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

University of California



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Michael C. Cline



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VNAP: A COMPUTER PROGRAM FOR
COMPUTATION OF TWO-DIMENSIONAL, TIME-DEPENDENT
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

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\epsilon \rho v}{y} = 0 , \quad (1)$$

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + \frac{1}{\rho} \frac{\partial p}{\partial x} = \frac{1}{\rho} \frac{\partial}{\partial x} \left[(\lambda + 2\mu) \frac{\partial u}{\partial x} + \lambda \frac{\partial v}{\partial y} \right] + \frac{1}{\rho} \frac{\partial}{\partial y} \left[\mu \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right] \\ + \frac{\epsilon}{\rho y} \left[(\lambda + \mu) \frac{\partial v}{\partial x} + \mu \frac{\partial u}{\partial y} \right] , \end{aligned} \quad (2)$$

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

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

$$p = \rho RT , \quad a^2 = \gamma P / \rho , \quad (5)$$

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

$$\lambda_A = C C_\lambda \Delta x \Delta y \rho \left| \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \epsilon \frac{v}{y} \right|, \quad (6)$$

$$\mu_A = C_\mu \lambda_A / C_\lambda, \quad (7)$$

$$k_A = \gamma R \mu_A / C_k (\gamma - 1), \quad (8)$$

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).

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

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

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

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

$$\lambda_T = \lambda \frac{\mu_T}{\mu} , \quad (12)$$

and

$$k_T = k \frac{\mu_T}{\mu} , \quad (13)$$

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

$$\ell = (0.125 - 0.015\epsilon)(y_2 - y_1) , \quad (14)$$

where

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

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

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

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

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

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

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

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

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

where

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

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

$$\delta = -\beta\eta \frac{\partial y_w}{\partial t}, \quad (24)$$

$$\bar{v} = \alpha u + \beta v + \delta, \quad (25)$$

$$\bar{\eta} = y = y_c + \eta/\beta. \quad (26)$$

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

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

$$\begin{aligned} \text{Equation (18)} = \frac{C_\rho}{\rho} & \left[\left(\frac{\partial}{\partial \zeta} + \alpha \frac{\partial}{\partial \eta} \right) \left(\mu_A \frac{\partial \rho}{\partial \zeta} + \mu_A \alpha \frac{\partial \rho}{\partial \eta} \right) \right. \\ & \left. + \beta \frac{\partial}{\partial \eta} \left(\mu_A \beta \frac{\partial \rho}{\partial \eta} \right) + \frac{\epsilon \mu_A}{\bar{\eta}} \beta \frac{\partial \rho}{\partial \eta} \right]. \end{aligned} \quad (28)$$

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

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

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

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 ($\epsilon = 0$) are

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

for the first step and

$$\begin{aligned}
u_{L,M}^{N+1} = & 0.5 \left\{ u_{L,M}^N + u_{L,M}^{-N+1} - \left[u_{L,M}^{-N+1} \left(\frac{u_{L+1,M}^{-N+1} - u_{L,M}^{-N+1}}{\Delta x} \right) + v_{L,M}^{-N+1} \left(\frac{u_{L,M+1}^{-N+1} - u_{L,M}^{-N+1}}{\Delta y} \right) \right. \right. \\
& \left. \left. + \frac{1}{\rho_{L,M}^{-N+1}} \left(\frac{p_{L+1,M}^{-N+1} - p_{L,M}^{-N+1}}{\Delta x} \right) \right] \Delta t + Q \right\} , \tag{32}
\end{aligned}$$

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 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 $\eta = \text{constant}$ 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

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

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 con-

vective 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.

$$P_T/P = [1 + (\gamma - 1) M^2/2]^{\gamma/(\gamma-1)} , \quad (34)$$

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

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 $\eta = \text{constant}$ 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 varia-

bles 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

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

$$(37)$$

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

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 $\zeta = \text{constant}$ 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

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

$$\begin{aligned} dp + \rho\alpha a du/\alpha^* + \rho\beta a dv/\alpha^* &= \left(\psi_4 + a^2\psi_1 + \rho\alpha a\psi_2/\alpha^* + \rho\beta a\psi_3/\alpha^* \right) d\tau \\ \text{for } d\eta &= (\bar{v} + \alpha^* a) d\tau. \end{aligned} \quad (41)$$

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

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

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

$$p = p_{\text{ambient}} \quad (43)$$

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 upper 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

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

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

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

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.

<u>Computer</u>	<u>Relative Machine Speed</u>
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 Serra¹³ 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 Moger¹⁷ and Brown and Ozcan¹⁸ 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 unaware of any other time-dependent analyses 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 -0.67μ . 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 assumption 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 ONEDIM 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 $\text{MASFL}\emptyset$. Next, subroutine $\text{PL}\emptyset\text{T}$ 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 $\text{VISC}\emptyset\text{US}$ 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 $\text{MASFL}\emptyset$ to compute the mass flow and momentum thrust; prints the solution surface; calls subroutine $\text{PL}\emptyset\text{T}$ 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 $\text{NPL}\emptyset\text{T} \geq 0$) at the end of the run for handling purposes.

2. Subroutine $\text{GE}\emptyset\text{M}$. VNAP calls subroutine $\text{GE}\emptyset\text{M}$ 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 $\text{GE}\emptyset\text{M}$ then calls subroutine MTLUP , which interpolates for equally spaced coordinates. Next, subroutine $\text{GE}\emptyset\text{M}$ 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 $\text{GE}\emptyset\text{MCB}$. VNAP calls $\text{GE}\emptyset\text{MCB}$ to calculate the centerbody coordinates and slopes for four different centerbody geometries. It is the same as subroutine $\text{GE}\emptyset\text{M}$.

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 modifying 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	}	No
N1D = 2 subsonic-sonic-subsonic		additional
N1D = 3 supersonic-sonic-supersonic		data are
N1D = 4 supersonic-sonic-subsonic		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.
- R \emptyset (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 velocity 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 (NGEOM = 1). The parameter XI, RI (duct radius), and XE must be specified.
- b. Circular-Arc Conical Wall (NGEOM = 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 (NGEOM = 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 (NGEOM = 4). An arbitrary 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.

ANGEGB 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 ANGEGB 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 \neq 0). The dependent variables are smoothed by
- $$u_{L,M} = \text{SMP} * u_{L,M} + (1.0 - \text{SMP}) * (u_{L+1,M} + u_{L,M+1} + u_{L-1,M} + u_{L,M-1}) / 4.0 .$$
- 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, These parameters specify the molecular viscosity, μ , by $\mu = \text{CMU} \cdot T^{\text{EMU}}$,
 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, These parameters specify the second coefficient of viscosity, λ , by
ELA $\lambda = \text{CLA} \cdot T^{\text{ELA}}$,
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, These parameters specify the thermal conductivity, k , by $k = \text{CK} \cdot T^{\text{EK}}$,
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 solution 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 preceded 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 $NGE\emptyset M = 3$ or 4 option could be used. The $NGE\emptyset M = 4$ 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 $640.0^{\circ}R$, 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 $TC\emptyset NV$ 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 $NGE\emptyset M$ 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 $NGE\emptyset M = 1$ 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 ANGECEB 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 ambient 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. There-

fore, 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 $CMU = 9.643 \times 10^{-7} \text{ Pa-s/K}^{1/2}$, $CLA = -6.429 \times 10^{-7} \text{ Pa-s/K}^{1/2}$, and $CK = 1.217 \times 10^{-3} \text{ W/m-K}^{3/2}$. 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, $IUI = IU\emptyset = 2$. Film is requested every 50 time steps, so $NPL\emptyset T = 50$. 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 $R\emptyset$.

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 $NGE\emptyset M = 1$. 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 $R\emptyset I$. 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 setting $IAV = 0$. No other input is required.

g. Namelist RVL. The viscosity coefficients are specified by $CMU = 1.813 \times 10^{-5} \text{ Pa-s}$ and $CLA = -1.208 \times 10^{-5} \text{ Pa-s}$. 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

$$\begin{aligned} \rho_\tau + u\rho_\zeta + \rho u_\zeta = & -\bar{v}\rho_\eta - \rho\alpha u_\eta - \rho\beta v_\eta - \epsilon\rho v/\bar{\eta} + \frac{C_p}{\rho} \left[(\mu_A \rho_\zeta + \mu_A \alpha \rho_\eta)_\zeta \right. \\ & \left. + \alpha(\mu_A \rho_\zeta + \mu_A \alpha \rho_\eta)_\eta + \beta(\mu_A \beta \rho_\eta)_\eta + \epsilon\mu_A \beta \rho_\eta/\bar{\eta} \right], \end{aligned} \quad (A-1)$$

$$\begin{aligned} u_\tau + uu_\zeta + p_\zeta/\rho = & -\bar{v}u_\eta - \alpha p_\eta/\rho + \left[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta \right]_\zeta/\rho \\ & + \alpha \left[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta \right]_\eta/\rho + \beta \left[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta) \right]_\eta/\rho \\ & + \epsilon \left[(\lambda + \mu)(v_\zeta + \alpha v_\eta) + \mu\beta u_\eta \right] / \rho \bar{\eta}, \end{aligned} \quad (A-2)$$

$$\begin{aligned} v_\tau + uv_\zeta = & -\bar{v}v_\eta - \beta p_\eta/\rho + \beta \left[(\lambda + 2\mu)\beta v_\eta + \lambda(u_\zeta + \alpha u_\eta) \right]_\eta/\rho \\ & + \left[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta) \right]_\zeta/\rho + \alpha \left[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta) \right]_\eta/\rho \\ & + \epsilon(\lambda + 2\mu)(\beta v_\eta - v/\bar{\eta})/\rho \bar{\eta}, \end{aligned} \quad (A-3)$$

$$\begin{aligned} p_\tau + up_\zeta - a^2(\rho_\tau + u\rho_\zeta) = & -\bar{v}p_\eta + a^2\bar{v}\rho_\eta + (\gamma-1) \left\{ (\lambda + 2\mu)(u_\zeta + \alpha u_\eta)^2 \right. \\ & + (\lambda + 2\mu)(\beta v_\eta)^2 + \mu(v_\zeta + \alpha v_\eta)^2 + \mu(\beta u_\eta)^2 + 2\lambda(u_\zeta + \alpha u_\eta)\beta v_\eta \\ & + 2\mu\beta u_\eta(v_\zeta + \alpha v_\eta) + \left[k(T_\zeta + \alpha T_\eta) \right]_\zeta + \alpha \left[k(T_\zeta + \alpha T_\eta) \right]_\eta + \beta(k\beta T_\eta)_\eta \\ & \left. + \epsilon \left[(\lambda + 2\mu)(v/\bar{\eta})^2 + 2\lambda v(\beta v_\eta + u_\zeta + \alpha u_\eta)/\bar{\eta} + k\beta T_\eta/\bar{\eta} \right] \right\}, \end{aligned} \quad (A-4)$$

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

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

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

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

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

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

$$\rho_\tau + u\rho_\zeta + \rho u_\zeta = \psi_1 , \quad (\text{A-9})$$

$$u_\tau + uu_\zeta + p_\zeta/\rho = \psi_2 , \quad (\text{A-10})$$

$$v_\tau + uv_\zeta = \psi_3 , \quad (\text{A-11})$$

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

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

$$\begin{aligned} & \ell_1(\rho_\tau + u\rho_\zeta + \rho u_\zeta - \psi_1) + \ell_2(u_\tau + uu_\zeta + p_\zeta/\rho - \psi_2) + \ell_3(v_\tau + uv_\zeta - \psi_3) \\ & + \ell_4(p_\tau + up_\zeta - a^2\rho_\tau - a^2u\rho_\zeta - \psi_4) = 0. \end{aligned} \quad (\text{A-13})$$

Rearrangement of Eq. (A-13) yields

$$\begin{aligned} & (u\ell_1 - a^2u\ell_4)\rho_\zeta + (\ell_1 - a^2\ell_4)\rho_\tau + (\rho\ell_1 + u\ell_2)u_\zeta + \ell_2u_\tau + u\ell_3v_\zeta + \ell_3v_\tau \\ & + (\ell_2/\rho + u\ell_4)p_\zeta + \ell_4p_\tau = \ell_1\psi_1 + \ell_2\psi_2 + \ell_3\psi_3 + \ell_4\psi_4 . \end{aligned} \quad (\text{A-14})$$

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

$$W_1 = (u\lambda_1 - a^2 u\lambda_4, \lambda_1 - a^2 \lambda_4), \quad (\text{A-15})$$

$$W_2 = (\rho\lambda_1 + u\lambda_2, \lambda_2), \quad (\text{A-16})$$

$$W_3 = (u\lambda_3, \lambda_3), \quad (\text{A-17})$$

$$W_4 = (\lambda_2/\rho + u\lambda_4, \lambda_4). \quad (\text{A-18})$$

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

$$d_{W_1} \rho + d_{W_2} u + d_{W_3} v + d_{W_4} p = \lambda_1 \psi_1 + \lambda_2 \psi_2 + \lambda_3 \psi_3 + \lambda_4 \psi_4, \quad (\text{A-19})$$

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 λ_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 λ_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

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

When Eq. (A-20) is expanded,

$$(u\lambda_1 - a^2 u\lambda_4) N_\zeta + (\lambda_1 - a^2 \lambda_4) N_\tau = 0, \quad (\text{A-21})$$

$$(\rho\lambda_1 + u\lambda_2) N_\zeta + \lambda_2 N_\tau = 0, \quad (\text{A-22})$$

$$u\ell_3 N_\zeta + \ell_3 N_\tau = 0 , \quad (\text{A-23})$$

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

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

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

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

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

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

$$uN_\zeta + N_\tau = 0. \quad (\text{A-27})$$

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

$$uN_\zeta + N_\tau = \pm aN_\zeta. \quad (\text{A-28})$$

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

$$d\zeta/d\tau = u , \quad (\text{A-29})$$

$$d\zeta/d\tau = u \mp a. \quad (\text{A-30})$$

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

III. SOLUTION FOR THE λ_i

If the compatibility equation (A-19) is to be used, the arbitrary parameters λ_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

$$\begin{vmatrix} 0 & 0 & 0 & 0 \\ \rho N_\zeta & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & N_\zeta/\rho & 0 & 0 \end{vmatrix} \begin{vmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{vmatrix} = 0 . \quad (\text{A-31})$$

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

$$\lambda_1 = \lambda_2 = 0, \lambda_3 \text{ and } \lambda_4 \text{ are arbitrary.} \quad (\text{A-32})$$

Therefore, two possible solutions are

$$\lambda_1 = \lambda_2 = \lambda_3 = 0, \lambda_4 = 1 , \quad (\text{A-33})$$

and

$$\lambda_1 = \lambda_2 = \lambda_4 = 0, \lambda_3 = 1 . \quad (\text{A-34})$$

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

$$\begin{vmatrix}
\pm a N_{\zeta} & 0 & 0 & \mp a^3 N_{\zeta} \\
\rho N_{\zeta} & \pm a N_{\zeta} & 0 & 0 \\
0 & 0 & \pm a N_{\zeta} & 0 \\
0 & N_{\zeta}/\rho & 0 & \pm a N_{\zeta}
\end{vmatrix}
\begin{vmatrix}
\lambda_1 \\
\lambda_2 \\
\lambda_3 \\
\lambda_4
\end{vmatrix}
= 0 . \tag{A-35}$$

Since the rank of the coefficient matrix of Eq. (A-35) is three, there is only one independent solution for λ_1 . From Eq. (A-35),

$$\lambda_3 = 0, \lambda_1 = a^2 \lambda_4, \lambda_2 = \mp \rho a \lambda_4 . \tag{A-36}$$

Therefore, one possible solution is

$$\lambda_1 = a^2, \lambda_2 = \mp \rho a, \lambda_3 = 0, \lambda_4 = 1 . \tag{A-37}$$

IV. COMPATIBILITY EQUATIONS

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

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

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

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

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

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

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

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

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

APPENDIX B

CONSTANT ZETA REFERENCE PLANE CHARACTERISTIC RELATIONS

I. GOVERNING EQUATIONS

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

$$\begin{aligned} \rho_\tau + \bar{v}\rho_\eta + \rho\alpha u_\eta + \rho\beta v_\eta = & -u\rho_\zeta - \rho u_\zeta - \varepsilon\rho v/\bar{\eta} + \frac{c_p}{\rho} \left[(\mu_A \rho_\zeta + \mu_A \alpha \rho_\eta)_\zeta + \alpha(\mu_A \rho_\zeta \right. \\ & \left. + \mu_A \alpha \rho_\eta)_\eta + \beta(\mu_A \beta \rho_\eta)_\eta + \varepsilon\mu_A \beta \rho_\eta/\bar{\eta} \right], \end{aligned} \quad (B-1)$$

$$\begin{aligned} u_\tau + \bar{v}u_\eta + \alpha p_\eta/\rho = & -uu_\zeta - p_\zeta/\rho + \left[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta \right]_\zeta / \rho \\ & + \alpha \left[(\lambda + 2\mu)(u_\zeta + \alpha u_\eta) + \lambda\beta v_\eta \right]_\eta / \rho + \beta \left[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta) \right]_\eta / \rho \\ & + \varepsilon \left[(\lambda + \mu)(v_\zeta + \alpha v_\eta) + \mu\beta u_\eta \right] / \rho \bar{\eta}, \end{aligned} \quad (B-2)$$

$$\begin{aligned} v_\tau + \bar{v}v_\eta + \beta p_\eta/\rho = & -uv_\zeta + \beta \left[(\lambda + 2\mu)\beta v_\eta + \lambda(u_\zeta + \alpha u_\eta) \right]_\eta / \rho \\ & + \left[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta) \right]_\zeta / \rho + \alpha \left[\mu(v_\zeta + \alpha v_\eta + \beta u_\eta) \right]_\eta / \rho \\ & + \varepsilon(\lambda + 2\mu)(\beta v_\eta - v/\bar{\eta})/\rho \bar{\eta}, \end{aligned} \quad (B-3)$$

$$\begin{aligned} p_\tau + \bar{v}p_\eta - a^2(\rho_\tau + \bar{v}\rho_\eta) = & -up_\zeta + a^2u\rho_\zeta + (\gamma-1) \left\{ (\lambda + 2\mu)(u_\zeta + \alpha u_\eta)^2 \right. \\ & + (\lambda + 2\mu)(\beta v_\eta)^2 + \mu(v_\zeta + \alpha v_\eta)^2 + \mu(\beta u_\eta)^2 + 2\lambda(u_\zeta + \alpha u_\eta)\beta v_\eta \\ & + 2\mu\beta u_\eta(v_\zeta + \alpha v_\eta) + \left[k(T_\zeta + \alpha T_\eta) \right]_\zeta + \alpha \left[k(T_\zeta + \alpha T_\eta) \right]_\eta + \beta(k\beta T_\eta)_\eta \\ & \left. + \varepsilon \left[(\lambda + 2\mu)(v/\bar{\eta})^2 + 2\lambda v(\beta v_\eta + u_\zeta + \alpha u_\eta)/\bar{\eta} + k\beta T_\eta/\bar{\eta} \right] \right\}, \end{aligned} \quad (B-4)$$

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

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

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

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

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

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

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

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

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

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

II. CHARACTERISTIC CURVES

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

$$d\eta/d\tau = \bar{v}, \quad (\text{B-13})$$

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

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

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

$$\begin{aligned} dp - \rho \alpha a du / \alpha^* - \rho \beta a dv / \alpha^* &= (\psi_4 + a^2 \psi_1 - \rho \alpha a \psi_2 / \alpha^* - \rho \beta a \psi_3 / \alpha^*) d\tau \\ \text{for } d\eta &= (\bar{v} - \alpha^* a) d\tau, \end{aligned} \quad \text{(B-16)}$$

and

$$\begin{aligned} dp + \rho \alpha a du / \alpha^* + \rho \beta a dv / \alpha^* &= (\psi_4 + a^2 \psi_1 + \rho \alpha a \psi_2 / \alpha^* + \rho \beta a \psi_3 / \alpha^*) d\tau \\ \text{for } d\eta &= (\bar{v} + \alpha^* a) d\tau. \end{aligned} \quad \text{(B-17)}$$

APPENDIX C
FORTRAN IV LISTING OF THE VNAP PROGRAM
LASL IDENTIFICATION: LP-686

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*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, NASMMCC
2 , ICHAR, NID, LJET, JFLAG, IERR, IUI, IUO, DXR, DYR, LD, MD, LMD1
3 , LMD3, IB, RSTAR, RSTARS, NPLOT, G, PC, TC, LC, PLOW, ROLOW, CD
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, XFCB, RECB, RCICB,
1 RCTCB, ANGICB, ANGEGB, XCR(LI), YCB(LI), XCB(LI), YCB(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), YCB(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
MCC 10
MCC 20
MCC 30
MCC 40
MCC 50
MCC 60
MCC 70
MCC 80
MCC 90
MCC 100
MCC 110
MCC 120
MCC 130
MCC 140
MCC 150
MCC 160
MCC 170
MCC 180
MCC 190
MCC 200
MCC 210
MCC 220
MCC 230
MCC 240
MCC 250
MCC 260
MCC 270
MCC 280
MCC 290
MCC 300
MCC 310
MCC 320
MCC 330
MCC 340
MCC 350
MCC 360
MCC 370
MCC 380
MCC 390
MCC 400
MCC 410
MCC 420
MCC 430
MCC 440
MCC 450
MCC 460
MCC 470

*DECK,VNAP
PROGRAM VNAP (ITAPE,OTAPE1,PUN1,TAPES=ITAPE,TAPE6=OTAPE1,TAPE8
1 =PUN1)
VNP 10
VNP 20
VNP 30
VNP 40
VNP 50
VNP 60
VNP 70
VNP 80
VNP 90
VNP 100
VNP 110
VNP 120
VNP 130
VNP 140
VNP 150
VNP 160
VNP 170
VNP 180
VNP 190
VNP 200
VNP 210
VNP 220
VNP 230
VNP 240
VNP 250
VNP 260
VNP 270
VNP 280
VNP 290
VNP 300
VNP 310
VNP 320
VNP 330
VNP 340
VNP 350
VNP 360
VNP 370
VNP 380
VNP 390
VNP 400
VNP 410
VNP 420
VNP 430
VNP 440
VNP 450
VNP 460
VNP 470

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

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*****

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 FREE
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.

DIMENSION TITLE(8)
VNP 280
VNP 290
VNP 300

*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,NID,NSTART,TSTART,RSTAR,RSTARS
NAMELIST /GEMTRY/ NDIM,XI,RI,RT,XE,RCI,RCT,ANGI,ANGE,NGEOM,XWI,YW
1 ,NWPTS,IINT,IDIF,LJET,JFLAG,NXNY,YW
NAMELIST /GCB/ NGCB,RICB,RTCB,RCICB,RCTCB,ANGICB,ANGEGB,YCB
1 ,NXNYCB,XCBI,YCBI,NCBPTS,IINTCB,IDIFCB
NAMELIST /RC/ 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
VNP 310
VNP 320
VNP 330
VNP 340
VNP 350
VNP 360
VNP 370
VNP 380
VNP 390
VNP 400
VNP 410
VNP 420
VNP 430
VNP 440
VNP 450
VNP 460
VNP 470

SET ARRAY SIZE FOR COMMONS SOLUTN AND AV
VNP 430
VNP 440
VNP 450
VNP 460
VNP 470

LD=LI
MD=MI
LMD=LD*MD
VNP 450
VNP 460
VNP 470

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C		VNP	480
C	SET DEFAULT VALUES	VNP	490
C		VNP	500
	10 TCONV=TSTART=THETA(1)=CAV=TC=CMU=CLACK=EMU=ELA=EK=RSTAR=0.0	VNP	510
	RSTARS=SMACH=PT(1)=TT(1)=0.0	VNP	520
	FDT=TSTOP=1.0	VNP	530
	NASM=ND=NDIM=JEX=NCONVI=IUI=IUO=IAV=IVPTS=1	VNP	540
	NSTAG=NAME=IPUNCH=NGCB=NMAX=NPRINT=NST=N=IERR=JFLAG=ISUPER=0	VNP	550
	IUNIT=NOSLIP=IEXTRA=NSTART=ITM=IVBC=0	VNP	560
	IINT=IDIF=IINTCB=IDIFCB=LSS=2	VNP	570
	GAMMA=1.4	VNP	580
	RGAS=33.35	VNP	590
	PE(1)=14.7	VNP	600
	SMP=0.95	VNP	610
	NPLOT=-1	VNP	620
	G=32.174	VNP	630
	PC=144.0	VNP	640
	LC=12.0	VNP	650
	XMU=0.4	VNP	660
	XLA=1.0	VNP	670
	RKMU=0.7	VNP	680
	XRO=0.6	VNP	690
	PLOW=0.01	VNP	700
	ROLOW=0.0001	VNP	710
	TW(1)=TCB(1)=PE(2)=-1.0	VNP	720
	DYW=0.001	VNP	730
C		VNP	740
C	READ IN INPUT DATA	VNP	750
C		VNP	760
	READ (5,730) TITLE	VNP	770
	IF (EOF(5)) 20,30	VNP	780
	20 CALL EXIT	VNP	790
	30 READ (5,CNTRL)	VNP	800
	READ (5,IVS)	VNP	810
	READ (5,GEMTRY)	VNP	820
	READ (5,GCBL)	VNP	830
	READ (5,BC)	VNP	840
	READ (5,AVL)	VNP	850
	READ (5,RVL)	VNP	860
	IF (NAME.EQ.0) GO TO 40	VNP	870
	WRITE (6,CNTRL)	VNP	880
	WRITE (6,IVS)	VNP	890
	WRITE (6,GEMTRY)	VNP	900
	WRITE (6,GCBL)	VNP	910
	WRITE (6,BC)	VNP	920
	WRITE (6,AVL)	VNP	930
	WRITE (6,RVL)	VNP	940
		VNP	950
C		VNP	960
C	PRINT INPUT DATA	VNP	970
C		VNP	980
	40 WRITE (6,740)	VNP	990
	WRITE (6,770)	VNP	1000
	WRITE (6,760)	VNP	1010
	WRITE (6,780)	VNP	1020
	WRITE (6,790)	VNP	1030
	WRITE (6,750)	VNP	1040
	WRITE (6,800) TITLE	VNP	1050
	WRITE (6,750)	VNP	1060
	WRITE (6,810)	VNP	1070
	NPRIND=ABS(FLOAT(NPRINT))	VNP	1080
	WRITE (6,820) LMAX,MMAX,NMAX,NPRIND,TCONV,FDT,NSTAG,NASM,IUNIT,IUI	VNP	1090
	1,IUO,IVPTS,NCONVI,TSTOP,ND,NPLOT,IPUNCH,RSTAR,RSTARS,PLOW,ROLOW	VNP	1100
	WRITE (6,750)	VNP	1110
	IF (IUI.EQ.1) WRITE (6,830) GAMMA,RGAS	VNP	1120
	IF (IUI.EQ.2) WRITE (6,840) GAMMA,RGAS	VNP	1130
	WRITE (6,750)	VNP	1140
	WRITE (6,850)	VNP	1150
	IF (NDIM.EQ.0) WRITE (6,860)	VNP	1160
	IF (NDIM.EQ.1) WRITE (6,870)	VNP	

C		VNP	1170
C	CALCULATE THE DUCT RADIUS AND SLOPE	VNP	1180
C		VNP	1190
	WRITE (6,750)	VNP	1200
	CALL GEOM	VNP	1210
	IF (IERR.NE.0) GO TO 10	VNP	1220
	DY=1.0/FLOAT(MMAX=1)	VNP	1230
	XICB=XI	VNP	1240
	XECB=XE	VNP	1250
	IF (NGCB.NE.0) GO TO 60	VNP	1260
	RICB=0.0	VNP	1270
	RTCB=0.0	VNP	1280
	DO 50 L=1,LMAX	VNP	1290
	YCB(L)=0.0	VNP	1300
	NXNYCB(L)=0.0	VNP	1310
50	CONTINUE	VNP	1320
	GO TO 90	VNP	1330
60	CALL GEOMCB	VNP	1340
	LT=1	VNP	1350
	YO=YW(1)=YCB(1)	VNP	1360
	DO 80 L=1,LMAX	VNP	1370
	IF (NDIM.EQ.0) Y=YW(L)=YCB(L)	VNP	1380
	IF (NDIM.EQ.1) Y=YW(L)**2=YCB(L)**2	VNP	1390
	IF (Y.GT.0.0) GO TO 70	VNP	1400
	WRITE (6,990)	VNP	1410
	GO TO 10	VNP	1420
70	IF (Y.LT.YO) LT=L	VNP	1430
	IF (LT.EQ.L) YO=Y	VNP	1440
80	CONTINUE	VNP	1450
		VNP	1460
C		VNP	1470
C	CONTINUE SET UP AND PRINTING OF INPUT DATA	VNP	1480
C		VNP	1490
	90 IF (PE(2).NE.=1.0) GO TO 110	VNP	1500
	DO 100 M=2,MMAX	VNP	1510
	PE(M)=PE(1)	VNP	1520
100	CONTINUE	VNP	1530
110	IF (NSTAG.NE.0) GO TO 130	VNP	1540
	DO 120 M=2,MMAX	VNP	1550
	PT(M)=PT(1)	VNP	1560
	TT(M)=TT(1)	VNP	1570
	THETA(M)=THETA(1)	VNP	1580
120	CONTINUE	VNP	1590
130	WRITE (6,740)	VNP	1600
	IF (IUI.EQ.1) WRITE (6,960)	VNP	1610
	IF (IUI.EQ.2) WRITE (6,970)	VNP	1620
	DO 140 M=1,MMAX	VNP	1630
	WRITE (6,980) M,PT(M),TT(M),THETA(M),PE(M)	VNP	1640
140	CONTINUE	VNP	1650
	WRITE (6,1240) IEXTRA,IEX,ISUPER,DYW,IVBC	VNP	1660
	IF (NOSLIP.EQ.0) WRITE (6,1130)	VNP	1670
	IF (NOSLIP.NE.0) WRITE (6,1140)	VNP	1680
	WRITE (6,750)	VNP	1690
	IF (TW(1).LT.0.0) WRITE (6,1200)	VNP	1700
	IF (TW(1).GE.0.0) WRITE (6,1210)	VNP	1710
	WRITE (6,750)	VNP	1720
	IF (TCB(1).LT.0.0.AND.NGCB.NE.0) WRITE (6,1220)	VNP	1730
	IF (TCB(1).GE.0.0) WRITE (6,1230)	VNP	1740
	WRITE (6,750)	VNP	1750
	WRITE (6,1120) CAV,XMU,XLA,RKMU,XRO,NST,SMP,LSS,SMACH,IAV	VNP	1760
	WRITE (6,750)	VNP	1770
	IF (IUI.EQ.1) WRITE (6,1150) CMU,CLA,CK,EMU,ELA,EK	VNP	1780
	IF (IUI.EQ.2) WRITE (6,1160) CMU,CLA,CK,EMU,ELA,EK	VNP	1790
	WRITE (6,750)	VNP	1800
	IF (ITM.EQ.0) WRITE (6,1170)	VNP	1810
	IF (ITM.EQ.1) WRITE (6,1180)	VNP	1820
		VNP	1830
C	CONVERT METRIC UNITS TO ENGLISH UNITS	VNP	1840
C		VNP	1850
	IF (IUI.EQ.1) GO TO 240	VNP	1860
	RSTAR=RSTAR/2.54	VNP	1860

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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 (NID.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 (NID.NE.0) GO TO 290
VNP 1870
VNP 1880
VNP 1890
VNP 1900
VNP 1910
VNP 1920
VNP 1930
VNP 1940
VNP 1950
VNP 1960
VNP 1970
VNP 1980
VNP 1990
VNP 2000
VNP 2010
VNP 2020
VNP 2030
VNP 2040
VNP 2050
VNP 2060
VNP 2070
VNP 2080
VNP 2090
VNP 2100
VNP 2110
VNP 2120
VNP 2130
VNP 2140
VNP 2150
VNP 2160
VNP 2170
VNP 2180
VNP 2190
VNP 2200
VNP 2210
VNP 2220
VNP 2230
VNP 2240
VNP 2250
VNP 2260
VNP 2270
VNP 2280
VNP 2290
VNP 2300
VNP 2310
VNP 2320
VNP 2330
VNP 2340
VNP 2350
VNP 2360
VNP 2370
VNP 2380
VNP 2390
VNP 2400
VNP 2410
VNP 2420
VNP 2430
VNP 2440
VNP 2450
VNP 2460
VNP 2470
VNP 2480
VNP 2490
VNP 2500
VNP 2510
VNP 2520
VNP 2530
VNP 2540
VNP 2550
VNP 2560

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DO 280 L=1,LMAX	VNP 2570
DO 280 M=1,MMAX	VNP 2580
P(L,M,1)=P(L,M,1)+PC	VNP 2590
RO(L,M,1)=RO(L,M,1)/G	VNP 2600
280 CONTINUE	VNP 2610
290 GAM1=GAMMA/(GAMMA-1.0)	VNP 2620
GAM2=(GAMMA-1.0)/2.0	VNP 2630
GAM3=(GAMMA+1.0)/(GAMMA-1.0)	VNP 2640
RG=RGAS+G	VNP 2650
IF (ISUPER.EQ.0) GO TO 310	VNP 2660
DO 300 M=1,MMAX	VNP 2670
U(1,M,1)=UI(M)	VNP 2680
V(1,M,1)=VI(M)	VNP 2690
P(1,M,1)=PI(M)+PC	VNP 2700
RO(1,M,1)=ROI(M)/G	VNP 2710
U(1,M,2)=U(1,M,1)	VNP 2720
V(1,M,2)=V(1,M,1)	VNP 2730
P(1,M,2)=P(1,M,1)	VNP 2740
RO(1,M,2)=RO(1,M,1)	VNP 2750
300 CONTINUE	VNP 2760
C	VNP 2770
C SET INDICIES AND ZERO VISCOUS TERM ARRAYS	VNP 2780
C	VNP 2790
310 L1=LMAX-1	VNP 2800
L2=LMAX-2	VNP 2810
L3=LMAX-3	VNP 2820
M1=MMAX-1	VNP 2830
M2=MMAX-2	VNP 2840
CHECK=ABS(CMU)+ABS(CLA)+ABS(CK)	VNP 2850
DO 320 L=1,LMAX	VNP 2860
DO 320 M=1,MMAX	VNP 2870
QUT(L,M)=0.0	VNP 2880
QVT(L,M)=0.0	VNP 2890
QPT(L,M)=0.0	VNP 2900
QROT(L,M)=0.0	VNP 2910
320 CONTINUE	VNP 2920
IF (NID.EQ.0) GO TO 330	VNP 2930
C	VNP 2940
C COMPUTE THE 1-D INITIAL-DATA SURFACE	VNP 2950
C	VNP 2960
CALL ONEDIM	VNP 2970
IF (IERR.NE.0) GO TO 10	VNP 2980
C	VNP 2990
C COMPUTE THE INITIAL-DATA SURFACE MASS FLOW AND THRUST	VNP 3000
C	VNP 3010
330 IF (NPRINT.GT.0) GO TO 340	VNP 3020
NPRINT=NPRINT	VNP 3030
GO TO 420	VNP 3040
340 CALL MASFLO (0)	VNP 3050
C	VNP 3060
C CALCULATE AND PRINT THE INITIAL-VALUE SURFACE	VNP 3070
C	VNP 3080
C	VNP 3090
DO 410 IU=1,2	VNP 3100
IF (IU.EQ.1.AND,IU.EQ.2) GO TO 410	VNP 3110
IF (IU.EQ.2.AND,IU.EQ.1) GO TO 410	VNP 3120
NLINE=0	VNP 3130
WRITE (6,740)	VNP 3140
WRITE (6,880) TSTART,NSTART	VNP 3150
WRITE (6,890)	VNP 3160
IF (IU,EQ.1) WRITE (6,900)	VNP 3170
IF (IU,EQ.2) WRITE (6,910)	VNP 3180
WRITE (6,750)	VNP 3190
X=XI+DX	VNP 3200
DO 370 L=1,LMAX	VNP 3210
X=X+DX	VNP 3220
CALL MAP (0,L,1,AL,BE,DE,LD1,AL1,BE1,DE1)	VNP 3230
DYIO=DY/BE	VNP 3240
Y=YCB(L)-DYIO	VNP 3250
IF (L.NE.1) WRITE (6,1190)	VNP 3260
NLINE=NLINE+1	VNP 3270

	DO 370 M=1,MMAX	VNP 3280
	Y=Y+DYIO	VNP 3290
	VELMAG=SQRT(U(L,M,1)**2+V(L,M,1)**2)	VNP 3300
	CALL EOS (S,P(L,M,1),RO(L,M,1),TEMP,AS,D2,D3)	VNP 3310
	XMACH=VELMAG/SQRT(AS)	VNP 3320
	PRES=P(L,M,1)/PC	VNP 3330
	RHO=RO(L,M,1)*G	VNP 3340
	XP=X	VNP 3350
	YP=Y	VNP 3360
	UP=U(L,M,1)	VNP 3370
	VP=V(L,M,1)	VNP 3380
	IF (IU.EQ.1) GO TO 350	VNP 3390
	XP=XP*2.54	VNP 3400
	YP=YP*2.54	VNP 3410
	UP=UP*0.3048	VNP 3420
	VP=VP*0.3048	VNP 3430
	PRES=PRES*6.8948	VNP 3440
	RHO=RHO*16.02	VNP 3450
	VELMAG=VELMAG*0.3048	VNP 3460
	TEMP=TEMP*5.0/9.0	VNP 3470
350	NLINE=NLINE+1	VNP 3480
	IF (NLINE.LT.54) GO TO 360	VNP 3490
	WRITE (6,740)	VNP 3500
	WRITE (6,880) TSTART,NSTART	VNP 3510
	WRITE (6,890)	VNP 3520
	IF (IU.EQ.1) WRITE (6,900)	VNP 3530
	IF (IU.EQ.2) WRITE (6,910)	VNP 3540
	WRITE (6,750)	VNP 3550
	NLINE=1	VNP 3560
360	WRITE (6,920) L,M,XP,YP,UP,VP,PRES,RHO,VELMAG,XMACH,TEMP	VNP 3570
370	CONTINUE	VNP 3580
	IF (IU.EQ.2) GO TO 380	VNP 3590
	WRITE (6,940) MASST,THRUST,MASSI,MASSE	VNP 3600
	GO TO 400	VNP 3610
380	MASST=MASST*0.4536	VNP 3620
	MASSI=MASSI*0.4536	VNP 3630
	MASSE=MASSE*0.4536	VNP 3640
	THRUST=THRUST*4.4477	VNP 3650
	IF (NDIM.NE.0) GO TO 390	VNP 3660
	MASST=MASST/2.54	VNP 3670
	MASSI=MASSI/2.54	VNP 3680
	MASSE=MASSE/2.54	VNP 3690
	THRUST=THRUST/2.54	VNP 3700
390	WRITE (6,950) MASST,THRUST,MASSI,MASSE	VNP 3710
400	IF (IUO.NE.3) GO TO 420	VNP 3720
410	CONTINUE	VNP 3730
420	IF (NPLOT.LE.0) GO TO 430	VNP 3740
	CALL PLOT (TITLE,TSTART,NSTART,IVPTS)	VNP 3750
	WRITE (6,1100) NSTART	VNP 3760
430	IF (NMAX.EQ.0) GO TO 10	VNP 3770
C		VNP 3780
C	INITIALIZE THE TIME STEP INTEGRATION LOOP PARAMETERS	VNP 3790
C		VNP 3800
	N1=1	VNP 3810
	N3=2	VNP 3820
	DQM=0.0	VNP 3830
	NCONV=NC=NPC=NPD=0	VNP 3840
	LDUM=1	VNP 3850
	DXR=1.0/DX	VNP 3860
	DYR=1.0/DY	VNP 3870
	DXRS=DXR*DXR	VNP 3880
	DYRS=DYR*DYR	VNP 3890
	IF (NASM.NE.0.AND.LT.NE.1) LDUM=LT-1	VNP 3900
	WRITE (6,760)	VNP 3910
	IF (JFLAG.EQ.0) GO TO 440	VNP 3920
	UD(1)=U(LJET=1,MMAX,N1)	VNP 3930
	VD(1)=V(LJET=1,MMAX,N1)	VNP 3940
	PD(1)=P(LJET=1,MMAX,N1)	VNP 3950
	ROD(1)=RO(LJET=1,MMAX,N1)	VNP 3960
	UD(2)=UD(1)	

	VD(2)=VD(1)	VNP 3970
	PD(2)=PD(1)	VNP 3980
	ROD(2)=ROD(1)	VNP 3990
C		VNP 4000
C	ENTER THE TIME STEP INTEGRATION LOOP	VNP 4010
C		VNP 4020
	440 DO 660 N=1,NMAX	VNP 4030
	LMD1=LMD*(N1-1)	VNP 4040
	LMD3=LMD*(N3-1)	VNP 4050
C		VNP 4060
C	CALCULATE DELTA T (SINGLE SUBSCRIPT LMN1=L,M,N1)	VNP 4070
C		VNP 4080
	DO 450 L=1,LMAX	VNP 4090
	CALL MAP (0,L,MD,AL,BE,DE,LD1,AL1,BE1,DE1)	VNP 4100
	DXDY=DXRS+BE*BE*DYRS	VNP 4110
	DO 450 M=1,MMAX	VNP 4120
	LMN1=L+LD*(M-1)+LMD1	VNP 4130
	CALL EOS (1,P(LMN1),RO(LMN1),TEMP,AS,D2,D3)	VNP 4140
	UPA=ABS(U(LMN1))*DXR+ABS(V(LMN1))*BE*DYR+SQRT(AS*DXDY)	VNP 4150
	IF (L.EQ.1,AND,M.EQ.1) UPAM=UPA	VNP 4160
	IF (UPA.GT,UPAM) UPAM=UPA	VNP 4170
	450 CONTINUE	VNP 4180
	DT=FDT/UPAM	VNP 4190
	T=T+DT	VNP 4200
	IF (T.LE,TSTOP) GO TO 460	VNP 4210
	T=T+DT	VNP 4220
	DT=TSTOP-T	VNP 4230
	T=TSTOP	VNP 4240
C		VNP 4250
C	PRINT N,T AND DT	VNP 4260
C		VNP 4270
	460 NPD=NPD+1	VNP 4280
	IF (NPD.NE.10) GO TO 470	VNP 4290
	NP=N+NSTART	VNP 4300
	TIME=T/LC	VNP 4310
	DTIME=DT/LC	VNP 4320
	WRITE (6,1110) NP,TIME,DTIME	VNP 4330
	NPD=0	VNP 4340
C		VNP 4350
C	CALCULATE THE PREDICTOR SOLUTION	VNP 4360
C		VNP 4370
	470 IF (CAV.NE.0.0.OR,CHECK.NE.0.0) CALL VISCOUS	VNP 4380
	ICHAR=1	VNP 4390
	IB=1	VNP 4400
	CALL INTER	VNP 4410
	CALL WALL	VNP 4420
	IF (IERR.NE.0) GO TO 10	VNP 4430
	IF (NGCB.EQ.0) GO TO 480	VNP 4440
	IB=2	VNP 4450
	CALL WALL	VNP 4460
	IF (IERR.NE.0) GO TO 10	VNP 4470
	480 IF (ISUPER.LE.0) CALL INLET	VNP 4480
	CALL EXITT	VNP 4490
C		VNP 4500
C	CALCULATE THE CORRECTOR SOLUTION	VNP 4510
C		VNP 4520
	ICHAR=2	VNP 4530
	IB=1	VNP 4540
	CALL INTER	VNP 4550
	CALL WALL	VNP 4560
	IF (IERR.NE.0) GO TO 10	VNP 4570
	IF (NGCB.EQ.0) GO TO 490	VNP 4580
	IB=2	VNP 4590
	CALL WALL	VNP 4600
	IF (IERR.NE.0) GO TO 10	VNP 4610
	490 IF (ISUPER.LE.0) CALL INLET	VNP 4620
	CALL EXITT	VNP 4630
	IF (N.LE.NST) CALL SMOOTH	VNP 4640

C		VNP 4650
C	DETERMINE THE MAXIMUM (DELTA U)/U	VNP 4660
C		VNP 4670
	IF (TCONV.LE.0.0) GO TO 510	VNP 4680
	DQM=0.0	VNP 4690
	DO 500 L=LDUM,LMAX	VNP 4700
	DO 500 M=1,MMAX	VNP 4710
	IF (U(L,M,N1).EQ.0.0) GO TO 500	VNP 4720
	DQ=ABS((U(L,M,N3)-U(L,M,N1))/U(L,M,N1))	VNP 4730
	IF (DQ.GT.DQM) DQM=DQ	VNP 4740
	500 CONTINUE	VNP 4750
	510 NC=NC+1	VNP 4760
	NPC=NPC+1	VNP 4770
	IF (DQM.GE.TCONV) GO TO 520	VNP 4780
	NCONV=NCONV+1	VNP 4790
	IF (NCONV.EQ.1) NCHECK=N+1	VNP 4800
	IF (NCONV.GE.NCONVI) NC=NPRINT	VNP 4810
	520 IF (N.EQ.NMAX) NC=NPRINT	VNP 4820
	IF (N.EQ.NMAX) NPC=NPLOT	VNP 4830
	IF (T.EQ.TSTOP) NPC=NPLOT	VNP 4840
	IF (NCONV.GE.NCONVI) NPC=NPLOT	VNP 4850
	IF (N.GE.NCHECK+NCONVI) NCONV=0	VNP 4860
	IF (T.EQ.TSTOP) NC=NPRINT	VNP 4870
	IF (NC.EQ.NPRINT) GO TO 530	VNP 4880
	IF (NPC.EQ.NPLOT) GO TO 630	VNP 4890
	GO TO 650	VNP 4900
		VNP 4910
C		VNP 4920
C	COMPUTE THE SOLUTION SURFACE MASS FLOW AND THRUST	VNP 4930
C		VNP 4940
	530 ICN=0	VNP 4950
	IF (JFLAG.EQ.0) GO TO 540	VNP 4960
	IF (LT.NE.LJET=1) GO TO 540	VNP 4970
	UDUM=U(LT,M,N3)	VNP 4980
	RODUM=RO(LT,M,N3)	VNP 4990
	U(LT,M,N3)=UD(3)	VNP 5000
	RO(LT,M,N3)=ROD(3)	VNP 5010
	ICN=1	VNP 5020
	540 CALL MASFLO (1)	VNP 5030
	IF (ICN.EQ.0) GO TO 550	VNP 5040
	U(LT,M,N3)=UDUM	VNP 5050
	RO(LT,M,N3)=RODUM	VNP 5060
		VNP 5070
C		VNP 5080
C	CALCULATE AND PRINT THE SOLUTION SURFACE	VNP 5090
C		VNP 5100
	550 DO 620 IU=1,2	VNP 5110
	IF (IU.EQ.1.AND,IU.EQ.2) GO TO 620	VNP 5120
	IF (IU.EQ.2.AND,IU.EQ.1) GO TO 620	VNP 5130
	NLINE=0	VNP 5140
	WRITE (6,740)	VNP 5150
	TIME=T/LC	VNP 5160
	DTIME=DT/LC	VNP 5170
	NP=N+NSTART	VNP 5180
	WRITE (6,930) NP,TIME,DTIME	VNP 5190
	WRITE (6,890)	VNP 5200
	IF (IU.EQ.1) WRITE (6,900)	VNP 5210
	IF (IU.EQ.2) WRITE (6,910)	VNP 5220
	WRITE (6,750)	VNP 5230
	X=XI-DX	VNP 5240
	DO 580 L=1,LMAX	VNP 5250
	X=X+DX	VNP 5260
	CALL MAP (0,L,1,AL,BE,DE,LD1,AL1,BE1,DE1)	VNP 5270
	DYIO=DY/BE	VNP 5280
	Y=YCB(L)-DYIO	VNP 5290
	IF (L.NE.1) WRITE (6,1190)	VNP 5300
	NLINE=NLINE+1	VNP 5310
	DO 580 M=1,MMAX	VNP 5320
	Y=Y+DYIO	VNP 5330
	VELMAG=SQRT(U(L,M,N3)**2+V(L,M,N3)**2)	VNP 5340
	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	VNP 5350
RHO=RO(L,M,N3)*G	VNP 5360
XP=X	VNP 5370
YP=Y	VNP 5380
UP=U(L,M,N3)	VNP 5390
VP=V(L,M,N3)	VNP 5400
IF (IU.EQ.1) GO TO 560	VNP 5410
XP=XP*2.54	VNP 5420
YP=YP*2.54	VNP 5430
UP=UP*0.3048	VNP 5440
VP=VP*0.3048	VNP 5450
PRES=PRES*6.8948	VNP 5460
RHO=RHO*16.02	VNP 5470
VELMAG=VELMAG*0.3048	VNP 5480
TEMP=TEMP*5.0/9.0	VNP 5490
560 NLINE=NLINE+1	VNP 5500
IF (NLINE.LT.54) GO TO 570	VNP 5510
WRITE (6,740)	VNP 5520
WRITE (6,930) NP,TIME,DTIME	VNP 5530
WRITE (6,890)	VNP 5540
IF (IU.EQ.1) WRITE (6,900)	VNP 5550
IF (IU.EQ.2) WRITE (6,910)	VNP 5560
WRITE (6,750)	VNP 5570
NLINE=1	VNP 5580
570 WRITE (6,920) L,M,XP,YP,UP,VP,PRES,RHO,VELMAG,XMACH,TEMP	VNP 5590
580 CONTINUE	VNP 5600
IF (IU.EQ.2) GO TO 590	VNP 5610
WRITE (6,940) MASST,THRUST,MASSI,MASSE	VNP 5620
GO TO 610	VNP 5630
590 MASST=MASST*0.4536	VNP 5640
MASSI=MASSI*0.4536	VNP 5650
MASSE=MASSE*0.4536	VNP 5660
THRUST=THRUST*4.4477	VNP 5670
IF (NDIM.NE.0) GO TO 600	VNP 5680
MASSI=MASSI/2.54	VNP 5690
MASST=MASST/2.54	VNP 5700
MASSE=MASSE/2.54	VNP 5710
THRUST=THRUST/2.54	VNP 5720
600 WRITE (6,950) MASST,THRUST,MASSI,MASSE	VNP 5730
610 IF (IUO.NE.3) GO TO 630	VNP 5740
620 CONTINUE	VNP 5750
C	VNP 5760
C	VNP 5770
C	VNP 5780
630 IF (NPLOT.LT.0) GO TO 640	VNP 5790
IF (NPC.NE.NPLOT) GO TO 640	VNP 5800
TIME=T/LC	VNP 5810
NP=N*NSTART	VNP 5820
CALL PLOT (TITLE,TIME,NP,IVPTS)	VNP 5830
WRITE (6,1100) NP	VNP 5840
C	VNP 5850
C	VNP 5860
C	VNP 5870
640 IF (DDM.LT.TCONV) GO TO 670	VNP 5880
IF (T.EQ.TSTOP) GO TO 670	VNP 5890
IF (N.EQ.NMAX) GO TO 670	VNP 5900
IF (NC.EQ.NPRINT) NC=0	VNP 5910
IF (NPC.EQ.NPLOT) NPC=0	VNP 5920
650 CONTINUE	VNP 5930
NNN=N1	VNP 5940
N1=N3	VNP 5950
N3=NNN	VNP 5960
660 CONTINUE	VNP 5970
C	VNP 5980
C	VNP 5990
C	VNP 6000
670 IF (NPLOT.GE.0) CALL ADV (10)	VNP 6010
IF (IPUNCH.EQ.0) GO TO 10	VNP 6020
DO 680 L=1,LMAX	VNP 6030
DO 680 M=1,MMAX	VNP 6040

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P(L,M,N3)=P(L,M,N3)/PC VNP 6050
RO(L,M,N3)=RO(L,M,N3)*G VNP 6060
680 CONTINUE VNP 6070
WRITE (8,1000) NP,TIME VNP 6080
DO 690 M=1,MMAX VNP 6090
WRITE (8,1010) M,U(1,M,N3) VNP 6100
WRITE (8,1020) (U(L,M,N3),L=2,LMAX) VNP 6110
690 CONTINUE VNP 6120
DO 700 M=1,MMAX VNP 6130
WRITE (8,1030) M,V(1,M,N3) VNP 6140
WRITE (8,1020) (V(L,M,N3),L=2,LMAX) VNP 6150
700 CONTINUE VNP 6160
DO 710 M=1,MMAX VNP 6170
WRITE (8,1040) M,P(1,M,N3) VNP 6180
WRITE (8,1050) (P(L,M,N3),L=2,LMAX) VNP 6190
710 CONTINUE VNP 6200
DO 720 M=1,MMAX VNP 6210
WRITE (8,1060) M,RO(1,M,N3) VNP 6220
WRITE (8,1070) (RO(L,M,N3),L=2,LMAX) VNP 6230
720 CONTINUE VNP 6240
WRITE (8,1080) VNP 6250
NCARDS=(LMAX/7+2)*MMAX*4+2 VNP 6260
WRITE (6,1090) NCARDS VNP 6270
GO TO 10 VNP 6280
C VNP 6290
C VNP 6300
C VNP 6310
730 FORMAT (8A10) VNP 6320
740 FORMAT (1H1) VNP 6330
750 FORMAT (1H ) VNP 6340
760 FORMAT (1H0) VNP 6350
770 FORMAT (1H0,10X,46HV NAP, A COMPUTER PROGRAM FOR THE COMPUTATION O,VNP 6360
1 62HF TWO-DIMENSIONAL, TIME-DEPENDENT, COMPRESSIBLE, VISCOUS INTERVNP 6370
2 ,8HNAL FLOW,/,37X,59HBY MICHAEL C. CLINE, T-3 - LOS ALAMOS SCIENVNP 6380
3TIFIC LABORATORY) VNP 6390
780 FORMAT (1H0,10X,16HPROGRAM ABSTRACT =,/,26X,17HTHE NAVIER=STOKES,VNP 6400
1 62H EQUATIONS FOR TWO-DIMENSIONAL, TIME-DEPENDENT FLOW ARE SOLVEDVNP 6410
2 ,10H USING THE,/,21X,62HSECOND-ORDER, MACCORMACK FINITE-DIFFERENCVNP 6420
3E SCHEME. ALL BOUNDAR,31HY CONDITIONS ARE COMPUTED USING,/,21X,13HVNP 6430
4A SECOND-ORDE,62HR, REFERENCE PLANE CHARACTERISTIC SCHEME WITH THEVNP 6440
5 VISCOUS TERM,19HS TREATED AS SOURCE) VNP 6450
790 FORMAT (1H ,20X,41HFUNCTIONS. THE FLUID IS ASSUMED TO BE A ,54HPEVNP 6460
1RFECT GAS. THE STEADY-STATE SOLUTION IS OBTAINED AS,/,21X,62HTHE VNP 6470
2ASYMPTOTIC SOLUTION FOR LARGE TIME. THE FLOW BOUNDARIES M,34HAY BVNP 6480
3E ARBITRARY CURVED SOLID WALLS,/,21X,62HAS WELL AS JET ENVELOPES. VNP 6490
4 PROBLEMS THAT CAN BE SOLVED ARE FLO,33HW IN PIPES AND DUCTS, CONVVNP 6500
5ERGING,/,21X,55HCONVERGING-DIVERGING, AND PLUG NOZZLES, SUBSONIC VNP 6510
6AND SU,41HPERSONIC INLETS, AND FREE JET EXPANSIONS.) VNP 6520
800 FORMAT (1H0,10X,11HJOB TITLE =//21X,8A10) VNP 6530
810 FORMAT (1H0,10X,20HCONTROL PARAMETERS =) VNP 6540
820 FORMAT (1H0,20X,5HLMAX=,I2,2X,5HMMAX=,I2,3X,5HNMAY=,I4,2X,7HNPRINTVNP 6550
1=,I4,2X,6HTCONV=,F6,3,3X,4HFDT=,F4.2,2X,6HNSTAG=,I1,5X,5HNAGM=,I1,VNP 6560
2 4X,6HIUNIT=,I1,/,21X,4HIUI=,I1,4X,4HIUO=,I1,5X,6HIVPTS=,I1,4X,7HNVPNP 6570
3CONV=,I2,4X,6HTSTOP=,F7.5,2X,4HNID=,I2,4X,6HNPLOT=,I4,2X,7HIPUNCHVNP 6580
4=,I1,2X,/,21X,6HRSTAR=,F11.6,2X,7HRSTARS=,F13.7,4X,5HPLOW=,F6.4,4XVNP 6590
5 ,6HROLOW=,F11.6) VNP 6600
830 FORMAT (1H0,10X,13HFLUID MODEL =,/,21X,36HTHE RATIO OF SPECIFIC HVNP 6610
1EATS, GAMMA =,F6.4,26H AND THE GAS CONSTANT, R =,F9.4,15H (FT-LBF/VNP 6620
2LBM-R)) VNP 6630
840 FORMAT (1H0,10X,13HFLUID MODEL =,/,21X,36HTHE RATIO OF SPECIFIC HVNP 6640
1EATS, GAMMA =,F6.4,26H AND THE GAS CONSTANT, R =,F9.4,9H (J/KG-K))VNP 6650
850 FORMAT (1H0,10X,15HFLOW GEOMETRY =) VNP 6660
860 FORMAT (1H0,20X,47HTWO-DIMENSIONAL, PLANAR FLOW HAS BEEN SPECIFIEDVNP 6670
1 ) VNP 6680
870 FORMAT (1H0,20X,36HAXISYMMETRIC FLOW HAS BEEN SPECIFIED) VNP 6690
880 FORMAT (1H ,30HINITIAL-DATA SURFACE = TIME = ,F10.8,8H SECONDS,4H VNP 6700
1(N=,I6,1H)) VNP 6710
890 FORMAT (1H0,11X,1HL,4X,1HM,9X,1HX,10X,1HY,10X,1HU,11X,1HV,12X,1HP,VNP 6720
1 11X,3HRHO,7X,4HVMAG,10X,4HMACH,8X,1HT) VNP 6730

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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 ,20HRESOLUTION SURFACE NO.,I6,3H = ,7HTIME = ,F10.8,20H SVNP 6790
1SECONDS (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(DFG),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) =,F10.5,1H,) VNP 6980
1070 FORMAT (1X,7(F10.6,1H,)) VNP 6990
1080 FORMAT (1X,1HS) 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
1SECONDS) VNP 7050
1120 FORMAT (1H0,10X,21HARTIFICIAL 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,4HLSB=,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=F4.2,18H, AND EK=F4.2) VNP 7160
1170 FORMAT (1H0,10X,18HTURBULENCE MODEL =,/,21X,21HNO MODEL IS SPECIFYNP 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,33HADIBATIC UPPER WALL IS SPECIFIED) VNP 7240
1210 FORMAT (1H ,20X,15HTW IS SPECIFIED) VNP 7250
1220 FORMAT (1H ,20X,39HADIBATIC 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,4HDIWVNP 7280
1 =,F6.4,3X,5HIVBC=,I1) VNP 7290
END VNP 7300

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*DECK,GEOM	GEO	10
SUBROUTINE GEOM	GEO	20
C	GEO	30
C	GEO	40
C	GEO	50
C	GEO	60
C	GEO	70
C	GEO	80
C	GEO	90
*CALL,MCC	GEO	100
GO TO (10,30,120,170), NGEOM	GEO	110
C	GEO	120
C	GEO	130
C	GEO	140
10 WRITE (6,230)	GEO	150
IF (IUI.EQ.1) WRITE (6,250) XI,RI,XE	GEO	160
IF (IUI.EQ.2) WRITE (6,260) XI,RI,XE	GEO	170
LT=LMAX	GEO	180
DX=(XE-XI)/FLOAT(LMAX-1)	GEO	190
XT=XE	GEO	200
RT=RI	GEO	210
RE=RI	GEO	220
DO 20 L=1,LMAX	GEO	230
YW(L)=RI	GEO	240
NXNY(L)=0.0	GEO	250
20 CONTINUE	GEO	260
GO TO 210	GEO	270
C	GEO	280
C	GEO	290
C	GEO	300
30 WRITE (6,230)	GEO	310
IF (RCI.EQ.0.0.OR.RCT.EQ.0.0) GO TO 200	GEO	320
ANI=ANGI*3.141593/180.0	GEO	330
ANE=ANGE*3.141593/180.0	GEO	340
XTAN=XI+RCI*SIN(ANI)	GEO	350
RTAN=RI+RCI*(COS(ANI)-1.0)	GEO	360
RT1=RT-RCT*(COS(ANI)-1.0)	GEO	370
XT1=XTAN+(RTAN-RT1)/TAN(ANI)	GEO	380
IF (XT1.GE.XTAN) GO TO 40	GEO	390
XT1=XTAN	GEO	400
RT1=RTAN	GEO	410
40 XT=XT1+RCT*SIN(ANI)	GEO	420
XT2=XT+RCT*SIN(ANE)	GEO	430
RT2=RT+RCT*(1.0-COS(ANE))	GEO	440
RE=RT2+(XE-XT2)*TAN(ANE)	GEO	450
LT=1	GEO	460
DX=(XE-XI)/FLOAT(LMAX-1)	GEO	470
IF (IUI.EQ.1) WRITE (6,270) XI,RI,RT,XE,RCI,RCT,ANGI,ANGE,XT,RE	GEO	480
IF (IUI.EQ.2) WRITE (6,280) XI,RI,RT,XE,RCI,RCT,ANGI,ANGE,XT,RE	GEO	490
DO 110 L=1,LMAX	GEO	500
X=XI+FLOAT(L-1)*DX	GEO	510
IF (X.LE.XTAN) GO TO 50	GEO	520
IF (X.GT.XTAN.AND.X.LE.XT1) GO TO 60	GEO	530
IF (X.GT.XT1.AND.X.LE.XT) GO TO 70	GEO	540
IF (X.GT.XT.AND.X.LE.XT2) GO TO 80	GEO	550
GO TO 90	GEO	560
C	GEO	570
50 YW(L)=RI+RCI*(COS(ASIN((X-XI)/RCI))-1.0)	GEO	580
NXNY(L)=(X-XI)/(YW(L)-RI+RCI)	GEO	590
GO TO 100	GEO	600
C	GEO	610
60 YW(L)=RT1+(XT1-X)*TAN(ANI)	GEO	620
NXNY(L)=TAN(ANI)	GEO	630
GO TO 100	GEO	640
C	GEO	650
70 YW(L)=RT+RCT*(1.0-COS(ASIN((XT-X)/RCT)))	GEO	660
NXNY(L)=(XT-X)/(RCT+RT-YW(L))	GEO	670
GO TO 100	GEO	680
C	GEO	690

	80	YW(L)=RT+RCT*(1.0-COS(ASIN((X-XT)/RCT)))	GEO	700
		NXNY(L)=(XT-X)/(RCT+RT-YW(L))	GEO	710
		GO TO 100	GEO	720
C			GEO	730
	90	YW(L)=RT2+(X-XT2)*TAN(ANE)	GEO	740
		NXNY(L)=TAN(ANE)	GEO	750
C			GEO	760
	100	IF (L.EQ.1) GO TO 110	GEO	770
		IF (YW(L).LT.YW(LT)) LT=L	GEO	780
	110	CONTINUE	GEO	790
		GO TO 210	GEO	800
C			GEO	810
C		GENERAL WALL CASE = INPUT WALL COORDINATES	GEO	820
C			GEO	830
	120	WRITE (6,240)	GEO	840
		WRITE (6,230)	GEO	850
		XI=XWI(1)	GEO	860
		XE=XWI(NWPTS)	GEO	870
		DX=(XE-XI)/FLOAT(LMAX-1)	GEO	880
		XW(1)=XI	GEO	890
		XW(LMAX)=XE	GEO	900
		YW(1)=YWI(1)	GEO	910
		YW(LMAX)=YWI(NWPTS)	GEO	920
		RI=YW(1)	GEO	930
		RE=YW(LMAX)	GEO	940
		LT=1	GEO	950
		DO 130 L=2,NWPTS	GEO	960
		IF (YWI(L).LE.YWI(LT)) LT=L	GEO	970
	130	CONTINUE	GEO	980
		XT=XWI(LT)	GEO	990
		RT=YWI(LT)	GEO	1000
		IF (IUI.EQ.1) WRITE (6,290) XT,RT,IINT,IDIF	GEO	1010
		IF (IUI.EQ.2) WRITE (6,300) XT,RT,IINT,IDIF	GEO	1020
		LT=1	GEO	1030
		L1=LMAX-1	GEO	1040
		IP=1	GEO	1050
		DO 140 L=2,L1	GEO	1060
		XW(L)=XI+DX*FLOAT(L-1)	GEO	1070
		CALL MTLUP (XW(L),YW(L),IINT,NWPTS,NWPTS,1,IP,XWI,YWI)	GEO	1080
		IF (L.EQ.1) GO TO 140	GEO	1090
		IF (YW(L).LE.YW(LT)) LT=L	GEO	1100
	140	CONTINUE	GEO	1110
		LDUM=NWPTS	GEO	1120
		IF (LMAX.GT.NWPTS) LDUM=LMAX	GEO	1130
		DO 160 L=1,LDUM	GEO	1140
		IF (L.GT.LMAX) GO TO 150	GEO	1150
		SLOPE=DIF(L,IDIF,LMAX,XW,YW)	GEO	1160
		NXNY(L)=SLOPE	GEO	1170
	150	IF (L.LE.NWPTS.AND.L.LE.LMAX) WRITE (6,330) L,XWI(L),YWI(L),XW(L)	GEO	1180
		1 ,YW(L),SLOPE	GEO	1190
		IF (L.GT.NWPTS.AND.L.LE.LMAX) WRITE (6,340) L,XW(L),YW(L),SLOPE	GEO	1200
		IF (L.LE.NWPTS.AND.L.GT.LMAX) WRITE (6,350) L,XWI(L),YWI(L)	GEO	1210
	160	CONTINUE	GEO	1220
		GO TO 210	GEO	1230
C			GEO	1240
C		GENERAL WALL CASE = INPUT WALL RADIUS AND SLOPE	GEO	1250
C			GEO	1260
	170	WRITE (6,240)	GEO	1270
		WRITE (6,230)	GEO	1280
		DX=(XE-XI)/FLOAT(LMAX-1)	GEO	1290
		RI=YW(1)	GEO	1300
		RE=YW(LMAX)	GEO	1310
		LT=1	GEO	1320
		DO 180 L=2,LMAX	GEO	1330
		IF (YW(L).LE.YW(LT)) LT=L	GEO	1340
	180	CONTINUE	GEO	1350
		XT=XI+FLOAT(LT-1)*DX	GEO	1360
		RT=YW(LT)	GEO	1370
		IF (IUI.EQ.1) WRITE (6,310) XT,RT	GEO	1380
		IF (IUI.EQ.2) WRITE (6,320) XT,RT	GEO	1390


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*DECK,GEOMCB
SUBROUTINE GEOMCB
C
C *****
C THIS SUBROUTINE CALCULATES THE CENTERBODY RADIUS AND SLOPE
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

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C		GCB	710
	90 YCB(L)=RT2+(X=XT2)*TAN(ANE)	GCB	720
	NXNYCB(L)=-TAN(ANE)	GCB	730
C		GCB	740
	100 YCB(L)=2.0*RTCB=YCB(L)	GCB	750
	NXNYCB(L)=-NXNYCB(L)	GCB	760
	IF (YCB(L).GE.0.0.OR.NDIM.EQ.0) GO TO 110	GCB	770
	YCB(L)=0.0	GCB	780
	NXNYCB(L)=0.0	GCB	790
	110 CONTINUE	GCB	800
	RETURN	GCB	810
C		GCB	820
C	GENERAL CENTERBODY CASE = INPUT CENTERBODY COORDINATES	GCB	830
C		GCB	840
	120 WRITE (6,200)	GCB	850
	IF (IUI.EQ.1) WRITE (6,250) IINTCB,IDIFCB	GCB	860
	IF (IUI.EQ.2) WRITE (6,260) IINTCB,IDIFCB	GCB	870
	L1=LMAX-1	GCB	880
	IP=1	GCB	890
	DO 130 L=1,LMAX	GCB	900
	XCB(L)=XICB+DX*FLOAT(L-1)	GCB	910
	CALL MTLUP (XCB(L),YCB(L),IINTCB,NCBPTS,NCBPTS,1,IP,XCBI,YCBI)	GCB	920
	130 CONTINUE	GCB	930
	LDUM=NCBPTS	GCB	940
	IF (LMAX.GT.NCBPTS) LDUM=LMAX	GCB	950
	DO 150 L=1,LDUM	GCB	960
	IF (L.GT.LMAX) GO TO 140	GCB	970
	SLOPE=DIF(L,IDIFCB,LMAX,XCB,YCB)	GCB	980
	NXNYCB(L)=-SLOPE	GCB	990
	IF (YCB(L).GE.0.0.OR.NDIM.EQ.0) GO TO 140	GCB	1000
	YCB(L)=0.0	GCB	1010
	NXNYCB(L)=0.0	GCB	1020
	SLOPE=-NXNYCB(L)	GCB	1030
	140 IF (L.LE.NCBPTS.AND.L.LE.LMAX) WRITE (6,290) L,XCBI(L),YCBI(L),XCB	GCB	1040
	1 (L),YCB(L),SLOPE	GCB	1050
	IF (L.GT.NCBPTS.AND.L.LE.LMAX) WRITE (6,300) L,XCB(L),YCB(L),SLOPE	GCB	1060
	IF (L.LE.NCBPTS.AND.L.GT.LMAX) WRITE (6,310) L,XCBI(L),YCBI(L)	GCB	1070
	150 CONTINUE	GCB	1080
	RETURN	GCB	1090
C		GCB	1100
C	GENERAL CENTERBODY CASE = INPUT CENTERBODY RADIUS AND SLOPE	GCB	1110
C		GCB	1120
	160 WRITE (6,200)	GCB	1130
	IF (IUI.EQ.1) WRITE (6,270)	GCB	1140
	IF (IUI.EQ.2) WRITE (6,280)	GCB	1150
	DO 180 L=1,LMAX	GCB	1160
	XCB(L)=XICB+DX*FLOAT(L-1)	GCB	1170
	IF (YCB(L).GE.0.0.OR.NDIM.EQ.0) GO TO 170	GCB	1180
	YCB(L)=0.0	GCB	1190
	NXNYCB(L)=0.0	GCB	1200
	170 SLOPE=-NXNYCB(L)	GCB	1210
	WRITE (6,320) L,XCB(L),YCB(L),SLOPE	GCB	1220
	180 CONTINUE	GCB	1230
	RETURN	GCB	1240
C		GCB	1250
	190 WRITE (6,330)	GCB	1260
	IERR=1	GCB	1270
	RETURN	GCB	1280
C		GCB	1290
C	FORMAT STATEMENTS	GCB	1300
C		GCB	1310
	200 FORMAT (1H1)	GCB	1320
	210 FORMAT (1H0,20X,52HA CYLINDRICAL CENTERBODY HAS BEEN SPECIFIED BY	GCB	1330
	1XICB=F8.4,12H (IN), RICB=F8.4,16H (IN), AND XECB=F8.4,5H (IN))	GCB	1340
	220 FORMAT (1H0,20X,52HA CYLINDRICAL CENTERBODY HAS BEEN SPECIFIED BY	GCB	1350
	1XICB=F8.4,12H (CM), RICB=F8.4,16H (CM), AND XECB=F8.4,5H (CM))	GCB	1360

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230 FORMAT (1H0,20X,62HA CIRCULAR-ARC, CONICAL CENTERBODY HAS BEEN SPEGCB 1370
1CIFIED BY XICB=F8.4,5H (IN),7H, RICB=F8.4,6H (IN),,/,21X,5HRTCB=GCB 1380
2 ,F8.4,7H (IN), ,5HXECB=F8.4,5H (IN),8H, RCICB=F8.4,5H (IN),8H, GCB 1390
3RCTCB=F8.4,5H (IN),9H, ANGICB=F6.2,7H (DEG),,/,21X,11HAND ANGECBGCB 1400
4=F6.2,8H (DEG), ,29HTHE COMPUTED VALUES ARE XTCB=F8.4,5H (IN),10GCB 1410
5 H AND RECB=F8.4,6H (IN).) GCB 1420
240 FORMAT (1H0,20X,62HA CIRCULAR-ARC, CONICAL CENTERBODY HAS BEEN SPEGCB 1430
1CIFIED BY XICB=F8.4,5H (CM),7H, RICB=F8.4,6H (CM),,/,21X,5HRTCB=GCB 1440
2 ,F8.4,7H (CM), ,5HXECB=F8.4,5H (CM),8H, RCICB=F8.4,5H (CM),8H, GCB 1450
3RCTCB=F8.4,5H (CM),9H, ANGICB=F6.2,7H (DEG),,/,21X,11HAND ANGECBGCB 1460
4=F6.2,8H (DEG), ,29HTHE COMPUTED VALUES ARE XTCB=F8.4,5H (CM),10GCB 1470
5 H AND RECB=F8.4,6H (CM).) GCB 1480
250 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE GCB 1490
1 ,29HFOLLOWING PARAMETERS, IINTCB=,I1,9H, IDIFCB=,I1,1H,,//,22X,1HGCB 1500
2L,10X,8HXCB(IN),10X,8HYCB(IN),9X,7HXCB(IN),10X,7HYCB(IN),11X,5HS GCB 1510
3SLOPE,/) GCB 1520
260 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE GCB 1530
1 ,29HFOLLOWING PARAMETERS, IINTCB=,I1,9H, IDIFCB=,I1,1H,,//,22X,1HGCB 1540
2L,10X,8HXCB(CM),10X,8HYCB(CM),9X,7HXCB(CM),10X,7HYCB(CM),11X,5HS GCB 1550
3SLOPE,/) GCB 1560
270 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE GCB 1570
1 ,21HFOLLOWING PARAMETERS,,//,22X,1HL,11X,7HXCB(IN),10X,7HYCB(IN),GCB 1580
2 11X,5HSLOPE,/) GCB 1590
280 FORMAT (1H0,20X,47HA GENERAL CENTERBODY HAS BEEN SPECIFIED BY THE GCB 1600
1 ,21HFOLLOWING PARAMETERS,,//,22X,1HL,11X,7HXCB(CM),10X,7HYCB(CM),GCB 1610
2 11X,5HSLOPE,/) GCB 1620
290 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4,7X,F10.4,7X,F10.4,7X,F10.4) GCB 1630
300 FORMAT (1H ,20X,I2,41X,F10.4,7X,F10.4,7X,F10.4) GCB 1640
310 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4) GCB 1650
320 FORMAT (1H ,20X,I2,7X,F10.4,7X,F10.4,7X,F10.4) GCB 1660
330 FORMAT (1H0,48H***** RCICB OR RCTCB WAS SPECIFIED AS ZERO *****) GCB 1670
END GCB 1680

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*DECK,MTLUP	MTL	10
SUBROUTINE MTLUP (X,Y,M,N,MAX,NTAB,I,VARI,VARD)	MTL	20
C	MTL	30
C *****	MTL	40
C	MTL	50
C THIS SUBROUTINE IS CALLED BY SUBROUTINES GEOM AND GEOMCB TO	MTL	60
C INTERPOLATE FOR EQUALLY SPACED WALL COORDINATES FOR THE TABULAR	MTL	70
C INPUT CASE. SUBROUTINE MTLUP WAS TAKEN FROM THE NASA-LANGLEY	MTL	80
C PROGRAM LIBRARY. THE DATE OF THIS VERSION IS 09-12-69.	MTL	90
C *****	MTL	100
C *****	MTL	110
C	MTL	120
C MODIFICATION OF LIBRARY INTERPOLATION SUBROUTINE FTLUP	MTL	130
C MULTIPLE TABLE LOOK-UP ON ONE INDEPENDENT VARIABLE TABLE	MTL	140
C USES AN EXTERNAL INTERVAL POINTER (I) TO START SEARCH	MTL	150
C I LESS THAN 0 WILL CHECK MONOTONICITY	MTL	160
C	MTL	170
C DIMENSION VARI(1), VARD(MAX,1), Y(1), V(3), YY(2)	MTL	180
C LOGICAL EX	MTL	190
C	MTL	200
C IF (M.EQ.0) GO TO 170	MTL	210
C IF (N.LE.1) GO TO 170	MTL	220
C EX=.FALSE.	MTL	230
C IF (I.GE.0) GO TO 60	MTL	240
C IF (N.LT.2) GO TO 60	MTL	250
C	MTL	260
C MONOTONICITY CHECK	MTL	270
C	MTL	280
C IF (VARI(2)=VARI(1)) 20,20,40	MTL	290
C	MTL	300
C ERROR IN MONOTONICITY	MTL	310
C	MTL	320
C 10 K=LOC(VARI(1))	MTL	330
C WRITE (6,190) J,K,(VARI(J),J=1,N)	MTL	340
C CALL EXIT	MTL	350
C	MTL	360
C MONOTONIC DECREASING	MTL	370
C	MTL	380
C 20 DO 30 J=2,N	MTL	390
C IF (VARI(J)=VARI(J-1)) 30,10,10	MTL	400
C 30 CONTINUE	MTL	410
C GO TO 60	MTL	420
C	MTL	430
C MONOTONIC INCREASING	MTL	440
C	MTL	450
C 40 DO 50 J=2,N	MTL	460
C IF (VARI(J)=VARI(J-1)) 10,10,50	MTL	470
C 50 CONTINUE	MTL	480
C	MTL	490
C INTERPOLATION	MTL	500
C	MTL	510
C 60 IF (I.LE.0) I=1	MTL	520
C IF (I.GE.N) I=N-1	MTL	530
C	MTL	540
C LOCATE I INTERVAL (X(I).LE.X.LT.X(I+1))	MTL	550
C	MTL	560
C IF ((VARI(I)=X)+(VARI(I+1)=X)) 100,100,70	MTL	570
C	MTL	580
C IN GIVES DIRECTION FOR SEARCH OF INTERVALS	MTL	590
C	MTL	600
C 70 IN=SIGN(1.0,(VARI(I+1)-VARI(I))*(X-VARI(I)))	MTL	610
C	MTL	620
C IF X OUTSIDE ENDPOINTS. EXTRAPOLATE FROM END INTERVAL	MTL	630
C	MTL	640
C 80 IF ((I+IN).LE.0) GO TO 90	MTL	650
C IF ((I+IN).GE.N) GO TO 90	MTL	660
C I=I+IN	MTL	670
C IF ((VARI(I)=X)+(VARI(I+1)=X)) 100,100,80	MTL	680

C		MTL	690
C	EXTRAPOLATION	MTL	700
C		MTL	710
	90 EX=,TRUE,	MTL	720
	100 IF (M.EQ,2) GO TO 120	MTL	730
C		MTL	740
C	FIRST ORDER	MTL	750
C		MTL	760
	DO 110 NT=1,NTAB	MTL	770
	110 Y(NT)=(VARD(I,NT)*(VARI(I+1)=X)-VARD(I+1,NT)*(VARI(I)=X))/(VARI(I+1)-VARI(I))	MTL	780
	111 Y(NT)=(VARD(I,NT)*(VARI(I+1)=X)-VARD(I+1,NT)*(VARI(I)=X))/(VARI(I+1)-VARI(I))	MTL	790
	IF (EX) I=I+IN	MTL	800
	RETURN	MTL	810
C		MTL	820
C	SECOND ORDER	MTL	830
C		MTL	840
	120 IF (N.EQ,2) GO TO 10	MTL	850
	IF (I.EQ,(N-1)) GO TO 140	MTL	860
	IF (I.EQ,1) GO TO 130	MTL	870
C		MTL	880
C	PICK THIRD POINT	MTL	890
C		MTL	900
	SK=VARI(I+1)-VARI(I)	MTL	910
	IF ((SK*(X-VARI(I=1))).LT.(SK*(VARI(I+2)=X))) GO TO 140	MTL	920
	130 L=I	MTL	930
	GO TO 150	MTL	940
	140 L=I-1	MTL	950
	150 V(1)=VARI(L)=X	MTL	960
	V(2)=VARI(L+1)=X	MTL	970
	V(3)=VARI(L+2)=X	MTL	980
	DO 160 NT=1,NTAB	MTL	990
	YY(1)=(VARD(L,NT)*V(2)-VARD(L+1,NT)*V(1))/(VARI(L+1)-VARI(L))	MTL	1000
	YY(2)=(VARD(L+1,NT)*V(3)-VARD(L+2,NT)*V(2))/(VARI(L+2)-VARI(L+1))	MTL	1010
	160 Y(NT)=(YY(1)*V(3)-YY(2)*V(1))/(VARI(L+2)-VARI(L))	MTL	1020
	IF (EX) I=I+IN	MTL	1030
	RETURN	MTL	1040
C		MTL	1050
C	ZERO ORDER	MTL	1060
C		MTL	1070
	170 DO 180 NT=1,NTAB	MTL	1080
	180 Y(NT)=VARD(1,NT)	MTL	1090
	RETURN	MTL	1100
C		MTL	1110
C	FORMAT STATEMENTS	MTL	1120
C		MTL	1130
	190 FORMAT (1H1,49H TABLE BELOW OUT OF ORDER FOR MTLUP AT POSITION	MTL	1140
	1 ,15,/31H X TABLE IS STORED IN LOCATION ,06,/(8G15,8))	MTL	1150
	END	MTL	1160


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*DECK,ONEDIM
SUBROUTINE ONEDIM
C
C *****
C THIS SUBROUTINE CALCULATES THE 1=D INITIAL-DATA SURFACE
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
ACOE=2.0/(GAMMA+1.0)
BCOE=(GAMMA-1.0)/(GAMMA+1.0)
CCOE=(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=YH(LT)-YCB(LT)
RSTARS=YH(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=YH(L)-YCB(L)
ARATIO=RAD/RSTAR
GO TO 80
70 RADS=YH(L)**2-YCB(L)**2
ARATIO=RADS/RSTARS
C
C NEWTON-RAPHSON ITERATION LOOP
C
80 DO 100 ITER=1,100
ABM=ACOE+BCOE*MN3*MN3
ABMC=ABM**CCOE
FM=ABMC/MN3-ARATIO
FPM=ABMC*(2.0*BCOE+CCOE/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

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	IF (MN3.GE.0.0) GO TO 90	ONE	710
	MN3=-MN3	ONE	720
	GO TO 100	ONE	730
	90 IF (ABS(MN3-OMN3)/OMN3.LE.0.0005) GO TO 110	ONE	740
	100 CONTINUE	ONE	750
	WRITE (6,150) L	ONE	760
C		ONE	770
C	FILL IN 2-D ARRAYS LOOP	ONE	780
C		ONE	790
	110 DNXNY=(NXNY(L)-NXNYCB(L))/FLOAT(M1)	ONE	800
	DO 130 M=1,MMAX	ONE	810
	CALL EOS (8,P(L,M,1),R0(L,M,1),TEMP,PT(M),TT(M),MN3)	ONE	820
	CALL EOS (8,P(L,M,1),R0(L,M,1),TEMP,AS,D2,D3)	ONE	830
	Q=MN3*SQRT(AS)	ONE	840
	DN=NXNYCB(L)+DNXNY*FLOAT(M=1)	ONE	850
	DNS=DN*DN	ONE	860
	IF (DNS.EQ.0.0) GO TO 120	ONE	870
	SIGN=1.0	ONE	880
	IF (DN.GT.0.0) SIGN=-1.0	ONE	890
	U(L,M,1)=Q/SQRT(1.0+DNS)	ONE	900
	V(L,M,1)=SIGN*Q/SQRT(1.0+1.0/DNS)	ONE	910
	GO TO 130	ONE	920
	120 U(L,M,1)=Q	ONE	930
	V(L,M,1)=0.0	ONE	940
	130 CONTINUE	ONE	950
	140 CONTINUE	ONE	960
	RETURN	ONE	970
C		ONE	980
C	FORMAT STATEMENTS	ONE	990
C		ONE	1000
	150 FORMAT (1H0,10X,47H***** THE 1-D SOLUTION FOR THE INITIAL=DATA SURONE	ONE	1010
	1 ,47HFACE FAILED TO CONVERGE IN 100 ITERATIONS AT L=,I2,6H *****)	ONE	1020
	160 FORMAT (1H0,10X,48H***** THE STAGNATION CONDITIONS FOR THE 1-D INIONE	ONE	1030
	1T,41HIAL=DATA SURFACE WERE NOT SPECIFIED *****)	ONE	1040
	END	ONE	1050

*DECK, EOS	EOS 10
SUBROUTINE EOS (II,PRESS,RHO,TEMP,D1,D2,MN3)	EOS 20
C	EOS 30
C	EOS 40
C	EOS 50
C	EOS 60
C	EOS 70
C	EOS 80
C	EOS 90
*CALL, MCC	EOS 100
GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,150), II	EOS 110
C	EOS 120
C	EOS 130
C	EOS 140
10 D1=GAMMA*PRESS/RHO	EOS 150
RETURN	EOS 160
C	EOS 170
C	EOS 180
C	EOS 190
20 TEMP=PRESS/(RHO*RG)	EOS 200
RETURN	EOS 210
C	EOS 220
C	EOS 230
C	EOS 240
30 PRESS=TEMP*RHO*RG	EOS 250
RETURN	EOS 260
C	EOS 270
C	EOS 280
C	EOS 290
40 RHO=PRESS/(TEMP*RG)	EOS 300
RETURN	EOS 310
C	EOS 320
C	EOS 330
C	EOS 340
50 TEMP=PRESS/(RHO*RG)	EOS 350
D1=GAMMA*PRESS/RHO	EOS 360
RETURN	EOS 370
C	EOS 380
C	EOS 390
C	EOS 400
60 RHO=PRESS/(TEMP*RG)	EOS 410
D1=GAMMA*PRESS/RHO	EOS 420
RETURN	EOS 430
C	EOS 440
C	EOS 450
C	EOS 460
70 D1=GAMMA*RG*TEMP	EOS 470
RETURN	EOS 480
C	EOS 490
C	EOS 500
C	EOS 510
C	EOS 520
80 DEM=1.0+GAM2*MN3*MN3	EOS 530
PRESS=D1/DEM**GAM1	EOS 540
TEMP=D2/DEM	EOS 550
RETURN	EOS 560
C	EOS 570
C	EOS 580
C	EOS 590
C	EOS 600
90 DEM=1.0+GAM2*MN3*MN3	EOS 610
D1=PRESS*DEM**GAM1	EOS 620
D2=TEMP*DEM	EOS 630
RETURN	EOS 640
C	EOS 650
C	EOS 660
C	EOS 670
100 MN3=SQRT((D2/TEMP-1.0)/GAM2)	EOS 680
RETURN	EOS 690

C		EOS	700
C	CALCULATE THE DENSITY FOR THE UNDER-EXPANDED JET (D1=PD, D2=ROD)	EOS	710
C		EOS	720
	110 RHO=D2*(PRESS/D1)**(1.0/GAMMA)	EOS	730
	RETURN	EOS	740
C		EOS	750
C	CALCULATE THE DENSITY FOR THE OVER-EXPANDED JET (D1=PD, D2=ROD)	EOS	760
C		EOS	770
	120 PRD=PRESS/D1	EOS	780
	RHO=D2*(GAM3*PRD+1.0)/(PRD+GAM3)	EOS	790
	RETURN	EOS	800
C		EOS	810
C	CALCULATE THE SQUARE ROOT OF GAM3 FOR THE SHARP EXPANSION CORNER	EOS	820
C		EOS	830
	130 D1=SQRT(GAM3)	EOS	840
	RETURN	EOS	850
C		EOS	860
C	CALCULATE GAMMA=1.0 FOR THE INTERNAL ENERGY EQUATION R.H.S.	EOS	870
C		EOS	880
	140 D1=GAMMA=1.0	EOS	890
	RETURN	EOS	900
C		EOS	910
C	CALCULATE THE TERM FOR THE ARTIFICIAL CONDUCTIVITY	EOS	920
C		EOS	930
	150 D1=GAM1*RG/RKMU	EOS	940
	RETURN	EOS	950
	END	EOS	960

*DECK,MAP		MAP	10
	SUBROUTINE MAP (IP,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)	MAP	20
C		MAP	30
C	*****	MAP	40
C		MAP	50
C	THIS SUBROUTINE CALCULATES THE MAPPING FUNCTIONS	MAP	60
C		MAP	70
C	*****	MAP	80
C		MAP	90
*CALL,MCC		MAP	100
	BE=1.0/(YW(L)=YCB(L))	MAP	110
	IF (IP.EQ.0) RETURN	MAP	120
	Y=FLOAT(M-1)*DY	MAP	130
	AL=BE*(NXNYCB(L)+Y*(NXNY(L)-NXNYCB(L)))	MAP	140
	DE=-BE*Y*XWI(L)	MAP	150
	IF (IP.EQ.1) RETURN	MAP	160
	BE1=1.0/(YW(LD1)=YCB(LD1))	MAP	170
	AL1=BE1*(NXNYCB(LD1)+Y*(NXNY(LD1)-NXNYCB(LD1)))	MAP	180
	DE1=-BE1*Y*XWI(LD1)	MAP	190
	RETURN	MAP	200
	END	MAP	210

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*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
*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,NID.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=(YH(1)-YCB(1))/LC2
AREAT=(YH(LT)-YCB(LT))/LC2
AREAE=(YH(LDUM)-YCB(LDUM))/LC2
GO TO 20
10 AREAI=3.141593*(YH(1)**2-YCB(1)**2)/LC2
AREAT=3.141593*(YH(LT)**2-YCB(LT)**2)/LC2
AREAE=3.141593*(YH(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
MA SST=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
MA SST=0.0
MASSE=0.0
THRUST=0.0
DYI=DY*(YH(1)-YCB(1))
DYT=DY*(YH(LT)-YCB(LT))
DYE=DY*(YH(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))*0.5
1 .5
ROUZE=(RO(LDUM,M,ND)*U(LDUM,M,ND)**2+RO(LDUM,M+1,ND)*U(LDUM,M+1,NDMFO
1)**2)*0.5
MASSI=MASSI+ROUI*AREAI*G
MA SST=MA SST+ROUT*AREAT*G
MASSE=MASSE+ROUE*AREAE*G
MFO 10
MFO 20
MFO 30
MFO 40
MFO 50
MFO 60
MFO 70
MFO 80
MFO 90
MFO 100
MFO 110
MFO 120
MFO 130
MFO 140
MFO 150
MFO 160
MFO 170
MFO 180
MFO 190
MFO 200
MFO 210
MFO 220
MFO 230
MFO 240
MFO 250
MFO 260
MFO 270
MFO 280
MFO 290
MFO 300
MFO 310
MFO 320
MFO 330
MFO 340
MFO 350
MFO 360
MFO 370
MFO 380
MFO 390
MFO 400
MFO 410
MFO 420
MFO 430
MFO 440
MFO 450
MFO 460
MFO 470
MFO 480
MFO 490
MFO 500
MFO 510
MFO 520
MFO 530
MFO 540
MFO 550
MFO 560
MFO 570
MFO 580
MFO 590
MFO 600
MFO 610
MFO 620
MFO 630
MFO 640
MFO 650
MFO 660
MFO 670
MFO 680
MFO 690
MFO 700

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THRUST*THRUST+ROUZE*AREAE
60 CONTINUE
RETURN
END

MFO 710
MFO 720
MFO 730
MFO 740

*DECK,PLOT	PLT 10
SUBROUTINE PLOT (TITLE,T,NP,IVPTS)	PLT 20
C	PLT 30
*****	PLT 40
C	PLT 50
THIS SUBROUTINE PLOTS THE VELOCITY VECTORS AND DEPENDENT VARIABLE	PLT 60
CONTOUR PLOTS	PLT 70
C	PLT 80
*****	PLT 90
C	PLT 100
DIMENSION CON(9), XCO(4), YCO(4), TITLE(8)	PLT 110
*CALL,MCC	PLT 120
C	PLT 130
SET UP THE PLOT SIZE	PLT 140
C	PLT 150
ND=N3	PLT 160
IF (N.EQ.0) ND=1	PLT 170
XL=XI	PLT 180
XR=XE	PLT 190
YT=YW(1)	PLT 200
YB=YCB(1)	PLT 210
DO 10 L=2,LMAX	PLT 220
YT=AMAX1(YT,YW(L))	PLT 230
YB=AMIN1(YB,YCB(L))	PLT 240
10 CONTINUE	PLT 250
VV=-0.1*DX	PLT 260
DO 60 IDUM=1,IVPTS	PLT 270
VV=VV+DX	PLT 280
FIYB=900.0	PLT 290
XD=(XR-XL)/(YT-YB)	PLT 300
FIR=(1022.0-1022.0/FLOAT(L1)-FLOAT(IDUM)*1022.0/FLOAT(L1))/854.0	PLT 310
IF (XD.LE.FIR) GO TO 20	PLT 320
FIXL=1022.0/FLOAT(L1)	PLT 330
FIXR=1022.0-FIXL-FLOAT(IDUM)*1022.0/FLOAT(L1)	PLT 340
FIYT=900.0-(FIXR-FIXL)/XD	PLT 350
GO TO 30	PLT 360
20 FIXL=511.0+450.0*XD	PLT 370
FIXR=511.0+450.0*XD	PLT 380
FIYT=16.0	PLT 390
30 XCONV=(FIXR-FIXL)/(XR-XL)	PLT 400
YCONV=(FIYT-FIYB)/(YT-YB)	PLT 410
C	PLT 420
GENERATE THE VELOCITY VECTOR PLOT	PLT 430
C	PLT 440
VMAX=0.0	PLT 450
DO 40 L=1,LMAX	PLT 460
DO 40 M=1,MMAX	PLT 470
VMAX=AMAX1(VMAX,ABS(U(L,M,ND)),ABS(V(L,M,ND)))	PLT 480
40 CONTINUE	PLT 490
IF (VMAX.LT.1.0E-10) GO TO 70	PLT 500
DROU=VV/VMAX	PLT 510
CALL ADV (1)	PLT 520
DO 50 L=1,LMAX	PLT 530
IX1=FIXL+(FLOAT(L-1)*DX)*XCONV	PLT 540
DY=(YW(L)-YCB(L))/FLOAT(M1)	PLT 550
DO 50 M=1,MMAX	PLT 560
IY1=FIYB+(YCB(L)+FLOAT(M-1)*DY-YB)*YCONV	PLT 570
IX2=FIXL+(FLOAT(L-1)*DX+U(L,M,ND)*DROU)*XCONV	PLT 580
IY2=FIYB+(YCB(L)+FLOAT(M-1)*DY-YB+V(L,M,ND)*DROU)*YCONV	PLT 590
CALL DRV (IX1,IY1,IX2,IY2)	PLT 600
CALL PLT (IX1,IY1,16)	PLT 610
50 CONTINUE	PLT 620
CALL LINCNT (58)	PLT 630
WRITE (7,430) IDUM,NP,T	PLT 640
WRITE (7,370) TITLE	PLT 650
60 CONTINUE	PLT 660
C	PLT 670
RESET PLOT SIZE FOR CONTOUR PLOTS	PLT 680
C	PLT 690

70	IF (XD.LE.FIR) GO TO 80	PLT 700
	FIXR=1022.0-FIXL=1022.0/FLOAT(L1)	PLT 710
	FIYT=900.0-(FIXR-FIXL)/XD	PLT 720
	XCONV=(FIXR-FIXL)/(XR-XL)	PLT 730
	YCONV=(FIYT-FIYR)/(YT-YB)	PLT 740
C		PLT 750
C	FILL PLOTTING ARRAY CQ FOR THE CONTOUR PLOTS	PLT 760
C		PLT 770
80	I=0	PLT 780
90	I=I+1	PLT 790
	GO TO (100,120,140,160,360), I	PLT 800
C		PLT 810
100	DO 110 L=1,LMAX	PLT 820
	DO 110 M=1,MMAX	PLT 830
	CQ(L,M)=RO(L,M,ND)*G	PLT 840
	IF (IUO.EQ.2) CQ(L,M)=CQ(L,M)*16.02	PLT 850
110	CONTINUE	PLT 860
	GO TO 180	PLT 870
C		PLT 880
120	DO 130 L=1,LMAX	PLT 890
	DO 130 M=1,MMAX	PLT 900
	CQ(L,M)=P(L,M,ND)/PC	PLT 910
	IF (IUO.EQ.2) CQ(L,M)=CQ(L,M)*6.8948	PLT 920
130	CONTINUE	PLT 930
	GO TO 180	PLT 940
C		PLT 950
140	DO 150 L=1,LMAX	PLT 960
	DO 150 M=1,MMAX	PLT 970
	CALL EOS (2,P(L,M,ND),RO(L,M,ND),TEMP,AS,D2,D3)	PLT 980
	CQ(L,M)=TEMP	PLT 990
	IF (IUO.EQ.2) CQ(L,M)=CQ(L,M)*0.555556	PLT 1000
150	CONTINUE	PLT 1010
	GO TO 180	PLT 1020
C		PLT 1030
160	DO 170 L=1,LMAX	PLT 1040
	DO 170 M=1,MMAX	PLT 1050
	CALL EOS (1,P(L,M,ND),RO(L,M,ND),TEMP,AS,D2,D3)	PLT 1060
	CQ(L,M)=SQRT((U(L,M,ND)**2+V(L,M,ND)**2)/AS)	PLT 1070
170	CONTINUE	PLT 1080
C		PLT 1090
C	DETERMINE THE PLOTTING LINE QUANTITIES AND LABEL THE FRAMES	PLT 1100
C		PLT 1110
180	QMN=1.0E06	PLT 1120
	QMX=-QMN	PLT 1130
	DO 190 L=1,LMAX	PLT 1140
	DO 190 M=1,MMAX	PLT 1150
	QMN=AMIN1(CQ(L,M),QMN)	PLT 1160
	QMX=AMAX1(CQ(L,M),QMX)	PLT 1170
190	CONTINUE	PLT 1180
	XX=QMX-QMN	PLT 1190
	DQ=0.1*XX	PLT 1200
	DO 200 K=1,9	PLT 1210
	CON(K)=QMN+(FLOAT(K))*DQ	PLT 1220
200	CONTINUE	PLT 1230
	K=9	PLT 1240
	CALL ADV (1)	PLT 1250
	CALL LINCNT (58)	PLT 1260
	GO TO (210,220,230,240), I	PLT 1270
210	WRITE (7,380) NP,T	PLT 1280
	GO TO 250	PLT 1290
220	WRITE (7,390) NP,T	PLT 1300
	GO TO 250	PLT 1310
230	WRITE (7,400) NP,T	PLT 1320
	GO TO 250	PLT 1330
240	WRITE (7,410) NP,T	PLT 1340
250	WRITE (7,420) QMN,QMX,CON(1),CON(K),DQ	PLT 1350
	WRITE (7,370) TITLE	PLT 1360
C		PLT 1370
C	DETERMINE THE LOCATION OF EACH CONTOUR LINE SEGMENT AND PLOT IT	PLT 1380
C		PLT 1390

DO 340 L=2, LMAX	PLT 1400
DY=(YW(L=1)-YCB(L=1))/FLOAT(M1)	PLT 1410
DY1=(YW(L)-YCB(L))/FLOAT(M1)	PLT 1420
DO 340 M=2, MMAX	PLT 1430
NN=0	PLT 1440
DO 340 KK=1, K	PLT 1450
K1=K2=K3=K4=0	PLT 1460
IF (CQ(L=1, M=1).LE.CON(KK)) K1=1	PLT 1470
IF (CQ(L, M=1).LE.CON(KK)) K2=1	PLT 1480
IF (CQ(L=1, M).LE.CON(KK)) K3=1	PLT 1490
IF (CQ(L, M).LE.CON(KK)) K4=1	PLT 1500
IF (K1+K2+K3+K4.NE.0) GO TO 340	PLT 1510
IF (K1+K2+K3+K4.EQ.0) GO TO 340	PLT 1520
IF (NN.NE.0) GO TO 260	PLT 1530
NN=1	PLT 1540
XCO(1)=XI+FLOAT(L=2)*DX	PLT 1550
XCO(2)=XCO(1)+DX	PLT 1560
XCO(3)=XCO(1)	PLT 1570
XCO(4)=XCO(2)	PLT 1580
YCO(1)=YCB(L=1)+FLOAT(M=2)*DY	PLT 1590
YCO(2)=YCB(L)+FLOAT(M=2)*DY1	PLT 1600
YCO(3)=YCB(L=1)+FLOAT(M=1)*DY	PLT 1610
YCO(4)=YCB(L)+FLOAT(M=1)*DY1	PLT 1620
260 LL=0	PLT 1630
IF (K1+K3.NE.1) GO TO 270	PLT 1640
IC1=1	PLT 1650
IC2=3	PLT 1660
LP1=L=1	PLT 1670
MP1=M=1	PLT 1680
LP2=L=1	PLT 1690
MP2=M	PLT 1700
ASSIGN 270 TO KR1	PLT 1710
GO TO 300	PLT 1720
270 IF (K1+K2.NE.1) GO TO 280	PLT 1730
IC1=1	PLT 1740
IC2=2	PLT 1750
LP1=L=1	PLT 1760
MP1=M=1	PLT 1770
LP2=L	PLT 1780
MP2=M=1	PLT 1790
ASSIGN 280 TO KR1	PLT 1800
GO TO 300	PLT 1810
280 IF (K2+K4.NE.1) GO TO 290	PLT 1820
IC1=2	PLT 1830
IC2=4	PLT 1840
LP1=L	PLT 1850
MP1=M=1	PLT 1860
LP2=L	PLT 1870
MP2=M	PLT 1880
ASSIGN 290 TO KR1	PLT 1890
GO TO 300	PLT 1900
290 IF (K3+K4.NE.1) GO TO 340	PLT 1910
IC1=3	PLT 1920
IC2=4	PLT 1930
LP1=L=1	PLT 1940
MP1=M	PLT 1950
LP2=L	PLT 1960
MP2=M	PLT 1970
ASSIGN 340 TO KR1	PLT 1980
300 LL=LL+1	PLT 1990
XX=(CON(KK)=CQ(LP1, MP1))/(CQ(LP2, MP2)=CQ(LP1, MP1))	PLT 2000
IF (LL.EQ.2) GO TO 310	PLT 2010
IX1=FIXL+(XCO(IC1)+XX*(XCO(IC2)-XCO(IC1))-XL)*XCONV	PLT 2020
IY1=FIYB+(YCO(IC1)+XX*(YCO(IC2)-YCO(IC1))-YB)*YCONV	PLT 2030
GO TO KR1, (270, 280, 290, 340)	PLT 2040
310 IX2=FIXL+(XCO(IC1)+XX*(XCO(IC2)-XCO(IC1))-XL)*XCONV	PLT 2050
IY2=FIYB+(YCO(IC1)+XX*(YCO(IC2)-YCO(IC1))-YB)*YCONV	PLT 2060
CALL DRV (IX1, IY1, IX2, IY2)	PLT 2070
IF (KK.NE.1) GO TO 320	PLT 2080
CALL PLT (IX1, IY1, 35)	PLT 2090

320	IF (KK,NE,K) GO TO 330	PLT 2100
	CALL PLT (IX1,IY1,24)	PLT 2110
330	LL=0	PLT 2120
	IF (LP2,NE,L) GO TO 340	PLT 2130
	IF (MP2,NE,M=1) GO TO 340	PLT 2140
	GO TO 280	PLT 2150
340	CONTINUE	PLT 2160
C		PLT 2170
C	DRAW THE GEOMETRY BOUNDARIES FOR THE CONTOUR PLOTS	PLT 2180
C		PLT 2190
	DO 350 L=2,LMAX	PLT 2200
	IX1=FIXL+(FLOAT(L=2)*DX)*XCONV	PLT 2210
	IX2=FIXL+(FLOAT(L=1)*DX)*XCONV	PLT 2220
	IY1=FIYB+(YCB(L=1)=YB)*YCONV	PLT 2230
	IY2=FIYB+(YCB(L)=YB)*YCONV	PLT 2240
	IY3=FIYB+(YH(L=1)=YB)*YCONV	PLT 2250
	IY4=FIYB+(YH(L)=YB)*YCONV	PLT 2260
	CALL DRV (IX1,IY1,IX2,IY2)	PLT 2270
	CALL DRV (IX1,IY3,IX2,IY4)	PLT 2280
350	CONTINUE	PLT 2290
	GO TO 90	PLT 2300
360	CONTINUE	PLT 2310
	DY=1.0/FLOAT(MMAX=1)	PLT 2320
	CALL ADV (1)	PLT 2330
	RETURN	PLT 2340
C		PLT 2350
C	FORMAT STATEMENTS	PLT 2360
C		PLT 2370
370	FORMAT (1H ,8A10)	PLT 2380
380	FORMAT (1H ,7HDENSITY,24X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)	PLT 2390
390	FORMAT (1H ,8HPRESSURE,23X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)	PLT 2400
400	FORMAT (1H ,11HTEMPERATURE,20X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)	PLT 2410
410	FORMAT (1H ,11HMACH NUMBER,20X,2HN=,I6,2X,2HT=,1PE10.4,4H SEC)	PLT 2420
420	FORMAT (1H ,10HLOW VALUE=,1PE11.4,2X,11HHIGH VALUE=,E11.4,2X,12HLOPLT 2430	
	1W CONTOUR=,E11.4,/,1X,13HHIGH CONTOUR=,E11.4,2X,14HDELTA CONTOUR=	PLT 2440
	2 ,E11.4)	PLT 2450
430	FORMAT (1H ,18HVELOCITY VECTORS (,11,2HX),10X,2HN=,I6,2X,2HT=,1PE1	PLT 2460
	1 0.4,4H SEC)	PLT 2470
	END	PLT 2480

*DECK,VISCOUS	VIS	10
SUBROUTINE VISCOUS	VIS	20
C	VIS	30
C	VIS	40
C	VIS	50
C	VIS	60
C	VIS	70
C	VIS	80
C	VIS	90
C	VIS	100
*CALL,MCC	VIS	110
REAL MU, LA, LP2M, LPM, K, MUT, LAT, KT	VIS	120
C	VIS	130
C	VIS	140
C	VIS	150
C	VIS	160
C	VIS	170
IF (N,NE,1) GO TO 10	VIS	180
NC=0	VIS	190
ECHECK=ABS(EMU)+ABS(ELA)+ABS(EK)	VIS	200
IF (ABS(EMU).EQ.ABS(ELA).AND.ABS(EMU).EQ.ABS(EK)) ECHECK=-1.0	VIS	210
RDUM=CAV+DX+DY*2.0	VIS	220
RLA=RLA1=RLA2=RLA3=RLA4=RMU=RMU1=RMU2=RMU3=RMU4=RK=RK1=RK2=0.0	VIS	230
RK3=RK4=RR0=RR01=RR02=RR03=RR04=RLP2M=RLP2M1=RLP2M2=RLP2M3=0.0	VIS	240
RLP2M4=RLPM=MU=LA=K=LP2M=LPM=RODIF=0.0	VIS	250
ATERM=ATERM1=ATERM2=ATERM3=ATERM4=TLMUR=0.0	VIS	260
10 NC=NC+1	VIS	270
NLINE=0	VIS	280
IF (IAV,NE,0) GO TO 20	VIS	290
IF (NC,NE,NPRINT,AND,N,NE,NMAX) GO TO 20	VIS	300
WRITE (6,450)	VIS	310
WRITE (6,440) N	VIS	320
C	VIS	330
20 DO 420 L=2,LMAX	VIS	340
IF (ITM,NE,0) CALL MIXLEN (L)	VIS	350
DO 420 M=1,MMAX	VIS	360
IF (L,EQ,LMAX,AND,M,EQ,1) GO TO 420	VIS	370
IF (L,EQ,LMAX,AND,M,EQ,MMAX) GO TO 420	VIS	380
LMD2=LD*(M-1)+LMD1	VIS	390
LMD2=LD*(M-2)+LMD1	VIS	400
LMPD2=LD*M+LMD1	VIS	410
LMN1=L+LMD2	VIS	420
LP=L+1+LMD2	VIS	430
LM=L+1+LMD2	VIS	440
MP=L+LMPD2	VIS	450
MM=L+LMD2	VIS	460
LMP=L+1+LMPD2	VIS	470
LPM=L+1+LMD2	VIS	480
LMMP=L+1+LMPD2	VIS	490
LMM=L+1+LMD2	VIS	500
CALL MAP (1,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)	VIS	510
DIV=0.0	VIS	520
IF (L,EQ,LMAX,AND,CHECK,EQ,0.0) GO TO 80	VIS	530
IF (L,EQ,LMAX) GO TO 90	VIS	540
IF (CAV,EQ,0.0) GO TO 90	VIS	550
IF (CHECK,EQ,0.0,AND,L,LT,LSS) GO TO 80	VIS	560
IF (SMACH,EQ,0.0) GO TO 30	VIS	570
XV=U(LMN1)*U(LMN1)+V(LMN1)*V(LMN1)	VIS	580
CALL EOS (1,P(LMN1),RO(LMN1),T,XA,D2,D3)	VIS	590
XM=XV/XA	VIS	600
IF (CHECK,EQ,0.0,AND,XM,LT,SMACH*SMACH) GO TO 80	VIS	610
IF (L,LT,LSS,OR,XM,LT,SMACH*SMACH) GO TO 90	VIS	620
C	VIS	630
C	VIS	640
C	VIS	650
CHECK TO SEE IF THE DIVERGENCE OF THE VELOCITY IS NEGATIVE	VIS	660
30 UX=(U(LP)-U(LMN1))*DXR	VIS	670
UXD=(U(LMN1)-U(LM))*DXR	VIS	680
IF (UXD,LT,UX) UX=UXD	VIS	690
IF (M,EQ,1) GO TO 40	VIS	700
IF (M,EQ,MMAX) GO TO 60	VIS	700

	UY=0.5*(U(MP)-U(MM))*DYR	VIS	710
	VY=(V(MP)-V(LMN1))*DYR	VIS	720
	VYD=(V(LMN1)-V(MM))*DYR	VIS	730
	IF (VYD.LT.VY) VY=VYD	VIS	740
	IF (NDIM.NE.0) ATERM=V(LMN1)/(FLOAT(M-1)*DY/BE+YCB(L))	VIS	750
	GO TO 70	VIS	760
40	UY=(U(MP)-U(LMN1))*DYR	VIS	770
	VY=(V(MP)-V(LMN1))*DYR	VIS	780
	IF (NDIM.EQ.0) GO TO 70	VIS	790
	IF (YCB(L).EQ.0.0) GO TO 50	VIS	800
	ATERM=V(LMN1)/YCB(L)	VIS	810
	IF (YCB(L-1).EQ.0.0) ATERM=0.5*(BE*V(LMMP)*DYR+V(LMN1)/YCB(L))	VIS	820
	IF (YCB(L+1).EQ.0.0) ATERM=0.5*(BE*V(LPMP)*DYR+V(LMN1)/YCB(L))	VIS	830
	GO TO 70	VIS	840
50	ATERM=BE*V(MP)*DYR	VIS	850
	IF (YCB(L-1).NE.0.0) ATERM=0.5*(V(LM)/YCB(L-1)+BE*V(MP)*DYR)	VIS	860
	IF (YCB(L+1).NE.0.0) ATERM=0.5*(V(LP)/YCB(L+1)+BE*V(MP)*DYR)	VIS	870
	GO TO 70	VIS	880
60	UY=(U(LMN1)-U(MM))*DYR	VIS	890
	VY=(V(LMN1)-V(MM))*DYR	VIS	900
	IF (NDIM.NE.0) ATERM=V(LMN1)/YH(L)	VIS	910
70	DIV=UX+AL+UY+BE*VY+ATERM	VIS	920
	IF (CHECK.NE.0.0) GO TO 90	VIS	930
	IF (DIV.LT.0.0) GO TO 90	VIS	940
80	QUT(L,M)=0.0	VIS	950
	QVT(L,M)=0.0	VIS	960
	QPT(L,M)=0.0	VIS	970
	QROT(L,M)=0.0	VIS	980
	GO TO 420	VIS	990
C		VIS	1000
90	UX1=(U(LMN1)-U(LM))*DXR	VIS	1010
	CALL EOS (2,P(LMN1),RO(LMN1),T,AS,D2,D3)	VIS	1020
	IF (L.EQ.LMAX) GO TO 110	VIS	1030
	VX1=(V(LMN1)-V(LM))*DXR	VIS	1040
	UX2=(U(LP)-U(LMN1))*DXR	VIS	1050
	VX2=(V(LP)-V(LMN1))*DXR	VIS	1060
	CALL EOS (2,P(LM),RO(LM),TLM,AS,D2,D3)	VIS	1070
	CALL EOS (2,P(LP),RO(LP),TLP,AS,D2,D3)	VIS	1080
	TX1=(T-TLM)*DXR	VIS	1090
	TX2=(TLP-T)*DXR	VIS	1100
	IF (CAV.EQ.0.0) GO TO 100	VIS	1110
	ROX1=(RO(LMN1)-RO(LM))*DXR	VIS	1120
	ROX2=(RO(LP)-RO(LMN1))*DXR	VIS	1130
100	LDUM=L-1	VIS	1140
	CALL MAP (1,LDUM,M,ALM,BEM,DE,LD1,AL1,BE1,DE1)	VIS	1150
	LDUM=L+1	VIS	1160
	CALL MAP (1,LDUM,M,ALP,BEP,DE,LD1,AL1,BE1,DE1)	VIS	1170
	BE1=0.5*(BEM+BE)	VIS	1180
	BE2=0.5*(BEP+BE)	VIS	1190
	AL1=0.5*(ALM+AL)	VIS	1200
	AL2=0.5*(ALP+AL)	VIS	1210
	IF (M.EQ.1) GO TO 130	VIS	1220
	IF (M.EQ.MMAX) GO TO 200	VIS	1230
C		VIS	1240
C		VIS	1250
C	CALCULATE THE INTERIOR POINT QUANTITIES	VIS	1260
	UY1=0.25*(U(MP)+U(LMMP)-U(MM)-U(LMMM))*DYR	VIS	1270
	UY2=0.25*(U(MP)+U(LPMP)-U(MM)-U(LPMM))*DYR	VIS	1280
	VY1=0.25*(V(MP)+V(LMMP)-V(MM)-V(LMMM))*DYR	VIS	1290
	VY2=0.25*(V(MP)+V(LPMP)-V(MM)-V(LPMM))*DYR	VIS	1300
	UX3=0.25*(U(LP)+U(LPMM)-U(LM)-U(LMMM))*DXR	VIS	1310
	UX4=0.25*(U(LP)+U(LPMP)-U(LM)-U(LMMP))*DXR	VIS	1320
	VX3=0.25*(V(LP)+V(LPMM)-V(LM)-V(LMMM))*DXR	VIS	1330
	VX4=0.25*(V(LP)+V(LPMP)-V(LM)-V(LMMP))*DXR	VIS	1340
110	VY3=(V(LMN1)-V(MM))*DYR	VIS	1350
	VY4=(V(MP)-V(LMN1))*DYR	VIS	1360
	UY3=(U(LMN1)-U(MM))*DYR	VIS	1370
	UY4=(U(MP)-U(LMN1))*DYR	VIS	1380
	CALL EOS (2,P(MM),RO(MM),TMM,AS,D2,D3)	VIS	1390
	CALL EOS (2,P(MP),RO(MP),TMP,AS,D2,D3)	VIS	1400

TY3=(T-TMM)*DYR	VIS 1410
TY4=(TMP-T)*DYR	VIS 1420
IF (L.EQ.LMAX) GO TO 120	VIS 1430
CALL EOS (2,P(LMMM),RO(LMMM),TLMMP,AS,D2,D3)	VIS 1440
CALL EOS (2,P(LMMP),RO(LMMP),TLMMP,AS,D2,D3)	VIS 1450
CALL EOS (2,P(LPMM),RO(LPMM),TLPMP,AS,D2,D3)	VIS 1460
CALL EOS (2,P(LPMP),RO(LPMP),TLPMP,AS,D2,D3)	VIS 1470
TY1=0.25*(TMP+TLMMP-TMM-TLMMM)*DYR	VIS 1480
TY2=0.25*(TLPMP+TMP-TLPMM-TMM)*DYR	VIS 1490
TX3=0.25*(TLP+TLPMM-TLM-TLMMM)*DXR	VIS 1500
TX4=0.25*(TLPMP+TLP-TLMMP-TLM)*DXR	VIS 1510
IF (CAV.EQ.0.0) GO TO 120	VIS 1520
ROY1=0.25*(RO(MP)+RO(LMMP)-RO(MM)-RO(LMMM))*DYR	VIS 1530
ROY2=0.25*(RO(MP)+RO(LPMP)-RO(MM)-RO(LPMM))*DYR	VIS 1540
ROX3=0.25*(RO(LP)+RO(LPMM)-RO(LM)-RO(LMMM))*DXR	VIS 1550
ROX4=0.25*(RO(LP)+RO(LPMP)-RO(LM)-RO(LMMP))*DXR	VIS 1560
ROY3=(RO(LMN1)-RO(MM))*DYR	VIS 1570
ROY4=(RO(MP)-RO(LMN1))*DYR	VIS 1580
IF (NDIM.EQ.0) GO TO 120	VIS 1590
IF (CAV.EQ.0.0.OR.DIV.GE.0.0) GO TO 120	VIS 1600
Y=FLOAT(M=1)*DY/BE+YCB(L)	VIS 1610
Y1=Y-YCB(L)+YCB(L-1)	VIS 1620
Y2=Y-YCB(L)+YCB(L+1)	VIS 1630
Y3=Y-0.5*DY/BE	VIS 1640
Y4=Y+0.5*DY/BE	VIS 1650
ATERM1=0.5*(V(LMN1)+V(LM))/Y1	VIS 1660
ATERM2=0.5*(V(LMN1)+V(LP))/Y2	VIS 1670
ATERM3=0.5*(V(LMN1)+V(MM))/Y3	VIS 1680
ATERM4=0.5*(V(LMN1)+V(MP))/Y4	VIS 1690
120 MDUM=M-1	VIS 1700
CALL MAP (1,L,MDUM,ALMY,BEMY,DE,LD1,AL1,RE1,DE1)	VIS 1710
MDUM=M+1	VIS 1720
CALL MAP (1,L,MDUM,ALPY,REPY,DE,LD1,AL1,RE1,DE1)	VIS 1730
BE3=0.5*(BEMY+BE)	VIS 1740
BE4=0.5*(BEPY+BE)	VIS 1750
AL3=0.5*(ALMY+AL)	VIS 1760
AL4=0.5*(ALPY+AL)	VIS 1770
IF (L.NE.LMAX) GO TO 250	VIS 1780
UX1=UX2=VX1=VX2=TX1=TX2=UY1=UY2=VY1=VY2=UX3=UX4=VX3=VX4=0.0	VIS 1790
TY1=TY2=TX3=TX4=AL1=AL2=RF1=RF2=AL=AL3=AL4=0.0	VIS 1800
ROX1=ROX2=ROY1=ROY2=ROX3=ROX4=ROY3=ROY4=0.0	VIS 1810
GO TO 250	VIS 1820
C	VIS 1830
C	VIS 1840
C	VIS 1850
130 UX4=0.25*(U(LP)+U(LPMP)-U(LM)-U(LMMP))*DXR	VIS 1860
VX4=0.25*(V(LP)+V(LPMP)-V(LM)-V(LMMP))*DXR	VIS 1870
UY4=(U(MP)-U(LMN1))*DYR	VIS 1880
VY4=(V(MP)-V(LMN1))*DYR	VIS 1890
CALL EOS (2,P(MP),RO(MP),TMP,AS,D2,D3)	VIS 1900
CALL EOS (2,P(LMMP),RO(LMMP),TLMMP,AS,D2,D3)	VIS 1910
CALL EOS (2,P(LPMP),RO(LPMP),TLPMP,AS,D2,D3)	VIS 1920
TX4=0.25*(TLPMP+TLP-TLMMP-TLM)*DXR	VIS 1930
TY4=(TMP-T)*DYR	VIS 1940
IF (CAV.EQ.0.0) GO TO 140	VIS 1950
ROX4=0.25*(RO(LP)+RO(LPMP)-RO(LM)-RO(LMMP))*DXR	VIS 1960
ROY4=(RO(MP)-RO(LMN1))*DYR	VIS 1970
C	VIS 1980
C	VIS 1990
C	VIS 2000
140 IF (NGCB.EQ.0) GO TO 150	VIS 2010
IF (IVBC.EQ.1) GO TO 160	VIS 2020
THEW=ATAN(-NXNYCB(L))	VIS 2030
THE=ATAN(V(MP)/U(MP))	VIS 2040
IF (U(MP).LT.0.0) THE=THE+3.14159	VIS 2050
VMAG=SQRT(U(MP)*U(MP)+V(MP)*V(MP))	VIS 2060
RTHE=2.0*THEW-THE	VIS 2070
IF (NOSLIP.EQ.1.AND.NGCB.NE.0) RTHE=3.14159+THE	VIS 2080
UR=VMAG*COS(RTHE)	VIS 2090
VR=VMAG*SIN(RTHE)	VIS 2100

	THEW=ATAN(-NXNYCB(L+1))	VIS 2110
	THE=ATAN(V(LPMP)/U(LPMP))	VIS 2120
	IF (U(LPMP),LT,0.0) THE=THE+3.14159	VIS 2130
	VMAG=SQRT(U(LPMP)*U(LPMP)+V(LPMP)*V(LPMP))	VIS 2140
	RTHE=2.0*THEW-THE	VIS 2150
	IF (NOSLIP, EQ, 1, AND, NGCB, NE, 0) RTHE=3.14159+THE	VIS 2160
	URP=VMAG*COS(RTHE)	VIS 2170
	VRP=VMAG*SIN(RTHE)	VIS 2180
	THEW=ATAN(-NXNYCB(L=1))	VIS 2190
	THE=ATAN(V(LMMP)/U(LMMP))	VIS 2200
	IF (U(LMMP),LT,0.0) THE=THE+3.14159	VIS 2210
	VMAG=SQRT(U(LMMP)*U(LMMP)+V(LMMP)*V(LMMP))	VIS 2220
	RTHE=2.0*THEW-THE	VIS 2230
	IF (NOSLIP, EQ, 1, AND, NGCB, NE, 0) RTHE=3.14159+THE	VIS 2240
	URM=VMAG*COS(RTHE)	VIS 2250
	VRM=VMAG*SIN(RTHE)	VIS 2260
	RFL=2.0*DY*NXNYCB(L)/(BE*(1.0+NXNYCB(L)*NXNYCB(L)))	VIS 2270
	RFLP=2.0*DY*NXNYCB(L+1)/(BE*(1.0+NXNYCB(L+1)*NXNYCB(L+1)))	VIS 2280
	RFLM=2.0*DY*NXNYCB(L-1)/(BE*(1.0+NXNYCB(L-1)*NXNYCB(L-1)))	VIS 2290
	TTERM=0.5*(TX1+TX2)	VIS 2300
	TR=TMP-TTERM*RFL	VIS 2310
	TRP=TLPMP-TTERM*RFLP	VIS 2320
	TRM=TLMMP-TTERM*RFLM	VIS 2330
	IF (CAV, EQ, 0.0) GO TO 170	VIS 2340
	ROTERM=0.5*(ROX1+ROX2)	VIS 2350
	ROR=RO(MP)=ROTERM*RFL	VIS 2360
	RORP=RO(LPMP)=ROTERM*RFLP	VIS 2370
	RORM=RO(LMMP)=ROTERM*RFLM	VIS 2380
	GO TO 170	VIS 2390
C		VIS 2400
C	REFLECT THE CENTERLINE OR MIDPLANE BOUNDARY CONDITIONS	VIS 2410
C		VIS 2420
150	UR=U(MP)	VIS 2430
	VR=V(MP)	VIS 2440
	URP=U(LPMP)	VIS 2450
	VRP=V(LPMP)	VIS 2460
	URM=U(LMMP)	VIS 2470
	VRM=V(LMMP)	VIS 2480
	TR=TMP	VIS 2490
	TRP=TLPMP	VIS 2500
	TRM=TLMMP	VIS 2510
	IF (CAV, EQ, 0.0) GO TO 170	VIS 2520
	ROR=RO(MP)	VIS 2530
	RORP=RO(LPMP)	VIS 2540
	RORM=RO(LMMP)	VIS 2550
	GO TO 170	VIS 2560
		VIS 2570
C		VIS 2580
C	EXTRAPOLATE THE CENTERBODY BOUNDARY CONDITIONS	VIS 2590
C		VIS 2600
160	UR=2.0*U(LMN1)-U(MP)	VIS 2610
	VR=2.0*V(LMN1)-V(MP)	VIS 2620
	URP=2.0*U(LP)-U(LPMP)	VIS 2630
	VRP=2.0*V(LP)-V(LPMP)	VIS 2640
	URM=2.0*U(LM)-U(LMMP)	VIS 2650
	VRM=2.0*V(LM)-V(LMMP)	VIS 2660
	TR=2.0*T-TMP	VIS 2670
	TRP=2.0*TLP-TLPMP	VIS 2680
	TRM=2.0*TLM-TLMMP	VIS 2690
	IF (CAV, EQ, 0.0) GO TO 170	VIS 2700
	ROR=2.0*RO(LMN1)-RO(MP)	VIS 2710
	RORP=2.0*RO(LP)-RO(LPMP)	VIS 2720
	RORM=2.0*RO(LM)-RO(LMMP)	VIS 2730
170	UY1=0.25*(U(MP)+U(LMMP)-UR-URM)*DYR	VIS 2740
	VY1=0.25*(V(MP)+V(LMMP)-VR-VRM)*DYR	VIS 2750
	UY2=0.25*(U(MP)+U(LPMP)-UR-URP)*DYR	VIS 2760
	VY2=0.25*(V(MP)+V(LPMP)-VR-VRP)*DYR	VIS 2770
	UY3=U(LMN1)-UR)*DYR	VIS 2780
	VY3=(V(LMN1)-VR)*DYR	VIS 2790
	UX3=0.25*(U(LP)+URP-U(LM)-URM)*DXR	VIS 2800
	VX3=0.25*(V(LP)+VRP-V(LM)-VRM)*DXR	VIS 2800

TY1=0.25*(TMP+TLMMP-TR-TRM)*DYZ	VIS 2810
TY2=0.25*(TMP+TLPMP-TR-TRP)*DYZ	VIS 2820
TX3=0.25*(TLP+TRP-TLM-TRM)*DXR	VIS 2830
TY3=(T-TR)*DYZ	VIS 2840
TMM=TR	VIS 2850
IF (CAV.EQ.0,0) GO TO 190	VIS 2860
ROY1=0.25*(RO(MP)+RO(LMMP)-ROR-RORM)*DYZ	VIS 2870
ROY2=0.25*(RO(MP)+RO(LPMP)-ROR-RORP)*DYZ	VIS 2880
ROY3=(RO(LMN1)-ROR)*DYZ	VIS 2890
ROX3=0.25*(RO(LP)+RORP-RO(LM)-RORM)*DXR	VIS 2900
IF (NDIM.EQ.0) GO TO 190	VIS 2910
IF (CAV.EQ.0,0,OR, DIV,GE.0,0) GO TO 190	VIS 2920
IF (YCB(L).EQ.0,0) GO TO 180	VIS 2930
ATERM1=0.5*((V(LMN1)+V(LM))/(YCB(L)+YCB(L-1)))	VIS 2940
ATERM2=0.5*((V(LMN1)+V(LP))/(YCB(L)+YCB(L+1)))	VIS 2950
IF (YCB(L-1).EQ.0,0) ATERM1=0.5*(REM*V(LMMP)*DYZ+V(LMN1)/YCB(L))	VIS 2960
IF (YCB(L+1).EQ.0,0) ATERM2=0.5*(RFP*V(LPMP)*DYZ+V(LMN1)/YCB(L))	VIS 2970
IF (YCB(L-1).EQ.0,0,OR, YCB(L+1).EQ.0,0) ATERM=0.5*(ATERM1+ATERM2)	VIS 2980
ATERM3=ATERM	VIS 2990
ATERM4=0.5*(V(LMN1)+V(MP))/(YCB(L)+0.5*DY/BE)	VIS 3000
GO TO 190	VIS 3010
180 ATERM1=BE1*0.5*(V(MP)+V(LMMP))*DYZ	VIS 3020
ATERM2=BE2*0.5*(V(MP)+V(LPMP))*DYZ	VIS 3030
IF (YCB(L-1).NE.0,0) ATERM1=0.5*(V(LM)/YCB(L-1)+BE*V(MP)*DYZ)	VIS 3040
IF (YCB(L+1).NE.0,0) ATERM2=0.5*(V(LP)/YCB(L+1)+BE*V(MP)*DYZ)	VIS 3050
IF (YCB(L-1).NE.0,0,OR, YCB(L+1).NE.0,0) ATERM=0.5*(ATERM1+ATERM2)	VIS 3060
ATERM4=0.5*V(MP)/(0.5*DY/BE)	VIS 3070
ATERM3=ATERM4	VIS 3080
190 MDUM=M+1	VIS 3090
CALL MAP (1,L,MDUM,AL4,BE4,DE,LD1,AL1,BE1,DE1)	VIS 3100
AL3=2.0*AL=AL4	VIS 3110
BE3=2.0*BE=BE4	VIS 3120
AL3=0.5*(AL3+AL)	VIS 3130
BE3=0.5*(BE3+BE)	VIS 3140
AL4=0.5*(AL4+AL)	VIS 3150
BE4=0.5*(BE4+BE)	VIS 3160
GO TO 250	VIS 3170
C	VIS 3180
C	VIS 3190
C	VIS 3200
200 UX3=0.25*(U(LP)+U(LPMM)-U(LM)-U(LMMM))*DXR	VIS 3210
VX3=0.25*(V(LP)+V(LPMM)-V(LM)-V(LMMM))*DXR	VIS 3220
UY3=(U(LMN1)-U(MM))*DYZ	VIS 3230
VY3=(V(LMN1)-V(MM))*DYZ	VIS 3240
CALL EOS (2,P(LPMM),RO(LPMM),TLPMM,AS,D2,D3)	VIS 3250
CALL EOS (2,P(MM),RO(MM),TMM,AS,D2,D3)	VIS 3260
CALL EOS (2,P(LMMM),RO(LMMM),TLM,AS,D2,D3)	VIS 3270
TX3=0.25*(TLP+TLPMM-TLM-TLMMM)*DXR	VIS 3280
TY3=(T-TMM)*DYZ	VIS 3290
IF (CAV.EQ.0,0) GO TO 210	VIS 3300
ROX3=0.25*(RO(LP)+RO(LPMM)-RO(LM)-RO(LMMM))*DXR	VIS 3310
ROY3=(RO(LMN1)-RO(MM))*DYZ	VIS 3320
C	VIS 3330
C	VIS 3340
C	VIS 3350
210 IF (IVBC.EQ.1) GO TO 220	VIS 3360
THE=ATAN(-NXNY(L))	VIS 3370
THE=ATAN(V(MM)/U(MM))	VIS 3380
IF (U(MM).LT.0,0) THE=THE+3.14159	VIS 3390
VMAG=SQRT(U(MM)*U(MM)+V(MM)*V(MM))	VIS 3400
RTHE=2.0*THE=THE	VIS 3410
IF (NOSLIP.EQ.1) RTHE=3.14159+THE	VIS 3420
UR=VMAG*COS(RTHE)	VIS 3430
VR=VMAG*SIN(RTHE)	VIS 3440
THE=ATAN(-NXNY(L+1))	VIS 3450
THE=ATAN(V(LPMM)/U(LPMM))	VIS 3460
IF (U(LPMM).LT.0,0) THE=THE+3.14159	VIS 3470
VMAG=SQRT(U(LPMM)*U(LPMM)+V(LPMM)*V(LPMM))	VIS 3480
RTHE=2.0*THE=THE	VIS 3490
IF (NOSLIP.EQ.1) RTHE=3.14159+THE	VIS 3500

	URP=VMAG*COS(RTHE)	VIS 3510
	VRP=VMAG*SIN(RTHE)	VIS 3520
	THEW=ATAN(-NXNY(L-1))	VIS 3530
	THE=ATAN(V(LMMM)/U(LMMM))	VIS 3540
	IF (U(LMMM).LT.0.0) THE=THE+3.14159	VIS 3550
	VMAG=SQRT(U(LMMM)*U(LMMM)+V(LMMM)*V(LMMM))	VIS 3560
	RTHE=2.0*THEW-THE	VIS 3570
	IF (NOSLIP.EQ.1) RTHE=3.14159+THE	VIS 3580
	URM=VMAG*COS(RTHE)	VIS 3590
	VRM=VMAG*SIN(RTHE)	VIS 3600
	RFL=2.0*DY*NXNY(L)/(BE*(1.0+NXNY(L)*NXNY(L)))	VIS 3610
	RFLP=2.0*DY*NXNY(L+1)/(BE*(1.0+NXNY(L+1)*NXNY(L+1)))	VIS 3620
	RFLM=2.0*DY*NXNY(L-1)/(BE*(1.0+NXNY(L-1)*NXNY(L-1)))	VIS 3630
	TTERM=0.5*(TX1+TX2)	VIS 3640
	TR=TMM-TTERM*RFL	VIS 3650
	TRP=TLPMM-TTERM*RFLP	VIS 3660
	TRM=TLMMM-TTERM*RFLM	VIS 3670
	IF (CAV.EQ.0.0) GO TO 230	VIS 3680
	ROTERM=0.5*(ROX1+ROX2)	VIS 3690
	ROR=RO(MM)-ROTERM*RFL	VIS 3700
	RORP=RO(LPMM)-ROTERM*RFLP	VIS 3710
	RORM=RO(LMMM)-ROTERM*RFLM	VIS 3720
	GO TO 230	VIS 3730
C		VIS 3740
C	EXTRAPOLATE THE WALL BOUNDARY CONDITIONS	VIS 3750
C		VIS 3760
220	UR=2.0*U(LMN1)-U(MM)	VIS 3770
	VR=2.0*V(LMN1)-V(MM)	VIS 3780
	URP=2.0*U(LP)-U(LPMM)	VIS 3790
	VRP=2.0*V(LP)-V(LPMM)	VIS 3800
	URM=2.0*U(LM)-U(LMMM)	VIS 3810
	VRM=2.0*V(LM)-V(LMMM)	VIS 3820
	TR=2.0*T-TMM	VIS 3830
	TRP=2.0*TLP-TLPMM	VIS 3840
	TRM=2.0*TLM-TLMMM	VIS 3850
	IF (CAV.EQ.0.0) GO TO 230	VIS 3860
	ROR=2.0*ROR(LMN1)-RO(MM)	VIS 3870
	RORP=2.0*ROR(LP)-RO(LPMM)	VIS 3880
	RORM=2.0*ROR(LM)-RO(LMMM)	VIS 3890
230	UY1=0.25*(UR+URM-U(MM)-U(LMMM))*DYR	VIS 3900
	VY1=0.25*(VR+VRM-V(MM)-V(LMMM))*DYR	VIS 3910
	UY2=0.25*(UR+URP-U(MM)-U(LPMM))*DYR	VIS 3920
	VY2=0.25*(VR+VRP-V(MM)-V(LPMM))*DYR	VIS 3930
	UY4=(UR-U(LMN1))*DYR	VIS 3940
	VY4=(VR-V(LMN1))*DYR	VIS 3950
	UX4=0.25*(U(LP)+URP-U(LM)-URM)*DXR	VIS 3960
	VX4=0.25*(V(LP)+VRP-V(LM)-VRM)*DXR	VIS 3970
	TY1=0.25*(TR+TRM-TMM-TLMMM)*DYR	VIS 3980
	TY2=0.25*(TR+TRP-TMM-TLPMM)*DYR	VIS 3990
	TX4=0.25*(TLP+TRP-TLM-TRM)*DXR	VIS 4000
	TY4=(TR-T)*DYR	VIS 4010
	TMP=TR	VIS 4020
	IF (CAV.EQ.0.0) GO TO 240	VIS 4030
	ROY1=0.25*(ROR+RORM-RO(MM)-RO(LMMM))*DYR	VIS 4040
	ROY2=0.25*(ROR+RORP-RO(MM)-RO(LPMM))*DYR	VIS 4050
	ROY4=(ROR-RO(LMN1))*DYR	VIS 4060
	ROX4=0.25*(RO(LP)+RORP-RO(LM)-RORM)*DXR	VIS 4070
	IF (NDIM.EQ.0) GO TO 240	VIS 4080
	IF (CAV.EQ.0.0,OR,DIR,GE.0.0) GO TO 240	VIS 4090
	ATERM1=0.5*((V(LMN1)+V(LM))/(YW(L)+YW(L+1)))	VIS 4100
	ATERM2=0.5*((V(LMN1)+V(LP))/(YW(L)+YW(L+1)))	VIS 4110
	ATERM3=0.5*(V(LMN1)+V(MM))/(YW(L)+0.5*DY/BE)	VIS 4120
	ATERM4=0.5*(V(LMN1)+VR)/(YW(L)+0.5*DY/BE)	VIS 4130
240	MDUM=M+1	VIS 4140
	CALL MAP (1,L,MDUM,AL3,BE3,DE,LD1,AL1,BE1,DE1)	VIS 4150
	AL4=2.0*AL-AL3	VIS 4160
	BE4=2.0*BE-BE3	VIS 4170
	AL3=0.5*(AL3+AL)	VIS 4180
	BE3=0.5*(BE3+BE)	VIS 4190
	AL4=0.5*(AL4+AL)	VIS 4200

	BE4=0.5*(BE4+BE)	VIS 4210
C		VIS 4220
C	COMBINE TERMS	VIS 4230
C		VIS 4240
250	UXY1=UX1+AL1*UY1	VIS 4250
	UXY2=UX2+AL2*UY2	VIS 4260
	UXY3=UX3+AL3*UY3	VIS 4270
	UXY4=UX4+AL4*UY4	VIS 4280
	UXY12=0.5*(UX1+UX2+AL3*UY3+AL4*UY4)	VIS 4290
	VXY1=VX1+AL1*VY1	VIS 4300
	VXY2=VX2+AL2*VY2	VIS 4310
	VXY3=VX3+AL3*VY3	VIS 4320
	VXY4=VX4+AL4*VY4	VIS 4330
	VXY12=0.5*(VX1+VX2+AL3*VY3+AL4*VY4)	VIS 4340
	BUY1=BE1*UY1	VIS 4350
	BUY2=BE2*UY2	VIS 4360
	BUY3=BE3*UY3	VIS 4370
	BUY4=BE4*UY4	VIS 4380
	BUY34=0.5*(BUY3+BUY4)	VIS 4390
	BVY1=BE1*VY1	VIS 4400
	BVY2=BE2*VY2	VIS 4410
	BVY3=BE3*VY3	VIS 4420
	BVY4=BE4*VY4	VIS 4430
	BVY34=0.5*(BVY3+BVY4)	VIS 4440
	TXY1=TX1+AL1*TY1	VIS 4450
	TXY2=TX2+AL2*TY2	VIS 4460
	TXY3=TX3+AL3*TY3	VIS 4470
	TXY4=TX4+AL4*TY4	VIS 4480
	BTY3=BE3*TY3	VIS 4490
	BTY4=BE4*TY4	VIS 4500
	BTY34=0.5*(BTY3+BTY4)	VIS 4510
	IF (CAV, EQ, 0, 0) GO TO 260	VIS 4520
	ROXY1=ROX1+AL1*ROY1	VIS 4530
	ROXY2=ROX2+AL2*ROY2	VIS 4540
	ROXY3=ROX3+AL3*ROY3	VIS 4550
	ROXY4=ROX4+AL4*ROY4	VIS 4560
	BROY3=BE3*ROY3	VIS 4570
	BROY4=BE4*ROY4	VIS 4580
	BROY34=0.5*(BROY3+BROY4)	VIS 4590
C		VIS 4600
C	CALCULATE THE ARTIFICIAL VISCOSITY COEFFICIENTS	VIS 4610
C		VIS 4620
260	IF (CAV, EQ, 0, 0) GO TO 300	VIS 4630
	IF (DIV, GE, 0, 0) DIV=0.0	VIS 4640
	IF (L, LT, LSS) DIV=0.0	VIS 4650
	IF (SMACH, EQ, 0, 0) GO TO 270	VIS 4660
	XV=U(LMN1)*U(LMN1)+V(LMN1)*V(LMN1)	VIS 4670
	CALL EOS (1, P(LMN1), RO(LMN1), T, XA, 02, 03)	VIS 4680
	XM=XV/XA	VIS 4690
	IF (XM, LT, SMACH+SMACH) DIV=0.0	VIS 4700
270	IF (DIV, NE, 0, 0) GO TO 280	VIS 4710
	DIV1=DIV2=DIV3=DIV4=0.0	VIS 4720
	GO TO 290	VIS 4730
280	DIV1=UXY1+BXY1+ATERM1	VIS 4740
	DIV2=UXY2+BXY2+ATERM2	VIS 4750
	DIV3=UXY3+BXY3+ATERM3	VIS 4760
	DIV4=UXY4+BXY4+ATERM4	VIS 4770
	DIV=UXY12+BXY34+ATERM	VIS 4780
290	DRLA=XLA*RDUM/BE*RO(LMN1)	VIS 4790
	RLA=DRLA*ABS(DIV)	VIS 4800
	RLA1=DRLA*ABS(DIV1)	VIS 4810
	RLA2=DRLA*ABS(DIV2)	VIS 4820
	RLA3=DRLA*ABS(DIV3)	VIS 4830
	RLA4=DRLA*ABS(DIV4)	VIS 4840
	XMULA=XMU/XLA	VIS 4850
	RMU=XMULA*RLA	VIS 4860
	RMU1=XMULA*RLA1	VIS 4870
	RMU2=XMULA*RLA2	VIS 4880
	RMU3=XMULA*RLA3	VIS 4890
	RMU4=XMULA*RLA4	VIS 4900

CALL EOS (15,P(LMN1),RO(LMN1),T,DRK,D2,D3)	VIS 4910
RK=DRK*RMU	VIS 4920
RK1=DRK*RMU1	VIS 4930
RK2=DRK*RMU2	VIS 4940
RK3=DRK*RMU3	VIS 4950
RK4=DRK*RMU4	VIS 4960
XXRO=XRO/RO(LMN1)	VIS 4970
RR0=XXRO*RMU	VIS 4980
RR01=XXRO*RMU1	VIS 4990
RR02=XXRO*RMU2	VIS 5000
RR03=XXRO*RMU3	VIS 5010
RR04=XXRO*RMU4	VIS 5020
RLP2M=RLA+2.0*RMU	VIS 5030
RLPM=RLA*RMU	VIS 5040
RLP2M1=RLA1+2.0*RMU1	VIS 5050
RLP2M2=RLA2+2.0*RMU2	VIS 5060
RLP2M3=RLA3+2.0*RMU3	VIS 5070
RLP2M4=RLA4+2.0*RMU4	VIS 5080
C	VIS 5090
C	VIS 5100
C	VIS 5110
300 IF (CHECK.EQ.0.0) GO TO 360	VIS 5120
IF (ECHECK.EQ.0.0) GO TO 310	VIS 5130
IF (ECHECK.LT.0.0) GO TO 320	VIS 5140
MU=CMU*T**EMU	VIS 5150
LA=CLA*T**ELA	VIS 5160
K=CK*T**EK	VIS 5170
GO TO 330	VIS 5180
310 MU=CMU	VIS 5190
LA=CLA	VIS 5200
K=CK	VIS 5210
GO TO 330	VIS 5220
320 SQT=T**EMU	VIS 5230
MU=CMU*SQT	VIS 5240
LA=CLA*SQT	VIS 5250
K=CK*SQT	VIS 5260
C	VIS 5270
C	VIS 5280
C	VIS 5290
330 IF (ITM.EQ.0) GO TO 350	VIS 5300
MUT=TML*TML*SQRT(BUY34*BUY34+VXY12*VXY12)*RO(LMN1)	VIS 5310
IF (M.NE.1.OR.NGCB.NE.0) GO TO 340	VIS 5320
MUT=TML*TML*TML*BE*BE*ABS(UY4=UY3)*DYR*RO(LMN1)	VIS 5330
340 TLMUR=MUT/MU	VIS 5340
C	VIS 5350
C	VIS 5360
C	VIS 5370
350 MU=MU*(1.0+TLMUR)	VIS 5380
LA=LA*(1.0+TLMUR)	VIS 5390
K=K*(1.0+TLMUR)	VIS 5400
LP2M=LA+2.0*MU	VIS 5410
LPM=LA+MU	VIS 5420
360 UVT=((LP2M+RLP2M2)*UXY2-(LP2M+RLP2M1)*UXY1+(LA+RLA2)*BVY2-(LA+RLA1	VIS 5430
1)*BVY1)*DXR+AL*((LP2M+RLP2M4)*UXY4-(LP2M+RLP2M3)*UXY3+(LA+RLA4)	VIS 5440
2)*BVY4-(LA+RLA3)*BVY3)*DYR+BF*((MU+RMU4)*(VXY4+BUY4)-(MU+RMU3)*	VIS 5450
3*(VXY3+BUY3))*DYR	VIS 5460
VVT=((MU+RMU2)*(VXY2+BUY2)-(MU+RMU1)*(VXY1+BUY1))*DXR+AL*((MU+RMU4	VIS 5470
1)*(VXY4+BUY4)-(MU+RMU3)*(VXY3+BUY3))*DYR+BE*((LA+RLA4)*UXY4-(LA	VIS 5480
2+RLA3)*UXY3+(LP2M+RLP2M4)*BVY4-(LP2M+RLP2M3)*BVY3)*DYR	VIS 5490
PVT=(LP2M+RLP2M)*UXY12*UXY12+BVY34*BVY34+(MU+RMU)*(VXY12+VXY12	VIS 5500
1+BUY34+BUY34)+2.0*(LA+RLA)*UXY12*BVY34+2.0*(MU+RMU)*BUY34*VXY12	VIS 5510
PCT=((K+RK2)*TXY2-(K+RK1)*TXY1)*DXR+AL*((K+RK4)*TXY4-(K+RK3)*TXY3)	VIS 5520
1)*DYR+BE*((K+RK4)*BTY4-(K+RK3)*BTY3)*DYR	VIS 5530
IF (CAV.EQ.0.0) GO TO 370	VIS 5540
RODIF=(RR02*ROXY2-RR01*ROXY1)*DXR+AL*(RR04*ROXY4-RR03*ROXY3)*DYR	VIS 5550
1+BE*(RR04*ROXY4-RR03*ROXY3)*DYR	VIS 5560
370 UVT=VVT+PVT+PCT+RODIF*0.0	VIS 5570
IF (NOIM.EQ.0) GO TO 390	VIS 5580

C		VIS 5590
C	CALCULATE THE AXISYMMETRIC TERMS	VIS 5600
C		VIS 5610
	IF (M, EQ, 1, AND, YCB(L), EQ, 0, 0) GO TO 380	VIS 5620
	Y=FLOAT(M=1)*DY/BE+YCB(L)	VIS 5630
	VYR=V(LMN1)/Y	VIS 5640
	UVTA=((LP2M+RLP2M)*VXY12+(MU+RMU)*BUY34)/Y	VIS 5650
	VVTA=(LP2M+RLP2M)*(BVY34-VYR)/Y	VIS 5660
	PVTA=(LP2M+RLP2M)*VYR**2+2.0*(LA+RLA)*(BVY34+UXY12)*VYR	VIS 5670
	PCTA=(K+RK)*BTY34/Y	VIS 5680
	IF (CAV, EQ, 0, 0) GO TO 390	VIS 5690
	RODIFA=RR0*BROY34/Y	VIS 5700
	GO TO 390	VIS 5710
380	UVTA=(LPM+RLPM)*BE*(VXY4-VXY3)*DYR+(MU+RMU)*BE*(BUY4-BUY3)*DYR	VIS 5720
	VVTA=(LP2M+RLP2M)*0.5*BE*(BVY4-BVY3)*DYR	VIS 5730
	PVTA=(LP2M+RLP2M+2.0*(LA+RLA))*BVY34+BVY34+2.0*(LA+RLA)*BVY34	VIS 5740
	1 *UXY12	VIS 5750
	PCTA=(K+RK)*BE*(BTY4-BTY3)*DYR	VIS 5760
	IF (CAV, EQ, 0, 0) GO TO 390	VIS 5770
	RODIFA=RR0*BE*(BROY4-BROY3)*DYR	VIS 5780
C		VIS 5790
390	QUT(L, M)=(UVT+UVTA-U(LMN1)*(RODIF+RODIFA))/RO(LMN1)	VIS 5800
	QVT(L, M)=(VVT+VVTA-V(LMN1)*(RODIF+RODIFA))/RO(LMN1)	VIS 5810
	CALL EOS (14, P(LMN1), RO(LMN1), T, GAM, D2, D3)	VIS 5820
	QPT(L, M)=GAM*(PVT+PVTA+PCT+PCTA+(U(LMN1)*U(LMN1)+V(LMN1)*V(LMN1))-PVIS	VIS 5830
	1 (LMN1)/RO(LMN1))*(RODIF+RODIFA)	VIS 5840
	QROT(L, M)=RODIF+RODIFA	VIS 5850
C		VIS 5860
C	PRINT THE VISCOUS TERMS	VIS 5870
C		VIS 5880
	IF (IAV, NE, 0) GO TO 420	VIS 5890
	IF (NC, NE, NPRINT, AND, N, NE, NMAX) GO TO 420	VIS 5900
	NLINE=NLINE+1	VIS 5910
	IF (NLINE, LT, 55) GO TO 400	VIS 5920
	WRITE (6, 450)	VIS 5930
	WRITE (6, 440) N	VIS 5940
	NLINE=1	VIS 5950
400	DQPT=DPT(L, M)/PC*DT	VIS 5960
	DQUT=QUT(L, M)*DT	VIS 5970
	DQVT=QVT(L, M)*DT	VIS 5980
	DQROT=QROT(L, M)*G*DT	VIS 5990
	IF (IUO, NE, 2) GO TO 410	VIS 6000
	DQUT=DQUT*0.3048	VIS 6010
	DQVT=DQVT*0.3048	VIS 6020
	DQPT=DQPT*6.8948	VIS 6030
	DQROT=DQROT*16.02	VIS 6040
410	WRITE (6, 430) L, M, DQUT, DQVT, DQPT, DQROT, TLMUR	VIS 6050
420	CONTINUE	VIS 6060
	IF (NC, EQ, NPRINT) NC=0	VIS 6070
	RETURN	VIS 6080
C		VIS 6090
C	FORMAT STATEMENTS	VIS 6100
C		VIS 6110
430	FORMAT (1H, 5X, 2I5, 5F14.4)	VIS 6120
440	FORMAT (1H, 51HLOCAL ARTIFICIAL VISCOSITY AND MOLECULAR VISCOSITY=HVIS	VIS 6130
	1, 24HEAT CONDUCTION TERMS, N=, I4, //, 10X, 1HL, 4X, 1HM, 10X, 3HQUT, 11X, 3VIS	VIS 6140
	2 HQVT, 11X, 3HQPT, 10X, 4HQROT, 10X, 5HTLMUR, //)	VIS 6150
450	FORMAT (1H1)	VIS 6160
	END	VIS 6170

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*DECK,SMOOTH
SUBROUTINE SMOOTH
C
C *****
C THIS SUBROUTINE SMOOTHS THE FLOW VARIABLES IF REQUESTED
C *****
*CALL,MCC
C THE SINGLE SUBSCRIPTS USED HERE ARE THOSE IN SUBROUTINE VISCIOUS
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.LJFT) 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 ,D2,03)
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,D2,03)
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
SMO 10
SMO 20
SMO 30
SMO 40
SMO 50
SMO 60
SMO 70
SMO 80
SMO 90
SMO 100
SMO 110
SMO 120
SMO 130
SMO 140
SMO 150
SMO 160
SMO 170
SMO 180
SMO 190
SMO 200
SMO 210
SMO 220
SMO 230
SMO 240
SMO 250
SMO 260
SMO 270
SMO 280
SMO 290
SMO 300
SMO 310
SMO 320
SMO 330
SMO 340
SMO 350
SMO 360
SMO 370
SMO 380
SMO 390
SMO 400
SMO 410
SMO 420
SMO 430
SMO 440
SMO 450
SMO 460
SMO 470
SMO 480
SMO 490
SMO 500
SMO 510
SMO 520
SMO 530

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★DECK,MIXLEN	MIX	10
SUBROUTINE MIXLEN (L)	MIX	20
C	MIX	30
C	MIX	40
C	MIX	50
C	MIX	60
C	MIX	70
C	MIX	80
C	MIX	90
★CALL,MCC	MIX	100
DO 30 M=1,M1	MIX	110
IF (U(L,1,N1).EQ.U(L,MMAX,N1)) GO TO 50	MIX	120
CALL MAP (0,L,M,AL,BE,DE,LD1,AL1,RE1,DE1)	MIX	130
UD1=(U(L,M,N1)-U(L,MMAX,N1))/(U(L,1,N1)-U(L,MMAX,N1))	MIX	140
UD2=(U(L,M+1,N1)-U(L,MMAX,N1))/(U(L,1,N1)-U(L,MMAX,N1))	MIX	150
IF (UD1.GE.0.9.AND.UD2.LE.0.9) GO TO 10	MIX	160
IF (UD1.GE.0.1.AND.UD2.LE.0.1) GO TO 20	MIX	170
GO TO 30	MIX	180
10 Y2=(FLOAT(M-1)+(0.9-UD1)/(UD2-UD1))*DY/RE	MIX	190
IF (UD1.GE.0.1.AND.UD2.LE.0.1) GO TO 20	MIX	200
GO TO 30	MIX	210
20 Y1=(FLOAT(M-1)+(0.1-UD1)/(UD2-UD1))*DY/BE	MIX	220
GO TO 40	MIX	230
30 CONTINUE	MIX	240
Y1=YW(L)	MIX	250
40 IF (NDIM.EQ.0) TML=0.125*ABS(Y2-Y1)	MIX	260
IF (NDIM.EQ.1) TML=0.11*ABS(Y2-Y1)	MIX	270
RETURN	MIX	280
C	MIX	290
50 TML=0.0	MIX	300
RETURN	MIX	310
END	MIX	320

*DECK,INTER	INR	10
SUBROUTINE INTER	INR	20
C	INR	30
C	INR	40
C	INR	50
C	INR	60
C	INR	70
C	INR	80
C	INR	90
*CALL,MCC	INR	100
ATERM=0.0	INR	110
IF (ICAR,NE.1) GO TO 40	INR	120
C	INR	130
C	INR	140
C	INR	150
C	INR	160
C	INR	170
MDUM=1	INR	180
IF (NGCB,NE.0) MDUM=2	INR	190
DO 30 L=2,L1	INR	200
DO 30 M=MDUM,M1	INR	210
CALL MAP (1,L,M,AL,BE,DE,LD1,AL1,BE1,DE1)	INR	220
LMD2=LD*(M=1)	INR	230
LMN1=L+LMD2+LMD1	INR	240
LMN3=L+LMD2+LMD3	INR	250
L1MN1=L-1+LMD2+LMD1	INR	260
LM1N1=L+LD*(M=2)+LMD1	INR	270
UB=U(LMN1)	INR	280
VB=V(LMN1)	INR	290
PB=P(LMN1)	INR	300
ROB=RO(LMN1)	INR	310
CALL EOS (1,PB,ROB,T,ASB,D2,D3)	INR	320
IF (M,NE.1) GO TO 10	INR	330
C	INR	340
DUDX=(UB=U(L1MN1))*DXR	INR	350
DPDX=(PB=P(L1MN1))*DXR	INR	360
DRDX=(ROB=RO(L1MN1))*DXR	INR	370
DVDY=(4.0*V(L,2,N1)-V(L,3,N1))*0.5*DYR	INR	380
V(LMN3)=0.0	INR	390
C	INR	400
URHS=-UB*DUDX+DPDX/ROB+QUT(L,M)	INR	410
RORHS=-UB*DRDX+ROB*DUDX=FLOAT(1+NDIM)*ROB*BE*DVDY+QROT(L,M)	INR	420
PRHS=-UB*DPDX+ASB*(RORHS+UB*DRDX)+QPT(L,M)	INR	430
GO TO 20	INR	440
10 IF (NDIM,EQ.1) ATERM=ROB*VB/(FLOAT(M=1)*DY/BE+YCB(L))	INR	450
UVB=UB*AL+VB*BE+DE	INR	460
DUDX=(UB=U(L1MN1))*DXR	INR	470
DVDX=(VB=V(L1MN1))*DXR	INR	480
DPDX=(PB=P(L1MN1))*DXR	INR	490
DRDX=(ROB=RO(L1MN1))*DXR	INR	500
DUDY=(UB=U(LM1N1))*DYR	INR	510
DVDY=(VB=V(LM1N1))*DYR	INR	520
DPDY=(PB=P(LM1N1))*DYR	INR	530
DRDY=(ROB=RO(LM1N1))*DYR	INR	540
C	INR	550
URHS=-UB*DUDX+UVB*DUDY=(DPDX+AL*DPDY)/ROB+QUT(L,M)	INR	560
VRHS=-UB*DVDX+UVB*DVDY=BE*DPDY/ROB+QVT(L,M)	INR	570
RORHS=-UB*DRDX+UVB*DRDY=ROB*(DUDX+AL*DUDY+BE*DVDY)+ATERM+QROT(L	INR	580
1,M)	INR	590
PRHS=-UB*DPDX+UVB*DPDY+ASB*(RORHS+UB*DRDX+UVB*DRDY)+QPT(L,M)	INR	600
V(LMN3)=V(LMN1)+VRHS*DT	INR	610
20 U(LMN3)=U(LMN1)+URHS*DT	INR	620
P(LMN3)=P(LMN1)+PRHS*DT	INR	630
RO(LMN3)=RO(LMN1)+RORHS*DT	INR	640
IF (P(LMN3).LE.0.0) P(LMN3)=PLOW*PC	INR	650
IF (RO(LMN3).LE.0.0) RO(LMN3)=ROLOW/G	INR	660
30 CONTINUE	INR	670
RETURN	INR	680

C		INR 690
C	COMPUTE THE FINAL SOLUTION AT T+DT = THE SINGLE SUBSCRIPTS USED	INR 700
C	HERE ARE LMN1=L,M,N1, LMN3=L,M,N3, L1MN3=L+1,M,N3 AND LM1N3=	INR 710
C	L,M+1,N3	INR 720
C		INR 730
	40 MDUM=1	INR 740
	IF (NGCB,NE,0) MDUM=2	INR 750
	DO 70 L=2,L1	INR 760
	DO 70 M=MDUM,M1	INR 770
	CALL MAP (1,L,M,AL,BE,DE,LD1,AL1,RE1,DE1)	INR 780
	LMD2=LD*(M-1)	INR 790
	LMN1=L+LMD2+LMD1	INR 800
	LMN3=L+LMD2+LMD3	INR 810
	L1MN3=L+1+LMD2+LMD3	INR 820
	LM1N3=L+LD*M+LMD3	INR 830
	UB=U(LMN3)	INR 840
	VB=V(LMN3)	INR 850
	PB=P(LMN3)	INR 860
	ROB=RO(LMN3)	INR 870
	CALL EOS (1,PB,ROB,T,ASB,D2,D3)	INR 880
	IF (M,NE,1) GO TO 50	INR 890
C		INR 900
	DUDX=(U(L1MN3)-UB)*DXR	INR 910
	DPDX=(P(L1MN3)-PB)*DXR	INR 920
	DRODX=(RO(L1MN3)-ROB)*DXR	INR 930
	DVDY=(4.0*V(L,2,N3)-V(L,3,N3))*0.5*DYR	INR 940
	V(LMN3)=0.0	INR 950
C		INR 960
	URHS=-UB*DUDX-DPDX/ROB+GUT(L,M)	INR 970
	RORHS=-UB*DRODX-ROB*DUDX-FLOAT(1+NDIM)*ROB*BE*DVDY+GROT(L,M)	INR 980
	PRHS=-UB*DPDX+ASB*(RORHS+UR*DRODX)+OPT(L,M)	INR 990
	GO TO 60	INR 1000
	50 IF (NDIM,EQ,1) ATERM=ROB*VB/(FLOAT(M-1)*DY/BE+YCB(L))	INR 1010
	UVB=UB*AL+VB*BE+DE	INR 1020
	DUDX=(U(L1MN3)-UB)*DXR	INR 1030
	DVDX=(V(L1MN3)-VB)*DXR	INR 1040
	DPDX=(P(L1MN3)-PB)*DXR	INR 1050
	DRODX=(RO(L1MN3)-ROB)*DXR	INR 1060
	DUDY=(U(LM1N3)-UB)*DYR	INR 1070
	DVDY=(V(LM1N3)-VB)*DYR	INR 1080
	DPDY=(P(LM1N3)-PB)*DYR	INR 1090
	DRODY=(RO(LM1N3)-ROB)*DYR	INR 1100
C		INR 1110
	URHS=-UB*DUDX-UVB*DUDY-(DPDX+AL*DPDY)/ROB+GUT(L,M)	INR 1120
	VRHS=-UB*DVDX-UVB*DVDY-BE*DPDY/ROB+GVT(L,M)	INR 1130
	RORHS=-UB*DRODX-UVB*DRODY-ROR*(DUDX+AL*DUDY+BE*DVDY)-ATERM+GROT(L	INR 1140
	1,M)	INR 1150
	PRHS=-UB*DPDX-UVB*DPDY+ASB*(RORHS+UR*DRODX+UVB*DRODY)+OPT(L,M)	INR 1160
	V(LMN3)=(V(LMN1)+V(LMN3)+VRHS*DT)*0.5	INR 1170
60	U(LMN3)=(U(LMN1)+U(LMN3)+URHS*DT)*0.5	INR 1180
	P(LMN3)=(P(LMN1)+P(LMN3)+PRHS*DT)*0.5	INR 1190
	RO(LMN3)=(RO(LMN1)+RO(LMN3)+RORHS*DT)*0.5	INR 1200
	IF (P(LMN3),LE,0.0) P(LMN3)=PLOW*PC	INR 1210
	IF (RO(LMN3),LE,0.0) RO(LMN3)=ROLOW/G	INR 1220
70	CONTINUE	INR 1230
	RETURN	INR 1240
	END	INR 1250

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*DECK,WALL
SUBROUTINE WALL
C
C *****
C THIS SUBROUTINE CALCULATES THE BOUNDARY MESH POINTS AT THE
C WALL, FREE=JET BOUNDARY, AND CENTERBODY
C *****
C
*CALL,MCC
C
C THE SINGLE SUBSCRIPTS USED HERE ARE LMN1=L,MDUM,N1, LMN3=
C L,MDUM,N3, LMN1=L,MDUM1,N1, LIMN1=L-1,MDUM,N1, LIMN3=L+1,MDUM,N3
C AND LIM1N1=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*DYS
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 (ICAR,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*(DUDY3))
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 (ICAR,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
WAL 10
WAL 20
WAL 30
WAL 40
WAL 50
WAL 60
WAL 70
WAL 80
WAL 90
WAL 100
WAL 110
WAL 120
WAL 130
WAL 140
WAL 150
WAL 160
WAL 170
WAL 180
WAL 190
WAL 200
WAL 210
WAL 220
WAL 230
WAL 240
WAL 250
WAL 260
WAL 270
WAL 280
WAL 290
WAL 300
WAL 310
WAL 320
WAL 330
WAL 340
WAL 350
WAL 360
WAL 370
WAL 380
WAL 390
WAL 400
WAL 410
WAL 420
WAL 430
WAL 440
WAL 450
WAL 460
WAL 470
WAL 480
WAL 490
WAL 500
WAL 510
WAL 520
WAL 530
WAL 540
WAL 550
WAL 560
WAL 570
WAL 580
WAL 590
WAL 600
WAL 610
WAL 620
WAL 630
WAL 640
WAL 650
WAL 660
WAL 670
WAL 680

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70	PB=0.5*(P(LMN1)+P(LMN3))	WAL	690
	ROB=0.5*(RO(LMN1)+RO(LMN3))	WAL	700
	CALL EOS (1,PB,ROB,TEMP,AS,D2,D3)	WAL	710
	P(LMN3)=P(LMN1)+AS*(RO(LMN3)-RO(LMN1))+OPT(L,M,DUM)*DT	WAL	720
80	IF (P(LMN3).LE.0.0) P(LMN3)=PLOW*PC	WAL	730
	GO TO 310	WAL	740
C		WAL	750
C	CALCULATE THE DEPENDENT VARIABLES FOR FREE-SLIP WALLS	WAL	760
C		WAL	770
90	IF (JFLAG.EQ.0) GO TO 120	WAL	780
	IF (IB.EQ.2) GO TO 120	WAL	790
	XWID=XWI(L)	WAL	800
	IF (ICHR.EQ.1) GO TO 100	WAL	810
C		WAL	820
C	USE THE DUMMY ARRAYS TO MANIPULATE THE ONE-SIDED SOLUTIONS	WAL	830
C	FOR THE FREE-JET OR SHARP EXPANSION CORNER CASES	WAL	840
C		WAL	850
	IF (L.NE.LJET=2) GO TO 100	WAL	860
	U(LMN3)=UD(3)	WAL	870
	V(LMN3)=VD(3)	WAL	880
	P(LMN3)=PD(3)	WAL	890
	RO(LMN3)=ROD(3)	WAL	900
	GO TO 120	WAL	910
100	IF (L.NE.LJET=1) GO TO 110	WAL	920
	IF (ICHR.EQ.1) UOLD=U(LMN1)	WAL	930
	U(LMN1)=UD(1)	WAL	940
	V(LMN1)=VD(1)	WAL	950
	P(LMN1)=PD(1)	WAL	960
	RO(LMN1)=ROD(1)	WAL	970
	GO TO 120	WAL	980
110	IF (L.NE.LJET) GO TO 120	WAL	990
	U(LMN1)=UD(2)	WAL	1000
	V(LMN1)=VD(2)	WAL	1010
	P(LMN1)=PD(2)	WAL	1020
	RO(LMN1)=ROD(2)	WAL	1030
C		WAL	1040
120	U1=U(LMN1)	WAL	1050
	V1=V(LMN1)	WAL	1060
	P1=P(LMN1)	WAL	1070
	RO1=RO(LMN1)	WAL	1080
	U2=U1	WAL	1090
	V2=V1	WAL	1100
	CALL EOS (1,P1,RO1,T,AS,D2,D3)	WAL	1110
	A1=SQRT(AS)	WAL	1120
	A2=A1	WAL	1130
	IF (ICHR.NE.1) GO TO 130	WAL	1140
	U3=U1	WAL	1150
	V3=V1	WAL	1160
	P3=P1	WAL	1170
	RO3=RO1	WAL	1180
	A3=A1	WAL	1190
	GO TO 140	WAL	1200
130	U3=U(LMN3)	WAL	1210
	V3=V(LMN3)	WAL	1220
	P3=P(LMN3)	WAL	1230
	RO3=RO(LMN3)	WAL	1240
	CALL EOS (1,P3,RO3,T,AS,D2,D3)	WAL	1250
	A3=SQRT(AS)	WAL	1260
C		WAL	1270
C	CALCULATE THE PROPERTY INTERPOLATING POLYNOMIAL COEFFICIENTS	WAL	1280
C		WAL	1290
140	BU=(U1-U(LMN1))*DYS	WAL	1300
	BV=(V1-V(LMN1))*DYS	WAL	1310
	BP=(P1-P(LMN1))*DYS	WAL	1320
	BR0=(RO1-RO(LMN1))*DYS	WAL	1330
	CU=U1-BU*Y3	WAL	1340
	CV=V1-BV*Y3	WAL	1350
	CP=P1-BP*Y3	WAL	1360
	CRO=RO1-BR0*Y3	WAL	1370
	IF (CHECK.EQ.0.0.AND.CAV.EQ.0.0) GO TO 150	WAL	1380

	BQUT=(QUT(L,MDUM)-QUT(L,MDUM1))*DYS	WAL 1390
	BQVT=(QVT(L,MDUM)-QVT(L,MDUM1))*DYS	WAL 1400
	BQPT=(QPT(L,MDUM)-QPT(L,MDUM1))*DYS	WAL 1410
	BQROT=(QROT(L,MDUM)-QROT(L,MDUM1))*DYS	WAL 1420
	CQUT=QUT(L,MDUM)-BQUT*Y3	WAL 1430
	CQVT=QVT(L,MDUM)-BQVT*Y3	WAL 1440
	CQPT=QPT(L,MDUM)-BQPT*Y3	WAL 1450
	CQROT=QROT(L,MDUM)-BQROT*Y3	WAL 1460
C		WAL 1470
C	CALCULATE THE CROSS DERIVATIVE INTERPOLATING POLYNOMIAL	WAL 1480
C	COEFFICIENTS	WAL 1490
C		WAL 1500
150	DU=(U1-U(L1MN1))*DXR	WAL 1510
	DV=(V1-V(L1MN1))*DXR	WAL 1520
	DP=(P1-P(L1MN1))*DXR	WAL 1530
	DRO=(RO1-RO(L1MN1))*DXR	WAL 1540
	DU1=(U(L1MN1)-U(L1MN1))*DXR	WAL 1550
	DV1=(V(L1MN1)-V(L1MN1))*DXR	WAL 1560
	DP1=(P(L1MN1)-P(L1MN1))*DXR	WAL 1570
	DRO1=(RO(L1MN1)-RO(L1MN1))*DXR	WAL 1580
	BDU=(DU-DU1)*DYS	WAL 1590
	BDV=(DV-DV1)*DYS	WAL 1600
	BDP=(DP-DP1)*DYS	WAL 1610
	BDRO=(DRO-DRO1)*DYS	WAL 1620
	CDU=DU-BDU*Y3	WAL 1630
	CDV=DV-BDV*Y3	WAL 1640
	CDP=DP-BDP*Y3	WAL 1650
	CDRO=DRO-BDRO*Y3	WAL 1660
C		WAL 1670
C	CALCULATE Y2	WAL 1680
C		WAL 1690
	ALS=SQRT(AL*AL+BE*BE)	WAL 1700
	UV3=U3*AL+V3*BE+DE	WAL 1710
	DO 170 ILL=1,3	WAL 1720
	UV2=U2*AL+V2*BE+DE	WAL 1730
	Y2=Y3-(UV2+SIGN*ALS*A2+UV3+SIGN*ALS*A3)*DT*0.5	WAL 1740
C		WAL 1750
C	INTERPOLATE FOR THE PROPERTIES	WAL 1760
C		WAL 1770
	U2=BU*Y2+CU	WAL 1780
	V2=BV*Y2+CV	WAL 1790
	P2=BP*Y2+CP	WAL 1800
	RO2=BRO*Y2+CRO	WAL 1810
	CALL EOS (1,P2,RO2,T,AD,D2,D3)	WAL 1820
	IF (AD.GT.0.0) GO TO 160	WAL 1830
	WRITE (6,520) N,L,MDUM	WAL 1840
	IERR=1	WAL 1850
	RETURN	WAL 1860
160	A2=SQRT(AD)	WAL 1870
170	CONTINUE	WAL 1880
	IF (CHECK.EQ.0.0.AND.CAV.EQ.0.0) GO TO 180	WAL 1890
	QUT2=BQUT*Y2+CQUT	WAL 1900
	QVT2=BQVT*Y2+CQVT	WAL 1910
	QPT2=BQPT*Y2+CQPT	WAL 1920
	QROT2=BQROT*Y2+CQROT	WAL 1930
C		WAL 1940
C	INTERPOLATE FOR THE CROSS DERIVATIVES	WAL 1950
C		WAL 1960
180	DU1=DU	WAL 1970
	DV1=DV	WAL 1980
	DP1=DP	WAL 1990
	DRO1=DRO	WAL 2000
	DU2=BDU*Y2+CDU	WAL 2010
	DV2=BDV*Y2+CDV	WAL 2020
	DP2=BDP*Y2+CDP	WAL 2030
	DRO2=BDRO*Y2+CDRO	WAL 2040
C		WAL 2050
C	CALCULATE THE PSI TERMS	WAL 2060
C		WAL 2070

	IF (NDIM, EQ, 0) GO TO 210	WAL 2080
	IF (IB, EQ, 2) GO TO 190	WAL 2090
	ATERM2=R02*V2/(YCB(L)+Y2/BE)	WAL 2100
	GO TO 210	WAL 2110
190	IF (YCB(L), EQ, 0.0) GO TO 200	WAL 2120
	ATERM2=R02*V2/(YCB(L)+Y2/BE)	WAL 2130
	GO TO 210	WAL 2140
200	ATERM2=R02*V(L, 2, N1)*DVR*BE	WAL 2150
210	PSI21=-U1*DU1*DP1/R01	WAL 2160
	PSI31=-U1*DV1	WAL 2170
	PSI41=-U1*DP1+A1*A1*U1*DR01	WAL 2180
	PSI12=-U2*DR02-R02*DU2=ATERM2	WAL 2190
	PSI22=-U2*DU2*DP2/R02	WAL 2200
	PSI32=-U2*DV2	WAL 2210
	PSI42=-U2*DP2+A2*A2*U2*DR02	WAL 2220
	IF (ICHR, EQ, 1) GO TO 240	WAL 2230
C		WAL 2240
C	CALCULATE THE CROSS DERIVATIVES AT THE SOLUTION POINT	WAL 2250
C		WAL 2260
	IF (JFLAG, EQ, 0) GO TO 220	WAL 2270
	IF (IB, NE, 1) GO TO 220	WAL 2280
	IF (L, EQ, 2) GO TO 220	WAL 2290
	IF (L, NE, LJET=1) GO TO 220	WAL 2300
	GO TO 230	WAL 2310
220	DU3=(U(L1MN3)-U3)*DXR	WAL 2320
	DV3=(V(L1MN3)-V3)*DXR	WAL 2330
	DP3=(P(L1MN3)-P3)*DXR	WAL 2340
	DR03=(RO(L1MN3)-R03)*DXR	WAL 2350
	GO TO 240	WAL 2360
230	DU3=(U3-U(L=1, MDUM, N3))*DXR	WAL 2370
	DV3=(V3-V(L=1, MDUM, N3))*DXR	WAL 2380
	DP3=(P3-P(L=1, MDUM, N3))*DXR	WAL 2390
	DR03=(R03-RO(L=1, MDUM, N3))*DXR	WAL 2400
C		WAL 2410
C	ENTER THE FREE-JET BOUNDARY ITERATION LOOP	WAL 2420
C		WAL 2430
240	YW(L)=YW(L)	WAL 2440
	DO 300 NJ=1, 10	WAL 2450
	IF (ICHR, EQ, 1) GO TO 340	WAL 2460
	IF (JFLAG, LE, 0) GO TO 300	WAL 2470
	IF (IB, NE, 1) GO TO 300	WAL 2480
	IF (L, LT, LJET) GO TO 300	WAL 2490
	IF (NJ, EQ, 1) GO TO 290	WAL 2500
	IF (NJ, GT, 2) GO TO 270	WAL 2510
250	YWOLD=YW(L)	WAL 2520
	POLD=P(LMN3)	WAL 2530
	IF (P(LMN3), LT, PE(MMAX)) GO TO 260	WAL 2540
	YW(L)=YW(L)+DELY	WAL 2550
	GO TO 280	WAL 2560
260	YW(L)=YW(L)-DELY	WAL 2570
	GO TO 280	WAL 2580
270	IF (P(LMN3), EQ, POLD) GO TO 250	WAL 2590
	DYDP=(YW(L)-YWOLD)/(P(LMN3)-POLD)	WAL 2600
	YWNEW=YW(L)+DYDP*(PE(MMAX)-P(LMN3))	WAL 2610
	YWOLD=YW(L)	WAL 2620
	POLD=P(LMN3)	WAL 2630
	YW(L)=YWNEW	WAL 2640
280	IF (YW(L), LT, (1.0-DYW)*YWOLD) YW(L)=(1.0-DYW)*YWOLD	WAL 2650
	IF (YW(L), GT, (1.0+DYW)*YWOLD) YW(L)=(1.0+DYW)*YWOLD	WAL 2660
290	NXNY(L)=-((YW(L)-YW(L=1))*DXR	WAL 2670
	XWI(L)=(YW(L)-YWI(L))/DT	WAL 2680
	XWID=XWI(L)	WAL 2690
	CALL MAP (1, L, MMAX, AL, BE, DE, LD1, AL1, BE1, DE1)	WAL 2700
	ALS=SQRT(AL*AL+BE*BE)	WAL 2710
C		WAL 2720
C	CALCULATE THE PSI TERMS AT THE SOLUTION POINT	WAL 2730
C		WAL 2740
300	IF (NDIM, EQ, 0) GO TO 330	WAL 2750
	IF (IB, EQ, 2) GO TO 310	WAL 2760
	ATERM3=R03*V3/(YCB(L)+1.0/BE)	WAL 2770

	GO TO 330	WAL 2780
310	IF (YCB(L),EQ,0,0) GO TO 320	WAL 2790
	ATERM3=RO3*V3/YCB(L)	WAL 2800
	GO TO 330	WAL 2810
320	ATERM3=RO3*V(L,2,N3)*DYR*BE	WAL 2820
330	PSI13=U3*DR03=RO3*DU3-ATERM3	WAL 2830
	PSI23=U3*DU3-DP3/RO3	WAL 2840
	PSI33=U3*DV3	WAL 2850
	PSI43=U3*DP3+A3*A3*U3*DR03	WAL 2860
340	ABR=NXNY(L)	WAL 2870
	IF (IB,EQ,2) ABR=NXNYCB(L)	WAL 2880
	ALB=AL/ALS	WAL 2890
	BEB=BE/ALS	WAL 2900
	A1B=(A1+A3)*0.5	WAL 2910
	A2B=(A2+A3)*0.5	WAL 2920
	RO2B=(RO2+RO3)*0.5	WAL 2930
	IF (ICHR,EQ,1) GO TO 350	WAL 2940
	PSI21B=(PSI21+PSI23)*0.5+QUT(L,MDUM)	WAL 2950
	PSI31B=(PSI31+PSI33)*0.5+QVT(L,MDUM)	WAL 2960
	PSI41B=(PSI41+PSI43)*0.5+QPT(L,MDUM)	WAL 2970
	PSI12B=(PSI12+PSI13+QROT(L,MDUM)+QROT2)*0.5	WAL 2980
	PSI22B=(PSI22+PSI23+QUT(L,MDUM)+QUT2)*0.5	WAL 2990
	PSI32B=(PSI32+PSI33+QVT(L,MDUM)+QVT2)*0.5	WAL 3000
	PSI42B=(PSI42+PSI43+QPT(L,MDUM)+QPT2)*0.5	WAL 3010
	GO TO 360	WAL 3020
350	PSI21B=PSI21+QUT(L,MDUM)	WAL 3030
	PSI31B=PSI31+QVT(L,MDUM)	WAL 3040
	PSI41B=PSI41+QPT(L,MDUM)	WAL 3050
	PSI12B=PSI12+QROT2	WAL 3060
	PSI22B=PSI22+QUT2	WAL 3070
	PSI32B=PSI32+QVT2	WAL 3080
	PSI42B=PSI42+QPT2	WAL 3090
C		WAL 3100
C	SOLVE THE COMPATIBILITY EQUATIONS FOR FREE-SLIP WALLS	WAL 3110
C		WAL 3120
360	U(LMN3)=(U1-ABR*(V1-XWID)+(PSI21B-ABR*PSI31B)*DT)/(1.0+ABR*ABR)	WAL 3130
	V(LMN3)=U(LMN3)*ABR+XWID	WAL 3140
	P(LMN3)=P2-SIGN*RO2B*A2B*(ALB*(U(LMN3)-U2)+REB*(V(LMN3)-V2))+	WAL 3150
	1 (PSI42B+A2B*A2B*PSI12B+SIGN*RO2B*A2B*(ALB*PSI22B+REB*PSI32B))*DT	WAL 3160
	IF (P(LMN3),LE,0,0) P(LMN3)=PLOW*PC	WAL 3170
	RO(LMN3)=RO1+(P(LMN3)-P1=PSI41B*DT)/(A1B+A1B)	WAL 3180
	IF (RO(LMN3),LE,0,0) RO(LMN3)=ROLOW/G	WAL 3190
	IF (IB,NE,1) GO TO 370	WAL 3200
	IF (TW(1),LT,0,0) GO TO 380	WAL 3210
	IF (JFLAG,EQ,1,AND,L,GE,LJET) GO TO 380	WAL 3220
	CALL EOS (3,P(LMN3),RO(LMN3),TW(L),AS,D2,D3)	WAL 3230
	GO TO 380	WAL 3240
370	IF (YCB(1),LT,0,0) GO TO 380	WAL 3250
	CALL EOS (3,P(LMN3),RO(LMN3),TCB(L),AS,D2,D3)	WAL 3260
C		WAL 3270
380	IF (JFLAG,EQ,0) GO TO 510	WAL 3280
	IF (IB,NE,1) GO TO 510	WAL 3290
	IF (L,LT,LJET=1) GO TO 510	WAL 3300
	IF (L,EQ,LJET=1) GO TO 400	WAL 3310
	IF (ICHR,EQ,1) GO TO 510	WAL 3320
	IF (JFLAG,EQ,-1,AND,L,NE,LJET) GO TO 510	WAL 3330
	IF (JFLAG,EQ,-1,AND,L,EQ,LJET) GO TO 500	WAL 3340
	DELP=ABS((P(LMN3)-PE(MMAX))/PE(MMAX))	WAL 3350
	IF (DELP,LE,0,001,AND,L,NE,LJET) GO TO 510	WAL 3360
	IF (DELP,LE,0,001,AND,L,EQ,LJET) GO TO 500	WAL 3370
390	CONTINUE	WAL 3380
	IF (L,EQ,LJET) GO TO 500	WAL 3390
	GO TO 510	WAL 3400
C		WAL 3410
C	SOLVE FOR THE DOWNSTREAM SIDE OF THE WALL EXIT POINT FOR	WAL 3420
C	EITHER SHARP EXPANSION CORNER CASE, UNDER-EXPANDED FREE-JET	WAL 3430
C	CASE OR OVER-EXPANDED FREE-JET CASE	WAL 3440
C		WAL 3450
400	UD(3)=U(LMN3)	WAL 3460

	VD(3)=V(LMN3)	WAL 3470
	PD(3)=P(LMN3)	WAL 3480
	ROD(3)=RO(LMN3)	WAL 3490
	PD(4)=PE(MMAX)	WAL 3500
	CALL EOS (5,PD(3),ROD(3),TD,AS,D2,D3)	WAL 3510
	XM1=SQRT((UD(3)*UD(3)+VD(3)*VD(3))/AS)	WAL 3520
	CALL EOS (9,PD(3),ROD(3),TD,PTD,TTD,XM1)	WAL 3530
C		WAL 3540
C	SHARP EXPANSION CORNER CASE	WAL 3550
C		WAL 3560
	IF (JFLAG,NE.=1) GO TO 440	WAL 3570
	CALL EOS (13,PD(3),ROD(3),TD,B,D2,D3)	WAL 3580
	C1=XM1*XM1-1.0	WAL 3590
	PMA1=B*ATAN(SQRT(C1/(B*B)))-ATAN(SQRT(C1))	WAL 3600
	PMA=ATAN(-NXNY(LJET))-ATAN(-NXNY(LJET=1))	WAL 3610
	PMAD=PMA+PMA1	WAL 3620
	XM2=2.0*XM1	WAL 3630
	DO 420 I=1,10	WAL 3640
	CI=XM2*XM2-1.0	WAL 3650
	PMAI=B*ATAN(SQRT(CI/(B*B)))-ATAN(SQRT(CI))	WAL 3660
	IF (ABS((PMAI-PMAD)/PMAD).LE.0.0001) GO TO 430	WAL 3670
	IF (I.NE.1) GO TO 410	WAL 3680
	XM0=XM2	WAL 3690
	XM2=0.9*XM2	WAL 3700
	PMA0=PMAI	WAL 3710
	GO TO 420	WAL 3720
410	DMDA=(XM2-XM0)/(PMAI-PMA0)	WAL 3730
	XM0=XM2	WAL 3740
	XM2=XM2+DMDA*(PMAD-PMAI)	WAL 3750
	PMA0=PMAI	WAL 3760
420	CONTINUE	WAL 3770
430	CALL EOS (8,PD(4),ROD(4),TD,PTD,TTD,XM2)	WAL 3780
	CALL EOS (4,PD(4),ROD(4),TD,AS,D2,D3)	WAL 3790
	GO TO 470	WAL 3800
		WAL 3810
C		WAL 3820
C	UNDER-EXPANDED FREE-JET CASE	WAL 3830
C		WAL 3840
440	IF (PE(MMAX).GT.PD(3).AND.XM1.GE.1.0) GO TO 450	WAL 3850
	CALL EOS (11,PE(MMAX),ROD(4),TD,PD(3),ROD(3),D3)	WAL 3860
	GO TO 460	WAL 3870
		WAL 3880
C		WAL 3890
C	OVER-EXPANDED FREE-JET CASE	WAL 3900
C		WAL 3910
450	CALL EOS (12,PE(MMAX),ROD(4),TD,PD(3),ROD(3),D3)	WAL 3920
460	CALL EOS (2,PE(MMAX),ROD(4),TE,AS,D2,D3)	WAL 3930
	CALL EOS (10,PE(MMAX),ROD(4),TE,PTD,TTD,XM2)	WAL 3940
470	CALL EOS (1,PD(4),ROD(4),T,AS,D2,D3)	WAL 3950
	VMAG=XM2*SQRT(AS)	WAL 3960
	UD(4)=VMAG/SQRT(1.0+NXNY(LJET)*NXNY(LJET))	WAL 3970
	VD(4)=UD(4)*NXNY(LJET)	WAL 3980
	IF (JFLAG.EQ.=1) GO TO 510	WAL 3990
	IF (XM1.GE.1.0) GO TO 510	WAL 4000
		WAL 4010
C		WAL 4020
C	AVERAGE THE 1=SIDED MACH NOS FOR THE INTERIOR POINT CALCULATIONS	WAL 4030
C	IF THE UPSTREAM FLOW IS SUBSONIC = FREE-JET CASE	WAL 4040
C		WAL 4050
	XMB=(XM1+XM2)/2.0	WAL 4060
	IF (XMB.GE.1.0) GO TO 480	WAL 4070
	DPL=1.0	WAL 4080
	DPR=1.0	WAL 4090
	GO TO 490	WAL 4100
480	DPL=XM2-1.0	WAL 4110
	DPR=1.0-XM1	WAL 4120
	XMB=1.0	WAL 4130
490	DPLR=DPR+DPL	WAL 4140
	CALL EOS (8,P(LMN3),RO(LMN3),TEMP,PTD,TTD,XMB)	WAL 4150
	CALL EOS (6,P(LMN3),RO(LMN3),TEMP,AS,D2,D3)	WAL 4160
	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	WAL 4170
	GO TO 510	WAL 4180
500	UD(1)=UD(3)	WAL 4190
	VD(1)=VD(3)	WAL 4200
	PD(1)=PD(3)	WAL 4210
	ROD(1)=ROD(3)	WAL 4220
	UD(2)=UD(4)	WAL 4230
	VD(2)=VD(4)	WAL 4240
	PD(2)=PD(4)	WAL 4250
	ROD(2)=ROD(4)	WAL 4260
510	CONTINUE	WAL 4270
	IF (JFLAG.EQ.0) RETURN	WAL 4280
	IF (IB.EQ.2) RETURN	WAL 4290
	IF (ICAR.EQ.1) RETURN	WAL 4300
	U(LJET=1,MMAX,N1)=UOLD	WAL 4310
	IF (JFLAG.EQ.=1) RETURN	WAL 4320
	YWI(LMAX)=YW(LMAX)	WAL 4330
	YW(LMAX)=2.0*YW(L1)-YW(L2)	WAL 4340
	NXNY(LMAX)=(YW(LMAX)-YW(L1))*DXR	WAL 4350
	XWI(LMAX)=(YW(LMAX)-YWI(LMAX))/DT	WAL 4360
	RETURN	WAL 4370
C		WAL 4380
C	FORMAT STATEMENTS	WAL 4390
C		WAL 4400
520	FORMAT (1H0,61H***** A NEGATIVE SQUARE ROOT OCCURED IN SUBROUTINE	WAL 4410
	1WALL AT N=,I4,4H, L=,I2,8H, AND M=,I2,6H *****)	WAL 4420
	END	WAL 4430

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*DECK, INLET
SUBROUTINE INLET
C
C *****
C THIS SUBROUTINE CALCULATES THE BOUNDARY MESH POINTS AT THE
C INLET FOR SUBSONIC FLOW
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 (NGCR.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=SQR(AS)
IF (ICAR.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

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INL 10
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INL 660
INL 670
INL 680
INL 690
INL 700

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	DU1=(U(LMN1)-U(LM1N1))*DYR	INL 710
	DV1=(V(LMN1)-V(LM1N1))*DYR	INL 720
	DP1=(P(LMN1)-P(LM1N1))*DYR	INL 730
	DRO1=(RO(LMN1)-RO(LM1N1))*DYR	INL 740
	GO TO 70	INL 750
50	IF (NGCB.NE.0) GO TO 60	INL 760
	DU=0.0	INL 770
	DV=(4.0*V(2,2,N1)-V(2,3,N1))*0.5*DYR	INL 780
	DP=0.0	INL 790
	DRO=0.0	INL 800
	DU1=0.0	INL 810
	DV1=(4.0*V(1,2,N1)-V(1,3,N1))*0.5*DYR	INL 820
	DP1=0.0	INL 830
	DRO1=0.0	INL 840
	GO TO 70	INL 850
60	DU=(U(2,2,N1)-U(2,1,N1))*DYR	INL 860
	DV=(V(2,2,N1)-V(2,1,N1))*DYR	INL 870
	DP=(P(2,2,N1)-P(2,1,N1))*DYR	INL 880
	DRO=(RO(2,2,N1)-RO(2,1,N1))*DYR	INL 890
	DU1=(U(1,2,N1)-U(1,1,N1))*DYR	INL 900
	DV1=(V(1,2,N1)-V(1,1,N1))*DYR	INL 910
	DP1=(P(1,2,N1)-P(1,1,N1))*DYR	INL 920
	DRO1=(RO(1,2,N1)-RO(1,1,N1))*DYR	INL 930
70	BDU=(DU-DU1)*DXR	INL 940
	BDV=(DV-DV1)*DXR	INL 950
	BDP=(DP-DP1)*DXR	INL 960
	BDRO=(DRO-DRO1)*DXR	INL 970
	CDU=DU1-RDU*X3	INL 980
	CDV=DV1-BDV*X3	INL 990
	CDP=DP1-BDP*X3	INL 1000
	CDRO=DRO1-BDRO*X3	INL 1010
C		INL 1020
C	CALCULATE X2	INL 1030
C		INL 1040
	IF (ICHR.EQ.1) GO TO 80	INL 1050
	CALL EOS (1,P(LMN3),RO(LMN3),T,AS,D2,D3)	INL 1060
	A3=SQRT(AS)	INL 1070
80	DO 90 IL=1,2	INL 1080
	X2=X3-(U(1,M,N3)-A3+U2-A2)*0.5*DT	INL 1090
C		INL 1100
C	INTERPOLATE FOR THE PROPERTIES	INL 1110
C		INL 1120
	U2=BU*X2+CU	INL 1130
	P2=BP*X2+CP	INL 1140
	RO2=BRO*X2+CRO	INL 1150
	CALL EOS (1,P2,RO2,T,AS,D2,D3)	INL 1160
	A2=SQRT(AS)	INL 1170
90	CONTINUE	INL 1180
	V2=BV*X2+CV	INL 1190
	YCB2=BYCB*X2+CYCB	INL 1200
	AL2=BAL*X2+CAL	INL 1210
	BE2=BBE*X2+CBE	INL 1220
	UV2=U2*AL2+V2*BE2	INL 1230
C		INL 1240
C	INTERPOLATE FOR THE CROSS DERIVATIVES	INL 1250
C		INL 1260
	DU2=BDU*X2+CDU	INL 1270
	DV2=BDV*X2+CDV	INL 1280
	DP2=BDP*X2+CDP	INL 1290
	DRO2=BDRO*X2+CDRO	INL 1300
C		INL 1310
C	CALCULATE THE PSI TERMS	INL 1320
C		INL 1330
	IF (NDIM.EQ.0) GO TO 110	INL 1340
	IF (M.EQ.1.AND.YCB(1).EQ.0.0) GO TO 100	INL 1350
	ATERM2=RO2*V2/(DY*FLOAT(M-1)/BE2+YCB2)	INL 1360
	GO TO 110	INL 1370
100	ATERM2=RO2*BE2*DV2	INL 1380
110	PSI12=UV2*DRO2-RO2*AL2*DU2-RO2*BE2*DV2-ATERM2	INL 1390
	PSI22=UV2*DU2-AL2*DP2/RO2	INL 1400

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PSI42=UV2*OP2+A2*A2*UV2*DROP INL 1410
IF (ICAR, EQ, 1) GO TO 170 INL 1420
C INL 1430
C CALCULATE THE CROSS DERIVATIVES AT THE SOLUTION POINT INL 1440
C INL 1450
IF (M, EQ, 1, AND, NGCB, EQ, 0) GO TO 120 INL 1460
IF (M, EQ, MMAX) GO TO 130 INL 1470
DU3=(U(LMN3)-U(LMN3))*DYS INL 1480
DV3=(V(LMN3)-V(LMN3))*DYS INL 1490
DP3=(P(LMN3)-P(LMN3))*DYS INL 1500
DRO3=(RO(LMN3)-RO(LMN3))*DYS INL 1510
GO TO 140 INL 1520
120 DU3=0.0 INL 1530
DV3=(4.0*V(1,2,N3)-V(1,3,N3))*0.5*DYS INL 1540
DP3=0.0 INL 1550
DRO3=0.0 INL 1560
GO TO 140 INL 1570
130 DU3=(U(1,MMAX,N3)-U(1,M1,N3))*DYS INL 1580
DV3=(V(1,MMAX,N3)-V(1,M1,N3))*DYS INL 1590
DP3=(P(1,MMAX,N3)-P(1,M1,N3))*DYS INL 1600
DRO3=(RO(1,MMAX,N3)-RO(1,M1,N3))*DYS INL 1610
C INL 1620
C CALCULATE THE PSI TERMS AT THE SOLUTION POINT INL 1630
C INL 1640
140 IF (NDIM, EQ, 0) GO TO 160 INL 1650
IF (M, EQ, 1, AND, YCB(1), EQ, 0.0) GO TO 150 INL 1660
ATERM3=RO(LMN3)*V(LMN3)/(DY+FLOAT(M-1)/RE+YCB(1)) INL 1670
GO TO 160 INL 1680
150 ATERM3=RO(LMN3)*BE*DV3 INL 1690
160 UV3=U(LMN3)*AL+V(LMN3)*BE INL 1700
PSI13=UV3*DRO3-RO(LMN3)*AL*DU3-RO(LMN3)*BE*DV3-ATERM3 INL 1710
PSI23=UV3*DU3-AL*DP3/RO(LMN3) INL 1720
PSI43=UV3*OP3+A3*A3*UV3*DRO3 INL 1730
GO TO 180 INL 1740
170 PSI23=PSI22 INL 1750
PSI43=PSI42 INL 1760
PSI13=PSI12 INL 1770
180 PSI1B=0.5*(PSI12+PSI13) INL 1780
PSI2B=0.5*(PSI22+PSI23) INL 1790
PSI4B=0.5*(PSI42+PSI43) INL 1800
C INL 1810
C SOLVE THE COMPATIBILITY EQUATION FOR P INL 1820
C INL 1830
IF (ISUPER, EQ, 0) GO TO 190 INL 1840
ROAB=0.5*(RO2*A2+RO(LMN3)*A3) INL 1850
AB=0.5*(A2+A3) INL 1860
P(LMN3)=P2+ROAB*(U(LMN3)-U2)+(PSI4B-ROAB*PSI2B+AB*AB*PSI1B)*DT INL 1870
GO TO 240 INL 1880
C INL 1890
C SOLVE THE COMPATIBILITY EQUATIONS FOR U, V, P, AND RO INL 1900
C INL 1910
190 MN3=SQRT(U(LMN3)*U(LMN3)+V(LMN3)*V(LMN3))/A3 INL 1920
CALL EOS (2,P2,RO2,T2,AS,D2,D3) INL 1930
TTHEA=TAN(THETA(M)) INL 1940
UCORR=1.0 INL 1950
IF (NOSLIP, EQ, 0) GO TO 200 INL 1960
IF (M, EQ, MMAX) UCORR=0.0 INL 1970
IF (M, EQ, 1, AND, NGCB, NE, 0) UCORR=0.0 INL 1980
C INL 1990
200 DO 220 ITER=1,20 INL 2000
CALL EOS (6,P(LMN3),RO(LMN3),T3,PT(M),TT(M),MN3) INL 2010
IF (M, EQ, MMAX, AND, TW(1), GT, 0.0) T3=TW(1) INL 2020
IF (M, EQ, 1, AND, TCB(1), GT, 0.0) T3=TCB(1) INL 2030
PB=(P2+P(LMN3))*0.5 INL 2040
TB=(T2+T3)*0.5 INL 2050
CALL EOS (6,PB,ROB,TB,AS,D2,D3) INL 2060
U(LMN3)=U2+DT*PSI2B+(P(LMN3)-P2-(PSI4B+AS*PSI1B)*DT)/(ROB*SQRT(AS)) INL 2070
1 ) INL 2080
U(LMN3)=U(LMN3)*UCORR INL 2090
V(LMN3)=U(LMN3)*TTHEA INL 2100

```

	OMN3=MN3	INL 2110
	CALL EOS (7,PB,ROB,T3,AS,D2,D3)	INL 2120
	MN3=SQRT((U(LMN3)*U(LMN3)+V(LMN3)*V(LMN3))/AS)	INL 2130
	IF (OMN3.NE.0.0) GO TO 210	INL 2140
	IF (ABS(MN3-OMN3).LE.0.0001) GO TO 230	INL 2150
	GO TO 220	INL 2160
	210 IF (ABS((MN3-OMN3)/OMN3).LE.0.001) GO TO 230	INL 2170
	220 CONTINUE	INL 2180
C		INL 2190
	WRITE (6,250) M,N	INL 2200
	230 CALL EOS (4,P(LMN3),RO(LMN3),T3,AS,D2,D3)	INL 2210
	240 CONTINUE	INL 2220
	RETURN	INL 2230
C		INL 2240
C	FORMAT STATEMENTS	INL 2250
C		INL 2260
	250 FORMAT (1H0,55H***** THE SOLUTION FOR THE ENTRANCE BOUNDARY POINT	INL 2270
	1(1,,I2,1H,,I4,43H) FAILED TO CONVERGE IN 20 ITERATIONS *****)	INL 2280
	END	INL 2290

```

*DECK,EXITT                                EXT 10
  SUBROUTINE EXITT                          EXT 20
C                                             EXT 30
C *****                                  EXT 40
C THIS SUBROUTINE CALCULATES THE BOUNDARY MESH POINTS AT THE EXIT EXT 50
C *****                                  EXT 60
C *****                                  EXT 70
C *****                                  EXT 80
C *****                                  EXT 90
*CALL,MCC                                    EXT 100
  X3=XE                                       EXT 110
  ATERM2=ATERM3=0.0                          EXT 120
  DO 100 M=1,MMAX                            EXT 130
  IF (IEXTRA,EQ.1) GO TO 10                  EXT 140
  CALL EOS (1,P(LMAX,M,N1),RO(LMAX,M,N1),T,AS,D2,D3) EXT 150
  A1=SORT(AS)                                EXT 160
  IF (IEXTRA,EQ.2) GO TO 20                 EXT 170
  Q=SQRT(U(LMAX,M,N1)*U(LMAX,M,N1)+V(LMAX,M,N1)*V(LMAX,M,N1)) EXT 180
  IF (Q/A1,LT.1.0) GO TO 20                 EXT 190
10 U(LMAX,M,N3)=U(L1,M,N3)+FLOAT(IEX)*(U(L1,M,N3)-U(L2,M,N3)) EXT 200
  V(LMAX,M,N3)=V(L1,M,N3)+FLOAT(IEX)*(V(L1,M,N3)-V(L2,M,N3)) EXT 210
  P(LMAX,M,N3)=P(L1,M,N3)+FLOAT(IEX)*(P(L1,M,N3)-P(L2,M,N3)) EXT 220
  RO(LMAX,M,N3)=RO(L1,M,N3)+FLOAT(IEX)*(RO(L1,M,N3)-RO(L2,M,N3)) EXT 230
  GO TO 100                                  EXT 240
20 CALL MAP (2,LMAX,M,AL,BE,DE,L1,AL1,BE1,DE1) EXT 250
  U1=U(LMAX,M,N1)                            EXT 260
  U2=U1                                       EXT 270
  A2=A1                                       EXT 280
  IF (ICHR,NE.1) GO TO 30                   EXT 290
  U(LMAX,M,N3)=U1                             EXT 300
  RO(LMAX,M,N3)=RO(LMAX,M,N1)                EXT 310
  A3=A1                                       EXT 320
C                                             EXT 330
C CALCULATE THE PROPERTY INTERPOLATING POLYNOMIAL COEFFICIENTS EXT 340
C                                             EXT 350
30 BU=(U(LMAX,M,N1)-U(L1,M,N1))*DXR          EXT 360
  BV=(V(LMAX,M,N1)-V(L1,M,N1))*DXR          EXT 370
  BP=(P(LMAX,M,N1)-P(L1,M,N1))*DXR          EXT 380
  BRO=(RO(LMAX,M,N1)-RO(L1,M,N1))*DXR       EXT 390
  BYCB=(YCB(LMAX)-YCB(L1))*DXR              EXT 400
  BAL=(AL-AL1)*DXR                          EXT 410
  BBE=(BE-BE1)*DXR                          EXT 420
  BDE=(DE-DE1)*DXR                          EXT 430
  CU=U(LMAX,M,N1)-BU*X3                      EXT 440
  CV=V(LMAX,M,N1)-BV*X3                      EXT 450
  CP=P(LMAX,M,N1)-BP*X3                      EXT 460
  CRO=RO(LMAX,M,N1)-BRO*X3                  EXT 470
  CYCB=YCB(LMAX)-BYCB*X3                   EXT 480
  CAL=AL-BAL*X3                             EXT 490
  CBE=BE-BBE*X3                             EXT 500
  CDE=DE-BDE*X3                             EXT 510
C                                             EXT 520
C CALCULATE THE CROSS DERIVATIVE INTERPOLATING POLYNOMIAL EXT 530
C COEFFICIENTS                               EXT 540
C                                             EXT 550
  IF (M,EQ.1) GO TO 40                      EXT 560
  DU=(U(LMAX,M,N1)-U(LMAX,M-1,N1))*DYR      EXT 570
  DV=(V(LMAX,M,N1)-V(LMAX,M-1,N1))*DYR      EXT 580
  DP=(P(LMAX,M,N1)-P(LMAX,M-1,N1))*DYR      EXT 590
  DRO=(RO(LMAX,M,N1)-RO(LMAX,M-1,N1))*DYR   EXT 600
  DU1=(U(L1,M,N1)-U(L1,M-1,N1))*DYR         EXT 610
  DV1=(V(L1,M,N1)-V(L1,M-1,N1))*DYR         EXT 620
  DP1=(P(L1,M,N1)-P(L1,M-1,N1))*DYR         EXT 630
  DRO1=(RO(L1,M,N1)-RO(L1,M-1,N1))*DYR      EXT 640
  GO TO 60                                    EXT 650
40 IF (NGCB,NE.0) GO TO 50                  EXT 660
  DU=0.0                                       EXT 670
  DV=(0.0*V(LMAX,2,N1)-V(LMAX,3,N1))*0.5*DYR EXT 680
  DP=0.0                                       EXT 690
  DRO=0.0                                       EXT 700

```

	DU1=0.0	EXT 710
	DV1=(4.0*V(L1,2,N1)-V(L1,3,N1))*0.5*DYR	EXT 720
	DP1=0.0	EXT 730
	DRO1=0.0	EXT 740
	GO TO 60	EXT 750
50	DU=(U(LMAX,2,N1)-U(LMAX,1,N1))*DYR	EXT 760
	DV=(V(LMAX,2,N1)-V(LMAX,1,N1))*DYR	EXT 770
	DP=(P(LMAX,2,N1)-P(LMAX,1,N1))*DYR	EXT 780
	DRO=(RO(LMAX,2,N1)-RO(LMAX,1,N1))*DYR	EXT 790
	DU1=(U(L1,2,N1)-U(L1,1,N1))*DYR	EXT 800
	DV1=(V(L1,2,N1)-V(L1,1,N1))*DYR	EXT 810
	DP1=(P(L1,2,N1)-P(L1,1,N1))*DYR	EXT 820
	DRO1=(RO(L1,2,N1)-RO(L1,1,N1))*DYR	EXT 830
60	BDU=(DU-DU1)*DXR	EXT 840
	BDV=(DV-DV1)*DXR	EXT 850
	BDP=(DP-DP1)*DXR	EXT 860
	BDRO=(DRO-DRO1)*DXR	EXT 870
	CDU=DU-BDU*X3	EXT 880
	CDV=DV-BDV*X3	EXT 890
	CDP=DP-BDP*X3	EXT 900
	CDRO=DRO-BDRO*X3	EXT 910
C		EXT 920
C	CALCULATE X1 AND X2	EXT 930
C		EXT 940
	IF (ICHR,EQ,1) GO TO 70	EXT 950
	CALL EOS (1,P(LMAX,M,N3),RO(LMAX,M,N3),T,AS,D2,D3)	EXT 960
	A3=SQRT(AS)	EXT 970
70	DO 80 IL=1,2	EXT 980
	X1=X3-(U(LMAX,M,N3)+U1)*0.5*DT	EXT 990
	X2=X3-(U(LMAX,M,N3)+A3+U2+A2)*0.5*DT	EXT 1000
C		EXT 1010
C	INTERPOLATE FOR THE PROPERTIES	EXT 1020
C		EXT 1030
	U1=BU*X1+CU	EXT 1040
	U2=BU*X2+CU	EXT 1050
	P1=BP*X1+CP	EXT 1060
	P2=BP*X2+CP	EXT 1070
	RO1=RO*X1+CRO	EXT 1080
	RO2=RO*X2+CRO	EXT 1090
	CALL EOS (1,P2,RO2,T2,AS,D2,D3)	EXT 1100
	A2=SQRT(AS)	EXT 1110
80	CONTINUE	EXT 1120
	V1=BV*X1+CV	EXT 1130
	P1=BP*X1+CP	EXT 1140
	RO1=RO*X1+CRO	EXT 1150
	AL1=BAL*X1+CAL	EXT 1160
	BE1=BBE*X1+CBE	EXT 1170
	DE1=BDE*X1+CDE	EXT 1180
	UV1=U1*AL1+V1*BE1+DE1	EXT 1190
	CALL EOS (1,P1,RO1,T1,AS,D2,D3)	EXT 1200
	A1=SQRT(AS)	EXT 1210
	V2=BV*X2+CV	EXT 1220
	YCB2=BYCB*X2+CYCB	EXT 1230
	AL2=BAL*X2+CAL	EXT 1240
	BE2=BBE*X2+CBE	EXT 1250
	DE2=BDE*X2+CDE	EXT 1260
	UV2=U2*AL2+V2*BE2+DE2	EXT 1270
C		EXT 1280
C	INTERPOLATE FOR THE CROSS DERIVATIVES	EXT 1290
C		EXT 1300
	DV1=BDV*X1+CDV	EXT 1310
	DP1=BDP*X1+CDP	EXT 1320
	DRO1=BDRO*X1+CDRO	EXT 1330
	DU2=BDU*X2+CDU	EXT 1340
	DV2=BDV*X2+CDV	EXT 1350
	DP2=BDP*X2+CDP	EXT 1360
	DRO2=BDRO*X2+CDRO	EXT 1370
C		EXT 1380
C	CALCULATE THE PSI TERMS	EXT 1390
C		EXT 1400
	IF (NDIM,EQ,0) GO TO 100	EXT 1400
	IF (M,EQ,1.AND.YCB(LMAX),EQ,0.0) GO TO 90	EXT 1400

```

    ATERM2=RO2*V2/(DY*FLOAT(M=1)/BE2+YCB2)          EXT 1410
    GO TO 100                                          EXT 1420
90  ATERM2=RO2*BE2*DV2                                EXT 1430
100 PSI31=-UV1*DV1-BE1*DP1/RO1                      EXT 1440
    PSI41=-UV1*DP1+A1*A1*UV1*DRO1                   EXT 1450
    PSI12=-UV2*DRO2=RO2*AL2*DU2=RO2*BE2*DV2-ATEM2  EXT 1460
    PSI22=-UV2*DU2=AL2*DP2/RO2                      EXT 1470
    PSI42=-UV2*DP2+A2*A2*UV2*DRO2                   EXT 1480
    IF (ICAR,EG.1) GO TO 160                          EXT 1490
C
C   CALCULATE THE CROSS DERIVATIVES AT THE SOLUTION POINT
C
    IF (M,EG,1,AND,NGCB,EG,0) GO TO 110              EXT 1500
    IF (M,EG,MMAX) GO TO 120                          EXT 1510
    DU3=(U(LMAX,M+1,N3)-U(LMAX,M,N3))*DYR            EXT 1520
    DV3=(V(LMAX,M+1,N3)-V(LMAX,M,N3))*DYR            EXT 1530
    DP3=(P(LMAX,M+1,N3)-P(LMAX,M,N3))*DYR            EXT 1540
    DRO3=(RO(LMAX,M+1,N3)-RO(LMAX,M,N3))*DYR         EXT 1550
    GO TO 130                                          EXT 1560
110 DU3=0.0                                           EXT 1570
    DV3=(4.0*V(LMAX,2,N3)-V(LMAX,3,N3))*0.5*DYR    EXT 1580
    DP3=0.0                                           EXT 1590
    DRO3=0.0                                          EXT 1600
    GO TO 130                                          EXT 1610
120 DU3=(U(LMAX,MMAX,N3)-U(LMAX,M1,N3))*DYR         EXT 1620
    DV3=(V(LMAX,MMAX,N3)-V(LMAX,M1,N3))*DYR         EXT 1630
    DP3=(P(LMAX,MMAX,N3)-P(LMAX,M1,N3))*DYR         EXT 1640
    DRO3=(RO(LMAX,MMAX,N3)-RO(LMAX,M1,N3))*DYR      EXT 1650
C
C   CALCULATE THE PSI TERMS AT THE SOLUTION POINT
C
130 IF (NDIM,EG,0) GO TO 150                          EXT 1660
    IF (M,EG,1,AND,YCB(LMAX),EG,0,0) GO TO 140      EXT 1670
    ATERM3=RO(LMAX,M,N3)+V(LMAX,M,N3)/(DY*FLOAT(M=1)/RE+YCB(LMAX))
    GO TO 150                                          EXT 1680
140 ATERM3=RO(LMAX,1,N3)+BE*DV3                      EXT 1690
150 UV3=U(LMAX,M,N3)+AL+V(LMAX,M,N3)+RE+DE         EXT 1700
    PSI13=-UV3*DRO3=RO(LMAX,M,N3)*(AL+DU3+BE*DV3)-ATEM3
    PSI23=-UV3*DU3=AL*DP3/RO(LMAX,M,N3)            EXT 1710
    PSI33=-UV3*DV3-BE*DP3/RO(LMAX,M,N3)            EXT 1720
    PSI43=-UV3*DP3+A3*A3*UV3*DRO3                  EXT 1730
    PSI31B=(PSI31+PSI33)*0.5+QVT(LMAX,M)            EXT 1740
    PSI41B=(PSI41+PSI43)*0.5+QPT(LMAX,M)            EXT 1750
    PSI12B=(PSI12+PSI13)*0.5+QROT(LMAX,M)           EXT 1760
    PSI22B=(PSI22+PSI23)*0.5+QUT(LMAX,M)            EXT 1770
    PSI42B=(PSI42+PSI43)*0.5+QPT(LMAX,M)            EXT 1780
    GO TO 170                                          EXT 1790
160 PSI31B=PSI31+QVT(LMAX,M)                         EXT 1800
    PSI41B=PSI41+QPT(LMAX,M)                         EXT 1810
    PSI12B=PSI12+QROT(LMAX,M)                       EXT 1820
    PSI22B=PSI22+QUT(LMAX,M)                         EXT 1830
    PSI42B=PSI42+QPT(LMAX,M)                         EXT 1840
C
C   SOLVE THE COMPATIBILITY EQUATIONS FOR U,V,P, AND RO
C
170 P(LMAX,M,N3)=PE(M)                               EXT 1850
    AB=0.5*(A2+A3)                                    EXT 1860
    ROB=0.5*(RO2+RO(LMAX,M,N3))                     EXT 1870
    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  EXT 1880
    U(LMAX,M,N3)=U2+((PSI42B+ROB*AB*PSI22B+AB*AB*PSI12B)*DT-(P(LMAX,M
    1,N3)-P2))/(ROB*AB)                               EXT 1890
    V(LMAX,M,N3)=V1+DT*PSI31B                       EXT 1900
C
C   CHECK FOR INFLOW AND IF SO SET INFLOW BOUNDARY CONDITIONS
C
    IF (U(LMAX,M,N1).GE.0.0) GO TO 180              EXT 1910
    V(LMAX,M,N3)=0.0                                  EXT 1920
    RO(LMAX,M,N3)=0.5*(RO(LMAX,1,N1)+RO(LMAX,MMAX,N1))
    EXT 1930
180 CONTINUE                                          EXT 1940
    EXT 1950
    EXT 1960
    EXT 1970
    EXT 1980
    EXT 1990
    EXT 2000
    EXT 2010
    EXT 2020
    EXT 2030
    EXT 2040
    EXT 2050
    EXT 2060
    EXT 2070
    EXT 2080
    EXT 2090
    EXT 2100

```

C
C
C

```
      SET BOUNDARY CONDITIONS FOR THE CORNER POINTS                                EXT 2110
      IF (NOSLIP.NE.0) U(LMAX,MMAX,N3)=0.0                                        EXT 2120
      IF (NOSLIP.NE.0.AND,NGCB.NE.0) U(LMAX,1,N3)=0.0                          EXT 2130
      V(LMAX,MMAX,N3)=U(LMAX,MMAX,N3)*NXNY(LMAX)+XWI(LMAX)                     EXT 2140
      V(LMAX,1,N3)=U(LMAX,1,N3)*NXNYCB(LMAX)                                    EXT 2150
      IF (NOSLIP.NE.0) RO(LMAX,MMAX,N3)=RO(L1,MMAX,N3)                         EXT 2160
      IF (NOSLIP.NE.0.AND,NGCB.NE.0) RO(LMAX,1,N3)=RO(L1,1,N3)                EXT 2170
      IF (TW(1).LT.0.0.AND,TCB(1).LT.0.0) RETURN                               EXT 2180
      IF (TW(1).GT.0.0.AND,P(LMAX,MMAX,N3).EQ,PE(MMAX)) CALL EOS (4,P          EXT 2190
1 (LMAX,MMAX,N3),RO(LMAX,MMAX,N3),TW(LMAX),AS,D2,D3)                          EXT 2200
      IF (TCB(1).GT.0.0.AND,P(LMAX,1,N3).EQ,PE(1)) CALL EOS (4,P(LMAX,1      EXT 2210
1 ,N3),RO(LMAX,1,N3),TCB(LMAX),AS,D2,D3)                                       EXT 2220
      IF (TW(1).GT.0.0.AND,P(LMAX,MMAX,N3).NE,PE(MMAX)) CALL EOS (3,P        EXT 2230
1 (LMAX,MMAX,N3),RO(LMAX,MMAX,N3),TW(LMAX),AS,D2,D3)                          EXT 2240
      IF (TCB(1).GT.0.0.AND,P(LMAX,1,N3).NE,PE(1)) CALL EOS (3,P(LMAX,1     EXT 2250
1 ,N3),RO(LMAX,1,N3),TCB(LMAX),AS,D2,D3)                                       EXT 2260
      RETURN                                                                      EXT 2270
      END                                                                          EXT 2280
      EXT 2290
      EXT 2300
```

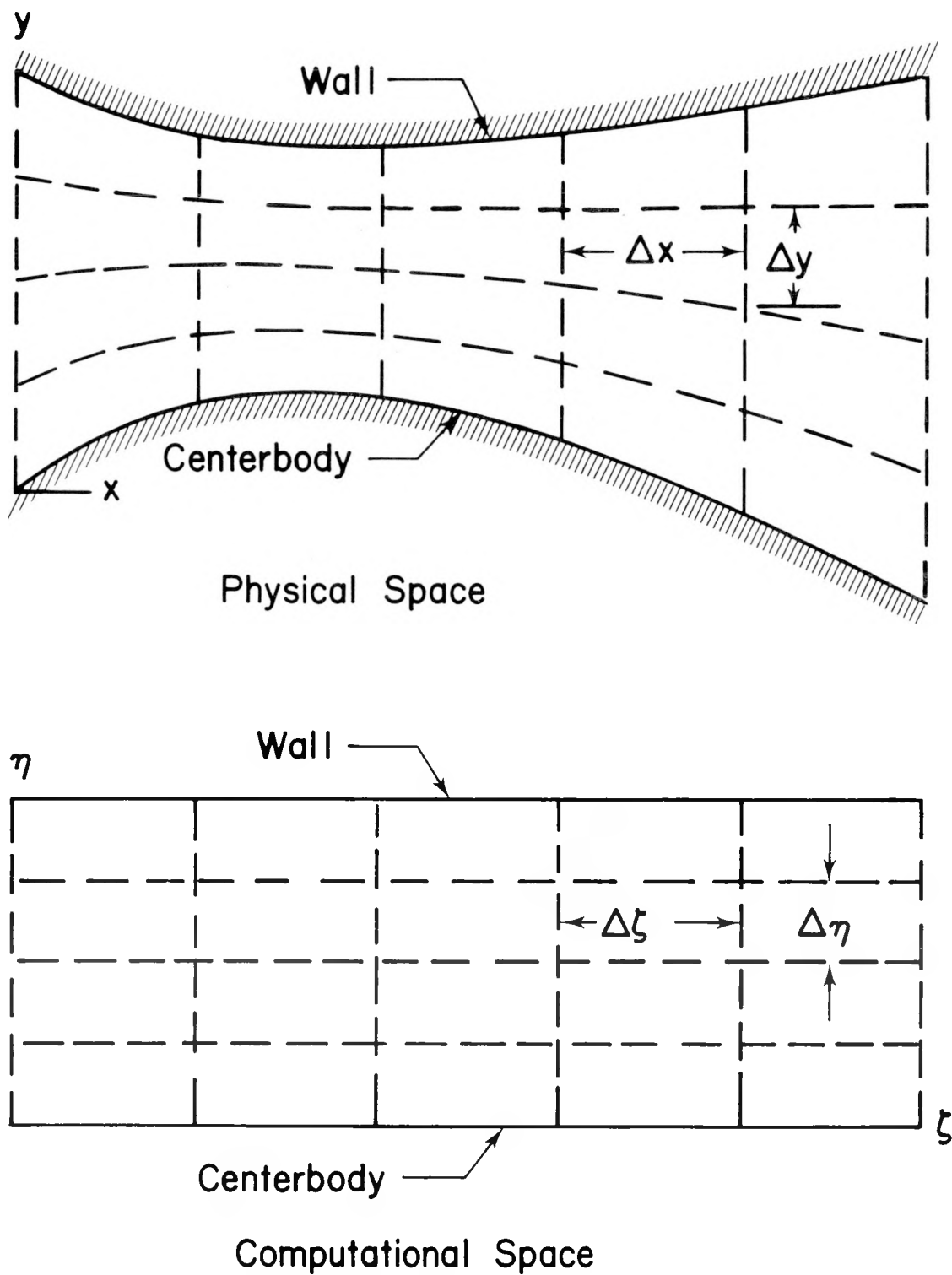


Fig. 1. Physical and computational spaces.

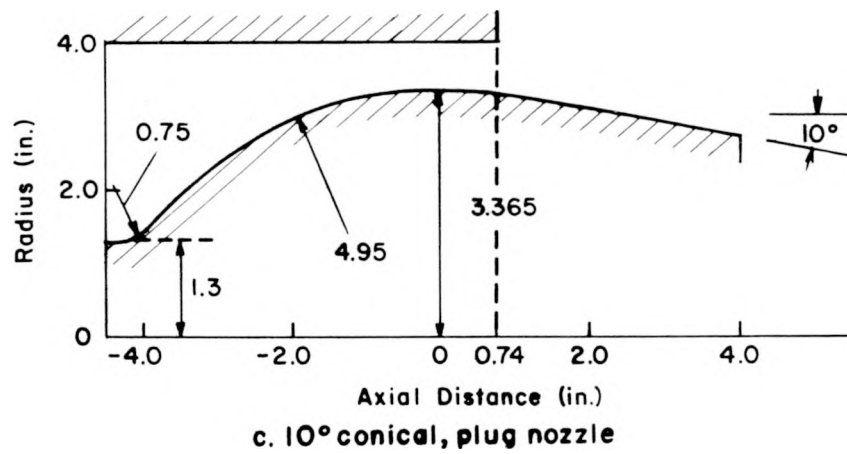
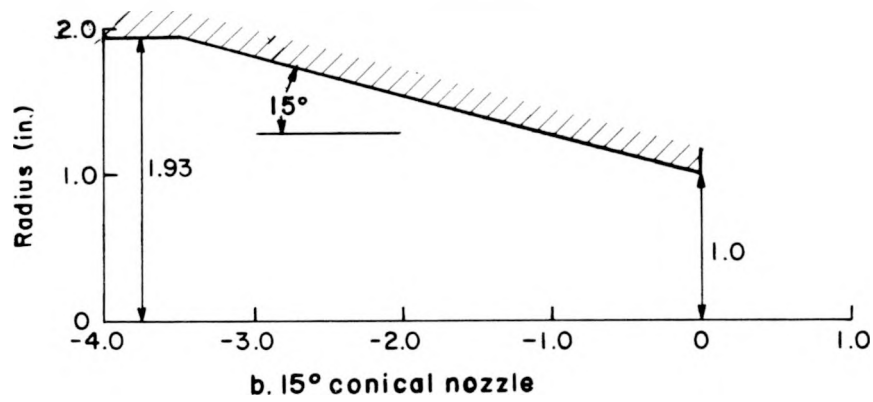
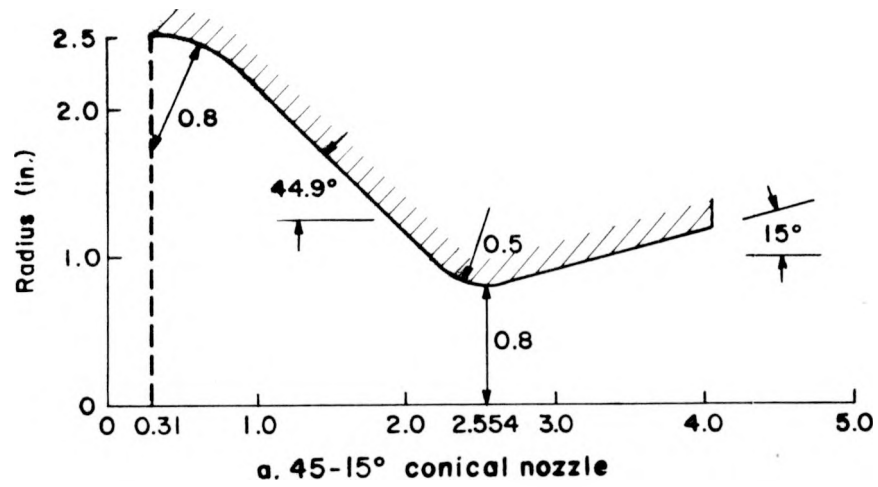


Fig. 2. Nozzle geometries for the inviscid flows.

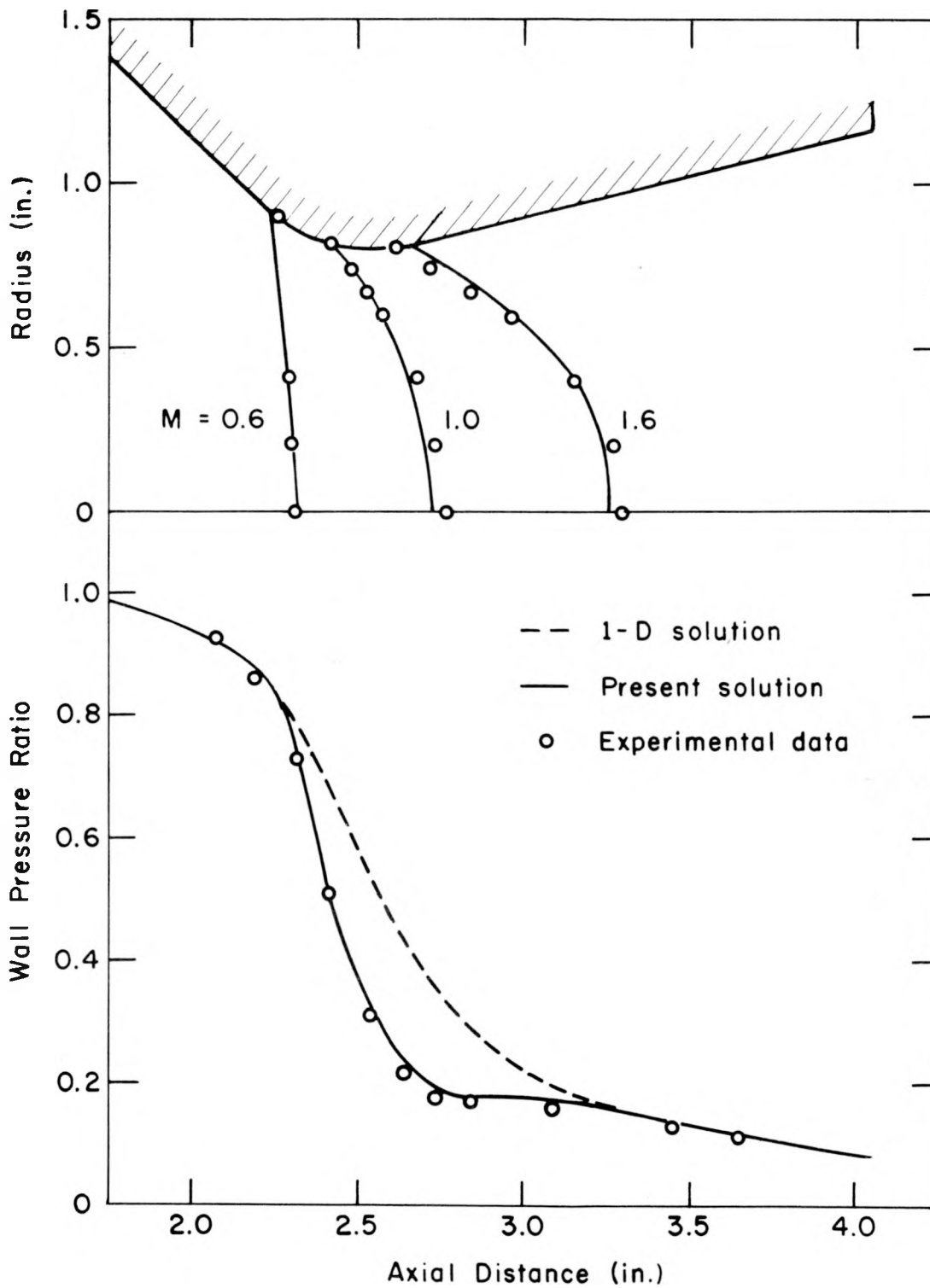


Fig. 3. Mach number contours (top) and wall pressure ratio for the 45-15° conical nozzle (inviscid flow).

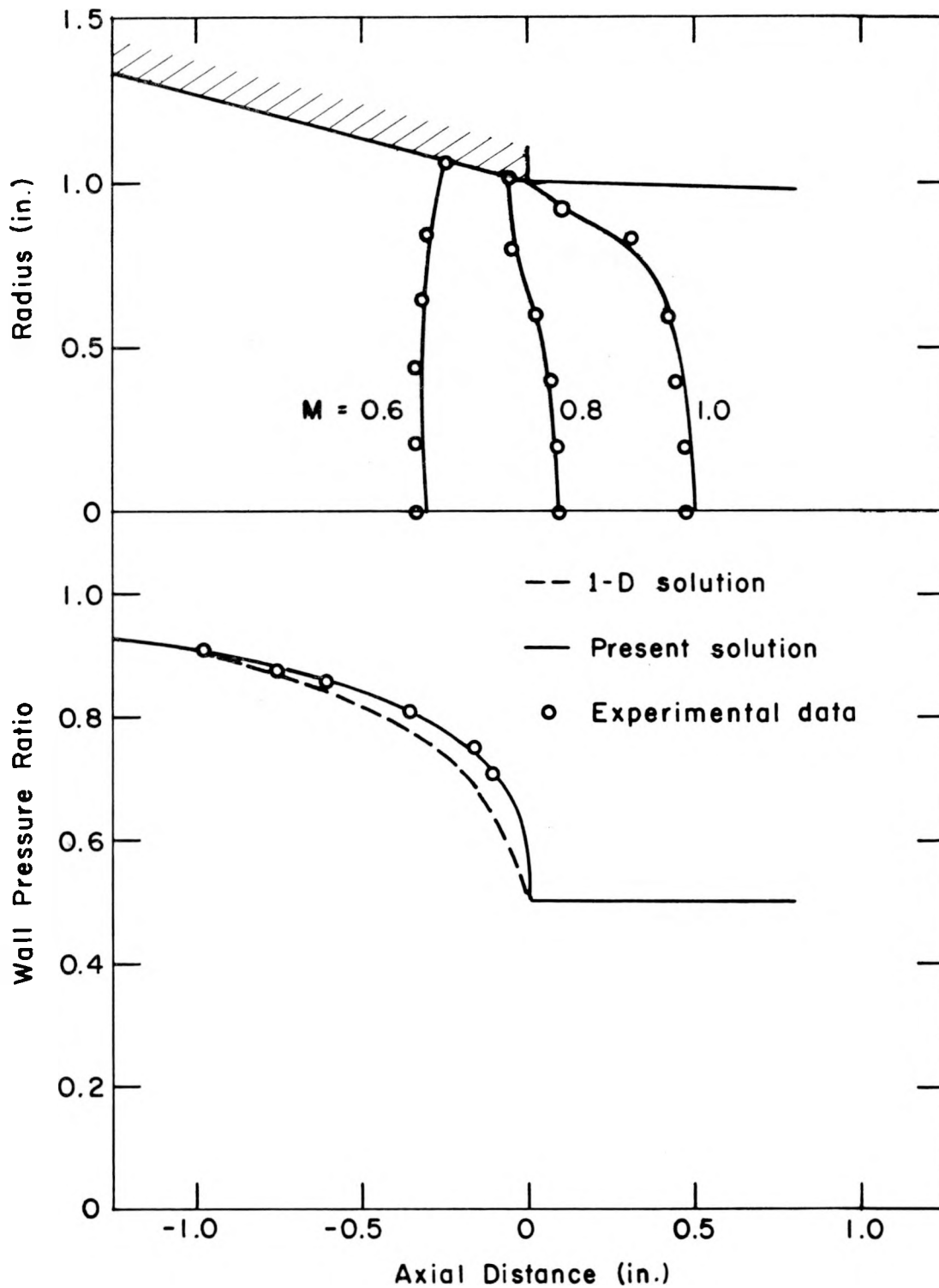


Fig. 4. Mach number contours (top) and wall pressure ratio for the 15° conical nozzle (inviscid flow).

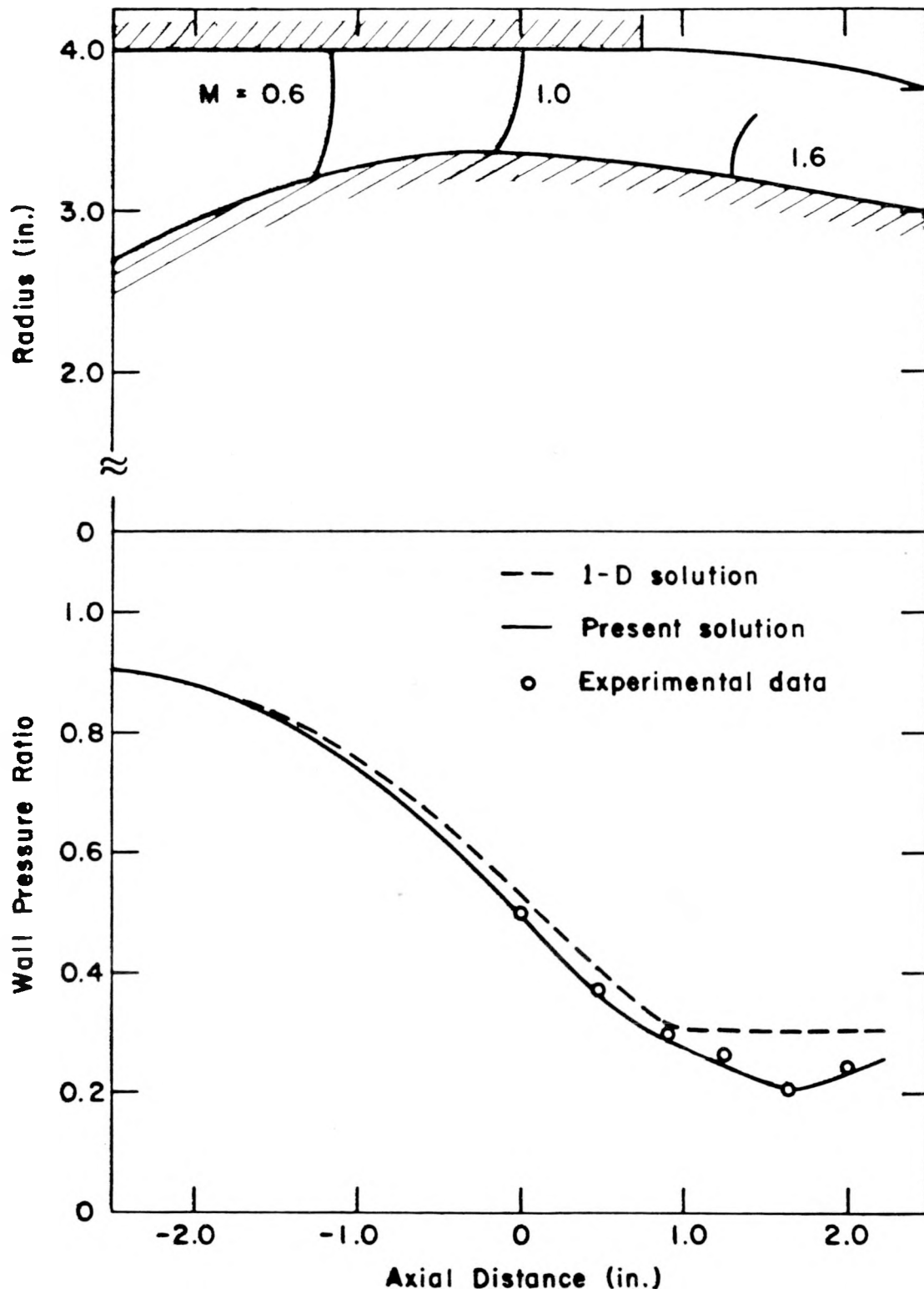


Fig. 5. Mach number contours (top) and plug pressure ratio for the 10° conical, plug nozzle (inviscid flow).

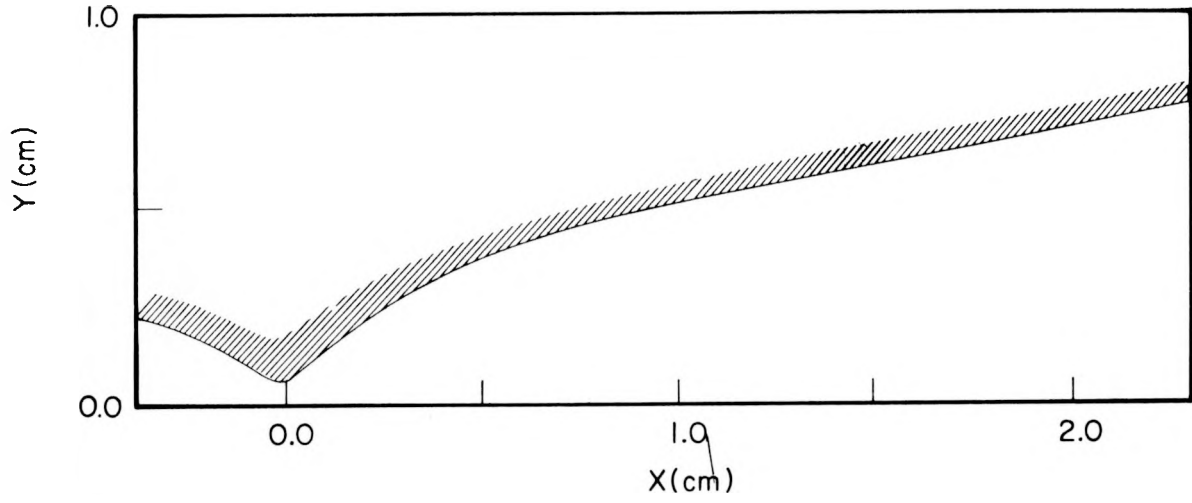


Fig. 6. Nozzle geometry for viscous flow.

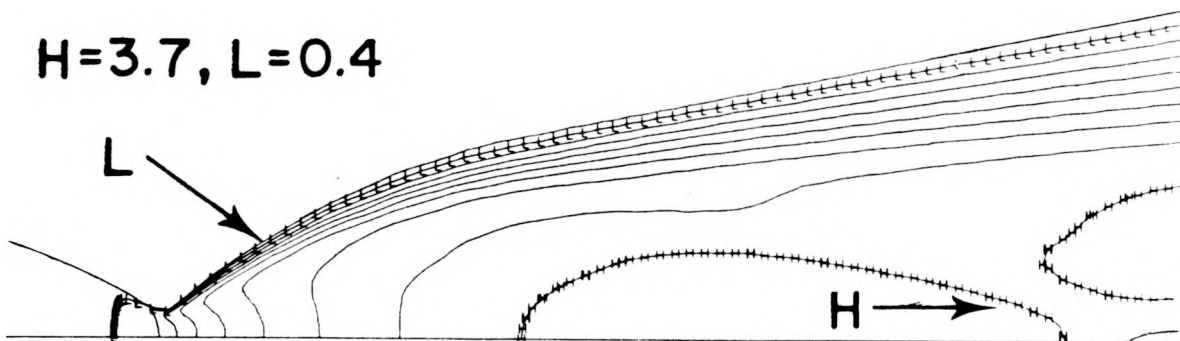


Fig. 7. Mach number contours for $Re^* = 1200$.

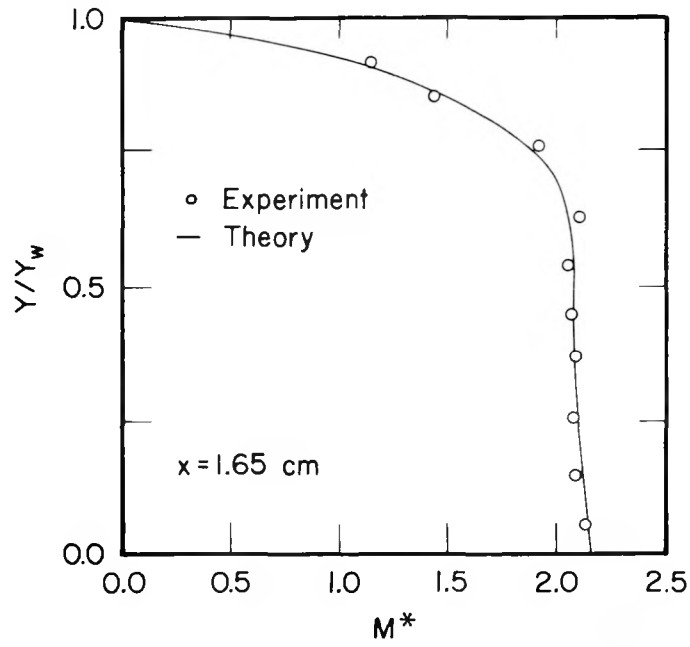


Fig. 8. Velocity profile at $x = 1.65$ cm for $Re^* = 1200$.

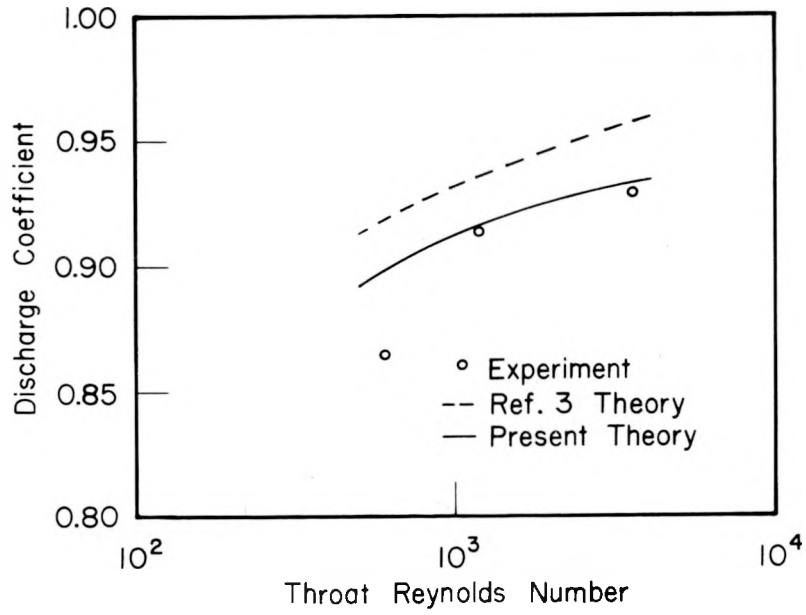


Fig. 9. Discharge coefficient vs Reynolds number.

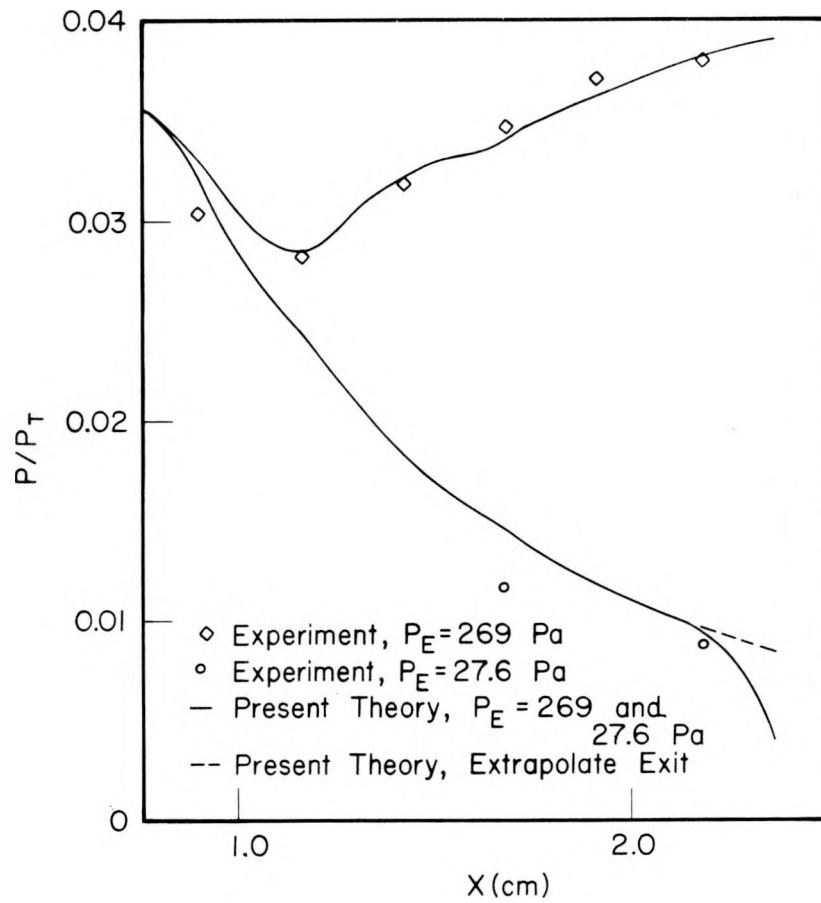


Fig. 10. Wall pressure ratio for $Re^* = 1200$.

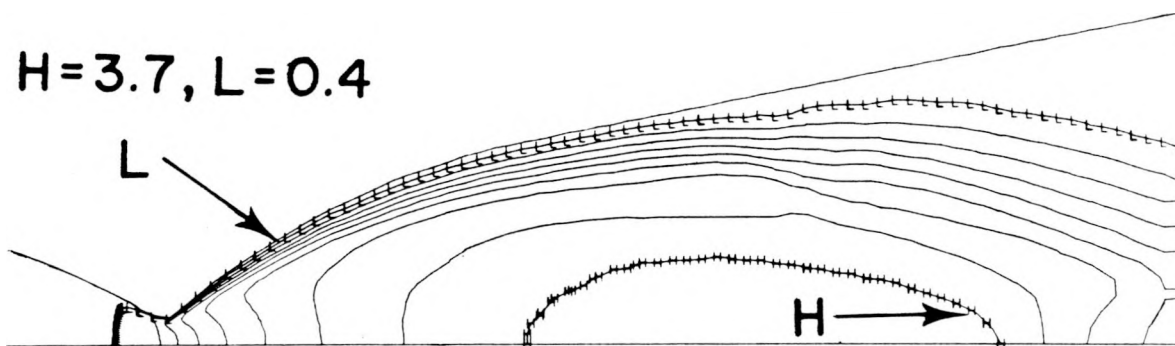


Fig. 11. Mach number contours for the separated case.

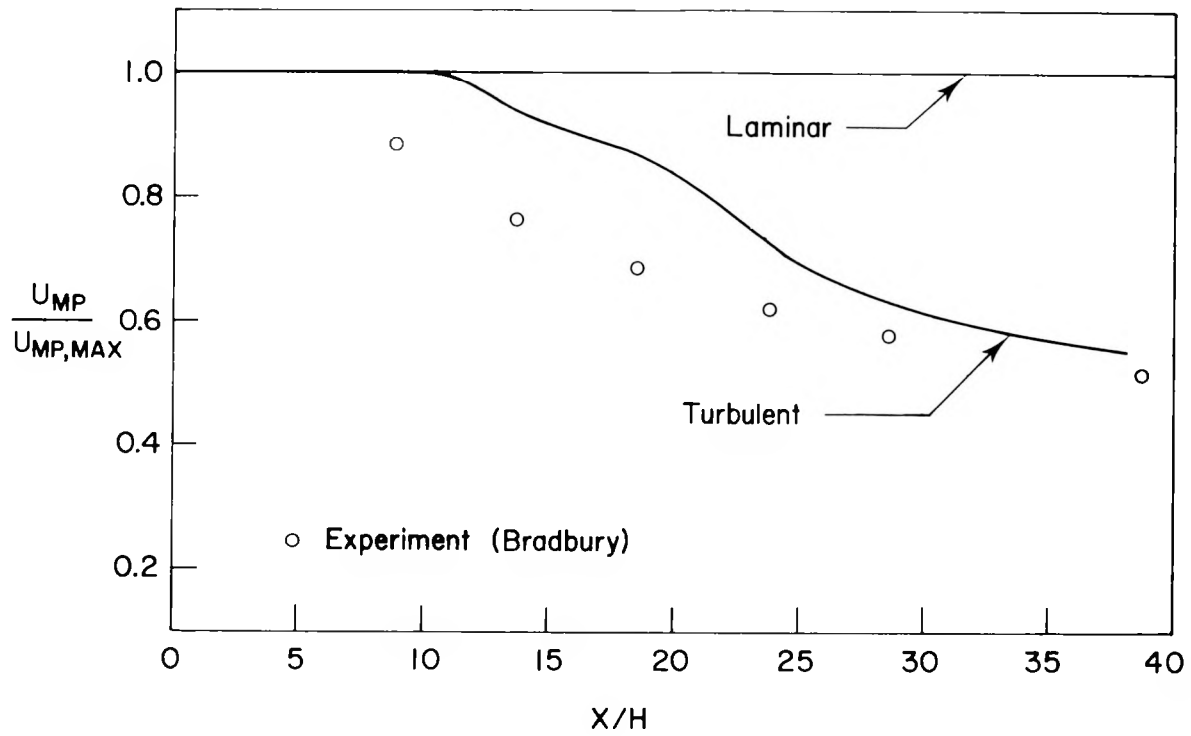


Fig. 12. Midplane velocity decay of a plane jet in a uniform stream ($Re_H = 3 \times 10^4$).

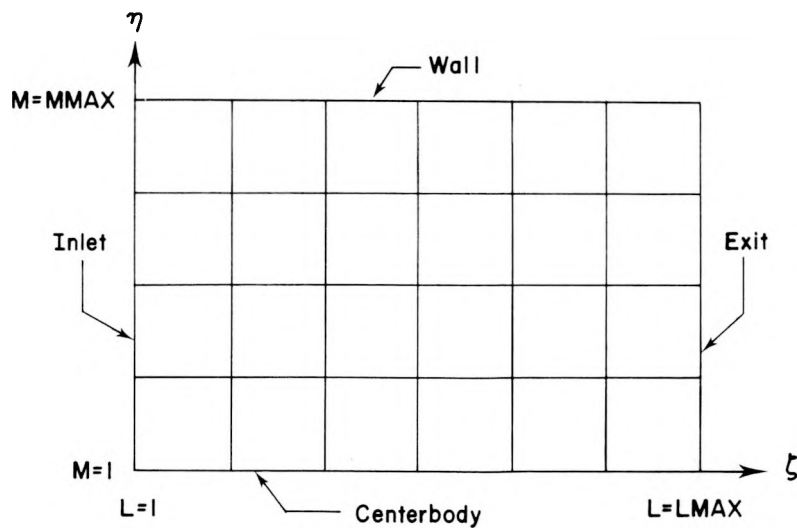


Fig. 13. Computational plane grid.

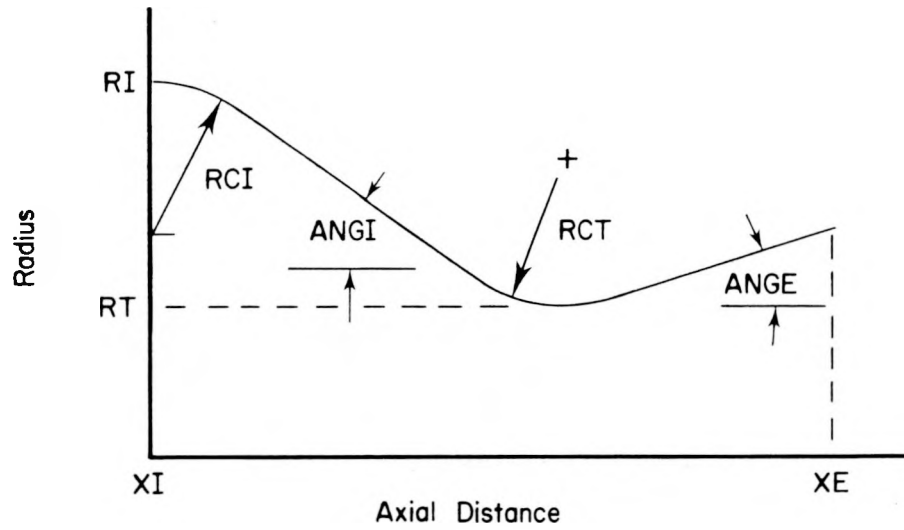


Fig. 14. Circular-arc, conical wall geometry.

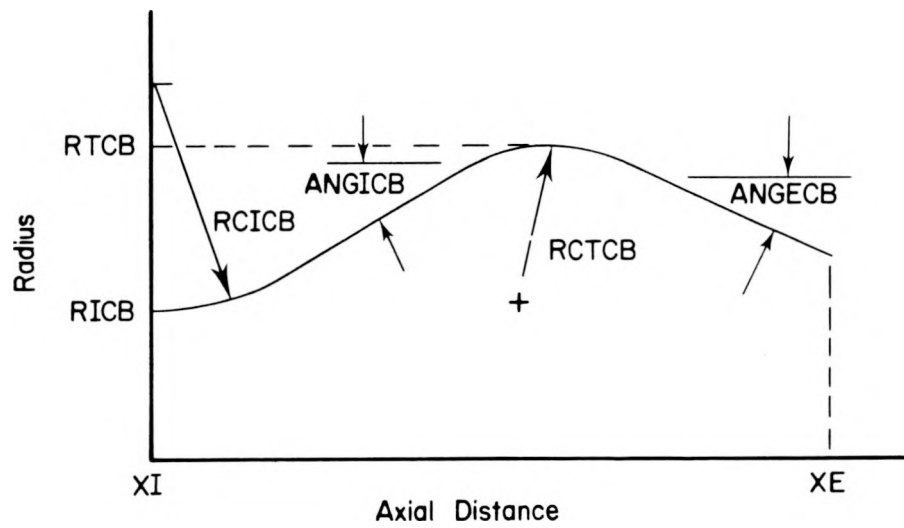


Fig. 15. Circular-arc, conical centerbody geometry.

```
CASE NO. 1 = CONVERGING-DIVERGING NOZZLE (45 DEG INLET, 15 DEG EXIT)
$CNTRL LMAX=21,MMAX=8,NMAX=400,TCNV=0.003,FDT=1.34 $
$IVS $
$GENTRY 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 NASH=1 IUNIT=0
 IUI=1 IUD=1 IVPTS=1 NCONVI= 1 TSTOP=1.00000 NID= 1 NPLOT= -1 IPUNCH=0
 RSTAR= 0.000000 RSTARS= 0.000000 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= 19.00 (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

ARTIFICIAL 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 = .00162600 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LRM/FT ³)	VMAG (F/S)	MACH NO	T (R)
1	1	.3100	0.0000	143.7907	0.0000	69.22194	.347100	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	.347897	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	.0599	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	540.1036

3	1	.6840	0.0000	152.6957	0.0000	69.14873	.346858	152.6957	.1343	538.0960
3	2	.6840	.3439	149.9519	-8.0659	69.17669	.346957	150.1686	.1321	538.1699
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	.0622	539.1708
3	7	.6840	2.0633	42.5390	-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	539.7940
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 = .00162600 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBM/FT ³)	VMAG (F/S)	MACH NO	T (R)
6	0	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	-25.3278	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	.338514	285.5186	.2522	533.1389
8	3	1.6190	.4359	271.2027	-56.1286	67.03153	.339120	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	529.8782
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	239.3805	-146.9885	67.06874	.339776	280.8344	.2482	532.7894
9	7	1.8060	1.1479	191.6545	-154.9091	67.58814	.341720	246.4311	.2176	533.8684
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	515.7802
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	60.74743	.317110	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	498.0649
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 = .00162600 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LRM/FT ³)	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	48,77183	.242871	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	-0,0522	22,74953	.157621	1368,9071	1,4140	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	1089,2204	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	1585,6551	403,4391	13,93935	.108603	1588,7688	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	1305,6104	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	341,0909
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	1390,3699	1,4610	376,9627
16	3	3,1150	.2665	1409,0961	117,0159	19,02755	.138233	1413,0464	1,4964	371,5345
16	4	3,1150	.3997	1443,4704	190,3050	17,32701	.129154	1455,9612	1,5688	362,1117
16	5	3,1150	.5330	1485,4488	277,1585	15,24586	.117608	1511,0840	1,6479	349,9082
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	1533,3823	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	420,0356	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	1630,5767	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 = .00162688 SECONDS (DELTA T = .00000544)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LRM/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	1685.0918	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	1761.0955	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	106.6073	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 (LRM/SEC) THRUST = 175.0481 (LRF) MASSI = 3.328738 MASSR = 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,TCNV=0.005,FDT=1,15 $
$IVS $
$GEMTRY NGEOM=4,XI=3.6,XE=0.8,JFLAG=1,LJET=20,
YH=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 $
```

Fig. 18. Case No. 2 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. 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 IUD#1 IVPTS#1 NCONV# 1 TSTOP#1.00000 NIO# 1 NPLOT# -1 IPUNCH#0
 RSTAR# 0.000000 RSTAR3# 0.000000 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.

BOUNDARY CONDITIONS =

M	PT(PSTA)	TT(R)	THETA(DEG)	PE(PSTA)
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 DYH=.0010 IVRC=0

FREE-SLIP WALLS ARE SPECIFIED

ADIABATIC UPPER WALL IS SPECIFIED

ARTIFICIAL 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#	.00009642 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

Fig. 19. (Cont)

N# 230, T# .00145216 SECONDS, DT# .00000639 SECONDS
N# 240, T# .00151610 SECONDS, DT# .00000639 SECONDS
N# 250, T# .00158004 SECONDS, DT# .00000639 SECONDS

SOLUTION SURFACE NO. 250 - TIME = .00150004 SECONDS (DELTA T = .00000639)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LRM/FT ³)	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	24.59210	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	218.6377	1760	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	226.9833	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	244.1905	-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 = .00150004 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	319.9202	.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	630.0007
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	.101720	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	333.0054	.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	400.6835	0.0000	23.14998	.099806	400.6835	.3332	626.0707
12	2	-1.4000	.2292	400.4256	-18.0931	23.16070	.099839	400.8271	.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	22.80422	.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	435.0601	-58.0600	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	625.1044
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 = .00000630)

L	M	X (IN)	Y (IN)	U (F/S)	V (F/S)	P (PSIA)	RHO (LBH/FT ³)	VMAG (F/S)	MACH NO	T (R)
14	2	-1.0000	.2113	490.0416	-21.5126	22.37103	.097399	490.5136	.4019	619.9530
14	3	-1.0000	.4227	486.3665	-42.8395	22.40060	.097491	488.2495	.3999	620.1833
14	4	-1.0000	.6340	479.9678	-63.8293	22.45248	.097654	484.1934	.3965	620.5087
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	22.20326	.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	.094808	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	627.4030	-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	.6463	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	.086567	793.3044	.6674	588.0000
18	7	-.2000	1.0536	730.3922	-195.7006	19.31069	.087723	756.1570	.6328	594.1696
19	1	.0000	0.0000	881.4584	0.0000	17.20735	.081007	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	.7600	573.6657
19	4	.0000	.5000	907.0613	-69.6505	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	.076030	980.1341	.8454	559.4012
19	7	.0000	1.0000	1015.2895	-147.5926	15.25511	.074007	1025.9612	.8878	555.7770
20	1	.2000	0.0000	1001.1951	0.0000	15.37076	.074562	1001.1951	.8650	556.4269
20	2	.2000	.1659	1006.4010	-10.3289	15.28366	.074257	1006.4540	.8711	555.5433
20	3	.2000	.3318	1010.3206	-20.3676	15.08446	.073550	1010.5322	.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	.070306	1074.4249	.9395	544.2613
20	6	.2000	.8295	1130.2406	-40.5070	13.14606	.066596	1130.9612	1.0066	532.8177

Fig. 19. (Cont)

SOLUTION SURFACE NO. 250 - TIME = .001580004 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	1193.6400	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	.065120	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	12.00023	.062714	1199.9907	1.0736	519.9193
23	2	.8000	.1661	1199.4532	2.2879	12.09361	.062762	1199.4534	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	521.0064
23	5	.8000	.6644	1191.5072	4.6861	12.24716	.063314	1191.5164	1.0637	522.1003
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,YCONV=0.005,PDY=1.25 $
$IVS $
$GENTRY NGEOM=1,XI=-4.440,XE=2.9600,RI=4.0,JFLAG=1,LJET=23 $
$GCBL NGCB=2,RCB=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.

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

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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 PDT=1.25 NSTAG=0 NASH=1 IUNIT=0
IUI=1 IUD=1 IVPTS=1 NCONVI= 1 TSTOP=1.00000 NID= 1 NPLOT= -1 IPUNCH=0
RSTAR= 0.000000 RSTARS= 0.000000 PLOW=.0100 RLOW= .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 ANGPCB= 10.00 (DEG). THE COMPUTED VALUES ARE XTCB= -.0140 (IN) AND RECB= 2.9170 (IN).

Fig. 21. Case No. 3 output.

BOUNDARY CONDITIONS =

M	PT(PSJA)	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 DYN=.0010 IVBC=0

PREF=SLIP WALLS ARE SPECIFIED

ADIABATIC UPPER WALL IS SPECIFIED

ADIABATIC LOWER CENTERBODY IS SPECIFIED

ARTIFICIAL 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=	.00019001 SECONDS,	DT=	.00000603 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=	.00088307 SECONDS,	DT=	.00000692 SECONDS
N=	140,	T=	.00095202 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=	.00143940 SECONDS,	DT=	.00000695 SECONDS
N=	220,	T=	.00150890 SECONDS,	DT=	.00000695 SECONDS

Fig. 21. (Cont)

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 (LRM/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	96.00790	.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	97.66888	.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	100.2771	.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	524.4056
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/FT ³)	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	364,0867	,3267	519,0906
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	109,0440	92,23745	,480718	381,5281	,3420	517,8988
9	2	-2.4667	2.9717	352,3059	139,8713	92,19150	,480508	379,1304	,3399	517,7812
9	3	-2.4667	3.2200	370,5508	103,2049	91,96707	,479741	392,3749	,3519	517,4328
9	4	-2.4667	3.4839	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	,3830	514,8824
10	2	-2.2200	3.0770	390,1309	141,8539	90,41719	,473971	422,6473	,3800	514,9054
10	3	-2.2200	3.3078	419,2070	100,0440	90,30007	,473518	431,9255	,3804	514,7303
10	4	-2.2200	3.5305	423,6886	65,4081	90,24300	,473205	428,7076	,3855	514,6577
10	5	-2.2200	3.7693	431,0499	31,8206	90,17101	,473013	432,2234	,3867	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	437,4800	180,5688	88,13104	,465344	476,3902	,4290	511,1907
11	2	-1.9733	3.1686	440,7429	141,3148	88,26827	,465907	470,4680	,4244	511,3681
11	3	-1.9733	3.3764	465,1931	103,2395	88,25838	,465053	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	,4270	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	490,3165	183,7661	85,40109	,455015	531,1200	,4814	506,6011
12	2	-1.7267	3.2474	505,0687	138,1022	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	522,3509	,4731	507,3688
12	6	-1.7267	4.0000	521,2890	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	575,4609	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	29,9200	82,95027	,445668	576,8719	,5250	502,3023
13	6	-1.4800	4.0000	575,6637	0,0000	83,03159	,445972	575,6637	,5238	502,5324
14	1	-1.2333	3.2125	638,7807	162,3501	78,16380	,427173	659,0987	,6050	493,8895
14	2	-1.2333	3.3700	636,5269	122,5099	78,70871	,429341	648,2244	,5945	494,8209
14	3	-1.2333	3.5275	640,3164	89,0415	79,06055	,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	27,0908	79,44612	,432163	637,9555	,5842	496,1958
14	6	-1.2333	4.0000	636,5701	0,0000	79,53728	,432506	636,5701	,5829	496,3714
15	1	-.9867	3.2605	710,6933	144,0327	73,52920	,400961	732,9039	,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	711,5029	79,2100	74,77400	,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	,415902	705,4630	,6510	488,6339
15	6	-.9867	4.0000	703,0001	0,0000	75,40745	,416374	703,0001	,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 (LRM/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	793.8872	98.6366	69.15333	.391521	798.1701	.7457	476.7450
16	3	.7400	3.5869	788.7592	66.8715	69.82658	.394210	791.5217	.7384	478.1822
16	4	.7400	3.7246	780.6709	42.6956	70.27658	.396801	781.8375	.7287	479.8882
16	5	.7400	3.8623	778.6408	20.9920	70.52669	.396998	778.9238	.7256	479.5847
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	899.8756	.8528	462.5663
17	2	.4933	3.4734	878.9476	66.7971	63.43505	.368161	881.4821	.8338	465.8711
17	3	.4933	3.6050	870.8826	49.1398	64.28736	.371654	872.2678	.8235	466.8902
17	4	.4933	3.7367	860.6876	32.8534	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	46.5882	55.78166	.335942	989.2217	.9532	448.1834
18	2	.2467	3.4876	968.8859	36.8786	57.24588	.342231	968.7877	.9381	451.4950
18	3	.2467	3.6157	956.4303	28.8257	58.28625	.346621	956.8488	.9162	453.8783
18	4	.2467	3.7438	944.2743	18.7469	58.98340	.349548	944.4604	.9028	458.4613
18	5	.2467	3.8719	939.6176	9.3521	59.35866	.351121	939.6642	.8973	456.3845
18	6	.2467	4.0000	937.3318	0.0000	59.49535	.351666	937.3318	.8948	456.6476

19	1	.0000	3.3650	1082.5310	-3.8579	49.08608	.386616	1082.5333	1.0623	432.1869
19	2	.0000	3.4920	1058.7809	-4.913	50.81290	.314291	1058.7810	1.0338	436.3857
19	3	.0000	3.6190	1043.8699	2.4124	52.04197	.319668	1043.8726	1.0158	439.4341
19	4	.0000	3.7460	1029.9397	2.6162	52.86285	.323217	1029.9438	1.0000	441.4461
19	5	.0000	3.8730	1024.8864	1.5876	53.29870	.325187	1024.8875	.9931	442.5852
19	6	.0000	4.0000	1021.3318	0.0000	53.44583	.325774	1021.3318	.9901	442.8121

20	1	.2467	3.3581	1172.2938	-61.8146	42.41376	.276464	1173.9224	1.1768	414.8988
20	2	.2467	3.4865	1146.3264	-42.3875	44.48104	.285641	1147.1869	1.1424	419.5657
20	3	.2467	3.6149	1129.2789	-27.2147	45.81150	.292834	1129.5987	1.1188	423.4178
20	4	.2467	3.7433	1113.7858	-15.7798	46.76510	.296316	1113.8175	1.1009	425.9861
20	5	.2467	3.8716	1106.7988	-7.3482	47.27951	.298612	1106.8152	1.0922	427.3686
20	6	.2467	4.0000	1104.2970	0.0000	47.46857	.299299	1104.2970	1.0889	428.8121

21	1	.4933	3.3389	1278.4821	-138.8986	35.64954	.243988	1277.2875	1.3120	394.3794
21	2	.4933	3.4711	1239.4578	-92.4747	37.81669	.254489	1242.9828	1.2668	401.8911
21	3	.4933	3.6034	1228.8878	-61.8452	39.44985	.262231	1221.6535	1.2367	406.8515
21	4	.4933	3.7356	1222.4466	-37.7258	40.61974	.267782	1203.8382	1.2127	409.5564
21	5	.4933	3.8678	1194.1855	-18.1823	41.25188	.270654	1194.3239	1.2012	411.3857
21	6	.4933	4.0000	1188.9844	0.0000	41.42354	.271747	1188.9844	1.1957	411.4436

22	1	.7400	3.3872	1332.4334	-285.3521	38.92988	.228332	1348.1647	1.4128	378.9819
22	2	.7400	3.4458	1306.8482	-154.9676	32.83888	.238863	1315.2898	1.3671	385.1783
22	3	.7400	3.5843	1287.3991	-111.7255	34.41888	.238898	1292.2388	1.3345	398.1829
22	4	.7400	3.7229	1271.4886	-73.1814	35.48967	.243548	1273.5884	1.3099	393.3281
22	5	.7400	3.8614	1265.7887	-37.8336	35.93843	.245833	1266.2748	1.3004	394.5582
22	6	.7400	4.0000	1269.3858	0.0000	35.88888	.244885	1269.3858	1.3017	395.6928

23	1	.9867	3.2649	1381.9673	-243.6781	27.48887	.201988	1403.2864	1.4958	366.2729
23	2	.9867	3.4119	1373.6494	-188.8385	28.38938	.208828	1386.4599	1.4714	369.4575
23	3	.9867	3.5598	1370.6477	-111.2142	29.88587	.218534	1376.9148	1.4566	371.8595
23	4	.9867	3.7068	1368.9781	-72.8824	29.38243	.211998	1378.8783	1.4478	373.8927

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 (LRM/FT3)	VMAG (F/S)	MACH NO	T (R)
23	5	.9867	3.8530	1370.4512	-16.4666	29.54203	.213014	1370.5501	1.4450	374.3347
23	6	.9867	4.0000	1350.4202	.1471	30.41990	.217498	1350.4202	1.4100	377.4013
24	1	1.2333	3.2214	1427.8738	-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	355.8609
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	.204007	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	1499.8380	1.6467	343.3980
25	2	1.4800	3.3356	1475.5512	-203.0855	22.03956	.172597	1489.4613	1.6366	344.6644
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	1536.0025	1.7146	333.0858
26	2	1.7267	3.2930	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	359.5371
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	1309.6510	-335.6970	31.34751	.222573	1343.2741	1.4054	380.1537
29	4	2.4667	3.4635	1303.0917	-364.4432	30.59275	.218437	1353.0053	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	-338.9974	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	1218.6330	-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/FT ³)	VMAG (F/S)	MACH NO	T (R)
31	2	2.9600	3.0652	1150.0658	-185.1262	43.46634	.200671	1164.8704	1.1623	410.0075
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	1259.0510	-223.3598	35.53752	.242985	1279.4976	1.3137	394.7631
31	5	2.9600	3.5098	1310.5247	-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# 33.077122		MASSE# 33.022534		

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 $

```

Fig. 22. Case No. 4 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. 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 NASH=1 IUNIT=0
 IUI=2 IUO=2 IVPTS=1 NCONV= 1 TSTOP=1.00000 NID= 1 NPLOT= 50 IPUNCH=0
 RSTAR= 0.000000 RSTARS= 0.000000 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	.1160	.2425	.1729	.4214
6	.0762	.0889	.2078	.1580	.4525
7	.0308	.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	.0762
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	19.00	14.70000

IEXTRA=1 IEX=1 ISUPER=0 DYH=.0010 IVRC=0

NO=8LIP WALLS ARE SPECIFIED

TW IS SPECIFIED

ARTIFICIAL 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)

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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

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Fig. 23. (Cont)

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      N# 500, T# .00003848 SECONDS, DT# .00000000 SECONDS
***** EXPECT FILM OUTPUT FOR N# 500 *****
      N# 510, T# .00003924 SECONDS, DT# .00000000 SECONDS
      N# 520, T# .00004001 SECONDS, DT# .00000000 SECONDS
      N# 530, T# .00004077 SECONDS, DT# .00000000 SECONDS
      N# 540, T# .00004154 SECONDS, DT# .00000000 SECONDS
      N# 550, T# .00004230 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 550 *****
      N# 560, T# .00004306 SECONDS, DT# .00000000 SECONDS
      N# 570, T# .00004382 SECONDS, DT# .00000000 SECONDS
      N# 580, T# .00004459 SECONDS, DT# .00000000 SECONDS
      N# 590, T# .00004535 SECONDS, DT# .00000000 SECONDS
      N# 600, T# .00004611 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 600 *****
      N# 610, T# .00004687 SECONDS, DT# .00000000 SECONDS
      N# 620, T# .00004763 SECONDS, DT# .00000000 SECONDS
      N# 630, T# .00004840 SECONDS, DT# .00000000 SECONDS
      N# 640, T# .00004916 SECONDS, DT# .00000000 SECONDS
      N# 650, T# .00004992 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 650 *****
      N# 660, T# .00005068 SECONDS, DT# .00000000 SECONDS
      N# 670, T# .00005144 SECONDS, DT# .00000000 SECONDS
      N# 680, T# .00005219 SECONDS, DT# .00000000 SECONDS
      N# 690, T# .00005295 SECONDS, DT# .00000000 SECONDS
      N# 700, T# .00005371 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 700 *****
      N# 710, T# .00005447 SECONDS, DT# .00000000 SECONDS
      N# 720, T# .00005523 SECONDS, DT# .00000000 SECONDS
      N# 730, T# .00005599 SECONDS, DT# .00000000 SECONDS
      N# 740, T# .00005675 SECONDS, DT# .00000000 SECONDS
      N# 750, T# .00005751 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 750 *****
      N# 760, T# .00005827 SECONDS, DT# .00000000 SECONDS
      N# 770, T# .00005903 SECONDS, DT# .00000000 SECONDS
      N# 780, T# .00005979 SECONDS, DT# .00000000 SECONDS
      N# 790, T# .00006055 SECONDS, DT# .00000000 SECONDS
      N# 800, T# .00006131 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 800 *****
      N# 810, T# .00006207 SECONDS, DT# .00000000 SECONDS
      N# 820, T# .00006283 SECONDS, DT# .00000000 SECONDS
      N# 830, T# .00006359 SECONDS, DT# .00000000 SECONDS
      N# 840, T# .00006435 SECONDS, DT# .00000000 SECONDS
      N# 850, T# .00006511 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 850 *****
      N# 860, T# .00006588 SECONDS, DT# .00000000 SECONDS
      N# 870, T# .00006664 SECONDS, DT# .00000000 SECONDS
      N# 880, T# .00006740 SECONDS, DT# .00000000 SECONDS
      N# 890, T# .00006816 SECONDS, DT# .00000000 SECONDS
      N# 900, T# .00006892 SECONDS, DT# .00000000 SECONDS

***** EXPECT FILM OUTPUT FOR N# 900 *****
      N# 910, T# .00006968 SECONDS, DT# .00000000 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

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	.000949	78.4910	.2316	285.9340
1	2	-.3810	.0113	78.3041	1.3668	6.64345	.000959	78.3161	.2310	285.9475
1	3	-.3810	.0226	77.8730	2.7194	6.64594	.000981	77.9205	.2299	285.9781
1	4	-.3810	.0339	77.1543	4.0435	6.65008	.001017	77.2601	.2279	286.0289
1	5	-.3810	.0452	76.1479	5.3248	6.65571	.001066	76.3339	.2251	286.0981
1	6	-.3810	.0565	74.8572	6.5492	6.66302	.001129	75.1431	.2216	286.1879
1	7	-.3810	.0678	73.2726	7.7013	6.67188	.001206	73.6762	.2172	286.2963
1	8	-.3810	.0791	71.3835	8.7648	6.68226	.001296	71.9196	.2120	286.4238
1	9	-.3810	.0904	69.1816	9.7228	6.69413	.001400	69.8615	.2059	286.5690
1	10	-.3810	.1017	66.6548	10.5571	6.70741	.001515	67.4856	.1988	286.7314
1	11	-.3810	.1130	63.7827	11.2466	6.72207	.001642	64.7666	.1908	286.9102
1	12	-.3810	.1243	60.5396	11.7677	6.73803	.001781	61.6727	.1816	287.1048
1	13	-.3810	.1356	56.8755	12.0893	6.75532	.001930	58.1462	.1711	287.3150
1	14	-.3810	.1469	52.7677	12.1824	6.77370	.002089	54.1557	.1593	287.5381
1	15	-.3810	.1582	48.2033	11.9835	6.79337	.002260	49.5347	.1457	287.7764
1	16	-.3810	.1695	42.7429	11.4529	6.81399	.002438	44.2507	.1301	288.0258
1	17	-.3810	.1808	36.3763	10.4307	6.83569	.002625	37.8422	.1122	288.2875
1	18	-.3810	.1922	29.1606	8.9153	6.85864	.002805	30.4930	.0906	288.5376
1	19	-.3810	.2035	20.2233	6.5709	6.87623	.002975	21.2640	.0624	288.7750
1	20	-.3810	.2148	10.7741	3.7098	6.88961	.003090	11.3949	.0334	288.9354
1	21	-.3810	.2261	0.0000	0.0000	6.89500	.003137	0.0000	0.0000	289.0000

2	1	-.3464	0.0000	75.0356	0.0000	6.65347	.001368	75.0356	.2218	284.9381
2	2	-.3464	.0107	74.9103	.7116	6.65480	.001381	74.9139	.2214	284.9519
2	3	-.3464	.0214	74.5843	1.4120	6.65810	.001411	74.5976	.2204	284.9853
2	4	-.3464	.0321	74.0411	2.0650	6.66366	.001463	74.0699	.2189	285.0415
2	5	-.3464	.0428	73.2839	2.6581	6.67106	.001533	73.3341	.2167	285.1142
2	6	-.3464	.0535	72.3157	3.1666	6.68017	.001619	72.3850	.2138	285.2016
2	7	-.3464	.0642	71.1291	3.5748	6.69006	.001720	71.2189	.2103	285.2983
2	8	-.3464	.0749	69.7192	3.8637	6.70226	.001832	69.8762	.2062	285.4009
2	9	-.3464	.0856	68.0816	4.0208	6.71474	.001954	68.2002	.2014	285.5053
2	10	-.3464	.0963	66.2141	4.0296	6.72703	.002084	66.3366	.1950	285.6110
2	11	-.3464	.1070	64.1058	3.8861	6.74144	.002220	64.2235	.1895	285.7147
2	12	-.3464	.1176	61.7589	3.5661	6.75521	.002356	61.8618	.1825	285.8239
2	13	-.3464	.1283	59.1306	3.0873	6.76946	.002497	59.2112	.1747	285.9383
2	14	-.3464	.1390	56.2639	2.3757	6.78313	.002621	56.3140	.1661	286.0866
2	15	-.3464	.1497	53.0215	1.5294	6.79793	.002747	53.0436	.1564	286.2727
2	16	-.3464	.1604	49.6088	.2698	6.81011	.002808	49.6095	.1462	286.5753
2	17	-.3464	.1711	45.5198	-.9727	6.82682	.002897	45.5302	.1341	286.9700
2	18	-.3464	.1818	41.4241	-3.2801	6.83311	.002888	41.5475	.1222	287.5420
2	19	-.3464	.1925	35.8844	-4.6709	6.85704	.002974	36.1871	.1064	288.0118
2	20	-.3464	.2032	29.0838	-8.2657	6.83729	.002612	30.2355	.0888	288.4025
2	21	-.3464	.2139	0.0000	0.0000	6.87553	.002870	0.0000	0.0000	289.0000

3	1	-.3117	0.0000	77.2751	0.0000	6.56966	.000288	77.2751	.2283	285.1353
3	2	-.3117	.0100	77.1660	.0482	6.57164	.000305	77.1660	.2280	285.1598
3	3	-.3117	.0201	76.8575	.0945	6.57675	.000349	76.8575	.2270	285.2250
3	4	-.3117	.0301	76.3511	.1714	6.58533	.000423	76.3513	.2255	285.3340
3	5	-.3117	.0402	75.6504	.2799	6.59675	.000522	75.6509	.2234	285.4793
3	6	-.3117	.0502	74.7583	.4411	6.61077	.000642	74.7598	.2207	285.6576
3	7	-.3117	.0603	73.6818	.6670	6.62678	.000780	73.6849	.2174	285.8612
3	8	-.3117	.0703	72.4205	.9748	6.64429	.000931	72.4270	.2136	286.0829

Fig. 23. (Cont)

SOLUTION SURFACE NO. 1000 - TIME = .00007654 SECONDS (DELTA T = .00000000)

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	.0004	70.9832	-1.3825	6.66260	.001009	70.9967	.2093	286.3137
3	10	.3117	.0004	69.3659	-1.8999	6.68149	.001253	69.3919	.2045	286.5444
3	11	.3117	.1005	67.5831	-2.5481	6.70010	.001417	67.6311	.1992	286.7637
3	12	.3117	.1105	65.6150	-3.3181	6.71833	.001582	65.6996	.1935	286.9622
3	13	.3117	.1206	63.4949	-4.2479	6.73538	.001743	63.6369	.1874	287.1232
3	14	.3117	.1306	61.1544	-5.2826	6.75188	.001908	61.3821	.1807	287.2451
3	15	.3117	.1407	58.7001	-6.5299	6.76613	.002065	59.0622	.1738	287.3037
3	16	.3117	.1507	55.9310	-7.8131	6.78061	.002226	56.4740	.1662	287.3537
3	17	.3117	.1608	53.1729	-9.4416	6.79108	.002348	54.0046	.1589	287.3713
3	18	.3117	.1708	49.6712	-10.8868	6.80368	.002447	50.8503	.1496	287.5580
3	19	.3117	.1809	46.2989	-12.8765	6.80886	.002469	48.0561	.1413	287.6993
3	20	.3117	.1909	35.0323	-11.8172	6.81091	.002288	36.9717	.1086	288.4214
3	21	.3117	.2010	0.0000	0.0000	6.82279	.002266	0.0000	0.0000	289.0000

4	1	.2771	0.0000	80.4525	0.0000	6.55643	.000588	80.4525	.2384	283.5004
4	2	.2771	.0004	80.3614	-.6327	6.55790	.000602	80.3641	.2381	283.5141
4	3	.2771	.0187	80.0887	-1.3020	6.56179	.000640	80.0993	.2373	283.5502
4	4	.2771	.0281	79.6437	-1.9663	6.56839	.000704	79.6680	.2360	283.6110
4	5	.2771	.0375	79.0240	-2.6439	6.57748	.000792	79.0682	.2342	283.6933
4	6	.2771	.0468	78.2335	-3.3458	6.58904	.000904	78.3050	.2319	283.7962
4	7	.2771	.0562	77.2745	-4.0760	6.60285	.001040	77.3819	.2291	283.9167
4	8	.2771	.0656	76.1533	-4.8462	6.61864	.001195	76.3073	.2259	284.0528
4	9	.2771	.0749	74.8727	-5.6621	6.63621	.001366	75.0865	.2222	284.2027
4	10	.2771	.0843	73.4465	-6.5403	6.65471	.001547	73.7371	.2181	284.3673
4	11	.2771	.0937	71.8698	-7.4799	6.67412	.001732	72.2980	.2137	284.5508
4	12	.2771	.1030	70.1745	-8.5886	6.69347	.001907	70.6884	.2090	284.7644
4	13	.2771	.1124	68.3294	-9.8039	6.71272	.002068	69.0010	.2039	285.0253
4	14	.2771	.1218	66.4030	-10.8241	6.73058	.002189	67.2802	.1987	285.3601
4	15	.2771	.1311	64.3081	-12.0952	6.74786	.002278	65.4356	.1931	285.7859
4	16	.2771	.1405	62.1903	-13.5505	6.76230	.002302	63.6494	.1877	286.3142
4	17	.2771	.1499	59.8242	-14.9942	6.77666	.002314	61.6746	.1817	286.8798
4	18	.2771	.1592	57.2950	-16.6325	6.78630	.002276	59.6604	.1756	287.4197
4	19	.2771	.1686	53.2133	-17.6554	6.79586	.002280	56.0657	.1649	287.8114
4	20	.2771	.1780	39.3634	-14.6156	6.79883	.002077	41.9911	.1233	288.6152
4	21	.2771	.1873	0.0000	0.0000	6.81217	.002138	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	.0006	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	.080468	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	640.8000	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	658.5834	-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	168.5088
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	134.7800	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	3.7088	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	660.8974	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	.06596	.002114	619.4715	2.9728	108.0667
79	14	2.3206	.5047	588.1492	26.2620	.06648	.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	341.5026	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	-20.4345	.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	.002620	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 = .00000000)

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	617.0907	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	40.3117	.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,PGAS=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 $
$SBC 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.

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 NSTAC=0 NASH=1 IUNIT=0
 IUI=2 IUO=2 IVPTS=1 NCONVI= 1 TSTOP=1.00000 NID= 0 NPLOT= 50 IPUNCH=0
 RSTAR= 0.000000 RSTARS= 0.000000 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= 30.1000 (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 DYH=.0010 IVBC=0

FREE-SLIP WALLS ARE SPECIFIED

ADIABATIC UPPER WALL IS SPECIFIED

ARTIFICIAL 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 *****

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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# .00110629 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

***** EXPECT 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

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Fig. 25. (Cont)

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      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# .00474953 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

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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
```

LOCAL ARTIFICIAL 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	-.0271	.0002	.0001	0.0000	31.6696
2	4	.0272	-.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	.0000	.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	.0000	.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	.0059

Fig. 25. (Cont)

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

L	M	QUT	QVT	QPT	QRQT	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	.0074	.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	39.4599
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 ARTIFICIAL VISCOSITY AND MOLECULAR VISCOSITY-HFAT 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	364.7339
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	102.1039
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	200.0039
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	355.9845
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 ARTIFICIAL 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	.0000	.0000	.0000	0.0000	174.0578
41	3	.0022	.0001	.0000	0.0000	297.4440
41	4	.0013	.0001	.0000	0.0000	352.7130
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	291.8880
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	292.0270
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	-.0802	100.94223	1.202618	7.5305	.0220	292.4822
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	7.5410	-.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	7.1545	-.3024	100.96348	1.202637	7.1609	.0209	292.5411
3	8	1.9050	1.6669	7.2069	-.2418	100.95767	1.202618	7.2009	.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	1.202509	7.3027	.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	101.00234	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	1.202810	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	292.5020
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	7.3110	-.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	101.00829	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	1.202862	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	7.0510	-.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	1.202492	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)

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)					
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)		MASS1=		.007206		MASSE=		.007419	

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

Fig. 25. (Cont)