A numerical investigation of the dynamics of liquid spray. (U)

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**Title (and Subtitle)**

A numerical investigation of the dynamics of liquid spray

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**Description**

An axisymmetric numerical model of a liquid spray is presented. The model consists of coupled sets of partial differential equations for the gas phase and ordinary differential equations for the liquid phase. A numerical method based on the MAC method is presented and calculations show good agreement with experiment. The effect of a ceiling on the entrainment performance of a spray is found to be negligible. The examination of the calculated pressure field shows that pressure does not play an important role in the flow and may be ignored. This is in agreement with experiment and contributes additional validation to existing models which ignore this effect.
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This technical report has been reviewed and is approved for publication.

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ABSTRACT

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LIST OF SYMBOLS

\( C_D \) drag coefficient of a sphere
\( C_N \) nozzle design parameter
\( d_0 \) inside diameter of nozzle (mm)
\( D \) droplet diameter (mm)
\( D_t \) diameter of spray envelope (m)
\( f_p \) fraction of mass flow through the nozzle assigned to given trajectory
\( f_r \) radial component of drag force acting on droplet (N)
\( f_z \) axial component of drag force acting on droplet (N)
\( F_r \) radial volume force term of momentum source (N/m^3)
\( F_{r\text{av}} \) average radial force acting on a particle in source cell (N)
\( F_z \) axial volume force term of momentum source (N/m^3)
\( g \) acceleration of gravity (m/s^2)
\( H \) spray height (m)
\( m \) droplet mass (kg)
\( N \) unit normal to boundary
\( N_P \) number of particles in source cell at given instant in time
\( P \) pressure (N/m^2)
\( \Delta P_N \) water delivery pressure (N/m^2)
\( Q_a \) volume flow of air entrained into spray (m^3/min)
\( Q_w \) volume flow of liquid through spray nozzle (l/min)
\( r \) variable of integration inside spray envelope
\( r_0 \) radial coordinate of particle trajectory
\( R \) radial coordinate
\( Re \) Reynolds number
\( RE \) Reynolds number of nondimensionlization
<table>
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<th>Description</th>
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<tr>
<td>t</td>
<td>time</td>
<td>(sec)</td>
</tr>
<tr>
<td>$u_r$</td>
<td>radial velocity of particle</td>
<td>(m/s)</td>
</tr>
<tr>
<td>$u_z$</td>
<td>axial velocity of particle</td>
<td>(m/s)</td>
</tr>
<tr>
<td>$U_0$</td>
<td>particle injection velocity</td>
<td>(m/s)</td>
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<td>$V_r$</td>
<td>radial component of velocity</td>
<td>(m/s)</td>
</tr>
<tr>
<td>$V_z$</td>
<td>axial component of velocity</td>
<td>(m/s)</td>
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<tr>
<td>$Z$</td>
<td>axial coordinate</td>
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<tr>
<td>$Z_0$</td>
<td>axial coordinate of particle trajectory</td>
<td>(m)</td>
</tr>
<tr>
<td>$\rho$</td>
<td>density of gas</td>
<td>(kg/m$^3$)</td>
</tr>
<tr>
<td>$\rho_L$</td>
<td>density of liquid</td>
<td>(kg/m$^3$)</td>
</tr>
<tr>
<td>$\theta$</td>
<td>initial angle of ejection of particle</td>
<td>(degrees)</td>
</tr>
<tr>
<td>$\theta_{\text{max}}$</td>
<td>maximum initial angle of particle ejection</td>
<td>(degrees)</td>
</tr>
<tr>
<td>$\eta$</td>
<td>efficiency of spray</td>
<td></td>
</tr>
<tr>
<td>$\delta s$</td>
<td>arc length of trajectory in source cell</td>
<td></td>
</tr>
<tr>
<td>$\delta t$</td>
<td>time for particle to pass through source cell</td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>kinematic viscosity of gas</td>
<td>(m$^2$/s)</td>
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<tr>
<td>$\Delta$</td>
<td>indicates incremental quantity</td>
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1. **INTRODUCTION**

The application of liquid sprays is made in many different fields. Examples of a few are fire suppression, combustion, ventilation, and the dispersion of heavy, possibly toxic or flammable, gases. Interest at VKI in the applicability of water sprays for use as water curtains for the dispersion of heavy gases has mandated a need for better prediction methods for the analysis/design of water sprays.

The configuration for the spray to be analysed in this study is shown in figure 1. Liquid particles are ejected through a nozzle into an environment which is at rest in the absence of the spray. The aerodynamic drag acting on the liquid particles results in a loss in momentum of the particles. Since momentum must be conserved, the momentum loss is translated into a momentum gain by the fluid, causing the fluid to be set in motion. Air is thereby entrained into the spray (in much the same way as a jet) resulting in a two-phase plume.

Modeling of this phenomenon has been done in the past. A one dimensional model (Refs. 3, 5) has been developed at VKI and has shown good results though its applicability for the inclusion of boundary effects is limited. Two dimensional models, existing in the literature (Refs. 1, 4, 7), are much more able to handle the effects of boundaries. In this light, it is found desirable to have such a two dimensional model at VKI to complement the range of applicability of the existing one dimensional model. Thus, this project concerns the implementation of an axisymmetric numerical model into a computer code. The basic approach is similar to that followed in references 1 and 4.

In this report the model used is outlined, the numerical method for the solution of the model equations is described, and, finally, the results presented and discussed. The implemented computer code is included as an appendix to this report.
2. THE SPRAY MODEL

2.1 Introduction

The model of the spray consists of two distinct sets of equations, one set governing the gas phase and another governing the liquid phase. Linkage between these two sets of equations accounts for the following two physical phenomena: the first concerns the momentum transfer between liquid phase and gas phase, while the second involves the modification of the particle trajectories by the motion of the gas phase.

The gas phase may be modelled as a continuum using an Eulerian approach while the liquid phase, using a Lagrangian approach is modelled by considering a finite set of particles of varying size/initial trajectory.

2.2 The gas phase model

2.2.1 Gas phase equations

Since the gas phase occupies the most significant portion of the flow domain, it may be treated as a continuum. Making the standard assumptions of incompressibility and Newtonian fluid the following form of the Navier Stokes equations may be used. Here, due to the axisymmetric nature of the problem, the equations are written in cylindrical coordinates:

Continuity

\[ \frac{1}{R} \frac{\partial}{\partial R} (RV_r) + \frac{\partial V_z}{\partial z} = 0 \]  
(2.1)
Momentum

\( r \)-component

\[
\frac{\partial V_r}{\partial R} + V_z \frac{\partial V_r}{\partial z} = - \frac{\partial p}{\partial R} + \left[ \frac{1}{R^2} \frac{\partial}{\partial R} \left( RV_r \right) \right] + \frac{\partial^2 V_r}{\partial z^2} + F_r
\]

\( z \)-component

\[
V_r \frac{\partial V_z}{\partial R} + V_z \frac{\partial V_z}{\partial z} = - \frac{\partial p}{\partial z} + \left[ \frac{1}{R} \frac{\partial}{\partial R} \left( \frac{V_z}{R} \right) \right] + \frac{\partial^2 V_z}{\partial z^2} + F_z
\]

where \( V_r, V_z, P \) are the radial and axial component of velocity, and the pressure respectively; \( R \) and \( z \) are the radial and axial coordinate and \( \rho \) and \( \nu \) represent the fluid density and kinematic viscosity. The terms \( F_r \) and \( F_z \) are the volume force terms which account for the contribution of momentum per unit volume from the liquid phase.

2.2.2 Boundary conditions for the gas phase

Considered here are three types of boundaries; a single axis of symmetry boundary, free boundaries and wall boundaries. These are shown in figure 1.

Velocity boundary conditions

Axis of symmetry

At the axis of symmetry the radial component of velocity must be equal to zero because of mass conservation and the symmetry assumption. Symmetry also requires that there be no shear stress in the axial direction, requiring the derivative of the axial velocity with respect to the radial coordinate to be zero.
Along the wall boundaries the usual conditions for an impermeable, non-slip wall are used:

\[ V_r = V_z = 0 \] \hspace{1cm} (2.6)

**Free boundary**

In the flow domain considered the free boundary is taken to be far from the spray domain. With this assumption the following approximate conditions may be applied. The velocity tangential to the boundary is small, and may be assumed equal to zero. Applying continuity, the boundary condition for the component of velocity normal to the boundary may be obtained.

**Vertical free boundary**

\[ V_z = 0 \] \hspace{1cm} (2.7)

\[ \frac{\partial (RV_r)}{\partial R} = 0 \] \hspace{1cm} (2.8)

**Horizontal free boundary**

\[ V_r = 0 \] \hspace{1cm} (2.9)

\[ \frac{\partial V_z}{\partial R} = 0 \] \hspace{1cm} (2.10)
Pressure boundary conditions

The pressure boundary conditions may be derived from the momentum equations 2.2 and 2.3. Since most gases have small viscosity it is permissible here to ignore the viscous terms of the momentum equations in deriving the pressure boundary conditions.

The resulting derivation shows that for the wall and axis of symmetry boundaries, the normal derivative of the pressure is equal to zero.

The resulting boundary condition on the free boundary is a bit more complicated using this approach. However, making use of experimental observation which has shown that variation of the pressure field is small throughout the flow domain, the pressure at the free boundary is assumed to be constant.

Wall or axis of symmetry

\[ \frac{\partial P}{\partial N} = 0 \]  \hspace{1cm} (2.11)

Free boundary

\[ P = P_{\text{ref}} \]  \hspace{1cm} (2.12)

2.3 The particle phase model

2.3.1 Particle equations

The liquid phase is modelled as a distribution of droplets of distinct sizes and trajectories. Using a Lagrangian approach individual particles are followed from injection until hitting the floor. By considering the number of particles of similar sizes/trajectories, the magnitude of droplet-gas
momentum exchange throughout the flow field may be determined. This approach assumes that the particles do not interact with each other, i.e., no collisions or particle break up. Making the additional assumptions that the particles are spherical and non-evaporating, the following equations of motion may be written.

\[
\frac{du_r}{dt} = -f_r \tag{2.13}
\]

\[
\frac{du_z}{dt} = -f_z + mg \tag{2.14}
\]

\[
\frac{dr_0(t)}{dt} = u_r \tag{2.15}
\]

\[
\frac{dz_0(t)}{dt} = u_z \tag{2.16}
\]

where \(u_r, u_z\) are the particle radial and axial velocities and \(r_0\) and \(z_0\) are the radial and axial position of the particles. "m" is the mass of the particle calculated as follows:

\[
m = \rho_L \frac{\pi D^3}{6} \tag{2.17}
\]

where \(\rho_L\) is the density of the liquid and \(D\) is the particle diameter. \(f_r\) and \(f_z\) are the radial and axial component of drag force, related to \(F_r\) and \(F_z\) in equations 2.2 and 2.3 and are calculated as follows:

\[
f_r = C_D \frac{\pi D \rho}{8} (u_r - V_r) \tag{2.18}
\]

\[
f_z = C_D \frac{\pi D \rho}{8} (u_z - V_z) \tag{2.19}
\]
Re is the Reynolds number defined as

\[
Re = \frac{\sqrt{(u_z - v_z)^2 + (u_r - v_r)^2}}{v} \quad (2.20)
\]

The drag coefficient \(C_D\) is calculated using a standard form fit for the drag coefficient of a sphere:

\[
C_D = \frac{24}{Re} + \frac{6}{1 + \sqrt{Re}} + .4 \quad (2.21)
\]

2.3.2 Initial conditions for the particle equations

The initial conditions are derived from the properties of the spray nozzle. By definition the coordinate system is fixed at the nozzle so the initial conditions for equations 2.15 and 2.16 are simply:

\[
r_0(0) = z_0(0) = 0 \quad (2.22)
\]

The initial conditions for the force equations are derived by considering the particle ejection velocity from the nozzle and the initial angle of ejection (see figure 2):

\[
u_r(0) = U_0 \sin \theta
\]

\[
u_z(0) = U_0 \cos \theta \quad (2.23)
\]

\(U_0\) is calculated from the volume flow of the nozzle, \(Q_w\):

\[
U_0 = \frac{Q_w}{\frac{\pi d_0^2}{4}} \quad (2.24)
\]
where \( d_0 \) is the inside diameter of the nozzle. The initial angle of ejection of the particle must be between 0 and \( \theta_{\text{max}} \). \( \theta_{\text{max}} \) and \( d_0 \) are available from the manufacturers data.

### 2.3.3 Particle size

Particle size is calculated by using the following expression

\[
D = C_N \frac{d_0^{2/3}}{\Delta P_N^{1/3}}
\]  

(2.25)

where \( C_N \) is a nozzle design parameter and \( \Delta P_N \) is the water delivery pressure. These values may be determined from experiment or from manufacturers data.

### 2.4 Nondimensionalization of the model equations

To allow the resulting program to be used easily with any system of units, the model equations are nondimensionalized.

Velocities are nondimensionalized by the particle ejection velocity

\[
\hat{V}_r = \frac{V_r}{U_0}, \quad \hat{V}_z = \frac{V_z}{U_0}, \quad \hat{u}_r = \frac{u_r}{U_0}, \quad \hat{u}_z = \frac{u_z}{U_0}
\]  

(2.26)

Pressure is nondimensionalized by the gas density, and the particle ejection velocity squared

\[
\hat{p} = \frac{p}{\rho U_0^2}
\]  

(2.27)
Lengths are nondimensionalized by the spray height, $H_k$, (see figure 1)

$$ \hat{R} = \frac{R}{H_k}, \quad \hat{z} = \frac{z}{H_k}, \quad \hat{r}_0 = \frac{r_0}{H_k}, \quad \hat{z}_0 = \frac{z_0}{H_k} $$ \hspace{1cm} (2.28)

Time is nondimensionalized by the spray height divided by the ejection velocity

$$ \hat{t} = \frac{tU_0}{H_k} $$ \hspace{1cm} (2.29)

The momentum source terms are nondimensionalized by the ejection velocity squared divided by the spray height

$$ \hat{F}_r = \frac{F_r H_k}{U_0^2}, \quad \hat{F}_z = \frac{F_z H_k}{U_0^2} $$ \hspace{1cm} (2.30)

Thus in the momentum equations (2.2) and (2.3), the viscosity is replaced by the reciprocal of the "Reynolds number of nondimensionalization"

$$ \frac{1}{Re} = \frac{\nu}{U_0 H_k} $$ \hspace{1cm} (2.31)

The nondimensionalization of the other model equations is straightforward. From this point on, the model equations are assumed nondimensional, and the hat ($\hat{\cdot}$) is neglected.
3. THE NUMERICAL METHOD

3.1 Introduction

It is difficult indeed to conceptualize a numerical method for the simultaneous solution of both sets of equations. A more natural method of solution involves iterative solution of these equations. Such an iterative solution is outlined by the flow chart in figure 3.

The specific numerical method to solve each set of equations differs due to their nature (ODE, PDE) and are considered in appropriate sections.

3.2 Numerical solution of the particle equations

The solution of the set of ordinary differential equations (ODE) governing the particle phase is made by a simultaneous fourth order Runge-Kutta technique which is well documented in the literature (Ref. 9).

3.3 Numerical solution of the gas equations

The numerical scheme for the solution of the gas phase equations is based on the MAC method (Refs. 8,10,11).

The gas phase equations are recast into the following form

\[
\frac{\partial V_r}{\partial t} + \frac{1}{R} \frac{\partial}{\partial R} \left( V_r^2 \right) + \frac{\partial}{\partial z} \left( V_r \frac{\partial V_z}{\partial R} \right) = - \frac{\partial P}{\partial R} + \\
+ \frac{1}{\text{RE}} \left[ \frac{\partial^2 V_r}{\partial R^2} + \frac{\partial}{\partial R} \left( \frac{V_r}{R} \right) + \frac{\partial^2 V_r}{\partial z^2} \right] + F_r \tag{3.1}
\]
These equations are written in unsteady form as the MAC solution procedure is an iterative one in which the steady state solution is the desired solution. To be noted here is the exchange of the continuity equation for a Poisson equation for the pressure. Contained in this Poisson equation is the variable \(D\) which is a dilation term representing the amount of continuity existing.

\[
D = \frac{1}{R} \left( \frac{\partial (V_r R)}{\partial R} + \frac{\partial V_z}{\partial z} \right)
\]

This term is used to reduce the nonlinear instabilities existing in the numerical solution of the Navier-Stokes equations (Ref. 11). Continuity is solved implicitly using this term.
3.3.1 Discretization of the MAC method equations

An appropriate discretization of the MAC method equation on a staggered grid (see Fig. 4) is given below:

\[ \bar{V}_{r,i+1/2,j} = V_{r,i+1/2,j} + \Delta t \left( \frac{1}{R_{i+1/2} \Delta R} \left\{ \frac{V_e^2}{R_{i+1,j}} - V_{r,i+1,j} - V_{r,i,j} \right\} \right) \]

\[ - \frac{1}{\Delta z} \left( V_r V_z_{i+1/2,j+1/2} - V_r V_z_{i+1/2,j-1/2} \right) \]

\[ - \frac{1}{\Delta R} \left( p_{i+1,j} - p_{i,j} \right) + \frac{1}{RE} \left( \frac{1}{2 \Delta R} \left\{ \left( \frac{V_r}{R} \right)_{i+3/2,j} \right\} \right) \]

\[ - \left( \frac{V_r}{R} \right)_{i-1/2,j} \]

\[ + \frac{V_r}{\Delta R} \left( \frac{-2V_r V_r_{i+1/2,j} + V_r V_r_{i-1/2,j}}{\Delta R^2} \right) \]

\[ + \frac{V_r}{\Delta z^2} \left( \frac{-2V_r V_r_{i+1/2,j+1} + V_r V_r_{i+1/2,j-1}}{\Delta z^2} \right) \]

\[ + F_r \]

(3.5)
\[
\begin{align*}
\hat{v}_{z_{i,j+1/2}} &= v_{z_{i,j+1/2}} + \Delta t \left\{ \frac{-1}{R_i \Delta R} \left( v_{r_{z_{i+1/2,j+1/2}}} R_{i+1/2} \right) - v_{r_{z_{i-1/2,j+1/2}}} R_{i-1/2} \right\} - \frac{1}{\Delta z} \left\{ v_{z_{i,j+1}}^2 - v_{z_{i,j}}^2 \right\} \\
&- \frac{1}{\Delta z} \left\{ p_{i,j+1} - p_{i,j} \right\} + \\
&+ \frac{1}{\text{RE}} \left\{ \frac{1}{R_i} \left( \frac{v_{z_{i+1,j+1/2}} - v_{z_{i-1,j+1/2}}}{2 \Delta R} \right) \right\} \\
&+ \frac{v_{z_{i,j+1/2}} - 2v_{z_{i,j+1/2}} + v_{z_{i,j-1/2}}}{\Delta R^2} \\
&+ \frac{v_{z_{i,j+1/2}} - 2v_{z_{i,j+1/2}} + v_{z_{i,j-1/2}}}{\Delta z^2} + F_z (3.6)
\end{align*}
\]

\[
\frac{1}{R_i} \frac{p_{i+1,j} - p_{i-1,j}}{2 \Delta R} + \frac{p_{i+1,j} - 2p_{i,j} + p_{i-1,j}}{\Delta R^2} + \frac{p_{i,j+1} - 2p_{i,j} + p_{i,j-1}}{\Delta z^2} = \\
\frac{\hat{v}_{r_{i+1,j}}^2 - 2\hat{v}_{r_{i,j}}^2 + \hat{v}_{r_{i-1,j}}^2}{\Delta R^2} + \frac{\hat{v}_{z_{i,j+1}}^2 - 2\hat{v}_{z_{i,j}}^2 + \hat{v}_{z_{i,j-1}}^2}{\Delta z^2}
\]
Here the tilde (~) indicates the updated quantities (N+1 iteration).

As can be seen, the MAC method is a two level scheme involving explicit solution of equations 3.5 and 3.6 for the velocities of the N+1 iteration and an iterative solution of equations 3.7 for the updated pressure field.

Note the discretization of the $\frac{\partial D}{\partial t}$ term. $D^{N+1}$ is set equal to zero in an attempt to force continuity to exist at the N+1 time step. At steady state the time derivative term disappears and continuity will be satisfied, thereby solving the original problem.
This method was applied to the solution of laminar flow in a pipe as a test case. Solutions were obtained for low Reynolds numbers \((Re < 100)\) but instabilities were observed for higher Reynolds numbers.

Because the solution of the gas equations involves a low gas viscosity \((\nu = 1.5 \times 10^{-5} \text{ m}^2/\text{s})\) and therefore high Reynolds numbers, the numerical method has to be modified.

### 3.3.2 Modification to the MAC method

To remove the instabilities upwind differencing was employed. This is not so straightforward for the staggered grid used and involves some additional approximations. The resulting discretization of the momentum equations is made below. Here only the convective terms are affected and therefore are the only ones considered.

\[
\begin{align*}
\frac{\partial V_r}{\partial t} + V_r \frac{\partial V_r}{\partial r} + V_z \frac{\partial V_r}{\partial z} &= \frac{V_{r i+1/2, j} - V_{r i+1/2, j}}{\Delta t} \\
& \begin{cases} 
V_{r i+1/2, j} - V_{r i-1/2, j} \\
+ V_{r i+3/2, j} - V_{r i+1/2, j}
\end{cases}
\end{align*}
\]

\[
\begin{cases}
\Delta r, \quad V_{r i+1/2, j} > 0 \\
\Delta r, \quad V_{r i+1/2, j} < 0
\end{cases}
\]
The pressure equation remains the same.

\[
\frac{V_r i+1/2, j+1}{\Delta z} \frac{V_r i+1/2, j}{\Delta z}, \quad VZAUE > 0
\]
\[
\frac{V_r i+1/2, j}{\Delta z} \frac{V_r i+1/2, j-1}{\Delta z}, \quad VZAUE < 0
\]

\[
VZAUE = \frac{1}{4} \left( V_z i, j+1/2 + V_z i+1, j+1/2 + V_z i, j-1/2 + V_z i+1, j-1/2 \right)
\]

\[
\frac{\partial V_z}{\partial t} + V_r \frac{\partial V_z}{\partial r} + V_z \frac{\partial V_z}{\partial z}
\]

\[
\frac{V_z i, j+1/2}{\Delta t} + \frac{V_z i+1, j+1/2}{\Delta R}, \quad VRAUE > 0
\]

\[
+ VRAUE
\]

\[
\frac{V_z i+1, j+1/2}{\Delta R} \frac{V_z i, j+1/2}{\Delta z}, \quad VRAUE < 0
\]

\[
\frac{V_z i, j+3/2}{\Delta z} \frac{V_z i, j+1/2}{\Delta z}, \quad V_z i, j+1/2 > 0
\]

\[
+ V_z i, j+1/2 \frac{V_z i+1/2}{\Delta z} \frac{V_z i, j+1/2}{\Delta z}, \quad V_z i, j+1/2 < 0
\]  \quad (3.9)
This modification allowed a stable solution to be obtained, though the scheme did not allow the lower wall to be sensed, and no recirculation occurred (see Fig. 5). There another modification was employed. This involved changing the unsteady term in the momentum equations along the lower and axis of symmetry boundaries.

\[ \frac{\partial V_z}{\partial t} = \vec{V}_{zi,j+1/2} - \frac{1}{2} \left( \frac{V_{zi,j+3/2} + V_{zi,j-1/2}}{\Delta t} \right) \]  

on lower boundary,

\[ \frac{\partial V_r}{\partial t} = \vec{V}_{ri+1/2,j} - \frac{1}{2} \left( \frac{V_{ri+3/2,j} + V_{ri-1/2,j}}{\Delta t} \right) \]  

on axis of symmetry boundary.

This finally yielded plausible results.

3.3.3 Solution procedure for the MAC method

The solution procedure for the MAC method, as mentioned previously, involves an explicit solution of equations (3.5) and (3.6) with the modifications for the velocity field at the N+1 iteration and an iterative solution of (3.7) for the pressure field at the N+1 iteration. This iterative solution was made using a point by point SOR method. The overrelaxation factor used was \( \omega = 1.5 \), though no optimization has been done on this parameter.
3.4 Calculation of the source terms in the Navier-Stokes equations

For the calculation of the source term, the particle trajectories are superimposed over the mesh used for the solution of the gas equations, (see figure 6). To calculate the source terms the arc length of each particle trajectory in a given cell is determined. Because the velocity along this trajectory is known, the time that a particle spends in this cell can be determined:

\[ \delta t = \frac{\delta s}{\sqrt{V_r^2 + V_z^2}} \approx \frac{\delta s}{\sqrt{V_r^2 + V_z^2}} \quad (3.12) \]

for small \( \delta s \) and gradually varying \( V_r \) and \( V_z \).

From this time the average number of particles in the cell is determined by considering the fraction of the mass flow through the nozzle assigned to this particular trajectory, \( f_p \). The average force along the arc length is determined and then the contribution to the momentum source term along this trajectory in this particular cell is found as follows.

Number of particles on given trajectory in control volume:

\[ N_p = \frac{Q \cdot f_p \cdot \delta t}{\frac{3}{6} D'} \quad (3.13) \]

\[ F_r = \frac{F_{rav} \times N_p}{\text{Volume of cell}} \quad (3.14) \]

similarly for \( F_z \).

It should be noted that \( F_r \) and \( F_z \) are not calculated in the same cell because of the staggered grid (see figure 4).
4. RESULTS

Results were obtained for the consideration of the effect of increase of mass flow through the nozzle and the effect of a ceiling on entrainment properties of the spray, and finally, to examine the pressure field. The results were obtained by using the properties of a Lechler SZ1 spray nozzle as input to the program (see Table 1).

4.1 Comparison with experiment

First to validate the program a comparison of the entrainment properties of the calculated spray was made with the experimental results of an unconfined spray. These results are shown in figure 7. Here the entrainment efficiency is plotted versus the inverse of the non dimensional spray envelope diameter squared. The entrainment efficiency is defined as the volume flow of air entrained into the spray divided by the volume flow of water through the nozzle. The amount of air entrained into the spray is defined as follows:

\[ Q_a = \frac{D_Dt/\Delta}{Q} \int_0^r r V_z(r) \, dr \]  

Results were obtained by considering a spray nozzle mounted on a ceiling two meters above the floor, for all three mass flows considered. Although this is not an unconfined spray, previous results have shown little effect of the presence of the ceiling (Ref. 6). The axial positions where these results were obtained ranged from 20 percent of the spray height from the nozzle to 55 percent of this distance. It was impossible to calculate these values any closer to the nozzle because of the lack of resolution with 21 x 21 pressure nodes. At axial positions greater than this the floor seems to have a significant effect on the entrainment, so no comparison is made in this area.
The results displayed in figure 7 show good agreement with the McQuaid correlation (solid line) and the ± 20% scatter of experimental data about this line. This gives confidence that the bulk of the flow field is well predicted.

4.2 Effect of increasing mass flow through nozzle

The effect of increasing mass flow is displayed in figures 8, 9 and 10. Here the velocity vectors are non dimensionalized by the ejection velocity of the particle. For the determination of the entrained air flow equation 4.1 is rearranged

\[
Q_a = 2\pi U_0 \int_0^{Dt/2} \frac{r V_z(r)}{U_0} dr \propto 2\pi Q_w \int_0^{Dt/2} \frac{r V_z(r)}{U_0} dr \tag{4.2}
\]

As can be seen from the results, the flow field non dimensionalized by the ejection velocity does not change significantly. Thus the integral in 4.2 is of the same order of magnitude for all three mass flows considered. It seems that the air entrainment in the spray is increased strongly by increasing the mass flow through the nozzle. This is a physically observable result.

Finally the efficiency of the spray is examined.

\[
\eta = \frac{Q_a}{Q_w} = 2\pi \int_0^{Dt} \frac{r V_z(r)}{U_0} dr \tag{4.3}
\]

Close examination of figures 8, 9 and 10 shows a very slight increase in the efficiency of the spray with increased mass flow, reflected by a slight increase in the above integral. This result is found to be true for some cases, though the inverse can also be true. This is because higher mass flow results in small droplets which exchange momentum with air more rapidly resulting in higher entrainment, but because of the
small droplet size the spray envelope contracts quickly slowing entrainment. Thus, for small spray lengths an increase in efficiency is observed relative to larger droplet sizes, but this is reversed as the spray length is increased.

4.3 Effect of ceiling on entrainment

Results were obtained for the case where the ceiling is removed. These results are shown in figures 11 and 12. Though not shown a free boundary was placed at a height of two meters above the spray nozzle. Comparison with the previous results of corresponding mass flow with ceiling included shows little change in the entrainment properties with or without a ceiling. This result is supported by experimental results (Ref. 3).

4.4 Examination of the pressure field

Along with the velocity field each calculation also gives the corresponding pressure field. The isobars of a typical pressure field are shown in figure 13. This figure validates the previous assumption in the derivation of the boundary condition that at the free boundary the pressure field varies little and the pressure can be set to a reference value.

The area of steepest pressure gradients is near the floor inside the spray envelope. However, the pressure gradient in this region is small compared to the momentum source term. The other area of high pressure gradient seems to be at the nozzle. In this region, again the pressure gradient is small compared to momentum source term inside the spray envelope, though outside the spray envelope the pressure gradient may be significant. Better resolution is necessary to draw a firm conclusion.
It can be concluded that for the bulk of the flow field ignoring the pressure gradient may be a good approximation. This is a particularly important result since the pressure calculations are the most time consuming and require the most number of statements in program. In the future the program may be modified to include only a closed form expression for a pressure-like variable which forces continuity to be satisfied. This should result in large savings in computer time and allow better resolution in the mesh.
5. **CONCLUSIONS**

It has been shown that the axisymmetric spray model implemented gives good results for the entrainment of air inside the spray envelope for the portion at the spray envelope which contains most of the entrained air. The bulk of the surrounding flow field is thus considered to be more or less correctly predicted.

The physically observable result that increasing the outflow from the nozzle increases entrainment of air is also found.

The effect of the ceiling on entrainment is seen to be negligible.

Finally, the examination of the pressure field indicates that neglecting the pressure gradient is a good approximation for the bulk of the flow field. This result leads to the recommendation that work continues on the model to incorporate a closed form expression for a pressure-like variable to force continuity to hold, while eliminating the need for the Poisson equation for the pressure. This will allow better results since the mesh may be made smaller due to the saving in computer time.

Application of this model to a spray in the upward facing mode is straightforward.
REFERENCES


Figure 2. Nozzle Configuration
Figure 1 Scheme for numerical solution
Figure 4. Staggered MAC grid with source cells.
Figure 5. Non-Recirculating Decay
Figure 9. Particle trajectory superimposed on source cells
Figure 7: Comparison of air entrainment with experimental results.
CORRESPONDS TO A GAS VELOCITY.
INJECTION VELOCITY RATIO OF 20 PERCENT.
O X O REPRESENT PARTILE TRAJECTORIES

G-P H-P I-P J-P K-P L-P M-P N-P O-P

G-SPRAY LOCATION 12.5 FT. OF WALL.
CORRESPONDING VELOCITY TO
IMPULSE VELOCITY RATION IN THE EQU.

REPRESENT PARTICULAR INSTANCES

\[ P = \text{PRESSURE} / \rho U_0^2 \]
<table>
<thead>
<tr>
<th>$d_o$ (mm)</th>
<th>$Q_w$ (lt/min)</th>
<th>$\Delta P_n$ (kPa)</th>
<th>$D$ (mm)</th>
<th>$\Theta_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>6.6</td>
<td>34.3</td>
<td>1.05</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td>13.3</td>
<td>176.5</td>
<td>.61</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td>21.1</td>
<td>617.8</td>
<td>.40</td>
<td>30°</td>
</tr>
</tbody>
</table>

*Table 1: Properties of Lockley S21 Board.*
## APPENDIX - LISTING OF SPRAY COMPUTER PROGRAM

<table>
<thead>
<tr>
<th>Component</th>
<th>Page</th>
</tr>
</thead>
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</tr>
<tr>
<td>Subroutine COEFF</td>
<td>p. 49</td>
</tr>
<tr>
<td>Subroutine PSOURC</td>
<td>p. 55</td>
</tr>
<tr>
<td>Subroutine SOR</td>
<td>p. 60</td>
</tr>
<tr>
<td>Subroutine GASVEL</td>
<td>p. 65</td>
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<td>Subroutine PARTCL</td>
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<tr>
<td>Input FILE</td>
<td>p. 74</td>
</tr>
<tr>
<td>Output FILE</td>
<td>p. 75</td>
</tr>
</tbody>
</table>
MAIN PROGRAM

100  DIMENSION V(50,50), V2(50,50), X(50), Y(50)
200  DIMENSION V(50,50), V2(50,50)
300  DIMENSION P(50,50), P2(50,50), X(50), Y(50)
400  DIMENSION P(50,50), P2(50,50), X(50), Y(50)
500  DIMENSION P(50,50), P2(50,50), X(50), Y(50)
600  DIMENSION P(50,50), P2(50,50), X(50), Y(50)
700  DIMENSION P(50,50), P2(50,50)
800  DIMENSION P(50,50), P2(50,50)
900  DIMENSION P(50,50), P2(50,50)
1000 DIMENSION P(50,50), P2(50,50)
1100 DIMENSION P(50,50), P2(50,50)
1200 DIMENSION P(50,50), P2(50,50)
1300 DIMENSION P(50,50), P2(50,50)
1400 DIMENSION P(50,50), P2(50,50)
1500 DIMENSION P(50,50), P2(50,50)
1600 DIMENSION P(50,50), P2(50,50)
1700 DIMENSION P(50,50), P2(50,50)
1800 DIMENSION P(50,50), P2(50,50)
1900 DIMENSION P(50,50), P2(50,50)
2000 DIMENSION P(50,50), P2(50,50)

***********************************************************************

2100 C
2200 C THIS PROGRAM SOLVES ITERATIVELY BOTH THE LIQUID STORES
2300 C EQUATIONS WITH CONTINUOUS SOURCE TERMS INCLUDED, USING THE
2400 C MC METHOD AND THE EQUATIONS OF MOTION OF A PARTICLE.
2500 C BOUNDARY CONDITIONS AND THE SOURCE TERMS ARE THE INPUT DATA
2600 C TO DETERMINE THE
2700 C SOURCE TERMS.
2800 C
2900 C THIS PLOT PROGRAM SOLVES THE EQUATIONS FOR THE FIVE SOURCES
3000 C AND FURTHER SOURCE SUPERIMPOSED, AND THEN ITERATES
3100 C FOR THE SOLUTION.
3200 C
3300 C CODES CALCULATES THE COEFFICIENTS OF THE LEFT-HAND SIDE OF
3400 C THE EQUATION FOR THE ITERATION. THIS CALCULATION
3500 C IS ONLY PERFORMED ONCE SINCE THE COEFFICIENTS ARE ONLY
3600 C CONSIDERED ON SPECIAL POSITIONS.
3700 C
3800 C SOURCE CALCULATES THE SOURCE TERMS (RIGHT-HAND SIDE) OF THE
3900 C EQUATION. THE SOURCE TERMS DEPEND ON THE LOCAL VELOCITY AND COULOMB AT EACH ITERATION.
4000 C
4100 C ALL COORDINATES THE SOLUTION OF THE DISCONTINUOUS HYDRODYNAMICS.
**C** EQUATION BY THE SAP METHOD USING THE COEFFICIENTS AND
**C** SOURCE FLOWS CALCULATED BY pHEN AND PHSOURC.
**C** GASEL CALCULATES EXPLICITLY THE UPDATED VELOCITY FIELD
**C** USING THE UPDATED PRESSURE FIELD AND THE OLD VELOCITY
**C** FIELD.
**C** PARTICLE CALCULATES THE PARTICLE TRAJECTORIES UNDER THE
**C** INFLUENCE FROM THE AIR FLOW AND THEN CALCULATES THE SEPARATOR
**C** SOURCE TURNS.

**C** THIS PROGRAM IS DIVIDED INTO FIVE PARTS:
**C** THE FIRST PART SETS UP THE GRID FOR THE SOLUTION.
**C** THE SECOND PART SETS UP THE SUBROUTINE INPUTS FOR THE
**C** SOLUTION OF THE DUAL EQUATION FOR THE PRESSURE.
**C** THE THIRD PART SETS UP THE SUBROUTINE INPUTS FOR THE
**C** SOLUTION OF THE UPDATED VELOCITY FIELD.
**C** THE FOURTH PART LOCS AT THE ITERATION FOR THE
**C** SOLUTION.
**C** AND THE FIFTH PART OUTPUTS THE SOLUTION.

**C*************************************************************************
**C** Inputs for program from data file 20

**C*************************************************************************
7000 C SET INITIAL VALUES:
7100 C RADIUS RADIAL GRID LENGTH, R, AND AXIAL DOME LENGTH, Zn.
7200 C
def(20,20.21,57,57)
7300 C PRINT //71x.72(1.5,5.72)
7400 C
def1(30,20,20,20)
7500 C LEAF SPRAY HEIGHT, H, AND SPRAY LENGTH TO NOZZLE DIAMETER RATIO
7600 C def(20,20,20,20)
7700 C LEAF SPRAY HEIGHT, H AND SPRAY LENGTH TO NOZZLE DIAMETER RATIO
7800 C
def(20.20,20,20)
7900 C
def(30.20,20,20)
8000 C
def(30.20,20,20)
8100 C LEAF SPRAY Width = 1.4x10.5x, SPRAY LENGTH TO NOZZLE DIAMETER RATIO 1.4x10.5x
8200 C
def(30.20,20,20)

**C****** NESTED LOOP OF MODEL STATE OF TRAJECTORIES
C SET SWITCH FOR INITIAL SOLUTION (0=START SOLN FROM AIR AT REST)
13100 C
13200 C 1=INITIAL SOLN PRODUCED IN FILE 19
13300 C READ(u,p,19) IN SOL
13400 214 READ(Z,Z)
13500 C***********************************************************************
13600 C
13700 C SET UP GRID
13800 C***********************************************************************
13900 C
14000 C SET NUMBER OF PRESSURE NODES IN RADIAL DIRECTION
14100 C SET NUMBER OF PRESSURE NODES IN AXIAL DIRECTION
14200 C READ(n,n)INXY
14300 259 FORMAT(7/1X,Z(2,2X))
14400 C WRITE(6,n,11)
14500 C 210 FORMAT(1X,'NX=',I2,'NX=',I2,'NX=',I2,'NX=',I2)
14600 C CALCULATE PRESSURE NODE LOCATIONS
14700 C DELX=2/RADIUS
14800 C DELY=2/RADIUS
14900 C X(I)=FLAT(I)*DELX
15000 C Y(J)=FLAT(J)*DELY
15100 C CONTINUE
15200 6 CONTINUE
15300 C***********************************************************************
15400 C SET UP SUBROUTINE INPUTS FOR SOLUTION OF POISSON EQUATION
15500 C***********************************************************************
15600 C SPECIFY TYPE OF BOUNDARY CONDITION ON EACH BOUNDARY
15700 C 1=DIRICHLET BC
15800 C 2=NEUMANN BC
15900 C 3=FIELD BC
16000 C 4=INTERNAL BC
16100 C 5=BC TO BE SPECIFIED BY USER
16200 C 6=NONE
16300 C 7=BC TO BE SPECIFIED BY USER
16400 C 8=INTERNAL BC
16500 C 1)=X BOUNDARY OR X=RADIUS BOUNDARY
16600 C 2)=Y BOUNDARY OR Y=RADIUS BOUNDARY
16700 C 3)=Z BOUNDARY OR X=RADIUS BOUNDARY
16800 C 4)=Z BOUNDARY OR Y=RADIUS BOUNDARY
16900 C 5)=Z BOUNDARY OR X=RADIUS BOUNDARY
17000 C 6)=Z BOUNDARY OR Y=RADIUS BOUNDARY
17100 C 7)=Z BOUNDARY OR X=RADIUS BOUNDARY
17200 C 8)=Z BOUNDARY OR Y=RADIUS BOUNDARY
17300 C
17100 C J=1 BOUNDARY OR Y=0 BOUNDARY
17200 IX0=1
17300 C PRESSURE SOLUTION AT BOUNDARIES
17400 C X=0 AND X=L BOUNDARIES
17500 C NORMAL DEVIATIVE OF PRESSURE EQUAL ZERO
17600 DO 20 J=1,71
17700 BC(J)=0.
17800 CONTINUE
17900 20 CONTINUE
18000 C NORMAL DEVIATIVE OF PRESSURE EQUALS VINDS FOR
18100 C PRESSURE GRADIENT AT Y=LENG BOUNDARY
18200 DO 21 I=1,10X
18300 BC(I)=0.
18400 CONTINUE
18500 21 CONTINUE
18600 C Y=0 ALL I=1 BOUNDARIES
18700 DO 30 I=1,10X
18800 PRESS(I,1)=0.
18900 PRESS(I,10X)=0.
19000 30 CONTINUE
19100 C CALCULATE INITIAL GUESSED PRESSURE AT INTERIOR POINTS
19200 C DO 10 I=1,6X-1
19300 DO 10 J=1,10I
19400 PRESS(I,J)=0.
19500 10 CONTINUE
19600 C SET MAXIMUM NUMBER OF ITERATIONS FOR SOR ROUTINE
19700 IMAX=10
19800 C SET INITIAL OVERRELAXATION FACTOR
19900 OMEGA=1.5
20000 C******************************************************************************
20100 C******************************************************************************
20200 C******************************************************************************
20300 C******************************************************************************
20400 C SET OF SIMULATION INPUTS FOR SOLUTION OF VELOCITY FIELD
20500 C******************************************************************************
20600 C******************************************************************************
20700 C******************************************************************************
20800 C GUESSED SOLUTION FOR VELOCITY
20900 C IF RESOLVE INITIAL FLOW FIELD SET TO ZERO
21000 C IF RESOLVE INITIAL FLOW FIELD FLOW FIELD BY
21100 C******************************************************************************
21200 DO 9 J=1,5X+1
21300 \(v)_{1,1}(\)x=0.
21400 9 CONTINUE
DO 19 I=1, M+1
DO 19 J=1, N
VR(I,J)=0.
19 CONTINUE
C CALCULATE BOUNDARY VALUES OF VELOCITY
DO 20 I=1, M
VZ(1,I)=VZ(1,2*I+1)
20 CONTINUE

C INITIAL SOLUTION READ FROM FILE 14 IN IF.SOL=1
91 READ(14,93)
93 FORMAT(yyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyy
25400        DO 42 J = 1, NY
25500        FR(I,J) = 0.
25600        FZ(I,J) = 0.
25700        42 CONTINUE
25800        C CALCULATE INITIAL SOURCE TERMS
25900        DO 81 I = 1, NX
26000        WRITE(26,307)
26100        CALL PARTICLE(R, Z, 1, I, DZ, DF(I), IQ, TAQ(I), FR(I,0), FZ(I,0))
26200        81 CONTINUE
26300        WRITE(26,308) I, J, Z(I, J), DF(I, J), DZ(J)
26400        84 CONTINUE
26500        81 CONTINUE
27000        DU 130 J = 1, NY
27100        WRITE(26,351) I, J, DF(I, J), FZ(I, J), FR(I, J), FR(4, J), FR(5, J)
27200        WRITE(26,351) I, J, DZ(I, J), DF(I, J), FZ(I, J), FR(I, J), FR(4, J), FR(5, J)
27300        351 CONTINUE
27400        130 CONTINUE
27500        DU 52 I = 1, NX
27600        C UPDATE SOURCE TERMS FOR PRESSURE EQUATION USING N
27700        26000        C VELOCITY
27800        26000        CALL SOURCE(HA, AT, PRES)
27900        28100        C UPDATE PARTICLE FIELDS AND PARTICLE SOURCE TERMS
28200        C EVERY TENTH ITERATION
28300        28300        IF(I+1, 1, 10) GO TO 234
28400        I = 0
28500        C IF SOURCE TERMS EQUAL TO ZERO
28600        28600        DU 84 I = 1, NY
28700        DU 63 J = 1, NY
28800        84 CONTINUE
28900        63 CONTINUE
29000        C RECALCULATE SOURCE TERMS
29100        29100        DU 65 I = 1, NY
29200        29200        CALL PARTICLE(R, Z, 1, DF, DZ, DF(I), IQ, TAQ(I), FR(I,0), FZ(I,0))
29300        85 CONTINUE
29400        29400        CALL PARTICLE(R, Z, 1, DF, DZ, DF(I), IQ, TAQ(I), FR(I,0), FZ(I,0))
29500        85 CONTINUE
29600        234 CONTINUE
29700        C
34730  303 FORMAT(1X,2X, 'POSITION', 4X, 'POSITION', 15X, 'POSITION', 4X, 'POSITION')
34800  1 'POSITION', 4X, 'POSITION', 15X, 'POSITION', 4X, 'POSITION'
34900  DO 35 J=1,1
35000  DO 36 I=1,1
35100  X(I+J)=X(I)+X(J)/2.
35200  Y(I+J)=Y(I)+Y(J)/2.
35300  WRITE(30,304)X(I,J),Y(I,J),Frac.Sr(1,J),X(1),Y(1),Vz(1,J)
35400  1.X(I,J)=Y(I,J)
35500  36 CONTINUE
35600  304 FORMAT(1X,5(F10.5,2X))
35700  X(I+J)=X(I)+X(J)/2.
35800  Y(I+J)=Y(I)+Y(J)/2.
35900  WRITE(30,305)X(I,J),Y(I,J),V(I,J)
36000  35 CONTINUE
36100  305 FORMAT(1X,72X,3(F10.5,2X))
36200  WRITE(30,306)X(1),Y(1),Vz(1,J)
36300  37 CONTINUE
36400  306 FORMAT(1X,30X,3(F10.5,2X))
36500  WRITE(30,307)X(1),Y(1),Vz(1,J)
36600  39 FORMAT(//,1X, 'PARTICLE TRANSITION')
36700  DO 310 J=1,1
36800  307 FORMAT(1X, 'RADIUS', 2X, 'AXIAL VEL', 2X, 'AXIAL VEL')
36900  311 FORMAT(1X, 'AXIAL VEL', 2X, 'AXIAL VEL')
37000  CALL .PART8(5,2,1,Z(J),THEMO(J),FACNO(J))
37100  WRITE(30,308)X(I,J),Y(I,J),Vz(I,J)
37200  32 IF(30,308,309)
37300  308 FORMAT(1X,5(F10.5,2X))
37400  FORMAT(//,1X, 'END')
37500  END
COEFF SUBROUTINE

100 SUBROUTINE COEFF (A, Y, X, W)
200 DIMENSION CD(Q, 50, 50), C, (50, 50), CS (50, 50), Csw (50, 50)
300 DIMENSION CR (50, 50), CP(50, 50), CR (50, 50), CF (50, 50)
400 DIMENSION AQ(50), AQ(50), AQ(50), AQ(50), AQ(50)
700 DIMENSION W (50, 50)

******************************************************************************

THE FUNCTION CALCULATES THE LEFT HAND SIDE OF THE DYNAMIC EQUATION FOR
THE PRESSURE.

**INPUT TO THIS SUBPROGRAM IS AS FOLLOWS:**

"A" AND "Y" ARE THE NUMBER OF PRESSURE NODES IN THE X AND Y DIRECTIONS.
X AND Y DIRECTIONS.
X AXIAL DIRECTION
X GUESS is the GUESSING SOLUTION VECTOR FOR USE WITH THE
ADDITIONAL CONDITIONS (not used here)

**INPUT FROM COMMON BLOCK**

A "SUBDOMAIN" COMMON BLOCK CONTAINS THE INFORMATION FOR THE
SUBDOMAINS AT THE FOUR BOUNDARIES. The
FIRST FOUR VECTORS CONTAIN THE COEFFICIENTS OF THE LOWER
DERIVATIVES, THE LAST FOUR VECTORS DEAL WITH THE CROSS
DERIVATIVES AT THE FOUR CORNERS. SET TO 0 FOR TOP.

**SUBDOMAIN** COMMON BLOCK CONTAINS THE SWITCHES FOR THE
SUBDOMAINS AT THE FOUR BOUNDARIES.
=1 FOR FIXED BOUNDARY CONDITIONS.
=0 FOR FLUID (FREE) BOUNDARY CONDITIONS.
THE "UNIFIED" COORDINATE BLOCK CONTAINS THE CONTRIBUTIONS TO
THE RIGHT HAND SIDE OF THE PDE DUE TO BOUNDARY CONDITIONS.
THE "DEL" CURVATURE BLOCK CONTAINS THE RADIAL AND AXIAL
INCREMENTAL LENGTHS "DELJ" AND "DELM", AND THE
INCREMENTAL TENS "DELT".
THE "CRUDE" CURVATURE BLOCK CONTAINS THE RADIAL AND AXIAL
CONSOLIDATED AX AND Y OF THE PRESSURE BUDS.

THE COORDINATE BLOCK Contains THE COEFFICIENTS OF THE
DISCRETIZED PDE AT EACH POINT IN THE COMPUTATIONAL MOCLE.
AS A FUNCTION OF THE MOLECULE'S POSITION IN THE DOMAIN. MOST
OF THESE COEFFICIENTS ARE CALCULATED IN THIS SUPPORTING AID.

THE NOTED BLOCKS:

CO = COEFF OF NORTH EAST POINT
CI = COEFF OF NORTH POINT
CS = COEFF OF SOUTH EAST POINT
CE = COEFF OF WEST POINT
CSW = COEFF OF SOUTH WEST POINT
CSO = COEFF OF SOUTH POINT
CSE = COEFF OF SOUTH EAST POINT
CF = COEFF OF CENTRAL POINT

THE "RIGHT HAND SIDE OF DISCRETIZED PDE (CALCULATED IN
THE SUPPORTING AID)"

CALCULATE COEFFICIENTS OF INTERIOR POINTS.

\[
\sum_{i,j=1}^{n} a_{i,j} u_{i,j} = f_{i,j}
\]

\[
\sum_{i,j=1}^{n} a_{i,j} u_{i,j} = f_{i,j}
\]

\[
\sum_{i,j=1}^{n} a_{i,j} u_{i,j} = f_{i,j}
\]

\[
\sum_{i,j=1}^{n} a_{i,j} u_{i,j} = f_{i,j}
\]

\[
\sum_{i,j=1}^{n} a_{i,j} u_{i,j} = f_{i,j}
\]
8100  C8(1,0)=C0(1,0)
8100  C0(1,0)=C0(1,0)
8500  C8(1,0)=C0(1,0)
8600  C0(1,0)=C0(1,0)
8700  C8(1,0)=C0(1,0)
8800  C0(1,0)=C0(1,0)
9000  C8(1,0)=C0(1,0)
9100  C0(1,0)=C0(1,0)
9200  C8(1,0)=C0(1,0)
9300  C0(1,0)=C0(1,0)
9400  C8(1,0)=C0(1,0)
9500  C0(1,0)=C0(1,0)
9600  C8(1,0)=C0(1,0)
9700  C0(1,0)=C0(1,0)
9800  C8(1,0)=C0(1,0)
9900  C0(1,0)=C0(1,0)
16000  C8(2,2)=C0(2,2)
16100  C0(2,2)=C0(2,2)
16200  C8(2,2)=C0(2,2)
16300  C0(2,2)=C0(2,2)
16400  C8(2,2)=C0(2,2)
16500  C0(2,2)=C0(2,2)
16600  C8(2,2)=C0(2,2)
16700  C0(2,2)=C0(2,2)
16800  C8(2,2)=C0(2,2)
16900  C0(2,2)=C0(2,2)
17000  C8(2,2)=C0(2,2)
17100  C0(2,2)=C0(2,2)
17200  C8(2,2)=C0(2,2)
17300  C0(2,2)=C0(2,2)
17400  C8(2,2)=C0(2,2)
17500  C0(2,2)=C0(2,2)
17600  C8(2,2)=C0(2,2)
17700  C0(2,2)=C0(2,2)
17800  C8(2,2)=C0(2,2)
17900  C0(2,2)=C0(2,2)
18000  C8(2,2)=C0(2,2)
18100  C0(2,2)=C0(2,2)
18200  C8(2,2)=C0(2,2)
18300  C0(2,2)=C0(2,2)
18400  C8(2,2)=C0(2,2)
18500  C0(2,2)=C0(2,2)
18600  C8(2,2)=C0(2,2)
18700  C0(2,2)=C0(2,2)
18800  C8(2,2)=C0(2,2)
18900  C0(2,2)=C0(2,2)
19000  C8(2,2)=C0(2,2)
19100  C0(2,2)=C0(2,2)
19200  C8(2,2)=C0(2,2)
19300  C0(2,2)=C0(2,2)
19400  C8(2,2)=C0(2,2)
19500  C0(2,2)=C0(2,2)
19600  C8(2,2)=C0(2,2)
19700  C0(2,2)=C0(2,2)
19800  C8(2,2)=C0(2,2)
19900  C0(2,2)=C0(2,2)
20000  C8(2,2)=C0(2,2)
20100  C0(2,2)=C0(2,2)
20200  C8(2,2)=C0(2,2)
20300  C0(2,2)=C0(2,2)
20400  C8(2,2)=C0(2,2)
20500  C0(2,2)=C0(2,2)
20600  C8(2,2)=C0(2,2)
20700  C0(2,2)=C0(2,2)
20800  C8(2,2)=C0(2,2)
20900  C0(2,2)=C0(2,2)
21000  C8(2,2)=C0(2,2)
21100  C0(2,2)=C0(2,2)
21200  C8(2,2)=C0(2,2)
21300  C0(2,2)=C0(2,2)
21400  C8(2,2)=C0(2,2)
21500  C0(2,2)=C0(2,2)
21600  C8(2,2)=C0(2,2)
21700  C0(2,2)=C0(2,2)
21800  C8(2,2)=C0(2,2)
21900  C0(2,2)=C0(2,2)
22000  C8(2,2)=C0(2,2)
22100  C0(2,2)=C0(2,2)
22200  C8(2,2)=C0(2,2)
22300  C0(2,2)=C0(2,2)
22400  C8(2,2)=C0(2,2)
22500  C0(2,2)=C0(2,2)
22600  C8(2,2)=C0(2,2)
22700  C0(2,2)=C0(2,2)
22800  C8(2,2)=C0(2,2)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
C(2, y-1) = C(2, y-1) + C(2, y-1) * FLOAT(11TOP)
**PSOURC SUBROUTINE**

100  SUBROUTINE PSOURC(CA, CO, CCR)
200  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
300  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
400  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
500  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
600  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
700  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
800  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
900  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1000  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1100  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1200  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1300  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1400  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1500  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1600  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))
1700  C(C(50,50), C(50,50), C(50,50), C(50,50), C(50,50))

*This subroutine calculates the right hand side of the*
THE PRESSURE.

**Input to this subroutine is as follows:**

"R" and "C" are the number of PRESSURE NODES in the
X and Y DIRECTIONS.

**Axial direction, Y Axial direction**

"GUESS" IS THE GUESSED SOLUTION VECTOR FOR USE WITH
MULTIPLE COEFFICIENTS.

THE "DEL" COMMON BLOCK CONTAINS THE RADIAL AND AXIAL
INCREMENTAL LENGTHS AND "DELX" AND "DELY", AND THE.

INCREMENTAL TIME "DELT".

THE "AIR" COMMON BLOCK CONTAINS THE RADIAL AND AXIAL
COORDINATES X AND Y OF THE PRESSURE NODES.

THE "BOUNDARY" COMMON BLOCK CONTAINS THE CONTRIBUTIONS
TO THE RIGHT HAND SIDE OF THE PDE DUE TO BOUNDARY
CONDITIONS.

THE "REYNOLDS" COMMON BLOCK CONTAINS THE REYNOLD'S NUMBER
OF NONDIMENSIONALIZATION.

THE "SOURCE", COMMON BLOCK CONTAINS THE SOURCE TERMS OF THE
INCREMENTAL EQUATIONS.

**Also used as input for this subroutine are the set of
FUNCTIONS subprogram which calculate the source of the
VELOCITIES, THE CROSS MULTIPLIERS OF THE VELOCITIES,
AND THE DISSIPATION TERMS. These are given after this
program.

**Output from the COMMON BLOCK**

THE COMMON BLOCK OUT DATA CONTAINS THE COEFFICIENTS OF THE
MULTIPLICATIVE FUNCTION AT EACH NODE IN THE COMPUTATIONAL MOUNTAIN.

**As a function of the MOUNTAIN'S position in the domain, the
COEFFICIENTS IS calculated in this subroutine.**
5600 C THESE COEFFICIENTS ARE CALCULATED BELOW
5700 C
6000 C CV = COEFF OF NORTH POINT (CALCULATED IN SUB COEFF)
6100 C CR = COEFF OF SOUTH POINT (CALCULATED IN SUB COEFF)
6200 C CS = COEFF OF EAST POINT (CALCULATED IN SUB COEFF)
6300 C SE = COEFF OF SOUTHEAST POINT (CALCULATED IN SUB COEFF)
6500 C
6600 C CV = COEFF OF EAST POINT (CALCULATED IN SUB COEFF)
6700 C CR = COEFF OF SOUTH POINT (CALCULATED IN SUB COEFF)
6800 C SE = COEFF OF SOUTHEAST POINT (CALCULATED IN SUB COEFF)
7000 C
7100 C
7300 C CALCULATE RIGHT HAND SIDE OF INTERIOR POINTS
7400 C
7500 C 0=0 1=2, N=1
7600 0=50 J=2, N=2-1
7700 r(1,J)=V(1,J)+V(1,J-1)-2.V(1,J-1)/DELX**2
7800 1-(V2(J+1,J)+1-2.V2(J+1,J-1))/DELX**2
7900 2-(V2(J+1,J)+V2(J+1,J-1))/DELX**2
8000 3-(V2(J+1,J)+V2(J+1,J-1))/DELX**2
8100 4=V(1,J)+V(1,J-1)/DELX
8200 5=DELX*DELX+1,J*1,J
8300 6=1.(X(1,J)+X(1,J-1)+X(1,J-1))/DELX**2
8400 7=1.J+1.J+X(1,J)+X(1,J-1))/(DELX**2
8500 8+1.J+1.J+X(1,J)+X(1,J-1))/(DELX**2
8600 9=DELX*DELX+1,J*1,J
8700 1=DELX*DELX+1,J+1,J
8800 50 CONTINUE
8900 C
9000 C MODIFY RIGHT HAND SIDE OF INTERIOR POINTS NEXT TO BOUNDARY
9100 C
9200 C
9300 C
9400 C
9500 C
9600 C
9700 C
9800 C
9900 C
1000 C
1010 C
1020 C
1030 C
1040 C
1050 C
1060 C
10 Continue
10790 C MODIFY RIGHT hand side AT LEFT for COUNTER FOR SEPARATE
10795 C Conditions on TOP & LEFT LEFT SIDES
10799 C f(z, y-1)=f(z, y-1)+end loneliness (2,1, y-1)
10803 C 11807 C MODIFY right hand side NEXT TO THE CURSORY FOR SEPARATE
10813 C Conditions on TOP SIDE
10817 C do 20 = J, w=2
10821 C f(1, j-1)=f(1, j-1)+end loneliness (1, j-1)
10825 C 20 Continue
10829 C 12000 C MODIFY right hand side AT RIGHT for COUNTER FOR SEPARATE
10830 C Conditions on TOP & RIGHT RIGHT SIDES
12300 C aJ = aJ = 1
12305 C bJ = bJ = 1
12310 C f(aj, bj) = f(aj, bj) + end loneliness (aj, bj)
12315 C 12600 C MODIFY RIGHT hand side NEXT TO RIGHT BOUNDARY FOR SEPARATE
12605 C Conditions on bottom SIDE
12609 C do 30 = J, w=2
12613 C f(ax-1, j-1)=f(ax-1, j-1)+end loneliness (ax-1, j-1)
12617 C 30 Continue
13000 C 13350 C MODIFY RIGHT hand side AT LEFT for COUNTER FOR SEPARATE
13355 C Conditions on bottom & LEFT LEFT SIDES
13360 C f(ax-1, 2)=f(ax-1, 2)+end loneliness (ax-1, 2)
13365 C 13600 C MODIFY RIGHT hand side NEXT TO LEFT BOUNDARY FOR SEPARATE
13605 C Conditions on bottom SIDE
13610 C do 40 = J, w=2
13614 C f(1, 2)=f(1, 2)+end loneliness (1, 2)
13618 C 40 Continue
14300 C return
14305 C end
14400 C 14800 C
**FUNCTION SUPPORTS FOR SOR sources and savel**

**FUNCTION SOR SOURCE (1,J)**

```fortran
FUNCTION VSOR(1,J)
  VSOR = 25*(V(1,J)*V(1,J))**2
  RETURN
END

**FUNCTION SOR AXIAL VELOCITY (1,J)**

```fortran
FUNCTION VSOR(1,J)
  VSOR = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```

**FUNCTION INTEGRAL VR*VZ AT PRESSURE NODES (1,J)**

```fortran
FUNCTION VR*VZ(1,J)
  VR*VZ = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```

**FUNCTION INTEGRAL VR*VZ AT THE CENTRAL OF A RECTANGULAR**

```fortran
FUNCTION VR*VZ(1,J)
  VR*VZ = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```

**FUNCTION INTEGRAL VR*VZ AT PRESSURE NODES (1,J)**

```fortran
FUNCTION VR*VZ(1,J)
  VR*VZ = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```

**FUNCTION INTEGRAL VR*VZ AT THE CENTRAL OF A RECTANGULAR**

```fortran
FUNCTION VR*VZ(1,J)
  VR*VZ = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```

**FUNCTION INTEGRAL VR*VZ AT PRESSURE NODES (1,J)**

```fortran
FUNCTION VR*VZ(1,J)
  VR*VZ = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```

**FUNCTION INTEGRAL VR*VZ AT THE CENTRAL OF A RECTANGULAR**

```fortran
FUNCTION VR*VZ(1,J)
  VR*VZ = 25*(V(1,J)*V(1,J))**2
  RETURN
END
```
SOR SUBROUTINE

**SOR SUBROUTINE**

100 SUBROUTINE SOR(N,N,TF,UX,UXM,UXL,UXR)
200 Declare subroutine variables.
300 Dimensions of arrays.
400 Dimensions of matrices.
500 Initializations.
600 Declarations of variables.
700 Calculations and updates.
800 End of subroutine.

---

**Description:**

The SOR subroutine is designed to solve the successive over-relaxation (SOR) method for elliptic equations. It takes in the following parameters:

- `N`: The size of the matrix.
- `TF`: The target function or residual.
- `UX`, `UXM`, `UXL`, `UXR`: Arrays for the solution and its previous values.

**Input to the Subroutine:**

- The guessed solution vector is initially set.
- After each iteration, the guessed solution is updated based on the new and old solutions.

**Details:**

- The guessed solution can be chosen at the initial points, or at the boundary points, at the given points, or only at the boundary points.
- The guessed solution value is updated at the boundary points, and then it is updated at the end points.
- The updated guessed values are then used in the calculation.

---

**Notes:**

- The subroutine contains the first guessed value of the relaxation factor, which is updated at successive iterations by using the ratio of the residuals at successive iterations.
- The values of the guessed points are updated at the boundary points.
- The relaxation factor and its value are the number of discretized points to be converged by the number of iterations.
The input to the subroutine is as follows:

The subroutine block contains the coefficients of the
line between each pair of the computational molecules. This information is
calculated in the subroutine block.

The "boundary" input block contains the information for the
boundary conditions at the four boundaries. The
first four vectors contain the coefficients of the normal
derivatives, the last four entries deal with the cross
derivatives at the four corners. See note of for more.

The "boundary" input block contains the switches for the
4 boundary conditions at the four boundaries.

=1 for standard boundary conditions
=2 for difficult boundary conditions
The boundary is defined as boundary 1 at any
Point boundary is defined as boundary 1 at vertex 1
Point boundary is defined as boundary 1 at vertex 3
Left boundary is defined as boundary 1 at vertex 1
The "delta" input block contains the radial and axial
4 capacitive lengths "delta" and "delta", and the
4 electrical time "delta".

The output of the subroutine is as follows:

"delta" is the solution vector solved for during the iterations.
It represents the updated solution vector during the iterations.
And the final solution at convergence.
"time" is the number of iterations required for convergence.

The output into data files.
The values of the fractional, fractional normalized by the
solution, and the fractional factor at each iteration are.

******************************************************************************
C PUT GUESSED SOLUTION INTO SOLUTION VECTOR
9600 DO 5 J=1,JA
9700 5  GUESS(I,J)=SOLN(I,J)
9800 CONTINUE
9900 C START ITERATION FOR SOLUTION
1000 C DO 100 1EVE=1,ITERR
1010 C DELETE SOLN AT INTERIOR POINTS FOR CURRENT SWEEP
1020 C 1EVE=(ITERR+1)/2
10300 C FOR ITER ON SWEEP DIRECTION IS FORWARD, ITER EVEN SWEEP
10400 C DIRECTION IS BACKWARD
10500 C 1EVE=0 FOR ITER=EVES; 1EVE=1 FOR ITER=0000
10600 1 FACT=0
10700 JFACT=0
10800 IF (1EVE.EQ.1) THEN 101
10900 IF (FACT.EQ.0) THEN 101
11000 JC=J-FACT
11100 IF (1EVE.EQ.1) THEN 101
11200 IC=I-FACT
11300 C PUT NEW SOLUTION INTO GUESS SOLUTION VECTOR AT POINT IC,JC
11400 GUESS(IC,JC)=SOLN(IC,JC)
11500 C CALCULATE NEW SOLUTION AT IC,JC
11600 CuCP=GC*(IC,JC)*SOLN(IC+1,JC)*C*(IC,JC)*SOLN(IC-1,JC)
11700 CuCP=GC*(IC,JC)*SOLN(IC+1,JC)*C*(IC,JC)*SOLN(IC-1,JC)
11800 CuCP=GC*(IC,JC)*SOLN(IC+1,JC)*C*(IC,JC)*SOLN(IC-1,JC)
11900 CuCP=GC*(IC,JC)*SOLN(IC+1,JC)*C*(IC,JC)*SOLN(IC-1,JC)
12000 CuCP=GC*(IC,JC)*SOLN(IC+1,JC)*C*(IC,JC)*SOLN(IC-1,JC)
12100 10 CONTINUE
12200 C CALCULATE RESIDUAL = QUADRATIC ERROR
12300 C SUM OF RESIDUAL NORMALIZED BY DURE OF SOLUTION
12400 C TO DETECT CONVERGENCE
12500 10 RESIDUAL=E*RESID
12600 IF (RESID.EQ.0) THEN 12400
12700  SOLN=0
12000          GO  TO  12400
12400          C     CR = CR + SUB(1+1,J)*SUB(1,J) + CR(1,J)*SUB(-1,J)
13000          END
13040          END
17100 30 IF (T(I)=0,0) GO TO 33
17200 31 GO TO 31
17300 32 SOLU(I,X,Y) = SOLU(I-1,Y) + SOLU(I,Y) + DELY * ABC(I)
17400 33 CONTINUE
17500 34 C DEFERRED SOLUTION AT BOUNDARY FOR NEUMANN BC AT BOTTOM
17600 35 IF (T(I) L.T. 0) GO TO 33
17700 36 I = 1, X = 1
17800 37 SOLU(1,1) = SOLU(1,2) + DELY * XYZ(I)
17900 38 C DEFERRED SOLUTION AT TOP LEFT CORNER FOR NEUMANN CONDITION
18000 39 C AT TOP AND LEFT SIDES
18100 40 IF (T(I) L.E. 0) GO TO 35
18200 41 SOLU(I,Y) = SOLU(I-1,Y) + SOLU(I,Y) + DELY * DELY * SOLU(I)
18300 42 C DEFERRED SOLUTION AT BOTTON LEFT CORNER FOR NEUMANN CONDITION
18400 43 C AT BOTTOM AND LEFT SIDES
18500 44 IF (T(I) L.E. 0) GO TO 35
18600 45 SOLU(I,Y) = SOLU(I-1,Y) + SOLU(I,Y) + DELY * DELY * SOLU(I)
18700 46 C DEFERRED SOLUTION AT TOP RIGHT CORNER FOR NEUMANN CONDITION
18800 47 C AT TOP AND RIGHT SIDES
18900 48 IF (T(I) L.E. 0) GO TO 35
19000 49 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
19100 50 C DEFERRED SOLUTION AT TOP LEFT CORNER FOR NEUMANN CONDITION
19200 51 C AT TOP AND LEFT SIDES
19300 52 IF (T(I) L.E. 0) GO TO 35
19400 53 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
19500 54 C DEFERRED SOLUTION AT TOP RIGHT CORNER FOR NEUMANN CONDITION
19600 55 C AT TOP AND RIGHT SIDES
19700 56 IF (T(I) L.E. 0) GO TO 35
19800 57 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
19900 58 C DEFERRED SOLUTION AT BOTTOM LEFT CORNER FOR NEUMANN CONDITION
20000 59 C AT BOTTOM AND LEFT SIDES
20100 60 IF (T(I) L.E. 0) GO TO 35
20200 61 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
20300 62 C DEFERRED SOLUTION AT BOTTOM RIGHT CORNER FOR NEUMANN CONDITION
20400 63 C AT BOTTOM AND RIGHT SIDES
20500 64 IF (T(I) L.E. 0) GO TO 35
20600 65 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
20700 66 C DEFERRED SOLUTION AT MIDDLE LEFT CORNER FOR NEUMANN CONDITION
20800 67 C AT MIDDLE AND LEFT SIDES
20900 68 IF (T(I) L.E. 0) GO TO 35
21000 69 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
21100 70 C DEFERRED SOLUTION AT MIDDLE RIGHT CORNER FOR NEUMANN CONDITION
21200 71 C AT MIDDLE AND RIGHT SIDES
21300 72 IF (T(I) L.E. 0) GO TO 35
21400 73 SOLU(X-1,Y) = SOLU(X-2,Y) + SOLU(X-1,Y) + DELY * DELY * SOLU(I)
21500 74 C DEFERRED SOLUTION AT MIDDLE CORNER FOR NEUMANN CONDITION
GASVEL SUBROUTINE

100 SUBROUTINE GASVEL(NA, VA, V2A, VP, VT, VPX, VTY, VZ, VPX, VTY, VZ, VPX, VTY, VZ, VPX, VTY, VZ)
200 /CUN2.5-J-V2A(50,50), V2A(50,50), V2A(50,50), V2A(50,50)
300 /CUN2.5-J-VTA(50,50), VTA(50,50), VTA(50,50)
400 /CUN2.5-J-VPX(50,50), VPX(50,50), VPX(50,50)
500 /CUN2.5-J-VTY(50,50), VTY(50,50), VTY(50,50)
600 /CUN2.5-J-VZ(50,50), VZ(50,50), VZ(50,50)
700 /CUN2.5-J-VY(50,50), VY(50,50), VY(50,50)
800 /CUN2.5-J-VW(50,50), VW(50,50), VW(50,50)
900 /CUN2.5-J-VFX(50,50), VFX(50,50), VFX(50,50)
1000 C***********************************************************************
1100 C THIS SUBROUTINE CALCULATES THE UPDATED VELOCITIES
1200 C (AXIAL VELOCITY = VA; RADIAL VELOCITY = VR)
1300 C EXPLICITLY FROM THE VELOCITY AND PRESSURE AT THE
1400 C PREVIOUS ITERATION. THESE EQUATIONS ARE DISCRETIZED
1500 C INTO THE AXIAL, RADIAL, AND Z DIAMETER EQUATIONS IN THE AXIAL AND
1600 C RADIAL DIRECTIONS, WHERE UPWIND DIFFERENCING IS USED
1700 C AND AVERAGING OF THE POINTS NEAR THE BOUNDARY IS DONE
1800 C (SEE REPORT)
1900 C***********************************************************************
2000 C***********************************************************************
2100 C INPUT TO THIS SUBROUTINE IS AS FOLLOWS
2200 C***********************************************************************
2300 C ** "n" AND "a" ARE THE NUMBER OF PRESSURE POINTS IN
2400 C THE AXIAL AND RADIAL DIRECTIONS
2500 C***********************************************************************
2600 C ** "n" IS THE AX BY AX ARRAY OF PRESSURES IN THE FLOW
2700 C FIELD
2800 C***********************************************************************
2900 C***********************************************************************
3000 C INPUT TO THIS SUBROUTINE
3100 C***********************************************************************
3200 C THE "VLA" COLUMN BLOCK CONTAINS THE RADIUS AND AXIAL
3300 C COMPONENTS OF THE "VTA" AND "VZ" COMPONENTS
3400 C***********************************************************************
3500 C***********************************************************************
3600 C THE "VTA" COLUMNS BLOCK CONTAINS THE RADIUS AND AXIAL
3700 C COMPONENTS OF THE PRESSURE POINTS
3800 C***********************************************************************
3900 C***********************************************************************
4000 C THE "VTA" COLUMN BLOCK CONTAINS THE AXIAL VELOCITY AT THE PREVIOUS ITERATION
4100 C***********************************************************************
4200 C THE "VTA" COLUMN BLOCK CONTAINS THE AXIAL VELOCITY AT THE PREVIOUS ITERATION
4300 C***********************************************************************
4400 C***********************************************************************
4500 C THE "VTA" COLUMN BLOCK CONTAINS THE AXIAL VELOCITY AT THE PREVIOUS ITERATION
4600 C***********************************************************************
4700 C***********************************************************************
4800 C***********************************************************************
4900 C***********************************************************************
5000 C***********************************************************************
C*** ALSO REQUIRED AS INPUT FOR THIS ROUTINE ARE THE SET
C OF FUNCTION, SUBROUTINES WHICH CALCULATE THE SQUARE OF THE
C VELOCITIES, AND THE CROSS CORRELATION OF THE VELOCITIES.
C THESE ARE GIVEN AFTER THE SUBROUTINE P3DUC

C

C** INITIAL

C "V14" AND "V16" ARE THE UPDATED ARRAYS OF RADIAL AND

C AXIAL VELOCITY

C*******************************************************************************/

C

C CALCULATE VELOCITIES AT INTERIOR NODES

C*******************************************************************************/

C

C CALCULATE THE AXIAL COMPONENT OF VELOCITY

C

C DO 10 J=2,4

C

6500 C UPWIND DIFFERENCING

6700 VAXV1J = .5*(V14(1,J)+V14(1,J+1))

6800 VAXV2J = V14(1,J+1)/DELX

6900 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

7000 VAXV1J = V14(1,J+1)/DELX

7100 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

7200 VAXV1J = V14(1,J)

7300 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

7400 VAXV1J = V14(1,J+1)/DELX

7500 VAXV1J = V14(1,J+1)/DELX

7600 VAXV1J = V14(J,J+1)/DELX

7700 VAXV1J = V14(J,J+1)/DELX

7800 VAXV1J = V14(J,J+1)/DELX

7900 VAXV1J = V14(J,J+1)/DELX

8000 10 CONTINUE

C

C CALCULATE THE RADIAL COMPONENT OF VELOCITY

C

C DO 20 J=2,4

C

8100 C UPWIND DIFFERENCING

8300 VAXV1J = .5*(V14(J,J)+V14(J,J+1))

8400 VAXV2J = V14(J,J+1)/DELX

8500 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

8600 VAXV1J = V14(J,J+1)/DELX

8700 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

8800 VAXV1J = V14(J,J)

8900 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

9000 VAXV1J = V14(J,J+1)/DELX

9100 VAXV1J = V14(J,J)

9200 IF(VAXV1J .LE. VAXV2J) THEN VAXV1J = VAXV2J

9300 VAXV1J = V14(J,J+1)/DELX

9400 20 CONTINUE
C CALCULATE VELOCITIES AT BOUNDARIES
10300 C
10400 C***CALCULATE SOLUTION ON LEFT BOUNDARY
10500 C ZERO SHEAR STRESS ON AXIS OF SYMMETRY
10600 C
10700 C
10800 DO 30 J=2,NY
10900 VZ0(I,J)=(4.*VZ0(I-1,J)+VZ0(I,J))/3.
11000 CONTINUE
11100 C NORMAL DERIVATIVE OF VELOCITY IS ZERO
11200 DO 40 J=2,NY-1
11300 VZ0(I,J)=VZ0(I,J-1)
11400 CONTINUE
11500 C***CALCULATE SOLUTION AT BOTTOM BOUNDARY
11600 C AXIAL VELOCITY = 0. SOLID BOUNDARY
11700 DO 50 I=1,NX
11800 VZ0(I,1)=0.
11900 CONTINUE
12000 C RADIAL VELOCITY = 0. NO SLIP CONDITION
12100 DO 60 I=1,NX+1
12200 VZ0(I,1)=0.
12300 CONTINUE
12400 C***CALCULATE SOLUTION AT TOP BOUNDARY
12500 C AXIAL VELOCITY = 0. SOLID BOUNDARY
12600 DO 70 I=1,NX
12700 VZ0(I,1)=-VZ0(I,2)
12800 CONTINUE
12900 C RADIAL VELOCITY = 0. NO SLIP CONDITION
13000 DO 80 I=1,NX+1
13100 VZ0(I,1)=0.
13200 CONTINUE
13300 C***CALCULATE SOLUTION AT RIGHT BOUNDARY
13400 C MASS CONSERVATION
13500 DO 90 J=2,NY
13600 VZ0((I-1,J)=VZ0((I,J-1)+(VZ0((I,J-1))/DELX/DELY
13700 CONTINUE
13800 CONTINUE
13900 C LUBRICITY
14000 DO 100 J=2,NY-1
14100 C VZ0((I,J)=(VZ0((I,J-1)+(VZ0((I,J-1))/DELX/DELY
14200 C AXIAL VELOCITY
14300 VZ0(I,J)=0.
14400 CONTINUE
14500 C
PARTCL SUBROUTINE

100 SUBROUTINE PARTICLE(X, Y, Z, U, V, W, THETA, PHA1)
200 DIMENSION X(50), Y(50), Z(50), U(50), V(50), W(50)
300 DIMENSION FORCE(50), FORCE2(50)
400 DIMENSION FR(50,50), FZ(50,50)
500 COMMON DELTA, DELT, DELT
600 COMMON SOURCE, XD, YD, ZD
700 COMMON RHOY, RHOY2
800 COMMON SOURCE2, FR, FC
900 REAL PI
1000 PI=3.14159

C~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
1100 C THIS SUBROUTINE CALCULATES THE PARAMETERS OF THE LIQUID
1200 C PHASE, BASED ON THE PARTICLE Trajectories, THE PARTICLE
1300 C VELOCITY ALONG THE TRAJECTORY, AND THE EXCHANGE OF MOMENTUM
1400 C TO THE GAS PHASE (THE SOURCE TERMS).
1500 C
1600 C THESE CALCULATIONS ARE MADE BY INTEGRATING THE EQUATIONS OF
1700 C MOTION OF THE PARTICLE, AND DEРЕТERMINING THE DROplet FORCE
1800 C ACTING ON THE PARTICLES IN A GIVEN VOLUME. 
1900 C A FOURTH ORDER INTEGRATION IS USED FOR THE INTEGRATION OF
2000 C THE EQUATIONS OF MOTION.
2100 C
2200 C NOTE: THIS PROGRAM IS SET UP ONLY FOR THE CASE WHERE THE NOZZLE
2300 C POSITION CORRESPONDS WITH A PRESSURE NOZZLE LOCATION
2400 C
2500 C***INPUT TO THIS PROGRAM IS AS FOLLOWS:
2600 C
2700 C "DP" - PARTICLE DIAMETER / NOZZLE DIAMETER
2800 C "THETA" - THE INITIAL TANGENT OF THE SPRAY AT THE
2900 C INCISION POINT
3000 C "PHA1" - IS THE FRACTION OF GAS PLEN OF EACH PARTICULAR
3100 C Trajectory OR droplet size
3200 C
3300 C
3400 C***INPUT TO COMMON BLOCK
The "SPRAY" COMMON BLOCK CONTAINS THE PARAMETERS OF THE
SPRAY

"L": THE AXIAL LENGTH OF THE DONUT DIVIDED BY THE HEIGHT OF
SPRAY

"D": NUMBER OF HOLES FOR A DISK-FACING SPRAY

"R": THE RADIAL LENGTH OF THE DONUT DIVIDED BY THE HEIGHT OF
SPRAY

U": GROUND / NOZZLE DIAMETER

v": INVERSE VELOCITY NUMBER SQUARED

a": ACCELERATION OF GRAVITY*HEIGHT OF SPRAY/EJECTION VELOCITY**2

"p": DENSITY OF GAS/DENSITY OF LIQUID

Q": THE "DEL" COMMON BLOCK CONTAINS THE RADIAL AND AXIAL INCREMENTAL
DISTANCE AND (THOUGH NOT USED IN THIS SUBROUTINE) THE INCREMENTAL
TIME

4": THE "REYNOLDS" COMMON BLOCK CONTAINS THE REYNOLDS NUMBER OF
LAMINAR/LAMINARIZATION - EJECTION VELOCITY*SPRAY HEIGHT/GAS
VISCOSSITY

***OUTPUT

"Az" AND "Ae" ARE THE ARRAYS CONTAINING THE AXIAL AND RADIAL
COMPONENTS OF THE PARTICLE TRAJECTORIES

"Bz" AND "Be" ARE THE ARRAYS CONTAINING THE AXIAL AND RADIAL
COMPONENTS OF THE SPRAY VELOCITY ALONG THE SPRAY TRAJECTORY

***OUTPUT INTO COMMON BLOCK

THE "SOURCE" COMMON BLOCK CONTAINS THE TWO DIMENSIONAL
ARRAY OF THE RADIAL AND AXIAL SOURCE TERMS "Fz" AND "Fz"

*****************************************************************************

DELZ=0.1*Y2
DELY=1/2*Z*
DELX=1/2*X*
DELK+1

*****************************************************************************

C DERIVATION OF PARTICLE TRAJECTORY AND VELOCITY

C ALONG THE TRAJECTORY

*****************************************************************************

C INITIAL CONDITIONS FOR PARTICLE EQUATIONS

U(1)=0.1*(H+0.1)
V(1)=0.1*(H+0.1)
W(1)=0.1*(H+0.1)

*****************************************************************************
C START FIRST STEP OF RUNGE-KUTTA INTEGRATION
2 = DELZ*(UR(1)/UZ(1))
1 = DELZ/UZ(1)
C CALCULATE AIRFIELD VELOCITY
CALL AIRVEL(R1,Z1,UR,VZ)
FVELD=RT*UP*KRTT((UR(1)-UR)**2+(UZ(1)-VZ)**2)/HP
C2=CU(PK)(UR(1)+UR(1)**2)
UZ1=UZ1*(C2*(UR(1)-VZ))/UZ(1)
C START SECOND STEP OF RUNGE-KUTTA INTEGRATION
1 = DELZ/UZ(1)
2 = DELZ*(UR1/UZ1)
C CALCULATE AIRFIELD VELOCITY
CALL AIRVEL(R1,Z1,UR,VZ)
FVELD=RT*UP*KRTT((UR1-UR)**2+(UZ1-VZ)**2)/HP
C2=CU(PK)(UR1+UR1**2)
UZ1=UZ1*(C2*(UR1-VZ))/UZ1
C START THIRD STEP OF RUNGE-KUTTA INTEGRATION
1 = DELZ/UZ1
2 = DELZ*(UR1/UZ1)
C CALCULATE AIRFIELD VELOCITY
CALL AIRVEL(R1,Z1,UR,VZ)
FVELD=RT*UP*KRTT((UR3-UR)**2+(UZ3-VZ)**2)/HP
C2=CU(PK)(UR1+UR1**2)
UZ1=UZ1*(C2*(UR3-VZ))/UZ1
C START FOURTH STEP OF RUNGE-KUTTA INTEGRATION
1 = DELZ/UZ3
2 = DELZ*(UR1/UZ3)
C CALCULATE INITIAL VELOCITY
C
CALL ALLVEL(U1,V1,U2,V2)
C2=0.0625*1.0+2*(U2-V2)**2/EP

C CALCULATE VALUE AT END OF INTEGRATION STEP

C
10 CALCULATION OF TRAJECTORY AND VELOCITIES ALONG TRAJECTORY

12600 C
12700 C CALCULATE NONDIMENSIONAL FORCE COMPONENTS ALONG THE

12700 C

12800 C

12900 C

13000 C

13100 C

13200 C

13300 C

13400 C

13500 C

13600 C

13700 C

13800 C

13900 C

14000 C

14100 C

14200 C

14300 C

14400 C

14500 C

14600 C

14700 C

14800 C

14900 C

15000 C

15100 C

15200 C

15300 C

15400 C

15500 C

15600 C

15700 C

15800 C

15900 C

16000 C

16100 C

16200 C

16300 C

16400 C

16500 C

16600 C

16700 C

16800 C

16900 C

17000 C
C This subroutine calculates the drag coefficient
C of a sphere as a function of Reynolds number:
C
C FUNCTION  COEF  
C
22000  C
22003  COEF=2.*W/((1.+0.617*RE))**4
22400  RETURN
22500  END

C This subroutine calculates the axial and radial components
C of air velocity at points internal to the mac cell by
C
C INTERPOLATING THE DISCRETIZED MAC CELL VELOCITIES
C
22900  SUBROUTINE  AVEL(UX,UY,UR,UX2,UY2,UR2)
23000  REAL  UH,RL,DELU,DELU2,DELV,DELV2,DELX,DELY,DELT
23100  COMMON  /AIR/ V1,V2,VR
23200  COMMON  /DISPLAY/ DL,D1,DL1,D11,DL2
23400  REAL  NL,NI
23500  JV=1
23600  JV=1*FIX((ZL=H+2)/DELY)+1
23700  JV=1*FIX((ZL=H+2)/DELY)+1
23800  JV=1*FIX((ZL=H+2)/DELY)+1
23900  JV=1*FIX((ZL=H+2)/DELY)+1
24000  JV=1*FIX((ZL=H+2)/DELY)+1
24100  XM=(IBM+1)*IBM+1+1
24200  XM=(IBM+1)*IBM+1+1
24300  XM=(IBM+1)*IBM+1+1
24400  XM=(IBM+1)*IBM+1+1
24500  XM=(IBM+1)*IBM+1+1
24600  XM=(IBM+1)*IBM+1+1
24700  RETURN
24800  END
**INPUT FILE**

100 | Input for Spray Program
200 | DOUBLE PRECISION
300 | Enter radial and axial impulse dimensions; R and Z
400 | Rectangularized by the spray height
500 | 1xxxxxx22xxxxxxx
600 | Enter spray height/spray length, D, and spray length/nozzle diameter, dp
700 | 1xxxxxx22xxxxxxxx
800 | Enter number of particle sizes or trajectories
900 | 1xx
1000 | 4
1100 | Enter droplet diameter/nozzle diameter, dp, initial angle of spray,
1200 | trajectory and volume flow fraction of each particular trajectory, Frac
1300 | 1xxxxxx22xxxxxxxxxx
1400 | 1
1500 | Frac
### PARTICLE TRAJECTORIES

**PARTICLE TRAJECTORY FOR Dp = 0.09041**

<table>
<thead>
<tr>
<th>RADIUS</th>
<th>AXIAL DIST</th>
<th>11/F</th>
<th>PARTIAL VEL.</th>
<th>AXIAL VEL.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.00000</td>
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<tr>
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<tr>
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<tr>
<td>PARTICLE TRAJECTORY FOR t1 = 0.09694</td>
<td>TAN1 Vel = 0.52140</td>
<td>VOLUME FLOW FRACTION = 0.33330</td>
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