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DIFFUSION ALGORITHMS AND DATA REDUCTION ROUTINE FOR ONSITE REAL-TIME LAUNCH PREDICTIONS FOR THE TRANSPORT OF DELTA-THOR EXHAUST EFFLUENTS

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16. ABSTRACT

The National Aeronautics and Space Administration/Marshall Space Flight Center Multilayer Diffusion Algorithms have been specialized for the prediction of the surface impact for the dispersive transport of the exhaust effluents from the launch of a Delta-Thor vehicle. This specialization permits these transport predictions to be made at the launch range in real time so that the effluent monitoring teams can optimize their monitoring grids.

Basically, the data reduction routine requires only the meteorology profiles for the thermodynamics and kinematics of the atmosphere as an input. These profiles are graphed along with the resulting exhaust cloud rise history, the centerline concentrations and dosages, and the hydrogen chloride isopleths.

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LIST OF SYMBOLS AND DEFINITIONS

Equations

$D(x,y,z)$	= dosage at the point x, y, and z (ppm-sec or mg sec/m^3)
F	= buoyancy term in the instantaneous cloud rise formula
	$= \dfrac{3g\, Q_H}{4c_p\, \pi\, T_s\, \rho_s}$
H	= height of the stabilized exhaust cloud (m)
$K(r,t,p,T)$	= diffusion coefficient
L_i	= ith dimension of the rocket exhaust cloud (m)
M	= molecular weight
Q_H	= heat release source strength (cal)
$\dot{Q}_H$	= rate of heat release for source (cal/sec)
Q_M	= mass source strength of the exhaust cloud (ppm)
R	= universal gas constant (0.289 Joules/g °K)
T	= temperature (°K)
c_p	= specific heat of air at constant pressure (0.24 cal/g °K or 1.003 Joule/g °K)
f	= fractional amount of the total effluent that is released by the rocket in the surface mixing layer
g	= gravitational acceleration (9.8 m/sec^2)
m	= power law exponent for the vertical profile of the wind azimuth
p	= power law exponent for the wind speed
q	= power law exponent for the vertical profile of the standard deviation of wind elevation angle in the surface mixing layer

r_R = initial cloud radius at the rocket exit

s = stability parameter

$$= \frac{g}{T} \frac{\partial \Phi}{\partial z}$$

t = time required for the exhaust cloud to reach equilibrium with the atmosphere at the stabilization height

$\bar{u}$ = mean (time) wind speed (m/sec)

$\langle u \rangle$ = average (space) wind speed (m/sec)

x = down range distance in the wind direction from the point of cloud stabilization (m)

y = distance from the centerline along the wind direction (m)

z = height of the stabilized exhaust cloud (m)

α = horizontal diffusion coefficient

β = vertical diffusion coefficient

γ = entrainment coefficient (solid rockets, 0.64; liquid rockets, 0.50)

ρ = density of the ambient air (mg/m^3)

σ_i = standard deviation of the distribution of the exhaust effluents in the exhaust cloud in the ith direction (m)

$$= \frac{L_i}{4.3}$$

σ_{AR} = standard deviation of the wind azimuth angle at the surface

σ_{AT} = standard deviation of the wind azimuth angle at the top of the layer

LIST OF SYMBOLS AND DEFINITIONS (Continued)

σ_{ER} = standard deviation of the wind elevation at the surface

σ_{ET} = standard deviation of the wind elevation angle at the top of the surface mixing layer

Φ = potential temperature

$\frac{\partial \Phi}{\partial z}$ = vertical gradient of the potential temperature (Φ)

$\Delta\theta$ = change in wind direction between the top and bottom of the surface mixing layer

= $\theta_T - \theta_B$

$\chi(\vec{r}, t)$ = the concentration (ppm or mg/m^3)

Terms

Centerline: the radial vector in the direction of the mean wind direction whose origin is the launch site.

Concentration: the amount of the effluent present at a specific time. The average concentration is the average amount present during the event.

Dosage: the measure of the total amount of effluent (time integrated concentration) due to the vehicle launch at a specific location.

Ground Cloud: that cloud of rocket effluents emitted during the initial phase of vehicle launch. This cloud is assumed to have an ellipsoidal shape.

Plume Cloud: the cloud of rocket effluents emitted from the vehicle in flight. This cloud has a cylindrical shape whose height is defined by the vertical thickness of the layer.

Potential Temperature (Φ): the temperature a volume of dry air would have if brought adiabatically from its initial state to the standard pressure of 100 mb.

Quasiadiabatic Layer:	a layer in which the vertical potential temperature gradient is zero or less.
Stable Layer:	a layer in which the vertical potential temperature gradient is positive.

Definitions for Variable and Register Storage in the Program

1. MET Routine

Lines 0→11

R0,... RB,... R90	altitude data (m or ft)
R1,... R(B+1),... R91	wind direction data (deg)
R2,... R(B+2),... R92	wind speed data (m/sec or kn)
R3,... R(B+3),... R93	temperature (dry bulb, °C)
R4,... R(B+5),... R94	Pressure (mb)

B	increment for storage (by "5's")
C	increment for register location (transfer)
X	transfer increment
Y	maximum transfer location
Z	transfer limit

Lines 12→20

Line 13	RX	temperature data
	RY, R(Y−5)	altitude data
	R(Y−1), R(Y+4)	pressure data
	R(Y+3), R(Y−2)	temperature data
Line 18	RX	wind speed data
Line 20	RX	temperature data
	R3	surface temperature (dry bulb, °C)
	R28	temperature data
	R97	Y-position of the word "TEMP-DRY"
	R98	surface pressure (mb)
	R99	surface temperature (dry bulb, °C)
	B	data conversion increment limit
	X	data increment
	Y	altitude calculation/conversion increment

LIST OF SYMBOLS AND DEFINITIONS (Continued)

Lines 21→26

R0	data count number
R1	surface temperature (dry bulb, °C)
R2	surface density
R25	X-position of the word "TEMP-DRY"

Line 21	A	increment for register storage
	C	transfer limit
Line 25	A	transfer increment
	C	increment for register storage and limit

R4, R8, R12...R76	altitude data (m)
R5, R9, R13...R77	wind direction (deg)
R6, R10, R14...R78	wind velocity (m/sec)
R8, R11, R15...R79	potential temperature (°C)

Lines 27→58

R7	potential temperature at the surface (°C)
R16	Y-position of the word "wind speed"
R18	X-position of the word "wind speed"
R24	Y-position of the word "wind dir."
R25	X-position of the word "wind dir."
R44	Y-position of the word "potential temp."
R47	X-position of the word "potential temp."
R88	maximum wind direction
R89	minimum wind direction
R90	month of meteorology data
R91	day of meteorology data
R92	year of meteorology data
R93	time of meteorology data
RX	altitude data
R(X+1)	wind direction data
R(X+2)	wind speed data
R(X+3)	temperature data

Line 37	RX	wind direction data
	A	X-position of the word "adiabatic potential temp. grad."
	B	Y-position of the word "adiabatic potential temp. grad."
	Y	adiabatic gradient increment

Line 42	A	conversion of maximum wind direction
Line 43	B	conversion of minimum wind direction
	Y	differences of A and B
	C	initial position for plotting wind direction scale
Line 46	X	plotting increment
Line 48	X	data increment

2. Cloud Rise Routine

Lines 0→25

R1	surface temperature (°K)
R64	time data count
R76	R(X+4)–R(X–4)
R82	slope of temperature over altitude
R85	time of rise
R86	cloud height
R99	wind velocity at maximum cloud height

Line 16	R85	time of maximum cloud rise
Line 16	R86	maximum cloud height
	R(X+4), R(X–4), RX	altitude data
	R(X+5), R(X–3)	wind direction data
	R(X+6), R(X–2)	wind speed data
	R(X+7)	temperature data
	R(64+Z)	time data
Line 18	R(64+Z)	time of maximum cloud rise
	A	time square of adiabatic cloud rise model
	B	altitude increment
	C	potential temperature gradient
	Y	time of cloud rise
	Z	time storage increment
Line 21	R82	wind direction at maximum cloud height

3. Diffusion Routine

Lines 0→12

R1	surface temperature (°K)
R1	σ_X

LIST OF SYMBOLS AND DEFINITIONS (Continued)

Line 5	R2	surface pressure (mb)
	R5	wind direction at the surface
	R77	σ_Y
	R78	Q_M
	R79	wind direction at the top of the layer
	R80	maximum concentration
	R81	wind speed at the top of the layer
	R83	σ_{AR}
	R84	σ_{AT}
	R85	time of maximum cloud rise
	R86	maximum cloud H
	R87	top of the layer
	R88	concentration
	R89	radius of cloud in standard deviations
	R90	month of meteorology data
	R91	day of meteorology data
	R92	year of meteorology data
	R93	time of meteorology data
	R97	dummy
	R98	down range distance of maximum concentration
	R101	$\sigma'_A = \sigma'_E$
	R102	plotter constant
	R103	plotter constant
	A	$(\sigma_Z{}^2)/2$
	B	vertical component of multilayer diffusion model
	C	power law exponent – vertical profile of deviation
	X	down range distance
	Y	dosage
Line 6	A	concentration

Lines 13→17

R76 R(X+4)–R(X–4)

R(X+4), R(X–4), RX	altitude data
R(X+5), R(X–3), R(X+1)	wind direction speed
R(X+6), R(X–2), R(X+2)	wind speed data

X data increment

LIST OF SYMBOLS AND DEFINITIONS (Continued)

Lines 18→30

R64	initial time location
R76	X-position at maximum cloud rise
R77	Y-position at maximum cloud rise
R82	wind direction at maximum cloud rise
R94	X-position at maximum cloud rise
R95	Y-position at maximum cloud rise
R96	time after maximum cloud rise at an arbitrary distance
R97	time count limit
R99	wind speed at maximum cloud rise

Line 26	R76	X-position at an arbitrary down range distance after maximum cloud rise
	R77	Y-position at an arbitrary down range distance after maximum cloud rise
	A	polar position of X-value of plotter
	B	time increment
	C	down range distance
	Y	polar position of Y-value of plotter
	Z	down range angle

Lines 31→49

R8	plotter constant
R9	plotter constant
R17	plotter constant
R18	plotter constant
R20	Y test value for zero in Y
R21	X test value for zero in Y
R22	X test value for zero in Y
R23	Y test value for zero in Y
R50	Y-coordinate in plotter
R51	–Y-coordinate in plotter
R52	X-coordinate in plotter
R53	–X-coordinate in plotter
X	down range distance
Y	cross range distance

FA Subroutine

P1	down range distance
P2	cross range distance

LIST OF SYMBOLS AND DEFINITIONS (Concluded)

P3	σ_Y
P4	σ_X
P5	vertical component of multilayer diffusion model
R0	L(X)
R1	σ_X
R2	$\bar{u}$
R5	wind direction at the surface
R6	wind speed at the surface
R77	σ_Y
R78	Q_M
R79	wind direction at the top of the layer
R81	wind speed at the top of the layer
R86	height of maximum cloud rise
R87	height of layer
R88	concentration
R89	radius of the cloud
R101	$\sigma'_E = \sigma'_A$
A	$(\sigma_Z)^2/2$
B	summation on multilayer diffusion model
Z	i

Line 4	B	vertical component of multilayer diffusion model
Line 6	Z	power law exponent for wind speed profile in surface layer

DIFFUSION ALGORITHMS AND DATA REDUCTION ROUTINE FOR ONSITE REAL-TIME LAUNCH PREDICTIONS FOR THE TRANSPORT OF DELTA-THOR EXHAUST EFFLUENTS

SUMMARY

Specialization of the National Aeronautics and Space Administration/Marshall Space Flight Center (NASA/MSFC) Multilayer Diffusion Model for the Delta-Thor vehicle permits a programmable calculator (HP9820A) to be utilized at the launch site to make a forecast of the surface effects resulting from the exhaust effluents of this vehicle. This specialization of the general diffusion model limits the scope of analysis to the surface mixing layer and the ellipsoidal dispersion of the exhaust cloud (model 3) – the resulting concentration and dosage prediction are limited to the earth's surface.

Because of the specialization, the only mandatory inputs to the Delta-Thor version of the NASA/MSFC Surface Layer Diffusion Model are the data points from a rawinsonde sounding and the altitude of the top of the surface mixing layer. The data reduction routine employs the calculator plotter to display the meteorological profile, the temporal history of the rise of the Delta-Thor exhaust cloud to the point of stabilization, and a ground-level delineation of the concentrations and dosage of hydrogen chloride (HCl) along the exhaust cloud path. In addition, the HCl concentration isopleths are plotted on a map of Kennedy Space Center and Cape Canaveral, Florida.

The NASA/MSFC Surface Layer Diffusion Calculator Routine for the Delta-Thor is designed for both real-time launch-site predictions and as a guide in determining the inputs for the NASA/MSFC Multilayer Diffusion Computer Program. This calculator routine is similar to the calculator routine for the Titan III [1], except for a more complex cloud rise routine and a change in source constants.

I. INTRODUCTION

The NASA/MSFC Multilayer Diffusion Algorithms have been specialized for the Delta-Thor vehicle into the NASA/MSFC Surface Layer Diffusion Calculator Program [2] to provide launch-site predictions of the rocket exhaust effluent transport. This calculator program has been designed for launches at Kennedy Space Center.

Investigations to develop quantitative procedures for assessing the environmental effects from the aerospace release of effluents into the atmosphere were initiated in 1962 at NASA's Marshall Space Flight Center because it was recognized that universally accepted and adequately validated prediction techniques for the transport of exhaust effluents were not available. It rapidly became apparent that some uncertainty existed concerning some of the fundamental aspects of this problem, such as the amount and composition of the rocket exhaust effluents, the deposition and scavenging of these effluents, and the dispersal and transport of these effluents in the atmosphere. The available atmospheric measurements to determine the reliability of the description of the rocket transport models in the atmosphere were sparse and of questionable accuracy in the 1960's. In conjunction with the National Environmental Policy Act of 1969 and the April 23, 1972, guidelines of the Council on Environmental Quality, which required environmental assessments for aerospace operations, the need for implementing a NASA program for monitoring the transport of exhaust effluents from large rockets to determine the reliability of the NASA/MSFC transport description was recognized.

As a result of informal discussions between representatives of NASA Headquarters, MSFC, Langley Research Center (LaRC), and Kennedy Space Center (KSC), it became apparent that a NASA in-house rocket exhaust effluent prediction and measurement program was desirable, possible, and feasible. A joint solid rocket motor exhaust prediction (MSFC) and measurement (LaRC and KSC) program evolved in 1972 utilizing the Titan and Delta launches as a source for empirical information that can be employed to more accurately predict the environmental effects from aerospace operations.

The NASA/MSFC Multilayer Diffusion Model is an Eulerian transport model derived from the gradient diffusion theory [1]. The Cramer coefficients are employed to correlate the atmospheric parameters with the eddy diffusion coefficients in this model. Because of the comprehensive nature of this model, the large computation facility at MSFC was normally employed when the model was exercised in the initial research stages of this quantitative investigation. However, from the initial experience in launch support of the rocket exhaust effluent prediction and monitoring activities, it became apparent that real-time, onsite effluent transport predictions are desirable, if feasible. This feasibility implies that a mobile substitute for the large computational facility was needed to transform the description of the atmospheric kinematics and thermodynamics obtained from rawinsonde soundings and meteorological towers into a predicted effluent transport description.

A mobile substitute for the large computer is a programmable calculator (HP9820A). Naturally, this means that the computer program, which requires a core storage of approximately 40K, must be reduced in size. This was achieved by taking the NASA/MSFC Multilayer Diffusion Model – which provides a transport description for any rocket exhaust effluents from any vehicle, anywhere in the troposphere, under any environmental conditions, and for different types of dispersive – and limiting the description's applicability to a specific effluent such as HCl, to a specific vehicle such as the Delta-Thor, to a specific layer in the troposphere such as the surface mixing layer, and to spherical diffusion without deposition effects. The requirement for real-time predictions led to the incorporation of meteorological and buoyancy algorithms as an integral part of the NASA/MSFC Surface Layer Diffusion Program. In addition, user requirements dictated that the surface concentration footprint of the exhaust cloud be superimposed on a map of the Kennedy Space Center area.

The modeling considerations utilized to achieve these results are discussed in Section II. The computational procedures and graphical results are discussed and provided in Section III.

II. NASA/MSFC SURFACE LAYER DIFFUSION MODEL

The spatial description, in terms of concentration and dosage, of the dispersive transport of effluents from a discrete source is afforded by the NASA/MSFC Multilayer Diffusion Model. Specifically, this application of the model is for the prediction of the distribution of the toxic effluents [hydrogen chloride (HCl), carbon monoxide (CO), and alundum (Al_2O_3)] associated with the rocket exhaust which are emitted during the launch of a Delta-Thor vehicle from Cape Canaveral, Florida. The prediction is used to assess the resulting environmental effects. The dispersive description afforded by this multilayer diffusion model is initiated at the point where the rocket exhaust cloud of effluents reaches thermodynamic equilibrium with the environment – cloud stabilization – and therefore depends strongly on the kinematic and thermodynamic profiles of the atmosphere, along with the chemical and thermodynamic composition of the exhaust cloud.

Thus, the initial considerations in this section are given to the atmospheric description employed as the input to the cloud rise algorithms. The discussion of the stabilized cloud considers the algorithms for both the cloud rise and cloud dimensions utilized as the initial inputs to the NASA/MSFC Multilayer Diffusion Model. The final portion of this section provides the significant mathematical expressions that were employed to obtain the centerline concentrations and dosages and the concentration isopleths.

A. Meteorological Profile

The influence of the atmospheric conditions on the dispersive transport of rocket exhaust effluents is the basis for the format of the meteorological profile. To illustrate, consider the diffusion equation. The solution of the differential equation for the diffusion dictates that the diffusion problem be treated in two stages [2]. The nonlinear differential form of the diffusion equation is

$$\frac{\partial \chi(\vec{r},t)}{\partial t} + \langle \vec{v} \rangle \cdot \nabla \chi(\vec{r},t) = \nabla \cdot [\tilde{K}(\vec{r},t,p,T) \cdot \nabla \chi(\vec{r},t)] \quad , \tag{1}$$

where

$\chi(\vec{r},t)$ is the scalar concentration of the diffusing gas.

$\langle\vec{v}\rangle$ is the average wind velocity (temporal-spatial average).

$\tilde{K}(\vec{r},t,p,T)$ is the diagonal diffusion tensor which is a function of position, time, and the thermodynamic parameters, pressure and temperature.

To solve this differential equation by the separation of variables, the necessary assumptions must be established to make this equation linear [3]. The normal technique – and the one used in the NASA/MSFC Multilayer Diffusion Model – to linearize the diffusion equation [equation (1)] is to restrict the model to a kinematic description by assuming that the diffusion coefficient $(\vec{K})$ is a time averaged value and is thermodynamically independent. This implies the initial conditions occur when the rocket exhaust cloud achieves thermodynamic equilibrium with the atmosphere at cloud stabilization. Consequently, the effluent transport problem can be separated into two phases, the thermodynamic phase during cloud rise and the kinematic phase of diffusion.

The atmospheric thermodynamic parameters (pressure, temperature, and density) govern the magnitude of the buoyant force on the exhaust cloud and thus dictate the height of cloud rise. Incorporating these atmospheric thermodynamic parameters into a suitable concise thermal description that will efficiently interface with the cloud rise algorithms requires the following considerations. Since the temperature (T) is a function of the pressure (p), as expressed in Poisson's equation,

$$\frac{T}{T_o} = \left(\frac{p}{p_o}\right)^{\frac{R}{C_p}} \quad , \tag{2}$$

where

R is the universal gas constant.

C_p is the specific heat at a constant pressure.

$R/C_p = 0.288.$

The concept of a potential temperature (Φ) is introduced to reference the temperature to a specific pressure (1000 mb) and is defined as

$$\Phi = T\left(\frac{1000}{p}\right)^{0.288} \quad . \tag{3}$$

The potential temperature can be shown to be a measure of the entropy ($s = C_p \ln \Phi$ + constant); therefore, the vertical potential gradient ($\partial\Phi/\partial z$) is a measure of the change in entropy [4]. Since in an adiabatic process there is not a change in entropy, the potential temperature gradient is zero (which corresponds to a straight vertical line on the meteorological profile).

To achieve exhaust cloud stabilization with the atmosphere, an entropy balance must be achieved between the exhaust cloud and the atmosphere, which can be determined by utilizing the thermodynamic description afforded by the potential temperature profile. In the case of a hot rocket exhaust cloud, this balance results from both entrainment due to the turbulent mixing of this cloud and the exhaust cloud rising in the atmosphere to a region of higher entropy. If the potential temperature difference between the surface and a cloud height is negative or zero – what shall be defined here as an adiabatic condition – the entropy difference between the exhaust cloud and atmosphere will continue to increase and cloud stabilization will not occur. However, if the potential temperature gradient is positive – a stable condition – the entropy difference between the exhaust cloud and the atmosphere decreases as the exhaust cloud rises until equilibrium is obtained. Thus, the thermodynamic influences of the atmosphere on the hot rocket exhaust cloud during the initial transport stage where the exhaust cloud is rising to the point of equilibrium can be determined directly from the potential temperature profile.

During the kinematic stage of the rocket exhaust effluent transport, the potential temperature profile can also be a guide to the top of the surface mixing layer in that the signature for the top of the surface mixing layer is characterized by a change in the meteorological conditions. Specifically, this signature can be a change in wind velocity, a change in thermal gradient, or both. The change in thermal gradient is normally a result of a temperature inversion or possibly an isothermal layer above the altitude of cloud stabilization – both of which result in a more positive potential temperature gradient.

The NASA/MSFC Multilayer Diffusion Model depends strongly on the wind direction and speed profiles in the surface mixing layer (first 2 km) to determine the surface effects from the kinematics of the exhaust cloud. These profiles are required not only for the mean wind speed and direction at the cloud stabilization height, but also for the wind speed and directional shears over the surface mixing layer.

The meteorological profile (wind speed, wind direction, temperature, and pressure) is normally obtained from a rawinsonde sounding of the atmosphere. To obtain the entropy profile required for these soundings, the dry bulb temperature and pressure are translated into the potential temperature in accordance with equation (3).

If the levels of the sounding are referenced only in terms of pressure, rather than altitude (z) and pressure, the altitude of the level is computed using

$$z = 29.3\,(T + T_o)\ln\frac{p_o}{p} \quad , \tag{4}$$

where the subscript "o" refers to the next lower level that is referenced in the sounding to an altitude.

Thus, the atmospheric thermodynamic parameters required for the cloud rise plume are the pressure and temperature which are utilized in obtaining the potential temperature profile. The atmospheric kinematic parameters required for the diffusion phase are the wind speed and direction. The delineation of these parameters as a function of altitude comprises the meteorological profile.

B. Delta-Thor Exhaust Cloud-Rise Relations

During a normal Delta-Thor launch, the burning of the rocket engine and motors results in the formation of a hot exhaust cloud of the rocket exhaust effluents. Subsequently, this exhaust cloud rises and entrains ambient air until thermodynamic equilibrium between the exhaust cloud and the ambient atmosphere is attained. The first stage of the Delta-Thor vehicle is comprised of a liquid-fueled engine and six solid rocket motors; therefore, the Delta-Thor has a moderate residence time on the launch pad – somewhere between that of the Titan [5] and the Saturn [6]. This characteristic results in a hybrid entrainment process that is a cross between spherical entrainment – an instantaneous source – and cylindrical entrainment – a continuous source. Since the propellant expenditure rate is approximately the same for the engine and the motors, the cloud rise relation for the Delta-Thor is, therefore, an average between the instantaneous and continuous models. In accordance with these assumptions, the cloud rise equations will be developed for the Delta-Thor vehicle that will afford similar results to those obtained by G. A. Briggs [7]. The description developed here for the temporal delineation of the cloud rise during the thermodynamic stage is designed to afford the maximum height as well as the temporal delineation of the cloud rise. This temporal delineation of the cloud rise is, in turn, coupled with the atmospheric kinematic profile to obtain the spatial history of the cloud rise in order to locate the point of the exhaust cloud stabilization.

The cloud rise formulation, as was pointed out previously, is dependent on the stability of the thermodynamic condition in the atmosphere. The potential temperature gradient ($d\Phi/dz$) is the index of the stability, which is given by

$$\frac{d\Phi}{dz} = \left(\frac{1000}{p}\right)^{\frac{R}{c_p}} \frac{\partial T}{\partial z} + \frac{g}{c_p} = \frac{\Phi}{T} + \frac{g}{c_p} \quad , \tag{5}$$

where the potential temperature (Φ) is defined in equation (3). The other variables in equation (5) are the dry bulb temperature (T, °K), the pressure (p, mb), and the altitude above the surface (z, m). The constants are the specific heat of air at constant pressure (C_p = 1.003 Joules/g °K), the gas constant (R = 0.289 Joules/g °K), and the gravitational acceleration (g, m/sec^2). If

$$\frac{\Delta\Phi}{\Delta z} \leqslant 0 \quad , \tag{6}$$

where $\Delta\Phi$ and Δz are the potential temperature difference and the altitude difference between the surface and the altitude of interest, then it is assumed that adiabatic rather than stable conditions exist. The cloud rise height (z) for a Delta-Thor for an adiabatic atmosphere is given by [8]

$$z_A = \frac{1}{2}\left\{\left[\frac{2\,F_s t^2}{\gamma_s^{\,3}} + \left(\frac{r_R}{\gamma_s}\right)^4\right]^{1/4} + \left[\frac{3\,F_l\,t^2}{2\,\gamma_\ell^2\,\bar{u}} + \left(\frac{r_R}{\gamma_\ell}\right)^3\right]^{1/3} - r_R\left(\frac{1}{\gamma_s} + \frac{1}{\gamma_\ell}\right)\right\} \quad , \tag{7}$$

whereas the cloud rise height (z_s) for a Delta-Thor for a stable atmosphere is given by [8]

$$\begin{aligned} z_s = \frac{1}{2}\Bigg[& \left\{\frac{4\,w_o\,r_R^{\,3}}{\gamma_s^{\,3}\,s^{1/2}}\sin\left(s^{1/2}t\right) + \frac{4F_s}{\gamma_s^{\,3}\,s}\left[1-\cos\left(s^{1/2}t\right)\right] + \left(\frac{r_R}{\gamma_s}\right)^4\right\}^{1/4} \\ & + \left\{\frac{3\,w_o^{\,2}\,r_o^{\,2}}{\gamma_\ell^2\,\bar{u}\,s^{1/2}}\sin\left(s^{1/2}t\right) + \frac{3\dot{F}_l}{\bar{u}\,\gamma_\ell^2\,s}\left[1-\cos\left(s^{1/2}t\right)\right] + \left(\frac{r_R}{\gamma_\ell}\right)^3\right\}^{1/3} \\ & - r_R\left(\frac{1}{\gamma_s} + \frac{1}{\gamma_\ell}\right)\Bigg] \quad . \end{aligned} \tag{8}$$

The variables are the initial vertical cloud speed (w_o, m/sec), the buoyancy term (F_s, m^4/sec^2 and $\dot{F}_\ell$, m^4/sec^3), the stability term (s, sec^{-2}), and the time after ignition (t,sec). The subscripts s and l denote solid or liquid. The constants are the entrainment coefficient ($\gamma_s = 0.64$ and $\gamma_\ell = 0.50$) and the initial cloud radius (r_R, m).

The buoyancy term for the solid motor is

$$F_s = \frac{3g\, Q_s}{4\, c_p\, \pi\, \rho_s\, T_s} \quad , \tag{9}$$

and the buoyancy flux for the liquid engine is

$$\dot{F}_\ell = \frac{g\, \dot{Q}_\ell}{c_p\, \pi\, \rho_s\, T_s} \quad , \tag{10}$$

where

ρ_s (g/m³) is the surface density.

T_s (°K) is the surface temperature.

Q_s (cal) is the effective heat release.

$\dot{Q}_\ell$ (cal/sec) is the rate of heat released.

Based on a least squares curve fit of Titan IIIC data [2], the heat release as a function of cloud height is

$$Q_s = 1.32095\, \dot{Q}_\ell\, z_R^{\,0.39457} = 7.58557 \times 10^8\, z^{0.39457} \quad , \tag{11}$$

since

$$\dot{Q}_\ell = 4.58812 \times 10^5 \text{ cal/sec} \quad .$$

Thus, the relationship between the buoyancy terms is

$$F_\ell = 1.009375\ F_s\ z^{-0.39457} \quad . \tag{12}$$

For the Delta-Thor, the initial cloud radius (r_R) is effectively zero, which permits equations (7) and (8) to be written as follows.

1. Adbiatic exhaust cloud rise time:

$$t_A = \frac{1}{2} \sqrt{\alpha\ (1 + 1.259756\ \bar{u}\ z^{-0.605430}} \quad , \tag{13}$$

where

$$\alpha \equiv \sqrt{\frac{z^4\ \gamma_s^{\ 3}}{2\ F_s}} = \sqrt{1.772533\ \times\ 10^{-11}\ \rho_s\ T_s\ z^{3.605430}} \quad . \tag{14}$$

2. Stable case:

$$t_s = \frac{\text{arc cos}\left[1 - \frac{s\alpha}{2}\right] + \text{arc cos}\left[1 - 0.629878\ s\ \alpha\ \bar{u}\ z^{-0.605430}\right]}{2\sqrt{s}} \quad , \tag{15}$$

where the stability term is

$$s = \frac{g}{T_s} \frac{\Delta\Phi}{\Delta z} = \frac{9.8}{T_s} \frac{\Delta\Phi}{\Delta z} \quad . \tag{16}$$

The potential temperature gradient is taken directly from the potential temperature profile at launch time.

The exhaust cloud rise algorithm for the Delta-Thor [equations (13) and (15)] affords only a temporal description of the ascent of the exhaust cloud to the point of cloud stabilization. Examination of the adiabatic cloud rise relation [equation (13)] reveals that a time for cloud stabilization is not defined, and this may be disturbing to some. However, two points should be remembered:

1. When there is an adiabatic lapse rate in the atmosphere, this lapse rate exists in a relatively thin layer near the ground, with a stable layer above it.

2. Since, as was pointed out previously, an entropy balance between the exhaust cloud and its local environment is required, cloud stabilization only can occur where there is a positive potential temperature difference between an altitude and the surface; that is, in a stable layer. The altitude range in kilometers of the stable cloud rise algorithm [equation (15)] is between the surface and cloud stabilization; i.e.,

$$0 \leqslant z \leqslant (\rho_S T_S s^2)^{-0.277} \left[1 + 4 \bar{u}^{-2/3} (\rho_S T_S)^{-0.05} \right] \mathrm{km} \quad . \tag{17}$$

Beyond these limits, the periodic nature of the algorithm results in variations outside these limits. Since the stability term (s) is a function of altitude [equation (16)], the maximum cloud rise height requires some form of an iterative solution to obtain this height.

To summarize, the temporal cloud rise delineation that is obtained from the cloud rise algorithms is interfaced with the meteorological kinematics to predict the cloud path before stabilization. It should be noted that the cloud rise algorithms given in this part are valid only for the Delta-Thor since the source strength utilized is for the Delta-Thor. In addition, these cloud rise relations are a hybrid cross between the instantaneous and continuous cloud rise relations.

C. Delta-Thor Version of NASA/MSFC Multilayer Diffusion Model

By specialization of the NASA/MSFC Multilayer Diffusion Model for the Delta-Thor exhaust effluents, the prediction for the ground-level concentration isopleths can be obtained from a small programmable desk calculator (HP9820) in real time. The modeling approach employed is as follows.

The general differential equation for kinematic diffusion [equation (1)] can be linearized by assuming that the meteorological profile represents the average atmospheric conditions over the area of interest and solved by separation of variables for the spatial distribution of the concentration and dosage resulting from the launch of the Delta-Thor.

The temporal variations are accounted for by the standard deviation terms for the elevation and azimuth. Because of the complexity of the resulting formulation, a generalized model will first be presented as an introduction to the actual algorithm [2].

The generalized concentration model for a nearly instantaneous source is expressed as the product of five modular terms:

$$\text{Concentration} = \{\text{Peak Concentration Term}\} \times \{\text{Along-Wind Term}\} \times \{\text{Lateral Term}\} \times \{\text{Vertical Term}\} \times \{\text{Depletion Term}\}\ ,$$

whereas the generalized dosage model for a nearly instantaneous source is defined by the product of four modular terms:

$$\text{Dosage} = \{\text{Peak Dosage Terms}\} \times \{\text{Lateral Term}\} \times \{\text{Vertical Term}\} \times \{\text{Depletion Term}\}\ .$$

Thus, the mathematical description for the concentration and dosage models permits flexibility in application to various sources and for changing atmospheric parameters while always maintaining a rigorous mass balance.

Two obvious differences exist. First, the peak concentration term refers to the concentration at the point x, y = 0, z = H (where x is the wind direction and H is any height) and is defined by the expression

$$\text{Peak Concentration} = \frac{Q_m}{(2\pi)^{3/2}\,\sigma_x\,\sigma_y\,\sigma_z}\ , \tag{18}$$

where Q_m is the mass source strength and σ_i is the standard deviation of the concentration distribution in the ith direction. The peak dosage term is given by

$$\text{Peak Dosage} = \frac{Q_m}{2\,\pi\,\bar{u}\,\sigma_y\,\sigma_z}\ , \tag{19}$$

where $\bar{u}$ is the mean wind speed over the layer. The second difference between these models is that the concentration contains a modular along-wind term to account for downstream temporal effects not considered in the dosage model. The along-wind term affords an exponential decay in concentration as a function of cloud transit time, concentration distribution, and the mean wind speed.

The lateral term (which is common to both models) is another exponential decay term and is a function of the Gaussian spreading rate and the distance laterally from the mean wind azimuth. The vertical term (again common to both models) is a rather complex decay function since it contains a multiple reflection term for the point source which stops the vertical cloud development at the top of the mixing layer and eventually changes the form of the vertical concentration distribution from Gaussian to rectangular. The last modular in both models is the depletion term. This term accounts for the loss of material by simple decay processes, precipitation scavenging, or gravitational settling. The depletion term will be neglected in the Delta-Thor version of the model.

The meteorological profile is utilized in layering the atmosphere in accordance with homogeneous kinematic and thermodynamic properties – hence the name "multilayer diffusion model." The specialization of the general NASA/MSFC Multilayer Diffusion Model has limited the number of layers for consideration to just the surface mixing layer. In addition, it is assumed that the source has a spherical shape with ellipsoidal expansion (model 3 of the NASA/MSFC Multilayer Diffusion Model [1]).

Thus, the dosage algorithm is

$$D\{x, y, z_B < z < z_T\} = \frac{Q_m}{2\pi \sigma_y \sigma_z \bar{u}} \left[\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\right] \left(\exp\left[\frac{-(H-z)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(H-2z_B+z)^2}{2\sigma_z^2}\right]\right.$$

$$+ \sum_{i=1}^{\infty} \left\{ \exp\left[\frac{-[2i(z_T-z_B)-(H-2z_B+z)]^2}{2\sigma_z^2}\right]\right.$$

$$+ \exp\left[\frac{-[2i(z_T-z_B)+(H-z)]^2}{2\sigma_z^2}\right] + \exp\left[\frac{-[2i(z_T-z_B)-(H-z)]^2}{2\sigma_z^2}\right]$$

$$\left.\left. + \exp\left[\frac{-[2i(z_T-z_B)+(H-2z_B+z)]^2}{2\sigma_z^2}\right]\right\}\right) \quad , \qquad (20)$$

where Q_m corresponds to the source strength or total mass of material in the layer, H is the height of the centroid of the stabilized cloud, and subscripts T and B stand for the top and bottom.

By restricting the dosage mapping to the surface and defining the bottom of the layer as the surface, equation (20) simplifies to

$$D\{x, y, o\} = \frac{Q}{2\pi \sigma_y \sigma_z \bar{u}} \left[\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\right]\left[\exp\left(\frac{-H}{\sigma_z^2}\right)\right]$$

$$+ \sum_{i=1}^{n} \left\{ \exp\left[\frac{-(2i\,z_T + H)^2}{\sigma_z^2}\right] + \exp\left[\frac{-(2i\,z_T - H)}{\sigma_z^2}\right]\right\} , \qquad (21)$$

where z_t is the altitude of the top of the surface mixing layer and n is such that the first exponential in the summation is greater than 100. This is the specialized dosage algorithm that is used.

The source strength (Q, ppm) for the HCl from the Delta-Thor is

$$Q = w_s \cdot 10^3 f_{HCl} \left(\frac{22.4}{M_{HCl}}\right)\left(\frac{T_s}{273.16}\right)\left(\frac{1013.2}{p_s}\right) , \qquad (22)$$

where

w_s is the fuel expenditure rate of the solid motors ($7.983386 \times 10^5\ z^{0.39457}$ g).

f_{HCl} is the factor of HCl in propellant (0.2083).

M_{HCl} is the molecular weight of HCl (36.5).

The source strength is

$$Q = 3.78538 \times 10^8 \frac{T_s}{p_s} \times H^{0.39457} , \qquad (23)$$

where the surface temperature (T_s, °K) and the surface pressure (p_s, mb) are used, since only the concentrations and dosages at the surface are of interest.

The standard deviation of the crosswind distribution (σ_y), the standard deviation of the vertical distribution (σ_z), and the mean wind speed ($\bar{u}$) are defined as follows.

1. The standard deviation of the crosswind dosage distribution is defined by

$$\sigma_y = \left\{ \left[\sigma'_A \{\tau\} x_{Ry} \left(\frac{x + x_y - x_y(1-\alpha)}{\alpha x_{Ry}} \right)^{\alpha} \right]^2 + \left(\frac{\Delta\theta' x}{4.3} \right)^2 \right\}^{1/2} , \qquad (24)$$

where $\sigma'_A(\tau)$ corresponds to the mean layer standard deviation of the wind azimuth for the cloud stabilization time (τ). The difference in the wind direction ($\Delta\theta'$, radians) is taken between the surface and the top of the surface mixing layer in accordance with

$$\Delta\theta' = (\theta_T - \theta_B)\left(\frac{\pi}{180} \right) , \qquad (25)$$

where θ_T and θ_B are the mean wind direction in degrees at the top and at the base of the layer, respectively. This is the wind shear. If the diffusion coefficient is again assumed to be one ($\alpha = 1$), equation (24) becomes

$$\sigma_y = \left\{ \left[\sigma'_A \{\tau\} (x + x_y) \right]^2 \left(\frac{\Delta\theta' x}{4.3} \right)^2 \right\}^{1/2} . \qquad (26)$$

From this relation, one can determine the importance of the wind shear in determining the crosswind distribution of the effluent. In the surface layer

$$\sigma'_A\{\tau\} = \frac{\sigma'_{AR}\{\tau\} \left[(z_T)^{m+1} - (z)^{m+1} \right]}{(m+1)(z_T - z)(z)^m} , \qquad (27)$$

where the standard deviation of the wind azimuth angle $[\sigma'_{AR}(\tau)]$ at height z_R and for the cloud stabilization time τ is

$$\sigma'_{AR}\{\tau\} = \sigma_{AR}\{\tau_o\}\left(\frac{\tau}{\tau_o}\right)^{1/5}\left(\frac{\pi}{180}\right) \quad . \tag{28}$$

Here $\sigma_{AR}\{\tau_o\}$ is the standard deviation of the wind azimuth angle at height z_R and for the reference time period (τ_o), and the power-law exponent (m) for the vertical profile of the standard deviation of the wind azimuth angle in the surface layer is

$$m = \log\left(\frac{\sigma'_{AT}\{\tau\}}{\sigma'_{AR}\{\tau\}}\right) \Bigg/ \log\left(\frac{z_T}{z_R}\right) \quad . \tag{29}$$

Then,

$$\sigma'_{AT}\{\tau\} = \sigma_{AT}(\tau_o)\left(\frac{\tau}{\tau_o}\right)^{1/5}\left(\frac{\pi}{180}\right) \quad , \tag{30}$$

where $\sigma_{AT}\{\tau_o\}$ is the standard deviation of the wind azimuth angle at the top of the surface layer for the reference time period.

The standard deviation of the wind azimuth angle cannot be determined at the top of the surface mixing layer because a temporal history of the wind azimuth cannot be obtained. This is normally calculated using the power-law relation

$$\sigma_{AT}\{\tau_o\} = \sigma_{AR}\{\tau\}\left(\frac{z_T}{z_R}\right)^{-p} \quad , \tag{31}$$

where

$$p = \log\left(\frac{u_T}{u_R}\right) \Big/ \log\left(\frac{z_T}{z_R}\right) \quad , \tag{32}$$

where u is the wind speed at the top of the surface mixing layer.

The crosswind virtual distance is

$$x_y = \frac{\sigma_{yo}}{\sigma'_A\{\tau\}} - x_{Ry} \quad , \tag{33}$$

where σ_{yo} is the standard deviation of the lateral source dimension, which is

$$\sigma_{yo} = \gamma H = 0.64 \, H \quad , \tag{34}$$

where H(m) is the height of the exhaust cloud stabilization.

2. The standard deviation of the vertical dosage distribution is defined by the expression

$$\sigma_z = \sigma'_E \, x_{Rz} \left[\frac{x + x_z - x_{Rz}(1-\beta)}{\beta \, x_{Rz}}\right]^{\beta} \quad , \tag{35}$$

where

σ'_E describes the mean standard deviation of the wind elevation angle.

x_z gives the vertical virtual distance.

β accounts for vertical diffusion.

x_{Rz} is the distance over which rectilinear vertical expansion occurs downwind from an ideal point source.

In this specialization, it is assumed that the vertical diffusion coefficient is one (β=1), which permits rewriting equation (35) as

$$\sigma_z = \sigma'_E (x + x_z) \quad , \tag{36}$$

where

$$\sigma'_E = \sigma'_A \quad . \tag{37}$$

Thus, σ'_A is obtained from equation (32), since (in general) the value for σ'_E cannot be obtained without special instrumentation.

The vertical distance x_z is given by the expression

$$x_z = \frac{\sigma_{zo}}{\sigma'_E} - x_{Rz} \quad , \tag{38}$$

where $\sigma_{zo} = \sigma_{yo}$ is the standard deviation of the vertical dosage distribution at x_{Rz}, the distance from the source where the measurement is made in the surface mixing layer.

3. The mean speed of cloud transport ($\bar{u}$) in the surface layer is defined in accordance with the power law

$$\bar{u}\{z\} = \bar{u}_R \left(\frac{z}{z_R}\right)^p \quad , \tag{39}$$

where $\bar{u}_R$ is the mean wind speed measured at the reference height z_R and the power-law exponent (p) for the wind speed profile in the surface layer is described by

$$p = \log\left(\frac{\bar{u}_T}{\bar{u}_R}\right) \Big/ \log\left(\frac{z_T}{z_R}\right) \quad . \tag{40}$$

Here, $\bar{u}_T$ corresponds to the mean wind speed at the top of the surface layer (z_T). Thus, in the surface layer, the mean cloud transport speed ($\bar{u}$) is

$$\bar{u} = \frac{\bar{u}_R}{(z_T - z_R)\, z_R{}^p} \int_{z_R}^{z_T} z^p\, dz \quad , \tag{41}$$

which reduces to

$$\bar{u} = \frac{\bar{u}_R \left[(z_T)^{1+p} - (z_R)^{1+p} \right]}{(z_T - z_R)\, (z_R)^p\, (1+p)} \quad . \tag{42}$$

The concentration (χ) follows directly from the results for the dosage (D) algorithm given in equation (21). The average concentration then is just

$$\bar{\chi}\,\{x, y, z\} = D\{x, y, z\} \left(\frac{\bar{u}}{4.3\, \sigma_x} \right) \quad , \tag{43}$$

where the standard deviation of the along-wind concentration distribution (σ_x) in the layer is

$$\sigma_x = \left\{ \left[\frac{L\,(x)}{4.3} \right]^2 + \sigma_{xo}{}^2 \right\}^{1/2} \tag{44}$$

and the along-wind cloud length ($L\{x\}$) for a point source in the layer at the distance x from the source is

$$L\{x\} = \frac{0.28\, (\Delta\, \bar{u})\, (x)}{\bar{u}} \quad . \tag{45}$$

Here, $\Delta\bar{u}$ is the vertical wind speed shear in the layer and is defined as

$$\Delta\, \bar{u} = \bar{u}_T - \bar{u}_R \tag{46}$$

and σ_{xo} is the standard deviation of the along-wind source dimension in the layer at the point of cloud stabilization. The above equation for $L\{x\}$ is based on the theoretical and empirical results reported by Tyldesley and Wallington [9], who analyzed ground-level concentration measurements made at distances of 5 to 120 km downwind from instantaneous line-source releases.

In summary, it should be pointed out that the standard deviations of the vertical, crosswind, and along-wind terms represent the cloud dimensions (L_i); that is,

$$L_i = 4.3\, \sigma_i \quad . \tag{47}$$

The factor 4.3 represents the 97-percent confidence level of a normal distribution. Hence, the initial source dimension is translated into the standard deviation initially for modeling. The standard deviations σ_x, σ_y, σ_z give the cloud size during the diffusion process.

III. NASA/MSFC SURFACE LAYER DIFFUSION CALCULATOR PROGRAM

The NASA/MSFC Multilayer Diffusion Calculator Program has been specialized to provide the NASA/MSFC Surface Layer Diffusion Computer Program in accordance with the discussion given in Section II. The specialization amounts to restricting the applicability to the surface prediction of the transport of HCl for the Delta-Thor. In addition to these modifications, the NASA/MSFC Surface Layer Diffusion Program also incorporates algorithms to calculate a meteorological profile and cloud rise.

Data requirements are a rawinsonde sounding from the surface to approximately 2 km (or about 7000 ft) and the standard deviation of the wind azimuth at the surface. This program utilizes this information to generate graphs for: (1) meteorological profile, (2) the temporal history of the exhaust cloud rise to the point of stabilization, (3) the surface centerline concentration and dosage of HCl along the cloud path, and (4) the surface HCl isopleth along with this path. The operations of the NASA/MSFC Surface Layer Diffusion Program are straightforward since inputs are called through calculator display. The overall block diagram, showing how the routines are interfaced, is given in Figure 1.

The initial discussion in this section affords a description of the operation of the program along with its inputs and outputs. The second part gives detailed instructions for operating the NASA/MSFC Surface Layer Diffusion Program. These instructions are summarized in Appendix A. The last part presents the operational sophistication for processing time reduction.

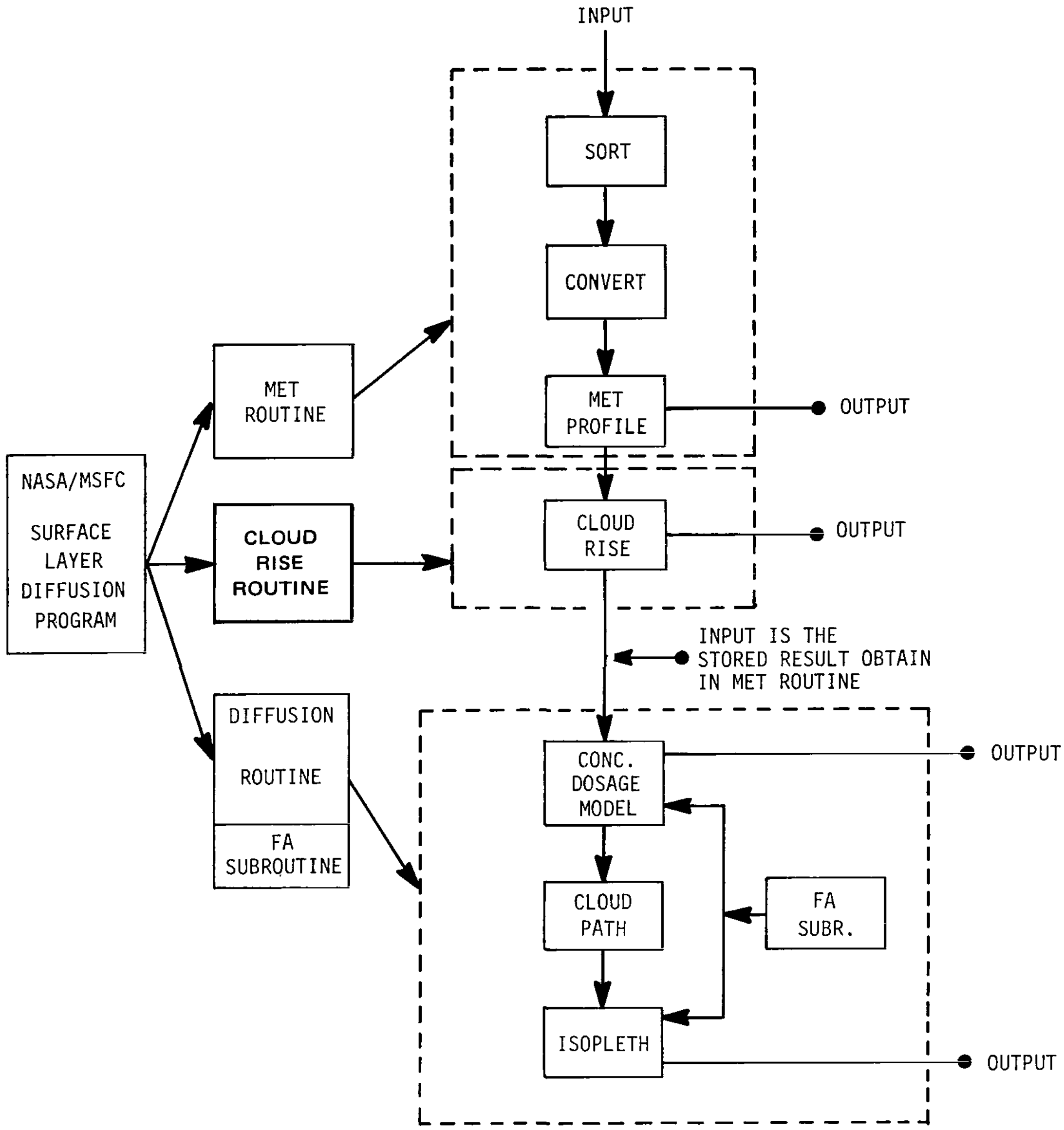


Figure 1. Block diagram of NASA/MSFC Surface Layer Diffusion Program.

A. Overviews of the Computations, Inputs, and Outputs Performed in Each Routine

The NASA/MSFC Surface Layer Diffusion Program is divided into three parts to meet storage limitations of the HP9820 calculator. The first part is the MET routine, the second part is the cloud rise routine, and the third part is the diffusion routine (Fig. 1).

During operations, the MET routine, which generates the inputs for the diffusion model, is erased after cloud rise computations with the loading of the diffusion routine. The meteorological and cloud rise data in storage are not affected during this transition.

Both of these routines can be subdivided into sections where a computational or plotting procedure is carried out. The MET routine performs four processes – two are involved with raw data processing, and the other two with plot generation. These sections are the sort, convert, meteorological profile, and cloud rise. Similarly, the diffusion routine contains four sections of which three sections are involved in generating the two diffusion mappings and the other section contains the basic algorithms for the concentration and dosage calculations. These are the centerline dosage and concentration section, cloud path section, isopleth section, and the FA subroutine. The FA subroutine differs from the other sections in that this subroutine is utilized more than once in part of the program.

The first subroutine of the MET routine is the sort subroutine, which takes the rawinsonde sounding (Table 1), sorts out the data sets (pressure, temperature, altitude, and wind velocity) by pressure, and places these sets in descending order into storage. Termination factors for ending processing loops are derived at the completion of data entry for use in the MET routine.

TABLE 1. INPUT DATA FOR THE SORT ROUTINE

TEST NBR 0475
RAWINSONDE RUN
CAPE CANAVERAL MTA. FLA.
12/20/73 1545Z
ASCENT NBR 0092

ALT FT.	WDIR	WKTS	TEMP	DEW PT	PRESS	RM	AS HUM	DEN	IR	VS	WS
16	200	12	17.0	10.8	1022.0	66	9.63	1220.8	330	668	
1000	213	19	13.5	5.3	986.5	57	6.74	1194.8	307	659	12
2000	236	15	11.6	2.5	951.4	58	5.96	1160.2	295	657	8
3000	211	12	15.1	-16.6	917.6	9	1.25	1108.0	254	661	6
4000	270	10	14.5	-18.1	885.1	8	1.10	1071.2	245	660	2
5000	259	5	13.7	-19.4	853.7	8	0.99	1035.8	236	660	4
6000	232	3	12.1	-20.4	823.2	8	0.91	1004.6	229	658	2
7000	237	4	9.9	-22.4	793.6	8	0.77	975.9	222	655	1

		MANDATORY LEVELS				
ALT FT.	WDIR	WKTS	TEMP	DEW PT	PRESS	RM
626	223	15	14.8	7.4	1000.0	61
2043	237	15	11.8	1.5	950.0	56
3539	213	11	14.7	-17.4	900.0	9
3120	256	5	13.6	-19.5	850.0	8
6751	233	4	10.5	-21.8	800.0	8

SIGNIFICANT LEVELS		
TEMP	DEW PT	PRESS
17.0	10.8	1022.0
13.4	5.2	986.0
11.2	4.7	955.0
9.0	-23.5	782.0

The second subroutine is the convert subroutine, which takes the data from the sort subroutine and converts the units of the parameters into units that are compatible with the calculations. Unit conversions are feet to meters (altitude), knots to meter/seconds (wind speed), and dry bulb temperature to potential temperature. If the altitude for a data set was not given in the rawinsonde sounding, the altitude is calculated using equation (4). The dry bulb temperature is plotted in this section (Fig. 2), and options exist at the end of this subroutine to record the processed meteorological data. The data from a formerly processed sounding can be reanalyzed by introducing the data at the end of this subroutine.

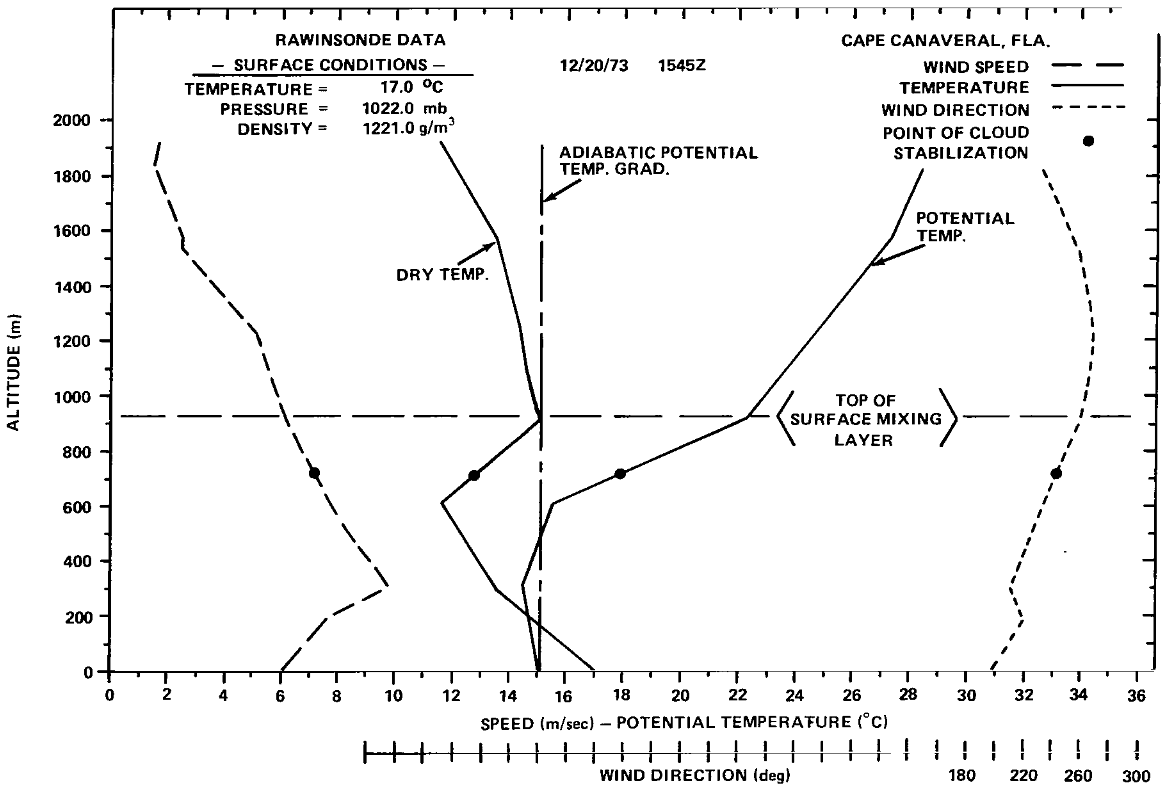


Figure 2. Meteorological profile.

The third subroutine, the meteorological profile subroutine, plots out wind direction, wind speed, and potential temperature (Fig. 2). This routine is strictly peripheral to the diffusion calculations since it does not contain any data processing.

The next routine is the cloud rise routine, which affords the temporary history of the rise of the exhaust cloud during the initial 15 minutes of transport (Fig. 3). The kinematic and geometric parameters associated with the stabilization of the exhaust cloud are stored for later operations. To prevent the necessity of repeating this data processing in the first two routines, the stored results can be recorded (REC "DA", R102).

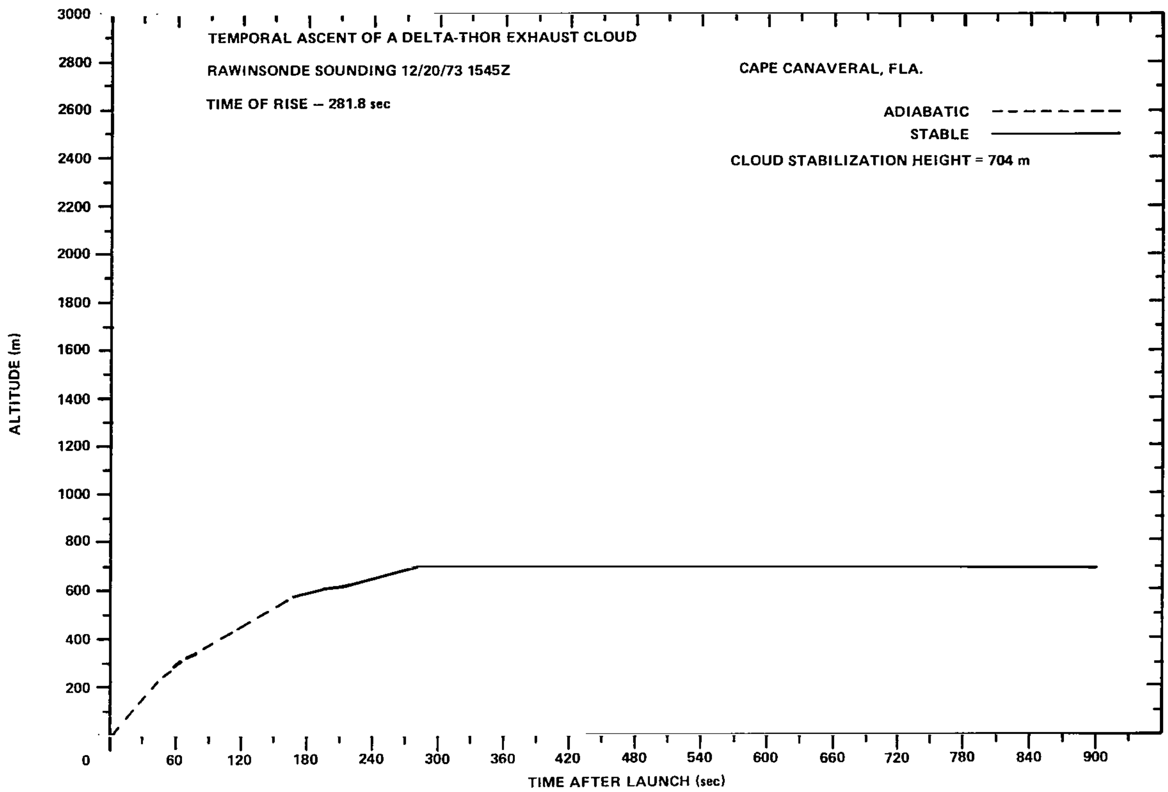


Figure 3. Temporal ascent history of exhaust effluents.

The first subroutine of the diffusion routine is the concentration and dosage subroutine. This subroutine generates concentration and dosage levels over a 20-km distance, initiating at the point of cloud stabilization (Fig. 4). Maximum concentration and the height of the surface mixing layer are printed out. It is often helpful to record the results in the calculator at this stage. The second subroutine is the cloud path subroutine which predicts and plots the exhaust cloud's transit path on a graphical map of the launch area (Fig. 5). This same graph also incorporates the predicted HCl concentration isopleths. Indices with time relations are generated to show the location of exhaust cloud stabilization, the point of maximum concentration, and the cloud's arrival time at some arbitrary down range distance. The third subroutine, the isopleth subroutine, is used strictly for plotting, since it illustrates where contours of constant concentration of HCl reside in the launch area. This subroutine recycles without termination, which permits several isopleths to be plotted. Termination is not necessary since this is the last operational portion of the program.

The FA subroutine in the diffusion routine contains portions of the specialized version of model 3 from the NASA/MSFC Multilayer Diffusion Models. Factors produced by this subroutine are combined by other subroutines to form concentrations and dosage values.

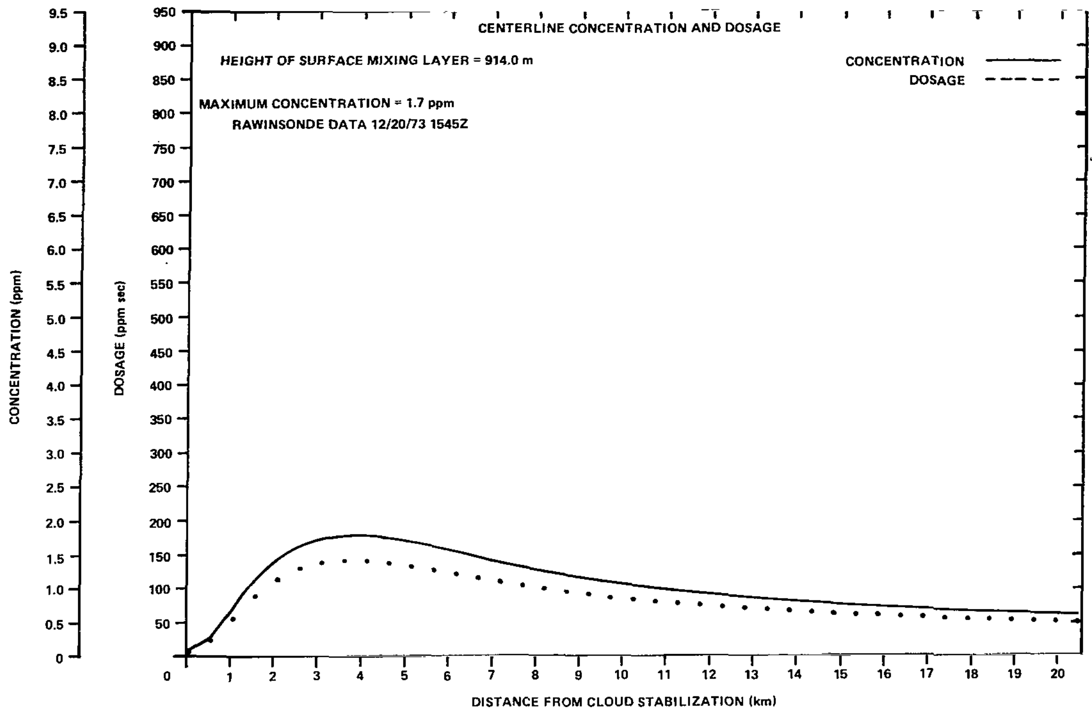


Figure 4. Centerline concentrations and dosages for hydrogen chloride.

Data requirements for the surface layer diffusion calculator program fall into two categories: (1) the parameters governing the exhaust cloud source as defined by the vehicle and (2) the meteorological parameters of the surface layer obtained from a rawinsonde sounding and surface measurements.

The exhaust cloud source data for the Delta-Thor are programmed into the command lines of the program as a portion of a constant to its respective equation. In Delta-Thor case studies, reentry of these parameters is not necessary. Altering source data requires the reprogramming of command lines in accordance with the discussion in Section II.

The four parameters that make up the source data are: (1) the heat released by the Delta-Thor exhaust [Q_H, equation (11)] and utilized in the buoyancy terms [F, equations (9) and (10)] (this is located in line 3 of the cloud rise routine); (2) the fractional amount of material expelled into the surface layer (f) and required for calculating the mass source strength [Q_m, equation (23)] (this is located in line 0 of the diffusion routine); (3) the entrainment coefficient [γ, equations (7) and (8)] utilized in the cloud rise relations and in the calculations for the standards in wind shear [σ_{xo}, σ_{yo}, σ_{zo}, equation (47)] (this is located in line 3 of the cloud rise routine and in line 1 of the

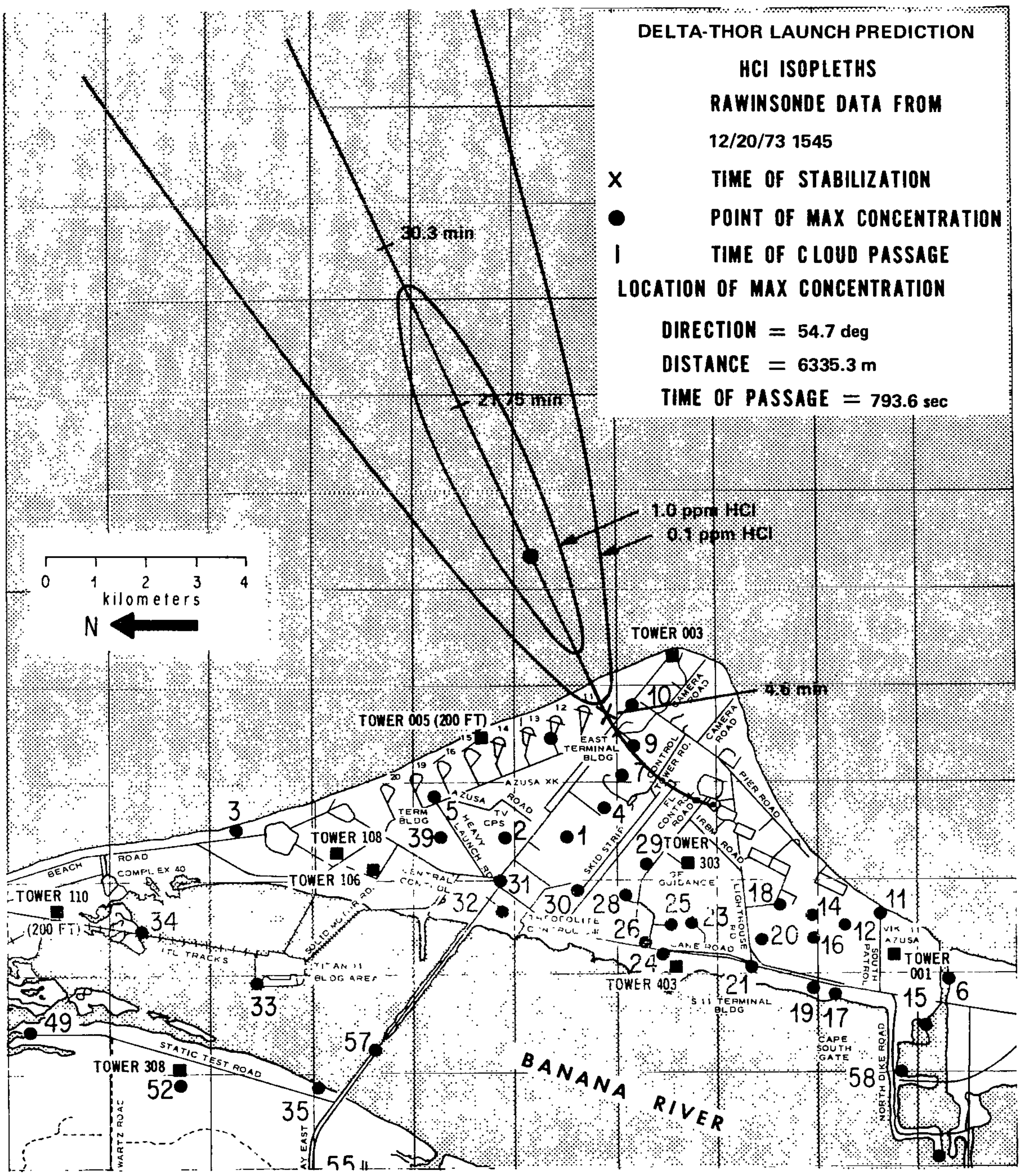


Figure 5. Predicted impact of Delta-Thor exhaust effluents.

diffusion routine); and (4) the molecular weight of the toxin of interest (M) and required for calculating Q_M (this is located in line 1 of the cloud routine). Respective values for Q_H, f, γ, and M for the Delta-Thor in HCl measurements are 7.585571×10^8,0.2083, 0.57, and 36.5 [8].

Meteorological data are entered into the HP9820 computer through the keyboard on display calls from the program. The program offers data card loading and recording to facilitate operations in case study reproductions and in forming data references. The five meteorological profile parameters utilized by the surface layer diffusion routine are altitude with its respective wind direction, wind speed, temperature, and pressure. Units for these parameters can be either English or metric, since the necessary conversion routines are contained within the program. The only data which impact the diffusion prediction are within the surface layer, which is normally contained in the first 2.1 km of the atmosphere. These five meteorological parameters constitute one data set. The maximum number of data sets that storage can handle is 19, although at least 15 are required to prevent processing overflows. Generally, from 15 to 18 sets of data can be derived from one rawinsonde recording. In cases where less exist, the program is designed to be recycled without a data entry until 15 levels of information are in the machine. The date of the rawinsonde data is requested by the program to be used for referencing the outputs. The input occurs following meteorology profile parameter plots. There are no data inputs required for the cloud rise routine.

The inputs for the diffusion routine correspond to wind direction, wind speed, altitude, and standard deviation of wind azimuth at ground level. These parameters are selected from the meteorology profile to indicate where the top of the surface layer mixing is. In general, this should be at a level that was entered into the calculator. The last input appears in the center of the isopleth routine. This requires a concentration value with which its corresponding isopleth is to be plotted.

The output generated by the NASA/MSFC Surface Layer Diffusion Calculator Program is designed to afford both a spatial and temporal prediction for the footprint from the transport of the solid rocket effluents. In addition, values that are important in the analysis of the resulting predictions are printed on these graphs. To reduce the data reduction time, separate programs exist to format each graph with respect to setting up the proper coordinate system and the proper labelings (in normal operation, it has been found that reproducing these from the master is a time saving operation).

The meteorological profile represents the atmospheric kinematics and thermodynamics that are relevant to the dispersion of the rocket exhaust effluents. The potential temperature is given in this profile because it is the primary determining parameter in predicting the altitude at which the rocket exhaust cloud will stabilize. The selection of whether the adiabatic or the stabilized cloud rise relation is utilized in the calculation of the cloud stabilization height depends on the adiabatic lapse rate relative to the surface. The adiabatic potential temperature regime, the stable potential temperature regime, and the stable potential temperature are defined on the meteorological profile. The dynamic range for wind speed and temperature (potential and dry bulb) profiles is from 0 to 36.5 m/sec and from -4°C to 36.5°C, respectively. Wind direction scaling varies in increments of 20 deg to actual conditions with a maximum range of 0 to 360 deg. The program calls for a stop after each profile is plotted so that the color of the pen can be changed, thereby making each profile easily distinguishable from the other profiles. In addition to the profiles, the surface conditions (such as temperature, pressure, and density), the date, and the time of the rawinsonde soundings are printed on the meteorological profile.

The cloud rise graph affords the temporal history over the initial 15 minutes after rocket ignition. The type of atmosphere (adiabatic or stable) is indicated in the delineation of the cloud rise. The exact values for the altitude and transport time to cloud stabilization are printed out to aid the investigator.

The third graph routine outputs the dosage and concentrations of HCl along the centerline of the exhaust cloud path. This delineation ranges over the first 20 km after cloud stabilization. The height of the surface mixing layer and the maximum concentration of the HCl are printed out. The concentration and dosages of other rocket exhaust constituents can be obtained by multiplying by the constants of proportionality, which are:

2.93 for CO (ppm)

2.89 for Al_2O_3 (mg/m^3)

The maximum values of the concentration and dosage that can be drawn are 9.5 ppm and 950 ppm-sec.

The final output is a graph of the HCl isopleths of constant concentration. This routine plots the actual cloud path showing where the cloud stabilization and the maximum concentration occur. In addition, an arbitrary point is marked with the time of cloud passage to enable the user to determine the passage time at any point (note that it is assumed that the cloud has a constant velocity after cloud stabilization). Numerical printouts give the time of cloud passage, the distance from the launch site, and the Cartesian angle to the point of maximum concentration.

The details of the operation of this calculator program in the next subsection will help illuminate points that are not clear.

B. Operating Instructions for the NASA/MSFC Surface Layer Diffusion Calculator Program

A detailed set of operating instructions for the NASA/MSFC Surface Layer Diffusion Program is provided in this subsection. While this set of instructions is helpful when initially running the program, the summary of operating instructions given in Appendix A should be sufficient in normal operations. The NASA/MSFC Surface Layer Diffusion Program is loaded into the machine (HP9820) in three parts, with the second and third parts depending on the preceding part. Each part has two sections, each affording one of the four graphs. The normal operation of this program can be summarized as loading the MET routine and then running the program. Data will be called for in the display. The user must terminate the data entry with a GO TO 12. Otherwise, all other instructions are called for until the meteorological profile graph is completed. Then the cloud rise routine is loaded. Loading of the third part (the diffusion routine) requires a bit more care, since the FA subroutine must also be entered. Once this is completed, the remainder of the program is straightforward.

In the following instructions, the names of calculator keys are underlined and the displays are both underlined and set off by quotation marks.

PART I. MET ROUTINE

SECTION I. SORT ROUTINE

A. Loading MET Routine

1. The MET routine consists of two cards, three sides, numerically listed for loading.

2. Press <u>ERASE MEMORY</u>, <u>LOAD</u>, <u>EXECUTE</u>. Insert each card in numerical order into the card reader. After each side is loaded, "<u>NOTE 14</u>" will be displayed, with the exception of side three. Press <u>EXECUTE</u> and insert the next side.

3. If side three is followed by a "<u>NOTE 14</u>" display, the calculator has misread program cards. Press <u>ERASE MEMORY</u> and reload the MET routine.

4. Place graph on plotter for meteorological profile (use when reprocessing data).

B. Data Cards

Input data can be recorded in converted form on magnetic cards for reference to a particular case study. Magnetic cards may also be used to enter data into the calculator. These operations center around the "<u>LOD OPT</u>" display and will be discussed later.

C. Entering Data Through the Keyboard

1. During processing the calculator will idle, generating a display for data entry.

2. Following the display, type in the corresponding data and press RUN PROGRAM.

Example:

"TIME" is displayed.

Enter the time through the keyboard and press RUN PROGRAM.

D. Initiating the MET Routine Loading Data by Cards

1. Press RUN PROGRAM until "Z" is displayed. Press STP, GTO 26, RUN PROGRAM. This jumps over data input and conversion routines required for raw information. "DS" will be displayed. Surface density is stored on the magnetic card so data entry for this call is unnecessary. Press RUN PROGRAM.

2. The card drive will activate, but in the record mode for converted raw data. Press STP, RUN PROGRAM.

3. "LOD OPT" will be displayed. Press LOD, EXECUTE, and load data into the calculator.

4. Dry bulb temperature will not plot out with the use of data cards.

E. Initiating the MET Routine with Raw Data

1. Press RUN PROGRAM until "Z" is displayed. Enter the following rawinsonde data to the corresponding display in accordance with C, above.

Z – Altitude	(ft or m)
θ – Wind Direction	(kn or m)
T – Temperature	(dry bulb, °C)
P – Pressure	(mb)

Each group of five parameters constitutes one data set. Fifteen data sets are required for processing, although nineteen sets are the maximum to be stored. In cases of missing data points, the following may be substituted.

Missing Parameter	Substitute
Altitude	0
Wind Direction	1000
Wind Speed	-1

In the event that there are less then 15 data sets, this number can be generated by cycling through with RUN PROGRAM until 15 sets are generated.

2. If data were miskeyed into the calculator, see subsection III.C for data correction or press STP, GTO 0, RUN PROGRAM, and reenter data sets.

3. After storing the rawinsonde data, press STP, GTO 12, RUN PROGRAM. "METRIC?" will be displayed. If rawinsonde data were in metric units, press GTO 19, RUN PROGRAM to jump over the conversion routine; otherwise press RUN PROGRAM.

4. Dry bulb temperature will plot out. Change pen colors.

5. "DS" will be displayed. Enter the surface density in g/m^3.

6. The card drive will activate. Converted data can be recorded by inserting a data card into the card drive; otherwise, press STP, RUN PROGRAM (when initially using the program, it is recommended that data be recorded). A "NOTE 14" display afterwards indicates a data error or a recorder malfunction. In such case, press STP, EXECUTE, GTO 26, RUN PROGRAM. With the "DS" display, press RUN PROGRAM and again record the data. After the second appearance of "NOTE 14", if any, see subsection III.C for data correction.

7. "LOD OPT" will be displayed. This concerns only data card loading and it should not be associated with raw data.

F. Plotting the Meteorology Profile

1. After the "LOD OPT" display, either with keyboard or card loaded data, press RUN PROGRAM.

2. Wind speed will plot out. Change pen colors and press RUN PROGRAM.

3. Potential temperature and adiabatic potential temperature gradient will plot out. Change pen colors and press RUN PROGRAM.

4. Wind direction and its scaling will plot out.

5. "MONTH" will be displayed. Enter in the date of the rawinsonde data with the following displays: "MONTH", "DAY", "YEAR", "TIME".

6. Date of rawinsonde data and surface temperature, pressure, and density will plot out.

7. The "C-GRAPH" displays the end of the meteorology profile routine.

8. For safety, enter REC, " ,D,A, ",',R( ),1,0,2, and EXECUTE. This enables returning to this point without rerunning the routine.

PART II. CLOUD RISE

1. Load cloud rise program (see Part I, Section I.A). There are two sides.

2. Set up the plotter. Press RUN PROGRAM. If an adiabatic condition exists, plotting will commence until the 900-sec limit is reached or until a stable condition prevails.

3. Once processing has stopped or if plotting did not initiate after pressing RUN PROGRAM at the start, change pen colors and press RUN PROGRAM until the completion of the plot. For each time the program stops, a numerical readout will be displayed, which is the time factor calculated for a given altitude. This effect indicates the processing of a stable condition.

4. After completion of the printing, "Stable Atmosphere" will be printed out beneath the line segments which it represents. Here the program will stop for a pen color change. Press RUN PROGRAM to resume processing. Dates of rawinsonde data, time to maximum cloud rise, and "adiabatic atmosphere" (if one exists) will be plotted out. This completes the graph and the MET routine.

5. If a note statement appears or the cloud rise plot seems unrealistic in accordance with the meteorology profile, data are in error. Most frequently trouble will arise in registers R1, the surface temperature in Kelvin; R2, the surface pressure in mb; and R3, the surface density in g/m^3. See subsection III.C for data correction and for recycling the program.

6. Again, for safety, do Part I, Section I.F.8.

PART III. DIFFUSION ROUTINE

SECTION I. CENTERLINE CONCENTRATION AND DOSAGE

1. The cloud diffusion routine requires two cards. Three sides are used for the concentration and dosage routines and one side for the FA subroutines. MEMORY ERASE should not be depressed, since data stored in the previous routine are used to

begin loading. Press DEF FA, EXECUTE, LOD, EXECUTE, and insert the FA subroutine program card. This is stored into the FA register and may be called back for inspection by pressing DEF FA, LIST or DEF FA, RECALL. To load the cloud routine, press END, EXECUTE, and insert the cloud routine program cards. The END function separates the program mode from the subroutine mode.

2. Set up the plotter for the centerline graph. Press RUN PROGRAM until "θT" appears in the display. Select from the meteorology profile the altitude, wind speed, and wind direction for the top of the surface layer. With each of the following displays, enter its corresponding data:

0T – Wind direction at the top of the layer

UT – Wind speed at the top of the layer

0AR – Wind deviation at ground level

HL – Height of the layer

3. After the last data input, plotting will initiate. If, for some period of time the calculator should idle with no apparent output, storage data are in error. See subsection III.C for data correction and for recycling the program.

4. Following the concentration and dosage plot, the height of the surface layer, maximum concentration, and the date of the rawinsonde data will be printed out on the graph. The "ISO-GRAPH" display indicates the end of this part of the cloud routine.

SECTION II. ISOPLETH

1. When "ISO-GRAPH" is displayed, set up the plotter for the isopleth graph, change pen colors, and press RUN PROGRAM.

2. Cloud path will plot out in a relatively straight line, with the majority of its deviations centered around the origin. If there are any signs of irregularities similar to a spike or a jump in the line, miscalculated data were stored in memory. To continue with processing will lead to inaccuracies. For data correction and to recycle the program, see subsection III.C.

3. In many cases the cloud path will go off scale and the arbitrary down range time value will be missing. This is a processing error. No action is necessary since this has no effect on the output. To prevent this, press STP before the cloud path reaches the limits of the graph, then press GTO 25, RUN PROGRAM.

4. Following the cloud path plot, time of cloud rise, an arbitrary down range time factor, and the position of maximum concentration are marked out. The maximum concentration parameter and date of the rawinsonde data are then plotted out.

5. "C" will be displayed. Enter a concentration greater than 0.1, for practicability, and no less than maximum concentration.

6. The time before initial plotting is dependent on the proximity of the entered value to maximum concentration. This lengthens as the two values approach each other. In some cases, a note statement will be displayed, indicating that the calculator is unable to determine the initial plotting location. Enter a new concentration value by pressing STP, EXECUTE, END, EXECUTE, GTO 31, RUN PROGRAM. If only one point is plotted and the calculator idles for a period of time, enter a new concentration value.

7. During plotting, if the isopleth should go off scale, the program will recycle for the entry of a new concentration value. If the isopleth remains within the limits of the graph, "NOTE 2" will usually appear. Press RUN PROGRAM to complete the isopleth. If "NOTE 2" appears a second time, press STP, EXECUTE, GTO 31, RUN PROGRAM. "C" will be displayed.

8. To initialize an isopleth with a concentration value, press SET/CLEAR FLAG during its plot.

9. This completes the isopleth and the cloud routine.

Subsection C affords some helpful tips on how to correct errors and shortcut data processing steps.

C. Corrective Procedures and Operational Shortcuts

Since errors can be introduced into the final results by incorrect inputs to the NASA/MSFC Surface Layer Diffusion Program, a careful check should be made of each graph for obvious errors – especially, the meteorological profile. If an error is detected, it is time saving to be able to correct the error and continue processing without having to go to the beginning and start the program at step 1. This subsection discusses the potential errors and how to correct them. Then the necessary steps to recycle the program are given.

Since there may be times when only the output of a specific section is desired, the methods for bypassing unwanted output are also considered. Appendix B gives the location of the meteorological, cloud rise, and diffusion algorithms used in the program along with a flow chart and listing of the program.

The need for a data correction can be indicated by the appearance of a note statement (not normal to the operation) or the results of an obviously questionable output which are the indications of erroneous data in storage. Mistakes in keying data into the calculator are generally the source of the error, although on rare occasions a misread in the program card would lead to a miscalculation. The case run can be salvaged if the error is located and corrected.

• With the display of "NOTE A in B", where A is the note type and B is the line number where the error takes place, one should identify the note and its possible cause.

NOTE 1: Illegal instruction. Program card misread.

NOTE 2: Improper store or taking the square root of a negative number.

NOTE 3: Illegal instruction. Program card misread.

NOTE 4: Illegal instruction. Program card misread.

NOTE 5: Miscount in data increment calling for a nonexisting or program register.

NOTE 6: Miscount in data increment storing a value in a nonexisting or program register.

NOTE 8: Recalling nonexisting program line.

NOTE 9: Illegal instruction. Program card misread.

NOTE 10: Underflow or overflow.

NOTE 12: Illegal instruction. Program card misread.

NOTE 14: Magnetic card operation incomplete.

NOTE 16: Printer out of paper.

• To correct program card misreads, press LIST, following the note statement. Inspect the printout with the listings given in Appendix B. Once the invalid line has been located, press GTO B (B is the program line), RECALL, BACK, and press DELETE until only the line number remains (ir. "64:"). Type in the corresponding command from Appendix A and press STORE (see item 1, Recycling Meteorology Profile, to recycle the routine). If the program card misread is extensive, press ERASE MEMORY and restart the program.

• For a single invalid data point, press GTO B, where B is the line number from the note statement, and LIST. Allow a few lines to print out and press STP.

• The first line in the listing contains some register (R0, R1 . . . R103, A, B, C, X, Y, Z) and the operation where the error developed. The content of these registers can be determined, for example, by pressing B, EXECUTE, where B is the register of interest.

• To correct data, press N→B, EXECUTE, where N is the new value for register B.

• If invalid data cannot be located by the above method or there are a number of data points at fault, a data dump will be required. To initiate, press 0→X, EXECUTE, PRT RX: JMP (X+1→X) 100, and press EXECUTE until approximately 100 figures have been printed out. From R0 down to R103 will be listed consecutively, and in this way irregularities in groups of data may be found. To insert a correction, press N→B, EXECUTE where N is the new value for register B.

• Following data correction, the program should be recycled to the beginning of the routine (see Part I, Section I.E, step 3 of the program). In cases where data correction cannot be handled, press ERASE MEMORY and restart the program.

Portions of the program, where an output is not needed, may be jumped during processing if the data required are accessible. The meteorology profile, cloud rise, and isopleth are a waste of operating time if the only output required is the centerline concentration and dosage. The method described below will show how this may be done.

1. Cloud Rise Plot

a. To plot cloud rise, the MET routine should be loaded into the calculator and the converted rawinsonde data must be present. If data are absent from storage, they should be entered by magnetic card at the "LOD OPT", displayed or keyed in at the beginning of the MET routine, and followed through until "LOD OPT" appears.

b. After the "LOD OPT" display, press GTO 58, RUN PROGRAM. Cloud rise, will plot out, but the date of rawinsonde data will be in error, unless Month R90, Day R91, Year R92, Time R93 are entered.

2. Centerline Concentration and Dosage

a. Load the cloud routine in the following sequence:

Press MEMORY ERASE

Press DEF FA, EXECUTE, LOD, EXECUTE. Insert FA subroutine.

Press END, EXECUTE, LOD, EXECUTE. Insert cloud routine.

b. Rawindsonde data are not required, but the following data are, although they are not called for by the program.

Data	Register
Surface Temperature, °K	R1
Surface Pressure, mb	R2
Time of Maximum Cloud Rise	R85
Maximum Cloud Height	R86

Enter uncalled data by pressing N→RB, EXECUTE where N is the data and B is the corresponding register number.

c. Press RUN PROGRAM until "θT" is displayed. Continue operations with instructions in Part III, Section II of the program.

d. Date of rawinsonde data will be in error.

3. Isopleth

a. Isopleth can only be generated by running the entire program. Data requirements are too large to calculate and enter. There are, however, methods to reduce processing time.

b. Load in the MET routine and input data by card or keyboard. Follow the meteorology profile instructions, Part I of the program, until the "LOD OPT" stage ends. Press GTO 58, RUN PROGRAM.

c. Let the cloud rise routine run out completely.

d. Follow through with instructions in Part III, Section I of the program for centerline concentrations and dosage.

e. After the plot has passed the point of maximum concentration, press END, EXECUTE, STP, EXECUTE, GTO 13, RUN PROGRAM.

f. Follow the instructions for isopleth, Part III, Section II of the program.

Recycling sections of the program, following a data correction, is required to reset calculations with the altered data values. Simple jumps from the point of correction to the start of a routine eliminate the need to run several sections of the program to generate an output. The commands listed below may be used in any point of a given routine for recycling back to its beginning unless stated otherwise.

1. Recycling Meteorology Profile

a. While entering raw data, if a miskeyed data point was input, two methods may be taken for correction. Either search for the data point and correct it, as in Part I, Section I.E, of the program and continue to enter data sets, or wipe out stored data and reenter the data sets by pressing STP, GTO 0, RUN PROGRAM.

b. If more than 19 data sets were entered, command lines are erased, rendering the program and data unsalvageable. Press ERASE MEMORY and reload the MET routine.

c. To recycle during the plotting sequence, press STP, 4→X, EXECUTE, GTO 27, RUN PROGRAM. If the graph is to be replotted, dry bulb temperature will be missing.

2. Recycling Cloud Rise

Processing should be in the stop mode. Press R1-273.15→R1, EXECUTE, GTO 58, RUN PROGRAM.

3. Recycling Centerline Concentration and Dosage

Press STP, EXECUTE, END, EXECUTE, GTO 0, if new top of the layer parameters are to be entered, otherwise GTO 2, RUN PROGRAM.

4. Recycling Isopleth

a. In the cloud path mode, press R97→R64, EXECUTE, GTO 13, RUN PROGRAM.

b. In the isopleth mode, press STP, EXECUTE, END, EXECUTE, GTO 13, RUN PROGRAM.

5. General recycling can be accomplished if at the completion of a subroutine the data are recorded. This is accomplished by REC,",D,A,",', R105, and EXECUTE. This permits the investigator to return to this point and reload the data by pressing LOAD, EXECUTE. Then the program can be rerun. This procedure is helpful in initial operation of this program or when doing extended investigations with this program.

Although these corrective procedures cover most cases that will be encountered, there will be times when the operator of the program will want to employ his own techniques. While these procedures may normally be satisfactory, great care should be exercised because of the complexity of the computational interfaces.

SECTION IV. CONCLUSION

The NASA/MSFC Surface Layer Diffusion Calculator Program affords a real-time, online transport description for the environmental dispersion of the Delta-Thor rocket exhaust effluents utilizing ellipsoidal dispersion in a Eulerian reference frame, as given by model 3 of the NASA/MSFC Multilayer Diffusion Model. This calculator program has been successfully employed at Cape Kennedy to make real-time predictions of the transport of Delta-Thor effluents for the deployment and evaluation of the Langley Research Center and Kennedy Space Center effluent monitoring network.

The primary difference between the NASA/MSFC Surface Layer Diffusion Calculator Program and the NASA/MSFC Multilayer Diffusion Computer Program is that the calculator program has been specialized for a specific vehicle, the Delta-Thor, and a specific altitude, the surface layer. This program is similar to the one for the Titan III [1]. The calculator program incorporates the meteorological and cloud rise algorithms into one program, permitting a rawinsonde sounding to be the input; whereas, the computer program utilizes the results of these algorithms. The predictions obtained from both programs are identical for the surface effects from the effluents. The data preparation and reduction time for the calculator program is approximately one-half hour, as compared to 2 hours for the computer program. The computer program, however, does afford a more detailed prediction than can be obtained with the calculator program.

The NASA/MSFC Surface Layer Calculator Program has features that make it a desirable vehicle for use in making diffusion predictions for the Delta-Thor launches, especially where the graphical output satisfies the prediction required. The NASA/MSFC Multilayer Diffusion Computer Program is a better vehicle for use in general analysis work, where flexibility and detail in the results are required. Thus, while the application of the calculator program to diffusion analysis is a step forward in online, real-time predictions, it does not eliminate the need for the computer program in diffusion analysis.

APPENDIX A

SUMMARY OF THE INSTRUCTIONS FOR THE OPERATION OF THE NASA/MSFC SURFACE LAYER DIFFUSION CALCULATOR PROGRAM

The objective of this summary is to provide a guide for the operation of the calculator program. The details for the initial operation of this program are given in Section III.B. Since, in normal operations of this calculator program, only a quick reminder of some key operations is all that the operator will require, the following summary is provided. Even this may be too detailed for many and, therefore, a flow chart for the operation of this calculator program has also been provided (Fig. A-1).

The user is reminded that the procedures for treating program errors and eliminating unwanted parts of the program are given in Section III.C. This discussion does not include the points covered in that section.

Operation of Program

Data called for by the machine are entered in the following sequence.

"DISPLAY" The program makes the call for data, type in data, and press RUN PROGRAM.

MET Profile — PART I. MET ROUTINE

Load Program — 1. This routine consists of two cards, three sides. Press MEMORY ERASE and load in the routine.

Loading Data by Card — 2a. If data are to be entered by magnetic cards, press RUN PROGRAM until "Z" appears in the display. Press STP, GTO 26, RUN PROGRAM. "DS" will appear in the display though data entry for it is not necessary. Press RUN PROGRAM. The card reader will activate in the record mode for data records, which at this point do not exist. Press STP, RUN PROGRAM. "LOD OPT" will be displayed. Press LOD, EXECUTE, and insert data card. Dry bulb temperature will not be plotted with data card usage. Press RUN PROGRAM to resume processing.

Entering Raw Data — 2b. The met routine should be loaded. Press RUN PROGRAM until "Z" appears in the display. Enter data with the corresponding display. "Z" altitude, "0" wind direction, "V" wind speed, "I" temperature, and "P" pressure. No more than

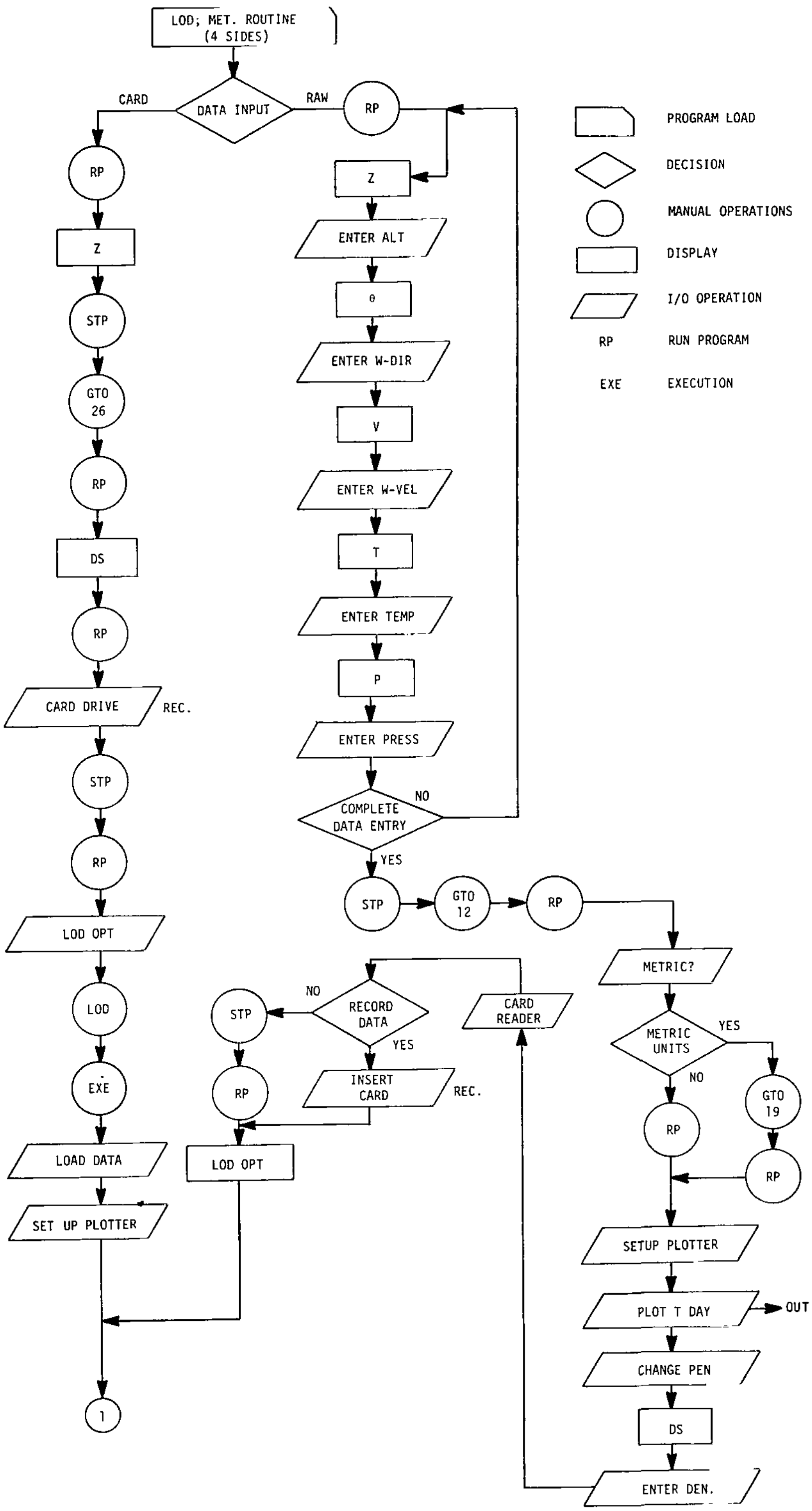


Figure A-1. Flow diagram for program operations.

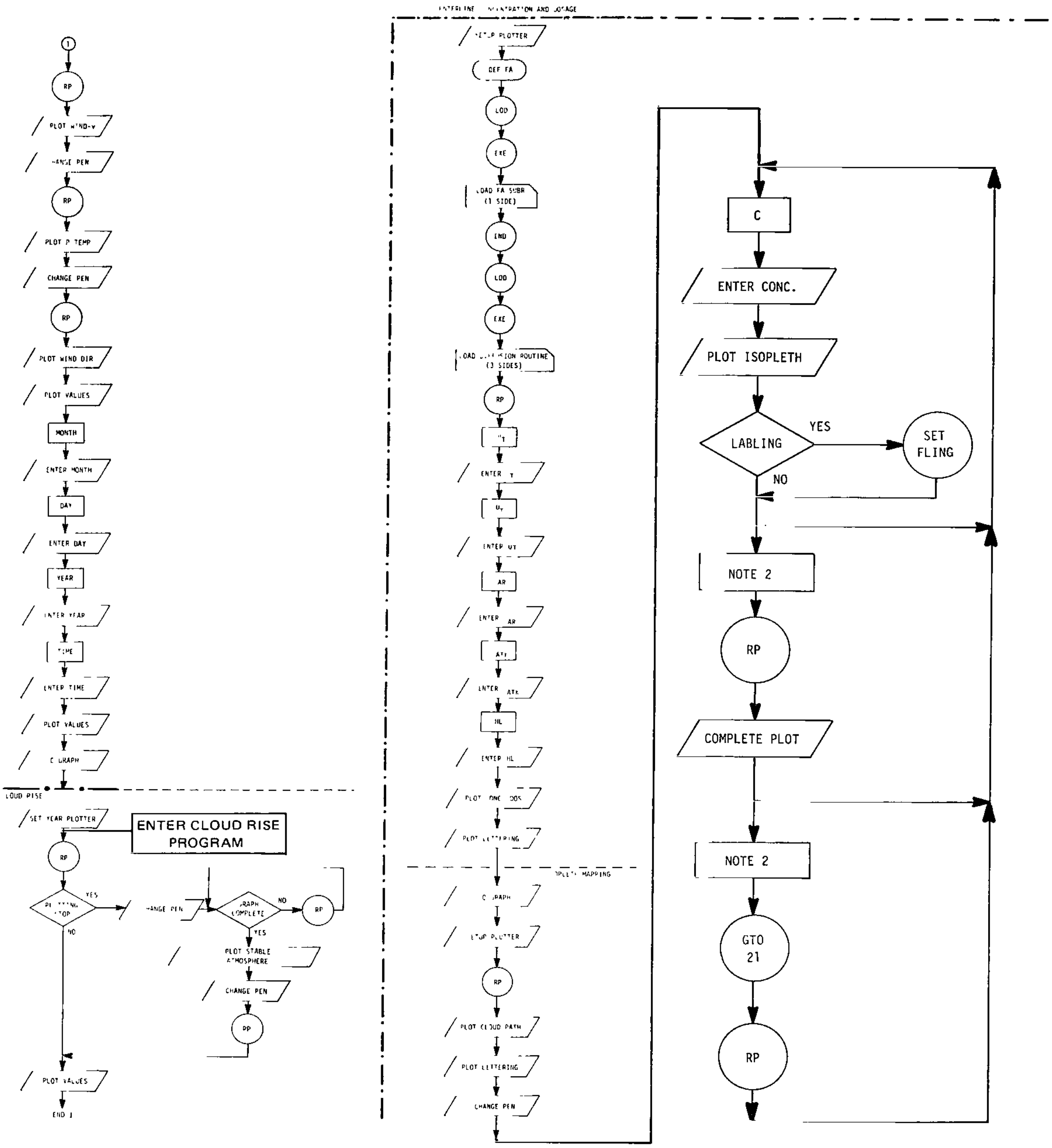


Figure A-1. (Concluded).

95 values may be entered. For missing data, the following may be substituted: Altitude, 0; wind direction, 1000; wind speed, -1.

3. After entering the last data value, press STP, GTO 12, RUN PROGRAM. "METRIC?" will be displayed. If data were in metric units, press GTO 19, RUN PROGRAM; otherwise press RUN PROGRAM.

4. Dry bulb temperature will plot out. "DS" will appear in the display. Set up plotter. Enter surface density value, change pen color, and press "RUN PROGRAM".

Recording Data

5. The card drive will activate. If converted data are to be recorded, insert a magnetic card; otherwise press STP, RUN PROGRAM.

6. "LOD OPT" will be displayed. Press RUN PROGRAM.

7. Wind speed will be plotted out, stopping afterwards for a pen color change. Press RUN PROGRAM.

8. Potential temperature will be plotted out, stopping afterwards for a pen color change. Press RUN PROGRAM.

9. Wind direction, wind direction scale, surface conditions, and date of meteorology data will be plotted out. "C-GRAPH" will be displayed.

Cloud Rise
Load Program

PART II. CLOUD RISE ROUTINE

1. This routine consists of one card, two sides. Load routine.

2. Center graph paper on plotter and press RUN PROGRAM.

3. During processing, if the plotter should stop, change pen color and press RUN PROGRAM as many times as needed to complete the graph.

4. After the plotting of "STABLE ATMOSPHERE", change pen color and press RUN PROGRAM. This completes the MET routine.

Centerline Concentration and Dosage Loading Cloud Routine

PART III. CENTERLINE CONCENTRATION AND DOSAGE CLOUD ROUTINE

1. Load cloud routine, two cards, three sides, and FA subroutine, one card, one side, in the following sequence. Do not press MEMORY ERASE; press END, EXECUTE, LOD, EXECUTE. Load cloud routine.

2. Press RUN PROGRAM until "OT" is displayed. Enter the corresponding data to each display: OT – wind direction at the top of the layer, UT – wind speed at the top of the layer, HL – height of layer, OAR – wind deviation at reference.

3. After the final data entry, the program will plot concentration and dosage and then print out height of layer, maximum concentration, and date of meteorology data. This completes the concentration and dosage graph. An "ISO-GRAPH" will be displayed.

Isopleth

PART IV. ISOPLETH CLOUD ROUTINE

1. Center graph paper on plotter and press cloud routine RUN PROGRAM.

2. Cloud path, maximum concentration parameters, and date of meteorology data will be plotted out.

3. "C" will appear in the display. Enter in a concentration value greater than 0.1 but less than maximum concentration. The corresponding isopleth will be plotted.

4. To initialize the isopleth during plotting with a concentration value, press SET/CLEAR FLAG.

5. If "NOTE 2" is displayed, press RUN PROGRAM to complete the plot. After the second appearance of "NOTE 2", press GTO 31, RUN PROGRAM. "C" will appear in the display.

6. If "NOTE 2" did not appear, the program cycles back to plot another isopleth, displaying "C" for a new concentration value.

7. This completes the cloud routine. For completion of each graph there is a corresponding routine for axis and lettering.

APPENDIX B

THE NASA/MSFC SURFACE LAYER DIFFUSION CALCULATOR PROGRAM LISTING AND ALGORITHMS

A listing of the NASA/MSFC Surface Layer Diffusion Calculator Program, along with flow charts, is given in this appendix. In addition, the location of the algorithms used in the program is presented.

This calculator program was designed for use on the HP9820 desk calculator, with option 001 (429 total registers). The user definable functions I-III ROM are required in this program. The program requires all the storage available in this configuration. A listing of the MET routine is given in Table B-1, the cloud rise routine is given in Table B-2, the diffusion routine is given in Table B-3, and the FA subroutine is given in Table B-4. Figures B-1 through B-8 are the flow diagrams for the program.

Since experience in making diffusion predictions generally leads to a desire to update the algorithms utilized, the meteorological, cloud rise, and diffusion algorithms are given in Table B-5 and B-6. However, the algorithms employed in this program have evolved from years of empirical experience in monitoring the dispersion of the Delta-Thor effluents and, therefore, should require practically no changes.

To assist the user in making his initial predictions with this program and to permit the checking of its operation, some average values have been included for the parameters in Table B-7. Table B-8 provides the four programs for formating and labeling each of the graphs. In general, time can be saved by making a master for each graph and reproducing it for use with the diffusion program.

TABLE B-1. LISTING OF MET ROUTINE

```
0:
0→B;0→X;3→C;CFG
2;SCL -4,36.5,-4
00,2400⊢
1:
ENT "Z",RB,"0",R
(B+1),"V",R(B+2)
,"T",R(B+3),"P",
R(B+4);RB+1→R(B+
5)⊢
2:
R(B+1)→R(B+6);R(
B+2)→R(B+7);R(B+
3)→R(B+8);R(B+4)
→R(B+9);IF FLG 2
=1;GTO 4⊢
3:
SFG 2;5→B;GTO 1⊢
4:
IF R(B+1)>R(B+4)
;GTO 11⊢
5:
IF R(B+4)>R(C+4)
;GTO 7⊢
6:
C+5→C;GTO 5⊢
7:
C→Y;B→C+4→Z⊢
8:
R(B+4-X)→R(B+9-X
);JMP (X+1→X)>Z⊢
9:
0→X⊢
10:
R(B+9-X)→R(Y+4-X
);JMP (X+1→X)>4⊢
11:
B+5→B;0→X;0→C;
GTO 1⊢
12:
3→X;B-5→B;R3→R99
;R4→R98⊢
13:
RX+273.15→RX;
JMP (X+5→X)>B⊢
14:
0→Y;DSP "METRIC
";STP ⊢
15:
.3048RY→RY⊢
16:
IF RY=0;R(Y-5)+2
9.3((R(Y+3)+R(Y-
2))/2)LN (R(Y-1)
/R(Y+4))→RY⊢
17:
IF B>Y;3→X;Y+5→Y
;GTO 15⊢
18:
.515RX→RX;JMP (X
+5→X)>B+5⊢
19:
3→X;R28-273.15→R
97⊢
20:
PLT RX-273.15,R(
X-3);RX(1000/R(X
+1))↑.286-273.15
→RX;JMP (X+5→X)>
B⊢
21:
80→A;4→C;0→X;
LTR R97+.5,R25,2
11;PLT "TEMP-DRY
"⊢
22:
R(A+X)→R(A+X-1);
JMP (X+1→X)>C⊢
23:
A-5→A;C+5→C⊢
24:
IF A≠0;0→X;GTO 2
2⊢
25:
4B/5+7→C;R(C-A)→
R(C-A+4);JMP (A+
1→A)>C⊢
26:
4→X;C→R0;R99→R1;
R98→R2;ENT "DS",
R3;PEC "DA",R80;
DSP "LOD OPT";
STP ⊢
27:
IF 0 R(X)2;GTO
29⊢
28:
PLT R(X+2),RX⊢
29:
IF R0>X;X+4→X;
GTO 27⊢
30:
4→X;LTR R18+.5,R
16,211;PLT "WIND
 SPEED";STP ⊢
31:
PLT R(X+3),RX;
JMP (X+4→X)>R0⊢
32:
0→Y;LTR R47+.5,R
44,211;PLT "POTE
NTIAL";LTR R47+1
.5,R44-75,211;
PLT "TEMP"⊢
33:
PLT R7,Y;PLT R7,
25+Y;PEN ;JMP (Y
+50→Y)>1900⊢
34:
R7+.5→A;1875→B⊢
35:
LTR A,B,211;PLT
"ADIABATIC POTEN
TIAL";LTR A,B-75
,211;PLT "TEMP.
GRAD. ⊢
36:
STP ;5→X;0→R88;3
60→R89⊢
37:
IF RX>360;GTO 40
⊢
38:
IF RX/R88;RX→R88
⊢
39:
IF R89 RX;RX→R89
⊢
40:
IF R0 X;X+4→X;
GTO 37⊢
41:
FXD 0⊢
42:
2INT (R88/40)+2→
A⊢
43:
2INT (R89/40)→B⊢
44:
A-B→Y⊢
45:
36-Y→C;0→X⊢
46:
LTR C+2X-.8,-370
,211;PLT 20B+40X
;JMP (X+1→X)>Y-2
⊢
47:
4→X⊢
48:
IF R(X+1)>360;
GTO 50⊢
49:
PLT 36-(20A-R(X+
1))/20,RX⊢
50:
IF R0>X;X+4→X;
GTO 48⊢
51:
LTR 32.5-(20A-R2
5)/20,R24,211;
PLT "WIND DIR"⊢
52:
FXD 1;LTR 8.5,21
00,211;PLT R1⊢
53:
LTR 8.5,2030,211
;PLT R2⊢
54:
ENT "MONTH",R90,
"DAY",R91,"YEAR
",R92,"TIME",R93⊢
55:
FXD 0⊢
56:
LTR 15,2310,211;
PLT R90;PLT "/";
PLT R91;PLT "/";
PLT R92;PLT " ";
;PLT R93;PLT "Z"
⊢
57:
LTR 8.5,1950,211
;PLT R3⊢
58:
SCL -75,1000,-20
0,3100;FXD 0;
TBL 2;DSP "C-GRA
PH ";END ⊢
R192
```

TABLE B-2. LISTING OF CLOUD RISE ROUTINE

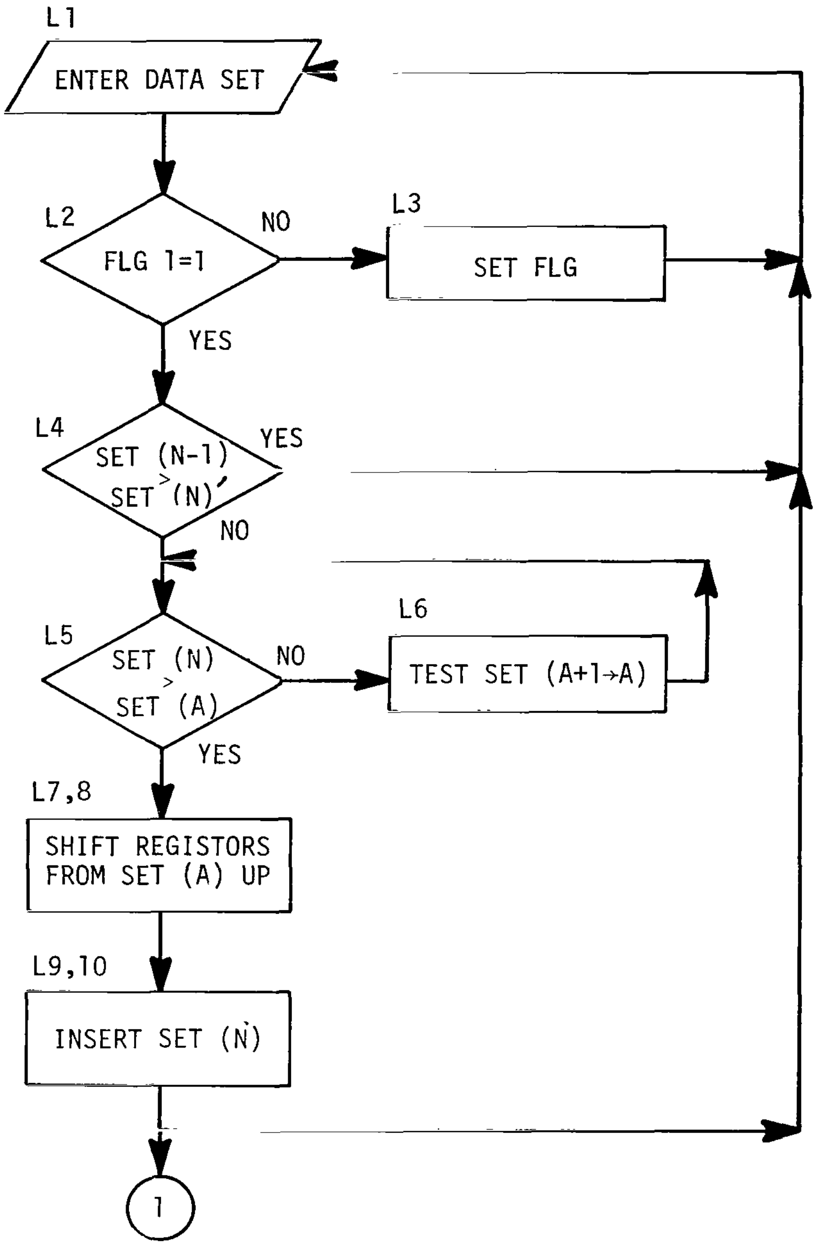
```
0:
R1+273.15→R1;4→X
;0→B;CFG 1;1→Z;
CFG 2;CFG 3;0→R1
04⊢
1:
SCL -75,1000,-20
0,3100;FXD 0;
TBL 2;PLT 0,0⊢
2:
R1R3*1.690741E-1
1(R(X+4)-B)↑3.61
54→A⊢
3:
(9.8/R1)(R(X+7)-
BR82-R7)/(R(X+4)
-B-R4+1E-8)→C⊢
4:
IF FLG 3=1;GTO 1
0⊢
5:
IF 1E-6>C;r(A(1+
1.2597R(X+2)RX↑(
-.6054)))→Y;SFG
2;PEN ;GTO 15⊢
6:
IF 1-AC/2>-1;
ACS (1-AC/2)/rC→
R102;R(X+4)-B→R1
03;GTO 9⊢
7:
(R(X+7)-R(X+3))/
(R(X+4)-RX)→R82⊢
8:
B+10→B;GTO 2;
SFG 4⊢
9:
IF B>0;SFG 3;
GTO 11⊢
10:
IF B=0;(R(X+4)-R
X)R(X+6)+R104→R1
04⊢
11:
(R104-BR(X+6))/(
R(X+4)-R4-B)↑1.6
0541→R105⊢
12:
IF 1-.629878R105
AC>-1;(ACS (1-.6
29878R105AC)/rC+
R102)/2→Y;GTO 15
⊢
13:
(R(X+7)-R(X+3))/
(R(X+4)-RX)→R82⊢
14:
B+10→B;SFG 1;
GTO 2⊢
15:
(R(X+4)-B+R103)/
2→R86;PLT Y,R86;
IF FLG 4=1;0→B;
CFG 4;X-4→X⊢
16:
IF FLG 1=1;PLT 9
00,R86;Y→R85;901
→Y⊢
17:
IF Y≤900;Y→R(64+
Z);X+4→X;1+Z→Z;
GTO 2⊢
18:
LTR 840,2500,321
;PLT R86;R85→R(6
4+Z);Z→R64⊢
19:
LTR 660,R86-100,
211;PLT "STABLE
ATMOSPHERE";STP
⊢
20:
R(X+4)-R(X-4)→R7
6;((R(X+6)-R(X-2
))/R76)(R(X+4)-B
-R(X-4))+R(X-2)→
R99⊢
21:
((R(X+5)-R(X-3))
/R76)(RX-B-R(X-4
))+R(X-3)-270→R8
2⊢
22:
LTR 15,2700,321;
PLT "MET. ";PLT
R90;PLT "/";PLT
R91;PLT "/";PLT
R92;PLT " ";PLT
R93;PLT "Z"⊢
23:
FXD 1;LTR 15,260
0,321;PLT "TIME
OF RISE-";PLT R8
5⊢
24:
IF FLG 2=1;LTR 3
0,100,211;PLT "A
DIABATIC ATMOSPH
ERE"⊢
25:
DSP "END I";END
⊢
R270
```

TABLE B-3. DIFFUSION ROUTINE

```
0:
ENT "0T",R79,"UT
",R81,"0AR",R83,
"HL",R87;0→R80→X
;FXD 0;1→R88⊢
1:
3.788E8*R86↑.394
57R1/R2→R78;.268
3721R86→R89;-200
00→R102→R103⊢
2:
R83(R87.5)↑(-(
LN (R81/R6)/LN (
R87/5)))→R84⊢
3:
SCL -3000,20500,
-100,970;LOG (R8
4/R83)/LOG (R87/
2)→C⊢
4:
(R85/600)↑.2πR83
(R87↑(C+1)-2↑(C+
1))/((C+1)(R87-
2)+2↑C*180)→R101
⊢
5:
CLL FA X,R47,R77
,R1,B⊢
6:
R73B (2πR77+R2r(
A/2)+Y;R75B/(f(
7+r(A/2)2π)(2π)R
1)→A⊢
7:
PLT X-500,R102;
PLT X,100A;PEN ;
100A→R102;PLT X-
500,R103;PEN ;
PLT X,Y;PEN ;Y→R
103⊢
8:
IF A R80;A→R60;X
→R98⊢
9:
IF 200JH X;X+500
→X;GTO 5⊢
10:
LTR 6200,775,211
;PLT R90;PLT "/"
;PLT R91;PLT "/"
;PLT R92;PLT "
;PLT R93;PLT "Z"
⊢
11:
FXD 1;LTR 6200,8
75,211;PLT R87⊢
12:
PRT R79-R5;SPC 1
0⊢
13:
LTR 6200,810,211
;PLT R80;4→X;
CFG 0;CFG 1;DSP
"ISO-GRAPH";STP
;CFG 2⊢
14:
FXD 1;IF R(X+2)>
0;GTO 17⊢
15:
R(X+4)-R(X-4)→R7
6;((R(X+6)-R(X-2
))/R76)(RX-R(X+4
))+R(X-2)→R(X+2)
⊢
16:
((R(X+5)-R(X-3))
/R76)(RX-R(X-4))
+R(X-3)→R(X+1)⊢
17:
IF R6A X;X+4→X;
GTO 14⊢
18:
SCL -32050,05950
,-5500,16550;
TBL 1⊢
19:
4→X;R64+R97;0→A+
B→Y→R64⊢
20:
R(X+2)(R(65+B)-R
(64+B))→C;R(X+1)
-270→Z⊢
21:
CCOS Z+Y→Y;CSIN
Z+A→A;PLT A,Y⊢
22:
IF R97-1>B;B+1→B
;X+4→X;GTO 20⊢
23:
IF FLG 2≠1;A→R76
→R94;Y→R77→R95;
CFG 2⊢
24:
C+60R99→C;R82→Z;
IF 4000>C;GTO 21
⊢
25:
LTR R76-50,R77-9
0,211;PLT "X
";PLT R85+R96⊢
26:
IF FLG 1≠1;A/R99
SIN Z→R96;A→R76;
Y→R77;SFG 1;GTO
25⊢
27:
R94+R98SIN R82→A
;R95+R98COS R82→
B;LTR A,B,211;
PLT "O"⊢
28:
LTR 03000,8300,2
11;PLT R85+R98/R
99;PLT " SEC"⊢
29:
LTR 1900,9100,21
1;PLT √(A↑2+B↑2)
;LTR 1900,9900,2
11;PLT ATN (B/A)
⊢
30:
FXD 0;LTR -600,1
3500,211;PLT R90
;PLT "/";PLT R91
;PLT "/";PLT R92
;PLT "  ";PLT R93
⊢
31:
ENT "C",R88→Z;-4
0000→R17→R18;0→X
⊢
32:
CLL FA X,Y⊢
33:
1000→R21⊢
34:
CLL FA R21,R20⊢
35:
X-Y(R21-X)/(R20-
Y)→R22⊢
36:
IF 20>ABS R20;
ABS Y→Y;GTO 49⊢
37:
CLL FA R22,R23⊢
38:
X→R21;Y→R20;R22→
X;R23→Y;GTO 35⊢
39:
√Y→Y;R95+XCOS R8
2-YSIN R82→R50;R
95+XCOS R82+Y
SIN R82→R51⊢
40:
R94+YCOS R82+X
SIN R82→R52;R94-
YCOS R82+XSIN R8
2→R53⊢
41:
PLT R9,R17;PLT R
52,R50;PEN ;R52→
R9;R50→R17⊢
42:
PLT R8,R18;PLT R
53,R51;PEN ;R53→
R8;R51→R18;X+
ABS (R17-R18+10)
/3→X⊢
43:
IF ABS R9>18000;
GTO 30⊢
44:
IF R17>18000;
GTO 31⊢
45:
IF -6000>R17;
GTO 31⊢
46:
FXD 1;IF FLG 0=1
;LTR R52,R50,211
;PLT R88;CFG 0⊢
47:
CLL FA X,Y⊢
48:
GTO 39⊢
49:
END ⊢
R147
```

TABLE B-4. FA SUBROUTINE

```
0:
0→B;2(P1R101+R89
)↑2→A;1→Z⊢
1:
IF (2ZR87+R86)↑2
/A>225;GTO 4⊢
2:
2EXP (-(2ZR87-R8
6)↑2/A)+2EXP (-(
2ZR87+R86)↑2/A)+
B→B⊢
3:
Z+1→Z;GTO 1⊢
4:
2EXP (-R86↑2/A)+
B→B→P5;0→Z⊢
5:
√((P1R101+R89)↑2
+(π(R79-R5)P1/77
4)↑2)→R77→P3⊢
6:
LOG (R81/R6)/
LOG (R87/2)→Z⊢
7:
R6(R87↑(Z+1)-2↑(
Z+1))/((Z+1)*(R8
7-2)*2↑Z)→R2⊢
8:
IF R81-R6>0;.28(
R81-R6)P1/R2→R0;
GTO 10⊢
9:
0→R0⊢
10:
√((R0/4.3)↑2+R89
↑2)→R1→P4⊢
11:
-2R77↑2LN (R88*2
π*√(2π)*R1*R77*√
(A/2)/(R78*B))→P
2⊢
12:
RET ⊢
13:
END ⊢
R340
```



L = LINE NUMBER

SET (N) = THE ENTERED DATA SET

SET (N-1) = LAST DATA SET STORED

SET (A) = DATA SET, INITIATING AT THE FIRST DATA SET

Figure B-1. Flow diagram for sort subroutine.

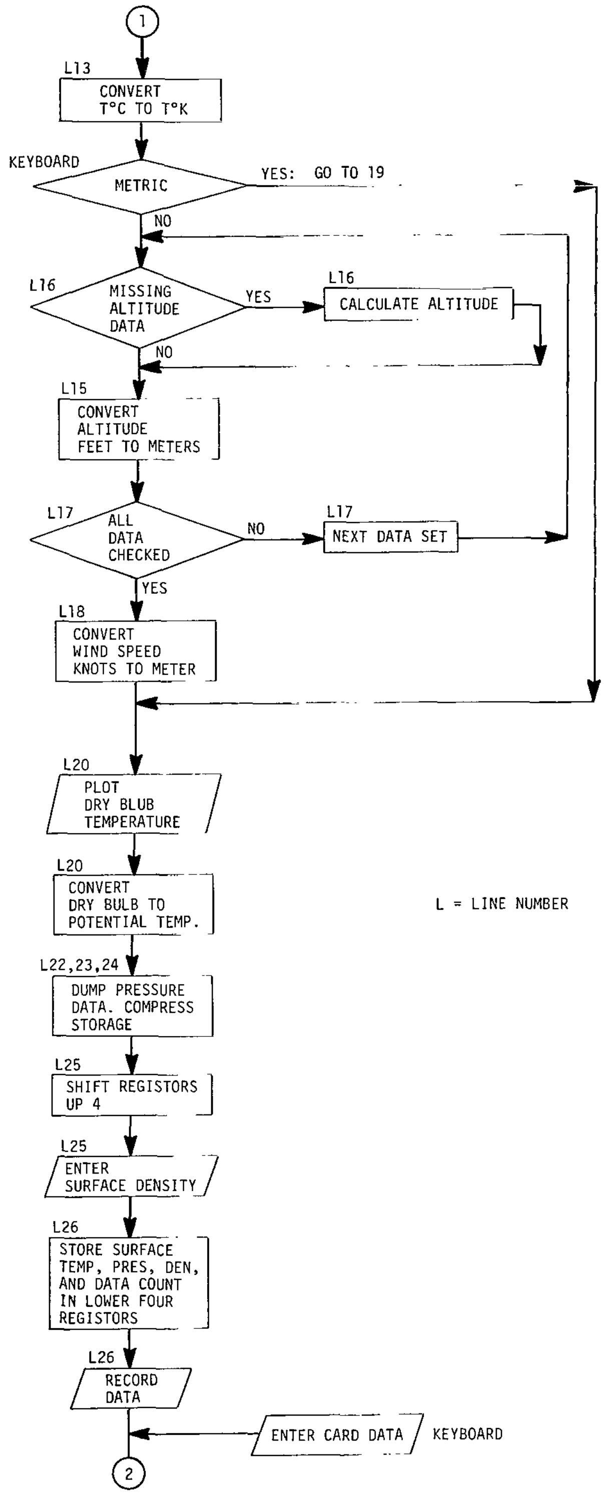


Figure B-2. Flow diagram for convert subroutine.

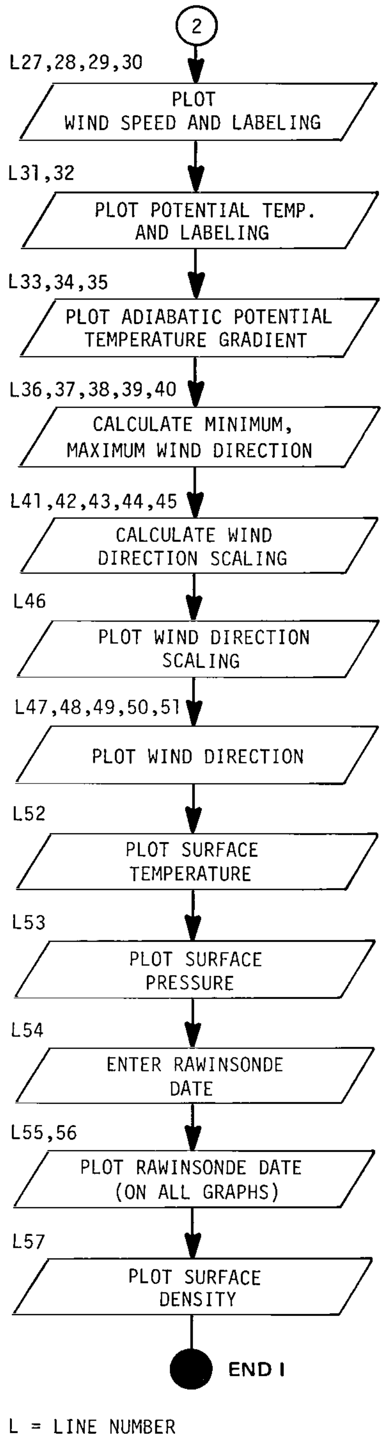


Figure B-3. Flow diagram for meteorology profile subroutine.

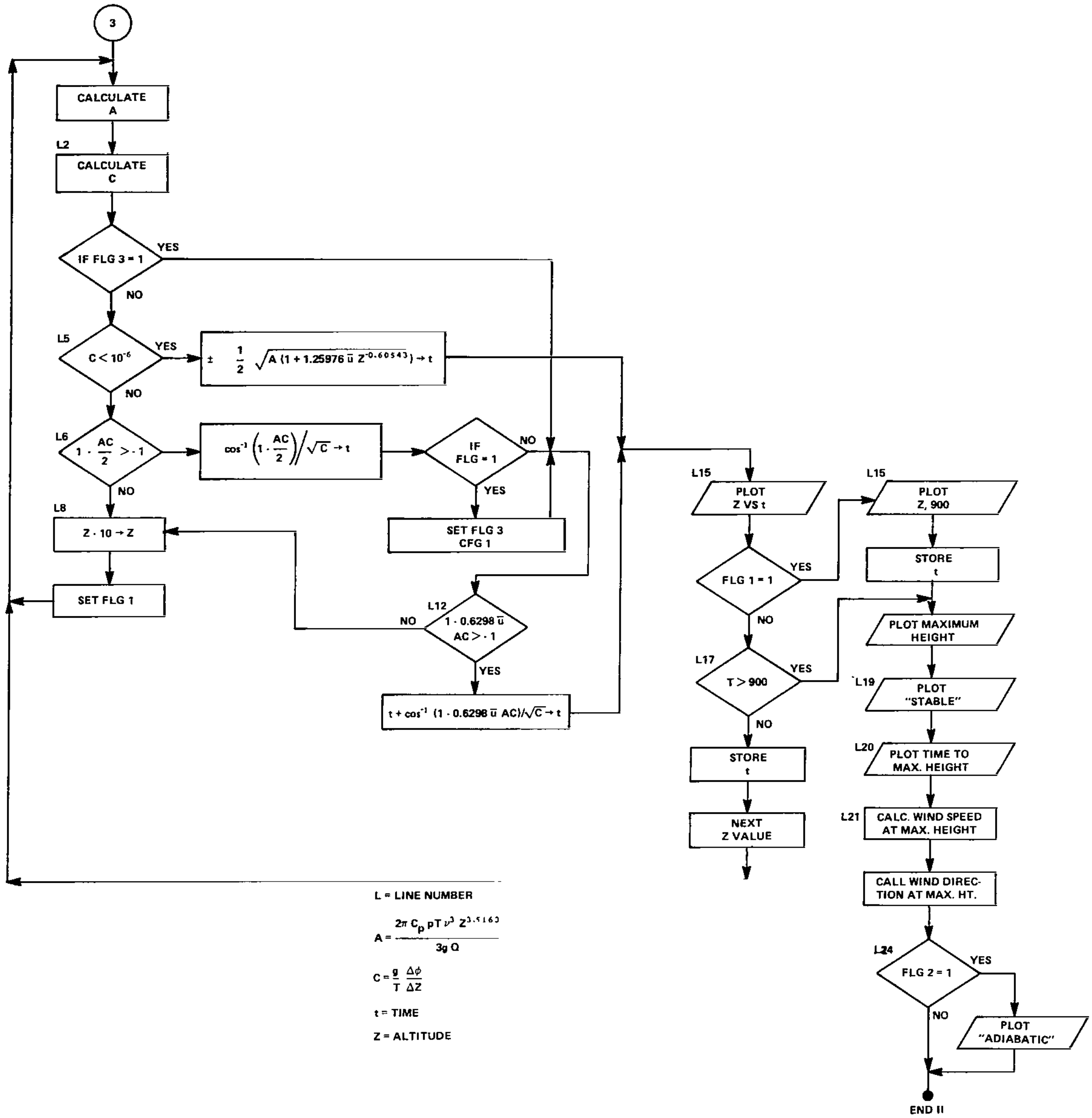


Figure B-4. Flow diagram for cloud rise routine.

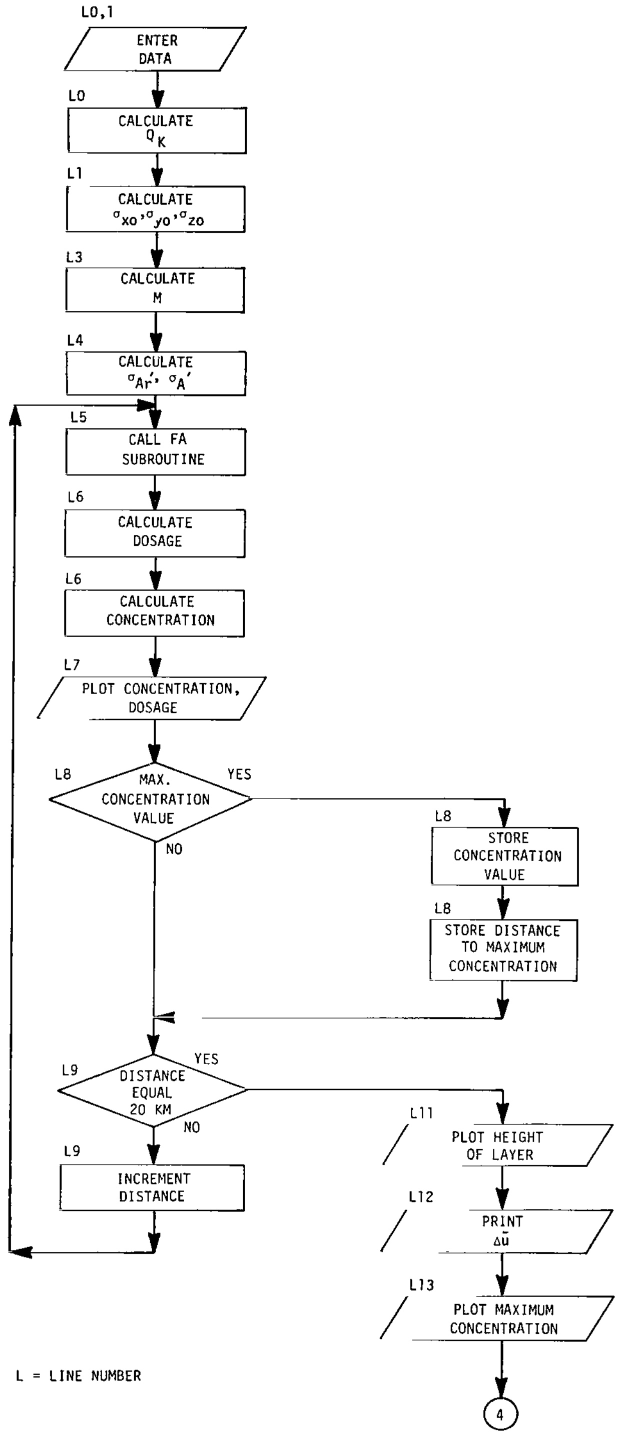


Figure B-5. Flow diagram for centerline concentration and dosage routine.

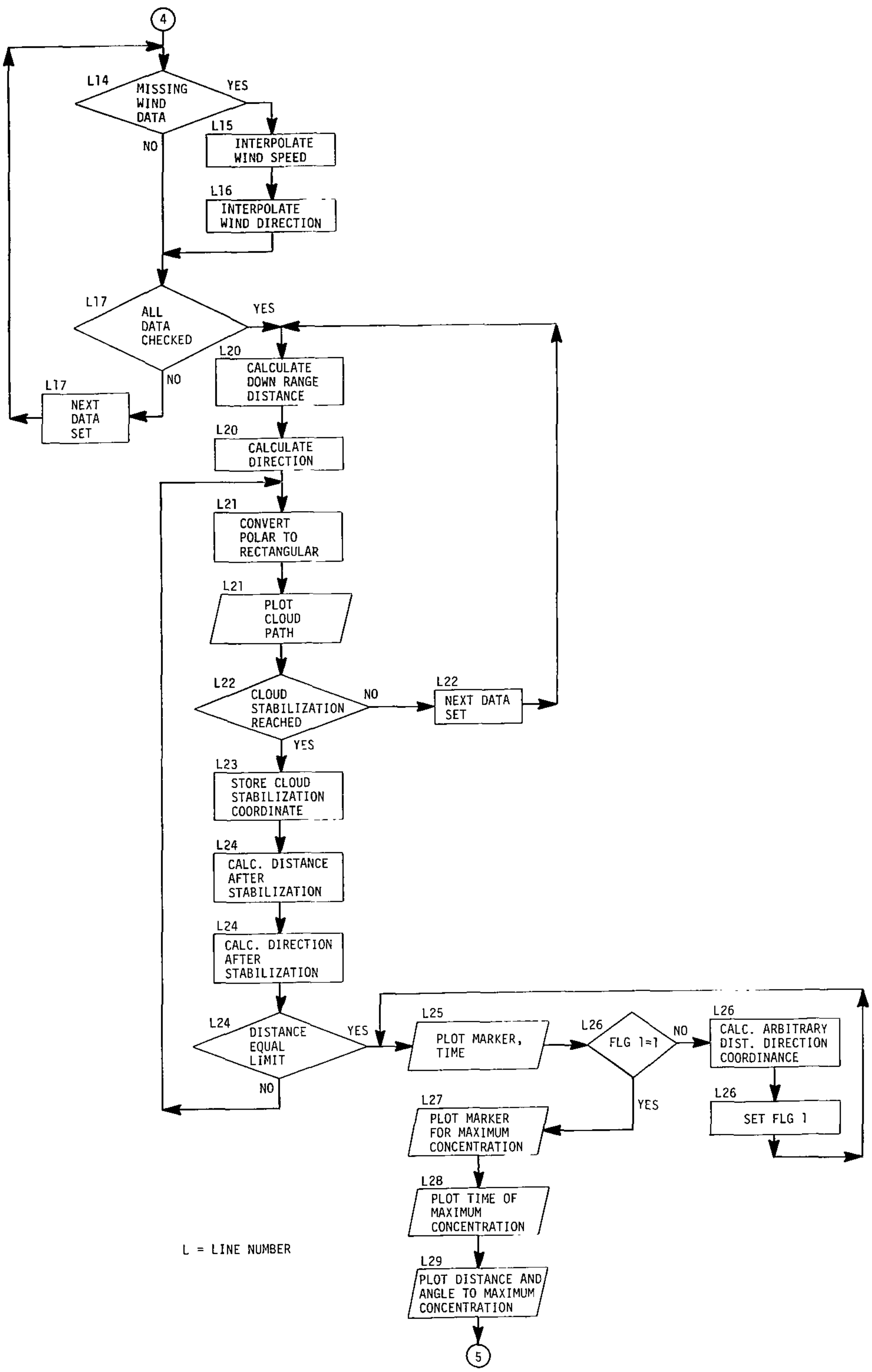


Figure B-6. Flow diagram for cloud path routine.

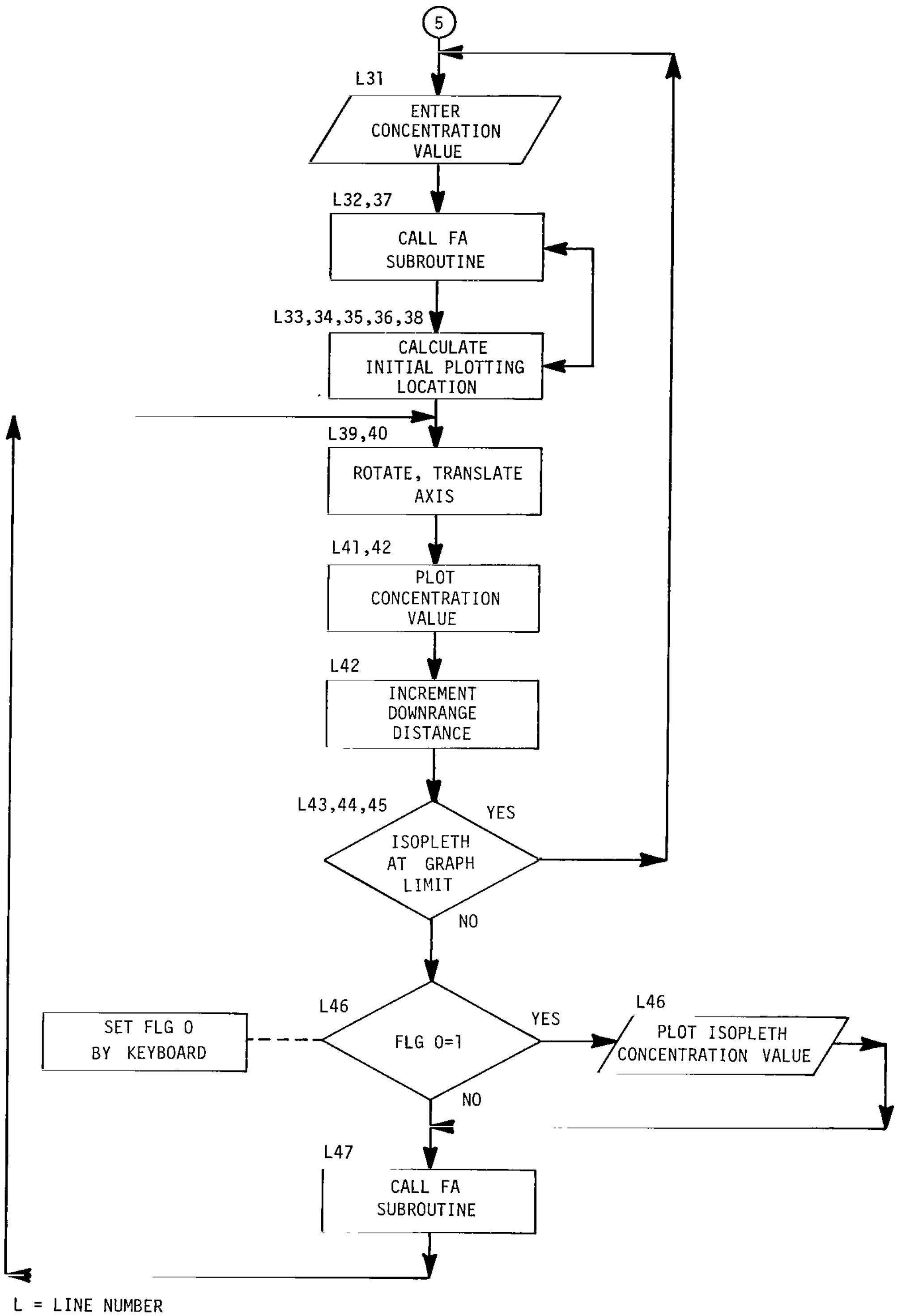
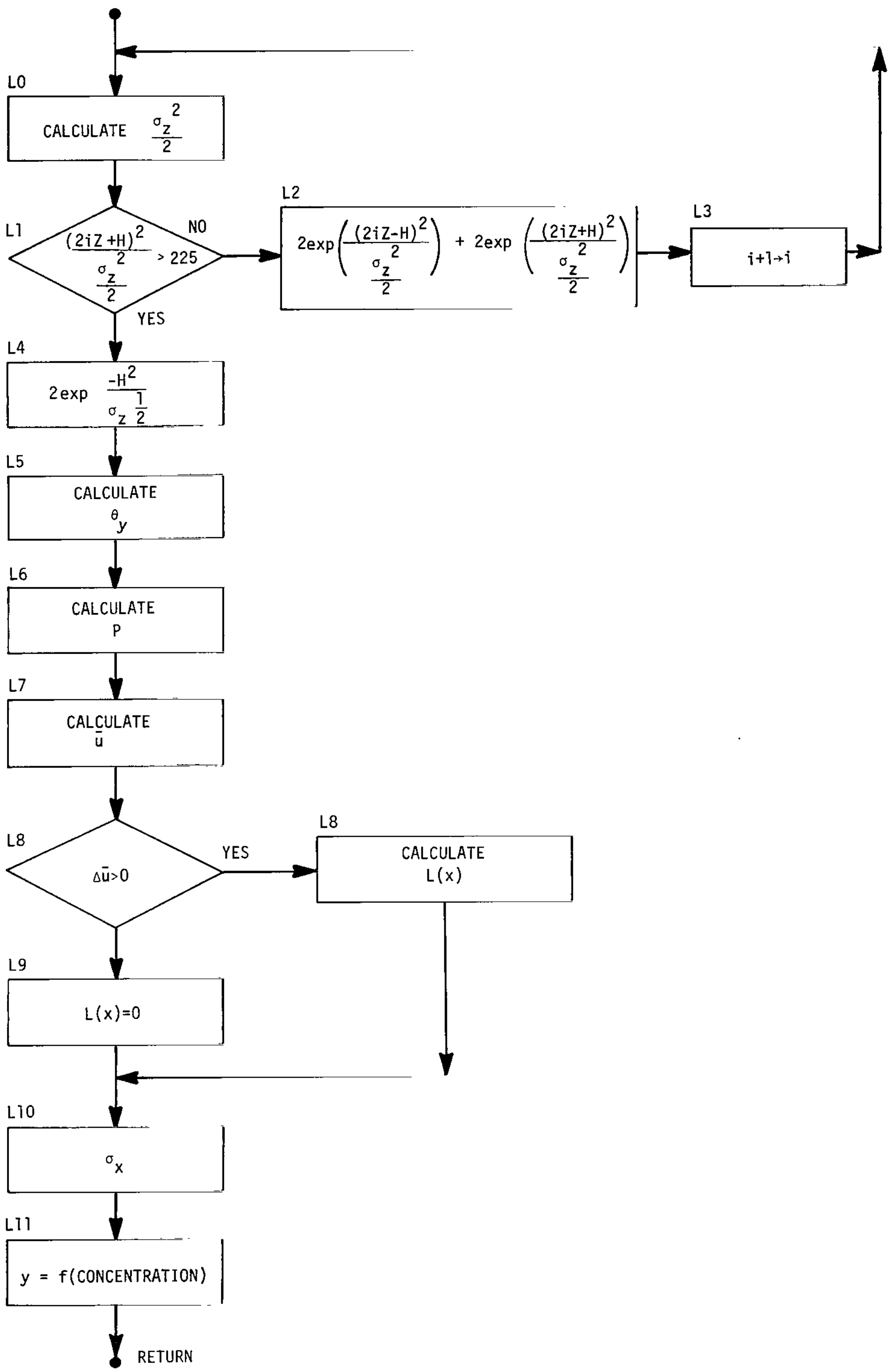


Figure B-7. Flow diagram for isopleth routine.



L = LINE NUMBER

Figure B-8. Flow diagram for FA subroutine.

TABLE B-5. LOCATION OF EQUATIONS IN THE NASA/MSFC SURFACE DIFFUSION PROGRAM (DIFFUSION ROUTINE)

Line 0

$$Q_K = F \left(\frac{10^3 \text{mg}}{g}\right)\left(\frac{22.4}{M}\right)\left(\frac{T\{z_R\}}{273.16}\right)\left(\frac{1013.2}{P\{z_R\}}\right)$$

Line 1

$$\sigma_{xo}, \sigma_{yo}, \sigma_{zo} = \frac{\gamma H}{4.3}$$

Line 3

$$m = \log\left(\frac{\sigma'_{ATK}}{\sigma'_{AR}}\right) \Big/ \log\left(\frac{z_T}{z_R}\right)$$

Line 4

$$\sigma'_{AR} = \sigma_{AR}\left(\frac{\tau_K}{\tau_{oK}}\right)^{1/5}\left(\frac{\pi}{180}\right)$$

$$\sigma'_A = \frac{\sigma'_{AR}\left[(z_T)^{m+1} - (z_R)^{m+1}\right]}{(m+1)(z_T - z_R)(z_R)^m}$$

Line 6

$$D = \frac{Q_K}{2\pi \sigma_y \sigma_z \bar{u}_K}\left(2 \exp\left[\frac{-(H)^2}{2\sigma_z^2}\right] + \sum_{i=1}^{\infty}\left\{2 \exp\left[\frac{-[2i(z_T - H)]^2}{2\sigma_z^2}\right] + 2 \exp\left[\frac{-[2i(z_T + H)]^2}{2\sigma_z^2}\right]\right\}\right)$$

$$\chi = \frac{D \bar{u}_K}{\sqrt{2\pi}\, \sigma_x}$$

TABLE B-6. LOCATION OF EQUATIONS IN THE NASA/MSFC SURFACE DIFFUSION PROGRAM (FA SUBROUTINE)

Line 0

$$\sigma_z = \sigma'_E x + x_z$$

Lines 1, 2, 3

$$\sum_{i=1}^{\infty} 2 \exp\left\{\frac{-[2i(z_T - H)]^2}{2\sigma_z^2}\right\} + 2 \exp\left\{\frac{-[2i(z_T + H)]^2}{2\sigma_z^2}\right\}$$

Line 4

$$2 \exp\left[\frac{-(H)^2}{2\sigma_z^2}\right]$$

Line 5

$$\sigma_y = \left[\left(\sigma'_A x + x_y\right)^2 + \left(\frac{\Delta\theta' x^2}{4.3}\right)^{½}\right]$$

Line 6

$$p = \log\left(\frac{\bar{u}_T}{\bar{u}_R}\right) \Big/ \log\left(\frac{z_T}{z_R}\right)$$

Line 7

$$\bar{u}K = \frac{\bar{u}_R\left[(z_T)^{1+p} - (z_R)^{1+p}\right]}{(z_T - z_R)(z_R)^p(1+p)}$$

Lines 8, 9

$$L\{x\} = \frac{0.28(\Delta\bar{u}_K)(x)}{\bar{u}_K}$$

Line 10

$$\sigma_x = \left[\left(\frac{L\{x\}}{4.3}\right)^2 + \sigma_{xo}^2\right]^{½}$$

Line 11

Concentration solved for y-position.

TABLE B-7. AVERAGE VALUES FOR SURFACE LAYER DIFFUSION ROUTINE

$\sigma_{yo}, \sigma_{xo}, \sigma_{zo}$	194.7			
m	-0.0979			
σ'_A	-0.07203			
Down range distance	0	500	1000	1500
$\sigma^2{}_z/z$	$7.58 \cdot 10^4$	$1.056 \cdot 10^5$	$1.430 \cdot 10^3$	$1.8 \cdot 10^5$
$\sum$	0	$2 \cdot 10^{-5}$	$4 \cdot 10^{-4}$	$2.61 \cdot 10^{-3}$
Vertical term	0.00163	0.01215	0.04329	0.10263
σ_y	194.7	261.03	362.61	477.4
P	0	0	0	0
$\overline{U}$	6.18	6.18	6.18	6.18
L(X)	0	0	0	0
σ_X	194.7	194.7	194.7	194.7

TABLE B-8. LABELING ROUTINES FOR GRAPHS

```
0:
SCL -4,36.5,-400
,2400;AXE 0,0,1,
100;AXE 0,-250,1
,0;AXE 36.5,2400
,1,100⊢
1:
LTR 1,2300,211;
PLT "SURFACE CON
DITIONS";FXD 0⊢
2:
0→A;A→B⊢
3:
LTR -[..],A-25,21[..]
PLT A;JMP (A+200
→A)>2[...]⊢
4:
LTR -3,[..]0,222;
PLT "ALTITUDE-ME
TERS"⊢
5:
LTR B-[..],-60,211
;PLT B;JMP (B+2[.]→
B)[...]
6:
[illegible]
7:
LTR 1[..],-40[..]
PLT "WIND DIR[..]
ION-DEGREES"⊢
8:
LTR 2[...]
PLT "[...]
DATA"⊢
9:
LTR 2[...]
PLT "CAPE KENNED
Y, FLA."⊢
10:
LTR 14,[...]
PLT "[.]+E AERO-YA
"⊢
11:
LTR 14,2325,211;
PLT "NASA / MSFC
"⊢
12:
LTR 14,2150,211;
PLT "(OCT. 73, P.
A.H.)"⊢
13:
END ⊢
R34[.]
```

```
0:
SCL -75,1000,-20
0,3100;AXE 0,0,3
0,100;FXD 0;0→X⊢
1:
LTR 9,2900,221;
PLT "TEMPORAL AS
CENT OF A TITAN
III EXHAUST CLOU
D"⊢
2:
LTR 270,2800,211
;PLT "CAPE KENNE
DY, FLA."⊢
3:
LTR 9,2600,211;
PLT "S+E-AERO-YA
   NASA / MSFC"⊢
4:
LTR 9,2500,211;
PLT "(OCT.73, P
.A.H.)"⊢
5:
LTR -60,950,222;
PLT "ALTITUDE-ME
TERS"⊢
6:
LTR -50,X-20,211
;PLT X;JMP (X+20
0→X)>3000⊢
7:
LTR 225,-160,221
;PLT "TIME AFTER
 LAUNCH-SECONDS"
;0→X⊢
8:
LTR X-10,-80,211
;PLT X;JMP (X+60
→X)>900⊢
9:
END ⊢
R[..]
```

```
0:
SCL -3000,20500,
-100,970;AXE 0,0
,1000,50;AXE -15
00,0,0,50⊢
1:
LTR -2700,300,22
2;PLT "CONCENTRA
TION-PPM";FXD 2;
0→X⊢
2:
LTR -2500,X-3,21
1;PLT X.100;JMP
(X+50→X)>950⊢
3:
FXD 0;LTR 7000,-
70,221;PLT "DIST
ANCE-KM";0→X⊢
4:
LTR 1000X-100,-3
0,211;PLT X;JMP
(X+1→X)>20⊢
5:
LTR 300,350,221;
PLT "CENTERLINE
CONCENTRATION AN
D DOSAGE"⊢
6:
LTR 300,870,211;
PLT "NASA / MFSC
   S+E-AERO-YA"⊢
7:
LTR 300,800,211;
PLT "(OCT. 73, P
.A.H.)"⊢
8:
LTR -1000,320,22
2;PLT "DOSAGE-PP
M-SEC";FXD 0;0→X
⊢
9:
LTR -600,X-3,211
;PLT X;JMP (X+50
→X)>950⊢
10:
LTR 1[.]000,9[.]0,[..]
1;PLT "CONCENTRA
TION-";PLT 20[.]00
,9[.]0;PLT 20500,9
[.]0⊢
11:
LTR 1[.]800,830,2[.]
1;PLT "DOSAGE-[.]
[...]⊢
12:
LTR [...]
PLT "RAWINSONDE
DAT[..]"
13:
```

```
0:
SCL -20000,18000
,-24000,6050;
AXE 0,0,1000,100
0;0→X;FXD 0⊢
1:
PLT 6000COS X,60
00SIN X;JMP (X+1
→X)>360⊢
2:
0→A;0→B⊢
3:
PLT (5900+B)COS
A,(5900+B)SIN A;
JMP (B+200→B)>20
0⊢
4:
PEN ;IF A≠360;A+
10→A;0→B;GTO 3⊢
5:
LTR -19500,-1900
0,221;PLT "TITAN
 III  HCL"⊢
6:
LTR -19500,-2000
0,211;PLT "RAWIN
SONDE DATA"⊢
7:
LTR -19500,-2200
0,211;PLT "NASA
/ MFSC   S+E-AER
O-YA";
8:
LTR -19500,-2300
0,211;PLT "(OCT.
 73, P.A.H.)"⊢
9:
LTR 500,-19000,2
11;PLT "CONC. MA
X. CONDITIONS"⊢
10:
END ⊢
R254
```

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