MATHEMATICAL MODEL FOR MULTIPLE COOLING TOWER PLUMES

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ABSTRACT

A mathematical model is developed resulting in a computer program for the prediction of the behavior of plumes from multiple cooling towers with multiple cells. A general integral method based on the conservation of mass, momentum, energy (heat), and moisture fluxes (before and after plume merging), were employed in the prediction scheme. The effects of ambient stratifications of temperature, moisture, and wind are incorporated in the model.

An axisymmetric round plume is assumed to be emitted from each individual cell before interference with neighboring plumes. A finite length slot plume in the central part and two half round plumes at both ends of the merged plume were used to approximate the plume after merging. The entrainment and drag functions are calculated based on the modified merged plume shape.

The computer output provides the predicted plume properties such as excess plume temperature, humidity and liquid phase moisture (water droplet), plume trajectory, width, and dilution at the merging locations and the beginning and ending points of the visible part of the plumes. Detailed printout and contour plots of excess temperature and moisture distribution can also be obtained if desired.

Based on comparison with laboratory data this model gives good predictions for the case of dry plumes (no moisture involved). It should be noted that several empirical coefficients are as yet not accurately known. Verification of this model for the wet plume (such as for prototype cooling tower plumes) and the determination of the values for these empirical coefficients to be used in prototype applications must await detailed comparison with field data.

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a_1	Entrainment coefficient associated with jet type entrainment
a_2	Entrainment coefficient associated with the effect of buoyancy
a_3	Entrainment coefficient associated with thermal type entrainment
a_4	Entrainment coefficient associated with ambient turbulence
a	Finite length of the slot plume in the central part of the merged plume
A	Finite length of the slot plume in the central part of the modified merged plume
b	Plume radius
b_{r1}, b_{r2}	Plume radii at the ends of the merged plume
b_s	Plume width of the slot plume in the central part of the merged plume
B1,B2	Plume radii at the ends of the modified merged plume
BXZ	Plume half height of the cross-section normal to s-axis
BY	Plume half width
C	Tracer concentration
C_d	Drag coefficient
C_{pa}	Specific heat at constant pressure
e_s	Saturation vapor pressure
E	Volume rate of entrainment
E_{1r}	Volume rate of entrainment associated with the effects of momentum and buoyancy for a round plume
E_{1s}	Volume rate of entrainment associated with jet type entrainment for slot plume
E_2	Volume rate of entrainment associated with thermal type entrainment

LIST OF SYMBOLS (Continued)

E_3	Volume rate of entrainment associated with ambient turbulence
F	Sum of excess vapor and liquid phase moisture fluxes (H+W)
F^2	Densimetric Froude number ($m^{5/2}/\mu^2\beta$)
Fr_L	Local densimetric Froude number ($U_p^2/[(\rho_a-\rho_p)bg/\rho_o]$)
Fr_{LC}	Critical local densimetric Froude number
g	Acceleration of gravity
G	$T - L_v W/C_{pa}$
H	Excess vapor phase (humidity) moisture flux
HT	Total height of the merged plume
L_v	Latent heat of evaporation or condensation
m	Kinematic momentum flux ($\int_A u_p^2 dA$)
M	Excess kinematic momentum flux
p_d	Dry air absolute pressure
p_t	Total absolute pressure ($p_d + e_s$)
P	Plume periphery
q	Specific vapor phase moisture (humidity)
Q	Plume volume flux
s	Plume trajectory
t	Temperature
t_s	Steam point temperature
T	Excess temperature flux
U	Velocity
U_a'	Measure of ambient turbulent fluctuation
U_{r1},U_{r2}	Plume velocities at both ends of merged plumes

LIST OF SYMBOLS (Continued)

U_s	Plume velocity at central part of merged plume
W	Excess liquid phase moisture flux
W_d	Plume width
WD	Total width of the merged plume
x	x-coordinate (parallel to wind direction)
y	y-coordinate (normal to x-axis)
z	z-coordinate (vertical coordinate)
α_j	Entrainment coefficient for pure jet ($F_1 \rightarrow \infty$)
α_p	Entrainment coefficient for pure plume
β	Buoyancy flux ($\int_A g U_p (\rho_a - \rho_p)/\rho_a dA$)
Γ	Adiabatic lapse rate
θ	Angle between the tangent of s and x-axis
ρ	Density
σ	Liquid phase moisture
ϕ	Angle between the centerline of the (inclined) plume cross-section and the horizontal line parallel to y-axis
μ	Volume flux ($\int_A U_p dA$)
$(\ )_a$	in ambient
$(\ )_o$	at tower exit
$(\ )_p$	in plume

CHAPTER 1

INTRODUCTION

The use of multiple cooling towers is a common means of disposal of waste heat from large power plants. A better understanding of the behavior and interaction of plumes from multiple towers would be useful not only to cooling tower design and operation, but also in the assessment of their environmental impact. Due to the relatively close proximity of neighboring tower exits, the individual plumes from multiple cooling towers rapidly interfere with one another, thus changing the overall plume shape and its mixing characteristics. In addition, the ambient stability (temperature profile), humidity, wind velocity and wind direction to the tower array also influence the plume behavior. In this report a mathematical model resulting in a computer program is developed which will provide the framework to allow reasonable predictions to be made of the characteristics of plumes from multiple cooling towers under various ambient conditions.

Throughout this report, no distinction will be made between a plume and a jet. Neither will the distinction be made between the multiple plumes from the several cells of a tower and the multiple plumes from several individual towers.

The plume from a cooling tower is a buoyant jet which has been studied in the past by numerous investigators, such as Morton, et al. (1956), Morton (1957), Slawson and Csanady (1967,1971), Koh and Brooks (1975). Several existing single tower plume models, including dry and wet plumes, were developed by Briggs (1969), Hoult et al. (1969), Abraham (1970), Fox (1970), Csanady (1971), Wigley and Slawson (1971, 1972), Hirst (1971), Hanna (1972), Weil (1974), Wigley (1975a,b), and Schatzmann (1977).

A model for multiple plumes was first developed by Koh and Fan (1970) in analysing the analogous problem of disposal of waste heat into the ocean by multiple port diffusers. The integral method was used and the individual round buoyant jets were approximated by a two-dimensional slot jet after interference. A transition region during merging was considered. Although a discontinuous centerline temperature resulted at the point of merging, the overall predictions of the plume properties were quite satisfactory. Jirka and Harleman (1974) approached the multiple port diffuser problem by replacing it with an equivalent slot jet having the same mass and momentum fluxes as the multi-port discharge. As expected this method generally over-estimates dilution except for those instances when the plumes are very close to each other initially. Briggs (1974) added an enhancement factor to his single tower equation for plume rise by considering the effects of number of towers and tower spacing. Meyer et al. (1974) modified Briggs' equation and used a "peak factor" to develop a model which can give a fairly good prediction of visible plume length. However, the prediction of the plume trajectory is less accurate. Davis (1975) developed a mathematical model for calculating plume rise and dilution from multiple cell mechanical draft cooling towers with the wind normal to the tower array. The entrainment function used includes the effects of plume interference and the changing entrainment surfaces during merging. The model also provides calculation techniques for various modes of plume development. The plume properties remain continuous when the calculations proceed smoothly from one zone to another. The values of the coefficients in his entrainment function still need to be determined from suitable laboratory and field experiments.

Data from multiple towers are very scarce. Chan et al. (1974) made laboratory simulations of plumes from multiple towers using water as the fluid medium. Two sets of normalized excess temperature distributions were presented. These are useful for model comparisons. The studies by Carpenter et al. (1968) and Slawson et al. (1975) at TVA gave field data on plume trajectory and some plume properties. More complete data including plume trajectory, width, dilution, and ambient conditions (i.e. temperature, humidity and wind velocity profiles, wind direction to tower array, tower configuration, etc.) however are required for proper verification.

The model developed in this report is based on a general integral method applied to the conservation equations for mass, momentum, energy, and moisture fluxes. An axisymmetric round plume is assumed initially for each tower exit. As the plumes merge, combinations of round and slot plumes are employed to simulate the shape of the resulting merged plumes. The merging criteria, merging processes, changes of plume shape and entrainment functions are a part of the model and are discussed in Chapter 2. Some results of model predictions and comparisons with laboratory and field data are presented and discussed in Chapter 4. A computer program has been written to perform the calculations and is included in Chapter 3 and Appendices A and C.

CHAPTER 2

THEORETICAL MODEL

The present mathemtical model is developed for the prediction of plume properties from multiple cooling towers. These include plume temperature, moisture (vapor and liquid phases), excess temperature, excess moisture, velocity, width, dilution, trajectory and visible plume length. For ease of application to practical situations, this model is capable of handling rather arbitrary vertical profiles of ambient temperature, humidity, and velocity; arbitrary but steady wind direction to the tower array; and randomly arranged tower configurations.

The assumptions made in developing this model are as follows:

1. The flow is fully turbulent. Molecular transport can be neglected in comparison with turbulent transport so that there is no Reynolds number dependence.

2. Longitudinal turbulent transport is small compared with longitudinal advective transport.

3. Pressure is hydrostatic throughout the flow field.

4. The cross-plume profiles are similar for plume velocity, temperature, density, humidity and liquid phase moisture.

5. The Boussinesq assumption is valid. This implies that the variations of fluid density throughout the flow field are small compared with the reference density chosen. The variations in density are only considered in the buoyancy term.

Using these assumptions, a general integral model for multiple cooling tower plumes based on the conservation of mass, momentum, energy and moisture fluxes along the plume trajectory is developed. By providing the ambient conditions and the empirical equations for entrainment and drag, the conservation equations are integrated stepwise for the center line properties along the plume trajectory. Before interference the plumes are assumed to be individual, axisymmetric, round buoyant jets. During the merging process, a combination of a finite slot jet in the central part and two half round jets at both ends is assumed to be the cross-sectional shape of the merged plume as an approximation but only for the calculation of entrainment and drag. Finally, the completely merged plume gradually tends to become round in cross section again, whereupon the individual axisymmetric analysis is reapplied. The formulations of the basic plume conservation equations, entrainment function, merging criterion and merging process are presented in the following sections.

2.1 Formulation

The coordinate system chosen with a typical cooling tower configuration is shown in Figures 2.1 and 2.2. The x-axis is parallel to the steady ambient wind direction. s is the coordinate along the plume path and θ is the angle between the tangent to s and the x-axis. The individual plumes from the cooling tower cells are presumed to be discharged vertically into a stratified atmosphere, and bent over due to the effect of ambient wind. The plume properties are defined as velocity U, density ρ, temperature t, specific humidity q, and liquid phase moisture σ. Here, the specific humidity (vapor phase moisture) q and liquid phase moisture σ are defined as the ratio of mass of vapor (or liquid) phase moisture to the total mass of the mixture in a unit volume. The subscripts o, p, and a are used for the values at tower

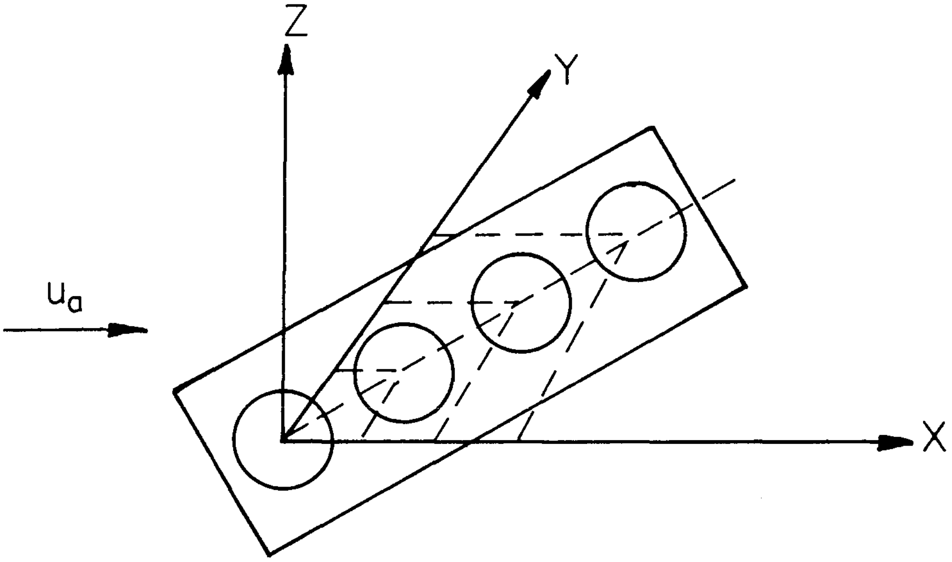


Figure 2.1 Top View of the Coordinate System Associated with the Cooling Tower Configuration

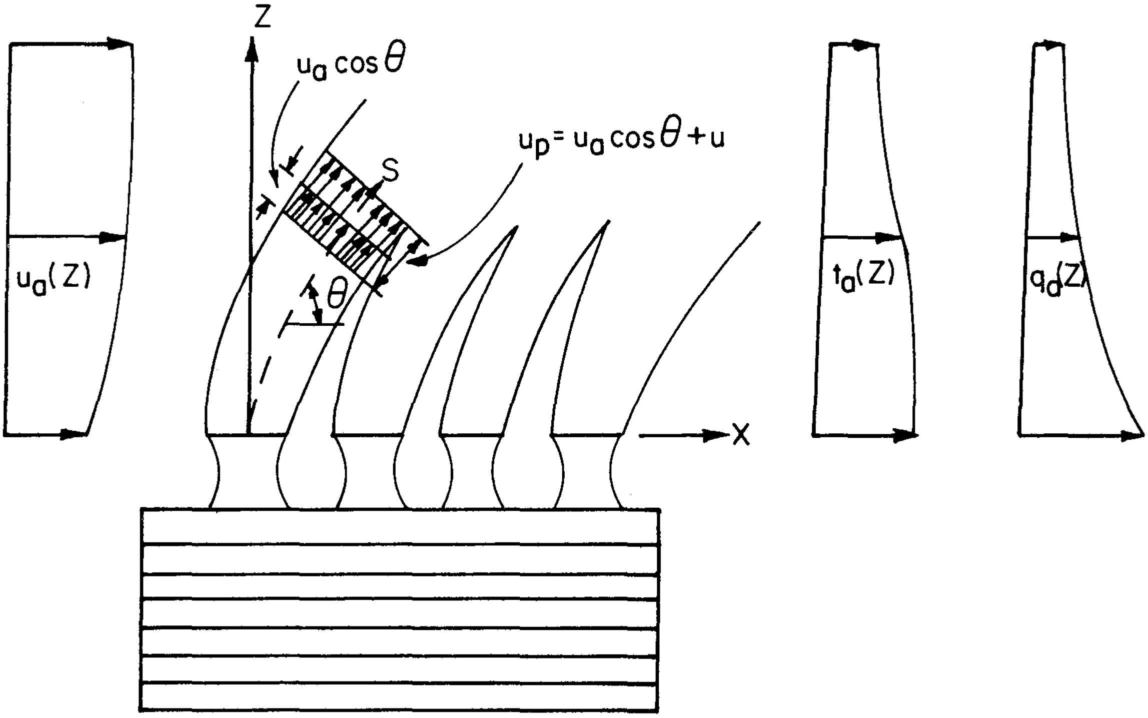


Figure 2.2 Side View of the Coordinate System Associated with the Cooling Tower Configuration

exit, in the plume, and in the ambient atmosphere, respectively. The plume volume flux Q, kinematic momentum flux M, temperature deficiency flux T, vapor phase moisture (or humidity) deficiency flux H, and liquid phase moisture deficiency flux W are defined as follows:

$$Q = \int_A U_p \, dA \tag{2.1}$$

$$M = \int_A U_p^2 \, dA \tag{2.2}$$

$$T = \int_A (t_p - t_a) \, U_p \, dA \tag{2.3}$$

$$H = \int_A (q_p - q_a) \, U_p \, dA \tag{2.4}$$

$$W = \int_A (\sigma_p - \sigma_a) \, U_p \, dA \tag{2.5}$$

Any 'rainout' of liquid droplets in the ambient atmosphere will be neglected so that σ_a is equal to zero.

The conservation of mass equation is:

$$\frac{d}{ds} \{ \int_A \rho_p \, U_p \, dA \} = \rho_a E \tag{2.6}$$

where E is the volume rate of entrainment of ambient fluid. The function used for E is an empirical expression including the effects of plume geometry, local mean velocity, buoyancy and ambient turbulence. The detailed form of E is presented in Section 2.2.

The conservation equation for horizontal momentum flux is:

$$\frac{d}{ds} \{ \int_A \rho_p \, U_p^2 \, dA \cdot \cos \theta \} = \rho_a \, U_a E + \frac{1}{2} \rho_a \, U_a^2 \sin^2 \theta \, C_d \, W_d |\sin \theta| \tag{2.7}$$

where the first term on the right hand side of equation (2.7) is due to the momentum of the entrained ambient fluid and the second term is due to the horizontal drag force (Fan, 1967) on the plume; C_d is a drag coefficient to be determined empirically and W_d is the width of the plume; the absolute value of $\sin\theta$ is used in order to account for both the ascending and descending parts of the plume.

The conservation equation for vertical momentum flux is:

$$\frac{d}{ds}\{\int_A \rho_p U_p^2 \, dA \cdot \sin\theta\} =$$

$$g\int_A (\rho_a - \rho_p)\, dA - g\int_A \rho_p \sigma_p dA \mp \frac{1}{2} \rho_a U_a^2 \cdot \sin^2\theta \, C_d W_d \cos\theta \tag{2.8}$$

where the first term on the right hand side of equation (2.8) is the buoyancy force due to the density difference between the plume and ambient fluid; the second term is the effect of the weight of liquid droplets suspended in the plume; the third term is the vertical drag force on the plume with the negative and positive signs corresponding to $0 \leq \theta \leq \pi/2$ and $-\pi/2 \leq \theta < 0$, respectively.

Koh and Fan (1970) have shown that the governing equation for the flux of a tracer quantity C is as follows:

$$\frac{d}{ds}\int_A (C_p - C_a)\, U_p \, dA = -\frac{dC_a}{ds}\int_A U_p \, dA \tag{2.9}$$

where C_p and C_a are the tracer concentrations in the plume and the ambient, respectively. Now considering the temperature flux and also taking into account the effects of atmospheric adiabatic lapse rate Γ

and the liberation of latent heat due to condensation of water vapor inside the plume (Csanady, 1971), the conservation equation for energy (or heat) flux is derived as follows:

$$\frac{d}{ds}\int_A (t_p - t_a)\, U_p\, dA = -\left(\frac{d\, T_a}{dz} + \Gamma\right) \sin\theta \int_A U_p\, dA + \frac{d}{ds}\int_A \frac{L_v}{C_{pa}}\, \sigma_p\, U_p\, dA \qquad (2.10)$$

where L_v is the latent heat of evaporation (or condensation) i.e., $L_v(t) = [597.31 - 0.57x(t°C)] \times 4.1868\ Jg^{-1}$ for $t \geq 0°C$ and $L_v = [677 + 0.622 \times (t°C)] \times 4.1868$ for $t<0°C$, and C_{pa} is the specific heat of air at constant pressure.

The conservation equation for (vapor and liquid phase) moisture flux is:

$$\frac{d}{ds}\int_A (q_p - q_a)\, U_p\, dA + \frac{d}{ds}\int_A \sigma_p\, U_p\, dA = -\frac{dq_a}{dz} \sin\theta \int_A U_p\, dA \qquad (2.11)$$

We assume a top-hat distribution of plume properties across the plume. Therefore, U_p, T_p, ρ_p, q_p, and σ_p are constants inside the plume. In particular, U_p is defined as follows:

$$U_p = U_a \cos\theta + U \qquad (2.12)$$

where U is the 'net' plume velocity relative to the ambient wind.

Applying the relationship between temperature and density for a constant pressure process (pressure variations in the plume cross section is neglected) we can write:

$$\frac{\rho_a}{\rho_p} = \frac{t_p}{t_a} \text{ ; and } \frac{\rho_a - \rho_p}{\rho_p} = \frac{t_p - t_a}{t_a} \tag{2.13}$$

The conservation equations may now be rewritten as:

$$\frac{dQ}{dS} = \frac{t_p}{t_a} E \tag{2.14}$$

$$\frac{d}{ds}\{M \cos\theta\} = \frac{t_p}{t_a}\{U_a E + 0.5\ U_a^2 \sin^2\theta\ C_d\ W_d|\sin\theta|\} \tag{2.15}$$

$$\frac{d}{ds}\{M \sin\theta\} = g\ \{\frac{t_p - t_a}{t_a} - \sigma_p\} \int_A dA \mp \frac{t_p}{t_a} 0.5\ U_a^2 \sin^2\theta\ C_d\ W_d \cos\theta \tag{2.16}$$

$$\frac{d}{ds}\{T - \frac{L_v}{C_{pa}} W\} = -\left(\frac{d\ t_a}{dz} + \Gamma\right) \cdot \sin\theta \cdot Q \tag{2.17}$$

$$\frac{d}{ds}\{H + W\} = -\frac{dq_a}{dz} \cdot \sin\theta \cdot Q \tag{2.18}$$

In addition, the equations for the geometrical relations yield

$$\frac{dx}{ds} = \cos\theta \tag{2.19}$$

$$\frac{dz}{ds} = \sin\theta \tag{2.20}$$

Since U_p, t_p, σ_p and W_d can be written in terms of M, Q, T and W (Koh and Fan, 1970); for instance, $U_p = 2M/Q$ for round plume, the system of equations (2.14) to (2.20) constitute seven ordinary differential equations for the eight unknowns, Q, M, θ, T, H, W, x and z as functions of s. For closure, one more equation is needed. This extra condition is:

$$\sigma_p = 0 \qquad \text{for } q_p < q_{sp} \text{ (dry plume)}$$

$$q_p = q_{sp}\ (t_p) \qquad \text{for } q_p \geq q_{sp} \text{ (wet plume)} \tag{2.21}$$

where q_{sp} is the plume saturation specific humidity.

Equation (2.21) implies that when the plume is unsaturated, no liquid phase moisture due to condensation need be considered and when the plume is saturated, the plume humidity is equal to the plume saturation specific humidity. To calculate the saturated specific humidity, thermodynamic equilibrium between liquid and vapor is assumed. The Clausius-Clapeyron equation (or tabulated values) can then be used to calculate the saturated humidity. The equation used in the model to calculate the saturated specific humidity q_s is (Linsley et al., 1975):

$$q_s(t,p) = \frac{0.622 e_s(t)}{P_t - 0.378\ e_s(t)} = \frac{0.622\ e_s(t)}{P_d(z) + e_s(t) - 0.378\ e_s(t)} \tag{2.22}$$

where t and p are absolute temperature and pressure, respectively; P_t is the total pressure which is the sum of the dry air pressure $P_d(z)$ and the saturated vapor pressure $e_s(t)$.

Since the variation of pressure is small (for instance, ΔP = 1% of P corresponding to $\Delta z \simeq$ 100M), the absolute pressure at sea level (i.e., P_d = 1013.25 mb) is used in equation (2.22), which becomes:

$$q_s(t) = \frac{0.622\ e_s(t)}{1013.25 + 0.622\ e_s(t)} \tag{2.23}$$

An approximate expression of $e_s(t)$ was developed by Richards (1971) as

$$e_s(t)=1013.25 \times \exp(13.3185\ t_v-1.9760\ t_v^2-0.6445\ t_v^3-0.1299\ t_v^4)$$

where

$$t_v = 1 - \frac{t_s}{t}$$

and t_s is the steam point temperature (°K). The result from this equation is very accurate (to within 0.1%) over the wide range of temperature -50°C to 140°C (Wigley, 1974). Within the range 0° to 100°C it is accurate to within the limits of accuracy of the accepted Goff-Gratch formula. In this study t_s is equal to 373.16°K. Because both q_s and t are unknown in the governing equations, the implicit form of equation (2.23) would require an iteration scheme in the calculation. In the model, the Newton method was adopted for this iteration.

With the additional equation (2.23) and the Newton iteration method, the system of equations (2.14) to (2.21) may now be solved given the initial values of the unknowns at tower exit (or s=o). The initial values are as follows;

$$Q_o = \int_A U_p\ dA = \frac{\pi}{4} D_o^2\ U_o$$

$$\theta_o = 90°$$

$$M_o \cos\theta_o = 0$$

$$M_o \sin\theta_o = \int_A U_p^2\ dA = \frac{\pi}{4} D_o^2\ U_o^2 = Q_o\ U_o$$

$$G_o = T_o - \frac{L_v}{C_{pa}} W_o = \frac{\pi}{4} D_o^2\ U_o\ (t_o - t_{ao} - \frac{L_v}{C_{pa}} \sigma_o) \qquad (2.24)$$

$$= Q_o(t_o - t_{ao} - \frac{L_v}{C_{pa}}\ \sigma_o)$$

$$F_o = H_o + W_o = \frac{\pi}{4} D_o^2\ U_o\ (q_o - q_{ao} + \sigma_o)$$

$$= Q_o\ (q_o - q_{ao} + \sigma_o)$$

$$x_o = 0$$

$$z_o = 0$$

where the subscripts o and ao are associated with the values at tower exit (or initial values) and the ambient at the same level, and $L_v(t) = [597.31 - 0.57 \times t_o(°C)] \times 4.1868\ Jg^{-1}$, and $C_{pa} = 1.005\ Jg^{-1}°K^{-1}$.

2.2 Entrainment

The entrainment of ambient fluid into the plume is a function of plume geometry, local mean velocity, buoyancy, and ambient turbulence. The entrainment function first proposed by Morton et al. (1956) is:

$$E_{1r} = \alpha\ 2\pi b\ U_p \tag{2.25}$$

where α is entrainment coefficient determined from experiments; b is the round jet radius; and U_p is the jet centerline velocity.

Based on the integral conservation equations of mass, momentum, energy, and mechanical energy, and assuming similar profiles, Fox (1970) and Hirst (1971) derived an entrainment function for round jets which includes the effect of buoyancy to the entrainment. It reads as follows:

$$E_{1r} = (a_1 + \frac{a_2}{Fr_L} \sin\theta)\ 2\pi b\ U_p \tag{2.26}$$

where a_1 and a_2 are entrainment coefficients, and Fr_L is the local densimetric Froude number defined as $Fr_L = U_p^2/[(\rho_a - \rho_p)\ b\ g/\rho_o] = U_p^2/[(t_p - t_a)\ t_o bg/t_p\ t_a]$, and g is gravitational acceleration. Based on experimental results, a_1 was determined to be 0.057 for pure round jet with Gaussian profile distribution (i.e., $Fr_L \rightarrow \infty$). Hirst (1971) suggested the value of $a_2 = 0.97$. This appears to be too large when his results are compared with experiments. A better estimate of the value of

a_2 can be made from the work of List and Imberger (1973), who, based on dimensional analysis and experimental data, derived a similar expression for E_{1r} for round jets (Koh and Brooks, 1975)

$$E_{1r} = (0.057 + \frac{0.083}{F^2})\ 2\pi b\ U_p \tag{2.27}$$

where $F^2 = m^{5/2}/\mu^2\beta$ with m being the kinematic momentum flux $= \int_A U_p^{\ 2}\ dA$, μ the volume flux $= \int_A U_p\ dA$, and β the buoyancy flux $= \int_A gU_p \frac{\rho_a - \rho_p}{\rho_a}\ dA$.

Comparing equations (2.26) and (2.27) in a quiescent ambient (i.e. $\sin\theta = 1$) and calculating F^2 by using the Gaussian similarity profiles for U_p and ρ_p, one finds $a_2 = 0.083\ Fr_L/F^2 \simeq 0.4775$. Hence equation (2.26) becomes

$$E_{1r} = (0.057 + \frac{0.4775}{Fr_L}\ \sin\theta)\ 2\pi b\ U_p \tag{2.28}$$

The entrainment coefficient α in equation (2.25) has the extreme values for pure jet (i.e., $Fr_L \to \infty$) $\alpha_j = 0.057$ and pure plume (i.e., $Fr_L \to 0$) $\alpha_p = 0.082$ in a quiescent ambient. A critical value of Fr_L may be determined from

$$0.082 = 0.057 + \frac{0.4775}{Fr_{LC}}$$

which gives

$$Fr_{LC} = 19.1$$

For Gaussian similarity profiles of plume properties it will be assumed that

$$\begin{aligned} E_{1r} &= (0.057 + \frac{0.4775}{Fr_L}\ \sin\theta)\ 2\pi b\ U_p && \text{for } Fr_L > 19.1 \\ &= 0.082 \cdot 2\pi b\ U_p && \text{for } Fr_L \leqslant 19.1 \end{aligned} \tag{2.29}$$

which implies that $Fr_L = 19.1$ was considered a small number below which the entrainment of a buoyant jet is similar to that of a pure plume.

Experimental results for two-dimensional slot jet are not sufficiently comprehensive to obtain a similar entrainment expression [i.e., equation (2.29)] (Koh and Brooks, 1975). Therefore, based on the experimentally determined entrainment coefficient, the following form will be used for the slot jet with Gaussian profile distribution, viz.,

$$E_{1s} = 0.14 \cdot 2A \cdot U_p \tag{2.30}$$

where A is the length of the slot jet.

The entrainment functions embodied in equations (2.29) and (2.30) are based on Gaussian profiles of plume properties. In this study, top-hat similarity profiles are assumed. The difference in the resulting entrainment functions [equations (2.29) and (2.30)] due to this is a factor of $\sqrt{2}$. Therefore, equations (2.29) and (2.30) can be rewritten as follows:

$$\begin{aligned} E_{1r} &= (0.0806 + \frac{0.6753}{Fr_L} \sin\theta)\ 2\pi b\ U_p && \text{for } Fr_L > 19.1 \\ &= 0.1160 \quad 2\pi b\ U_p && \text{for } Fr_L \leqslant 19.1 \end{aligned} \tag{2.31}$$

$$E_{1s} = 0.198 \cdot 2AU_p \tag{2.32}$$

As the plume bends over towards the direction of the ambient wind, the plume velocity is about equal to the wind velocity. Then the entrainment should be nearly as if the plume were a two-dimensional thermal in a stagnant atmosphere. This entrainment is proportional to the jet periphery and the velocity of the thermal. Abraham (1970) proposed the following form

$$E_2 = a_3 \; P \; U_a \; \sin\theta \; \cos\theta \qquad (2.33)$$

where P is the jet periphery, cosθ is arbitrarily chosen to diminish the thermal type of entrainment closed to the initial stage of the vertical jet, and a_3 is the entrainment coefficient for a line thermal. For large Reynolds number, the experimentally determined value of a_3 is 0.5 (Richards, 1963). But a better value suggested by Koh and Chang (1973) from their plume measurements and numerical model is 0.3536, which will be used in this present model. Thus

$$E_2 = 0.3536 \; P \; U_a \; \sin\theta \; \cos\theta \qquad (2.34)$$

Another type of entrainment is associated with ambient turbulence, and expressed as

$$E_3 = a_4 \; P \; U_a' \qquad (2.35)$$

where a_4 and U_a' are the entrainment coefficient and a measure of turbulent velocity fluctuations. Based on dimensional analysis, Briggs (1969) found that U_a' is associated with eddy energy dissipation in the inertial subrange and gave an estimate of $a_4 = 1$. In practice, the root-mean-square value of the ambient wind velocity fluctuation may be used to approximate U_a', which is equal to a few percent of the mean wind velocity under normal atmospheric conditions.

Finally, we may combine equations (2.31), (2.32), (2.34) and (2.35) to construct a complete entrainment function as

$$E = P \; \{\alpha|U|+0.3536 \; U_a|\sin\theta|\cos\theta+1.0 \; U_a'\} \qquad (2.36)$$

where for a round jet,

$$P = 2\pi b$$

$$\alpha = 0.0806 + \frac{0.6753}{Fr_L}|\sin\theta| \quad \text{for } Fr_L > 19.1$$

$$= 0.1160 \qquad \text{for } Fr_L \leqslant 19.1$$

and for a slot jet,

$$P = 2A$$

$$\alpha = 0.198$$

Here U is the net velocity in the plume relative to the ambient velocity; the absolute value is used here to account for both the ascending and descending parts of the plume.

In the literature on buoyant jets, various investigators employing the integral approach have devised differing entrainment functions. A recent survey for the round jet can be found in Wright (1977). The entrainment function expressed in equation (2.36) and incorporated in the present model is but one possible expression. Should a different form be shown to be superior in the future, the model can readily be modified.

2.3 Merging Process

The individual plumes from the multiple cells of a cooling tower typically merge within a relatively short distance from the exits. Before the plumes merge, equations for individual round buoyant jets are applied in this model to calculate the plume behavior. When several individual plumes are merged, the resulting plume cross-section is no longer round, but rather tends to be elliptical in shape. In this model, this merged plume is approximated by a slot jet in the central part and two half round jets at the two ends of the merged plume as shown by the solid lines in Figure 2.3. The nonuniform size of the plume is due to the effect of the wind direction with respect to the tower configuration. In general, it is necessary to consider all types of plume merging including all the possible combinations between individual round plumes and modified merged plumes as shown in Figure 2.4. The basic merging criterion considered here is that the plume cross-sections are in contact with each other. An additional criterion is incorporated for the merging between two individual round plumes: the area of the trapezoid should be equal to the sum of the areas of the two half round plumes as circled by the dashed lines in Figure 2.3. When the plumes satisfy these merging criteria, they are merged. The fluxes of the merged plumes are summed to maintain the conservation of fluxes. Moreover, the new shape and the new centroids of the merged plumes are determined, and the integration of the equations is continued. Upon merging, the entrainment and drag functions are altered due to the change in plume shape. The merged plume shape is characterized by the radii B1 and B2 of the two half round plumes, length of the slot jet A, and the angle ϕ (shown in Figure 2.3) between the centerline of the (inclined) plume cross-section and the horizontal line parallel to the y-axis. As the plumes merge a new set of B1, B2, A and ϕ should be determined in order to calculate the entrainment and drag and to check if any other new plume merging occurred. To determine B1, B2, A and ϕ the plumes are classified into two categories: one will be called horizontal for which the total width (WD) of the new merged plume is larger than the total

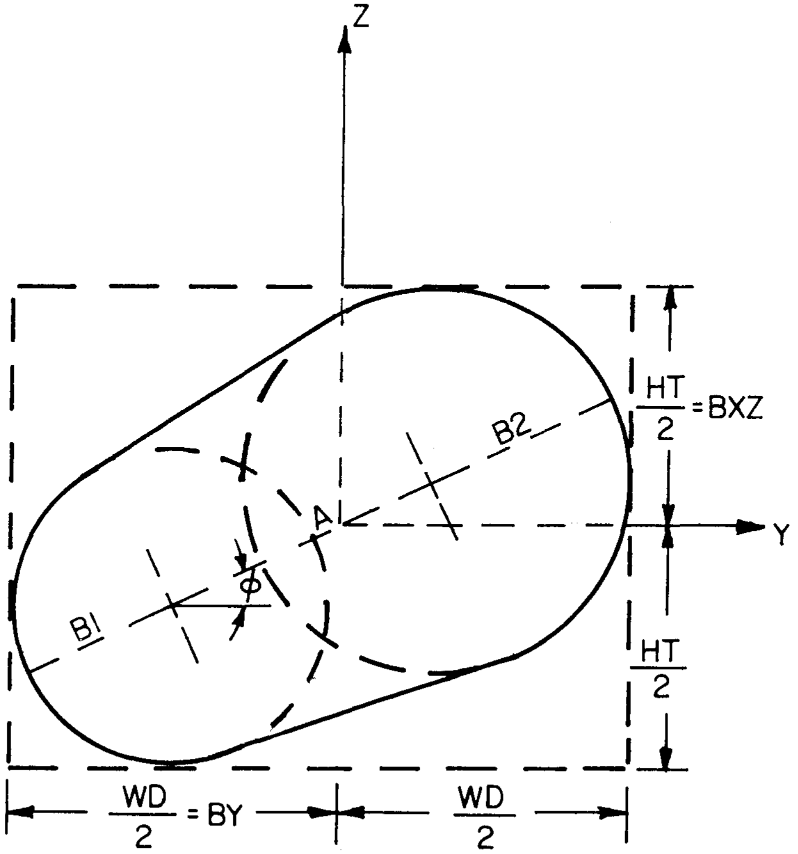


Figure 2.3 Merged Plume Shape

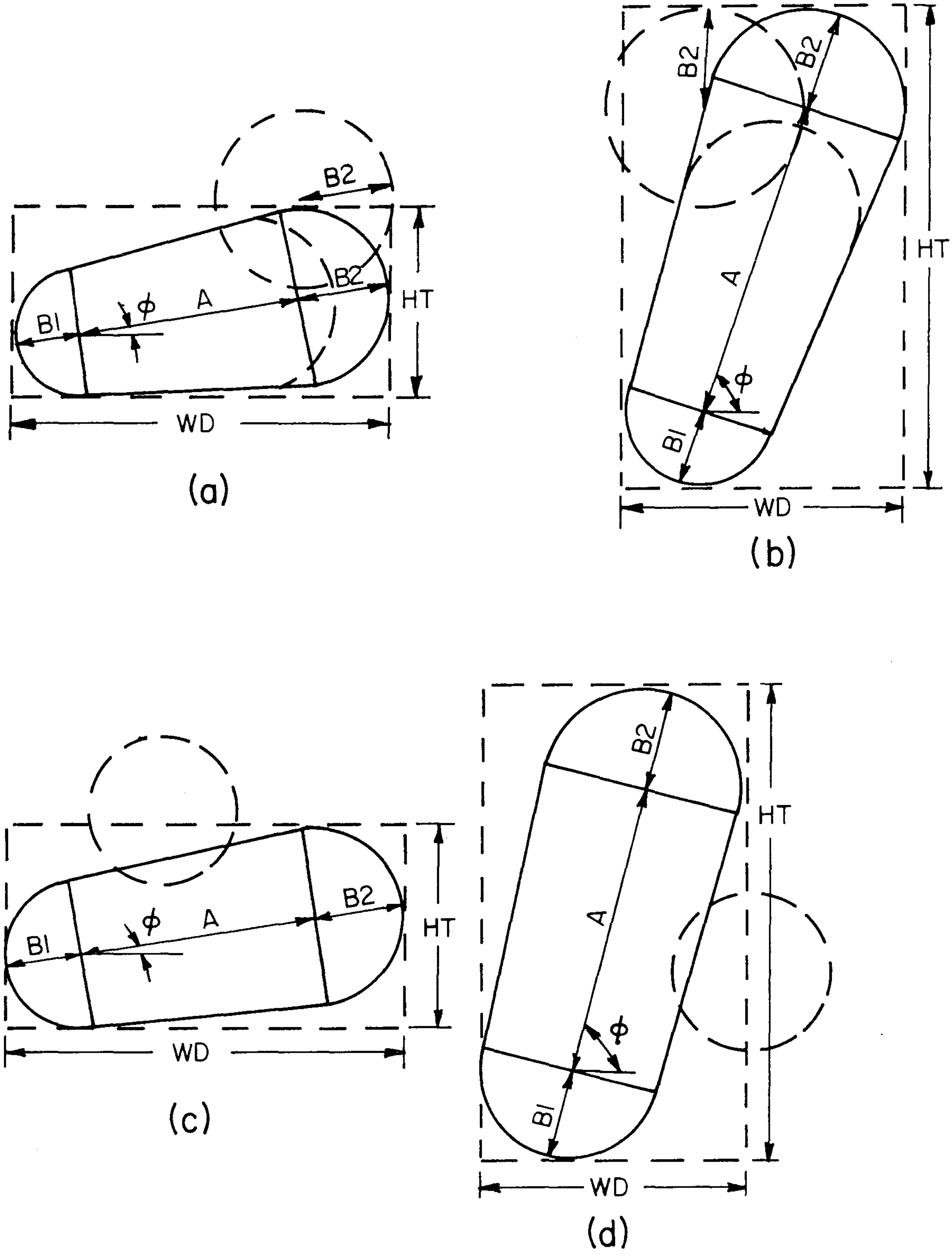
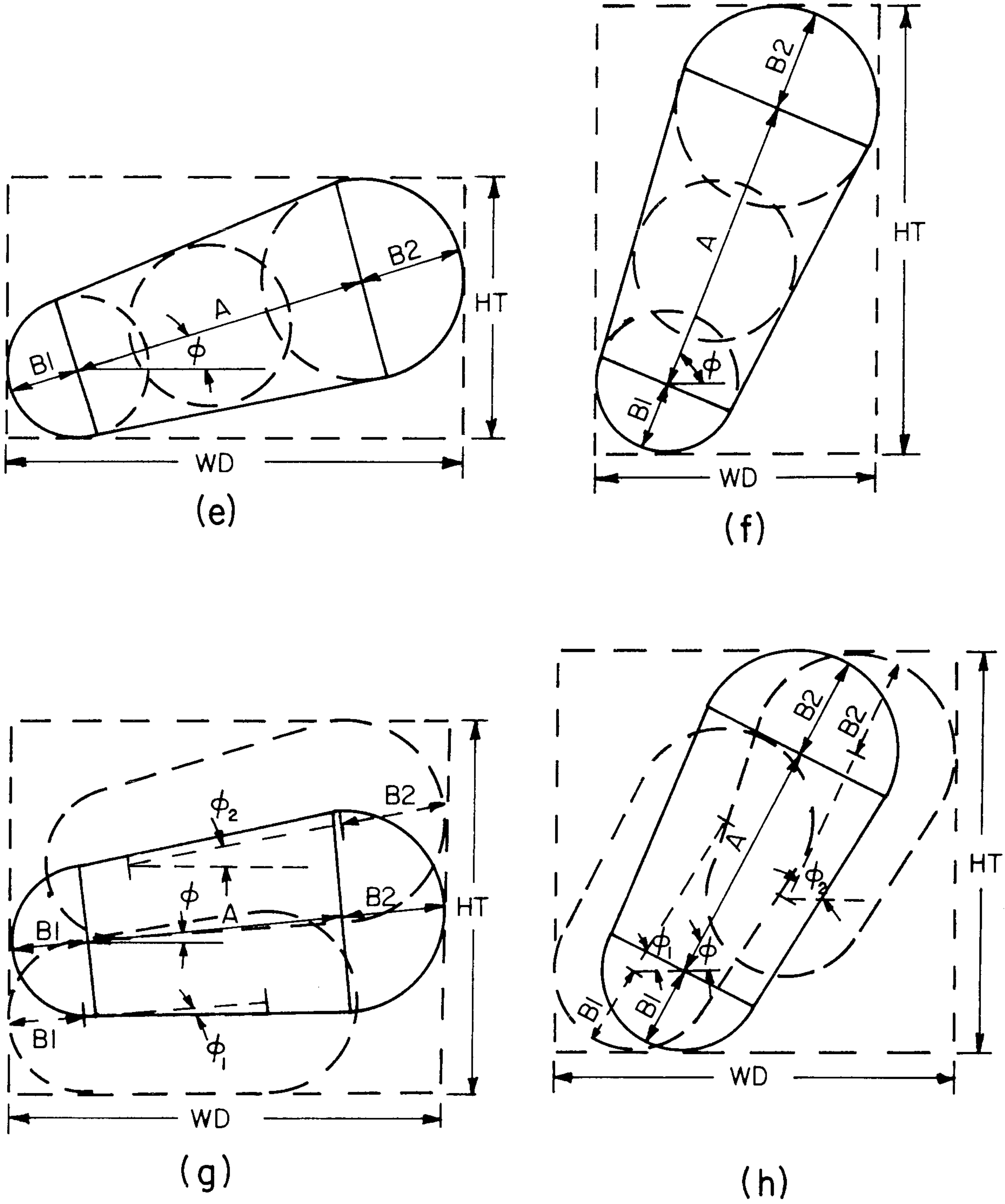


Figure 2.4 Definition Sketch



(e) (f) (g) (h)

Figure 2.4 Definition Sketch

height (HT), otherwise, it will be called vertical. Both types are illustrated by Figures 2.4(a), (c) and (e); and (b), (d) and (f), respectively. These two categories are not different in substance and the distinction is made primarily for coding convenience in the computer program. B1 and B2 are chosen to be the radii of the left end (or lowest end) and the right end (or highest end) of the horizontal (or vertical) plumes, respectively. The left end of the plume is the end closer to the x-axis. For the cases of merging among individual round plumes as shown by Figure 2.4(a) and (b), ϕ is the angle between the horizontal line and the line connecting the two centers of the merged ending plumes. For the cases of merging between merged plumes, ϕ is the average of angles ϕ_1 and ϕ_2 of the merging plumes 1 and 2, respectively, as shown in Figures 2.4(c) and (d). For the cases of individual round plume 2 joining the merged plume 1 as shown in Figures 2.4(e), (f), (g) and (h), ϕ is assumed to maintain the original value of the merged plume 2 since the resulting merged plume is envisioned to be dominated by the merged plume 2. After B1, B2 and ϕ are determined, A can be calculated by the following equations.

For horizontal plumes:

$$A = (WD-B1-B2)/\cos\phi \qquad \text{for } \cos\phi \neq 0$$

$$A = HT-B1-B2 \qquad \text{for } \cos\phi = 0$$

For vertical plumes:

$$A = (HT-B1-B2)/\sin\phi \qquad \text{for } \sin\phi \neq 0$$

$$A = WD-B1-B2 \qquad \text{for } \sin\phi = 0 \tag{2.37}$$

When the new shape of the merged plume is determined, then the calculation can be performed forward one integration step for the round jets at the ends and the slot jet (with unit fluxes found by dividing the total fluxes of the slot jet by the finite length A) in the central part. This will result in new values for the radii of the round jets at the ends of the merged plumes, b_{r1} and b_{r2} and the half width and length of the central part slot jet b_s and a. Because of the different entrainment rates for round and slot jets, the calculated plume cross-section determined by b_{r1}, b_{r2}, b_s and a may not be smooth enough to represent a realistic shape. The discontinuities occurring at the junctions of the round and slot jets are demonstrated by the dashed line curve in Figure 2.5. In order to eliminate the discontinuity and to obtain a modified smooth plume cross-section described by B1, B2, and A, the following set of equations is proposed:

$$0.5\pi\ (b_{r1}^2\ U_{r1} + b_{r2}^2\ U_{r2}) + 2b_s a U_s = [0.5\pi\ (B1^2 + B2^2) + A\ (B1 + B2)] \cdot U \tag{2.38}$$

$$a + b_{r1} + b_{r2} = A + B1 + B2 \tag{2.39}$$

$$B1/B2 = b_{r1}/b_{r2} \tag{2.40}$$

where U_{r1}, U_{r2}, U_s and U are the plume velocities corresponding to the half round jets with radii b_{r1} and b_{r2}, the slot jet with half width b_s, and the overall merged plume defined by B1, B2 and A, respectively.

Equation (2.38) describes the redistribution of the volume flux from the calculated merged plume to the proposed modified plume. Equation (2.39) maintains the same plume length between the calculated and modified plumes. Equation (2.40) keeps the same ratios of the radii of the two half round plumes between calculated and modified plumes.

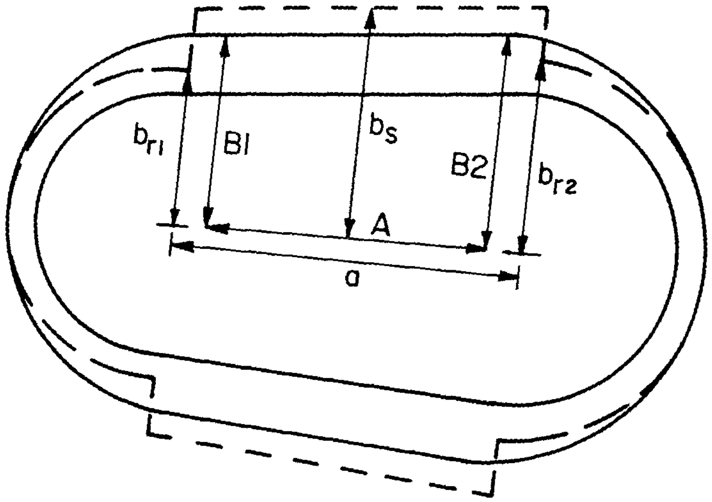


Figure 2.5 Modified Merged Plume Shape

After the modified plume shape is determined, the half width, BY and the half height, BXZ of the merged plume, indicated in Figure 2.3, can be determined by the following equations for the purpose of checking plume merging at the next step:

$$
\begin{aligned}
BY &= 0.5\times (A \cdot \cos\phi + B1 + B2) && \text{for } \cos\phi \neq 0 \\
&= B1 && \text{for } \cos\phi = 0 \text{ and } B1 \geq B2 \\
&= B2 && \text{for } \cos\phi = 0 \text{ and } B2 > B1 \\
BXZ &= 0.5\times (A \cdot \sin\phi + B1 + B2) && \text{for } \sin\phi \neq 0 \\
&= B1 && \text{for } \sin\phi = 0 \text{ and } B1 \geq B2 \\
&= B2 && \text{for } \sin\phi = 0 \text{ and } B2 > B1
\end{aligned}
\tag{2.41}
$$

Due to the uneven change of B1, B2 and A for each integration step, the y-coordinate of the plume centroid also needs to be readjusted. The amount of adjustment Δy noted in Figure 2.6 is

$$
\begin{aligned}
\Delta y &= \left[\frac{A_j + B1_j + B2_j}{2} \times \frac{A_{j+1}}{A_j} + B2_{j+1} - \frac{A_{j+1} + B1_{j+1} + B2_{j+1}}{2} \right] \cdot |\cos\phi| \\
&= 0.5\times|\cos\phi|\times \left[(B1_j - B2_j) \times \frac{A_{j+1}}{A_j} + B2_{j+1} - B1_{j+1} \right]
\end{aligned}
$$

where j and j+1 refer to the calculation steps.

With the modified merged plume cross-sectional shape, the entrainment and drag force can be determined and the conservation equations integrated. During the calculation, barring further merging, the length of the slot jet A generally will be reduced and the radii of the two ending round plumes will be increased. Finally, when A diminishes to zero, the shape of the merged plume cross-section becomes practically

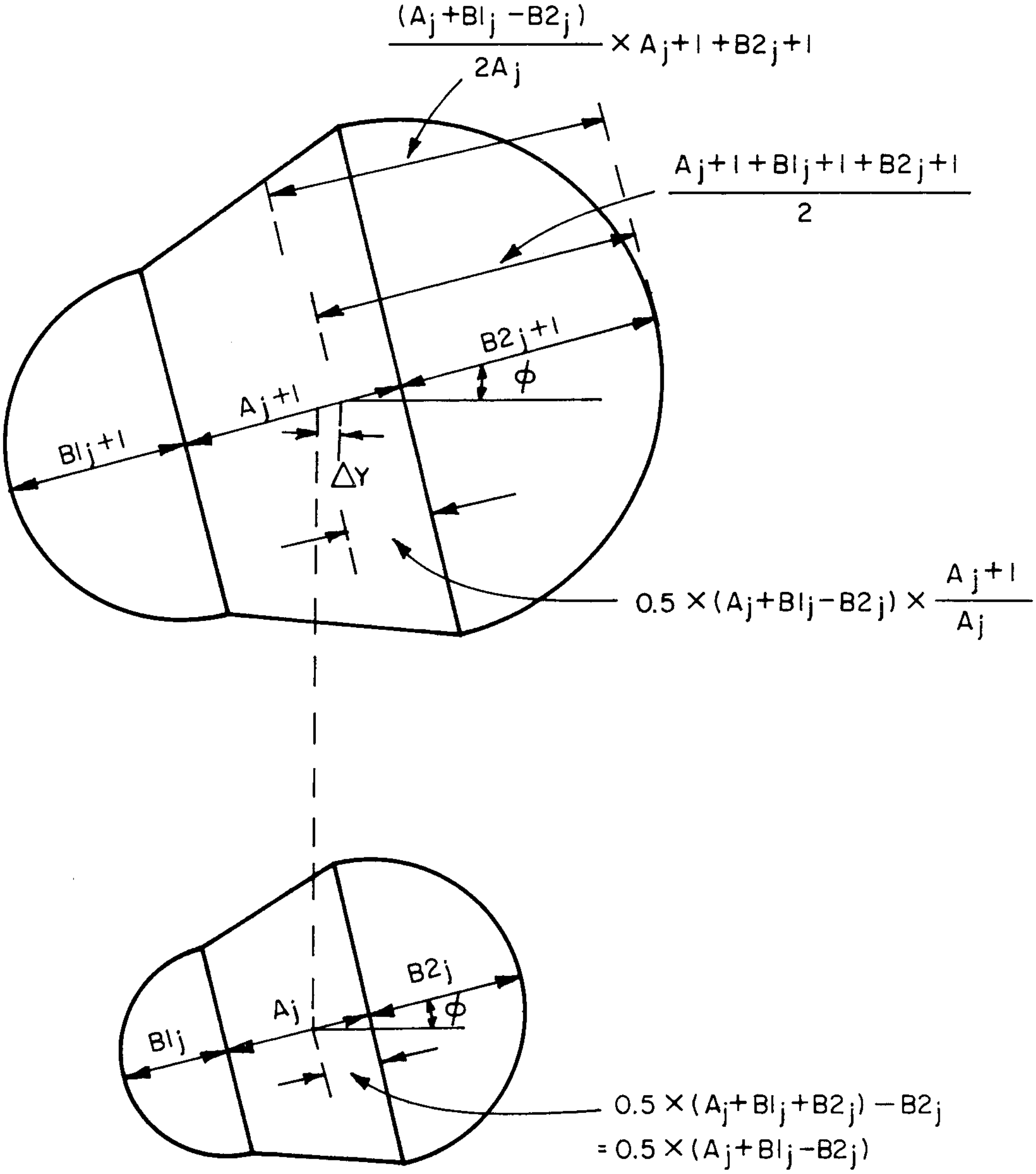


Figure 2.6 Correction of Δy for the Merged Plume

round. At that point, a round plume is again adopted to carry through the final stage of plume calculation.

CHAPTER 3

COMPUTER PROGRAM

The governing equations for predicting the dynamic behavior of multiple cooling tower plumes were presented in Chapter 2. No analytical solution can be obtained due to their complexity as well as the arbitrary ambient conditions in the governing equations. Therefore, a computer program written in Fortran IV language was developed to solve these equations. A standard fourth order Runge-Kutta method was employed in the solution. The inputs to the program include tower exit conditions, ambient conditions, tower configuration, entrainment and drag coefficients, and some control parameters. The basic routine of the computer program begins with inputting data, setting initial conditions (subroutine SETIC) and calculating the first plume (from the tower with the smallest value of x) by setting an indicator IND(I) = 1 for i^{th} individual round plume (subroutines RUNGS and DERIVR). As the calculation continues, the subroutines CHKNWP, ALIGN and PLMERG are called to check for the appearance of any new plumes, to align the existing plumes at approximately the same x-coordinate, and to check for the merging among the existing plumes, respectively, along the direction of the plume trajectory. If new plumes appear (whenever x exceeds the x-location of downstream tower exits), the results for such new plumes are calculated stepwise until the stage is reached to necessitate the checking of the merging criterion. If the plumes merge, the indicator of the i^{th} and the j^{th} plumes are changed to IND(I) = 2 and IND(J) = 0 (J>I). In the subroutine RESETI, the fluxes of the merged plumes are added together, and the initial conditions for the merged plumes are reset. The subroutines DERIVR and DERIVS are called to calculate the plume half widths and velocities of the round and slot jets in order to determine the shape of the modified merged plume. Then, subroutine DERIVE is used to calculate the dynamic properties of the modified merged plume. The calculation stops when the integration step number is equal to the desired (input) step number. The outputs include the input information, and the calculated plume properties such as temperature, excess temperature, moisture, excess moisture, half width and trajectory at visible, merging and final stages of the plumes. The detailed listings and examples of the input and output are presented in Appendix A. The general structure of the computer program is described by the flow chart shown in Figure 3.1. Some important variables in the text and program are compiled and listed in Appendix B. The complete computer program is presented in Appendix C.

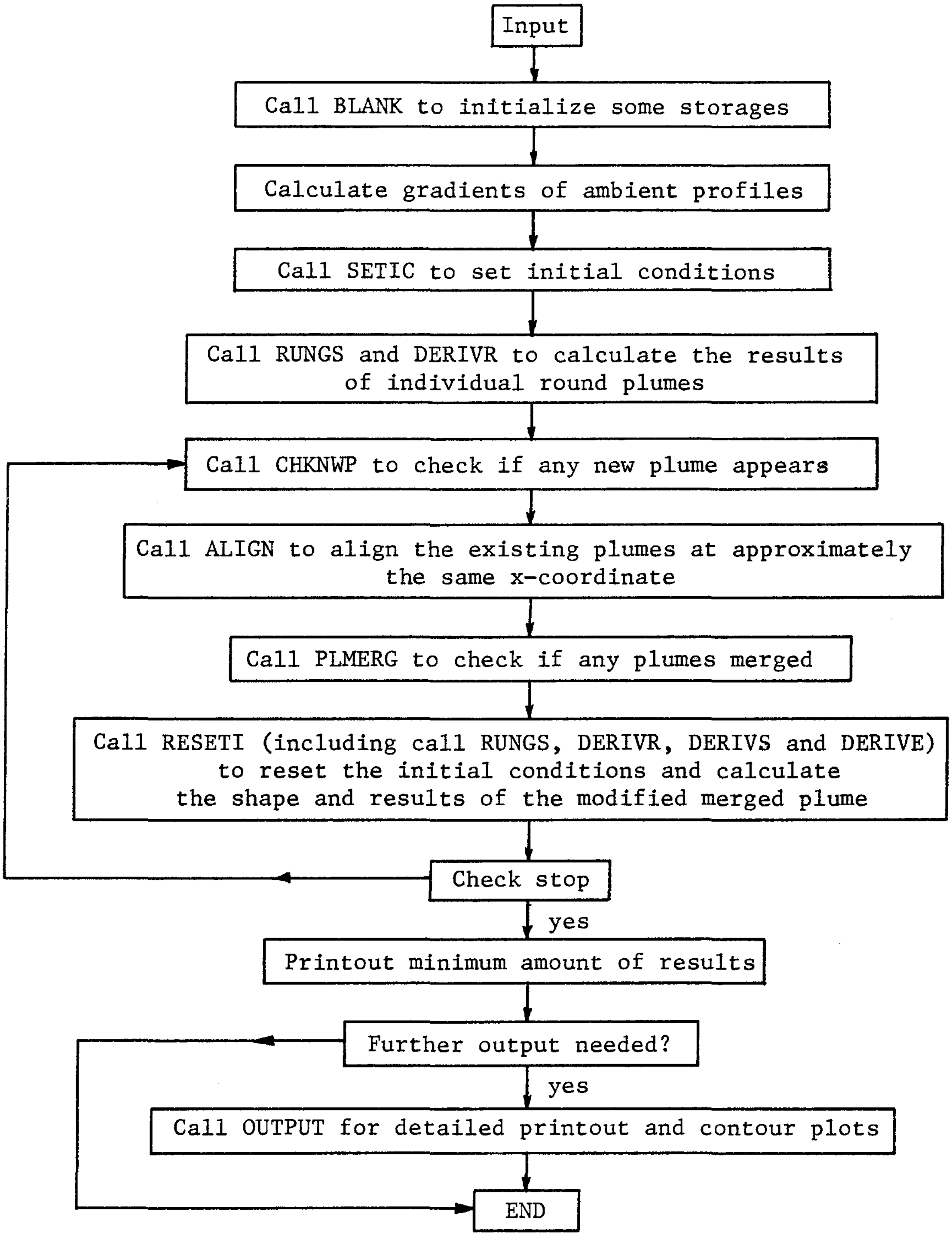


Figure 3.1 Flow Chart of the Computer Program

CHAPTER 4

RESULTS, COMPARISONS AND DISCUSSIONS

In this chapter, four example cases are presented. The results of the present theory are also compared with the laboratory results of Fan (1967), Chan et al. (1974), and field data from TVA (Carpenter et al., 1968).

In the example runs, a line array of four cooling towers and a round array of five cooling towers are considered. For the cases with the line array, three wind directions (i.e. 0°, 90°, and 135° with respect to the tower array) are chosen. The input data cards are shown in Table 4.1, which include the number of towers, the desired number of calculation steps, control parameters, tower configuration, ambient levels, temperature profile, humidity profile, wind velocity profile, tower exit conditions, coefficients of contour plots and heading of plots. Normally, the outputs consist only of the input information, the results at the merging points, and those at the beginning and ending points of the visible phases of plumes. However, detailed printouts and/or contour plots can also be provided by the program upon request. The contour plots of excess temperature, humidity and liquid phase moisture for these examples are shown in Figures 4.1 through 4.12. The plots represent the distribution of the highest values projected onto the X-Z plane. Detailed explanations of the input and output parameters are presented in Appendix A.

Three sets of data from Fan (1967) for a single jet, one set from Chan et al. (1974) for six towers and two sets from Carpenter et al. (1968) for a single tower and multiple towers are chosen for comparison with the model.

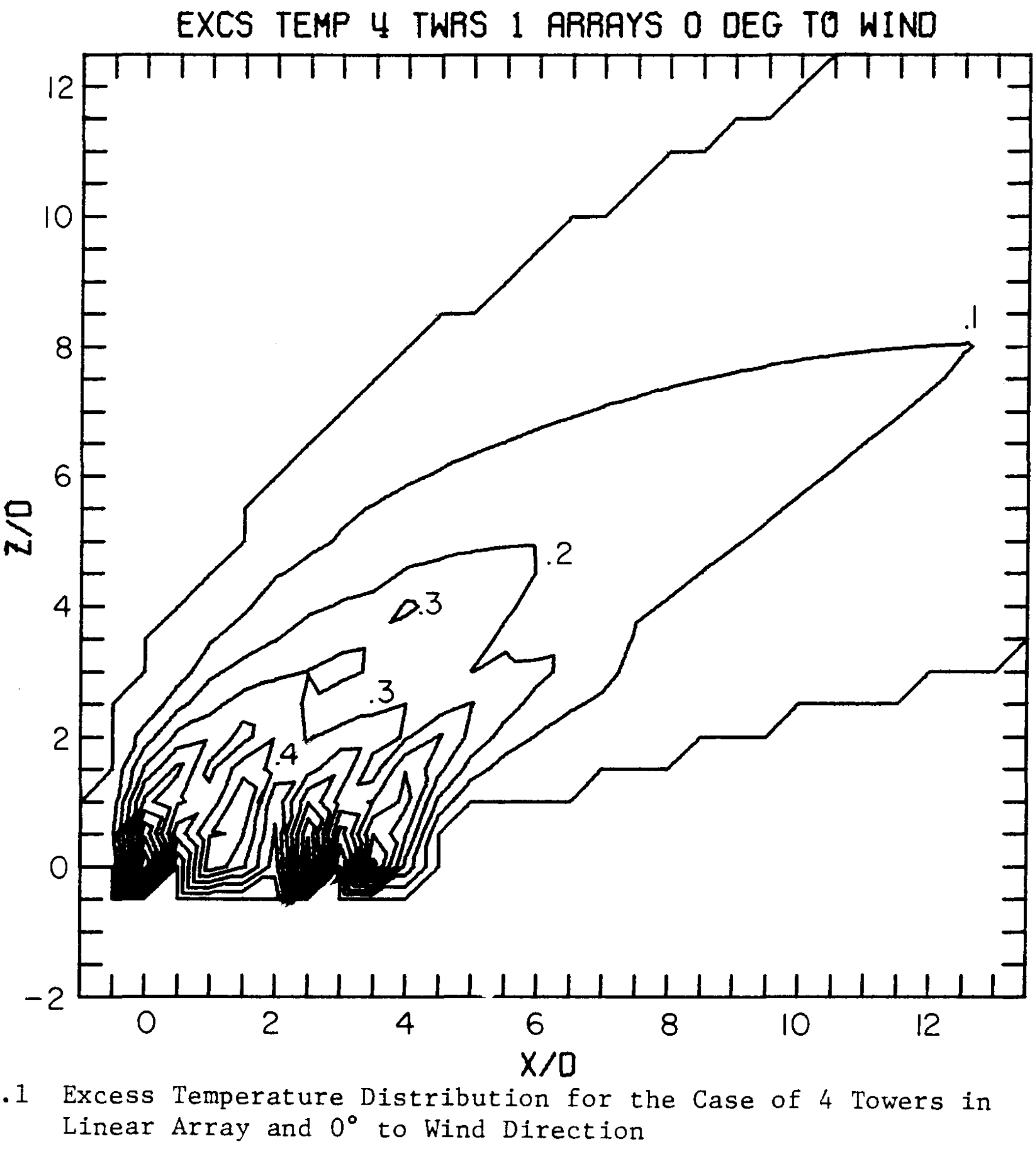


Figure 4.1 Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction

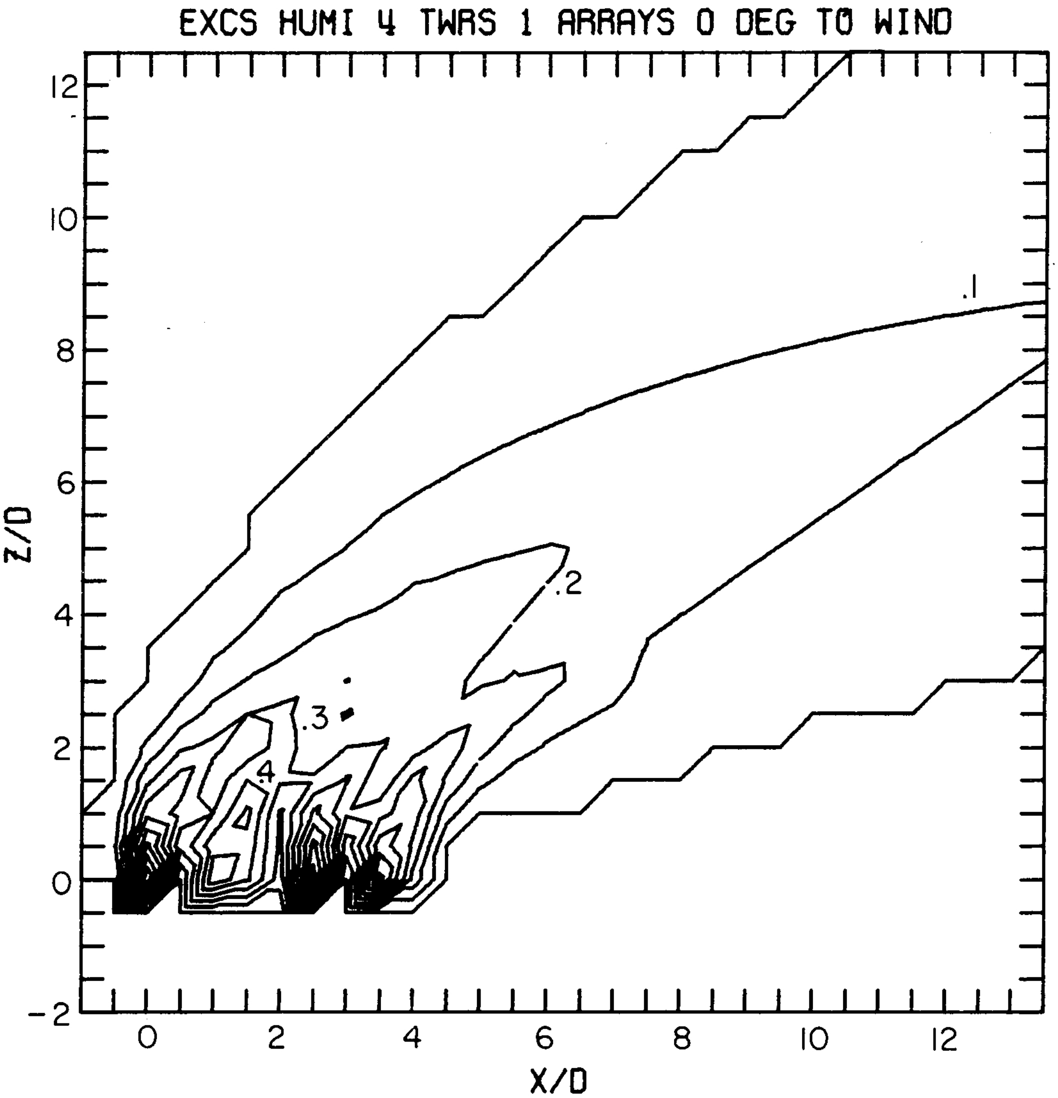


Figure 4.2 Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction

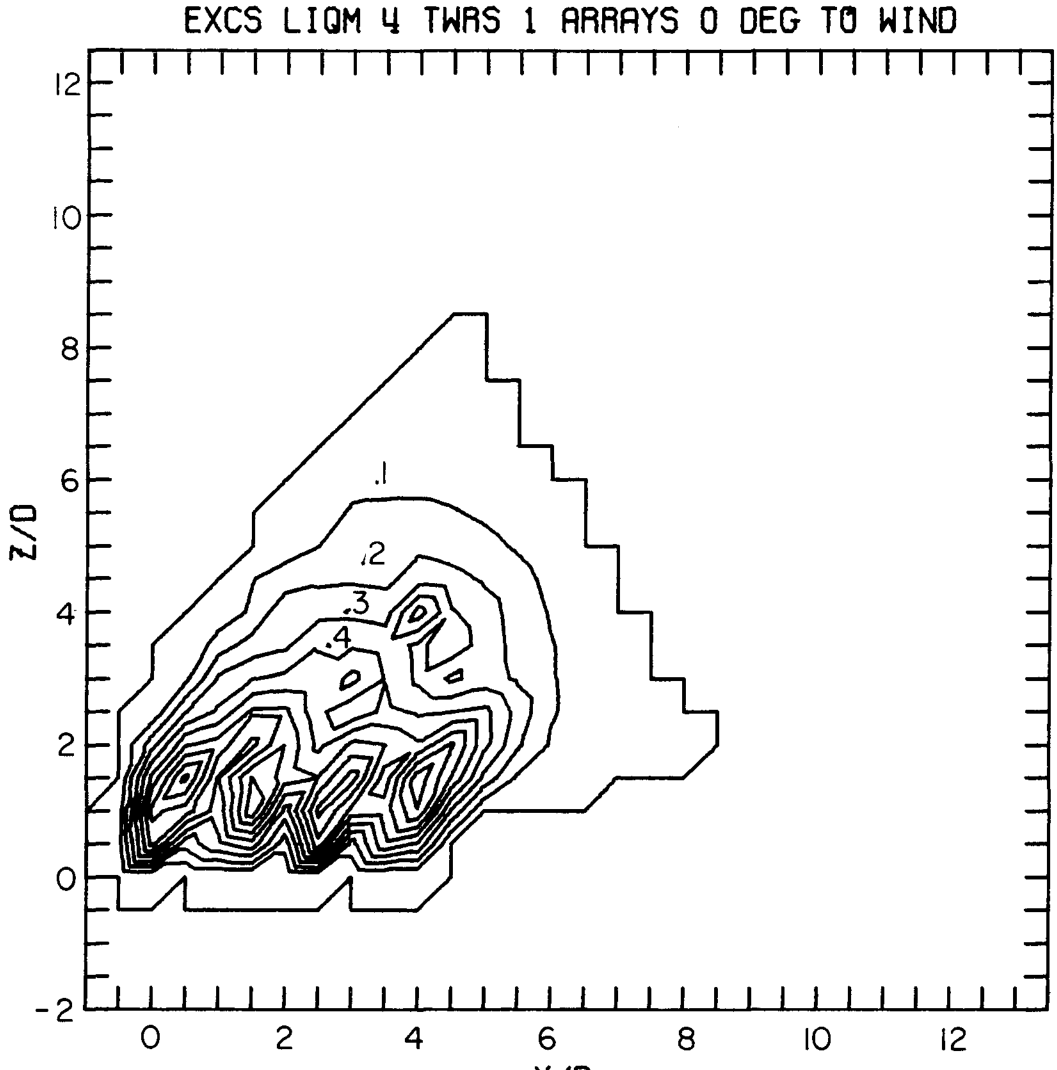


Figure 4.3 Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction

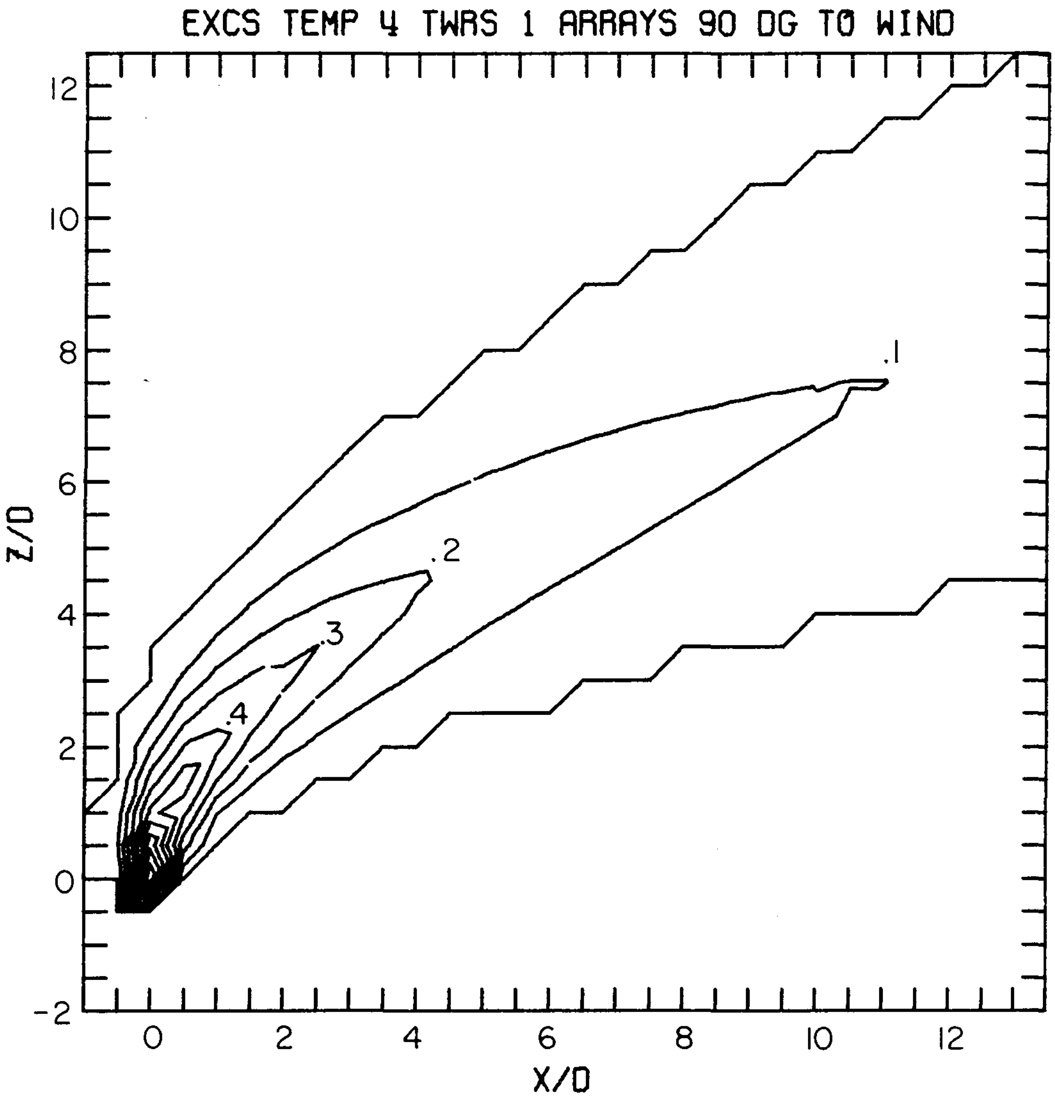


Figure 4.4 Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction

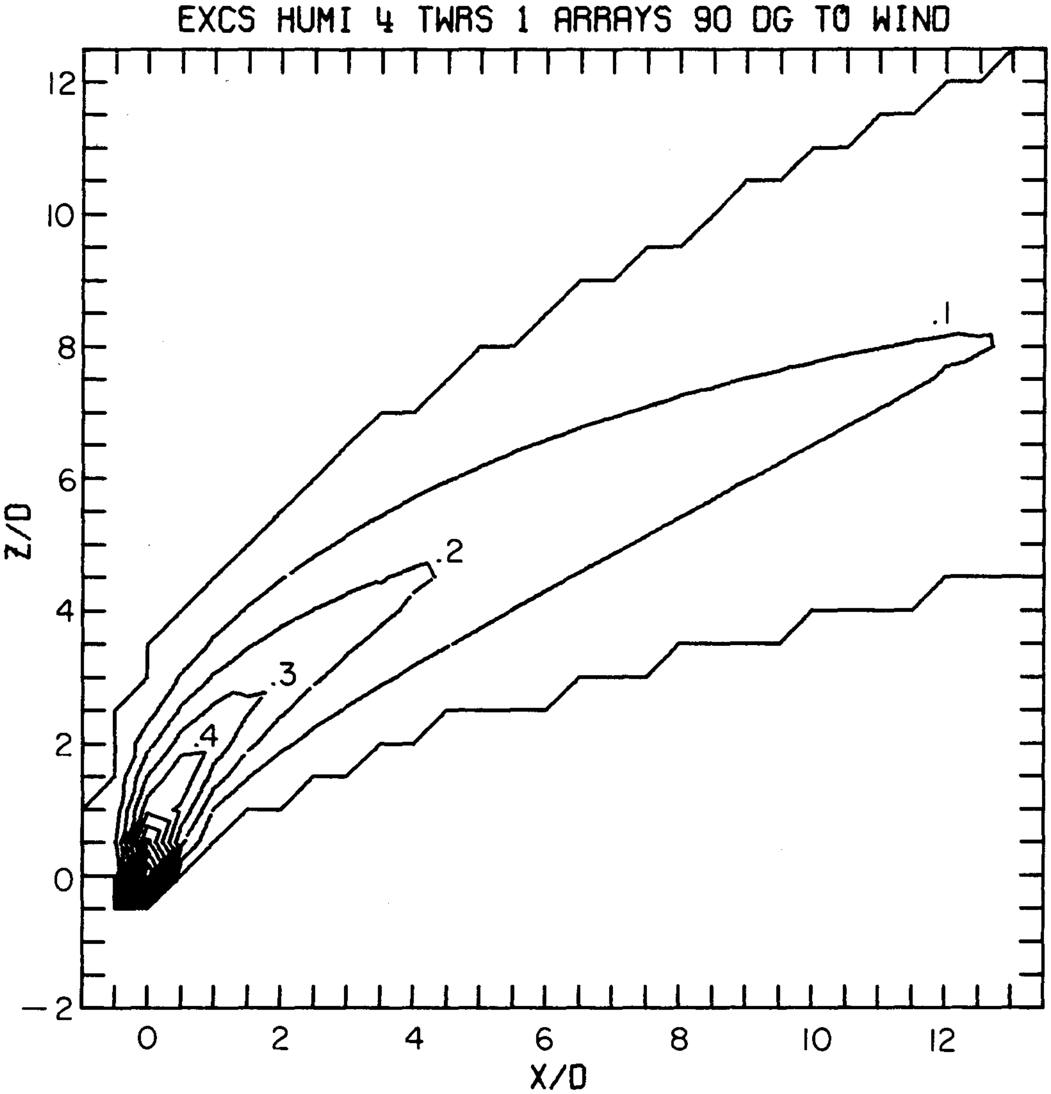


Figure 4.5 Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction

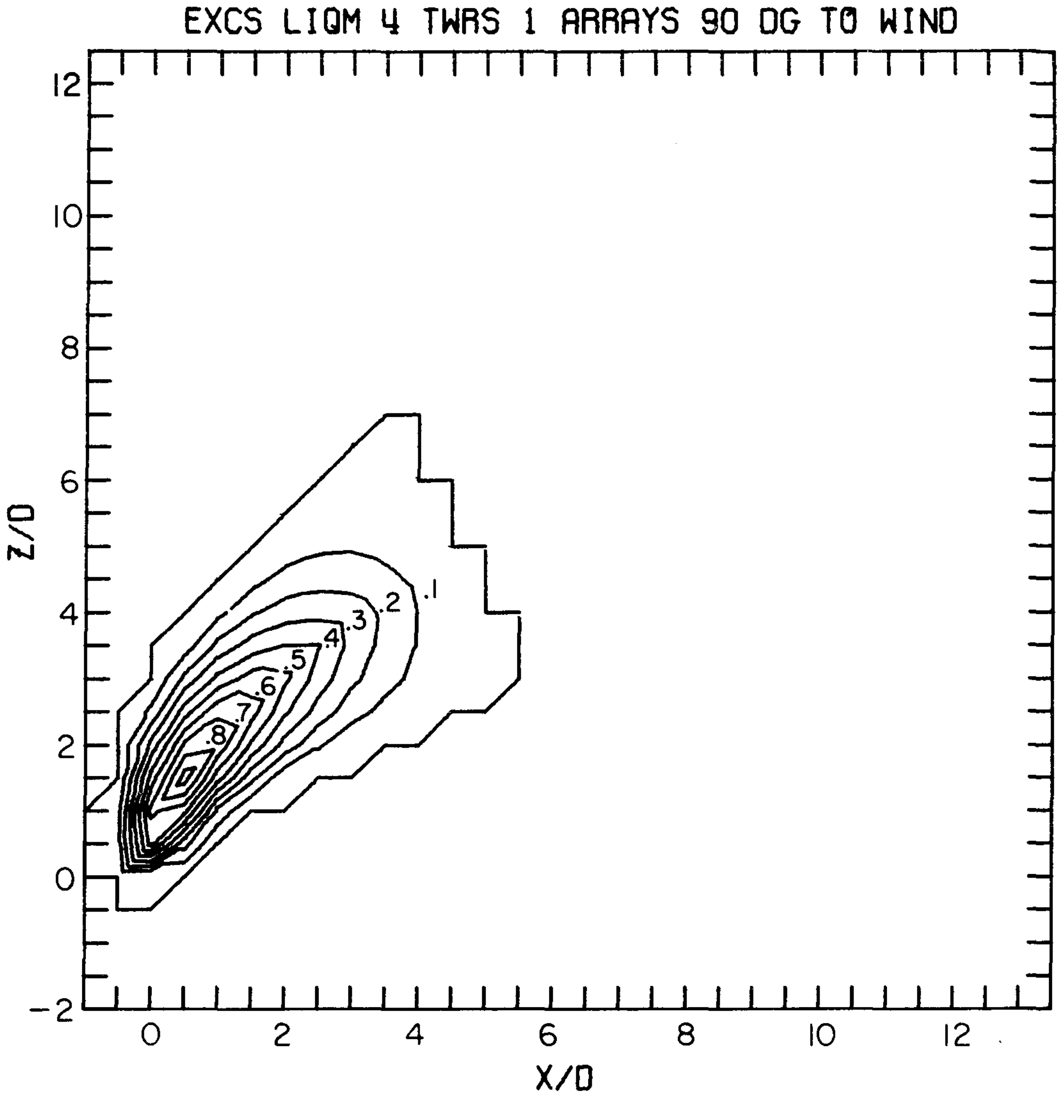


Figure 4.6 Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction

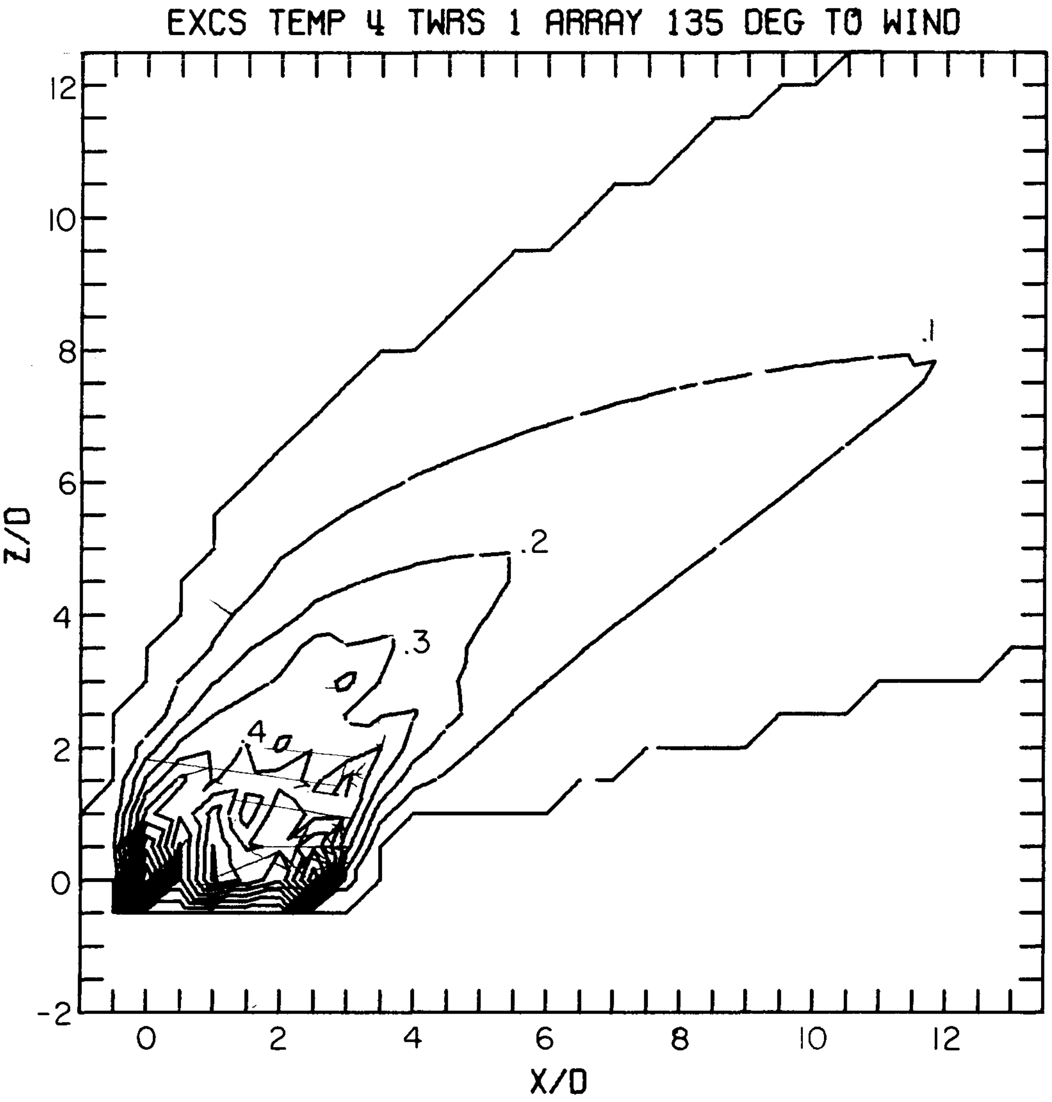


Figure 4.7 Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction

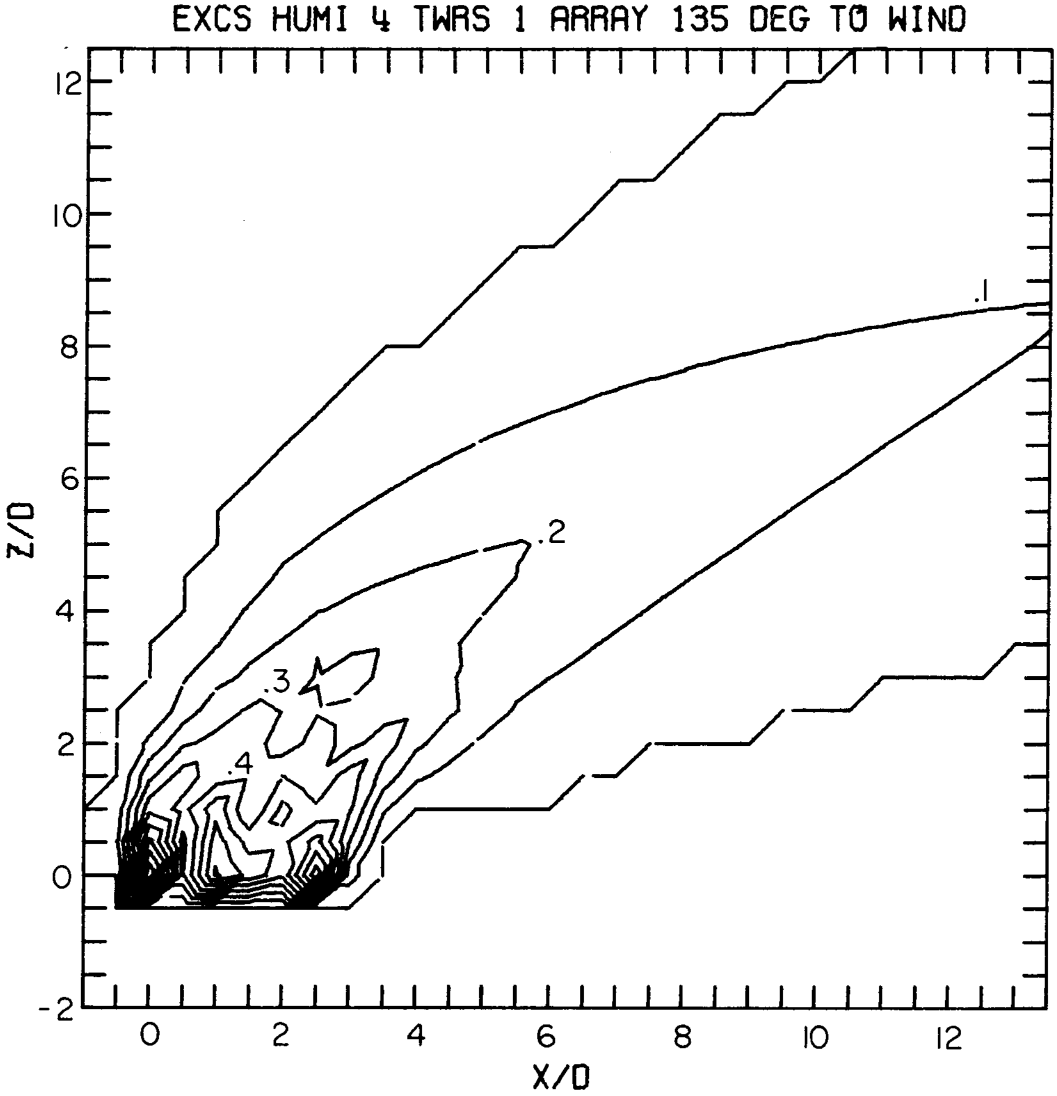


Figure 4.8 Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction

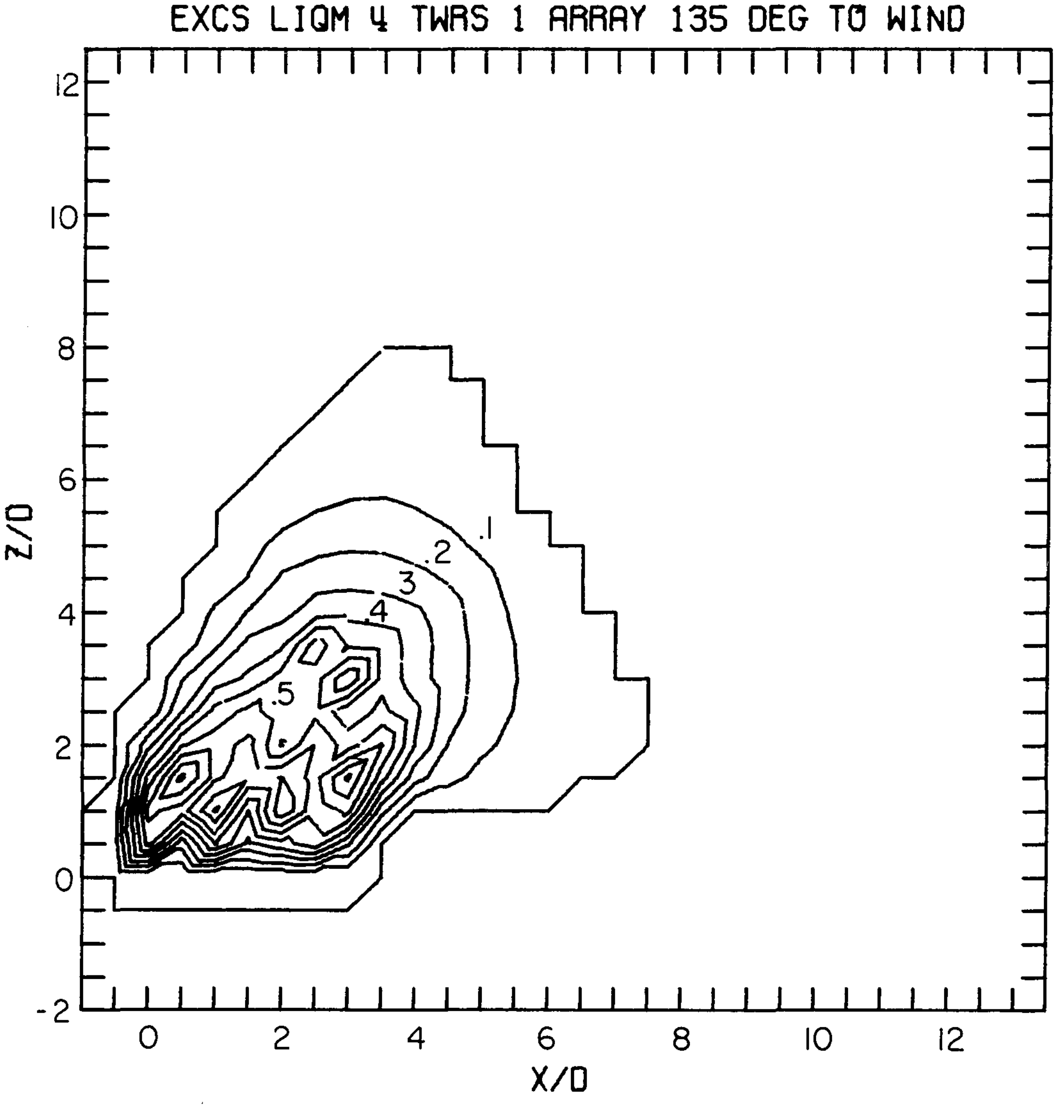


Figure 4.9 Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction

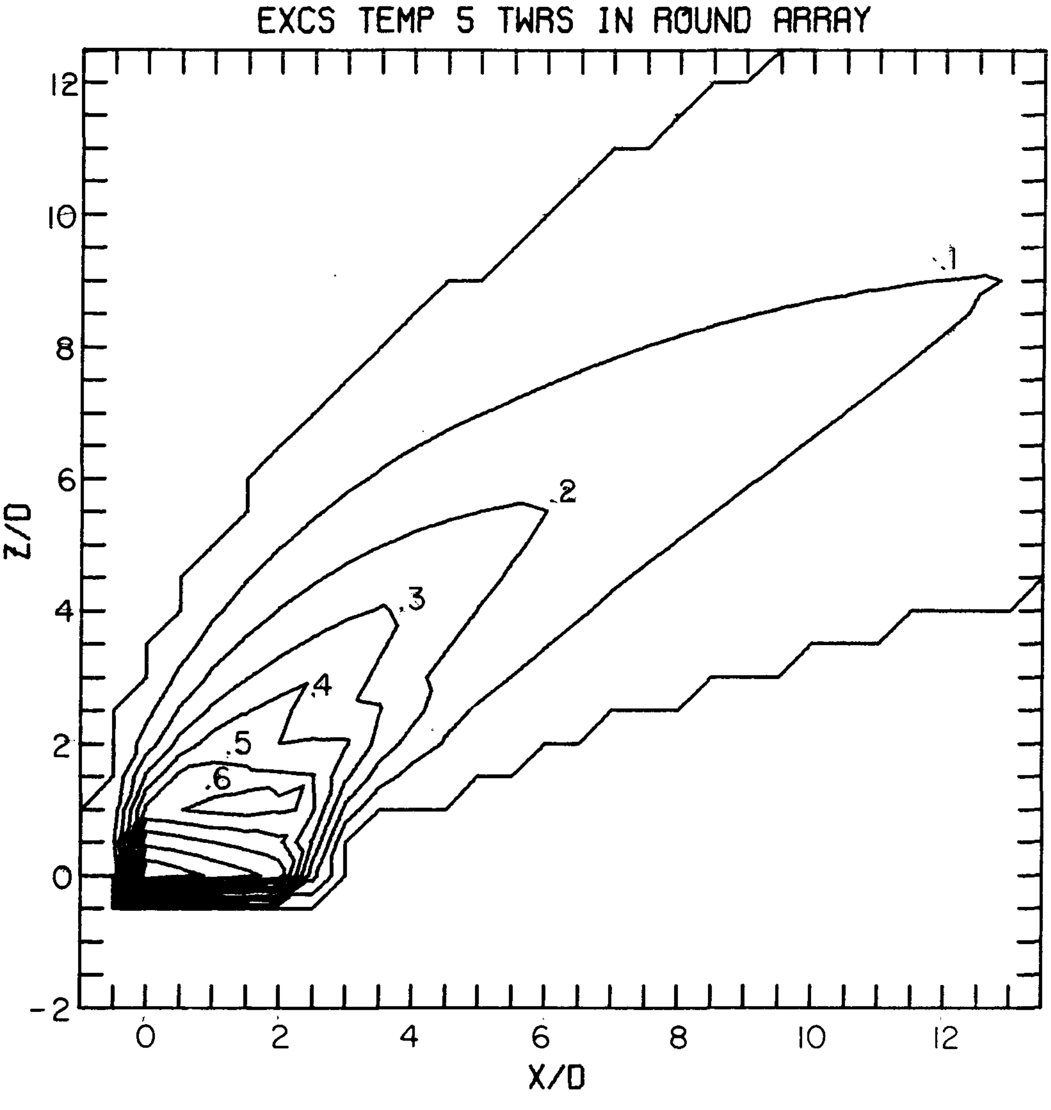


Figure 4.10 Excess Temperature Distribution for the Case of 5 Towers in Round Array

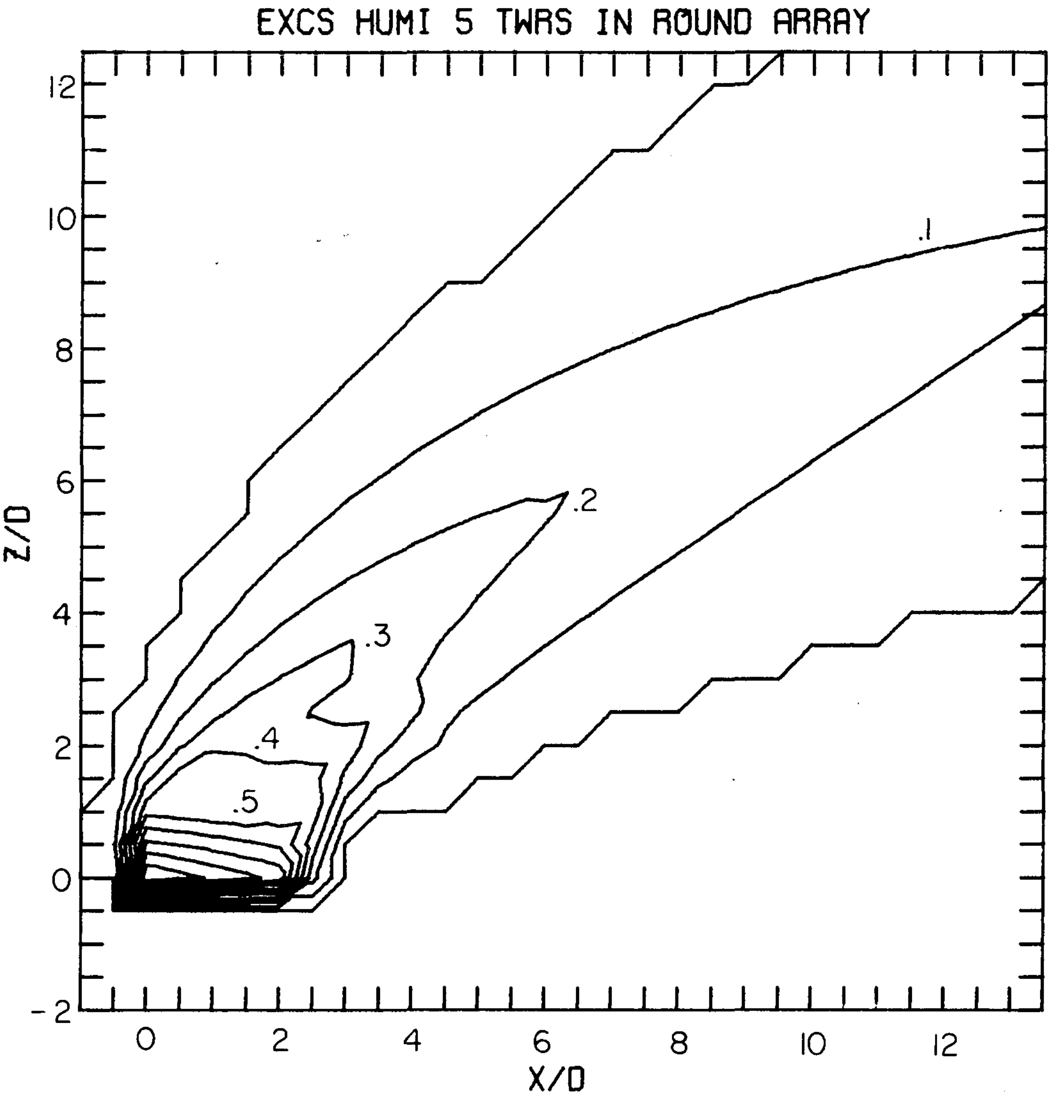


Figure 4.11 Excess Humidity Distribution for the Case of 5 Towers in Round Array

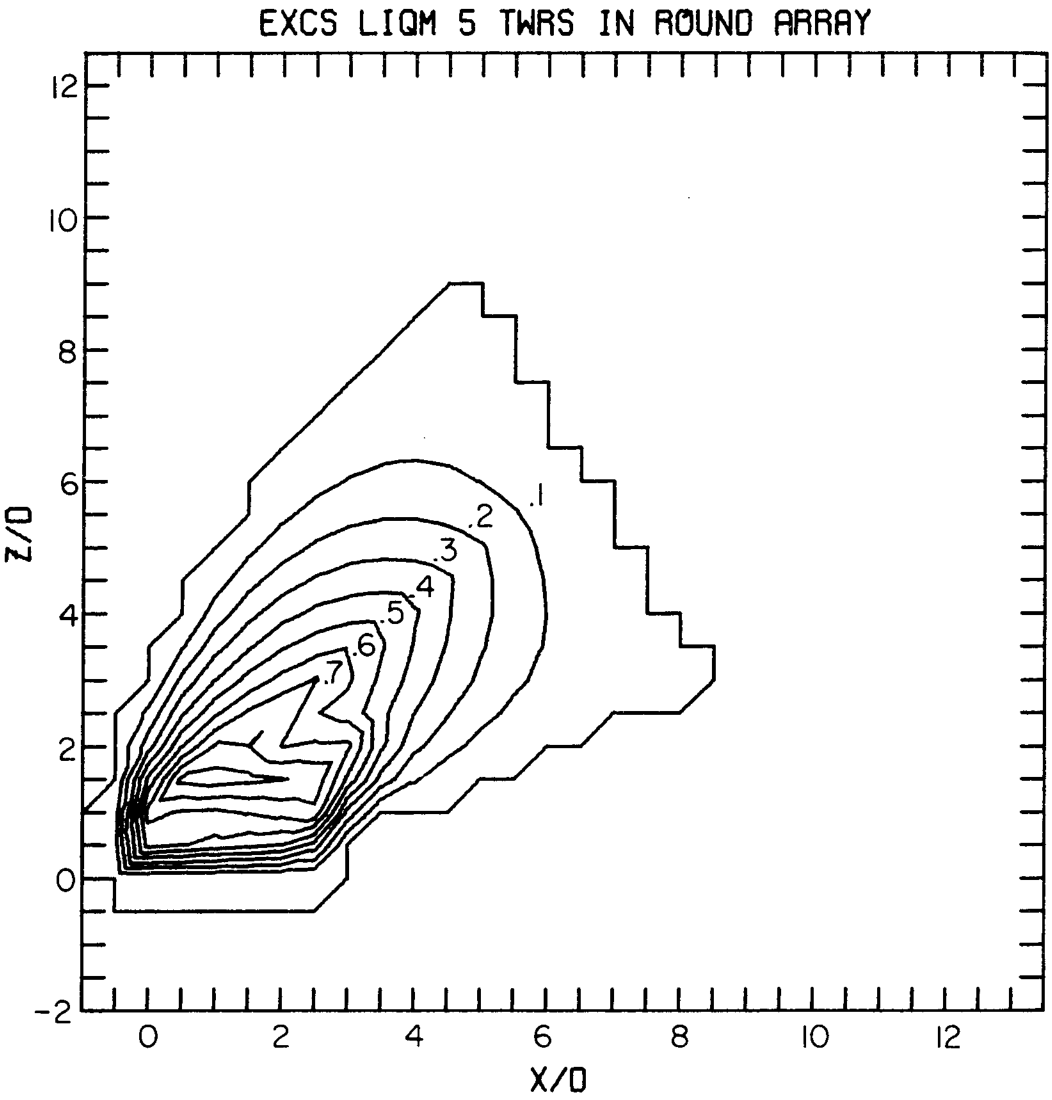
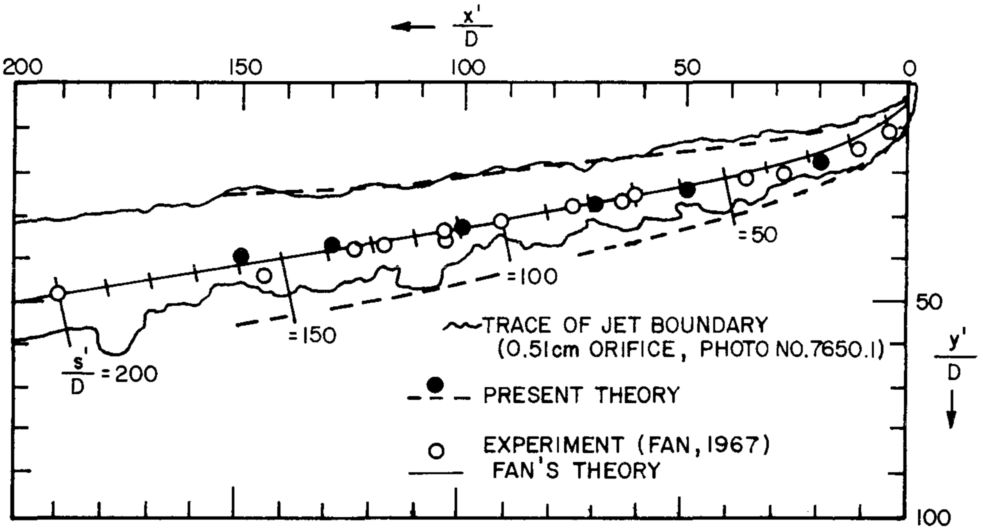


Figure 4.12 Excess Liquid Phase Moisture Distribution for the Case of 5 Towers in Round Array

The input data cards for these cases are shown in Tables 4.2 through 4.5. The ambient conditions for the data from Fan and Chan et al. are uniform. The velocity and temperature at the tower exit and ambient are chosen to satisfy the given values of densimetric Froude number F and velocity ratio K. The predicted results of dilution, plume trajectory and width for Fan's cases are shown in Figures 4.13, 4.14 and 4.15, and are compared with his experimental results. The comparisons are generally good. The predicted excess temperature distribution for the six tower case from Chan et al. is shown in Figure 4.16, together with the experimental results. In this case the six towers are in one line array and the ambient flow to it is normal. The contour plot is for the distribution of values in the central x-z plane. It seems that the present model tends to overpredict the excess temperature. The main reason might be because of the neglect of the effect of the mixing in the plume wake zone in the present model. However it should also be noted that the experimental results of Chan et al. may have been influenced by the blockage of the flow by the model towers due to the finite width of the experimental flume.

The field results from TVA at the Paradise power plant include two cases. One is for a single tower in a stable ambient (TVA-11, potential temperature gradient $\frac{\partial\theta}{\partial z} = 0.59$ °k/100m, $0 < \frac{\partial\theta}{\partial z} \leqslant 1.0$ °k/m). The other is for two towers in an ambient with a temperature inversion (TVA-14, $\frac{\partial\theta}{\partial z} = 1.42$ °k/100m > 1.0 °k/m). Since only the average temperature gradient and average wind velocities at a few levels were available only rough estimates of ambient temperature and wind velocity profiles were constructed based on the limited data.



F=20 k=8 60(d)

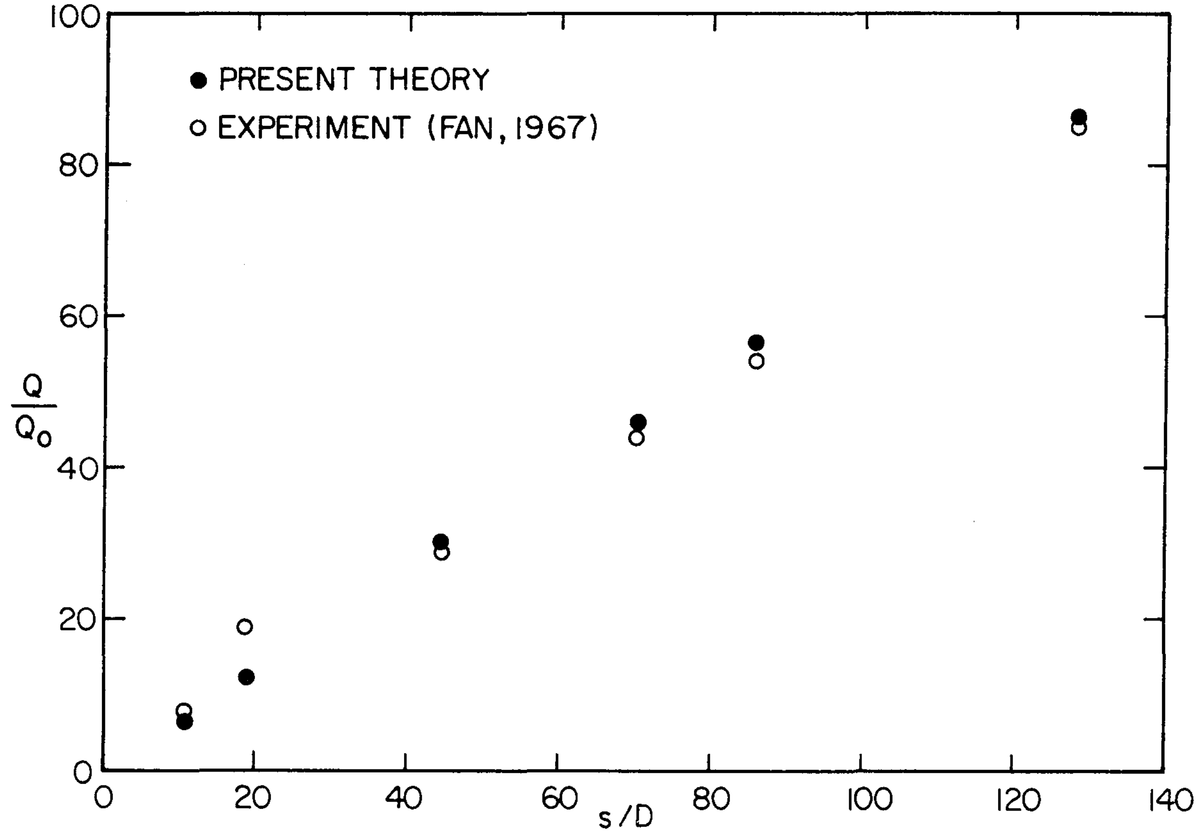


Figure 4.13 Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for F = 20 and K = 8

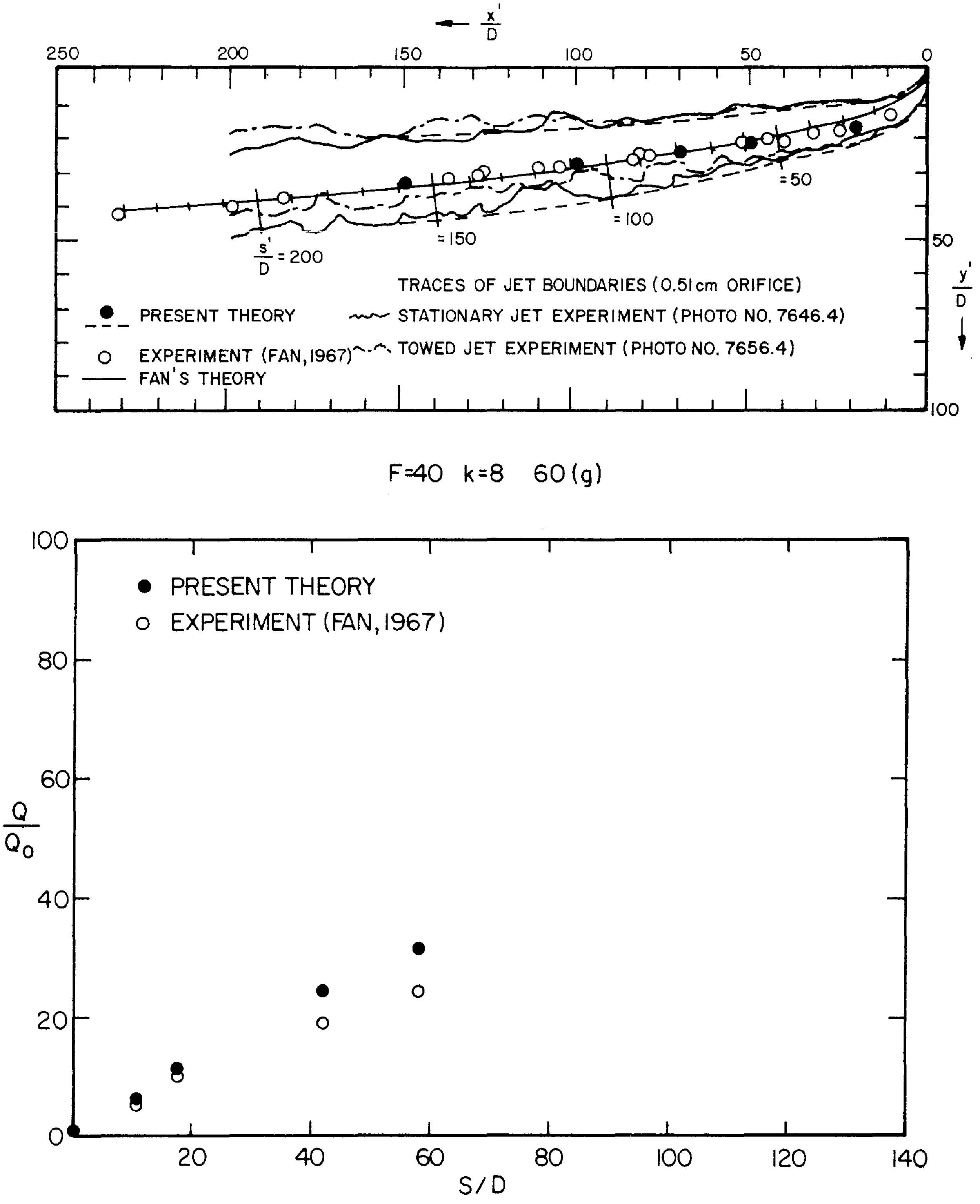


Figure 4.14 Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for F = 40 and K = 8

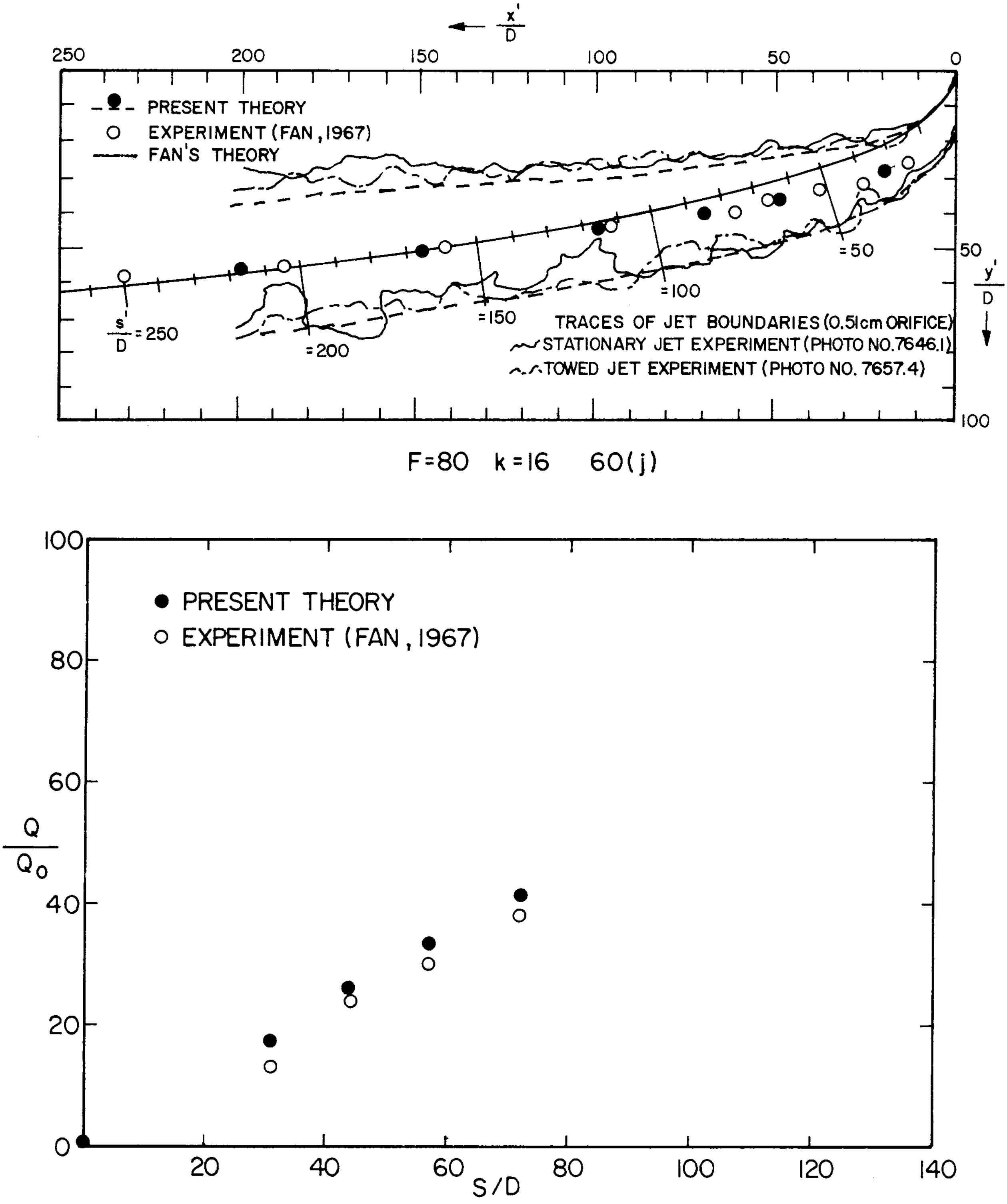


Figure 4.15 Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for F = 80 and k = 16

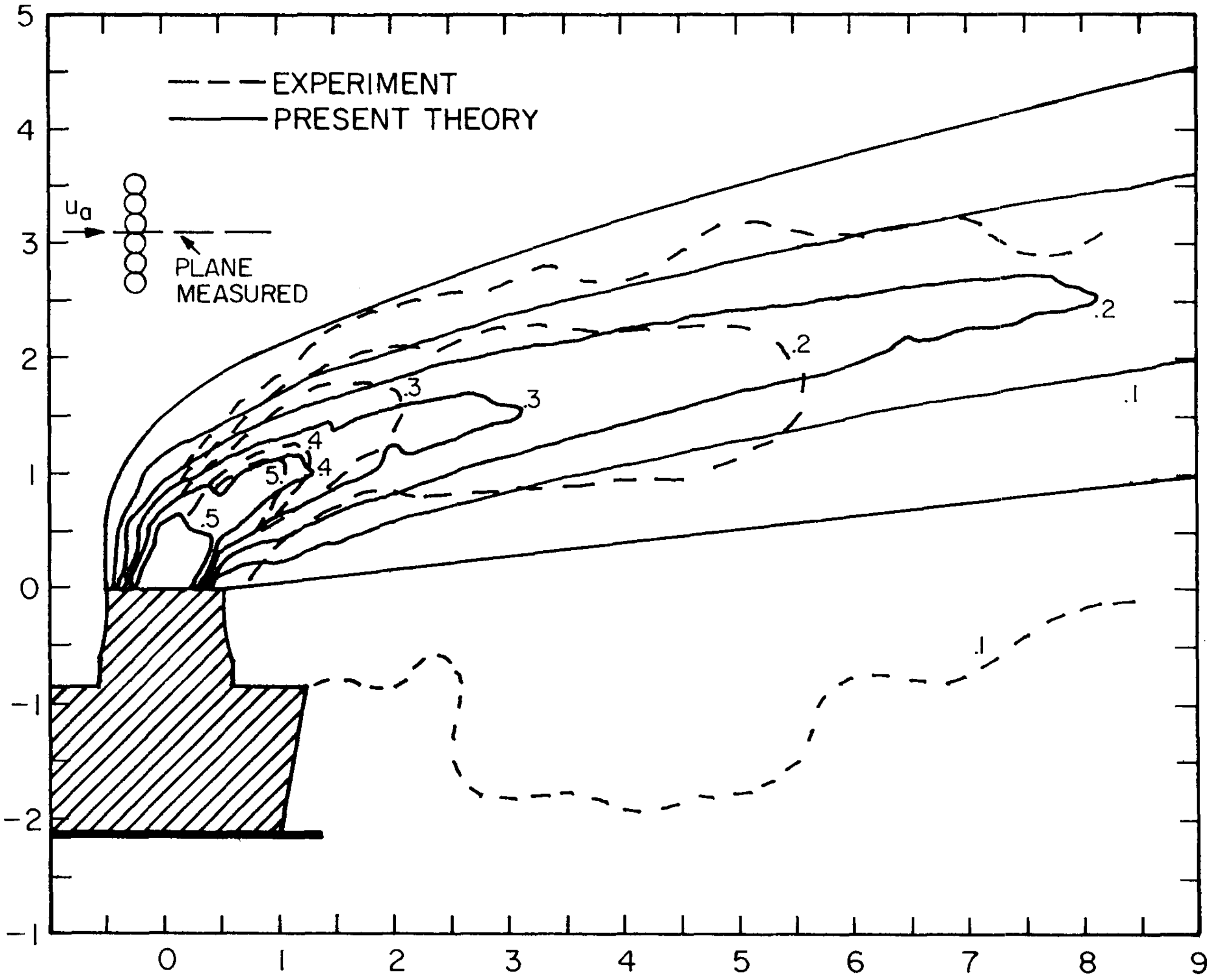


Figure 4.16 Comparisons of Plume Excess Temperature Between the Present Theory and Chan et al.'s (1974) Experiments for F = 4 and K = 1.02

Three ambient relative humidity profiles (100%, 70%, 0%) associated with the relative temperature profiles were generated and tested. The exit plume humidities were assumed 100% (saturated) except for one dry plume case which is 0% for ambient and exit humidities. The input data cards are presented in Tables 4.4 and 4.5. The predicted results and the comparisons are shown in Figures 4.17 and 4.18. From the variations of plume trajectory for different ambient humidity conditions, the effect of the ambient humidity can be seen to be quite significant. Similar conclusions could be drawn for the effect of ambient temperature and wind velocity. The present model overpredicts the plume trajectories for TVA's cases. This could be due to the incomplete information of the ambient conditions and the neglect of drift in the tower initial conditions. Adequate ambient and source conditions are mandatory for proper model validation.

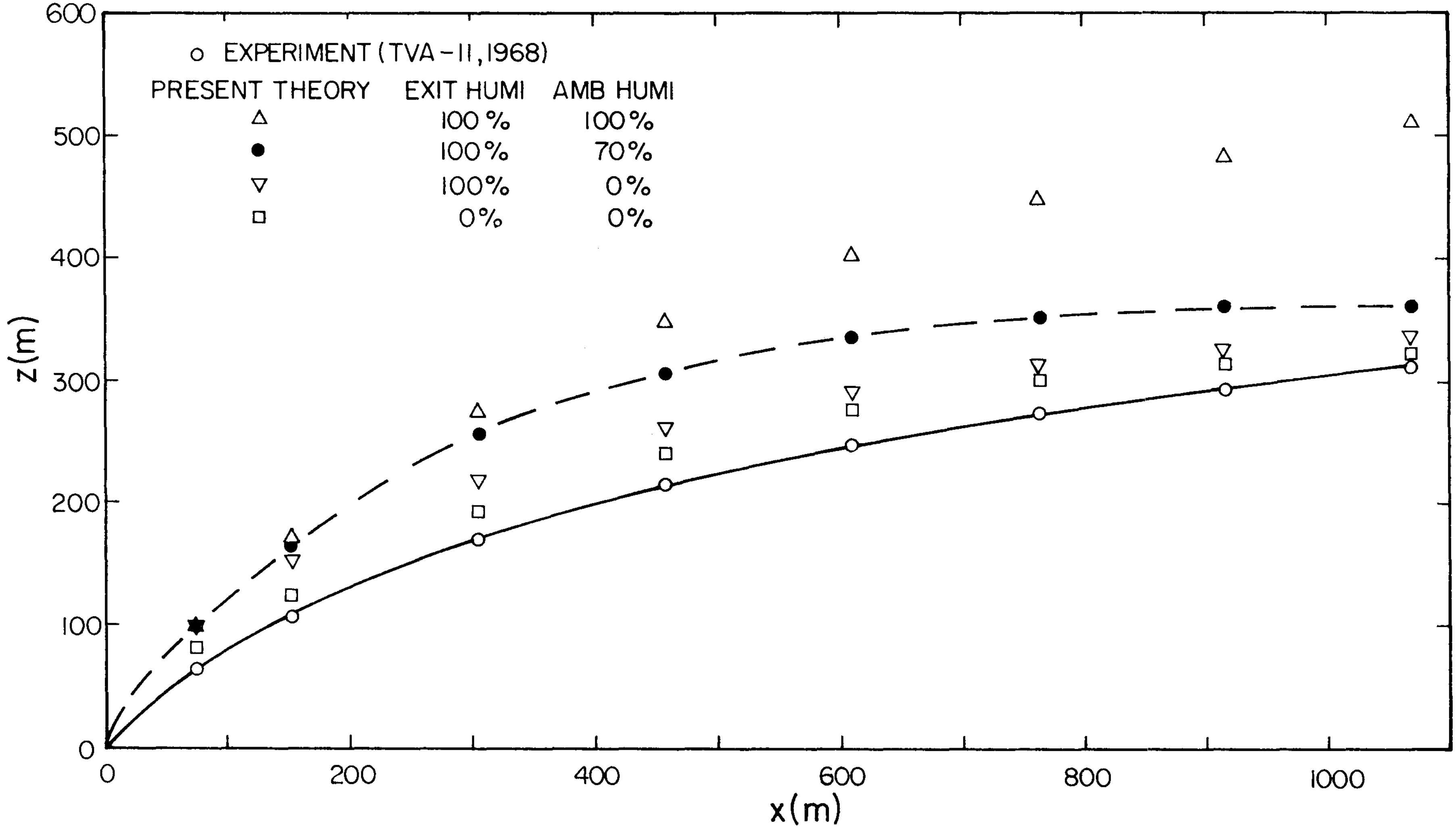


Figure 4.17 Comparisons of Plume Trajectories Between the Present Theory and TVA (1968, TVA-11, single tower) Field Data in a Stable Atmospheric Condition ($\partial\theta/\partial z$=0.59°K/100 m)

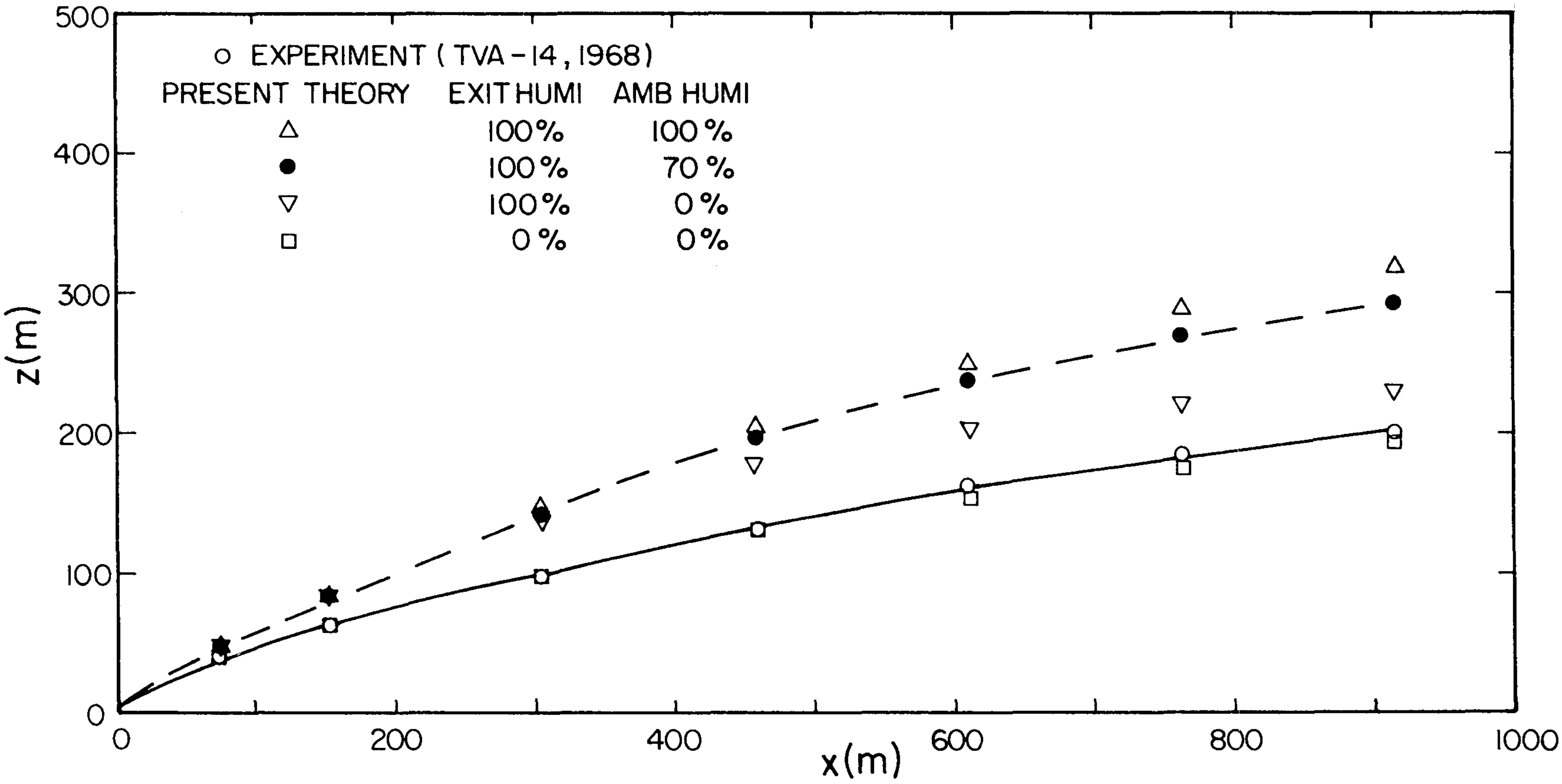


Figure 4.18 Comparisons of Plume Trajectories Between the Present Theory and TVA (1968, TVA, two towers) Field Data in an Atmosphere with an Inversion ($\partial\theta/\partial z$=1.42°K/100 m)

Table 4.1 Input Data Cards for Example Cases (Different Wind Directions to a Line Array (3 cases) and Round Array (one case) of Towers)

```
 CASE (1)  4 TOWERS IN ONE ARRAY   0 DEGREES TO WIND
    4 120   30   30   11
    0    0    0    3   10    0    1    1    1    1    1
     .00000   11.45000   22.90000   34.35000
     .00000     .00000     .00000     .00000
     .00000  100.00000  200.00000
   10.50000   10.30000   10.10000
   70.00000   70.00000   70.00000
    4.10000    5.22504    5.76969    4.10000    5.22504    5.76969    4.10000    5.22504
    5.76969    4.10000    5.22504    5.76969
    9.44880   10.26800   31.90000     .02821     .00000
    5.00000    5.00000    0    0    0    0
 EXCS TEMP 4 TWRS 1 ARRAYS 0 DEG TO WIND Z/D                 X/D
 EXCS HUMI 4 TWRS 1 ARRAYS 0 DEG TO WIND Z/D                 X/D
 EXCS LIQM 4 TWRS 1 ARRAYS 0 DEG TO WIND Z/D                 X/D

 CASE (2)  4 TOWERS IN ONE ARRAY  90 DEGREES TO WIND
    4 120   30   30   11
    0    0    0    3   10    0    1    1    1    1    1
     .00000     .00000     .00000     .00000
     .00000   11.45000   22.90000   34.35000
     .00000  100.00000  200.00000
   10.50000   10.30000   10.10000
   70.00000   70.00000   70.00000
    4.10000    5.22504    5.76969    4.10000    5.22504    5.76969    4.10000    5.22504
    5.76969    4.10000    5.22504    5.76969
    9.44880   10.26800   31.90000     .02821     .00000
    5.00000    5.00000    0    0    0    0
 EXCS TEMP 4 TWRS 1 ARRAYS 90 DG TO WIND Z/D                 X/D
 EXCS HUMI 4 TWRS 1 ARRAYS 90 DG TO WIND Z/D                 X/D
 EXCS LIQM 4 TWRS 1 ARRAYS 90 DG TO WIND Z/D                 X/D

 CASE (3)  4 TOWERS IN ONE ARRAY 135 DEGREES TO WIND
    4 120   30   30   11
    0    0    0    3   10    0    1    1    1    1    1
     .00000    8.10000   16.19000   24.29000
     .00000    8.10000   16.19000   24.29000
     .00000  100.00000  200.00000
   10.50000   10.30000   10.10000
   70.00000   70.00000   70.00000
    4.10000    5.22504    5.76969    4.10000    5.22504    5.76969    4.10000    5.22504
    5.76969    4.10000    5.22504    5.76969
    9.44880   10.26800   31.90000     .02821     .00000
    5.00000    5.00000    0    0    0    0
 EXCS TEMP 4 TWRS 1 ARRAY 135 DEG TO WINDZ/D                 X/D
 EXCS HUMI 4 TWRS 1 ARRAY 135 DEG TO WINDZ/D                 X/D
 EXCS LIQM 4 TWRS 1 ARRAY 135 DEG TO WINDZ/D                 X/D
 CASE (4)  5 TOWERS IN ROUND ARRAY
    5 100   30   30   11
    0    0    0    3   10    0    0    1    1    1    1
     .00000    5.00000   10.00000   15.00000   20.00000
   10.00000     .00000   20.00000    2.00000   12.00000
     .00000  100.00000  200.00000
   10.50000   10.30000   10.10000
   70.00000   70.00000   70.00000
    4.10000    5.22504    5.76969    4.10000    5.22504    5.76969    4.10000    5.22504
    5.76969    4.10000    5.22504    5.76969    4.10000    5.22504    5.76969
    9.44880   10.26800   31.90000     .02821     .00000
    5.00000    5.00000    0    0    0    0
 EXCS TEMP 5 TWRS IN ROUND ARRAY        Z/D                  X/D
 EXCS HUMI 5 TWRS IN ROUND ARRAY        Z/D                  X/D
 EXCS LIQM 5 TWRS IN ROUND ARRAY        Z/D                  X/D
```

Table 4.2 Input Data Cards for Three Cases of Fan's (1967) Experiments with F = 20, K = 8; F = 40, K = 8; and F = 80, K = 16

```
CASE (1)  60(D)  F=20  K=8

    1 350   1   1   1
    0   0   0   2   1   0   0   0   0   0   0
     .0
     .0
     .00000 -50.00000
  31.87000  31.87000
     .00000    .00000
     .13700    .13700
     .00760  -1.10000  20.00000    .00000    .00000
```

```
CASE (2)  60(G)  F=40  K=8

    1 350   1   1   1
    0   0   0   2   1   0   0   0   0   0   0
     .0
     .0
     .00000 -50.00000
  26.57000  26.57000
     .00000    .00000
     .20400    .20400
     .00760  -1.63000  20.00000    .00000    .00000
```

```
CASE (3)  60(J)  F=80  K=16

    1 350   1   1   1
    0   0   0   2   1   0   0   0   0   0   0
     .0
     .0
     .00000 -50.00000
  23.31000  23.31000
     .00000    .00000
     .14600    .14600
     .00760  -2.32000  20.00000    .00000    .00000
```

Table 4.3 Input Data Cards for Chan et al.'s (1974) Experiment with F = 4, K = 1.02

Case (1) 6 Towers in One Array 90 Degrees to Wind F=4, K=1.02

```
  6 100   21  17  11
  0   0   1   2   0   0   1  1   0   0  1
    .00000     .00000    .00000   .00000   .00000   .00000
    .00000     .06501    .13003   .19504   .26006   .32507
    .00000  900.00000
  25.00000   25.00000
    .00000     .00000
    .37621     .37621    .37621   .37621   .37621   .37621   .37621   .37621
    .37621     .37621    .37621   .37621
    .05690     .38374  30.00000   .00000   .00000
    .50000     .50000   1.00000  3.00000
   6.31250    5.06250   0   0   0   0
EXCS TEMP 6 TWRS 1 ARRAY 90 DEG TO WIND Z/D           X/D A3=0.3536 CD=1.5
```

Table 4.4 Input Data Cards for TVA (1968, TVA-11, single tower) Field Data in a Stable Atmospheric Condition ($\partial\theta/\partial z=0.59^\circ$K/100 m)

```
 CASE (1)  100% EXIT HUMI & 100% AMB HUMI

     1 300    1    1    1
     0   0    0    8    1    0    0    0    0    0    0
      .00000
      .00000
      .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
   20.00000  20.16000  20.24000  20.32000  20.40000  20.48000  20.56000  20.64000
  100.00000 100.00000 100.00000 100.00000 100.00000 100.00000 100.00000 100.00000
    4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
    7.90000  17.10000 139.00000    .67883    .00000
```

```
 CASE (2)  100% EXIT HUMI &  70% AMB HUMI

     1 300    1    1    1
     0   0    0    8    1    0    0    0    0    0    0
      .00000
      .00000
      .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
   20.00000  19.61000  19.42000  19.23000  19.04000  18.84000  18.65000  18.46000
   70.00000  70.00000  70.00000  70.00000  70.00000  70.00000  70.00000  70.00000
    4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
    7.90000  17.10000 139.00000    .67883    .00000
```

```
 CASE (3)  100% EXIT HUMI &   0% AMB HUMI

     1 300    1    1    1
     0   0    0    8    1    0    0    0    0    0    0
      .00000
      .00000
      .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
   20.00000  19.61000  19.42000  19.23000  19.04000  18.84000  18.65000  18.46000
     .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
    4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
    7.90000  17.10000 139.00000    .67883    .00000
```

```
 CASE (4)    0% EXIT HUMI &   0% AMB HUMI

     1 300    1    1    1
     0   0    0    8    1    0    0    0    0    0    0
      .00000
      .00000
      .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
   20.00000  19.61000  19.42000  19.23000  19.04000  18.84000  18.65000  18.46000
     .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
    4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
    7.90000  17.10000 139.00000    .00000    .00000
```

Table 4.5 Input Data Cards for TVA (1968, TVA-14, two towers) Field Data in an Atmosphere with an Inversion ($\partial\theta/\partial z=1.42°K/100$ m)

```
CASE (1)  100% EXIT HUMI & 100% AMB HUMI

    2 300    1    1    1
    0    0    0    6    1    0    1    0    0    0    0
       .00000  29.06000
       .00000  54.65000
       .00000  50.00000 100.00000 150.00000 200.00000 250.00000
      7.00000   7.43000   7.86000   8.29000   8.72000   9.15000
    100.00000 100.00000 100.00000 100.00000 100.00000 100.00000
      8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
      9.10000  10.50000  11.60000  12.60000
      7.90000  20.20000 149.00000    .73951    .00000

CASE (2)  100% EXIT HUMI &  70% AMB HUMI

    2 300    1    1    1
    0    0    0    6    1    0    1    0    0    0    0
       .00000  29.06000
       .00000  54.65000
       .00000  50.00000 100.00000 150.00000 200.00000 250.00000
      7.00000   7.22000   7.44000   7.67000   7.89000   8.11000
     70.00000  70.00000  70.00000  70.00000  70.00000  70.00000
      8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
      9.10000  10.50000  11.60000  12.60000
      7.90000  20.20000 149.00000    .73951    .00000

CASE (3)  100% EXIT HUMI &   0% AMB HUMI

    2 300    1    1    1
    0    0    0    6    1    0    1    0    0    0    0
       .00000  29.06000
       .00000  54.65000
       .00000  50.00000 100.00000 150.00000 200.00000 250.00000
      7.00000   7.22000   7.44000   7.67000   7.89000   8.11000
       .00000    .00000    .00000    .00000    .00000    .00000
      8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
      9.10000  10.50000  11.60000  12.60000
      7.90000  20.20000 149.00000    .73951    .00000

CASE (4)    0% EXIT HUMI &   0% AMB HUMI

    2 300    1    1    1
    0    0    0    6    1    0    1    0    0    0    0
       .00000  29.06000
       .00000  54.65000
       .00000  50.00000 100.00000 150.00000 200.00000 250.00000
      7.00000   7.22000   7.44000   7.67000   7.89000   8.11000
       .00000    .00000    .00000    .00000    .00000    .00000
      8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
      9.10000  10.50000  11.60000  12.60000
      7.90000  20.20000 149.00000    .00000    .00000
```

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this study, a mathematical model and corresponding computer program have been developed for the prediction of plume behavior from multiple cooling towers. Some comparisons between the predictions based on the present model and the measured results from laboratories and the field are made in order to test the model. The following conclusions and recommendations are made based on this study.

(1) The model is developed for arbitrary vertical profiles of ambient temperature, humidity, wind velocity, and arbitrary tower arrangement. The velocity defect for the downstream towers due to the effect of the upstream towers and plumes can be included by specifying different ambient velocity profiles for each plume. A general expression for the velocity defect of the downstream towers might be developed in the future.

(2) The temperature range for which this model is valid is -50°C to 140°C, because of the accuracy associated with the calculation of the saturation humidity.

(3) A set of suggested values of entrainment and drag coefficients have been incorporated in the computer program. Because of the rapid merging and usually rapid bending over of the plumes, the coefficients a_3, α_s and C_d are the most important ones. Better estimates of their values are needed such as by further experimental study or field program.

(4) The merging criteria and processes (defined in this model by equations (2.38) (2.39) and (2.40)) could also be improved when further

research results on plume interaction are available.

(5) The blockage and recirculation effects in the wake zone of the towers and plumes have not been incorporated in the present model. Future effort could be made to include these effects.

(6) Based on comparisons between model and laboratory results (Fan, and Chan et al.), good predictions of dry plume behavior can be obtained. In order to verify the model for actual cooling tower plumes, a more complete set of experimental data (including the plume width, trajectory, dilution and detailed ambient profiles of temperature, humidity and wind velocity) are required. Therefore, a complete set of field measurement are strongly recommended for validation of the model.

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APPENDIX A

COMPUTER PROGRAM

The computer program based on the model and listed in Appendix C was tested on an IBM 370/158. The detailed input and output information are listed in this Appendix. The input ambient wind velocity profiles (AU(NP,MG)) for each tower are designed to allow consideration of the velocity defect in the wake of upstream towers (i.e., the tower array parallel to the ambient wind direction). In addition, some suggested input values are listed below for reference:

NS = 300

NX = 40

NY = 40

NCONT = 11

IX(3) = IX(6) = IX(11) =0

In this Appendix, the input sequence as well as the input and output variables are tabulated, explained and related to the symbols used in the text of this report.

INPUT SEQUENCE

Symbol	Parameter	Format	Subroutine
NP,NS,NX,NY,NCONT		5I4	CTPS
(IX(I),I=1,11)		11I4	MTP
(CX(I),I=1,NP)		8F10.5	MTP
(CY(I),I=1,NP)		8F10.5	MTP
(AZ(I),I=1,MG)		8F10.5	MTP
(AT(I),I=1,MG)		8F10.5	MTP
(AH(I),I=1,MG)		8F10.5	MTP
((AU(I,J),J=1,MG),I=1,NP)		8F10.5	MTP
DI(1),UO(1), TO(1),HO(1),WO(1)	IX(1)=0+	8F10.5	MTP
(DI(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(UO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(TO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(HO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(WO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
A1,A2,A3,A4,CD,TURBF	IX(2)=1*	8F10.5	MTP
DX,DZ,XO,ZO	IX(3)=1*	4F10.5	OUTPUT
WIDTH, HITE,MORE,NOMAP,ICENT NOTICK	IX(11)=1*	2F10.5 4I4	OUTPUT
(HEDN(k),k=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)	IX(8)=1*	20A4	OUTPUT
(HEDN(k),k=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)	IX(9)=1*	20A4	OUTPUT
(HEDN(k),k=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)	IX(10)=1*	20A4	OUTPUT

+ Skip card if IX(1)=1

* Skip card if the corresponding IX(I)=0, (I=1,2,3,11,8,9,10)

EXPLANATION OF THE INPUT SYMBOLS

In Program	In Text	Remarks	
NP		Total number of towers	
NS		Desired number of calculation steps	
NX, NY [CONTA(NX,NY)]		Horizontal and vertical grid sizes, respectively (for contour plot)	
NCONT [CONTB(NCONT)]		Desired contour levels for plotting	
IX(1)		IX(1)=0	Same exit conditions of all the plumes (Input one card only)
		IX(1)=1	Different exit conditions of the plumes
IX(2)		IX(2)=0	No input card of entrainment and drag coefficients is needed
		IX(2)=1	Input the desired entrainment and drag coefficients
IX(3)		IX(3)=0	No input card of DX, DZ, XO and ZO is needed
		IX(3)=1	Input the desired values of DX, DZ, XO and ZO
		IX(3)=-1	No plot needed
IX(4)		MG	Number of vertical levels for ambient conditions
IX(5)		INRPR	Interval of detailed printout for plume 1
IX(6)		IPNT=0	For contour plot (always use IPNT=0)
IX(7)		LC=0	For cluster array (round array) of towers
		LC=1	For line or random array of towers
IX(8)		IX(8)=0	No contour map plotted for plume excess temperature
		IX(8)=1	Contour map plotted for plume excess temperature
IX(9)		IX(9)=0	No contour map plotted for plume excess humidity
		IX(9)=1	Contour map plotted for plume excess humidity
IX(10)		IX(10)=0	No contour map plotted for plume excess liquid moisture
		IX(10)=1	Contour map plotted for plume excess liquid moisture
IX(11)		IX(11)=0	No input card of WIDTH, HITE, MORE, NOMAP, ICENT, and NOTICK is needed
		IX(11)=1	Input the desired values of WIDTH, HITE, MORE, NOMAP, ICENT and NOTICK

In Program	In Text	Remarks
CX(NP)	x	x-coordinates of towers (in m)
CY(NP)	y	y-coordinates of towers (in m)
AZ(MG)	z	Ambient levels (in m)
AT(MG)	ta	Ambient temperature profile corresponding to AZ(I) (in °C)
AH(MG)	q_a	Ambient relative humidty profile corresponding to AZ(I) (in percentage of the saturation humidity)
AU(NP,MG)	U_a	Ambient wind velocity profile corresponding to AZ(I) for each tower (in m/sec)
DI(NP)	D_o	Diameter of each tower (in m)
UO(NP)	U_o	Exit velocity of each plume (in m/sec)
TO(NP)	t_o	Exit temperature of each plume (in °C)
HO(NP)	q_o	Exit specific humidity of each plume (in kg/kg)
WO(NP)	σ_o	Exit liquid phase moisture of each plume (in kg/kg)
A1,A2,A3 and A4	a_1,a_2,a_3 and a_4	Entrainment coefficients (Default: A1=0.0806, A2=0.4775, A3=0.3536, A4=0.)
CD	C_d	Drag coefficient (Default: CD=1.5)
TURBF	U'_a	Intensity of ambient turbulent fluctuations (in percentage, decimal; Default: TURBF=0.)
DX,DZ		Increments of grid size in x and z directions, respectively (Normalized by the diameter of the first tower; Default:DX=0.5, DZ=0.5)
XO,ZO		Location of the center of the top of the first tower in the grid (Normalized by the diameter of the first tower; Default:XO=1, ZO=2.)
WIDTH,HITE		Width and height of contour map, respectively (Inches; Default: 8", 8")
MORE		MORE=1 Do not finish off the map (Default: MORE=0)
NOMAP		NOMAP=1 Do not force grid to be square (Default:NOMAP=0)
ICENT		ICENT=1 Do not center the title (Default: ICENT=0)
NOTICK		NOCITK=1 Do not draw tick marks (Default: NOTICK=0)

In Program	In Text	Remarks
HEDN(10)		40 characters to plot as title on top (Default: Blank)
LABY(5)		20 characters to plot as label on vertical left (Default: Blank)
LABX(5)		20 characters to plot as label on horizontal bottom (Default: Blank)

EXPLANATIONS OF THE OUTPUT SYMBOLS

In Program	In Text	Remarks
EXIT,COEF,TWLC,AMBL, INPR,IPNT,LC,ETPL, EHPL,EMPL,COPL		Correspond to IX(1) to IX(11) respectively
A1,A2,A3,A4,CD, TURBF	a_1, a_2, a_3, a_4, C_d, U'_a	Same as input symbols
NTHP		The N^{th} plume
CX,CY [(CX(I),CY(I)]		Same as input symbols
DIA,VELO,TEMP,HUMI, LPMO [DI(I),UO(I), HO(I)WO(I)]	D_o, U_o, t_o, q_o, σ_o	Tower diameter, exit values of plume velocity, temperature, specific humidity and liquid phase moisture, respectively
NSTEP*		The N^{th} step of calculation referred to each tower
X,Y,Z [PX(NP,NS),PY(NP,NS), PZ(NP,NS)]	x,y,z	The horizontal, lateral and vertical coordinates of plume center
PTEMP,PHUMI,PLQDMOIST [PT(NP,NS),PH(NP,NS), PW(NP,NS)]	t_p, q_p, σ_p	Plume temperature, specific humidity and liquid phase moisture respectively
EXCEST, EXCESH [PET(NP,NS),PEH (NP,NS)]	Δt, Δq	Excess plume temperature and specific humidity
PCROSEC [BXZ(I)]	HT/2	Half height of plume cross-section
SLOTLEN[A(I)]	A	Finite length of slot jet of the merged plume
PANGLE[PCOS(NP,NS) PSIN(NP,NS)]	θ	The angle between the tangent of plume trajectory and the horizontal line
DILUTN [PDIL(NP,NS)]	Q/Q_o	Plume dilution
PVELO [PU(NP,NS)]	U_p	Plume velocity

* NSTEP refers to the number of calculation step of plume 1 when each plume first appeared

APPENDIX B

EXPLANATION OF THE IMPORTANT SYMBOLS IN THE PROGRAM MTP

In Program	In Text	Remarks
PX(NP,NS)	x	*
PY(NP,NS)	y	*
PZ(NP,NS)	z	*
PS(NP,NS)	s	*
PCOS(NP,NS)	$\cos\theta$	*
PSIN(NP,NS)	$\sin\theta$	*
PQ(NP,NS)	Q	*
PMX(NP,NS)	M_x	*
PMZ(NP,NS)	M_z	*
PF(NP,NS)	F	*
PG(NP,NS)	G	*
PH(NP,NS)	H	*
PW(NP,NS)	W	*
PT(NP,NS)	T	*
PET(NP,NS)	$t_p - t_a$	Excess temperature
PEH(NP,NS)	$q_p - q_a$	Excess humidity
PAN(NP,NS)	θ	*
PU(NP,NS)	U	Net plume velocity
PENT(NP,NS)	E	*
PA(NP,NS)	A	*
PB(NP,NS)	b or $(B1+B2)/2$	Average plume width
PC(NP,NS)	BXZ	*
PDIL(NP,NS)	Q/Q_o	Plume dilution
CONTA(NX,NY)		Normalized PET,PEH & PW (or PEW)
CONTB(NCONT)		Contour levels
IND(I)		Indication of the status of each plume
	IND(I)=5	Plume which has not been started
	IND(I)=1	Single plume
	IND(I)=2	Merged plume
	IND(I)=3	All plumes are merged
IS(I)		Beginning step number for each plume
MP(I)		Merged plume pair
MS(I)		Merged plume step numbers associated with MP(I)
A(I)	A	*
B1(I)	B1	*
B2(I)	B2	*
BXZ(I)	BXZ	*
BY(I)	BY	*
PMCOS(I)	$\cos\phi$	*
PMSIN(I)	$\sin\phi$	*
DW(I)	$2 \cdot BY$	*
NBV(I)		Beginning step number for visible plume
NEV(I)		Ending step number for visible plume
PAI	π	3.1415926
GRA	g	*
A1	a_1	*
A2	a_2	*
A3	a_3	*
A4	a_4	*

In Program	In Text		Remarks
CD	C_d		*
TURBF	U_a'		*
UC	U_p		*
B			Plume width
TP	t_p		*
HP	q_p		*
WP	σ_p		*
ET	$t_p - t_a$		Excess temperature
EH	$q_p - q_a$		Excess humidity
MG			Elevation level
CFRL	Fr_{LC}		*
ALV	L_v		*
CPA	C_{pa}		*
ANG	θ		*
ITHP			i^{th} plume
ENTRAN	E		*
IQ		<3	All the plumes have not been completely merged
		$=3$	All the plumes have merged
		>3	All the plumes have merged and become a round plume again
IL			Number of merged pairs
IK			Plume step number
KE(I)			Ending step number of each plume
Y(I)	$Y(1)=Q$		*
	$Y(2)=M\cos\theta$		*
	$Y(3)=M\sin\theta$		*
	$Y(4)=G$		*
	$Y(5)=F$		*
	$Y(6)=x$		*
	$Y(7)=z$		*
YP(I)			Derivatives of Y(I) with respect to s
YR1(I),YR2(I), & YS(I)			Y(I) associated with the two half round plumes and the central slot plume for the merged plume
YR1P(I),YR2P(I), & YSP(I)			YP(I) associated with the two half round plumes and the central slot plume for the merged plume

* Refer to "List of Symbols"

APPENDIX C

LISTING OF PROGRAM

```
FORTRAN IV G LEVEL 20.7 VS              MAIN                DATE =    6/07/77      14:32:

 0001                 DIMENSION IA(3),I(26)
                C     NP=NUMBER OF PLUME,NS=NUMBER OF CALCULATION STEP, NX,NY=DESIRED
                C     GRID OF CONTOUR PLOT, NCONT=DESIRED CONTOUR LEVELS
 0002               3 READ(5,2,END=9) NP,NS,NX,NY,NCONT
 0003               2 FORMAT(5I4)
 0004                 N4=MAX0(NX,NY)
 0005                 NTOTAL=NP*NS
 0006                 IA(2)=NTOTAL*23+NX*NY+NCONT+N4
 0007                 CALL GETVEC(IA)
 0008                 I(1)=IA(3)
 0009                 DO 1 J=2,24
 0010               1 I(J)=I(J-1)+NTOTAL
 0011                 I(25)=I(24)+NX*NY
 0012                 I(26)=I(25)+NCONT
 0013                 CALL MTP(IA(I(1)),IA(I(2)),IA(I(3)),IA(I(4)),IA(I(5)),IA(I(6)),
                     1IA(I(7)),IA(I(8)),IA(I(9)),IA(I(10)),IA(I(11)),IA(I(12)),IA(I(13))
                     2,IA(I(14)),IA(I(15)),IA(I(16)),IA(I(17)),IA(I(18)),IA(I(19)),
                     3IA(I(20)),IA(I(21)),IA(I(22)),IA(I(23)),IA(I(24)),IA(I(25)),
                     4IA(I(26)),NP,NS,NX,NY,NCONT,N4)
 0014                 CALL FREEUP(IA)
 0015                 GO TO 3
 0016               9 STOP
 0017                 END
```

```
 0001                  SUBROUTINE MTP(PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PS,PB,PA,
                      1PT,PET,PH,PEH,PW,PAN,PDIL,PY,PC,CONTA,CONTB,CONTC,NP,NS,NX,NY,
                      2NCONT,N4)
 0002                  EXTERNAL DERIVE,DERIVS,DERIVF
 0003                  DOUBLE PRECISION AQ,BQ,CQ,DQ
 0004                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                      1        /STORE2/MP(30),MS(30),IIP(30)
                      2        /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                      A                  AUG(30,30)
                      3        /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                      4                  PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                      5        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                      6                  MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                      7        /CONST2/IL,NII,IK,NI,NIP1
                      8        /CONST3/AQ,BQ,CQ,DQ
                      9        /CONTUU/WIDTH,HITE,MORE,NOMAP,ICENT,NOTICK,HEDN(10),
                      *                  LABY(5),LABX(5)
                      B        /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
 0005                  DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
                      1PB(NP,NS),PU(NP,NS),PF(NP,NS),PG(NP,NS),PCOS(NP,NS),PSIN(NP,NS),
                      2PENT(NP,NS),PH(NP,NS),PW(NP,NS),PEH(NP,NS),CX(30),CY(30),KE(30),
                      3PT(NP,NS),PS(NP,NS),PA(NP,NS),PET(NP,NS),PAN(NP,NS),PY(NP,NS),
                      4Y(8),YP(8),YS(8),YSP(8),YR1(8),YR1P(8),YR2(8),YR2P(8),PDIL(NP,NS,
                      5CONTA(NX,NY),CONTB(NCONT),CONTC(N4),IX(12),MGPA2(30),MGST1(30),
                      6PC(NP,NS),LCHK(30),AHP(30)
                C      INITIALIZE STORAGES
 0006                  CALL BLANK(PX,PZ,PQ,PMX,PMZ,PB,PU,PF,PG,PCOS,PSIN,PENT,PT,PS,PA,
                      1PET,PEH,PAN,PY,PDIL,PH,PW,PC,NP,NS,NX,NY,NCONT,N4,CONTA,CONTB,
                      2CONTC,MGPA2,MGST1,DX,DZ,XO,ZO,IPNT,KE,LCHK,AHP)
                C      INPUT CONTROL PARAMETERS
 0007                  READ(5,2) (IX(I),I=1,11)
 0008                  MG=IX(4)
 0009                  INTPR=IX(5)
 0010                  IPNT=IX(6)
 0011                  LC=IX(7)
                C      INPUT TOWER CONFIGURATION
 0012                  READ(5,1) (CX(I),I=1,NP)
 0013                  READ(5,1) (CY(I),I=1,NP)
                C      INPUT AMBIENT CONDITIONS
 0014                  READ(5,1) (AZ(I),I=1,MG)
 0015                  READ(5,1) (AT(I),I=1,MG)
 0016                  READ(5,1) (AHP(I),I=1,MG)
 0017                  READ(5,1) ((AU(I,J),J=1,MG),I=1,NP)
 0018                  IF(IX(1) .GT. 0) GO TO 34
                C      INPUT TOWER EXIT CONDITIONS;DI=DIA. UO=VELO., TO=TEMP., HO=HUMID
                C      WO=LIQUID PHASE MOISTURE
 0019                  READ(5,1)DI(1),UO(1),TO(1),HO(1),WO(1)
 0020                  DO 24 I=2,NP
 0021                  DI(I)=DI(1)
 0022                  UO(I)=UO(1)
 0023                  TO(I)=TO(1)
 0024                  HO(I)=HO(1)
 0025               24 WO(I)=WO(1)
 0026                  GO TO 35
 0027               34 READ(5,1) (DI(I),I=1,NP)
 0028                  READ(5,1) (UO(I),I=1,NP)
```

```
 0029                READ(5,1) (TO(I),I=1,NP)
 0030                READ(5,1) (HO(I),I=1,NP)
 0031                READ(5,1) (WO(I),I=1,NP)
 0032             35 IF(IX(2) .LE. 0) GO TO 32
            C        INPUT COEFFICIENTS OF ENTRAINMENT AND DRAG ;TURBF=TURB. FLUCT.
            C        TURBF=%(IN DECIMAL) OF AMBIENT WIND VELOCITY
 0033                READ(5,1)A1,A2,A3,A4,CD,TURBF
 0034                CFRL=A2/(0.116-A1)
 0035              1 FORMAT(8F10.5)
 0036              2 FORMAT(12I4)
 0037             32 WRITE(6,555)
 0038            555 FORMAT(1H1)
 0039                WRITE(6,3)
 0040              3 FORMAT(1X,'UNITS OF THE VARIABLES')
 0041                WRITE(6,4)
 0042              4 FORMAT(1X,'LENGTH:M,  TEMP:C,  MOISTURE:KG/KG,   VELO:M/SEC,  ANGL
                    1:DEG')
 0043                WRITE(6,50)NP,NS,NX,NY,NCONT
 0044                WRITE(6,49)
 0045                WRITE(6,36)
 0046                WRITE(6,48) (IX(J),J=1,11)
 0047             50 FORMAT(1X,'NO. OF TOWERS=',I4,'  NO. OF CALCULATION STEPS=',I4,
                    1'  GRID SIZE (X,Y)=',I4,'  X',I4,'  CONTOUR LEVELS=',I4//)
 0048             49 FORMAT(1X,'CONTROL PARAMETERS')
 0049             36 FORMAT(' EXIT  COEF  TWLC  AMBL  INPR  IPNT   LC   ETPL  EHPL  '
                    1'EMPL  COPL')
 0050             48 FORMAT(1X,11(I4,2X)//)
 0051                WRITE(6,5)
 0052              5 FORMAT(1X,'COEFFICIENTS OF ENTRAINMENT AND DRAG')
 0053                WRITE(6,6)A1,A2,A3,A4,CD,TURBF
 0054              6 FORMAT(1X,'A1=',F8.5,5X,'A2=',F8.5,5X,'A3=',F8.5,5X,'A4=',F8.5,5
                    1'CD=',F8.5,5X,'TURBF=',F8.5//)
 0055                WRITE(6,7)
 0056              7 FORMAT(1X,'AMBIENT PROFILES')
 0057                WRITE(6,8)
 0058              8 FORMAT(3X,'HEIGHT',7X,'TEMP',12X,'HUMIDITY',9X,'VELOCITY')
 0059                DO 556 I=1,MG
 0060                TK=AT(I)+273.16
 0061                T=1.-373.16/TK
 0062                EST=EXP((13.3185-(1.976+(0.6445+0.1229*T)*T)*T)*T)
 0063                ES=0.622*1013.25*EST
 0064                FSH=ES/(1013.25+ES)
 0065            556 AH(I)=AHP(I)*0.01*FSH
 0066                DO 9 I=1,MG
 0067              9 WRITE(6,10)AZ(I),AT(I),AH(I),AHP(I),AU(1,I)
 0068             10 FORMAT(1X,2(F10.5,2X),F10.6,1X,'(',F6.2,'%)',2X,F10.5)
 0069                WRITE(6,11)
 0070             11 FORMAT(/)
 0071                WRITE(6,12)
 0072             12 FORMAT(1X,'TOWER CONFIGURATION AND EXIT CONDITIONS')
 0073                WRITE(6,18)
 0074             18 FORMAT(2X,'NTHP',6X,'CX',8X,'CY',8X,'DIA',4X,'VELO',6X,'TEMP',9X
                    1'HUMI',9X,'LPMO')
 0075                DO 17 I=1,NP
 0076             17 WRITE(6,13)I,CX(I),CY(I),DI(I),UO(I),TO(I),HO(I),WO(I)
 0077             13 FORMAT(1X,I5,3X,F7.2,3X,F7.2,3X,F6.2,3X,F6.2,3X,F8.3,3X,F12.8,3X
```

```
                        1F12.8)
 0078                   WRITE(6,242)
                C       CALCULATION OF TEMPERATURE,HUMIDITY AND VELOCITY GRADIENTS
 0079                   MG1=MG-1
 0080                   DO 14 I=1,MG1
 0081                   II=I+1
 0082                   DV=AZ(II)-AZ(I)
 0083                   ATG(I)=(AT(II)-AT(I))/DV
 0084                14 AHG(I)=(AH(II)-AH(I))/DV
 0085                   DO 47 J=1,NP
 0086                   DO 47 I=1,MG1
 0087                   II=I+1
 0088                   DV=AZ(II)-AZ(I)
 0089                47 AUG(J,I)=(AU(J,II)-AU(J,I))/DV
 0090                   DO 148 I=1,NP
 0091                   DO2=DI(I)/2.
 0092                   BXZ(I)=DO2
 0093                   BY(I)=DO2
 0094                   B1(I)=DO2
 0095               148 B2(I)=DO2
 0096                   WRITE(6,15)
 0097                15 FORMAT(1X,'PLUME    1  APPEARS AT NSTEP=    1',//)
                C       SET INITIAL CONDITIONS
 0098                   TP=TO(1)
 0099                   ALV=FALV(TP)
 0100                   CALL SETIC(Y,ITHP,CX)
                C       INTEGRATION BY RUNGE-KUTTA METHOD
 0101                   L=0
 0102                   S=0.
 0103                   IKT=1
 0104                   DS=DI(ITHP)/20.
 0105                   GO TO 598
 0106                86 IF(NIP1 .GT. NP) GO TO 19
                C       CHECK IF ANY NEW PLUME APPEARS
 0107                   CALL CHKNWP(PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PS,PB,PA,PT,
                       1PET,PH,PEH,PW,PAN,PY,PDIL,PC,CX,NP,NS,DERIVR,CY,KE)
 0108                19 IF(NII-1)16,105,105
 0109               357 IKT=IK+NOVIK(1)
 0110                   ITHP=1
 0111                   ALV=FALV(TP)
 0112                   DS=0.1*PB(1,IKT-1)
 0113               598 CALL RUNGS(S,DS,7,Y,YP,L,DERIVR)
 0114                   B1(1)=B
 0115                   B2(1)=B
 0116                   BXZ(1)=B
 0117                   BY(1)=B
                C       SOLUTIONS FOR SINGLE PLUME
 0118                   CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN
                       1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,ITHP,IKT,NP,NS)
 0119                   GO TO 78
                C       CHECK IF ANY NEW PLUME MERGING OCCURS
 0120               105 CALL ALIGN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PC,PCOS,
                       1PSIN,PT,PET,PH,PEH,PW,PAN,PDIL,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,YR2P,
                       2DERIVE,DERIVS,DERIVR,S,LC,NP,NS,KE)
 0121                   CALL PLMERG(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PB,PAN,PDIL,PCOS,PSIN,
                       1CY,NP,NS,KE,MGPA2,MGST1,PC,LCHK,PU)
```

```
   16 DO 23 I=1,NI
      ITHP=I
      IKT=IK+NCVIK(I)-IS(I)+1
      IF(IND(I) .LT.1) GO TO 23
      DS=0.1*PB(I,IKT-1)
C     RESET INITIAL CONDITIONS AND CALCULATE PLUME PROPERTIES FOR SINGLE
C     AND MERGED PLUMES
      CALL RESETI(I,IKT,DS,S,NP,NS,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,YR2P,
     1CERIVE,DERIVS,DERIVR,PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PB,
     2PA,PT,PET,PEH,PW,LC)
C     SOLUTIONS OF PLUMES INCLUDING SINGLE & MERGED PLUMES
      CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN,
     1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,I,IKT,NP,NS)
   23 CONTINUE
      IL=0
   78 DO 77 I=1,NP
      IF((IK+NOVIK(I)) .LT. NS) GO TO 77
      IND(I)=0
   77 CONTINUE
      DO 75 I=1,NP
      IF(IND(I) .GT. 0) GO TO 79
   75 CONTINUE
      GO TO 80
   79 IK=IK+1
      IF(IQ-3)86,16,397
   80 DO 81 I=1,NP
      IF(KE(I) .LE. 0) GO TO 82
      IF(LCHK(I) .LT. 1)GO TO 81
      KE(I)=KE(I)+1
      J=KE(I)
      K=MGPA2(I)
      L=MGSI1(I)+1
      PX(I,J)=PX(K,L)
      PZ(I,J)=PZ(K,L)
      PB(I,J)=PB(K,L)
      PC(I,J)=PC(K,L)
      PCOS(I,J)=PCOS(K,L)
      PSIN(I,J)=PSIN(K,L)
      PET(I,J)=PET(K,L)
      PEH(I,J)=PEH(K,L)
      PW(I,J)=PW(K,L)
      GO TO 81
   82 KE(I)=NS
   81 CONTINUE
      WRITE(6,808)
  808 FORMAT(1X,'RESULTS OF THE VISIBLE PLUMES')
      WRITE(6,225)
      CH=0.
      DO 807 I=1,NP
      KEN=KE(I)
      DO 803 J=1,KEN
      IF(PW(I,J).GT.0.)GO TO 802
      IF(NCV(I).EQ.0)GO TO 803
      NEV(I)=J
      NCV(I)=0
      CH=2.
```

```
 0172               WRITE(6,809)J,I,PX(I,J),PZ(I,J),PY(I,J),PT(I,J),PET(I,J),PH(I,J),
                   1PEH(I,J),PW(I,J),PB(I,J),PC(I,J),PA(I,J),PAN(I,J),PDIL(I,J),
                   2PU(I,J)
 0173           809 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X),/)
 0174               GO TO 803
 0175           802 IF(NCV(I).NE.0)GO TO 803
 0176               NBV(I)=J
 0177               NCV(I)=1
 0178               CH=1.
 0179               WRITE(6,241)J,I,PX(I,J),PZ(I,J),PY(I,J),PT(I,J),PET(I,J),PH(I,J),
                   1PEH(I,J),PW(I,J),PB(I,J),PC(I,J),PA(I,J),PAN(I,J),PDIL(I,J),
                   2PU(I,J)
 0180           241 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X))
 0181           803 CONTINUE
 0182               IF(CH-1.) 804,805,807
 0183           804 WRITE(6,233)I
 0184           233 FORMAT(1X,'NO VISIBLE PART OF PLUME FOR PLUME',I4/)
 0185               GO TO 807
 0186           805 WRITE(6,243)I,J
 0187           243 FORMAT(1X,'PLUME',I4,' STILL VISIBLE AT THE TERMINATION STEP',I4/
 0188           807 CONTINUE
 0189               WRITE(6,242)
 0190           242 FORMAT(//)
 0191               WRITE(6,224)
 0192           224 FORMAT(1X,'RESULTS AT THE LAST STEP OF CALCULATION')
 0193               WRITE(6,225)
 0194           225 FORMAT(1X,'NSTEP   NTHP     X          Z           Y        PTEMP  EXCEST
                   1,' PHUMI    EXCESH PLQDMOIST PAVHFWD PCROSEC SLOTLEN  PANGLE  ',
                   2'DILUTN  PVELO')
 0195               NTHP=1
 0196               WRITE(6,226)NS,NTHP,PX(1,NS),PZ(1,NS),PY(1,NS),PT(1,NS),PET(1,NS)
                   1PH(1,NS),PEH(1,NS),PW(1,NS),PB(1,NS),PC(1,NS),PA(1,NS),PAN(1,NS),
                   2PDIL(1,NS),PU(1,NS)
 0197           226 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X),//
 0198               CALL OUTPUT(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PC,PAN,PDIL,PSIN,PCOS,
                   1CONTA,CONTB,CONTC,KE,INTPR,IPNT,NX,NY,NCONT,N4,NP,NS,IX,DX,DZ,X0,
                   2Z0,PB,PS,PU)
 0199               RETURN
 0200               END
```

```
FORTRAN IV G LEVEL 20.7 VS              BLANK              DATE =     6/07/77       14:32:

0001                SUBROUTINE BLANK(PX,PZ,PQ,PMX,PMZ,PB,PU,PF,PG,PCOS,PSIN,PENT,
                   1PT,PS,PA,PET,PEH,PAN,PY,PDIL,PH,PW,PC,NP,NS,NX,NY,NCONT,N4,CONTA,
                   2CONTB,CONTC,MGPA2,MGST1,DX,DZ,XO,ZO,IPNT,KE,LCHK,AHP)
0002                DOUBLE PRECISION AQ,BQ,CQ,DQ
0003                COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                   1         /STORE2/MP(30),MS(30),IIP(30)
                   2         /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                   A                  AUG(30,30)
                   3         /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                   4                  PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                   5         /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                   6                  MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                   7         /CONST2/IL,NII,IK,NI,NIP1
                   8         /STORE5/DI(30),UO(30),TO(30),HC(30),WO(30)
                   9         /CONST3/AQ,BQ,CQ,DQ
0004                DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
                   1PB(NP,NS),PU(NP,NS),PF(NP,NS),PG(NP,NS),PCOS(NP,NS),PSIN(NP,NS),
                   2PENT(NP,NS),PT(NP,NS),PS(NP,NS),PA(NP,NS),PET(NP,NS),PEH(NP,NS),
                   3PAN(NP,NS),PH(NP,NS),PW(NP,NS),PY(NP,NS),PDIL(NP,NS),CONTA(NX,NY),
                   4CONTB(NCONT),CONTC(N4),MGPA2(30),MGST1(30),PC(NP,NS),KE(30),
                   5LCHK(30),AHP(30)
0005                DO 4 I=1,NP
0006                MGPA2(I)=0
0007                MGST1(I)=0
0008                IS(I)=0
0009                LCHK(I)=0
0010                A(I)=0.
0011                NBV(I)=0
0012                NEV(I)=0
0013                NCV(I)=0
0014                DW(I)=0.
0015                PMSIN(I)=0.
0016                PMCOS(I)=0.
0017                IND(I)=5
0018                MP(I)=0
0019                MS(I)=0
0020                IIP(I)=0
0021                INDT(I)=0
0022              4 NOVIK(I)=0
0023                DO 1 I=1,NP
0024                DO 1 J=1,NS
0025                PX(I,J)=0.
0026                PZ(I,J)=0.
0027                PQ(I,J)=0.
0028                PMX(I,J)=0.
0029                PMZ(I,J)=0.
0030                PF(I,J)=0.
0031                PG(I,J)=0.
0032                PC(I,J)=0.
0033                PB(I,J)=0.
0034                PCOS(I,J)=0.
0035                PSIN(I,J)=0.
0036                PU(I,J)=0.
0037                PENT(I,J)=0.
0038                PET(I,J)=0.
0039                PEH(I,J)=0.
```

```
      PT(I,J)=0.
      PS(I,J)=0.
      PA(I,J)=0.
      PH(I,J)=0.
      PY(I,J)=0.
      PAN(I,J)=0.
      PDIL(I,J)=0.
    1 PW(I,J)=0.
      DO 2 I=1,NX
      DO 2 J=1,NY
    2 CCNTA(I,J)=0.
      DO 3 I=1,NCONT
    3 CCNTB(I)=0.
      DO 5 I=1,N4
    5 CONTC(I)=0.
      DO 6 I=1,30
      DO 6 J=1,30
      AUG(I,J)=0.
    6 AU(I,J)=0.
      DO 7 I=1,30
      KE(I)=0
      AZ(I)=0.
      AT(I)=0.
      AHP(I)=0.
      AH(I)=0.
      ATG(I)=0.
    7 AHG(I)=0.
      AQ=0.000009153132
      BQ=0.0002112502
      CQ=0.003660244
      DQ=0.009494118
      CPA=1.005
      PAI=3.14159265
      GRA=9.8066
      A1=0.0806
      A2=0.6753
      A3=0.3536
      A4=0.
      CD=1.5
      TURBF=0.
      DX=0.5
      DZ=0.5
      XO=1.
      ZO=2.
      IPNT=0
      CFRL=A2/(0.116-A1)
      IL=0
      NII=0
      IK=1
      IQ=1
      NI=1
      NIP1=2
      ITHP=1
      IND(1)=1
      IS(1)=1
      RETURN
```

```
FORTRAN IV G LEVEL 20.7 VS                BLANK              DATE =     6/07/77      14:
 0096                  END
```

```
FORTRAN IV G LEVEL 20.7 VS                FALV               DATE =    6/07/77       14:3
 0001                    FUNCTION FALV(TC)
                   C     TO DETERMINE LATEN HEAT ALV
 0002                    IF(TC .LT. 0.) GO TO 1
 0003                    FALV=(597.31-0.57*TC)*4.1868
 0004                    GO TO 2
 0005                  1 FALV=(677.01+0.622*TC)*4.1868
 0006                  2 RETURN
 0007                    END
```

```
FORTRAN IV G LEVEL 20.7 VS            SETIC               DATE =     6/07/77      14:

 0001                SUBROUTINE SETIC(Y,I,CX)
 0002                COMMON /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                    1          MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                    2     /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                    *          AUG(30,30)
                    3     /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
 0003                DIMENSION Y(8),CX(30)
 0004                Y(1)=PAI*DI(I)*DI(I)*ABS(UO(I))/4.
 0005                Y(2)=0.
 0006                Y(3)=Y(1)*UO(I)
 0007                Y(4)=Y(1)*(TO(I)-AT(1)-WO(I)*ALV/CPA)
 0008                Y(5)=Y(1)*(HO(I)-AH(1)+WO(I))
 0009                Y(6)=CX(I)
 0010                Y(7)=0.
 0011                RETURN
 0012                END
```

```
FORTRAN IV G LEVEL 20.7 VS                RUNGS               DATE =     6/07/77       14:32

                  SUBROUTINE RUNGS(X,H,N,Y,YPRIME,INDEX,DERIV)
                  DIMENSION Y(8),YPRIME(8),Z(8),W1(8),W2(8),W3(8),W4(8)
         C        RUNGS-RUNGE-KUTTA SOLUTION OF SET OF FIRST ORDER O.D.E. FORTRAN I
         C        DIMENSIONS MUST BE SET FOR EACH PROGRAM
         C        X   INDEPENDENT VARIABLE
         C        H   INCREMENT DELTA X,MAY BE CHANGED IN VALUE
         C        N   NUMBER OF EQUATIONS
         C        Y   DEPENDENT VARIABLE BLOCK      ONE DIMENSIONAL ARRAY
         C        YPRIME   DERIVATIVE BLOCK     ONE DIMENSIONAL ARRAY
         C        THE PROGRAMMER MUST SUPPLY INITIAL VALUES OF Y(1) TO Y(N)
         C        INDEX   IS A VARIABLE WHICH SHOULD BE SET TO ZERO BEFORE EACH
         C        INITIAL ENTRY TO THE SUBROUTINE, I.E., TO SOLVE A DIFFERENT
         C        SET OF EQUATIONS OR TO START WITH NEW INITIAL CONDITIONS.
         C        THE PROGRAMMER MUST WRITE A SUBROUTINE CALLED DERIVE WHICH
         C        COMPUTES THE DERIVATIVES AND STORES THEM
         C        THE ARGUMENT LIST IS SUBROUTINE DERIVE(X,N,Y,YPRIME)
                  IF(INDEX) 5,5,1
                1 DO 2 I=1,N
                  W1(I)=H*YPRIME(I)
                2 Z(I)=Y(I)+(W1(I)*.5)
                  A=X+0.5*H
                  CALL DERIV(A,N,Z,YPRIME)
                  DO 3 I=1,N
                  W2(I)=H*YPRIME(I)
                3 Z(I)=Y(I)+.5*W2(I)
                  A=X+0.5*H
                  CALL DERIV(A,N,Z,YPRIME)
                  DO 4 I=1,N
                  W3(I)=H*YPRIME(I)
                4 Z(I)=Y(I)+W3(I)
                  A=X+H
                  CALL DERIV(A,N,Z,YPRIME)
                  DO 7 I=1,N
                  W4(I)=H*YPRIME(I)
                7 Y(I)=Y(I)+(((2.*(W2(I)+W3(I)))+W1(I)+W4(I))/6.)
                  X=X+H
                  CALL DERIV(X,N,Y,YPRIME)
                  GO TO 6
                5 CALL DERIV(X,N,Y,YPRIME)
                  INDEX=1
                6 RETURN
                  END
```

```
      SUBROUTINE DERIVR(S,N,Y,YP)
      DOUBLE PRECISION AQ,BQ,CQ,DQ
      COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
     1       /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
     A              AUG(30,30)
     3       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
     4              MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
     5       /CONST3/AQ,BQ,CQ,DQ
     6       /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
      DIMENSION Y(8),YP(8)
C     DETERMINE AMBIENT CONDITIONS
      TPK=TP+273.16
      TOK=TO(ITHP)+273.16
      DO 88 I=2,MG
      IF(Y(7) .GT. AZ(I)) GO TO 88
      II=I-1
      DZZ=Y(7)-AZ(II)
      TA=AT(II)+ATG(II)*DZZ
      HA=AH(II)+AHG(II)*DZZ
      UA=AU(ITHP,II)+AUG(ITHP,II)*DZZ
      TG=ATG(II)
      HG=AHG(II)
      GO TO 90
   88 CONTINUE
      DZ1=Y(7)-AZ(MG1)
      TA=AT(MG1)+ATG(MG1)*DZ1
      HA=AH(MG1)+AHG(MG1)*DZ1
      UA=AU(ITHP,MG1)+AUG(ITHP,MG1)*DZ1
      HG=AHG(MG1)
      TG=ATG(MG1)
   90 TAK=TA+273.16
      UP=UA*TURBF
C     DETERMINE MOMENTUM,TRAJECTORY AND VELOCITY OF PLUME
      PM=SQRT(Y(2)*Y(2)+Y(3)*Y(3))
      PCOS=Y(2)/PM
      PSIN=Y(3)/PM
      IF(PCOS .NE. 0.) GO TO 86
      ANG=90.
      GO TO 85
   86 ANG=ATAN(PSIN/PCOS)*180./PAI
   85 SIGN=1.
      IF(PSIN .LT. 0.) SIGN=-1.
      APSIN=ABS(PSIN)
      SY=PSIN*Y(1)
      UC=PM/Y(1)
      U=UC-UA*PCOS
      SPM=SQRT(PAI*PM)
      B=Y(1)/SPM
      USU=UC*PAI*B*B
      PMC=CD*B*UA*UA*PSIN*PSIN
      Y4=Y(4)/USU
      Y5=Y(5)/USU
      C1=ALV/CPA
      C2=Y4+TA+C1*(Y5+HA)
      C3=Y5+HA
C     TO ASSUME THE PLUME IS SATURATED AND CALCULATE THE SATURATED PLU
```

```
C      HUMIDITY AND TEMPERATURE
       CALL ITER(TPK,HP,EST,C1,C2)
C      TO DETERMINE THE PLUME LIQUID PHASE MOISTURE
       WP=C3-HP
       IF(WP .GT. 0.) GO TO 79
C      DRY PLUME
       WP=0.
       HP=C3
       TP=TA+Y4
       TPK=TP+273.16
       GO TO 178
C      WET PLUME
    79 TP=TPK-273.16
   178 ET=TP-TA
       EH=HP-HA
C      TO DETERMINE ADIABATIC LAPSE RATE
       GAMA=FGAMA(TAK,HA)
C      DETERMINE PLUME ENTRAINMENT
       RT=TPK/TAK
       PER=2.*PAI*B
       IF(RT .EQ. 1.) GO TO 99
       FRL=UC*UC*TPK/(GRA*TCK*ABS(RT-1.)*B)
       IF(FRL .GT. CFRL) GO TO 9
       A12=0.116
       GO TO 10
     9 A12=A1+A2*APSIN/FRL
       GO TO 10
    99 A12=A1
    10 ENTRAN=PER*(A12*ABS(U)+A3*UA*APSIN*PCOS+A4*UP)
C      EQUATIONS OF CONSERVATION OF VOLUME,MOM.,ENERGE AND MOIST. FLUXES
       YP(1)=ENTRAN*RT
       YP(2)=(UA*ENTRAN+PMC*APSIN)*RT
       YP(3)=(RT-1.-WP)*GRA*LSL/UC-SIGN*PMC*PCOS*RT
       YP(4)=-(TG+GAMA)*SY
       YP(5)=-HG*SY
       YP(6)=PCOS
       YP(7)=PSIN
       RETURN
       END
```

```
FORTRAN IV G LEVEL 20.7 VS              DERIVS            DATE =    6/07/77       15:27

0001                  SUBROUTINE DERIVS(S,N,Y,YP)
0002                  DOUBLE PRECISION AQ,BQ,CQ,DQ
0003                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                    1        /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                    A               AUG(30,30)
                    3        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WF,
                    4               MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
                    5        /CONST3/AQ,BQ,CQ,DQ
                    6        /STORE5/DI(30),UC(30),TO(30),HO(30),WO(30)
0004                  DIMENSION Y(8),YP(8)
0005                  TPK=TP+273.16
              C       DETERMINE AMBIENT CONDITIONS
0006                  TOK=TO(ITHP)+273.16
0007                  DO 88 I=2,MG
0008                  IF(Y(7) .GT. AZ(I)) GO TO 88
0009                  II=I-1
0010                  DZZ=Y(7)-AZ(II)
0011                  TA=AT(II)+ATG(II)*DZZ
0012                  HA=AH(II)+AHG(II)*DZZ
0013                  UA=AU(ITHP,II)+AUG(ITHP,II)*DZZ
0014                  TG=ATG(II)
0015                  HG=AHG(II)
0016                  GO TO 90
0017               88 CONTINUE
0018                  DZ1=Y(7)-AZ(MG1)
0019                  TA=AT(MG1)+ATG(MG1)*DZ1
0020                  HA=AH(MG1)+AHG(MG1)*DZ1
0021                  UA=AU(ITHP,MG1)+AUG(ITHP,MG1)*DZ1
0022                  TG=ATG(MG1)
0023                  HG=AHG(MG1)
0024               90 TAK=TA+273.16
0025                  UP=UA*TURBF
              C       DETERMINE MOMENTUM,TRAJECTORY AND VELOCITY OF PLUME
0026                  PM=SQRT(Y(2)*Y(2)+Y(3)*Y(3))
0027                  PCOS=Y(2)/PM
0028                  PSIN=Y(3)/PM
0029               85 SIGN=1.
0030                  IF(PSIN .LT. 0.) SIGN=-1.
0031                  APSIN=ABS(PSIN)
0032                  SY=PSIN*Y(1)
0033                  UC=PM/Y(1)
0034                  U=UC-UA*PCOS
0035                  B=Y(1)*Y(1)/(2.*PM)
0036                  USU=2.*B*UC
0037                  PMC=CD*UA*UA*PSIN*PSIN*0.5
0038                  Y4=Y(4)/USU
0039                  Y5=Y(5)/USU
0040                  C1=ALV/CPA
0041                  C2=Y4+TA+C1*(Y5+HA)
0042                  C3=Y5+HA
              C       TO ASSUME THE PLUME IS SATURATED AND CALCULATE THE SATURATED PLUME
              C       HUMIDITY AND TEMPERATURE
0043                  CALL ITER(TPK,HP,EST,C1,C2)
              C       TO DETERMINE THE PLUME LIQUID PHASE MOISTURE
0044                  WP=C3-HP
0045                  IF(WP .GT. 0.) GO TO 79
```

```
FORTRAN IV G LEVEL 20.7 VS              DERIVS              DATE =    6/07/77      15:27:
                C      DRY PLUME
 0046                  WP=0.
 0047                  HP=C3
 0048                  TP=TA+Y4
 0049                  TPK=TP+273.16
 0050                  GO TO 178
                C      WET PLUME
 0051              79  TP=TPK-273.16
 0052             178  ET=TP-TA
 0053                  EH=HP-HA
                C      TO DETERMINE ADIABATIC LAPSE RATE
 0054                  GAMA=FGAMA(TAK,HA)
                C      DETERMINE PLUME ENTRAINMENT
 0055                  TPK=TP+273.16
 0056                  RT=TPK/TAK
 0057                  ENTRAN=2.*(0.198*ABS(U)+A3*UA*APSIN*PCOS+A4*UP)
                C      EQUATIONS OF CONSERVATION OF VOLUME,MOM.,ENERGE AND MOIST. FLUXES
 0058                  YP(1)=ENTRAN*RT
 0059                  YP(2)=(UA*ENTRAN+PMC*APSIN)*RT
 0060                  YP(3)=(RT-1.-WP)*GRA*LSL/UC-SIGN*PMC*PCOS*RT
 0061                  YP(4)=-(TG+GAMA)*SY
 0062                  YP(5)=-HG*SY
 0063                  YP(6)=PCOS
 0064                  YP(7)=PSIN
 0065                  RETURN
 0066                  END
```

```
              SUBROUTINE DERIVE(S,N,Y,YP)
              DOUBLE PRECISION AQ,BQ,CQ,DQ
              COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
             1        /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
             A             AUG(30,30)
             2        /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
             3             PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
             4        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HF,EH,WF,
             5             MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
             6        /CONST3/AQ,BQ,CQ,DQ
             7        /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
              DIMENSION Y(8),YP(8)
              TPK=TP+273.16
        C     DETERMINE AMBIENT CONDITIONS
              TOK=TO(ITHP)+273.16
              DO 88 I=2,MG
              IF(Y(7) .GT. AZ(I)) GO TO 88
              II=I-1
              DZZ=Y(7)-AZ(II)
              TA=AT(II)+ATG(II)*DZZ
              HA=AH(II)+AHG(II)*DZZ
              UA=AU(ITHP,II)+AUG(ITHP,II)*DZZ
              TG=ATG(II)
              HG=AHG(II)
              GO TO 90
           88 CONTINUE
              DZ1=Y(7)-AZ(MG1)
              TA=AT(MG1)+ATG(MG1)*DZ1
              HA=AH(MG1)+AHG(MG1)*DZ1
              UA=AU(ITHP,MG1)+AUG(ITHP,MG1)*DZ1
              TG=ATG(MG1)
              HG=AHG(MG1)
           90 TAK=TA+273.16
              UP=UA*TURBF
        C     DETERMINE MOMENTUM,TRAJECTORY AND VELOCITY OF PLUME
              PM=SQRT(Y(2)*Y(2)+Y(3)*Y(3))
              PCOS=Y(2)/PM
              PSIN=Y(3)/PM
              IF(PCOS .NE. 0.) GO TO 86
              ANG=90.
              GO TO 85
           86 ANG=ATAN(PSIN/PCOS)*180./PAI
           85 SIGN=1.
              IF(PSIN .LT. 0.) SIGN=-1.
              APSIN=ABS(PSIN)
              SY=PSIN*Y(1)
              UC=PM/Y(1)
              U=UC-UA*PCOS
              USU=UC*(A(ITHP)*(B1(ITHP)+B2(ITHP))+0.5*PAI*(B1(ITHP)*B1(ITHP)+
             1B2(ITHP)*B2(ITHP)))
              PMC=0.5*CD*UA*UA*PSIN*PSIN*DW(ITHP)
              Y4=Y(4)/USU
              Y5=Y(5)/USU
              C1=ALV/CPA
              C2=Y4+TA+C1*(Y5+HA)
              C3=Y5+HA
```

```
              C      TO ASSUME THE PLUME IS SATURATED AND CALCULATE THE SATURATED PLUM
              C      HUMIDITY AND TEMPERATURE
 0046                CALL ITER(TPK,HP,EST,C1,C2)
              C      TO DETERMINE THE PLUME LIQUID PHASE MOISTURE
 0047                WP=C3-HP
 0048                IF(WP .GT. 0.) GO TO 79
              C      DRY PLUME
 0049                WP=0.
 0050                HP=C3
 0051                TP=TA+Y4
 0052                TPK=TP+273.16
 0053                GO TO 178
              C      WET PLUME
 0054             79 TP=TPK-273.16
 0055            178 ET=TP-TA
 0056                EH=HP-HA
              C      TO DETERMINE ADIABATIC LAPSE RATE
 0057                GAMA=FGAMA(TAK,HA)
              C      DETERMINE PLUME ENTRAINMENT
 0058                TPK=TP+273.16
 0059                RT=TPK/TAK
 0060                PER=2.*A(ITHP)
 0061                A12=0.198
 0062                IF(RT .EQ. 1.) GO TO 99
 0063                FRC=UC*UC*TPK/(GRA*TCK*ABS(RT-1.))
 0064                FRL=FRC/B1(ITHP)
 0065                IF(FRL .GT. CFRL) GO TO 106
 0066                B12=0.116
 0067                GO TO 108
 0068            106 B12=A1+A2*APSIN/FRL
 0069            108 FRL=FRC/B2(ITHP)
 0070                IF(FRL .GT. CFRL) GO TO 104
 0071                C12=0.116
 0072                GO TO 107
 0073            104 C12=A1+A2*APSIN/FRL
 0074                GO TO 107
 0075             99 B12=A1
 0076                C12=A1
              C      ENTRAINMENT OF TWO HALF ROUND ENDING PLUMES
 0077            107 ENTR=PAI*(ABS(U)*(B1(ITHP)*B12+B2(ITHP)*C12)+(B1(ITHP)+B2(ITHP))
                    1*(A3*UA*APSIN*PCOS+A4*UP))
              C      ENTRAINMENT OF TWO HALF ROUND PLUMES AND SLOT JET
 0078                ENTRAN=PER*(A12*ABS(U)+A3*UA*APSIN*PCOS+A4*UP)+ENTR
              C      EQUATIONS OF CONSERVATION OF VOLUME,MOM.,ENERGE AND MOIST. FLUXES
 0079                YP(1)=ENTRAN*RT
 0080                YP(2)=(UA*ENTRAN+PMC*APSIN)*RT
 0081                YP(3)=(RT-1.-WP)*GRA*USL/UC-SIGN*PMC*PCOS*RT
 0082                YP(4)=-(TG+GAMA)*SY
 0083                YP(5)=-HG*SY
 0084                YP(6)=PCOS
 0085                YP(7)=PSIN
 0086                RETURN
 0087                END
```

```
FORTRAN IV G LEVEL 20.7 VS              PHI                DATE =     6/07/77      14:32
 0001             SUBROUTINE PHI(I,JR,M,CY,PZ,NP,NS,IKQ,IKP)
 0002             COMMON /STORE1/IND(30),INDT(30),NDVIK(30),IS(30)
                 1         /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                 2                   PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
 0003             DIMENSION PZ(NP,NS),CY(30)
            C     TO CALCULATE THE ANGLE OF THE INCLINATION OF MERGED PLUME (PHI)
 0004             IJR=INDT(JR)
 0005             IM=INDT(M)
 0006             IF(IJR .NE. IM) GO TO 1
 0007             IF(IJR .EQ. 1 .AND. IM .EQ. 1) GO TO 2
 0008             IF(JR .EQ. M) GO TO 6
 0009             IF(IJR .EQ. 2 .AND. IM .EQ. 2) GO TO 4
 0010           2 DY=ABS(CY(JR)-CY(M))
 0011             DZ=ABS(PZ(JR,IKP)-PZ(M,IKQ))
 0012             DS=SQRT(DY*DY+DZ*DZ)
 0013             PMCOS(I)=DY/DS
 0014             PMSIN(I)=DZ/DS
 0015             GO TO 5
 0016           1 IF(IJR .NE. 1) GO TO 6
 0017           7 PMCOS(I)=PMCOS(M)
 0018             PMSIN(I)=PMSIN(M)
 0019             GO TO 5
 0020           6 PMCOS(I)=PMCOS(JR)
 0021             PMSIN(I)=PMSIN(JR)
 0022             GO TO 5
 0023           4 COSS=PMCOS(JR)*PMCOS(M)-PMSIN(JR)*PMSIN(M)
 0024             PMCOS(I)=SQRT(0.5*(1.+COSS))
 0025             PMSIN(I)=SQRT(0.5*(1.-COSS))
 0026           5 RETURN
 0027             END
```

```
FORTRAN IV G LEVEL 20.7 VS              ITER              DATE =    6/07/77       14:32
                       SUBROUTINE ITER(TPK,HP,EST,C1,C2)
                     1 TS=373.16/TPK
                       T=1.-TS
                       EST=1013.25*EXP((13.3185-(1.976+(0.6445+0.1299*T)*T)*T)*T)
                       ES=0.622*EST
                       HP=ES/(1013.25+ES)
                       FTPK=C2-C1*HP+273.16-TPK
                       IF(ABS(FTPK) .LT. 0.01) RETURN
                       DST=(13.3185-(3.952+(1.9335+0.5196*T)*T)*T)*TS/TPK
                       FTPKD=-1.+C1*HP*DST*(HP-1.)
                       TPK=TPK-FTPK/FTPKD
                       GO TO 1
                       END
```

```
FORTRAN IV G LEVEL 20.7 VS               FGAMA              DATE =     6/07/77       14:32

 0001                 FUNCTION FGAMA(TAK,HA)
                C     TO DETERMINE ADIABATIC LAPSE RATE
 0002                 T=1.-373.16/TAK
 0003                 EST=EXP((13.3185-(1.976+(0.6445+0.1229*T)*T)*T)*T)
 0004                 ES=0.622*1013.25*EST
 0005                 HAS=0.99*ES/(1013.25+ES)
 0006                 IF(HA .GE. HAS) GO TO 1
                C     DRY ADIABATIC LAPSE RATE
 0007                 FGAMA=0.00976
 0008                 GO TO 2
 0009               1 RESP=EST/TAK
                C     SATURATED ADIABATIC LAPSE RATE
 0010                 FGAMA=0.00976*(1.+5420.*RESP)/(1.+8390000.*RESP/TAK)
 0011               2 RETURN
 0012                 END
```

```
FORTRAN IV G LEVEL 20.7 VS              SOLUTN              DATE =    6/07/77       14:32:

 0001                SUBROUTINE SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,
                    1PSIN,PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,I,J,NP,NS)
 0002                COMMON /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                    1          PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                    2    /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                    3          MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                    4    /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
 0003                DIMENSION PX(NP,NS),PY(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),
                    1PMZ(NP,NS),PG(NP,NS),PF(NP,NS),PU(NP,NS),PENT(NP,NS),PS(NP,NS),
                    2PA(NP,NS),PB(NP,NS),PCOS(NP,NS),PSIN(NP,NS),PT(NP,NS),PET(NP,NS),
                    3PH(NP,NS),PEH(NP,NS),PW(NP,NS),PAN(NP,NS),PDIL(NP,NS),CY(30),Y(8),
                    4YP(8),PC(NP,NS)
 0004                PX(I,J)=Y(6)
 0005                PZ(I,J)=Y(7)
 0006                PY(I,J)=CY(I)
 0007                PQ(I,J)=Y(1)
 0008                PMX(I,J)=Y(2)
 0009                PMZ(I,J)=Y(3)
 0010                PG(I,J)=Y(4)
 0011                PF(I,J)=Y(5)
 0012                PU(I,J)=UC
 0013                PENT(I,J)=ENTRAN
 0014                PS(I,J)=S
 0015                PA(I,J)=A(I)
 0016                PC(I,J)=BXZ(I)
 0017                PB(I,J)=B
 0018                PCOS(I,J)=YP(6)
 0019                PSIN(I,J)=YP(7)
 0020                PT(I,J)=TP
 0021                PET(I,J)=ET
 0022                PH(I,J)=HP
 0023                PEH(I,J)=EH
 0024                PW(I,J)=WP
 0025                PAN(I,J)=ANG
 0026                PDIL(I,J)=Y(1)/PQ(I,1)
 0027                RETURN
 0028                END
```

```
      SUBROUTINE CHKNWP(PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PS,PB,
     1PA,PT,PET,PH,PEH,PW,PAN,PY,PDIL,PC,CX,NP,NS,DERIVR,CY,KE)
      EXTERNAL DERIVR
      COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
     1        /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
     2                PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
     3        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
     4                MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
     5        /CONST2/IL,NII,IK,NI,NIP1
     6        /STORE5/DI(30),UO(30),TO(30),HC(30),WO(30)
      DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
     1PB(NP,NS),PU(NP,NS),PF(NP,NS),PG(NP,NS),PCOS(NP,NS),PSIN(NP,NS),
     2PENT(NP,NS),PA(NP,NS),PT(NP,NS),CX(30),Y(8),YP(8),PS(NP,NS),
     3PH(NP,NS),PW(NP,NS),PET(NP,NS),PEH(NP,NS),PAN(NP,NS),PY(NP,NS),
     4PDIL(NP,NS),CY(30),KE(30),PC(NP,NS)
C     CHECK IF ANY NEW PLUME APPEARS
      IKK=IK+NOVIK(1)-IS(1)
      IF(PX(1,IKK) .LT. CX(NIP1)) GO TO 19
      NIPP=NIP1
      DO 22 J=NIPP,NP
      DS=DI(J)/20.
      IF(ABS(CX(NIPP)-CX(J)) .GE. DS) GO TO 22
      NI=NI+1
      WRITE(6,40)J,IKK
   40 FORMAT(1X,'PLUME',2X,I3,'  APPEARS AT NSTEP=',I5//)
      NII=1
      IS(J)=IKK
      NOVIK(J)=NOVIK(1)
      NIP1=J+1
      IND(J)=1
      IKS=1
C     SET INITIAL CONDITIONS
      TP=TO(J)
      ALV=FALV(TP)
      CALL SETIC(Y,J,CX)
      L=0
      S=0.
      ITHP=J
   30 CALL RUNGS(S,DS,7,Y,YP,L,DERIVR)
      BXZ(J)=B
C     SOLUTIONS FOR UNMERGED SINGLE ROUND PLUME
      CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN,
     1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,J,IKS,NP,NS)
C     CHECKING THE CRITERION FOR STOPPING THE CALCULATION OF THE NEW
C     ISSUED SINGLE PLUME
      IF(PZ(J,IKS) .GE. PZ(1,IKK)) GO TO 23
      IF(IKS .GE. NS) GO TO 22
      IKS=IKS+1
      DS=B*0.1
      ALV=FALV(TP)
      GO TO 30
   23 KE(J)=IKS
   22 CONTINUE
   19 RETURN
      END
```

```
      SUBROUTINE ALIGN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PC,
     1PCOS,PSIN,PT,PET,PH,PEH,PW,PAN,PDIL,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,
     2YR2P,DERIVE,DERIVS,DERIVR,S,LC,NP,NS,KE)
      EXTERNAL DERIVE,DERIVS,DERIVR
      COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
     1        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
     2                 MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
     3        /CONST2/IL,NIL,IK,NI,NIP1
     4        /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
     5                 PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
      DIMENSION PX(NP,NS),PY(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),
     1PMZ(NP,NS),PG(NP,NS),PF(NP,NS),PU(NP,NS),PENT(NP,NS),PS(NP,NS),
     2PA(NP,NS),PB(NP,NS),PC(NP,NS),PCOS(NP,NS),PSIN(NP,NS),PT(NP,NS),
     3PET(NP,NS),PH(NP,NS),PEH(NP,NS),PW(NP,NS),PAN(NP,NS),PDIL(NP,NS),
     4CY(30),Y(8),YP(8),YS(8),YSP(8),YR1(8),YR1P(8),YR2(8),YR2P(8),
     5KE(30)
      I1=IK+NOVIK(1)-1
      PXMAX=PX(1,I1)
      DO 1 I=1,NI
      IM=IK+NOVIK(I)-IS(I)
      IF(PXMAX .LT. PX(I,IM)) PXMAX=PX(I,IM)
    1 CONTINUE
      DO 2 I=1,NI
      IF(IND(I) .LT. 1) GO TO 2
      IM=IK+NOVIK(I)-IS(I)
   11 IF(IM .GE. NS) GO TO 2
      DS=PB(I,IM)*0.1
      IF((PXMAX-PX(I,IM)-DS) .LT. 0.) GO TO 2
      IM=IM+1
      IF(IND(I) .GT. 1) GO TO 8
      IF(IM .GT. KE(I)) GO TO 8
      B1(I)=PB(I,IM)
      B2(I)=PB(I,IM)
      BXZ(I)=PB(I,IM)
      BY(I)=PB(I,IM)
      PC(I,IM)=PB(I,IM)
      GO TO 9
    8 ITHP=I
      IKT=IM
      CALL RESETI(I,IKT,DS,S,NP,NS,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,YR2P,
     1DERIVE,DERIVS,DERIVR,PX,PZ,PC,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PB,
     2PA,PT,PET,PEH,PW,LC)
      CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN,
     1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,I,IKT,NP,NS)
    9 NOVIK(I)=NOVIK(I)+1
      GO TO 11
    2 CONTINUE
      RETURN
      END
```

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FORTRAN IV G LEVEL  20.7 VS                  PLMERG               DATE =     6/07/77       14:32:

 0001              SUBROUTINE PLMERG(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PB,PAN,PDIL,PCOS,
                  1PSIN,CY,NP,NS,KE,MGPA2,MGST1,PC,LCHK,PU)
 0002              COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                  1       /STORE2/MP(30),MS(30),IIP(30)
                  2       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                  3               PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                  4       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                  5               MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                  6       /CONST2/IL,NII,IK,NI,NIP1
 0003              DIMENSION PX(NP,NS),PZ(NP,NS),PB(NP,NS),PCOS(NP,NS),PXI(30),
                  1PYI(30),PZI(30),PBI(30),PCOSI(30),CY(30),IRE(30),PSIN(NP,NS),
                  2PSINI(30),KE(30),PY(NP,NS),PT(NP,NS),PET(NP,NS),PH(NP,NS),
                  3PEH(NP,NS),PW(NP,NS),PA(NP,NS),PAN(NP,NS),PDIL(NP,NS),MGPA2(30),
                  4MGST1(30),PC(NP,NS),B1I(30),B2I(30),BXZI(30),BYI(30),AI(30),
                  5LCHK(30),PU(NP,NS)
             C     REARRANGE THE TRAJECTORIES OF THE EXISTING PLUMES
 0004              NJ=0
 0005              DO 101 I=1,NI
 0006              IF(IND(I)-1)101,102,102
 0007          102 ISC=IK+NOVIK(I)-IS(I)
 0008              NJ=NJ+1
 0009              PXI(NJ)=PX(I,ISC)
 0010              PYI(NJ)=CY(I)
 0011              PZI(NJ)=PZ(I,ISC)
 0012              PBI(NJ)=PB(I,ISC)
 0013              PCOSI(NJ)=PCOS(I,ISC)
 0014              PSINI(NJ)=PSIN(I,ISC)
 0015              AI(NJ)=A(I)
 0016              B1I(NJ)=B1(I)
 0017              B2I(NJ)=B2(I)
 0018              BXZI(NJ)=BXZ(I)
 0019              BYI(NJ)=BY(I)
 0020              IRE(NJ)=I
 0021          101 CONTINUE
             C     CHECK PLUME MERGING
 0022              IL=0
 0023              NI1=NJ-1
 0024              DO 103 I=1,NI1
 0025              J1=I+1
 0026              DO 103 J=J1,NJ
 0027              PYD=ABS(PYI(I)-PYI(J))
 0028              PZD=ABS(PZI(I)-PZI(J))
 0029              PYZ=SQRT(PZD*PZD+PYD*PYD)
 0030              SR=BXZI(I)*PCOSI(I)+BXZI(J)*PCOSI(J)
 0031              SR2=BYI(I)+BYI(J)
 0032              IF(SR-PZD)103,10,10
 0033           10 IF(SR2-PYD)103,104,104
 0034          104 IF(AI(I) .EQ. 0. .AND. AI(J) .EQ. 0.) GO TO 1
 0035              GO TO 106
 0036            1 AREA1=0.5*PAI*(B1I(I)*B1I(I)+B1I(J)*B1I(J))
 0037              AREA2=PYZ*(B1I(I)+B1I(J))
 0038              IF(AREA1-AREA2) 103,106,106
 0039          106 IL=IL+1
             C     RECORD THE PAIRS OF THE MERGED PLUMES
 0040              MP(IL)=IRE(I)
 0041              MS(IL)=IRE(J)
```

```
          II=IRE(I)
          JJ=IRE(J)
          INDT(JJ)=IND(JJ)
          INDT(II)=IND(II)
C         RESET IND(II)=2,IND(JJ)=0 FOR JJ>II WHEN PLUMES II AND JJ MERGED
          IND(JJ)=0
          IIP(JJ)=IK+NOVIK(JJ)-IS(JJ)
          IF(IND(II)-1) 103,111,113
      111 IND(II)=2
      113 IIP(II)=IK+NOVIK(II)-IS(II)
      103 CONTINUE
          IF(IL-1)16,107,205
      205 K=1
      206 II=K+1
          DO 200 I=II,IL
          IF(MS(K).NE.MS(I))GO TO 200
          IF(MP(I)-MP(K))204,200,203
      203 IF(IND(I).EQ.0)GO TO 200
          IND(I)=0
          IIP(I)=IK+NOVIK(I)-IS(I)
          GO TO 200
      204 IF(IND(K).EQ.0)GO TO 200
          IND(K)=0
          IIP(K)=IK+NOVIK(K)-IS(K)
      200 CONTINUE
          K=K+1
          IF(K.LT.IL)GO TO 206
C         PLUME M5RGING OCCURS
      107 WRITE(6,108)
      108 FORMAT(1X,'RESULTS OF THE PAIRS OF MERGED PLUMES AT MERGING PLACE'
         1)
          WRITE(6,112)
      112 FORMAT(1X,'NSTEP   NTHP    X         Z         Y       PTEMP  EXCEST'
         1,'  PHUMI    EXCESH PLQDMOIST PAVHFWD PCROSEC SLOTLEN  PANGLE ',
         2'DILUTN  PVELO')
          DO 109 I=1,IL
          INDX=1
          LP=MP(I)
          LS=MS(I)
          MT=IIP(LP)
          NT=IIP(LS)
          MGPA2(LS)=LP
          MGST1(LS)=MT
          IF(KE(LS) .GT. NT) GO TO 116
          LCHK(LS)=1
          KE(LS)=NT
      116 WRITE(6,110)MT,LP,PX(LP,MT),PZ(LP,MT),PY(LP,MT),PT(LP,MT),
         1PET(LP,MT),PH(LP,MT),PEH(LP,MT),PW(LP,MT),PB(LP,MT),PC(LP,MT),
         2PA(LP,MT),PAN(LP,MT),PDIL(LP,MT),PU(LP,MT)
      110 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X))
          IF(INDX-1)117,117,118
      117 INDX=2
          LP=LS
          MT=NT
          GO TO 116
      118 WRITE(6,119)
```

```
0091           119 FORMAT(/)
0092           109 CONTINUE
0093               DO 777 I=2,NI
0094               IF(IND(I)-1) 777,779,779
0095           777 CONTINUE
0096               NII=0
0097               ITHP=1
0098           779 DO 400 I=2,NP
0099               IF(IND(I))16,400,16
0100           400 CONTINUE
            C      ALL THE PLUMES ARE MERGED WHEN IND(I)=0 FOR 1<I<NP+1
0101               IND(1)=3
0102               IQ=3
0103               NI=1
0104               ITHP=1
0105            16 RETURN
0106               END
```

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FORTRAN IV G LEVEL 20.7 VS                  RESETI              DATE =    6/07/77      19:42:

0001                    SUBROUTINE RESETI(I,IKT,DS,S,NP,NS,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,
                       1YR2P,DERIVE,DERIVS,DERIVR,PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,
                       2PU,PB,PA,PT,PET,PEH,PW,LC)
0002                    EXTERNAL DERIVE,DERIVS,DERIVR
0003                    COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                       1         /STORE2/MP(30),MS(30),IIP(30)
                       2         /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCJS( 30),
                       3                  PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                       4         /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TUREF,UC,B,TP,ET,HF,EH,WP,
                       5                  MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
                       6         /CONST2/IL,NII,IK,NI,NIP1
0004                    DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
                       1PB(NP,NS),PF(NP,NS),PG(NP,NS),PENT(NP,NS),IRP(30),COB(30 ),Y(8),
                       2YP(8),CY(30),PT(NP,NS),PET(NP,NS),PU(NP,NS),YS(8),YSP(8),
                       3PA(NP,NS),PCOS(NP,NS),PSIN(NP,NS),YR1(8),YR1P(8),YR2(8), YR2P(8),
                       4PEH(NP,NS),PW(NP,NS),IH(30)
0005                    IK1=IKT-1
0006                    Y(1)=PQ(I,IK1)
0007                    Y(2)=PMX(I,IK1)
0008                    Y(3)=PMZ(I,IK1)
0009                    Y(4)=PG(I,IK1)
0010                    Y(5)=PF(I,IK1)
0011                    Y(6)=PX(I,IK1)
0012                    Y(7)=PZ(I,IK1)
0013                    APT=PT(I,IK1)
0014                    IF(IND(I)-2)29,30,30
0015                 30 IF(IL)32,32,33
               C        RESET INITIAL CONDITIONS WHEN ANY NEW PLUME MERGING OCCURS
0016                 33 IRP(1)=I
0017                    IJK=1
0018                    MM=1
0019                    JR=I
0020                    M=I
0021                    JRZ=I
0022                    MZ=I
0023                    CYMANI=CY(I)+BY(I)
0024                    CYMINI=CY(I)-BY(I)
0025                    PZMANI=PZ(I,IK1)+BXZ(I)
0026                    PZMINI=PZ(I,IK1)-BXZ(I)
0027                    CYMAN=CYMANI
0028                    CYMIN=CYMINI
0029                    PZMAN=PZMANI
0030                    PZMIN=PZMINI
0031                 60 DO 34 J=1,IL
0032                    IF(IRP(MM)-MP(J))34,35,34
0033                 35 JJ=MS(J)
0034                    DO 86 NR=1,IJK
0035                    IF(JJ-IRP(NR)) 86,34,86
0036                 86 CONTINUE
               C        SUMMING UP VOLUME,MOMENTUM,ENERGY AND MOISTURE FLUXES OF THE
               C        MERGED PLUMES
0037                    IKP=IK+NOVIK(JJ)-IS(JJ)
0038                    Y(1)=Y(1)+PQ(JJ,IKP)
0039                    Y(2)=Y(2)+PMX(JJ,IKP)
0040                    Y(3)=Y(3)+PMZ(JJ,IKP)
0041                    Y(4)=Y(4)+PG(JJ,IKP)
```

```
0042                Y(5)=Y(5)+PF(JJ,IKP)
0043                PQ(I,1)=PQ(I,1)+PQ(JJ,1)
0044                APT=APT+PT(JJ,IKP)
0045                IJK=IJK+1
0046                IRP(IJK)=JJ
0047                CYMANC=CY(JJ)+BY(JJ)
0048                CYMINC=CY(JJ)-BY(JJ)
0049                PZMANC=PZ(JJ,IKP)+BXZ(JJ)
0050                PZMINC=PZ(JJ,IKP)-BXZ(JJ)
0051                IF(INDT(JJ) .GT. 1) GO TO 401
0052                IF(INDT(I)-2) 401,400,401
0053            400 IF(IH(I) .GT. 2) GO TO 404
0054                IF(CYMANI .GE. CYMANC .AND. CYMINI .LE. CYMINC) GO TO 34
0055                GO TO 401
0056            404 IF(PZMANI .GE. PZMANC .AND. PZMINI .LE. PZMINC) GO TO 34
0057            401 IF(CYMAN .GE. CYMANC) GO TO 244
0058                CYMAN=CYMANC
0059                JR=JJ
0060            244 IF(CYMIN .LE. CYMINC) GO TO 28
0061                CYMIN=CYMINC
0062                M=JJ
0063             28 IF(PZMAN .GE. PZMANC) GO TO 26
0064                PZMAN=PZMANC
0065                JRZ=JJ
0066             26 IF(PZMIN .LE. PZMINC) GO TO 34
0067                PZMIN=PZMINC
0068                MZ=JJ
0069             34 CONTINUE
0070                IF(MM-IJK) 58,59,59
0071             58 MM=MM+1
0072                GO TO 60
0073             59 IF(MM-1) 32,32,859
0074            859 APT=APT/FLOAT(IJK)
0075                Y(7)=0.5*(PZMAN+PZMIN)
              C     LC=0 MEANS CLUSTER OF TOWERS; LC=1 MEANS LINE TOWER ARRAY
0076                IF(LC-1)575,572,575
0077            575 CY(I)=0.5*(CYMAN+CYMIN)
0078                GO TO 571
0079            572 IKQ=IK+NCVIK(M)-IS(M)
0080                IKP=IK+NCVIK(JR)-IS(JR)
0081                DCYAI=CYMAN-CYMIN
0082                DPZAI=PZMAN-PZMIN
0083                IF(DCYAI .LT. DPZAI) GO TO 402
0084                IF((CYMAN-CYMIN) .LT. (PZMAN-PZMIN)) GO TO 402
0085                IF(CY(M) .EQ. CY(JR)) GO TO 407
0086                CYDZ=ABS(PZ(M,IKQ)-PZ(JR,IKP))
              C     TO CALCULATE THE ANGLE OF THE INCLINATION OF MERGED PLUME (PHI)
0087                CALL PHI(I,JR,M,CY,PZ,AF,NS,IKQ,IKP)
0088                IF(CYDZ.NE.0.)GO TO 408
0089                IH(I)=2
0090                GO TO 409
0091            408 IH(I)=1
0092            409 B1(I)=PB(M,IKQ)
0093                B2(I)=PB(JR,IKP)
0094                IF(PMCOS(I) .EQ. 0.) GO TO 988
0095                A(I)=(DCYAI-B1(I)-B2(I))/PMCOS(I)
```

```
 0096                GO TO 573
 0097            988 A(I)=DPZAI-B1(I)-B2(I)
 0098                GO TO 573
 0099            402 JR=JRZ
 0100                M=MZ
 0101                IKQ=IK+NOVIK(M)-IS(M)
 0102                IKP=IK+NOVIK(JR)-IS(JR)
 0103                IF(PZ(JR,IKP) .EQ. PZ(M,IKQ)) GO TO 407
 0104                PZY=ABS(CY(JR)-CY(M))
           C         TO CALCULATE THE ANGLE OF THE INCLINATION OF MERGED PLUME (PHI)
 0105                CALL PHI(I,JR,M,CY,PZ,NF,NS,IKQ,IKP)
 0106                IF(PZY.NE.0.)GO TO 431
 0107                IH(I)=3
 0108                GO TO 432
 0109            431 IH(I)=1
 0110            432 B1(I)=PB(M,IKQ)
 0111                B2(I)=PB(JR,IKP)
 0112                IF(PMSIN(I) .EQ. 0.) GO TO 989
 0113                A(I)=(DPZAI-B1(I)-B2(I))/PMSIN(I)
 0114                GO TO 573
 0115            989 A(I)=DCYAI-B1(I)-B2(I)
 0116                GO TO 573
 0117            407 A(I)=A(JR)
 0118                B1(I)=B1(JR)
 0119                B2(I)=B2(JR)
 0120                PMCOS(I)=PMCOS(JR)
 0121                PMSIN(I)=PMSIN(JR)
 0122                IH(I)=IH(JR)
 0123            573 CY(I)=0.5*(CYMAN+CYMIN)
 0124                IF(A(I) .EQ. 0.)GO TO 38
 0125                GO TO 574
 0126             32 IF(LC-1)571,570,571
 0127            571 IF(IND(I)-3)29,41,29
 0128            570 IF(A(I))38,38,39
 0129             38 A(I)=0.
 0130                IF(IND(I)-3)40,41,40
 0131             41 IQ=4
 0132                IND(I)=4
 0133                GO TO 29
 0134             40 IND(I)=1
 0135                GO TO 29
 0136             39 JR=I
 0137                IKP=IK1
 0138                M=I
 0139                IKQ=IK1
           C         RESET I.C. FOR THE HALF ROUND PLUME
 0140            574 BBB=PAI*B1(I)*B1(I)*ABS(PU(M,IKQ))
 0141                ALV1=FALV(PT(M,IKQ))
 0142                ALV2=FALV(PT(JR,IKP))
 0143                YR1(1)=BBB
 0144                YR1(2)=BBB*PU(M,IKQ)*PCOS(M,IKQ)
 0145                YR1(3)=BBB*PU(M,IKQ)*PSIN(M,IKQ)
 0146                YR1(4)=BBB*(PET(M,IKQ)-ALV1*PW(M,IKQ))
 0147                YR1(5)=BBB*(PEH(M,IKQ)+PW(M,IKQ))
 0148                YR1(6)=PX(M,IKQ)
 0149                YR1(7)=PZ(M,IKQ)
```

```
               C      RESET I.C. FOR THE HALF ROUND PLUME
 0150                 BBB=PAI*B2(I)*B2(I)*ABS(PU(JR,IKP))
 0151                 YR2(1)=BBB
 0152                 YR2(2)=BBB*PU(JR,IKP)*PCOS(JR,IKP)
 0153                 YR2(3)=BBB*PU(JR,IKP)*PSIN(JR,IKP)
 0154                 YR2(4)=BBB*(PET(JR,IKP)-ALV2*PW(JR,IKP))
 0155                 YR2(5)=BBB*(PEH(JR,IKP)+PW(JR,IKP))
 0156                 YR2(6)=PX(JR,IKP)
 0157                 YR2(7)=PZ(JR,IKP)
               C      RESET I.C. FOR THE CENTRAL SLOT JET
 0158                 YS(1)=(Y(1)-0.5*(YR1(1)+YR2(1)))/A(I)
 0159                 YS(2)=(Y(2)-0.5*(YR1(2)+YR2(2)))/A(I)
 0160                 YS(3)=(Y(3)-0.5*(YR1(3)+YR2(3)))/A(I)
 0161                 YS(4)=(Y(4)-0.5*(YR1(4)+YR2(4)))/A(I)
 0162                 YS(5)=(Y(5)-0.5*(YR1(5)+YR2(5)))/A(I)
 0163                 YS(6)=Y(6)
 0164                 YS(7)=Y(7)
               C      CALCULATE NEW HALF WIDTH AND VELO. OF THE HALF ROUND PLUME
 0165                 L=0
 0166                 ALV=ALV1
 0167                 CALL RUNGS(S,DS,5,YR1,YR1P,L,DERIVR)
 0168                 CALL RUNGS(S,DS,5,YR1,YR1P,L,DERIVR)
 0169                 BR1=B
 0170                 UR1=UC
 0171                 S=S-DS
               C      CALCULATE NEW HALF WIDTH AND VELO. OF THE HALF ROUND PLUME
 0172                 L=0
 0173                 ALV=ALV2
 0174                 CALL RUNGS(S,DS,5,YR2,YR2P,L,DERIVR)
 0175                 CALL RUNGS(S,DS,5,YR2,YR2P,L,DERIVR)
 0176                 BR2=B
 0177                 UR2=UC
 0178                 S=S-DS
               C      CALCULATE NEW HALF WIDTH AND VELO. OF THE SLOT JET
 0179                 L=0
 0180                 ALV=FALV(APT)
 0181                 CALL RUNGS(S,DS,5,YS,YSP,L,DERIVS)
 0182                 CALL RUNGS(S,DS,5,YS,YSP,L,DERIVS)
 0183                 BS=B
 0184                 US=UC
 0185                 S=S-DS
               C      CALCULATE MERGED PLUME WITH THE MODIFIED PLUME SHAPE DETERMINED C
               C      THE PREVIOUS STEP
 0186                 L=0
 0187                 CALL RUNGS(S,DS,7,Y,YP,L,DERIVE)
 0188                 CALL RUNGS(S,DS,7,Y,YP,L,DERIVE)
               C      DETERMINE B1,B2 AND A OF THE MODIFIED PLUME SHAPE FOR CALCULATING
               C      ENTRAINMENT AND DRAG FOR NEXT STEP
 0189                 UU=UC
 0190                 W=A(I)
 0191                 CB1=BR2/BR1
 0192                 CB2=W+BR1+BR2
 0193                 CB3=(1.5707963*(BR1*BR1*UR1+BR2*BR2*UR2)+2.*BS*W*US)/UU
 0194                 CB4=1.+CB1
 0195                 AP1=1.5707963*(1.+CB1*CB1)-CB4*CB4
 0196                 BP1=CB2*CB4
```

```
FORTRAN IV G LEVEL 20.7 VS                    RESETI              DATE =    6/07/77      19:42:
0197                 CP1=-CB3
0198                 B1P=B1(I)
0199                 B2P=B2(I)
0200                 AP=A(I)
               C     THE DETERMINED B1,B2 AND A
0201                 B1(I)=(-BP1+SQRT(BP1*BP1-4.*AP1*CP1))/(2.*AP1)
0202                 B2(I)=CB1*B1(I)
0203                 A(I)=CB2-CB4*B1(I)
0204                 B=(B1(I)+B2(I))*0.5
0205                 IF(A(I))418,418,419
0206             418 A(I)=0.
0207                 IF(IND(I)-3) 420,421,420
0208             421 IQ=4
0209                 IND(I)=4
0210                 GO TO 31
0211             420 IND(I)=1
0212                 GO TO 31
0213             419 DY=0.5*(B2(I)-B1(I)+(B1P-B2P)*A(I)/AP)*ABS(PMCOS(I))
0214                 CY(I)=CY(I)+DY
               C     DETERMINE SOME LENGTH SCALES FOR THE USE OF MERGING CRITERION
0215                 AL=0.5*(B1(I)+B2(I))
0216                 ALC=AL+0.5*PMCOS(I)*A(I)
0217                 ALS=AL+0.5*PMSIN(I)*A(I)
0218                 LQ=IH(I)
0219                 GO TO (411,412,413),LQ
0220             411 BY(I)=ALC
0221                 BXZ(I)=ALS
0222                 GO TO 416
0223             412 BY(I)=ALC
0224                 BXZ(I)=AMAX1(B1(I),B2(I))
0225                 GO TO 416
0226             413 BXZ(I)=ALS
0227                 BY(I)=AMAX1(B1(I),B2(I))
0228             416 DW(I)=2.*BY(I)
0229                 GO TO 31
               C     CALCULATE SINGLE ROUND PLUME
0230              29 L=0
0231                 ALV=FALV(PT(I,IK1))
0232                 CALL RUNGS(S,DS,7,Y,YF,L,DERIVR)
0233                 CALL RUNGS(S,DS,7,Y,YF,L,DERIVR)
0234                 B1(I)=B
0235                 B2(I)=B
0236                 BXZ(I)=B
0237                 BY(I)=B
0238              31 RETURN
0239                 END
```

```
FORTRAN IV G LEVEL 20.7 VS                OUTPUT              DATE =    6/07/77      19:42:

 0001                SUBROUTINE OUTPUT(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PC,PAN,PDIL,PSIN,
                    1PCOS,CONTA,CONTB,CONTC,KE,INTPR,IFNT,NX,NY,NCONT,N4,NP,NS,IX,DX,
                    2DZ,XO,ZO,PB,PS,PU)
 0002                COMMON /STORE1/INC(30),INDT(30),NOVIK(30),IS(30)
                    1        /CCNTUU/WICTH,HITE,MORE,NCMAP,ICENT,NOTICK,HEDN(10),
                    2                LABY(5),LABX(5)
                    3        /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
 0003                DIMENSION PX(NP,NS),PY(NP,NS),PZ(NP,NS),PT(NP,NS),PET(NP,NS),
                    1PH(NP,NS),PEH(NP,NS),PW(NP,NS),PA(NP,NS),PC(NP,NS),PAN(NP,NS),
                    2PDIL(NP,NS),PSIN(NP,NS),PCOS(NP,NS),CONTA(NX,NY),CONTB(NCONT),
                    3CONTC(N4),KE(30),IX(12),PB(NP,NS),PS(NP,NS),PU(NP,NS)
 0004                IF(INTPR .LE. 0) GO TC 10
 0005                WRITE(6,1)
 0006              1 FORMAT(1X,'DETAILED RESULTS CF PLUME 1')
 0007                WRITE(6,2)
 0008              2 FORMAT(1X,'NSTEP    NTHP     X          Z          Y        PTEMP  EXCEST
                    1,'  PHUMI   EXCESH PLQDMOIST PAVHFWD PCRCSEC SLOTLEN  PANGLE  ',
                    2'DILUTN  PVELO')
 0009                I=1
 0010                DO 3 J=1,NS,INTPR
 0011              3 WRITE(6,241)J,I,PX(I,J),PZ(I,J),PY(I,J),PT(I,J),PET(I,J),PH(I,J),
                    1PEH(I,J),PW(I,J),PB(I,J),PC(I,J),PA(I,J),PAN(I,J),PDIL(I,J),
                    2PU(I,J)
 0012            241 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X))
 0013             10 IF(IX(3))15,21,20
 0014             20 READ(5,22)DX,DZ,XC,ZC
 0015             22 FORMAT(4F10.5)
 0016             21 IF(IX(11) .LE. 0) GO TO 26
 0017                READ(5,28)WIDTH,HITE,MORE,NOMAP,ICENT,NOTICK
 0018             28 FORMAT(2F10.5,4I4)
 0019                NCONB=-NCCNT
 0020             26 PETO=PMAX(PET,NP,NS,KE)
 0021                PEHC=PMAX(PEH,NP,NS,KE)
 0022                PEWO=PMAX(PW,NP,NS,KE)
 0023                IF(PETC .GT. 0.) GO TC 14
 0024                IX(8)=0
 0025                PETO=1.
 0026                WRITE(6,40)
 0027             40 FORMAT(1X,'NO EXCESS TEMP PLOT DUE TO ZERC CR NEGATIVE EXCESS',
                    1' TEMPERATURE')
 0028             14 IF(PEHC .GT. 0.) GO TC 42
 0029                IX(9)=0
 0030                PEHC=1.
 0031                WRITE(6,43)
 0032             43 FORMAT(1X,'NO EXCESS HUMI PLOT DUE TO ZERO CR NEGATIVE EXCESS',
                    1' HUMIDITY')
 0033             42 IF(PEWC .GT. 0.) GO TC 47
 0034                IX(10)=0
 0035                PEWC=1.
 0036                WRITE(6,46)
 0037             46 FORMAT(1X,'NO EXCESS LIQUIC PHASE MOISTURE PLOT DUE TO ZERO OR',
                    1' NEGATIVE EXCESS LIQUIC PHASE MOISTURE')
              C      DETERMINE GRID DISTRIBUTICN
 0038             47 DO 11 I=1,NP
 0039                DO 11 J=1,NS
 0040                PX(I,J)=PX(I,J)/DI(1)
```

```
              PZ(I,J)=PZ(I,J)/DI(1)
              PB(I,J)=PB(I,J)/DI(1)
              PC(I,J)=PC(I,J)/DI(1)
              PS(I,J)=PS(I,J)/DI(1)
              PW(I,J)=PW(I,J)/PEWO
              PEH(I,J)=PEH(I,J)/PEHC
           11 PET(I,J)=PET(I,J)/PETC
              I=8
              IF(IX(I) .LE. 0) GO TC 5
              CALL GRD2(CONTA,DX,DZ,PX,PZ,PC,PET,PCOS,PSIN,NP,NS,KE,XJ,ZO,NX,NY)
              WRITE(6,31)
           31 FORMAT(1X,'EXCESS TEMPERATURE PLOT',//)
              GO TO 37
            8 CALL GRD2(CONTA,DX,DZ,PX,PZ,PC,PEH,PCOS,PSIN,NP,NS,KE,XJ,ZO,NX,NY)
              WRITE(6,32)
           32 FORMAT(1X,'EXCESS SPECIFIC HUMIDITY PLOT',//)
              GO TO 37
            9 CALL GRD2(CONTA,DX,DZ,PX,PZ,PC,PW,PCOS,PSIN,NP,NS,KE,XO, ZO,NX,NY)
              WRITE(6,33)
           33 FORMAT(1X,'EXCESS LIQUIC PHASE MOISTURE PLOT',//)
           37 READ(5,30) (HEDN(K),K=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)
           30 FORMAT(20A4)
            7 CALL CCNTU(CCNTA,CCNTE,CONTC,NX,NY,NCONB,IFNT)
            5 I=I+1
              IF(I-10)16,17,15
           16 IF(IX(I))5,5,8
           17 IF(IX(I))5,5,9
           15 RETURN
              END
```

```
FORTRAN IV G LEVEL 20.7 VS              PMAX              DATE =     6/07/77      14:32

 0001                FUNCTION PMAX(PT,NP,NS,KE)
 0002                DIMENSION PT(NP,NS),KE(30)
 0003                PMAX=PT(1,1)
 0004                DO 1 I=1,NP
 0005                K=KE(I)
 0006                DO 1 J=1,K
 0007                IF(PT(I,J) .GT. PMAX) PMAX=PT(I,J)
 0008              1 CONTINUE
 0009                RETURN
 0010                END
```

```
      SUBROUTINE GRD2(A,DX,DZ,PX,PZ,PB,PG,PCOS,PSIN,NP,NS,KE,XO,ZO,ID,
     1JD)
      COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
      DIMENSION A(ID,JD),RM(5),C(5),IC(4),PX(NP,NS),PZ(NP,NS),PG(NP,NS),
     1PB(NP,NS),PCOS(NP,NS),PSIN(NP,NS),KE(30)
      DO 210 I=1,ID
      DO 210 J=1,JD
  210 A(I,J)=0.
      DO 1 N=1,NP
      DO 1 I=1,NS
      PX(N,I)=PX(N,I)+XO
    1 PZ(N,I)=PZ(N,I)+ZO
      KX=1
      DO 2 N=1,NP
      KY=KE(N)-1
      IF(KX .GE. KY) GO TO 2
      RM(1)=0.
      C(1)=PZ(N,KX)
      IC(1)=(PX(N,KX)-PB(N,KX))/DX+1.0005
      IC1=PX(N,KX)/DX+1.0005
      IC(2)=(PX(N,KX)+PB(N,KX))/DX+1.0005
      DO 2 K=KX,KY
      PB2S=PB(N,K+1)*PSIN(N,K+1)
      IC(3)=(PX(N,K+1)-PB2S)/DX+1.0005
      IC2=PX(N,K+1)/DX+1.0005
      IC(4)=(PX(N,K+1)+PB2S)/DX+1.0005
      PB2C=PB(N,K+1)*PCOS(N,K+1)
      PB1C=PB(N,K)*PCOS(N,K)
      PB1S=PB(N,K)*PSIN(N,K)
      DZZ=PZ(N,K+1)-PZ(N,K)
      DXX=PX(N,K+1)-PX(N,K)
      DPBC=PB2C-PB1C
      DPBS=PB2S-PB1S
      DS=SQRT(DZZ*DZZ+DXX*DXX)
      DB=PB(N,K+1)-PB(N,K)
      DG=PG(N,K)-PG(N,K+1)
      IF(PSIN(N,K+1) .LT. 0.) GO TO 101
      IF(IC(1)-IC(3)) 103,104,105
  105 IL=IC(3)+1
      GO TO 112
  104 IL=IC(3)+1
      GO TO 113
  103 IL=IC(1)+1
  112 RM(3)=(DZZ+DPBC)/(DXX-DPBS)
      C(3)=PZ(N,K+1)+PB2C-(PX(N,K+1)-PB2S)*RM(3)
  113 DXPB=DXX+DPBS
      IF(DXPB .EQ. 0.) GO TO 20
      RM(4)=(DZZ-DPBC)/DXPB
      C(4)=PZ(N,K+1)-PB2C-(PX(N,K+1)+PB2S)*RM(4)
   20 IF(PSIN(N,K+1) .EQ. 0.) GO TO 109
      RM(2)=-PCOS(N,K+1)/PSIN(N,K+1)
      C(2)=PZ(N,K+1)-PX(N,K+1)*RM(2)
  109 IR=IC(4)
      IF(IL .GT. IR) GO TO 99
      DO 12 I=IL,IR
      IF(I .GT. ID) GO TO 12
```

```
 0055              IF(I .LT. 1) GO TO 12
 0056              X=DX*FLOAT(I-1)
 0057              IF(I .GT. IC(3)) GO TO 7
 0058              ZU=RM(3)*X+C(3)
 0059              GO TO 8
 0060            7 ZU=RM(2)*X+C(2)
 0061            8 JU=ZU/DZ+1.0001
 0062              IF(I .GT. IC(2)) GO TO 10
 0063              IF(I .GT. IC(1)) GO TO 115
 0064              ZL=RM(3)*X+C(3)
 0065              GO TO 11
 0066          115 ZL=RM(1)*X+C(1)
 0067              GO TO 11
 0068           10 ZL=RM(4)*X+C(4)
 0069           11 IF((ZL-DZ*FLOAT(JU-1)) .GT. 0.) GO TO 12
 0070              JL=ZL/DZ+1.9999
 0071              IF(JU .LT. JL) GO TO 12
 0072              CALL PD2(A,PX,PZ,PB,PG,PCOS,PSIN,RM,C,NP,NS,N,JL,JU,DB,DG,DZ,X,
                  1DXX,DZZ,I,K,ID,JD)
 0073           12 CONTINUE
 0074              GO TO 99
 0075          101 IF(IC(2)-IC(4)) 121,122,123
 0076          122 IL=IC(2)+1
 0077              GO TO 124
 0078          123 IL=IC(4)+1
 0079              GO TO 125
 0080          121 IL=IC(2)+1
 0081          125 RM(4)=(DZZ-DPBC)/(DXX+DPBS)
 0082              C(4)=PZ(N,K+1)-PB2C-(PX(N,K+1)+PB2S)*RM(4)
 0083          124 DXDP=DXX-DPBS
 0084              IF(DXDP .EQ. 0.) GO TO 21
 0085              RM(3)=(DZZ+DPBC)/DXDP
 0086              C(3)=PZ(N,K+1)+PB2C-(PX(N,K+1)-PB2S)*RM(3)
 0087           21 RM(2)=-PCOS(N,K+1)/PSIN(N,K+1)
 0088              C(2)=PZ(N,K+1)-PX(N,K+1)*RM(2)
 0089              IR=IC(3)
 0090              IF(IL .GT. IR) GO TO 99
 0091              DO 128 I=IL,IR
 0092              IF(I .GT. ID) GO TO 128
 0093              IF(I .LT. 1) GO TO 128
 0094              X=DX*FLOAT(I-1)
 0095              IF(I .GT. IC(1)) GO TO 130
 0096              IF(I .GT. IC(2)) GO TO 132
 0097              ZU=RM(4)*X+C(4)
 0098              GO TO 133
 0099          132 ZU=RM(1)*X+C(1)
 0100              GO TO 133
 0101          130 ZU=RM(3)*X+C(3)
 0102          133 JU=ZU/DZ+1.0001
 0103              IF(I .GT. IC(4)) GO TO 135
 0104              ZL=RM(4)*X+C(4)
 0105              GO TO 136
 0106          135 ZL=RM(2)*X+C(2)
 0107          136 IF((ZL-DZ*FLOAT(JU-1)) .GT. 0.) GO TO 128
 0108              JL=ZL/DZ+1.9999
 0109              IF(JU .LT. JL) GO TO 128
```

```
      CALL PD2(A,PX,PZ,PB,PG,PCOS,PSIN,RM,C,NP,NS,N,JL,JU,DB,DG,DZ,X,
     1DXX,DZZ,I,K,ID,JD)
  128 CONTINUE
   99 RM(1)=RM(2)
      C(1)=C(2)
      IC(1)=IC(3)
      IC(2)=IC(4)
      IC1=IC2
    2 CONTINUE
      CH=1.
      IP=1
      IW=20
  171 IF(ID .GT. IW) GO TO 172
      IW=ID
      CH=0.
  172 WRITE(6,178)
  178 FORMAT(1H1)
      DO 662 J=1,JD
      L=JD+1-J
  662 WRITE(6,3) (A(I,L),I=IP,IW)
    3 FORMAT(1X,20(F5.2,1X))
      IF(CH .EQ. 0.) GO TO 173
      IP=IP+20
      IW=IW+20
      GO TO 171
  173 DO 310 N=1,NP
      DO 310 I=1,NS
      PX(N,I)=PX(N,I)-X0
  310 PZ(N,I)=PZ(N,I)-Z0
      RETURN
      END
```

```
      SUBROUTINE PD2(A,PX,PZ,PB,PG,PCOS,PSIN,RM,C,NP,NS,N,JL,JU,DB,DG,
     1DZ,X,DXX,DZZ,I,K,ID,JD)
      DIMENSION A(ID,JD),PX(NP,NS),PZ(NP,NS),PB(NP,NS),PG(NP,NS),
     1PCOS(NP,NS),PSIN(NP,NS),RM(5),C(5)
      DO 1 J=JL,JU
      IF(J .GT. JD) GO TO 1
      IF(J .LT. 1) GO TO 1
      Z=DZ*FLOAT(J-1)
      PDX=PX(N,K)-PX(N,K+1)
      IF(PDX .NE. 0.) GO TO 5
      XK1=X
      XK=X
      ZK1=RM(2)*XK1+C(2)
      ZK=RM(1)*XK+C(1)
      GO TO 7
    5 RM(5)=DZZ/DXX
      C(5)=PZ(N,K+1)-PX(N,K+1)*RM(5)
      CP=Z-X*RM(5)
      IF(PSIN(N,K+1) .EQ. 0.) GO TO 3
      XK1=(C(2)-CP)/(RM(5)-RM(2))
      GO TO 4
    3 XK1=PX(N,K+1)
    4 ZK1=RM(5)*XK1+CP
    7 DXK1=XK1-X
      DZK1=ZK1-Z
      DSB=SQRT(DXK1*DXK1+DZK1*DZK1)
      IF(PSIN(N,K) .EQ. 0.) GO TO 9
      IF(PDX .EQ. 0.) GO TO 10
      XK=(C(1)-CP)/(RM(5)-RM(1))
      GO TO 11
    9 XK=PX(N,K)
   11 ZK=RM(5)*XK+CP
   10 DXK=XK-XK1
      DZK=ZK-ZK1
      DSP=SQRT(DXK*DXK+DZK*DZK)
      RDSBP=DSB/DSP
      XPC=PX(N,K+1)-RDSBP*DXX
      ZPC=PZ(N,K+1)-RDSBP*DZZ
      DXPC=X-XPC
      DZPC=Z-ZPC
      DSC=SQRT(DXPC*DXPC+DZPC*DZPC)
      B=PB(N,K+1)-RDSBP*DB
      AN=(1.-DSC/B)*(PG(N,K+1)+RDSBP*DG)
      IF(AN .GT. A(I,J)) A(I,J)=AN
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CONTU(A,B,C,ISET,LIM,NN,IPNT)
      DIMENSION A(ISET,1),B(1),C(1)
      COMMON/CONTUU/WIT,HITE,KEY(4),HEDN(20),
     * XNIN,XNAX,YNIN,YNAX,XOFF,YOFF,XSIZ ,YSIZ ,NCONT ,IFLAG
      COMMON/LBLCOM/ITEST,SLBL,STTL,SSCL,STICKL
      IF(IPNT.LT.0) GOTO 999
      IF(IPNT.GT.0) GOTO 888
      IF(NN.EQ.0) NN=-10
      NCONT=IABS(NN)
      MAX=MAX0(LIM,ISET)
      DO 2 I=1,LIM
    2 CALL MAXMIN(A(1,I),ISET,C(I),C(LIM+I))
      CALL MAXMIN(C,LIM*2,YMAX1,YMIN1)
      CALL SCALE(YMAX1,YMIN1,TOP,BOT,NCONT,IERR)
      IF(IERR.NE.0)  GOTO 1000
      CALL MAXMIN(B,NCONT,BMAX,BMIN)
      IF(BMAX.LT.YMIN1.OR.BMIN.GT.YMAX1) GOTO 4
      IF(NN.GT.0) GOTO 1
    4 DELTA=(TOP-BOT)/NCONT
      B(1)=BOT
      DO 3 I=2,NCONT
    3 B(I)=B(I-1)+DELTA
    1 IF(IFLAG.NE.0) GOTO 6
      ISET1=ISET-1
      LIM1=LIM-1
      YSIZE=HITE
      XSIZE=WIT
      XMIN=1.
      YMIN=1.
      XMAX=ISET
      YMAX=LIM
      YNAX=YMAX
      YNIN=YMIN
      XNAX=XMAX
      XNIN=XMIN
      IF(KEY(2).EQ.1) GOTO 10
      DX=XMAX-XMIN
      DY=YMAX-YMIN
      IF(DX.GT.DY) GOTO 11
      DUM=XSIZE
      XSIZE=YSIZE
      YSIZE=DUM
   11 YSIZE=AMIN1(YSIZE,26.)
      DX=AMIN1(XSIZE/DX,YSIZE/DY)
      XSIZE=DX*(XMAX-XMIN)
      YSIZE=DX*(YMAX-YMIN)
   10 XBIG=1.3*XSIZE
      IF(XBIG.LT.15.) XBIG=15.
      IF(XBIG.GT.50.) CALL SYSXMX(XBIG)
      YBIG=10.
      IF(YSIZE.LE.10.) GOTO 12
      YBIG=29.
      CALL SYSPSZ(1)
   12 YOFF=0.5*IFIX(YBIG-YSIZE)
      XOFF=0.5*IFIX(XBIG-XSIZE)+0.5
      XD=XSIZE/(XMAX-XMIN)
```

```
      YD=YSIZE/(YMAX-YMIN)
      XTOFF=0.1
      IF(YSIZE.GT.10.) XTOFF=YSIZE*.01
      IF(YSIZE.LT.5..AND.XSIZE.LT.7.5) XTOFF=YSIZE*.02
      XTOFF=AMAX1(XTOFF,.05)
      ITEST=1
      SLBL=1.1*XTOFF
      STTL=1.2*XTOFF
      SSCL=XTOFF
      STICKL=STTL
      IF(KEY(4).NE.0) STICKL=0
      SYMS=0.8*XTOFF
      YT     =YOFF+YSIZE+XTOFF
      IF(YT+STTL.GT.YBIG) YT=YOFF+YSIZE-XTOFF-XTOFF-STTL
      XSIZ=XSIZE
      YSIZ=YSIZE
      IF(LIM.GT.ISET) XSIZ=XSIZ*LIM1/ISET1
      IF(ISET.GT.LIM) YSIZ=YSIZ*ISET1/LIM1
      CALL LABEL(XOFF,YSIZE+YOFF,XMIN,XMAX,XSIZE,-ISET1,' ',-1,0)
      CALL LABEL(XSIZE+XOFF,YOFF,YMIN,YMAX,YSIZE,-LIM1 ,' ',-1,1)
      CALL FINDMT(HEDN(16),MT16,20)
      CALL FINDMT(HEDN(11),MT   ,20)
      CALL LABEL(XOFF,YOFF,XMAX,XMIN,XSIZE,-ISET1,HEDN(16),MT16,0)
      CALL LABEL(XOFF,YOFF,YMAX,YMIN,YSIZE,-LIM1,HEDN(11),MT,1)
      CALL FINDMT(HEDN,MT,40)
      IF(MT.EQ.0) GOTO 6
      XBEGIN=XOFF+XTOFF
      IF(KEY(3).EQ.0)XBEGIN=XOFF+.5*XSIZE+(.1-.4286*MT)*STTL
      CALL SYSSYM(XBEGIN    ,YT,STTL,HEDN,MT,0.)
    6 IDUM1=1
      IDUM2=IDUM1+MAX
      IDUM3=IDUM2+MAX
      IDUM4=IDUM3+MAX
      CALL TOPO(A,B,C(IDUM1),C(IDUM2),C(IDUM3),C(IDUM4),LIM,ISET)
      WRITE(6,100)                 (B(I),I=1,NCONT)
  100 FORMAT(' ++ CONTU LEVELS ',8G13.5/(1X1P10G13.5))
      IFLAG=1
      IF(KEY(1).NE.0) RETURN
   50 CALL SYSPLT(0.,0.,999)
      IFLAG=0
      RETURN
 1000 WRITE(6,1001) YMIN1,YMAX1,NCONT
 1001 FORMAT(' ** TROUBLES **   MIN,MAX,NCONTOUR = ',2G13.5,I5)
      RETURN
  888 IDUM1=IPNT
      DO 88 I=1,ISET
      XBIG=XOFF+(B(I)-XMIN)*XD
      YBIG=YOFF+(A(I,1)-YMIN)*YD
   88 CALL SYSSYM(XBIG,YBIG,SYMS,IDUM1,-1,0)
      RETURN
  999 XBIG=XOFF+(B(1)-XMIN)*XD
      YBIG=YOFF+(A(1,1)-YMIN)*YD
      CALL SYSPLT(XBIG,YBIG,3)
      IDUM1=MAX0(LIM,1)
      DO 99 I=1,ISET,IDUM1
      XBIG=XOFF+(B(I)-XMIN)*XD
```

```
 0112               YBIG=YOFF+(A(I,1)-YMIN)*YD
 0113            99 CALL SYSPLT(XBIG,YBIG,2)
 0114               RETURN
 0115               END
```

```
FORTRAN IV G LEVEL 20.7 VS              BLK DATA          DATE =     8/03/77      10:1

 0001               BLOCK DATA
 0002               COMMON/CONTUU/WIT,HITE,KEY(4),HEDN(20),STUFF(9),IFLAG
 0003               DATA WIT,HITE,KEY,HEDN/8.,8.       ,4*0,20*1H /
 0004               DATA IFLAG/0/
 0005               END
```

```
      SUBROUTINE TOPO(      V,CNTR,RA,RB,X,Y,M,N)
      DIMENSION V(  N ,1),CNTR(1),RA(1),RB(1),X(1),Y(1)
      COMMON/CONTUU/SKUPO(26),
     *              XMIN,XMAX,YMIN,YMAX,XOFF,YOFF,XSIZ ,YSIZ ,NCONT
       SX=XMAX-XMIN
       SY=YMAX-YMIN
      SMAX=AMAX1(SX,SY)
      SMAX1=1./SMAX
       SS=SX*SMAX1
      SYS=SY*SMAX1
      SSS=0.5*SYS
      Y1 = SY*SMAX1- .001
      X2 = SX*SMAX1- .001
      YCONV=SMAX1
       DELTAX=N-1
       DELTAX=(XMAX-XMIN)/DELTAX
       X(1) = 0.
      RB(1) = V(1,1)
      DO 27 J=2,N
       RB(J)=V(J,1)
   27  X(J)=X(J-1)+DELTAX
       DELTAY=M-1
       DELTAY=(YMAX-YMIN)/DELTAY
       Y(1) = 0.
      DO 28 J=2,M
   28  Y(J)=Y(J-1)+DELTAY
      DO 118  K=2,M
       DO 30 J=1,N
       RA(J)=RB(J)
   30 RB (J)=V(J,K)
      DO 118  J=2,N
   35 ASSIGN 112 TO L
      RR=RA(J)
      XX=X(J)
      YY=Y(K-1)
   37 RL=RR
      XL=XX
      YL=YY
   39 IF(RL.LT.RA(J-1)) GOTO 41
   40 IF(RL-RB(J))42,50 ,50
   41 RL=RA(J-1)
      XL=X (J-1)
      YL= Y(K-1)
      GO TO 40
   42 RL=RB(J)
      XL=X (J)
      YL=Y(K)
   50 RS=RR
      XS=XX
      YS=YY
      IF(RS.GT.RA(J-1)) GOTO 53
   52 IF(RS-RB(J)) 60,60,54
   53 RS=RA(J-1)
      XS=X (J-1)
      YS =Y(K-1)
      GO TO 52
```

```
   54 RS=RB(J)
      XS=X (J)
      YS=Y (K)
   60 RM=RR
      XM=XX
      YM=YY
       IF (RM-RS) 62,2062,61
 2062  IF (XM.EQ.XS .AND. YM.EQ.YS) GO TO 62
  61   IF (RM-RL) 70,2065,62
 2065  IF(XM.EQ.XL .AND. YM.EQ.YL) GO TO 62
       GO TO 70
   62 RM=RA(J-1)
      XM=X (J-1)
      YM=Y (K-1)
       IF (RM-RS) 64,2063,63
 2063  IF (XM.EQ.XS .AND.YM.EQ.YS) GO TO 64
  63   IF (RM-RL) 70,2064,64
 2064  IF (XM.EQ.XL .AND. YM.EQ.YL) GO TO 64
       GO TO 70
   64 RM = RB(J)
      XM=X (J)
      YM=Y (K)
   70 YCS=YS*YCONV
      YCM=YM*YCONV
      YCL=YL*YCONV
   71 YS=YS-YMAX+YMIN
      YM=YM-YMAX+YMIN
      YL=YL-YMAX+YMIN
   72  XCS=XS*SMAX1
       XCM=XM*SMAX1
       XCL=XL*SMAX1
      NC=1
      RC=CNTR(1)
   80 IF(NC.GT.NCONT) GOTO110
      IF ( RC .NE. RM ) GO TO 91
   81 IF ( RM .NE. RS ) GO TO 91
   82 IF ( RL .EQ. RM ) GO TO 100
   91 IF(RC.LT.RS) GOTO 100
      IF(RC-RM)96,93,94
   93 XPA=XCM
      YPA=YCM
      GO TO 99
   94 IF(RC-RL)106,103,110
   96 Q = (RC-RS)/(RM-RS)
   97 XPA = XCS-Q*(XCS-XCM)
      YPA = YCS-Q*(YCS-YCM)
   99 Q = (RC-RS)/(RL-RS)
      XPB = XCS-Q*(XCS-XCL)
      YPB = YCS-Q*(YCS-YCL)
      IF(RC)10115,10116,10116
10115 XPB1=0.5*(XPA+XPB)
      YPB1=0.5*(YPA+YPB)
      IF(ABS (XPA-XPB1)-.001)5001,5002,5002
 5001 IF(ABS (YPA-YPB1)-.001)100,5002,5002
 5002 CALL PLOTZ(XPA,YPA,XPB1,YPB1)
      GO TO 100
```

```
10116 IF(ABS (XPA-XPB)-.001)5003,5004,5004
 5003 IF(ABS (YPA-YPB)-.001)100,5004,5004
 5004 CALL   PLOTZ(XPA,YPA,XPB,YPB)
  100 RC=CNTR(NC+1)
      NC=NC+1
      GO TO 80
  103 XPA = XCL
      YPA = YCL
      GO TO 99
  106 Q=(RC-RM)/(RL-RM)
      XPA=XCM-Q*(XCM-XCL)
      YPA=YCM-Q*(YCM-YCL)
      GO TO 99
  110  GO TO L,(112,118)
  112  ASSIGN 118 TO L
      RR   =RB(J-1)
      XX   =X (J-1)
      YY   =Y (K)
      GO TO 37
  118 CONTINUE
       RETURN
       END
```

```
      SUBROUTINE PLOTZ(X1,Y1,X2,Y2)
      INTEGER EC
      LOGICAL*1 LXS
      DIMENSION X(2),Y(2),LXS(1)
      COMMON/CONTUL/SKIUP(26),
     *              XMIN,XMAX,YMIN,YMAX,XOFF,YOFF,XSIZE,YSIZE,NCONT
      X(1)=XSIZE *X1+XOFF
      X(2)=XSIZE *X2+XOFF
      Y(1)=YSIZE *Y1+YOFF
      Y(2)=YSIZE *Y2+YOFF
      CALL SYSPLT(X(1),Y(1),3)
      CALL SYSPLT(X(2),Y(2),2)
      RETURN
      ENTRY FINDMT(LXS,MT,NBT)
      MT=NBT
      DO 44 J=1,NBT
      IF(EC(LXS(MT),' ').EQ.0) RETURN
   44 MT=MT-1
      RETURN
       END
```

```
FDYN     SUPPORT FOR FORTRAN DYNAMIC BIT AND FULLWORD ARRAYS.                                                         PAGE    2

 LOC  OBJECT CODE      ADDR1 ADDR2  STMT   SOURCE STATEMENT                                            ASM 0200 10.13 08/03/77

                              0000F    2 X15      EQU   15                                                                           11
                              00000    3 X0       EQU   0                                                                            12
                              00001    4 X1       EQU   1                                                                            13
                              00002    5 X2       EQU   2                                                                            14
                              00003    6 X3       EQU   3                                                                            15
                              00004    7 X4       EQU   4                                                                            16
                                       8          ENTRY FREEUP                            FREE A DYNAMIC ARRAY.                      23
0C0000                                 9 GETVEC   CSECT
                                      10          SAVE  (14,4),,*                         SAVE REGISTERS.
0C0000 47F0 F00C        0000C         11+         B     12(0,15)                                        BRANCH AROUND ID       00860000
000004 06                             12+         DC    AL1(6)                                                                 00880000
000005 C7C5E3E5C5C3                   13+         DC    CL6'GETVEC'                                     IDENTIFIER             00900000
00000B 00
C0000C 90E4 D00C        0000C         14+         STM   14,4,12(13)                                     SAVE REGISTERS         01180000
000010 184F                           15          LR    X4,X15                            SET UP A BASE REGISTER.                    55
                              00000   16          USING GETVEC,X4             #X4                                                    56
000012 1821                           17          LR    X2,X1                             (X2)= A(PARAMETER LIST).                   57
000014 5830 2000        00000         18          L     X3,0(,X2)                         (X3)= A(ARRAY ANCHOR).
                              00000   19          USING ANCHOR,X3             #X3                                                    59
000018 5800 3004        00004         20          L     X0,DIMEN                          (X0)= DIMENSION OF ARRAY.                  60
00001C 8800 0002        00002         21          SLA   X0,2                              (X0)= LENGTH OF ARRAY IN BYTES.            61
000020 5000 3000        00000         22          ST    X0,LENGTH
                                      23          GETMAIN R,LV=(0)                        (X1)= A(ARRAY).                            62
0C0024 4510 4028        00028         24+         BAL   1,*+4                                           INDICATE GETMAIN       68800001
000028 0A0A                           25+         SVC   10                                              ISSUE GETMAIN SVC      69000001
0C002A 5010 3004        00004         26          ST    X1,LENGTH+4
00002E 4130 3000        00000         27          LA    X3,0(,X3)                         (X3)= A(ANCHOR(1)).                        65
000032 1B13                           28          SR    X1,X3                             (X1)= A(ARRAY(1)) - A(ANCHOR(1))           66
000034 8A10 0002        00002         29          SRA   X1,2                              CONVERT TO ARRAY INDEX WITH                67
000038 4110 1001        00001         30          LA    X1,1(,X1)                         RESPECT TO THE ANCHOR:                 *   68
                                                                                          ARRAY(1) = ANCHOR(INDEX).                  69
00003C 5010 3008        00008         31          ST    X1,INDEX                          PLANT INDEX IN ARRAY ANCHOR.               70
                                      32          DROP  X3                    #X3                                                    71
                                      33          RETURN (14,4),T,RC=0                    RETURN TO CALLER.
000040 98E4 D00C        0000C         34+         LM    14,4,12(13)                                     RESTORE THE REGISTERS  00260000
000044 92FF D00C        0000C         35+         MVI   12(13),X'FF'                                    SET RETURN INDICATION  00640000
000048 41F0 0000        00000         36+         LA    15,0(0,0)                                       LOAD RETURN CODE       00700000
00004C 07FE                           37+         BR    14                                              RETURN                 00800000
                                      38 FREEUP   SAVE  (14,4),,*                         SAVE REGISTERS.                           124
00004E 47F0 F00C        0000C         39+FREEUP   B     12(0,15)                                        BRANCH AROUND ID       00860000
000052 06                             40+         DC    AL1(6)                                                                 00880000
0C0053 C6D9C5C5E4D7                   41+         DC    CL6'FREEUP'                                     IDENTIFIER             00900000
000059 00
00005A 90E4 D00C        0000C         42+         STM   14,4,12(13)                                     SAVE REGISTERS         01180000
0C005E 184F                           43          LR    X4,X15                            SET UP A BASE REGISTER.                   125
                              0004E   44          USING FREEUP,X4             #X4                                                   126
000060 1821                           45          LR    X2,X1                             (X2)= A(PARAMETER LIST).                  127
000062 5830 2000        00000         46          L     X3,0(,X2)                         (X3)= A(ARRAY ANCHOR).
                              00000   47          USING ANCHOR,X3             #X3                                                   129
0C0066 9801 3000        00000         48          LM    X0,X1,LENGTH                      (X0,X1)= FREEMAIN PARAMETERS.             130
                                      49          DROP  X3                    #X3                                                   131
                                      50          FREEMAIN R,LV=(0),A=(1)                 RELEASE THE CORE.                         132
0C006A 4111 0000        00000         51+         LA    1,0(1)                                  CLEAR THE HIGH ORDER BYTE      03130018
00006E 0A0A                           52+         SVC   10                                ISSUE FREEMAIN SVC                     03140018
                                      53          RETURN (14,4),T,RC=0                    RETURN TO CALLER.
```

```
  LOC  OBJECT CODE     ADDR1 ADDR2  STMT    SOURCE STATEMENT                                       ASM 0200 10.13 08/03/77

000070 98E4 D00C       0000C          54+            LM    14,4,12(13)                          RESTCRE THE REGISTERS  00260000
000074 92FF D00C       0000C          55+            MVI   12(13),X'FF'                         SET RETURN INDICATION  00640000
000078 41F0 0000       00000          56+            LA    15,0(0,0)                            LOAD RETURN CODE       00700000
0C007C 07FE                           57+            ER    14                                   RETURN                 00800000
000000                                58 ANCHOR      DSECT                                                                 465
CC0000                                59             CS    F                    UNUSED WORD.                                469
000004                                60 DIMEN       DS    F                    BITS/ROW OR # OF FULLWORDS.                 470
000008                     00000      61             ORG   ANCHOR                                                          475
CC0000                                62 LENGTH      CS    2F                   LENGTH OF THE ARRAY, BYTES.                 476
000008                                63 INCR        DS    F                    BYTES BETWEEN ROWS IN A BIT       *         480
                                                                                ARRAY.                                      481
                           00008      64 INDEX       EQU   INCR                 INDEX FROM START OF ANCHOR TO     *         482
                                                                                START OF ARRAY FOR FULLWORD       *         483
                                                                                ARRAYS.                                     484
                                      65             END                                                                    486
```