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NUREG/CR-0690
LA-7725-MS
Informal Report
R4

SOLA-DF: A Solution Algorithm for Nonequilibrium Two-Phase Flow

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Manuscript submitted: February 1979
Date published: June 1979

Prepared for
Division of Nuclear Reactor Safety Research
US Nuclear Regulatory Commission
Washington, DC 20555

NRC FIN No. A-7027

LASL

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

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SOLA-DF: A SOLUTION ALGORITHM FOR NONEQUILIBRIUM TWO-PHASE FLOW

by

C. W. Hirt, N. C. Romero, M. D. Torrey, and J. R. Travis

ABSTRACT

A numerical solution algorithm, SOLA-DF, is presented for the solution of gas-liquid mixture dynamics in two space dimensions and time. The two-phase system is described by a set of mixture equations plus a relation describing the relative flow of one phase with respect to the other. In addition, the algorithm contains models to represent the interphase exchange rates of mass, momentum, and energy for water-steam mixtures.

I. INTRODUCTION

Fluid dynamic problems involving multiphase mixtures occur in abundance in nearly all branches of engineering and technology. Yet the ability to theoretically study these flows in more than one space dimension and with time-dependent behavior has only recently evolved.[1,2] For many applications it is unnecessary to solve complete sets of mass, momentum, and energy conservation equations for each phase.[3] For example, when the two phases are moving together, a mixture momentum equation can replace the individual momentum equations, or if the phases are in thermodynamic equilibrium, it is unnecessary to keep two energy equations. When small deviations are expected from equilibrium or equal phase velocities, it is possible to introduce correction terms into the mixture equations without having to increase the number of equations. It is the latter approach that is considered in this report.

In the next section a theoretical formulation is described for a two-phase mixture using one variation of the so-called "drift-flux" approximation.[4]

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These equations are formulated for two-dimensional planar or axisymmetric coordinate systems. All constitutive relations and equations of state are relatively simple models designed for water-steam mixtures. These relations have been used successfully for many important applications arising in nuclear reactor safety studies.[5] They should not, however, be used indiscriminately. For other applications, consideration should always be given to their suitability for the temperature-pressure ranges of interest and to the possibility that additional physical processes may be needed in the basic theoretical description. In any case, it is emphasized that the constitutive relations used in this report may be easily changed without alt ring the basic numerical solution algorithm that forms the heart of the SOLA-DF code.

The solution algorithm used in SOLA-DF has evolved from algorithms used in earlier codes in the SOLA series. The original SOLA code[6] was designed for problems involving a single, incompressible fluid in a fixed region. The SOLA-SURF code[6] is an extended form of SOLA that allows for the inclusion of free surfaces. SOLA-ICE,[7] the third member of the family, was designed to handle single-component, com le fluids. An implicit solution method is used in SOLA-ICE so that, in addition to shock and rarefaction dominated flows, it can also treat very low speed (incompressible) fluid flows. All of these SOLA codes are available from the National Energy Software Center, 9700 South Cass Avenue, Argonne, Illinois 60439.

The SOLA-DF code is a direct descendent of SOLA-ICE. It utilizes finite-difference approximations with respect to a mesh of equal rectangular cells covering the flow region of interest. A semi-implicit formulation is available as a user option so that large time steps can be used in many circumstances to reduce problem run times.

The solution algorithm also has an option for one-dimensional computations. In this case the mesh is limited to one column of cells, and derivatives of dependent variables normal to this column are automatically suppressed by the setting of a large mesh-interval in the normal direction. Futhermore, for one-dimensional computations of flow in pipes there is an option for a two-phase flow pipe friction model.

In addition, SOLA-DF is formulated with a variable, denoted by A, representing the "thickness" of a mesh cell. That is, in a one-dimensional computation the volume of a cell of length δy is $A\delta y$. In two-dimensional computations the volume of a cell of width δx and height δy is $A\delta x\delta y$. The presence

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of the A quantity provides SOLA-DF with many useful features. For example, in one-dimensional appplications a variable A can be used to model nozzles or other pipe area changes. If A increases as the square of the distance from the bottom of the mesh column then the equations reduce to a one-dimensional spherical system that could be used to study spherical bubbles or explosive flashing processes.

In two-dimensional applications a variable A may be used to represent flow through a two-dimensional duct of slowly varying thickness. The use of zero values of A in selected mesh cells provides a convenient means of including internal obstacles in the flow region. In particular, a cell with A = 0 will allow no flow across its boundaries. Axisymmetric coordinates are generated by having A increase linearly with distance from the axis. In the present version of SOLA-DF the A-quantity must be constant in time. However, it would not be difficult to introduce time-dependent corrections so that flows in flexible pipes and ducts might be modeled.[8]

In constructing SOLA-DF some consideration has been given to providing subroutines for most of the important or controversial constitutive relations and for the equations of state for each phase. Thus, changes in these quantities can be made with relative ease. Although the code was developed on a CDC-7600 computer, ANSI-Standard FORTRAN has been used throughout to facilitate its use on other computers. This does not apply, however, to the output subroutines used in the code for graphic display purposes. A list of these subroutines and their functions is provided in Section IV for those users who have access to graphic display systems and wish to convert them to their system routines. All calls to graphic output routines can be avoided by inputing a plot time larger than the requested problem time.

A sample problem is discussed in Section V to illustrate the type of results that may be obtained with the SOLA-DF code. The results of this test problem are presented in detail so that new users may check that their codes are running correctly.

A listing of the code and its subroutines are provided in the Appendix.

Two SOLA codes,[5,8] which were referenced above, offer complementary capabilities to SOLA-DF and deserve an expanded explanation. A variation of SOLA-DF is contained in SOLA-LOOP, which is a one-dimensional network code.[5] The SOLA-LOOP program is designed to handle systems of one-dimensional components coupled together through junctions. Variable time steps may be used in different components, and provisions are available for defining trips, breaks, valves, and other transient features. SOLA-FLX consists of SOLA-DF coupled to a three-dimensional shell code.[8] This combination may be used for problems involving coupled fluid-structure interactions in which the structure is a cylindrical shell. Following the basic procedure used in SOLA-FLX, other types of structure models could be coupled to SOLA-DF.

II. EQUATIONS AND CONSTITUTIVE RELATIONS

The drift-flux equations describing the dynamics of two-phase fluid mixtures have been cast in many forms.[9] In the present case we choose as dependent variables the mixture density ρ, the macroscopic vapor density ρ_v, (vapor mass per unit volume of mixture) the center-of-mass velocity $\underline{u} = (u,v)$, and the mixture specific internal energy I. Important auxiliary variables are the void fraction θ, the relative velocity between phases $\underline{u}_r = (u_r, v_r)$, and the mixture pressure p.

A. Equations of Motion

In terms of the chosen dependent variables, the basic two-dimensional drift-flux equations used in SOLA-DF are

the continuity equations,

$$\frac{\partial \rho}{\partial t} + \frac{1}{A}\left(\frac{\partial A\rho u}{\partial x} + \frac{\partial A\rho v}{\partial y}\right) = 0 \qquad (2.1)$$

$$\frac{\partial \rho_v}{\partial t} + \frac{1}{A}\left[\frac{\partial}{\partial x} A\left(\rho_v u + \frac{\rho_v \rho_\ell}{\rho} u_r\right) + \frac{\partial}{\partial y} A\left(\rho_v v + \frac{\rho_v \rho_\ell}{\rho} v_r\right)\right] = \Gamma \quad ; \qquad (2.2)$$

the momentum equations,

$$\frac{\partial \rho u}{\partial t} + \frac{1}{A}\left[\frac{\partial}{\partial x} A\left(\rho u^2 + \frac{\rho_v \rho_\ell}{\rho} u_r^2\right) + \frac{\partial}{\partial y} A\left(\rho uv + \frac{\rho_v \rho_\ell}{\rho} u_r v_r\right)\right]$$

$$= -\frac{\partial p}{\partial x} + \rho g_x + f_{visx}$$

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$$\frac{\partial \rho v}{\partial t} + \frac{1}{A}\left[\frac{\partial}{\partial x} A \left(\rho u v + \frac{\rho_v \rho_\ell}{\rho} u_r v_r\right) + \frac{\partial}{\partial y} A \left(\rho v^2 + \frac{\rho_v \rho_\ell}{\rho} v_r^2\right)\right]$$

$$= - \frac{\partial p}{\partial y} + \rho g_y + f_{visy} \quad ; \tag{2.3}$$

and the internal energy equation,

$$\frac{\partial \rho I}{\partial t} + \frac{1}{A}\left\{\frac{\partial}{\partial x} A \left[\rho I u + \frac{\rho_v \rho_\ell}{\rho} (I_v - I_\ell) u_r\right] + \frac{\partial}{\partial y} A \left[\rho I v + \frac{\rho_v \rho_\ell}{\rho} (I_v - I_\ell) v_r\right]\right\}$$

$$= - \frac{p}{A}\left\{\frac{\partial}{\partial x} A \left[u + \frac{\rho_v \rho_\ell}{\rho}\left(\frac{1}{\rho_v^o} - \frac{1}{\rho_\ell^o}\right) u_r\right] + \frac{\partial}{\partial y} A \left[v + \frac{\rho_v \rho_\ell}{\rho}\left(\frac{1}{\rho_v^o}\right.\right.\right.$$

$$\left.\left.\left. - \frac{1}{\rho_\ell^o}\right) v_r\right]\right\} + K\left(u_r^2 + v_r^2\right) + J_{vis} \quad . \tag{2.4}$$

In these equations, the independent variables are time t and coordinates x,y. The exchange functions for mass and momentum are Γ and K, respectively. Subscripts v and ℓ refer to properties in the vapor and liquid states while a superscript zero refers to microscopic quantities. The gravitational acceleration is denoted by $\underline{g} = (g_x, g_y)$.

The quantity A is the time-independent "thickness" of the flow channel. That is, A Δx Δy is the volume associated with an area Δx wide and Δy high. In addition to representing variable area ducts, we may use suitably defined A values to represent cylindrical coordinates (A = x, the circumferential area per unit azimuthal angle) or obstacle regions (A = 0).

To complete these equations a variety of constitutive relations must be defined. It is in the definition of these relations that considerable caution must be exercised. The choices made are governed by the applications for which the code is intended. The best choices are those that can be tested against suitable experimental data. Even with careful testing, however, the prejudices of different researchers often lead to different constitutive relations. In the following we describe one set of simple constitutive models that have been used in the initial development of the SOLA-DF, SOLA-FLX, and SOLA-LOOP codes. These models should not, therefore, be taken as invariant features of these codes. Instead, the codes are to be thought of as skeletons offering numerical solution algorithms that will work with a variety of constitutive relations.

B. Void Fraction

The volume of vapor per unit volume of mixture, that is, the void fraction θ is defined through the relation

$$\theta = \left(\rho_\ell^o - \rho + \rho_v\right)\Big/\rho_\ell^o \quad . \tag{2.5}$$

C. Equation of State

In the present formulation of SOLA-DF the equation of state is assumed to be a relation that gives pressure as a function of density and internal energy. Although fits to steam table data could be inserted in the equation-of-state subroutine, for developmental purposes we have chosen to use a much simpler approach. When the void fraction is below a small, predetermined value, $\theta < \theta_c$, (typically $\theta_c \approx 0.005$) the fluid is assumed to be a pure liquid with the equation of state

$$p = p_o + a^2\left(\rho - \rho_\ell^o\right) \quad ,$$

where a is a representative speed of sound in the liquid phase and p_o is chosen (see Eq. 2.6) to ensure pressure continuity between the pure liquid and two-phase states when $\theta = \theta_c$. In the two-phase region, $\theta > \theta_c$, the mixture pressure is equal to that of the vapor and is given by the polytropic gas equation,

$$p = (\gamma - 1)\ \rho_v^o\ I_v \quad .$$

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In the code these equations are combined into the single equation

$$p = (\gamma - 1)\,\rho_v I_v/\theta^* + a^2\,\rho_\ell^o(\theta^* - \theta) \quad , \tag{2.6}$$

$$\text{where } \theta^* = \begin{cases} \theta \text{ if } \theta \geq \theta_c \\ \theta_c \text{ if } \theta < \theta_c \end{cases} \quad .$$

For saturated conditions we have found that $\gamma = 1.07$ and $a^2 \approx 10^4\ cm^2/ms^2$ offer reasonable approximations for many reactor safety problems.

D. Vapor and Liquid Internal Energies

In the equation of state and in the relative velocity convection terms in the internal energy equation, it is necessary to have separate values for vapor and liquid internal energies. Because the basic dependent energy variable is the mixture internal energy, a separate prescription must be given for unfolding the individual phase energies. Two prescriptions have been used. In one the phases are assumed to be at equal temperatures. In the other, the vapor phase is assumed to be saturated. For many applications there is little difference between the two assumptions, because the large heat content of the more massive liquid phase keeps the liquid temperature nearly the same in either case.

To implement either of these assumptions we approximate the temperature dependence of the internal energies as

$$\begin{aligned} I_v &= E_v + C_v(T_v - T_o) \\ I_\ell &= E_\ell + C_\ell(T_\ell - T_o) \quad , \end{aligned} \tag{2.7}$$

where E_v and E_ℓ are saturated internal energies at temperature T_o and C_v and C_ℓ are constants chosen to fit the steam table versus T curves in the temperature range of interest. For example, in the system of units g, cm, ms, K the values $E_v = 2.506 \times 10^4$, $E_\ell = 0.4174 \times 10^4$, $C_v = 6.67$ and $C_\ell = 44.34$ are good approximations for temperatures up to about T = 550 K.

With these definitions, and assuming equal phase temperatures, the mixture temperature can be computed from the mixture internal energy as the solution of the linear equation,

$$\rho I = \rho_v I_v + \rho_\ell I_\ell \quad . \tag{2.8}$$

When the vapor is assumed to be saturated its temperature and pressure are related by

$$T_v = 255.2 + 117.8\ p^{0.223} \quad , \tag{2.9}$$

where in this expression p must be in bars and T in kelvins. Knowing the vapor temperature it is then an easy task to compute the separate liquid and vapor internal energies and liquid temperature using Eqs. (2.7) and (2.8).

E. Relative Velocity

An equation of motion for the relative velocity can be derived from equations describing a complete two-fluid model,[10] given by

$$\frac{\partial u_r}{\partial t} + \frac{1}{2}\frac{\partial}{\partial x}\left\{u_r\left[2u + \frac{u_r}{\rho}(\rho_\ell - \rho_v)\right]\right\} + v_v\frac{\partial u_v}{\partial y} - v_\ell\frac{\partial u_\ell}{\partial y}$$
$$= \left(\frac{1}{\rho_\ell^o} - \frac{1}{\rho_v^o}\right)\frac{\partial p}{\partial x} - K\frac{\rho}{\rho_v\rho_\ell}u_r$$

$$\frac{\partial v_r}{\partial t} + \frac{1}{2}\frac{\partial}{\partial y}\left\{v_r\left[2v + \frac{v_r}{\rho}(\rho_\ell - \rho_v)\right]\right\} + u_v\frac{\partial v_v}{\partial x} - u_\ell\frac{\partial v_\ell}{\partial x}$$
$$= \left(\frac{1}{\rho_\ell^o} - \frac{1}{\rho_v^o}\right)\frac{\partial p}{\partial y} - K\frac{\rho}{\rho_v\rho_\ell}v_r \quad , \tag{2.10}$$

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where $u_r = u_v - u_\ell$, $v_r = v_v - v_\ell$,

$$u = \frac{\rho_v u_v + \rho_\ell u_\ell}{\rho} \quad , \quad v = \frac{\rho_v v_v + \rho_\ell v_\ell}{\rho} \quad ,$$

$$\rho = \rho_v + \rho_\ell \quad ,$$

and K is the interfacial friction coefficient.

The current version of SOLA-DF neglects all but the temporal term on the left side of Eq. 2.10. Assuming the vapor is a dispersed phase of small bubbles when θ is small, or the liquid is a dispersed phase of small droplets when θ is large, we can estimate K from the drag on an individual bubble (or droplet) times the number of bubbles (droplets) per unit volume, N. The result is

$$K = \frac{\rho S}{8\theta_1}\left[C_d \left|\underline{u}_r\right| + \frac{12\nu}{r_o}\right] \quad , \qquad (2.11)$$

where

$$\theta_1 = \theta, \ \nu = \nu_\ell (1-\theta)^{-2.5} \ \text{for } \theta \leq 1/2$$

$$\theta_1 = 1-\theta, \ \nu = \nu_v \theta^{-2.5} \ \text{for } \theta > 1/2 \quad .$$

C_d is a drag coefficient (generally of order unity), S is the cross-sectional area per unit volume of bubbles (droplets) with radius r_o,

$$S = \begin{cases} \dfrac{3\theta}{4r_b} \text{ and } r_o = r_b \quad \text{if } \theta \leq 1/2 \\ \\ \dfrac{3(1-\theta)}{4r_d} \text{ and } r_o = r_d \text{ if } \theta > 1/2 \end{cases} \quad , \qquad (2.12)$$

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and ν is the kinematic viscosity. The average radius is related to the number density by the expressions

$$r_b = \left(\frac{3\theta}{4\pi N}\right)^{1/3} \qquad \text{for } \theta \leq 1/2$$

$$r_d = \left[\frac{3(1-\theta)}{4\pi N}\right]^{1/3} \qquad \text{for } \theta > 1/2 \quad . \qquad (2.13)$$

The bubble number N is often assumed to be a constant independent of space and time. This, of course, is an approximation that will not work when preferential nucleating sites are desired. Although N must be estimated for each calculation, as described in the next section, a locally variable N can sometimes be estimated in terms of a critical Weber number.

F. Phase Transitions

The form of the phase change model embodied in Γ is crucial if nonequilibrium effects are to be correctly predicted. The model we describe here is still under development and is not yet sophisticated enough to be used as a predictive tool without some adjustment. Nevertheless, this model has proven useful in numerous applications and its presentation here illustrates the types of considerations necessary in the development of such models.

Defining q as the interfacial heat flux, a simple energy balance shows that

$$\Gamma = \frac{qZ}{\lambda} \quad ,$$

where λ is the latent heat of vaporization and interfacial area Z is related to the bubble radius, r, according to $Z = 3\theta/r$. The heat flux can be further defined as

$$q = k(T_\ell - T_s)/\ell \quad ,$$

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where T_s is the saturation temperature and k_ℓ is the thermal conductivity of the liquid whose bulk temperature is T_ℓ. The length ℓ characterizes the thickness of the thermal boundary layer over which the liquid temperature changes from its interior, bulk value, T_ℓ, to the value T_s assumed to exist at the two-phase interface. Thus,

$$\Gamma = \frac{k_\ell (T_\ell - T_s) Z}{\lambda \ell} \quad . \tag{2.14}$$

For a single, nontranslating bubble growing in an infinite fluid region, it has been shown[11] that $\ell = \ell_c$, where

$$\ell_c = r \left[\frac{6}{\pi} \frac{\rho_\ell^o}{\rho_v^o} \frac{C_\ell |T_\ell - T_s|}{\lambda} \right]^{-1} \quad .$$

In this expression r is the instantaneous bubble radius, which is defined later.

When the bubbles are translating with respect to the surrounding liquid with speed, U, then $\ell = \ell_u$, and Moalem and Sideman[12] give the general expression

$$\ell_u = r \left(\frac{\pi}{Re_b Pr} \right)^{\frac{1}{2}} \quad ,$$

where $Re_b = 2rU \rho_\ell^o/\mu_\ell$ is the bubble Reynolds number, $Pr = C_\ell \mu_\ell / k_\ell$ is the liquid Prandtl number, and μ_ℓ is the liquid shear viscosity. As the relative speed U increases, the length ℓ_u rapidly decreases below the value of ℓ_c, which represents stripping away of the thermal boundary layer by relative flow. In an attempt to smoothly combine both these effects, we have defined ℓ as the reciprocal average of these limiting characteristic lengths,

$$\frac{1}{\ell} = \frac{1}{\ell_c} + \frac{1}{\ell_u} \quad . \tag{2.15}$$

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Equation (2.14) with ℓ defined by the above equation is a vapor generation rate that includes both finite heat conduction and relative velocity effects. However, the model still requires the definition of r and U.

If we know the number of bubbles per unit volume, then we can calculate the average bubble radius by Eq. (2.13) and use $r=r_o$. Unfortunately, the number of bubbles generally does not remain constant in a dynamic flow environment because bubbles larger than a certain size will break up. The maximum stable bubble radius r_w can be estimated in terms of a critical Weber number W_c,

$$r_w = \frac{\sigma W_c}{2\rho_\ell^o U^2} \quad , \tag{2.16}$$

where σ is the interfacial surface tension. The value of W_c is often taken as 4 for turbulent flow conditions.[13] Thus, we define r as equal to the minimum of r_o and r_w and reserve N as an input parameter that defines the initial number of nucleating sites per unit volume (or more correctly, the minimum number of bubbles).

Finally, the relative speed U could simply be set equal to the magnitude of the average relative speed $|\underline{u}_r|$ between phases, but this would not account for local turbulent fluctuations that have been averaged out in the definition of $\underline{u}_r$. Fluctuations in $\underline{u}_r$ can locally strip away the individual bubble thermal boundary layers and break up large bubbles. To account for such local effects we define

$$U = |\underline{u}_r| + \beta|\underline{u}| \quad , \tag{2.17}$$

where $\underline{u}$ is the mass averaged mixture velocity and β is a parameter. The β term accounts for turbulent fluctuations. We might expect β to have a magnitude of 0.1 or less because large turbulent velocity fluctuations are often observed to have magnitudes as large as 10% of the mean velocities. In general, the best value of β must be determined by comparisons with experimental data.

Again, it should be stressed that the vapor generation rate described above is preliminary and needs to be critically tested against a wide variety of situations before it can be recommended for general use. Nevertheless, this model does embrace, as special cases, the models used by many other investigators and it has produced good results in several different applications.

G. Pipe Friction

In one-dimensional applications involving flow in pipes it is desirable to have a model for pipe wall friction. SOLA-DF contains a subroutine, PFRIC for this purpose. This subroutine is only called when the one-dimensional option (DIM = 1) is set in the input data list, and only when the pipe radius, RPIPE, is initialized to a nonzero value.

Flow losses arising from wall friction affect the momentum and energy of the flow through the terms f_{vis} and W_{vis} in Eqs. (2.3) and (2.4), respectively. The pipe friction model f_{vis} contained in PFRIC is based on the Armand two-phase flow friction multiplier and uses the Colebrook approximation for the single-phase friction factor

$$f_{vis} = - \frac{f}{R} \frac{\rho}{\rho_\ell^o} (1-\psi)^2 \phi_{TP} \; \rho_\ell^o u^2 \quad . \tag{2.18}$$

Here the friction coefficient f depends on the relative roughness (k/R) and the Reynolds number $Re = 2uR/\nu_\ell$,

$$f = a + b \; Re^{-c} \quad , \tag{2.19}$$

where

$$a = 0.026 \; (k/2R)^{0.225} + 0.133 \; (k/2R) \quad ,$$

$$b = 22.0 \; (k/2R)^{0.44} \quad ,$$

$$c = 1.62\ (k/2R)^{0.134} \quad ,$$

and R is the hydraulic radius. The quantity ϕ_{TP} is a two-phase friction multiplier

$$\phi_{TP}^2 = (1-\theta)^{-1.75} \quad ,$$

and ψ accounts for the effects of relative velocity

$$\psi = \rho_v[1 + (\rho-\rho_v)u_r/\rho u]^2/\rho \quad .$$

The value of W_{vis} is determined from the rate of change of the fluid kinetic energy associated with the f_{vis} flow loss.

III. NUMERICAL SOLUTION METHOD

Numerous schemes can be devised to numerically solve the equations outlined in the previous section. Different schemes will have varying degrees of accuracy, numerical stability, programming simplicity, flexibility for change, and computational efficiency. Unfortunately, these desirable traits are often mutually exclusive. For example, the use of implicit difference equations to achieve unconditional numerical stability can also result in poor accuracy and generally requires more complex programming and more computer memory. Because different applications require different mixtures of the desirable features, the choice of an optimum solution algorithm can rarely be made. Thus, the choice of a numerical solution procedure generally requires a balance to be made primarily between programming simplicity and the flexibility for future evolution versus stability, accuracy, and computational speed. Inevitably, the choice rests on the particular experience and prejudices of the developer.

In the SOLA-DF code an attempt has been made to keep the programming simple and to use a limited implicitness. In all cases, point relaxation methods have been retained in place of direct solvers for coupled sets of equations.

Although point relaxation methods are generally recognized as simple, but inferior to direct methods for linear equation systems, this is not necessarily the case for nonlinear equations where iterative methods must be used anyway. The point relaxation method permits considerable latitude for adding new features, changing boundary conditions, varying time steps, and making other gross changes in the basic code to adapt it to new applications.

Additionally, the code has been written in a modular form consisting of numerous subroutines that isolate individual logical and physical processes. This structure makes the present code particularly easy to modify and extend for new applications.

A. Mesh Construction

The finite-difference mesh used for numerical solution of the above equations consists of rectangular cells of width δx and height δy. The part of the mesh that contains fluid is composed of IBAR cells in the x-direction, labeled with the index i, and JBAR cells in the y-direction, labeled with the index j. This region is surrounded by a single layer of fictitious cells so that the complete mesh is IMAX = IBAR + 2 by JMAX = JBAR + 2 cells (see Fig. 1). The dependent variables are located within a cell as shown in Fig. 2: x-directed velocities at the middle of the vertical sides, y-directed velocities at the middle of the horizontal sides, and all other variables at the cell center.

Finite-difference subscripting used in the computer code is based on the convention that (i,j) refers to the center of the cell labeled by (i,j) or to the right or top boundary of the cell in the case of velocities, which are located at those cell boundaries.

B. Solution Algorithm

A time cycle of calculation is broken down into four tasks. First, the momentum equations, Eq. (2.3), are advanced explicitly using the previous cycle values for evaluating all contributions. Next an iteration is undertaken to replace the pressure used in the first task with advanced time values. An iteration is needed because the advanced pressures depend on the velocities being calculated. This part of the cycle contains the main implicitness of the numerical scheme. The pressure iteration permits sound waves to propagate more than one mesh cell per cycle. In fact, this scheme is a variant of the ICE technique,[14] which may be used for very low speed (incompressible) flows as well as for high-speed flows containing shock waves and rarefactions. The third

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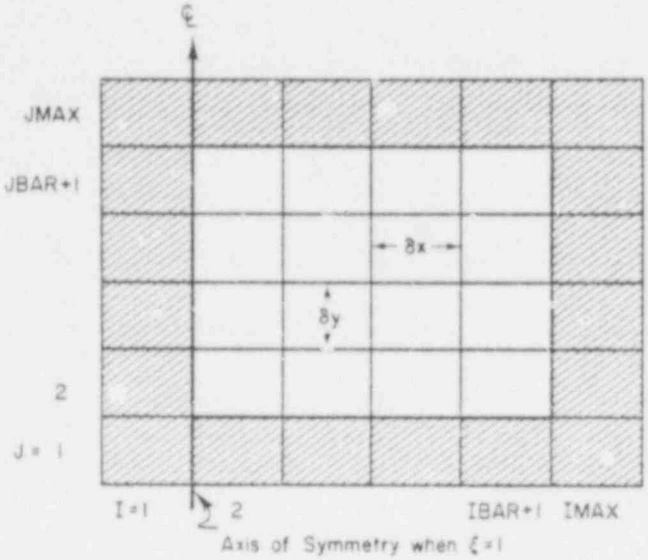

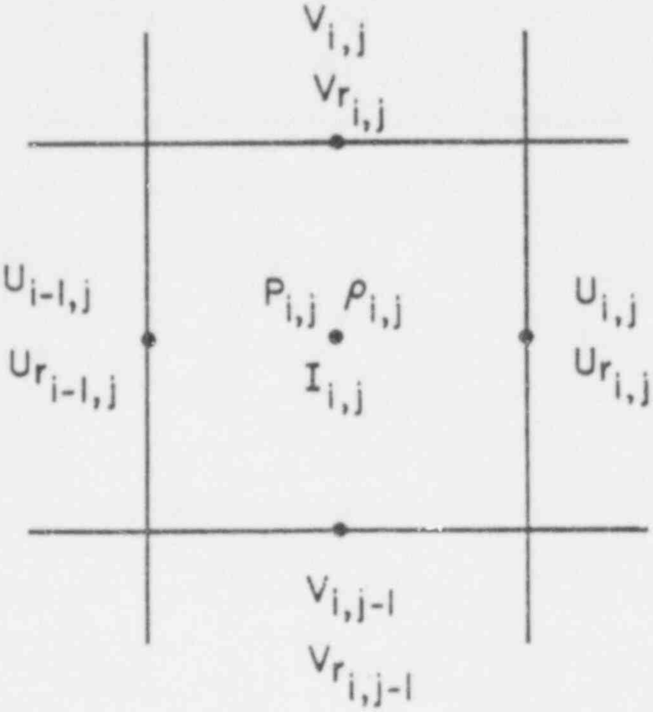

Fig. 1. General mesh arrangement. Fictitious boundary cells are shaded.

Fig. 2. Arrangement of finite difference variables in a typical mesh cell.

task in a cycle is to update all other dependent variables. Finally, the fourth task consists of data output, time step controls, and bookkeeping operations.

For a purely explicit calculation, the iteration making up the second task may be omitted by setting the input number IMP equal to zero.

1. Explicit Updating of Velocities. Before introducing finite difference approximations for the momentum equation, Eq. (2.3), it is first written in the equivalent differential form,

$$\frac{\partial u}{\partial t} + u\,\frac{\partial u}{\partial x} + \frac{1}{\rho A}\,\frac{\partial}{\partial x}\left(\frac{A\rho_v\rho_\ell}{\rho}\;u_r^{\,2}\right) + v\,\frac{\partial u}{\partial y} + \frac{1}{\rho A}\,\frac{\partial}{\partial y}\left(\frac{A\rho_v\rho_\ell}{\rho}\;u_r v_r\right)$$

$$= -\frac{1}{\rho}\,\frac{\partial p}{\partial x} + g_x + \frac{1}{\rho}\,f_{visx}$$

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$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + \frac{1}{\rho A}\frac{\partial}{\partial x}\left(\frac{A\rho_v\rho_\ell}{\rho}\,u_r v_r\right) + v\frac{\partial v}{\partial y} + \frac{1}{\rho A}\frac{\partial}{\partial y}\left(\frac{A\rho_v\rho_\ell}{\rho}\,v_r^{\,2}\right)$$

$$= -\frac{1}{\rho}\frac{\partial p}{\partial y} + g_y + \frac{1}{\rho}f_{visy} \quad . \tag{3.1}$$

This form is a carryover from previous codes in the SOLA series. Its advantage is that u^{n+1} and v^{n+1} are calculated directly rather than $(\rho u)^{n+1}$ and $(\rho v)^{n+1}$. The disadvantage of this equation is that it is not in conservation form so we do not get rigorous conservation of momentum in the difference approximation. When percentage changes in dependent variables from one cell to the next are not large this nonconservation form of the momentum equations should not cause any problems. In general, it would probably be a good idea to monitor the total momentum of the system in order to have a check on the accuracy of Eq. (3.1), but this has not been included in the present version of the code. The difference equations used to approximate Eq. (3.1) are

$$\tilde{u}_{i,j} = u_{i,j} + \delta t\left[\frac{2(p_{i,j} - p_{i+1,j})}{\delta x(\rho_{i,j}+\rho_{i+1,j})} + g_x + f_{visx_{i,j}} - FUX - FUY - FDU\right]$$

$$\tilde{v}_{i,j} = v_{i,j} + \delta t\left[\frac{2(p_{i,j} - p_{i,j+1})}{\delta y(\rho_{i,j}+\rho_{i,j+1})} + g_y + f_{visy_{i,j}} - FVX - FVY - FDV\right] \quad , \tag{3.2}$$

where $\tilde{u}_{i,j}$ and $\tilde{v}_{i,j}$ are the explicit guesses for $u^{n+1}_{i,j}$ and $v^{n+1}_{i,j}$, respectively. In all cases, the boundary values of cell-centered quantities will be defined by linear interpolation, as for ρ used above, unless otherwise noted. The indexing in this equation looks uncentered but recall from Fig. 2 that $u_{i,j}$ and $v_{i,j}$ refer to the velocities at the boundary between cells i and i+1 and j and j+1, respectively. The convective fluxes are defined as

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$$FUX = \frac{1}{2\delta x} [u_{i,j}(u_{i+1,j} - u_{i-1,j})$$

$$- \alpha|u_{i,j}| (u_{i+1,j} - 2u_{i,j} + u_{i-1,j})]$$

$$FUY = \frac{1}{8\delta y} [(v_{i,j} + v_{i+1,j} + v_{i,j-1} + v_{i+1,j-1})(u_{i,j+1} - u_{i,j-1})$$

$$- \alpha|v_{i,j} + v_{i+1,j} + v_{i,j-1} + v_{i+1,j-1}|(u_{i,j+1} - 2u_{i,j} + u_{i,j-1})]$$

The parameter α appearing in the convective fluxes is used to give a variable amount of upstream differencing. When α is zero the approximations reduce to the usual centered differenced form; however, this is known to result in an unstable algorithm.[15] When α is unity the approximations are the so-called donor cell or fully upstream (or upwind) difference expressions, which are stable provided fluid does not convect through more than one mesh cell in one time step. In general, numerical stability is expected (see Ref. 15) when α is chosen such that

$$\alpha > \max\left[\frac{u\delta t}{\delta x} , \frac{v\delta t}{\delta y} , \frac{\rho_v \rho_\ell u_r \delta t}{\rho^2 \delta x} , \frac{\rho_v \rho_\ell v_r \delta t}{\rho^2 \delta y} \right] .$$

The remaining flux terms are

$$FDU = \frac{1}{A_R} \left\{ \frac{1}{\delta x} \left[(RUR)\left(u_{r_{i,j}} + u_{r_{i+1,j}}\right) + \alpha|(RUR)|\left(u_{r_{i,j}} - u_{r_{i+1,j}}\right) \right. \right.$$

$$\left. - (RUL)\left(u_{r_{i-1,j}} + u_{r_{i,j}}\right) - \alpha|(RUL)|\left(u_{r_{i-1,j}} - u_{r_{i,j}}\right) \right]$$

$$+ \frac{1}{\delta y} \left[(VDT)(RUC + RUT) + \alpha|(VDT)|(RUC - RUT) - (VDB)(RUB + RUC) \right.$$

$$\left. \left. - \alpha|(VDB)|(RUB - RUC) \right] \right\} / (\rho_{i,j} + \rho_{i+1,j}) .$$

$$FVX = \frac{1}{8\delta x}\,[(u_{i-1,j+1} + u_{i,j+1} + u_{i-1,j} + u_{i,j})(v_{i+1,j} + v_{i-1,j})$$

$$- \alpha|u_{i-1,j+1} + u_{i,j+1} + u_{i-1,j} + u_{i,j}|(v_{i+1,j} - 2v_{i,j}$$

$$+ v_{i-1,j})] \quad ,$$

$$FVY = \frac{1}{2\delta y}\,[v_{i,j}(v_{i,j+1} - v_{i,j-1}) - \alpha|v_{i,j}|(v_{i,j+1} - 2v_{i,j} + v_{i,j-1})] \quad ,$$

$$FDV = \frac{1}{A_T}\left\{\frac{1}{\delta x}\,[(UDR)(RVC + RVR) + \alpha|(UDR)|(RVC - RVR) - (UDL)(RVL + RVC)\right.$$

$$- \alpha|UDL|(RVL - RVC)] + \frac{1}{\delta y}\left[RVT\left(v_{r_{i,j}} + v_{r_{i,j+1}}\right) + \alpha|(RVT)|\left(v_{r_{i,j}}\right.\right.$$

$$\left.- v_{r_{i,j+1}}\right) - (RVB)\left(v_{r_{i,j-1}} + v_{r_{i,j}}\right) - \alpha|(RVB)|\left(v_{r_{i,j-1}}\right.$$

$$\left.\left.\left.- v_{r_{i,j}}\right)\right]\right\}/(\rho_{i,j} + \rho_{i,j+1}) \quad ,$$

where

$$A_R = \frac{2\,A_{i,j}\,A_{i+1,j}}{A_{i,j} + A_{i+1,j}} \quad ,$$

$$RUR = \frac{\rho_{v_{i+1,j}}\,\rho_{\ell_{i+1,j}}}{\rho_{i+1,j}}\;\frac{\left(u_{r_{i,j}} + u_{r_{i+1,j}}\right)}{2}\;A_{i+1,j} \quad ,$$

$$RUL = \frac{\rho_{v_{i,j}}\,\rho_{\ell_{i,j}}}{\rho_{i,j}}\;\frac{\left(u_{r_{i-1,j}} + u_{r_{i,j}}\right)}{2}\;A_{i,j} \quad ,$$

$$VDT = \frac{\left(v_{r_{i,j}} + v_{r_{i+1,j}}\right)}{2}\left(\frac{A_{i,j}\,A_{i,j+1}}{A_{i,j}+A_{i,j+1}} + \frac{A_{i+1,j}\,A_{i+1,j+1}}{A_{i+1,j}+A_{i+1,j+1}}\right) \quad ,$$

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$$RUC = \frac{u_{r_{i,j}}}{2}\left(\frac{\rho_{v_{i,j}}\,\rho_{\ell_{i,j}}}{\rho_{i,j}} + \frac{\rho_{v_{i+1,j}}\,\rho_{\ell_{i+1,j}}}{\rho_{i+1,j}}\right) ,$$

$$RUT = \frac{u_{r_{i,j+1}}}{2}\left(\frac{\rho_{v_{i,j+1}}\,\rho_{\ell_{i,j+1}}}{\rho_{i,j+1}} + \frac{\rho_{v_{i+1,j+1}}\,\rho_{\ell_{i+1,j+1}}}{\rho_{i+1,j+1}}\right) ,$$

$$VDB = \frac{\left(v_{r_{i,j-1}} + v_{r_{i+1,j-1}}\right)}{2}\left(\frac{A_{i,j}\,A_{i,j-1}}{A_{i,j}+A_{i,j-1}} + \frac{A_{i+1,j}\,A_{i+1,j-1}}{A_{i+1,j}\,A_{i+1,j-1}}\right) ,$$

$$RUB = \frac{u_{r_{i,j-1}}}{2}\left(\frac{\rho_{v_{i,j-1}}\,\rho_{\ell_{i,j-1}}}{\rho_{i,j-1}} + \frac{\rho_{v_{i+1,j-1}}\,\rho_{\ell_{i+1,j-1}}}{\rho_{i+1,j-1}}\right) ,$$

$$A_T = \frac{2\,A_{i,j}\,A_{i,j+1}}{A_{i,j} + A_{i,j+1}} ,$$

$$UDR = \frac{\left(u_{r_{i,j}} + u_{r_{i,j+1}}\right)}{2}\left(\frac{A_{i,j}\,A_{i+1,j}}{A_{i,j}+A_{i+1,j}} + \frac{A_{i,j+1}\,A_{i+1,j+1}}{A_{i,j+1}+A_{i+1,j+1}}\right) ,$$

$$RVC = \frac{v_{r_{i,j}}}{2}\left(\frac{\rho_{v_{i,j}}\,\rho_{\ell_{i,j}}}{\rho_{i,j}} + \frac{\rho_{v_{i,j+1}}\,\rho_{\ell_{i,j+1}}}{\rho_{i,j+1}}\right) ,$$

$$RVR = \frac{v_{r_{i+1,j}}}{2}\left(\frac{\rho_{v_{i+1,j}}\,\rho_{\ell_{i+1,j}}}{\rho_{i+1,j}} + \frac{\rho_{v_{i+1,j+1}}\,\rho_{\ell_{i+1,j+1}}}{\rho_{i+1,j+1}}\right) ,$$

$$UDL = \frac{\left(u_{r_{i-1,j}} + u_{r_{i-1,j+1}}\right)}{2}\left(\frac{A_{i,j}\,A_{i-1,j}}{A_{i,j}+A_{i-1,j}} + \frac{A_{i,j+1}\,A_{i-1,j+1}}{A_{i,j+1}+A_{i-1,j+1}}\right) ,$$

$$RVL = \frac{v_{r_{i-1,j}}}{2}\left(\frac{\rho_{v_{i-1,j}}\,\rho_{\ell_{i-1,j}}}{\rho_{i-1,j}} + \frac{\rho_{v_{i-1,j+1}}\,\rho_{\ell_{i-1,j+1}}}{\rho_{i-1,j+1}}\right) ,$$

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$$RVT = \frac{\rho_{v_{i,j+1}} \rho_{\ell_{i,j+1}}}{\rho_{i,j+1}} \left(\frac{v_{r_{i,j}} + v_{r_{i,j+1}}}{2}\right) A_{i,j+1} \quad , \text{ and}$$

$$RVB = \frac{\rho_{v_{i,j}} \rho_{\ell_{i,j}}}{\rho_{i,j}} \left(\frac{v_{r_{i,j-1}} + v_{r_{i,j}}}{2}\right) A_{i,j} \quad .$$

For the cell boundary areas, we do not use a linearly interpolated value, but instead, prefer a combined geometric and arithmetic average, e.g.,

$$A_{i,j+\frac{1}{2}} = \frac{2 A_{i,j} A_{i,j+1}}{(A_{i,j} + A_{i,j+}} \quad .$$

This choice has the convenient feature that $A_{i,j+\frac{1}{2}}$ vanishes when either $A_{i,j}$ or $A_{i,j+1}$ is zero.

2. Implicit Pressure Calculation. In this part of the calculational cycle the n level pressures appearing in Eq. (3.2) are to be replaced by approximations for the n+1 level pressures. This is done by solving for the pressure in each cell that satisfies the implicit equation

$$F = p - f(\bar{\rho}, \bar{\rho}_v, \bar{I}) = 0 \quad , \tag{3.3}$$

where $f(\bar{\rho}, \bar{\rho}_v, \bar{I})$ is the equation of state evaluated using

$$\bar{\rho} = \rho^n/(1 + D) \quad ,$$

$$\bar{\rho}_v = \rho_v{}^n/(1 + D) \quad ,$$

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$$\bar{I} = I^n - \frac{p^n}{\rho^n} D \quad , \tag{3.4}$$

and D is an approximation to cell volume change per unit volume,

$$\begin{aligned} D &= \frac{\delta t}{A} \left[\frac{\partial}{\partial x} (Au) + \frac{\partial}{\partial y} (Av) \right] \\ &= \frac{\delta t}{A} \left[\frac{1}{\delta x} (A_{i+\frac{1}{2},j} \, u_{i,j} - A_{i-\frac{1}{2},j} \, u_{i-1,j}) \right. \\ &\quad \left. + \frac{1}{\delta y} (A_{i,j+\frac{1}{2}} \, v_{i,j} - A_{i,j-\frac{1}{2}} \, v_{i,j-1}) \right] \quad . \end{aligned} \tag{3.5}$$

The n+1 level velocities must be used in evaluating D; that is,

$$u^{n+1}_{i,j} = \tilde{u}_{i,j} - \frac{2\delta t}{(\rho_{i+1,j} + \rho_{i,j})} (p_{i+1,j} - p^n_{i+1,j} - p_{i,j} + p^n_{i,j}) \quad , \tag{3.6}$$

and

$$v^{n+1}_{i,j} = v_{i,j} - \frac{2\delta t}{(\rho_{i,j+1} + \rho_{i,j})} (p_{i,j+1} - p^n_{i,j+1} - p_{i,j} + p^n_{i,j}) \quad . \tag{3.7}$$

Because the n+1 level velocities depend on p the implicit nature of Eq. (3.3) is obvious. The pressure that satisfies Eqs. (3.3)-(3.7) is not quite p^{n+1}, because convective fluxes are omitted from the estimates of the new densities $\bar{\rho}$, $\bar{\rho}_v$, and energy $\bar{I}$. It would be equal to p^{n+1} if the remainder of the equations were in Lagrangian form. The difference is not significant, however, because the iteration is always trying to drive p to its equation-of-state value every cycle. In this sense p is a stored variable and is not identically equal to the equation-of-state value unless the iterations are omitted and an explicit

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calculation is used. It is important to note that densities and energies are not actually changed during the iteration, because Eq. (3.4) is only used to estimate the new values. To obtain a solution of Eqs. (3.3)-(3.7) a local Newton-Raphson procedure is followed. For this purpose an estimate is needed for $\partial F/\partial p$ in each cell. In SOLA-DF, first guesses for these values are computed by a numerical differentiation. This is done at the beginning of each cycle and the values stored. Once the iteration has started, new values are computed and stored after each iteration. In summary, the following steps are performed for a single cell (i,j):

a. compute D according to Eq. (3.5) using the most updated values of u and v from Eqs. (3.6) and (3.7),

b. compute $\bar{\rho}$, $\bar{\rho}_v$, and $\bar{I}$ from Eq. (3.4),

c. evaluate the equation-of-state function and calculate $\delta p = - F/\partial F/\partial p)$,

d. replace $p_{i,j}$ by $p_{i,j} + \delta p_{i,j}$, and $u_{i,j}$, $u_{i-1,j}$, $v_{i,j}$, and $v_{i,j-1}$ by

$$u_{i,j} = u_{i,j} + \frac{2\,\delta t\,\delta p}{\delta x(\rho_{i,j}+\rho_{i+1,j})} \quad ,$$

$$u_{i-1,j} = u_{i-1,j} - \frac{2\,\delta t\,\delta p}{\delta x(\rho_{i-1,j}+\rho_{i,j})} \quad ,$$

$$v_{i,j} = v_{i,j} + \frac{2\,\delta t\,\delta p}{\delta y(\rho_{i,j}+\rho_{i,j+1})} \quad ,$$

and

$$v_{i,j-1} = v_{i,j-1} - \frac{2\,\delta t\,\delta p}{\delta y(\rho_{i,j-1}+\rho_{i,j})} \quad .$$

This iteration process is continued until all cells satisfy the convergence test

$$\left| \frac{p - f(\bar{\rho}, \bar{\rho}_v, \bar{I})}{p + f(\bar{\rho}, \bar{\rho}_v, \bar{I})} \right| < \varepsilon \quad ,$$

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where ε is typically equal to 0.001.

3. Updating of Remaining Variables. After the implicit portion of the cycle has been completed new time values for the remaining variables are readily computed. The mixture density changes only by convection,

$$\rho_{i,j}^{n+1} = \rho_{i,j} - \frac{\delta t}{A_{i,j}} \left\{ \frac{1}{\delta x} \left[A_{i+\frac{1}{2},j} \ (\rho u)_{i+\frac{1}{2},j} - A_{i-\frac{1}{2},j} \ (\rho u)_{i-\frac{1}{2},j} \right] + \frac{1}{\delta y} \left[A_{i,j+\frac{1}{2}} \ (\rho v)_{i,j+\frac{1}{2}} - A_{i,j-\frac{1}{2}} (\rho v)_{i,j-\frac{1}{2}} \right] \right\} \quad , \tag{3.8}$$

where

$$(\rho u)_{i+\frac{1}{2},j} = \frac{1}{2}\left[u_{i,j}(\rho_{i,j} + \rho_{i+1,j}) + \alpha |u_{i,j}| \ (\rho_{i,j} - \rho_{i+1,j}) \right] \quad ,$$

$$(\rho u)_{i-\frac{1}{2},j} = \frac{1}{2}\left[u_{i-1,j} \ (\rho_{i-1,j} + \rho_{i,j}) + \alpha |u_{i-1,j}| \ (\rho_{i-1,j} - \rho_{i,j}) \right] \quad ,$$

$$(\rho v)_{i,j+\frac{1}{2}} = \frac{1}{2}\left[v_{i,j} \ (\rho_{i,j} + \rho_{i,j+1}) + \alpha |v_{i,j}| \ (\rho_{i,j} - \rho_{i,j+1}) \right] \quad ,$$

and

$$(\rho v)_{i,j-\frac{1}{2}} = \frac{1}{2}\left[v_{i,j-1} \ (\rho_{i,j} + \rho_{i,j-1}) + \alpha |v_{i,j-1}| \ (\rho_{i,j} - \rho_{i,j-1}) \right] \quad .$$

Quantities on the right side of Eq. (3.8) are evaluated using n level values for ρ and the available n+1 level values of u.

The mixture energy equation is next approximated by

$$I_{i,j}^{n+1} = \frac{\rho_{i,j} \ I_{i,j}}{\rho_{i,j}^{n+1}} + \frac{\delta t}{\rho_{i,j}^{n+1}} \left\{ - FU - FV - FWK + \frac{1}{4} K_{i,j} \left[\left(u_{r_{i,j}} + u_{r_{i-1,j}} \right)^2 + \left(v_{r_{i,j}} + v_{r_{i,j-1}} \right)^2 \right] + \left(W_{vis_{i,j}} \right) \right\} , \tag{3.9}$$

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where

$$FU = \frac{1}{A_{i,j}\,\delta x}\left\{A_{i+\frac{1}{2},j}\left[(\rho Iu)_{i+\frac{1}{2},j} + \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)u_r\right)_{i+\frac{1}{2},j}\right]\right.$$

$$\left. - A_{i-\frac{1}{2},j}\left[(\rho Iu)_{i-\frac{1}{2},j} + \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)u_r\right)_{i-\frac{1}{2},j}\right]\right\} ,$$

$$FV = \frac{1}{A_{i,j}\,\delta y}\left\{A_{i,j+\frac{1}{2}}\left[(\rho Iv)_{i,j+\frac{1}{2}} + \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)v_r\right)_{i,j+\frac{1}{2}}\right]\right.$$

$$\left. - A_{i,j-\frac{1}{2}}\left[(\rho Iv)_{i,j-\frac{1}{2}} + \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)v_r\right)_{i,j-\frac{1}{2}}\right]\right\} .$$

For this formulation the boundary convective fluxes are approximated by

$$\left[(\rho Iu)_{i+\frac{1}{2},j} + \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)u_r\right)\right]_{i+\frac{1}{2},j}$$

$$= \frac{1}{2}\left\{u_{i,j}\left[(\rho I)_{i,j} + (\rho I)_{i+1,j}\right] + \alpha|u_{i,j}|\left[(\rho I)_{i,j}\right.\right.$$

$$\left. - (\rho I)_{i+1,j}\right] + u_{r_{i,j}}\left[\left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)\right)_{i,j}\right.$$

$$\left. + \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)\right)_{i+1,j}\right]$$

$$\left. + \alpha|u_{r_{i,j}}|\left[\left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)\right)_{i,j} - \left(\frac{\rho_v\rho_\ell}{\rho}(I_v - I_\ell)\right)_{i+1,j}\right]\right\} ,$$

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and similarly for $\left[(\rho I u)_{i-\frac{1}{2},j} + \left(\frac{\rho_v \rho_\ell}{\rho}(I_v - I_\ell)u_r\right)_{i-\frac{1}{2},j}\right]$,

$\left[(\rho I v)_{i,j+\frac{1}{2}} + \left(\frac{\rho_v \rho_\ell}{\rho}(I_v - I_\ell)v_r\right)_{i,j+\frac{1}{2}}\right]$, and $\left[(\rho I v)_{i,j-\frac{1}{2}} + \left(\frac{\rho_v \rho_\ell}{\rho}(I_v - I_\ell)v_r\right)_{i,j-\frac{1}{2}}\right]$.

The pressure work term in Eq. (3.9) is approximated as

$$
\begin{aligned}
\text{FWK} = \frac{p_{i,j}}{A_{i,j}} \Bigg\{ & \frac{1}{\delta x}\Bigg[A_{i+\frac{1}{2},j}\Bigg(u_{i,j} + \frac{\rho_{v_{i+\frac{1}{2},j}}\,\rho_{\ell_{i+\frac{1}{2},j}}}{\rho_{i+\frac{1}{2},j}}\Bigg(\frac{1}{\rho^o_{v_{i+\frac{1}{2},j}}} \\
& - \frac{1}{\rho^o_{\ell_{i+\frac{1}{2},j}}}\Bigg)u_{r_{i,j}}\Bigg) - A_{i-\frac{1}{2},j}\Bigg(u_{i-1,j} \\
& + \frac{\rho_{v_{i-\frac{1}{2},j}}\,\rho_{\ell_{i-\frac{1}{2},j}}}{\rho_{i-\frac{1}{2},j}}\Bigg(\frac{1}{\rho^o_{v_{i-\frac{1}{2},j}}} - \frac{1}{\rho^o_{\ell_{i-\frac{1}{2},j}}}\Bigg)\, u_{r_{i-1,j}}\Bigg)\Bigg] \\
& + \frac{1}{\delta y}\Bigg[A_{i,j+\frac{1}{2}}\Bigg(v_{i,j} + \frac{\rho_{v_{i,j+\frac{1}{2}}}\,\rho_{\ell_{i,j+\frac{1}{2}}}}{\rho_{i,j+\frac{1}{2}}}\Bigg(\frac{1}{\rho^o_{v_{i,j+\frac{1}{2}}}} \\
& - \frac{1}{\rho^o_{\ell_{i,j+\frac{1}{2}}}}\Bigg)v_{r_{i,j}}\Bigg) - A_{i,j-\frac{1}{2}}\Bigg(v_{i,j-1} \\
& + \frac{\rho_{v_{i,j-\frac{1}{2}}}\,\rho_{\ell_{i,j-\frac{1}{2}}}}{\rho_{i,j-\frac{1}{2}}}\Bigg(\frac{1}{\rho^o_{v_{i,j-\frac{1}{2}}}} - \frac{1}{\rho^o_{\ell_{i,j-\frac{1}{2}}}}\Bigg)v_{r_{i,j-1}}\Bigg)\Bigg]\Bigg\}
\end{aligned}
$$

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Quantities on the right side of Eq. (3.9) are evaluated using n level values for ρ, ρ_v, and I while n+1 level values are used for $u_{i,j}$, $p_{i,j}$, and the overall divisor $\rho_{i,j}$. Finally, the vapor density is updated as

$$(\rho_v)^{n+1}_{i,j} = (\rho_v)_{i,j} + \delta t \left[- FRU + \Gamma_{i,j}\right] \quad , \tag{3.10}$$

where

$$FRU = \frac{1}{A_{i,j}} \left\{ \frac{1}{\delta x} \left[A_{i+\frac{1}{2},j} (\rho_v u_v)_{i+\frac{1}{2},j} - A_{i-\frac{1}{2},j} (\rho_v u_v)_{i-\frac{1}{2},j} \right] + \frac{1}{\delta y} \left[A_{i,j+\frac{1}{2}} (\rho_v v_v)_{i,j+\frac{1}{2}} - A_{i,j-\frac{1}{2}} (\rho_v v_v)_{i,j-\frac{1}{2}} \right] \right\}$$

and

$$(\rho_v u_v)_{i+\frac{1}{2},j} = \frac{1}{2} \left\{ (u_v)_{i,j} \left[(\rho_v)_{i,j} + (\rho_v)_{i+1,j} \right] + \alpha |u_v|_{i,j} \left[(\rho_v)_{i,j} - (\rho_v)_{i+1,j} \right] \right\} \quad .$$

The $i-\frac{1}{2}$ boundary flux is obtained by replacing i with i-1 in the above expression. In a similar fashion,

$$\left(\rho_v v_v\right)_{i,j+\frac{1}{2}} = \frac{1}{2} \left\{ \left(v_v\right)_{i,j} \left[\left(\rho_v\right)_{i,j} + \left(\rho_v\right)_{i,j+1} \right] + \alpha |v_v|_{i,j} \left[\left(\rho_v\right)_{i,j} - \left(\rho_v\right)_{i,j+1} \right] \right\}$$

where the $j-\frac{1}{2}$ boundary flux is obtained by replacing j with j-1 in the above equation. The vapor velocities used in these expressions are defined as

$$\left(u_v\right)_{i,j} = u_{i,j} + \left(\rho_\ell\right)_{i+\frac{1}{2},j} \left(u_r\right)_{i,j} / \rho_{i+\frac{1}{2},j} \quad ,$$

with a corresponding expression for the $i-\frac{1}{2}$ boundary obtained by replacing i with i-1, and

$$\left(v_v\right)_{i,j} = v_{i,j} + \left(\rho_\ell\right)_{i,j+\frac{1}{2}} \left(v_r\right)_{i,j} / \rho_{i+\frac{1}{2},j} \quad ,$$

with a corresponding expression for the $j-\frac{1}{2}$ boundary obtained by replacing j with j-1.

Some care must be taken with the way the vapor source term Γ, is approximated. When the mixture is not at equilibrium and the relaxation rate is fast, Γ can be large. Under such circumstances Eq. (3.10) may be numerically unstable. To avoid this the densities in Γ should be evaluated at level n+1. For general formulations of Γ it is usually necessary to use an iterative technique to solve Eq. (3.10). Such an iteration is provided in subroutine PHCHR for the Γ given by Eq. (2.14). There is, however, another more serious problem that can arise when phase transitions are important. Because the effect of Γ is included at the end of a cycle of calculation, its influence on the pressure, and hence the dynamics, is not accounted for in the implicit pressure iteration. This means that some inaccuracies can be introduced in the propagation of compression and rarefaction waves when significant phase change occurs during a single time step. In addition, a large phase change may also drive the equation-of-state pressure far from the value arrived at in the pressure iteration; so that excessive iterations may be required to solve the implicit equation in the next time cycle. In extreme cases the iteration may not even converge. The above problem can be eliminated by using sufficiently small time increments, δt, but in some cases this may lead to long computing times. A better solution that has been utilized recently in the multidimensional code K-FIX (see Ref. 2) is to incorporate the Γ into the implicit portion of the cycle. Basically, the idea is to include Γ in

Eq. (3.4) for the estimated new time vapor density. Since this more complicated formulation is not in SOLA-DF, the user should check his results for time step dependence (accuracy) by performing a smaller time step calculation when necessary.

Thermodynamic equilibrium calculations can be achieved by using a large phase change rate or by replacing the vapor density equation with a calculation of the saturated vapor density and using an equilibrium equation of state. The latter procedure is often preferable because it effectively puts Γ into the pressure iteration.

C. Boundary Conditions

Various types of boundary conditions may be used at the ends and sides of the computational mesh. Prescribed velocities or prescribed pressures together with densities and temperatures may be used to represent inlet and exit conditions. For example, a guillotine break in a pipe of a reactor system can be represented by assigning the ambient pressure in the containment structure to the end of the mesh.

These boundary conditions are easily imposed by setting appropriate values of the dependent variables in the fictitious cells surrounding the mesh. Five kinds of boundary conditions have been specifically built into the code: (1) rigid free-slip, (2) rigid no-slip, (3) continuative outflow, (4) periodic, and (5) constant pressure. As an example of how to treat these boundary conditions, consider the left boundary.

1. Rigid Free-Slip. The normal velocity component must be zero and the tangential velocity component must have no normal gradient, i.e.,

$$\left.\begin{aligned} u_{1,j} &= 0 \\ v_{1,j} &= v_{2,j} \end{aligned}\right\} \text{ for all } j.$$

The variables ρ, p, and I are treated the same as v.

2. Rigid No-Slip. The normal velocity component must be zero and the tangential velocity component at the wall must also be zero, i.e.,

$$\left.\begin{aligned} u_{1,j} &= 0 \\ v_{1,j} &= -v_{2,j} \end{aligned}\right\} \text{ for all } j.$$

The variables ρ, p, and I are treated the same as for a free-slip boundary.

For both of the above rigid boundary conditions, the designated conditions are imposed after each pass through the mesh during the pressure iteration.

3. Continuative Outflow. Continuative or outflow boundaries always pose a problem for low-speed calculations, because whatever prescription is chosen it can potentially affect the entire flow field upstream. What is needed is a prescription that permits fluid to flow out of the mesh with a minimum of upstream influence. In this code we have used a continuative boundary condition that involves setting, for the left boundary, for example,

$$\left.\begin{aligned} u_{1,j} &= u_{2,j} \\ v_{1,j} &= v_{2,j} \end{aligned}\right\} \text{ for all } j.$$

These conditions, however, are only imposed after applying the complete momentum equations (3.2) and not after each pass through the mesh during the pressure iteration. During the iteration the normal boundary velocities can vary with the changes in pressure, as any interior velocity component. The treatment of ρ, p, and I is the same as (u,v).

4. Periodic. For periodic boundary conditions in the x-direction, the left and right boundaries must be set to reflect the periodicity. This is easiest when the period length is chosen equal to (IBAR-1)δx. Then the boundary condition for the fictitious cells on the left are

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$$\left.\begin{aligned}
u_{1,j} &= u_{IBAR,j} \\
v_{1,j} &= v_{IBAR,j} \\
\rho_{1,j} &= \rho_{IBAR,j} \\
p_{1,j} &= p_{IBAR,j} \\
I_{1,j} &= I_{IBAR,j}
\end{aligned}\right\} \quad \text{for all } j.$$

and on the right

$$\left.\begin{aligned}
u_{IBAR+1,j} &= u_{2,j} \\
v_{IBAR+2,j} &= v_{3,j} \\
\rho_{IBAR+2,j} &= \rho_{3,j} \\
p_{IBAR+2,j} &= p_{3,j} \\
I_{IBAR+2,j} &= I_{3,j}
\end{aligned}\right\} \quad \text{for all } j.$$

In this case these conditions are imposed after applying Eqs. (3.2) and after each pressure iteration.

5. Constant Pressure. When constant pressure is prescribed at a boundary, the fluid must stream freely into or out of the specified pressure region, i.e.,

$$\left.\begin{aligned}
p_{1,j} &= p_{2,j} = p_{bc} \\
u_{1,j} &= u_{2,j} \\
v_{1,j} &= v_{2,j}
\end{aligned}\right\} \quad \text{for all } j.$$

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The variables ρ and I are treated the same as v.

Boundary conditions similar to those for the left wall are used at the right, top, and bottom boundaries of the mesh. Of course, the normal and tangential velocities at the top and bottom boundaries are v and u, respectively.

For convenience, the SOLA-DF code has been written so that any of the above boundary conditions can be automatically imposed by setting input numbers. The appropriate input number for the left wall is designated WL, where

$$WL = \begin{cases} 1, \text{ rigid free-slip left wall} \\ 2, \text{ rigid no-slip left wall} \\ 3, \text{ continuative outflow left wall} \\ 4, \text{ periodic in x (provided WR = 4)} \\ 5. \text{ constant pressure left wall.} \end{cases}$$

Similar input numbers are used for the right boundary (WR), top boundary (WT), and bottom boundary (WB). Clearly, when periodic conditions are desired in a given direction, both boundaries in that direction must be assigned wall numbers of 4.

D. Internal Obstacles

To increase the usefulness of the basic code, internal obstacles may be inserted within the fluid region. Internal obstacles with rigid boundary conditions can be taken into account by simply setting $A_{i,j} = 0.0$ for the desired obstacle cell. The code is equipped to handle these simple obstacles by means of the INPUT stream; however, if a more complex internal obstacle treatment is desired, the user must provide additional coding at the end of the boundary condition routine BC.

E. Variable Time Steps

SOLA-DF contains provisions that allow the use of different time steps of integration. The time steps are determined by numerical stability requirements and other user-specified conditions. For numerical stability the time step is limited by the flux criterion that $u\delta t/\delta x \leq 1/4$, $u_r\delta t/\delta x \leq 1/4$, $v\delta t/\delta y \leq 1/4$, and $v_r\delta t/\delta x \leq 1/4$. The minimum time step determined according to this criterion is then increased or decreased by 1%. The direction of this adjustment is deter-

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mined by the relative ease of the previous time integration of the system. If fewer than five system iterations were required, the time step is increased, otherwise it is decreased. The time step determined by the above methods is never allowed to be greater than the user-specified maximum time step DELTMX.

IV. INPUT DATA, COMMON VARIABLES, AND SUBROUTINES AND GRAPHICS OUTPUT

The input data, COMMON variables, and subroutines and FORTRAN functions in SOLA-DF are listed and described in this section. While the input quantities are tabulated and defined separately, they also appear in the COMMON variable lists and are identified there simply as an input quanity. These descriptions of the input and COMMON variables are necessarily brief but hopefully will assist in relating the methodology, described in Sec. III, to its implementation in the code. The units the code was written for are g, cm, ms, K with pressure in bars.

A. Input Data

DEFAULT VALUE	FORTRAN SYMBOL	ALGEBRAIC SYMBOL	DEFINITION
1.0	ALPHA	α	Parameter that determines the amount of upstream differencing in the convective flux terms. Equal to one gives full donor cell differencing.
1.234×10^4	ASQ	a^2	Square of the speed of sound for the liquid phase.
10^4	BUBN	N	Representative bubble (or droplet) number density per cm^3, used in phase change and interfacial friction model.
0.50	CDG	C_d	Drag coefficient used in the interfacial friction model.

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44.34	CHL	C_ℓ	Coefficient of the linear term in the liquid internal energy function.
6.67	CHV	C_v	Similar to CHL but for the vapor energy function.
1.0	CYL	-	Define coordinate system; cylindrical (CYL = 1.0) and Cartesian (CYL = 0.0).
1.0×10^{-4}	DELT	δt	Starting time step for the calculation in ms.
1.0×10^{3}	DELTMX	δt_{max}	Maximum time step in ms.
1.0	DELX	δx	Cell length in cm - radial length in cylindrical coordinates.
1.0	DELY	δy	Cell length in cm - axial length in cylindrical coordinates.
0.0	DFVEL	-	Program control parameter that determines whether the relative velocity is to be calculated (DFVEL = 1.) or set to zero (DFVEL = 0.)
2.0	DIM	-	Problem dimension: (DIM = 2.0) is a two-dimensional problem and (DIM = 1.0) is a one-di-dimensional problem.
4.174×10^{3}	ECL	E_ℓ	Contant in the liquid internal energy function.

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2.506×10^4	ECV	E_v	Similar to ECL but for the vapor energy function.
1.6×10^{-6}	EDL	-	Ratio of the thermal conductivity to the specific heat for the liquid.
1.6×10^{-7}	EDV	-	Ratio of the thermal conductivity to the specific heat for the vapor.
1.76×10^4	ELHT	λ	Latent heat of vaporization.
0.001	EPSI	ε	Pressure iteration convergence test parameter.
1.0	ETEM	-	The liquid and vapor phases are maintained at equal temperatures if ETEM = 1.0 whereas if ETEM = 0.0 the vapor temperature is maintained equal to the saturattion temperature at the local pressure.
0.07	GAM1	$(\gamma-1)$	Parameter in the equation of state.
0.0	GX	g_x	Gravitational acceleration in the x- or r-direction.
0.0	GY	g_y	Gravitational acceleration in the y- or z-direction.
10.0	IBAR	-	Number of active computational cells in the x- or r-direction.

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1.0	IMP	-	Program control parameter whose values determines whether an implicit (IMP = 1) or explicit (IMP = 0) solution method is utilized.
10.0	JBAR	-	Number of active computational cells in the y- or z-direction.
NØ NAME	NAME	-	80-character problem name.
1.0	OMG	-	Relaxation parameter for the calculation of δp in the pressure iteration. A value of OMG = 1.7 often improves the rate of convergences for low Mach number flows.
0.0	PBC	-	Constant pressure boundary condition in bars.
1.0	PHCH	-	Parameter whose value determines whether phase change is computed (PHCH = 1) or omitted (PHCH = 0).
1.0	PIN	-	Initial pressure condition in bars.
0.1	PLTDT	-	Time intervals between plots in ms.
0.1	PRTDT	-	Time intervals between prints in ms.
0.0	RADIUS	-	Inner radius of an annulus in cm.
0.0	RG	k	Pipe wall roughness.

0.958	ROL	ρ_ℓ^o	Microscopic density of the liquid in g/cm^3.
0.0	RPIPE	-	Pipe radius in cm.
.0008	SGWN	-	Product of the liquid surface tension and the critical Weber number.
373.0	TC	T_o	Reference temperature for liquid and vapor internal energy functions in K.
0.001	THC	θ_c	Void fraction below which the fluid is treated as pure liquid.
0.0	THIN	-	Initial void fraction condition.
373.0	TIN	-	Initial temperature condition in K.
10^4	TWFIN	-	Time when the problem is complete in ms.
0.	UI	-	Initial u velocity in cm/ms.
2.0	VELMX	-	Normalizing velocity for velocity plots in cm/ms.
0.	VI	-	Initial v velocity in cm/ms.
3.0×10^{-6}	VISL	ν_ℓ	Kinematic viscosity of the liquid.
2×10^{-4}	VISV	ν_v	Kinematic viscosity of the vapor.

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1.0	WB	-	Parameter that specifies the boundary condition for the bottom boundary.
1.0	WL	-	Parameter that specifies the boundary condition for the left boundary.
1.0	WR	-	Parameter that specifies the boundary condition for the right boundary.
1.0	WT	-	Parameter that specifies the boundary condition for the top boundary.

Following the NAMELIST data INPUT, the user has the option of defining rigid interior obstacles. If no interior obstacles are going to be defined, one blank card must follow the NAMELIST data INPUT defined above.

First Card After NAMELIST INPUT: NØ (Format I5)

NØ = Number of interior obstacles. If NØ ≠ 0, NØ additional cards are read; i.e., there is one card defining each obstacle.

NO Cards Following the Above Card: IBØB, IEØB, JBØB, JEØB, (Format 4I5)

IBØB = total number of δx cells, including the fictitious boundary cells, to the left side of the obstacle.

IEØB = total number of δx cells, including the fictitious boundary cells, to the right side of the obstacle.

JBØB = total number of δy cells, including the fictitious boundary cells, to the bottom side of the obstacle.

JEØB = total number of δy cells, including the fictitious boundary cells, to the top side of the obstacle.

B. COMMON Variables

FORTRAN SYMBOL	ALGEBRAIC SYMBOL	DEFINITION
ASQ	a^2	Input quantity
CDG	C_d	Input quantity

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CHL	C_ℓ	Input quantity
CHV	C_V	Input quantity
CYL	-	Input quantity
DELT	δt	Input quantity
DELTMX	δt_{max}	Input quantity
DELX	δx	Input quantity
DELY	δy	Input quantity
DFVEL	-	Input quantity
DIM	-	Input quantity
ECL	E_ℓ	Input quantity
ECV	E_V	Input quantity
EDL	-	Input quantity
EDV	-	Input quantity
EIL	-	Initial total energy of the liquid state
EIV	-	Initial total energy of the vapor state
EI2	-	Initial total energy of the two-phase mixture
ELHT	λ	Input quantity
EPSI	ε	Input quantity
ET	-	Total energy
ETEM	-	Input quantity
ETEM1	-	1.0 - ETEM
FLG	-	Iteration logic control flag
GAM1	$(\gamma-1)$	Input quantity
II	-	Indexing variable
IMAX	-	Total number of cells in the x-direction (including fictitious cells)
IM1	-	IMAX - 1
IM2	-	IMAX - 2
IPL	-	Index of the first cell in the x-direction whose centered quantities are computed
IPR	-	Index of the last cell in the x-direction whose centered quantities are computed
ITER	-	Counter for the number of iterations between junctions and components to achieve convergence during one system time step
JJ	-	Indexing variable

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JMAX	–	Total number of cells in the y-direction (including fictitious cells)
JM1	–	JMAX - 1
JM2	–	JMAX - 2
JPB	–	Index of the first cell in the y-direction whose centered quantities are computed
JPT	–	Index of the last cell in the y-direction whose centered quantities are computed
ØMG	–	Input quantity
PBC	–	Input quantity
PIN	–	Input quantity
PMAX	–	Temporary pressure variable
PNV	–	4/3 π N
PT	–	Temporary pressure variable
RDX	$1/\delta x$	Reciprocal δx
RDY	$1/\delta y$	Reciprocal δy
RG	k	Input quantity
RØIL	–	Initial total density of the liquid state
RØIV	–	Initial total density of the vapor state
RØI2	–	Initial total density of the two-phase mixture
RØL	ρ_ℓ^o	Input quantity
RØT	–	Temporary total density variable
RPIPE	–	Pipe radius in cm
RVIL	–	Initial vapor density in the liquid state
RVIV	–	Initial vapor density in the vapor state
RVI2	–	Initial vapor density in the two-phase mixture
RVT	–	Temporary total vapor density variable
SGWN	–	Input quantity
TC	T_o	Input quantity
THC	θ_c	Input quantity
THC1	–	1.0 - θ_c
THIN	–	Input quantity
THTM	–	Temporary void fraction variable
TH1	–	Temporary void fraction variable

VISL	ν_ℓ	Input quantity
VISV	ν_v	Input quantity
WB	-	Input quantity
WL	-	Input quantity
WR	-	Input quantity
WT	-	Input quantity
A(I,J)	-	Thickness of a mesh cell
BETA(I,J)	$(\partial F/\partial p)^{-1}_{i,j}$	Recriprocal derivative of the pressure function
E(I,J)	$I^{n+1}_{i,j}$	Time n+1 specific internal energy
EN(I,J)	$I^{n}_{i,j}$	Time n specific internal energy
ITITLE(K)	-	Two-word array used by LASL plotting package
NAME(K)	-	Input quantity
P(I,J)	$p_{i,j}$	Pressure
Q(I,J)	-	Two-dimensional array used by LASL plotting package
QL(K)	-	One-dimensional used to set up plotting
RØ(I,J)	$\rho^{n+1}_{i,j}$	Time n+1 mixture densities
RØN(I,J)	$\rho^{n}_{i,j}$	Time n mixture densities
RV(I,J)	$(\rho_v)^{n+1}_{i,j}$	Time n+1 macroscopic vapor density
RVN(I,J)	$(\rho_v)^{n}_{i,j}$	Time n macroscopic vapor density
U(I,J)	$u^{n+1}_{i,j}$	Time n+1 center-of-mass velocity in the x-direction
UD(I,J)	$(u_r)^{n+1}_{i,j}$	Time n+1 relative or drift velocity in the x-direction
UN(I,J)	$u^{n}_{i,j}$	Time n center-of-mass velocity in the x-direction
V(I,J)	$u^{n+1}_{i,j}$	Time n+1 center-of-mass velocity in the y-direction
VD(I,J)	$(u_r)^{n+1}_{i,j}$	Time n+1 relative or drift velocity in the y-direction
VN(I,J)	$u^{n}_{i,j}$	Time n center-of-mass velocity in the y-direction

XC(K)	-	One-dimensional array used by LASL plotting package
YC(K)	-	One-dimensional array used by LASL plotting package

C. Subroutines and Graphics Output

BC	Implements specified boundary conditions.
DRIFT	Calculates the relative velocity between phases.
EØS	Calculates the equation of state.
PFRIC	Calculates the effects of pipe friction.
PHCHR	Calculates the phase change rate
PITER	Determines the n+1 pressure and velocities by an iterative procedure.
TSTEP	Calculates the variable time step and the iteration parameter BETA(I,J).

Installations without graphics capabilities should delete lines SOLADF.613 thru SOLADF.698. to eliminate film writing and plotting commands. Installations with graphics should have routines equivalent to those listed below. A brief description of their function is included.

In addition the FORTRAN WRITE(N,XX) has special meaning under LASL operating systems. Its use results in printed data being sent automatically to the system graphics file.

ROUTINE	COMMENTS
ADV	Advance film
CONTRJB	Produce contour plots
CONVRT	Convert problem coordinates to plotting coordinates
DRV	Draw a vector
FRAME	Draw a frame
LINCNT	Position film line counter
SPLOT	Standard plotting routine

V. EXAMPLE PROBLEM

To verify the proper implementation of the SOLA-DF code on a users computing system, the following example problem is included. A schematic of the problem geometry is shown in Fig. 3. A two-phase equilibrium mixture of steam and water (void fraction = 0.329, temperature = 557.1 K, and pressure = 68.0

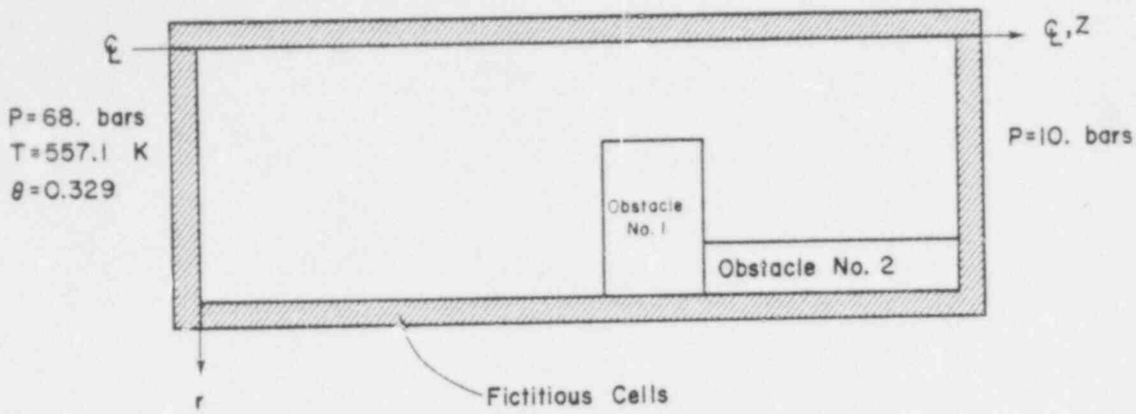

Fig. 3. Schematic of the computing mesh for the example problem.

bars) flows through a nozzle before exiting into a region of constant pressure = 10.0 bars. The flow, which begins from rest, is calculated until a steady state is achieved. The input data that specifies the problem is presented in Table I. The second part of this table shows a listing of the A(I,J) array, which in this case (cylindrical coordinates) merely represents the radial distance from the center line to the center of the mesh cell. Note that obstacle cells set A(I,J) = 0. The data that specifies the initial states in the computational mesh is printed in Table II as the CYCLE = 0, TIME = 0 solution. The solution after 1000 time steps or 1s is given in Table III to provide the user with the transient solution check. The steady state solution is 4000 time steps or 4s and is given in Table IV. Velocity vector plots are presented at 1s and 4s in Figs. 4 and 5, respectively.

VI. SUMMARY

A description has been presented of a new computer program, SOLA-DF, for the solution of transient, one- and two-dimensional, two-phase flows. The one-dimensional formulation includes a variable area treatment. The fluid dynamics is described by a nonequilibrium, drift-flux formulation of the fluid conservation laws. An effort has been made to use relatively simple numerical solution procedures and modular programming in order to provide a framework that can be easily modified and adapted to different kinds of flow problems. In addition, a limited amount of implicitness is used to relax excessively restrictive time step limitations encountered in purely explicit integration methods. Even though the SOLA-DF code has a simple structure its flexibility offers capabilities for treating a wide range of two-phase flow problems.

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TABLE I

EXAMPLE PROBLEM INPUT DATA

SOLA-DF EXAMPLE PROBLEM 01/20/79

ALPHA=	1.00000E+00
ASQ=	1.12470E+04
BUBN=	1.00000E+02
CDG=	5.00000E-01
CHL=	4.43400E+01
CHV=	6.67000E+00
CYL=	1.00000E+00
DELT=	4.00000E-03
DELTMX=	1.00000E-03
DELX=	2.20027E-01
DELY=	4.81753E-01
DFVEL=	0.
DIM=	2.00000E+00
ECL=	4.17400E+03
ECV=	2.50000E+04
EDL=	1.46600E-06
EDV=	6.00000E-07
ELHT=	1.76000E+04
EPSI=	1.00000E-04
ETEM=	1.00000E+00
GAMI=	7.00000E-02
GX=	0.
GY=	0.
IBAR=	10
IMP=	1.00000E+00
JBAR=	30
OMG=	1.00000E+00
PBC=	1.00000E+01
PHCH=	1.00000E+00
PIN=	6.80000E+01
PLTDT=	1.00000E+00
PRTDT=	1.00000E+00
RADIUS=	0.
RG=	3.66000E-03
ROL=	7.41900E-01
RPIPE=	0.
SGWN=	8.00000E-04
TC=	3.73000E+02
THC=	5.00000E-03
THIN=	3.29000E-01
TIN=	5.57100E+02
TWFIN=	1.00000E+01
UI=	0.
VELMX=	2.00000E+00
VI=	0.
VISL=	2.50000E-06
VISV=	1.23000E-04
WB=	5
WL=	1
WR=	1
WT=	5

TABLE I (con't)

AREA ARRAY

0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	0.	0.	0.	0.	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	0.	0.	0.	0.	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	0.	0.	0.	0.	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	0.	0.	0.	0.	0.	0.	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.
0.	1.10E-01	3.30E-01	5.50E-01	7.70E-01	9.90E-01	1.21E+00	1.43E+00	1.65E+00	1.87E+00	2.09E+00	0.

TABLE II

EXAMPLE PROBLEM INITIAL DATA

ITER= 0 TIME= 0. CYCLE= 0 DELT= 4.00000E-03 F= 0. FI= 6.80000E+01

I	J	U	V	P	RO	TH	TEM
2	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	2	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	3	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	4	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	5	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	6	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02

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TABLE II (con't)

10	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	7	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	8	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	9	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	10	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	11	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	12	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	13	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02

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TABLE II (con't)

2	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	14	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	15	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	16	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	17	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.5705[illegible]
7	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.5705[illegible]
8	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02

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TABLE II (con't)

4	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	20	0.	0	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	[illegible].57053E+02
8	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	25	0.	0.	[illegible]	5.09973E-01	3.29000E-01	5.57053E+02
5	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02

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TABLE II (con't)

6	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	27	0.	0.	6.8000[illegible]+01	5.09973E-01	3.29000E-01	5.57053E+02
2	28	0.	0.	6.80000[illegible]	5.09973E-01	3.29000E-01	5.57053E+02
3	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	29	0.	0.	6.80000E+01	[illegible].09973E-01	3.29000E-01	5.57053E+02
2	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	30	0.	0.	6.[illegible]00E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	31	0.	[illegible]	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02

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TABLE III

EXAMPLE PROBLEM SOLUTION AT CYCLE 1000

ITER= 2 TIME= 1.00000E+00 CYCLE= 1000 DELT= 1.00000E-03 F= 1.91639E+00 FI= 6.66668E+01

I	J	U	V	P	RO	TH	TEM
2	2	0.	4.93766E-01	[illegible].80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	2	0.	4.92385E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	2	0.	4.90343E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	2	0.	4.87702E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	2	0.	4.84719E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	2	0.	4.81695E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	2	0.	4.78924E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	2	0.	4.76658E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	2	0.	4.75079E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	2	0.	4.74284E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	3	-3.06617E-03	4.86618E-01	6.77802E+01	5.09430E-01	3.29714E-01	5.57049E+02
3	3	-4.53113E-03	4.85957E-01	6.77904E+01	5.09455E-01	3.29681E-01	5.57049E+02
4	3	-5.86615E-03	4.84971E-01	6.78058E+01	5.09493E-01	3.29631E-01	5.57050E+02
5	3	-6.62983E-03	4.83680E-01	6.78260E+01	5.09543E-01	3.29565E-01	5.57050E+02
6	3	-6.72538E-03	4.82199E-01	6.78494E+01	5.09601E-01	3.29489E-01	5.57050E+02
7	3	-6.16631E-03	4.80673E-01	6.78737E+01	5.09661E-01	3.29410E-01	5.57051E+02
8	3	-5.04665E-03	[illegible].79252E-01	6.78964E+01	5.09717E-01	3.29336E-01	5.57051E+02
9	3	-3.51869E-03	[illegible].78072E-01	6.79154E+01	5.09764E-01	3.29275E-01	5.57051E+02
10	3	-1.76983E-03	4.77240E-01	6.79288E+01	5.09797E-01	3.29231E-01	5.57051E+02
11	3	0.	4.76819E-01	6.79356E+01	5.09814E-01	3.29209E-01	5.57052E+02
2	4	-4.51694E-03	4.80544E-01	6.76420E+01	5.09087E-01	3.30166E-01	5.57047E+02
3	4	-6.69533E-03	4.80647E-01	6.76565E+01	5.09123E-01	3.30118E-01	5.57047E+02
4	4	-8.70128E-03	4.80775E-01	6.76783E+01	5.09177E-01	3.30047E-01	5.57048E+02
5	4	-9.87953E-03	4.80902E-01	6.77074E+01	5.09249E-01	3.29952E-01	[illegible]9E+02
6	4	-1.00729E-02	4.80991E-01	6.77412E+01	5.09333E-01	3.29842E-01	[illegible]
7	4	-9.28277E-03	4.81023E-01	6.77766E+01	5.09421E-01	3.29726E-01	5.57049E+02
8	4	-7.63261E-03	4.80999E-01	6.78101E+01	5.09504E-01	3.29617E-01	5.57050E+02
9	4	-5.34156E-03	4.80939E-01	6.78383E+01	5.09573E-01	3.29525E-01	5.570[illegible]+02
10	4	-2.69320E-03	4.80876E-01	6.78584E+01	5.09623E-01	3.29460E-01	5.57050E+02
11	4	0.	4.80837E-01	6.78686E+01	5.09648E-01	3.29427E-01	5.57051E+02
2	5	-4.29691E-03	4.79990E-01	6.76052E+01	5.08995E-01	3.30286E-01	5.57047E+02
3	5	-6.42284E-03	4.80399E-01	6.76172E+01	5.09025E-01	3.30247E-01	5.57047E+02
4	5	-8.43373E-03	4.80978E-01	6.76355E+01	5.09070E-01	3.30187E-01	5.57047E+02
5	5	-9.69201E-03	4.81690E-01	6.76602E+01	5.09132E-01	3.30107E-01	5.57047E+02
6	5	-1.00096E-02	4.82444E-01	6.76892E+01	5.09204E-01	3.30012E-01	5.57048E+02
7	5	-9.34046E-03	4.83153E-01	6.77201E+01	5.092[illegible]0E-01	3.29911E-01	5.57048E+02
8	5	-7.76530E-03	4.83753E-01	6.77496E+01	5.09354E-01	3.29814E-01	5.57049E+02
9	5	-5.48145E-03	4.84208E-01	6.77747E+01	5.09416E-01	3.29733E-01	5.57049E+02
10	5	-2.77887E-03	4.84505E-01	6.77926E+01	5.09460E-01	3.29674E-01	5.57049E+02
11	5	0.	4.84649E-01	6.78018E+01	5.09483E-01	3.29644E-01	5.57050E+02
2	6	-3.40798E-03	4.81527E-01	6.76329E+01	5.09064E-01	3.30196E-01	5.57047E+02
3	6	-5.16127E-03	4.81944E-01	6.76381E+01	5.09077E-01	3.30179E-01	5.57047E+02
4	6	-6.88357E-03	4.82562E-01	6.76461E+01	5.09097E-01	3.30153E-01	5.57047E+02
5	6	-8.05020E-03	4.83363E-01	6.76567E+01	5.09123E-01	3.30118E-01	5.57047E+02
6	6	-8.46348E-03	4.84271E-01	6.76691E+01	5.091[illegible]4E-01	3.30077E-01	5.57048E+02
7	6	-8.02967E-03	4.85196E-01	6.76822E+01	5.0918[illegible]-01	3.30035E-01	5.57048E+02
8	6	-6.76078E-03	4.86047E-01	6.76945E+01	5.09217E-01	3.29994E-01	5.57048E+02
9	6	-4.82939E-03	4.86747E-01	6.77049E+01	5.0924[illegible]-01	3.29960E-01	5.57048E+02
10	6	-2.46430E-03	4.87236E-01	6.77123E+01	5.09261E-01	3.29936E-01	5.57048E+02
11	6	0.	4.87482E-01	6.77161E+01	5.09271E-01	3.29924E-01	5.57048E+02
2	7	-2.49839E-03	4.82576E-01	6.76469E+01	5.09099E-01	3.30150E-01	5.57047E+02
3	7	-3.81468E-03	4.82905E-01	6.76444E+01	5.09092E-01	3.30158E-01	5.57047E+02
4	7	-5.13544E-03	4.83422E-01	6.76401E+01	5.09082E-01	3.30172E-01	5.57047E+02
5	7	-6.06674E-03	4.84140E-01	6.76337E+01	5.09066E-01	3.30193E-01	5.57047E+02
6	7	-6.44157E-03	4.85015E-01	6.76252E+01	5.09045E-01	3.30221E-01	5.57047E+02
7	7	-6.18589E-03	4.85970E-01	6.76154E+01	5.09021E-01	3.30253E-01	5.57047E+02
8	7	-5.23662E-03	4.86903E-01	6.76053E+01	5.08996E-01	3.30286E-01	5.57047E+02
9	7	-3.75594E-03	4.87707E-01	6.75963E+01	5.08973E-01	3.30315E-01	5.57046E+02

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TABLE III (con't)

10	7	-1.92288E-03	4.88289E-01	6.75895E+01	5.08956E-01	3.30337E-01	5.57046E+02
11	7	0.	4.88587E-01	6.75860E+01	5.08948E-01	3.30349E-01	5.57046E+02
2	8	-1.78343E-03	4.83188E-01	6.75756E+01	5.08922E-01	3.30383E-01	5.57046E+02
3	8	-2.68944E-03	4.83291E-01	6.75686E+01	5.08904E-01	3.30406E-01	5.57046E+02
4	8	-3.57002E-03	4.83486E-01	6.75571E+01	5.08876E-01	3.30444E-01	5.57046E+02
5	8	-4.15566E-03	4.83804E-01	6.75404E+01	5.08834E-01	3.30498E-01	5.57046E+02
6	8	-4.35283E-03	4.84248E-01	6.75191E+01	5.08781E-01	3.30568E-01	5.57045E+02
7	8	-4.12117E-03	4.84790E-01	6.74950E+01	5.08721E-01	3.30647E-01	5.57045E+02
8	8	-3.47342E-03	4.85364E-01	6.74706E+01	5.08660E-01	3.30727E-01	5.57045E+02
9	8	-2.48001E-03	4.85890E-01	6.74491E+01	5.08607E-01	3.30797E-01	5.57044E+02
10	8	-1.26688E-03	4.86285E-01	6.74333E+01	5.08567E-01	3.30849E-01	5.57044E+02
11	8	0.	4.86492E-01	6.74251E+01	5.08547E-01	3.30876E-01	5.57044E+02
2	9	-1.56255E-03	4.82421E-01	6.74138E+01	5.08519E-01	3.30913E-01	5.57044E+02
3	9	-2.27048E-03	4.82228E-01	6.74065E+01	5.08501E-01	3.30937E-01	5.57044E+02
4	9	-2.88179E-03	4.81969E-01	6.73946E+01	5.08471E-01	3.30976E-01	5.57043E+02
5	9	-3.18769E-03	4.81680E-01	6.73774E+01	5.08428E-01	3.31033E-01	5.57043E+02
6	9	-3.16943E-03	4.81416E-01	6.73553E+01	5.08373E-01	3.31105E-01	5.57043E+02
7	9	-2.86107E-03	4.81224E-01	6.73302E+01	5.08310E-01	3.31188E-01	5.57043E+02
8	9	-2.31959E-03	4.81120E-01	6.73045E+01	5.08246E-01	3.31272E-01	5.57042E+02
9	9	-1.61109E-03	4.81091E-01	6.72817E+01	5.08189E-01	3.31348E-01	5.57042E+02
10	9	-8.09873E-04	4.81103E-01	6.72646E+01	5.08146E-01	3.31404E-01	5.57042E+02
11	9	0.	4.81120E-01	6.72557E+01	5.08124E-01	3.31433E-01	5.57041E+02
2	10	-1.98936E-03	4.79032E-01	6.71927E+01	5.07966E-01	3.31640E-01	5.57040E+02
3	10	-2.84288E-03	4.78433E-01	6.71866E+01	5.07951E-01	3.31661E-01	5.57040E+02
4	10	-3.52214E-03	4.77567E-01	6.71767E+01	5.07926E-01	3.31693E-01	5.57040E+02
5	10	-3.76727E-03	4.76476E-01	6.71626E+01	5.07890E-01	3.31740E-01	5.57040E+02
6	10	-3.58909E-03	4.75291E-01	6.71447E+01	5.07845E-01	3.31799E-01	5.57040E+02
7	10	-3.08415E-03	4.74146E-01	6.71243E+01	5.07794E-01	3.31866E-01	5.57039E+02
8	10	-2.37720E-03	4.73151E-01	6.71033E+01	5.07742E-01	3.31936E-01	5.57039E+02
9	10	-1.57933E-03	4.72375E-01	6.70844E+01	5.07694E-01	3.31998E-01	5.57039E+02
10	10	-7.69902E-04	4.71854E-01	6.70702E+01	5.07658E-01	3.32045E-01	5.57039E+02
11	10	0.	4.71597E-01	6.70627E+01	5.07639E-01	3.32070E-01	5.57038E+02
2	11	-3.30235E-03	4.74266E-01	6.69131E+01	5.07263E-01	3.32565E-01	5.57036E+02
3	11	-4.74546E-03	4.72631E-01	6.69094E+01	5.07254E-01	3.32577E-01	5.57036E+02
4	11	-5.91393E-03	4.70311E-01	6.69028E+01	5.07237E-01	3.32599E-01	5.57036E+02
5	11	-6.36074E-03	4.67432E-01	6.68930E+01	5.07213E-01	3.32632E-01	5.57036E+02
6	11	-6.08935E-03	4.64313E-01	6.68801E+01	5.07180E-01	3.32674E-01	5.57036E+02
7	11	-5.25506E-03	4.61267E-01	6.68653E+01	5.07143E-01	3.32724E-01	5.57036E+02
8	11	-4.06661E-03	4.58563E-01	6.68501E+01	5.07104E-01	3.32774E-01	5.57035E+02
9	11	-2.71233E-03	4.56409E-01	6.68365E+01	5.07070E-01	3.32819E-01	5.57035E+02
10	11	-1.32547E-03	4.54939E-01	6.68262E+01	5.07044E-01	3.32854E-01	5.57035E+02
11	11	0.	4.54207E-01	6.68208E+01	5.07030E-01	3.32872E-01	5.57035E+02
2	12	-6.87591E-03	4.74470E-01	6.65517E+01	5.06349E-01	3.33767E-01	5.57031E+02
3	12	-9.82204E-03	4.70441E-01	6.65526E+01	5.06352E-01	3.33765E-01	5.57031E+02
4	12	-1.22123E-02	4.64742E-01	6.65520E+01	5.06350E-01	3.33767E-01	5.57031E+02
5	12	-1.31813E-02	4.57719E-01	6.65489E+01	5.06342E-01	3.33777E-01	5.57031E+02
6	12	-1.27450E-02	4.50199E-01	6.65434E+01	5.06328E-01	3.33796E-01	5.57031E+02
7	12	-1.11624E-02	4.42984E-01	6.65361E+01	5.06309E-01	3.33820E-01	5.57031E+02
8	12	-8.76820E-03	4.36753E-01	6.65278E+01	5.06289E-01	3.33847E-01	5.57030E+02
9	12	-5.92035E-03	4.31991E-01	6.65194E+01	5.06267E-01	3.33876E-01	5.57030E+02
10	12	-2.92152E-03	4.28902E-01	6.65113E+01	5.06248E-01	3.33901E-01	5.57030E+02
11	12	0.	4.27430E-01	6.65076E+01	5.06237E-01	3.33915E-01	5.57030E+02
2	13	-1.56377E-02	4.97533E-01	6.61149E+01	5.05236E-01	3.35233E-01	5.57024E+02
3	13	-2.22604E-02	4.86278E-01	6.61175E+01	5.05242E-01	3.35224E-01	5.57024E+02
4	13	-2.75395E-02	4.74765E-01	6.61220E+01	5.05254E-01	3.35209E-01	5.57024E+02
5	13	-2.96050E-02	4.57850E-01	6.61274E+01	5.05268E-01	3.35191E-01	5.57024E+02
6	13	-2.85057E-02	4.39951E-01	6.61319E+01	5.05279E-01	3.35176E-01	5.57024E+02
7	13	-2.47773E-02	4.23484E-01	6.61338E+01	5.05284E-01	3.35169E-01	5.57024E+02
8	13	-1.91725E-02	4.09991E-01	6.61315E+01	5.05278E-01	3.35177E-01	5.57024E+02
9	13	-1.26644E-02	4.00165E-01	6.61253E+01	5.05262E-01	3.35198E-01	5.57024E+02
10	13	-6.13007E-03	3.94048E-01	6.61172E+01	5.05241E-01	3.35225E-01	5.57024E+02
11	13	0.	3.91232E-01	6.61114E+01	5.05227E-01	3.35245E-01	5.57024E+02

TABLE III (con't)

2	14	-3.55428E-02	5.86690E-01	6.56253E+01	5.03976E-01	3.36890E-01	5.57017E+02
3	14	-5.15844E-02	5.65247E-01	6.56222E+01	5.03968E-01	3.36901E-01	5.57017E+02
4	14	-6.42868E-02	5.33224E-01	6.56273E+01	5.03981E-01	3.36384E-01	5.57017E+02
5	14	-6.85708E-02	4.91757E-01	6.56449E+01	5.04026E-01	3.36824E-01	5.57017E+02
6	14	-6.44257E-02	4.47870E-01	6.56680E+01	5.04086E-01	3.36746E-01	5.57017E+02
7	14	-5.42459E-02	4.09690E-01	6.56861E+01	5.04133E-01	3.36684E-01	5.57018E+02
8	14	-4.06429E-02	3.79934E-01	6.56945E+01	5.04154E-01	3.36656E-01	5.57018E+02
9	14	-2.60222E-02	3.58875E-01	6.56969E+01	5.04161E-01	3.36647E-01	5.57018E+02
10	14	-1.22584E-02	3.45902E-01	6.56964E+01	5.04159E-01	3.36649E-01	5.57018E+02
11	14	0.	3.39971E-01	6.56943E+01	5.04154E-01	3.36657E-01	5.57018E+02
2	15	-8.04607E-02	8.31414E-01	6.50894E+01	5.02582E-01	3.38724E-01	5.57008E+02
3	15	-1.20059E-01	7.82558E-01	6.50949E+01	5.02597E-01	3.38705E-01	5.57008E+02
4	15	-1.53270E-01	7.06972E-01	6.50919E+01	5.02589E-01	3.38715E-01	5.57008E+02
5	15	-1.63358E-01	6.01351E-01	6.51118E+01	5.02641E-01	3.38647E-01	5.57009E+02
6	15	-1.47525E-01	4.85506E-01	6.51508E+01	5.02743E-01	3.38513E-01	5.57009E+02
7	15	-1.19231E-01	4.00707E-01	6.51984E+01	5.02867E-01	3.38350E-01	5.57010E+02
8	15	-8.66769E-02	3.40556E-01	6.52454E+01	5.02989E-01	3.38189E-01	5.57011E+02
9	15	-5.43474E-02	3.00008E-01	6.52927E+01	5.03112E-01	3.38027E-01	5.57011E+02
10	15	-2.51312E-02	2.75526E-01	6.53339E+01	5.03219E-01	3.37886E-01	5.57012E+02
11	15	0.	2.64383E-01	6.53559E+01	5.03276E-01	3.37811E-01	5.57012E+02
2	16	-1.77715E-01	1.40477E+00	6.44483E+01	5.00896E-01	3.40942E-01	5.56998E+02
3	16	-2.75205E-01	1.33491E+00	6.44966E+01	5.01024E-01	3.40774E-01	5.56999E+02
4	16	-3.71320E-01	1.18822E+00	6.45337E+01	5.01122E-01	3.40645E-01	5.57000E+02
5	16	-4.06605E-01	9.06923E-01	6.46006E+01	5.01298E-01	3.40413E-01	5.57001E+02
6	16	-3.33136E-01	4.97246E-01	6.46718E+01	5.01486E-01	3.40167E-01	5.57002E+02
7	16	-2.51395E-01	3.35886E-01	6.47470E+01	5.01684E-01	3.39906E-01	5.57003E+02
8	16	-1.75620E-01	2.46905E-01	6.48309E+01	5.01904E-01	3.39616E-01	5.57004E+02
9	16	-1.07817E-01	1.95724E-01	6.49297E+01	5.02163E-01	3.39275E-01	5.57006E+02
10	16	-4.92099E-02	1.66866E-01	6.50361E+01	5.02442E-01	3.38909E-01	5.57008E+02
11	16	0.	1.53717E-01	6.51070E+01	5.02627E-01	3.38665E-01	5.57009E+02
2	17	-2.98669E-01	2.90869E+00	6.33738E+01	4.58711E-01	4.00352E-01	5.54689E+02
3	17	-5.23241E-01	2.96732E+00	6.33641E+01	4.57054E-01	4.02692E 01	5.54585E+02
4	17	-8.41856E-01	2.99763E+00	6.34369E+01	4.58450E-01	4.00740E-01	5.54661E+02
5	17	-1.14810E+00	2.64362E+00	6.38362E+01	4.74694E-01	3.77890E-01	5.55591E+02
6	17	-7.14797E-01	0.	6.43107E+01	5.00531E-01	3.41423E-01	5.56996E+02
7	17	-4.55897E-01	0.	6.45002E+01	5.01032E-01	3.40764E-01	5.56999E+02
8	17	-2.89584E-01	0.	6.46219E+01	5.01353E-01	3.40341E-01	5.57001E+02
9	17	-1.71106E-01	0.	6.47144E+01	5.01597E-01	3.40020E-01	5.57003E+02
10	17	-7.75216E-02	0.	6.48354E+01	5.01915E-01	3.39672E-01	5.57004E+02
11	17	0.	0.	6.49385E+01	5.02186E-01	3.39246E-01	5.57006E+02
2	18	-8.66567E-02	4.27947E+00	5.96560E+01	3.77858E-01	5.13252E-01	5.49370E+02
3	18	-1.05781E-01	4.30759E+00	5.95148E+01	3.75997E-01	5.15824E-01	5.49236E+02
4	18	-6.50200E-02	4.27994E+00	5.92436E+01	3.72263E-01	5.20998E-01	5.48958E+02
5	18	0.	3.88442E+00	5.87519E+01	3.69495E-01	5.24701E-01	5.48842E+02
6	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	19	8.30592E-03	5.61365E+00	5.55525E+01	3.17999E-01	5.95798E-01	5.44418E+02
3	19	2.86174E 02	5.62759E+00	5.55141E+01	3.17557E-01	5.96403E-01	5.44377E+02
4	19	5.18300E-02	5.59424E+00	5.54048E+01	3.16259E-01	5.98163E-01	5.44262E+02
5	19	0.	5.30635E+00	5.52862E+01	3.15343E-01	5.99403E-01	5.44204E+02
6	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	20	5.10297E-02	7.16563E+00	5.13675E+01	2.68167E-01	6.63739E-01	5.39281E+02
3	20	7.03789E-02	7.20343E+00	5.13829E+01	2.68256E-01	6.63516E-01	5.39293E+02

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TABLE III (con't)

4	20	7.64582E-02	7.22778E+00	5.13135E+01	2.67776E-01	6.64275E-01	5.39230E+02
5	20	0.	7.08588E+00	5.12815E+01	2.67463E-01	6.64682E-01	5.39214E+02
6	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	21	1.42057E-01	8.91352E+00	4.67900E+01	2.22956E-01	7.24602E-01	5.33480E+02
3	21	2.01133E-01	9.07760E+00	4.67169E+01	2.22351E-01	7.25406E-01	5.33397E+02
4	21	2.07763E-01	9.36120E+00	4.65668E+01	2.20960E-01	7.27267E-01	5.33193E+02
5	21	0.	9.80650E+00	4.64211E+01	2.19574E-01	7.29130E-01	5.32981E+02
6	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	22	5.27337E-01	1.01670E+01	4.18037E+01	1.81109E-01	7.80124E-01	5.26654E+02
3	22	9.53176E-01	1.02501E+01	4.14104E+01	1.78237E-01	7.83399E-01	5.26124E+02
4	22	1.66567E+00	1.03179E+01	4.06353E+01	1.72665E-01	7.91214E-01	5.25058E+02
5	22	2.95846E+00	1.02084E+01	3.91551E+01	1.62615E-01	8.04339E-01	5.23076E+02
6	22	1.11179E+00	4.36016E+00	3.69069E+01	1.62096E-01	8.03454E-01	5.25687E+02
7	22	4.53415E-01	2.08142E+00	3.69908E+01	1.95101E-01	7.57701E-01	5.34910E+02
8	22	3.19656E-01	1.54262E+00	3.68766E+01	2.08029E-01	7.39707E-01	5.37857E+02
9	22	0.	1.44054E+00	3.63273E+01	2.07909E-01	7.39564E-01	5.38290E+02
10	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	23	7.11971E-01	1.08186E+01	3.78987E+01	1.52287E-01	8.17792E-01	5.20736E+02
3	23	1.17115E+00	1.07827E+01	3.76315E+01	1.50424E-01	8.20208E-01	5.20310E+02
4	23	1.70296E+00	1.06688E+01	3.72974E+01	1.48013E-01	8.23334E-01	5.19746E+02
5	23	2.13710E+00	1.03790E+01	3.69362E+01	1.45618E-01	8.26437E-01	5.19178E+02
6	23	1.35084E+00	6.77062E+00	3.70332E+01	1.4696[illegible]	8.24531E-01	5.19833E+02
7	23	8.81194E-01	4.60567E+00	3.68301E+01	1.5508[illegible]-01	8.13149E-01	5.23419E+02
8	23	4.16199E-01	3.76429E+00	3.64112E+01	1.64795E-01	7.99387E-01	5.27430E+02
9	23	0.	3.53939E+00	3.59688E+01	1.67256E-01	7.95704E-01	5.28723E+02
10	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	24	6.31266E-01	1.12441E+01	3.52991E+01	1.34825E-01	8.40328E-01	5.16475E+02
3	24	9.58922E-01	1.11623E+01	3.52629E+01	1.34416E-01	8.40869E-01	5.16333E+02
4	24	1.25206E+00	1.10176E+01	3.53357E+01	1.34711E-01	8.40481E-01	5.16428E+02
5	24	1.45141E+00	1.07821E+01	3.55320E+01	1.35679E-01	8.39257E-01	5.16642E+02
6	24	1.03889E+00	8.39504E+00	3.57654E+01	1.37492E-01	8.36862E-01	5.17268E+02
7	24	5.99631E-01	6.73977E+00	3.58558E+01	1.39373E-01	8.34325E-01	5.18131E+02
8	24	2.43612E-01	6.10357E+00	3.58028E+01	1.40336E-01	8.32971E-01	5.18748E+02
9	24	0.	5.96067E+00	3.58049E+01	1.41010E-01	8.32036E-01	5.19125E+02
10	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	25	4.56556E-01	1.18198E+01	3.34368E+01	1.23177E-01	8.50237E-01	5.13235E+02
3	25	6.67861E-01	1.17478E+01	3.35202E+01	1.23629E-01	8.54654E-01	5.13377E+02
4	25	8.69688E-01	1.16449E+01	3.36895E+01	1.24458E-01	8.53615E-01	5.13571E+02
5	25	1.01738E+00	1.14785E+01	3.39147E+01	1.25756E-01	8.51955E-01	5.13953E+02
6	25	8.21457E-01	9.81713E+00	3.41034E+01	1.26979E-01	8.50368E-01	5.14387E+02
7	25	4.96073E-01	8.56974E+00	3.41966E+01	1.27733E-01	8.49400E-01	5.14726E+02
8	25	2.08905E-01	8.07215E+00	3.42146E+01	1.27848E-01	8.49230E-01	5.14929E+02
9	25	0.	7.95608E+00	3.42225E+01	1.27861E-01	8.49216E-01	5.14987E+02
10	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	26	3.08673E-01	1.27509E+01	3.17520E+01	1.13251E-01	8.67844E-01	5.10201E+02
3	26	4.64919E-01	1.27017E+01	3.18303E+01	1.13709E-01	8.67270E-01	5.10330E+02
4	26	6.10512E-01	1.26300E+01	3.19509E+01	1.14383E-01	8.66412E-01	5.10557E+02
5	26	7.28446E-01	1.25104E+01	3.21120E+01	1.15286E-01	8.65268E-01	5.10839E+02

TABLE III (con't)

6	26	6.29152E-01	1.13137E+01	3.22459E+01	1.16025E-01	8.64329E-01	5.11112E+02
7	26	4.03106E-01	1.03855E+01	3.23216E+01	1.16364E-01	8.63896E-01	5.11323E+02
8	26	1.80217E-01	1.00021E+01	3.23275E+01	1.16414E-01	8.63851E-01	5.11391E+02
9	26	0.	9.90407E+00	3.23513E+01	1.16395E-01	8.63871E-01	5.11442E+02
10	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	27	2.12902E-01	1.41400E+01	2.98623E+01	1.02983E-01	8.80780E-01	5.06762E+02
3	27	3.30814E-01	1.41081E+01	2.99055E+01	1.03219E-01	8.80469E-01	5.06828E+02
4	27	4.37235E-01	1.40573E+01	2.99707E+01	1.03564E-01	8.80051E-01	5.06964E+02
5	27	5.26643E-01	1.39675E+01	3.00676E+01	1.04079E-01	8.79404E-01	5.07145E+02
6	27	4.69815E-01	1.30903E+01	3.01430E+01	1.04440E-01	8.78953E-01	5.07305E+02
7	27	3.08514E-01	1.24057E+01	3.01845E+01	1.04552E-01	8.78822E-01	5.07402E+02
8	27	1.39920E-01	1.21196E+01	3.02052E+01	1.04570E-01	8.78809E-01	5.07456E+02
9	27	0.	1.20430E+01	3.02080E+01	1.04543E-01	8.78849E-01	5.07470E+02
10	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	28	1.55952E-01	1.61958E+01	2.75477E+01	9.11775E-02	8.95514E-01	5.02319E+02
3	28	2.43678E-01	1.61750E+01	2.75513E+01	9.12226E-02	8.95460E-01	5.02327E+02
4	28	3.19094E-01	1.61394E+01	2.75754E+01	9.13310E-02	8.95323E-01	5.02380E+02
5	28	3.90869E-01	1.60739E+01	2.76153E+01	9.15496E-02	8.95054E-01	5.02460E+02
6	28	3.50941E-01	1.54272E+01	2.76407E+01	9.16276E-02	8.94962E-01	5.02517E+02
7	28	2.30672E-01	1.49277E+01	2.76576E+01	9.15850E-02	8.95022E-01	5.02554E+02
8	28	1.04408E-01	1.47194E+01	2.76577E+01	9.15474E-02	8.95081E-01	5.02559E+02
9	28	0.	1.46624E+01	[illegible]	9.15199E-02	8.95115E-01	5.02580E+02
10	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	29	1.24154E-01	1.94840E+01	2.44554E+01	7.67776E-02	9.13253E-01	4.96008E+02
3	29	1.91311E-01	1.94697E+01	2.44421E+01	7.67210E-02	9.13326E-01	4.95980E+02
4	29	2.46998E-01	1.94442E+01	2.44381E+01	7.66999E-02	9.13348E-01	4.95970E+02
5	29	3.07863E-01	1.93974E+01	2.44439E+01	7.67298E-02	9.13312E-01	4.95986E+02
6	29	2.75077E-01	1.89250E+01	2.44328E+01	7.66326E-02	9.13434E-01	4.95964E+02
7	29	1.77560E-01	1.85658E+01	2.44193E+01	7.65011E-02	9.13603E-01	4.95936E+02
8	29	7.95699E-02	1.84185E+01	2.44108E+01	7.64162E-02	9.13713E-01	4.95921E+02
9	29	0.	1.83778E+01	2.44067E+01	7.63776E-02	9.13764E-01	.95915E+02
10	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	30	1.07179E-01	2.59769E+01	1.99430E+01	5.80527E-02	9.35875E-01	4.85683E+02
3	30	1.61900E-01	2.59586E+01	1.99252E+01	5.79816E-02	9.35959E-01	4.85637E+02
4	30	2.09543E-01	2.59316E+01	[illegible]	5.79249E-02	9.36027E-01	4.85600E+02
5	30	2.67661E-01	2.58887E+01	[illegible]	5.78731E-02	9.36089E-01	4.85569E+02
6	30	2.36996E-01	2.55385E+01	1.98698E+01	5.77173E-02	9.36278E-01	4.85490E+02
7	30	1.50268E-01	2.52773E+01	1.98439E+01	5.75641E-02	9.36467E-01	4.85420E+02
8	30	6.63849E-02	2.51701E+01	1.98265E+01	5.74650E-02	9.36589E-01	4.85376E+02
9	30	0.	2.51395E+01	1.98186E+01	5.74211E-02	9.36644E-01	4.85357E+02
10	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	31	0.	2.59769E+01	1.00000E+01	5.90198E-02	9.34738E-01	4.86228E+02
3	31	0.	2.59586E+01	1.00000E+01	5.89517E-02	9.34819E-01	4.86185E+02
4	31	0.	2.59316E+01	1.00000E+01	5.86760E-02	9.34910E-01	4.86132E+02
5	31	0.	2.58887E+01	1.00000E+01	5.88350E-02	9.34960E-01	4.86108E+02
6	31	0.	2.55385E+01	1.00000E+01	[illegible]	9.35040E-01	[illegible]
7	31	0.	2.52773E+01	1.00000E+01	5.87138E-02	9.35114E-01	[illegible]
8	31	0.	2.51701E+01	1.00000E+01	5.86953E-02	9.35141E-01	[illegible]
9	31	0.	2.51395E+01	1.00000E+01	5.86951E-02	[illegible]	4.86083E+02
10	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02

POOR ORIGINAL

532 260

TABLE IV

EXAMPLE PROBLEM SOLUTION AT CYCLE 4000

ITER= 2 TIME= 4.00000E+00 CYCLE= 4000 DELT= 1.00000E-03 F= 2.68191E+00 F1= 6.83025E+01

I	J	U	V	P	RO	TH	TEM
2	2	0.	8.60350E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
3	2	0.	8.60322E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
4	2	0.	8.60280E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
5	2	0.	8.60229E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
6	2	0.	8.60174E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	2	0.	8.60121E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	2	0.	8.60077E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	2	0.	8.60043E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.5705 E+02
10	2	0.	8.60021E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	2	0.	8.60011E-01	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	3	-2.88329E-05	8.60080E-01	6.80328E+01	5.10054E-01	3.28894E-01	5.57053E+02
3	3	-4.21305E-05	8.60050E-01	6.80329E+01	5.10054E-01	3.28893E-01	5.57053E+02
4	3	-5.35231E-05	8.60006E-01	6.80330E+01	5.10054E-01	3.28893E-01	5.57053E+02
5	3	-5.87578E-05	8.59951E-01	6.80332E+01	5.10054E-01	3.28892E-01	5.57053E+02
6	3	-5.72863E-05	8.59892E-01	6.80334E+01	5.10055E-01	3.28892E-01	5.57053E+02
7	3	-5.00591E-05	8.59834E-01	6.80337E+01	5.10056E-01	3.28891E-01	5.57053E+02
8	3	-3.89228E-05	8.59785E-01	6.80340E+01	5.10056E-01	3.28890E-01	5.57053E+02
9	3	-2.59036E-05	8.59748E-01	6.80342E+01	5.10057E-01	3.28889E-01	5.57053E+02
10	3	-1.26071E-05	8.59720E-01	6.80344E+01	5.10057E-01	3.28889E-01	5.57053E+02
11	3	0.	8.59708E-01	6.80345E+01	5.10058E-01	3.28888E-01	5.57053E+02
2	4	-6.41577E-05	8.59648E-01	6.80674E+01	5.10139E-01	3.28782E-01	5.57054E+02
3	4	-9.44277E-05	8.59614E-01	6.80675E+01	5.10139E-01	3.28781E-01	5.57054E+02
4	4	-1.21214E-04	8.59565E-01	6.80676E+01	5.10139E-01	3.28781E-01	5.57054E+02
5	4	-1.34952E-04	8.59503E-01	6.80679E+01	5.10140E-01	3.28780E-01	5.57054E+02
6	4	-1.33856E-04	8.59434E-01	6.80682E+01	5.10141E-01	3.28779E-01	5.57054E+02
7	4	-1.19218E-04	8.59366E-01	6.80686E+01	5.10142E-01	3.28778E-01	5.57054E+02
8	4	-9.44644E-05	8.59306E-01	6.80689E+01	5.10142E-01	3.28777E-01	5.57054E+02
9	4	-6.38978E-05	8.59257E-01	6.80692E+01	5.10143E-01	3.28776E-01	5.57054E+02
10	4	-3.14454E-	8.59225E-01	6.80694E+01	5.10144E-01	3.28775E-01	5.57054E+02
11	4	0.	8.59208E-01	6.80695E+01	5.10144E-01	3.28775E-01	5.57054E+02
2	5	-1.12056E-04	8.59126E-01	6.81038E+01	5.10228E-01	3.28664E-01	5.57054E+02
3	5	-1.65507E-04	8.59082E-01	6.81038E+01	5.10228E-01	3.28664E-01	5.57054E+02
4	5	-2.13868E-04	8.59017E-01	6.81040E+01	5.10229E-01	3.28663E-01	5.57054E+02
5	5	-2.40681E-04	8.58933E-01	6.81041E+01	5.10229E-01	3.28663E-01	5.57054E+02
6	5	-2.42341E-04	8.58839E-01	6.81043E+01	5.10230E-01	3.28662E-01	5.57054E+02
7	5	-2.19841E-04	8.58745E-01	6.81045E+01	5.10230E-01	3.28661E-01	5.57054E+02
8	5	-1.77643E-04	8.58659E-01	6.81047E+01	5.10230E-01	3.28661E-01	5.57054E+02
9	5	-1.22319E-04	8.58589E-01	6.81048E+01	5.10231E-01	3.28660E-01	5.57054E+02
10	5	-6.09572E-05	8.58540E-01	6.81049E+01	5.10231E-01	3.28660E-01	5.57054E+02
11	5	0.	8.58516E-01	6.81050E+01	5.10231E-01	3.28660E-01	5.57054E+02
2	6	-1.88445E-04	8.58731E-01	6.81409E+01	5.10320E-01	3.28544E-01	5.57055E+02
3	6	-2.79084E-04	8.58658E-01	6.81409E+01	5.10320E-01	3.28544E-01	5.57055E+02
4	6	-3.62334E-04	8.58550E-01	6.81408E+01	5.10319E-01	3.28544E-01	5.57055E+02
5	6	-4.10865E-04	8.58409E-01	6.81407E+01	5.10319E-01	3.28544E-01	5.57055E+02
6	6	-4.18219E-04	8.58250E-01	6.81406E+01	5.10319E-01	3.28545E-01	5.57055E+02
7	6	-3.84651E-04	8.58089E-01	6.81404E+01	5.10318E-01	3.28545E-01	5.57055E+02
8	6	-3.15589E-04	8.57941E-01	6.81403E+01	5.10318E-01	3.28546E-01	5.57055E+02
9	6	-2.20412E-04	8.57820E-01	6.81402E+01	5.10318E-01	3.28546E-01	5.57055E+02
10	6	-1.10967E-04	8.57735E-01	6.81401E+01	5.10318E-01	3.28546E-01	5.57055E+02
11	6	0.	8.57692E-01	6.81400E+01	5.10317E-01	3.28546E-01	5.57055E+02
2	7	-3.33658E-04	8.58799E-01	6.81768E+01	5.10408E-01	3.28427E-01	5.57055E+02
3	7	-4.95548E-04	8.58653E-01	6.81766E+01	5.10407E-01	3.28428E-01	5.57055E+[illegible]
4	7	-6.45376E-04	8.58435E-01	6.81763E+01	5.10407E-01	3.28429E-01	5.57055E+02
5	7	-7.34327E-04	8.58152E-01	6.81759E+01	5.10406E-01	3.28430E-01	5.57055E+02
6	7	-7.50320E-04	8.57831E-01	6.81753E+01	5.10404E-01	3.28432E-01	5.57055E+02
7	7	-6.93060E-04	8.57505E-01	6.81748E+01	5.10403E-01	3.28434E-01	5.57055E+02
8	7	-5.71254E-04	8.57206E-01	6.81742E+01	5.10402E-01	3.28436E-01	5.57055E+02
9	7	-4.00717E-04	8.56962E-01	6.81737E+01	5.10400E-01	3.28437E-01	5.57055E+02

TABLE IV (con't)

10	7	-2.02382E-04	8.56791E-01	6.81734E+01	5.10400E-01	3.28438E-01	5.57055E+02
11	7	0.	8.56706E-01	6.81732E+01	5.10399E-01	3.28439E-01	5.57055E+02
2	8	-6.46514E-04	8.59839E-01	6.82099E+01	5.10489E-01	3.28320E-01	5.57056E+02
3	8	-9.60232E-04	8.59514E-01	6.82095E+01	5.10488E-01	3.28321E-01	5.57056E+02
4	8	-1.25036E-03	8.59036E-01	6.82090E+01	5.10487E-01	3.28323E-01	5.57056E+02
5	8	-1.42182E-03	8.58416E-01	6.82084E+01	5.10486E-01	3.28325E-01	5.57056E+02
6	8	-1.450[illegible]E-03	8.57716E-01	6.82076E+01	5.10484E-01	3.28328E-01	5.57056E+02
7	8	-1.33780E-03	8.57005E-01	6.82067E+01	5.10481E-01	3.28331E-01	5.57056E+02
8	8	-1.10028E-03	8.56353E-01	6.82059E+01	5.10479E-01	3.28333E-01	5.57056E+02
9	8	-7.70210E-04	8.55818E-01	6.82052E+01	5.10478E-01	3.28336E-01	5.57056E+02
10	8	-3.88432E-04	8.55445E-01	6.82047E+01	5.10476E-01	3.28337E-01	5.57056E+02
11	8	0.	8.55258E-01	6.82044E+01	5.10476E-01	3.28338E-01	5.57056E+02
2	9	-1.35278E-03	8.62926E-01	6.82399E+01	5.10563E-01	3.28223E-01	5.57056E+02
3	9	-2.00217E-03	8.62204E-01	6.82396E+01	5.10562E-01	3.28224E-01	5.57056E+02
4	9	-2.59894E-03	8.61143E-01	6.82391E+01	5.10561E-01	3.28226E-01	5.57056E+02
5	9	-2.94734E-03	8.59776E-01	6.82384E+01	5.10559E-01	3.28228E-01	5.57056E+02
6	9	-3.00098E-03	8.58236E-01	6.82375E+01	5.10557E-01	3.28231E-01	5.57056E+02
7	9	-2.76123E-03	8.56676E-01	6.82367E+01	5.10555E-01	3.28234E-01	5.57056E+02
8	9	-2.26652E-03	8.55248E-01	6.82359E+01	5.10553E-01	3.28236E-01	5.57056E+02
9	9	-1.58371E-03	8.54079E-01	6.82353E+01	5.10552E-01	3.28238E-01	5.57056E+02
10	9	-7.97642E-04	8.53263E-01	6.82349E+01	5.10551E-01	3.28240E-01	5.57056E+02
11	9	0.	8.52953E-01	6.82347E+01	5.10550E-01	3.28240E-01	5.57056E+02
2	10	-2.92841E-03	8.70797E-01	6.82679E+01	5.10632E-01	3.28133E-01	5.57056E+02
3	10	-4.31912E-03	8.69170E-01	6.82675E+01	5.10631E-01	3.28134E-01	5.57056E+02
4	10	-5.58677E-03	8.66795E-01	6.82670E+01	5.10629E-01	3.28136E-01	5.57056E+02
5	10	-6.31365E-03	8.63746E-01	6.82663E+01	5.10628E-01	3.28138E-01	5.57056E+02
6	10	-6.40916E-03	8.60336E-01	6.82655E+01	5.10626E-01	3.28141E-01	5.57056E+02
7	10	-5.88349E-03	8.56915E-01	6.82648E+01	5.10624E-01	3.28143E-01	5.57056E+02
8	10	-4.82169E-03	8.53809E-01	6.82642E+01	5.10623E-01	3.28145E-01	5.57056E+02
9	10	-3.36584E-03	8.51284E-01	6.82638E+01	5.10622E-01	3.28146E-01	5.57056E+02
10	10	-1.69443E-03	8.49532E-01	6.82635E+01	5.10621E-01	3.28147E-01	5.57056E+02
11	10	0.	8.48650E-01	6.82634E+01	5.10621E-01	3.28147E-01	5.57056E+02
2	11	-6.45974E-03	8.90232E-01	6.82919E+01	5.10690E-01	3.28056E-01	5.57057E+02
3	11	-9.49851E-03	8.86375E-01	6.82915E+01	5.10690E-01	3.28057E-01	5.57057E+02
4	11	-1.22368E-02	8.80837E-01	6.82911E+01	5.10689E-01	3.28058E-01	5.57057E+02
5	11	-1.37545E-02	8.73817E-01	6.82907E+01	5.10688E-01	3.28059E-01	5.57057E+02
6	11	-1.38794E-02	8.66087E-01	6.82904E+01	5.10687E-01	3.28060E-01	5.57057E+02
7	11	-1.26701E-02	8.58457E-01	6.82901E+01	5.10686E-01	3.28061E-01	5.57057E+02
8	11	-1.03373E-02	8.51636E-01	6.82899E+01	5.10686E-01	3.28062E-01	5.57057E+02
9	11	-7.19464E-03	8.46168E-01	6.82898E+01	5.10685E-01	3.28062E-01	5.57057E+02
10	11	-3.61640E-03	8.42409E-01	6.82898E+01	5.10685E-01	3.28062E-01	5.57057E+02
11	11	0.	8.40527E-01	6.82898E+01	5.10685E-01	3.28062E-01	5.57057E+02
2	12	-1.47323E-02	9.37135E-01	6.83049E+01	5.10723E-01	3.28013E-01	5.57057E+02
3	12	-2.14983E-02	9.27544E-01	6.83058E+01	5.10725E-01	3.28010E-01	5.57057E+02
4	12	-2.74642E-02	9.14158E-01	6.83071E+01	5.10728E-01	3.28006E-01	5.57057E+02
5	12	-3.05552E-02	8.97523E-01	6.83087E+01	5.10732E-01	3.28001E-01	5.57057E+02
6	12	-3.04921E-02	8.79662E-01	6.83104E+01	5.10736E-01	3.27996E-01	5.57057E+02
7	12	-2.75416E-02	8.62501E-01	6.83121E+01	5.10740E-01	3.27990E-01	5.57057E+02
8	12	-2.22690E-02	8.47531E-01	6.83136E+01	5.10744E-01	3.27985E-01	5.57057E+02
9	12	-1.53961E-02	8.35766E-01	6.83147E+01	5.10747E-01	3.27982E-01	5.57057E+02
10	12	-7.70944E-03	8.27787E-01	6.83155E+01	5.10748E-01	3.27979E-01	5.57057E+02
11	12	0.	8.23813E-01	6.83158E+01	5.10749E-01	3.27978E-01	5.57057E+02
2	13	-3.47936E-02	1.04981E+00	6.82998E+01	5.10710E-01	3.28030E-01	5.57057E+02
3	13	-5.01244E-02	1.02508E+00	6.83040E+01	5.10720E-01	3.28016E-01	5.57057E+02
4	13	-6.31510E-02	9.91672E-01	6.83093E+01	5.10733E-01	3.27999E-01	5.57057E+02
5	13	-6.90715E-02	9.51045E-01	6.83157E+01	5.10749E-01	3.27979E-01	5.57057E+02
6	13	-6.76604E-02	9.08995E-01	6.83225E+01	5.10766E-01	3.27957E-01	5.57057E+02
7	13	-6.00695E-02	8.70446E-01	6.83290E+01	5.10782E-01	3.27936E-01	5.57057E+02
8	13	-4.78772E-02	8.36176E-01	6.83347E+01	5.10796E-01	3.27917E-01	5.57057E+02
9	13	-3.27522E-02	8.13615E-01	6.83392E+01	5.10805E-01	3.27903E-01	5.57058E+02
10	13	-1.63001E-02	7.97301E-01	6.83421E+01	5.10814E-01	3.27893E-01	5.57058E+02
11	13	0.	7.89218E-01	6.83435E+01	5.10817E-01	3.27889E-01	5.57058E+02

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2	14	-8.39742E-02	1.32418E+00	6.82558E+01	5.10602E-01	3.28172E-01	5.57056E+02
3	14	-1.19691E-01	1.25945E+00	6.82668E+01	5.10629E-01	3.28136E-01	5.57056E+02
4	14	-1.48487E-01	1.17318E+00	6.80819E+01	5.10666E-01	3.28088E-01	5.57057E+02
5	14	-1.58510E-01	1.06929E+00	6.83004E+01	5.10712E-01	3.28028E-01	5.57057E+02
6	14	-1.50513E-01	9.66533E-01	6.83201E+01	5.10760E-01	3.27964E-01	5.57057E+02
7	14	-1.29858E-01	8.80531E-01	6.83384E+01	5.10805E-01	3.27905E-01	5.57058E+02
8	14	-1.01133E-01	8.13501E-01	6.83532E+01	5.10841E-01	3.27858E-01	5.57058E+02
9	14	-6.80485E-02	7.65177E-01	6.83642E+01	5.10868E-01	3.27822E-01	5.57058E+02
10	14	-3.35472E-02	7.34172E-01	6.83713E+01	5.10885E-01	3.27799E-01	5.57058E+02
11	14	0.	7.18932E-01	6.83747E+01	5.10893E-01	3.27789E-01	5.57058E+02
2	15	-2.02274E-01	1.98855E+00	6.80798E+01	5.10171E-01	3.28740E-01	5.57054E+02
3	15	-2.90648E-01	1.83340E+00	6.81134E+01	5.10253E-01	3.28631E-01	5.57054E+02
4	15	-3.56912E-01	1.61242E+00	6.81602E+01	5.10368E-01	3.28480E-01	5.57055E+02
5	15	-3.72786E-01	1.33188E+00	6.82197E+01	5.10514E-01	3.28287E-01	5.57056E+02
6	15	-3.34554E-01	1.05709E+00	6.82812E+01	5.10665E-01	3.28089E-01	5.57057E+02
7	15	-2.74614E-01	8.71568E-01	6.83317E+01	5.10789E-01	3.27927E-01	5.57057E+02
8	15	-2.05598E-01	7.43431E-01	6.83687E+01	5.10879E-01	3.27808E-01	5.57058E+02
9	15	-1.34534E-01	6.58946E-01	6.83928E+01	5.10938E-01	3.27730E-01	5.57058E+02
10	15	-6.52558E-02	6.07777E-01	6.84070E+01	5.10973E-01	3.27684E-01	5.57059E+02
11	15	0.	5.83021E-01	6.84135E+01	5.10988E-01	3.27664E-01	5.57059E+02
2	16	-4.51145E-01	3.49172E+00	6.73963E+01	[illegible]	3.37824E-01	5.56780E+02
3	16	-6.89359E-01	3.23160E+00	6.74947E+01	5.06971E-01	3.33129E-01	5.56950E+02
4	16	-8.91421E-01	2.76253E+00	6.76395E+01	5.08801E-01	3.30570E-01	5.57032E+02
5	16	-9.28325E-01	1.99564E+00	6.78588E+01	5.09629E-01	3.29452E-01	5.57050E+02
6	16	-7.41788E-01	1.06570E+00	6.81205E+01	5.10272E-01	3.28606E-01	5.57054E+02
7	16	-5.56499E-01	7.29581E-01	6.82771E+01	5.10655E-01	3.28102E-01	5.57057E+02
8	16	-3.89445E-01	5.39475E-01	6.83709E+01	5.10885E-01	3.27800E-01	5.57058E+02
9	16	-2.43053E-01	4.31640E-01	6.84242E+01	5.11015E-01	3.27629E-01	5.57059E+02
10	16	-1.14559E-01	3.72565E-01	6.84520E+01	5.11083E-01	3.27540E-01	5.57059E+02
11	16	0.	3.45032E-01	6.84635E+01	5.11111E-01	3.27503E-01	5.57059E+02
2	17	-7.57993E-01	6.36348E+00	6.48306E+01	4.53420E-01	4.06285E-01	5.54103E+02
3	17	-1.31705E+00	6.38409E+00	6.49595E+01	4.55446E-01	4.05447E-01	5.54221E+02
4	17	-2.04419E+00	6.25574E+00	6.51177E+01	4.58848E-01	4.00692E-01	5.54410E+02
5	17	-2.55570E+00	5.20298E+00	6.56170E+01	4.71831E-01	3.82480E-01	5.55140E+02
6	17	-1.58569E+00	0.	6.75804E+01	5.08888E-01	3.30433E-01	5.57043E+02
7	17	-1.00898E+00	0.	6.81306E+01	5.10298E-01	3.28572E-01	5.57054E+02
8	17	-6.33448E-01	0.	6.83547E+01	5.10845E-01	3.27852E-01	5.57058E+02
9	17	-3.68461E-01	0.	6.84518E+01	5.11082E-01	3.27540E-01	5.57059E+02
10	17	-1.66439E-01	0.	6.84945E+01	5.11187E-01	3.27403E-01	5.57060E+02
11	17	0.	0.	6.85107E+01	5.11226E-01	3.27351E-01	5.57060E+02
2	18	-2.28677E-01	9.09712E+00	5.75928E+01	3.44314E-01	5.59753E-01	5.46664E+02
3	18	-2.77905E-01	9.10771E+00	5.69506E+01	3.36249E-01	5.70847E-01	5.46000E+02
4	18	-1.96968E-01	8.91705E+00	5.57590E+01	3.21756E-01	5.90735E-01	5.44757E+02
5	18	0.	7.78329E+00	5.39212E+01	3.00781E-01	6.19375E-01	5.42874E+02
6	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	18	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	19	1.53179E-01	1.16846E+01	5.01579E+01	2.56624E-01	6.79420E-01	5.37943E+02
3	19	2.51099E-01	1.16335E+01	4.96919E+01	2.51666E-01	6.86113E-01	5.37344E+02
4	19	2.91867E-01	1.13734E+01	4.90712E+01	2.44901E-01	6.95231E-01	5.36502E+02
5	19	0.	1.03367E+01	4.85549E+01	2.38611E-01	7.03689E-01	5.35716E+02
6	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	19	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	20	2.88779E-01	1.44952E+01	4.33796E+01	1.93917E-01	7.63299E-01	5.28971E+02
3	20	3.79980E-01	1.44836E+01	4.32081E+01	1.92298E-01	7.65442E-01	5.28695E+02

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TABLE IV (con't)

4	20	3.43752E-01	1.43396E+01	4.30542E+01	1.90664E-01	7.67607E-01	5.28409E+02
5	20	0.	1.36139E+01	4.30039E+01	1.89660E-01	7.68934E-01	5.28254E+02
6	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
9	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	20	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	20	0.	C.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	21	4.49768E-01	1.80571E+01	3.65273E+01	1.43750E-01	8.28920E-01	5.18817E+02
3	21	6.17451E-01	1.83423E+01	3.632[illegible]E+01	1.42421E-01	8.30637E-01	5.18495E+02
4	21	6.20887E-01	1.88582E 01	3.60[illegible]E+01	1.40659E-01	8.32911E-01	5.18064E+02
5	21	0	1.97540E+01	3.57664E+01	1.38632E-01	8.35527E-01	5.17570E+02
6	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
7	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
8	21	0.	0.	6.80000E+01	5.09973E 01	3.29000E-01	5.57053E+02
9	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
10	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	21	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	22	1.25666E+00	2.21328E+01	2.87475E+01	9.87755E-02	8.86133E-01	5.05513E+02
3	22	2.36718E+00	2.25679E+01	2.78733E+01	9.45504E-02	8.91407E-01	5.03951E+02
4	22	4.57561E+00	2.31896E+01	2.61351E+01	8.65452E-02	9.01342E-01	5.00792E+02
5	22	1.02896E+01	2.37741E+01	2.23095E+01	7.04360E-02	9.21085E-01	4.93457E+02
6	22	7.74648E+00	1.44161E+01	1.51804E+01	4.19587E-02	9.54595E-01	4.76931E+02
7	22	3.10440E+00	8.65347E+00	1.51486E+01	3.99345E-02	9.57040E-01	4.74249E+02
8	22	6.63907E-01	4.52284E+00	1.55455E+01	4.08213E-02	9.56094E-01	4.74411E+02
9	22	0.	1.33291E+00	1.55939E+01	4.10204E-02	9.55860E-01	4.74604E+02
10	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	22	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	23	2.32253E+00	2.62111E+01	2.13930E+01	6.45713E-02	9.28150E-01	4.89967E+02
3	23	4.22336E+00	2.65567E+01	2.03163E+01	6.02615E-02	9.33323E-01	4.87446E+02
4	23	7.10971E+00	2.68658E+01	1.86596E+01	5.38329E-02	9.40978E-01	4.83321E+02
5	23	1.07171E+01	2.67269E+01	1.62168E+01	4.46514E-02	9.51770E-01	4.76480E+02
6	23	8.26143E+00	2.08516E+01	1.44624E+01	3.73256E-02	9.60221E-01	4.69893E+02
7	23	4.21510E+00	1.45880E+01	1.51023E+01	3.87455E-02	9.58606E-01	4.71269E+02
8	23	1.56767E+00	9.02387E 00	1.55917E+01	4.02822E-02	9.56865E-01	4.72578E+02
9	23	0.	4.48256E-00	1.56789E+01	4.07186E-02	9.56337E-01	4.73214E+02
10	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	23	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	24	3.08280E+00	2.97059E+01	1.56798E+01	4.24743E-02	9.54277E-01	4.74476E+02
3	24	5.16599E+00	2.97585E+01	1.48892E+01	3.97070E-02	9.57476E-01	4.72007E+02
4	24	7.49026E+00	2.95342E+01	1.40157E+01	3.66261E-02	9.61015E-01	4.69031E+02
5	24	8.78639E+00	2.86463E+01	1.32333E+01	3.36739E-02	9.64385E-01	4.65919E+02
6	24	6.40206E+00	2.40539E+01	1.35950E+01	3.40634E-02	9.63952E-01	4.66276E+02
7	24	3.52285E+00	1.82292E+01	1.47297E+01	3.73954E-02	9.60178E-01	4.69683E+02
8	24	1.49825E+00	1.24857E+01	1.52849E+01	3.92054E-02	9.58119E-01	4.71388E+02
9	24	0.	7.56585E+00	1.54151E+01	3.98488E-02	9.57336E-01	4.72403E+02
10	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	24	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	25	3.14566E+00	3.19897E+01	1.19331E+01	2.98028E-02	9.68743E-01	4.61413E+02
3	25	4.76982E+00	3.16323E+01	1.16178E+01	2.87290E-02	9.69948E-01	4.60069E+02
4	25	5.97177E+00	3.08688E+0	1.15541E+01	2.83221E-02	9.70405E-01	4.59507E+02
5	25	5.76222E+00	2.95089E+01	1.19387E+01	2.91243E-02	9.6951[illegible]E-01	4.60495E+02
6	25	3.96656E+00	2.56503E+01	1.31235E+01	3.23922E-02	9.65848E-01	4.64370E+02
7	25	2.37812E+00	2.04627E+01	1.42013E+01	3.57947E-02	9.61992E-01	4.68155E+02
8	25	1.13793E+00	1.50085E+01	1.46616E+01	3.73404E-02	9.60223E-01	4.69829E+02
9	25	0.	1.01538E+01	1.47770E+01	3.80977E-02	9.59269E-01	4.71403E+02
10	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	25	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	26	2.35123E+00	3.25967E+01	9.98430E+00	2.36378E-02	9.75598E-01	4.52917E+02
3	26	3.13058E+00	3.19377E+01	1.01294E+01	2.39291E-02	9.75278E-01	4.53329E+02
4	26	3.33742E+00	3.09686E+01	1.06465E+01	2.52423E-02	9.73830E-01	4.55221E+02
5	26	2.72666E+00	2.96861E+01	1.15949E+01	2.78198E-02	9.70973E-01	4.58745E+02

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TABLE IV (con't)

6	26	1.90987E+00	2.65044E+01	1.27843E+01	3.13681E-02	9.67002E-01	4.63183E+02
7	26	1.34006E+00	2.19408E+01	1.35614E+01	3.38370E-02	9.64215E-01	4.66039E+02
8	26	7.30983E-01	1.69420E+01	1.38846E+01	3.48997E-02	9.63007E-01	4.67253E+02
9	26	0.	1.23919E+01	1.39929E+01	3.53486E-02	9.62468E-01	4.68036E+02
10	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	26	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	27	9.75137E-01	3.17932E+01	9.53500E+00	2.20091E-02	9.77387E-01	4.50244E+02
3	27	1.03747E+00	3.12037E+01	9.96543E+00	2.31305E-02	9.76159E-01	4.52019E+02
4	27	8.49159E-01	3.05162E+01	1.06821E+01	2.51114E-02	9.73976E-01	4.55013E+02
5	27	5.82177E-01	2.97166E+01	1.15948E+01	2.77505E-02	9.71053E-01	4.58628E+02
6	27	5.86646E-01	2.70868E+01	1.24002E+01	3.02442E-02	9.68265E-01	4.61819E+02
7	27	6.21527E-01	2.30276E+01	1.28617E+01	3.17052E-02	9.66624E-01	4.63591E+02
8	27	4.25708E-01	1.84796E+01	1.30689E+01	3.23548E-02	9.65888E-01	4.64418E+02
9	27	0.	1.42768E+01	1.31441E+01	3.26224E-02	9.65573E-01	4.64886E+02
10	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	27	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	28	-2.28070E-01	3.07341E+01	1.01167E+01	2.33562E-02	9.75919E-01	4.52330E+02
3	28	-4.44996E-01	3.04749E+01	1.05239E+01	2.45147E-02	9.74644E-01	4.54089E+02
4	28	-5.84845E-01	3.02319E+01	1.10467E+01	2.60756E-02	9.72914E-01	4.56359E+02
5	28	-4.47151E-01	2.98198E+01	1.15781E+01	2.77218E-02	9.71082E-01	4.58625E+02
6	28	-6.86925E-02	2.75861E+01	1.19633E+01	2.89624E-02	9.69696E-01	4.60257E+02
7	28	2.17916E-01	2.39495E+01	1.21886E+01	2.96571E-02	9.68920E-01	4.61155E+02
8	28	2.36443E-01	1.97[illegible]92E+01	1.23052E+01	2.99333E-02	9.68545E-01	4.61580E+02
9	28	0.	1.59187E+01	1.23509E+01	3.01441E-02	9.68363E-01	4.61934E+02
10	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	28	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	29	-7.08758E-01	3.04778E+01	1.09105E+01	2.55364E-02	9.73520E-01	4.55650E+02
3	29	-9.32277E-01	3.04627E+01	1.10781E+01	2.60872E-02	9.72910E-01	4.56377E+02
4	29	-9.63059E-01	3.04816E+01	1.12570E+01	2.67091E-02	9.72212E-01	4.57246E+02
5	29	-6.70082E-01	3.02427E+01	1.14056E+01	2.72462E-02	9.71611E-01	4.57975E+02
6	29	-2.34953E-01	2.82432E+01	1.14952E+01	2.75807E-02	9.71236E-01	4.58449E+02
7	29	8.07452E-02	2.49196E+01	1.15509E+01	2.77604E-02	9.71036E-01	4.58730E+02
8	29	1.57163E-01	2.10938E+01	1.15930E+01	2.78633E-02	9.70925E-01	4.58848E+02
9	29	0.	1.74947E+01	1.16144E+01	2.79200E-02	9.70855E-01	4.59034E+02
10	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	29	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	30	-6.55800E-01	3.18081E+01	1.11120E+01	2.[illegible]2380E-02	9.72745E-01	4.56647E+02
3	30	-8.06014E-01	3.17675E+01	1.10893E+01	2.62358E-02	9.72743E-01	4.56612E+02
4	30	-7.74254E-01	3.17273E+01	1.10440E+01	2.61843E-02	9.72792E-01	4.56529E+02
5	30	-4.93386E-01	3.13943E+01	1.09803E+01	2.60696E-02	9.72915E-01	4.56377E+02
6	30	-1.35281E-01	2.94113E+01	1.03222E+01	2.59324E-02	9.73066E-01	4.56176E+02
7	30	1.12993E-01	2.62255E+01	1.08932E+01	2.58424E-02	9.73166E-01	4.56084E+02
8	30	1.63176E-01	2.26174E+01	1.08833E+01	2.38010E-02	9.73213E-01	4.56038E+02
9	30	0.	1.92560E+01	1.08798E+01	2.57871E-02	9.73226E-01	4.56071E+02
10	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	30	0.	0.	6.80000E+01	5.09973E-01	3.29000E-01	5.57053E+02
2	31	0.	3.18081E+01	1.00000E+01	2.62316E-02	9.72752E-01	4.56638E+02
3	31	0.	3.17675E+01	1.00000E+01	2.62291E-02	9.72750E-01	4.56608E+02
4	31	0.	3.17273E+01	1.00000E+01	2.61774E-02	9.72800E-01	4.56520E+02
5	31	0.	3.13943E+01	1.00000E+01	2.60620E-02	9.72924E-01	4.56357E+02
6	31	0.	2.94113E+01	1.00000E+01	2.59255E-02	9.73074E-01	4.56165E+02
7	31	0.	2.62255E+01	1.00000E+01	2.58355E-02	9.73174E-01	4.56066E+02
8	31	0.	2.26174E+01	1.00000E+01	2.57920E-02	9.73223E-01	4.56026E+02
9	31	0.	1.92560E+01	1.00000E+01	2.57777E-02	9.73237E-01	4.56052E+02
10	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02
11	31	0.	0.	1.00000E+01	5.09973E-01	3.29000E-01	5.57053E+02

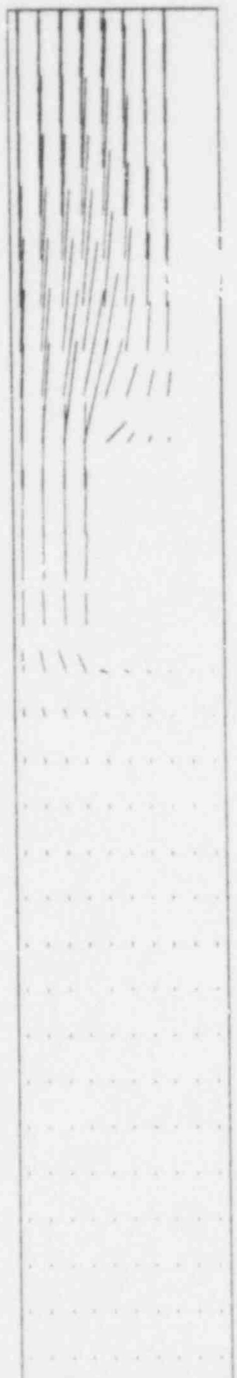

Fig. 4. Velocity vector plot of cycle 1000 for the example problem.

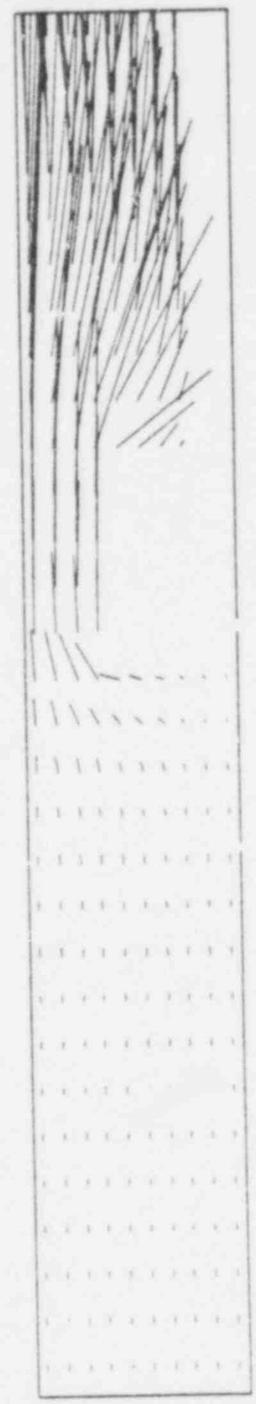

Fig. 5. Velocity vector plot of cycle 4000 for the example problem.

ACKNOWLEDGMENTS

The authors have profited greatly from discussions with all their colleagues. They especially thank W. C. Rivard for his assistance with the preparation of this report. In addition, they wish to thank the members of the Analysis Branch of the U. S. Nuclear Regulatory Commission, Division of Reactor Safety Research, for their interest, critical comments, and financial support.

REFERENCES

1. F. H. Harlow and A. A. Amsden, "Numerical Calculation of Multiphase Fluid Flow," J. Comput. Phys. 17, 19 (1975).

2. W. C. Rivard and M. D. Torrey, "K-FIX: A Computer Program for Transient, Two-Dimensional, Two-Fluid Flow," Los Alamos Scientific Laboratory report LA-NUREG-6623 (1977).

3. G. B. Wallis, One Dimensional Two-Phase Flow, McGraw-Hill (1969).

4. N. Zuber, "Flow Excursions and Oscillations in Boiling Two-Phase Flow Systems with Heat Addition," Sym. Two-Phase Flow Dynamics, E.U.R. 4288e, 1071 (1967).

5. C. W. Hirt, T. A. Oliphant, W. C. Rivard, N. C. Romero, and M. D. Torrey, "SOLA-LOOP: A Non-Equilibrium, Drift-Flux Code for Two-Phase Flow in Networks," manuscript in preparation.

6. C. W. Hirt, B. D. Nichols, and N. C. Romero, "SOLA - A Numerical Solution Algorithm for Transient Fluid Flows," Los Alamos Scientific Laboratory report LA-5852 (1975) and "SOLA - A Numerical Solution Algorithm for Transient Fluid Flows - Addendum," Los Alamos Scientific Laboratory report LA-5852, Add. (1976).

7. L. D. Cloutman, C. W. Hirt, and N. C. Romero, "SOLA-ICE: A Numerical Solution Algorithm for Transient Compressible Fluid Flows," Los Alamos Scientific Laboratory report LA-6236 (1976).

8. C. W. Hirt, J. K. Dienes, and L. R. Stein, "SOLA-FLX: A Solution Algorithm for Fluid-Structure Interactions of Cylindrical Shells," manuscript in preparation.

9. M. Ishii, Thermo-Fluid Dynamic Theory of Two-Phase Flow, (collection de la Direction des Etudes et Recherches d'Electricite de France, Eyrolles, Paris 1975).

10. J. R. Travis, F. H. Harlow, and A. A. Amsden, "Numerical Calculation of Two-Phase Flows," Nuc. Sci. and Eng. 61, 1 (1976).

11. T. G. Theofanous, T. Bohrer, M. Chen, and P. D. Patel, "Universal Solutions for Bubble Growth and the Influence of Microlayers, 15th Nat. Heat Transfer Conf., Paper 15, San Francisco, CA (August 1975).

12. D. Moalem and S. Sideman, "The Effect of Motion on Bubble Collapse," Int. J. Heat and Mass Transfer 16, 2321 (1973).

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13. G. B. Wallis, H. J. Richter, and J. T. Kuo, "The Separated Flow Model for Two-Phase Flow," Electric Power Research Institute report NP-275, 88 (1976).

14. F. H. Harlow and A. A. Amsden, "A Numerical Fluid Dynamics Calculation Method for All Flow Speeds," J. Comput. Phys. 8, 197 (1971).

15. C. W. Hirt, "Heuristic Theory for Finite-Difference Equations," J. Comput. Phys. 2, 339 (1968).

APPENDIX

FORTRAN IV Listing of the SOLA-DF Code   LASL Code: LP#-0772

```
*COMDECK,COMDK
C
      COMMON / SOL1 /
     1A    (27,82),   BETA(27,82),   E   (27,82),   EN  (27,82),
     2ITITLE (2),    NAME   (10),   P   (27,82),   Q   (27,82),
     3QL      (82),  RO  (27,82),   RON (27,82),   RV  (27,82),
     4RVN (27,82),   U   (27,82),   UD  (27,82),   UN  (27,82),
     5V   (27,82),   VD  (27,82),   VN  (27,82),   XC      (27),
     6YC      (82)
C
      COMMON / SOL2 /
     1ASQ,     CDG,     CHL,     CHV,     CYL,     DELT,    DELTMX,
     2DELX,    DELY,    ECL,     ECV,     EDL,     EDV,     EIL,
     3EIV,     E12,     ELHT,    EPSI,    ET,      ETEM,    ETEM1,
     4FLG,     GAM1,    II,      IMAX,    IM1,     IM2,     IPL,
     5IPR,     ITER,    JJ,      JMAX,    JM1,     JM2,     JPB,
     6JPT,     OMG,     PBC,     PIN,     PMAX,    PNV,     PT,
     7RDX,     RDY,     RG,      ROIL,    ROIV,    ROI2,    ROL,
     8RDT,     RPIPE,   RVIL,    RVIV,    RVI2,    RVT,     SGWN,
     9TC,      THC,     THC1,    THIN,    THTM,    THI,     VISL,
     1VISV,    WB,      WL,      WR,      WT
C
      INTEGER  CYCLE, WB, WL, WR, WT
      REAL  IMP, LONG, NUA, NUC
C
```


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```
*DECK,SOLADF
      PROGRA: SOLA(INPUT,TAPE10=INPUT,OUTPUT,TAPE9=OUTPUT)
*CALL COMDK
C
      DIMENSION ZC(10)
C
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
C
      NAMELIST / SOLDA /
     1ALPHA,     ASQ,       BUBN,      CDG,       CHL,       CHV,
     2CYL,       DELT,      DELTMX,    DELX,      DELY,      DFVEL,
     3DIM,       ECL,       ECV,       EDL,       EDV,       ELHT,
     4EPSI,      ETEM,      GAMI,      GX,        GY,        IBAR,
     5IMP,       JBAR,      NAME,      OMG,       PBC,       PHCH,
     6PIN,       PLTDT,     PRTDT,     RADIUS,    RG,        ROL,
     7R?IPE,     SGWN,      TC,        THC,       THIN,      TIN,
     8TW'IN,     UI,        VELMX,     VI,        VISL,      VISV,
     9WB,        WL,        WR,        WT
C
C     ZERO OUT THE DATA AND CONSTANT STORAGES
      DO 1 I=1,35518
    1 A(I)=0.
      DO 2 I=1,27
    2 XC(I)=0.
      DO 3 I=1,82
    3 YC(I)=0.
C
C     SET DEFAULT VALUES
C
      ALPHA=1.
      ASQ=1.234E+4
      BUBN=1.E+4
      CDG=0.5
      CHL=44.34
      CHV=6.67
      CYL=1.0
      DFVEL = 0.0
      DELT=1.0E-4
      DELTMX=1.0E-3
      DELX=1.0
      DELY=1.0
      DIM=2.0
      ECL=4.174E+3
      ECV=2.506E+4
      EDL=1.6E-6
      EDV=1.6E-7
      ELHT=1.76E+4
      EPSI=0.001
      ETEM=1.0
      GAMI=0.07
      GX = 0.0
      GY = 0.0
      IBAR=10
      IMP=1.0
      JBAR=10
```

```
      NAME(1)=10H *NO NAME*
      OMG=1.0
      PBC=1.0
      PHCH=1.0
      PIN=1.0
      PLTDT=0.1
      PRTDT=0.1
      RADIUS = 0.0
      RG = 0.0
      ROL=0.958
      RPIPE = 0.0
      SGWN=8.0E-4
      TC=373.0
      THC=0.001
      THIN = 0.0
      TIN=373.0
      TWFIN=1.E+4
      UI = 0.0
      VELMX=2.0
      VI = 0.0
      VISL=3.0E-6
      VISV=2.0E-4
      WB=1
      WL=1
      WR=1
      WT=1
C
C     READ AND WRITE INITIAL INPUT DATA
C
      READ(10,SOLDA)
C
      WRITE(9,901) (NAME(I),I=1,10)
      WRITE(9,985) ALPHA
      WRITE(9,1015) ASQ
      WRITE(9,1050) BUBN
      WRITE(9,1055) CDG
      WRITE(9,1090) CHL
      WRITE(9,1085) CHV
      WRITE(9,930) CYL
      WRITE(9,920) DELT
      WRITE(9,890) DELTMX
      WRITE(9,910) DELX
      WRITE(9,915) DELY
      WRITE(9,1030) DFVEL
      WRITE(9,880) DIM
      WRITE(9,1100) ECL
      WRITE(9,1095) ECV
      WRITE(9,1115) EDL
      WRITE(9,1110) EDV
      WRITE(9,1120) ELHT
      WRITE(9,935) EPSI
      WRITE(9,1025) ETEM
      WRITE(9,1010) GAMI
      WRITE(9,940) GX
      WRITE(9,945) GY
      WRITE(9,900) IBAR
      WRITE(9,1020) IMP
      WRITE(9,905) JBAR
```


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```
      WRITE(9,980) OMG
      WRITE(9,1028) PBC
      WRITE(9,1035) PHCH
      WRITE(9,1130) PIN
      WRITE(9,975) PLTDT
      WRITE(9,970) PRTDT
      WRITE(9,1125) RADIUS
      WRITE(9,1070) RG
      WRITE(9,1045) ROL
      WRITE(9,1065) RPIPE
      WRITE(9,1060) SGWN
      WRITE(9,1105) TC
      WRITE(9,1040) THC
      WRITE(9,1140) THIN
      WRITE(9,1135) TIN
      WRITE(9,965) TWFIN
      WRITE(9,950) UI
      WRITE(9,960) VELMX
      WRITE(9,955) VI
      WRITE(9,1080) VISL
      WRITE(9,1075) VISV
      WRITE(9,1005) WB
      WRITE(9,990) WL
      WRITE(9,995) WR
      WRITE(9,1000) WT
  880 FORMAT(10X, 10H      DIM=  ,1PE12.5)
  890 FORMAT(10X, 10H DELTMX=  ,1PE12.5)
  900 FORMAT(10X, 10H     IBAR=  ,I5)
  905 FORMAT(10X, 10H     JBAR=  ,I5)
  910 FORMAT(10X, 10H     DELX=  ,1PE12.5)
  915 FORMAT(10X, 10H     DELY=  ,1PE12.5)
  920 FORMAT(10X, 10H     DELT=  ,1PE12.5)
  930 FORMAT(10X, 10H      CYL=  ,1PE12.5)
  935 FORMAT(10X, 10H     EPSI=  ,1PE12.5)
  940 FORMAT(10X, 10H       GX=  ,1PE12.5)
  945 FORMAT(10X, 10H       GY=  ,1PE12.5)
  950 FORMAT(10X, 10H       UI=  ,1PE12.5)
  955 FORMAT(10X, 10H       VI=  ,1PE12.5)
  960 FORMAT(10X, 10H   VELMX=  ,1PE12.5)
  965 FORMAT(10X, 10H   TWFIN=  ,1PE12.5)
  970 FORMAT(10X, 10H   PRTDT=  ,1PE12.5)
  975 FORMAT(10X, 10H   PLTDT=  ,1PE12.5)
  980 FORMAT(10X, 10H      OMG=  ,1PE12.5)
  985 FORMAT(10X, 10H   ALPHA=  ,1PE12.5)
  990 FORMAT(10X, 10H       WL=  ,I5)
  995 FORMAT(10X, 10H       WR=  ,I5)
 1000 FORMAT(10X, 10H       WT=  ,I5)
 1005 FORMAT(10X, 10H       WB=  ,I5)
 1010 FORMAT(10X, 10H     GAMI=  ,1PE12.5)
 1015 FORMAT(10X, 10H      ASQ=  ,1PE12.5)
 1020 FORMAT(10X, 10H      IMP=  ,1PE12.5)
 1025 FORMAT(10X, 10H     ETEM=  ,1PE12.5)
 1028 FORMAT(10X, 10H      PBC=  ,1PE12.5)
 1030 FORMAT(10X, 10H   DFVEL=  ,1PE12.5)
 1035 FORMAT(10X, 10H     PHCH=  ,1PE12.5)
 1040 FORMAT(10X, 10H      THC=  ,1PE12.5)
 1045 FORMAT(10X, 10H      ROL=  ,1PE12.5)
 1050 FORMAT(10X, 10H     BUBN=  ,1PE12.5)
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1055 FORMAT(10X, 10H     CDG=  ,1PE12.5)
1060 FORMAT(10X, 10H    SGWN=  ,1PE12.5)
1065 FORMAT(10X, 10H   RPIPE=  ,1PE12.5)
1070 FORMAT(10X, 10H      RG=  ,1PE12.5)
1075 FORMAT(10X, 10H    VISV=  ,1PE12.5)
1080 FORMAT(10X, 10H    VISL=  ,1PE12.5)
1085 FORMAT(10X, 10H     CHV=  ,1PE12.5)
1090 FORMAT(10X, 10H     CHL=  ,1PE12.5)
1095 FORMAT(10X, 10H     ECV=  ,1PE12.5)
1100 FORMAT(10X, 10H     ECL=  ,1PE12.5)
1105 FORMAT(10X, 10H      TC=  ,1PE12.5)
1110 FORMAT(10X, 10H     EDV=  ,1PE12.5)
1115 FORMAT(10X, 10H     EDL=  ,1PE12.5)
1120 FORMAT(10X, 10H    ELHT=  ,1PE12.5)
1125 FORMAT(10X, 10H RADIUS=  ,1PE12.5)
1130 FORMAT(10X, 10H     PIN=  ,1PE12.5)
1135 FORMAT(10X, 10H     TIN=  ,1PE12.5)
1140 FORMAT(10X, 10H    THIN=  ,1PE12.5)
   5 FORMAT(6X,1HI,7X,1HJ,12X,2HUD,17X,2HVD,18X,2HRV)
  10 FORMAT(5X,I2,6X,I2,5X,1PE12.5,6X,E12.5,6X,E12.5)
  35 FORMAT(1H1)
 901 FORMAT(1H1,10A10,//)
  44 FORMAT(6X,7HCYCLE= ,I5,8X,4HTD= ,1PE12.5,8X,4HT2= ,E12.5,
    19X,5HITER= ,I5)
  45 FORMAT(10A8)
  46 FORMAT(1H+,80X,2HT=,1PE10.3,4X,6HCYCLE=,I4)
  47 FORMAT(6X,1HI,4X,1HJ,12X 1HU,12X,1HV,17X,1HP,14X,2HRO,14X,2HTH,
    114X,3HTEM)
  48 FORMAT(5X,I2,3X,I2,5X,1PE12.5,3X,E12.5,3X,E12.5,3X,E12.5,3X,E12.5,
    15X,E12.5)
  49 FORMAT(2X,6HITER= ,I5,3X,6HTIME= ,1PE12.5,3X,7HCYCLE= ,I4,
    14X,6HDELT= ,E12.5,4X,3HF= ,E12.5,4X,4HF1= ,E12.5)
C     COMPUTE CONSTANT TERMS
      IMAX=IBAR+2
      JMAX=JBAR+2
      IM1=IMAX-1
      JM1=JMAX-1
      JM2=JMAX-2
      IM2=IMAX-2
      RDX=1.0/DELX
      RDY=1.0/DELY
C     CONTOUR PLOT, SETTING UP VARIABLE VALUES
      XC(1)=0.0
      DO 15 I=2,IM1
      XC(I)=DELX*(FLOAT(I)-1.5)
  15  CONTINUE
      NNX=-IBAR
      YC(1)=0.0
      DO 20 J=2,JM1
      YC(J)=DELY*(FLOAT(J)-1.5)
  20  CONTINUE
      NNY=-JBAR
      NZX=27
      NZY=82
      NC=10
      ZMN=-1.0
      ZMX=-1.0
      DLZ=0.0
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      ZC=1.0
      DMPX=DELX*(FLOAT(IBAR))
      DMPY=DELY*(FLOAT(JBAR))
      IGRD=0.0
      NTITLE=10
      XLABEL=1HX
      YLABEL=1HY
      NXLBL=1
      NYLBL=1
      LONG=IBAR*DELX
      HIGH=JBAR*DELY
      IYB=916
      IF(LONG.LE.(1.13556*HIGH))GO TO 30
      IXL=0
      IXR=1022
      IYT=916-HIGH*1022/LONG
      GO TO 33
   30 X=LONG*450/HIGH
      IXL=511-X
      IXR=511+X
      IYT=16
   33 CONTINUE
      VELMX1=AMIN1(DELX,DELY)/VELMX
C       INITIALIZE NUMERICAL CONSTANTS
      TWPRT=0.
      TWPLT=0.
      T=0.
      ITER=0
      CYCLE=0
      NEX=0
      IPL=2
      IF(WL.EQ.5)IPL=3
      IPR=IM1
      IF(WR.EQ.5)IPR=IM1-1
      JPB=2
      IF(WB.EQ.5)JPB=3
      JPT=JM1
      IF(WT.EQ.5)JPT=JM1-1
C     INITIALIZE PHYSICAL CONSTANTS
      IF(DIM.LT.1.5)DELX=1.0E+10
      ETEM1=1.0-ETEM
      THC1=1.0-THC
      PNV=BUBN*4.1888
      TC2=2.0*TC
C     INITIALIZE AREAS
      DO 53 J=1,JMAX
      DO 53 I=1,IMAX
      A(I,J)=1.0-CYL+CYL*(RADIUS+DELX*(FLOAT(I)-1.5))
      IF(I.EQ.1.AND.WL.LT.3)A(I,J)=0.0
      IF(I.EQ.IMAX.AND.WR.LT.3)A(I,J)=0.0
      IF(J.EQ.1.AND.WB.LT.3)A(I,J)=0.0
      IF(J.EQ.JMAX.AND.WT.LT.3)A(I,J)=0.0
   53 CONTINUE
C     DEFINE SPECIAL AREAS
      READ(10,210) NO
  210 FORMAT(4I5)
      IF(NO.LE.0)GO TO 216
      DO 215 K=1,NO
```


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      READ(10,210) IBOB,IEOB,JBOB,JEOB
      DO 211 J=JBOB,JEOB
      DO 211 I=IBOB,IEOB
  211 A(I,J)=0.0
  215 CONTINUE
  216 CONTINUE
      WRITE(9,220)
  220 FORMAT(1H1,12H  AREA ARRAY )
      DO 230 J=1,JMAX
      JU=JMAX+1-J
  230 WRITE(9,225)(A(I,JU),I=1,IMAX)
  225 FORMAT(1H ,12(1X,1PE9.2))
      WRITE(9,235)
  235 FORMAT(1H1)
C       INITIALIZE VARIABLES
      DO 36 J=1,JMAX
      DO 56 I=1,IMAX
      U(I,J)=UI
      V(I,J)=VI
      UD(I,J)=VD(I,J)=0.0
      IF(THIN.LT.THC)GO TO 38
      IF(THIN.LT.THC1)GO TO 36
C     VAPOR STATE (P,T)
      TH=THIN
      EVT=EVCAL(TIN)
      RV(I,J)=RVIV=TH*PIN/(GAM1*EVT)
      RO(I,J)=ROIV=RV(I,J)+(1.0-TH)*ROL
      E(I,J)=EIV=(RV(I,J)*EVT+(RO(I,J)-RV(I,J))*ELCAL(TIN))/
     1RO(I,J)
      GO TO 40
   36 CONTINUE
      TSAT=SATT(PIN)
      EVSAT=EVCAL(TSAT)
      IF(THIN.LT.THC)GO TO 38
C       SATURATED STATE (P,TH)
      RVI2=RV(I,J)=THIN*PIN/(GAM1*EVSAT)
      ROI2=RO(I,J)=RV(I,J)+(1.0-THIN)*ROL
      EI2=E(I,J)=(RV(I,J)*EVSAT+(1.0-THIN)*ROL*ELCAL(TSAT))/RO(I,J)
      GO TO 40
   38 CONTINUE
C     LIQUID STATE (P,T)
      EVSAT=EVCAL(TIN)
      PSAT=SATP(TIN)
      RV(I,J)=RVIL=THC*PSAT/(GAM1*EVSAT)
      TH=(PSAT-PIN)/(ASQ*ROL)+THC
      RO(I,J)=ROIL=RV(I,J)+(1.0-TH)*ROL
      E(I,J)=EIL=(RV(I,J)*EVSAT+(1.0-TH)*ROL*ELCAL(TIN))/RO(I,J)
   40 CONTINUE
      ET=E(I,J)
      ROT=RO(I,J)
      RVT=RV(I,J)
      II=I
      JJ=J
      CALL EOS
      P(I,J)=PT
   56 CONTINUE
      CALL BC
      GO TO 502
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C     START CYCLE
   59 CONTINUE
      TER=0
      FLG=IMP
      PMAX=0.0
C     COMPUTE TEMPERARY U AND V
      DO 70 J=2,JM1
      DO 70 I=2,IM1
      U(I,J)=0.0
      AUB=2.0*A(I,J)*A(I+1,J)
      IF(AUB.EQ.0.0)GO TO 60
      AUBR=(A(I,J)+A(I+1,J))/AUB
      FUX=0.5*RDX*(UN(I,J)*(UN(I+1,J)-UN(I-1,J))
     1-ALPHA*ABS(UN(I,J))*(UN(I+1,J)-2.0*UN(I,J)+UN(I-1,J)))
      FUY=RDY/8.0*((VN(I,J)+VN(I+1,J)+VN(I,J-1)+VN(I+1,J-1))
     1*(UN(I,J+1)-UN(I,J-1))
     2-ALPHA*ABS(VN(I,J)+VN(I+1,J)+VN(I,J-1)+VN(I+1,J- ))
     3*(UN(I,J+1)-2.0*UN(I,J)+UN(I,J-1)))
      VDT=0.5*(VD(I,J)+VD(I+1,J))*(A(I,J)*A(I,J+1)/(A(I,J)+A(I,J+1))+
     1A(I+1,J)*A(I+1,J+1)/(A(I+1,J)+A(I+1,J+1)))
      VDB=0.5*(VD(I,J-1)+VD(I+1,J-1))*(A(I,J)* A(I,J-1)/(A(I,J)+
     1A(I,J-1))+A(I+1,J)*A(I+1,J-1)/(A(I+1,J)+A(I+1,J-1)))
      RUR=0.5*RVN(I+1,J)*(RON(I+1,J)-RVN(I+1,J))/RO I+1,J)*
     1(UD(I,J)+UD(I+1,J))*A(I+1,J)
      RUL=0.5*RVN(I,J)*(RON(I,J)-RVN(I,J))/RON(I,J)*(UD(I-1,J)+UD(I,J))
     1*A(I,J)
      RUC=0.5*UD(I,J)*(RVN(I,J)*(RON(I,J)-RVN(I,J))/RON(I,J)+RVN(I+1,J)*
     1(RON(I+1,J)-RVN(I+1,J))/RON(I+1,J))
      RUT=0.5*UD(I,J+1)*(RVN(I,J+1)*(RON(I,J+1)-RVN(I,J+1))/RON(I,J+1)+
     1RVN(I+1,J+1)*(RON(I+1,J+1)-RVN(I+1,J+1))/RON(I+1,J+1))
      RUB=0.5*UD(I,J-1)*(RVN(I,J-1)*(RON(I,J-1)-RVN(I,J-1))/RON(I,J-1)+
     1RVN(I+1,J-1)*(RON(I+1,J-1)-RVN(I+1,J-1))/RON(I+1,J-1))
      FDU=AUBR*(RDX*(RUR*(UD(I,J)+UD(I+1,J))+ALPHA*ABS(RUR)*(UD(I,J)-
     1UD(I+1,J))-RUL*(UD(I-1,J)+UD(I,J))-ALPHA*ABS(RUL)*(UD(I-1,J)-
     2UD(I,J)))+RDY*(VDT*(RUC+RUT)+ALPHA*ABS(VDT)*(RUC-RUT)-
     3VDB*(RUB+RUC)-ALPHA*ABS(VDB)*(RUB-RUC)))/(RO(I,J)+RO(I+1,J))
      VISX=0.0
      U(I,J)=UN(I,J)+DELT*(2.0*(P(I,J)-P(I+1,J))*RDX/(RO(I,J)+RO(I+1,J))
     1+GX-FUX-FUY+VISX-FDU)
   60 CONTINUE
      V(I,J)=0.0
      AVB=2.0*A(I,J)*A(I,J+1)
      IF(AVB.EQ.0.0)GO TO 65
      AVBR=(A(I,J)+A(I,J+1))/AVB
      FVX=RDX/8.0*((UN(I-1,J+1)+UN(I,J+1)+UN(I-1,J)+UN(I,J))*
     1(VN(I+1,J)-VN(I-1,J))-
     2ALPHA*ABS(UN(I-1,J+1)+UN(I,J+1)+UN(I-1,J)+UN(I,J))*
     3(VN(I+1,J)-2.0*VN(I,J)+VN(I-1,J)))
      FVY=0.5*RDY*(VN(I,J)*(VN(I,J+1)-VN(I,J-1))-
     1ALPHA*ABS(VN(I,J))*(VN(I,J+1)-2.0*VN(I,J)+VN(I,J-1)))
      UDR=0.5*(UD(I,J)+UD(I,J+1))*(A(I,J)*A(I+1,J)/(A(I,J)+A(I+1,J))
     1+A(I,J+1)*A(I+1,J+1)/(A(I,J+1)+A(I+1,J+1)))
      UDL=0.5*(UD(I-1,J)+UD(I-1,J+1))*(A(I,J)*A(I-1,J)/(A(I,J)+A(I-1,J))
     1+A(I,J+1)*A(I-1,J+1)/(A(I,J+1)+A(I-1,J+1)))
      RVT=0.5*RVN(I,J+1)*(RON(I,J+1)-RVN(I,J+1))/RON(I,J+1)*(VD(I,J)+
     1VD(I,J+1))*A(I,J+1)
      RVB=0.5*RVN(I,J)*(RON(I,J)-RVN(I,J))/RON(I,J)*(VD(I,J-1)+VD(I,J))
     1*A(I,J)
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      RVR=0.5*VD(I+1,J)*(RVN(I+1,J)*(RON(I+1,J)-RVN(I+1,J))/RON(I+1,J)+
     1RVN(I+1,J+1)*(RON(I+1,J+1)-RVN(I+1,J+1))/RON(I+1,J+1))
      RVC=0.5*VD(I,J)*(RVN(I,J)*(RON(I,J)-RVN(I,J))/RON(I,J)+RVN(I,J+1)*
     1(RON(I,J+1)-RVN(I,J+1))/RON(I,J+1))
      RVL=0.5*VD(I-1,J)*(RVN(I-1,J)*(RON(I-1,J)-RVN(I-1,J))/RON(I-1,J)+
     1RVN(I-1,J+1)*(RON(I-1,J+1)-RVN(I-1,J+1))/RON(I-1,J+1))
      FDV=AVBR*(RDX*(UDR*(RVC+RVR)+ALPHA*ABS(UDR)*(RVC-RVR)-UDL*(RVL+RVC
     1)-ALPHA*ABS(UDL)*(RVL-RVC))+RDY*(RVT*(VD(I,J)+VD(I,J+1))+
     2ALPHA*ABS(RVT)*(VD(I,J)-VD(I,J+1))-RVB*(VD(I,J-1)+VD(I,J))-
     3ALPHA*ABS(RVB)*(VD(I,J-1)-VD(I,J))))/(RON(I,J)+RON(I,J+1))
      VISY=0.0
      V(I,J)=VN(I,J)+DELT*(2.0*(P(I,J)-P(I,J+1))*RDY/(RO(I,J)+RO(I,J+1))
     1+GY-FVX-FVY+VISY-FDV)
   65 CONTINUE
C     ADD PIPE FRICTION
      IF(RPIPE.EQ.0.0.OR.DIM.GT.1.5)GO TO 70
      II=I
      JJ=J
      CALL PFRIC
   70 CONTINUE
      CALL BC
  250 CONTINUE
C     HAS CONVERGENCE BEEN REACHED
      IF(FLG.EQ.0.)GO TO 400
      ITER=ITER+1
      IF(ITER.LT.50)GO TO 255
      NEX=NEX+1
      IF(NEX.LT.1000) GO TO 400
      T=1000000000.0
      GO TO 502
C     COMPUTE UPDATED CELL VELOCITIES U,V
  255 CONTINUE
      CALL PITER
      CALL BC
      GO TO 250
  400 CONTINUE
C     COMPUTE UPDATED QUANTITIES RO, E,RV
      DO 4500 J=2,JM1
      DO 4500 I=2,IM1
      IF(A(I,J).EQ.0.0)GO TO 4500
      ABR=2.0*A(I,J)*A(I+1,J)/(A(I,J)+A(I+1,J))
      ABL=2.0*A(I,J)*A(I-1,J)/(A(I,J)+A(I-1,J))
      ABT=2.0*A(I,J)*A(I,J+1)/(A(I,J)+A(I,J+1))
      ABB=2.0*A(I,J)*A(I,J-1)/(A(I,J)+A(I,J-1))
C     DENSITY EQUATION
      ULR=U(I,J)-UD(I,J)*(RVN(I,J)+RVN(I+1,J))/(RON(I,J)+RON(I+1,J))
      ULL=U(I-1,J)-UD(I-1,J)*(RVN(I-1,J)+RVN(I,J))/(RON(I-1,J)+RON(I,J))
      ULT=V(I,J)-VD(I,J)*(RVN(I,J)+RVN(I,J+1))/(RON(I,J)+RON(I,J+1))
      ULB=V(I,J-1)-VD(I,J-1)*(RVN(I,J-1)+RVN(I,J))/(RON(I,J-1)+RON(I,J))
      UVR=U(I,J)+UD(I,J)*(RON(I,J)+RON(I+1,J)-RVN(I,J)-RVN(I+1,J))/
     1(RON(I,J)+RON(I+1,J))
      UVL=U(I-1,J)+UD(I-1,J)*(RON(I-1,J)+RON(I,J)-RVN(I-1,J)-RVN(I,J))/
     1(RON(I-1,J)+RON(I,J))
      UVT=V(I,J)+VD(I,J)*(RON(I,J)+RON(I,J+1)-RVN(I,J)-RVN(I,J+1))/
     1(RON(I,J)+RON(I,J+1))
      UVB=V(I,J-1)+VD(I,J-1)*(RON(I,J-1)+RON(I,J)-RVN(I,J-1)-RVN(I,J))/
     1(RON(I,J-1)+RON(I,J))
      FLR=(ULR*(RON(I,J)-RVN(I,J)+RON(I+1,J)-RVN(I+1,J))+ALPHA*ABS(ULR)*
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```
     1(RON(I,J)-RVN(I,J)-RON(I+1,J)+RVN(I+1,J)))*ABR
      FLL=(ULL*(RON(I-1,J)-RVN(I-1,J)+RON(I,J)-RVN(I,J))+ALPHA*ABS(ULL)*
     1(RON(I-1,J)-RVN(I-1,J)-RON(I,J)+RVN(I,J)))*ABL
      FLT=(ULT*(RON(I,J)-RVN(I,J)+RON(I,J+1)-RVN(I,J+1))+ALPHA*ABS(ULT)*
     1(RON(I,J)-RVN(I,J)-RON(I,J+1)+RVN(I,J+1)))*ABT
      FLB=(ULB*(RON(I,J-1)-RVN(I,J-1)+RON(I,J)-RVN(I,J))+ALPHA*ABS(ULB)*
     1(RON(I,J-1)-RVN(I,J-1)-RON(I,J)+RVN(I,J)))*ABB
      FVR=(UVR*(RVN(I,J)+RVN(I+1,J))+ALPHA*ABS(UVR)*(RVN(I,J)-
     1RVN(I+1,J)))*ABR
      FVL=(UVL*(RVN(I-1,J)+RVN(I,J))+ALPHA*ABS(UVL)*(RVN(I-1,J)-
     1RVN(I,J)))*ABL
      FVT=(UVT*(RVN(I,J)+RVN(I,J+1))+ALPHA*ABS(UVT)*(RVN(I,J)-
     1RVN(I,J+1)))*ABT
      FVB=(UVB*(RVN(I,J-1)+RVN(I,J))+ALPHA*ABS(UVB)*(RVN(I,J-1)-
     1RVN(I,J)))*ABB
C     UPDATE RO
      RO(I,J)=RON(I,J)-0.5*DELT*((FLR+FVR-FLL-FVL)*RDX+(FLT+FVT-FLB-
     1FVB)*RDY)/A(I,J)
C     ENERGY EQUATION
      ROEC=RON(I,J)*EN(I,J)
      ROER=RON(I+1,J)*EN(I+1,J)
      ROEL=RON(I-1,J)*EN(I-1,J)
      ROET=RON(I,J+1)*EN(I,J+1)
      ROEB=RON(I,J-1)*EN(I,J-1)
      IF(ETEM.GT.0.5)GO TO 425
      TVC=SATT(P(I,J))
      TVR=SATT(P(I+1,J))
      TVL=SATT(P(I-1,J))
      TVT=SATT(P(I,J+1))
      TVB=SATT(P(I,J-1))
      GO TO 430
  425 TVC=TC+(ROEC-RON(I,J)*ECL-RVN(I,J)*(ECV-ECL))/(RON(I,J)*CHL+
     1RVN(I,J)*(CHV-CHL))
      TVR=TC+(ROER-RON(I+1,J)*ECL-RVN(I+1,J)*(ECV-ECL))/(RON(I+1,J)*
     1CHL+RVN(I+1,J)*(CHV-CHL))
      TVL=TC+(ROEL-RON(I-1,J)*ECL-RVN(I-1,J)*(ECV-ECL))/(RON(I-1,J)*
     1CHL+RVN(I-1,J)*(CHV-CHL))
      TVT=TC+(ROET-RON(I,J+1)*ECL-RVN(I,J+1)*(ECV-ECL))/(RON(I,J+1)*
     1CHL+RVN(I,J+1)*(CHV-CHL))
      TVB=TC+(ROEB-RON(I,J-1)*ECL-RVN(I,J-1)*(ECV-ECL))/(RON(I,J-1)*
     1CHL+RVN(I,J-1)*(CHV-CHL))
  430 CONTINUE
      REVC=RVN(I,J)*EVCAL(TVC)
      REVR=RVN(I+1,J)*EVCAL(TVR)
      REVL=RVN(I-1,J)*EVCAL(TVL)
      REVT=RVN(I,J+1)*EVCAL(TVT)
      REVB=RVN(I,J-1)*EVCAL(TVB)
      RELC=ROEC-REVC
      RELR=ROER-REVR
      RELL=ROEL-REVL
      RELT=ROET-REVT
      RELB=ROEB-REVB
      FRER=0.5*(UVR*(REVC+REVR)+ALPHA*ABS(UVR)*(REVC-REVR)
     1+ULR*(RELC+RELR)+ALPHA*ABS(ULR)*(RELC-RELR))*ABR
      FREL=0.5*(UVL*(REVL+REVC)+ALPHA*ABS(UVL)*(REVL-REVC)+ULL*
     1(RELL+RELC)+ALPHA*ABS(ULL)*(RELL-RELC))*ABL
      FRET=0.5*(UVT*(REVC+REVT)+ALPHA*ABS(UVT)*(REVC-REVT)+ULT*(RELC+
     1RELT)+ALPHA*ABS(ULT)*(RELC-RELT))*ABT
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      FREB=0.5*(UVB*(REVB+REVC)+ALPHA*ABS(UVB)*(REVB-REVC)+ULB*(RELB+
     1RELC)+ALPHA*ABS(ULB)*(RELB-RELC))*ABB
      FEL=(RDX*(FRER-FREL)+RDY*(FRET-FREB))/A(I,J)
      FPW=-P(I,J)*((ABR*U(I,J)-ABL*U(I-1,J))*RDX+(ABT*V(I,J)-
     1ABB*V(I,J-1))*RDY)/A(I,J)
      TH=(ROL+RVN(I,J)-RON(I,J))/ROL
      TH=AMAX1(TH,THC)
      TH=AMIN1(TH,THC1)
      TH1=TH
      IF(TH1.GT.0.5)TH1=1.0-TH1
  440 RB=(TH1/PNV)**0.333
      CKN=0.5*CDG*((UD(I,J)+UD(I-1,J))**2+(VD(I,J)+VD(I,J-1))**2)**0.5
     1+12.0*VISV/RB
      FDIS=0.25*CKN*(0.375*TH1/RB)*((UD(I,J)+UD(I-1,J))**2+(VD(I,J)+
     1VD(I,J-1))**2)*RO(I,J)
      FDP=-P(I,J)*((((RVN(I,J)+RVN(I+1,J)-RON(I,J)-RON(I+1,J)+
     12.0*ROL)/(ROL*2.0)-(RVN(I,J)+RVN(I+1,J))/(RON(I,J)+RON(I+1,J)))*
     1ABR*
     2UD(I,J)-((RVN(I-1,J)+RVN(I,J)-RON(I-1,J)-RON(I,J)+2.0*ROL)/(2.0*
     3ROL)-(RVN(I-1,J)+RVN(I,J))/(RON(I-1,J)+RON(I,J)))*UD(I-1,J)
     3*ABL)/DELX+
     4(((RVN(I,J)+RVN(I,J+1)-RON(I,J)-RON(I,J+1)+2.0*ROL)/(2.0*ROL)
     5-(RVN(I,J)+RVN(I,J+1))/(RON(I,J)+RON(I,J+1)))*VD(I,J)*ABT
     5-((RVN(I,J-1)
     5+RVN(I,J)-
     6RON(I,J-1)-RON(I,J)+2.0*ROL)/(2.0*ROL)-(RVN(I,J-1)+RVN(I,J))/
     7(RON(I,J-1)+RON(I,J)))*VD(I,J-1)*ABB)/DELY)/A(I,J)
C     ENERGY DIFFUSION
      TEM=EN(I,J)
      TEMR=EN(I+1,J)
      TEML=EN(I-1,J)
      TEMT=EN(I,J+1)
      TEMB=EN(I,J-1)
      THR=(ROL+RVN(I+1,J)-RON(I+1,J))/ROL
      THR=AMAX1(THR,THC)
      THR=AMIN1(THR,THC1)
      THL=(ROL+RVN(I-1,J)-RON(I-1,J))/ROL
      THL=AMAX1(THL,THC)
      THL=AMIN1(THL,THC1)
      THT=(ROL+RVN(I,J+1)-RON(I,J+1))/ROL
      THT=AMAX1(THT,THC)
      THT=AMIN1(THT,THC1)
      THB=(ROL+RVN(I,J-1)-RON(I,J-1))/ROL
      THB=AMAX1(THB,THC)
      THB=AMIN1(THB,THC1)
      EKR=0.5*(EDV*(TH+THR)+EDL*(2.0-TH-THR))*ABR
      EKT=0.5*(EDV*(TH+THT)+EDL*(2.0-TH-THT))*ABT
      EKL=0.5*(EDV*(TH+THL)+EDL*(2.0-TH-THL))*ABL
      EKB=0.5*(EDV*(TH+THB)+EDL*(2.0-TH-THB))*ABB
      DIFE=(RDX*RDX*(EKR*(TEMR-TEM)-EKL*(TEM-TEML))
     1+RDY*RDY*(EKT*(TEMT-TEM)-EKB*(TEM-TEMB)))/A(I,J)
C     UPDATE ENERGY
      E(I,J)=(ROEC+DELT*(-FEC+FDIS+FDP+DIFE+FPW))/RO(I,J)
C     VAPOR DENSITY EQUATION
      RV(I,J)=RVN(I,J)-DELT*0.5*((FVR-FVL)*RDX+(FVT-FVB)*
     1RDY)/A(I,J)
      RV(I,J)=AMIN1(RV(I,J),RO(I,J))
      RV(I,J)=AMAX1(RV(I,J),0.0)
```

```
C     PHASE CHANGE
      IF(PHCH.LT.0.5)GO TO 4500
      II=I
      JJ=J
      CALL PHCHR
 4500 CONTINUE
      CALL BC
 4600 CONTINUE
C     COMPUTE DRIFT VELOCITY
      IF(DFVEL.LT.0.5)GO TO 502
      CALL DRIFT
  500 CONTINUE
      CALL BC
  502 CONTINUE
C     PRINT AND PLOT
      IF(T.GT.0.)GO TO 503
      CALL LINCNT(1)
      WRITE(12,45)
  503 CONTINUE
C     DEFINE OUTPUT QUANTITY F AND FI
      F=0.0
      INZ=4
      J=20
      DO 505 I=2,5
  505 F=F+RO(I,J  )*V(I,J  )*(FLOAT(I)-1.5)
      F=2.0*F/INZ**2
      FI=0.34264*P(5,11)+0.65736*P(5,12)
      WRITE(9,49)ITER,T,CYCLE,DELT,F,FI
      IF(CYCLE.LE.0)GO TO 510
      IF(T.LT.TWPLT)GO TO 560
      TWPLT=TWPLT+PLTDT
  510 CONTINUE
C     FILM LONG PRINT
      CALL ADV(1)
      CALL LINCNT(3)
      WRITE(12,49)ITER,T,CYCLE,DELT,F,FI
      CALL LINCNT(4)
      WRITE(12,47)
      DO 525 J=2,JM1
      DO 525 I=2,IM1
      TH=(ROL-RO(I,J)+RV(I,J))/ROL
      D=RDX*(U(I,J)-U(I-1,J))+RDY*(V(I,J)-V(I,J-1))+CYL*(U(I,J)
     1+U(I-1,J))/(2.*DELX*(FLOAT(I)-1.5))
      TSAT=SATT(P(I,J))
      EVT=EVCAL(TSAT)*ETEMI+ECV*ETEM
      TEM=TC+(RO(I,J)*(E(I,J)-ECL)-RV(I,J)*(EVT-ECL))/(RV(I,J)*(CHV*
     1ETEM-CHL)+RO(I,J)*CHL)
      WRITE(12,48) (I,J,U(I,J),V(I,J),P(I,J),RO(I,J),TH,TEM)
  525 CONTINUE
      CALL ADV(1)
      CALL LINCNT(3)
      WRITE(12,49)ITER,T,CYCLE,DELT,F,FI
      CALL LINCNT(4)
      WRITE(12,5)
      DO 528 J=2,JM1
      DO 528 I=2,IM1
      WRITE(12,10)(I,J,UD(I,J),VD(I,J),RV(I,J))
  528 CONTINUE
```

```
C     VELOCITY VECTOR PLOT
      CALL ADV(1)
      CALL DGA(IXL,IXR,IYT,IYB,0.,LONG,HIGH,0.)
      CALL FRAME(IXL,IXR,IYT,IYB)
      CALL FRAME(IXL,IXR,IYT,IYB)
      CALL LINCNT(61)
      WRITE(12,45)
      CALL LINCNT(61)
      WRITE(12,46)T,CYCLE
      DO 530 J=2,JM1
      DO 530 I=2,IM1
      XCC=DELX*(FLOAT(I)-1.5)
      YCC=DELY*(FLOAT(J)-1.5)
      UVEC=(U(I-1,J)+U(I,J))*0.5*VELMX1+XCC
      VVEC=(V(I,J-1)+V(I,J))*0.5*VELMX1+YCC
      CALL CONVRT(UVEC,IUVEC,0.,LONG,IXL,IXR)
      CALL CONVRT(VVEC,JVVEC,HIGH,0.,IYT,IYB)
      CALL CONVRT(XCC,IXCC,0.,LONG,IXL,IXR)
      CALL CONVRT(YCC,JYCC,HIGH,0.,IYT,IYB)
      CALL DRV(IXCC,JYCC,IUVEC,JVVEC)
  530 CONTINUE
C     CONTOURS PLOT STARTS
      NCO=0
  532 NCO=NCO+1
      DO 545 I=1,IM1
      DO 545 J=1,JM1
      GO TO(533,534,535,536,537,560),NCO
  533 Q(I,J)=RO(I+1,J+1)
      GO TO 540
  534 Q(I,J)=E(I+1,J+1)
      GO TO 540
  535 Q(I,J)=P(I+1,J+1)
      GO TO 540
  536 Q(I,J)=RV(I+1,J+1)
      GO TO 540
  537 Q(I,J)=(ROL+RV(I+1,J+1)-RO(I+1,J+1))/ROL
  540 QL(J)=Q(I,J)
  545 CONTINUE
      CALL LINCNT(61)
      WRITE(12,45)
      CALL LINCNT(61)
      WRITE(12,46)T,CYCLE
      GO TO (553,554,555,556,557),NCO
  553 ITITLE(1)=10HRO CONTOUR
      GO TO 559
  554 ITITLE(1)=9HE CONTOUR
      GO TO 559
  555 ITITLE(1)=9HP CONTOUR
      GO TO 559
  556 ITITLE(1)=10HRV CONTOUR
      GO TO 559
  557 ITITLE(1)=9HVOID FRAC
  559 CONTINUE
      IF(IBAR.GT.1)GO TO 5601
      CALL SPLOT(1,JBAR,YC(2),QL(2),42,1)
      GO TO 532
 5601 CONTINUE
      CALL CONTRJB(XC(2),NNX,YC(2),NNY,Q,NZX,NZY,NC,ZMN,ZMX,DLZ,ZC,
```

```
     1DMPX,DMPY,IGRD,ITITLE,NTITLE,XLABEL,NXLBL,YLABEL,NYLBL)
      GO TO 532
  560 CONTINUE
C     LONG PRINT
      IF(CYCLE.LE.0) GO TO 565
      IF(T.LT.TWPRT)GO TO 580
      TWPRT=TWPRT+PRTDT
  565 CONTINUE
      WRITE(9,35)
      WRITE(9,49)ITER,T,CYCLE,DELT,F,F1
      WRITE(9,47)
      DO 575 J=2,JM1
      DO 575 I=2,IM1
      TH=(ROL-RO(I,J)+RV(I,J))/ROL
      TSAT=SATT(P(I,J))
      EVT=EVCAL(TSAT)*ETEM1+ECV*ETEM
      TEM=TC    +(RO(I,J)*(E(I,J)-ECL)-RV(I,J)*(EVT-ECL))/(RV(I,J)*(CHV*
     1ETEM-CHL)+RO(I,J)*CHL)
      WRITE(9,48)(I,J,U(I,J),V(I,J),P(I,J),RO(I,J),TH,TEM)
  575 CONTINUE
C      SET THE ADVANCE TIME QUANTITIES INTO OLD ARRAYS
  580 CONTINUE
      DO 600 J=1,JMAX
      DO 600 I=1,IMAX
      UN(I,J)=U(I,J)
      VN(I,J)=V(I,J)
      RON(I,J)=ROT=RO(I,J)
      RVN(I,J)=RVT=RV(I,J)
      EN(I,J)=ET=E(I,J)
      IF(IMP.GT.0.5)GO TO 600
      II=I
      JJ=J
      CALL EOS
      P(I,J)=PT
  600 CONTINUE
C     ADJUST TIME STEP
      CALL TSTEP
C     ADVANCE TIME T=T+DELT
      IF(T.GT.TWFIN)GO TO 650
      T=T+DELT
      CYCLE=CYCLE+1
      GO TO 59
  650 CALL EXIT(1)
      END
```

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      SUBROUTINE BC
*CALL COMDK
C     SET BOUNDARY CONDITION
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
      DO 140 J=2,JM1
```

```
      RO(1,J)=RO(2,J)
      RV(1,J)=RV(2,J)
      P(1,J)=P(2,J)
      E(1,J)=E(2,J)
      RO(IMAX,J)=RO(IM1,J)
      RV(IMAX,J)=RV(IM1,J)
      P(IMAX,J)=P(IM1,J)
      E(IMAX,J)=E(IM1,J)
      GO TO (102,104,106,108,106),WL
  102 U(1,J)=0.0
      V(1,J)=V(2,J)
      GO TO 111
  104 U(1,J)=0.0
      V(1,J)=-V(2,J)
      GO TO 111
  106 IF(WL.EQ.5)P(2,J)=PBC
      IF(ITER.GT.0.AND.FLG.GT.0)GO TO 111
      U(1,J)=U(2,J)
      V(1,J)=V(2,J)
      GO TO 111
  108 U(1,J)=U(IM2,J)
      V(1,J)=V(IM2,J)
      RO(1,J)=RO(IM2,J)
      RV(1,J)=RV(IM2,J)
      P(1,J)=P(IM2,J)
      E(1,J)=E(IM2,J)
      GO TO 111
  111 GO TO (122,124,126,128,126),WR
  122 U(IM1,J)=0.0
      V(IMAX,J)=V(IM1,J)
      GO TO 140
  124 U(IM1,J)=0.0
      V(IMAX,J)=-V(IM1,J)
      GO TO 140
  126 IF(WR.EQ.5)P(IM1,J)=PBC
      IF(ITER.GT.0.AND.FLG.GT.0)GO TO 140
      U(IM1,J)=U(IM2,J)*((IM2-1)/(IM1-1)*CYL+(1.0-CYL))
      V(IMAX,J)=V(IM1,J)
      GO TO 140
  128 U(IM1,J)=U(2,J)
      V(IMAX,J)=V(3,J)
      RO(IMAX,J)=RO(3,J)
      RV(IMAX,J)=RV(3,J)
      P(IMAX,J)=P(3,J)
      E(IMAX,J)=E(3,J)
  140 CONTINUE
      DO 180 I=2,IM1
      RO(I,1)=RO(I,2)
      RV(I,1)=RV(I,2)
      P(I,1)=P(I,2)
      E(I,1)=E(I,2)
      RO(I,JMAX)=RO(I,JM1)
      RV(I,JMAX)=RV(I,JM1)
      P(I,JMAX)=P(I,JM1)
      E(I,JMAX)=E(I,JM1)
      GO TO (152,154,156,158,156),WT
  152 V(I,JM1)=0.0
      U(I,JMAX)=U(I,[illegible]
```

```
      GO TO 161
  154 V(I,JM1)=0.0
      U(I,JMAX)=-U(I,JM1)
      GO TO 161
  156 IF(WT.EQ.5)P(I,JM1)=PBC
      IF(ITER.GT.0.AND.FLG.GT.0)GO TO 161
      V(I,JM1)=V(I,JM2)
      U(I,JMAX)=U(I,JM1)
      GO TO 161
  158 V(I,JM1)=V(I,2)
      U(I,JMAX)=U(I,3)
      RO(I,JMAX)=RO(I,3)
      RV(I,JMAX)=RV(I,3)
      P(I,JMAX)=P(I,3)
      E(I,JMAX)=E(I,3)
      GO TO 161
  161 GO TO (172,174,176,178,176),WB
  172 V(I,1)=0.0
      U(I,1)=U(I,2)
      GO TO 180
  174 V(I,1)=0.0
      U(I,1)=-U(I,2)
      GO TO 180
  176 IF(WB.EQ.5)P(I,2)=PBC
      IF(ITER.GT.0.AND.FLG.GT.0)GO TO 180
      V(I,1)=V(I,2)
      U(I,1)=U(I,2)
      GO TO 180
  178 V(I,1)=V(I,JM2)
      U(I,1)=U(I,JM2)
      RO(I,1)=RO(I,JM2)
      RV(I,1)=RV(I,JM2)
      P(I,1)=P(I,JM2)
      E(I,1)=E(I,JM2)
  180 CONTINUE
  182 CONTINUE
C     SPECIAL BOUNDARY CONDITION
      DO 188 I=2,IM1
      P(I,2)=PIN
      U(I,2)=0.0
      U(I,JM1)=0.0
      IF(THIN.LT.THC) GO TO 38
      IF(THIN.LT.THC1) GO TO 36
      RV(I,2)=RVIV
      RO(I,2)=ROIV
      E(I,2)=EIV
      GO TO 188
   36 RV(I,2)=RVI2
      RO(I,2)=ROI2
      E(I,2)=EI2
      GO TO 188
   38 RV(I,2)=RVIL
      RO(I,2)=ROIL
      E(I,2)=EIL
  188 CONTINUE
      RETURN
      END
```

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      SUBROUTINE DRIFT
*CALL COMDK
C      CALCULATE RELATIVE OR DRIFT VELOCITY
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
      DO 5000 J=2,JM1
      DO 5000 I=2,IM1
      IF(A(I,J).EQ.0.0)GO TO 5000
      TH=(ROL-RO(I,J)+RV(I,J))/ROL
      IF(TH.GT.THC.AND.TH.LT.THC1)GO TO 4700
      UD(I,J)=VD(I,J)=0.0
      GO TO 5000
 4700 CONTINUE
      TH1=TH
      IF(TH1.GT.0.5)TH1=1.0-TH1
 4800 RB=(TH1/PNV)**0.333
      UDN=UD(I,J)
      VDN=VD(I,J)
      AREA=3.0*TH1/RB
      NUC=VISL
      IF(TH.GT.0.5)NUC=VISV
      NUA=NUC/( .0-TH1)**2.5
      UDO=DELT*(1.0/ROL-2.0*TH/(RV(I,J)+RV(I+1,J)))*RDX*(P(I+1,J)-
     1P(I,J))
      IF(A(I+1,J).EQ.0.0)UDO=0.0
      VDO=DELT*(1.0/ROL-2.0*TH/(RV(I,J)+RV(I,J+1)))*RDY*(P(I,J+1)-
     1P(I,J))
      IF(A(I,J+1).EQ.0.0)VDO=0.0
      UDM=(UD(I,J)**?+VD(I,J)**2)**0.5+1.0E-10
      UKPM=DELT*0.25*AREA*(RO(I,J)+RO(I+1,J))**2/((RV(I,J)+RV(I+1,J))*
     1(RO(I,J)+RO(I+1,J)-RV(I,J)-RV(I+1,J)))
      VKPM=DELT*0.25*AREA*(RO(I,J)+RO(I,J+1))**2/((RV(I,J)+RV(I,J+1))*
     1(RO(I,J)+RO(I,J+1)-RV(I,J)-RV(I,J+1)))
 4950 UDMT=UDM
      UKP=UKPM*(CDG*UDM+12.0*NUA/RB)/TH1
      VKP=VKPM*(CDG*UDM+12.0*NUA/RB)/TH1
      UD(I,J)=UD(I,J)-(UD(I,J)+UKP*UD(I,J)-UDO-UDN)/(1.0+UKP+UKPM*CDG
     1*UD(I,J)**2/UDM)
      VD(I,J)=VD(I,J)-(VD(I,J)+VKP*VD(I,J)-VDO-VDN)/(1.0+VKP+VKPM*CDG
     1*VD(I,J)**2/UDM)
      UDM=+(UD(I,J)**2+VD(I,J)**2)**0.5+1.0E-10
      IF(ABS((UDMT-UDM)/(UDMT+UDM)).GT.0.01)GO TO 4950
 5000 CONTINUE
      RETURN
      END

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      SUBROUTINE EOS
*CALL COMDK
C      EQUATION OF STATE ROUTINE
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
```


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      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
      TH=THTM=(ROL+RVT-ROT)/ROL
      IF(TH.LT.THC)THTM=THC
      ETEMT=ETEM
      IF(TH.GT.THC1)ETEMT=1.0
      TEM=TC+(ROT*(ET-ECL)-RVT*(ECV-ECL))/(RVT*(CHV-CHL)+ROT*CHL)
      IF(ETEMT.LT.0.5)TEM=255.2
      PT=PTT=GAM1*RVT*(ECV+CHV*(TEM   -TC))/THTM+ASQ*ROL*(THTM-TH)
      IF(ETEMT.GT.0.5)GO TO 6300
      PCC=117.8*GAM1*RVT*CHV/THTM
      PT=PTT+2.0*(0.223*PCC)**1.287
 6260 PTG=PT
      PTA=PCC*PTG**0.223
      PT=PTG+(PTT+PTA-PTG)/(1.0-0.223*PTA/PTG)
      IF(ABS((PT-PTG)/(PT+PTG)).GT.0.01)GO TO 6260
      PT=AMAX1(PT,0.0)
      IF(PT.GT.0.0)GO TO 6300
      WRITE(9,6200)
 6200 FORMAT(5X,1HJ,12X,2HP(,12X,3HROT,17X,3HRVT,17X,2HET)
      WRITE(9,6263)II,JJ,PT,ROT,RVT,ET
 6263 FORMAT(6X,2I3,5X,1PE12.5,6X,E12.5,6X,E12.5,6X,E12.5)
 6300 CONTINUE
      RETURN
      END
```

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      SUBROUTINE PFRIC
*CALL COMDK
C     PIPE FRICTION ROUTINE
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
      I=II
      J=JJ
      VAI=ABS(V(I,J))
      IF(VAI.LT.EPSI)GO TO 60
      TH=THI=(ROL+RV(I,J)-RO(I,J))/ROL
      IF(TH.LT.THC)TH=THC
      IF(TH.GT.THC1)TH=THC1
      CHI=RV(I,J)/RO(I,J)*(1.0+(RO(I,J)-RV(I,J))/RO(I,J)*VD(I,J)/V(I,J))
      REN=2.0*RPIPE*ABS(V(I,J))/VISL
      RGR=0.5*RG/RPIPE
      FLA=0.026*RGR**0.225+0.133*RGR
      FLB=22.0*RGR**0.44
      FLC=1.62*RGR**0.134
      FLC2=(FLA+FLB/REN**FLC)
      PHIS=1.0/(1.0-TH)**1.75
```

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      FLC=FLC2*(RO(I,J)/ROL)*(1.0-CHI)**2.0/RPIPE*PHIS
      FLCT=2.0*DELT*FLC
      V(I,J)=SIGN(1.0,V(I,J))*(-1.0+(1.0+2.0*FLCT*VA1)**0.5)/FLCT
      EE=0.25*(VA1**2-V(I,J)**2)
      E(I,J)=E(I,J)+EE
      E(I,J+1)=E(I,J+1)+EE
   60 CONTINUE
      RETURN
      END
```

* * * * * * * * * * * * * * * * ///// * * * * * * * * * * * * * * * *

```
      SUBROUTINE PHCHR
*CALL COMDK
C     PHASE CHANGE ROUTINE
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
      I=II
      J=JJ
      RVT=RVO=RV(I,J)
      ROT=RO(I,J)
      ET=E(I,J)
      TH1=TH=(ROL-ROT+RVO)/ROL
      IF(TH.LT.THC.OR.TH.GT.THC1)GO TO 5000
      IF(TH.GT.0.5)TH1=1.0-TH
      VAVE=0.5*((U(I,J)+U(I-1,J) )**2+
     1(V(I,J)+V(I,J-1))**2)**0.5
      VDAVE=0.5*((UD(I,J)+UD(I-1,J))**2+(VD(I,J)+VD(I,J-1))**2)**0.5
      VTB=VDAVE+0.1*VAVE
 4410 RB=(TH1/PNV)**0.333
      RBW=SUWN/(ROT*VTB**2+1.0E-10)
      RB=AMIN1(RB,RBW)
      AREA=3.0*TH1/RB
      TVAP=SATT(P(I,J))
      EVT=EVCAL(TVAP)*ETEM1+ECV*ETEM
      TLQ=TC+(ROT*ET-RVO*EVT-(ROT-RVO)*ECL)/(RVL*CHV*ETEM+(ROT-RVO)*CHL)
      TLQ=AMAX1(TLQ,256.0)
      PSAT=SATP(TLQ)
      EVSAT=EVCAL(TLQ)
      RSAT=TH*PSAT/(GAM1*EVSAT)
      IVSL=0
      RBETA=1.0E-5*ROL
      IRVT=0
      RTOT=(RSAT+RVO)/2.0
      RET=ROT*(ET-ECL)
      RCH=ROT*CHL
      CEC=CHV*ETEM-CHL
C      START ITERATION
 4412 CONTINUE
      RVT=RV(I,J)
      II=I
      JJ=J
      CALL EOS
```


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```
      TVAP=SATT(PT)
      EVTM=EVCAL(TVAP)*ETEMI+ECV*ETEM-ECL
      TLQ=TC+(RET-RVT*EVTM)/(RCH+RVT*CEC)
      ELTBL=(1.0+1.91*ROL*TH/RTOT*CHL/ELHT*ABS(TLQ-TVAP)
     1+(0.637*VTB*RB*ROL/EOL)**0.5)/RB
      RATE=DELT*(ELTBL*AREA/ELHT*E?L*CHL*(TLQ-TVAP))*100.0
      RVEQ=RVT-RVO-RATE
      IF(ABS(RVEQ/RTOT).LT.0.001)GO TO 5000
      IRVT=IRVT+1
      IF(IPVT.GT.25)GO TO 5000
      IF(IRV. EQ.1)SRH=SIGN(1.0,RVEQ)
      IF(IVSL.EC 1)GO TO  4418
      IF(RVEQ.GE.L.0)GO TO 4415
C      SEEK BOUNDS
      FMN=RVEQ
      RVMN=RV(I,J)
      IF(SRH.GE.0.0)IVSL=1
      RV(I,J)=AMIN1(RVT+RBETA,ROT)
      IF(IVSL.EQ.1)RV(I,J)=0.5*(RVMN+RVMX)
      RBETA=2.0*RBETA
      GO TO 4412
 4415 FMX=RVEQ
      RVMX=RV(I,J)
      IF(SRH.LT.0.0)IVSL=1
      RV(I,J)=AMAX1(RVT-RBETA,0.0)
      IF(IVSL.EQ.1)RV(I,J)=0.5*(RVMN-RVMX)
      RRETA=2.0*RBETA
         TO 4412
 -.   NTINUE
C        NVERGE BOUNDS
      IF(RVEQ.LT.0.0)GO TO 4422
      VTP=RVT-RVEQ*(RVMX-RVT)/(FMX-RVEQ)
      FN =RVEQ
      RVMX=RVT
      RV(I,J)=RVTP
      IF(RVTP.LT.RVMN)RV(I,J)=0.5*(RVMN+RVMX)
      GO TO 4412
 4422 RVTP=RVT-RVEQ*(RVT-RVMN)/(RVEQ-FMN)
      FMN=RVEQ
      RVMN=RVT
      RV(I,J)=RVTP
      IF(RVTP.GT.RVMX)RV(I,J)=0.5*(RVMN+RVMX)
      GO TO 4412
 5000 CONTINUE
      RETURN
      END
```

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```
      SUBROUTINE PITER
C     PRESSURE ITERATION ROUTINE
*CALL COMDK
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
```

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```
      SATP(X)=((X-255.2)/117.8)**4.48
      FLG=0.0
      DO 300 J=JPB,JPT
      DO 300 I=IPL,IPR
      IF(A(I,J).EQ.0.0)GO TO 300
      ABR=2.0*A(I,J)*A(I+1,J)/(A(I,J)+A(I+1,J))
      ABL=2.0*A(I,J)*A(I-1,J)/(A(I,J)+A(I-1,J))
      ABT=2.0*A(I,J)*A(I,J+1)/(A(I,J)+A(I,J+1))
      ABB=2.0*A(I,J)*A(I,J-1)/(A(I,J)+A(I,J-1))
      PMAX=AMAX1(PMAX,P(I,J))
      SM=-1.0E+10
      ICT=0
      XMX=1.0E+10
      XMN=0.0
      PBB=0.0
  260 PB=P(I,J)
      D=(RDX*(ABR*U(I,J)-ABL*U(I-1,J))+RDY*(ABT* V(I,J)-
     1ABB*V(I,J-1)))*DELT/A(I,J)
      DMAX=EN(I,J)*RO(I,J)/PB
      D=AMIN1(D,DMAX)
      D=AMAX1(D,-0.99)
      ROT=RON(I,J)/(1.0+D)
      RVT=RV(I,J)/(1.0+D)
      ET=EN(I,J)-P(I,J)*D/RO(I,J)
      II=I
      JJ=J
      CALL EOS
      S=PB-PT
      IF(ICT.NE.0)BETA(I,J)=(PB-PBB)/(S-SM)
      P(I,J)=PB-BETA(I,J)*S
      IF(S.GE.0.0)GO TO 262
      XMN=PB
      IF(P(I,J).GE.XMX)P(I,J)=0.5*(XMN+XMX)
      GO TO 266
  262 XMX=PB
      IF(P(I,J).LE.XMN)P(I,J)=0.5*(XMN+XMX)
  266 CONTINUE
      DELP=P(I,J)-PB
      IF(ABS(DELP).LE.EPSI*PMAX)ICT=100
      IF(ABR.EQ.0.0)GO TO 270
      U(I,J)=U(I,J)+2.0*DELT*RDX*DELP/(RO(I,J)+RO(I+1,J))
  270 IF(ABL.EQ.0.0)GO TO 272
      U(I-1,J)=U(I-1,J)-2.0*DELT*RDX*DELP/(RO(I-1,J)+RO(I,J))
  272 IF(ABB.EQ.0.0)GO TO 274
      V(I,J-1)=V(I,J-1)-2.0*DELT*RDY*DELP/(RO(I,J-1)+RO(I,J))
  274 IF(ABT.EQ.0.0)GO TO 276
      V(I,J)=V(I,J)+2.0*DELT*RDY*DELP/(RO(I,J)-RO(I,J+1))
  276 CONTINUE
      SM=S
      PBB=PB
      ICT=ICT+1
      IF(ICT.GT.10)GO TO 300
      FLG=1.0
      GO TO 260
  300 CONTINUE
      RETURN
      END
```


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```
      SUBROUTINE TSTEP
*CALL COMDK
C     VARIABLE TIME STEP AND ITERATION PARAMETER ROUTINE
      EVCAL(X)=ECV+CHV*(X-TC)
      ELCAL(X)=ECL+CHL*(X-TC)
      SATT(X)=255.2+117.8*X**0.223
      SATP(X)=((X-255.2)/117.8)**4.48
      DUMX=DVMX=1.0E-10
      DO 615 I=2,IM1
      DO 615 J=2,JM1
      UDM=ABS(UD(I,J))
      VDM=ABS(VD(I,J))
      UMM=ABS(U(I,J))
      VMM=ABS(V(I,J))
      DUMX=AMAX1(DUMX,UDM,UMM)
  615 DVMX=AMAX1(DVMX,VDM,VMM)
      DUMX=4.0*DUMX
      DVMX=4.0*DVMX
      DTMY=1.01
      IF(ITER.GT.5)DTMY=0.99
      DELTO=DELT*DTMY
      DELT=AMIN1(DELTO,DELX/DUMX,DELY/DVMX)
      DELT=AMIN1(DELT,DELTMX)
C     RELAXATION FACTOR
      DO 620 I=IPL,IPR
      DO 620 J=JPB,JPT
      IF(A(I,J).EQ.0.0)GO TO 620
      ET=E(I,J)
      ROT=RO(I,J)
      RVT=RV(I,J)
      II=I
      JJ=J
      CALL EOS
      PTO=PT
      DELP=-EPSI*PTO*THTM*RO(I,J)
      UR=4.0*DELT*RDX*DELP/(RO(I,J)+RO(I+1,J))*A(I,J)*A(I+1,J)/
     1(A(I,J)+A(I+1,J))
      IF(A(I+1,J).EQ.0.0)UR=0.0
      UL=-4.0*DELT*RDX*DELP/(RO(I-1,J)+RO(I,J))*A(I,J)*A(I-1,J)/
     1(A(I,J)+A(I-1,J))
      IF(A(I-1,J).EQ.0.0)UL=0.0
      VT=4.0*DELT*RDY*DELP/(RO(I,J)+RO(I,J+1))*A(I,J)*A(I,J+1)/
     1(A(I,J)+A(I,J+1))
      IF(A(I,J+1).EQ.0.0)VT=0.0
      VB=-4.0*DELT*RDY*DELP/(RO(I,J-1)+RO(I,J))*A(I,J)*A(I,J-1)/
     1(A(I,J)+A(I,J-1))
      IF(A(I,J-1).EQ.0.0)VB=0.0
      DT=DELT*(RDX*(UR-UL)+RDY*(VT-VB))/A(I,J)
      ROT=RO(I,J)/(1.0+DT)
      RVT=RV(I,J)/(1.0+DT)
      ET=E(I,J)-PTO/RO(I,J)*DT
      II=I
      JJ=J
```

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