XI)/FLOAT(LMAX-1)
      RI=YW(1)
      RE=YW(LMAX)
      LT=1
      DO 180 L=2,LMAX
      IF (YW(L).LE.YW(LT)) LT=L
  180 CONTINUE
      XT=XI+FLOAT(LT-1)*DX
      RT=YW(LT)
      IF (IUI.EQ.1) WRITE (6,310) XT,RT
      IF (IUI.EQ.2) WRITE (6,320) XT,RT
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```
      DO 190 L=1,LMAX
      XW(L)=XI+DX*FLOAT(L-1)
      SLOPE=-NXNY(L)
      WRITE (6,360) L,XW(L),YW(L),SLOPE
  190 CONTINUE
      GO TO 210
C
  200 WRITE (6,390)
      IERR=1
      RETURN
C
  210 IF (JFLAG.EQ.0) RETURN
      XWL=XI+FLOAT(LJET-2)*DX
      IF (JFLAG.EQ.-1) GO TO 220
      IF (IUI.EQ.1) WRITE (6,370) XWL,LJET,LMAX
      IF (IUI.EQ.2) WRITE (6,380) XWL,LJET,LMAX
      RETURN
  220 IF (IUI.EQ.1) WRITE (6,400) XWL
      IF (IUI.EQ.2) WRITE (6,410) XWL
      RETURN
C
C     FORMAT STATEMENTS
C
  230 FORMAT (1H0,10X,15HDUCT GEOMETRY -)
  240 FORMAT (1H1)
  250 FORMAT (1H0,20X,46HA CONSTANT AREA DUCT HAS BEEN SPECIFIED BY XI=
     1 ,F8.4,10H (IN), RI=,F8.4,14H (IN), AND XE=,F8.4,5H (IN))
  260 FORMAT (1H0,20X,46HA CONSTANT AREA DUCT HAS BEEN SPECIFIED BY XI=
     1 ,F8.4,10H (CM), RI=,F8.4,14H (CM), AND XE=,F8.4,5H (CM))
  270 FORMAT (1H0,20X,56HA CIRCULAR-ARC, CONICAL NOZZLE HAS BEEN SPECIFI
     1ED BY XI=,F8.4,10H (IN), RI=,F8.4,6H (IN),,/,21X,3HRT=,F8.4,10H (I
     2N), XE=,F8.4,11H (IN), RCI=,F8.4,11H (IN), RCT=,F8.4,12H (IN), ANG
     3I=,F6.2,7H (DEG),,/,21X,9HAND ANGE=,F6.2,35H (DEG). THE COMPUTED V
     4ALUES ARE XT=,F8.4,13H (IN) AND RE=,F8.4,6H (IN).)
  280 FORMAT (1H0,20X,56HA CIRCULAR-ARC, CONICAL NOZZLE HAS BEEN SPECIFI
     1ED BY XI=,F8.4,10H (CM), RI=,F8.4,6H (CM),,/,21X,3HRT=,F8.4,10H (C
     2M), XE=,F8.4,11H (CM), RCI=,F8.4,11H (CM), RCT=,F8.4,12H (CM), ANG
     3I=,F6.2,7H (DEG),,/,21X,9HAND ANGE=,F6.2,35H (DEG). THE COMPUTED V
     4ALUES ARE XT=,F8.4,13H (CM) AND RE=,F8.4,6H (CM).)
  290 FORMAT (1H0,20X,45HA GENERAL WALL HAS BEEN SPECIFIED BY THE FOLL,2
     1 1HOWING PARAMETERS, XT=,F8.4,10H (IN), RT=,F8.4,6H (IN),,/,21X,5H
     2IINT=,I1,7H, IDIF=,I1,1H,,//,22X,1HL,10X,7HXWI(IN),10X,7HYWI(IN),1
     3 1X,6HXW(IN),11X,6HYW(IN),12X,5HSLOPE,/)
  300 FORMAT (1H0,20X,45HA GENERAL WALL HAS BEEN SPECIFIED BY THE FOLL,2
     1 1HOWING PARAMETERS, XT=,F8.4,10H (CM), RT=,F8.4,6H (CM),,/,21X,5H
     2IINT=,I1,7H, IDIF=,I1,1H,,//,22X,1HL,10X,7HXWI(CM),10X,7HYWI(CM),1
     3 1X,6HXW(CM),11X,6HYW(CM),12X,5HSLOPE,/)
  310 FORMAT (1H0,20X,45HA GENERAL WALL HAS BEEN SPECIFIED BY THE FOLL,2
     1 1HOWING PARAMETERS, XT=,F8.4,10H (IN), RT=,F8.4,6H (IN),,//,22X,1
     2 HL,11X,6HXW(IN),11X,6HYW(IN),12X,5HSLOPE,/)
  320 FORMAT (1H0,20X,45HA GENERAL WALL HAS BEEN SPECIFIED BY THE FOLL,2
     1 1HOWING PARAMETERS, XT=,F8.4,10H (CM), RT=,F8.4,6H (CM),,//,22X,1
     2 HL,11X,6HXW(CM),11X,6HYW(CM),12X,5HSLOPE,/)
  330 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4,7X,F10.4,7X,F10.4,7X,F10.4)
  340 FORMAT (1H ,20X,I2,41X,F10.4,7X,F10.4,7X,F10.4)
  350 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4)
  360 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4,7X,F10.4)
  370 FORMAT (1H0,20X,43HA FREE-JET CALCULATION HAS BEEN REQUESTED. ,20H
     1 THE WALL ENDS AT X=,F8.4,11H (IN).  THE,/,21X,14HMESH POINTS L=
     2 ,I3,6H TO L=,I3,55H ARE AN INITIAL APPROXIMATION TO THE FREE-JET
     3BOUNDARY.)
  380 FORMAT (1H0,20X,43HA FREE-JET CALCULATION HAS BEEN REQUESTED. ,20H
     1 THE WALL ENDS AT X=,F8.4,11H (CM).  THE,/,21X,14HMESH POINTS L=
     2 ,I3,6H TO L=,I3,55H ARE AN INITIAL APPROXIMATION TO THE FREE-JET
     3BOUNDARY.)
  390 FORMAT (1H0,44H***** RCI OR RCT WAS SPECIFIED AS ZERO *****)
  400 FORMAT (1H0,20X,54HTHE WALL CONTOUR HAS AN EXPANSION CORNER LOCATE
     1D AT X=,F8.4,6H (IN).)
  410 FORMAT (1H0,20X,54HTHE WALL CONTOUR HAS AN EXPANSION CORNER LOCATE
     1D AT X=,F8.4,6H (CM).)
      END
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```
*DECK,GEOMCB
      SUBROUTINE GEOMCB
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE CENTERBODY RADIUS AND SLOPE
C
C     ******************************************************************
C
*CALL,MCC
      GO TO (10,30,120,160), NGCB
C
C     CYLINDRICAL CENTERBODY CASE
C
   10 IF (IUI.EQ.1) WRITE (6,210) XICB,RICB,XECB
      IF (IUI.EQ.2) WRITE (6,220) XICB,RICB,XECB
      DO 20 L=1,LMAX
      YCB(L)=RICB
      NXNYCB(L)=0.0
   20 CONTINUE
      RETURN
C
C     CIRCULAR-ARC, CONICAL CENTERBODY CASE
C
   30 RICB=2.0*RTCB-RICB
      IF (RCICB.EQ.0.0.OR.RCTCB.EQ.0.0) GO TO 190
      ANI=ANGICB*3.141593/180.0
      ANE=ANGECB*3.141593/180.0
      XTAN=XICB+RCICB*SIN(ANI)
      RTAN=RICB+RCICB*(COS(ANI)-1.0)
      RT1=RTCB-RCTCB*(COS(ANI)-1.0)
      XT1=XTAN+(RTAN-RT1)/TAN(ANI)
      IF (XT1.GE.XTAN) GO TO 40
      XT1=XTAN
      RT1=RTAN
   40 XTCB=XT1+RCTCB*SIN(ANI)
      XT2=XTCB+RCTCB*SIN(ANE)
      RT2=RTCB+RCTCB*(1.0-COS(ANE))
      RECB=RT2+(XECB-XT2)*TAN(ANE)
      RICB=2.0*RTCB-RICB
      RECB=2.0*RTCB-RECB
      IF (IUI.EQ.1) WRITE (6,230) XICB,RICB,RTCB,XECB,RCICB,RCTCB,ANGICB
     1 ,ANGECB,XTCB,RECB
      IF (IUI.EQ.2) WRITE (6,240) XICB,RICB,RTCB,XECB,RCICB,RCTCB,ANGICB
     1 ,ANGECB,XTCB,RECB
      RICB=2.0*RTCB-RICB
      RECB=2.0*RTCB-RECB
      DO 110 L=1,LMAX
      X=XICB+FLOAT(L-1)*DX
      IF (X.LE.XTAN) GO TO 50
      IF (X.GT.XTAN.AND.X.LE.XT1) GO TO 60
      IF (X.GT.XT1.AND.X.LE.XTCB) GO TO 70
      IF (X.GT.XTCB.AND.X.LE.XT2) GO TO 80
      GO TO 90
C
   50 YCB(L)=RICB+RCICB*(COS(ASIN((X-XICB)/RCICB))-1.0)
      NXNYCB(L)=(X-XICB)/(YCB(L)-RICB+RCICB)
      GO TO 100
C
   60 YCB(L)=RT1+(XT1-X)*TAN(ANI)
      NXNYCB(L)=TAN(ANI)
      GO TO 100
C
   70 YCB(L)=RTCB+RCTCB*(1.0-COS(ASIN((XTCB-X)/RCTCB)))
      NXNYCB(L)=(XTCB-X)/(RCTCB+RTCB-YCB(L))
      GO TO 100
C
   80 YCB(L)=RTCB+RCTCB*(1.0-COS(ASIN((X-XTCB)/RCTCB)))
      NXNYCB(L)=(XTCB-X)/(RCTCB+RTCB-YCB(L))
      GO TO 100
```

```
C
   90 YCB(L)=RT2+(X-XT2)*TAN(ANE)
      NXNYCB(L)=-TAN(ANE)
C
  100 YCB(L)=2.0*RTCB-YCB(L)
      NXNYCB(L)=-NXNYCB(L)
      IF (YCB(L).GE.0.0.OR.NDIM.EQ.0) GO TO 110
      YCB(L)=0.0
      NXNYCB(L)=0.0
  110 CONTINUE
      RETURN
C
C     GENERAL CENTERBODY CASE - INPUT CENTERBODY COORDINATES
C
  120 WRITE (6,200)
      IF (IUI.EQ.1) WRITE (6,250) IINTCB,IDIFCB
      IF (IUI.EQ.2) WRITE (6,260) IINTCB,IDIFCB
      L1=LMAX-1
      IP=1
      DO 130 L=1,LMAX
      XCB(L)=XICB+DX*FLOAT(L-1)
      CALL MTLUP (XCB(L),YCB(L),IINTCB,NCBPTS,NCBPTS,1,IP,XCBI,YCBI)
  130 CONTINUE
      LDUM=NCBPTS
      IF (LMAX.GT.NCBPTS) LDUM=LMAX
      DO 150 L=1,LDUM
      IF (L.GT.LMAX) GO TO 140
      SLOPE=DIF(L,IDIFCB,LMAX,XCB,YCB)
      NXNYCB(L)=-SLOPE
      IF (YCB(L).GE.0.0.OR.NDIM.EQ.0) GO TO 140
      YCB(L)=0.0
      NXNYCB(L)=0.0
      SLOPE=-NXNYCB(L)
  140 IF (L.LE.NCBPTS.AND.L.LE.LMAX) WRITE (6,290) L,XCBI(L),YCBI(L),XCB
     1 (L),YCB(L),SLOPE
      IF (L.GT.NCBPTS.AND.L.LE.LMAX) WRITE (6,300) L,XCB(L),YCB(L),SLOPE
      IF (L.LE.NCBPTS.AND.L.GT.LMAX) WRITE (6,310) L,XCBI(L),YCBI(L)
  150 CONTINUE
      RETURN
C
C     GENERAL CENTERBODY CASE - INPUT CENTERBODY RADIUS AND SLOPE
C
  160 WRITE (6,200)
      IF (IUI.EQ.1) WRITE (6,270)
      IF (IUI.EQ.2) WRITE (6,280)
      DO 180 L=1,LMAX
      XCB(L)=XICB+DX*FLOAT(L-1)
      IF (YCB(L).GE.0.0.OR.NDIM.EQ.0) GO TO 170
      YCB(L)=0.0
      NXNYCB(L)=0.0
  170 SLOPE=-NXNYCB(L)
      WRITE (6,320) L,XCB(L),YCB(L),SLOPE
  180 CONTINUE
      RETURN
C
  190 WRITE (6,330)
      IERR=1
      RETURN
C
C     FORMAT STATEMENTS
C
  200 FORMAT (1H1)
  210 FORMAT (1H0,20X,52HA CYLINDRICAL CENTERBODY HAS BEEN SPECIFIED BY
     1XICB=,F8.4,12H (IN), RICB=,F8.4,16H (IN), AND XECB=,F8.4,5H (IN))
  220 FORMAT (1H0,20X,52HA CYLINDRICAL CENTERBODY HAS BEEN SPECIFIED BY
     1XICB=,F8.4,12H (CM), RICB=,F8.4,16H (CM), AND XECB=,F8.4,5H (CM))
```

```
230 FORMAT (1H0,20X,62HA CIRCULAR=ARC, CONICAL CENTERBODY HAS BEEN SPE
   1CIFIED BY XICB=,F8.4,5H (IN),7H, RICB=,F8.4,6H (IN),,/,21X,5HRTCB=
   2 ,F8.4,7H (IN), ,5HXECB=,F8.4,5H (IN),8H, RCICB=,F8.4,5H (IN),8H,
   3RCTCB=,F8.4,5H (IN),9H, ANGICB=,F6.2,7H (DEG),,/,21X,11HAND ANGECB
   4=,F6.2,8H (DEG), ,29HTHE COMPUTED VALUES ARE XTCB=,F8.4,5H (IN),10
   5 H AND RECB=,F8.4,6H (IN),)
240 FORMAT (1H0,20X,62HA CIRCULAR=ARC, CONICAL CENTERBODY HAS BEEN SPE
   1CIFIED BY XICB=,F8.4,5H (CM),7H, RICB=,F8.4,6H (CM),,/,21X,5HRTCB=
   2 ,F8.4,7H (CM), ,5HXECB=,F8.4,5H (CM),8H, RCICB=,F8.4,5H (CM),8H,
   3RCTCB=,F8.4,5H (CM),9H, ANGICB=,F6.2,7H (DEG),,/,21X,11HAND ANGECB
   4=,F6.2,8H (DEG), ,29HTHE COMPUTED VALUES ARE XTCB=,F8.4,5H (CM),10
   5 H AND RECB=,F8.4,6H (CM),)
250 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE
   1 ,29HFOLLOWING PARAMETERS, IINTCB=,I1,9H, IDIFCB=,I1,1H,,//,22X,1H
   2L,10X,8HXCBI(IN),10X,8HYCBI(IN),9X,7HXCB(IN),10X,7HYCB(IN),11X,5HS
   3LOPE,/)
260 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE
   1 ,29HFOLLOWING PARAMETERS, IINTCB=,I1,9H, IDIFCB=,I1,1H,,//,22X,1H
   2L,10X,8HXCBI(CM),10X,8HYCBI(CM),9X,7HXCB(CM),10X,7HYCB(CM),11X,5HS
   3LOPE,/)
270 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE
   1 ,21HFOLLOWING PARAMETERS,,//,22X,1HL,11X,7HXCB(IN),10X,7HYCB(IN),
   2 11X,5HSLOPE,/)
280 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE
   1 ,21HFOLLOWING PARAMETERS,,//,22X,1HL,11X,7HXCB(CM),10X,7HYCB(CM),
   2 11X,5HSLOPE,/)
290 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4,7X,F10.4,7X,F10.4,7X,F10.4)
300 FORMAT (1H ,20X,I2,41X,F10.4,7X,F10.4,7X,F10.4)
310 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4)
320 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4,7X,F10.4)
330 FORMAT (1H0,48H***** RCICB OR RCTCB WAS SPECIFIED AS ZERO *****)
    END
```

```
*DECK,MTLUP
      SUBROUTINE MTLUP (X,Y,M,N,MAX,NTAB,I,VARI,VARD)
C
C     ****************************************************************
C
C     THIS SUBROUTINE IS CALLED BY SUBROUTINES GEOM AND GEOMCB TO
C     INTERPOLATE FOR EQUALLY SPACED WALL COORDINATES FOR THE TABULAR
C     INPUT CASE. SUBROUTINE MTLUP WAS TAKEN FROM THE NASA-LANGLEY
C     PROGRAM LIBRARY. THE DATE OF THIS VERSION IS 09-12-69.
C
C     ****************************************************************
C
C        MODIFICATION OF LIBRARY INTERPOLATION SUBROUTINE  FTLUP
C       MULTIPLE TABLE LOOK-UP ON ONE INDEPENDENT VARIABLE TABLE
C      USES AN EXTERNAL INTERVAL POINTER (I) TO START SEARCH
C      I LESS THAN 0 WILL CHECK MONOTONICITY
C
      DIMENSION VARI(1), VARD(MAX,1), Y(1), V(3), YY(2)
      LOGICAL EX
C
      IF (M.EQ.0) GO TO 170
      IF (N.LE.1) GO TO 170
      EX=.FALSE.
      IF (I.GE.0) GO TO 60
      IF (N.LT.2) GO TO 60
C
C     MONOTONICITY CHECK
C
      IF (VARI(2)-VARI(1)) 20,20,40
C
C     ERROR IN MONOTONICITY
C
   10 K=LOCF(VARI(1))
      WRITE (6,190) J,K,(VARI(J),J=1,N)
      CALL EXIT
C
C     MONOTONIC DECREASING
C
   20 DO 30 J=2,N
      IF (VARI(J)-VARI(J-1)) 30,10,10
   30 CONTINUE
      GO TO 60
C
C     MONOTONIC INCREASING
C
   40 DO 50 J=2,N
      IF (VARI(J)-VARI(J-1)) 10,10,50
   50 CONTINUE
C
C     INTERPOLATION
C
   60 IF (I.LE.0) I=1
      IF (I.GE.N) I=N-1
C
C     LOCATE I INTERVAL (X(I).LE.X.LT.X(I+1))
C
      IF ((VARI(I)-X)*(VARI(I+1)-X)) 100,100,70
C
C     IN GIVES DIRECTION FOR SEARCH OF INTERVALS
C
   70 IN=SIGN(1.0,(VARI(I+1)-VARI(I))*(X-VARI(I)))
C
C     IF X OUTSIDE ENDPOINTS, EXTRAPOLATE FROM END INTERVAL
C
   80 IF ((I+IN).LE.0) GO TO 90
      IF ((I+IN).GE.N) GO TO 90
      I=I+IN
      IF ((VARI(I)-X)*(VARI(I+1)-X)) 100,100,80
```

```
C
C     EXTRAPOLATION
C
   90 EX=.TRUE.
  100 IF (M.EQ.2) GO TO 120
C
C     FIRST ORDER
C
      DO 110 NT=1,NTAB
  110 Y(NT)=(VARD(I,NT)*(VARI(I+1)-X)-VARD(I+1,NT)*(VARI(I)-X))/(VARI(I+
     1 1)-VARI(I))
      IF (EX) I=I+IN
      RETURN
C
C     SECOND ORDER
C
  120 IF (N.EQ.2) GO TO 10
      IF (I.EQ.(N-1)) GO TO 140
      IF (I.EQ.1) GO TO 130
C
C     PICK THIRD POINT
C
      SK=VARI(I+1)-VARI(I)
      IF ((SK*(X-VARI(I-1))).LT.(SK*(VARI(I+2)-X))) GO TO 140
  130 L=I
      GO TO 150
  140 L=I-1
  150 V(1)=VARI(L)-X
      V(2)=VARI(L+1)-X
      V(3)=VARI(L+2)-X
      DO 160 NT=1,NTAB
      YY(1)=(VARD(L,NT)*V(2)-VARD(L+1,NT)*V(1))/(VARI(L+1)-VARI(L))
      YY(2)=(VARD(L+1,NT)*V(3)-VARD(L+2,NT)*V(2))/(VARI(L+2)-VARI(L+1))
  160 Y(NT)=(YY(1)*V(3)-YY(2)*V(1))/(VARI(L+2)-VARI(L))
      IF (EX) I=I+IN
      RETURN
C
C     ZERO ORDER
C
  170 DO 180 NT=1,NTAB
  180 Y(NT)=VARD(1,NT)
      RETURN
C
C     FORMAT STATEMENTS
C
  190 FORMAT (1H1,49H TABLE BELOW OUT OF ORDER FOR MTLUP AT POSITION
     1 ,I5,/31H X TABLE IS STORED IN LOCATION ,O6,//(8G15.8))
      END
```

```
*DECK,DIF
      FUNCTION DIF (L,M,NP,VARI,VARD)
C
C     ******************************************************************
C
C     THIS FUNCTION IS CALLED BY SUBROUTINES GEOM AND GEOMCB TO
C     CALCULATE THE WALL SLOPE FOR THE TABULAR INPUT CASE. FUNCTION DIF
C     WAS TAKEN FROM THE NASA-LANGLEY PROGRAM LIBRARY. THE DATE OF THIS
C     VERSION IS 08-01-68.
C
C     ******************************************************************
C
C        THIS FUNCTION SUBPROGRAM FINDS THE DERIVATIVE AT A GIVEN POINT,
C        L, FOR THE DESIRED X AND Y IN A GIVEN TABLE.  THE N-POINT
C        LAGRANGIAN FORMULA IS USED WHERE N IS ODD.
C
C        L = INTEGER, THE POINT OF X AND Y AT WHICH DERIVATIVE IS FOUND
C        M = INTEGER, 1-5, TO DETERMINE THE POINT FORMULA, N.  N=2*M+1
C        NP= INTEGER, THE NUMBER OF POINTS IN TABLE OF VARIABLES
C        VARI = ARRAY OF INDEPENDENT VARIABLE, X.  VARI(NP)
C        VARD = ARRAY OF DEPENDENT VARIABLE, Y.    VARD(NP)
C
      DIMENSION VARI(NP), VARD(NP), X(11), Y(11)
      DIF=17770000000000000000B
      IF (M.LT.1) RETURN
      N=2*M+1
      IF (M.GT.5.OR.N.GT.NP) RETURN
      M1=M+1
      M2=NP-M+1
      K=L
      IF (L.LE.M1.OR.N.EQ.NP) GO TO 10
      K=M1
      IF (L.LT.M2) GO TO 10
      K=L-(NP-N)
   10 MX=L-K
      DO 20 J=1,N
      MJ=MX+J
      X(J)=VARI(MJ)
   20 Y(J)=VARD(MJ)
      A=1.
      B=0.
      C=0.
      DO 40 J=1,N
      IF (J.EQ.K) GO TO 40
      P=1.
      DO 30 I=1,N
      IF (I.EQ.J) GO TO 30
      P=P*(X(J)-X(I))
   30 CONTINUE
      T=X(K)-X(J)
      B=B+Y(J)/(P*T)
      A=A*T
      C=C+1./T
   40 CONTINUE
      DIF=A*B+Y(K)*C
      RETURN
      END
```

```
*DECK,ONEDIM
      SUBROUTINE ONEDIM
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE 1-D INITIAL-DATA SURFACE
C
C     ******************************************************************
C
*CALL,MCC
      IF (PT(1).NE.0.0.AND.TT(1).NE.0.0) GO TO 10
      IERR=1
      WRITE (6,160)
      RETURN
   10 MN3=0.01
      IF (N1D.EQ.-1.OR.N1D.GT.2) MN3=2.0
      NXCK=0
      ACOEF=2.0/(GAMMA+1.0)
      BCOEF=(GAMMA-1.0)/(GAMMA+1.0)
      CCOEF=(GAMMA+1.0)/2.0/(GAMMA-1.0)
      IF (N1D.LT.0) GO TO 30
C
C     OVERALL LOOP
C
      IF (NGCB.NE.0) GO TO 20
      RSTAR=RT
      RSTARS=RT*RT
      GO TO 30
   20 RSTAR=YW(LT)-YCB(LT)
      RSTARS=YW(LT)**2-YCB(LT)**2
   30 DO 140 L=1,LMAX
      IF (L.EQ.1.AND.ISUPER.EQ.1) GO TO 140
      IF (L.EQ.1.AND.ISUPER.EQ.-1) GO TO 140
      X=XI+DX*FLOAT(L-1)
      IF (N1D.LT.0) GO TO 60
      IF (NGCB.NE.0) GO TO 40
      IF (X.LT.XT) GO TO 60
      IF (X.GT.XT) GO TO 50
      MN3=1.0
      GO TO 110
   40 IF (L.LT.LT) GO TO 60
      IF (L.GT.LT) GO TO 50
      MN3=1.0
      GO TO 110
   50 IF (NXCK.EQ.1) GO TO 60
      IF (N1D.EQ.1.OR.N1D.EQ.3) MN3=1.1
      IF (N1D.EQ.2.OR.N1D.EQ.4) MN3=0.9
      NXCK=1
   60 IF (NDIM.EQ.1) GO TO 70
      RAD=YW(L)-YCB(L)
      ARATIO=RAD/RSTAR
      GO TO 80
   70 RADS=YW(L)**2-YCB(L)**2
      ARATIO=RADS/RSTARS
C
C     NEWTON-RAPHSON ITERATION LOOP
C
   80 DO 100 ITER=1,100
      ABM=ACOEF+BCOEF*MN3*MN3
      ABMC=ABM**CCOEF
      FM=ABMC/MN3-ARATIO
      FPM=ABMC*(2.0*BCOEF*CCOEF/ABM-1.0/(MN3*MN3))
      OMN3=MN3
      MN3=OMN3-FM/FPM
      IF (OMN3.GT.0.99.AND.OMN3.LT.1.01) MN3=0.5*(OMN3+MN3)
      IF (MN3.GT.1.0.AND.OMN3.LT.1.0) MN3=0.99
      IF (MN3.LT.1.0.AND.OMN3.GT.1.0) MN3=1.01
      IF (N1D.EQ.-1.AND.MN3.LE.1.0) MN3=1.01
      IF (N1D.EQ.-2.AND.MN3.GE.1.0) MN3=0.99
      IF (MN3.GT.50.0) MN3=50.0
```

```
      IF (MN3.GE.0.0) GO TO 90
      MN3=-MN3
      GO TO 100
   90 IF (ABS(MN3-OMN3)/OMN3.LE.0.0005) GO TO 110
  100 CONTINUE
      WRITE (6,150) L
C
C     FILL IN 2-D ARRAYS LOOP
C
  110 DNXNY=(NXNY(L)-NXNYCB(L))/FLOAT(M1)
      DO 130 M=1,MMAX
      CALL EOS (8,P(L,M,1),RO(L,M,1),TEMP,PT(M),TT(M),MN3)
      CALL EOS (6,P(L,M,1),RO(L,M,1),TEMP,AS,D2,D3)
      Q=MN3*SQRT(AS)
      DN=NXNYCB(L)+DNXNY*FLOAT(M-1)
      DNS=DN*DN
      IF (DNS.EQ.0.0) GO TO 120
      SIGN=1.0
      IF (DN.GT.0.0) SIGN=-1.0
      U(L,M,1)=Q/SQRT(1.0+DNS)
      V(L,M,1)=SIGN*Q/SQRT(1.0+1.0/DNS)
      GO TO 130
  120 U(L,M,1)=Q
      V(L,M,1)=0.0
  130 CONTINUE
  140 CONTINUE
      RETURN
C
C     FORMAT STATEMENTS
C
  150 FORMAT (1H0,10X,47H***** THE 1-D SOLUTION FOR THE INITIAL-DATA SUR
     1 ,47HFACE FAILED TO CONVERGE IN 100 ITERATIONS AT L=,I2,6H *****)
  160 FORMAT (1H0,10X,48H***** THE STAGNATION CONDITIONS FOR THE 1-D INI
     1T,41HIAL-DATA SURFACE WERE NOT SPECIFIED *****)
      END
```

```
*DECK,EOS
      SUBROUTINE EOS (II,PRESS,RHO,TEMP,D1,D2,MN3)
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE EQUATION OF STATE QUANTITIES
C
C     ******************************************************************
C
*CALL,MCC
      GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,150), II
C
C     CALCULATE THE SOUND SPEED SQUARED (D1=AS)
C
   10 D1=GAMMA*PRESS/RHO
      RETURN
C
C     CALCULATE THE TEMPERATURE
C
   20 TEMP=PRESS/(RHO*RG)
      RETURN
C
C     CALCULATE THE PRESSURE
C
   30 PRESS=TEMP*RHO*RG
      RETURN
C
C     CALCULATE THE DENSITY
C
   40 RHO=PRESS/(TEMP*RG)
      RETURN
C
C     CALCULATE THE TEMPERATURE AND SOUND SPEED SQUARED (D1=AS)
C
   50 TEMP=PRESS/(RHO*RG)
      D1=GAMMA*PRESS/RHO
      RETURN
C
C     CALCULATE THE DENSITY AND SOUND SPEED SQUARED (D1=AS)
C
   60 RHO=PRESS/(TEMP*RG)
      D1=GAMMA*PRESS/RHO
      RETURN
C
C     CALCULATE THE SOUND SPEED SQUARED FROM THE TEMPERATURE (D1=AS)
C
   70 D1=GAMMA*RG*TEMP
      RETURN
C
C     CALCULATE THE PRESSURE AND TEMPERATURE FROM THE STAGNATION
C     CONDITIONS (D1=PT, D2=TT, MN3=MACH NO)
C
   80 DEM=1.0+GAM2*MN3*MN3
      PRESS=D1/DEM**GAM1
      TEMP=D2/DEM
      RETURN
C
C     CALCULATE THE STAGNATION PRESSURE AND TEMPERATURE FROM THE
C     STATIC CONDITIONS (D1=PT, D2=TT, MN3=MACH NO)
C
   90 DEM=1.0+GAM2*MN3*MN3
      D1=PRESS*DEM**GAM1
      D2=TEMP*DEM
      RETURN
C
C     CALCULATE THE MACH NUMBER (D2=TT, MN3=MACH NO)
C
  100 MN3=SQRT((D2/TEMP-1.0)/GAM2)
      RETURN
```

```
C
C     CALCULATE THE DENSITY FOR THE UNDER-EXPANDED JET (D1=PD, D2=ROD)
C
  110 RHO=D2*(PRESS/D1)**(1.0/GAMMA)
      RETURN
C
C     CALCULATE THE DENSITY FOR THE OVER-EXPANDED JET (D1=PD, D2=ROD)
C
  120 PRD=PRESS/D1
      RHO=D2*(GAM3*PRD+1.0)/(PRD+GAM3)
      RETURN
C
C     CALCULATE THE SQUARE ROOT OF GAM3 FOR THE SHARP EXPANSION CORNER
C
  130 D1=SQRT(GAM3)
      RETURN
C
C     CALCULATE GAMMA-1.0 FOR THE INTERNAL ENERGY EQUATION R.H.S.
C
  140 D1=GAMMA-1.0
      RETURN
C
C     CALCULATE THE TERM FOR THE ARTIFICAL CONDUCTIVITY
C
  150 D1=GAM1*RG/RKMU
      RETURN
      END
```

```
*DECK,MAP
      SUBROUTINE MAP (IP,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)
C
C     *****************************************************************
C
C     THIS SUBROUTINE CALCULATES THE MAPPING FUNCTIONS
C
C     *****************************************************************
C
*CALL,MCC
      BE=1.0/(YW(L)-YCB(L))
      IF (IP.EQ.0) RETURN
      Y=FLOAT(M-1)*DY
      AL=BE*(NXNYCB(L)+Y*(NXNY(L)-NXNYCB(L)))
      DE=-BE*Y*XWI(L)
      IF (IP.EQ.1) RETURN
      BE1=1.0/(YW(LD1)-YCB(LD1))
      AL1=BE1*(NXNYCB(LD1)+Y*(NXNY(LD1)-NXNYCB(LD1)))
      DE1=-BE1*Y*XWI(LD1)
      RETURN
      END
```

```
*DECK,MASFLO
      SUBROUTINE MASFLO (ISURF)
C
C     ****************************************************************
C
C     THIS SUBROUTINE CALCULATES THE INITIAL-DATA OR SOLUTION SURFACE
C     MASS FLOW AND THRUST
C
C     ****************************************************************
C
*CALL,MCC
      LC2=LC*LC
      LDUM=LMAX-1
      IF (LT.EQ.LMAX) LT=LMAX-1
      IF (JFLAG.EQ.1) LDUM=LJET-1
      IF (ISURF.EQ.1.OR.N1D.EQ.0) GO TO 30
C
C     CALCULATE THE MASS FLOW AND THRUST FOR THE 1-D INITIAL-DATA
C     SURFACE
C
      IF (NDIM.EQ.1) GO TO 10
      AREAI=(YW(1)-YCB(1))/LC2
      AREAT=(YW(LT)-YCB(LT))/LC2
      AREAE=(YW(LDUM)-YCB(LDUM))/LC2
      GO TO 20
   10 AREAI=3.141593*(YW(1)**2-YCB(1)**2)/LC2
      AREAT=3.141593*(YW(LT)**2-YCB(LT)**2)/LC2
      AREAE=3.141593*(YW(LDUM)**2-YCB(LDUM)**2)/LC2
   20 VMI=SQRT(U(1,1,1)**2+V(1,1,1)**2)
      VMT=SQRT(U(LT,1,1)**2+V(LT,1,1)**2)
      VME=SQRT(U(LDUM,1,1)**2+V(LDUM,1,1)**2)
      MASSI=RO(1,1,1)*VMI*AREAI*G
      MASST=RO(LT,1,1)*VMT*AREAT*G
      MASSE=RO(LDUM,1,1)*VME*AREAE*G
      THRUST=RO(LDUM,1,1)*U(LDUM,1,1)**2*AREAE
      RETURN
C
C     CALCULATE THE MASS FLOW AND THRUST FOR THE 2-D INITIAL-DATA
C     AND SOLUTION SURFACES
C
   30 MASSI=0.0
      MASST=0.0
      MASSE=0.0
      THRUST=0.0
      DYI=DY*(YW(1)-YCB(1))
      DYT=DY*(YW(LT)-YCB(LT))
      DYE=DY*(YW(LDUM)-YCB(LDUM))
      ND=1
      IF (ISURF.EQ.1) ND=N3
      DO 60 M=1,M1
      RADI=FLOAT(M-1)*DYI+YCB(1)
      RADT=FLOAT(M-1)*DYT+YCB(LT)
      RADE=FLOAT(M-1)*DYE+YCB(LDUM)
      IF (NDIM.EQ.1) GO TO 40
      AREAI=DYI/LC2
      AREAT=DYT/LC2
      AREAE=DYE/LC2
      GO TO 50
   40 AREAI=3.141593*((RADI+DYI)**2-RADI**2)/LC2
      AREAT=3.141593*((RADT+DYT)**2-RADT**2)/LC2
      AREAE=3.141593*((RADE+DYE)**2-RADE**2)/LC2
   50 ROUI=(RO(1,M,ND)*U(1,M,ND)+RO(1,M+1,ND)*U(1,M+1,ND))*0.5
      ROUT=(RO(LT,M,ND)*U(LT,M,ND)+RO(LT,M+1,ND)*U(LT,M+1,ND))*0.5
      ROUE=(RO(LDUM,M,ND)*U(LDUM,M,ND)+RO(LDUM,M+1,ND)*U(LDUM,M+1,ND))*0
     1 .5
      ROU2E=(RO(LDUM,M,ND)*U(LDUM,M,ND)**2+RO(LDUM,M+1,ND)*U(LDUM,M+1,ND
     1 )**2)*0.5
      MASSI=MASSI+ROUI*AREAI*G
      MASST=MASST+ROUT*AREAT*G
      MASSE=MASSE+ROUE*AREAE*G
```

```
      THRUST=THRUST+ROU2E*AREAE
   60 CONTINUE
      RETURN
      END
```

```
*DECK,PLOT
      SUBROUTINE PLOT (TITLE,T,NP,IVPTS)
C
C     ****************************************************************
C
C     THIS SUBROUTINE PLOTS THE VELOCITY VECTORS AND DEPENDENT VARIABLE
C     CONTOUR PLOTS
C
C     ****************************************************************
C
      DIMENSION CON(9), XCO(4), YCO(4), TITLE(8)
*CALL,MCC
C
C     SET UP THE PLOT SIZE
C
      ND=N3
      IF (N.EQ.0) ND=1
      XL=XI
      XR=XE
      YT=YW(1)
      YB=YCB(1)
      DO 10 L=2,LMAX
      YT=AMAX1(YT,YW(L))
      YB=AMIN1(YB,YCB(L))
   10 CONTINUE
      VV=-0.1*DX
      DO 60 IDUM=1,IVPTS
      VV=VV+DX
      FIYB=900.0
      XD=(XR-XL)/(YT-YB)
      FIR=(1022.0-1022.0/FLOAT(L1)-FLOAT(IDUM)*1022.0/FLOAT(L1))/884.0
      IF (XD.LE.FIR) GO TO 20
      FIXL=1022.0/FLOAT(L1)
      FIXR=1022.0-FIXL-FLOAT(IDUM)*1022.0/FLOAT(L1)
      FIYT=900.0-(FIXR-FIXL)/XD
      GO TO 30
   20 FIXL=511.0-450.0*XD
      FIXR=511.0+450.0*XD
      FIYT=16.0
   30 XCONV=(FIXR-FIXL)/(XR-XL)
      YCONV=(FIYT-FIYB)/(YT-YB)
C
C     GENERATE THE VELOCITY VECTOR PLOT
C
      VMAX=0.0
      DO 40 L=1,LMAX
      DO 40 M=1,MMAX
      VMAX=AMAX1(VMAX,ABS(U(L,M,ND)),ABS(V(L,M,ND)))
   40 CONTINUE
      IF (VMAX.LT.1.0E-10) GO TO 70
      DROU=VV/VMAX
      CALL ADV (1)
      DO 50 L=1,LMAX
      IX1=FIXL+(FLOAT(L-1)*DX)*XCONV
      DY=(YW(L)-YCB(L))/FLOAT(M1)
      DO 50 M=1,MMAX
      IY1=FIYB+(YCB(L)+FLOAT(M-1)*DY-YB)*YCONV
      IX2=FIXL+(FLOAT(L-1)*DX+U(L,M,ND)*DROU)*XCONV
      IY2=FIYB+(YCB(L)+FLOAT(M-1)*DY-YB+V(L,M,ND)*DROU)*YCONV
      CALL DRV (IX1,IY1,IX2,IY2)
      CALL PLT (IX1,IY1,16)
   50 CONTINUE
      CALL LINCNT (58)
      WRITE (7,430) IDUM,NP,T
      WRITE (7,370) TITLE
   60 CONTINUE
C
C     RESET PLOT SIZE FOR CONTOUR PLOTS
C
```

```
   70 IF (XD.LE.FIR) GO TO 80
      FIXR=1022.0-FIXL-1022.0/FLOAT(L1)
      FIYT=900.0-(FIXR-FIXL)/XD
      XCONV=(FIXR-FIXL)/(XR-XL)
      YCONV=(FIYT-FIYB)/(YT-YB)
C
C     FILL PLOTTING ARRAY CQ FOR THE CONTOUR PLOTS
C
   80 I=0
   90 I=I+1
      GO TO (100,120,140,160,360), I
C
  100 DO 110 L=1,LMAX
      DO 110 M=1,MMAX
      CQ(L,M)=RO(L,M,ND)*G
      IF (IUO.EQ.2) CQ(L,M)=CQ(L,M)*16.02
  110 CONTINUE
      GO TO 180
C
  120 DO 130 L=1,LMAX
      DO 130 M=1,MMAX
      CQ(L,M)=P(L,M,ND)/PC
      IF (IUO.EQ.2) CQ(L,M)=CQ(L,M)*6.8948
  130 CONTINUE
      GO TO 180
C
  140 DO 150 L=1,LMAX
      DO 150 M=1,MMAX
      CALL EOS (2,P(L,M,ND),RO(L,M,ND),TEMP,AS,D2,D3)
      CQ(L,M)=TEMP
      IF (IUO.EQ.2) CQ(L,M)=CQ(L,M)*0.555556
  150 CONTINUE
      GO TO 180
C
  160 DO 170 L=1,LMAX
      DO 170 M=1,MMAX
      CALL EOS (1,P(L,M,ND),RO(L,M,ND),TEMP,AS,D2,D3)
      CQ(L,M)=SQRT((U(L,M,ND)**2+V(L,M,ND)**2)/AS)
  170 CONTINUE
C
C     DETERMINE THE PLOTTING LINE QUANTITIES AND LABEL THE FRAMES
C
  180 QMN=1.0E06
      QMX=-QMN
      DO 190 L=1,LMAX
      DO 190 M=1,MMAX
      QMN=AMIN1(CQ(L,M),QMN)
      QMX=AMAX1(CQ(L,M),QMX)
  190 CONTINUE
      XX=QMX-QMN
      DQ=0.1*XX
      DO 200 K=1,9
      CON(K)=QMN+(FLOAT(K))*DQ
  200 CONTINUE
      K=9
      CALL ADV (1)
      CALL LINCNT (58)
      GO TO (210,220,230,240), I
  210 WRITE (7,380) NP,T
      GO TO 250
  220 WRITE (7,390) NP,T
      GO TO 250
  230 WRITE (7,400) NP,T
      GO TO 250
  240 WRITE (7,410) NP,T
  250 WRITE (7,420) QMN,QMX,CON(1),CON(K),DQ
      WRITE (7,370) TITLE
C
C     DETERMINE THE LOCATION OF EACH CONTOUR LINE SEGMENT AND PLOT IT
C
```

```
      DO 340 L=2,LMAX
      DY=(YW(L-1)-YCB(L-1))/FLOAT(M1)
      DY1=(YW(L)-YCB(L))/FLOAT(M1)
      DO 340 M=2,MMAX
      NN=0
      DO 340 KK=1,K
      K1=K2=K3=K4=0
      IF (CQ(L-1,M-1).LE.CON(KK)) K1=1
      IF (CQ(L,M-1).LE.CON(KK)) K2=1
      IF (CQ(L-1,M).LE.CON(KK)) K3=1
      IF (CQ(L,M).LE.CON(KK)) K4=1
      IF (K1*K2*K3*K4.NE.0) GO TO 340
      IF (K1+K2+K3+K4.EQ.0) GO TO 340
      IF (NN.NE.0) GO TO 260
      NN=1
      XCO(1)=XI+FLOAT(L-2)*DX
      XCO(2)=XCO(1)+DX
      XCO(3)=XCO(1)
      XCO(4)=XCO(2)
      YCO(1)=YCB(L-1)+FLOAT(M-2)*DY
      YCO(2)=YCB(L)+FLOAT(M-2)*DY1
      YCO(3)=YCB(L-1)+FLOAT(M-1)*DY
      YCO(4)=YCB(L)+FLOAT(M-1)*DY1
  260 LL=0
      IF (K1+K3.NE.1) GO TO 270
      IC1=1
      IC2=3
      LP1=L-1
      MP1=M-1
      LP2=L-1
      MP2=M
      ASSIGN 270 TO KR1
      GO TO 300
  270 IF (K1+K2.NE.1) GO TO 280
      IC1=1
      IC2=2
      LP1=L-1
      MP1=M-1
      LP2=L
      MP2=M-1
      ASSIGN 280 TO KR1
      GO TO 300
  280 IF (K2+K4.NE.1) GO TO 290
      IC1=2
      IC2=4
      LP1=L
      MP1=M-1
      LP2=L
      MP2=M
      ASSIGN 290 TO KR1
      GO TO 300
  290 IF (K3+K4.NE.1) GO TO 340
      IC1=3
      IC2=4
      LP1=L-1
      MP1=M
      LP2=L
      MP2=M
      ASSIGN 340 TO KR1
  300 LL=LL+1
      XX=(CON(KK)-CQ(LP1,MP1))/(CQ(LP2,MP2)-CQ(LP1,MP1))
      IF (LL.EQ.2) GO TO 310
      IX1=FIXL+(XCO(IC1)+XX*(XCO(IC2)-XCO(IC1))-XL)*XCONV
      IY1=FIYB+(YCO(IC1)+XX*(YCO(IC2)-YCO(IC1))-YB)*YCONV
      GO TO KR1, (270,280,290,340)
  310 IX2=FIXL+(XCO(IC1)+XX*(XCO(IC2)-XCO(IC1))-XL)*XCONV
      IY2=FIYB+(YCO(IC1)+XX*(YCO(IC2)-YCO(IC1))-YB)*YCONV
      CALL DRV (IX1,IY1,IX2,IY2)
      IF (KK.NE.1) GO TO 320
      CALL PLT (IX1,IY1,35)
```

```
  320 IF (KK.NE.K) GO TO 330
      CALL PLT (IX1,IY1,24)
  330 LL=0
      IF (LP2.NE.L) GO TO 340
      IF (MP2.NE.M-1) GO TO 340
      GO TO 280
  340 CONTINUE
C
C     DRAW THE GEOMETRY BOUNDARIES FOR THE CONTOUR PLOTS
C
      DO 350 L=2,LMAX
      IX1=FIXL+(FLOAT(L-2)*DX)*XCONV
      IX2=FIXL+(FLOAT(L-1)*DX)*XCONV
      IY1=FIYB+(YCB(L-1)-YB)*YCONV
      IY2=FIYB+(YCB(L)-YB)*YCONV
      IY3=FIYB+(YW(L-1)-YB)*YCONV
      IY4=FIYB+(YW(L)-YB)*YCONV
      CALL DRV (IX1,IY1,IX2,IY2)
      CALL DRV (IX1,IY3,IX2,IY4)
  350 CONTINUE
      GO TO 90
  360 CONTINUE
      DY=1.0/FLOAT(MMAX-1)
      CALL ADV (1)
      RETURN
C
C     FORMAT STATEMENTS
C
  370 FORMAT (1H ,8A10)
  380 FORMAT (1H ,7HDENSITY,24X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)
  390 FORMAT (1H ,8HPRESSURE,23X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)
  400 FORMAT (1H ,11HTEMPERATURE,20X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)
  410 FORMAT (1H ,11HMACH NUMBER,20X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)
  420 FORMAT (1H ,10HLOW VALUE=,1PE11.4,2X,11HHIGH VALUE=,E11.4,2X,12HLO
     1W CONTOUR=,E11.4,/,1X,13HHIGH CONTOUR=,E11.4,2X,14HDELTA CONTOUR=
     2 ,E11.4)
  430 FORMAT (1H ,18HVELOCITY VECTORS (,I1,2HX),10X,2HN=,I6,2X,2HT=,1PE1
     1 0.4,4H SEC)
      END
```

```
*DECK,VISCOUS
      SUBROUTINE VISCOUS
C
C     ****************************************************************
C
C     THIS SUBROUTINE CALCULATES THE LOCAL ARTIFICAL VISCOSITY AND
C     MOLECULAR VISCOSITY-HEAT CONDUCTION TERMS
C
C     ****************************************************************
C
*CALL,MCC
      REAL MU, LA, LP2M, LPM, K, MUT, LAT, KT
C
C     THE SINGLE SUBSCRIPTS USED HERE ARE LMN1=L,M,N1, LP=L+1,M,N1,
C     LM=L-1,M,N1, MP=L,M+1,N1, MM=L,M-1,N1, LPMP=L+1,M+1,N1, LPMM=
C     L+1,M-1,N1, LMMP=L-1,M+1,N1 AND LMMM=L-1,M-1,N1
C
      IF (N.NE.1) GO TO 10
      NC=0
      ECHECK=ABS(EMU)+ABS(ELA)+ABS(EK)
      IF (ABS(EMU).EQ.ABS(ELA).AND.ABS(EMU).EQ.ABS(EK)) ECHECK=-1.0
      RDUM=CAV*DX*DY*2.0
      RLA=RLA1=RLA2=RLA3=RLA4=RMU=RMU1=RMU2=RMU3=RMU4=RK=RK1=RK2=0.0
      RK3=RK4=RRO=RRO1=RRO2=RRO3=RRO4=RLP2M=RLP2M1=RLP2M2=RLP2M3=0.0
      RLP2M4=RLPM=MU=LA=K=LP2M=LPM=RODIF=0.0
      ATERM=ATERM1=ATERM2=ATERM3=ATERM4=TLMUR=0.0
   10 NC=NC+1
      NLINE=0
      IF (IAV.NE.0) GO TO 20
      IF (NC.NE.NPRINT.AND.N.NE.NMAX) GO TO 20
      WRITE (6,450)
      WRITE (6,440) N
C
   20 DO 420 L=2,LMAX
      IF (ITM.NE.0) CALL MIXLEN (L)
      DO 420 M=1,MMAX
      IF (L.EQ.LMAX.AND.M.EQ.1) GO TO 420
      IF (L.EQ.LMAX.AND.M.EQ.MMAX) GO TO 420
      LMD2=LD*(M-1)+LMD1
      LMMD2=LD*(M-2)+LMD1
      LMPD2=LD*M+LMD1
      LMN1=L+LMD2
      LP=L+1+LMD2
      LM=L-1+LMD2
      MP=L+LMPD2
      MM=L+LMMD2
      LPMP=L+1+LMPD2
      LPMM=L+1+LMMD2
      LMMP=L-1+LMPD2
      LMMM=L-1+LMMD2
      CALL MAP (1,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)
      DIV=0.0
      IF (L.EQ.LMAX.AND.CHECK.EQ.0.0) GO TO 80
      IF (L.EQ.LMAX) GO TO 90
      IF (CAV.EQ.0.0) GO TO 90
      IF (CHECK.EQ.0.0.AND.L.LT.LSS) GO TO 80
      IF (SMACH.EQ.0.0) GO TO 30
      XV=U(LMN1)*U(LMN1)+V(LMN1)*V(LMN1)
      CALL EOS (1,P(LMN1),RO(LMN1),T,XA,D2,D3)
      XM=XV/XA
      IF (CHECK.EQ.0.0.AND.XM.LT.SMACH*SMACH) GO TO 80
      IF (L.LT.LSS.OR.XM.LT.SMACH*SMACH) GO TO 90
C
C     CHECK TO SEE IF THE DIVERGENCE OF THE VELOCITY IS NEGATIVE
C
   30 UX=(U(LP)-U(LMN1))*DXR
      UXD=(U(LMN1)-U(LM))*DXR
      IF (UXD.LT.UX) UX=UXD
      IF (M.EQ.1) GO TO 40
      IF (M.EQ.MMAX) GO TO 60
```

```
      UY=0.5*(U(MP)-U(MM))*DYR
      VY=(V(MP)-V(LMN1))*DYR
      VYD=(V(LMN1)-V(MM))*DYR
      IF (VYD.LT.VY) VY=VYD
      IF (NDIM.NE.0) ATERM=V(LMN1)/(FLOAT(M-1)*DY/BE+YCB(L))
      GO TO 70
   40 UY=(U(MP)-U(LMN1))*DYR
      VY=(V(MP)-V(LMN1))*DYR
      IF (NDIM.EQ.0) GO TO 70
      IF (YCB(L).EQ.0.0) GO TO 50
      ATERM=V(LMN1)/YCB(L)
      IF (YCB(L-1).EQ.0.0) ATERM=0.5*(BE*V(LMMP)*DYR+V(LMN1)/YCB(L))
      IF (YCB(L+1).EQ.0.0) ATERM=0.5*(BE*V(LPMP)*DYR+V(LMN1)/YCB(L))
      GO TO 70
   50 ATERM=BE*V(MP)*DYR
      IF (YCB(L-1).NE.0.0) ATERM=0.5*(V(LM)/YCB(L-1)+BE*V(MP)*DYR)
      IF (YCB(L+1).NE.0.0) ATERM=0.5*(V(LP)/YCB(L+1)+BE*V(MP)*DYR)
      GO TO 70
   60 UY=(U(LMN1)-U(MM))*DYR
      VY=(V(LMN1)-V(MM))*DYR
      IF (NDIM.NE.0) ATERM=V(LMN1)/YW(L)
   70 DIV=UX+AL*UY+BE*VY+ATERM
      IF (CHECK.NE.0.0) GO TO 90
      IF (DIV.LT.0.0) GO TO 90
   80 QUT(L,M)=0.0
      QVT(L,M)=0.0
      QPT(L,M)=0.0
      QROT(L,M)=0.0
      GO TO 420
C
   90 UX1=(U(LMN1)-U(LM))*DXR
      CALL EOS (2,P(LMN1),RO(LMN1),T,AS,D2,D3)
      IF (L.EQ.LMAX) GO TO 110
      VX1=(V(LMN1)-V(LM))*DXR
      UX2=(U(LP)-U(LMN1))*DXR
      VX2=(V(LP)-V(LMN1))*DXR
      CALL EOS (2,P(LM),RO(LM),TLM,AS,D2,D3)
      CALL EOS (2,P(LP),RO(LP),TLP,AS,D2,D3)
      TX1=(T-TLM)*DXR
      TX2=(TLP-T)*DXR
      IF (CAV.EQ.0.0) GO TO 100
      ROX1=(RO(LMN1)-RO(LM))*DXR
      ROX2=(RO(LP)-RO(LMN1))*DXR
  100 LDUM=L-1
      CALL MAP (1,LDUM,M,ALM,BEM,DE,LD1,AL1,BE1,DE1)
      LDUM=L+1
      CALL MAP (1,LDUM,M,ALP,BEP,DE,LD1,AL1,BE1,DE1)
      BE1=0.5*(BEM+BE)
      BE2=0.5*(BEP+BE)
      AL1=0.5*(ALM+AL)
      AL2=0.5*(ALP+AL)
      IF (M.EQ.1) GO TO 130
      IF (M.EQ.MMAX) GO TO 200
C
C     CALCULATE THE INTERIOR POINT QUANTITIES
C
      UY1=0.25*(U(MP)+U(LMMP)-U(MM)-U(LMMM))*DYR
      UY2=0.25*(U(MP)+U(LPMP)-U(MM)-U(LPMM))*DYR
      VY1=0.25*(V(MP)+V(LMMP)-V(MM)-V(LMMM))*DYR
      VY2=0.25*(V(MP)+V(LPMP)-V(MM)-V(LPMM))*DYR
      UX3=0.25*(U(LP)+U(LPMM)-U(LM)-U(LMMM))*DXR
      UX4=0.25*(U(LP)+U(LPMP)-U(LM)-U(LMMP))*DXR
      VX3=0.25*(V(LP)+V(LPMM)-V(LM)-V(LMMM))*DXR
      VX4=0.25*(V(LP)+V(LPMP)-V(LM)-V(LMMP))*DXR
  110 VY3=(V(LMN1)-V(MM))*DYR
      VY4=(V(MP)-V(LMN1))*DYR
      UY3=(U(LMN1)-U(MM))*DYR
      UY4=(U(MP)-U(LMN1))*DYR
      CALL EOS (2,P(MM),RO(MM),TMM,AS,D2,D3)
      CALL EOS (2,P(MP),RO(MP),TMP,AS,D2,D3)
```

```
      TY3=(T-TMM)*DYR
      TY4=(TMP-T)*DYR
      IF (L.EQ.LMAX) GO TO 120
      CALL EOS (2,P(LMMM),RO(LMMM),TLMMM,AS,D2,D3)
      CALL EOS (2,P(LMMP),RO(LMMP),TLMMP,AS,D2,D3)
      CALL EOS (2,P(LPMM),RO(LPMM),TLPMM,AS,D2,D3)
      CALL EOS (2,P(LPMP),RO(LPMP),TLPMP,AS,D2,D3)
      TY1=0.25*(TMP+TLMMP-TMM-TLMMM)*DYR
      TY2=0.25*(TLPMP+TMP-TLPMM-TMM)*DYR
      TX3=0.25*(TLP+TLPMM-TLM-TLMMM)*DXR
      TX4=0.25*(TLPMP+TLP-TLMMP-TLM)*DXR
      IF (CAV.EQ.0.0) GO TO 120
      ROY1=0.25*(RO(MP)+RO(LMMP)-RO(MM)-RO(LMMM))*DYR
      ROY2=0.25*(RO(MP)+RO(LPMP)-RO(MM)-RO(LPMM))*DYR
      ROX3=0.25*(RO(LP)+RO(LPMM)-RO(LM)-RO(LMMM))*DXR
      ROX4=0.25*(RO(LP)+RO(LPMP)-RO(LM)-RO(LMMP))*DXR
      ROY3=(RO(LMN1)-RO(MM))*DYR
      ROY4=(RO(MP)-RO(LMN1))*DYR
      IF (NDIM.EQ.0) GO TO 120
      IF (CAV.EQ.0.0.OR.DIV.GE.0.0) GO TO 120
      Y=FLOAT(M-1)*DY/BE+YCB(L)
      Y1=Y-YCB(L)+YCB(L-1)
      Y2=Y-YCB(L)+YCB(L+1)
      Y3=Y-0.5*DY/BE
      Y4=Y+0.5*DY/BE
      ATERM1=0.5*(V(LMN1)+V(LM))/Y1
      ATERM2=0.5*(V(LMN1)+V(LP))/Y2
      ATERM3=0.5*(V(LMN1)+V(MM))/Y3
      ATERM4=0.5*(V(LMN1)+V(MP))/Y4
  120 MDUM=M-1
      CALL MAP (1,L,MDUM,ALMY,BEMY,DE,LD1,AL1,BE1,DE1)
      MDUM=M+1
      CALL MAP (1,L,MDUM,ALPY,BEPY,DE,LD1,AL1,BE1,DE1)
      BE3=0.5*(BEMY+BE)
      BE4=0.5*(BEPY+BE)
      AL3=0.5*(ALMY+AL)
      AL4=0.5*(ALPY+AL)
      IF (L.NE.LMAX) GO TO 250
      UX1=UX2=VX1=VX2=TX1=TX2=UY1=UY2=VY1=VY2=UX3=UX4=VX3=VX4=0.0
      TY1=TY2=TX3=TX4=AL1=AL2=BE1=BE2=AL=AL3=AL4=0.0
      ROX1=ROX2=ROY1=ROY2=ROX3=ROX4=ROY3=ROY4=0.0
      GO TO 250
C
C     CALCULATE THE CENTERBODY POINT QUANTITIES
C
  130 UX4=0.25*(U(LP)+U(LPMP)-U(LM)-U(LMMP))*DXR
      VX4=0.25*(V(LP)+V(LPMP)-V(LM)-V(LMMP))*DXR
      UY4=(U(MP)-U(LMN1))*DYR
      VY4=(V(MP)-V(LMN1))*DYR
      CALL EOS (2,P(MP),RO(MP),TMP,AS,D2,D3)
      CALL EOS (2,P(LMMP),RO(LMMP),TLMMP,AS,D2,D3)
      CALL EOS (2,P(LPMP),RO(LPMP),TLPMP,AS,D2,D3)
      TX4=0.25*(TLPMP+TLP-TLMMP-TLM)*DXR
      TY4=(TMP-T)*DYR
      IF (CAV.EQ.0.0) GO TO 140
      ROX4=0.25*(RO(LP)+RO(LPMP)-RO(LM)-RO(LMMP))*DXR
      ROY4=(RO(MP)-RO(LMN1))*DYR
C
C     REFLECT THE CENTERBODY BOUNDARY CONDITIONS
C
  140 IF (NGCB.EQ.0) GO TO 150
      IF (IVBC.EQ.1) GO TO 160
      THEW=ATAN(-NXNYCB(L))
      THE=ATAN(V(MP)/U(MP))
      IF (U(MP).LT.0.0) THE=THE+3.14159
      VMAG=SQRT(U(MP)*U(MP)+V(MP)*V(MP))
      RTHE=2.0*THEW-THE
      IF (NOSLIP.EQ.1.AND.NGCB.NE.0) RTHE=3.14159+THE
      UR=VMAG*COS(RTHE)
      VR=VMAG*SIN(RTHE)
```

```
      THEW=ATAN(-NXNYCB(L+1))
      THE=ATAN(V(LPMP)/U(LPMP))
      IF (U(LPMP).LT.0.0) THE=THE+3.14159
      VMAG=SQRT(U(LPMP)*U(LPMP)+V(LPMP)*V(LPMP))
      RTHE=2.0*THEW-THE
      IF (NOSLIP.EQ.1.AND.NGCB.NE.0) RTHE=3.14159+THE
      URP=VMAG*COS(RTHE)
      VRP=VMAG*SIN(RTHE)
      THEW=ATAN(-NXNYCB(L-1))
      THE=ATAN(V(LMMP)/U(LMMP))
      IF (U(LMMP).LT.0.0) THE=THE+3.14159
      VMAG=SQRT(U(LMMP)*U(LMMP)+V(LMMP)*V(LMMP))
      RTHE=2.0*THEW-THE
      IF (NOSLIP.EQ.1.AND.NGCB.NE.0) RTHE=3.14159+THE
      URM=VMAG*COS(RTHE)
      VRM=VMAG*SIN(RTHE)
      RFL=2.0*DY*NXNYCB(L)/(BE*(1.0+NXNYCB(L)*NXNYCB(L)))
      RFLP=2.0*DY*NXNYCB(L+1)/(BE*(1.0+NXNYCB(L+1)*NXNYCB(L+1)))
      RFLM=2.0*DY*NXNYCB(L-1)/(BE*(1.0+NXNYCB(L-1)*NXNYCB(L-1)))
      TTERM=0.5*(TX1+TX2)
      TR=TMP-TTERM*RFL
      TRP=TLPMP-TTERM*RFLP
      TRM=TLMMP-TTERM*RFLM
      IF (CAV.EQ.0.0) GO TO 170
      ROTERM=0.5*(ROX1+ROX2)
      ROR=RO(MP)-ROTERM*RFL
      RORP=RO(LPMP)-ROTERM*RFLP
      RORM=RO(LMMP)-ROTERM*RFLM
      GO TO 170
C
C     REFLECT THE CENTERLINE OR MIDPLANE BOUNDARY CONDITIONS
C
  150 UR=U(MP)
      VR=-V(MP)
      URP=U(LPMP)
      VRP=-V(LPMP)
      URM=U(LMMP)
      VRM=-V(LMMP)
      TR=TMP
      TRP=TLPMP
      TRM=TLMMP
      IF (CAV.EQ.0.0) GO TO 170
      ROR=RO(MP)
      RORP=RO(LPMP)
      RORM=RO(LMMP)
      GO TO 170
C
C     EXTRAPOLATE THE CENTERBODY BOUNDARY CONDITIONS
C
  160 UR=2.0*U(LMN1)-U(MP)
      VR=2.0*V(LMN1)-V(MP)
      URP=2.0*U(LP)-U(LPMP)
      VRP=2.0*V(LP)-V(LPMP)
      URM=2.0*U(LM)-U(LMMP)
      VRM=2.0*V(LM)-V(LMMP)
      TR=2.0*T-TMP
      TRP=2.0*TLP-TLPMP
      TRM=2.0*TLM-TLMMP
      IF (CAV.EQ.0.0) GO TO 170
      ROR=2.0*RO(LMN1)-RO(MP)
      RORP=2.0*RO(LP)-RO(LPMP)
      RORM=2.0*RO(LM)-RO(LMMP)
  170 UY1=0.25*(U(MP)+U(LMMP)-UR-URM)*DYR
      VY1=0.25*(V(MP)+V(LMMP)-VR-VRM)*DYR
      UY2=0.25*(U(MP)+U(LPMP)-UR-URP)*DYR
      VY2=0.25*(V(MP)+V(LPMP)-VR-VRP)*DYR
      UY3=(U(LMN1)-UR)*DYR
      VY3=(V(LMN1)-VR)*DYR
      UX3=0.25*(U(LP)+URP-U(LM)-URM)*DXR
      VX3=0.25*(V(LP)+VRP-V(LM)-VRM)*DXR
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```
      TY1=0.25*(TMP+TLMMP-TR-TRM)*DYR
      TY2=0.25*(TMP+TLPMP-TR-TRP)*DYR
      TX3=0.25*(TLP+TRP-TLM-TRM)*DXR
      TY3=(T-TR)*DYR
      TMM=TR
      IF (CAV.EQ.0.0) GO TO 190
      ROY1=0.25*(RO(MP)+RO(LMMP)-ROR-RORM)*DYR
      ROY2=0.25*(RO(MP)+RO(LPMP)-ROR-RORP)*DYR
      ROY3=(RO(LMN1)-ROR)*DYR
      ROX3=0.25*(RO(LP)+RORP-RO(LM)-RORM)*DXR
      IF (NDIM.EQ.0) GO TO 190
      IF (CAV.EQ.0.0.OR.DIV.GE.0.0) GO TO 190
      IF (YCB(L).EQ.0.0) GO TO 180
      ATERM1=0.5*((V(LMN1)+V(LM))/(YCB(L)+YCB(L-1)))
      ATERM2=0.5*((V(LMN1)+V(LP))/(YCB(L)+YCB(L+1)))
      IF (YCB(L-1).EQ.0.0) ATERM1=0.5*(BEM*V(LMMP)*DYR+V(LMN1)/YCB(L))
      IF (YCB(L+1).EQ.0.0) ATERM2=0.5*(BEP*V(LPMP)*DYR+V(LMN1)/YCB(L))
      IF (YCB(L-1).EQ.0.0.OR.YCB(L+1).EQ.0.0) ATERM=0.5*(ATERM1+ATERM2)
      ATERM3=ATERM
      ATERM4=0.5*(V(LMN1)+V(MP))/(YCB(L)+0.5*DY/BE)
      GO TO 190
  180 ATERM1=BE1*0.5*(V(MP)+V(LMMP))*DYR
      ATERM2=BE2*0.5*(V(MP)+V(LPMP))*DYR
      IF (YCB(L-1).NE.0.0) ATERM1=0.5*(V(LM)/YCB(L-1)+BE*V(MP)*DYR)
      IF (YCB(L+1).NE.0.0) ATERM2=0.5*(V(LP)/YCB(L+1)+BE*V(MP)*DYR)
      IF (YCB(L-1).NE.0.0.OR.YCB(L+1).NE.0.0) ATERM=0.5*(ATERM1+ATERM2)
      ATERM4=0.5*V(MP)/(0.5*DY/BE)
      ATERM3=ATERM4
  190 MDUM=M+1
      CALL MAP (1,L,MDUM,AL4,BE4,DE,LD1,AL1,BE1,DE1)
      AL3=2.0*AL-AL4
      BE3=2.0*BE-BE4
      AL3=0.5*(AL3+AL)
      BE3=0.5*(BE3+BE)
      AL4=0.5*(AL4+AL)
      BE4=0.5*(BE4+BE)
      GO TO 250
C
C     CALCULATE THE WALL POINT QUANTITIES
C
  200 UX3=0.25*(U(LP)+U(LPMM)-U(LM)-U(LMMM))*DXR
      VX3=0.25*(V(LP)+V(LPMM)-V(LM)-V(LMMM))*DXR
      UY3=(U(LMN1)-U(MM))*DYR
      VY3=(V(LMN1)-V(MM))*DYR
      CALL EOS (2,P(LPMM),RO(LPMM),TLPMM,AS,D2,D3)
      CALL EOS (2,P(MM),RO(MM),TMM,AS,D2,D3)
      CALL EOS (2,P(LMMM),RO(LMMM),TLMMM,AS,D2,D3)
      TX3=0.25*(TLP+TLPMM-TLM-TLMMM)*DXR
      TY3=(T-TMM)*DYR
      IF (CAV.EQ.0.0) GO TO 210
      ROX3=0.25*(RO(LP)+RO(LPMM)-RO(LM)-RO(LMMM))*DXR
      ROY3=(RO(LMN1)-RO(MM))*DYR
C
C     REFLECT THE WALL BOUNDARY CONDITIONS
C
  210 IF (IVBC.EQ.1) GO TO 220
      THEW=ATAN(-NXNY(L))
      THE=ATAN(V(MM)/U(MM))
      IF (U(MM).LT.0.0) THE=THE+3.14159
      VMAG=SQRT(U(MM)*U(MM)+V(MM)*V(MM))
      RTHE=2.0*THEW-THE
      IF (NOSLIP.EQ.1) RTHE=3.14159+THE
      UR=VMAG*COS(RTHE)
      VR=VMAG*SIN(RTHE)
      THEW=ATAN(-NXNY(L+1))
      THE=ATAN(V(LPMM)/U(LPMM))
      IF (U(LPMM).LT.0.0) THE=THE+3.14159
      VMAG=SQRT(U(LPMM)*U(LPMM)+V(LPMM)*V(LPMM))
      RTHE=2.0*THEW-THE
      IF (NOSLIP.EQ.1) RTHE=3.14159+THE
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      URP=VMAG*COS(RTHE)
      VRP=VMAG*SIN(RTHE)
      THEW=ATAN(-NXNY(L-1))
      THE=ATAN(V(LMMM)/U(LMMM))
      IF (U(LMMM).LT.0.0) THE=THE+3.14159
      VMAG=SQRT(U(LMMM)*U(LMMM)+V(LMMM)*V(LMMM))
      RTHE=2.0*THEW-THE
      IF (NOSLIP.EQ.1) RTHE=3.14159+THE
      URM=VMAG*COS(RTHE)
      VRM=VMAG*SIN(RTHE)
      RFL=2.0*DY*NXNY(L)/(BE*(1.0+NXNY(L)*NXNY(L)))
      RFLP=2.0*DY*NXNY(L+1)/(BE*(1.0+NXNY(L+1)*NXNY(L+1)))
      RFLM=2.0*DY*NXNY(L-1)/(BE*(1.0+NXNY(L-1)*NXNY(L-1)))
      TTERM=0.5*(TX1+TX2)
      TR=TMM-TTERM*RFL
      TRP=TLPMM-TTERM*RFLP
      TRM=TLMMM-TTERM*RFLM
      IF (CAV.EQ.0.0) GO TO 230
      ROTERM=0.5*(ROX1+ROX2)
      ROR=RO(MM)-ROTERM*RFL
      RORP=RO(LPMM)-ROTERM*RFLP
      RORM=RO(LMMM)-ROTERM*RFLM
      GO TO 230
C
C     EXTRAPOLATE THE WALL BOUNDARY CONDITIONS
C
  220 UR=2.0*U(LMN1)-U(MM)
      VR=2.0*V(LMN1)-V(MM)
      URP=2.0*U(LP)-U(LPMM)
      VRP=2.0*V(LP)-V(LPMM)
      URM=2.0*U(LM)-U(LMMM)
      VRM=2.0*V(LM)-V(LMMM)
      TR=2.0*T-TMM
      TRP=2.0*TLP-TLPMM
      TRM=2.0*TLM-TLMMM
      IF (CAV.EQ.0.0) GO TO 230
      ROR=2.0*RO(LMN1)-RO(MM)
      RORP=2.0*RO(LP)-RO(LPMM)
      RORM=2.0*RO(LM)-RO(LMMM)
  230 UY1=0.25*(UR+URM-U(MM)-U(LMMM))*DYR
      VY1=0.25*(VR+VRM-V(MM)-V(LMMM))*DYR
      UY2=0.25*(UR+URP-U(MM)-U(LPMM))*DYR
      VY2=0.25*(VR+VRP-V(MM)-V(LPMM))*DYR
      UY4=(UR-U(LMN1))*DYR
      VY4=(VR-V(LMN1))*DYR
      UX4=0.25*(U(LP)+URP-U(LM)-URM)*DXR
      VX4=0.25*(V(LP)+VRP-V(LM)-VRM)*DXR
      TY1=0.25*(TR+TRM-TMM-TLMMM)*DYR
      TY2=0.25*(TR+TRP-TMM-TLPMM)*DYR
      TX4=0.25*(TLP+TRP-TLM-TRM)*DXR
      TY4=(TR-T)*DYR
      TMP=TR
      IF (CAV.EQ.0.0) GO TO 240
      ROY1=0.25*(ROR+RORM-RO(MM)-RO(LMMM))*DYR
      ROY2=0.25*(ROR+RORP-RO(MM)-RO(LPMM))*DYR
      ROY4=(ROR-RO(LMN1))*DYR
      ROX4=0.25*(RO(LP)+RORP-RO(LM)-RORM)*DXR
      IF (NDIM.EQ.0) GO TO 240
      IF (CAV.EQ.0.0.OR.DIV.GE.0.0) GO TO 240
      ATERM1=0.5*((V(LMN1)+V(LM))/(YW(L)+YW(L-1)))
      ATERM2=0.5*((V(LMN1)+V(LP))/(YW(L)+YW(L+1)))
      ATERM3=0.5*(V(LMN1)+V(MM))/(YW(L)-0.5*DY/BE)
      ATERM4=0.5*(V(LMN1)+VR)/(YW(L)+0.5*DY/BE)
  240 MDUM=M-1
      CALL MAP (1,L,MDUM,AL3,BE3,DE,LD1,AL1,BE1,DE1)
      AL4=2.0*AL-AL3
      BE4=2.0*BE-BE3
      AL3=0.5*(AL3+AL)
      BE3=0.5*(BE3+BE)
      AL4=0.5*(AL4+AL)
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```
      BE4=0.5*(BE4+BE)
C
C     COMBINE TERMS
C
  250 UXY1=UX1+AL1*UY1
      UXY2=UX2+AL2*UY2
      UXY3=UX3+AL3*UY3
      UXY4=UX4+AL4*UY4
      UXY12=0.5*(UX1+UX2+AL3*UY3+AL4*UY4)
      VXY1=VX1+AL1*VY1
      VXY2=VX2+AL2*VY2
      VXY3=VX3+AL3*VY3
      VXY4=VX4+AL4*VY4
      VXY12=0.5*(VX1+VX2+AL3*VY3+AL4*VY4)
      BUY1=BE1*UY1
      BUY2=BE2*UY2
      BUY3=BE3*UY3
      BUY4=BE4*UY4
      BUY34=0.5*(BUY3+BUY4)
      BVY1=BE1*VY1
      BVY2=BE2*VY2
      BVY3=BE3*VY3
      BVY4=BE4*VY4
      BVY34=0.5*(BVY3+BVY4)
      TXY1=TX1+AL1*TY1
      TXY2=TX2+AL2*TY2
      TXY3=TX3+AL3*TY3
      TXY4=TX4+AL4*TY4
      BTY3=BE3*TY3
      BTY4=BE4*TY4
      BTY34=0.5*(BTY3+BTY4)
      IF (CAV.EQ.0.0) GO TO 260
      ROXY1=ROX1+AL1*ROY1
      ROXY2=ROX2+AL2*ROY2
      ROXY3=ROX3+AL3*ROY3
      ROXY4=ROX4+AL4*ROY4
      BROY3=BE3*ROY3
      BROY4=BE4*ROY4
      BROY34=0.5*(BROY3+BROY4)
C
C     CALCULATE THE ARTIFICAL VISCOSITY COEFFICIENTS
C
  260 IF (CAV.EQ.0.0) GO TO 300
      IF (DIV.GE.0.0) DIV=0.0
      IF (L.LT.LSS) DIV=0.0
      IF (SMACH.EQ.0.0) GO TO 270
      XV=U(LMN1)*U(LMN1)+V(LMN1)*V(LMN1)
      CALL EOS (1,P(LMN1),RO(LMN1),T,XA,D2,D3)
      XM=XV/XA
      IF (XM.LT.SMACH*SMACH) DIV=0.0
  270 IF (DIV.NE.0.0) GO TO 280
      DIV1=DIV2=DIV3=DIV4=0.0
      GO TO 290
  280 DIV1=UXY1+BVY1+ATERM1
      DIV2=UXY2+BVY2+ATERM2
      DIV3=UXY3+BVY3+ATERM3
      DIV4=UXY4+BVY4+ATERM4
      DIV=UXY12+BVY34+ATERM
  290 DRLA=XLA*RDUM/BE*RO(LMN1)
      RLA=DRLA*ABS(DIV)
      RLA1=DRLA*ABS(DIV1)
      RLA2=DRLA*ABS(DIV2)
      RLA3=DRLA*ABS(DIV3)
      RLA4=DRLA*ABS(DIV4)
      XMULA=XMU/XLA
      RMU=XMULA*RLA
      RMU1=XMULA*RLA1
      RMU2=XMULA*RLA2
      RMU3=XMULA*RLA3
      RMU4=XMULA*RLA4
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      CALL EOS (15,P(LMN1),RO(LMN1),T,DRK,D2,D3)
      RK=DRK*RMU
      RK1=DRK*RMU1
      RK2=DRK*RMU2
      RK3=DRK*RMU3
      RK4=DRK*RMU4
      XXRO=XRO/RO(LMN1)
      RRO=XXRO*RMU
      RRO1=XXRO*RMU1
      RRO2=XXRO*RMU2
      RRO3=XXRO*RMU3
      RRO4=XXRO*RMU4
      RLP2M=RLA+2.0*RMU
      RLPM=RLA+RMU
      RLP2M1=RLA1+2.0*RMU1
      RLP2M2=RLA2+2.0*RMU2
      RLP2M3=RLA3+2.0*RMU3
      RLP2M4=RLA4+2.0*RMU4
C
C     CALCULATE THE MOLECULAR VISCOSITY COEFFICIENTS
C
  300 IF (CHECK.EQ.0.0) GO TO 360
      IF (ECHECK.EQ.0.0) GO TO 310
      IF (ECHECK.LT.0.0) GO TO 320
      MU=CMU*T**EMU
      LA=CLA*T**ELA
      K=CK*T**EK
      GO TO 330
  310 MU=CMU
      LA=CLA
      K=CK
      GO TO 330
  320 SQT=T**EMU
      MU=CMU*SQT
      LA=CLA*SQT
      K=CK*SQT
C
C     CALCULATE THE TURBULENT VISCOSITY COEFFICIENTS
C
  330 IF (ITM.EQ.0) GO TO 350
      MUT=TML*TML*SQRT(BUY34*BUY34+VXY12*VXY12)*RO(LMN1)
      IF (M.NE.1.OR.NGCB.NE.0) GO TO 340
      MUT=TML*TML*TML*BE*BE*ABS(UY4-UY3)*DYR*RO(LMN1)
  340 TLMUR=MUT/MU
C
C     CALCULATE THE VISCOSITY AND HEAT CONDUCTION TERMS
C
  350 MU=MU*(1.0+TLMUR)
      LA=LA*(1.0+TLMUR)
      K=K*(1.0+TLMUR)
      LP2M=LA+2.0*MU
      LPM=LA+MU
  360 UVT=((LP2M+RLP2M2)*UXY2-(LP2M+RLP2M1)*UXY1+(LA+RLA2)*BVY2-(LA+RLA1
     1 )*BVY1)*DXR+AL*((LP2M+RLP2M4)*UXY4-(LP2M+RLP2M3)*UXY3+(LA+RLA4)
     2 *BVY4-(LA+RLA3)*BVY3)*DYR+BE*((MU+RMU4)*(VXY4+BUY4)-(MU+RMU3)*
     3 (VXY3+BUY3))*DYR
      VVT=((MU+RMU2)*(VXY2+BUY2)-(MU+RMU1)*(VXY1+BUY1))*DXR+AL*((MU+RMU4
     1 )*(VXY4+BUY4)-(MU+RMU3)*(VXY3+BUY3))*DYR+BE*((LA+RLA4)*UXY4-(LA
     2 +RLA3)*UXY3+(LP2M+RLP2M4)*BVY4-(LP2M+RLP2M3)*BVY3)*DYR
      PVT=(LP2M+RLP2M)*(UXY12*UXY12+BVY34*BVY34)+(MU+RMU)*(VXY12*VXY12
     1 +BUY34*BUY34)+2.0*(LA+RLA)*UXY12*BVY34+2.0*(MU+RMU)*BUY34*VXY12
      PCT=((K+RK2)*TXY2-(K+RK1)*TXY1)*DXR+AL*((K+RK4)*TXY4-(K+RK3)*TXY3)
     1 *DYR+BE*((K+RK4)*BTY4-(K+RK3)*BTY3)*DYR
      IF (CAV.EQ.0.0) GO TO 370
      RODIF=(RRO2*ROXY2-RRO1*ROXY1)*DXR+AL*(RRO4*ROXY4-RRO3*ROXY3)*DYR
     1 +BE*(RRO4*BROY4-RRO3*BROY3)*DYR
  370 UVTA=VVTA=PVTA=PCTA=RODIFA=0.0
      IF (NDIM.EQ.0) GO TO 390
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C
C     CALCULATE THE AXISYMMETRIC TERMS
C
      IF (M.EQ.1.AND.YCB(L).EQ.0.0) GO TO 380
      Y=FLOAT(M-1)*DY/BE+YCB(L)
      VYR=V(LMN1)/Y
      UVTA=((LPM+RLPM)*VXY12+(MU+RMU)*BUY34)/Y
      VVTA=(LP2M+RLP2M)*(BVY34-VYR)/Y
      PVTA=(LP2M+RLP2M)*VYR**2+2.0*(LA+RLA)*(BVY34+UXY12)*VYR
      PCTA=(K+RK)*BTY34/Y
      IF (CAV.EQ.0.0) GO TO 390
      RODIFA=RRO*BROY34/Y
      GO TO 390
  380 UVTA=(LPM+RLPM)*BE*(VXY4-VXY3)*DYR+(MU+RMU)*BE*(BUY4-BUY3)*DYR
      VVTA=(LP2M+RLP2M)*0.5*BE*(BVY4-BVY3)*DYR
      PVTA=(LP2M+RLP2M+2.0*(LA+RLA))*BVY34*BVY34+2.0*(LA+RLA)*BVY34
     1 *UXY12
      PCTA=(K+RK)*BE*(BTY4-BTY3)*DYR
      IF (CAV.EQ.0.0) GO TO 390
      RODIFA=RRO*BE*(BROY4-BROY3)*DYR
C
  390 QUT(L,M)=(UVT+UVTA-U(LMN1)*(RODIF+RODIFA))/RO(LMN1)
      QVT(L,M)=(VVT+VVTA-V(LMN1)*(RODIF+RODIFA))/RO(LMN1)
      CALL EOS (14,P(LMN1),RO(LMN1),T,GAM,D2,D3)
      QPT(L,M)=GAM*(PVT+PVTA+PCT+PCTA+(U(LMN1)*U(LMN1)+V(LMN1)*V(LMN1)-P
     1 (LMN1)/RO(LMN1))*(RODIF+RODIFA))
      QROT(L,M)=RODIF+RODIFA
C
C     PRINT THE VISCOUS TERMS
C
      IF (IAV.NE.0) GO TO 420
      IF (NC.NE.NPRINT.AND.N.NE.NMAX) GO TO 420
      NLINE=NLINE+1
      IF (NLINE.LT.55) GO TO 400
      WRITE (6,450)
      WRITE (6,440) N
      NLINE=1
  400 DQPT=QPT(L,M)/PC*DT
      DQUT=QUT(L,M)*DT
      DQVT=QVT(L,M)*DT
      DQROT=QROT(L,M)*G*DT
      IF (IUO.NE.2) GO TO 410
      DQUT=DQUT*0.3048
      DQVT=DQVT*0.3048
      DQPT=DQPT*6.8948
      DQROT=DQROT*16.02
  410 WRITE (6,430) L,M,DQUT,DQVT,DQPT,DQROT,TLMUR
  420 CONTINUE
      IF (NC.EQ.NPRINT) NC=0
      RETURN
C
C     FORMAT STATEMENTS
C
  430 FORMAT (1H ,5X,2I5,5F14.4)
  440 FORMAT (1H ,51HLOCAL ARTIFICAL VISCOSITY AND MOLECULAR VISCOSITY-H
     1 ,24HEAT CONDUCTION TERMS, N=,I4,//,10X,1HL,4X,1HM,10X,3HQUT,11X,3
     2 HQVT,11X,3HQPT,10X,4HQROT,10X,5HTLMUR,/)
  450 FORMAT (1H1)
      END
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*DECK,SMOOTH
      SUBROUTINE SMOOTH
C
C     ******************************************************************
C
C     THIS SUBROUTINE SMOOTHS THE FLOW VARIABLES IF REQUESTED
C
C     ******************************************************************
C
*CALL,MCC
C
C     THE SINGLE SUBSCRIPTS USED HERE ARE THOSE IN SUBROUTINE VISCOUS
C
      IF (SMP.LT.0.0.OR.SMP.GE.1.0) RETURN
      SMP4=.25*(1.0-SMP)
      DO 20 L=2,L1
      U(L,MMAX,N3)=SMP4*(U(L-1,MMAX,N3)+U(L+1,MMAX,N3)+2.0*U(L,M1,N3))
     1 +SMP*U(L,MMAX,N3)
      IF (NOSLIP.NE.0) U(L,MMAX,N3)=0.0
      V(L,MMAX,N3)=-U(L,MMAX,N3)*NXNY(L)+XWI(L)
      IF (JFLAG.EQ.1.AND.L.GE.LJET) GO TO 10
      P(L,MMAX,N3)=SMP4*(P(L-1,MMAX,N3)+P(L+1,MMAX,N3)+2.0*P(L,M1,N3))
     1 +SMP*P(L,MMAX,N3)
   10 RO(L,MMAX,N3)=SMP4*(RO(L-1,MMAX,N3)+RO(L+1,MMAX,N3)+2.0*RO(L,M1,N3
     1 ))+SMP*RO(L,MMAX,N3)
      IF (TW(1).GE.0.0) CALL EOS (3,P(L,MMAX,N3),RO(L,MMAX,N3),TW(L),AS
     1 ,D2,D3)
      U(L,1,N3)=SMP4*(U(L-1,1,N3)+U(L+1,1,N3)+2.0*U(L,2,N3))+SMP*U(L,1
     1 ,N3)
      IF (NOSLIP.NE.0.AND.NGCB.NE.0) U(L,1,N3)=0.0
      V(L,1,N3)=-U(L,1,N3)*NXNYCB(L)
      P(L,1,N3)=SMP4*(P(L-1,1,N3)+P(L+1,1,N3)+2.0*P(L,2,N3))+SMP*P(L,1
     1 ,N3)
      RO(L,1,N3)=SMP4*(RO(L-1,1,N3)+RO(L+1,1,N3)+2.0*RO(L,2,N3))+SMP*RO
     1 (L,1,N3)
      IF (TCB(1).GE.0.0.AND.NGCB.NE.0) CALL EOS (3,P(L,1,N3),RO(L,1,N3)
     1 ,TCB(L),AS,D2,D3)
      DO 20 M=2,M1
      LMD2=LD*(M-1)+LMD3
      LMMD2=LD*(M-2)+LMD3
      LMPD2=LD*M+LMD3
      LMN3=L+LMD2
      LP=L+1+LMD2
      LM=L-1+LMD2
      MP=L+LMPD2
      MM=L+LMMD2
      U(LMN3)=SMP4*(U(LM)+U(LP)+U(MM)+U(MP))+SMP*U(LMN3)
      V(LMN3)=SMP4*(V(LM)+V(LP)+V(MM)+V(MP))+SMP*V(LMN3)
      P(LMN3)=SMP4*(P(LM)+P(LP)+P(MM)+P(MP))+SMP*P(LMN3)
      RO(LMN3)=SMP4*(RO(LM)+RO(LP)+RO(MM)+RO(MP))+SMP*RO(LMN3)
   20 CONTINUE
      RETURN
      END
```

```
*DECK,MIXLEN
      SUBROUTINE MIXLEN (L)
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE TURBULENT MIXING LENGTH
C
C     ******************************************************************
C
*CALL,MCC
      DO 30 M=1,M1
      IF (U(L,1,N1).EQ.U(L,MMAX,N1)) GO TO 50
      CALL MAP (0,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)
      UD1=(U(L,M,N1)-U(L,MMAX,N1))/(U(L,1,N1)-U(L,MMAX,N1))
      UD2=(U(L,M+1,N1)-U(L,MMAX,N1))/(U(L,1,N1)-U(L,MMAX,N1))
      IF (UD1.GE.0.9.AND.UD2.LE.0.9) GO TO 10
      IF (UD1.GE.0.1.AND.UD2.LE.0.1) GO TO 20
      GO TO 30
   10 Y2=(FLOAT(M-1)+(0.9-UD1)/(UD2-UD1))*DY/BE
      IF (UD1.GE.0.1.AND.UD2.LE.0.1) GO TO 20
      GO TO 30
   20 Y1=(FLOAT(M-1)+(0.1-UD1)/(UD2-UD1))*DY/BE
      GO TO 40
   30 CONTINUE
      Y1=YW(L)
   40 IF (NDIM.EQ.0) TML=0.125*ABS(Y2-Y1)
      IF (NDIM.EQ.1) TML=0.11*ABS(Y2-Y1)
      RETURN
C
   50 TML=0.0
      RETURN
      END
```

```
*DECK,INTER
      SUBROUTINE INTER
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE INTERIOR MESH POINTS
C
C     ******************************************************************
C
*CALL,MCC
      ATERM=0.0
      IF (ICHAR.NE.1) GO TO 40
C
C     COMPUTE THE TENTATIVE SOLUTION AT T+DT - THE SINGLE SUBSCRIPTS
C     USED HERE ARE LMN1=L,M,N1, LMN3=L,M,N3, L1MN1=L-1,M,N1 AND
C     LM1N1=L,M-1,N1
C
      MDUM=1
      IF (NGCB.NE.0) MDUM=2
      DO 30 L=2,L1
      DO 30 M=MDUM,M1
      CALL MAP (1,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)
      LMD2=LD*(M-1)
      LMN1=L+LMD2+LMD1
      LMN3=L+LMD2+LMD3
      L1MN1=L-1+LMD2+LMD1
      LM1N1=L+LD*(M-2)+LMD1
      UB=U(LMN1)
      VB=V(LMN1)
      PB=P(LMN1)
      ROB=RO(LMN1)
      CALL EOS (1,PB,ROB,T,ASB,D2,D3)
      IF (M.NE.1) GO TO 10
C
      DUDX=(UB-U(L1MN1))*DXR
      DPDX=(PB-P(L1MN1))*DXR
      DRODX=(ROB-RO(L1MN1))*DXR
      DVDY=(4.0*V(L,2,N1)-V(L,3,N1))*0.5*DYR
      V(LMN3)=0.0
C
      URHS=-UB*DUDX-DPDX/ROB+QUT(L,M)
      RORHS=-UB*DRODX-ROB*DUDX-FLOAT(1+NDIM)*ROB*BE*DVDY+QROT(L,M)
      PRHS=-UB*DPDX+ASB*(RORHS+UB*DRODX)+QPT(L,M)
      GO TO 20
   10 IF (NDIM.EQ.1) ATERM=ROB*VB/(FLOAT(M-1)*DY/BE+YCB(L))
      UVB=UB*AL+VB*BE+DE
      DUDX=(UB-U(L1MN1))*DXR
      DVDX=(VB-V(L1MN1))*DXR
      DPDX=(PB-P(L1MN1))*DXR
      DRODX=(ROB-RO(L1MN1))*DXR
      DUDY=(UB-U(LM1N1))*DYR
      DVDY=(VB-V(LM1N1))*DYR
      DPDY=(PB-P(LM1N1))*DYR
      DRODY=(ROB-RO(LM1N1))*DYR
C
      URHS=-UB*DUDX-UVB*DUDY-(DPDX+AL*DPDY)/ROB+QUT(L,M)
      VRHS=-UB*DVDX-UVB*DVDY-BE*DPDY/ROB+QVT(L,M)
      RORHS=-UB*DRODX-UVB*DRODY-ROB*(DUDX+AL*DUDY+BE*DVDY)-ATERM+QROT(L
     1 ,M)
      PRHS=-UB*DPDX-UVB*DPDY+ASB*(RORHS+UB*DRODX+UVB*DRODY)+QPT(L,M)
      V(LMN3)=V(LMN1)+VRHS*DT
   20 U(LMN3)=U(LMN1)+URHS*DT
      P(LMN3)=P(LMN1)+PRHS*DT
      RO(LMN3)=RO(LMN1)+RORHS*DT
      IF (P(LMN3).LE.0.0) P(LMN3)=PLOW*PC
      IF (RO(LMN3).LE.0.0) RO(LMN3)=ROLOW/G
   30 CONTINUE
      RETURN
```

```
C
C     COMPUTE THE FINAL SOLUTION AT T+DT - THE SINGLE SUBSCRIPTS USED
C     HERE ARE LMN1=L,M,N1, LMN3=L,M,N3, L1MN3=L+1,M,N3 AND LM1N3=
C     L,M+1,N3
C
   40 MDUM=1
      IF (NGCB.NE.0) MDUM=2
      DO 70 L=2,L1
      DO 70 M=MDUM,M1
      CALL MAP (1,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)
      LMD2=LD*(M-1)
      LMN1=L+LMD2+LMD1
      LMN3=L+LMD2+LMD3
      L1MN3=L+1+LMD2+LMD3
      LM1N3=L+LD*M+LMD3
      UB=U(LMN3)
      VB=V(LMN3)
      PB=P(LMN3)
      ROB=RO(LMN3)
      CALL EOS (1,PB,ROB,T,ASB,D2,D3)
      IF (M.NE.1) GO TO 50
C
      DUDX=(U(L1MN3)-UB)*DXR
      DPDX=(P(L1MN3)-PB)*DXR
      DRODX=(RO(L1MN3)-ROB)*DXR
      DVDY=(4.0*V(L,2,N3)-V(L,3,N3))*0.5*DYR
      V(LMN3)=0.0
C
      URHS=-UB*DUDX-DPDX/ROB+QUT(L,M)
      RORHS=-UB*DRODX-ROB*DUDX-FLOAT(1+NDIM)*ROB*BE*DVDY+QROT(L,M)
      PRHS=-UB*DPDX+ASB*(RORHS+UB*DRODX)+QPT(L,M)
      GO TO 60
   50 IF (NDIM.EQ.1) ATERM=ROB*VB/(FLOAT(M-1)*DY/BE+YCB(L))
      UVB=UB*AL+VB*BE+DE
      DUDX=(U(L1MN3)-UB)*DXR
      DVDX=(V(L1MN3)-VB)*DXR
      DPDX=(P(L1MN3)-PB)*DXR
      DRODX=(RO(L1MN3)-ROB)*DXR
      DUDY=(U(LM1N3)-UB)*DYR
      DVDY=(V(LM1N3)-VB)*DYR
      DPDY=(P(LM1N3)-PB)*DYR
      DRODY=(RO(LM1N3)-ROB)*DYR
C
      URHS=-UB*DUDX-UVB*DUDY-(DPDX+AL*DPDY)/ROB+QUT(L,M)
      VRHS=-UB*DVDX-UVB*DVDY-BE*DPDY/ROB+QVT(L,M)
      RORHS=-UB*DRODX-UVB*DRODY-ROB*(DUDX+AL*DUDY+BE*DVDY)-ATERM+QROT(L
     1 ,M)
      PRHS=-UB*DPDX-UVB*DPDY+ASB*(RORHS+UB*DRODX+UVB*DRODY)+QPT(L,M)
      V(LMN3)=(V(LMN1)+V(LMN3)+VRHS*DT)*0.5
   60 U(LMN3)=(U(LMN1)+U(LMN3)+URHS*DT)*0.5
      P(LMN3)=(P(LMN1)+P(LMN3)+PRHS*DT)*0.5
      RO(LMN3)=(RO(LMN1)+RO(LMN3)+RORHS*DT)*0.5
      IF (P(LMN3).LE.0.0) P(LMN3)=PLOW*PC
      IF (RO(LMN3).LE.0.0) RO(LMN3)=ROLOW/G
   70 CONTINUE
      RETURN
      END
```

```
*DECK,WALL
      SUBROUTINE WALL
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE BOUNDARY MESH POINTS AT THE
C     WALL, FREE-JET BOUNDARY, AND CENTERBODY
C
C     ******************************************************************
C
*CALL,MCC
C
C     THE SINGLE SUBSCRIPTS USED HERE ARE LMN1=L,MDUM,N1, LMN3=
C     L,MDUM,N3, LM1N1=L,MDUM1,N1, L1MN1=L-1,MDUM,N1, L1MN3=L+1,MDUM,N3
C     AND L1M1N1=L-1,MDUM1,N1
C
      IF (N.EQ.1.AND.JFLAG.NE.0) DELY=0.0001*YW(LJET-1)
      XWID=QUT2=QVT2=QPT2=QROT2=ATERM2=ATERM3=0.0
      IF (IB.EQ.1) GO TO 10
      Y3=0.0
      MDUM=1
      MDUM1=2
      MDUM2=3
      SIGN=-1.0
      GO TO 20
   10 Y3=1.0
      MDUM=MMAX
      MDUM1=M1
      MDUM2=M2
      SIGN=1.0
   20 LMDM=LD*(MDUM-1)
      LMDM1=LD*(MDUM1-1)
      DYS=SIGN*DYR
      DO 510 L=2,L1
      LMN1=L+LMDM+LMD1
      LMN3=L+LMDM+LMD3
      LM1N1=L+LMDM1+LMD1
      L1MN1=L-1+LMDM+LMD1
      L1MN3=L+1+LMDM+LMD3
      L1M1N1=L-1+LMDM1+LMD1
      CALL MAP (1,L,MDUM,AL,BE,DE,LD1,AL1,BE1,DE1)
      IF (NOSLIP.EQ.0) GO TO 90
C
C     CALCULATE THE DEPENDENT VARIABLES FOR NO-SLIP WALLS
C
      U(LMN3)=0.0
      V(LMN3)=0.0
      DUDY=0.5*(-4.0*U(LM1N1)+U(L,MDUM2,N1))*DYS
      DVDY=0.5*(-4.0*V(LM1N1)+V(L,MDUM2,N1))*DYS
      IF (ICHAR.NE.1) GO TO 30
      RO(LMN3)=RO(LMN1)-RO(LMN1)*DT*(AL*DUDY+BE*DVDY)
      GO TO 40
   30 DUDY3=0.5*(-4.0*U(L,MDUM1,N3)+U(L,MDUM2,N3))*DYS
      DVDY3=0.5*(-4.0*V(L,MDUM1,N3)+V(L,MDUM2,N3))*DYS
      RO(LMN3)=RO(LMN1)-0.25*(RO(LMN1)+RO(LMN3))*DT*(AL*(DUDY+DUDY3)+BE*
     1 (DVDY+DVDY3))
   40 IF (RO(LMN3).LE.0.0) RO(LMN3)=ROLOW/G
      IF (IB.EQ.2) GO TO 50
      IF (TW(1).LT.0.0) GO TO 60
      CALL EOS (3,P(LMN3),RO(LMN3),TW(L),AS,D2,D3)
      GO TO 80
   50 IF (TCB(1).LT.0.0) GO TO 60
      CALL EOS (3,P(LMN3),RO(LMN3),TCB(L),AS,D2,D3)
      GO TO 80
   60 IF (ICHAR.NE.1) GO TO 70
      CALL EOS (1,P(LMN1),RO(LMN1),TEMP,AS,D2,D3)
      P(LMN3)=P(LMN1)+AS*(RO(LMN3)-RO(LMN1))+QPT(L,MDUM)*DT
      GO TO 80
```

```
   70 PB=0.5*(P(LMN1)+P(LMN3))
      ROB=0.5*(RO(LMN1)+RO(LMN3))
      CALL EOS (1,PB,ROB,TEMP,AS,D2,D3)
      P(LMN3)=P(LMN1)+AS*(RO(LMN3)-RO(LMN1))+DPT(L,MDUM)*DT
   80 IF (P(LMN3).LE.0.0) P(LMN3)=PLOW*PC
      GO TO 510
C
C     CALCULATE THE DEPENDENT VARIABLES FOR FREE-SLIP WALLS
C
   90 IF (JFLAG.EQ.0) GO TO 120
      IF (IB.EQ.2) GO TO 120
      XWID=XWI(L)
      IF (ICHAR.EQ.1) GO TO 100
C
C     USE THE DUMMY ARRAYS TO MANIPULATE THE ONE-SIDED SOLUTIONS
C     FOR THE FREE-JET OR SHARP EXPANSION CORNER CASES
C
      IF (L.NE.LJET-2) GO TO 100
      U(L1MN3)=UD(3)
      V(L1MN3)=VD(3)
      P(L1MN3)=PD(3)
      RO(L1MN3)=ROD(3)
      GO TO 120
  100 IF (L.NE.LJET-1) GO TO 110
      IF (ICHAR.EQ.1) UOLD=U(LMN1)
      U(LMN1)=UD(1)
      V(LMN1)=VD(1)
      P(LMN1)=PD(1)
      RO(LMN1)=ROD(1)
      GO TO 120
  110 IF (L.NE.LJET) GO TO 120
      U(L1MN1)=UD(2)
      V(L1MN1)=VD(2)
      P(L1MN1)=PD(2)
      RO(L1MN1)=ROD(2)
C
  120 U1=U(LMN1)
      V1=V(LMN1)
      P1=P(LMN1)
      RO1=RO(LMN1)
      U2=U1
      V2=V1
      CALL EOS (1,P1,RO1,T,AS,D2,D3)
      A1=SQRT(AS)
      A2=A1
      IF (ICHAR.NE.1) GO TO 130
      U3=U1
      V3=V1
      P3=P1
      RO3=RO1
      A3=A1
      GO TO 140
  130 U3=U(LMN3)
      V3=V(LMN3)
      P3=P(LMN3)
      RO3=RO(LMN3)
      CALL EOS (1,P3,RO3,T,AS,D2,D3)
      A3=SQRT(AS)
C
C     CALCULATE THE PROPERTY INTERPOLATING POLYNOMIAL COEFFICIENTS
C
  140 BU=(U1-U(LM1N1))*DYS
      BV=(V1-V(LM1N1))*DYS
      BP=(P1-P(LM1N1))*DYS
      BRO=(RO1-RO(LM1N1))*DYS
      CU=U1-BU*Y3
      CV=V1-BV*Y3
      CP=P1-BP*Y3
      CRO=RO1-BRO*Y3
      IF (CHECK.EQ.0.0.AND.CAV.EQ.0.0) GO TO 150
```

```
      BQUT=(QUT(L,MDUM)-QUT(L,MDUM1))*DYS
      BQVT=(QVT(L,MDUM)-QVT(L,MDUM1))*DYS
      BQPT=(QPT(L,MDUM)-QPT(L,MDUM1))*DYS
      BQROT=(QROT(L,MDUM)-QROT(L,MDUM1))*DYS
      CQUT=QUT(L,MDUM)-BQUT*Y3
      CQVT=QVT(L,MDUM)-BQVT*Y3
      CQPT=QPT(L,MDUM)-BQPT*Y3
      CQROT=QROT(L,MDUM)-BQROT*Y3
C
C     CALCULATE THE CROSS DERIVATIVE INTERPOLATING POLYNOMIAL
C     COEFFICIENTS
C
  150 DU=(U1-U(L1MN1))*DXR
      DV=(V1-V(L1MN1))*DXR
      DP=(P1-P(L1MN1))*DXR
      DRO=(RO1-RO(L1MN1))*DXR
      DU1=(U(LM1N1)-U(L1M1N1))*DXR
      DV1=(V(LM1N1)-V(L1M1N1))*DXR
      DP1=(P(LM1N1)-P(L1M1N1))*DXR
      DRO1=(RO(LM1N1)-RO(L1M1N1))*DXR
      BDU=(DU-DU1)*DYS
      BDV=(DV-DV1)*DYS
      BDP=(DP-DP1)*DYS
      BDRO=(DRO-DRO1)*DYS
      CDU=DU-BDU*Y3
      CDV=DV-BDV*Y3
      CDP=DP-BDP*Y3
      CDRO=DRO-BDRO*Y3
C
C     CALCULATE Y2
C
      ALS=SQRT(AL*AL+BE*BE)
      UV3=U3*AL+V3*BE+DE
      DO 170 ILL=1,3
      UV2=U2*AL+V2*BE+DE
      Y2=Y3-(UV2+SIGN*ALS*A2+UV3+SIGN*ALS*A3)*DT*0.5
C
C     INTERPOLATE FOR THE PROPERTIES
C
      U2=BU*Y2+CU
      V2=BV*Y2+CV
      P2=BP*Y2+CP
      RO2=BRO*Y2+CRO
      CALL EOS (1,P2,RO2,T,AD,D2,D3)
      IF (AD.GT.0.0) GO TO 160
      WRITE (6,520) N,L,MDUM
      IERR=1
      RETURN
  160 A2=SQRT(AD)
  170 CONTINUE
      IF (CHECK.EQ.0.0.AND.CAV.EQ.0.0) GO TO 180
      QUT2=BQUT*Y2+CQUT
      QVT2=BQVT*Y2+CQVT
      QPT2=BQPT*Y2+CQPT
      QROT2=BQROT*Y2+CQROT
C
C     INTERPOLATE FOR THE CROSS DERIVATIVES
C
  180 DU1=DU
      DV1=DV
      DP1=DP
      DRO1=DRO
      DU2=BDU*Y2+CDU
      DV2=BDV*Y2+CDV
      DP2=BDP*Y2+CDP
      DRO2=BDRO*Y2+CDRO
C
C     CALCULATE THE PSI TERMS
C
```

```
      IF (NDIM.EQ.0) GO TO 210
      IF (IB.EQ.2) GO TO 190
      ATERM2=RO2*V2/(YCB(L)+Y2/BE)
      GO TO 210
  190 IF (YCB(L).EQ.0.0) GO TO 200
      ATERM2=RO2*V2/(YCB(L)+Y2/BE)
      GO TO 210
  200 ATERM2=RO2*V(L,2,N1)*DYR*BE
  210 PSI21=-U1*DU1-DP1/RO1
      PSI31=-U1*DV1
      PSI41=-U1*DP1+A1*A1*U1*DRO1
      PSI12=-U2*DRO2-RO2*DU2-ATERM2
      PSI22=-U2*DU2-DP2/RO2
      PSI32=-U2*DV2
      PSI42=-U2*DP2+A2*A2*U2*DRO2
      IF (ICHAR.EQ.1) GO TO 240
C
C     CALCULATE THE CROSS DERIVATIVES AT THE SOLUTION POINT
C
      IF (JFLAG.EQ.0) GO TO 220
      IF (IB.NE.1) GO TO 220
      IF (L.EQ.2) GO TO 220
      IF (L.NE.LJET-1) GO TO 220
      GO TO 230
  220 DU3=(U(L1MN3)-U3)*DXR
      DV3=(V(L1MN3)-V3)*DXR
      DP3=(P(L1MN3)-P3)*DXR
      DRO3=(RO(L1MN3)-RO3)*DXR
      GO TO 240
  230 DU3=(U3-U(L-1,MDUM,N3))*DXR
      DV3=(V3-V(L-1,MDUM,N3))*DXR
      DP3=(P3-P(L-1,MDUM,N3))*DXR
      DRO3=(RO3-RO(L-1,MDUM,N3))*DXR
C
C     ENTER THE FREE-JET BOUNDARY ITERATION LOOP
C
  240 YWI(L)=YW(L)
      DO 390 NJ=1,10
      IF (ICHAR.EQ.1) GO TO 340
      IF (JFLAG.LE.0) GO TO 300
      IF (IB.NE.1) GO TO 300
      IF (L.LT.LJET) GO TO 300
      IF (NJ.EQ.1) GO TO 290
      IF (NJ.GT.2) GO TO 270
  250 YWOLD=YW(L)
      POLD=P(LMN3)
      IF (P(LMN3).LT.PE(MMAX)) GO TO 260
      YW(L)=YW(L)+DELY
      GO TO 280
  260 YW(L)=YW(L)-DELY
      GO TO 280
  270 IF (P(LMN3).EQ.POLD) GO TO 250
      DYDP=(YW(L)-YWOLD)/(P(LMN3)-POLD)
      YWNEW=YW(L)+DYDP*(PE(MMAX)-P(LMN3))
      YWOLD=YW(L)
      POLD=P(LMN3)
      YW(L)=YWNEW
  280 IF (YW(L).LT.(1.0-DYW)*YWOLD) YW(L)=(1.0-DYW)*YWOLD
      IF (YW(L).GT.(1.0+DYW)*YWOLD) YW(L)=(1.0+DYW)*YWOLD
  290 NXNY(L)=-(YW(L)-YW(L-1))*DXR
      XWI(L)=(YW(L)-YWI(L))/DT
      XWID=XWI(L)
      CALL MAP (1,L,MMAX,AL,BE,DE,LD1,AL1,BE1,DE1)
      ALS=SQRT(AL*AL+BE*BE)
C
C     CALCULATE THE PSI TERMS AT THE SOLUTION POINT
C
  300 IF (NDIM.EQ.0) GO TO 330
      IF (IB.EQ.2) GO TO 310
      ATERM3=RO3*V3/(YCB(L)+1.0/BE)
```

```
      GO TO 330
  310 IF (YCB(L).EQ.0.0) GO TO 320
      ATERM3=RO3*V3/YCB(L)
      GO TO 330
  320 ATERM3=RO3*V(L,2,N3)*DYR*BE
  330 PSI13=-U3*DRO3-RO3*DU3-ATERM3
      PSI23=-U3*DU3-DP3/RO3
      PSI33=-U3*DV3
      PSI43=-U3*DP3+A3*A3*U3*DRO3
  340 ABR=NXNY(L)
      IF (IB.EQ.2) ABR=NXNYCB(L)
      ALB=AL/ALS
      BEB=BE/ALS
      A1B=(A1+A3)*0.5
      A2B=(A2+A3)*0.5
      RO2B=(RO2+RO3)*0.5
      IF (ICHAR.EQ.1) GO TO 350
      PSI21B=(PSI21+PSI23)*0.5+QUT(L,MDUM)
      PSI31B=(PSI31+PSI33)*0.5+QVT(L,MDUM)
      PSI41B=(PSI41+PSI43)*0.5+QPT(L,MDUM)
      PSI12B=(PSI12+PSI13+QROT(L,MDUM)+QROT2)*0.5
      PSI22B=(PSI22+PSI23+QUT(L,MDUM)+QUT2)*0.5
      PSI32B=(PSI32+PSI33+QVT(L,MDUM)+QVT2)*0.5
      PSI42B=(PSI42+PSI43+QPT(L,MDUM)+QPT2)*0.5
      GO TO 360
  350 PSI21B=PSI21+QUT(L,MDUM)
      PSI31B=PSI31+QVT(L,MDUM)
      PSI41B=PSI41+QPT(L,MDUM)
      PSI12B=PSI12+QROT2
      PSI22B=PSI22+QUT2
      PSI32B=PSI32+QVT2
      PSI42B=PSI42+QPT2
C
C     SOLVE THE COMPATIBILITY EQUATIONS FOR FREE-SLIP WALLS
C
  360 U(LMN3)=(U1-ABR*(V1-XWID)+(PSI21B-ABR*PSI31B)*DT)/(1.0+ABR*ABR)
      V(LMN3)=-U(LMN3)*ABR+XWID
      P(LMN3)=P2-SIGN*RO2B*A2B*(ALB*(U(LMN3)-U2)+BEB*(V(LMN3)-V2))+
     1 (PSI42B+A2B*A2B*PSI12B+SIGN*RO2B*A2B*(ALB*PSI22B+BEB*PSI32B))*DT
      IF (P(LMN3).LE.0.0) P(LMN3)=PLOW*PC
      RO(LMN3)=RO1+(P(LMN3)-P1-PSI41B*DT)/(A1B*A1B)
      IF (RO(LMN3).LE.0.0) RO(LMN3)=ROLOW/G
      IF (IB.NE.1) GO TO 370
      IF (TW(1).LT.0.0) GO TO 380
      IF (JFLAG.EQ.1.AND.L.GE.LJET) GO TO 380
      CALL EOS (3,P(LMN3),RO(LMN3),TW(L),AS,D2,D3)
      GO TO 380
  370 IF (TCB(1).LT.0.0) GO TO 380
      CALL EOS (3,P(LMN3),RO(LMN3),TCB(L),AS,D2,D3)
C
  380 IF (JFLAG.EQ.0) GO TO 510
      IF (IB.NE.1) GO TO 510
      IF (L.LT.LJET-1) GO TO 510
      IF (L.EQ.LJET-1) GO TO 400
      IF (ICHAR.EQ.1) GO TO 510
      IF (JFLAG.EQ.-1.AND.L.NE.LJET) GO TO 510
      IF (JFLAG.EQ.-1.AND.L.EQ.LJET) GO TO 500
      DELP=ABS((P(LMN3)-PE(MMAX))/PE(MMAX))
      IF (DELP.LE.0.001.AND.L.NE.LJET) GO TO 510
      IF (DELP.LE.0.001.AND.L.EQ.LJET) GO TO 500
  390 CONTINUE
      IF (L.EQ.LJET) GO TO 500
      GO TO 510
C
C     SOLVE FOR THE DOWNSTREAM SIDE OF THE WALL EXIT POINT FOR
C     EITHER SHARP EXPANSION CORNER CASE, UNDER-EXPANDED FREE-JET
C     CASE OR OVER-EXPANDED FREE-JET CASE
C
  400 UD(3)=U(LMN3)
```

```
      VD(3)=V(LMN3)
      PD(3)=P(LMN3)
      ROD(3)=RO(LMN3)
      PD(4)=PE(MMAX)
      CALL EOS (5,PD(3),ROD(3),TD,AS,D2,D3)
      XM1=SQRT((UD(3)*UD(3)+VD(3)*VD(3))/AS)
      CALL EOS (9,PD(3),ROD(3),TD,PTD,TTD,XM1)
C
C     SHARP EXPANSION CORNER CASE
C
      IF (JFLAG.NE.-1) GO TO 440
      CALL EOS (13,PD(3),ROD(3),TD,B,D2,D3)
      C1=XM1*XM1-1.0
      PMA1=B*ATAN(SQRT(C1/(B*B)))-ATAN(SQRT(C1))
      PMA=ATAN(-NXNY(LJET))-ATAN(-NXNY(LJET-1))
      PMAD=PMA+PMA1
      XM2=2.0*XM1
      DO 420 I=1,10
      CI=XM2*XM2-1.0
      PMAI=B*ATAN(SQRT(CI/(B*B)))-ATAN(SQRT(CI))
      IF (ABS((PMAI-PMAD)/PMAD).LE.0.0001) GO TO 430
      IF (I.NE.1) GO TO 410
      XMO=XM2
      XM2=0.9*XM2
      PMAO=PMAI
      GO TO 420
  410 DMDA=(XM2-XMO)/(PMAI-PMAO)
      XMO=XM2
      XM2=XM2+DMDA*(PMAD-PMAI)
      PMAO=PMAI
  420 CONTINUE
  430 CALL EOS (8,PD(4),ROD(4),TD,PTD,TTD,XM2)
      CALL EOS (4,PD(4),ROD(4),TD,AS,D2,D3)
      GO TO 470
C
C     UNDER-EXPANDED FREE-JET CASE
C
  440 IF (PE(MMAX).GT.PD(3).AND.XM1.GE.1.0) GO TO 450
      CALL EOS (11,PE(MMAX),ROD(4),TD,PD(3),ROD(3),D3)
      GO TO 460
C
C     OVER-EXPANDED FREE-JET CASE
C
  450 CALL EOS (12,PE(MMAX),ROD(4),TD,PD(3),ROD(3),D3)
  460 CALL EOS (2,PE(MMAX),ROD(4),TE,AS,D2,D3)
      CALL EOS (10,PE(MMAX),ROD(4),TE,PTD,TTD,XM2)
  470 CALL EOS (1,PD(4),ROD(4),T,AS,D2,D3)
      VMAG=XM2*SQRT(AS)
      UD(4)=VMAG/SQRT(1.0+NXNY(LJET)*NXNY(LJET))
      VD(4)=-UD(4)*NXNY(LJET)
      IF (JFLAG.EQ.-1) GO TO 510
      IF (XM1.GE.1.0) GO TO 510
C
C     AVERAGE THE 1-SIDED MACH NOS FOR THE INTERIOR POINT CALCULATIONS
C     IF THE UPSTREAM FLOW IS SUBSONIC - FREE-JET CASE
C
      XMB=(XM1+XM2)/2.0
      IF (XMB.GE.1.0) GO TO 480
      DPL=1.0
      DPR=1.0
      GO TO 490
  480 DPL=XM2-1.0
      DPR=1.0-XM1
      XMB=1.0
  490 DPLR=DPR+DPL
      CALL EOS (8,P(LMN3),RO(LMN3),TEMP,PTD,TTD,XMB)
      CALL EOS (6,P(LMN3),RO(LMN3),TEMP,AS,D2,D3)
      QA=XMB*SQRT(AS)
      DNXNY=(DPR*NXNY(LJET)+DPL*NXNY(L))/DPLR
      U(LMN3)=QA/SQRT(1.0+DNXNY*DNXNY
```

```
      V(LMN3)=-U(LMN3)*DNXNY
      GO TO 51Ø
  5ØØ UD(1)=UD(3)
      VD(1)=VD(3)
      PD(1)=PD(3)
      ROD(1)=ROD(3)
      UD(2)=UD(4)
      VD(2)=VD(4)
      PD(2)=PD(4)
      ROD(2)=ROD(4)
  51Ø CONTINUE
      IF (JFLAG.EQ.Ø) RETURN
      IF (IB.EQ.2) RETURN
      IF (ICHAR.EQ.1) RETURN
      U(LJET-1,MMAX,N1)=UOLD
      IF (JFLAG.EQ.-1) RETURN
      YWI(LMAX)=YW(LMAX)
      YW(LMAX)=2.Ø*YW(L1)-YW(L2)
      NXNY(LMAX)=-(YW(LMAX)-YW(L1))*DXR
      XWI(LMAX)=(YW(LMAX)-YWI(LMAX))/DT
      RETURN
C
C     FORMAT STATEMENTS
C
  52Ø FORMAT (1HØ,61H***** A NEGATIVE SQUARE ROOT OCCURED IN SUBROUTINE
     1WALL AT N=,I4,4H, L=,I2,8H, AND M=,I2,6H *****)
      END
```

```
*DECK,INLET
      SUBROUTINE INLET
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE BOUNDARY MESH POINTS AT THE
C     INLET FOR SUBSONIC FLOW
C
C     ******************************************************************
C
*CALL,MCC
C
C     THE SINGLE SUBSCRIPTS USED HERE ARE LMN1=1,M,N1, LMN3=1,M,N3,
C     L1MN1=2,M,N1, L1M1N1=2,M-1,N1, LM1N1=1,M-1,N1 AND LM1N3=
C     1,M+1,N3
C
      X3=XI
      ATERM2=ATERM3=0.0
      DO 240 M=1,MMAX
      LMN1=1+LD*(M-1)+LMD1
      LMN3=1+LD*(M-1)+LMD3
      L1MN1=2+LD*(M-1)+LMD1
      L1M1N1=2+LD*(M-2)+LMD1
      LM1N1=1+LD*(M-2)+LMD1
      LM1N3=1+LD*M+LMD3
      IF (ISUPER.EQ.0) GO TO 20
      IF (M.EQ.MMAX) GO TO 10
      IF (M.NE.1) GO TO 20
      IF (NGCB.EQ.0) GO TO 20
      IF (TCB(1).LT.0.0) GO TO 20
      CALL EOS (3,P(LMN3),RO(LMN3),TCB(1),AS,D2,D3)
      GO TO 240
   10 IF (TW(1).LT.0.0) GO TO 20
      CALL EOS (3,P(LMN3),RO(LMN3),TW(1),AS,D2,D3)
      GO TO 240
   20 CALL MAP (2,1,M,AL,BE,DE,2,AL1,BE1,DE1)
      U2=U(LMN1)
      CALL EOS (1,P(LMN1),RO(LMN1),T,AS,D2,D3)
      A2=SQRT(AS)
      IF (ICHAR.NE.1) GO TO 40
      IF (ISUPER.EQ.-1) GO TO 30
      U(LMN3)=U2
      V(LMN3)=V(LMN1)
   30 A3=A2
C
C     CALCULATE THE PROPERTY INTERPOLATING POLYNOMIAL COEFFICIENTS
C
   40 BU=(U(L1MN1)-U(LMN1))*DXR
      BV=(V(L1MN1)-V(LMN1))*DXR
      BP=(P(L1MN1)-P(LMN1))*DXR
      BRO=(RO(L1MN1)-RO(LMN1))*DXR
      BYCB=(YCB(2)-YCB(1))*DXR
      BAL=(AL1-AL)*DXR
      BBE=(BE1-BE)*DXR
      CU=U(1,M,N1)-BU*X3
      CV=V(1,M,N1)-BV*X3
      CP=P(1,M,N1)-BP*X3
      CRO=RO(1,M,N1)-BRO*X3
      CYCB=YCB(1)-BYCB*X3
      CAL=AL-BAL*X3
      CBE=BE-BBE*X3
C
C     CALCULATE THE CROSS DERIVATIVE INTERPOLATING POLYNOMIAL
C     COEFFICIENTS
C
      IF (M.EQ.1) GO TO 50
      DU=(U(L1MN1)-U(L1M1N1))*DYR
      DV=(V(L1MN1)-V(L1M1N1))*DYR
      DP=(P(L1MN1)-P(L1M1N1))*DYR
      DRO=(RO(L1MN1)-RO(L1M1N1))*DYR
```

```
      DU1=(U(LMN1)-U(LM1N1))*DYR
      DV1=(V(LMN1)-V(LM1N1))*DYR
      DP1=(P(LMN1)-P(LM1N1))*DYR
      DRO1=(RO(LMN1)-RO(LM1N1))*DYR
      GO TO 70
   50 IF (NGCB.NE.0) GO TO 60
      DU=0.0
      DV=(4.0*V(2,2,N1)-V(2,3,N1))*0.5*DYR
      DP=0.0
      DRO=0.0
      DU1=0.0
      DV1=(4.0*V(1,2,N1)-V(1,3,N1))*0.5*DYR
      DP1=0.0
      DRO1=0.0
      GO TO 70
   60 DU=(U(2,2,N1)-U(2,1,N1))*DYR
      DV=(V(2,2,N1)-V(2,1,N1))*DYR
      DP=(P(2,2,N1)-P(2,1,N1))*DYR
      DRO=(RO(2,2,N1)-RO(2,1,N1))*DYR
      DU1=(U(1,2,N1)-U(1,1,N1))*DYR
      DV1=(V(1,2,N1)-V(1,1,N1))*DYR
      DP1=(P(1,2,N1)-P(1,1,N1))*DYR
      DRO1=(RO(1,2,N1)-RO(1,1,N1))*DYR
   70 BDU=(DU-DU1)*DXR
      BDV=(DV-DV1)*DXR
      BDP=(DP-DP1)*DXR
      BDRO=(DRO-DRO1)*DXR
      CDU=DU1-BDU*X3
      CDV=DV1-BDV*X3
      CDP=DP1-BDP*X3
      CDRO=DRO1-BDRO*X3
C
C     CALCULATE X2
C
      IF (ICHAR.EQ.1) GO TO 80
      CALL EOS (1,P(LMN3),RO(LMN3),T,AS,D2,D3)
      A3=SQRT(AS)
   80 DO 90 IL=1,2
      X2=X3-(U(1,M,N3)-A3+U2-A2)*0.5*DT
C
C     INTERPOLATE FOR THE PROPERTIES
C
      U2=BU*X2+CU
      P2=BP*X2+CP
      RO2=BRO*X2+CRO
      CALL EOS (1,P2,RO2,T,AS,D2,D3)
      A2=SQRT(AS)
   90 CONTINUE
      V2=BV*X2+CV
      YCB2=BYCB*X2+CYCB
      AL2=BAL*X2+CAL
      BE2=BBE*X2+CBE
      UV2=U2*AL2+V2*BE2
C
C     INTERPOLATE FOR THE CROSS DERIVATIVES
C
      DU2=BDU*X2+CDU
      DV2=BDV*X2+CDV
      DP2=BDP*X2+CDP
      DRO2=BDRO*X2+CDRO
C
C     CALCULATE THE PSI TERMS
C
      IF (NDIM.EQ.0) GO TO 110
      IF (M.EQ.1.AND.YCB(1).EQ.0.0) GO TO 100
      ATERM2=RO2*V2/(DY*FLOAT(M-1)/BE2+YCB2)
      GO TO 110
  100 ATERM2=RO2*BE2*DV2
  110 PSI12=-UV2*DRO2-RO2*AL2*DU2-RO2*BE2*DV2-ATERM2
      PSI22=-UV2*DU2-AL2*DP2/RO2
```

```
      PSI42=-UV2*DP2+A2*A2*UV2*DRO2
      IF (ICHAR.EQ.1) GO TO 170
C
C     CALCULATE THE CROSS DERIVATIVES AT THE SOLUTION POINT
C
      IF (M.EQ.1.AND.NGCB.EQ.0) GO TO 120
      IF (M.EQ.MMAX) GO TO 130
      DU3=(U(LM1N3)-U(LMN3))*DYR
      DV3=(V(LM1N3)-V(LMN3))*DYR
      DP3=(P(LM1N3)-P(LMN3))*DYR
      DRO3=(RO(LM1N3)-RO(LMN3))*DYR
      GO TO 140
  120 DU3=0.0
      DV3=(4.0*V(1,2,N3)-V(1,3,N3))*0.5*DYR
      DP3=0.0
      DRO3=0.0
      GO TO 140
  130 DU3=(U(1,MMAX,N3)-U(1,M1,N3))*DYR
      DV3=(V(1,MMAX,N3)-V(1,M1,N3))*DYR
      DP3=(P(1,MMAX,N3)-P(1,M1,N3))*DYR
      DRO3=(RO(1,MMAX,N3)-RO(1,M1,N3))*DYR
C
C     CALCULATE THE PSI TERMS AT THE SOLUTION POINT
C
  140 IF (NDIM.EQ.0) GO TO 160
      IF (M.EQ.1.AND.YCB(1).EQ.0.0) GO TO 150
      ATERM3=RO(LMN3)*V(LMN3)/(DY*FLOAT(M-1)/BE+YCB(1))
      GO TO 160
  150 ATERM3=RO(LMN3)*BE*DV3
  160 UV3=U(LMN3)*AL+V(LMN3)*BE
      PSI13=-UV3*DRO3-RO(LMN3)*AL*DU3-RO(LMN3)*BE*DV3-ATERM3
      PSI23=-UV3*DU3-AL*DP3/RO(LMN3)
      PSI43=-UV3*DP3+A3*A3*UV3*DRO3
      GO TO 180
  170 PSI23=PSI22
      PSI43=PSI42
      PSI13=PSI12
  180 PSI1B=0.5*(PSI12+PSI13)
      PSI2B=0.5*(PSI22+PSI23)
      PSI4B=0.5*(PSI42+PSI43)
C
C     SOLVE THE COMPATIBILITY EQUATION FOR P
C
      IF (ISUPER.EQ.0) GO TO 190
      ROAB=0.5*(RO2*A2+RO(LMN3)*A3)
      AB=0.5*(A2+A3)
      P(LMN3)=P2+ROAB*(U(LMN3)-U2)+(PSI4B-ROAB*PSI2B+AB*AB*PSI1B)*DT
      GO TO 240
C
C     SOLVE THE COMPATIBILITY EQUATIONS FOR U, V, P, AND RO
C
  190 MN3=SQRT(U(LMN3)*U(LMN3)+V(LMN3)*V(LMN3))/A3
      CALL EOS (2,P2,RO2,T2,AS,D2,D3)
      TTHETA=TAN(THETA(M))
      UCORR=1.0
      IF (NOSLIP.EQ.0) GO TO 200
      IF (M.EQ.MMAX) UCORR=0.0
      IF (M.EQ.1.AND.NGCB.NE.0) UCORR=0.0
C
  200 DO 220 ITER=1,20
      CALL EOS (8,P(LMN3),RO(LMN3),T3,PT(M),TT(M),MN3)
      IF (M.EQ.MMAX.AND.TW(1).GT.0.0) T3=TW(1)
      IF (M.EQ.1.AND.TCB(1).GT.0.0) T3=TCB(1)
      PB=(P2+P(LMN3))*0.5
      TB=(T2+T3)*0.5
      CALL EOS (6,PB,ROB,TB,AS,D2,D3)
      U(LMN3)=U2+DT*PSI2B+(P(LMN3)-P2-(PSI4B+AS*PSI1B)*DT)/(ROB*SQRT(AS)
     1 )
      U(LMN3)=U(LMN3)*UCORR
      V(LMN3)=U(LMN3)*TTHETA
```

```
      OMN3=MN3
      CALL EOS (7,PB,ROB,T3,AS,D2,D3)
      MN3=SQRT((U(LMN3)*U(LMN3)+V(LMN3)*V(LMN3))/AS)
      IF (OMN3.NE.0.0) GO TO 210
      IF (ABS(MN3-OMN3).LE.0.0001) GO TO 230
      GO TO 220
  210 IF (ABS((MN3-OMN3)/OMN3).LE.0.001) GO TO 230
  220 CONTINUE
C
      WRITE (6,250) M,N
  230 CALL EOS (4,P(LMN3),RO(LMN3),T3,AS,D2,D3)
  240 CONTINUE
      RETURN
C
C     FORMAT STATEMENTS
C
  250 FORMAT (1H0,55H***** THE SOLUTION FOR THE ENTRANCE BOUNDARY POINT
     1( 1,,I2,1H,,I4,43H) FAILED TO CONVERGE IN 20 ITERATIONS *****)
      END
```

```
*DECK,EXITT
      SUBROUTINE EXITT
C
C     ******************************************************************
C
C     THIS SUBROUTINE CALCULATES THE BOUNDARY MESH POINTS AT THE EXIT
C
C     ******************************************************************
C
*CALL,MCC
      X3=XE
      ATERM2=ATERM3=0.0
      DO 180 M=1,MMAX
      IF (IEXTRA.EQ.1) GO TO 10
      CALL EOS (1,P(LMAX,M,N1),RO(LMAX,M,N1),T,AS,D2,D3)
      A1=SQRT(AS)
      IF (IEXTRA.EQ.2) GO TO 20
      Q=SQRT(U(LMAX,M,N1)*U(LMAX,M,N1)+V(LMAX,M,N1)*V(LMAX,M,N1))
      IF (Q/A1.LT.1.0) GO TO 20
   10 U(LMAX,M,N3)=U(L1,M,N3)+FLOAT(IEX)*(U(L1,M,N3)-U(L2,M,N3))
      V(LMAX,M,N3)=V(L1,M,N3)+FLOAT(IEX)*(V(L1,M,N3)-V(L2,M,N3))
      P(LMAX,M,N3)=P(L1,M,N3)+FLOAT(IEX)*(P(L1,M,N3)-P(L2,M,N3))
      RO(LMAX,M,N3)=RO(L1,M,N3)+FLOAT(IEX)*(RO(L1,M,N3)-RO(L2,M,N3))
      GO TO 180
   20 CALL MAP (2,LMAX,M,AL,BE,DE,L1,AL1,BE1,DE1)
      U1=U(LMAX,M,N1)
      U2=U1
      A2=A1
      IF (ICHAR.NE.1) GO TO 30
      U(LMAX,M,N3)=U1
      RO(LMAX,M,N3)=RO(LMAX,M,N1)
      A3=A1
C
C     CALCULATE THE PROPERTY INTERPOLATING POLYNOMIAL COEFFICIENTS
C
   30 BU=(U(LMAX,M,N1)-U(L1,M,N1))*DXR
      BV=(V(LMAX,M,N1)-V(L1,M,N1))*DXR
      BP=(P(LMAX,M,N1)-P(L1,M,N1))*DXR
      BRO=(RO(LMAX,M,N1)-RO(L1,M,N1))*DXR
      BYCB=(YCB(LMAX)-YCB(L1))*DXR
      BAL=(AL-AL1)*DXR
      BBE=(BE-BE1)*DXR
      BDE=(DE-DE1)*DXR
      CU=U(LMAX,M,N1)-BU*X3
      CV=V(LMAX,M,N1)-BV*X3
      CP=P(LMAX,M,N1)-BP*X3
      CRO=RO(LMAX,M,N1)-BRO*X3
      CYCB=YCB(LMAX)-BYCB*X3
      CAL=AL-BAL*X3
      CBE=BE-BBE*X3
      CDE=DE-BDE*X3
C
C     CALCULATE THE CROSS DERIVATIVE INTERPOLATING POLYNOMIAL
C     COEFFICIENTS
C
      IF (M.EQ.1) GO TO 40
      DU=(U(LMAX,M,N1)-U(LMAX,M-1,N1))*DYR
      DV=(V(LMAX,M,N1)-V(LMAX,M-1,N1))*DYR
      DP=(P(LMAX,M,N1)-P(LMAX,M-1,N1))*DYR
      DRO=(RO(LMAX,M,N1)-RO(LMAX,M-1,N1))*DYR
      DU1=(U(L1,M,N1)-U(L1,M-1,N1))*DYR
      DV1=(V(L1,M,N1)-V(L1,M-1,N1))*DYR
      DP1=(P(L1,M,N1)-P(L1,M-1,N1))*DYR
      DRO1=(RO(L1,M,N1)-RO(L1,M-1,N1))*DYR
      GO TO 60
   40 IF (NGCB.NE.0) GO TO 50
      DU=0.0
      DV=(4.0*V(LMAX,2,N1)-V(LMAX,3,N1))*0.5*DYR
      DP=0.0
      DRO=0.0
```

```
      DU1=0.0
      DV1=(4.0*V(L1,2,N1)-V(L1,3,N1))*0.5*DYR
      DP1=0.0
      DRO1=0.0
      GO TO 60
   50 DU=(U(LMAX,2,N1)-U(LMAX,1,N1))*DYR
      DV=(V(LMAX,2,N1)-V(LMAX,1,N1))*DYR
      DP=(P(LMAX,2,N1)-P(LMAX,1,N1))*DYR
      DRO=(RO(LMAX,2,N1)-RO(LMAX,1,N1))*DYR
      DU1=(U(L1,2,N1)-U(L1,1,N1))*DYR
      DV1=(V(L1,2,N1)-V(L1,1,N1))*DYR
      DP1=(P(L1,2,N1)-P(L1,1,N1))*DYR
      DRO1=(RO(L1,2,N1)-RO(L1,1,N1))*DYR
   60 BDU=(DU-DU1)*DXR
      BDV=(DV-DV1)*DXR
      BDP=(DP-DP1)*DXR
      BDRO=(DRO-DRO1)*DXR
      CDU=DU-BDU*X3
      CDV=DV-BDV*X3
      CDP=DP-BDP*X3
      CDRO=DRO-BDRO*X3
C
C     CALCULATE X1 AND X2
C
      IF (ICHAR.EQ.1) GO TO 70
      CALL EOS (1,P(LMAX,M,N3),RO(LMAX,M,N3),T,AS,D2,D3)
      A3=SQRT(AS)
   70 DO 80 IL=1,2
      X1=X3-(U(LMAX,M,N3)+U1)*0.5*DT
      X2=X3-(U(LMAX,M,N3)+A3+U2+A2)*0.5*DT
C
C     INTERPOLATE FOR THE PROPERTIES
C
      U1=BU*X1+CU
      U2=BU*X2+CU
      P2=BP*X2+CP
      RO2=BRO*X2+CRO
      CALL EOS (1,P2,RO2,T2,AS,D2,D3)
      A2=SQRT(AS)
   80 CONTINUE
      V1=BV*X1+CV
      P1=BP*X1+CP
      RO1=BRO*X1+CRO
      AL1=BAL*X1+CAL
      BE1=BBE*X1+CBE
      DE1=BDE*X1+CDE
      UV1=U1*AL1+V1*BE1+DE1
      CALL EOS (1,P1,RO1,T1,AS,D2,D3)
      A1=SQRT(AS)
      V2=BV*X2+CV
      YCB2=BYCB*X2+CYCB
      AL2=BAL*X2+CAL
      BE2=BBE*X2+CBE
      DE2=BDE*X2+CDE
      UV2=U2*AL2+V2*BE2+DE2
C
C     INTERPOLATE FOR THE CROSS DERIVATIVES
C
      DV1=BDV*X1+CDV
      DP1=BDP*X1+CDP
      DRO1=BDRO*X1+CDRO
      DU2=BDU*X2+CDU
      DV2=BDV*X2+CDV
      DP2=BDP*X2+CDP
      DRO2=BDRO*X2+CDRO
C
C     CALCULATE THE PSI TERMS
C
      IF (NDIM.EQ.0) GO TO 100
      IF (M.EQ.1.AND.YCB(LMAX).EQ.0.0) GO TO 90
```

```
      ATERM2=RO2*V2/(DY*FLOAT(M-1)/BE2+YCB2)
      GO TO 100
   90 ATERM2=RO2*BE2*DV2
  100 PSI31=-UV1*DV1-BE1*DP1/RO1
      PSI41=-UV1*DP1+A1*A1*UV1*DRO1
      PSI12=-UV2*DRO2-RO2*AL2*DU2-RO2*BE2*DV2-ATERM2
      PSI22=-UV2*DU2-AL2*DP2/RO2
      PSI42=-UV2*DP2+A2*A2*UV2*DRO2
      IF (ICHAR.EQ.1) GO TO 160
C
C     CALCULATE THE CROSS DERIVATIVES AT THE SOLUTION POINT
C
      IF (M.EQ.1.AND.NGCB.EQ.0) GO TO 110
      IF (M.EQ.MMAX) GO TO 120
      DU3=(U(LMAX,M+1,N3)-U(LMAX,M,N3))*DYR
      DV3=(V(LMAX,M+1,N3)-V(LMAX,M,N3))*DYR
      DP3=(P(LMAX,M+1,N3)-P(LMAX,M,N3))*DYR
      DRO3=(RO(LMAX,M+1,N3)-RO(LMAX,M,N3))*DYR
      GO TO 130
  110 DU3=0.0
      DV3=(4.0*V(LMAX,2,N3)-V(LMAX,3,N3))*0.5*DYR
      DP3=0.0
      DRO3=0.0
      GO TO 130
  120 DU3=(U(LMAX,MMAX,N3)-U(LMAX,M1,N3))*DYR
      DV3=(V(LMAX,MMAX,N3)-V(LMAX,M1,N3))*DYR
      DP3=(P(LMAX,MMAX,N3)-P(LMAX,M1,N3))*DYR
      DRO3=(RO(LMAX,MMAX,N3)-RO(LMAX,M1,N3))*DYR
C
C     CALCULATE THE PSI TERMS AT THE SOLUTION POINT
C
  130 IF (NDIM.EQ.0) GO TO 150
      IF (M.EQ.1.AND.YCB(LMAX).EQ.0.0) GO TO 140
      ATERM3=RO(LMAX,M,N3)*V(LMAX,M,N3)/(DY*FLOAT(M-1)/BE+YCB(LMAX))
      GO TO 150
  140 ATERM3=RO(LMAX,1,N3)*BE*DV3
  150 UV3=U(LMAX,M,N3)*AL+V(LMAX,M,N3)*BE+DE
      PSI13=-UV3*DRO3-RO(LMAX,M,N3)*(AL*DU3+BE*DV3)-ATERM3
      PSI23=-UV3*DU3-AL*DP3/RO(LMAX,M,N3)
      PSI33=-UV3*DV3-BE*DP3/RO(LMAX,M,N3)
      PSI43=-UV3*DP3+A3*A3*UV3*DRO3
      PSI31B=(PSI31+PSI33)*0.5+QVT(LMAX,M)
      PSI41B=(PSI41+PSI43)*0.5+QPT(LMAX,M)
      PSI12B=(PSI12+PSI13)*0.5+QROT(LMAX,M)
      PSI22B=(PSI22+PSI23)*0.5+QUT(LMAX,M)
      PSI42B=(PSI42+PSI43)*0.5+QPT(LMAX,M)
      GO TO 170
  160 PSI31B=PSI31+QVT(LMAX,M)
      PSI41B=PSI41+QPT(LMAX,M)
      PSI12B=PSI12+QROT(LMAX,M)
      PSI22B=PSI22+QUT(LMAX,M)
      PSI42B=PSI42+QPT(LMAX,M)
C
C     SOLVE THE COMPATIBILITY EQUATIONS FOR U,V,P, AND RO
C
  170 P(LMAX,M,N3)=PE(M)
      AB=0.5*(A2+A3)
      ROB=0.5*(RO2+RO(LMAX,M,N3))
      RO(LMAX,M,N3)=RO1+2.0*(P(LMAX,M,N3)-P1-DT*PSI41B)/(A3*A3+A1*A1)
      IF (RO(LMAX,M,N3).LE.0.0) RO(LMAX,M,N3)=ROLOW/G
      U(LMAX,M,N3)=U2+((PSI42B+ROB*AB*PSI22B+AB*AB*PSI12B)*DT-(P(LMAX,M
     1 ,N3)-P2))/(ROB*AB)
      V(LMAX,M,N3)=V1+DT*PSI31B
C
C     CHECK FOR INFLOW AND IF SO SET INFLOW BOUNDARY CONDITIONS
C
      IF (U(LMAX,M,N1).GE.0.0) GO TO 180
      V(LMAX,M,N3)=0.0
      RO(LMAX,M,N3)=0.5*(RO(LMAX,1,N1)+RO(LMAX,MMAX,N1))
  180 CONTINUE
```

```
C
C     SET BOUNDARY CONDITIONS FOR THE CORNER POINTS
C
      IF (NOSLIP.NE.Ø) U(LMAX,MMAX,N3)=Ø.Ø
      IF (NOSLIP.NE.Ø.AND.NGCB.NE.Ø) U(LMAX,1,N3)=Ø.Ø
      V(LMAX,MMAX,N3)=-U(LMAX,MMAX,N3)*NXNY(LMAX)+XWI(LMAX)
      V(LMAX,1,N3)=-U(LMAX,1,N3)*NXNYCB(LMAX)
      IF (NOSLIP.NE.Ø) RO(LMAX,MMAX,N3)=RO(L1,MMAX,N3)
      IF (NOSLIP.NE.Ø.AND.NGCB.NE.Ø) RO(LMAX,1,N3)=RO(L1,1,N3)
      IF (TW(1).LT.Ø.Ø.AND.TCB(1).LT.Ø.Ø) RETURN
      IF (TW(1).GT.Ø.Ø.AND.P(LMAX,MMAX,N3).EQ.PE(MMAX)) CALL EOS (4,P
     1 (LMAX,MMAX,N3),RO(LMAX,MMAX,N3),TW(LMAX),AS,D2,D3)
      IF (TCB(1).GT.Ø.Ø.AND.P(LMAX,1,N3).EQ.PE(1)) CALL EOS (4,P(LMAX,1
     1 ,N3),RO(LMAX,1,N3),TCB(LMAX),AS,D2,D3)
      IF (TW(1).GT.Ø.Ø.AND.P(LMAX,MMAX,N3).NE.PE(MMAX)) CALL EOS (3,P
     1 (LMAX,MMAX,N3),RO(LMAX,MMAX,N3),TW(LMAX),AS,D2,D3)
      IF (TCB(1).GT.Ø.Ø.AND.P(LMAX,1,N3).NE.PE(1)) CALL EOS (3,P(LMAX,1
     1 ,N3),RO(LMAX,1,N3),TCB(LMAX),AS,D2,D3)
      RETURN
      END
```

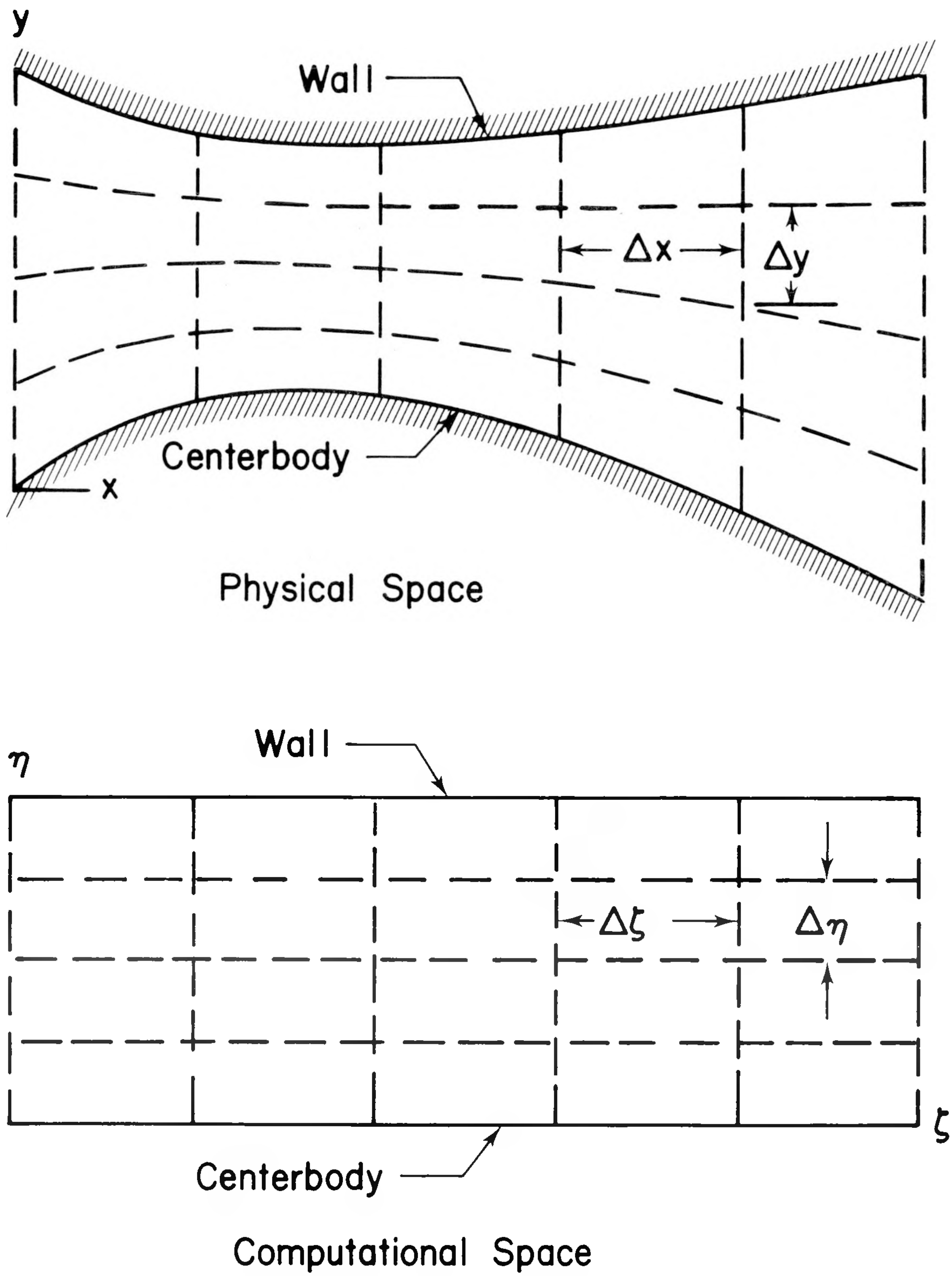

Fig. 1. Physical and computational spaces.

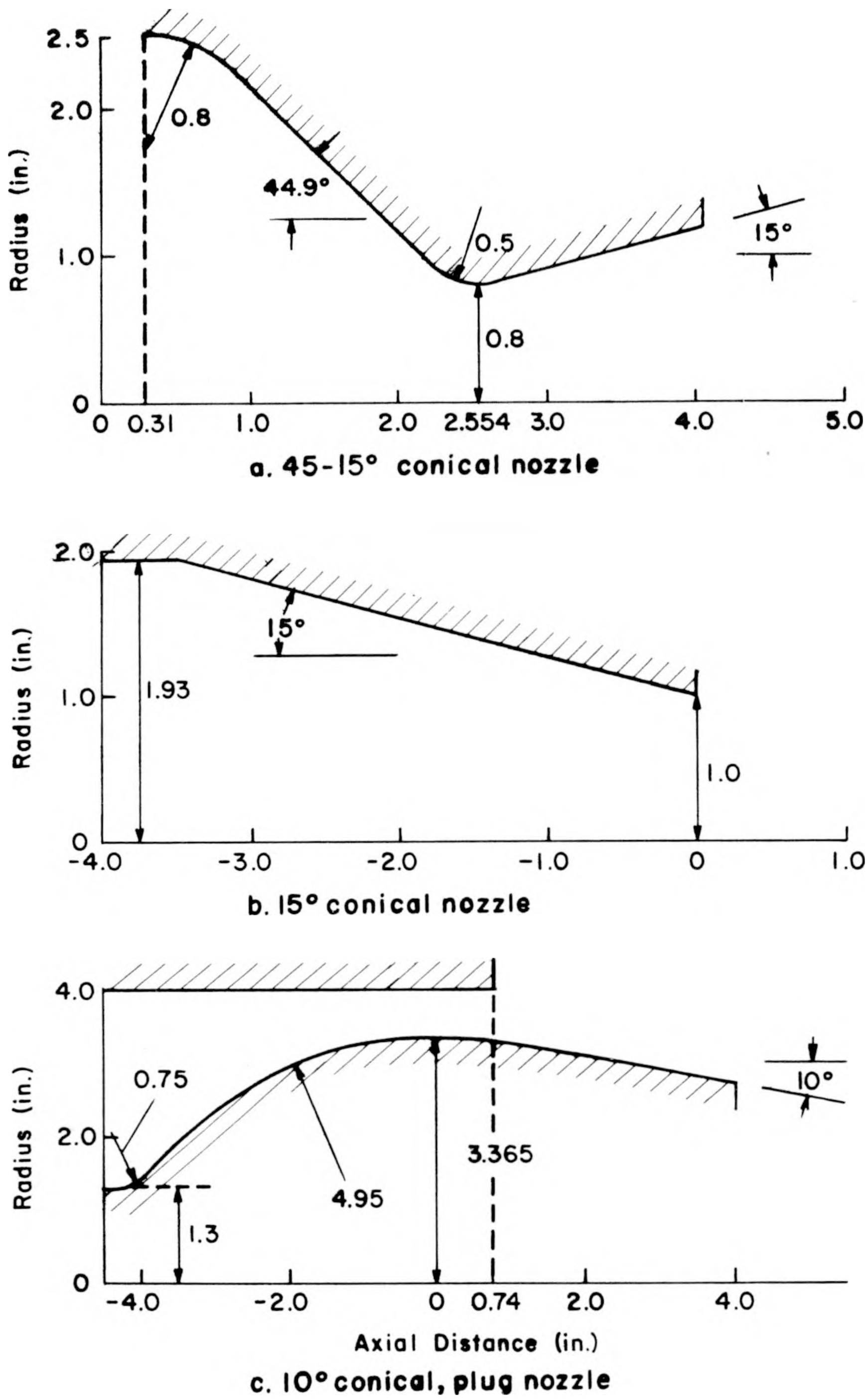

Fig. 2. Nozzle geometries for the inviscid flows.

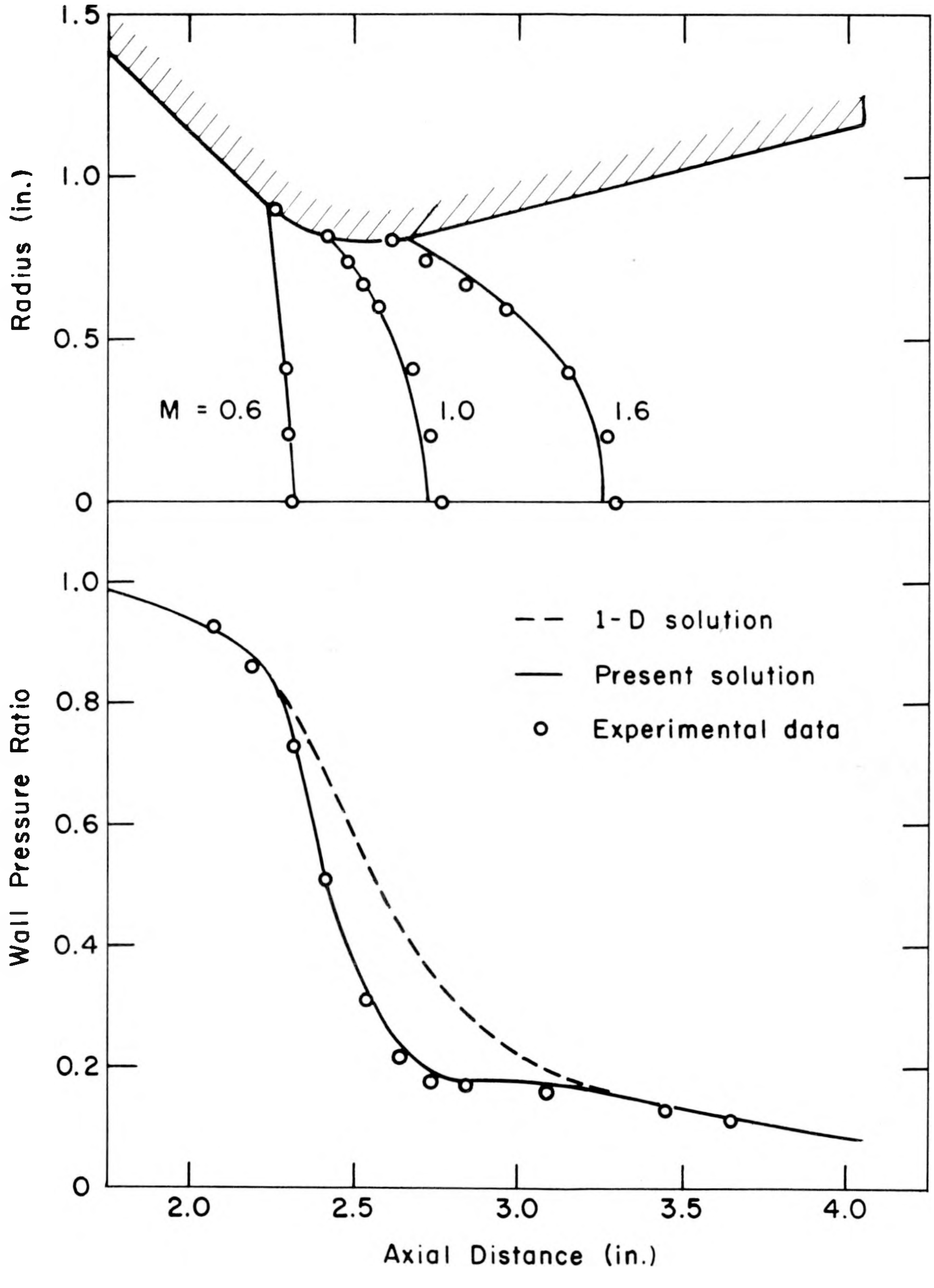

Fig. 3. Mach number contours (top) and wall pressure ratio for the 45-15° conical nozzle (inviscid flow).

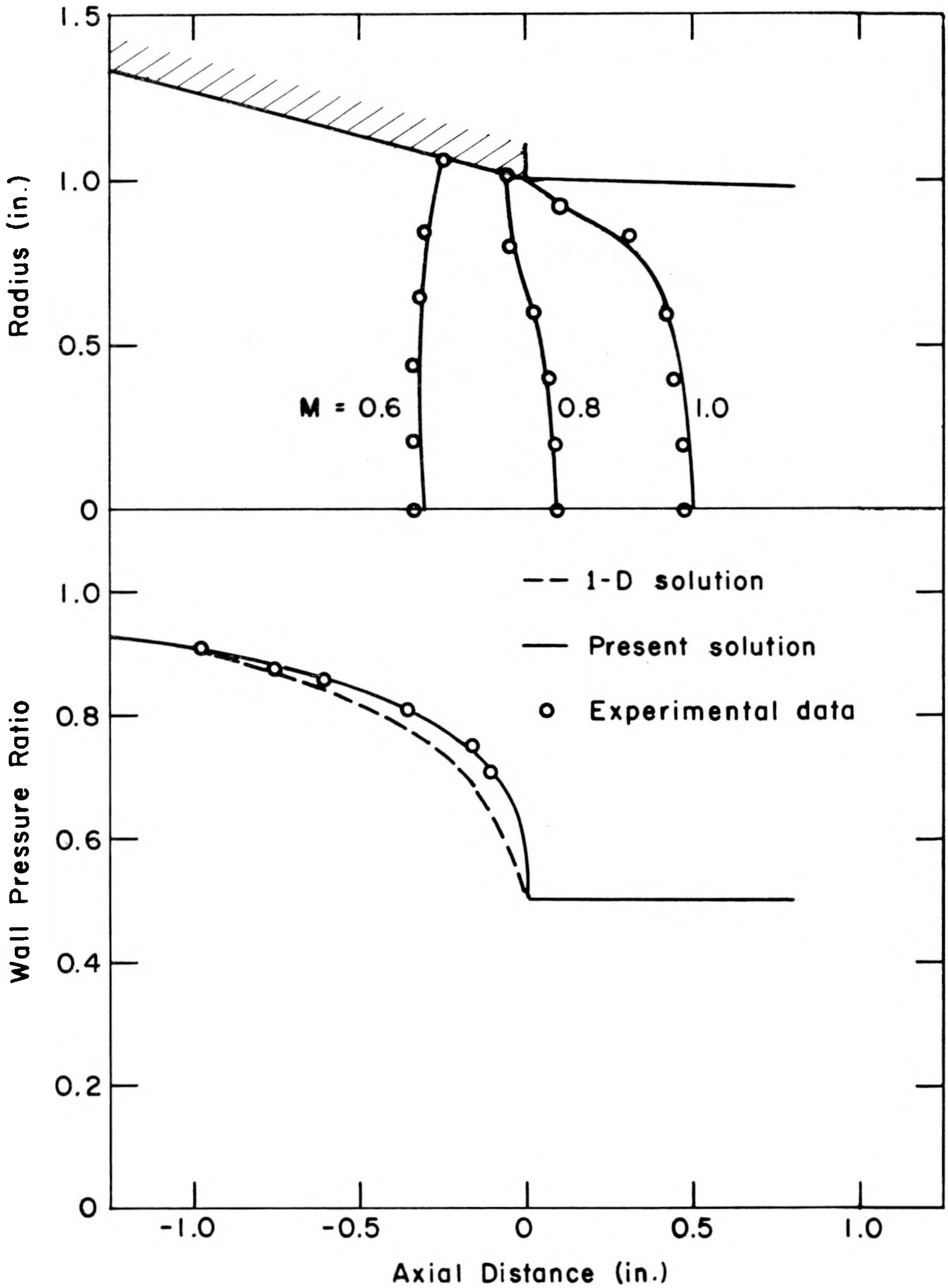

Fig. 4. Mach number contours (top) and wall pressure ratio for the 15° conical nozzle (inviscid flow).

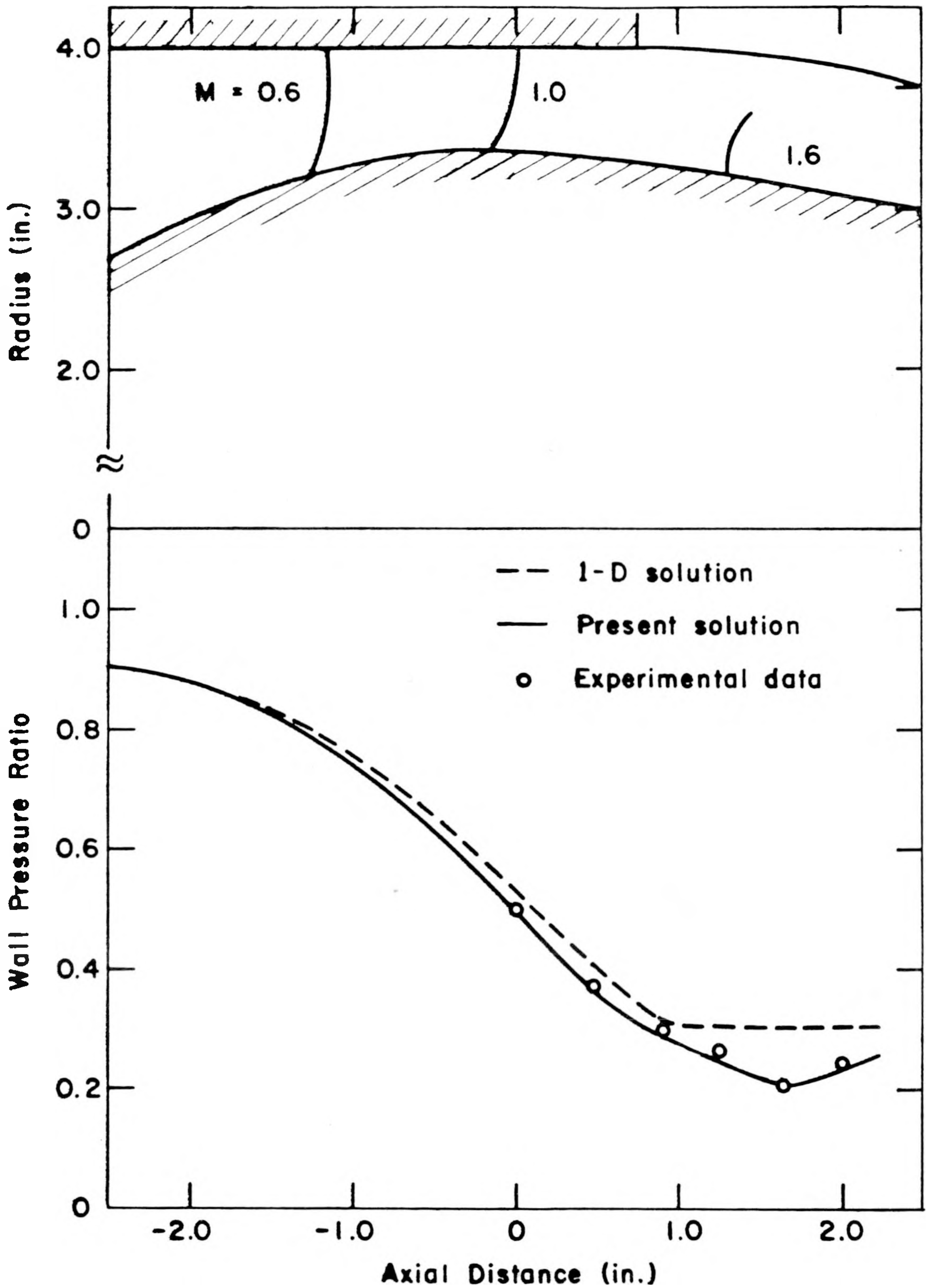

Fig. 5. Mach number contours (top) and plug pressure ratio for the 10° conical, plug nozzle (inviscid flow).

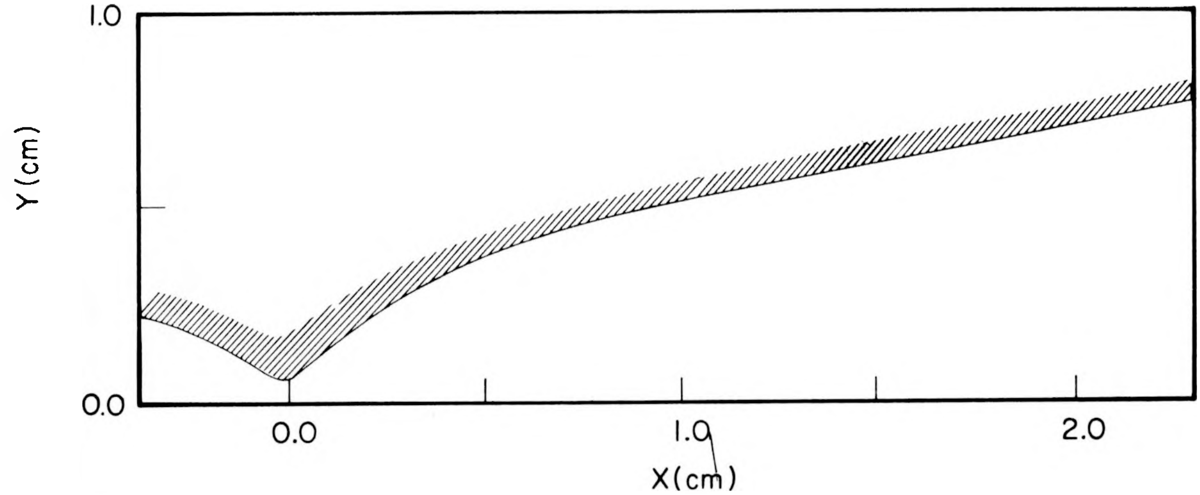

Fig. 6. Nozzle geometry for viscous flow.

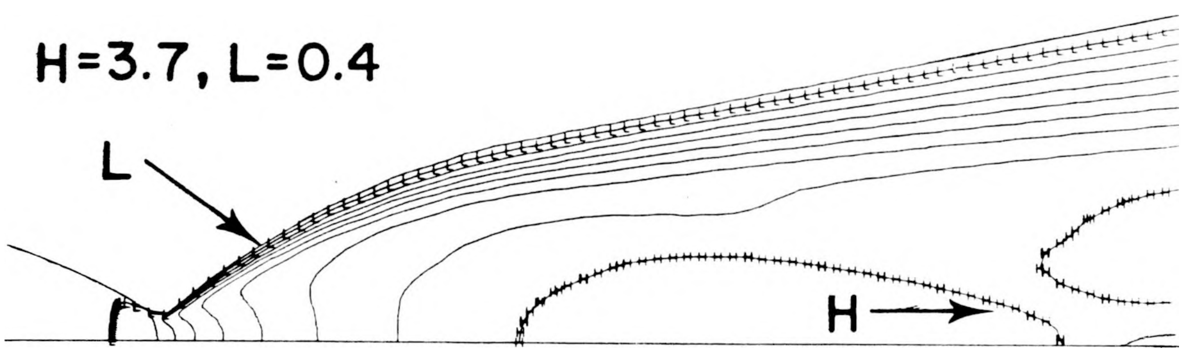

Fig. 7. Mach number contours for $Re^{*} = 1200$.

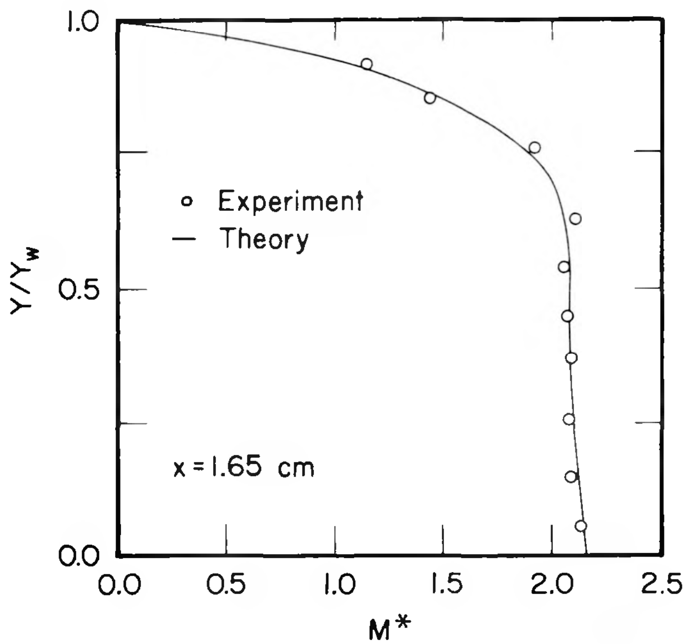

Fig. 8. Velocity profile at x = 1.65 cm for Re^* = 1200.

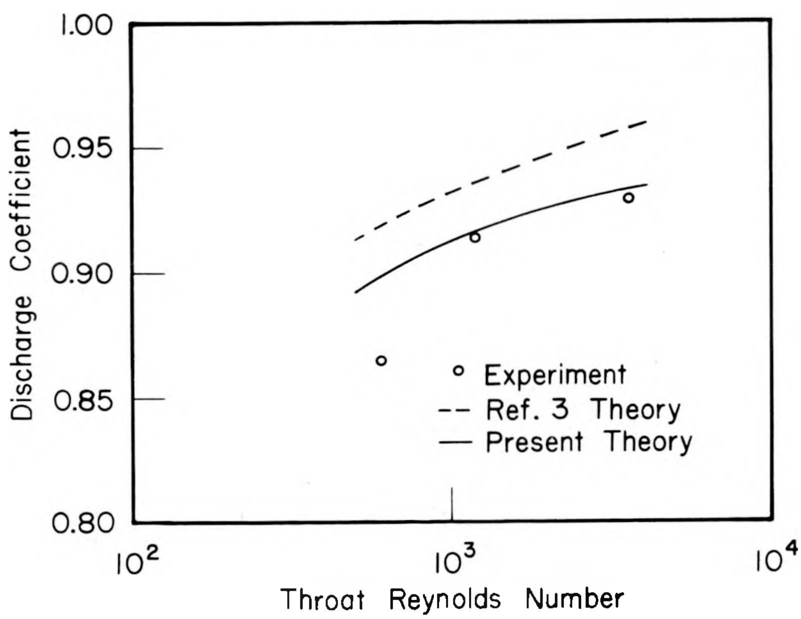

Fig. 9. Discharge coefficient vs Reynolds number.

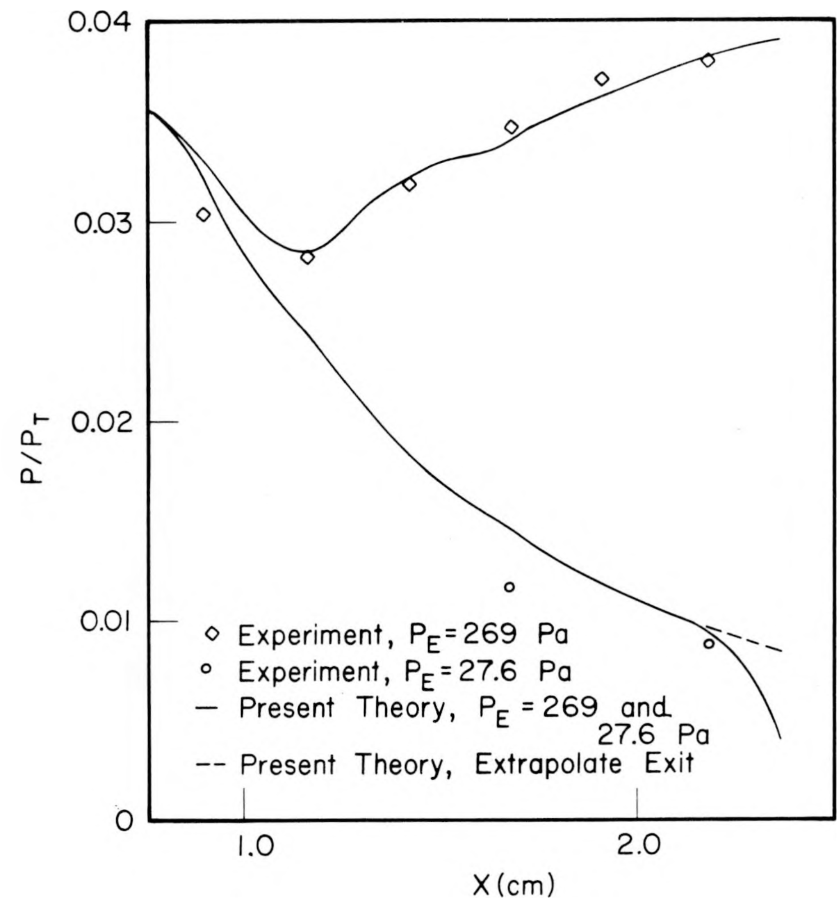

Fig. 10. Wall pressure ratio for Re^* = 1200.

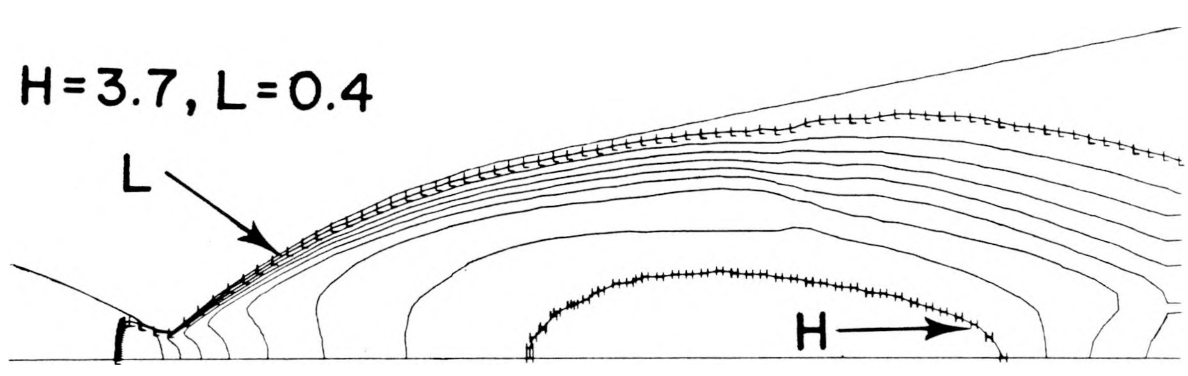

Fig. 11. Mach number contours for the separated case.

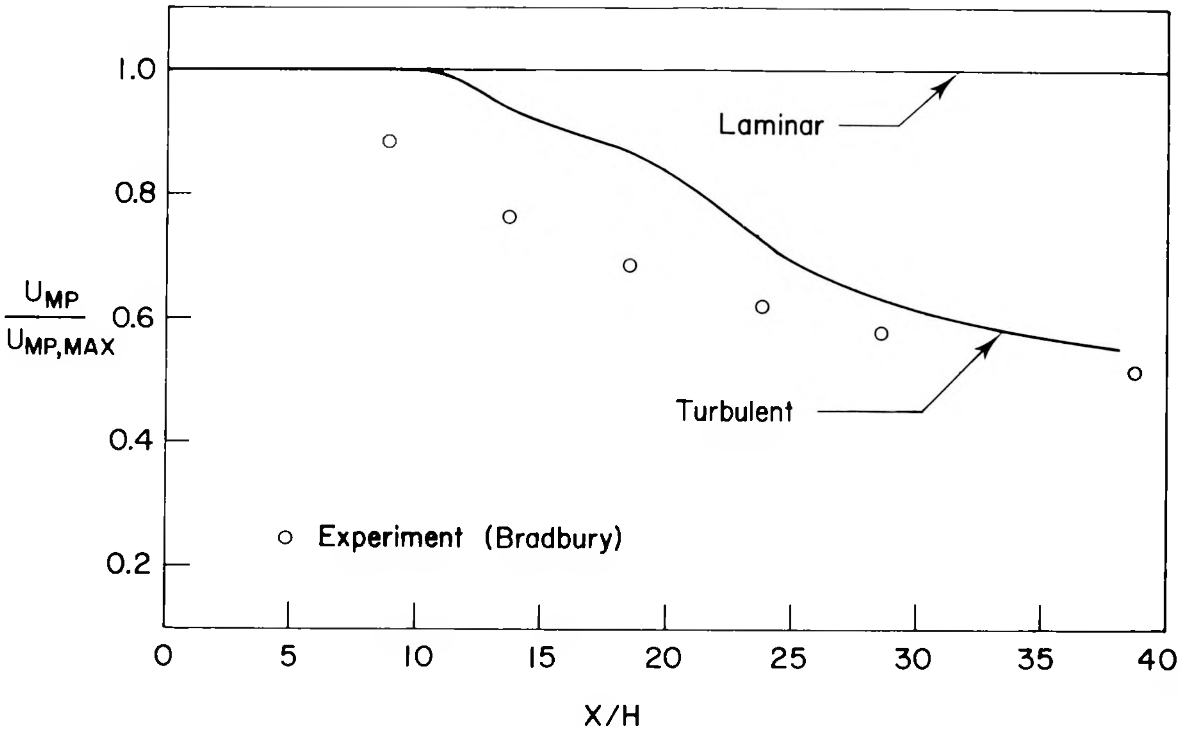

Fig. 12. Midplane velocity decay of a plane jet in a uniform stream ($Re_H = 3 \times 10^4$).

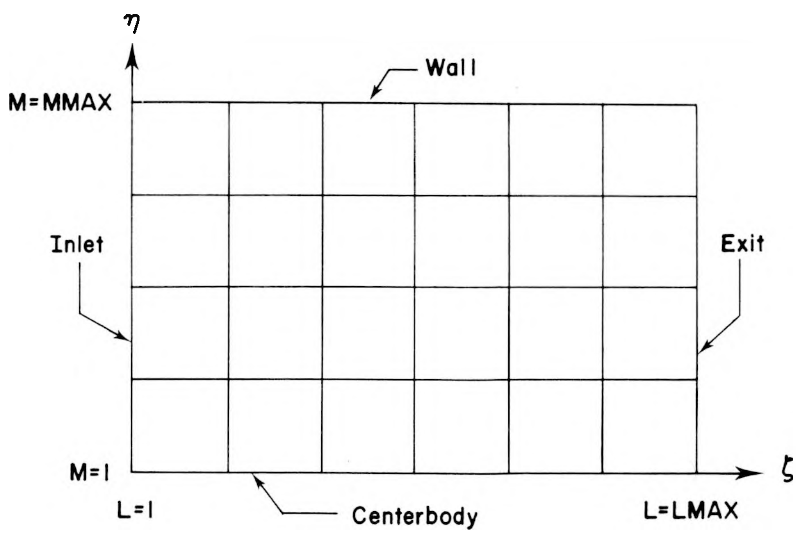

Fig. 13. Computational plane grid.

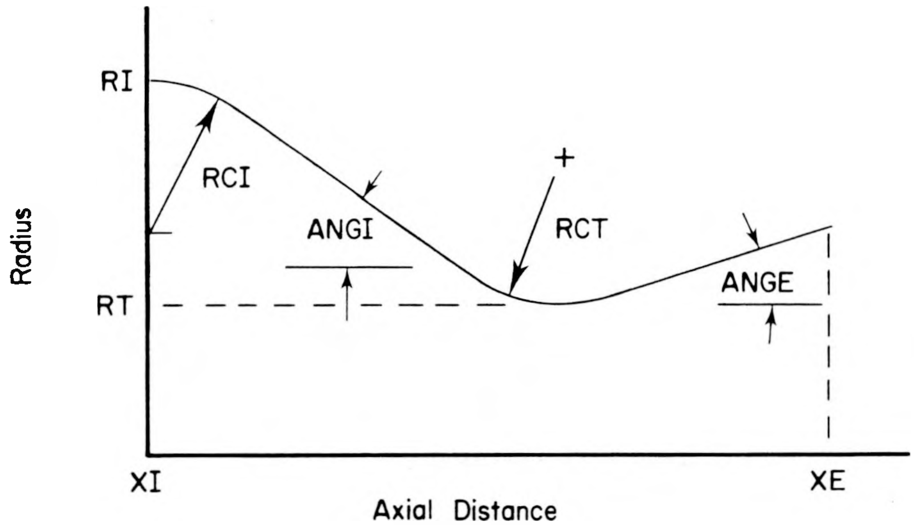

Fig. 14. Circular-arc, conical wall geometry.

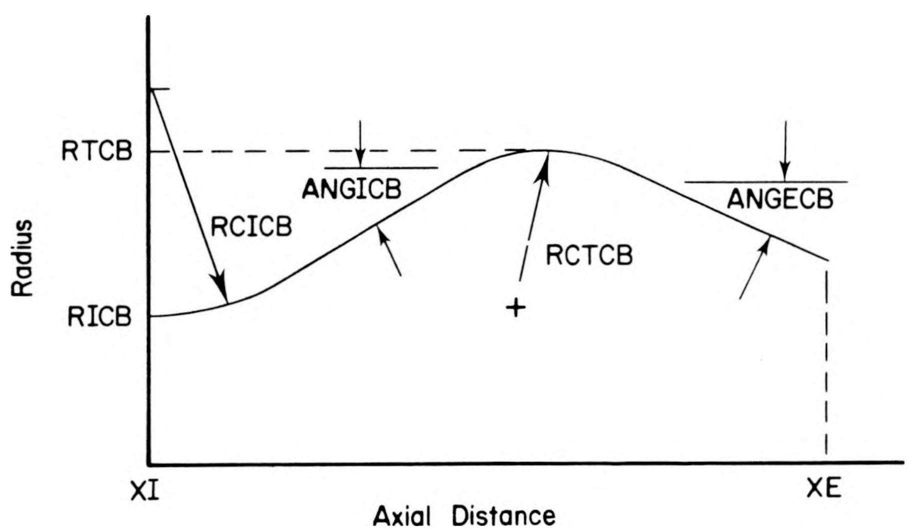

Fig. 15. Circular-arc, conical centerbody geometry.

```
CASE NO. 1 - CONVERGING-DIVERGING NOZZLE (45 DEG INLET, 15 DEG EXIT)
 $CNTRL LMAX=21,MMAX=8,NMAX=400,TCONV=0.003,FDT=1.34   $
 $IVS   $
 $GEMTRY NGEOM=2,XI=0.31,RI=2.5,RT=0.8,XE=4.05,RCI=0.8,RCT=0.5,ANGI=44.88,
 ANGE=15.0   $
 $GCBL   $
 $BC PT=70.0,TT=540.0   $
 $AVL   $
 $RVL   $
```

Fig. 16. Case No. 1 data deck.

```
VNAP, A COMPUTER PROGRAM FOR THE COMPUTATION OF TWO-DIMENSIONAL, TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERNAL FLOW

                         BY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIENTIFIC LABORATORY


PROGRAM ABSTRACT -

             THE NAVIER-STOKES EQUATIONS FOR TWO-DIMENSIONAL, TIME-DEPENDENT FLOW ARE SOLVED USING THE
          SECOND-ORDER, MACCORMACK FINITE-DIFFERENCE SCHEME. ALL BOUNDARY CONDITIONS ARE COMPUTED USING
          A SECOND-ORDER, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THE VISCOUS TERMS TREATED AS SOURCE
          FUNCTIONS.  THE FLUID IS ASSUMED TO BE A PERFECT GAS.  THE STEADY-STATE SOLUTION IS OBTAINED AS
          THE ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW BOUNDARIES MAY BE ARBITRARY CURVED SOLID WALLS
          AS WELL AS JET ENVELOPES.  PROBLEMS THAT CAN BE SOLVED ARE FLOW IN PIPES AND DUCTS, CONVERGING,
          CONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC AND SUPERSONIC INLETS, AND FREE JET EXPANSIONS.


JOB TITLE -

          CASE NO. 1 - CONVERGING-DIVERGING NOZZLE (45 DEG INLET, 15 DEG EXIT)


CONTROL PARAMETERS -

          LMAX=21  MMAX= 8    NMAX= 400  NPRINT=   0  TCONV=  .003    FDT=1.34  NSTAG=0      NASM=1    IUNIT=0
          IUI=1    IUO=1      IVPTS=1    NCONVI= 1    TSTOP=1.00000   N1D= 1    NPLOT=  -1   IPUNCH=0
          RSTAR=   0.000000   RSTARS=    0.0000000    PLOW= .0100     ROLOW=    .000100


FLUID MODEL -

          THE RATIO OF SPECIFIC HEATS, GAMMA =1.4000 AND THE GAS CONSTANT, R =  53.3500 (FT-LBF/LBM-R)


FLOW GEOMETRY -

          AXISYMMETRIC FLOW HAS BEEN SPECIFIED


DUCT GEOMETRY -

          A CIRCULAR-ARC, CONICAL NOZZLE HAS BEEN SPECIFIED BY XI=   .3100 (IN), RI=  2.5000 (IN),
          RT=   .8000 (IN), XE=  4.0500 (IN), RCI=   .8000 (IN), RCT=   .5000 (IN), ANGI= 44.88 (DEG),
          AND ANGE= 15.00 (DEG). THE COMPUTED VALUES ARE XT=  2.5540 (IN) AND RE=  1.1832 (IN).
```

Fig. 17. Case No. 1 output.

```
BOUNDARY CONDITIONS =

          M          PT(PSIA)        TT(R)        THETA(DEG)        PE(PSIA)

          1          70.0000         540.00          0.00           14.70000
          2          70.0000         540.00          0.00           14.70000
          3          70.0000         540.00          0.00           14.70000
          4          70.0000         540.00          0.00           14.70000
          5          70.0000         540.00          0.00           14.70000
          6          70.0000         540.00          0.00           14.70000
          7          70.0000         540.00          0.00           14.70000
          8          70.0000         540.00          0.00           14.70000

         IEXTRA=0   IEX=1   ISUPER= 0   DYW= .0010   IVBC=0

         FREE-SLIP WALLS ARE SPECIFIED

         ADIABATIC UPPER WALL IS SPECIFIED


ARTIFICAL VISCOSITY =

         CAV=0.00   XMU= .40   XLA=1.00   RKMU= .70   XRO= .60   NST=   0   SMP= .95   LSS= 2   SMACH=0.00   IAV=1

MOLECULAR VISCOSITY =

         CMU=0.        (LBF-S/FT2),  CLA= 0.        (LBF-S/FT2),  CK=0.        (LBF/S-R),  EMU=0.00,  ELA=0.00,
         AND EK=0.00

TURBULENCE MODEL =

         NO MODEL IS SPECIFIED


N=    10,  T= .00005775 SECONDS,  DT= .00000560 SECONDS
N=    20,  T= .00011222 SECONDS,  DT= .00000540 SECONDS
N=    30,  T= .00016613 SECONDS,  DT= .00000539 SECONDS
N=    40,  T= .00022012 SECONDS,  DT= .00000541 SECONDS
N=    50,  T= .00027432 SECONDS,  DT= .00000542 SECONDS
N=    60,  T= .00032843 SECONDS,  DT= .00000540 SECONDS
N=    70,  T= .00038235 SECONDS,  DT= .00000539 SECONDS
N=    80,  T= .00043626 SECONDS,  DT= .00000540 SECONDS
N=    90,  T= .00049040 SECONDS,  DT= .00000543 SECONDS
N=   100,  T= .00054482 SECONDS,  DT= .00000545 SECONDS
N=   110,  T= .00059930 SECONDS,  DT= .00000544 SECONDS
N=   120,  T= .00065365 SECONDS,  DT= .00000544 SECONDS
N=   130,  T= .00070805 SECONDS,  DT= .00000544 SECONDS
N=   140,  T= .00076234 SECONDS,  DT= .00000542 SECONDS
N=   150,  T= .00081655 SECONDS,  DT= .00000542 SECONDS
N=   160,  T= .00087078 SECONDS,  DT= .00000542 SECONDS
N=   170,  T= .00092504 SECONDS,  DT= .00000543 SECONDS
N=   180,  T= .00097933 SECONDS,  DT= .00000543 SECONDS
N=   190,  T= .00103367 SECONDS,  DT= .00000543 SECONDS
N=   200,  T= .00108800 SECONDS,  DT= .00000543 SECONDS
N=   210,  T= .00114232 SECONDS,  DT= .00000543 SECONDS
```

Fig. 17. (Cont)

```
N=   220,  T= .00119664 SECONDS,  DT= .00000543 SECONDS
N=   230,  T= .00125095 SECONDS,  DT= .00000543 SECONDS
N=   240,  T= .00130526 SECONDS,  DT= .00000543 SECONDS
N=   250,  T= .00135961 SECONDS,  DT= .00000544 SECONDS
N=   260,  T= .00141398 SECONDS,  DT= .00000544 SECONDS
N=   270,  T= .00146836 SECONDS,  DT= .00000544 SECONDS
N=   280,  T= .00152275 SECONDS,  DT= .00000544 SECONDS
N=   290,  T= .00157714 SECONDS,  DT= .00000544 SECONDS
```

Fig. 17. (Cont)

SOLUTION SURFACE NO. 299 - TIME = .00162608 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
1	1	.3100	0.0000	143.7907	0.0000	69.22194	.347108	143.7907	.1264	538.2782
1	2	.3100	.3571	141.2734	0.0000	69.24886	.347205	141.2734	.1242	538.3380
1	3	.3100	.7143	127.8731	0.0000	69.38415	.347689	127.8731	.1124	538.6383
1	4	.3100	1.0714	108.9187	0.0000	69.55283	.348293	108.9187	.0957	539.0121
1	5	.3100	1.4286	86.1395	0.0000	69.72009	.348891	86.1395	.0757	539.3822
1	6	.3100	1.7857	61.7718	0.0000	69.85597	.349376	61.7718	.0542	539.6823
1	7	.3100	2.1429	40.2960	0.0000	69.93869	.349672	40.2960	.0354	539.8648
1	8	.3100	2.5000	18.6344	0.0000	69.98689	.349844	18.6344	.0164	539.9711
2	1	.4970	0.0000	145.5617	0.0000	69.29447	.347302	145.5617	.1280	538.5412
2	2	.4970	.3540	143.0372	-4.4468	69.32399	.347403	143.1063	.1258	538.6139
2	3	.4970	.7080	129.6092	-8.4414	69.45395	.347857	129.8838	.1141	538.9205
2	4	.4970	1.0619	110.4865	-10.9071	69.61634	.348404	111.0236	.0975	539.3312
2	5	.4970	1.4159	87.5025	-11.7681	69.77537	.348924	88.2903	.0775	539.7587
2	6	.4970	1.7699	62.8109	-10.7230	69.89791	.349339	63.7197	.0559	540.0641
2	7	.4970	2.1239	41.0150	-8.3413	69.97179	.349703	41.8546	.0367	540.0725
2	8	.4970	2.4778	19.0109	-4.5704	70.00816	.349863	19.5526	.0172	540.1056
3	1	.6840	0.0000	152.6957	0.0000	69.14873	.346858	152.6957	.1343	538.0968
3	2	.6840	.3439	149.9519	-8.0659	69.17669	.346957	150.1686	.1321	538.1609
3	3	.6840	.6878	136.1414	-15.1937	69.29982	.347391	136.9866	.1204	538.4451
3	4	.6840	1.0317	115.9893	-19.6046	69.46034	.347957	117.6344	.1034	538.8143
3	5	.6840	1.3755	91.8012	-21.1587	69.62019	.348564	94.2080	.0828	539.1143
3	6	.6840	1.7194	65.6961	-19.5374	69.75245	.349190	68.5396	.0602	539.1708
3	7	.6840	2.0633	42.5398	-15.9711	69.83754	.349477	45.4384	.0399	539.3846
3	8	.6840	2.4072	20.1490	-10.6558	69.89317	.349779	22.7931	.0200	539.3480
4	1	.8710	0.0000	164.4828	0.0000	69.04215	.346382	164.4828	.1447	538.0063
4	2	.8710	.3243	161.3574	-12.7114	69.07658	.346498	161.8573	.1423	538.0940
4	3	.8710	.6487	147.6713	-24.0403	69.21600	.346982	149.6154	.1315	538.4276
4	4	.8710	.9730	127.1608	-31.7921	69.40677	.347651	131.0748	.1152	538.8726
4	5	.8710	1.2973	102.5569	-35.8047	69.60539	.348393	108.6273	.0954	539.2635
4	6	.8710	1.6217	75.5866	-34.9444	69.78593	.348980	83.2733	.0731	539.7540
4	7	.8710	1.9460	51.7104	-32.3346	69.91140	.349397	60.9876	.0535	540.0790
4	8	.8710	2.2703	28.2891	-27.8262	70.02489	.349040	39.6809	.0348	541.5081
5	1	1.0580	0.0000	183.4921	0.0000	68.79867	.345603	183.4921	.1615	537.3169
5	2	1.0580	.2977	179.9678	-16.5592	68.83272	.345725	180.7281	.1590	537.3938
5	3	1.0580	.5955	166.5791	-31.6634	68.96548	.346207	169.5617	.1492	537.6806
5	4	1.0580	.8932	145.7249	-42.8376	69.15432	.346918	151.8908	.1336	538.0469
5	5	1.0580	1.1909	120.2303	-49.3420	69.36099	.347735	129.9613	.1143	538.3868
5	6	1.0580	1.4887	91.6986	-49.5244	69.56996	.348518	104.2176	.0916	538.7966
5	7	1.0580	1.7864	66.4332	-46.9654	69.72888	.349054	81.3580	.0715	539.1977
5	8	1.0580	2.0841	44.5315	-44.3454	69.89706	.351203	62.8456	.0553	537.1914
6	1	1.2450	0.0000	208.0595	0.0000	68.37059	.343954	208.0595	.1832	536.5345
6	2	1.2450	.2711	203.9930	-20.3209	68.41395	.344104	205.0027	.1805	536.6401
6	3	1.2450	.5423	190.6492	-39.1761	68.56063	.344633	194.6327	.1713	536.9653
6	4	1.2450	.8134	169.0475	-54.0109	68.78165	.345440	177.4661	.1562	537.4369
6	5	1.2450	1.0845	142.0727	-63.7117	69.03684	.346343	155.7043	.1369	538.0248
6	6	1.2450	1.3557	111.0906	-65.5047	69.31814	.347243	128.9650	.1133	538.8175
6	7	1.2450	1.6268	84.0372	-64.8023	69.52639	.348032	106.1207	.0932	539.2109

Fig. 17. (Cont)

SOLUTION SURFACE NO. 299 - TIME = .00162608 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
6	8	1.2450	1.8979	59.6509	-59.4016	69.82175	.348098	84.1830	.0738	541.3987
7	1	1.4320	0.0000	243.8332	0.0000	67.88415	.342351	243.8332	.2150	535.2106
7	2	1.4320	.2445	239.2062	-25.3270	67.93558	.342540	240.5433	.2121	535.3203
7	3	1.4320	.4891	226.0278	-49.2519	68.08661	.343108	231.3316	.2039	535.6220
7	4	1.4320	.7336	203.6779	-69.1687	68.32164	.344001	215.1023	.1895	536.0761
7	5	1.4320	.9781	174.3715	-82.8380	68.60746	.345060	193.0480	.1700	536.6671
7	6	1.4320	1.2226	139.5742	-87.3322	68.92759	.346293	164.6447	.1449	537.2511
7	7	1.4320	1.4672	107.5294	-86.2791	69.19120	.347338	137.8646	.1213	537.6841
7	8	1.4320	1.7117	77.7724	-77.4473	69.60341	.349587	109.7572	.0966	537.4063
8	1	1.6190	0.0000	289.2275	0.0000	66.79481	.338271	289.2275	.2556	532.9740
8	2	1.6190	.2179	284.0828	-28.5977	66.86391	.338516	285.5186	.2522	533.1389
8	3	1.6190	.4359	271.2027	-56.1286	67.03153	.33912[illegible]	276.9501	.2446	533.5112
8	4	1.6190	.6538	248.1237	-80.2632	67.30899	.340128	260.7826	.2302	534.1439
8	5	1.6190	.8717	216.4252	-98.7018	67.67228	.341386	237.8696	.2098	535.0481
8	6	1.6190	1.0896	177.2357	-108.0148	68.11668	.342924	207.5565	.1829	536.1465
8	7	1.6190	1.3076	138.9477	-110.8621	68.52206	.344411	177.7551	.1565	537.0095
8	8	1.6190	1.5255	101.5220	-101.0976	69.40651	.346008	143.2740	.1256	541.4299
9	1	1.8060	0.0000	352.8414	0.0000	65.59373	.334134	352.8414	.3127	529.8702
9	2	1.8060	.1913	347.6569	-34.5781	65.67751	.334446	349.3723	.3096	530.0516
9	3	1.8060	.3826	336.0680	-68.6264	65.84928	.335101	343.0033	.3038	530.3995
9	4	1.8060	.5740	314.2194	-100.7425	66.14900	.336237	329.9741	.2921	531.0140
9	5	1.8060	.7653	282.1929	-128.4146	66.55829	.337768	310.0374	.2742	531.8776
9	6	1.8060	.9566	239.3005	-146.9805	67.06874	.339776	280.8344	.2482	532.7894
9	7	1.8060	1.1479	191.6545	-154.9091	67.58814	.341720	246.4311	.2176	533.8604
9	8	1.8060	1.3393	130.9637	-130.4163	68.78128	.346896	184.8240	.1630	535.1795
10	1	1.9930	0.0000	436.2885	0.0000	62.95406	.324269	436.2885	.3888	524.0189
10	2	1.9930	.1647	431.5936	-35.8032	63.03406	.324554	433.0761	.3859	524.2241
10	3	1.9930	.3294	422.4131	-71.9104	63.16806	.325039	428.4903	.3816	524.5534
10	4	1.9930	.4942	403.5627	-108.0135	63.41742	.325925	417.7676	.3719	525.1931
10	5	1.9930	.6589	373.0093	-142.3257	63.80512	.327270	399.2400	.3550	526.2315
10	6	1.9930	.8236	327.2380	-171.5532	64.31657	.329094	369.4797	.3282	527.5102
10	7	1.9930	.9883	263.6084	-186.1216	65.03155	.331690	322.6928	.2862	529.2000
10	8	1.9930	1.1530	170.6378	-169.9246	65.91961	.333393	240.8145	.2126	533.6869
11	1	2.1800	0.0000	548.8858	0.0000	59.73642	.312716	548.8858	.4931	515.6045
11	2	2.1800	.1381	546.4423	-38.8982	59.79764	.312963	547.8250	.4921	515.7257
11	3	2.1800	.2762	542.6444	-79.4630	59.85796	.313241	548.4317	.4926	515.7882
11	4	2.1800	.4144	534.0945	-124.4016	60.00303	.313883	548.3910	.4925	515.9803
11	5	2.1800	.5525	518.2476	-175.4465	60.27465	.315050	547.1399	.4912	516.3968
11	6	2.1800	.6906	490.7531	-234.5488	60.74243	.317118	543.9226	.4880	517.0102
11	7	2.1800	.8287	448.5116	-304.4772	61.52507	.320582	542.0968	.4859	518.0130
11	8	2.1800	.9668	391.6781	-390.0409	61.67709	.321879	552.7601	.4958	517.2009
12	1	2.3670	0.0000	702.9724	0.0000	53.40387	.288624	702.9724	.6417	499.4231
12	2	2.3670	.1195	705.2675	-30.2904	53.27879	.288147	705.9176	.6446	499.0780
12	3	2.3670	.2389	711.7995	-62.3772	52.91235	.286746	714.5275	.6531	498.0669
12	4	2.3670	.3584	723.9143	-98.8357	52.24824	.284214	730.6302	.6691	496.1969
12	5	2.3670	.4779	742.5301	-142.7548	51.19124	.280212	756.1282	.6946	493.1030
12	6	2.3670	.5974	769.5246	-199.7372	49.54103	.274189	795.0239	.7344	487.6884

Fig. 17. (Cont)

SOLUTION SURFACE NO. 299 - TIME = .00162608 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
12	7	2.3670	.7168	806.8133	-275.0182	47.05424	.265854	852.3982	.7955	477.7316
12	8	2.3670	.8363	928.3784	-374.4274	40.77183	.242071	1001.0406	.9577	454.6171
13	1	2.5540	0.0000	867.8598	0.0000	45.72596	.258974	867.8598	.8110	476.5796
13	2	2.5540	.1143	873.8369	-18.6979	45.40602	.257734	874.0369	.8176	475.5210
13	3	2.5540	.2286	887.5692	-37.8754	44.64755	.254769	888.3770	.8332	473.0197
13	4	2.5540	.3429	914.6104	-56.5372	43.22432	.249192	916.3561	.8639	468.1910
13	5	2.5540	.4571	958.3316	-72.9660	40.88604	.239901	961.1054	.9141	460.0141
13	6	2.5540	.5714	1029.2702	-84.1302	37.07268	.224331	1032.7028	.9975	446.0595
13	7	2.5540	.6857	1148.6538	-75.5211	30.87447	.197443	1151.1338	1.1430	422.0706
13	8	2.5540	.8000	1368.9071	-.0522	22.74953	.157621	1368.9071	1.4148	389.5716
14	1	2.7410	0.0000	1057.8502	0.0000	36.02705	.218548	1057.8502	1.0230	444.9487
14	2	2.7410	.1189	1067.7796	4.8619	35.49408	.216257	1067.7906	1.0349	443.0100
14	3	2.7410	.2378	1089.2284	11.4109	34.32407	.211177	1089.2882	1.0609	438.7132
14	4	2.7410	.3568	1130.2852	26.9905	32.19886	.201809	1130.6074	1.1114	430.6526
14	5	2.7410	.4757	1193.1534	59.7303	28.97241	.187106	1194.6475	1.1920	417.9513
14	6	2.7410	.5946	1286.8179	125.9063	24.37073	.164997	1292.9628	1.3210	398.6775
14	7	2.7410	.7135	1418.8413	259.6962	18.24216	.133048	1442.4121	1.5295	370.0814
14	8	2.7410	.8325	1505.6551	403.4391	13.93935	.108603	1558.7688	1.7084	346.4401
15	1	2.9280	0.0000	1229.8897	0.0000	27.42814	.179800	1229.8897	1.2364	411.7500
15	2	2.9280	.1261	1240.8981	32.2414	26.85929	.177116	1241.3169	1.2516	409.3209
15	3	2.9280	.2522	1263.7378	67.2635	25.64904	.171344	1265.5266	1.2843	404.0465
15	4	2.9280	.3782	1305.6184	116.2271	23.54122	.161076	1310.7815	1.3463	394.4807
15	5	2.9280	.5043	1363.6527	186.2816	20.65046	.146437	1376.3174	1.4391	380.6340
15	6	2.9280	.6304	1434.7153	284.1822	17.24963	.128262	1462.5893	1.5660	363.0026
15	7	2.9280	.7565	1496.0195	379.7514	14.34173	.111721	1543.4654	1.6915	346.4942
15	8	2.9280	.8826	1523.2443	408.1521	13.22637	.104662	1576.9786	1.7418	341.0989
16	1	3.1150	0.0000	1379.5069	0.0000	20.53453	.146062	1379.5069	1.4446	379.4678
16	2	3.1150	.1332	1389.3872	57.3391	20.04922	.143558	1390.5699	1.4610	376.9627
16	3	3.1150	.2665	1409.0961	117.0159	19.02755	.138233	1413.9464	1.4964	371.5345
16	4	3.1150	.3997	1443.4704	190.3059	17.32701	.129154	1455.9612	1.5608	362.1117
16	5	3.1150	.5330	1485.4488	277.1585	15.24586	.117608	1511.0840	1.6479	349.9002
16	6	3.1150	.6662	1525.9635	367.7075	13.26962	.106102	1569.6412	1.7427	337.5698
16	7	3.1150	.7994	1549.0567	421.7527	12.10812	.098933	1605.4445	1.8019	330.3426
16	8	3.1150	.9327	1556.5592	417.0788	11.98606	.097596	1611.4687	1.8055	331.4929
17	1	3.3020	0.0000	1507.5970	0.0000	15.33398	.118359	1507.5970	1.6446	349.6897
17	2	3.3020	.1404	1515.1529	77.3416	14.97461	.116340	1517.1256	1.6604	347.4209
17	3	3.3020	.2808	1529.6176	155.4748	14.21178	.112018	1537.4988	1.6949	342.4423
17	4	3.3020	.4212	1553.3823	242.8911	13.00261	.104995	1572.2572	1.7543	334.2627
17	5	3.3020	.5616	1577.9459	331.5653	11.69893	.097150	1612.4047	1.8244	325.0358
17	6	3.3020	.7020	1595.4754	403.6983	10.72733	.091028	1645.7564	1.8824	318.0851
17	7	3.3020	.8424	1597.5087	431.6029	10.46546	.089124	1654.7855	1.8961	316.9495
17	8	3.3020	.9828	1597.4503	428.0356	10.58594	.089322	1653.8023	1.8863	319.8902
18	1	3.4890	0.0000	1611.0497	0.0000	11.57469	.096702	1611.0497	1.8284	323.0730
18	2	3.4890	.1476	1615.9553	91.7102	11.33435	.095238	1618.5556	1.8422	321.2295
18	3	3.4890	.2951	1624.8917	182.3015	10.80927	.092020	1635.0862	1.8732	317.0598
18	4	3.4890	.4427	1638.5767	276.1953	10.02156	.087065	1661.6911	1.9231	310.6842
18	5	3.4890	.5902	1649.1819	359.4133	9.30458	.082395	1687.8919	1.9722	304.8055

Fig. 17. (Cont)

SOLUTION SURFACE NO. 299 - TIME = .00162608 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
18	6	3.4890	.7378	1651.5701	413.0305	8.97823	.080102	1702.4330	1.9966	302.5345
18	7	3.4890	.8853	1641.5406	428.0980	9.15920	.081026	1696.4444	1.9812	305.1143
18	8	3.4890	1.0329	1638.6335	439.0706	9.24544	.081097	1696.4382	1.9728	307.7155
19	1	3.6760	0.0000	1706.7195	0.0000	8.78082	.079214	1706.7195	2.0128	299.2014
19	2	3.6760	.1547	1708.9526	101.3547	8.63746	.078270	1711.9555	2.0235	297.8647
19	3	3.6760	.3094	1712.5395	199.5904	8.30667	.076088	1724.1310	2.0489	294.6728
19	4	3.6760	.4641	1716.5516	293.8175	7.85790	.073045	1741.5161	2.0848	290.3648
19	5	3.6760	.6189	1714.0633	365.9785	7.58481	.071115	1752.6988	2.1073	287.8799
19	6	3.6760	.7736	1702.6938	402.9917	7.68899	.071684	1749.7339	2.0977	289.5159
19	7	3.6760	.9283	1685.8918	419.5189	8.00559	.073619	1737.3046	2.0686	293.5156
19	8	3.6760	1.0830	1682.3865	450.7942	7.97941	.073009	1741.7347	2.0687	294.9993
20	1	3.8630	0.0000	1776.8986	0.0000	7.18710	.068096	1776.8986	2.1476	284.8790
20	2	3.8630	.1619	1776.8830	104.0210	7.10619	.067556	1779.9251	2.1549	283.9234
20	3	3.8630	.3237	1776.3352	203.1801	6.90101	.066172	1787.9175	2.1739	281.4910
20	4	3.8630	.4856	1773.1313	292.3047	6.65621	.064504	1797.0633	2.1966	278.5278
20	5	3.8630	.6475	1761.8955	355.0497	6.60102	.064147	1797.3136	2.1999	277.7548
20	6	3.8630	.8094	1743.5524	389.3675	6.81573	.065600	1786.5000	2.1762	280.4386
20	7	3.8630	.9712	1725.6214	416.7000	7.07392	.067216	1775.2206	2.1486	284.0642
20	8	3.8630	1.1331	1721.8620	461.3716	6.99604	.066265	1782.6027	2.1541	284.9697
21	1	4.0500	0.0000	1847.0778	0.0000	5.59338	.056978	1847.0778	2.3148	264.9674
21	2	4.0500	.1690	1844.8133	106.6873	5.57492	.056842	1847.8957	2.3168	264.7265
21	3	4.0500	.3381	1840.1309	206.7699	5.49535	.056257	1851.7115	2.3263	263.6625
21	4	4.0500	.5071	1829.7109	290.7919	5.45453	.055963	1852.6743	2.3301	263.0776
21	5	4.0500	.6761	1809.7277	344.1209	5.61724	.057179	1842.1546	2.3077	265.1619
21	6	4.0500	.8451	1784.4110	375.7433	5.94247	.059515	1823.5421	2.2659	269.5052
21	7	4.0500	1.0142	1765.3510	413.8812	6.14225	.060813	1813.2186	2.2402	272.6224
21	8	4.0500	1.1832	1761.3375	471.9490	6.01266	.059520	1823.4708	2.2527	272.6669

MASS= 3.164965 (LBM/SEC) THRUST= 175.0481 (LBF) MASSI= 3.328738 MASSE= 3.223211

Fig. 17. (Cont)

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CASE NO. 2 - CONVERGING NOZZLE (15 DEG INLET, PT/PE=2.0)
 $CNTRL LMAX=23,MMAX=7,NMAX=400,TCONV=0.005,FDT=1.15   $
 $IVS   $
 $GEMTRY NGEOM=4,XI=-3.6,XE=0.8,JFLAG=1,LJET=20,
 YW=1.93,1.91103,1.85744,1.80385,1.75026,1.69667,1.64308,1.58949,1.5359,
 1.48231,1.42872,1.37513,1.32154,1.26795,1.21436,1.16077,1.10718,1.05359,
 1.0,1.01,1.02,1.03,1.04,
 NXNY=0.0,18*0.26795,4*-0.05   $
 $GCBL   $
 $BC PT=25.0,TT=640.0,PE=12.5   $
 $AVL   $
 $RVL   $
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Fig. 18. Case No. 2 data deck.

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VNAP, A COMPUTER PROGRAM FOR THE COMPUTATION OF TWO-DIMENSIONAL, TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERNAL FLOW

                     BY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIENTIFIC LABORATORY


PROGRAM ABSTRACT -

          THE NAVIER-STOKES EQUATIONS FOR TWO-DIMENSIONAL, TIME-DEPENDENT FLOW ARE SOLVED USING THE
      SECOND-ORDER, MACCORMACK FINITE-DIFFERENCE SCHEME. ALL BOUNDARY CONDITIONS ARE COMPUTED USING
      A SECOND-ORDER, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THE VISCOUS TERMS TREATED AS SOURCE
      FUNCTIONS.  THE FLUID IS ASSUMED TO BE A PERFECT GAS.  THE STEADY-STATE SOLUTION IS OBTAINED AS
      THE ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW BOUNDARIES MAY BE ARBITRARY CURVED SOLID WALLS
      AS WELL AS JET ENVELOPES.  PROBLEMS THAT CAN BE SOLVED ARE FLOW IN PIPES AND DUCTS, CONVERGING,
      CONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC AND SUPERSONIC INLETS, AND FREE JET EXPANSIONS.

JOB TITLE -

      CASE NO. 2 - CONVERGING NOZZLE (15 DEG INLET, PT/PE=2.0)

CONTROL PARAMETERS -

      LMAX=23  MMAX= 7   NMAX= 400  NPRINT=   0  TCONV=  .005    FDT=1.15  NSTAG=0     NASM=1    IUNIT=0
      IUI=1    IUO=1     IVPTS=1    NCONVI= 1    TSTOP=1.00000  N1D= 1    NPLOT=  -1  IPUNCH=0
      RSTAR=   0.000000  RSTARS=    0.0000000    PLOW= .0100    ROLOW=    .000100

FLUID MODEL -

      THE RATIO OF SPECIFIC HEATS, GAMMA =1.4000 AND THE GAS CONSTANT, R =  53.3500 (FT-LBF/LBM-R)

FLOW GEOMETRY -

      AXISYMMETRIC FLOW HAS BEEN SPECIFIED
```

Fig. 19. Case No. 2 output.

DUCT GEOMETRY -

A GENERAL WALL HAS BEEN SPECIFIED BY THE FOLLOWING PARAMETERS, XT= 0.0000 (IN), RT= 1.0000 (IN).

L	XW(IN)	YW(IN)	SLOPE
1	-3.6000	1.9300	0.0000
2	-3.4000	1.9110	-.2680
3	-3.2000	1.8574	-.2680
4	-3.0000	1.8039	-.2680
5	-2.8000	1.7503	-.2680
6	-2.6000	1.6967	-.2680
7	-2.4000	1.6431	-.2680
8	-2.2000	1.5895	-.2680
9	-2.0000	1.5359	-.2680
10	-1.8000	1.4823	-.2680
11	-1.6000	1.4287	-.2680
12	-1.4000	1.3751	-.2680
13	-1.2000	1.3215	-.2680
14	-1.0000	1.2680	-.2680
15	-.8000	1.2144	-.2680
16	-.6000	1.1608	-.2680
17	-.4000	1.1072	-.2680
18	-.2000	1.0536	-.2680
19	0.0000	1.0000	-.2680
20	.2000	1.0100	.0500
21	.4000	1.0200	.0500
22	.6000	1.0300	.0500
23	.8000	1.0400	.0500

A FREE-JET CALCULATION HAS BEEN REQUESTED. THE WALL ENDS AT X= 0.0000 (IN). THE MESH POINTS L= 20 TO L= 23 ARE AN INITIAL APPROXIMATION TO THE FREE-JET BOUNDARY.

Fig. 19. (Cont)

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BOUNDARY CONDITIONS =

            M          PT(PSIA)        TT(R)        THETA(DEG)       PE(PSIA)

            1          25.0000        640.00          0.00          12.50000
            2          25.0000        640.00          0.00          12.50000
            3          25.0000        640.00          0.00          12.50000
            4          25.0000        640.00          0.00          12.50000
            5          25.0000        640.00          0.00          12.50000
            6          25.0000        640.00          0.00          12.50000
            7          25.0000        640.00          0.00          12.50000

           IEXTRA=0   IEX=1   ISUPER= 0   DYW= .0010   IVBC=0

           FREE-SLIP WALLS ARE SPECIFIED

           ADIABATIC UPPER WALL IS SPECIFIED


ARTIFICAL VISCOSITY =

           CAV=0.00   XMU= .40   XLA=1.00   RKMU= .70   XRO= .60   NST=   0   SMP= .95   LSS= 2   SMACH=0.00   IAV=1

MOLECULAR VISCOSITY =

           CMU=0.        (LBF-S/FT2),  CLA= 0.        (LBF-S/FT2),  CK=0.        (LBF/S-R),  EMU=0.00,  ELA=0.00,
           AND EK=0.00

TURBULENCE MODEL =

           NO MODEL IS SPECIFIED


N=    10,  T= .00005842 SECONDS,  DT= .00000554 SECONDS
N=    20,  T= .00011270 SECONDS,  DT= .00000579 SECONDS
N=    30,  T= .00017468 SECONDS,  DT= .00000631 SECONDS
N=    40,  T= .00023833 SECONDS,  DT= .00000639 SECONDS
N=    50,  T= .00030216 SECONDS,  DT= .00000638 SECONDS
N=    60,  T= .00036598 SECONDS,  DT= .00000639 SECONDS
N=    70,  T= .00042984 SECONDS,  DT= .00000638 SECONDS
N=    80,  T= .00049367 SECONDS,  DT= .00000638 SECONDS
N=    90,  T= .00055747 SECONDS,  DT= .00000638 SECONDS
N=   100,  T= .00062125 SECONDS,  DT= .00000638 SECONDS
N=   110,  T= .00068512 SECONDS,  DT= .00000639 SECONDS
N=   120,  T= .00074911 SECONDS,  DT= .00000640 SECONDS
N=   130,  T= .00081311 SECONDS,  DT= .00000640 SECONDS
N=   140,  T= .00087706 SECONDS,  DT= .00000639 SECONDS
N=   150,  T= .00094097 SECONDS,  DT= .00000639 SECONDS
N=   160,  T= .00100485 SECONDS,  DT= .00000639 SECONDS
N=   170,  T= .00106872 SECONDS,  DT= .00000639 SECONDS
N=   180,  T= .00113260 SECONDS,  DT= .00000639 SECONDS
N=   190,  T= .00119648 SECONDS,  DT= .00000639 SECONDS
N=   200,  T= .00126038 SECONDS,  DT= .00000639 SECONDS
N=   210,  T= .00132429 SECONDS,  DT= .00000639 SECONDS
N=   220,  T= .00138822 SECONDS,  DT= .00000639 SECONDS
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Fig. 19. (Cont)

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N=   230,  T= .00145216 SECONDS,  DT= .00000639 SECONDS
N=   240,  T= .00151610 SECONDS,  DT= .00000639 SECONDS
N=   250,  T= .00158004 SECONDS,  DT= .00000639 SECONDS
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Fig. 19. (Cont)

SOLUTION SURFACE NO. 250 - TIME = .00158004 SECONDS (DELTA T = .00000639)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
1	1	-3.6000	0.0000	218.2003	0.0000	24.46206	.103810	218.2003	.1765	636.0347
1	2	-3.6000	.3217	216.2474	0.0000	24.47156	.103839	216.2474	.1749	636.1053
1	3	-3.6000	.6433	210.9465	0.0000	24.49693	.103916	210.9465	.1706	636.2936
1	4	-3.6000	.9650	202.2934	0.0000	24.53700	.104037	202.2934	.1636	636.5908
1	5	-3.6000	1.2867	189.7507	0.0000	24.59218	.104204	189.7507	.1534	636.9995
1	6	-3.6000	1.6083	174.0169	0.0000	24.65652	.104399	174.0169	.1406	637.4752
1	7	-3.6000	1.9300	164.4304	0.0000	24.69380	.104512	164.4304	.1328	637.7505
2	1	-3.4000	0.0000	220.4311	0.0000	24.49981	.103926	220.4311	.1783	636.3081
2	2	-3.4000	.3185	218.6377	-4.0510	24.51160	.103962	218.6753	.1768	636.3953
2	3	-3.4000	.6370	213.7004	-8.2987	24.54080	.104050	213.8615	.1729	636.6112
2	4	-3.4000	.9555	205.8307	-13.4728	24.59024	.104200	206.2711	.1667	636.9752
2	5	-3.4000	1.2740	194.5586	-20.2023	24.66437	.104425	195.6047	.1580	637.5199
2	6	-3.4000	1.5925	180.8303	-29.6523	24.76254	.104723	183.2454	.1480	638.2367
2	7	-3.4000	1.9110	173.9657	-46.6141	24.84230	.104963	180.1026	.1454	638.8306
3	1	-3.2000	0.0000	227.0757	0.0000	24.44769	.103767	227.0757	.1837	635.9253
3	2	-3.2000	.3096	225.6527	-5.3911	24.45546	.103791	225.7171	.1826	635.9831
3	3	-3.2000	.6191	221.5594	-10.9702	24.47488	.103850	221.8308	.1794	636.1272
3	4	-3.2000	.9287	215.4282	-17.4639	24.50567	.103943	216.1349	.1748	636.3546
3	5	-3.2000	1.2383	206.8901	-25.0448	24.55548	.104094	208.4005	.1685	636.7216
3	6	-3.2000	1.5479	198.0574	-35.7112	24.60934	.104258	201.2511	.1626	637.1143
3	7	-3.2000	1.8574	198.1068	-53.0827	24.64829	.104376	205.0953	.1657	637.4044
4	1	-3.0000	0.0000	235.5484	0.0000	24.41958	.103683	235.5484	.1906	635.7121
4	2	-3.0000	.3006	234.3156	-7.3567	24.42679	.103704	234.4311	.1897	635.7657
4	3	-3.0000	.6013	230.6882	-14.8749	24.44377	.103756	231.1673	.1870	635.8915
4	4	-3.0000	.9019	225.4063	-23.0646	24.47102	.103839	226.5833	.1833	636.0922
4	5	-3.0000	1.2026	218.2140	-31.7549	24.51493	.103973	220.5124	.1783	636.4138
4	6	-3.0000	1.5032	211.8584	-43.1398	24.55402	.104093	216.2060	.1748	636.6911
4	7	-3.0000	1.8039	212.1338	-56.8413	24.60122	.104233	219.6171	.1775	637.0584
5	1	-2.8000	0.0000	247.4010	0.0000	24.34879	.103467	247.4010	.2002	635.1886
5	2	-2.8000	.2917	246.3814	-8.7867	24.35508	.103486	246.5381	.1995	635.2354
5	3	-2.8000	.5834	243.1979	-17.7327	24.36864	.103527	243.8435	.1973	635.3365
5	4	-2.8000	.8751	238.5941	-27.0792	24.39152	.103597	240.1258	.1943	635.5056
5	5	-2.8000	1.1668	232.6940	-37.0447	24.42558	.103701	235.6243	.1906	635.7569
5	6	-2.8000	1.4586	227.5761	-48.4324	24.45745	.103798	232.6727	.1882	635.9870
5	7	-2.8000	1.7503	228.5398	-61.2372	24.50093	.103930	236.6019	.1913	636.3097
6	1	-2.6000	0.0000	261.5385	0.0000	24.26835	.103224	261.5385	.2118	634.5826
6	2	-2.6000	.2828	260.6401	-10.1605	24.27410	.103241	260.8381	.2112	634.6255
6	3	-2.6000	.5656	257.6824	-20.3979	24.28721	.103281	258.4885	.2093	634.7229
6	4	-2.6000	.8483	253.4832	-30.9182	24.30857	.103347	255.3619	.2067	634.8799
6	5	-2.6000	1.1311	248.1964	-41.6913	24.33957	.103441	251.6736	.2037	635.1060
6	6	-2.6000	1.4139	243.6718	-53.3323	24.36755	.103529	249.4399	.2019	635.3005
6	7	-2.6000	1.6967	244.1985	-65.4330	24.41373	.103666	252.8130	.2046	635.6645
7	1	-2.4000	0.0000	278.4914	0.0000	24.15929	.102892	278.4914	.2257	633.7704
7	2	-2.4000	.2738	277.6453	-11.4213	24.16533	.102910	277.8802	.2252	633.8158
7	3	-2.4000	.5477	274.8147	-22.8722	24.17888	.102951	275.7648	.2234	633.9175
7	4	-2.4000	.8215	270.7740	-34.4480	24.20099	.103019	272.9565	.2211	634.0822

Fig. 19. (Cont)

SOLUTION SURFACE NO. 250 - TIME = .00158004 SECONDS (DELTA T = .00000639)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
7	5	-2.4000	1.0954	265.7561	-46.0684	24.23125	.103111	269.7195	.2185	634.3078
7	6	-2.4000	1.3692	261.2414	-58.0006	24.25985	.103198	267.6026	.2167	634.5182
7	7	-2.4000	1.6431	261.1405	-69.9726	24.30876	.103348	270.3526	.2189	634.8749
8	1	-2.2000	0.0000	298.0507	0.0000	24.02767	.102492	298.0507	.2417	632.7748
8	2	-2.2000	.2649	297.2048	-12.6604	24.03422	.102512	297.4744	.2412	632.8242
8	3	-2.2000	.5298	294.3825	-25.2900	24.04948	.102559	295.4668	.2396	632.9386
8	4	-2.2000	.7947	290.2950	-37.9079	24.07409	.102634	292.7596	.2373	633.1215
8	5	-2.2000	1.0597	285.1955	-50.3223	24.10665	.102734	289.6011	.2347	633.3613
8	6	-2.2000	1.3246	280.3614	-62.7302	24.13816	.102832	287.2936	.2328	633.5836
8	7	-2.2000	1.5895	279.2868	-74.8349	24.19214	.102992	289.1390	.2342	634.0121
9	1	-2.0000	0.0000	320.5210	0.0000	23.86616	.101998	320.5210	.2602	631.5642
9	2	-2.0000	.2560	319.6255	-13.9130	23.87359	.102021	319.9282	.2597	631.6208
9	3	-2.0000	.5120	316.7277	-27.7399	23.89125	.102075	317.9401	.2580	631.7548
9	4	-2.0000	.7680	312.4191	-41.4175	23.91983	.102162	315.1526	.2557	631.9708
9	5	-2.0000	1.0239	306.9984	-54.6992	23.95666	.102274	311.8333	.2530	632.2497
9	6	-2.0000	1.2799	301.5700	-67.7157	23.99351	.102386	309.0791	.2507	632.5281
9	7	-2.0000	1.5359	299.3459	-80.2097	24.05426	.102574	309.9058	.2513	632.9679
10	1	-1.8000	0.0000	346.1351	0.0000	23.67195	.101407	346.1351	.2813	630.0807
10	2	-1.8000	.2471	345.1488	-15.2139	23.68035	.101432	345.4840	.2808	630.1446
10	3	-1.8000	.4941	342.1042	-30.2869	23.70074	.101495	343.4423	.2791	630.2992
10	4	-1.8000	.7412	337.4366	-45.0855	23.73399	.101597	340.4352	.2766	630.5491
10	5	-1.8000	.9882	331.5041	-59.3259	23.77655	.101728	336.7707	.2735	630.8657
10	6	-1.8000	1.2353	325.3022	-73.1299	23.82059	.101865	333.4209	.2707	631.1812
10	7	-1.8000	1.4823	321.7358	-86.2091	23.89036	.102072	333.0854	.2703	631.7457
11	1	-1.6000	0.0000	375.2848	0.0000	23.43545	.100680	375.2848	.3054	628.2880
11	2	-1.6000	.2381	374.1762	-16.5806	23.44506	.100709	374.5434	.3048	628.3620
11	3	-1.6000	.4762	370.9472	-32.9785	23.46852	.100781	372.4103	.3030	628.5423
11	4	-1.6000	.7144	365.8484	-49.0184	23.50726	.100900	369.1177	.3003	628.8393
11	5	-1.6000	.9525	359.3021	-64.3898	23.55699	.101052	365.0261	.2969	629.2218
11	6	-1.6000	1.1906	352.1741	-79.1577	23.61000	.101213	360.9606	.2934	629.6320
11	7	-1.6000	1.4287	347.0916	-93.0032	23.69155	.101468	359.3357	.2920	630.2204
12	1	-1.4000	0.0000	408.6835	0.0000	23.14998	.099806	408.6835	.3332	626.0707
12	2	-1.4000	.2292	407.4256	-18.0931	23.16070	.099839	407.8271	.3325	626.1534
12	3	-1.4000	.4584	403.9960	-35.9712	23.18668	.099919	405.5943	.3306	626.3527
12	4	-1.4000	.6876	398.4059	-53.4201	23.23021	.100053	401.9713	.3276	626.6845
12	5	-1.4000	.9168	391.1129	-70.0815	23.28701	.100230	397.3420	.3237	627.1124
12	6	-1.4000	1.1459	382.9039	-86.0088	23.35017	.100428	392.4448	.3196	627.5716
12	7	-1.4000	1.3751	376.0547	-100.7638	23.44620	.100713	389.3205	.3168	628.3697
13	1	-1.2000	0.0000	446.9114	0.0000	22.79188	.098697	446.9114	.3652	623.3091
13	2	-1.2000	.2203	445.5003	-19.6256	22.80420	.098735	445.9323	.3643	623.4061
13	3	-1.2000	.4405	441.9035	-39.0438	22.83305	.098824	443.6249	.3624	623.6326
13	4	-1.2000	.6608	435.8601	-58.0680	22.88257	.098977	439.7112	.3591	624.0211
13	5	-1.2000	.8810	427.8636	-76.3370	22.94889	.099180	434.6200	.3548	624.5452
13	6	-1.2000	1.1013	418.4814	-93.7589	23.02495	.099412	428.8560	.3499	625.1544
13	7	-1.2000	1.3215	409.6634	-109.7693	23.14290	.099786	424.1149	.3458	626.0021
14	1	-1.0000	0.0000	491.5962	0.0000	22.35780	.097358	491.5962	.4028	619.8496

Fig. 19. (Cont)

SOLUTION SURFACE NO. 250 - TIME = .00158004 SECONDS (DELTA T = .00000639)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
14	2	-1.0000	.2113	490.0416	-21.5126	22.37103	.097399	490.5136	.4019	619.9538
14	3	-1.0000	.4227	486.3665	-42.8395	22.40060	.097491	488.2495	.3999	620.1853
14	4	-1.0000	.6340	479.9678	-63.8293	22.45248	.097654	484.1934	.3965	620.5887
14	5	-1.0000	.8453	471.1497	-83.9617	22.52422	.097879	478.5724	.3917	621.1384
14	6	-1.0000	1.0566	460.3759	-103.1559	22.61113	.098155	471.7914	.3860	621.7787
14	7	-1.0000	1.2680	448.7798	-120.2505	22.74952	.098565	464.6111	.3797	622.9827
15	1	-.8000	0.0000	543.4576	0.0000	21.78258	.095556	543.4576	.4469	615.2878
15	2	-.8000	.2024	541.8065	-22.9514	21.79726	.095602	542.2924	.4459	615.4080
15	3	-.8000	.4048	538.2148	-45.8426	21.82731	.095696	540.1636	.4441	615.6540
15	4	-.8000	.6072	531.6365	-68.6735	21.88249	.095867	536.0536	.4406	616.1063
15	5	-.8000	.8096	522.3407	-91.1310	21.96401	.096118	530.2307	.4355	616.7838
15	6	-.8000	1.0120	510.1603	-112.8807	22.06731	.096433	522.4994	.4289	617.6629
15	7	-.8000	1.2144	496.1400	-132.9407	22.26326	.097067	513.6420	.4211	619.0765
16	1	-.6000	0.0000	605.5625	0.0000	21.09173	.093397	605.5625	.5003	609.5487
16	2	-.6000	.1935	604.0059	-25.2687	21.10536	.093440	604.5342	.4995	609.6589
16	3	-.6000	.3869	600.9720	-50.6567	21.12978	.093519	603.1032	.4982	609.8527
16	4	-.6000	.5804	595.1660	-76.5310	21.17666	.093670	600.0662	.4955	610.2206
16	5	-.6000	.7738	586.0147	-102.2219	21.25110	.093911	594.8634	.4910	610.7909
16	6	-.6000	.9673	573.3140	-128.0769	21.34925	.094236	587.4459	.4846	611.4966
16	7	-.6000	1.1608	552.6541	-148.0837	21.55719	.094848	572.1497	.4712	613.4676
17	1	-.4000	0.0000	679.6711	0.0000	20.11323	.090275	679.6711	.5654	601.3702
17	2	-.4000	.1845	678.4239	-25.3196	20.12159	.090301	678.8962	.5647	601.4455
17	3	-.4000	.3691	676.5323	-51.0948	20.12968	.090326	678.4590	.5643	601.5225
17	4	-.4000	.5536	672.1010	-77.9446	20.15207	.090395	676.6056	.5627	601.7352
17	5	-.4000	.7381	664.4030	-106.3020	20.20157	.090543	672.8532	.5593	602.2239
17	6	-.4000	.9227	649.4890	-136.3301	20.26651	.090727	663.6429	.5513	602.9382
17	7	-.4000	1.1072	627.4838	-168.1343	20.71345	.092207	649.6192	.5382	606.3436
18	1	-.2000	0.0000	767.4655	0.0000	18.96425	.086590	767.4655	.6439	591.1477
18	2	-.2000	.1756	767.4626	-26.9418	18.96126	.086582	767.9354	.6443	591.1079
18	3	-.2000	.3512	768.4391	-55.0339	18.93921	.086516	770.4073	.6465	590.8756
18	4	-.2000	.5268	769.7693	-86.4643	18.90431	.086414	774.6101	.6503	590.4761
18	5	-.2000	.7024	770.3779	-121.8521	18.88761	.086389	779.9552	.6550	590.1268
18	6	-.2000	.8780	773.6813	-175.3544	18.70584	.085867	793.3044	.6674	588.0008
18	7	-.2000	1.0536	730.3922	-195.7086	19.31069	.087723	756.1578	.6328	594.1696
19	1	.0000	0.0000	881.4584	0.0000	17.28735	.081087	881.4584	.7496	575.4447
19	2	.0000	.1667	884.5543	-21.8093	17.23803	.080927	884.8231	.7520	574.9363
19	3	.0000	.3333	892.1117	-44.5530	17.11323	.080519	893.2236	.7608	573.6657
19	4	.0000	.5000	907.0613	-69.6585	16.87605	.079745	909.7321	.7765	571.2101
19	5	.0000	.6667	929.3687	-95.5005	16.53298	.078620	934.2626	.8000	567.6021
19	6	.0000	.8333	970.5470	-136.7530	15.75891	.076038	980.1341	.8454	559.4012
19	7	.0000	1.0000	1015.2895	-147.5926	15.25511	.074087	1025.9612	.8878	555.7770
20	1	.2000	0.0000	1001.1951	0.0000	15.37076	.074562	1001.1951	.8658	556.4269
20	2	.2000	.1659	1006.4010	-10.3289	15.28366	.074257	1006.4540	.8711	555.5433
20	3	.2000	.3318	1018.3286	-20.3676	15.08446	.073558	1018.5322	.8831	553.5150
20	4	.2000	.4977	1041.3365	-28.3219	14.70744	.072226	1041.7215	.9064	549.6325
20	5	.2000	.6636	1074.0316	-29.0679	14.19269	.070386	1074.4249	.9395	544.2613
20	6	.2000	.8295	1138.2406	-40.5078	13.14606	.066596	1138.9612	1.0066	532.8177

Fig. 19. (Cont)

SOLUTION SURFACE NO. 250 - TIME = .00158004 SECONDS (DELTA T = .00000639)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
20	7	.2000	.9954	1193.3309	-27.1959	12.49727	.064252	1193.6408	1.0627	524.9982
21	1	.4000	0.0000	1100.2767	0.0000	13.73827	.068764	1100.2767	.9665	539.2595
21	2	.4000	.1658	1103.8646	-.9617	13.67991	.068553	1103.8650	.9703	538.6262
21	3	.4000	.3317	1111.9556	-1.9506	13.54884	.068076	1111.9573	.9787	537.1978
21	4	.4000	.4975	1126.1549	-2.3811	13.32025	.067244	1126.1574	.9935	534.6730
21	5	.4000	.6634	1140.5684	1.1334	13.09743	.066429	1140.5690	1.0086	532.1807
21	6	.4000	.8292	1163.5413	-.2607	12.74342	.065128	1163.5413	1.0328	528.1393
21	7	.4000	.9951	1190.9601	-2.3240	12.50181	.064269	1190.9624	1.0603	525.0491
22	1	.6000	0.0000	1150.1337	0.0000	12.90925	.065739	1150.1337	1.0191	530.0343
22	2	.6000	.1660	1151.6589	.6631	12.88676	.065657	1151.6591	1.0207	529.7717
22	3	.6000	.3319	1155.1977	1.1976	12.83498	.065468	1155.1983	1.0244	529.1703
22	4	.6000	.4979	1161.2895	1.3994	12.74344	.065133	1161.2904	1.0309	528.0999
22	5	.6000	.6639	1166.0378	2.9098	12.67230	.064872	1166.0414	1.0359	527.2654
22	6	.6000	.8299	1173.6143	2.3724	12.58639	.064552	1173.6167	1.0436	526.2847
22	7	.6000	.9958	1189.0264	4.7349	12.49750	.064253	1189.0358	1.0586	524.9972
23	1	.8000	0.0000	1199.9907	0.0000	12.08023	.062714	1199.9907	1.0736	519.9193
23	2	.8000	.1661	1199.4532	2.2879	12.09361	.062762	1199.4554	1.0729	520.1003
23	3	.8000	.3322	1198.4399	4.3458	12.12113	.062859	1198.4477	1.0716	520.4766
23	4	.8000	.4983	1196.4242	5.1799	12.16663	.063021	1196.4354	1.0692	521.0864
23	5	.8000	.6644	1191.5072	4.6861	12.24716	.063314	1191.5164	1.0637	522.1083
23	6	.8000	.8305	1183.6874	5.0055	12.42935	.063976	1183.6980	1.0545	524.3967
23	7	.8000	.9966	1187.0926	4.7272	12.49318	.064237	1187.1020	1.0569	524.9453

MASS= 1.575193 (LBM/SEC) THRUST= 44.7375 (LBF) MASSI= 1.590456 MASSE= 1.575193

Fig. 19. (Cont)

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CASE NO. 3 - CONVERGING-DIVERGING, PLUG NOZZLE (10 DEG CONE, PT/PE=3.29)
 $CNTRL LMAX=31,MMAX=6,NMAX=400,TCONV=0.005,FDT=1.25   $
 $IVS   $
 $GEMTRY NGEOM=1,XI=-4.440,XE=2.9600,RI=4.0,JFLAG=1,LJET=23   $
 $GCBL NGCB=2,RICB=1.3,RTCB=3.365,RCICB=0.75,RCTCB=4.95,
 ANGICB=45.0,ANGECB=10.0   $
 $BC PT=100.0,TT=530.0,PE=30.4   $
 $AVL   $
 $RVL   $
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Fig. 20. Case No. 3 data deck.

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VNAP, A COMPUTER PROGRAM FOR THE COMPUTATION OF TWO-DIMENSIONAL, TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERNAL FLOW

                     BY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIENTIFIC LABORATORY


PROGRAM ABSTRACT -

          THE NAVIER-STOKES EQUATIONS FOR TWO-DIMENSIONAL, TIME-DEPENDENT FLOW ARE SOLVED USING THE
     SECOND-ORDER, MACCORMACK FINITE-DIFFERENCE SCHEME. ALL BOUNDARY CONDITIONS ARE COMPUTED USING
     A SECOND-ORDER, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THE VISCOUS TERMS TREATED AS SOURCE
     FUNCTIONS.  THE FLUID IS ASSUMED TO BE A PERFECT GAS.  THE STEADY-STATE SOLUTION IS OBTAINED AS
     THE ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW BOUNDARIES MAY BE ARBITRARY CURVED SOLID WALLS
     AS WELL AS JET ENVELOPES.  PROBLEMS THAT CAN BE SOLVED ARE FLOW IN PIPES AND DUCTS, CONVERGING,
     CONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC AND SUPERSONIC INLETS, AND FREE JET EXPANSIONS.


JOB TITLE -

     CASE NO. 3 - CONVERGING-DIVERGING, PLUG NOZZLE (10 DEG CONE, PT/PE=3.29)


CONTROL PARAMETERS -

     LMAX=31  MMAX= 6   NMAX= 400  NPRINT=   0  TCONV=  .005   FDT=1.25  NSTAG=0    NASM=1    IUNIT=0
     IUI=1    IUO=1     IVPTS=1    NCONVI= 1    TSTOP=1.00000  NID= 1    NPLOT=  =1  IPUNCH=0
     RSTAR=   0.000000  RSTARS=    0.0000000    PLOW= .0100    ROLOW=    .000100


FLUID MODEL -

     THE RATIO OF SPECIFIC HEATS, GAMMA =1.4000 AND THE GAS CONSTANT, R =  53.3500 (FT-LBF/LBM-R)


FLOW GEOMETRY -

     AXISYMMETRIC FLOW HAS BEEN SPECIFIED


DUCT GEOMETRY -

     A CONSTANT AREA DUCT HAS BEEN SPECIFIED BY XI= -4.4400 (IN), RI=  4.0000 (IN), AND XE=  2.9600 (IN)

     A FREE-JET CALCULATION HAS BEEN REQUESTED.  THE WALL ENDS AT X=    .7400 (IN).  THE
     MESH POINTS L= 23 TO L= 31 ARE AN INITIAL APPROXIMATION TO THE FREE-JET BOUNDARY.

     A CIRCULAR-ARC, CONICAL CENTERBODY HAS BEEN SPECIFIED BY XICB= -4.4400 (IN), RICB=  1.3000 (IN),
     RTCB=  3.3650 (IN), XECB=  2.9600 (IN), RCICB=   .7500 (IN), RCTCB=  4.9500 (IN), ANGICB= 45.00 (DEG),
     AND ANGFCB= 10.00 (DEG). THE COMPUTED VALUES ARE XTCB=  -.0140 (IN) AND RECB=  2.9170 (IN).
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Fig. 21. Case No. 3 output.

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BOUNDARY CONDITIONS =

          M          PT(PSIA)        TT(R)        THETA(DEG)        PE(PSIA)

          1          100.0000        530.00          0.00           30.40000
          2          100.0000        530.00          0.00           30.40000
          3          100.0000        530.00          0.00           30.40000
          4          100.0000        530.00          0.00           30.40000
          5          100.0000        530.00          0.00           30.40000
          6          100.0000        530.00          0.00           30.40000

          IEXTRA=0   IEX=1   ISUPER= 0   DYW= .0010   IVBC=0

          FREE-SLIP WALLS ARE SPECIFIED

          ADIABATIC UPPER WALL IS SPECIFIED

          ADIABATIC LOWER CENTERBODY IS SPECIFIED

ARTIFICAL VISCOSITY =

          CAV=0.00   XMU= .40   XLA=1.00   RKMU= .70   XRO= .60   NST=   0   SMP= .95   LSS= 2   SMACH=0.00   IAV=1

MOLECULAR VISCOSITY =

          CMU=0.          (LBF-S/FT2),  CLA= 0.          (LBF-S/FT2),  CK=0.          (LBF/S-R),  EMU=0.00,  ELA=0.00,
          AND EK=0.00

TURBULENCE MODEL =

          NO MODEL IS SPECIFIED


N=    10,  T= .00006599 SECONDS,  DT= .00000620 SECONDS
N=    20,  T= .00012658 SECONDS,  DT= .00000605 SECONDS
N=    30,  T= .00019081 SECONDS,  DT= .00000683 SECONDS
N=    40,  T= .00025939 SECONDS,  DT= .00000674 SECONDS
N=    50,  T= .00032789 SECONDS,  DT= .00000703 SECONDS
N=    60,  T= .00039772 SECONDS,  DT= .00000699 SECONDS
N=    70,  T= .00046736 SECONDS,  DT= .00000689 SECONDS
N=    80,  T= .00053649 SECONDS,  DT= .00000701 SECONDS
N=    90,  T= .00060643 SECONDS,  DT= .00000692 SECONDS
N=   100,  T= .00067550 SECONDS,  DT= .00000693 SECONDS
N=   110,  T= .00074473 SECONDS,  DT= .00000693 SECONDS
N=   120,  T= .00081438 SECONDS,  DT= .00000698 SECONDS
N=   130,  T= .00088387 SECONDS,  DT= .00000692 SECONDS
N=   140,  T= .00095282 SECONDS,  DT= .00000690 SECONDS
N=   150,  T= .00102240 SECONDS,  DT= .00000698 SECONDS
N=   160,  T= .00109217 SECONDS,  DT= .00000695 SECONDS
N=   170,  T= .00116141 SECONDS,  DT= .00000692 SECONDS
N=   180,  T= .00123106 SECONDS,  DT= .00000699 SECONDS
N=   190,  T= .00130076 SECONDS,  DT= .00000694 SECONDS
N=   200,  T= .00137004 SECONDS,  DT= .00000693 SECONDS
N=   210,  T= .00143949 SECONDS,  DT= .00000695 SECONDS
N=   220,  T= .00150898 SECONDS,  DT= .00000695 SECONDS
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Fig. 21. (Cont)

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N=   230,   T= .00157841 SECONDS,   DT= .00000694 SECONDS
N=   240,   T= .00164785 SECONDS,   DT= .00000694 SECONDS
N=   250,   T= .00171733 SECONDS,   DT= .00000695 SECONDS
N=   260,   T= .00178687 SECONDS,   DT= .00000695 SECONDS
N=   270,   T= .00185634 SECONDS,   DT= .00000695 SECONDS
N=   280,   T= .00192584 SECONDS,   DT= .00000695 SECONDS
N=   290,   T= .00199533 SECONDS,   DT= .00000695 SECONDS
N=   300,   T= .00206483 SECONDS,   DT= .00000695 SECONDS
N=   310,   T= .00213433 SECONDS,   DT= .00000695 SECONDS
```

Fig. 21. (Cont)

SOLUTION SURFACE NO. 316 - TIME = .00217601 SECONDS (DELTA T = .00000695)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
1	1	-4.4400	1.3000	71.5652	0.0000	99.71865	.508251	71.5652	.0634	529.5735
1	2	-4.4400	1.8400	123.4776	0.0000	99.16420	.506231	123.4776	.1095	528.7306
1	3	-4.4400	2.3800	199.9893	0.0000	97.81738	.501310	199.9893	.1778	526.6688
1	4	-4.4400	2.9200	237.1279	0.0000	96.94227	.498103	237.1279	.2111	525.3183
1	5	-4.4400	3.4600	268.8863	0.0000	96.08790	.494963	268.8863	.2396	523.9913
1	6	-4.4400	4.0000	271.2122	0.0000	96.01969	.494712	271.2122	.2417	523.8850
2	1	-4.1933	1.3417	70.4222	24.5255	99.46744	.507325	74.5707	.0661	529.2034
2	2	-4.1933	1.8734	122.7668	24.8445	98.95158	.505444	125.2555	.1112	528.4182
2	3	-4.1933	2.4050	200.4593	20.5977	97.66848	.500766	201.5148	.1792	526.4381
2	4	-4.1933	2.9367	237.6544	13.7478	96.90321	.497960	238.0517	.2119	525.2573
2	5	-4.1933	3.4683	269.4206	6.6767	96.10851	.495040	269.5034	.2402	524.0225
2	6	-4.1933	4.0000	271.8219	0.0000	96.07381	.494911	271.8219	.2422	523.9699
3	1	-3.9467	1.4851	81.5556	71.2223	99.32400	.506813	108.2771	.0960	528.9747
3	2	-3.9467	1.9881	136.7052	57.8982	98.76654	.504792	148.4604	.1318	528.1116
3	3	-3.9467	2.4911	213.5828	47.3585	97.38742	.499754	218.7702	.1946	525.9860
3	4	-3.9467	2.9940	246.1233	29.7337	96.69102	.497185	247.9128	.2207	524.9236
3	5	-3.9467	3.4970	275.7695	14.5197	95.95157	.494464	276.1514	.2461	523.7757
3	6	-3.9467	4.0000	277.2779	0.0000	95.94592	.494441	277.2779	.2472	523.7696
4	1	-3.7000	1.7293	111.2422	111.2423	98.52275	.503882	157.3203	.1397	527.7594
4	2	-3.7000	2.1835	165.3145	80.6785	97.93840	.501756	183.9508	.1635	526.8513
4	3	-3.7000	2.6376	234.3154	65.1677	96.74384	.497395	243.2088	.2165	524.9887
4	4	-3.7000	3.0917	260.0687	39.1250	96.23197	.495496	262.9952	.2343	524.2127
4	5	-3.7000	3.5459	285.4306	19.5120	95.65705	.493380	286.0967	.2551	523.3158
4	6	-3.7000	4.0000	286.0270	0.0000	95.69215	.493506	286.0270	.2550	523.3742
5	1	-3.4533	1.9750	150.3559	145.2617	97.63324	.500637	209.0642	.1859	526.3841
5	2	-3.4533	2.3800	199.0033	102.2124	97.11654	.498763	223.7179	.1991	525.5662
5	3	-3.4533	2.7850	257.6974	80.5386	96.13076	.495150	269.9897	.2406	524.0275
5	4	-3.4533	3.1900	277.4089	47.9548	95.72858	.493647	281.5232	.2510	523.4239
5	5	-3.4533	3.5950	298.8340	23.9471	95.27279	.491966	299.7920	.2675	522.7116
5	6	-3.4533	4.0000	298.9271	0.0000	95.32474	.492153	298.9271	.2667	522.7978
6	1	-3.2067	2.1978	195.4426	164.9554	96.37815	.496028	255.7500	.2278	524.4456
6	2	-3.2067	2.5582	235.8197	116.1808	96.01075	.494701	262.8858	.2343	523.8483
6	3	-3.2067	2.9187	283.5567	89.5741	95.29681	.492076	297.3683	.2653	522.7261
6	4	-3.2067	3.2791	298.6672	53.5208	95.01443	.491013	303.4248	.2708	522.3061
6	5	-3.2067	3.6396	316.1365	26.6263	94.68383	.489791	317.2558	.2833	521.7863
6	6	-3.2067	4.0000	316.1408	0.0000	94.74711	.490020	316.1408	.2823	521.8912
7	1	-2.9600	2.3929	238.7180	176.7947	95.19199	.491663	297.0566	.2651	522.5897
7	2	-2.9600	2.7143	272.0034	127.5662	94.93328	.490740	300.4313	.2682	522.1499
7	3	-2.9600	3.0357	311.1932	96.4764	94.42215	.488849	325.8050	.2911	521.3471
7	4	-2.9600	3.3571	323.0878	58.5921	94.20107	.488010	328.3577	.2935	521.0207
7	5	-2.9600	3.6786	337.4561	28.8926	93.94936	.487077	338.6907	.3028	520.6240
7	6	-2.9600	4.0000	337.5862	0.0000	94.01219	.487304	337.5862	.3018	520.7294
8	1	-2.7133	2.5642	284.1826	184.8803	93.79582	.486502	339.0288	.3032	520.3873
8	2	-2.7133	2.8514	310.8413	135.2572	93.65256	.486008	338.9938	.3032	520.1211
8	3	-2.7133	3.1385	342.9186	100.7327	93.30312	.484705	357.4076	.3199	519.5732

Fig. 21. (Cont)

SOLUTION SURFACE NO. 316 - TIME = .00217601 SECONDS (DELTA T = .00000695)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
8	4	-2.7133	3.4257	352.0190	61.9954	93.14113	.484084	357.4364	.3200	519.3369
8	5	-2.7133	3.7128	363.6221	30.3525	92.96048	.483411	364.8867	.3267	519.0506
8	6	-2.7133	4.0000	363.8652	0.0000	93.02225	.483634	363.8652	.3258	519.1560
9	1	-2.4667	2.7146	331.4001	189.0440	92.23745	.480718	381.5281	.3420	517.8988
9	2	-2.4667	2.9717	352.3859	139.8713	92.19150	.480588	379.1304	.3399	517.7812
9	3	-2.4667	3.2288	378.5588	103.2049	91.96707	.479741	392.3749	.3519	517.4328
9	4	-2.4667	3.4859	385.2594	64.3101	91.85464	.479302	390.5900	.3503	517.2729
9	5	-2.4667	3.7429	394.6036	31.3492	91.72977	.478835	395.8469	.3551	517.0741
9	6	-2.4667	4.0000	394.8954	0.0000	91.78999	.479052	394.8954	.3542	517.1785
10	1	-2.2200	2.8463	382.2114	190.2770	90.37401	.473766	426.9554	.3838	514.8824
10	2	-2.2200	3.0770	398.1309	141.8539	90.41719	.473971	422.6473	.3800	514.9054
10	3	-2.2200	3.3078	419.2070	104.0440	90.30007	.473518	431.9255	.3884	514.7303
10	4	-2.2200	3.5385	423.6886	65.4081	90.24300	.473285	428.7076	.3855	514.6577
10	5	-2.2200	3.7693	431.0499	31.8286	90.17101	.473013	432.2234	.3887	514.5430
10	6	-2.2200	4.0000	431.2863	0.0000	90.23248	.473236	431.2863	.3878	514.6520
11	1	-1.9733	2.9607	437.4808	188.5688	88.13104	.465344	476.3902	.4298	511.1907
11	2	-1.9733	3.1686	448.7429	141.3148	88.26827	.465907	470.4680	.4244	511.3681
11	3	-1.9733	3.3764	465.1931	103.2395	88.25838	.465853	476.5113	.4299	511.3702
11	4	-1.9733	3.5843	467.5629	65.3333	88.26354	.465854	472.1054	.4259	511.3991
11	5	-1.9733	3.7921	473.1561	31.7969	88.24275	.465772	474.2233	.4278	511.3678
11	6	-1.9733	4.0000	473.2432	0.0000	88.30844	.466012	473.2432	.4269	511.4853
12	1	-1.7267	3.0593	498.3165	183.7661	85.40109	.455015	531.1208	.4814	506.6011
12	2	-1.7267	3.2474	505.0687	138.1822	85.64936	.456005	523.6303	.4744	506.9702
12	3	-1.7267	3.4356	517.1731	100.6659	85.75239	.456378	526.8791	.4773	507.1653
12	4	-1.7267	3.6237	517.4779	64.0140	85.82776	.456646	521.4223	.4722	507.3131
12	5	-1.7267	3.8119	521.4267	31.1935	85.85847	.456759	522.3569	.4731	507.3688
12	6	-1.7267	4.0000	521.2858	0.0000	85.93116	.457026	521.2858	.4720	507.5021
13	1	-1.4800	3.1429	565.2946	175.2843	82.10507	.442418	591.8467	.5394	500.9163
13	2	-1.4800	3.3143	567.5627	132.1042	82.48798	.443936	582.7341	.5308	501.5314
13	3	-1.4800	3.4858	575.4689	96.0464	82.71360	.444783	583.4290	.5312	501.9463
13	4	-1.4800	3.6572	573.7079	61.3123	82.86740	.445354	576.9749	.5252	502.2341
13	5	-1.4800	3.8286	576.0950	29.9288	82.95027	.445668	576.8719	.5250	502.3823
13	6	-1.4800	4.0000	575.6637	0.0000	83.03159	.445972	575.6637	.5238	502.5324
14	1	-1.2333	3.2125	638.7887	162.3581	78.16380	.427173	659.0987	.6050	493.8895
14	2	-1.2333	3.3700	636.5269	122.5899	78.70871	.429341	648.2244	.5945	494.8209
14	3	-1.2333	3.5275	640.3164	89.0415	79.06855	.430720	646.4777	.5924	495.4926
14	4	-1.2333	3.6850	636.4704	57.0361	79.31007	.431640	639.0209	.5853	495.9469
14	5	-1.2333	3.8425	637.3452	27.8988	79.44612	.432163	637.9555	.5842	496.1958
14	6	-1.2333	4.0000	636.5781	0.0000	79.53728	.432506	636.5781	.5829	496.3714
15	1	-.9867	3.2685	718.6933	144.0327	73.52928	.408961	732.9839	.6787	485.2956
15	2	-.9867	3.4148	711.8479	109.0031	74.26571	.411922	720.1452	.6659	486.6332
15	3	-.9867	3.5611	711.5829	79.2100	74.77440	.413910	715.9779	.6614	487.6132
15	4	-.9867	3.7074	705.6152	50.9290	75.11437	.415232	707.4507	.6531	488.2706
15	5	-.9867	3.8537	705.0211	24.9675	75.30605	.415982	705.4630	.6510	488.6339
15	6	-.9867	4.0000	703.8801	0.0000	75.40745	.416374	703.8801	.6494	488.8308

Fig. 21. (Cont)

SOLUTION SURFACE NO. 316 - TIME = .00217601 SECONDS (DELTA T = .00000695)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
16	1	-.7400	3.3115	804.4291	119.2757	68.19629	.387610	813.2238	.7613	474.8905
16	2	-.7400	3.4492	793.0072	90.6366	69.15333	.391521	798.1701	.7457	476.7450
16	3	-.7400	3.5869	788.7592	66.0715	69.82658	.394210	791.5217	.7384	478.1022
16	4	-.7400	3.7246	780.6709	42.6956	70.27658	.396001	781.8375	.7287	479.0082
16	5	-.7400	3.8623	778.6408	20.9920	70.52669	.396998	778.9238	.7256	479.5047
16	6	-.7400	4.0000	777.1101	0.0000	70.63933	.397435	777.1101	.7238	479.7424
17	1	-.4933	3.3417	894.8500	87.0651	62.23258	.363138	899.0756	.8528	462.5663
17	2	-.4933	3.4734	878.9476	66.7971	63.43505	.368161	881.4821	.8338	465.0711
17	3	-.4933	3.6050	870.8826	49.1398	64.28736	.371654	872.2678	.8235	466.8902
17	4	-.4933	3.7367	860.6876	32.0534	64.85708	.373977	861.2842	.8121	468.1023
17	5	-.4933	3.8683	857.2881	15.8249	65.16901	.375250	857.4341	.8079	468.7575
17	6	-.4933	4.0000	855.3526	0.0000	65.29279	.375756	855.3526	.8057	469.0153
18	1	-.2467	3.3595	988.1282	46.5002	55.78166	.335942	989.2217	.9532	448.1834
18	2	-.2467	3.4876	968.0859	36.8706	57.24588	.342231	968.7877	.9301	451.4950
18	3	-.2467	3.6157	956.4303	28.0257	58.28625	.346621	956.8408	.9162	453.8783
18	4	-.2467	3.7438	944.2743	18.7469	58.90340	.349548	944.4604	.9028	455.4613
18	5	-.2467	3.8719	939.6176	9.3521	59.35866	.351121	939.6642	.8973	456.3045
18	6	-.2467	4.0000	937.3318	0.0000	59.49535	.351666	937.3318	.8948	456.6476
19	1	.0000	3.3650	1082.5310	-3.0579	49.08608	.306616	1082.5353	1.0623	432.1069
19	2	.0000	3.4920	1058.7009	.4913	50.81290	.314291	1058.7010	1.0338	436.3857
19	3	.0000	3.6190	1043.8699	2.4124	52.04197	.319668	1043.8726	1.0158	439.4341
17	4	.0000	3.7460	1029.9397	2.6162	52.86205	.323217	1029.9430	1.0000	441.4461
19	5	.0000	3.8730	1024.0864	1.5076	53.29870	.325107	1024.0875	.9931	442.5052
19	6	.0000	4.0000	1021.3318	0.0000	53.44503	.325774	1021.3318	.9901	442.8121
20	1	.2467	3.3581	1172.2938	-61.8146	42.41376	.276464	1173.9224	1.1768	414.0908
20	2	.2467	3.4865	1146.3264	-42.3075	44.40104	.285641	1147.1069	1.1424	419.5657
20	3	.2467	3.6149	1129.2709	-27.2147	45.81150	.292034	1129.5987	1.1198	423.4178
20	4	.2467	3.7433	1113.7058	-15.7798	46.76510	.296316	1113.8175	1.1009	425.9861
20	5	.2467	3.8716	1106.7908	-7.3402	47.27951	.298612	1106.8152	1.0922	427.3606
20	6	.2467	4.0000	1104.2970	0.0000	47.46057	.299299	1104.2970	1.0889	428.0121
21	1	.4933	3.3389	1270.4821	-130.8986	35.64954	.243988	1277.2075	1.3120	394.3794
21	2	.4933	3.4711	1239.4578	-92.4747	37.81669	.254489	1242.9028	1.2660	401.0911
21	3	.4933	3.6034	1220.0870	-61.8452	39.44905	.262231	1221.6535	1.2367	406.0515
21	4	.4933	3.7356	1202.4466	-37.7250	40.61974	.267702	1203.0382	1.2127	409.5564
21	5	.4933	3.8678	1194.1855	-18.1823	41.25108	.270654	1194.3239	1.2012	411.3857
21	6	.4933	4.0000	1188.9044	0.0000	41.42354	.271747	1188.9044	1.1957	411.4436
22	1	.7400	3.3072	1332.4334	-205.3521	30.92980	.220332	1348.1647	1.4128	378.9019
22	2	.7400	3.4458	1306.0482	-154.9676	32.83008	.230063	1315.2098	1.3671	385.1703
22	3	.7400	3.5843	1287.3991	-111.7255	34.41880	.238098	1292.2380	1.3345	390.1829
22	4	.7400	3.7229	1271.4006	-73.1014	35.48967	.243548	1273.5004	1.3099	393.3201
22	5	.7400	3.8614	1265.7087	-37.8336	35.93543	.245833	1266.2740	1.3004	394.5582
22	6	.7400	4.0000	1269.3050	0.0000	35.88808	.244805	1269.3050	1.3017	395.6928
23	1	.9867	3.2649	1381.9673	-243.6781	27.40847	.201980	1403.2864	1.4958	366.2729
23	2	.9867	3.4119	1373.6494	-188.0385	28.30930	.206820	1386.4599	1.4714	369.4575
23	3	.9867	3.5590	1370.6477	-131.2142	29.00507	.210534	1376.9140	1.4566	371.8595
23	4	.9867	3.7060	1368.9781	-72.0024	29.30243	.211990	1370.8703	1.4478	373.0927

Fig. 21. (Cont)

SOLUTION SURFACE NO. 316 - TIME = .00217601 SECONDS (DELTA T = .00000695)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
23	5	.9867	3.8530	1370.4512	-16.4666	29.54203	.213010	1370.5501	1.4450	374.3347
23	6	.9867	4.0000	1350.4202	.1471	30.41098	.217498	1350.4202	1.4180	377.4013
24	1	1.2333	3.2214	1427.8238	-251.7639	24.57586	.186972	1449.8503	1.5702	354.7816
24	2	1.2333	3.3749	1431.6659	-197.1552	24.84357	.188435	1445.1772	1.5628	355.8605
24	3	1.2333	3.5283	1435.9227	-140.1639	25.13012	.189854	1442.7474	1.5571	357.2744
24	4	1.2333	3.6818	1425.0181	-95.1488	25.93527	.194042	1428.1912	1.5339	360.7642
24	5	1.2333	3.8352	1394.0066	-71.3453	27.97215	.204807	1395.8311	1.4830	368.6462
24	6	1.2333	3.9886	1350.7690	-62.3119	30.40474	.217466	1352.2054	1.4199	377.3798
25	1	1.4800	3.1779	1473.1129	-259.7496	21.74939	.170953	1495.8380	1.6467	343.3980
25	2	1.4800	3.3356	1475.5512	-203.0855	22.03956	.172597	1489.4613	1.6366	344.6664
25	3	1.4800	3.4932	1468.1482	-162.0541	23.06282	.178325	1477.0649	1.6127	349.0818
25	4	1.4800	3.6509	1433.9704	-145.1213	25.20851	.190094	1441.2951	1.5541	357.9376
25	5	1.4800	3.8085	1394.2732	-133.0172	27.78247	.203805	1400.6039	1.4895	367.9454
25	6	1.4800	3.9662	1343.8149	-122.5255	30.39680	.217426	1349.3891	1.4170	377.3509
26	1	1.7267	3.1344	1512.7460	-266.7380	20.06399	.162150	1536.0825	1.7146	333.9858
26	2	1.7267	3.2938	1502.0108	-253.6951	20.72534	.165796	1523.2852	1.6917	337.4077
26	3	1.7267	3.4532	1462.5104	-245.4370	22.97005	.178137	1482.9619	1.6215	348.0463
26	4	1.7267	3.6126	1417.1658	-232.1042	25.59962	.192291	1436.0471	1.5454	359.3371
26	5	1.7267	3.7719	1376.8644	-212.8900	28.16796	.205839	1393.2256	1.4788	369.3644
26	6	1.7267	3.9313	1338.8667	-189.1584	30.42205	.217553	1352.1630	1.4198	377.4435
27	1	1.9733	3.0909	1441.4752	-254.1710	23.44212	.179546	1463.7123	1.5906	352.4108
27	2	1.9733	3.2504	1430.3778	-272.7781	23.60212	.180682	1456.1554	1.5819	352.5853
27	3	1.9733	3.4098	1409.8747	-278.8182	24.94980	.188395	1437.1799	1.5507	357.4587
27	4	1.9733	3.5692	1389.5684	-267.0506	26.49092	.196829	1414.9969	1.5144	363.2751
27	5	1.9733	3.7286	1366.1342	-249.1654	28.29739	.206457	1388.6707	1.4728	369.9512
27	6	1.9733	3.8880	1330.6463	-233.6961	30.42632	.217584	1351.0120	1.4186	377.4431
28	1	2.2200	3.0475	1435.7701	-253.1650	23.88563	.185053	1457.9192	1.5934	348.3920
28	2	2.2200	3.2046	1424.4754	-307.9838	23.87634	.184528	1457.3895	1.5908	349.2470
28	3	2.2200	3.3618	1404.2224	-336.0508	24.79763	.188759	1443.8735	1.5642	354.5935
28	4	2.2200	3.5190	1379.2322	-334.0915	26.30716	.196396	1419.1190	1.5225	361.5515
28	5	2.2200	3.6762	1349.6346	-320.2399	28.44187	.207374	1387.1074	1.4707	370.1963
28	6	2.2200	3.8334	1311.5685	-290.0971	30.41180	.217489	1343.2678	1.4105	377.4267
29	1	2.4667	3.0040	1277.1966	-225.2042	34.19650	.236995	1296.8994	1.3406	389.4666
29	2	2.4667	3.1571	1287.2018	-283.3683	32.86765	.230462	1318.0235	1.3704	384.9433
29	3	2.4667	3.3103	1300.6510	-335.6970	31.34751	.222573	1343.2741	1.4054	380.1537
29	4	2.4667	3.4635	1303.0917	-364.4432	30.59275	.218437	1353.0953	1.4197	378.0256
29	5	2.4667	3.6167	1301.8375	-365.3886	30.68628	.218802	1352.1426	1.4177	378.5487
29	6	2.4667	3.7698	1313.6555	-338.5974	30.41777	.217564	1356.5909	1.4246	377.3714
30	1	2.7133	2.9605	1201.7574	-211.9023	39.32233	.261010	1220.2965	1.2345	406.6407
30	2	2.7133	3.1112	1218.6338	-234.2473	38.16700	.255566	1240.9432	1.2608	403.0994
30	3	2.7133	3.2618	1251.3560	-265.1588	35.70539	.243670	1279.1407	1.3121	395.5128
30	4	2.7133	3.4125	1281.4713	-293.9015	33.06514	.230711	1314.7421	1.3636	386.8396
30	5	2.7133	3.5632	1310.1811	-306.5315	30.96384	.220214	1345.5616	1.4090	379.5221
30	6	2.7133	3.7139	1327.1021	-300.8944	30.41170	.217482	1360.7856	1.4288	377.4386
31	1	2.9600	2.9170	1126.3182	-198.6003	44.44816	.285024	1143.6935	1.1372	420.9208

Fig. 21. (Cont)

SOLUTION SURFACE NO. 316 - TIME = .00217601 SECONDS (DELTA T = .00000695)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT3)	VMAG (F/S)	MACH NO	T (R)
31	2	2.9600	3.0652	1150.0658	-185.1262	43.46634	.280671	1164.8704	1.1623	418.0075
31	3	2.9600	3.2134	1202.0611	-194.6206	40.06326	.264766	1217.7142	1.2292	408.4242
31	4	2.9600	3.3616	1259.8510	-223.3598	35.53752	.242985	1279.4976	1.3137	394.7631
31	5	2.9600	3.5098	1318.5247	-247.6743	31.24141	.221627	1341.5848	1.4030	380.4832
31	6	2.9600	3.6580	1340.5488	-303.9432	30.40563	.217399	1374.5736	1.4432	377.5058

MASS= 33.969294 (LBM/SEC)   THRUST= 1350.7465 (LBF)   MASSI= 33.877122   MASSE= 33.822534

Fig. 21. (Cont)

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CASE NO. 4 - CONVERGING-DIVERGING VISCOUS NOZZLE (RE*=1200.0)
 $CNTRL LMAX=80,MMAX=21,NMAX=1000,RGAS=287.0,IUI=2,IUO=2,NPLOT=50    $
 $IVS    $
 $GEMTRY NDIM=0,NGEOM=3,NWPTS=37,
 XWI=-0.381,-0.3175,-0.254,-0.1905,-0.127,-0.0762,-0.0508,-0.0254,
 0.0,0.0635,0.127,0.1905,0.254,0.3175,0.381,0.4445,0.508,0.5715,
 0.635,0.6985,0.762,0.8255,0.889,0.9525,1.016,1.0795,1.143,1.2065,
 1.27,1.3335,1.397,1.4605,1.524,1.5875,1.651,1.7145,2.355266,
 YWI=0.22606,0.2032,0.1778,0.14986,0.11684,0.0889,0.07409,0.06607,
 0.0635,0.1143,0.1651,0.20828,0.24892,0.28702,0.32258,0.35052,0.381,
 0.4064,0.42672,0.44704,0.46482,0.47752,0.49022,0.50292,0.51562,
 0.52832,0.54102,0.55372,0.56642,0.57912,0.59182,0.60452,0.61722,
 0.62992,0.64262,0.65532,0.78346    $
 $GCBL $
 $BC NSTAG=1,PT=21*6.895,TT=21*289.0,IEXTRA=1,NOSLIP=1,
 THETA=0.0,1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0,11.0,12.0,13.0,
 14.0,15.0,16.0,17.0,18.0,19.0,19.8,
 TW=80*289.0    $
 $AVL NST=50,SMP=0.5    $
 $RVL CMU=9.643E-07,CLA=-6.429E-07,CK=1.217E-03,EMU=0.5,ELA=0.5,EK=0.5    $
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Fig. 22. Case No. 4 data deck.

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VNAP, A COMPUTER PROGRAM FOR THE COMPUTATION OF TWO-DIMENSIONAL, TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERNAL FLOW

                    BY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIENTIFIC LABORATORY


PROGRAM ABSTRACT -

          THE NAVIER-STOKES EQUATIONS FOR TWO-DIMENSIONAL, TIME-DEPENDENT FLOW ARE SOLVED USING THE
      SECOND-ORDER, MACCORMACK FINITE-DIFFERENCE SCHEME. ALL BOUNDARY CONDITIONS ARE COMPUTED USING
      A SECOND-ORDER, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THE VISCOUS TERMS TREATED AS SOURCE
      FUNCTIONS.  THE FLUID IS ASSUMED TO BE A PERFECT GAS.  THE STEADY-STATE SOLUTION IS OBTAINED AS
      THE ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW BOUNDARIES MAY BE ARBITRARY CURVED SOLID WALLS
      AS WELL AS JET ENVELOPES.  PROBLEMS THAT CAN BE SOLVED ARE FLOW IN PIPES AND DUCTS, CONVERGING,
      CONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC AND SUPERSONIC INLETS, AND FREE JET EXPANSIONS.

JOB TITLE -

      CASE NO. 4 - CONVERGING-DIVERGING VISCOUS NOZZLE (RE*=1200.0)

CONTROL PARAMETERS -

      LMAX=80   MMAX=21   NMAX=1000  NPRINT=   0  TCONV= 0.000   FDT=1.00  NSTAG=1     NASM=1    IUNIT=0
      IUI=2     IUO=2     IVPTS=1    NCONVI= 1    TSTOP=1.00000  N1D= 1    NPLOT=  50  IPUNCH=0
      RSTAR=    0.000000  RSTARS=    0.0000000    PLOW= .0100    ROLOW=    .000100

FLUID MODEL -

      THE RATIO OF SPECIFIC HEATS, GAMMA =1.4000 AND THE GAS CONSTANT, R = 287.0000 (J/KG-K)

FLOW GEOMETRY -

      TWO-DIMENSIONAL, PLANAR FLOW HAS BEEN SPECIFIED
```

Fig. 23. Case No. 4 output.

DUCT GEOMETRY -

A GENERAL WALL HAS BEEN SPECIFIED BY THE FOLLOWING PARAMETERS, XT= 0.0000 (CM), RT= .0635 (CM), IINT=2, IDIF=2,

L	XWI(CM)	YWI(CM)	XW(CM)	YW(CM)	SLOPE
1	-.3810	.2261	-.3810	.2261	-.3400
2	-.3175	.2032	-.3464	.2139	-.3618
3	-.2540	.1778	-.3117	.2010	-.3836
4	-.1905	.1499	-.2771	.1873	-.4061
5	-.1270	.1168	-.2425	.1729	-.4214
6	-.0762	.0889	-.2078	.1580	-.4525
7	-.0508	.0741	-.1732	.1414	-.5085
8	-.0254	.0661	-.1385	.1230	-.5335
9	0.0000	.0635	-.1039	.1044	-.5714
10	.0635	.1143	-.0693	.0842	-.5510
11	.1270	.1651	-.0346	.0684	-.3420
12	.1905	.2083	-.0000	.0635	.1612
13	.2540	.2489	.0346	.0811	.8762
14	.3175	.2870	.0693	.1189	1.0140
15	.3810	.3226	.1039	.1475	.7726
16	.4445	.3505	.1385	.1735	.7056
17	.5080	.3810	.1732	.1968	.6606
18	.5715	.4064	.2078	.2196	.6500
19	.6350	.4267	.2425	.2417	.6273
20	.6985	.4470	.2771	.2631	.6055
21	.7620	.4648	.3117	.2837	.5836
22	.8255	.4775	.3464	.3035	.5700
23	.8890	.4902	.3810	.3226	.4873
24	.9525	.5029	.4156	.3375	.4279
25	1.0160	.5156	.4503	.3532	.4826
26	1.0795	.5283	.4849	.3705	.4812
27	1.1430	.5410	.5195	.3860	.4247
28	1.2065	.5537	.5542	.4000	.3827
29	1.2700	.5664	.5888	.4124	.3279
30	1.3335	.5791	.6235	.4230	.3079
31	1.3970	.5918	.6581	.4341	.3253
32	1.4605	.6045	.6927	.4453	.3100
33	1.5240	.6172	.7274	.4554	.2852
34	1.5875	.6299	.7620	.4648	.2336
35	1.6510	.6426	.7966	.4717	.1941
36	1.7145	.6553	.8313	.4787	.2000
37	2.3553	.7835	.8659	.4856	.2000
38			.9005	.4925	.2000
39			.9352	.4995	.2000
40			.9698	.5064	.2000
41			1.0045	.5133	.2000
42			1.0391	.5202	.2000
43			1.0737	.5272	.2000
44			1.1084	.5341	.2000
45			1.1430	.5410	.2000
46			1.1776	.5479	.2000
47			1.2123	.5549	.2000
48			1.2469	.5618	.2000
49			1.2815	.5687	.2000
50			1.3162	.5757	.2000
51			1.3508	.5826	.2000

Fig. 23. (Cont)

52	1.3855	.5895	.2000
53	1.4201	.5964	.2000
54	1.4547	.6034	.2000
55	1.4894	.6103	.2000
56	1.5240	.6172	.2000
57	1.5586	.6241	.2000
58	1.5933	.6311	.2000
59	1.6279	.6380	.2000
60	1.6625	.6449	.2000
61	1.6972	.6519	.2000
62	1.7318	.6588	.2000
63	1.7664	.6657	.2000
64	1.8011	.6726	.2000
65	1.8357	.6796	.2000
66	1.8704	.6865	.2000
67	1.9050	.6934	.2000
68	1.9396	.7003	.2000
69	1.9743	.7073	.2000
70	2.0089	.7142	.2000
71	2.0435	.7211	.2000
72	2.0782	.7281	.2000
73	2.1128	.7350	.2000
74	2.1474	.7419	.2000
75	2.1821	.7488	.2000
76	2.2167	.7558	.2000
77	2.2514	.7627	.2000
78	2.2860	.7696	.2000
79	2.3206	.7765	.2000
80	2.3553	.7835	.2000

Fig. 23. (Cont)

BOUNDARY CONDITIONS =

M	PT(KPA)	TT(K)	THETA(DEG)	PE(KPA)
1	6.8950	289.00	0.00	14.70000
2	6.8950	289.00	1.00	14.70000
3	6.8950	289.00	2.00	14.70000
4	6.8950	289.00	3.00	14.70000
5	6.8950	289.00	4.00	14.70000
6	6.8950	289.00	5.00	14.70000
7	6.8950	289.00	6.00	14.70000
8	6.8950	289.00	7.00	14.70000
9	6.8950	289.00	8.00	14.70000
10	6.8950	289.00	9.00	14.70000
11	6.8950	289.00	10.00	14.70000
12	6.8950	289.00	11.00	14.70000
13	6.8950	289.00	12.00	14.70000
14	6.8950	289.00	13.00	14.70000
15	6.8950	289.00	14.00	14.70000
16	6.8950	289.00	15.00	14.70000
17	6.8950	289.00	16.00	14.70000
18	6.8950	289.00	17.00	14.70000
19	6.8950	289.00	18.00	14.70000
20	6.8950	289.00	19.00	14.70000
21	6.8950	289.00	19.80	14.70000

IEXTRA=1 IEX=1 ISUPER= 0 DYW= .0010 IVBC=0

NO-SLIP WALLS ARE SPECIFIED

TW IS SPECIFIED

ARTIFICAL VISCOSITY =

CAV=0.00 XMU= .40 XLA=1.00 RKMU= .70 XRO= .60 NST= 50 SMP= .50 LSS= 2 SMACH=0.00 IAV=1

MOLECULAR VISCOSITY =

CMU= .9643E-06 (PA-S), CLA= -.6429E-06 (PA-S), CK= .1217E-02 (W/M-K), EMU= .50, ELA= .50, AND EK= .50

TURBULENCE MODEL =

NO MODEL IS SPECIFIED

***** EXPECT FILM OUTPUT FOR N= 0 *****

```
N=    10,  T= .00000078 SECONDS,  DT= .00000008 SECONDS
N=    20,  T= .00000164 SECONDS,  DT= .00000009 SECONDS
N=    30,  T= .00000251 SECONDS,  DT= .00000009 SECONDS
N=    40,  T= .00000338 SECONDS,  DT= .00000009 SECONDS
N=    50,  T= .00000424 SECONDS,  DT= .00000009 SECONDS
```

***** EXPECT FILM OUTPUT FOR N= 50 *****

Fig. 23. (Cont)

```
          N=    60,  T= .00000508 SECONDS,  DT= .00000008 SECONDS
          N=    70,  T= .00000587 SECONDS,  DT= .00000008 SECONDS
          N=    80,  T= .00000668 SECONDS,  DT= .00000008 SECONDS
          N=    90,  T= .00000748 SECONDS,  DT= .00000008 SECONDS
          N=   100,  T= .00000825 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   100 *****
          N=   110,  T= .00000900 SECONDS,  DT= .00000008 SECONDS
          N=   120,  T= .00000976 SECONDS,  DT= .00000008 SECONDS
          N=   130,  T= .00001052 SECONDS,  DT= .00000008 SECONDS
          N=   140,  T= .00001128 SECONDS,  DT= .00000008 SECONDS
          N=   150,  T= .00001203 SECONDS,  DT= .00000007 SECONDS

***** EXPECT FILM OUTPUT FOR N=   150 *****
          N=   160,  T= .00001277 SECONDS,  DT= .00000007 SECONDS
          N=   170,  T= .00001350 SECONDS,  DT= .00000007 SECONDS
          N=   180,  T= .00001424 SECONDS,  DT= .00000007 SECONDS
          N=   190,  T= .00001499 SECONDS,  DT= .00000008 SECONDS
          N=   200,  T= .00001575 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   200 *****
          N=   210,  T= .00001650 SECONDS,  DT= .00000008 SECONDS
          N=   220,  T= .00001725 SECONDS,  DT= .00000008 SECONDS
          N=   230,  T= .00001800 SECONDS,  DT= .00000007 SECONDS
          N=   240,  T= .00001875 SECONDS,  DT= .00000007 SECONDS
          N=   250,  T= .00001950 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   250 *****
          N=   260,  T= .00002025 SECONDS,  DT= .00000007 SECONDS
          N=   270,  T= .00002100 SECONDS,  DT= .00000008 SECONDS
          N=   280,  T= .00002175 SECONDS,  DT= .00000008 SECONDS
          N=   290,  T= .00002250 SECONDS,  DT= .00000008 SECONDS
          N=   300,  T= .00002325 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   300 *****
          N=   310,  T= .00002401 SECONDS,  DT= .00000008 SECONDS
          N=   320,  T= .00002476 SECONDS,  DT= .00000008 SECONDS
          N=   330,  T= .00002551 SECONDS,  DT= .00000008 SECONDS
          N=   340,  T= .00002626 SECONDS,  DT= .00000008 SECONDS
          N=   350,  T= .00002702 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   350 *****
          N=   360,  T= .00002778 SECONDS,  DT= .00000008 SECONDS
          N=   370,  T= .00002854 SECONDS,  DT= .00000008 SECONDS
          N=   380,  T= .00002930 SECONDS,  DT= .00000008 SECONDS
          N=   390,  T= .00003006 SECONDS,  DT= .00000008 SECONDS
          N=   400,  T= .00003082 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   400 *****
          N=   410,  T= .00003159 SECONDS,  DT= .00000008 SECONDS
          N=   420,  T= .00003235 SECONDS,  DT= .00000008 SECONDS
          N=   430,  T= .00003312 SECONDS,  DT= .00000008 SECONDS
          N=   440,  T= .00003388 SECONDS,  DT= .00000008 SECONDS
          N=   450,  T= .00003465 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   450 *****
          N=   460,  T= .00003542 SECONDS,  DT= .00000008 SECONDS
          N=   470,  T= .00003618 SECONDS,  DT= .00000008 SECONDS
          N=   480,  T= .00003695 SECONDS,  DT= .00000008 SECONDS
          N=   490,  T= .00003771 SECONDS,  DT= .00000008 SECONDS
```

Fig. 23. (Cont)

```
           N=   500,  T= .00003848 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   500 *****
           N=   510,  T= .00003924 SECONDS,  DT= .00000008 SECONDS
           N=   520,  T= .00004001 SECONDS,  DT= .00000008 SECONDS
           N=   530,  T= .00004077 SECONDS,  DT= .00000008 SECONDS
           N=   540,  T= .00004154 SECONDS,  DT= .00000008 SECONDS
           N=   550,  T= .00004230 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   550 *****
           N=   560,  T= .00004306 SECONDS,  DT= .00000008 SECONDS
           N=   570,  T= .00004382 SECONDS,  DT= .00000008 SECONDS
           N=   580,  T= .00004459 SECONDS,  DT= .00000008 SECONDS
           N=   590,  T= .00004535 SECONDS,  DT= .00000008 SECONDS
           N=   600,  T= .00004611 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   600 *****
           N=   610,  T= .00004687 SECONDS,  DT= .00000008 SECONDS
           N=   620,  T= .00004763 SECONDS,  DT= .00000008 SECONDS
           N=   630,  T= .00004840 SECONDS,  DT= .00000008 SECONDS
           N=   640,  T= .00004916 SECONDS,  DT= .00000008 SECONDS
           N=   650,  T= .00004992 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   650 *****
           N=   660,  T= .00005068 SECONDS,  DT= .00000008 SECONDS
           N=   670,  T= .00005144 SECONDS,  DT= .00000008 SECONDS
           N=   680,  T= .00005219 SECONDS,  DT= .00000008 SECONDS
           N=   690,  T= .00005295 SECONDS,  DT= .00000008 SECONDS
           N=   700,  T= .00005371 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   700 *****
           N=   710,  T= .00005447 SECONDS,  DT= .00000008 SECONDS
           N=   720,  T= .00005523 SECONDS,  DT= .00000008 SECONDS
           N=   730,  T= .00005599 SECONDS,  DT= .00000008 SECONDS
           N=   740,  T= .00005675 SECONDS,  DT= .00000008 SECONDS
           N=   750,  T= .00005751 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   750 *****
           N=   760,  T= .00005827 SECONDS,  DT= .00000008 SECONDS
           N=   770,  T= .00005903 SECONDS,  DT= .00000008 SECONDS
           N=   780,  T= .00005979 SECONDS,  DT= .00000008 SECONDS
           N=   790,  T= .00006055 SECONDS,  DT= .00000008 SECONDS
           N=   800,  T= .00006131 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   800 *****
           N=   810,  T= .00006207 SECONDS,  DT= .00000008 SECONDS
           N=   820,  T= .00006283 SECONDS,  DT= .00000008 SECONDS
           N=   830,  T= .00006359 SECONDS,  DT= .00000008 SECONDS
           N=   840,  T= .00006435 SECONDS,  DT= .00000008 SECONDS
           N=   850,  T= .00006511 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   850 *****
           N=   860,  T= .00006588 SECONDS,  DT= .00000008 SECONDS
           N=   870,  T= .00006664 SECONDS,  DT= .00000008 SECONDS
           N=   880,  T= .00006740 SECONDS,  DT= .00000008 SECONDS
           N=   890,  T= .00006816 SECONDS,  DT= .00000008 SECONDS
           N=   900,  T= .00006892 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   900 *****
           N=   910,  T= .00006968 SECONDS,  DT= .00000008 SECONDS
```

Fig. 23. (Cont)

```
            N=   920,  T= .00007044 SECONDS,  DT= .00000008 SECONDS
            N=   930,  T= .00007121 SECONDS,  DT= .00000008 SECONDS
            N=   940,  T= .00007197 SECONDS,  DT= .00000008 SECONDS
            N=   950,  T= .00007273 SECONDS,  DT= .00000008 SECONDS

***** EXPECT FILM OUTPUT FOR N=   950 *****
            N=   960,  T= .00007349 SECONDS,  DT= .00000008 SECONDS
            N=   970,  T= .00007425 SECONDS,  DT= .00000008 SECONDS
            N=   980,  T= .00007502 SECONDS,  DT= .00000008 SECONDS
            N=   990,  T= .00007578 SECONDS,  DT= .00000008 SECONDS
            N=  1000,  T= .00007654 SECONDS,  DT= .00000008 SECONDS
```

Fig. 23. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00007654 SECONDS (DELTA T = .00000008)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
1	1	-.3810	0.0000	78.4910	0.0000	6.64235	.080949	78.4910	.2316	285.9340
1	2	-.3810	.0113	78.3041	1.3668	6.64345	.080959	78.3161	.2310	285.9475
1	3	-.3810	.0226	77.8730	2.7194	6.64594	.080981	77.9205	.2299	285.9781
1	4	-.3810	.0339	77.1543	4.0435	6.65008	.081017	77.2601	.2279	286.0289
1	5	-.3810	.0452	76.1479	5.3248	6.65571	.081066	76.3339	.2251	286.0981
1	6	-.3810	.0565	74.8572	6.5492	6.66302	.081129	75.1431	.2216	286.1879
1	7	-.3810	.0678	73.2726	7.7013	6.67188	.081206	73.6762	.2172	286.2965
1	8	-.3810	.0791	71.3835	8.7648	6.68226	.081296	71.9196	.2120	286.4238
1	9	-.3810	.0904	69.1816	9.7228	6.69413	.081400	69.8615	.2059	286.5690
1	10	-.3810	.1017	66.6548	10.5571	6.70741	.081515	67.4856	.1988	286.7314
1	11	-.3810	.1130	63.7827	11.2466	6.72207	.081642	64.7666	.1908	286.9102
1	12	-.3810	.1243	60.5396	11.7677	6.73803	.081781	61.6727	.1816	287.1048
1	13	-.3810	.1356	56.8755	12.0893	6.75532	.081930	58.1462	.1711	287.3150
1	14	-.3810	.1469	52.7677	12.1824	6.77370	.082089	54.1557	.1593	287.5381
1	15	-.3810	.1582	48.0633	11.9835	6.79337	.082260	49.5347	.1457	287.7764
1	16	-.3810	.1695	42.7429	11.4529	6.81399	.082438	44.2507	.1301	288.0258
1	17	-.3810	.1808	36.3763	10.4307	6.83569	.082625	37.8422	.1112	288.2875
1	18	-.3810	.1922	29.1606	8.9153	6.85646	.082805	30.4930	.0896	288.5376
1	19	-.3810	.2035	20.2233	6.5709	6.87623	.082975	21.2640	.0624	288.7750
1	20	-.3810	.2148	10.7741	3.7098	6.88961	.083090	11.3949	.0334	288.9354
1	21	-.3810	.2261	0.0000	0.0000	6.89500	.083137	0.0000	0.0000	289.0000
2	1	-.3464	0.0000	75.0356	0.0000	6.65347	.081368	75.0356	.2218	284.9381
2	2	-.3464	.0107	74.9105	.7116	6.65480	.081381	74.9139	.2214	284.9519
2	3	-.3464	.0214	74.5843	1.4120	6.65810	.081411	74.5976	.2204	284.9855
2	4	-.3464	.0321	74.0411	2.0650	6.66366	.081463	74.0699	.2189	285.0415
2	5	-.3464	.0428	73.2859	2.6581	6.67106	.081533	73.3341	.2167	285.1142
2	6	-.3464	.0535	72.3157	3.1666	6.68017	.081619	72.3850	.2138	285.2016
2	7	-.3464	.0642	71.1291	3.5748	6.69066	.081720	71.2189	.2103	285.2983
2	8	-.3464	.0749	69.7192	3.8637	6.70226	.081832	69.8262	.2062	285.4009
2	9	-.3464	.0856	68.0816	4.0208	6.71474	.081954	68.2002	.2014	285.5055
2	10	-.3464	.0963	66.2141	4.0296	6.72783	.082084	66.3366	.1958	285.6110
2	11	-.3464	.1070	64.1058	3.8861	6.74144	.082220	64.2235	.1895	285.7147
2	12	-.3464	.1176	61.7589	3.5661	6.75521	.082356	61.8618	.1825	285.8239
2	13	-.3464	.1283	59.1306	3.0873	6.76946	.082497	59.2112	.1747	285.9383
2	14	-.3464	.1390	56.2639	2.3757	6.78313	.082621	56.3140	.1661	286.0866
2	15	-.3464	.1497	53.0215	1.5294	6.79793	.082747	53.0436	.1564	286.2727
2	16	-.3464	.1604	49.6088	.2698	6.81011	.082808	49.6095	.1462	286.5753
2	17	-.3464	.1711	45.5198	-.9727	6.82682	.082897	45.5302	.1341	286.9700
2	18	-.3464	.1818	41.4241	-3.2001	6.83311	.082808	41.5475	.1222	287.5420
2	19	-.3464	.1925	35.8844	-4.6709	6.85794	.082974	36.1871	.1064	288.0118
2	20	-.3464	.2032	29.0838	-8.2657	6.83729	.082612	30.2355	.0888	288.4025
2	21	-.3464	.2139	0.0000	0.0000	6.87353	.082878	0.0000	0.0000	289.0000
3	1	-.3117	0.0000	77.2751	0.0000	6.56966	.080288	77.2751	.2283	285.1355
3	2	-.3117	.0100	77.1660	-.0482	6.57164	.080305	77.1660	.2280	285.1598
3	3	-.3117	.0201	76.8575	-.0945	6.57675	.080349	76.8575	.2270	285.2250
3	4	-.3117	.0301	76.3511	-.1714	6.58533	.080423	76.3513	.2255	285.3340
3	5	-.3117	.0402	75.6504	-.2799	6.59675	.080522	75.6509	.2234	285.4793
3	6	-.3117	.0502	74.7585	-.4411	6.61077	.080642	74.7598	.2207	285.6576
3	7	-.3117	.0603	73.6818	-.6670	6.62678	.080780	73.6849	.2174	285.8612
3	8	-.3117	.0703	72.4205	-.9748	6.64429	.080931	72.4270	.2136	286.0829

Fig. 23. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00007654 SECONDS (DELTA T = .00000008)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
3	9	-.3117	.0804	70.9832	-1.3825	6.66268	.081089	70.9967	.2093	286.3137
3	10	-.3117	.0904	69.3659	-1.8999	6.68149	.081253	69.3919	.2045	286.5444
3	11	-.3117	.1005	67.5831	-2.5481	6.70010	.081417	67.6311	.1992	286.7637
3	12	-.3117	.1105	65.6158	-3.3181	6.71833	.081582	65.6996	.1935	286.9622
3	13	-.3117	.1206	63.4949	-4.2479	6.73538	.081743	63.6369	.1874	287.1232
3	14	-.3117	.1306	61.1544	-5.2826	6.75188	.081908	61.3821	.1807	287.2451
3	15	-.3117	.1407	58.7001	-6.5299	6.76613	.082065	59.0622	.1738	287.3037
3	16	-.3117	.1507	55.9310	-7.8131	6.78061	.082226	56.4740	.1662	287.3537
3	17	-.3117	.1608	53.1729	-9.4416	6.79108	.082348	54.0046	.1589	287.3713
3	18	-.3117	.1708	49.6712	-10.8868	6.80368	.082447	50.8503	.1496	287.5580
3	19	-.3117	.1809	46.2989	-12.8765	6.80886	.082469	48.0561	.1413	287.6993
3	20	-.3117	.1909	35.0323	-11.8172	6.81091	.082288	36.9717	.1086	288.4214
3	21	-.3117	.2010	0.0000	0.0000	6.82279	.082266	0.0000	0.0000	289.0000
4	1	-.2771	0.0000	80.4525	0.0000	6.55643	.080588	80.4525	.2384	283.5004
4	2	-.2771	.0094	80.3614	-.6527	6.55790	.080602	80.3641	.2381	283.5141
4	3	-.2771	.0187	80.0887	-1.3020	6.56179	.080640	80.0993	.2373	283.5502
4	4	-.2771	.0281	79.6437	-1.9663	6.56839	.080704	79.6680	.2360	283.6110
4	5	-.2771	.0375	79.0240	-2.6439	6.57748	.080792	79.0682	.2342	283.6933
4	6	-.2771	.0468	78.2335	-3.3458	6.58904	.080904	78.3050	.2319	283.7962
4	7	-.2771	.0562	77.2745	-4.0760	6.60285	.081040	77.3819	.2291	283.9167
4	8	-.2771	.0656	76.1533	-4.8462	6.61864	.081195	76.3073	.2259	284.0528
4	9	-.2771	.0749	74.8727	-5.6621	6.63611	.081366	75.0865	.2222	284.2027
4	10	-.2771	.0843	73.4465	-6.5403	6.65471	.081547	73.7371	.2181	284.3673
4	11	-.2771	.0937	71.8698	-7.4799	6.67412	.081732	72.2580	.2137	284.5508
4	12	-.2771	.1030	70.1745	-8.5886	6.69347	.081907	70.6884	.2090	284.7644
4	13	-.2771	.1124	68.3294	-9.6039	6.71272	.082068	69.0010	.2039	285.0253
4	14	-.2771	.1218	66.4038	-10.8241	6.73058	.082189	67.2802	.1987	285.3601
4	15	-.2771	.1311	64.3081	-12.0952	6.74786	.082278	65.4356	.1931	285.7859
4	16	-.2771	.1405	62.1903	-13.5505	6.76230	.082302	63.6494	.1877	286.3142
4	17	-.2771	.1499	59.8242	-14.9942	6.77666	.082314	61.6746	.1817	286.8798
4	18	-.2771	.1592	57.2950	-16.6325	6.78630	.082276	59.6604	.1756	287.4197
4	19	-.2771	.1686	53.2133	-17.6554	6.79586	.082280	56.0657	.1649	287.8114
4	20	-.2771	.1780	39.3654	-14.6156	6.79803	.082077	41.9911	.1233	288.6152
4	21	-.2771	.1873	0.0000	0.0000	6.81217	.082138	0.0000	0.0000	289.0000
5	1	-.2425	0.0000	85.9201	0.0000	6.51153	.079788	85.9201	.2542	284.3837
5	2	-.2425	.0086	85.8388	-1.1262	6.51287	.079799	85.8462	.2540	284.4021
5	3	-.2425	.0173	85.5929	-2.2491	6.51629	.079827	85.6224	.2533	284.4518
5	4	-.2425	.0259	85.1900	-3.3860	6.52211	.079874	85.2572	.2521	284.5363
5	5	-.2425	.0346	84.6295	-4.5350	6.53005	.079939	84.7509	.2506	284.6538
5	6	-.2425	.0432	83.9132	-5.7024	6.54008	.080019	84.1067	.2486	284.8051
5	7	-.2425	.0519	83.0449	-6.8905	6.55201	.080113	83.3302	.2463	284.9892
5	8	-.2425	.0605	82.0254	-8.1012	6.56569	.080220	82.4245	.2435	285.2052
5	9	-.2425	.0692	80.8642	-9.3391	6.58083	.080336	81.4017	.2404	285.4499
5	10	-.2425	.0778	79.5611	-10.6027	6.59722	.080460	80.2645	.2369	285.7182
5	11	-.2425	.0865	78.1336	-11.9012	6.61440	.080590	79.0348	.2331	285.9991
5	12	-.2425	.0951	76.5794	-13.2288	6.63214	.080728	77.7136	.2291	286.2781
5	13	-.2425	.1037	74.9312	-14.6038	6.64980	.080872	76.3411	.2250	286.5271
5	14	-.2425	.1124	73.1756	-16.0105	6.66725	.081030	74.9066	.2207	286.7203
5	15	-.2425	.1210	71.3694	-17.4788	6.68368	.081202	73.4786	.2164	286.8178
5	16	-.2425	.1297	69.4631	-18.9707	6.69912	.081386	72.0070	.2121	286.8287
5	17	-.2425	.1383	67.4809	-20.4892	6.71288	.081571	70.5229	.2078	286.7665

Fig. 23. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00007654 SECONDS (DELTA T = .00000008)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
78	3	2.2860	.0770	640.6117	-15.5688	.09164	.003659	640.8008	3.4218	87.2801
78	4	2.2860	.1154	648.8716	-40.7285	.07277	.003104	650.1485	3.5886	81.6879
78	5	2.2860	.1539	652.2742	-51.6990	.06771	.002955	654.3198	3.6528	79.8602
78	6	2.2860	.1924	655.9314	-48.3155	.06378	.002826	657.7085	3.6999	78.6449
78	7	2.2860	.2309	657.9418	-43.1974	.06262	.002775	659.3584	3.7096	78.6265
78	8	2.2860	.2694	659.7321	-36.0353	.06255	.002748	660.7156	3.7011	79.3143
78	9	2.2860	.3078	660.2399	-26.9880	.06298	.002714	660.7913	3.6662	80.8531
78	10	2.2860	.3463	658.5854	-16.9414	.06382	.002660	658.8033	3.5941	83.6200
78	11	2.2860	.3848	653.0655	-6.2714	.06486	.002560	653.0956	3.4677	88.2788
78	12	2.2860	.4233	641.5060	4.8181	.06599	.002401	641.5241	3.2705	95.7627
78	13	2.2860	.4618	621.6516	15.8201	.06685	.002174	621.8529	2.9971	107.1404
78	14	2.2860	.5002	591.3447	26.2787	.06768	.001913	591.9283	2.6596	123.2769
78	15	2.2860	.5387	549.2009	34.6507	.06808	.001646	550.2930	2.2866	144.1433
78	16	2.2860	.5772	494.6752	41.1061	.06855	.001418	496.3802	1.9077	168.5048
78	17	2.2860	.6157	426.9995	43.9381	.06840	.001219	429.2541	1.5317	195.4583
78	18	2.2860	.6542	345.7139	43.3562	.06866	.001071	348.4219	1.1628	223.4659
78	19	2.2860	.6926	248.8729	36.7852	.06804	.000945	251.5768	.7922	251.0103
78	20	2.2860	.7311	134.7840	23.9420	.06824	.000866	136.8939	.4121	274.6406
78	21	2.2860	.7696	0.0000	0.0000	.06685	.000806	0.0000	0.0000	289.0000
79	1	2.3206	0.0000	624.5575	0.0000	.12486	.004576	624.5575	3.1953	95.0865
79	2	2.3206	.0388	623.3450	19.7143	.12653	.004592	623.6567	3.1752	96.0128
79	3	2.3206	.0777	635.9415	-5.9051	.09884	.003859	635.9689	3.3582	89.2607
79	4	2.3206	.1165	646.5919	-34.5815	.07597	.003198	647.5160	3.5508	82.7623
79	5	2.3206	.1553	652.3308	-48.5752	.06774	.002954	654.1368	3.6507	79.9035
79	6	2.3206	.1941	656.1228	-46.6151	.06306	.002801	657.7766	3.7048	78.4551
79	7	2.3206	.2330	658.3521	-42.2042	.06173	.002744	659.7035	3.7170	78.3982
79	8	2.3206	.2718	660.0186	-35.2230	.06154	.002711	660.9578	3.7071	79.1170
79	9	2.3206	.3106	660.3322	-26.3424	.06189	.002671	660.8574	3.6691	80.7375
79	10	2.3206	.3494	658.3168	-16.4357	.06268	.002611	658.5220	3.5917	83.6611
79	11	2.3206	.3883	652.2245	-5.8927	.06367	.002505	652.2512	3.4578	88.5546
79	12	2.3206	.4271	639.9460	5.1249	.06474	.002342	639.9665	3.2527	96.3404
79	13	2.3206	.4659	619.2649	15.9975	.06556	.002114	619.4715	2.9728	108.0667
79	14	2.3206	.5047	588.1492	26.2620	.06640	.001858	588.7352	2.6323	124.4960
79	15	2.3206	.5436	545.3284	34.4790	.06679	.001600	546.4173	2.2602	145.4667
79	16	2.3206	.5824	490.3715	40.8089	.06727	.001381	492.0667	1.8843	169.7151
79	17	2.3206	.6212	422.5648	43.5995	.06714	.001191	424.8081	1.5123	196.3902
79	18	2.3206	.6601	341.5826	43.0728	.06740	.001048	344.2876	1.1475	224.0427
79	19	2.3206	.6989	245.5609	36.6257	.06678	.000926	248.2773	.7814	251.2442
79	20	2.3206	.7377	132.8812	23.9022	.06695	.000849	135.0138	.4064	274.6622
79	21	2.3206	.7765	0.0000	0.0000	.06555	.000790	0.0000	0.0000	289.0000
80	1	2.3553	0.0000	628.4678	0.0000	.11250	.004253	628.4678	3.2656	92.1812
80	2	2.3553	.0392	623.3148	23.3675	.12648	.004597	623.7527	3.1781	95.8670
80	3	2.3553	.0783	631.2714	3.7585	.10604	.004059	631.2825	3.3006	91.0463
80	4	2.3553	.1175	644.3123	-28.4345	.07916	.003293	644.9394	3.5153	83.7751
80	5	2.3553	.1567	652.3874	-45.4514	.06776	.002953	653.9688	3.6488	79.9467
80	6	2.3553	.1959	656.3141	-44.9147	.06235	.002776	657.8491	3.7098	78.2620
80	7	2.3553	.2350	658.7623	-41.2109	.06084	.002712	660.0501	3.7245	78.1647
80	8	2.3553	.2742	660.3051	-34.4107	.06054	.002673	661.2011	3.7132	78.9141
80	9	2.3553	.3134	660.4244	-25.6967	.06080	.002628	660.9242	3.6722	80.6181
80	10	2.3553	.3526	658.0483	-15.9300	.06153	.002561	658.2410	3.5893	83.7039
80	11	2.3553	.3917	651.3835	-5.5140	.06247	.002450	651.4069	3.4478	88.8427

Fig. 23. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00007654 SECONDS (DELTA T = .00000008)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
80	12	2.3553	.4309	638.3861	5.4316	.06349	.002282	638.4092	3.2346	96.9484
80	13	2.3553	.4701	616.8782	16.1749	.06428	.002054	617.0902	2.9481	109.0471
80	14	2.3553	.5092	584.9537	26.2454	.06511	.001804	585.5422	2.6045	125.7893
80	15	2.3553	.5484	541.4559	34.3074	.06550	.001554	542.5417	2.2334	146.8683
80	16	2.3553	.5876	486.0679	40.5117	.06598	.001345	487.7532	1.8608	170.9912
80	17	2.3553	.6268	418.1302	43.2609	.06589	.001163	420.3622	1.4927	197.3670
80	18	2.3553	.6659	337.4514	42.7893	.06614	.001026	340.1534	1.1322	224.6447
80	19	2.3553	.7051	242.2490	36.4663	.06552	.000908	244.9783	.7707	251.4875
80	20	2.3553	.7443	130.9783	23.8623	.06566	.000833	133.1343	.4007	274.6847
80	21	2.3553	.7835	0.0000	0.0000	.06555	.000790	0.0000	0.0000	289.0000

MASS= .000101 (KG/SEC) THRUST= .0675 (NEWTONS) MASSI= .000104 MASSE= .000108

***** EXPECT FILM OUTPUT FOR N= 1000 *****

Fig. 23. (Cont)

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CASE NO. 5 - TURBULENT PLANE JET IN A PARALLEL STREAM
 $CNTRL LMAX=41,MMAX=21,NMAX=1000,RGAS=287.0,IUI=2,IUO=2,NPLOT=50    $
 $IVS N1D=0,U(1,12,1)=810*7.5895,V=1701*0.0,P=1701*101.35,RO=1701*1.2047,
 U(1,1,1)=47.366,47.0,46.5,46.0,45.5,45.0,44.5,44.0,43.5,43.0,42.5,
 42.0,41.5,41.0,40.5,40.0,39.5,39.0,38.5,38.0,37.5,37.0,36.5,36.0,
 35.5,35.0,34.5,34.0,33.5,33.0,32.5,32.0,31.5,31.0,30.5,30.0,29.5,
 29.0,28.5,28.0,27.5,
 U(1,2,1)=47.366,46.5,45.5,44.5,43.5,43.0,42.5,42.0,41.5,41.0,40.5,
 40.0,39.5,39.0,38.5,38.0,37.5,37.0,36.5,36.0,35.5,35.0,34.5,34.0,
 33.5,33.0,32.5,32.0,31.5,31.0,30.5,30.0,29.5,29.0,28.5,28.0,27.5,
 27.0,26.5,26.0,25.5,
 U(1,3,1)=47.366,45.5,43.5,41.5,39.5,39.0,38.5,38.0,37.5,37.0,36.5,
 36.0,35.5,35.0,34.5,34.0,33.5,33.0,32.5,32.0,31.5,31.0,30.5,30.0,
 29.5,29.0,28.5,28.0,27.5,27.0,26.5,26.0,25.5,25.0,24.5,24.0,23.5,
 23.0,22.5,22.0,21.5,
 U(1,4,1)=7.5895,10.0,12.0,14.0,16.0,36*18.0,
 U(1,5,1)=7.5895,10.0,12.0,14.0,16.0,36*18.0,
 U(1,6,1)=7.5895,8.0,8.5,9.0,9.5,10.0,10.5,11.0,11.5,12.0,12.5,13.0,
 13.5,14.0,14.5,26*15.0,
 U(1,7,1)=7.5895,8.0,8.5,9.0,9.5,10.0,10.5,11.0,11.5,12.0,12.5,13.0,
 13.5,14.0,14.5,26*15.0,
 U(1,8,1)=7.5895,7.6,7.8,8.0,8.2,8.4,8.6,8.8,9.0,9.2,9.4,9.6,9.8,
 10.0,10.2,10.4,10.6,10.8,11.0,11.2,11.4,11.6,11.8,18*12.0,
 U(1,9,1)=7.5895,7.6,7.8,8.0,8.2,8.4,8.6,8.8,9.0,9.2,9.4,9.6,9.8,
 10.0,10.2,10.4,10.6,10.8,11.0,11.2,11.4,11.6,11.8,18*12.0,
 U(1,10,1)=7.5895,7.6,7.6,7.65,7.7,7.75,7.8,7.85,7.9,7.95,8.0,8.05,
 8.1,8.15,8.2,8.25,8.3,8.35,8.4,8.45,8.5,8.55,8.6,8.65,8.7,8.75,8.8,
 8.85,8.9,8.95,11*9.0,
 U(1,11,1)=7.5895,7.6,7.6,7.65,7.7,7.75,7.8,7.85,7.9,7.95,8.0,8.05,
 8.1,8.15,8.2,8.25,8.3,8.35,8.4,8.45,8.5,8.55,8.6,8.65,8.7,8.75,8.8,
 8.85,8.9,8.95,11*9.0    $
 $GEMTRY NDIM=0,NGEOM=1,RI=4.7625,XI=0.0,XE=38.1    $
 $GCBL    $
 $BC ISUPER=-1,PE=101.35,
 UI=3*47.366,18*7.5895,VI=21*0.0,PI=21*101.35,ROI=21*1.2047    $
 $AVL IAV=0    $
 $RVL CMU=1.813E-05,CLA=-1.208E-05,ITM=1    $
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Fig. 24. Case No. 5 data deck.

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VNAP, A COMPUTER PROGRAM FOR THE COMPUTATION OF TWO-DIMENSIONAL, TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERNAL FLOW

                         BY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIENTIFIC LABORATORY


PROGRAM ABSTRACT -

          THE NAVIER-STOKES EQUATIONS FOR TWO-DIMENSIONAL, TIME-DEPENDENT FLOW ARE SOLVED USING THE
     SECOND-ORDER, MACCORMACK FINITE-DIFFERENCE SCHEME. ALL BOUNDARY CONDITIONS ARE COMPUTED USING
     A SECOND-ORDER, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THE VISCOUS TERMS TREATED AS SOURCE
     FUNCTIONS.  THE FLUID IS ASSUMED TO BE A PERFECT GAS.  THE STEADY-STATE SOLUTION IS OBTAINED AS
     THE ASYMPTOTIC SOLUTION FOR LARGE TIME.  THE FLOW BOUNDARIES MAY BE ARBITRARY CURVED SOLID WALLS
     AS WELL AS JET ENVELOPES.  PROBLEMS THAT CAN BE SOLVED ARE FLOW IN PIPES AND DUCTS, CONVERGING,
     CONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC AND SUPERSONIC INLETS, AND FREE JET EXPANSIONS.


JOB TITLE -

     CASE NO. 5 - TURBULENT PLANE JET IN A PARALLEL STREAM


CONTROL PARAMETERS -

     LMAX=41   MMAX=21    NMAX=1000  NPRINT=   0  TCONV= 0.000    FDT=1.00  NSTAG=0     NASM=1    IUNIT=0
     IUI=2     IUO=2      IVPTS=1    NCONVI= 1    TSTOP=1.00000   N1D= 0    NPLOT=  50  IPUNCH=0
     RSTAR=    0.000000   RSTARS=    0.0000000    PLOW= .0100     ROLOW=    .000100


FLUID MODEL -

     THE RATIO OF SPECIFIC HEATS, GAMMA =1.4000 AND THE GAS CONSTANT, R = 287.0000 (J/KG-K)


FLOW GEOMETRY -

     TWO-DIMENSIONAL, PLANAR FLOW HAS BEEN SPECIFIED


DUCT GEOMETRY -

     A CONSTANT AREA DUCT HAS BEEN SPECIFIED BY XI=  0.0000 (CM), RI=  4.7625 (CM), AND XE= 38.1000 (CM)
```

Fig. 25. Case No. 5 output.

BOUNDARY CONDITIONS -

M	PT(KPA)	TT(K)	THETA(DEG)	PE(KPA)
1	0.0000	0.00	0.00	101.35000
2	0.0000	0.00	0.00	101.35000
3	0.0000	0.00	0.00	101.35000
4	0.0000	0.00	0.00	101.35000
5	0.0000	0.00	0.00	101.35000
6	0.0000	0.00	0.00	101.35000
7	0.0000	0.00	0.00	101.35000
8	0.0000	0.00	0.00	101.35000
9	0.0000	0.00	0.00	101.35000
10	0.0000	0.00	0.00	101.35000
11	0.0000	0.00	0.00	101.35000
12	0.0000	0.00	0.00	101.35000
13	0.0000	0.00	0.00	101.35000
14	0.0000	0.00	0.00	101.35000
15	0.0000	0.00	0.00	101.35000
16	0.0000	0.00	0.00	101.35000
17	0.0000	0.00	0.00	101.35000
18	0.0000	0.00	0.00	101.35000
19	0.0000	0.00	0.00	101.35000
20	0.0000	0.00	0.00	101.35000
21	0.0000	0.00	0.00	101.35000

IEXTRA=0   IEX=1   ISUPER=-1   DYW= .0010   IVBC=0

FREE-SLIP WALLS ARE SPECIFIED

ADIABATIC UPPER WALL IS SPECIFIED

ARTIFICAL VISCOSITY -

CAV=0.00   XMU= .40   XLA=1.00   RKMU= .70   XRO= .60   NST= 0   SMP= .95   LSS= 2   SMACH=0.00   IAV=0

MOLECULAR VISCOSITY -

CMU= .1813E-04 (PA-S), CLA= -.1208E-04 (PA-S), CK=0,   (W/M-K), EMU=0.00, ELA=0.00, AND EK=0.00

TURBULENCE MODEL -

MIXING-LENGTH MODEL IS SPECIFIED

***** EXPECT FILM OUTPUT FOR N=   0 *****

N=   10, T= .00006500 SECONDS, DT= .00000650 SECONDS
N=   20, T= .00013003 SECONDS, DT= .00000650 SECONDS
N=   30, T= .00019505 SECONDS, DT= .00000650 SECONDS
N=   40, T= .00026006 SECONDS, DT= .00000650 SECONDS
N=   50, T= .00032509 SECONDS, DT= .00000650 SECONDS

***** EXPECT FILM OUTPUT FOR N=   50 *****

Fig. 25. (Cont)

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          N=    60,  T= .00039014 SECONDS,  DT= .00000651 SECONDS
          N=    70,  T= .00045520 SECONDS,  DT= .00000651 SECONDS
          N=    80,  T= .00052027 SECONDS,  DT= .00000651 SECONDS
          N=    90,  T= .00058536 SECONDS,  DT= .00000651 SECONDS
          N=   100,  T= .00065046 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   100 *****
          N=   110,  T= .00071559 SECONDS,  DT= .00000651 SECONDS
          N=   120,  T= .00078072 SECONDS,  DT= .00000651 SECONDS
          N=   130,  T= .00084585 SECONDS,  DT= .00000651 SECONDS
          N=   140,  T= .00091098 SECONDS,  DT= .00000651 SECONDS
          N=   150,  T= .00097610 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   150 *****
          N=   160,  T= .00104119 SECONDS,  DT= .00000651 SECONDS
          N=   170,  T= .00110625 SECONDS,  DT= .00000651 SECONDS
          N=   180,  T= .00117133 SECONDS,  DT= .00000651 SECONDS
          N=   190,  T= .00123640 SECONDS,  DT= .00000651 SECONDS
          N=   200,  T= .00130147 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   200 *****
          N=   210,  T= .00136655 SECONDS,  DT= .00000651 SECONDS
          N=   220,  T= .00143163 SECONDS,  DT= .00000651 SECONDS
          N=   230,  T= .00149673 SECONDS,  DT= .00000651 SECONDS
          N=   240,  T= .00156182 SECONDS,  DT= .00000651 SECONDS
          N=   250,  T= .00162691 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   250 *****
          N=   260,  T= .00169201 SECONDS,  DT= .00000651 SECONDS
          N=   270,  T= .00175710 SECONDS,  DT= .00000651 SECONDS
          N=   280,  T= .00182220 SECONDS,  DT= .00000651 SECONDS
          N=   290,  T= .00188728 SECONDS,  DT= .00000651 SECONDS
          N=   300,  T= .00195237 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   300 *****
          N=   310,  T= .00201745 SECONDS,  DT= .00000651 SECONDS
          N=   320,  T= .00208253 SECONDS,  DT= .00000651 SECONDS
          N=   330,  T= .00214760 SECONDS,  DT= .00000651 SECONDS
          N=   340,  T= .00221267 SECONDS,  DT= .00000651 SECONDS
          N=   350,  T= .00227773 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   350 *****
          N=   360,  T= .00234279 SECONDS,  DT= .00000651 SECONDS
          N=   370,  T= .00240783 SECONDS,  DT= .00000650 SECONDS
          N=   380,  T= .00247286 SECONDS,  DT= .00000650 SECONDS
          N=   390,  T= .00253788 SECONDS,  DT= .00000650 SECONDS
          N=   400,  T= .00260290 SECONDS,  DT= .00000650 SECONDS

***** EXPECT FILM OUTPUT FOR N=   400 *****
          N=   410,  T= .00266790 SECONDS,  DT= .00000650 SECONDS
          N=   420,  T= .00273291 SECONDS,  DT= .00000650 SECONDS
          N=   430,  T= .00279791 SECONDS,  DT= .00000650 SECONDS
          N=   440,  T= .00286292 SECONDS,  DT= .00000650 SECONDS
          N=   450,  T= .00292793 SECONDS,  DT= .00000650 SECONDS

***** EXPPCT FILM OUTPUT FOR N=   450 *****
          N=   460,  T= .00299295 SECONDS,  DT= .00000650 SECONDS
          N=   470,  T= .00305797 SECONDS,  DT= .00000650 SECONDS
          N=   480,  T= .00312300 SECONDS,  DT= .00000650 SECONDS
          N=   490,  T= .00318804 SECONDS,  DT= .00000650 SECONDS
```

Fig. 25. (Cont)

```
            N=    500,  T= .00325309 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=    500 *****
            N=    510,  T= .00331816 SECONDS,  DT= .00000651 SECONDS
            N=    520,  T= .00338322 SECONDS,  DT= .00000651 SECONDS
            N=    530,  T= .00344831 SECONDS,  DT= .00000651 SECONDS
            N=    540,  T= .00351341 SECONDS,  DT= .00000651 SECONDS
            N=    550,  T= .00357851 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=    550 *****
            N=    560,  T= .00364362 SECONDS,  DT= .00000651 SECONDS
            N=    570,  T= .00370874 SECONDS,  DT= .00000651 SECONDS
            N=    580,  T= .00377385 SECONDS,  DT= .00000651 SECONDS
            N=    590,  T= .00383893 SECONDS,  DT= .00000651 SECONDS
            N=    600,  T= .00390401 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=    600 *****
            N=    610,  T= .00396908 SECONDS,  DT= .00000651 SECONDS
            N=    620,  T= .00403414 SECONDS,  DT= .00000650 SECONDS
            N=    630,  T= .00409917 SECONDS,  DT= .00000650 SECONDS
            N=    640,  T= .00416421 SECONDS,  DT= .00000650 SECONDS
            N=    650,  T= .00422925 SECONDS,  DT= .00000650 SECONDS

***** EXPECT FILM OUTPUT FOR N=    650 *****
            N=    660,  T= .00429429 SECONDS,  DT= .00000650 SECONDS
            N=    670,  T= .00435932 SECONDS,  DT= .00000650 SECONDS
            N=    680,  T= .00442435 SECONDS,  DT= .00000650 SECONDS
            N=    690,  T= .00448938 SECONDS,  DT= .00000650 SECONDS
            N=    700,  T= .00455442 SECONDS,  DT= .00000650 SECONDS

***** EXPECT FILM OUTPUT FOR N=    700 *****
            N=    710,  T= .00461945 SECONDS,  DT= .00000650 SECONDS
            N=    720,  T= .00468449 SECONDS,  DT= .00000650 SECONDS
            N=    730,  T= .00474955 SECONDS,  DT= .00000651 SECONDS
            N=    740,  T= .00481462 SECONDS,  DT= .00000651 SECONDS
            N=    750,  T= .00487971 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=    750 *****
            N=    760,  T= .00494480 SECONDS,  DT= .00000651 SECONDS
            N=    770,  T= .00500989 SECONDS,  DT= .00000651 SECONDS
            N=    780,  T= .00507500 SECONDS,  DT= .00000651 SECONDS
            N=    790,  T= .00514010 SECONDS,  DT= .00000651 SECONDS
            N=    800,  T= .00520520 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=    800 *****
            N=    810,  T= .00527030 SECONDS,  DT= .00000651 SECONDS
            N=    820,  T= .00533540 SECONDS,  DT= .00000651 SECONDS
            N=    830,  T= .00540048 SECONDS,  DT= .00000651 SECONDS
            N=    840,  T= .00546556 SECONDS,  DT= .00000651 SECONDS
            N=    850,  T= .00553062 SECONDS,  DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=    850 *****
            N=    860,  T= .00559568 SECONDS,  DT= .00000651 SECONDS
            N=    870,  T= .00566073 SECONDS,  DT= .00000650 SECONDS
            N=    880,  T= .00572576 SECONDS,  DT= .00000650 SECONDS
            N=    890,  T= .00579080 SECONDS,  DT= .00000650 SECONDS
            N=    900,  T= .00585583 SECONDS,  DT= .00000650 SECONDS

***** EXPECT FILM OUTPUT FOR N=    900 *****
            N=    910,  T= .00592086 SECONDS,  DT= .00000650 SECONDS
```

Fig. 25. (Cont)

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          N=   920,   T= .00598588 SECONDS,   DT= .00000650 SECONDS
          N=   930,   T= .00605092 SECONDS,   DT= .00000650 SECONDS
          N=   940,   T= .00611596 SECONDS,   DT= .00000650 SECONDS
          N=   950,   T= .00618101 SECONDS,   DT= .00000651 SECONDS

***** EXPECT FILM OUTPUT FOR N=   950 *****
          N=   960,   T= .00624607 SECONDS,   DT= .00000651 SECONDS
          N=   970,   T= .00631113 SECONDS,   DT= .00000651 SECONDS
          N=   980,   T= .00637620 SECONDS,   DT= .00000651 SECONDS
          N=   990,   T= .00644128 SECONDS,   DT= .00000651 SECONDS
          N=  1000,   T= .00650636 SECONDS,   DT= .00000651 SECONDS
```

Fig. 25. (Cont)

LOCAL ARTIFICAL VISCOSITY AND MOLECULAR VISCOSITY-HEAT CONDUCTION TERMS, N=1000

L	M	QUT	QVT	QPT	QROT	TLMUR
2	1	.0000	-.0000	.0000	0.0000	.0576
2	2	-.0000	.0000	.0000	0.0000	.0178
2	3	-.0221	-.0002	.0001	0.0000	31.6696
2	4	.0222	-.0000	.0001	0.0000	31.7042
2	5	.0000	.0000	.0000	0.0000	.2860
2	6	.0000	.0000	.0000	0.0000	.1047
2	7	-.0000	-.0000	.0000	0.0000	.0628
2	8	-.0000	-.0000	.0000	0.0000	.0528
2	9	-.0000	-.0000	.0000	0.0000	.0460
2	10	-.0000	-.0000	.0000	0.0000	.0405
2	11	-.0000	-.0000	.0000	0.0000	.0362
2	12	-.0000	.0000	.0000	0.0000	.0322
2	13	-.0000	.0000	.0000	0.0000	.0285
2	14	-.0000	.0000	.0000	0.0000	.0250
2	15	-.0000	.0000	.0000	0.0000	.0215
2	16	-.0000	.0000	.0000	0.0000	.0180
2	17	-.0000	.0000	.0000	0.0000	.0144
2	18	-.0000	.0000	.0000	0.0000	.0109
2	19	-.0000	.0000	.0000	0.0000	.0073
2	20	-.0000	.0000	.0000	0.0000	.0039
2	21	-.0000	-.0000	.0000	0.0000	.0000
3	1	.0000	-.0000	.0000	0.0000	.2010
3	2	-.0001	.0000	.0000	0.0000	.8296
3	3	-.0219	-.0008	.0001	0.0000	35.8429
3	4	.0218	.0003	.0001	0.0000	37.0674
3	5	.0001	.0000	.0000	0.0000	3.1664
3	6	.0000	.0000	.0000	0.0000	.5779
3	7	.0000	-.0000	.0000	0.0000	.1943
3	8	-.0000	-.0000	.0000	0.0000	.2224
3	9	-.0000	-.0000	.0000	0.0000	.1167
3	10	-.0000	-.0000	.0000	0.0000	.0534
3	11	-.0000	.0000	.0000	0.0000	.0375
3	12	.0000	.0000	.0000	0.0000	.0304
3	13	-.0000	.0000	.0000	0.0000	.0293
3	14	-.0000	.0000	.0000	0.0000	.0241
3	15	.0000	.0000	.0000	0.0000	.0206
3	16	.0000	.0000	.0000	0.0000	.0173
3	17	.0000	.0000	.0000	0.0000	.0139
3	18	.0000	.0000	.0000	0.0000	.0104
3	19	.0000	.0000	.0000	0.0000	.0070
3	20	.0000	.0000	.0000	0.0000	.0036
3	21	.0000	.0000	.0000	0.0000	.0000
4	1	.0000	.0000	.0000	0.0000	.4842
4	2	-.0003	.0001	.0000	0.0000	4.5607
4	3	-.0376	-.0018	.0002	0.0000	73.6302
4	4	.0366	.0008	.0002	0.0000	80.3094
4	5	.0011	.0001	.0000	0.0000	14.7839
4	6	.0001	.0000	.0000	0.0000	2.6456
4	7	.0000	-.0000	.0000	0.0000	.9761
4	8	-.0000	-.0000	.0000	0.0000	1.0165
4	9	-.0000	-.0000	.0000	0.0000	.4404
4	10	.0000	-.0000	.0000	0.0000	.1735
4	11	-.0000	-.0000	.0000	0.0000	.1109
4	12	.0000	-.0000	.0000	0.0000	.0859

Fig. 25. (Cont)

LOCAL ARTIFICAL VISCOSITY AND MOLECULAR VISCOSITY-HEAT CONDUCTION TERMS, N=1000

L	M	QUT	QVT	QPT	QROT	TLMUR
4	13	-.0000	-.0000	.0000	0.0000	.0920
4	14	-.0000	-.0000	.0000	0.0000	.0681
4	15	-.0000	-.0000	.0000	0.0000	.0594
4	16	-.0000	-.0000	.0000	0.0000	.0508
4	17	-.0000	-.0000	.0000	0.0000	.0410
4	18	-.0000	-.0000	.0000	0.0000	.0309
4	19	-.0000	-.0000	.0000	0.0000	.0209
4	20	-.0000	.0000	.0000	0.0000	.0109
4	21	-.0000	.0000	.0000	0.0000	.0000
5	1	.0000	.0000	.0000	0.0000	.4651
5	2	-.0007	-.0001	.0000	0.0000	10.7944
5	3	-.0422	-.0024	.0002	0.0000	100.9223
5	4	.0393	.0009	.0003	0.0000	115.6633
5	5	.0034	.0002	.0000	0.0000	32.8734
5	6	.0003	.0000	.0000	0.0000	6.4852
5	7	.0000	-.0000	.0000	0.0000	1.7835
5	8	-.0000	-.0000	.0000	0.0000	1.9042
5	9	-.0000	-.0000	.0000	0.0000	.7975
5	10	.0000	-.0000	.0000	0.0000	.3510
5	11	-.0000	-.0000	.0000	0.0000	.2440
5	12	.0000	-.0000	.0000	0.0000	.1878
5	13	-.0000	-.0000	.0000	0.0000	.1949
5	14	-.0000	-.0000	.0000	0.0000	.1440
5	15	-.0000	-.0000	.0000	0.0000	.1250
5	16	-.0000	-.0000	.0000	0.0000	.1059
5	17	-.0000	-.0000	.0000	0.0000	.0848
5	18	-.0000	-.0000	.0000	0.0000	.0641
5	19	-.0000	-.0000	.0000	0.0000	.0426
5	20	-.0000	.0000	.0000	0.0000	.0210
5	21	-.0000	.0000	.0000	0.0000	.0000
6	1	-.0000	0.0000	.0000	0.0000	.3938
6	2	-.0017	.0002	.0000	0.0000	21.6355
6	3	-.0439	-.0028	.0002	0.0000	132.3063
6	4	.0377	.0006	.0004	0.0000	156.5993
6	5	.0071	.0003	.0000	0.0000	59.4592
6	6	.0008	.0000	.0000	0.0000	14.2294
6	7	.0000	.0000	.0000	0.0000	1.3594
6	8	-.0000	.0000	.0000	0.0000	2.5573
6	9	-.0000	.0000	.0000	0.0000	1.1887
6	10	.0000	-.0000	.0000	0.0000	.5991
6	11	-.0000	.0000	.0000	0.0000	.4035
6	12	.0000	.0000	.0000	0.0000	.2860
6	13	-.0000	.0000	.0000	0.0000	.3048
6	14	-.0000	.0000	.0000	0.0000	.2087
6	15	-.0000	.0000	.0000	0.0000	.1787
6	16	-.0000	.0000	.0000	0.0000	.1504
6	17	-.0000	.0000	.0000	0.0000	.1211
6	18	-.0000	.0000	.0000	0.0000	.0909
6	19	-.0000	.0000	.0000	0.0000	.0592
6	20	-.0000	.0000	.0000	0.0000	.0290
6	21	-.0000	.0000	.0000	0.0000	0.0000
7	1	-.0001	.0000	.0000	0.0000	4.2589
7	2	-.0037	.0004	.0000	0.0000	41.4384
7	3	-.0440	-.0031	.0002	0.0000	174.7869

Fig. 25. (Cont)

LOCAL ARTIFICAL VISCOSITY AND MOLECULAR VISCOSITY-HEAT CONDUCTION TERMS, N=1000

L	M	QUT	QVT	QPT	QROT	TLMUR
38	1	-.0035	-.0000	.0000	0.0000	189.7750
38	2	-.0032	-.0000	.0000	0.0000	180.0663
38	3	-.0024	-.0001	.0000	0.0000	308.2530
38	4	-.0014	-.0001	.0000	0.0000	366.7339
38	5	-.0005	-.0001	.0000	0.0000	392.1720
38	6	.0004	-.0001	.0000	0.0000	393.4541
38	7	.0010	-.0001	.0000	0.0000	376.0883
38	8	.0013	-.0001	.0000	0.0000	344.8347
38	9	.0013	-.0000	.0000	0.0000	304.3212
38	10	.0012	-.0000	.0000	0.0000	258.6899
38	11	.0010	-.0000	.0000	0.0000	210.4728
38	12	.0008	-.0000	.0000	0.0000	159.4358
38	13	.0006	-.0000	.0000	0.0000	102.1035
38	14	.0002	-.0000	.0000	0.0000	43.8518
38	15	.0000	-.0000	.0000	0.0000	9.0079
38	16	.0000	-.0000	.0000	0.0000	1.2736
38	17	-.0000	-.0000	.0000	0.0000	.8729
38	18	-.0000	-.0000	.0000	0.0000	.7686
38	19	-.0000	-.0000	.0000	0.0000	.5892
38	20	.0000	-.0000	.0000	0.0000	.3338
38	21	.0000	.0000	.0000	0.0000	.0000
39	1	-.0033	.0000	.0000	0.0000	186.0293
39	2	-.0031	-.0000	.0000	0.0000	176.7001
39	3	-.0023	-.0000	.0000	0.0000	302.8459
39	4	-.0014	-.0001	.0000	0.0000	360.2814
39	5	-.0004	-.0001	.0000	0.0000	385.0929
39	6	.0004	-.0001	.0000	0.0000	386.1995
39	7	.0009	-.0001	.0000	0.0000	369.1126
39	8	.0012	-.0001	.0000	0.0000	338.5884
39	9	.0013	-.0000	.0000	0.0000	299.1997
39	10	.0012	-.0000	.0000	0.0000	254.9181
39	11	.0010	-.0000	.0000	0.0000	208.0035
39	12	.0008	-.0000	.0000	0.0000	157.9871
39	13	.0006	-.0000	.0000	0.0000	101.3121
39	14	.0002	-.0000	.0000	0.0000	43.3316
39	15	.0000	-.0000	.0000	0.0000	8.7592
39	16	.0000	-.0000	.0000	0.0000	1.4657
39	17	-.0000	-.0000	.0000	0.0000	1.1238
39	18	-.0000	-.0000	.0000	0.0000	.9521
39	19	.0000	-.0000	.0000	0.0000	.6745
39	20	.0000	-.0000	.0000	0.0000	.3680
39	21	.0000	.0000	.0000	0.0000	.0000
40	1	-.0032	-.0000	.0000	0.0000	183.2217
40	2	-.0030	-.0000	.0000	0.0000	174.5808
40	3	-.0022	-.0000	.0000	0.0000	299.4203
40	4	-.0013	-.0001	.0000	0.0000	355.5845
40	5	-.0004	-.0001	.0000	0.0000	379.6578
40	6	.0004	-.0001	.0000	0.0000	380.4640
40	7	.0009	-.0001	.0000	0.0000	363.4733
40	8	.0012	-.0001	.0000	0.0000	333.4298
40	9	.0012	-.0000	.0000	0.0000	294.8628
40	10	.0011	-.0000	.0000	0.0000	251.6293
40	11	.0010	-.0000	.0000	0.0000	205.8145
40	12	.0008	-.0000	.0000	0.0000	156.7741

Fig. 25. (Cont)

LOCAL ARTIFICAL VISCOSITY AND MOLECULAR VISCOSITY-HEAT CONDUCTION TERMS, N=1000

L	M	QUT	QVT	QPT	QROT	TLMUR
40	13	.0006	-.0000	.0000	0.0000	100.8413
40	14	.0002	.0000	.0000	0.0000	43.4135
40	15	.0000	.0000	.0000	0.0000	9.3250
40	16	.0000	.0000	.0000	0.0000	2.0711
40	17	-.0000	.0000	.0000	0.0000	1.4915
40	18	.0000	-.0000	.0000	0.0000	1.1202
40	19	-.0000	-.0000	.0000	0.0000	.7432
40	20	-.0000	-.0000	.0000	0.0000	.3993
40	21	.0000	-.0000	.0000	0.0000	0.0000
41	2	-.0030	-.0000	.0000	0.0000	174.0578
41	3	-.0022	-.0001	.0000	0.0000	297.4440
41	4	-.0013	-.0001	.0000	0.0000	352.7139
41	5	-.0004	-.0001	.0000	0.0000	376.2764
41	6	.0003	-.0001	.0000	0.0000	376.8560
41	7	.0009	-.0001	.0000	0.0000	359.9238
41	8	.0011	-.0001	.0000	0.0000	330.2458
41	9	.0012	-.0001	.0000	0.0000	292.3573
41	10	.0011	-.0000	.0000	0.0000	250.0643
41	11	.0009	-.0000	.0000	0.0000	205.3195
41	12	.0008	-.0000	.0000	0.0000	157.2951
41	13	.0006	.0000	.0000	0.0000	102.1214
41	14	.0002	.0000	.0000	0.0000	44.9153
41	15	.0000	.0000	.0000	0.0000	10.4631
41	16	.0000	.0000	.0000	0.0000	2.4913
41	17	.0000	.0000	.0000	0.0000	1.5278
41	18	.0000	.0000	.0000	0.0000	1.0230
41	19	.0000	.0000	.0000	0.0000	.6412
41	20	.0000	.0000	.0000	0.0000	.3557

Fig. 25. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00650636 SECONDS (DELTA T = .00000651)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
1	1	0.0000	0.0000	47.3660	0.0000	101.05440	1.204700	47.3660	.1382	292.3030
1	2	0.0000	.2381	47.3660	0.0000	100.94549	1.204700	47.3660	.1383	291.9880
1	3	0.0000	.4763	47.3660	0.0000	101.03552	1.204700	47.3660	.1382	292.2484
1	4	0.0000	.7144	7.5895	0.0000	100.80054	1.204700	7.5895	.0222	291.5688
1	5	0.0000	.9525	7.5895	0.0000	100.97247	1.204700	7.5895	.0222	292.0661
1	6	0.0000	1.1906	7.5895	0.0000	100.97478	1.204700	7.5895	.0222	292.0728
1	7	0.0000	1.4288	7.5895	0.0000	100.96412	1.204700	7.5895	.0222	292.0419
1	8	0.0000	1.6669	7.5895	0.0000	100.95543	1.204700	7.5895	.0222	292.0168
1	9	0.0000	1.9050	7.5895	0.0000	100.94822	1.204700	7.5895	.0222	291.9959
1	10	0.0000	2.1431	7.5895	0.0000	100.94206	1.204700	7.5895	.0222	291.9781
1	11	0.0000	2.3813	7.5895	0.0000	100.93587	1.204700	7.5895	.0222	291.9602
1	12	0.0000	2.6194	7.5895	0.0000	100.93053	1.204700	7.5895	.0222	291.9448
1	13	0.0000	2.8575	7.5895	0.0000	100.92502	1.204700	7.5895	.0222	291.9288
1	14	0.0000	3.0956	7.5895	0.0000	100.91998	1.204700	7.5895	.0222	291.9143
1	15	0.0000	3.3338	7.5895	0.0000	100.91532	1.204700	7.5895	.0222	291.9008
1	16	0.0000	3.5719	7.5895	0.0000	100.91117	1.204700	7.5895	.0222	291.8888
1	17	0.0000	3.8100	7.5895	0.0000	100.90763	1.204700	7.5895	.0222	291.8785
1	18	0.0000	4.0481	7.5895	0.0000	100.90479	1.204700	7.5895	.0222	291.8703
1	19	0.0000	4.2863	7.5895	0.0000	100.90272	1.204700	7.5895	.0222	291.8643
1	20	0.0000	4.5244	7.5895	0.0000	100.90145	1.204700	7.5895	.0222	291.8606
1	21	0.0000	4.7625	7.5895	0.0000	100.90045	1.204700	7.5895	.0222	291.8577
2	1	.9525	0.0000	47.1481	0.0000	100.98670	1.204730	47.1481	.1376	292.1000
2	2	.9525	.2381	47.3264	.0122	100.96115	1.205371	47.3264	.1382	291.8707
2	3	.9525	.4763	47.1713	.1217	101.00477	1.205243	47.1715	.1377	292.0278
2	4	.9525	.7144	7.8439	-.0297	100.89850	1.203562	7.8440	.0229	292.1280
2	5	.9525	.9525	7.5871	-.2232	100.95843	1.202691	7.5903	.0221	292.5132
2	6	.9525	1.1906	7.5040	-.2024	100.96786	1.202714	7.5067	.0219	292.5350
2	7	.9525	1.4288	7.5037	-.1537	100.96219	1.202707	7.5052	.0219	292.5203
2	8	.9525	1.6669	7.5147	-.1197	100.95478	1.202692	7.5157	.0219	292.5025
2	9	.9525	1.9050	7.5234	-.1003	100.94782	1.202656	7.5241	.0219	292.4909
2	10	.9525	2.1431	7.5300	-.0882	100.94223	1.202618	7.5305	.0220	292.4842
2	11	.9525	2.3813	7.5339	-.0784	100.93629	1.202574	7.5343	.0220	292.4777
2	12	.9525	2.6194	7.5366	-.0696	100.93081	1.202526	7.5370	.0220	292.4733
2	13	.9525	2.8575	7.5392	-.0610	100.92507	1.202480	7.5394	.0220	292.4678
2	14	.9525	3.0956	7.5418	-.0532	100.91966	1.202435	7.5419	.0220	292.4631
2	15	.9525	3.3338	7.5441	-.0455	100.91456	1.202393	7.5442	.0220	292.4587
2	16	.9525	3.5719	7.5462	-.0379	100.90993	1.202354	7.5463	.0220	292.4547
2	17	.9525	3.8100	7.5481	-.0305	100.90589	1.202320	7.5482	.0220	292.4512
2	18	.9525	4.0481	7.5496	-.0231	100.90259	1.202293	7.5497	.0220	292.4483
2	19	.9525	4.2863	7.5507	-.0158	100.90014	1.202272	7.5508	.0220	292.4462
2	20	.9525	4.5244	7.5514	-.0085	100.89862	1.202260	7.5514	.0220	292.4449
2	21	.9525	4.7625	7.5521	0.0000	100.89769	1.202252	7.5521	.0220	292.4440
3	1	1.9050	0.0000	46.9743	0.0000	101.01187	1.203335	46.9743	.1370	292.5115
3	2	1.9050	.2381	47.4443	-.0097	100.94408	1.203752	47.4443	.1385	292.2140
3	3	1.9050	.4763	46.1152	.4126	101.06725	1.204257	46.1171	.1345	292.4477
3	4	1.9050	.7144	10.3716	-.1744	100.89022	1.203362	10.3731	.0303	292.1526
3	5	1.9050	.9525	7.7500	-.4622	100.95120	1.202371	7.7638	.0226	292.5701
3	6	1.9050	1.1906	7.0923	-.3978	100.96621	1.202654	7.1035	.0207	292.5448
3	7	1.9050	1.4288	7.1549	-.3024	100.96348	1.202637	7.1609	.0209	292.5411
3	8	1.9050	1.6669	7.2869	-.2418	100.95767	1.202618	7.2909	.0213	292.5289

Fig. 25. (Cont.

SOLUTION SURFACE NO. 1000 - TIME = .00650636 SECONDS (DELTA T = .00000651)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
3	9	1.9050	1.9050	7.3797	-.2113	100.95221	1.202589	7.3827	.0215	292.5200
3	10	1.9050	2.1431	7.3998	-.1875	100.94800	1.202555	7.4021	.0216	292.5162
3	11	1.9050	2.3813	7.4193	-.1684	100.94299	1.202516	7.4212	.0216	292.5111
3	12	1.9050	2.6194	7.4175	-.1488	100.93861	1.202477	7.4190	.0216	292.5079
3	13	1.9050	2.8575	7.4268	-.1309	100.93387	1.202438	7.4280	.0217	292.5035
3	14	1.9050	3.0956	7.4311	-.1138	100.92946	1.202401	7.4319	.0217	292.4999
3	15	1.9050	3.3338	7.4346	-.0970	100.92533	1.202366	7.4352	.0217	292.4965
3	16	1.9050	3.5719	7.4379	-.0805	100.92158	1.202334	7.4383	.0217	292.4934
3	17	1.9050	3.8100	7.4407	-.0642	100.91833	1.202306	7.4410	.0217	292.4907
3	18	1.9050	4.0481	7.4431	-.0482	100.91568	1.202283	7.4432	.0217	292.4885
3	19	1.9050	4.2863	7.4447	-.0323	100.91372	1.202267	7.4448	.0217	292.4869
3	20	1.9050	4.5244	7.4459	-.0166	100.91251	1.202257	7.4459	.0217	292.4859
3	21	1.9050	4.7625	7.4465	0.0000	100.91177	1.202250	7.4465	.0217	292.4852
4	1	2.8575	0.0000	47.0340	0.0000	101.01274	1.201253	47.0340	.1371	293.0209
4	2	2.8575	.2381	47.3705	.0039	100.95206	1.201924	47.3705	.1381	292.6815
4	3	2.8575	.4763	44.9325	.4932	101.09234	1.201381	44.9352	.1309	293.2206
4	4	2.8575	.7144	13.4216	-.1774	100.90610	1.203665	13.4227	.0392	292.1251
4	5	2.8575	.9525	7.9753	-.4905	100.95417	1.202383	7.9903	.0233	292.5759
4	6	2.8575	1.1906	6.6113	-.4433	100.97154	1.202810	6.6262	.0193	292.5223
4	7	2.8575	1.4288	6.7572	-.3561	100.97131	1.202818	6.7666	.0197	292.5197
4	8	2.8575	1.6669	7.0586	-.3037	100.96704	1.202791	7.0651	.0206	292.5139
4	9	2.8575	1.9050	7.2228	-.2712	100.96214	1.202781	7.2278	.0211	292.5021
4	10	2.8575	2.1431	7.2563	-.2426	100.95781	1.202727	7.2604	.0212	292.5028
4	11	2.8575	2.3813	7.2914	-.2178	100.95255	1.202691	7.2947	.0213	292.4962
4	12	2.8575	2.6194	7.2913	-.1934	100.94795	1.202645	7.2938	.0213	292.4940
4	13	2.8575	2.8575	7.3118	-.1708	100.94292	1.202605	7.3138	.0213	292.4892
4	14	2.8575	3.0956	7.3204	-.1490	100.93820	1.202563	7.3220	.0214	292.4858
4	15	2.8575	3.3338	7.3276	-.1274	100.93375	1.202524	7.3287	.0214	292.4824
4	16	2.8575	3.5719	7.3343	-.1060	100.92966	1.202488	7.3351	.0214	292.4793
4	17	2.8575	3.8100	7.3400	-.0849	100.92608	1.202456	7.3405	.0214	292.4766
4	18	2.8575	4.0481	7.3443	-.0638	100.92314	1.202431	7.3446	.0214	292.4744
4	19	2.8575	4.2863	7.3476	-.0429	100.92094	1.202411	7.3477	.0214	292.4726
4	20	2.8575	4.5244	7.3496	-.0220	100.91958	1.202400	7.3496	.0214	292.4715
4	21	2.8575	4.7625	7.3505	0.0000	100.91875	1.202393	7.3505	.0214	292.4709
5	1	3.8100	0.0000	47.0646	0.0000	101.01558	1.200856	47.0646	.1371	293.1261
5	2	3.8100	.2381	47.2394	.0092	100.96079	1.201310	47.2394	.1377	292.8565
5	3	3.8100	.4763	43.7630	.4940	101.09829	1.201113	43.7658	.1275	293.3032
5	4	3.8100	.7144	16.3624	-.1184	100.92920	1.203863	16.3629	.0478	292.1438
5	5	3.8100	.9525	8.4555	-.4728	100.95755	1.202062	8.4687	.0247	292.6638
5	6	3.8100	1.1906	6.3127	-.5007	100.97553	1.202515	6.3326	.0185	292.6055
5	7	3.8100	1.4288	6.4738	-.4623	100.97965	1.202580	6.4903	.0189	292.6016
5	8	3.8100	1.6669	6.8543	-.4216	100.97826	1.202559	6.8673	.0200	292.6029
5	9	3.8100	1.9050	7.0518	-.3850	100.97476	1.202581	7.0623	.0206	292.5874
5	10	3.8100	2.1431	7.0892	-.3486	100.97137	1.202520	7.0977	.0207	292.5924
5	11	3.8100	2.3813	7.1406	-.3165	100.96697	1.202502	7.1476	.0208	292.5841
5	12	3.8100	2.6194	7.1388	-.2841	100.96326	1.202459	7.1444	.0208	292.5837
5	13	3.8100	2.8575	7.1672	-.2530	100.95902	1.202428	7.1716	.0209	292.5789
5	14	3.8100	3.0956	7.1764	-.2221	100.95904	1.202392	7.1799	.0209	292.5762
5	15	3.8100	3.3338	7.1838	-.1909	100.95124	1.202358	7.1864	.0210	292.5734
5	16	3.8100	3.5719	7.1910	-.1594	100.94772	1.202327	7.1927	.0210	292.5708
5	17	3.8100	3.8100	7.1968	-.1278	100.94461	1.202299	7.1979	.0210	292.5685

Fig. 25. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00650636 SECONDS (DELTA T = .00000651)

L	M	X (CM)	Y (CM)	U (M/S)	V (M/S)	P (KPA)	RHO (KG/M3)	VMAG (M/S)	MACH NO	T (K)
39	12	36.1950	2.6194	8.3311	.2431	101.38302	1.204974	8.3346	.0243	293.1870
39	13	36.1950	2.8575	7.5703	.2192	101.38394	1.204987	7.5735	.0221	293.1864
39	14	36.1950	3.0956	7.1627	.1936	101.38508	1.204998	7.1653	.0209	293.1871
39	15	36.1950	3.3338	7.0706	.1668	101.38629	1.205008	7.0726	.0206	293.1881
39	16	36.1950	3.5719	7.0628	.1396	101.38747	1.205018	7.0641	.0206	293.1890
39	17	36.1950	3.8100	7.0589	.1124	101.38850	1.205027	7.0598	.0206	293.1899
39	18	36.1950	4.0481	7.0547	.0850	101.38931	1.205034	7.0552	.0206	293.1906
39	19	36.1950	4.2863	7.0512	.0571	101.38987	1.205039	7.0515	.0205	293.1910
39	20	36.1950	4.5244	7.0490	.0288	101.39019	1.205041	7.0491	.0205	293.1913
39	21	36.1950	4.7625	7.0480	0.0000	101.39032	1.205042	7.0480	.0205	293.1914
40	1	37.1475	0.0000	26.6299	0.0000	101.36684	1.204842	26.6299	.0776	293.1722
40	2	37.1475	.2381	26.1299	.0615	101.36747	1.204791	26.1300	.0761	293.1865
40	3	37.1475	.4763	24.6289	.1196	101.36768	1.204466	24.6292	.0717	293.2661
40	4	37.1475	.7144	22.6970	.1701	101.36771	1.204445	22.6976	.0661	293.2713
40	5	37.1475	.9525	20.5517	.2107	101.36761	1.204570	20.5528	.0599	293.2406
40	6	37.1475	1.1906	18.3439	.2403	101.36744	1.204678	18.3455	.0534	293.2138
40	7	37.1475	1.4288	16.1894	.2586	101.36722	1.204741	16.1914	.0472	293.1979
40	8	37.1475	1.6669	14.1762	.2659	101.36701	1.204777	14.1787	.0413	293.1886
40	9	37.1475	1.9050	12.3660	.2631	101.36686	1.204797	12.3688	.0360	293.1833
40	10	37.1475	2.1431	10.7950	.2520	101.36682	1.204812	10.7979	.0315	293.1794
40	11	37.1475	2.3813	9.4806	.2344	101.36695	1.204828	9.4835	.0276	293.1761
40	12	37.1475	2.6194	8.4351	.2125	101.36727	1.204840	8.4378	.0246	293.1739
40	13	37.1475	2.8575	7.6831	.1882	101.36777	1.204850	7.6854	.0224	293.1731
40	14	37.1475	3.0956	7.2788	.1631	101.36840	1.204856	7.2806	.0212	293.1733
40	15	37.1475	3.3338	7.1854	.1384	101.36906	1.204862	7.1867	.0209	293.1738
40	16	37.1475	3.5719	7.1731	.1149	101.36968	1.204867	7.1740	.0209	293.1743
40	17	37.1475	3.8100	7.1657	.0920	101.37020	1.204872	7.1663	.0209	293.1748
40	18	37.1475	4.0481	7.1598	.0693	101.37060	1.204875	7.1602	.0209	293.1751
40	19	37.1475	4.2863	7.1558	.0464	101.37088	1.204877	7.1560	.0208	293.1753
40	20	37.1475	4.5244	7.1534	.0233	101.37104	1.204879	7.1535	.0208	293.1755
40	21	37.1475	4.7625	7.1523	0.0000	101.37110	1.204879	7.1523	.0208	293.1755
41	1	38.1000	0.0000	26.4055	0.0000	101.35000	1.204699	26.4055	.0769	293.1582
41	2	38.1000	.2381	25.9088	.0579	101.35000	1.204644	25.9088	.0755	293.1718
41	3	38.1000	.4763	24.4314	.1121	101.35000	1.204339	24.4317	.0712	293.2460
41	4	38.1000	.7144	22.5342	.1587	101.35000	1.204326	22.5348	.0656	293.2492
41	5	38.1000	.9525	20.4295	.1958	101.35000	1.204442	20.4305	.0595	293.2208
41	6	38.1000	1.1906	18.2650	.2222	101.35000	1.204542	18.2664	.0532	293.1965
41	7	38.1000	1.4288	16.1538	.2377	101.35000	1.204601	16.1555	.0471	293.1821
41	8	38.1000	1.6669	14.1812	.2425	101.35000	1.204635	14.1833	.0413	293.1738
41	9	38.1000	1.9050	12.4065	.2375	101.35000	1.204655	12.4088	.0362	293.1690
41	10	38.1000	2.1431	10.8638	.2244	101.35000	1.204670	10.8661	.0317	293.1654
41	11	38.1000	2.3813	9.5691	.2050	101.35000	1.204684	9.5713	.0279	293.1620
41	12	38.1000	2.6194	8.5342	.1819	101.35000	1.204694	8.5362	.0249	293.1596
41	13	38.1000	2.8575	7.7845	.1573	101.35000	1.204699	7.7861	.0227	293.1584
41	14	38.1000	3.0956	7.3754	.1334	101.35000	1.204700	7.3767	.0215	293.1581
41	15	38.1000	3.3338	7.2747	.1116	101.35000	1.204700	7.2756	.0212	293.1581
41	16	38.1000	3.5719	7.2570	.0919	101.35000	1.204700	7.2576	.0211	293.1581
41	17	38.1000	3.8100	7.2470	.0731	101.35000	1.204700	7.2473	.0211	293.1581
41	18	38.1000	4.0481	7.2401	.0547	101.35000	1.204700	7.2403	.0211	293.1581
41	19	38.1000	4.2863	7.2357	.0364	101.35000	1.204700	7.2358	.0211	293.1581
41	20	38.1000	4.5244	7.2330	.0182	101.35000	1.204700	7.2331	.0211	293.1581

Fig. 25. (Cont)

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SOLUTION SURFACE NO.  1000 - TIME =  .00650636 SECONDS (DELTA T =  .00000651)
         L     M          X          Y          U          V           P            RHO        VMAG          MACH        T
                        (CM)       (CM)       (M/S)      (M/S)       (KPA)        (KG/M3)     (M/S)          NO         (K)

        41    21      38.1000     4.7625     7.2318     0.0000     101.35000     1.204700     7.2318        .0211     293.1581

        MASS=   .007419 (KG/SEC)     THRUST=      .1221 (NEWTONS)     MASSI=   .007206     MASSE=   .007419

***** EXPECT FILM OUTPUT FOR N=  1000 *****
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Fig. 25. (Cont)