FULL SCALE STUDY OF

DISPERSION OF STACK GASES

A Summary Report

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A Summary Report

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INTRODUCTION

Description of the Study

During fiscal years 1958-1962 the Tennessee Valley Authority conducted an air pollution research project entitled "Full-Scale Study of Dispersion of Stack Gases" under the sponsorship of the Public Health Service. In this project advantage was taken of unique opportunities for full-scale appraisal of dispersion of air pollutants from large coal-burning, steam-electric generating plants. Advantages offered for diffusion studies included: (1) large isolated sources where intermixture with extraneous pollutants is not significant; (2) complete plant operational data and emission rates; (3) sufficient fly ash emission to provide a visible plume aloft out to distances of 10-15 miles under meteorological conditions of special interest; (4) a helicopter equipped with special instruments for sampling and recording SO_2 concentrations, as well as extensive auxiliary instruments; (5) tower-mounted meteorological instruments for providing basic information on wind and temperature parameters; and (6) computer facilities for data analysis.

Work Plan

The initial work plan envisaged the compilation of sufficient field measurements for reasonably adequate definition of dispersion during inversion conditions, high wind conditions, and low wind conditions. While it is considered that dispersion was defined for inversion and high wind conditions, sampling techniques employed proved unsuitable for effective definition of dispersion during low wind and unstable conditions where excessive variability was presented by looping of the plume.

In addition to the primary studies to determine diffusion parameters, a limited investigation was made of plume rise or effective stack heights. A reasonably accurate estimate of effective stack height is required for useful application of diffusion parameters. Some corollary studies were considered desirable for appraising the validity or reliability of derived diffusion parameters. Principal among these corollary studies was an extensive investigation of the oxidation of SO_2 in the atmosphere after emission from the stack. Oxidation was studied with ground-based facilities and also in the plume at various distances and travel times, and under various weather conditions. In the course of this investigation interrelationships among SO_2, H_2SO_4, and fly ash also were studied.

Location of Field Studies

The Colbert Steam Plant (figures 1 and 2) located on the south bank of the Tennessee River 8 miles west of Tuscumbia, Alabama, was the site of most of the fieldwork. One flight used in the studies to define dispersion from a single stack was made at the Gallatin Steam Plant near Gallatin, Tennessee. The Colbert plant has four 200,000-kw units with four 300-foot stacks. The Colbert plant was selected for study because the plant is located in an area of reasonably flat topography, and the weather regime of the area includes a wide range of wind speeds and environmental temperature lapse rate conditions. The axis of the line of four stacks is oriented in a northwest-southeast direction (figure 3). This plant is located in a broad, relatively flat valley with the exception of a range of hills beginning about 3 miles southwest of the plant and extending 300-400 feet above the general valley floor.

Instrumentation

Helicopter and Auxiliary Equipment--Equipment used in the Bell Model 47-D-1 helicopter (figure 4) included:

1. A portable Model 26-103 Titrilog, with Esterline-Angus recorder, for measuring continuous SO_2 plume concentrations. The Titrilog was positioned on a cushion mount between the pilot and the flight director.
2. A sample intake probe for the Titrilog extended about 12 inches forward from left bottom of cockpit canopy. A constant sample rate of about 1,000 cc per minute was maintained by utilizing the manifold vacuum of the helicopter.
3. A Model 8425 Cole-Parmer thermistor thermometer with interchangeable probe for taking ambient air vertical temperature profiles, as well as special temperatures in and out of the plume. The probe extended about 12 inches immediately forward from center bottom of the cockpit canopy.
4. A precision spring-wound clock for time documenting of flight sampling and observing.
5. A standard aircraft-type altimeter for indicating and maintaining desired heights aboveground.
6. A standard aircraft-type airspeed indicator for obtaining desired sampling airspeeds.
7. A secretarial-type voice recorder for recording temperature, height aboveground, and pertinent plume geometry observations.

Meteorological Facilities--A fixed meteorological station, common to most TVA steam plants, was located 0.78 mile southeast of the Colbert

Steam Plant (figure 1). Station instrumentation included: (1) a 220-foot steel tower; (2) an anemograph model wind system for continuous recording of wind speed and wind direction at the 220-foot tower level; (3) a Brown temperature instrument, with 3-channel, sequential-type recorder, for continuous recording of ambient air temperature and wet-bulb depression at the 4-foot tower level and continuous temperature difference between the 220- and 4-foot tower levels; and (4) a standard cotton-region temperature shelter with hygrothermograph and maximum-minimum thermometers.

Wind profiles, using single theodolite, were obtained at a launching point near the fixed meteorological station. Hourly (later in the study, half hourly) pibals, using 10-gram ceiling balloon, were released during the sampling period for providing wind speed and wind direction profile data between surface and 2,000 feet.

Ambient air temperature profiles, using helicopter, were made at 100-foot vertical intervals from surface to 500 feet above the plume at a distance of about 1 mile from the plume. Temperature readings within the plume were considered unreliable, as the flight time through the plume generally was insufficient to allow probe readings to become stabilized to conditions encountered in transecting the plume, e.g., traversing through cooler ambient air into warmer plume air.

Aerial Sampling Plan

The procedural objective of the sampling plan was to provide adequate definition of SO_2 distribution in plume cross sections while allowing sufficient time for sampling and other essential measuring and observational activities. During inversion conditions, replicate flights were made across the plumes at the observed top and bottom elevations and at subjectively selected centerline and quarter section elevations (figure 5). Cross-sectional flights were made at selected distances, usually 1/2, 3/4, 1, 3, and 5 to 10 miles from the plant. During high wind and neutral conditions, the flight plan was modified to take care of the greater variations in plume geometry than were found during inversion conditions. Replicate flights were made across the plume at the observed top of the plume and at successively lower 100- to 200-foot elevations to the bottom of the plume. Cross-sectional flights were made at selected distances of 1/2, 1, 2, and 3 miles from the plant. During high wind and neutral conditions, the SO_2 concentrations beyond 3 miles from the plant had diminished to such low levels that plume definition, based on SO_2 recorder registration, was not attainable.

Flight Speed and Sampling Rate

The flight speed for sampling was set at the minimum safe forward speed of the helicopter, 30 mph or 44 fps. Because of the excessive friction in the sample line and the fixed sample rate, it was not practical to attain isokinetic sampling at this airspeed. The SO_2 sample was drawn through a 0.075-inch-diameter orifice at the point of takeoff (figure 6), which provided a sample flow of about 20 fps.

Laboratory tests made under simulated field conditions showed that 90 percent of the average SO_2 concentration was being recorded. To compensate for this factor, the instrument factor applied to all Titrilog charts was increased by 10 percent.

Data Collection and Analysis

The project consisted of four principal activities: (1) field sampling and observations, (2) reduction and consolidation of data, (3) data analysis and formulation, and (4) summary of results and final reporting. From table 1, which lists all helicopter flights in chronological order, it will be noted that from September 10, 1957, to October 28, 1960, 59 flights were made, totaling 149 hours of flight time. Classification of flights included: 13 for experimental developing and testing of sampling techniques and special instrumentation, 12 for successful dispersion definition of inversion plumes, 12 for successful dispersion definition of high wind plumes, 4 for observing and recording plume rise, and 12 for studying SO_2 oxidation. Because of sudden changes in meteorological conditions, 2 flights were discontinued; 3 flights were of limited value because of voice recorder failure; and 1 flight was made for tracking a constant-volume tetroon.

To provide information on plant emission rates for correlation with dispersion data, average SO_2 concentrations were obtained by concurrent sampling of flue gas during all sampling flights. Sampling was obtained for successive 30-minute periods using the iodometric titration procedure. Representative samples of coal were taken concurrently from each plant unit in operation for analysis of average sulfur content of coal. Additional design and operational data included coal consumption per unit day, temperature of flue gas, exit velocity of flue gas, diameter and height of stack, etc. (table 2).

Following each flight all charts, recordings, data sheets, and observations were labeled. Later the data were abstracted, compiled, and tabulated or graphed for convenient use in the investigative studies of plume dispersion. Data made available for these dispersion studies included:

1. Average and axial SO_2 concentration in cross section
2. Plume width and depth
3. Plume height aboveground
4. Average wind speed in plume
5. Vertical temperature gradient, ^{o}F./1,000 ft., in plume environmental area
6. Plume cross-sectional area
7. Standard deviation along the y and z axes
8. Plume direction in relation to line of stacks
9. SO_2 (flux) in cross sections, expressed in arbitrary units in a 1-foot plume segment

Following the establishment of suitable mathematical models, the consolidated data were applied initially in manual calculation of diffusion parameters. A program was developed in which the data were subjected to more extensive analysis through use of TVA's computer facilities.

Analysis was limited to generalized dispersion equations. Data are presented in sufficient detail and completeness for independent study and use by others working in this field.

Order of Reporting

To facilitate review and appraisal of extensive data analysis, tabulations, and illustrations, this report is arranged as follows.

Summary - Part I. Diffusion in Inversion Conditions

Summary - Part II. Diffusion in High Wind Neutral Conditions

Summary - Part III. Plume Rise

Summary - Part IV. Corollary Studies of SO_2 Oxidation

Because of the volume of tables and figures in the analysis of data, only summaries of the four parts are being published. However, a limited number of copies of the data analysis which has been summarized will be made available to interested persons upon request.

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A SUMMARY REPORT

Part I. Diffusion in Inversion Conditions

Diffusion in inversion conditions was defined on 12 sampling days. SO_2 registrations, from Titrilog recorder charts, were obtained during repetitive plume transections from 1/2 mile to 10 miles from the plant source (figure 7). From these sampling activities data shown in table 3 were collected and compiled.

Plume Geometry

Perimeter--The plume transection widths were determined from the length of the record trace registrations, e. g., chart speed of 1-1/2 inches per minute and flight speed of 44 feet per second. The depth or vertical distance of the plume was determined from altimeter readings at the top and bottom of the plume. A typical plume cross section developed for day 1 is shown in figure 8.

Cross-Sectional Area--The cross-sectional area was determined from the formula:

$$\text{Area} = \frac{\pi \times \text{Width} \times \text{Depth}}{4} \qquad 1$$

Plume SO_2 Data

Maximum Axial and Average SO_2 Concentrations--Maximum axial SO_2 concentration was determined from the flight transection through the centerline of the plume. Average SO_2 concentration was determined from planimetric analysis of the area under the SO_2 distribution curves.

SO2 Flux--SO_2 flux, expressed in terms of cubic feet of SO_2 per linear foot of plume, was determined from the plume cross-sectional area and average SO_2 concentration in the plume section.

Meteorological Data

Helicopter soundings provided data on vertical temperature gradient at 100-foot intervals from surface to heights well above the plume top (figure 9). Pilot balloon observations provided vertical wind direction and wind speed profile data from surface to 3,000 to 5,000 feet aboveground (figure 10). Supplementary data, including wind direction, wind speed, vertical temperature gradient, and wet bulb depression, were provided from the fixed meteorological station near the plant area.

Plant Operational Data

Concurrently with field sampling activities, coal and flue gas samples were taken and coal consumption rates were noted, thus providing a measure of SO_2 and heat emission rates.

Data Analysis

The objectives of the analysis of diffusion data were to express the results in terms of the mathematical model which best fits observed dispersion patterns and to develop coefficient values appropriate to the selected mathematical model.

Mathematical Diffusion Model--Examination of records or measured distribution of concentrations about the plume centerline in these studies indicates that Gaussian distribution is closely approximated. In a few instances the distribution is slightly skewed, and two maxima occurred in some instances when the plumes from separate stacks had not become uniformly blended. Where Gaussian distribution exists, a plot of the distribution on normal probability paper yields a straight line. This test, applied to data taken on day 2 (figure 7), is illustrated in figure 11. While skewness exists in a few instances, most of the points have a very good straight-line fit.

The symmetry and results of the analytical test of distribution about the plume centerline are considered to justify the use of Gaussian distribution in mathematical analysis of diffusion of plumes in an inversion. From the basic equation for Gaussian distribution,

$$\underline{\bar{X}} = \underline{\bar{X}}_{max}\, e^{-1/2 \left(\frac{x_g}{\sigma}\right)^2} \qquad 2$$

the following general equation for distribution at any single section of the plume in both horizontal and vertical directions is developed:

$$\underline{\bar{X}} = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-1/2\left(\frac{y^2}{\sigma_y{}^2} + \frac{z^2}{\sigma_z{}^2}\right)\right] \qquad 3$$

where the maximum concentration at the plume centerline is given by

$$\underline{\bar{X}}_{max} = \frac{Q}{2\pi\sigma_y\sigma_z u} \qquad 3a$$

Where the diffusion parameters C_y, C_z, and m are constants under fixed meteorological conditions, the variability of the standard deviations, σ_y and σ_z, along the y and z axes has the following relationship with x, distance downwind from the source:

$$\sigma_y = C_y x^{m_y} \qquad 4$$

$$\sigma_z = C_z x^{m_z} \qquad 5$$

or when $m_y = m_z$ or $m_y + m_z = m$

$$\sigma_y = C_y x^{\frac{m}{2}} \qquad 6$$

$$\sigma_z = C_z x^{\frac{m}{2}} \qquad 7$$

Then the following equations express the distribution at any point in the plume, along the x, y, and z axes.

$$\overline{X} = \frac{Q}{2\pi C_y C_z u x^m} \exp\left[-\frac{1}{2x^m}\left(\frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right)\right] \qquad 8$$

or

$$\overline{X} = \frac{Q}{2\pi C_y C_z u x^{(m_y + m_z)}} \exp\left[-\frac{1}{2}\left(\frac{y^2}{C_y^2 x^{2m_y}} + \frac{z^2}{C_z^2 x^{2m_z}}\right)\right] \qquad 8a$$

General dispersion formulas 8 and 8a correspond to the Sutton equation for distribution in an elevated plume when the diffusion coefficients C_y and C_z are multiplied by $\sqrt{2}$ and the value of m or $(m_y + m_z)$ is set at 2-n.

Standard Deviation--Since SO_2 concentration was measured with a continuous recording instrument at a known uniform rate of speed through the plume, the curves show actual distribution in relation to time and distance. The area under the curves representing SO_2 distribution along the line of flight can be obtained by integrating equation 2 between the limits of $\pm\infty$ which give

$$\sigma = \frac{\text{Area}}{\overline{X}_{max}\sqrt{2\pi}} \qquad 9$$

The area under the curve is equal to the base (width or depth in feet) times the average height (average SO_2 concentration in ppm along the axis).

Computer Program - Diffusion Parameters--A FORTRAN program was developed for calculation of σ_y, σ_z, m, m_y, m_z, C_y, C_z, and $\bar{\underline{X}}$ from parameters measured in the plume and from SO_2 emission rates. These values were determined as follows.

$$\sigma_y = \frac{(\text{Plume width})(\text{Average } SO_2 \text{ concentration})}{(\text{Peak } SO_2 \text{ concentration})\sqrt{2\pi}} \qquad 10$$

$$\sigma_z = \frac{(\text{Plume depth})(\text{Average } SO_2 \text{ concentration})}{(\text{Peak } SO_2 \text{ concentration})\sqrt{2\pi}} \qquad 11$$

$$m = \log\left(\frac{\underline{X}_1}{\bar{\underline{X}}_2}\right) \Big/ \log\left(\frac{x_1}{x_2}\right) \qquad 12$$

$$m_y = \log\left(\frac{\sigma_{y_1}}{\sigma_{y_2}}\right) \Big/ \log\left(\frac{x_1}{x_2}\right) \qquad 13$$

$$m_z = \log\left(\frac{\sigma_{z_1}}{\sigma_{z_2}}\right) \Big/ \log\left(\frac{x_1}{x_2}\right) \qquad 14$$

C_y and C_z from equations 4, 5, 6, and 7, and $\bar{\underline{X}}$ at 36 points in the quarter section of the plume illustrated by figure 12 from equation 8a.

The computed values of SO_2 concentrations determined for field conditions from the measured values of standard deviation and axial and average SO_2 concentrations at points along the y and z axes (figure 12) were plotted for each section sampled, and are illustrated for day 2 in figure 13. From these plots, the values of average SO_2 concentration and plume widths and depths were calculated. With the exception of two cases, the calculated values of plume widths and depths agreed closely with field-measured values (figure 14). The ratio of the measured axial concentration to the average SO_2 concentration (figure 15) was approximately 2.33:1. For the computed values, the ratio was 2.18:1 (figure 16).

Parameters m_y and m_z--Average values of the parameters m_y and m_z for each day (table 3) were determined for field conditions from the ratio of the standard deviation along each axis to the distance. Average m_z values were much less than average m_y values, indicating that the rate of diffusion is much greater along the y axis and that separate m values for the y and z axes would be required.

Since an appreciable range in the values of parameters m_y and m_z was evident for the 12 sampling days, values considered to be the most representative of the more accurate dispersion data were grouped into four ranges of decreasing stability (table 4). Variation of these parameters with stability is illustrated in figure 17.

Coefficients C_y and C_z--Values of m_y and m_z (table 4) were determined for the various ranges of stability and were used to develop estimates of C_y and C_z for each cross section for days grouped according to stability, from which the average values of C_y and C_z (table 4) were obtained. The variation of these coefficients with stability is shown in figure 17.

While the parameters m_y, m_z, C_y, and C_z developed to this point have a limited value for application to general diffusion problems, they should provide reasonably accurate estimates of diffusion during the full range of inversion conditions at distances of more than 1 mile from the source.

Modification of Line-Source Parameters to Point-Source Parameters

To provide broader application for use in general diffusion problems, all measured plume dimensional data and axial and average plume concentrations were modified to approximate a single stack or point source. Modification was derived from the relationships between the wind direction and the observed horizontal and vertical spread of the plume width and depth with a line of stacks (figure 18).

Analysis of data measured in a plume from a line of two to four stacks affirms that both the plume width and plume depth vary with respect to the relation between plume direction and direction of the line of stacks. Thus, wind direction, per se, may effectuate variations in the diffusion coefficients for identical meteorological parameters. Minimum widths of plumes from a line of stacks occur when the azimuth direction of the plume is the same as the alignment axis of the stacks; and conversely, maximum widths occur when the plume direction is at right angles to the alignment axis of the stacks. On the other hand, minimum depths of plumes occur when the azimuth direction of the plume is at right angles to the alignment axis of the stacks; and conversely, maximum depths occur when the plume direction is the same as the stack alignment axis. With the addition of one stack, at a stack separation distance Δ (figure 19), the plume width is increased by an increment equivalent to distance Δ when the plume direction is at right angles to the alignment axis of the stacks. As the plume direction varies from 90° to 0° from the stack alignment, the increase in plume width decreases from Δ to zero. The data plotted in figure 18 indicate that for the Colbert Steam Plant the magnitude of increase in plume width is approximately four times the decrease in plume depth. Thus the process of converting line-source plume dimensions, plume width and depth, to dimensions representative of one stack is approximated by:

1. Reducing the width by $(n-1)\,\Delta \sin\theta$
2. Reducing the depth by $(n-1)\,\frac{\Delta}{4}\cos\theta$

where n = Number of stacks

θ = Degrees plume direction varies from stack alignment

Δ = Linear separation between stacks

When a normal distribution exists for both point- and line-source emissions, axial and average concentrations for the single stack point source should have the same ratio as axial and average SO_2 concentrations for a line source. This relation is confirmed from field data with 2-, 3-, and 4-stack sources (figure 15). On the basis of this relation, point-source concentrations were estimated from line-source data by using the following formula.

$$SO_2 \text{ Concentration (point source)} = \frac{\text{Plume cross-sectional area (line)}}{\text{Plume cross-sectional area (point)}} \times \frac{\text{Line-source } SO_2 \text{ concentration}}{\text{Number of units on line}} \qquad 15$$

Thus the line-source values were adjusted according to this single stack point-source formula. These data were then processed through the computer in the same manner as the original field data for compiling estimates of m_y, m_z, C_y, and C_z for a point source (table 5).

Parameters m_y and m_z--In the same manner as for line sources, the values of m_y and m_z were determined from the combined values considered to be most representative of the more accurate dispersion data and were grouped into four ranges of decreasing stability from which the best estimates of the average values (table 6) were obtained. The variation of the m_y and m_z parameters with stability is shown in figure 20.

<u>Coefficients C_y and C_z</u>--Values of m_y and m_z (table 6) derived for the four ranges of stability were used to develop C_y and C_z values for each cross section according to classification of stability. Average C_y and C_z coefficients (table 6) were then determined for each of the groups of stability. Variation of these coefficients with stability is given in figure 20.

Modification of Point-Source Parameters for General Diffusion Problems

As the number of stacks is increased beyond one, the plume widths and depths are increased (figure 19) in accordance with the following equations.

$$\Delta_{y_n} = (n-1)\, \Delta \, \text{Sin}\, \theta \qquad 16$$

$$\Delta_{z_n} = (n-1)\, \frac{\Delta}{4} \, \text{Cos}\, \theta \qquad 17$$

Where:

n = Number of stacks

Δ_{y_n} = Increase along y axis

Δ_{z_n} = Increase along z axis

Δ = Distance between stacks

θ = Degrees plume off line of stacks

These relationships provided the means for estimating the rate of change in parameters m_y and m_z (figure 21) and C_y and C_z (figure 22) in relation to Δ_{y_n} and Δ_{z_n}, as a point or single stack source is enlarged to a line of two or more stacks.

To utilize the point-source parameter for line-source determinations, the following steps are necessary.

1. Determine the increase in plume widths, Δ_{y_n}, and plume depths, Δ_{z_n}, due to additional stacks and plume direction from equations 16 and 17.

2. Determine the line-source parameters m_y, m_z, C_y, and C_z by multiplying the corresponding point-source parameters by their respective ratios shown by the curves in figures 21 and 22 for the increase in plume widths, Δ_{y_n}, and plume depths, Δ_{z_n}.

Table 7 shows the line-source parameters developed for each day from the best estimate of the point-source parameters, and gives the field values of the axial concentration shown in line B, table 8.

Comparison - Field Concentrations and Concentrations Derived from Calculated Diffusion Parameters

Table 8 summarizes the results from field sampling and mathematical analysis. A values in this table are axial concentrations measured in the plume, and B values are concentrations calculated from point-source parameters modified to simulate line-source field conditions.

Reasonably good agreement exists between measured and calculated values for days 1, 2, 3, and 9. The relation of measured A values and calculated B values is evident in the following table. Data from these four

	Percent Measured Axial Concentration Distance (Miles)				
Day	1/2	3/4	1	2	x
1	117	106	90	83	77
2	101	95	95	92	86
3	82	79	104	110	-
9	-	-	90	-	85

days suggest that use of the calculated diffusion coefficients in the general dispersion equation should yield concentrations within ±25 percent of the actual field values and that SO_2 distribution should closely approximate the actual plume geometry or dimensions.

Greater differences in measured and calculated concentrations were evident for the other sampling days. These differences primarily are attributed to use of diffusion coefficients based on a single fixed temperature gradient or stable condition to calculate diffusion over a 2- to 2-1/2-hour period. Actually, stability over such an interval may undergo significant changes which affect both measured concentrations and diffusion rates. Simultaneous sampling at two or more sections would be required to overcome this problem.

Part II. Diffusion in High Wind and Neutral Conditions

Field instrumentation and sampling procedures used during high winds and neutral conditions were similar to those used in the study of dispersion during inversion conditions. Because of the greater variance in the plume configurations, in comparison to the relatively stable and unvarying conditions of the inversion plume, the aerial sampling plan was modified slightly. Additional horizontal flights across the plume from top to bottom at successively lower elevations were made to determine the cross-sectional areas. Some flights were made in the plume between 1/2 mile and 3 miles from the source and along paths parallel to the x axis of the plume. The purpose of these flights was to compare the SO_2 distribution along the vertical axes with the concentrations determined from the cross-sectional flights. In most cases the plume was widely dispersed in both horizontal and vertical directions within a relatively short distance or travel time. Because of the larger cross sections and the increase in time required for sampling each cross section, the maximum sampling distance from the plant was restricted to 3 miles. Generally, SO_2 concentrations at this distance had diminished to such a low level that plume definition from recorded charts no longer was discernible.

Plume Geometry

Constant shifting of the plume along the vertical axis, primarily attributed to cyclical variations in wind speed, interfered with precise definition of plume cross sections. As a result of continuous vertical shifting, the measured depth of the plume (table 9), based on the difference in elevation between the bottom of plume and the first higher elevation when no SO_2 was recorded, may have varied slightly with the true depth of the plume. Such discrepancies were dependent upon vertical shifting and the progression status of the sampling flight. The transit widths, determined from the recorder chart speed and flight speed, indicated that during the sampling of a single cross section it could be possible to traverse the plume centerline (figure 23) more than once. The plume width used in this analysis (figure 23) was the maximum width determined by several transection flights through a representative plume segment which was selected to best define the plume depth.

Plume SO_2 Data

Maximum and average SO_2 concentrations (table 9) associated with each cross section were determined from SO_2 charts (figure 24), as they were in the analysis of data taken in inversion conditions. The SO_2 distribution determined from these Titrilog charts was similar to that observed in inversion conditions and approximated a Gaussian distribution. The average ratio of maximum to average concentrations (figure 25) was about 2.00:1.

To estimate SO_2 flux, a true cross section was required. This condition was unobtainable because of plume fluctuation during the sampling period (figure 23).

Meteorological Data

The same type of meteorological information obtained under inversion conditions was obtained for high wind and neutral conditions.

In the 11 sampling days average temperature change with elevation (figure 26) closely approximated the adiabatic lapse rate from the surface to elevations well above the plume. The average vertical temperature gradient in the plume during all sampling periods varied from -4° F. to -6.5° F. per 1,000 feet.

Average wind speed in the plume section (table 9) based on pibal observations (figure 23) varied from 8 to 23 miles per hour.

Data Analysis

The same approach and procedures as those used in the analysis of data for inversion conditions were followed in the analysis of field data for high wind and neutral conditions (table 9), with the exception of the determination of standard deviation about the z axis. Here the value of σ_z was determined indirectly from σ_y through the general dispersion equation 3a. This indirect determination is considered preferable to the determination of σ_z from the variable SO_2 distribution along the z axis (figure 27). While there is only 7-percent variability in the average of values by the two methods, significant variability exists in individual sections.

To facilitate the application to general problems, values of the parameters for line-source field conditions (table 9) were modified as outlined in Part I to approximate values representative of a single stack point source (table 10). Thus field values of standard deviation were modified to approximate the standard deviation along the y and z axes and were used in calculation of the diffusion parameters m, m_y, m_z, C_y, and C_z for a single stack point source (table 10). Finally, the values of parameters developed for a single stack point source were modified to approximate line-source field sampling conditions. The modified parameters were used to calculate SO_2 concentrations for comparison with field-measured values.

Parameters m, m_y, and m_z--The values of m, m_y, and m_z determined for each sampling day show a range of 0.500 to 0.847 with an average of 0.686 for m_y and a range of 0.800 to 0.968 with an average of 0.759 for m_z (table 10). The relationship of σ_y values to σ_z values (figure 28) indicates that the average values of m_y and m_z probably were equal. The maximum average values for m_y and m_z (line 4, figure 29) for all days were about 0.75.

Diffusion Coefficients C_y and C_z--The values of C_y and C_z are determined from formulas 4 and 5 for each plume cross section for each day, using values of $m_y = m_z = 0.80$, 0.75, and 0.70 (table 11). The values 0.80 and 0.70 selected to bracket the average value 0.75 show a significant variation among the days. Analyses of C_y and C_z values plotted against average wind speed (figures 30, 31, and 32) reveal a slight scatter; also the relationship reveals a trend for decreasing C_y and C_z values with increasing wind speed. The best estimate of C_y and C_z values at wind speed intervals of 2 miles per hour is given in table 12. The variation of the coefficients C_y, C_z, and C for $m_y = m_z = 0.75$ to wind speed is given in figure 33.

Modification of Point-Source Parameters for General Problems

As the number of stacks is increased, plume widths and plume depths are increased (figure 19) in the amount of Δ_{y_n} and Δ_{z_n} in accordance with equations 16 and 17. These increases in plume widths and depths were used in estimating the change in m_y and m_z (figure 34) and C_y and C_z (figure 35) in relation to Δ_{y_n} and Δ_{z_n} as plant units were added.

To utilize the point-source parameters for line-source determinations, the following steps are necessary.

1. Determine the increase in plume widths, Δ_{y_n}, and plume depths, Δ_{z_n}, due to additional stacks and plume direction from equations 16 and 17.
2. Determine the line-source parameters m_y, m_z, C_y, and C_z by multiplying the corresponding point-source parameters by their respective ratios shown by the curves in figures 34 and 35 for the increase in plume widths, Δ_{y_n}, and plume depths, Δ_{z_n}.

The point-source values for $m_y = m_z = 0.75$ (table 12) modified to represent line-source field conditions outlined above are shown in table 13 for each cross section sampled.

Summary of Results

Final m_y, m_z, C_y, and C_z values estimated for field line-source conditions (table 13) were employed in equation 8a to calculate axial concentrations. Field-measured and calculated concentrations are summarized in table 14 and are plotted in figure 36. Good agreement is indicated in most of the sections sampled. The variation for individual points is attributed to application of a steady-state mathematical model to the relatively variable plume pattern.

Part III. Plume Rise

This over-all project was concerned primarily with the investigation of diffusion rates in steam plant smoke plumes. While detailed data on plume rise were obtained (on a limited basis) during each plume diffusion sampling period, the scope of data collections, restricted by project objectives, was not considered extensive enough to support a comprehensive study designed specifically to improve present analytical procedures for determining plume rise.

Plume rise observed during each sampling day for temperature inversion and lapse conditions is shown in figures 37 and 38. During inversion conditions maximum plume rise usually was attained within the first 1/2 mile from the emission source. During lapse conditions most of the plume rise was attained in the first 1/2 mile, but a slight continuous increase in plume height occurred beyond this point.

The average observed relationships of plume rise to wind speed and stability for cases occurring within the first 2-mile section of the plume during inversion conditions and within the 1/2- and 1-mile sections during lapse conditions are given in figures 39 through 43. The wide variation of plume rise with wind speed during inversion conditions (figure 39) probably is due to the variance in stability for comparable wind speeds.

Part IV. Corollary Studies of SO_2 Oxidation

In the analysis of data taken in inversion conditions, some variability of SO_2 flux was noted in progressive plume cross sections. The apparent consistency in a trend of decreasing SO_2 flux with distance, along with published information on SO_2 oxidation, indicated a need for study of oxidation of SO_2 in a steam plant plume. The following principal phases of the SO_2 oxidation studies were defined.

1. Develop equipment and techniques for the collection of representative samples of flue gas and fly ash from steam plant ducts or stacks.
2. Collect and analyze sufficient samples of flue gas and fly ash to establish the relative proportions and concentrations of SO_2 and SO_3, as well as pertinent physical and chemical characteristics of fly ash.
3. Develop facilities for controlled dilution and cooling of flue gas simulating atmospheric dispersion and cooling.
4. Develop instrumentation for evaluating changes in sulfur oxides and fly ash subjected to controlled dilution and cooling.
5. Modify instrumentation and techniques developed in the preceding step for study of sulfur oxides and fly ash in the dispersed plume.
6. Collect and analyze sufficient plume samples to establish the relative proportions of SO_2 and SO_3.
7. Interpret and analyze data and observations.

In steps 1 through 4, flue gas and fly ash samples were taken at ground level from the duct section connecting the mechanical fly ash collectors and the induced draft fan, or from a dilution chamber adjoining this duct. A report on these studies follows.

Oxidation Studies in Duct and Dilution Chamber

Gas samples were collected from the duct for SO_2 and SO_3 analyses. The tests considered to yield the most reliable values for 30-minute average concentrations of SO_2 and SO_3 are tabulated below.

SO_2-SO_3 Analysis

Colbert Steam Plant Flue Gas

Date	SO_3 ppm as SO_2	SO_2 ppm
7/10/59	42	2317
7/15/59	66	1886
7/21/59	18	2388
7/21/59	12	2241
7/21/59	17	2192
7/29/59	17	2258
7/29/59	17	2312

These data suggest that only 1 to 2 percent of sulfur in coal exists as SO_3 in flue gas at the Colbert plant.

Fly ash samples were collected directly from the duct for size consist, identification of principal physical characteristics, and chemical analysis.

Concurrent with the collection of samples directly from the duct, flue gas was aspirated into a large dilution chamber (figure 44) where it was held for 2 to 5 hours. Gas samples were taken from the chamber for SO_2 and SO_3 analyses and fly ash samples were taken for other chemical analysis. While exceptions and unexplained events were noted, the data suggest an increase in SO_2 oxidation with holding time. In these tests, data from the Titrilog and autometer indicate that 10 to 30 percent of SO_2 in the trailer was oxidized in 2 to 3 hours (table 15).

Using the difference in recorded values for the same sample on an autometer and a Titrilog as a measure of oxidation is not a recommended technique. However, data taken with and without a filter for removal of acid aerosol indicate that the technique has some validity. In figure 45 where acid aerosol is removed, Titrilog and autometer values are approximately equal. In figure 46 where the acid is not removed and is presumably registered on the autometer, a significant difference exists.

In a second series of tests, oxidation in the dilution chamber was evaluated by direct sampling of SO_2 and SO_3. While results are random (table 16), the extent of oxidation was similar to that derived indirectly from autometer-Titrilog data and was as high as 30 percent on two tests.

Fly Ash Studies

Fly ash may influence the oxidation of SO_2 in coal flue gases because of its catalytic and nucleating properties. Therefore, concurrent with the estimate of SO_2 oxidation in the dilution chamber, studies were made of the physical and chemical characteristics of fly ash. Principal data are presented in table 17.

Because of deposition in the transfer line and aspirator system, fly ash transfer from the duct to the dilution chamber was only 25-75 percent efficient. However, a number of factors were indicative of oxidation of SO_2.

1. Large crystals of aluminum sulfate were identified on the aluminum foil electrostatic precipitator liners. This is attributed to the reaction of precipitated H_2SO_4 aerosol with the aluminum foil lining.
2. Sulfate content of fly ash increased from about 2.5 percent in the duct to 5 to 10 percent in the chamber. This increase is attributed to deposition of sulfuric acid mist or aerosols on fly ash particles.

3. The pH of fly ash generally decreased with holding time in the chamber--from about neutral in the duct to a low of 4.5.

Peripheral fly ash studies included size analysis, study of acid-alkaline characteristics, and microchemical-petrographic studies. While the information disclosed by these studies is of general interest from an operational and industrial hygiene viewpoint, its relation to SO_2 oxidation is indirect. However, the acid-alkaline characteristics of fly ash are of particular interest.

Fly ash taken in the duct remained essentially neutral for all dilutions. However, the pH of fly ash from the chamber increased with increasing dilution and time. Investigation suggested that the low pH with minimum dilution was due to rapid solution of acid aerosol on the fly ash surface. As dilution was increased, the solubility of calcium oxides increased, and a part of the initial acidity was neutralized with resultant higher pH values. Data on these tests are provided in table 18. Figure 47 illustrates a change in the pH of a fly ash sample taken from the mechanical collector from 4.4 to 12.0 in about 2 hours. The heterogenous acid and alkaline fly ash characteristics were clearly demonstrated when colorimetric acid indicator on fly ash samples revealed random distribution of acid sub-samples. Microchemical-petrographic tests indicated that the minor component responsible for the alkalization of fly ash is a dehydrated form of calcium sulfate, probably calcium oxide-calcium hydroxide formed during brief retention in the fire chamber.

Studies in Power Plant Plumes

While the SO_2 oxidation studies were beset with numerous problems and limitations, some useful information was disclosed; and, through elimination, the most satisfactory sampling and analytical procedures were identified. Thus, for sampling in the plume, filter paper was used to collect the acid aerosol, and SO_2 was collected in a subsequent series H_2O_2 scrubber (figure 48). SO_3 concentrations were based on the sulfate content of the filter.

Samples were taken in an inversion plume on 8 days from 1/2 mile to 10 miles from the steam plant. Plume travel time from the source ranged from 5 to 108 minutes. Data from the 8 sampling days are compiled in tables 19 and 20. Data for 5 sampling days (August 2, September 2, and October 14, 26, and 28, 1960) do not indicate significant oxidation of SO_2. Oxidation of this magnitude, 1 to 3 percent, approximates that determined for undiluted hot flue gas. Relatively high oxidation, 8 to 55 percent, was observed on 3 days (May 3, August 19, and October 11, 1960).

More tests of this type are needed for confirmation of these limited data. However, the data derived with these sampling and analytical techniques suggest that in periods of 1 to 2 hours, oxidation of SO_2 in the plume may range from almost none to 50 percent. Moisture within the plume or ambient strata apparently is the factor which exerts predominant control over the rate of oxidation. When relative humidity is below 70 percent, oxidation is very slow. Atmospheric moisture above this level but at less than saturation conditions produces a maximum initial rate of oxidation.

A primary reason for initiating a study of atmospheric oxidation of SO_2 was to appraise its effect on diffusion parameters based on data from the Titrilog which does not record acidified SO_2. Analysis suggests that SO_2 oxidation may not have significantly affected the values of diffusion parameters during most days when field dispersion measurements were taken. On most days the observed variation may be ascribed to limitations of the field sampling procedure rather than to the sampling instrument. Also, meteorological criteria established for dispersion measurements excluded high humidity conditions favorable to a high rate of SO_2 oxidation.

APPENDIXES

TENNESSEE VALLEY AUTHORITY
Division of Health and Safety

and

PUBLIC HEALTH SERVICE
Division of Air Pollution

APPENDIX A

TABLES

Chattanooga, Tennessee
August 1964

Table 1

HELICOPTER FLIGHTS

Date	Duration Hr.	Duration Min.	Type of Flight
9/10/57	0	45	Experimental
9/11/57	3	20	Experimental
9/12/57	3	0	Experimental
9/17/57	1	10	Experimental
9/23/57	0	15	Experimental
9/24/57	4	35	Inversion
9/25/57	3	40	Inversion
9/26/57	4	5	Inversion
9/27/57	3	45	Inversion
10/4/57	1	0	Experimental
10/7/57	4	50	Inversion
10/8/57	4	40	Inversion
10/9/57	4	20	Inversion
10/10/57	3	0	Inversion
10/11/57	2	0	Experimental
10/14/57	0	35	Experimental
10/15/57	0	20	Experimental
3/27/58	0	35	Experimental
3/28/58	3	45	High wind
3/31/58	2	55	High wind
4/2/58	3	20	High wind
4/4/58	2	15	Temp. checks
4/7/58	4	30	High wind
4/9/58	3	30	High wind
4/10/58	1	15	Experimental
4/11/58	2	30	High wind
4/14/58	2	10	Experimental
4/16/58	6	15	High wind
3/27/59	3	15	High wind
4/1/59	5	0	High wind
4/2/59	0	25	High wind
4/3/59	2	30	High wind
4/7/59	3	45	Inversion
4/17/59	2	50	Inversion
4/20/59	4	55)	
4/23/59	1	0)	Voice recorder out
4/24/59	3	30)	
1/26/60	0	41	SO_2 - SO_3
2/2/60	1	35	SO_2 - SO_3
2/3/60	1	5	SO_2 - SO_3
2/24/60	1	16	SO_2 - SO_3
4/12/60	1	14	SO_2 - SO_3
5/3/60	1	34	SO_2 - SO_3
8/2/60	2	16	SO_2 - SO_3
8/19/60	1	18	SO_2 - SO_3
9/2/60	1	25	SO_2 - SO_3
10/4/60	3	0	Inversion
10/11/60	2	45	SO_2 - SO_3
10/13/60	1	25	Plume observation
10/14/60	2	55	Plume observation
10/17/60	2	45	Plume observation
10/18/60	0	40	Plume observation
10/19/60	0	50	Discontinued
10/20/60	0	15	Experimental
10/24/60	2	55	High wind
10/25/60	2	0	Inversion
10/26/60	2	30	SO_2 - SO_3
10/27/60	0	50	Tetroon
10/28/60	3	10	SO_2 - SO_3 and tetroon release

Table 2

PLANT DESIGN AND OPERATIONAL DATA

	Steam Plant	
	Colbert	Gallatin
Total rated capacity, kw	720,000	450,000
Number of units	4	2
Unit rated capacity, kw	180,000	225,000
Unit capability, kw	200,000	250,000
Total capability, kw	800,000	500,000
Number of stacks	4	1
Spacing of stacks, feet, approximately	100	-
Height of stack, feet	300	500
Diameter of stack, feet	16.5	25
Exit velocity of flue gas, fps	47	44
Temperature of flue gas, ^{o}F.	290	290
Coal consumption per unit day, tons	1,800	1,928
Sulfur content of coal, percent	1-3.5	3.2

Table 3

SUMMARY - PRINCIPAL DATA, BY SECTIONS (FIELD-MEASURED VALUES)

Day	Dist. (Mi.)	Time	Units Operating	Plume Dir.[a]	Elev. (Ft.)[b]	Plume Width (Ft.)	Plume Depth (Ft.)	SO_2 Conc. (ppm) Max.	SO_2 Conc. (ppm) Avg.	Wind Speed (mph) ℄[c]	Temp. Gradient °F./1,000' Plume[d]	Standard Deviation (Ft.) σ_y	Standard Deviation (Ft.) σ_z	Diffusion Parameters (Dimensionless) m_y	Diffusion Parameters (Dimensionless) m_z	Diffusion Parameters C_y (Ft.$^{m_y/2}$)	Diffusion Parameters C_z (Ft.$^{m_z/2}$)	Plume Cross-Sectional Area (Sq. Ft.)	SO_2 Emission Rate (cfs)	Measured SO_2 Flux (Cu. Ft. per Lin. Ft.)
1	1/2	0636	2, 3, & 4	84	680	1660	460	18.1	8.5	9.8	8.3	299	83	0.346	0.053	19.629	54.655	599,426	41.8	2.6
	3/4	0649	2, 3, & 4	84	680	1856	460	16.0	7.5	9.9	7.4	334	83			19.059	53.492	670,202		2.5
	1	0700	2, 3, & 4	84	680	2188	420	16.3	7.1	10.0	7.4	394	76			20.355	48.239	721,384		2.6
	2	0716	2, 3, & 4	84	660	2837	400	12.3	5.5	10.0	6.8	511	72			20.774	44.051	890,818		2.5
	6	0741	2, 3, & 4	84	660	3441	440	7.9	3.4	10.1	5.0	619	79			17.213	45.598	1,188,521		2.0
	9-1/2	0801	2, 3, & 4	84	680	3848	480	6.1	2.3	10.0	4.0	693	86			-		1,449,926		1.7
2	1/2	0655	2, 3, & 4	3	720	1026	530	28.7	12.8	7.8	4.3	181	93	0.262	0.081	23.041	49.021	426,867	47.4	2.8
	3/4	0704	2, 3, & 4	3	820	1041	540	24.1	9.8	7.6	4.6	183	95			20.951	48.452	441,280		2.2
	1	0645	2, 3, & 4	3	740	1192	575	20.1	7.4	7.3	2.6	210	101			22.299	50.322	538,039		2.2
	2	0740	2, 3, & 4	3	800	1373	575	12.9	5.9	6.8	3.0	242	101			21.436	47.565	619,738		1.9
	8	0752	2, 3, & 4	3	1080	2173	625	5.6	3.0	6.6	4.0	382	110			23.543	46.284	1,066,128		1.6
3	1/2	0623	2, 3, & 4	15	670	875	550	25.4	11.6	12.0	9.3	168	106	0.849	0.069	0.208	61.494	377,781	48.3	2.2
	3/4	0631	2, 3, & 4	15	680	1328	525	21.1	10.1	12.0	7.8	255	101			0.224	56.974	547,302		2.8
	1	0638	2, 3, & 4	15	680	2037	515	13.9	6.4	11.9	7.4	391	99			0.269	54.747	823,508		2.7
	2	0657	2, 3, & 4	15	600	2248	560	9.0	4.7	11.6	8.4	432	108			0.165	56.930	988,221		2.3
4	1/2	0637	2, 3, & 4	39	720	1117	550	17.2	6.9	13.2	4.2	173	85	0.493	0.197	3.545	18.058	482,265	46.3	1.7
	3/4	0647	2, 3, & 4	39	750	1418	650	16.9	6.5	13.4	3.5	220	101			3.690	19.813	723,535		2.4
	1	0657	2, 3, & 4	39	720	1494	720	15.2	5.9	13.7	2.6	232	112			3.376	20.763	844,409		2.5
	2	0707	2, 3, & 4	39	750	2233	750	9.6	3.8	14.0	2.0	346	116			3.577	18.765	1,314,679		2.5
	8	0737	2, 3, & 4	39	740	4904	820	4.4	1.6	12.8	0.7	760	127			3.964	15.643	3,156,705		2.6
5	1/2	0638	1, 2, 3, & 4	89	750	1388	850	24.4	10.7	9.4	5.7	232	142	0.380	0.152	11.589	42.764	926,143	69.2	5.0
	3/4	0646	1, 2, 3, & 4	89	750	1554	750	18.2	8.6	9.2	2.9	260	125			11.131	35.390	914,918		4.0
	1	0655	1, 2, 3, & 4	89	700	1766	870	19.1	8.0	9.0	2.3	295	145			11.321	39.292	1,206,090		4.8
	2	0703	1, 2, 3, & 4	89	720	2113	825	16.8	6.0	8.9	1.8	353	138			10.407	33.648	1,368,432		4.1
	10-1/2	0809	1, 2, 3, & 4	89	850	5116	1050	4.5	1.8	9.5	0.8	854	175			13.400	33.145	4,216,863		3.8
6	1/2	0805	1, 2, 3, & 4	67	1300	1147	780	20.1	9.2	7.6	-2.6	200	136	0.432	0.199	6.650	28.317	702,308	70.1	3.3
	3/4	0757	1, 2, 3, & 4	67	1350	1403	900	15.2	7.0	7.5	-2.3	244	157			6.809	30.154	991,220		3.5
	1	0748	1, 2, 3, & 4	67	1050	1464	950	14.5	6.4	7.4	-2.7	255	165			6.284	29.925	1,091,778		4.5
	2	0734	1, 2, 3, & 4	67	1000	1750	950	16.8	7.3	7.2	-2.1	305	165			5.571	26.067	1,305,063		4.8
	9	0638	1, 2, 3, & 4	67	560	5749	540	13.2	5.0	6.6	+8.7	1000	94			9.538	11.006	2,437,001		6.1
7	1/2	0712	1, 2, 3, & 4	74	950	1660	700	20.1	11.2	6.8	2.7	300	127	0.428	0.385	10.286	6.107	912,170	55.4	5.1
	3/4	0720	1, 2, 3, & 4	74	1050	1509	900	19.1	10.1	6.4	4.9	287	163			8.272	6.705	1,119,096		5.3
	1	0731	1, 2, 3, & 4	74	850	2082	900	22.4	10.9	5.9	5.3	377	163			9.607	6.002	1,470,933		8.0
	2	0744	1, 2, 3, & 4	74	900	2384	900	20.5	6.6	6.1	4.4	432	163			8.182	4.595	1,684,296		5.6
	9	0618	1, 2, 3, & 4	74	550	4904	290	11.2	4.5	9.5	20.7	888	52			8.833	0.821	1,116,396		2.5
8	1/2	0740	1, 2, 3, & 4	74	850	1841	680	25.1	7.7	7.3	3.1	287	106	0.579	0.136	3.009	36.294	982,726	74.7	3.8
	1	0727	1, 2, 3, & 4	74	850	2792	700	6.6	3.1	8.0	3.3	436	109			3.061	33.963	1,534,204		2.4
	2	0708	1, 2, 3, & 4	74	1000	4104	820	4.6	1.8	8.3	0.6	640	128			3.009	36.294	2,641,745		2.4
9	1	0648	1, 2, & 3	69	650	2501	510	8.0	2.8	13.8	5.3	388	79	0.461	0.0	7.469	79.000	1,001,510	33.6	1.4
	4-1/2	0810	1, 2, & 3	69	700	5009	470	3.3	1.4	11.5	2.3	776	73			7.469	73.000	1,848,071		1.3
10	1	0815	1 & 2	0	1100	2022	900	2.2	1.2	14.0	-2.1	400	178	0.563	0.419	3.204	4.901	1,428,543	39.4	0.9
	2	0845	1 & 2	0	1800	2983	1200	0.9	0.4	11.0	-2.4	591	238			3.204	4.901	2,809,986		0.6
11	1/2	0659	1 & 3	71	550	1724	500	12.1	5.4	9.6	*	288	84	0.335	0.0	20.640	84.000	676,670	37.1	1.9
	5-3/4	0738	1 & 3	71	550	3903	480	7.5	3.0	8.2	*	652	80			20.640	80.000	1,470,650		2.2
12	1/2	0706	1 & 2	33	600	1188	440	17.5	8.7	13.7	15.7	217	81	0.457	0.0	5.944	81.000	410,335	29.4	1.8
	5	0746	1 & 2	33	500	3392	335	9.1	3.8	11.5	11.0	621	61			5.944	61.000	892,011		1.7

[a]Degrees off line of stacks.
[b]Elevation of flight where maximum concentration was recorded.
[c]Average wind speed along elevation of maximum concentration.
[d]From approximately bottom to top of plume.
*No data.

Table 4

BEST ESTIMATE OF AVERAGE m_y, m_z, C_y, AND C_z BY RANGES OF STABILITY

(FIELD-MEASURED VALUES)

Group	Temperature Gradient °F./1,000' Range	Av.	m_y	m_z	C_y	C_z
1	13.4	13.4	.396	0	11.067	76.500
2	(6.5 to 8.2)	7.4	.430	.090	8.667	48.323
3	(2.3 to 3.8)	3.0	.458	.174	5.710	23.976
4	(-0.2 to -2.3)	-1.3	.531	.273	3.255	14.606

Table 5

SUMMARY - PRINCIPAL DATA, BY SECTIONS

FOR SINGLE STACK POINT SOURCE

Day	Dist. (Mi.)	Plume Width (Ft.)	Plume Depth (Ft.)	SO_2 Conc. (ppm) Max.	SO_2 Conc. (ppm) Av.	σ_y (Ft.)	σ_z (Ft.)	Diffusion Parameters (Dimensionless) m_y	(Dimensionless) m_z	$(Ft.^{m_y/2})$ C_y	$(Ft.^{m_z/2})$ C_z	SO_2 Emission (cfs)
1	1/2	1461	455	6.9	3.3	263	82	0.381	0.054	13.111	53.696	13.9
	3/4	1657	455	6.0	2.8	298	82			12.731	52.538	
	1	1989	415	6.0	2.6	358	75			13.708	47.316	
	2	2638	395	4.5	2.0	475	71			13.971	43.155	
	6	3242	435	2.8	1.2	584	78			11.307	44.692	
2	1/2	1016	460	11.1	4.8	179	84	0.264	0.089	22.280	41.529	15.8
	3/4	1031	490	8.9	3.6	181	86			20.246	41.004	
	1	1182	525	7.4	2.7	208	92			21.561	42.751	
	2	1363	525	4.7	2.2	240	92			20.712	40.182	
	8	2163	575	2.0	1.1	381	101			22.789	38.970	
3	1/2	823	502	9.8	4.5	158	96	0.883	0.067	0.151	56.457	16.1
	3/4	1276	477	8.1	3.9	245	92			0.163	52.647	
	1	1985	467	5.2	2.4	381	90			0.197	50.513	
	2	2196	512	3.4	1.8	422	98			0.118	52.494	
4	1/2	991	511	6.9	2.8	154	79	0.529	0.209	2.385	15.225	15.4
	3/4	1292	611	6.6	2.5	200	95			2.500	16.820	
	1	1368	681	5.8	2.3	212	106			2.276	17.673	
	2	2107	711	3.6	1.4	327	110			2.433	15.867	
	8	4778	781	1.6	0.6	741	121			2.648	13.063	
5	1/2	1088	849	7.8	3.4	182	142	0.447	0.152	5.388	42.764	17.3
	3/4	1254	749	5.7	2.7	209	125			5.162	35.390	
	1	1466	869	5.8	2.4	245	145			5.321	39.292	
	2	1813	824	4.9	1.8	303	138			4.828	33.648	
	10-1/2	4816	1049	1.2	0.5	804	175			6.108	33.145	
6	1/2	871	751	6.9	3.2	152	131	0.506	0.206	2.831	25.846	17.5
	3/4	1127	871	4.9	2.3	196	152			2.974	27.586	
	1	1188	921	4.6	2.0	207	160			2.716	27.367	
	2	1474	921	5.1	2.2	256	160			2.366	23.725	
	9	5473	511	3.7	1.4	952	89			4.113	9.681	
7	1/2	1372	679	6.3	3.5	248	123	0.524	0.396	3.989	5.422	13.9
	3/4	1221	879	6.1	3.0	221	159			2.874	5.969	
	1	1794	879	6.7	3.3	325	159			3.635	5.326	
	2	2096	879	6.0	1.9	379	159			2.947	4.047	
	9	4616	269	3.2	1.3	835	49			2.951	0.687	
8	1/2	1553	659	7.7	2.4	253	107	0.649	0.140	1.524	35.385	18.7
	1	2504	679	1.9	0.9	408	111			1.567	33.303	
	2	3816	799	1.3	0.5	622	130			1.524	35.385	
9	1	2314	492	3.0	1.0	359	76	0.487	0.0	5.515	76.000	11.2
	4-1/2	4822	452	1.2	0.5	747	70			5.515	70.000	
10	1	2022	900	2.2	1.2	400	178	0.563	0.419	3.204	4.901	39.4
	2	2983	1200	0.9	0.4	591	238			3.204	4.901	
11	1/2	1629	492	6.6	2.9	272	82	0.348	0.0	17.563	82.000	18.6
	5-3/4	3808	472	3.9	1.5	636	79			17.563	79.000	
12	1/2	1134	419	9.7	4.8	208	77	0.468	0.0	5.210	77.000	14.7
	5	3338	314	4.9	2.1	611	57			5.210	57.000	

Table 6

BEST ESTIMATE OF m_y, m_z, C_y, AND C_z FOR POINT SOURCE

IN FOUR RANGES OF TEMPERATURE GRADIENT

Group	Average Temperature Gradient	m_y	m_z	C_y	C_z
1	13.4° F./1,000'	.408	0	9.578	73.750
2	7.4° F./1,000'	.466	.096	5.708	45.945
3	3.0° F./1,000'	.505	.182	3.459	22.110
4	-1.3° F./1,000'	.606	.279	1.490	15.090

Table 7

CALCULATED POINT- AND LINE-SOURCE DIFFUSION PARAMETERS

	Temperature Gradient	Point Source				Added Distance (Ft.)		Line Source			
Day	°F./1,000'	m_y	m_z	C_y	C_z	Width	Depth	m_y	m_z	C_y	C_z
1	6.5	.466	.096	5.9	41.0	199	5	.419	.095	9.4	41.8
2	3.7	.505	.182	3.9	25.5	10	50	.500	.169	4.0	29.3
3	8.2	.466	.096	5.9	41.0	52	48	.452	.090	6.6	47.2
4	2.6	.505	.182	3.9	25.5	126	39	.475	.171	5.3	28.6
5	2.7	.505	.182	3.9	25.5	300	1	.434	.182	7.7	25.5
6	-0.2	.606	.279	1.7	15.0	276	29	.527	.268	3.2	16.2
7	7.6	.466	.096	5.9	41.0	288	21	.410	.093	11.3	43.5
8	2.3	.505	.182	3.9	25.5	288	21	.439	.177	7.5	27.0
9	3.8	.505	.182	3.9	25.5	187	18	.460	.178	6.0	26.8
10	-2.3	.606	.279	1.7	15.0	0	0	.606	.279	1.7	15.0
11	-	.408	0	9.5	75.0	95	8	.371	0	14.7	75.0
12	13.4	.408	0	9.5	75.0	54	21	.396	0	10.7	75.0

Table 8

MEASURED AND CALCULATED AXIAL SO_2 CONCENTRATIONS IN PLUME (PPM)

Day		Distance (Miles) 1/2	3/4	1	2	x
1	(A)	18.1	16.0	16.3	12.3	7.9
	(B)	21.1	17.0	14.7	10.2	6.1
2	(A)	29.8	24.2	20.1	12.9	5.6
	(B)	30.0	22.9	19.0	11.9	4.8
3	(A)	25.4	21.1	13.9	9.0	
	(B)	20.9	16.7	14.4	9.9	
4	(A)	17.2	16.9	15.2	9.6	4.4
	(B)	15.3	11.7	9.7	6.2	2.6
5	(A)	24.4	18.2	19.1	16.8	4.5
	(B)	34.7	26.6	22.7	14.8	5.3
6	(A)	20.1	15.2	14.5	16.8	13.2
	(B)	37.6	27.3	21.6	12.4	3.9
	(B)*	34.1	23.8	18.5	10.0	12.5
7	(A)	20.1	19.1	22.4	20.5	11.2
	(B)	31.4	25.7	22.4	16.0	7.7
8	(A)	25.1		6.6	4.6	
	(B)	39.7		26.0	16.9	
9	(A)			8.0		3.3
	(B)			7.2		2.8
10	(A)			2.2	0.9	
	(B)			6.8	3.7	
11	(A)	12.1				7.5
	(B)	23.1				9.5
12	(A)	17.5				9.1
	(B)	13.7				5.4

(A) Field-measured values.
(B) Values calculated from point-source coefficients modified to simulate line-source field conditions.
* Temperature gradient at 1/2, 3/4, 1, and 2 miles = -2.4° F./1,000 feet. Temperature gradient at x miles = 8.7° F./1,000 feet.

Table 9

SUMMARY - PRINCIPAL DATA, BY SECTIONS - HIGH WIND AND NEUTRAL CONDITIONS

(FIELD-MEASURED VALUES)

Day	Dist. (Mi.)	Time	Units Operating	Degrees Off Line of Stacks	Elev. (Ft.) at Maximum Conc.	Elev. (Ft.) at Maximum Plume Width	Plume Width (Ft.)	Plume Depth (Ft.)	SO_2 Conc. (ppm) Max.	SO_2 Conc. (ppm) Av.	Average Wind Speed in Plume (mph)	Temp. Gradient Plume Bottom to Top °F./1,000'	σ_y (Ft.)	σ_z (Ft.)	Diffusion Parameters (Dimensionless) m	m_y	m_z	SO_2 Emission Rate (cfs)
1	1/2	1229-1238 9 min.	1, 2, 4	4-1/2	800	800	1465	800	10.0	4.8	8.2	-6.4	279	212	0.969	0.384	0.586	44.86
	1	1242-1331 49 min.	1, 2, 4	4-1/2	800	800	2020	1200	4.0	2.2	8.0	-5.8	385	384				
	2	1340-1449 69 min.	1, 2, 4	4-1/2	1800	1200	2495	1800	2.0	0.9	10.7	-5.9	475	478				
2	1/2	1315-1327 12 min.	1, 2, 4	4	600	600	910	600	15.3	7.8	13.1	-5.8	173	127	1.387	0.704	0.682	40.57
	1	1329-1342 13 min.	1, 2, 4	4	800	800	1310	850	7.9	4.1	11.5	-5.6	250	193				
	2	1346-1417 31 min.	1, 2, 4	4	1000	1000	2410	1450	3.2	1.3	9.1	-5.9	459	327				
3	1/2	1145-1155 10 min.	1, 3, 4	85-1/2	800	800	900	650	12.9	5.8	14.2	-6.5	171	145	1.254	0.563	0.691	41.83
	1	1159-1219 20 min.	1, 3, 4	85-1/2	800	800	1575	1250	4.3	2.4	12.8	-6.3	300	275				
	2	1224-1246 22 min.	1, 3, 4	85-1/2	1000	1000	1957	1300	2.7	1.3	11.9	-6.7	373	378				
4	1/2	1223-1234 11 min.	1, 3, 4	86	1000	1000	826	800	13.9	7.1	21.6	-5.4	157	106	1.665	0.675	0.993	46.24
	1	1236-1249 13 min.	1, 3, 4	86	600	600	1200	1050	3.5 4.0*	2.1	20.4	-4.8	229	202				
	2	1255-1326 31 min.	1, 3, 4	86	800-1600	1000	2100	1650	1.3	0.9	14.9	-5.5	400	420				
5	1/2	0929-0942 13 min.	1, 3, 4	45	1000	600-1000	1186	800	8.9	4.6	13.9	-3.5	226	167	1.035	0.543	0.493	43.09
	1	0946-1011 25 min.	1, 3, 4	45	1000	800-1000	1705	1000	3.5	1.9	14.5	-4.7	325	284				
	2	1017-1043 26 min.	1, 3, 4	45	800	800-1000	2520	1100	2.1	1.1	14.0	-3.9	480	331				
6	1/2	1326-1337 11 min.	1, 3, 4	2	600-1000	600-1000	957	900	8.4	4.6	9.9	-6.0	182	171	1.309	0.672	0.640	41.83
	1	1340-1403 23 min.	1, 3, 4	2	800-1600	800-1600	1517	1300	6.6	2.8	6.6	-5.8	289	360				
	2	1407-1427 20 min.	1, 3, 4	2	800-1400	800-1400	2427	1500	0.7	0.4	8.5	-6.0	462	415				
7	1/2	1021-1036 15 min.	1, 2, 3, 4	54	800	800	1042	1150	6.0 10.5*	3.2	11.5	-6.5	198	223	0.800	0.384	0.418	49.27
	1	1042-1115 27 min.	1, 2, 3, 4	54	600	600-1000	1476	1450	5.1	2.6	12.9	-6.1	281	289				
	2	1119-1146 27 min.	1, 2, 3, 4	54	1200	600-1400	1770	1500	1.4 2.8*	0.8	17.3	-6.6	337	398				
8	1	1401-1500	1, 2, 3	11	1200	400-1200	880	1200	4.7	2.3	16.1	-4.6	168	327	1.109	0.721	0.385	38.03
	2	1505-1638	1, 2, 3	11	1200	1200	1452	1800	2.4	1.3	14.6	-6.5	277	427				
9	1	0929-1000	1, 2, 3	55	500	500	1520	800	3.0 5.2*	1.5	11.1	-5.5	290	271	0.800	0.516	0.291	41.83
	2	1016-1037	1, 2, 3	55	1000	600	2162	1050	1.6	0.8	13.3	-5.3	412	352				
	3	1039-1105	1, 2, 3	55	800	800	2680	1300	1.5	1.0	15.6	-5.4	510	380				
10	1	1115-1445	1, 2, 3	65	1000	800	1012	1100	6.2	2.7	20.6	-5.9	193	219	1.034	0.474	0.561	49.77
	2	1129-1506	1, 2, 3	65	1400	800	1408	1400	2.7	1.1	23.1	-6.1	268	323				
11	1/2	1238-1300	1, 2	11	800	700	1408	1000	4.9	1.7	12.2	-5.2	268	195	1.338	0.582	0.755	28.85
	1	1302-1344	1, 2	11	800	1000	2640	1500	2.2	1.3	8.5	-5.0	503	332				
	2-1/2	1418-1519	1, 2	11	1200	1200	3430	2500	0.7	0.4	10.4	-5.2	653	656				

*Concentration measured along horizontal flight parallel to x axis.

Table 10

SUMMARY - PRINCIPAL DATA, BY SECTIONS

(FOR SINGLE STACK POINT SOURCE)

Day	Dist. (Mi.)	Plume Width (Ft.)	Plume Depth (Ft.)	SO_2 Conc. (ppm) Max.	SO_2 Conc. (ppm) Av.	σ_y (Ft.)	σ_z (Ft.)	Diffusion Parameters m All	m *	m_y All	m_y *	m_z All	m_z *	SO_2 Emission (cfs)
1	1/2	1442	725	3.7	1.8	275	198	0.996	1.411	0.388	0.500	0.614	0.758	14.95
	1	1997	1125	1.4	0.8	381	370							
	2	2472	1725	0.7	0.3	471	464							
2	1/2	889	525	6.0	3.0	169	113	1.444	1.444	0.714	0.714	0.735	0.735	13.52
	1	1289	775	2.9	1.5	246	179							
	2	2389	1375	1.1	0.5	455	313							
3	1/2	601	644	6.5	2.9	114	144	1.476	1.476	0.735	0.735	0.694	0.811	13.95
	1	1276	1244	1.8	1.0	243	274							
	2	1658	1294	1.1	0.5	316	377							
4	1/2	527	795	7.3	3.7	106	105	1.896	1.806	0.847	0.847	0.998	0.968	15.41
	1	901	1045	1.6	1.0	172	201							
	2	1801	1645	0.5	0.3	343	419							
5	1/2	974	747	3.9	2.0	186	157	1.123	1.348	0.621	0.621	0.516	0.660	14.36
	1	1493	947	1.4	0.8	285	274							
	2	2308	1047	0.8	0.4	440	321							
6	1/2	946	825	3.1	1.7	180	157	1.354	1.383	0.677	0.677	0.676	0.676	13.94
	1	1506	1225	2.4	1.0	287	346							
	2	2416	1425	0.2	0.1	460	401							
7	1/2	799	1106	2.0	1.1	152	215	0.903	1.007	0.468	0.629	0.430	0.500	12.32
	1	1233	1406	1.6	0.8	235	281							
	2	1527	1456	0.4	0.2	291	390							
8	1	842	1151	1.7	0.8	161	318	1.140	1.140	0.746	0.746	0.394	0.500	12.68
	2	1414	1751	0.8	0.4	270	418							
9	1	1356	771	1.2	0.6	259	265	1.186	1.425	0.560	0.560	0.297	0.500	13.94
	2	1998	1221	0.6	0.3	381	346							
	3	2516	1571	0.5	0.3	479	374							
10	1	831	1079	2.6	1.1	159	215	1.147	1.147	0.557	0.557	0.569	0.569	16.59
	2	1227	1379	1.0	0.4	234	319							
11	1/2	1389	979	2.5	0.9	264	191	1.365	1.365	0.588	0.739	0.764	0.764	14.43
	1	2621	1479	1.1	0.7	499	328							
	2-1/2	3411	2479	0.4	0.2	649	652							
							Average	1.294	1.418	0.624	0.686	0.625	0.759	

*m $\geq$ 1.000 and $<$ 2.000
m_y and m_z $\geq$ 0.500 and $<$ 1.000

Table 11

VALUES OF C_y AND C_z (FT. $\frac{m}{2}$) CALCULATED FOR EACH SECTION (POINT SOURCE)

FOR VALUES OF $m_y = m_z$ = 0.80, 0.75, AND 0.70 OR m = 1.6, 1.5, AND 1.4

Day	Dist. (Mi.)	$m_y = m_z = 0.80$ C_y	C_z	$m_y = m_z = 0.75$ C_y	C_z	$m_y = m_z = 0.70$ C_y	C_z	Wind Speed (fps)
1	1/2	.504	.363	.747	.538	1.107	.797	12.1
	1	.401	.398	.616	.598	.944	.917	11.8
	2	.285	.280	.452	.445	.719	.708	15.7
	Average	(.396)	(.347)	(.605)	(.523)	(.923)	(.807)	(13.2)
2	1/2	.309	.207	.459	.307	.680	.455	19.2
	1	.259	.188	.397	.289	.610	.444	16.9
	2	.275	.186	.437	.300	.694	.478	13.4
	Average	(.281)	(.194)	(.431)	(.299)	(.661)	(.459)	(16.5)
3	1/2	.209	.264	.310	.391	.459	.580	20.8
	1	.256	.288	.393	.443	.602	.679	18.9
	2	.191	.228	.303	.361	.482	.575	17.5
	Average	(.218)	(.260)	(.335)	(.398)	(.514)	(.611)	(19.1)
4	1/2	.194	.192	.288	.285	.427	.423	31.8
	1	.181	.211	.278	.325	.426	.498	30.0
	2	.207	.253	.329	.402	.523	.639	21.9
	Average	(.194)	(.219)	(.298)	(.337)	(.459)	(.520)	(27.9)
5	1/2	.341	.287	.505	.427	.749	.632	20.4
	1	.300	.288	.460	.443	.706	.679	21.3
	2	.266	.194	.422	.308	.671	.490	20.6
	Average	(.302)	(.256)	(.462)	(.393)	(.709)	(.600)	(20.7)
6	1/2	.330	.287	.489	.427	.725	.632	14.5
	1	.302	.364	.464	.559	.711	.857	9.7
	2	.278	.242	.441	.385	.702	.612	12.4
	Average	(.303)	(.298)	(.465)	(.457)	(.713)	(.700)	(12.2)
7	1/2	.278	.394	.413	.584	.612	.866	16.9
	1	.274	.296	.380	.454	.582	.696	19.0
	2	.176	.236	.279	.374	.444	.595	25.4
	Average	(.243)	(.308)	(.357)	(.471)	(.546)	(.719)	(20.4)
8	1	.169	.334	.260	.514	.399	.788	23.6
	2	.163	.252	.259	.401	.412	.638	21.5
	Average	(.166)	(.293)	(.260)	(.458)	(.405)	(.713)	(22.5)
9	1	.272	.279	.418	.428	.642	.657	16.3
	2	.230	.209	.366	.332	.581	.528	19.6
	3	.209	.163	.339	.265	.550	.430	22.9
	Average	(.237)	(.217)	(.374)	(.342)	(.591)	(.538)	(19.6)
10	1	.167	.226	.257	.347	.394	.533	30.3
	2	.141	.193	.225	.306	.357	.487	34.0
	Average	(.154)	(.209)	(.241)	(.327)	(.376)	(.510)	(32.2)
11	1/2	.483	.350	.717	.519	1.063	.769	17.9
	1	.525	.345	.806	.530	1.237	.813	12.5
	2-1/2	.328	.329	.527	.529	.847	.852	15.3
	Average	(.445)	(.341)	(.683)	(.526)	(1.049)	(.811)	(15.2)
	Average All days	(.267)	(.267)	(.410)	(.412)	(.631)	(.635)	

Table 12

WIND SPEED, C_y AND C_z, AND m_y AND m_z VALUES

Wind Speed (mph)	Wind Speed (fps)	Calculated Values C_y and C_z, $Ft.^{\frac{m}{2}}$ — $m_y = m_z = 0.80$* C_y	C_z	$C_y = C_z$	$m_y = m_z = 0.75$** C_y	C_z	$C_y = C_z$	$m_y = m_z = 0.70$*** C_y	C_z	$C_y = C_z$
8	11.76	.339	.343	.341	.522	.524	.523	.807	.803	.805
10	14.70	.305	.316	.310	.470	.484	.477	.727	.742	.735
12	17.64	.275	.291	.283	.423	.447	.435	.654	.687	.670
14	20.58	.248	.268	.257	.381	.412	.396	.589	.635	.612
16	23.52	.223	.247	.234	.343	.381	.361	.530	.588	.558
18	26.46	.201	.227	.214	.309	.351	.330	.477	.544	.509
20	29.40	.181	.209	.194	.279	.324	.300	.430	.503	.465
22	32.30	.163	.193	.177	.251	.300	.274	.387	.466	.424
					Best Estimate ←→					

*$m_y = m_z = 0.80$

$\text{Log } C_y = -.287579 - .015489\, u$
$\text{Log } C_z = -.322238 - .012142\, u$
$\text{Log } (C_y = C_z) = -.304646 - .013834\, u$

**$m_y = m_z = 0.75$

$\text{Log } C_y = -.101167 - .015439\, u$
$\text{Log } C_z = -.141965 - .011797\, u$
$\text{Log } (C_y = C_z) = -.121340 - .013635\, u$

***$m_y = m_z = 0.70$

$\text{Log } C_y = .089745 - .015531\, u$
$\text{Log } C_z = .039957 - .011517\, u$
$\text{Log } (C_y = C_z) = .065006 - .013538\, u$

u - Wind speed in fps

Table 13

DIFFUSION COEFFICIENTS m_y, m_z, C_y, AND C_z - POINT AND LINE SOURCES

			Point-Source Values						Line-Source Field Values			
Day	Dist. (Mi.)	Wind Speed (fps)	m_y	m_z	C_y (Ft.$^{\frac{m}{2}}$)	C_z (Ft.$^{\frac{m}{2}}$)	Δy_n (Ft.)	Δz_n (Ft.)	m_y	m_z	C_y (Ft.$^{\frac{m}{2}}$)	C_z (Ft.$^{\frac{m}{2}}$)
1	1/2	12.0	.75	.75	.510	.510	23	75	.74	.71	.561	.740
	1	11.7			.515	.515					.567	.745
	2	15.7			.450	.465					.495	.674
2	1/2	19.2	.75	.75	.400	.425	21	75	.74	.71	.440	.616
	1	16.9			.430	.450					.473	.653
	2	13.4			.490	.490					.539	.711
3	1/2	20.8	.75	.75	.378	.408	299	6	.60	.74	1.550	.409
	1	18.7			.405	.430					1.661	.430
	2	17.5			.420	.440					1.722	.440
4	1/2	31.7	.75	.75	.260	.305	299	5	.60	.74	1.066	.305
	1	29.9			.270	.320					1.107	.320
	2	21.9			.360	.395					1.476	.395
5	1/2	20.3	.75	.75	.380	.410	212	53	.64	.72	1.102	.533
	1	21.2			.370	.400					1.073	.520
	2	20.1			.385	.420					1.117	.546
6	1/2	14.5	.75	.75	.470	.480	11	75	.74	.71	.494	.696
	1	9.7			.550	.540					.578	.783
	2	12.4			.505	.505					.530	.732
7	1/2	16.9	.75	.75	.430	.450	243	44	.62	.73	1.419	.563
	1	18.9			.400	.425					1.320	.531
	2	25.4			.320	.360					1.056	.450
8	1	23.6	.75	.75	.340	.378	38	49	.73	.72	.408	.476
	2	21.4			.370	.400					.444	.504
9	1	16.3	.75	.75	.440	.460	164	29	.66	.74	1.021	.520
	2	19.5			.390	.420					.905	.470
	3	22.9			.350	.385					.812	.319
10	1	29.6	.75	.75	.275	.320	181	21	.66	.74	.688	.352
	2	33.9			.240	.285					.600	.314
11	1/2	17.9	.75	.75	.420	.440	19	21	.74	.74	.462	.484
	1	12.5			.505	.505					.556	.556
	2-1/2	15.2			.460	.470					.506	.517

Table 14

MEASURED AND CALCULATED

AXIAL SO_2 CONCENTRATIONS IN PLUME

Day		Concentrations (ppm) at 1/2 Mi.	1 Mi.	2 Mi.	2-1/2 Mi.	3 Mi.
1	(A)	10.0	4.0	2.0		
	(B)	13.4	5.8	2.0		
2	(A)	15.3	7.9	3.2		
	(B)	11.6	4.9	1.8		
3	(A)	12.9	4.3	2.7		
	(B)	11.4	5.1	2.0		
4	(A)	13.9	5.3	2.0		
	(B)	16.1	7.1	2.3		
5	(A)	8.9	3.5	2.1		
	(B)	11.0	5.0	1.9		
6	(A)	8.4	6.6	0.7		
	(B)	12.5	6.2	2.0		
7	(A)	10.0	5.1	2.3		
	(B)	12.1	5.6	2.4		
8	(A)		4.7	2.4		
	(B)		5.3	1.9		
9	(A)		5.2	1.6		1.5
	(B)		4.7	1.9		1.5
10	(A)		6.2	2.7		
	(B)		6.8	2.9		
11	(A)	4.9	2.2		0.7	
	(B)	8.4	3.7		0.9	

(A) = Field-measured values.
(B) = Values calculated from point-source coefficients modified to line-source field conditions.

Table 15

CHAMBER SO_2 OXIDATION STUDIES

Date (1959)	Type of Run	Percent SO_2 Oxidation - Successive 30-Minute Periods													
		Uniform SO_2 Supply			No SO_2 Supply - Natural Decay										
		2a	1	2	3	4	5	6	7	8	9	10	11	12	13
10/13	Fly ash and moisture	16.5	8.6	9.7 /	24.0	25.8	27.0 /	3.7	-1.3						
10/16	Fly ash and dry		-2.1	-2.8 /	3.9	15.6	23.5	33.3	22.8	28.4 /	-2.1				
10/19	Fly ash and moisture		-6.9	-1.8 /	12.2	11.5	9.5 /	19.2	14.0	11.9	14.3	15.3	8.5	-2.3	
10/20	Moisture (Fly ash removal)		-6.5	-6.9 /	11.3	13.2	17.3	12.3 /	11.8	7.6	9.9	2.4	4.6	0	-4.0
10/22	Fly ash and moisture		-1.2	4.3 /	13.5	15.6 /	6.9	7.7	9.7	8.8	8.4	10.4	10.5		

Calibration Runs

10/9	SO_2 cylinder (Not through chamber)	7.8	0.0	2.7	6.3 /				
10/23	SO_2 cylinder (Through chamber)	/ 0.8	-1.7	-4.9	-4.8	3.9	0		

Negative (-) Values (Titrilog concentration more than autometer concentration)
/ Instruments switched from controlled diluted sample to straight sample

Table 16

CHAMBER SO_2 OXIDATION STUDIES

COLBERT STEAM PLANT

Date (1959)	Time Sampling Period	Dust Counts (mppcf) Impinger*	Dust Counts (mppcf) Millipore Filter	Geometric Mean Particle Size (Microns)	Relative Humidity (%)	Dry Bulb Temp. (°F.)	SO_2 Titrilog (ppm by Vol.)	Total Sulfates as SO_3 (ppm by Vol.)	SO_2 Oxidation (%)
10/29	1335-1405	1.83	-	-	96	65	2.0	.640	24.2
10/29	1406-1431	.98	-	-	96	65	2.0	1.004	33.4
11/2	1310-1330	2.94	1.28	.56	95	71	2.7	1.03	27.6
11/2	1337-1353	-	1.35	1.50	98	72	2.6	1.22	31.9
11/2	1438-1458	-	6.7	.63	99	72	2.4	.75	23.8
11/2	1528-1548	-	6.3	1.29	95	72	2.3	1.13	32.9
	Average	2.94	3.90	.99	97	72	2.5	1.06	29.8
11/3	0947-1007	6.37	4.9	.74	98	64	5.9	.88	13.0
11/3	1014-1034	6.28	4.9	.74	96	66	5.5	1.00	15.4
11/3	1051-1111	3.18	7.2	.40	95	69	5.3	.81	13.3
11/3	1131-1151	5.4	6.7	.40	97	71	5.3	.69	11.5
	Average	5.31	5.93	.57	97	68	5.5	.84	13.2
11/3	1351-1400	1.13	3.6	.54	57	79	5.6	2.81	33.4
11/3	1416-1436	1.30	2.7	.54	58	80	5.5		
11/3	1500-1520	1.47	2.5	.91	56	81	5.5	1.07	16.3
11/3	1546-1606	1.30	2.6	.86	56	81	5.2	.84	13.9
	Average	1.30	2.85	.71	57	80	5.5	.96	14.9
11/4	0859-0920	1.87	6.3	.48	100	73	9.4	.59	5.9
11/4	0926-0947	1.87	6.3	.48	100	73	9.6	.59	5.8
11/4	1022-1042	1.12	5.2	.32	99	73	9.1	1.05	10.3
11/4	1103-1123	.75	3.5	.32	98	73	9.2	1.12	10.9
	Average	1.40	5.33	.40	99	73	9.3	.85	8.4

*Average ratio impinger counts to millipore filter counts = 1:2.97.

Table 16

(Continued)

Date (1959)	Time Sampling Period	Dust Counts (mppcf) Impinger*	Millipore Filter	Geometric Mean Particle Size (Microns)	Relative Humidity (%)	Dry Bulb Temp. (°F.)	SO_2 Titrilog (ppm by Vol.)	Total Sulfates as SO_3 (ppm by Vol.)	SO_2 Oxidation (%)
11/4	1340-1410	8.72	-	-	96	71	64.7	.94	1.4
11/4	1412-1440	3.10	-	-	96	71	39.7	.31	0.8
11/4	1442-1504	1.42	-	-	96	71	19.9	.29	1.4
11/4	1505-1530	1.58	-	-	96	71	11.8	.60	4.8
	Average				96	71		.54	1.6
11/5	0958-1017	.83	5.3	.32	53	85	5.3	1.08	16.9
11/5	1027-1047	1.15	5.3	.32	49	84	5.6	1.28	18.6
	Average	.99	5.3	.32	51	85	5.5	1.19	17.8
11/5	1300-1320	.64	.91	1.06	45	81	10.4	.45	4.1
11/5	1327-1345	.54	1.58	.86	43	81	10.6	.20	1.9
11/5	1420-1440	1.07	1.89	.49	42	81	10.5	.36	3.3
11/5	1457-1517	.94	1.37	.49	40	81	10.4	.53	4.8
	Average	.94	1.44	.73	43	81	10.4	.39	3.6
11/6	0904-0924	.13	.54	1.07	90	46	10.3	.03	0.3
11/6	0924-0944	.13	.54	1.07	96	46	10.6	.03	0.3
11/6	1009-1029	.22	1.22	1.06	97	46	10.1	.05	0.5
11/6	1100-1120	.22	1.22	1.06	97	47	9.2	.05	0.5
	Average	.18	.88	1.07	95	46	10.1	.04	0.4
11/6	1156-1216	1.46	4.8	.80	86	47	22.9	1.15	4.8

*Average ratio impinger counts to millipore filter counts = 1:2.97.

Table 17

CHAMBER SO_2 OXIDATION STUDIES

COLBERT STEAM PLANT

Date	Test	Electrostatic Precipitator Samples						Scrubber Samples			Duct - Fly Ash Samples						SO_2 Concentration			
(1959)	No.	Wt. (mg.)	Dil.	pH	Resist. (Ohms)	Est. SO_4 (%)	Minutes Operated	A[a] SO_2 (ppm)	B[b] SO_2 (ppm)	Filter B (mg.)	Wt. (mg.)[c]	Dil.	pH	Resist. (Ohms)	Est. SO_4 (%)	% SO_4 Grav.	Autometer (ppm)	Titrilog (ppm)	Autometer Minus Titrilog (ppm)	% Oxidation
9/30	1	51.4	10:1	5.6	46,500	6.2	30	58.3	62.9	0.0	1287.1	10:1	6.5	52,000	5.6					
	2	30.6	10:1	6.4	44,300	6.4	30	50.1	56.3	0.0										
	3	6.0	10:1	4.9	32,600	8.3	30	29.6	32.2											
	4	2.3	10:1	4.8			30	16.9												
	5							8.9												
	6							4.5												
10/1	1	2.5	10:1	4.8			30	20.7	20.5	0.0	2584.3	10:1	7.0	77,000	3.9					
	2	1.3					30	13.8	13.2	0.0										
	3	0.4					30	7.9	8.9	0.0										
	4	0.5					30	6.3	6.2	0.0										
	5							5.2	4.9	0.0										
	6							3.9	3.6	0.0										
10/2	1	68.6	10:1	6.6	67,000	4.4	30	50.0	50.1	0.1	1644.3	10:1	7.2	67,000	4.4					
	2	18.3	10:1	5.6	44,500	6.4	30	44.1	45.0	0.2										
	3	8.5	10:1	6.0	53,000	5.4	30	29.1	30.4	0.0										
	4	4.2	10:1	4.9	27,200	9.6	30	21.5	22.5	0.0										
	5	3.1	10:1	4.7			60	15.8	17.1	0.0										
	6							12.5	12.3	0.0										
10/12	1	5.7	10:1	4.9	22,600	11.2	30	24.9	24.2	0.6	2350.0	10:1	7.1	74,000	4.0					
	2	2.2	10:1	5.0			30	3.2	3.3	0.4	1117.4									
	3	1.2	10:1	5.6			30	0.8	0.5	0.2										
10/13	1	17.7	10:1	5.2	49,000	5.8	30	41.4	40.2	1.4	2750.2	10:1	6.7	53,000	5.4		45.19	41.31	3.88	8.59
	2	12.2	10:1	4.6			30	39.7	40.6	1.0	2336.1						45.29	40.90	4.39	9.69
	3	10.2					30	41.1	37.4	0.8							43.76	36.52	7.24	16.54
	4	2.4	10:1	4.8			30	20.1	20.7	1.2							31.52	23.96	7.56	23.98
	5						30	10.5	10.0	0.7							15.40	11.42	3.98	25.84
	6						30	5.1	6.3	1.1							9.08	6.63	2.45	26.98
10/16	1	26.7	10:1	4.0			30	42.3	41.0	0.8	924.9	10:1	8.0	41,500	6.8		48.81	49.83	-1.02	-2.09
	2	26.7	10:1	6.6[d]		5.6[e]	30	45.4	46.3	0.4	507.3		6.6[d]				52.24	53.72	-1.48	-2.83
	3	14.0	10:1	6.6	42,500	6.6	29	38.8	38.4	0.2							49.61	47.66	1.95	3.93
	4	6.6	10:1	5.5	37,000	7.6	29	27.9	22.8	0.0							33.03	27.89	5.14	15.56
	5	3.0	10:1	5.5			30	16.1	17.2	0.0							21.37	16.34	5.03	23.54
	6							11.6	10.8	0.0							14.74	9.83	4.91	33.31
10/19	1	43.2	10:1	6.1			33	36.2	31.3	0.6	2219.0	10:1	7.2	68,000	4.4		36.90	39.46	-2.56	-6.94
			1:1	4.6																
	2	37.7	10:1	6.3			29	38.5	35.9	0.2	2031.1		3.7[d]			2.6	38.75	39.46	-0.71	-1.83
			1:1	4.5																
	3	11.7	10:1	6.0			29	19.9	16.9	0.0							25.22	22.14	3.08	12.21
			3:1	4.7																
	4	4.7	10:1	5.4			28	9.9	10.4	0.0							12.51	11.07	1.44	11.51
	5	2.9	10:1	5.6			30	6.7	6.4	0.0							7.59	6.87	0.72	9.49
	6						30	5.2	4.9								4.59	3.71	0.88	19.17
10/20	1	35.4					57	42.0	39.6	0.5	2309.3						39.87	42.47	-2.60	-6.52
	2	11.5		6.7[d]		10.4[e]	58	42.8	38.8	0.7	1530.6		3.5[d]			2.3	38.81	41.51	-2.70	-6.96
	3	2.9					58	24.4	21.6	0.0							28.22	25.04	3.18	11.27
	4							12.1	11.2	0.7							13.87	12.04	1.83	13.19
	5							6.9	7.1	0.4							7.80	6.45	1.35	17.31
	6							4.7	4.9	0.7							4.72	4.14	0.58	12.29
10/22	1	7.7					30	32.8									32.70	33.10	-0.40	-1.22
	2	6.6					150	25.4			2271.0		3.7[d]				25.60	24.50	1.10	4.30
	3							10.9									12.60	10.90	1.70	13.49
	4							4.7									4.50	3.80	0.70	15.56
	5							2.7									2.45	2.28	0.17	6.94
	6							2.0									1.95	1.80	0.15	7.69

a. Without filter
b. With filter
c. Sample period, 40-70 minutes
d. Soxhlet extraction entire sample, diluted to 250 ml. and refluxed for 2 hours
e. Gravimetric analysis

Table 18

EFFECT OF DILUTION ON FLY ASH pH

	Date					
	10/21/59		10/21/59		10/22/59	
	Time	pH	Time	pH	Time	pH
Sample 1: Electrostatic precipitator No. 1 collected from Colbert trailer on 10/20/59, weight 35.4 mg., and initially diluted to 45 cc.						
Instrument check against standard solution pH - 7.00		7.00		7.00		7.00
1a. Aliquot of initial dilution, unfiltered	0900	4.50	1334	4.55	0842	4.50
1b. Aliquot of initial dilution, filtered	0903	4.49	1332	4.50	0843	4.50
1c. Aliquot, dilution increased to 10 cc.	0910	6.20	1346	6.00		
per mg., filtered	0909	6.22	1335	6.00	0845	6.16
*1d. Aliquot, dilution increased to 10 cc.	0913	5.82			0900	5.84
per mg., unfiltered	0912	5.80	1337	5.70	0843	5.90
Sample 2: Thimble fly ash sample collected inside unit 2 duct on 10/20/59 - 100 mg. diluted to 100 cc. of distilled water	0950	7.18				
2a. Aliquot of initial dilution, unfiltered	0947	7.20	1339	7.30	0849	7.22
2b. Aliquot of initial dilution, filtered	0958	6.85	1341	6.92	0852	6.88
2c. Aliquot dilution increased to 10 cc. per mg., filtered	1000	7.00	1343	7.00	0854	6.99
2d. Aliquot, dilution increased to 10 cc. per mg., unfiltered	0954	6.90	1345	6.99	0856	6.90
Inst. check against standard solution		7.00		7.01		7.00
pH distilled water, unfiltered	0924	6.90				
pH distilled water, filtered	0925	6.70				

*This was bottom sample, more visible fly ash

Table 17

CHAMBER SO_2 OXIDATION STUDIES

COLBERT STEAM PLANT

Date (1959)	Test No.	Electrostatic Precipitator Samples: Wt. (mg.)	Dil.	pH	Resist. (Ohms)	Est. SO_4 (%)	Minutes Operated	Scrubber Samples: A[a] SO_2 (ppm)	B[b] SO_2 (ppm)	Filter B (mg.)	Duct - Fly Ash Samples: Wt. (mg.)[c]	Dil.	pH	Resist. (Ohms)	Est. SO_4 (%)	% SO_4 Grav.	SO_2 Concentration: Autometer (ppm)	Titrilog (ppm)	Autometer Minus Titrilog (ppm)	% Oxidation
9/30	1	51.4	10:1	5.6	46.500	6.2	30	58.3	62.9	0.0	1287.1	10:1	6.5	52,000	5.6					
	2	30.6	10:1	6.4	44,300	6.4	30	50.1	56.3	0.0										
	3	6.0	10:1	4.9	32,600	6.3	30	29.6	32.2											
	4	2.3	10:1	4.8			30	16.9												
	5							8.9												
	6							4.5												
10/1	1	2.5	10:1	4.8			30	20.7	20.5	0.0	2584.3	10:1	7.0	77,000	3.9					
	2	1.3					30	13.8	13.2	0.0										
	3	0.4					30	7.9	8.9	0.0										
	4	0.5					30	6.3	6.2	0.0										
	5							5.2	4.9	0.0										
	6							3.9	3.6	0.0										
10/2	1	68.6	10:1	6.6	67,000	4.4	30	50.0	50.1	0.1	1644.3	10:1	7.2	67,000	4.4					
	2	18.3	10:1	5.6	44,500	6.4	30	44.1	45.0	0.2										
	3	8.5	10:1	6.0	53,000	5.4	30	29.1	30.4	0.0										
	4	4.2	10:1	4.9	27,200	9.6	30	21.5	22.5	0.0										
	5	3.1	10:1	4.7			60	15.8	17.1	0.0										
	6							12.5	12.3	0.0										
10/12	1	5.7	10:1	4.9	22,600	11.2	30	24.9	24.2	0.6	2350.0	10:1	7.1	74,000	4.0					
	2	2.2	10:1	5.0			30	3.2	3.3	0.4	1117.4									
	3	1.2	10:1	5.6			30	0.8	0.5	0.2										
10/13	1	17.7	10:1	5.2	49,000	5.8	30	41.4	40.2	1.4	2750.2	10:1	6.7	53,000	5.4		45.19	41.31	3.88	8.59
	2	12.2	10:1	4.6			30	39.7	40.6	1.0	2336.1						45.29	40.90	4.39	9.69
	3	10.2					30	41.1	37.4	0.8							43.76	36.52	7.24	16.54
	4	2.4	10:1	4.8			30	20.1	20.7	1.2							31.52	23.96	7.56	23.98
	5						30	10.5	10.0	0.7							15.40	11.42	3.98	25.84
	6						30	5.1	6.3	1.1							9.08	6.63	2.45	26.98
10/16	1	26.7	10:1	4.0			30	42.3	41.0	0.8	924.9	10:1	8.0	41,500	6.8		48.81	49.83	-1.02	-2.09
	2	26.7	10:1	6.6[d]		5.6[e]	30	45.4	46.3	0.4	507.3		6.6[d]				52.24	53.72	-1.48	-2.83
	3	14.0	10:1	6.6	42,500	6.6	29	38.8	38.4	0.2							49.61	47.66	1.95	3.93
	4	6.6	10:1	5.5	37,000	7.6	29	27.9	22.8	0.0							33.03	27.89	5.14	15.56
	5	3.0	10:1	5.5			30	16.1	17.2	0.0							21.37	16.34	5.03	23.54
	6							11.6	10.8	0.0							14.74	9.83	4.91	33.31
10/19	1	43.2	10:1	6.1			33	36.2	31.3	0.6	2219.0	10:1	7.2	68,000	4.4		36.90	39.46	-2.56	-6.94
			1:1	4.6																
	2	37.7	10:1	6.3			29	38.5	35.9	0.2	2031.1		3.7[d]			2.6	38.75	39.46	-0.71	-1.83
			1:1	4.5																
	3	11.7	10:1	6.0			29	19.9	16.9	0.0							25.22	22.14	3.08	12.21
			3:1	4.7																
	4	4.7	10:1	5.4			28	9.9	10.4	0.0							12.51	11.07	1.44	11.51
	5	2.9	10:1	5.6			30	6.7	6.4	0.0							7.59	6.87	0.72	9.49
	6						30	5.2	4.9								4.59	3.71	0.88	19.17
10/20	1	35.4					57	42.0	39.6	0.5	2309.3						39.87	42.47	-2.60	-6.52
	2	11.5		6.7[d]		10.4[e]	58	42.8	38.8	0.7	1530.6		3.5[d]			2.3	38.81	41.51	-2.70	-6.96
	3	2.9					58	24.4	21.6	0.0							28.22	25.04	3.18	11.27
	4							12.1	11.2	0.7							13.87	12.04	1.83	13.19
	5							6.9	7.1	0.4							7.80	6.45	1.35	17.31
	6							4.7	4.9	0.7							4.72	4.14	0.58	12.29
10/22	1	7.7					30	32.8									32.70	33.10	-0.40	-1.22
	2	6.6					150	25.4			2271.0		3.7[d]				25.60	24.50	1.10	4.30
	3							10.9									12.60	10.90	1.70	13.49
	4							4.7									4.50	3.80	0.70	15.56
	5							2.7									2.45	2.28	0.17	6.94
	6							2.0									1.95	1.80	0.15	7.69

a. Without filter
b. With filter
c. Sample period, 40-70 minutes
d. Soxhlet extraction entire sample, diluted to 250 ml. and refluxed for 2 hours
e. Gravimetric analysis

Table 18

EFFECT OF DILUTION ON FLY ASH pH

	Date					
	10/21/59		10/21/59		10/22/59	
	Time	pH	Time	pH	Time	pH
Sample 1: Electrostatic precipitator No. 1 collected from Colbert trailer on 10/20/59, weight 35.4 mg., and initially diluted to 45 cc.						
Instrument check against standard solution pH - 7.00		7.00		7.00		7.00
1a. Aliquot of initial dilution, unfiltered	0900	4.50	1334	4.55	0842	4.50
1b. Aliquot of initial dilution, filtered	0903	4.49	1332	4.50	0843	4.50
1c. Aliquot, dilution increased to 10 cc.	0910	6.20	1346	6.00		
per mg., filtered	0909	6.22	1335	6.00	0845	6.16
*1d. Aliquot, dilution increased to 10 cc.	0913	5.82			0900	5.84
per mg., unfiltered	0912	5.80	1337	5.70	0843	5.90
Sample 2: Thimble fly ash sample collected inside unit 2 duct on 10/20/59 - 100 mg. diluted to 100 cc. of distilled water	0950	7.18				
2a. Aliquot of initial dilution, unfiltered	0947	7.20	1339	7.30	0849	7.22
2b. Aliquot of initial dilution, filtered	0958	6.85	1341	6.92	0852	6.88
2c. Aliquot dilution increased to 10 cc. per mg., filtered	1000	7.00	1343	7.00	0854	6.99
2d. Aliquot, dilution increased to 10 cc. per mg., unfiltered	0954	6.90	1345	6.99	0856	6.90
Inst. check against standard solution		7.00		7.01		7.00
pH distilled water, unfiltered	0924	6.90				
pH distilled water, filtered	0925	6.70				

*This was bottom sample, more visible fly ash

Table 19

SO$_2$ OXIDATION STUDIES - COLBERT STEAM PLANT PLUME

Date (1960)	Sample No.	Travel from Point of Emission: Time (Min.)	Travel from Point of Emission: Distance (Mi.)	Relative Humidity in Plume (%)	SO$_2$ Oxidation (%)
					Low Rates:
8/2	1	5	.25-1		0
	2	5	.25-1		0
	3	5	.25-1		1.20
	4	15	1-1.5		0
9/2	1	30	2-3		3.70
	2	78	8		2.20
10/14	1	12	.5-1.5	62	2.15
	2	60	5-6	54	3.23
10/26	1	6	.25-1.25	45	1.50
	2	84	8-9	48	2.70
10/28	1	12	.5-1.5	68	1.10
	2	84	8-9	70	4.10
					High Rates:
5/3	1	13	1.1		13.80
	2	13	1.1		10.00
	3	13	1.1		19.20
8/19	1	108	8-10		55.50
	2	23	.75-2		8.00
10/11	1	12	.5-1.5	74	21.60
	2	96	8	73	32.00

Table 20

SO_2 OXIDATION STUDIES - COLBERT STEAM PLANT PLUME

Date (1960)	Sample No.	Distance from Plant (Miles)	Plume Travel Time (Min.)	Time Start	Time Stop	*Sample Elev. (Ft.)	Approx. Wind Speed (mph)	Plume Temp. (°F.)	Ground Temp. (°F.)	Rel. Humidity Ground (%)	Rel. Humidity Plume (%)	SO_3** (ppm)	SO_2** (ppm)	Total** (ppm)	Oxidation (%)	Weather Observations
5/3	1	1.1	13	0526	0553	812	5	56	43			2.4	15.0	17.4	13.6	Fair; slight fog at ground.
	2	1.1	13	0627	0658	713	5	56	45			2.0	18.0	20.0	10.0	Fair; slight haze to the E and N of plant.
	3	1.1	13	0719	0750	800	5	56	35			3.8	16.0	19.2	19.2	Fair.
8/2	1	.25-1	5	0507	0538	660	7	77	74	92		0.0	6.0	6.0	0.0	No clouds; very hazy and smoky; no sunshine.
	2	.25-1	5	0555	0627	700	7	77	76	86		0.0	6.0	6.0	0.0	Very hazy and smoky; no sunshine due to haze and smoke.
	3	.25-1	5	0641	0711	730	7	76	80	80		0.06	5.0	5.06	1.2	Hazy and smoky; bright red sun visible through smoke and haze.
	4	1-1.5	15	0728	0811	920	5	79	83	73		0.0	3.0	3.0	0.0	
8/19	1	8-10	108	0514	0607	950	5	69	71	+95		1.0	0.8	1.8	55.5	Mist and fog over general area; complete cloud cover.
	2	.75-2	23	0630	0655	950	5	67	71	+95		0.2	2.3	2.5	8.0	Discontinued because of rain.
9/2	1	2-3	30	0521	0602	850	5	74	65	96		0.07	1.9	1.97	3.7	Haze; no mist.
	2	8	78	0656	0743	1600	5	74	74	96		0.06	2.4	2.46	2.2	Fair; sun shining.
10/11	1	.5-1.5	12	0633	0708	800	5	65	57	99	74	1.0	3.6	4.6	21.6	.8 cloud cover; fog and haze in low areas.
	2	8	96	0736	0824	800	5	65	60	98	73	0.08	0.17	0.25	32.0	.4 cloud cover; haze in area.
10/14	1	.5-1.5	12	0630	0652	700	5	68	58	96	62	0.11	5.0	5.11	2.15	.6 cloud cover; fog and haze in low areas.
	2	5-6	60	0724	0814	700	5	70	61	89	54	0.07	2.1	2.17	3.23	.8 cloud cover; fog and haze in low areas.
10/26	1	.25-1.25	6	0628	0704	600	6	62	58	89	45	0.07	4.6	4.67	1.5	High overcast of clouds; no sunlight.
	2	8-9	84	0724	0820	750	6	60	62	75	48	0.03	1.1	1.13	2.7	High overcast of clouds; no sunlight.
10/28	1	.5-1.5	12	0647	0721	800	5	50	47	99	68	0.04	3.6	3.64	1.1	Clear and sun shining.
	2	8-9	84	0800	0855	900	5	48	56	83	70	0.03	0.71	0.74	4.1	Clear; slightly hazy near ground.

*Elevation above ground level at point of emission.
**Based on soluble sulfate; first decimal determinations were gravimetric; second decimal determinations were colorimetric.

TENNESSEE VALLEY AUTHORITY
Division of Health and Safety

and

PUBLIC HEALTH SERVICE
Division of Air Pollution

APPENDIX B

FIGURES

Chattanooga, Tennessee
August 1964

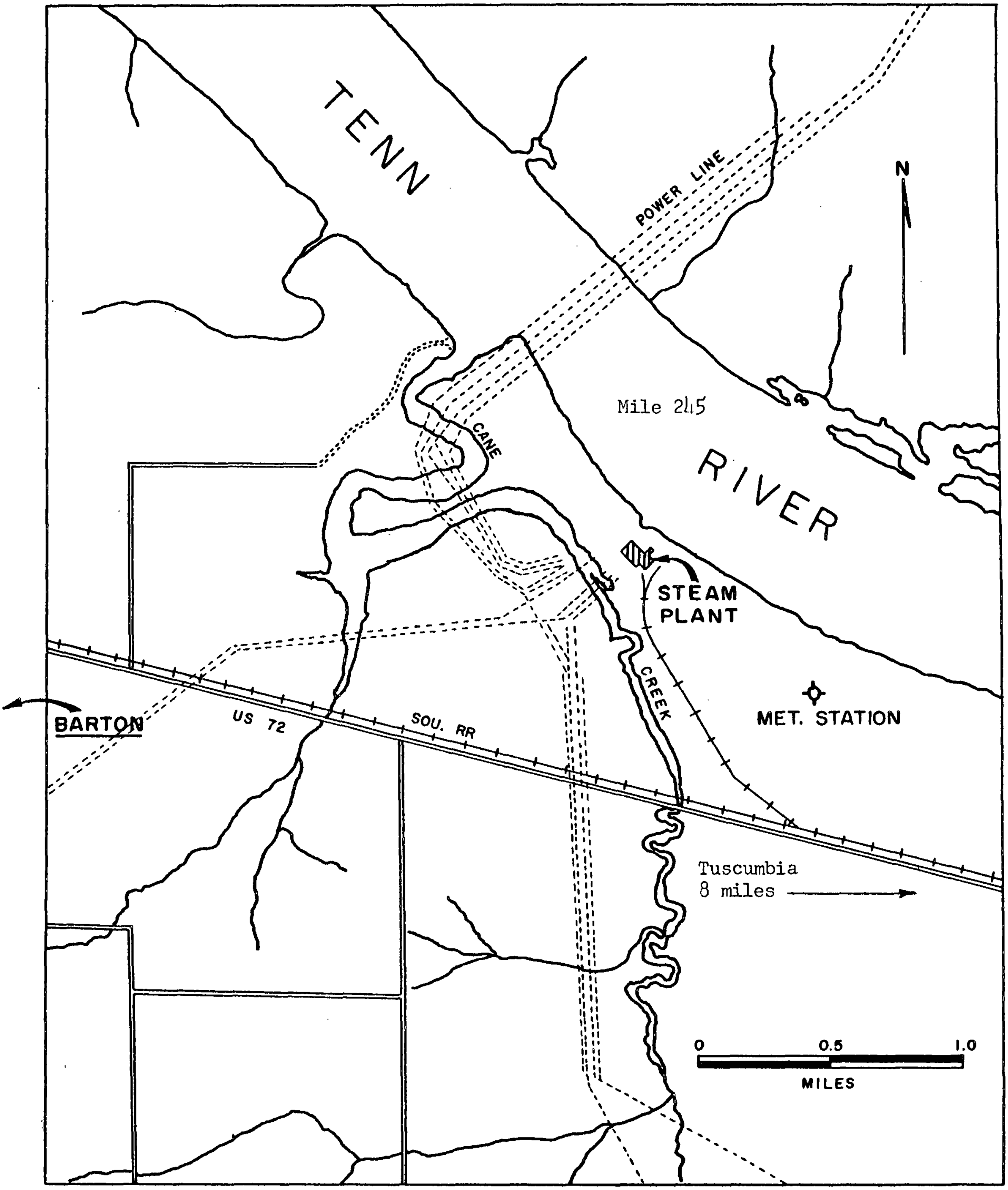


Figure 1. MAP OF COLBERT STEAM PLANT SITE - NEAR TUSCUMBIA, ALABAMA

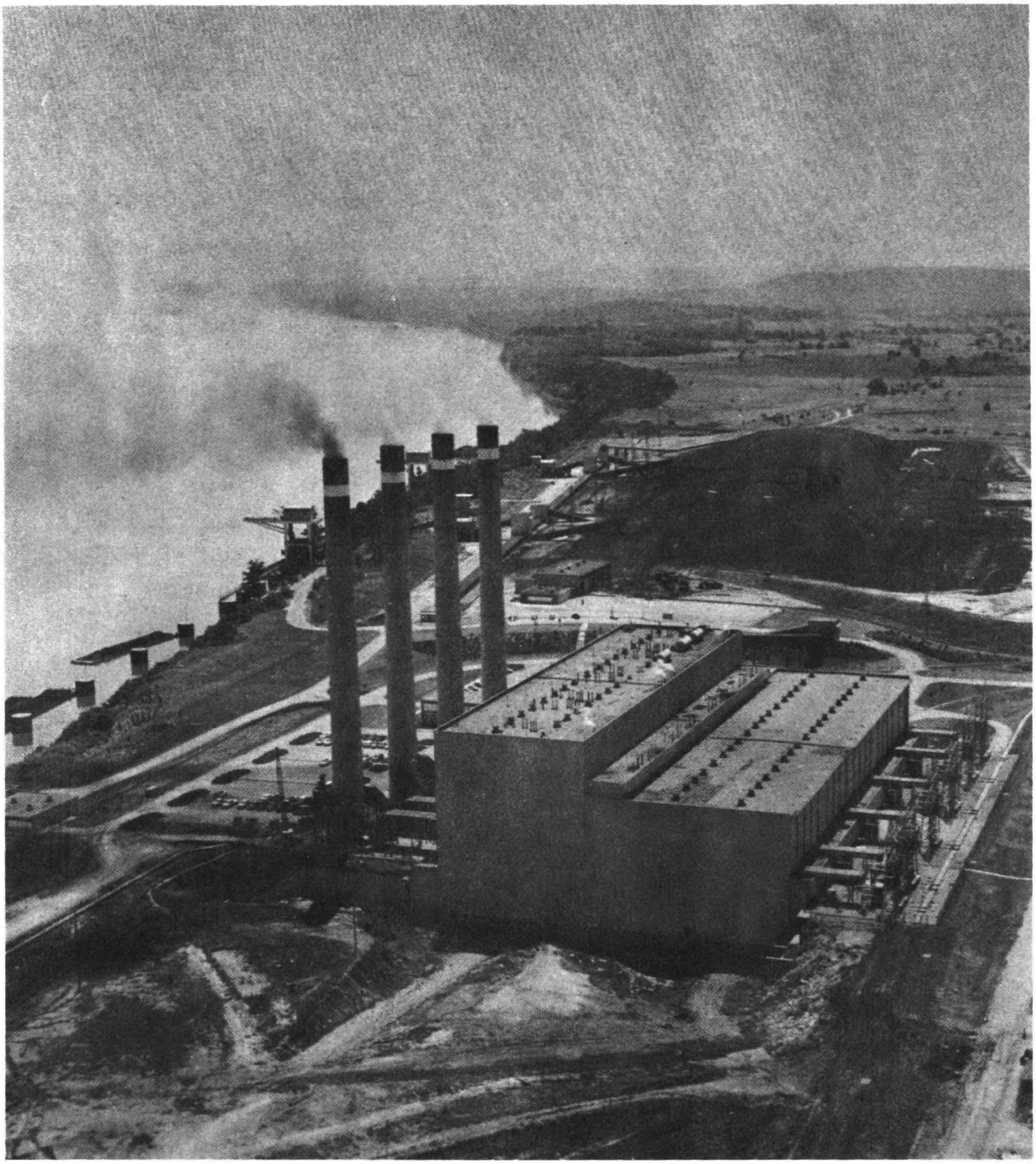


Figure 2. COLBERT STEAM PLANT

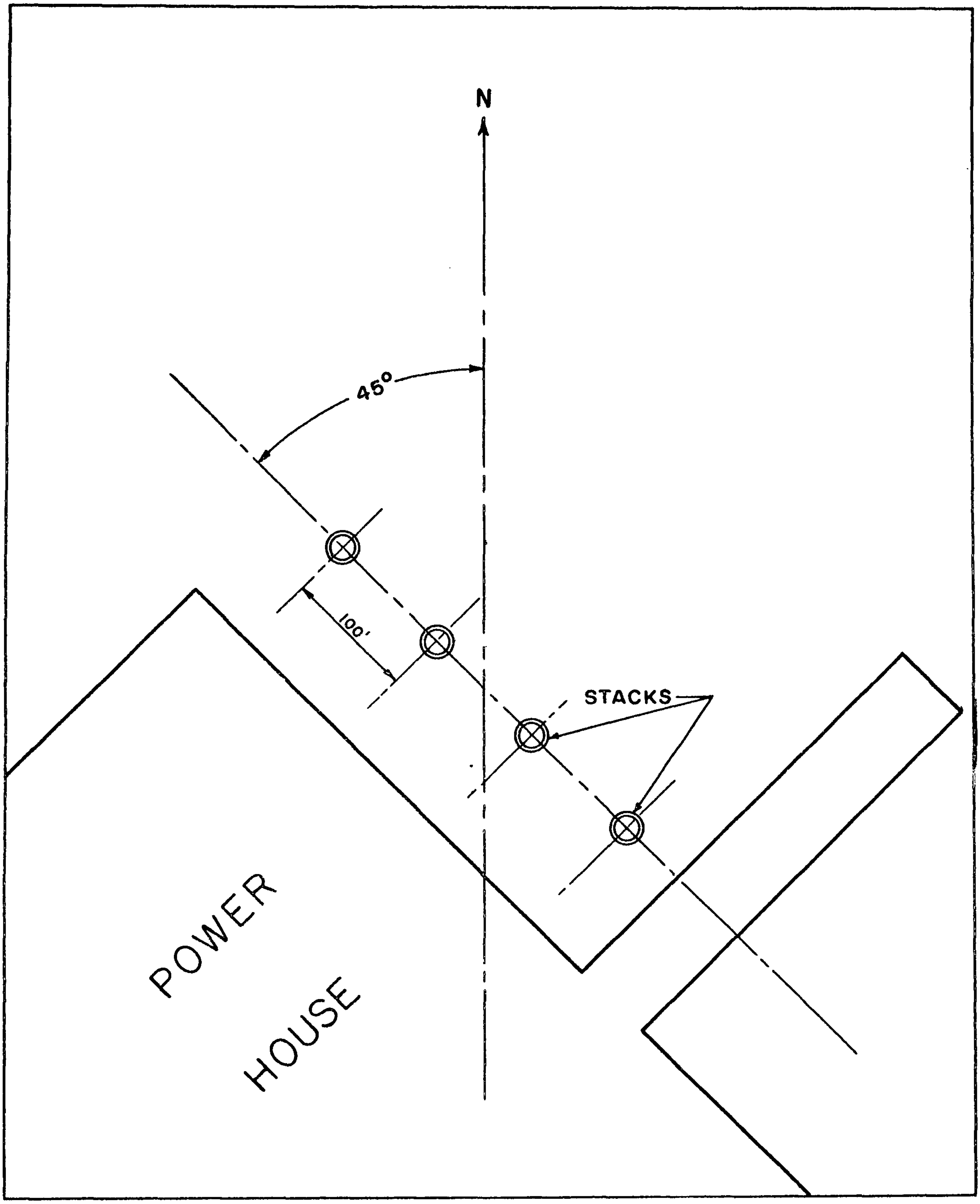


Figure 5. SEPARATION AND ORIENTATION OF STACKS - COLBERT STEAM PLANT

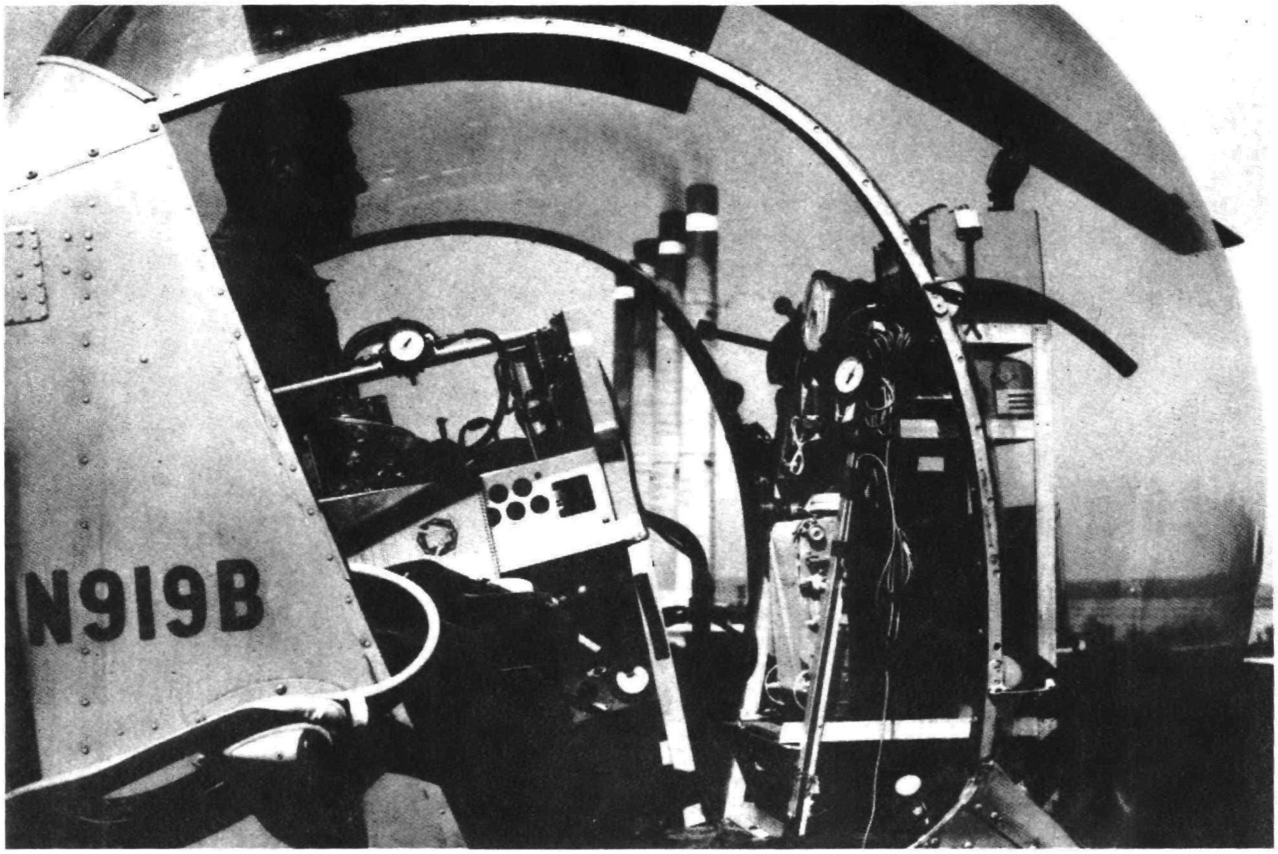


Figure 4. AIR SAMPLING AND AUXILIARY INSTRUMENTS IN HELICOPTER

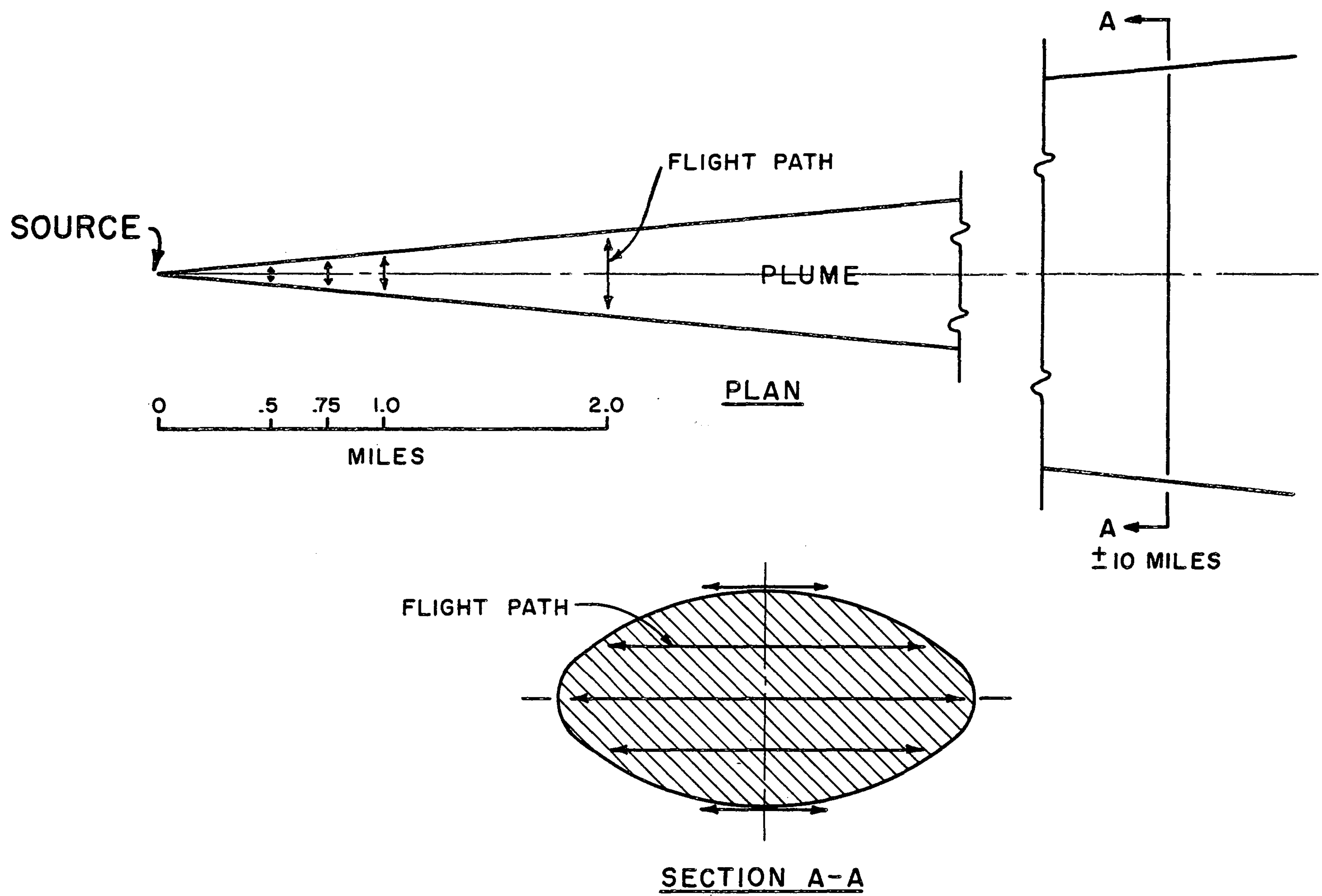


Figure 5. SAMPLE PLAN - INVERSION CONDITIONS

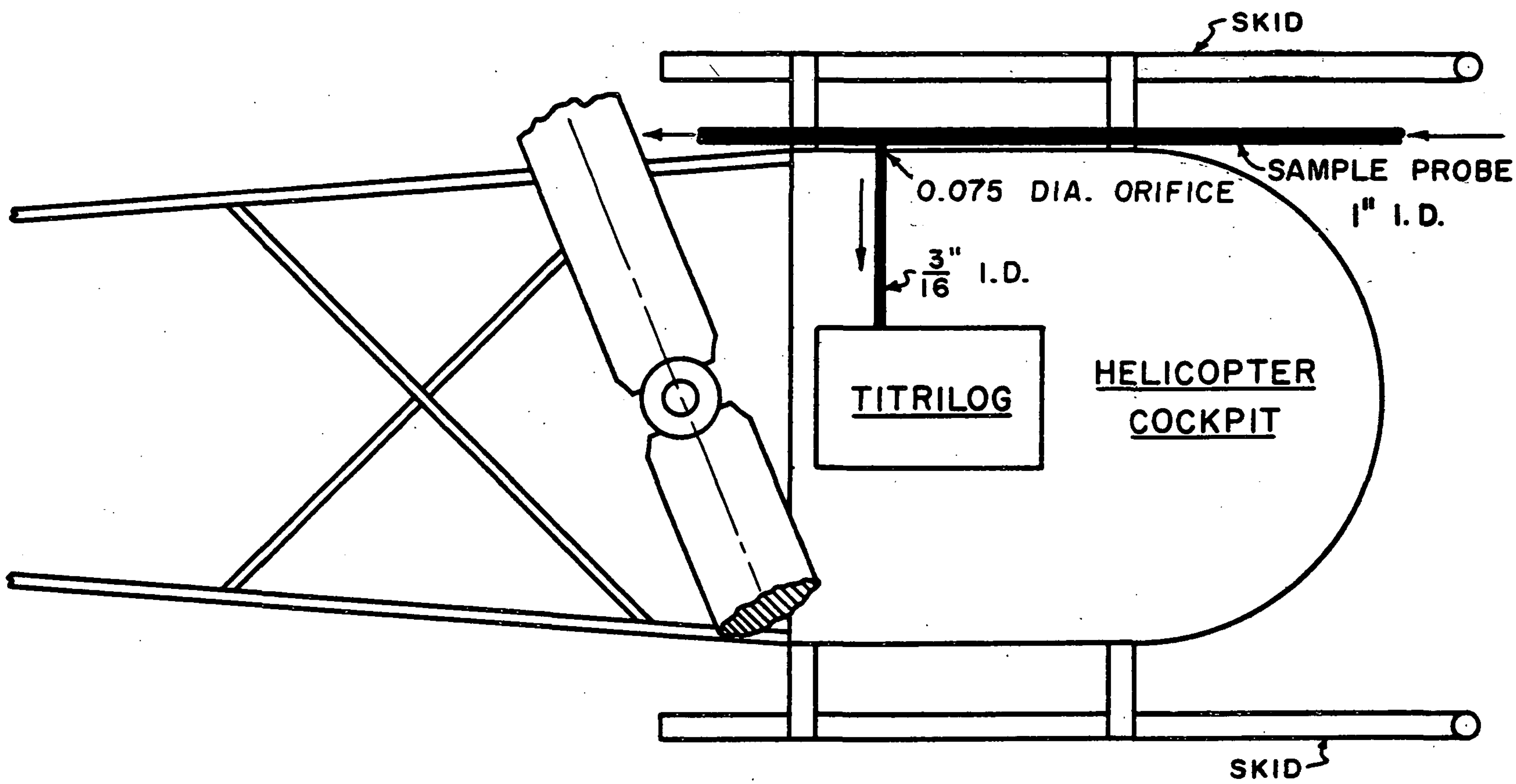


Figure 6. SCHEMATIC PLAN - HELICOPTER AIR SAMPLING EQUIPMENT

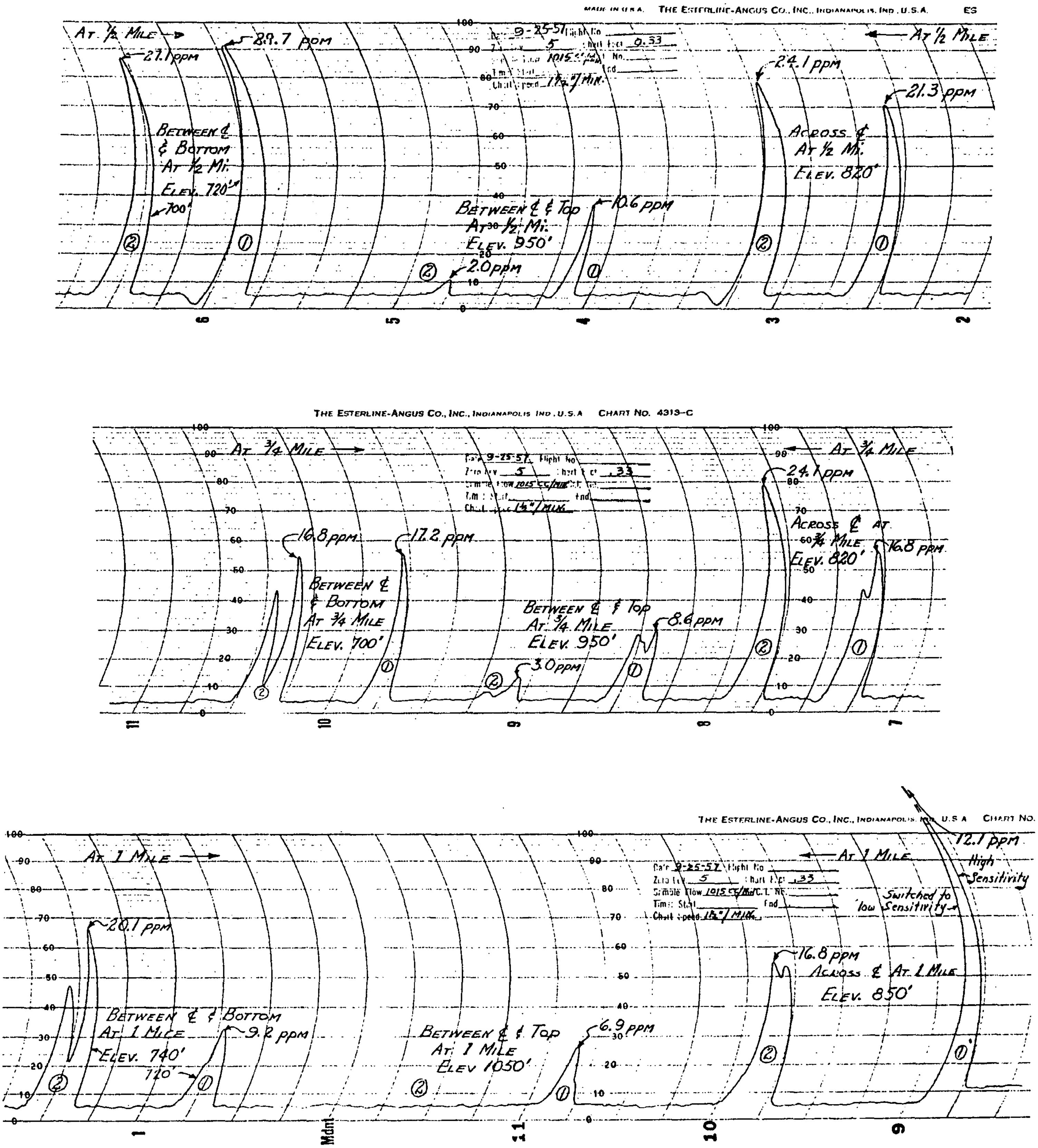


Figure 7. TITRILOG CHART ILLUSTRATING SO_2 DISTRIBUTION, DAY 2

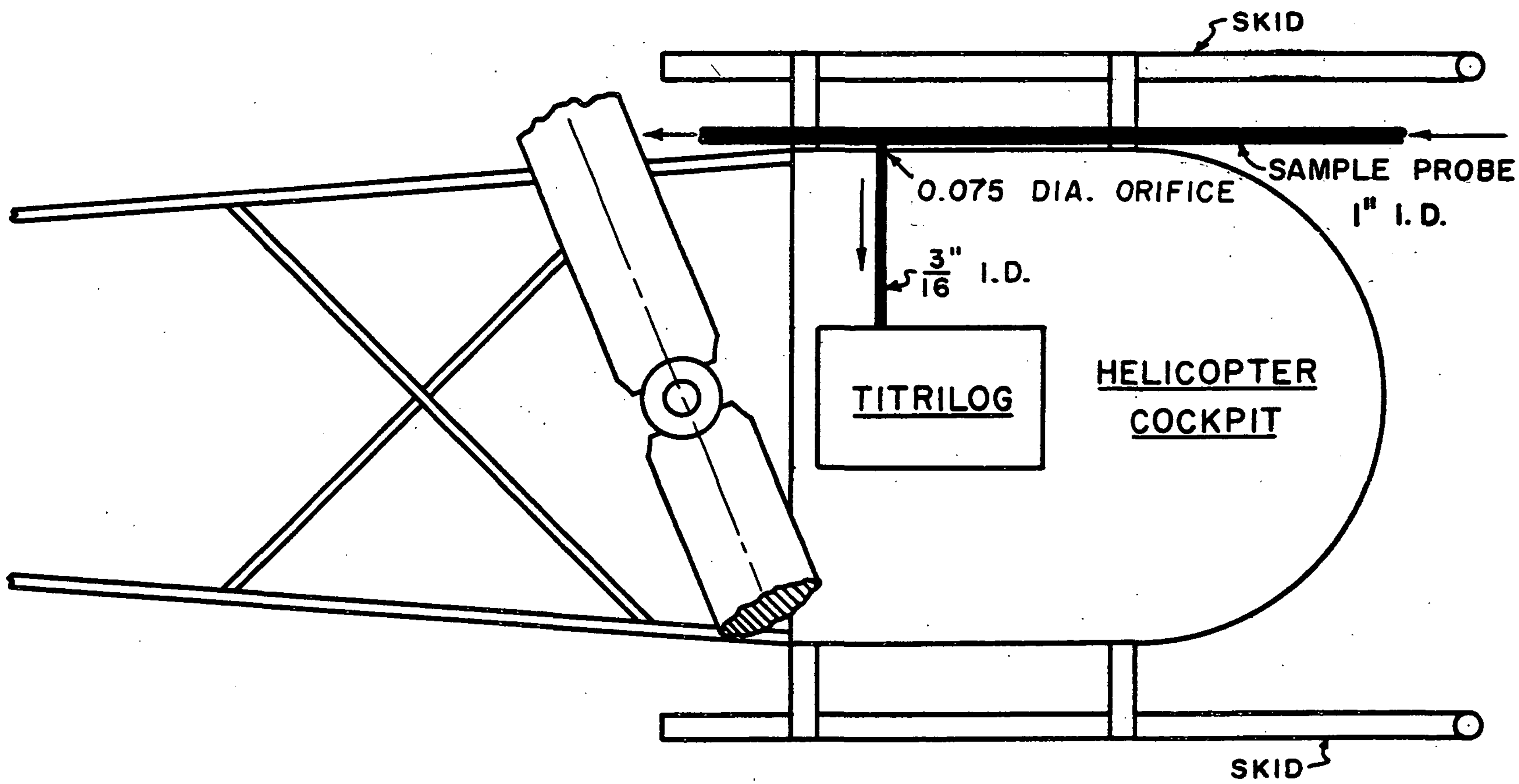


Figure 6. SCHEMATIC PLAN - HELICOPTER AIR SAMPLING EQUIPMENT

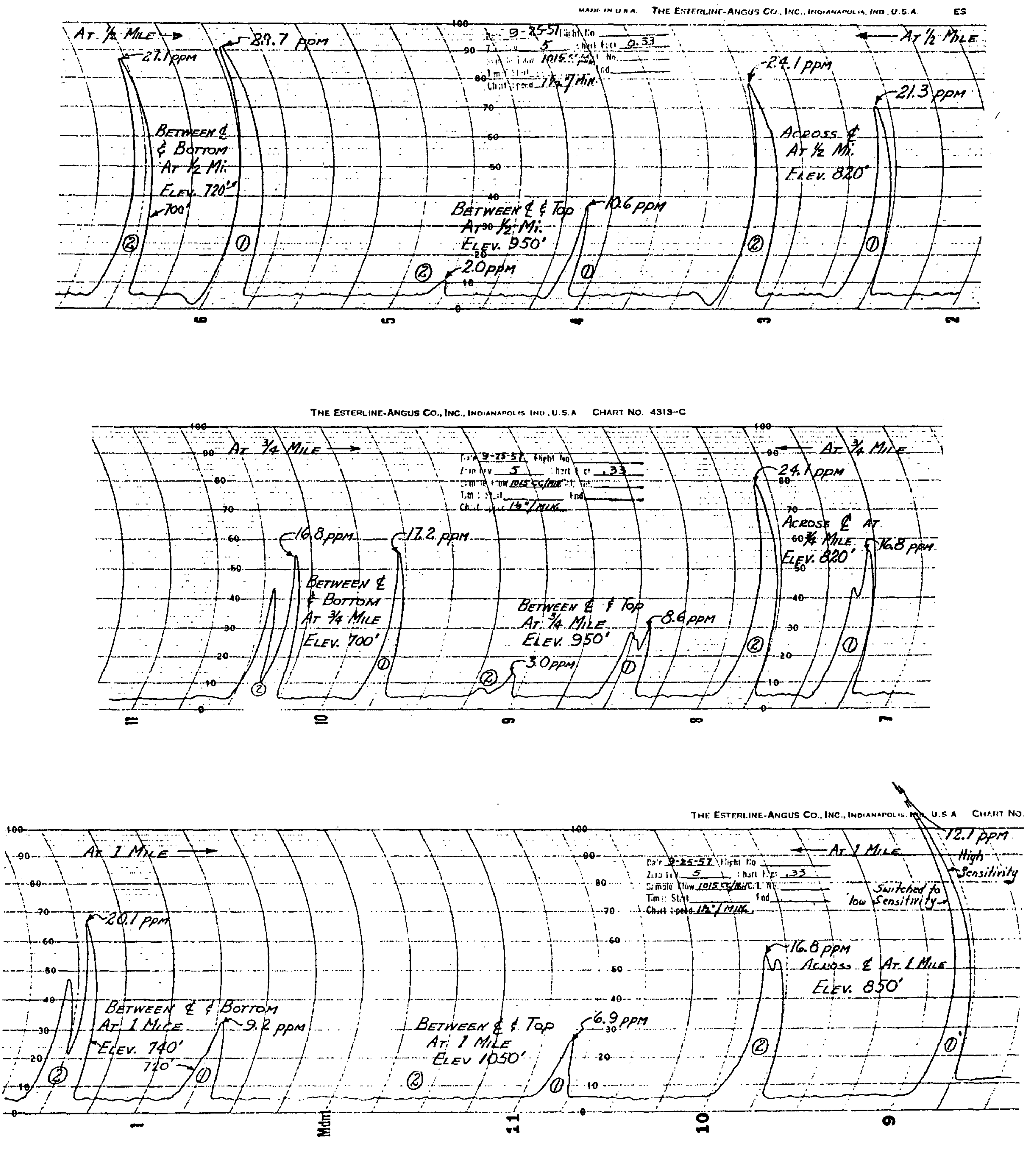


Figure 7. TITRILOG CHART ILLUSTRATING SO_2 DISTRIBUTION, DAY 2

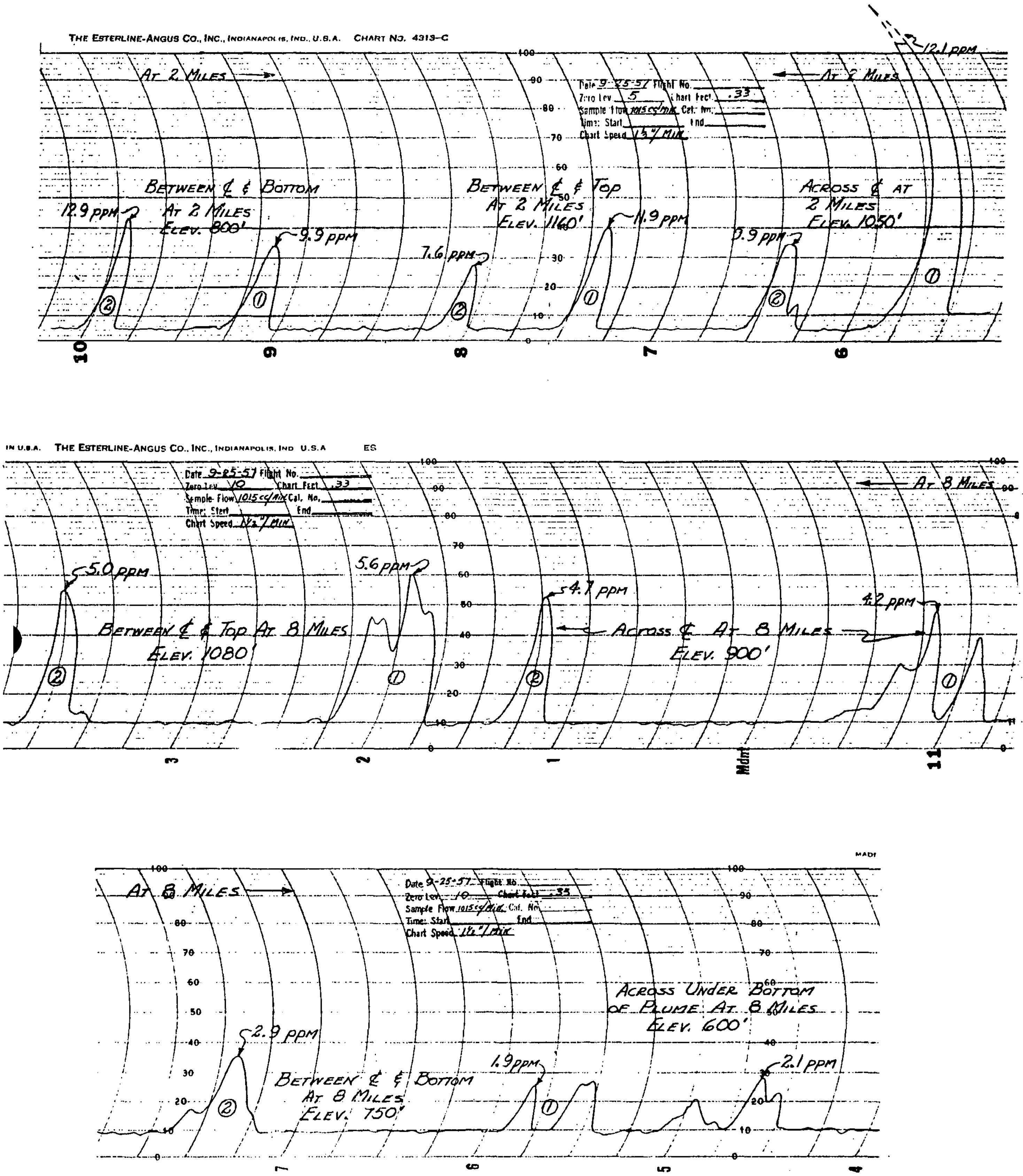


Figure 7. TITRILOG CHART ILLUSTRATING SO_2 DISTRIBUTION, DAY 2

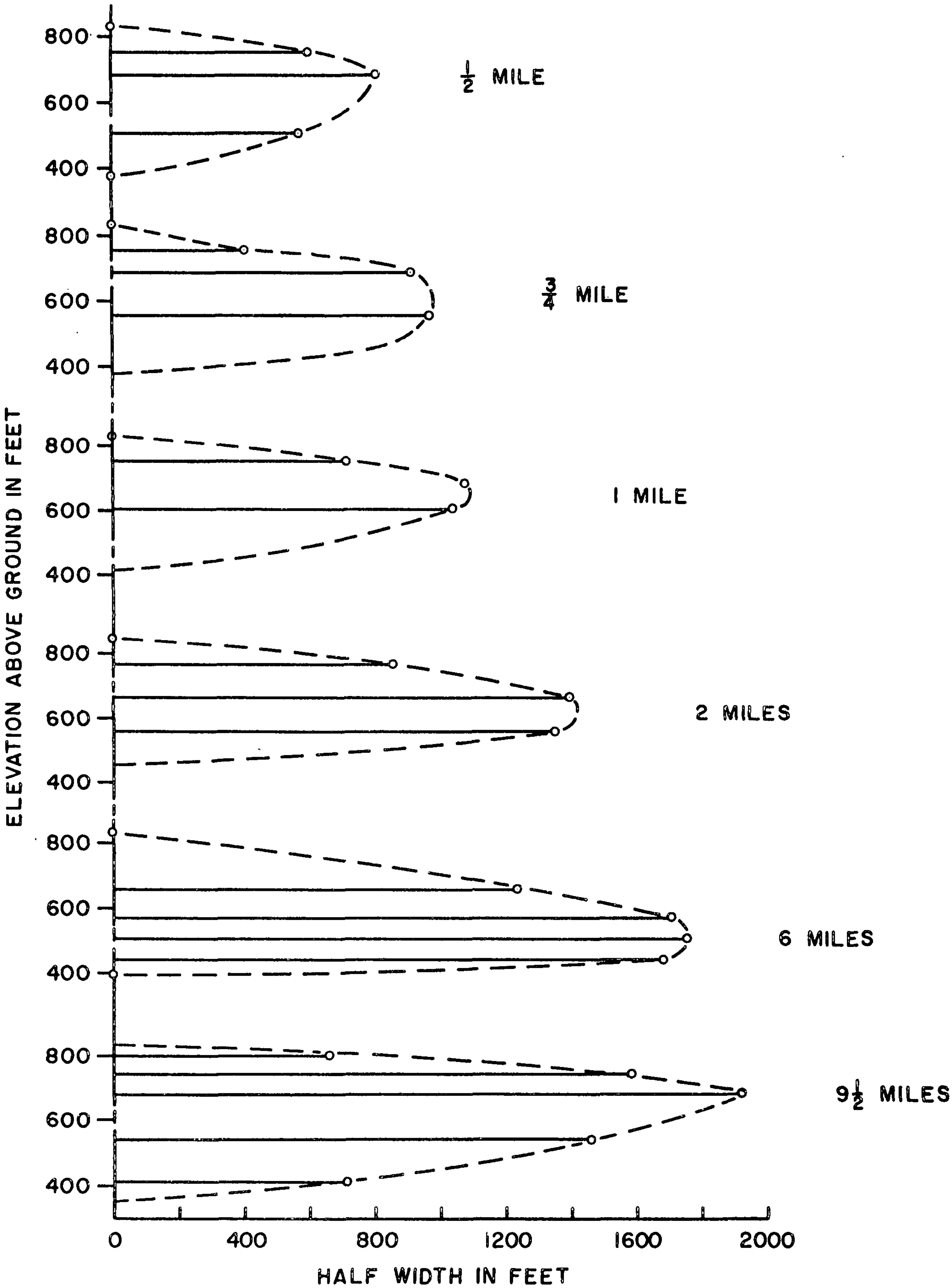


Figure 8. TYPICAL PLUME CROSS SECTION, 9/24/57, DAY 1

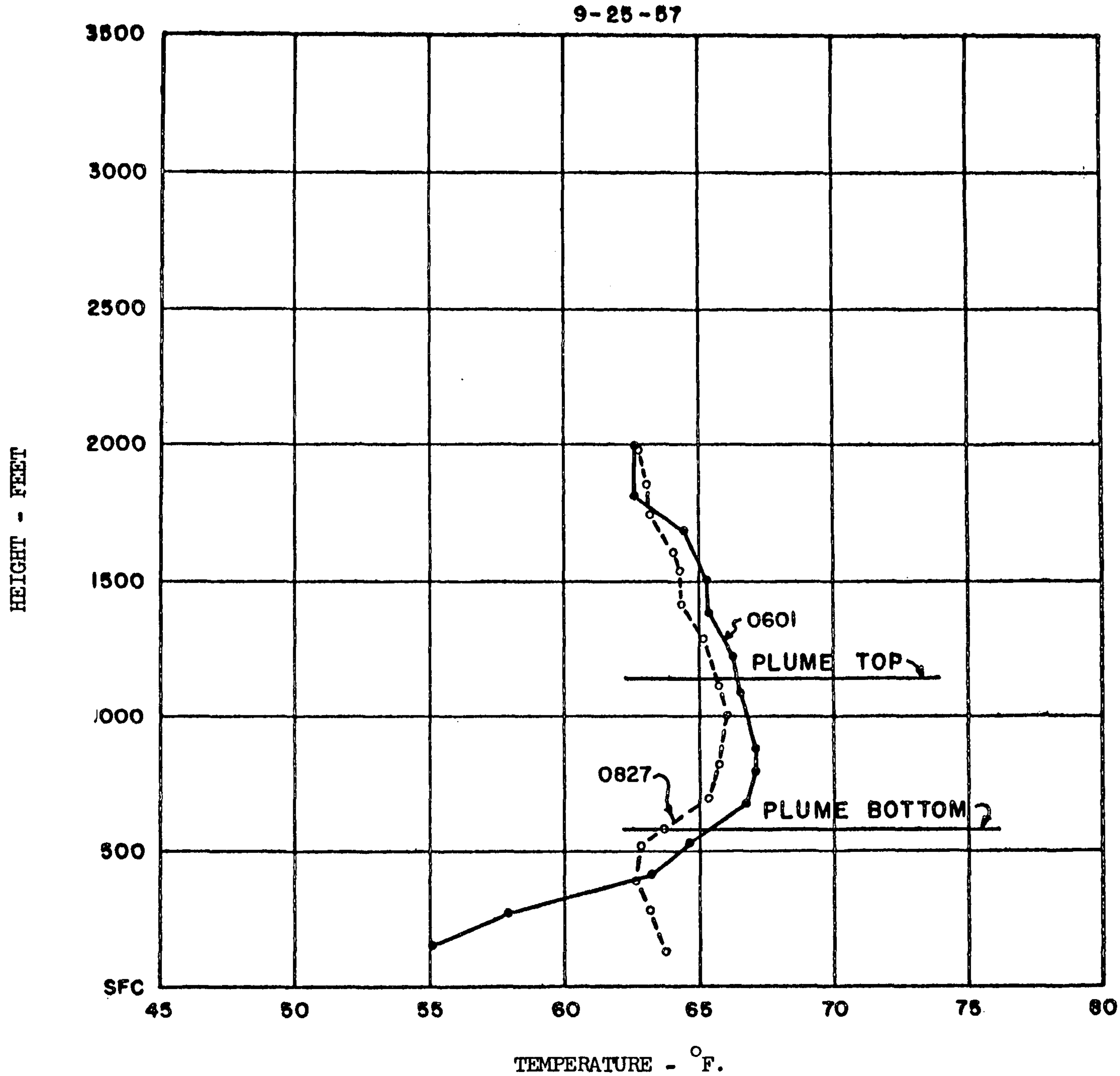


Figure 9. TEMPERATURE PROFILES, DAY 2

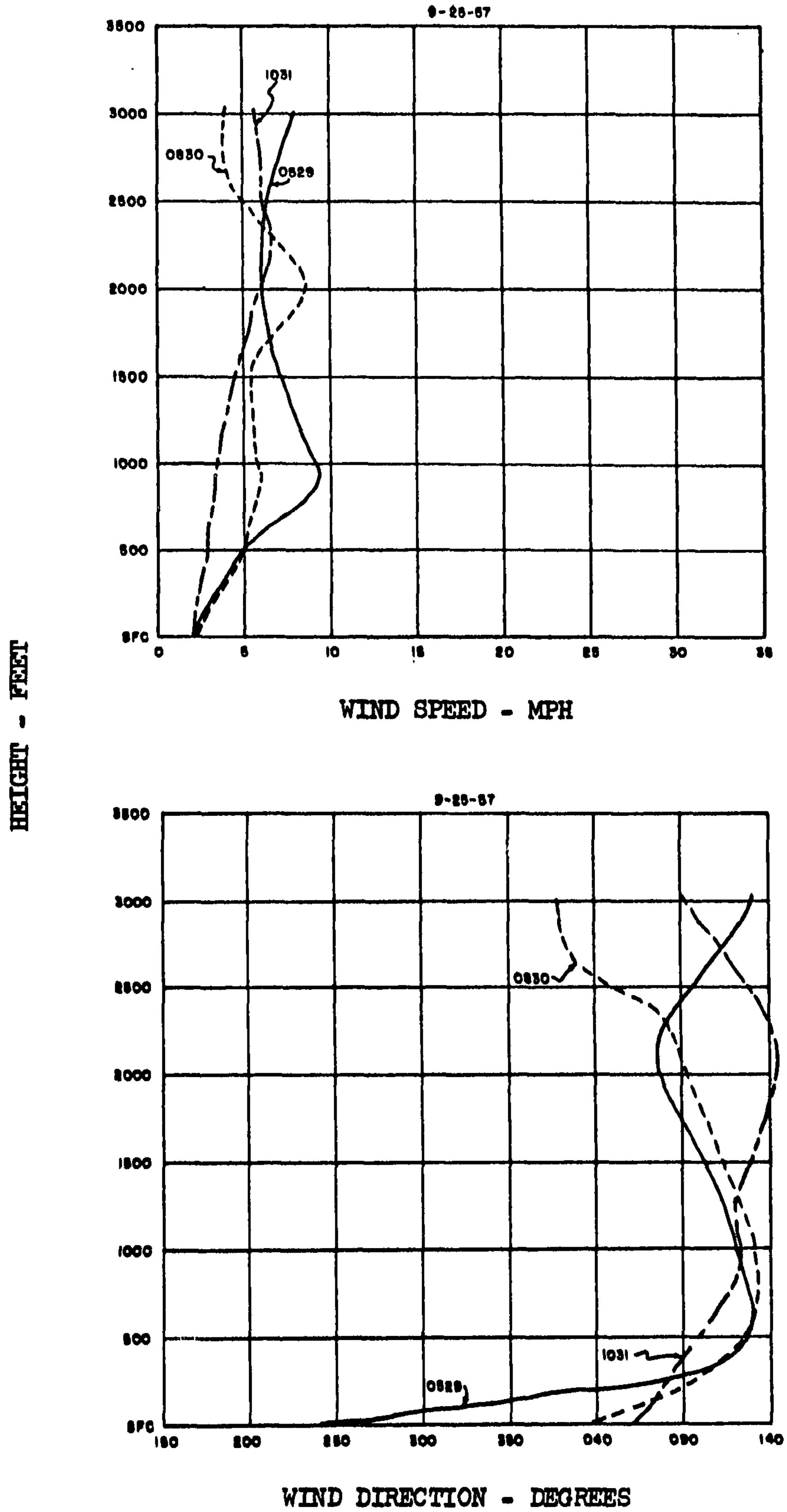


Figure 10. RELATION - WIND SPEED AND WIND DIRECTION TO ELEVATION, DAY 2

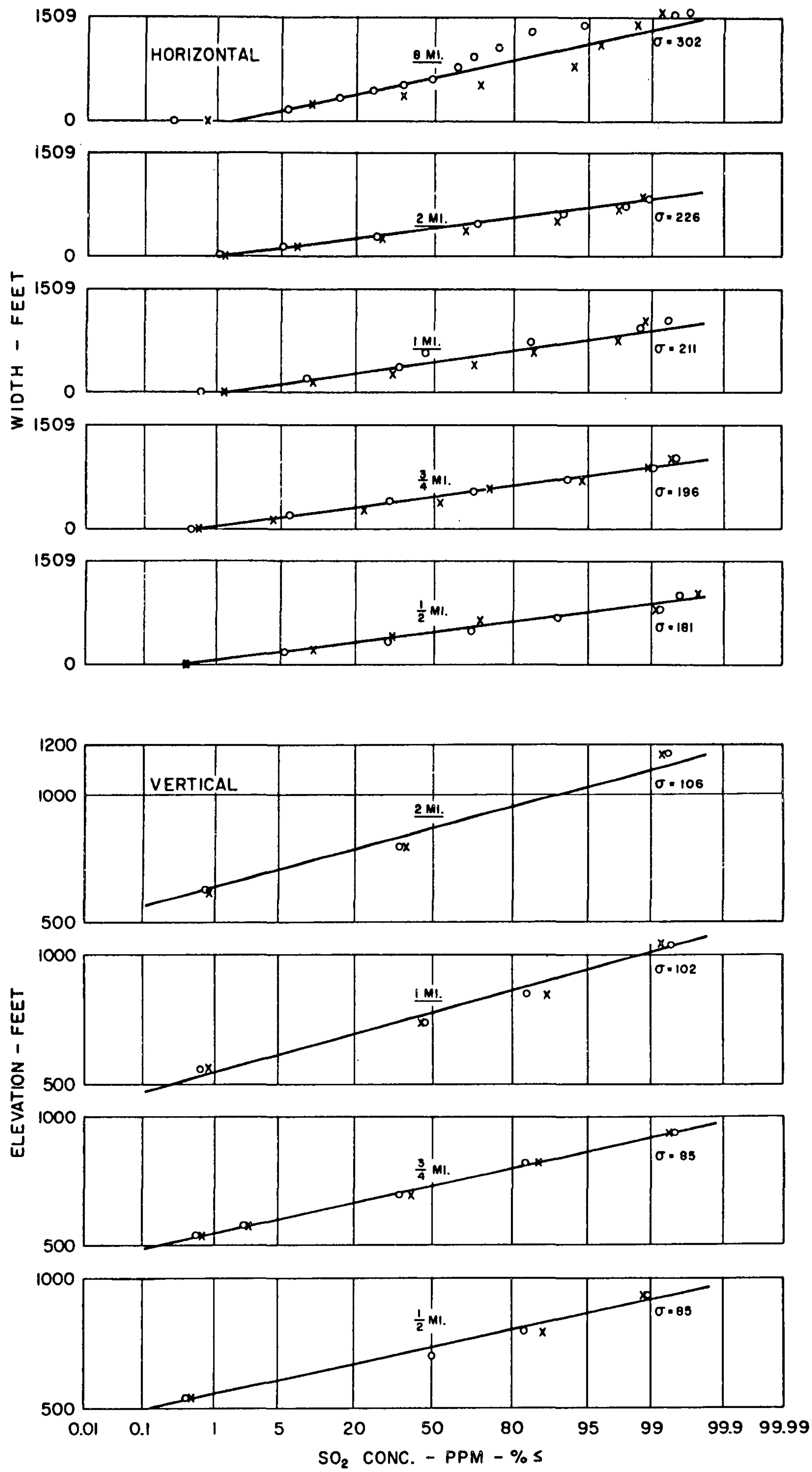


Figure 11. DISTRIBUTION OF SO_2 IN PLUME, DAY 2

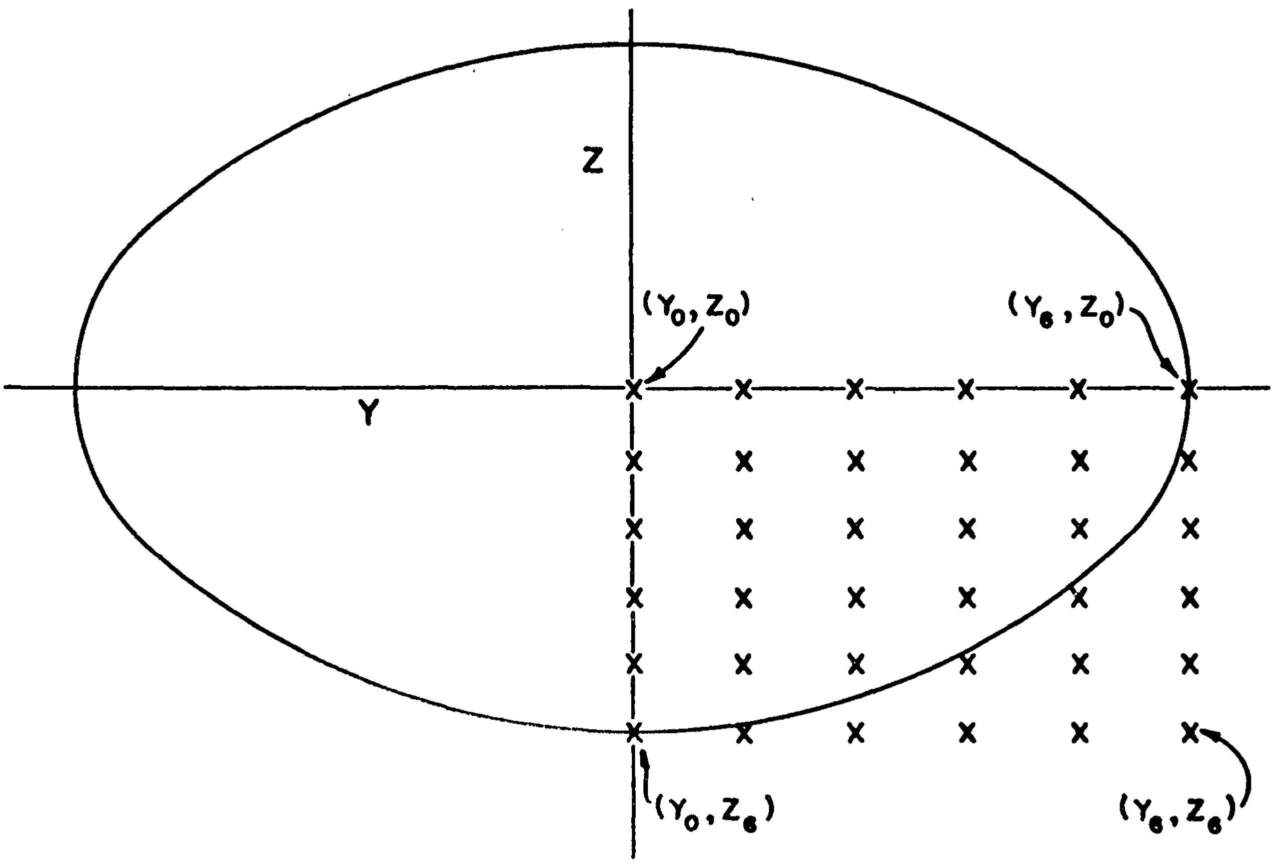


Figure 12. DISTRIBUTION OF POINTS FOR CALCULATED SO_2 CONCENTRATION

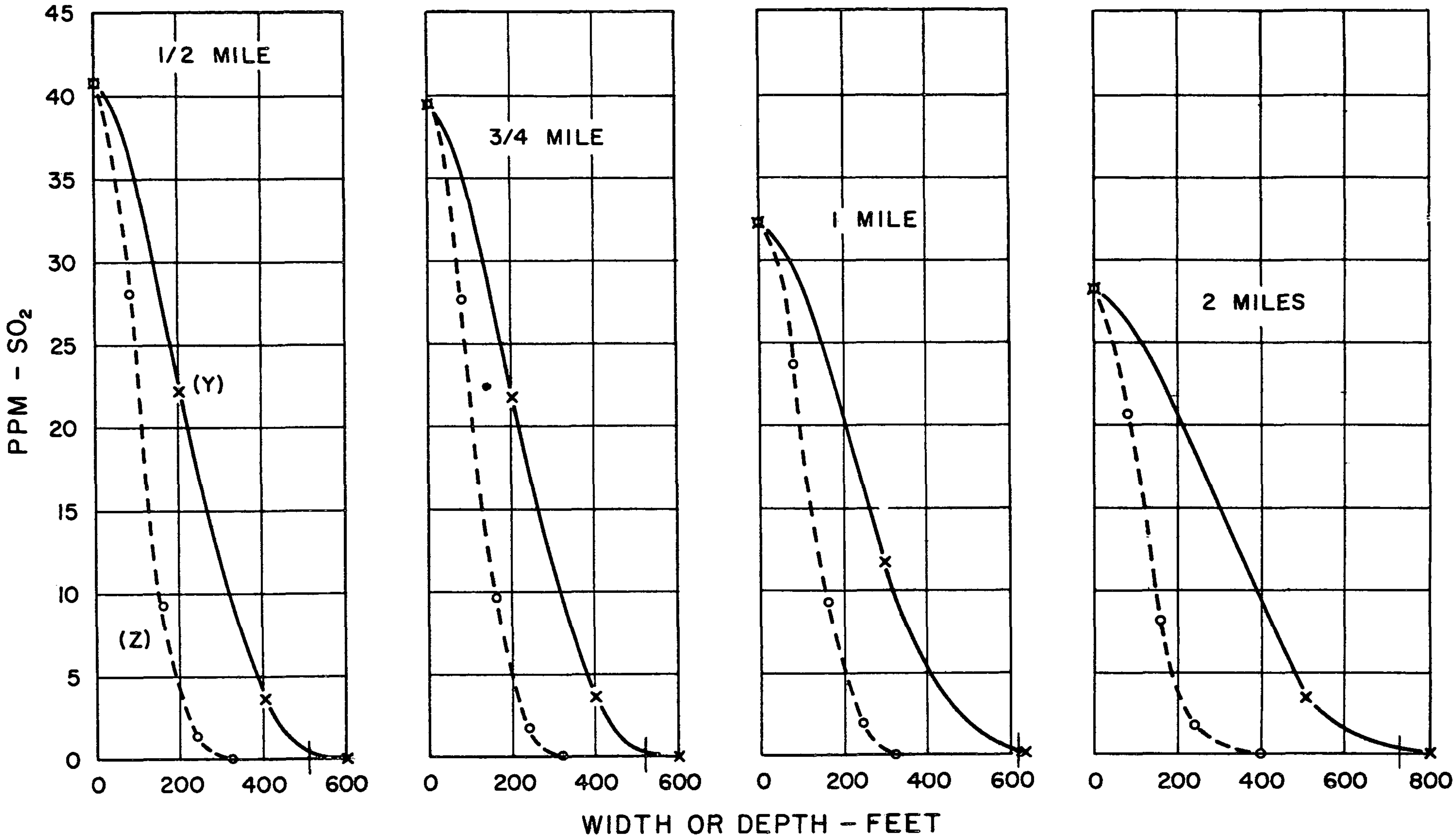


Figure 13. CALCULATED SO_2 DISTRIBUTION ALONG Y AND Z AXES, DAY 2

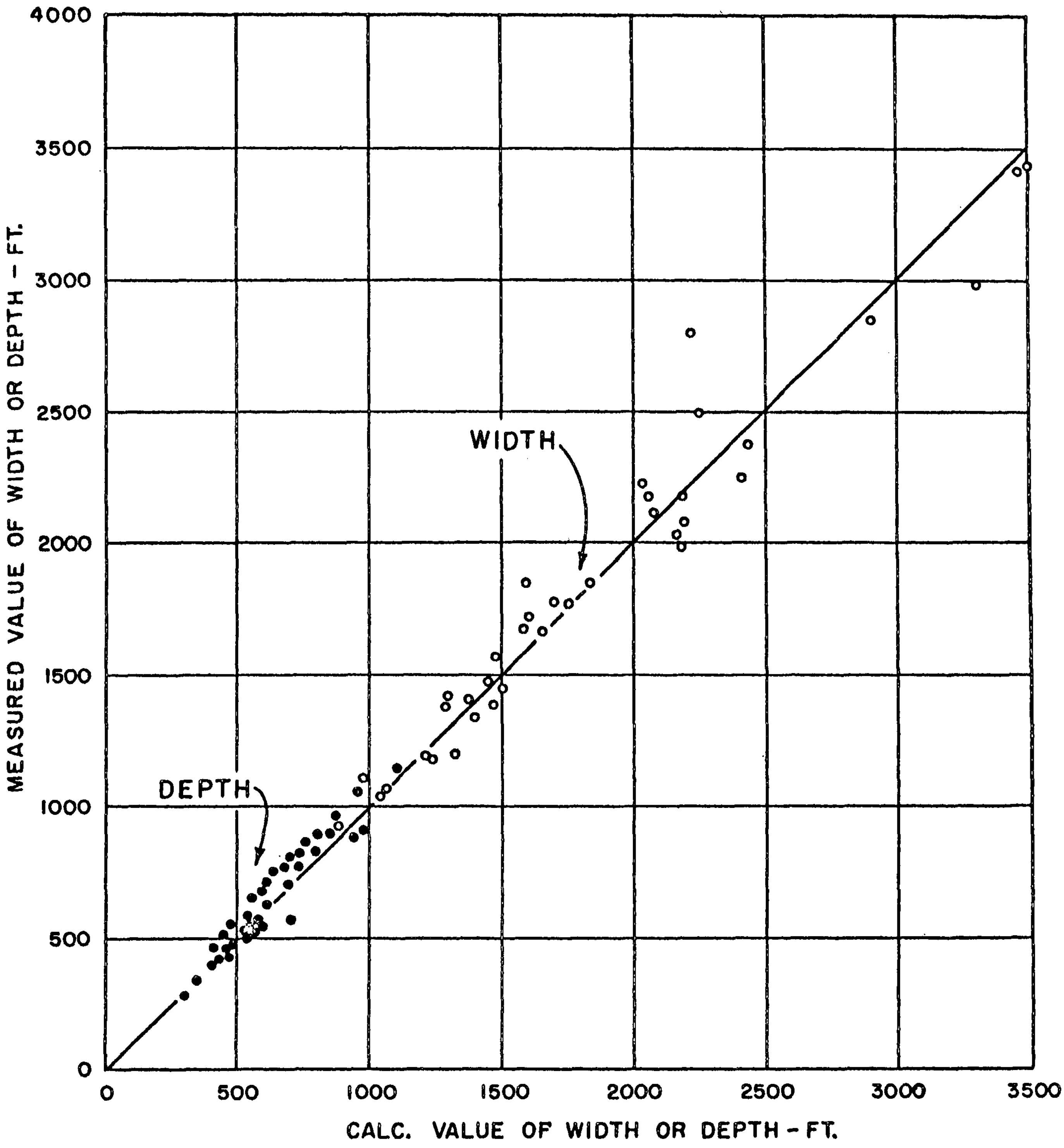


Figure 14. RELATION - MEASURED AND CALCULATED PLUME WIDTH AND DEPTH

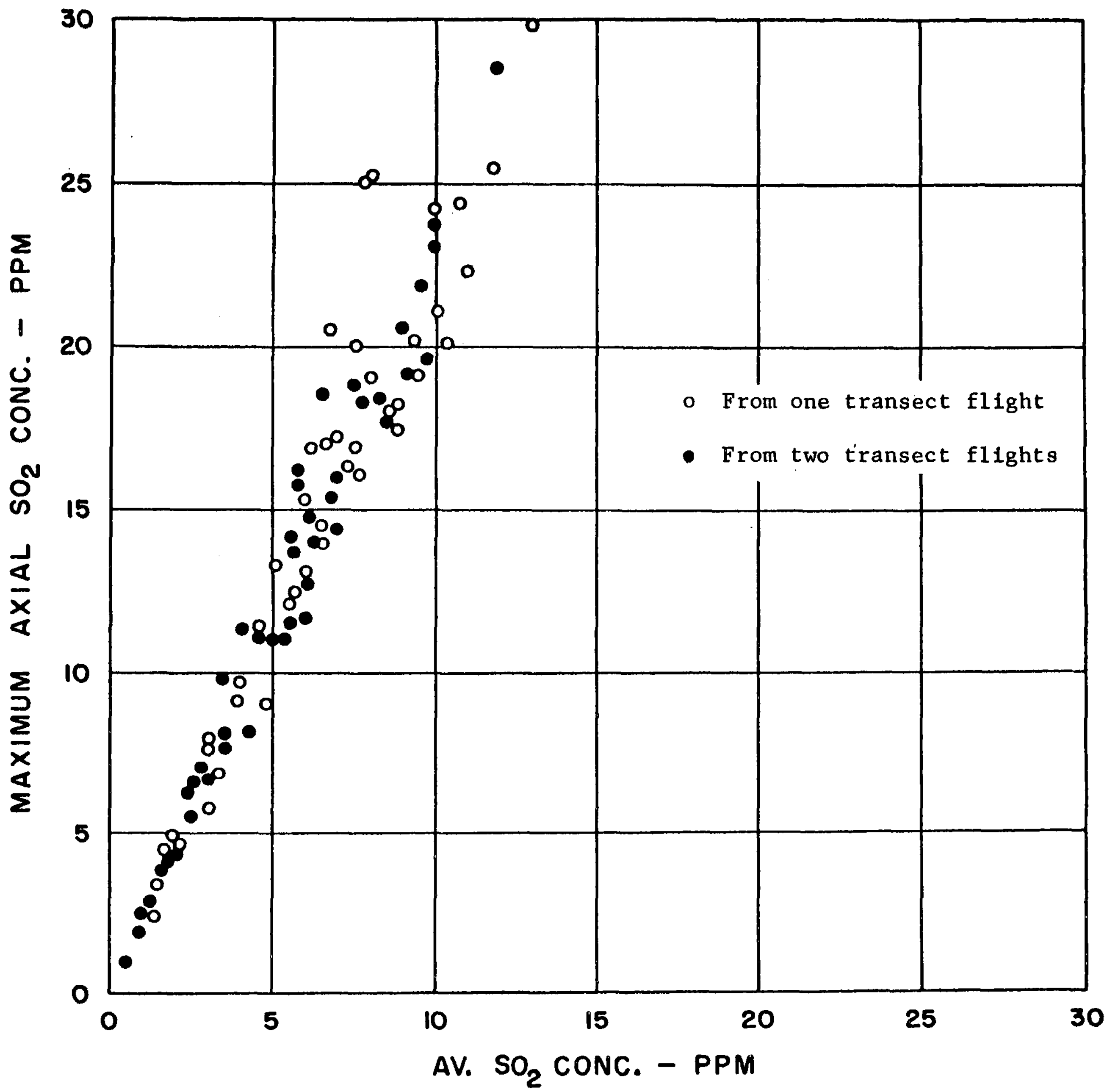


Figure 15. RELATION - MAXIMUM AXIAL CONCENTRATION TO AVERAGE CONCENTRATION ALONG PLUME AXES (AS MEASURED)

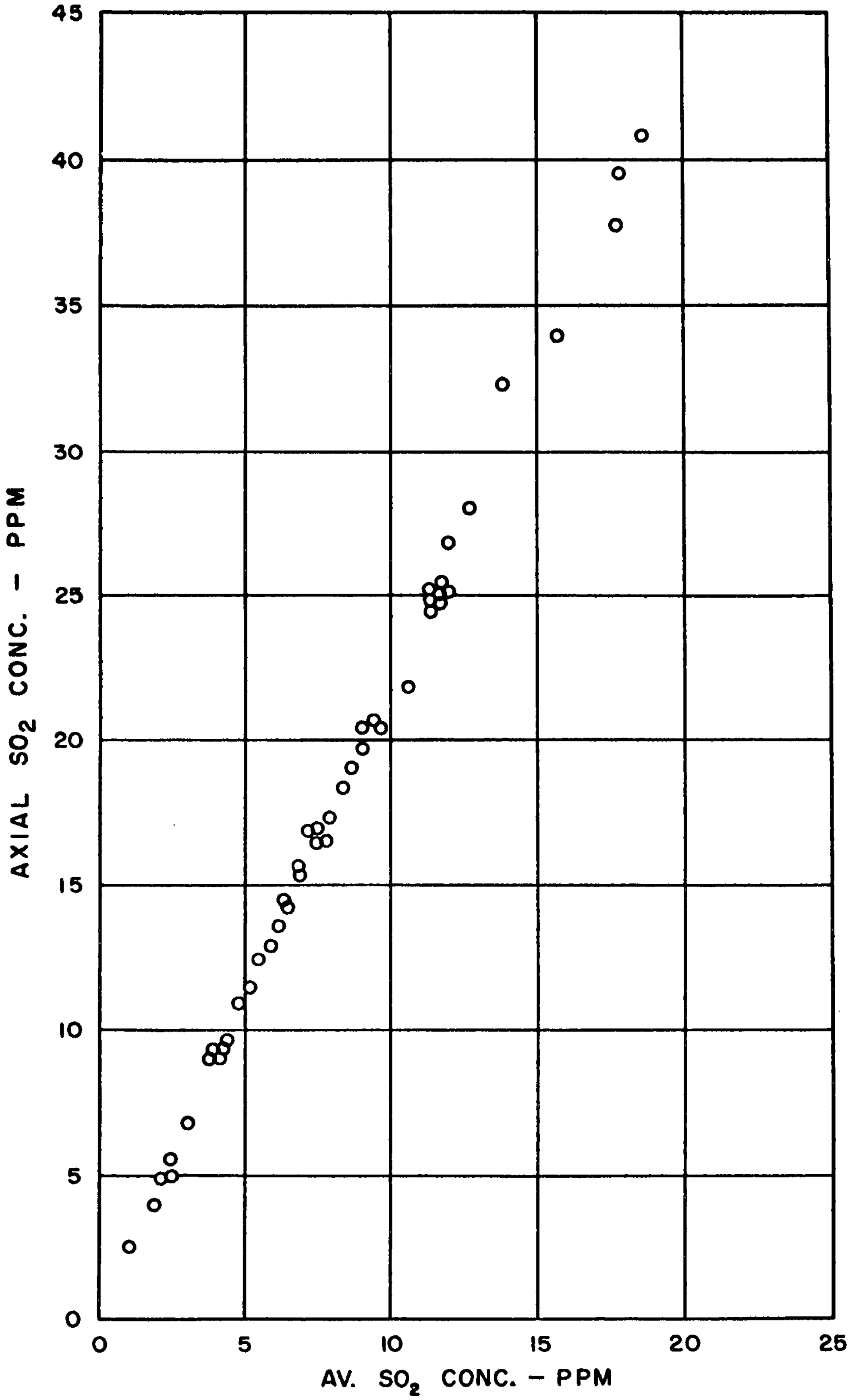


Figure 16. RELATION - CALCULATED AXIAL AND AVERAGE CONCENTRATIONS

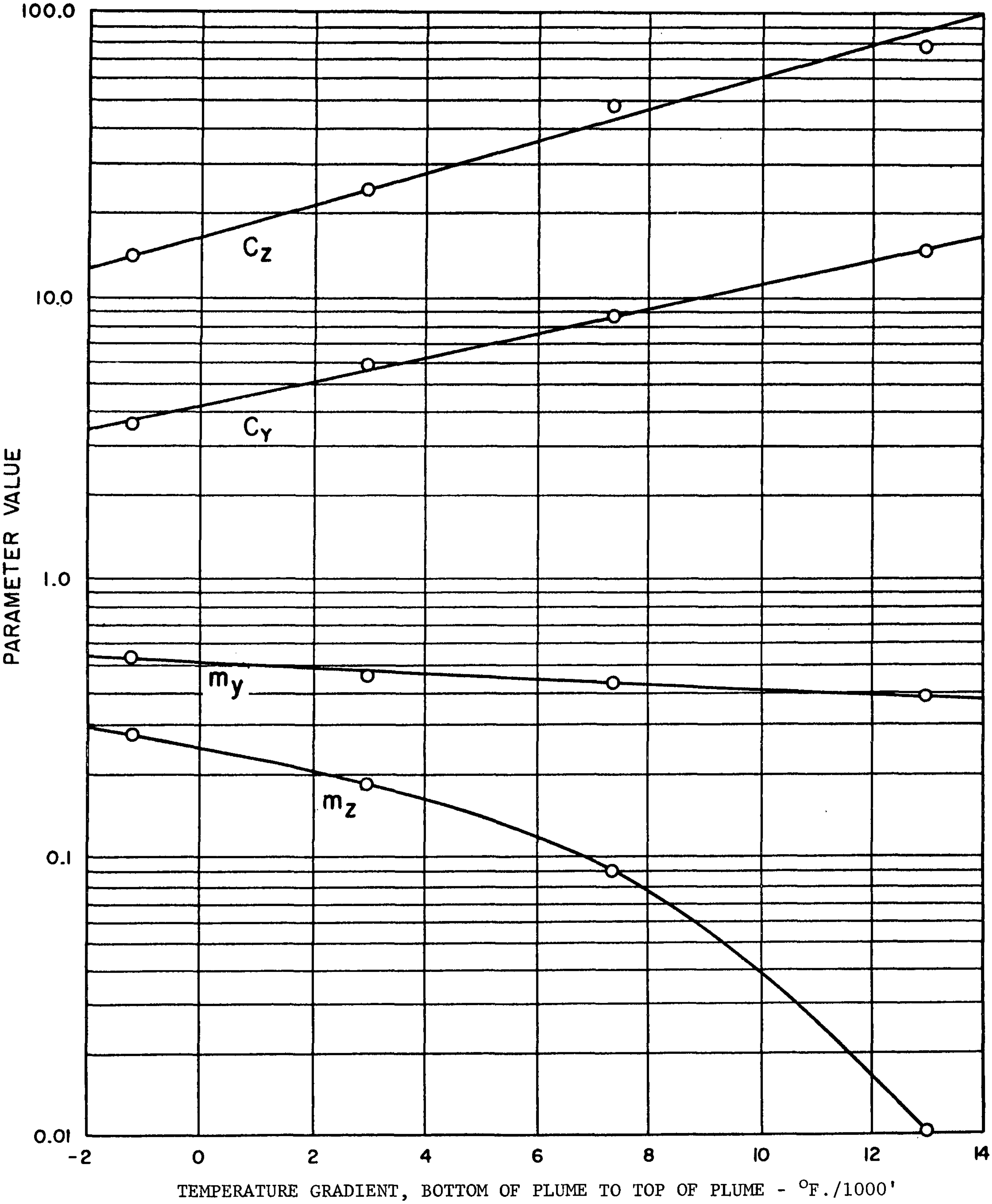


Figure 17. RELATION - m_y, m_z, C_y, AND C_z TO TEMPERATURE GRADIENT (LINE SOURCE)

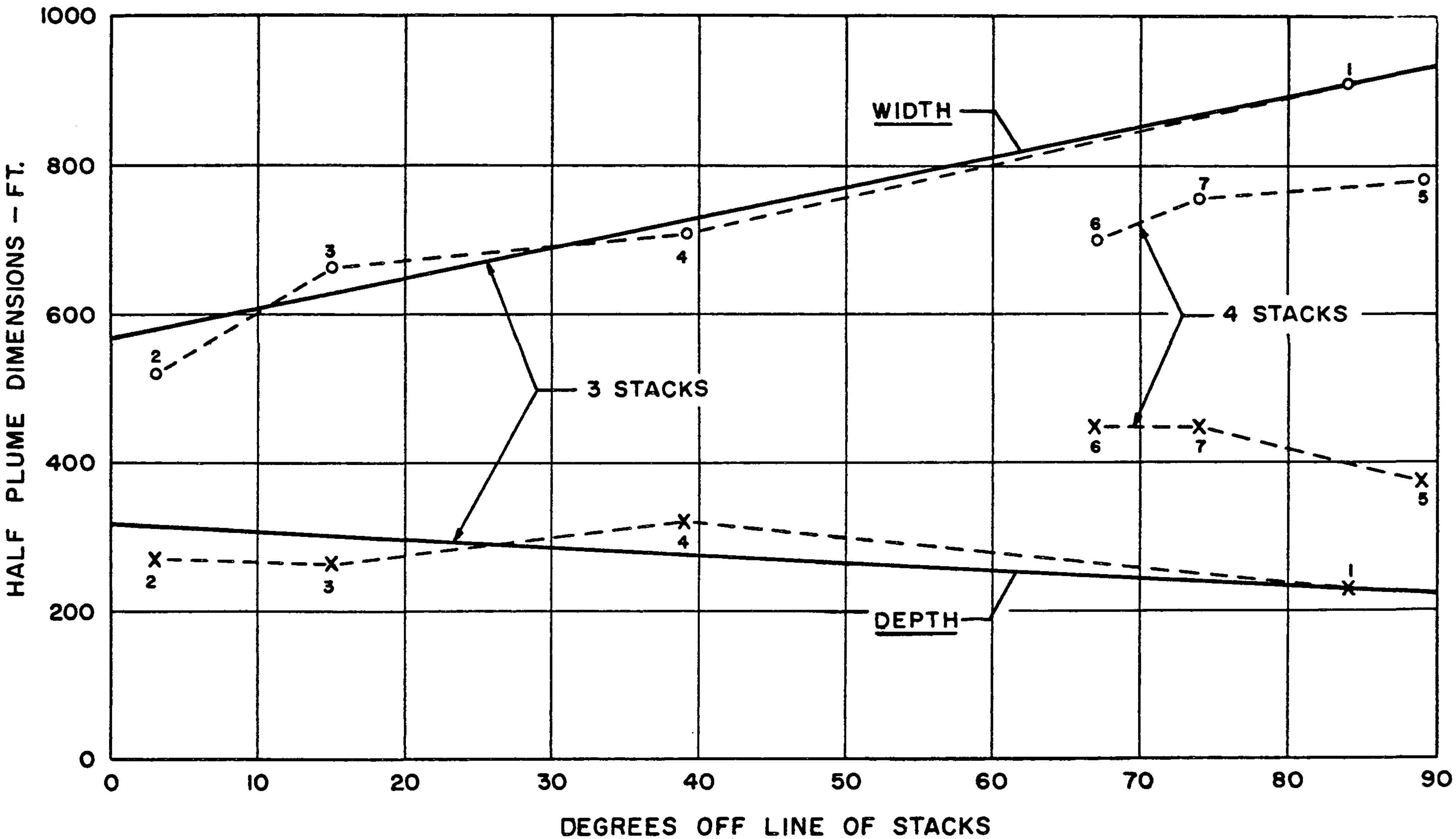


Figure 18. RELATION - PLUME WIDTH AND DEPTH TO WIND DIRECTION AND STACK ALIGNMENT

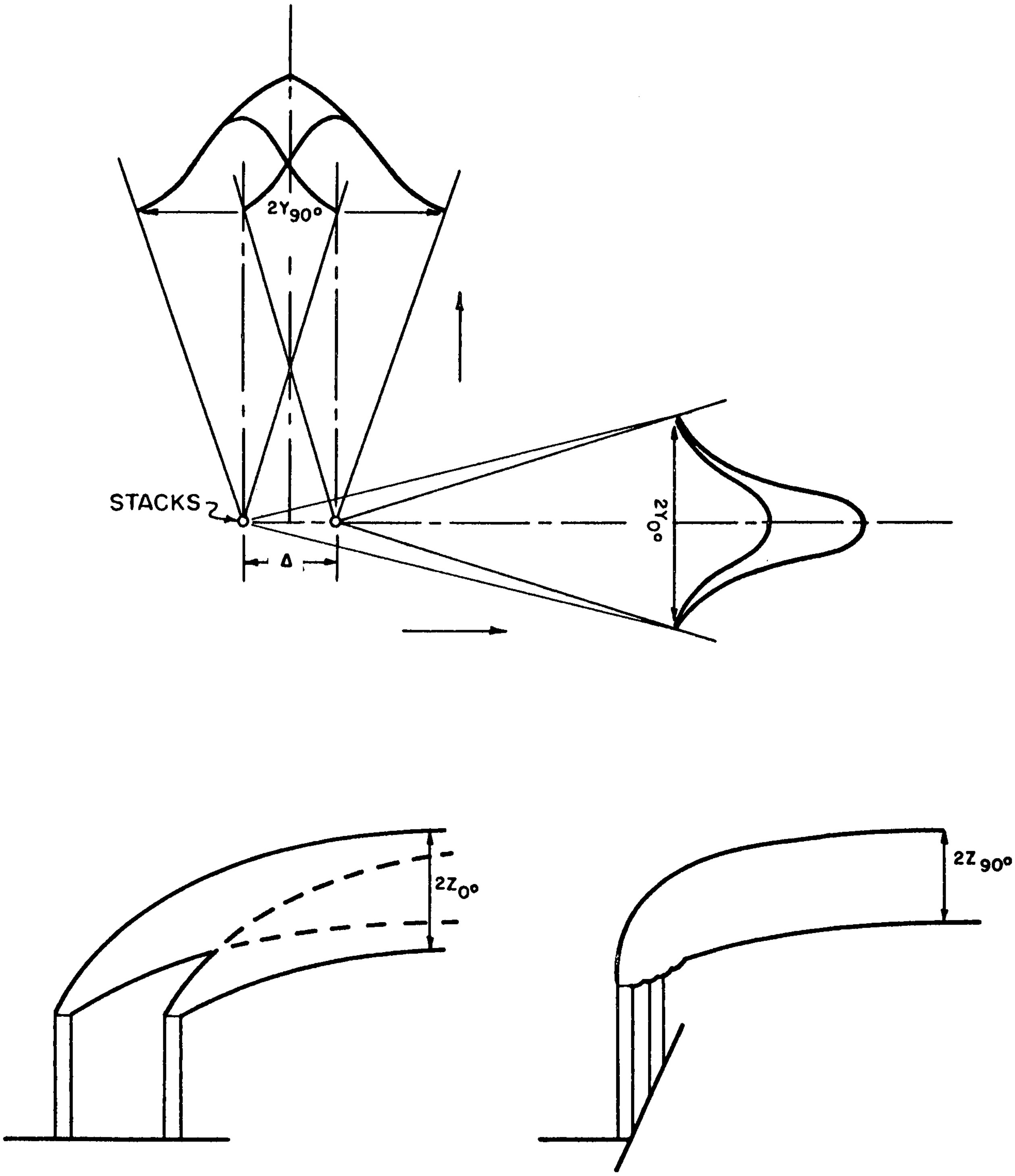


Figure 19. RELATION - PLUME WIDTH AND DEPTH TO WIND DIRECTION (FROM TWO OR MORE STACKS)

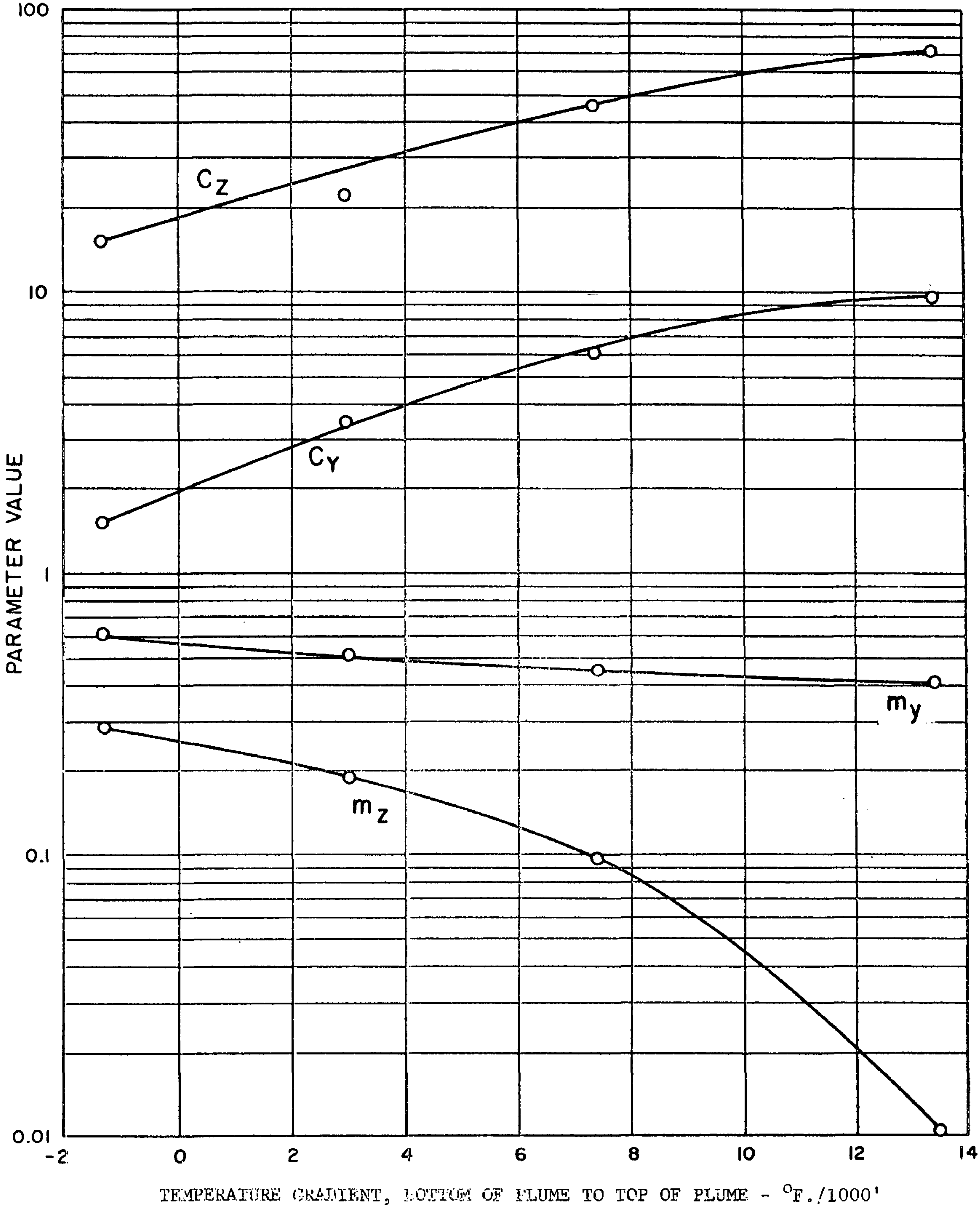
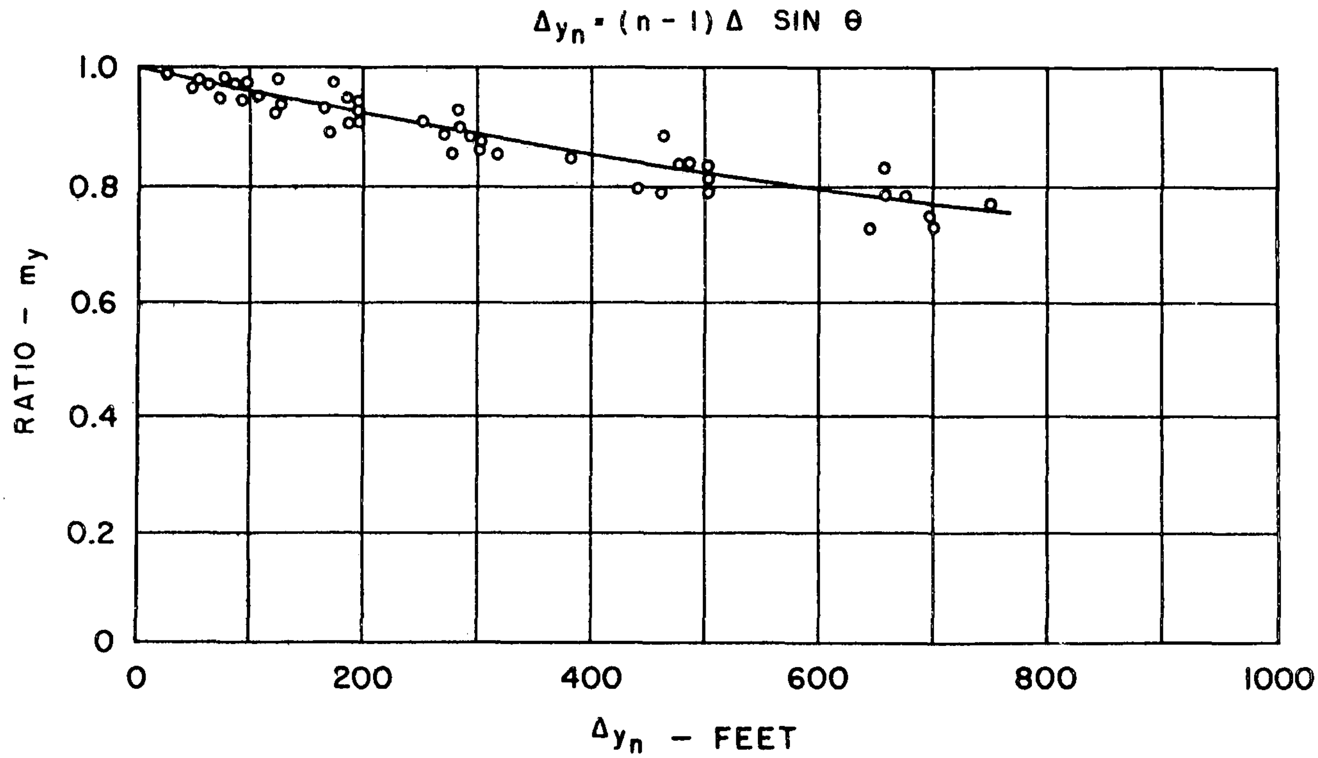
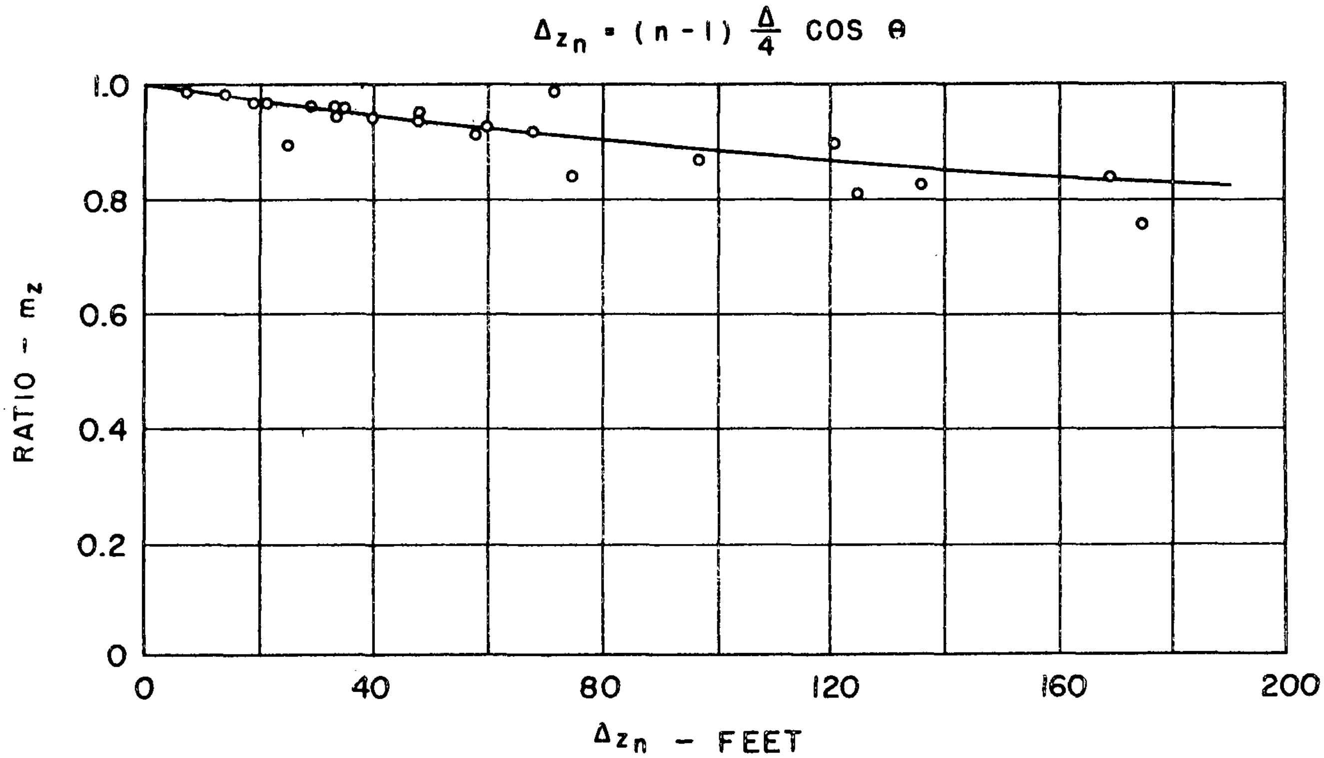


Figure 20. BEST ESTIMATE m_y, m_z, C_y, C_z - POINT SOURCE

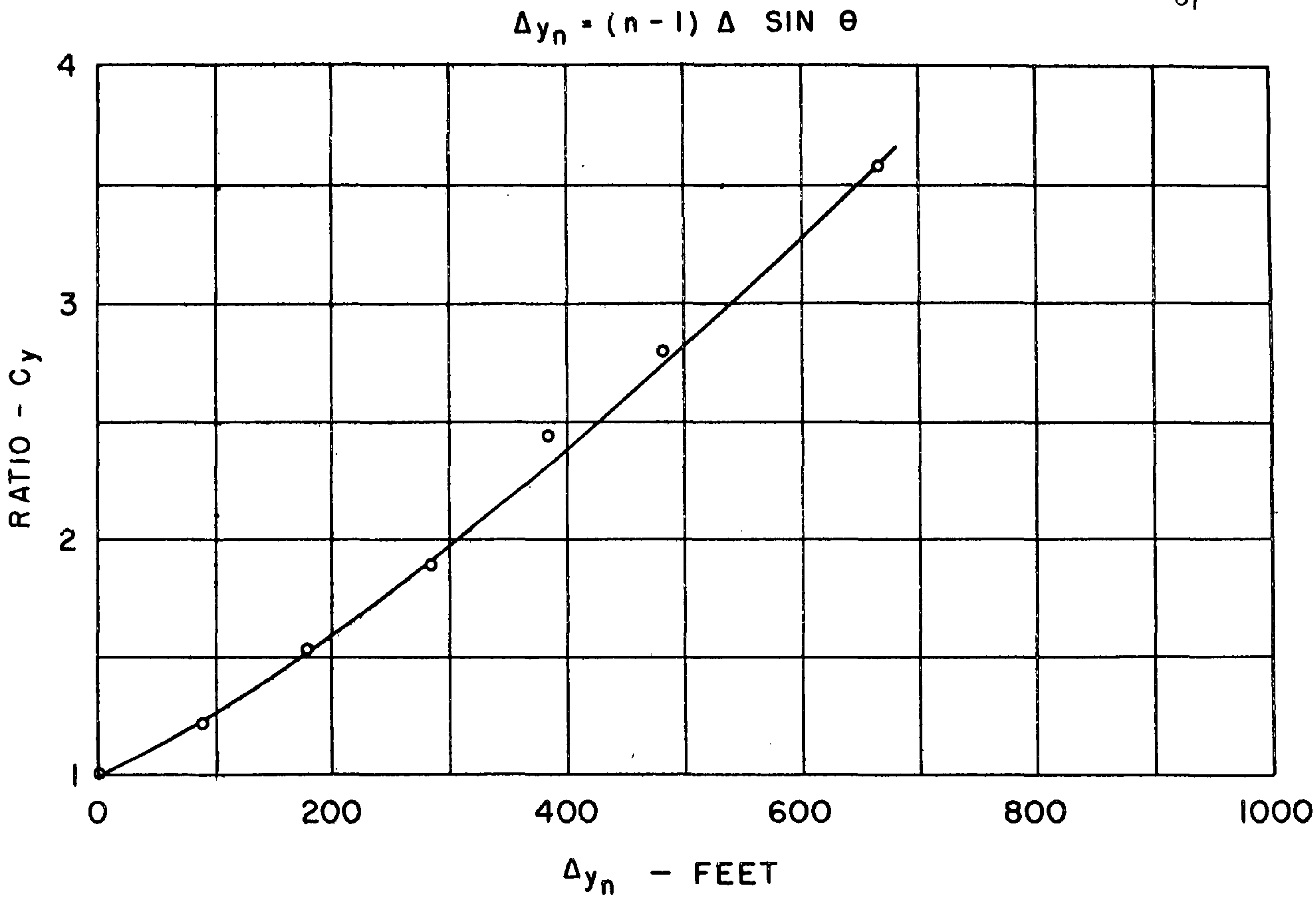


RELATION - RATIO OF m_y TO Δy_n

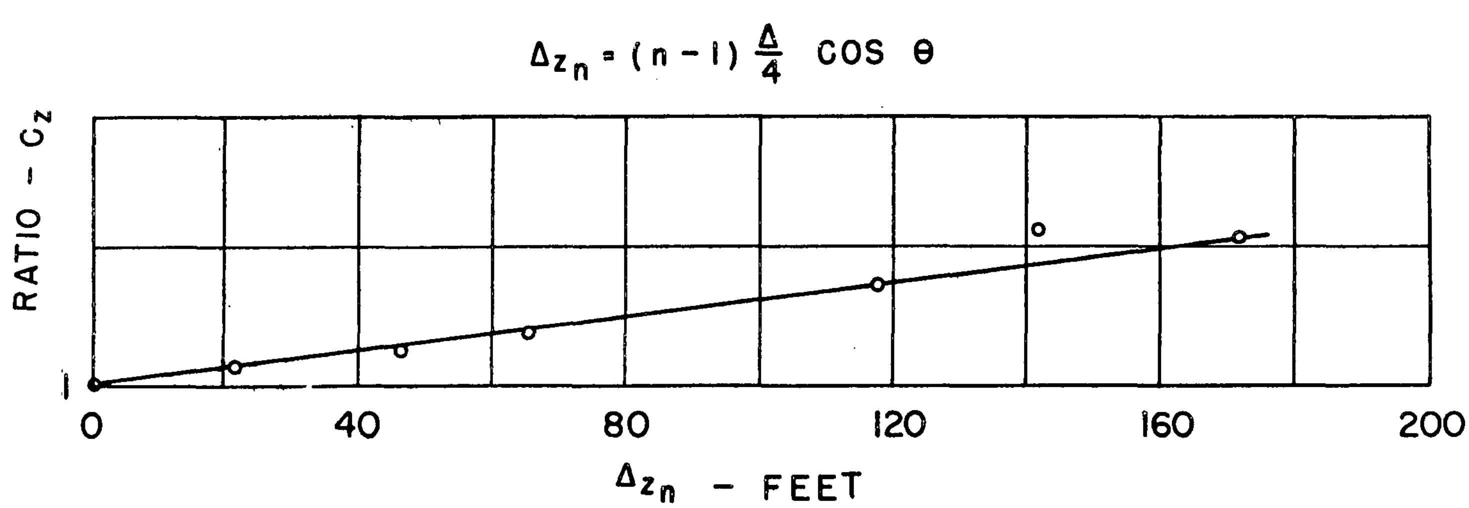


RELATION - RATIO OF m_z TO Δz_n

Figure 21



RELATION - RATIO OF C_y TO Δ_{y_n}



RELATION - RATIO OF C_z TO Δ_{z_n}

Figure 22

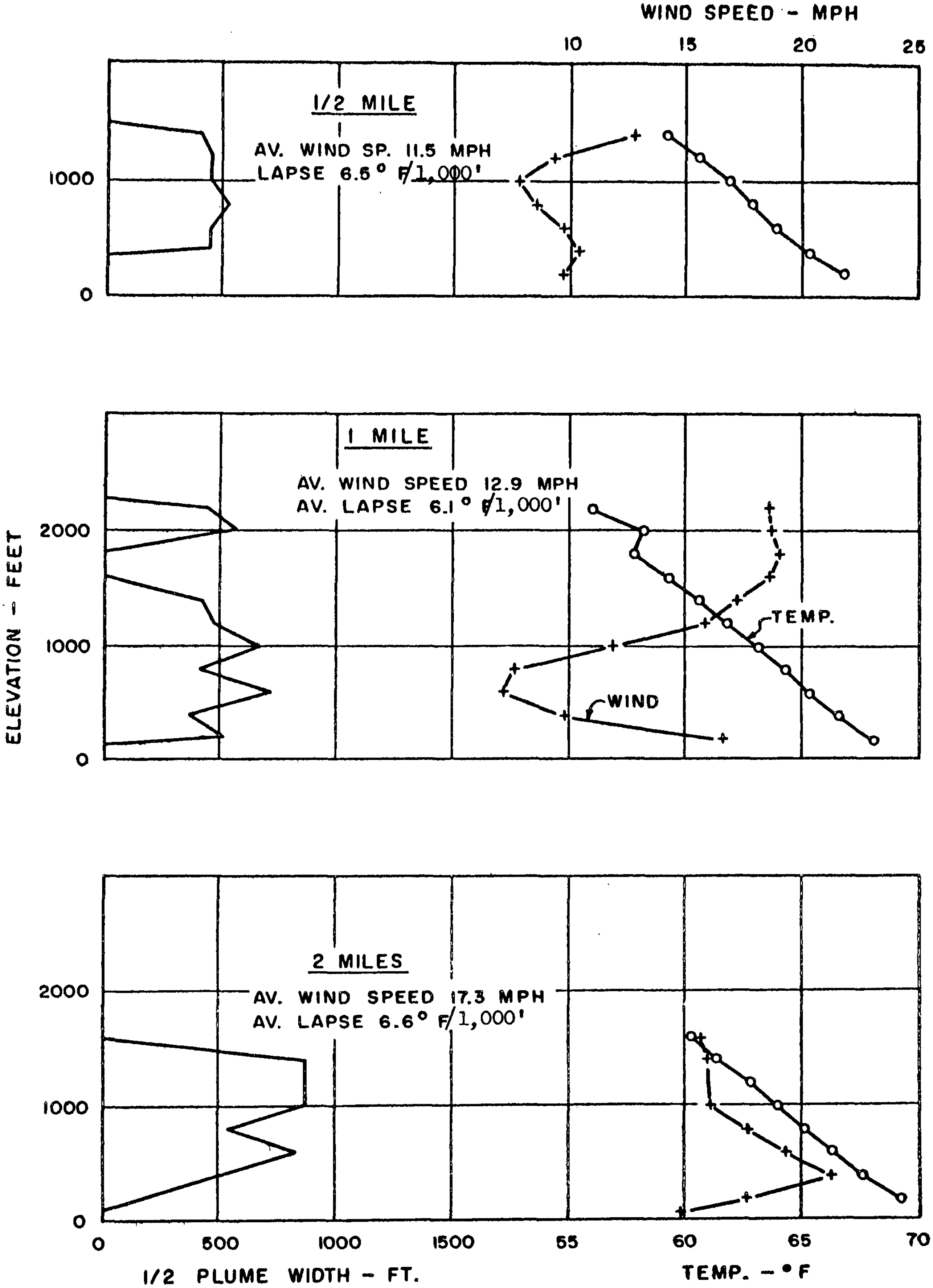


Figure 23. PLUME CROSS SECTION, TEMPERATURE PROFILE, AND WIND SPEED PROFILE, DAY 7

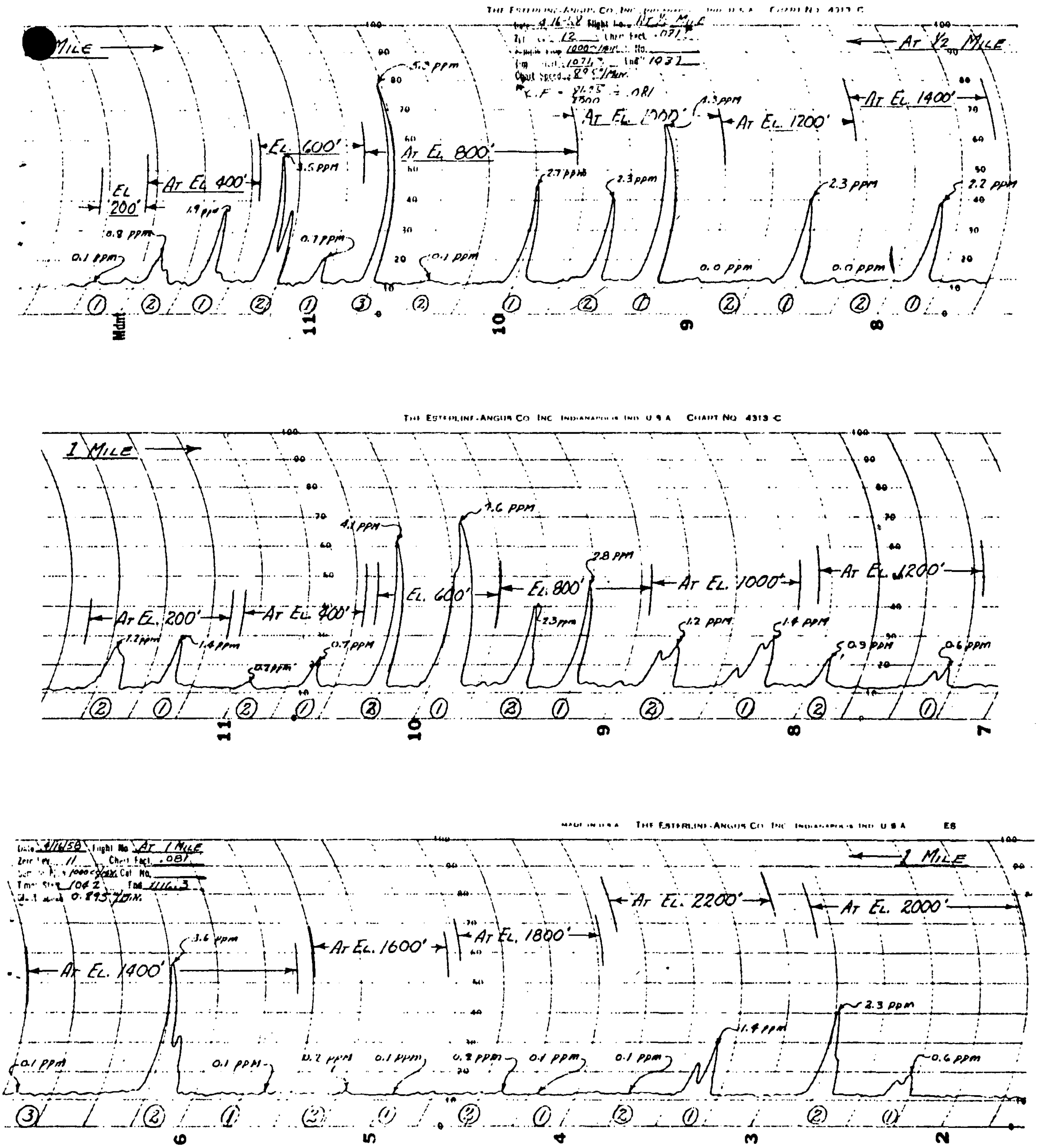
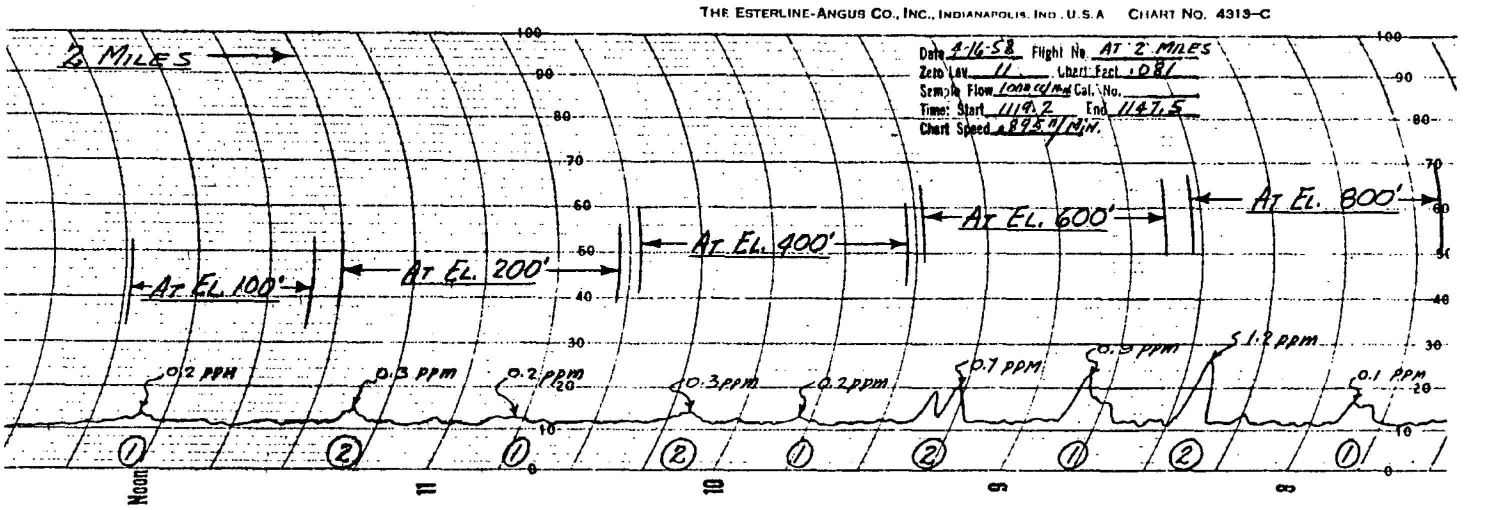


Figure 24. TITRILOG CHARTS ILLUSTRATING SO_2 DISTRIBUTION, DAY 7



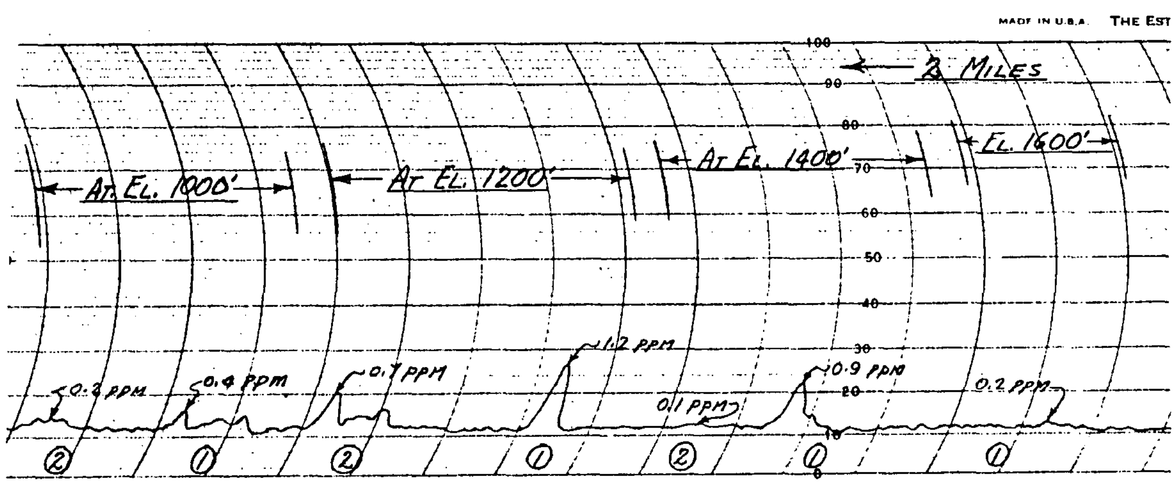


Figure 24. TITRILOG CHARTS ILLUSTRATING SO_2 DISTRIBUTION, DAY 7

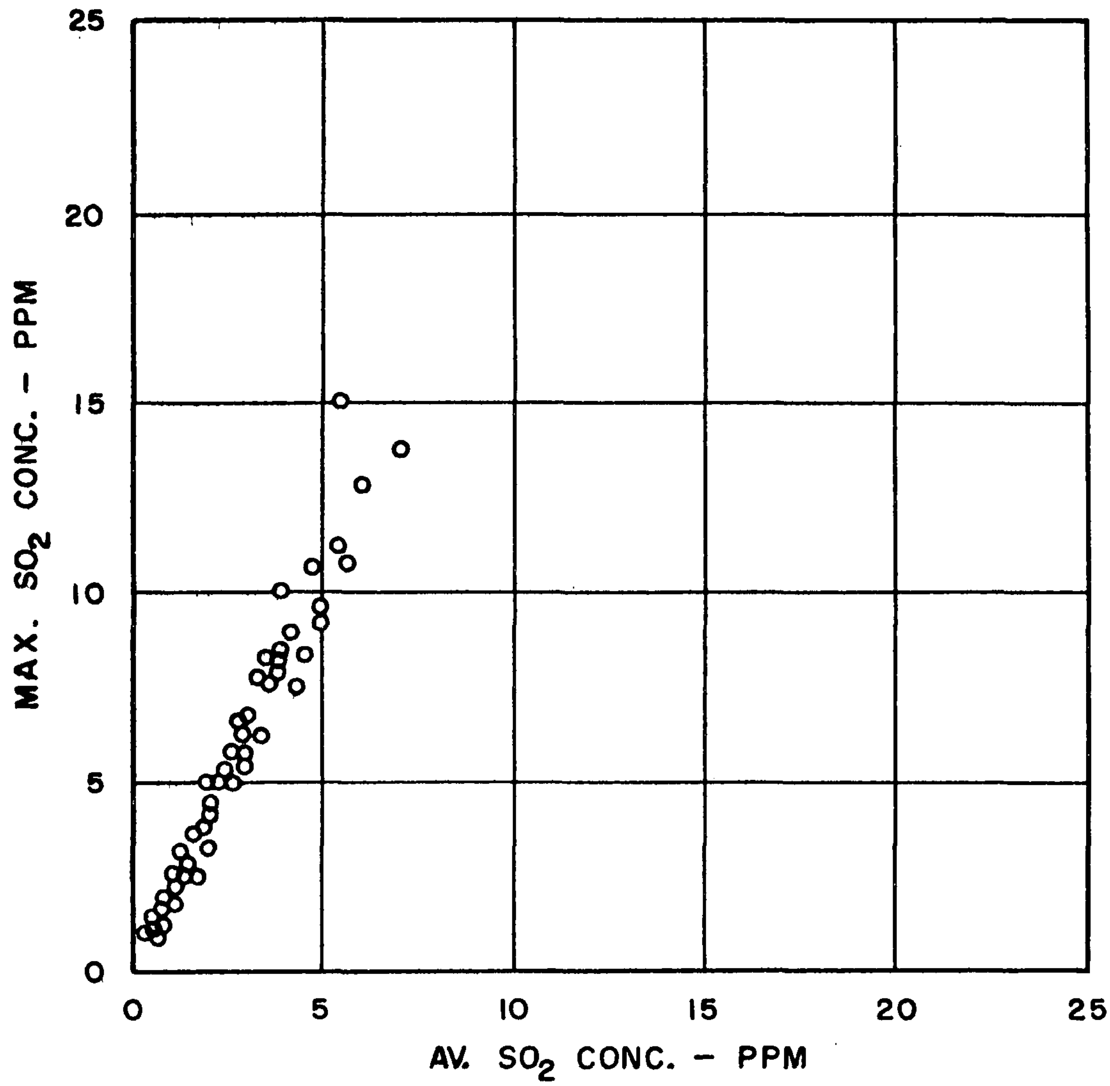


Figure 25. RELATION - MAXIMUM TO AVERAGE SO_2 CONCENTRATION

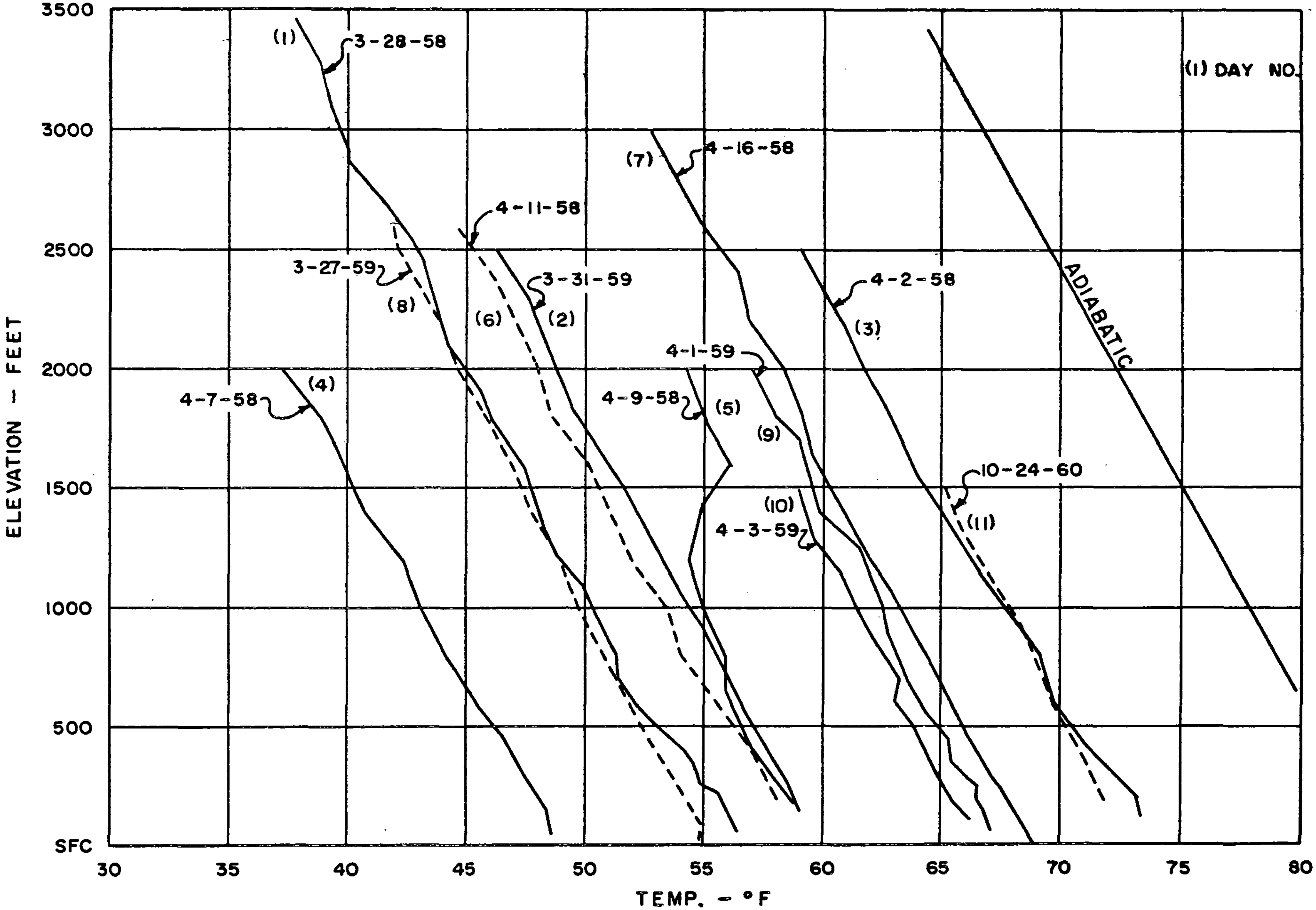


Figure 26. AVERAGE CHANGE OF TEMPERATURE WITH ELEVATION - EACH SAMPLING PERIOD

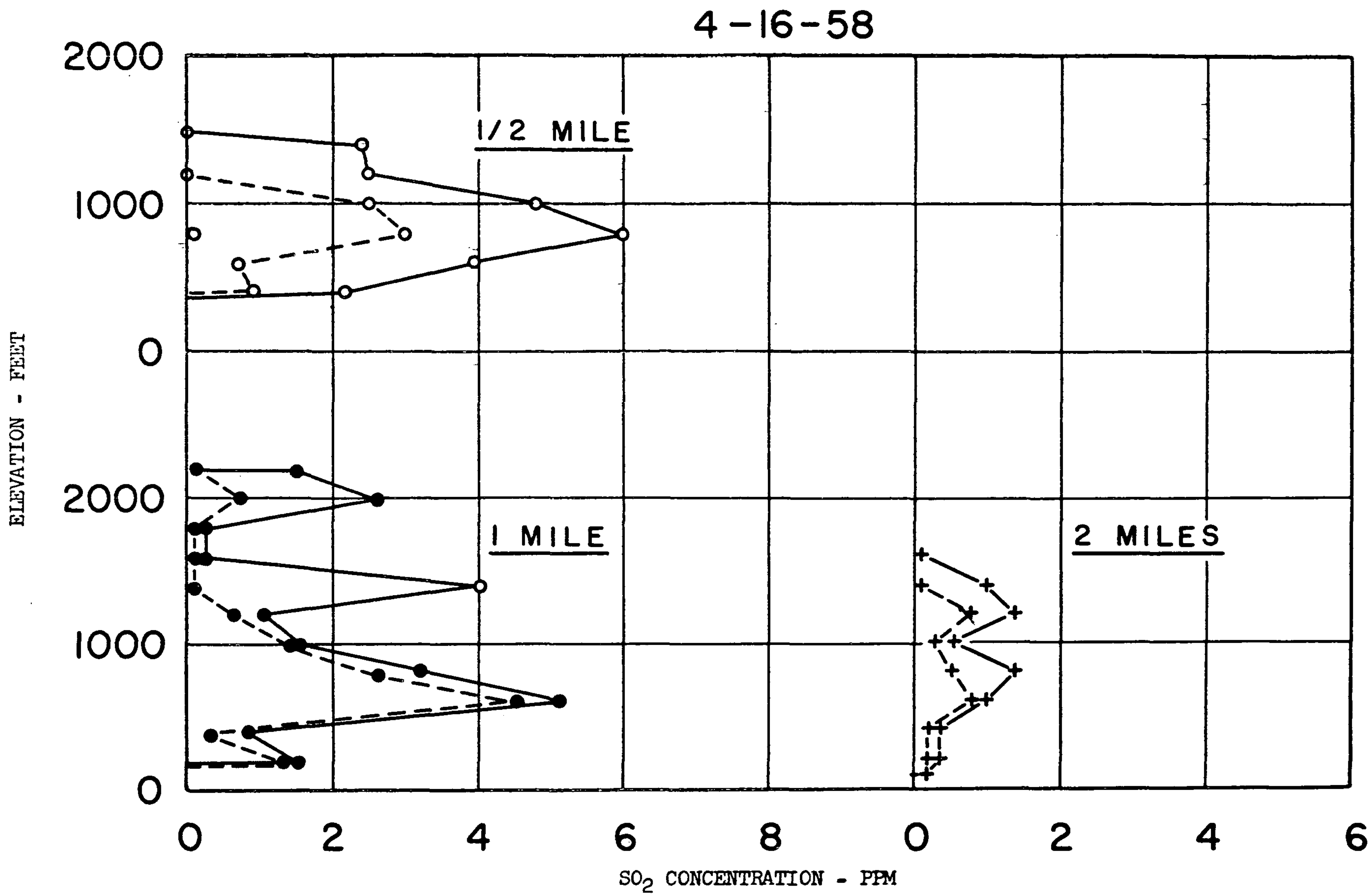


Figure 27. PROFILE OF SO_2 ALONG Z AXIS, DAY 7

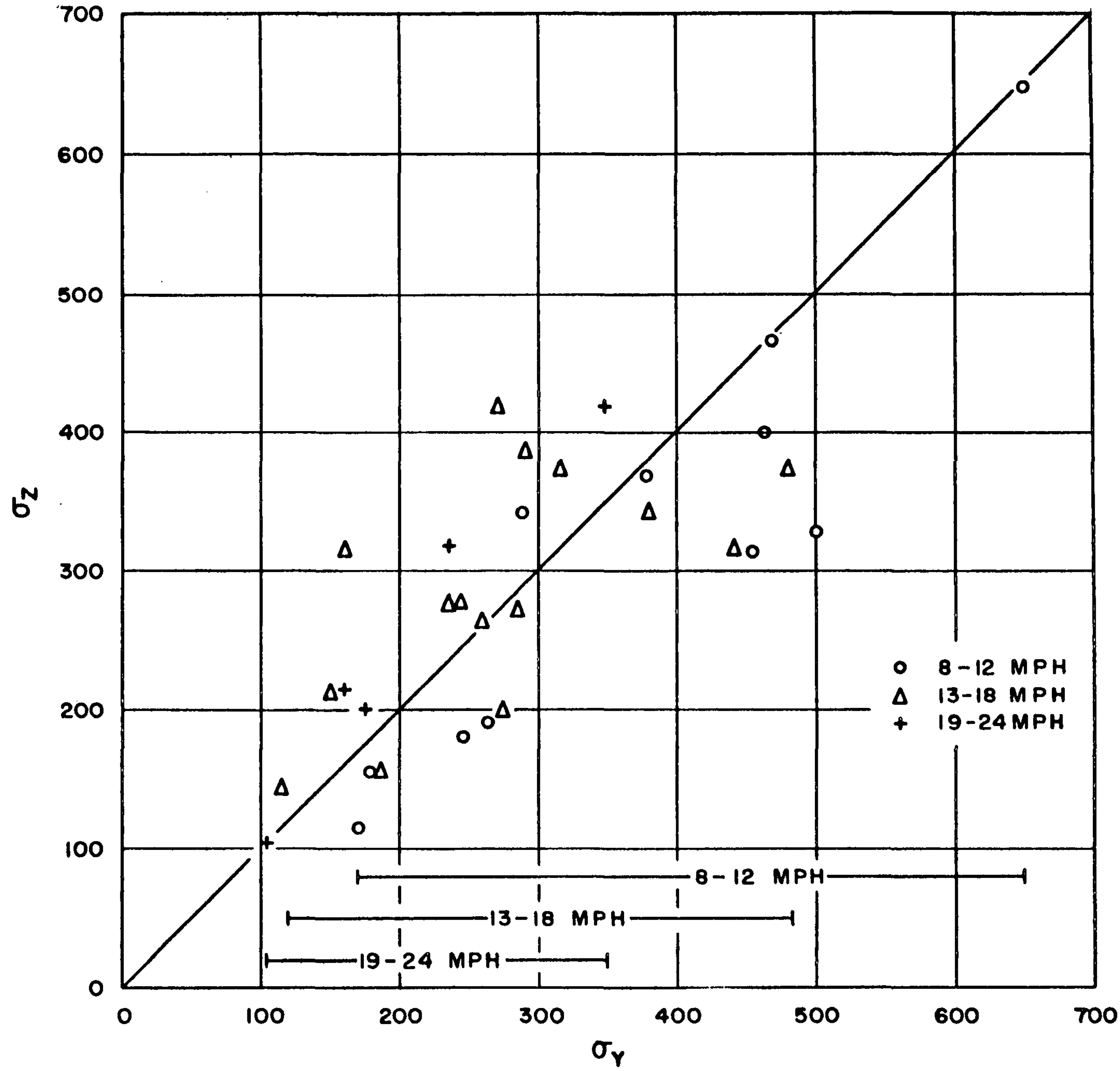


Figure 28. RELATION - σ_y AND σ_z

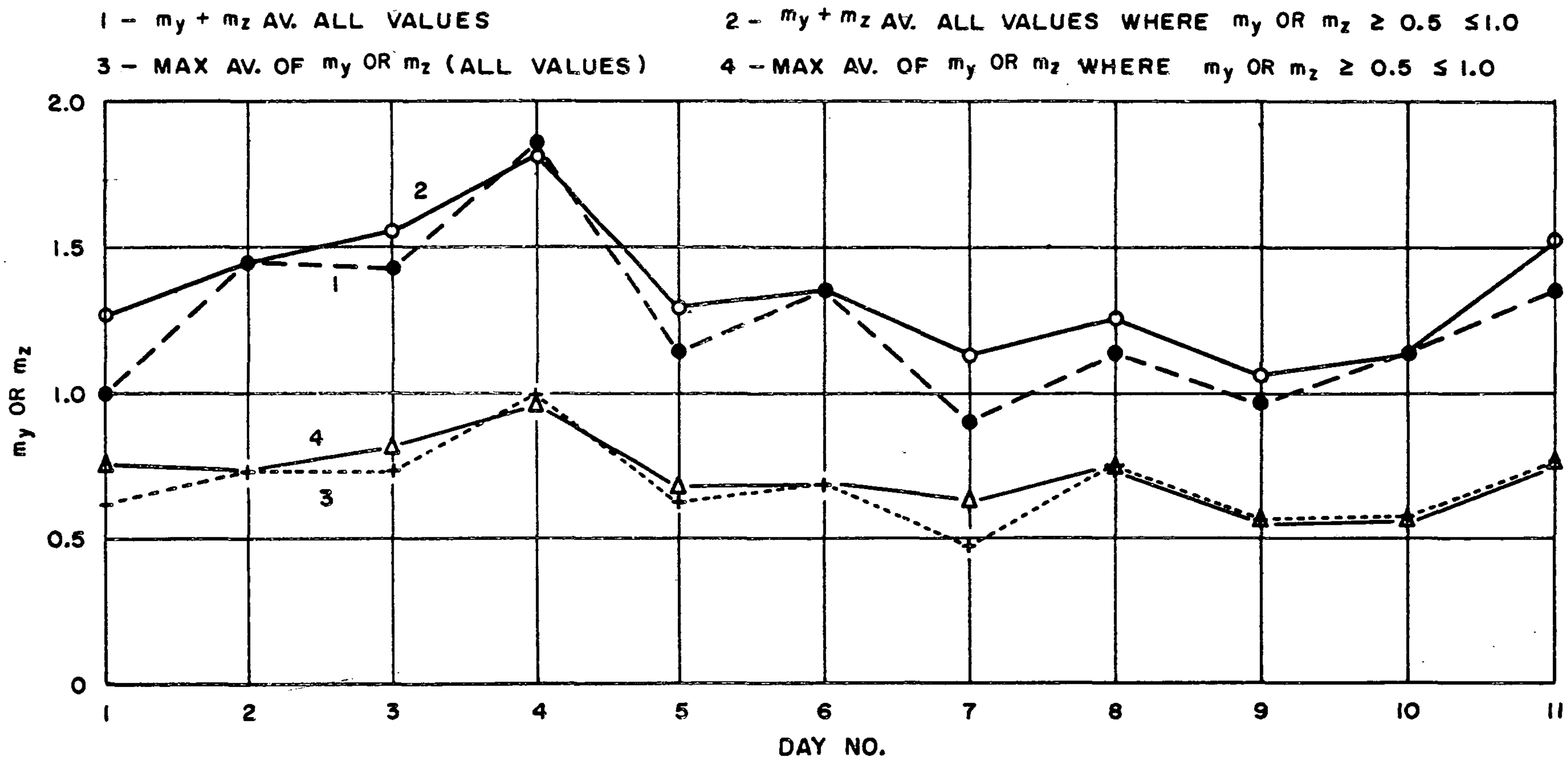


Figure 29. m_y AND m_z - EACH SAMPLING DAY

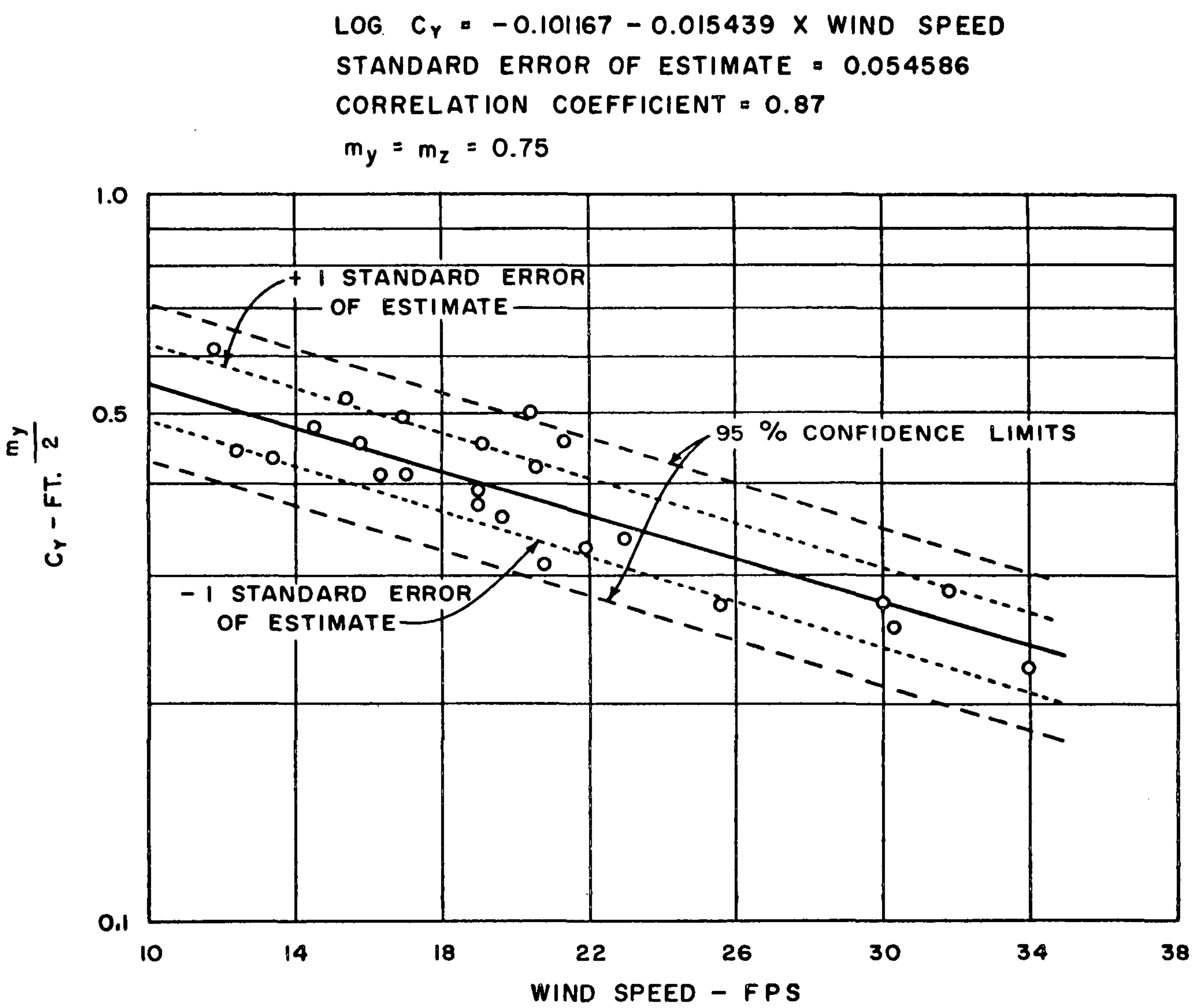


Figure 30. STATISTICAL ANALYSIS - RELATION C_y TO WIND SPEED

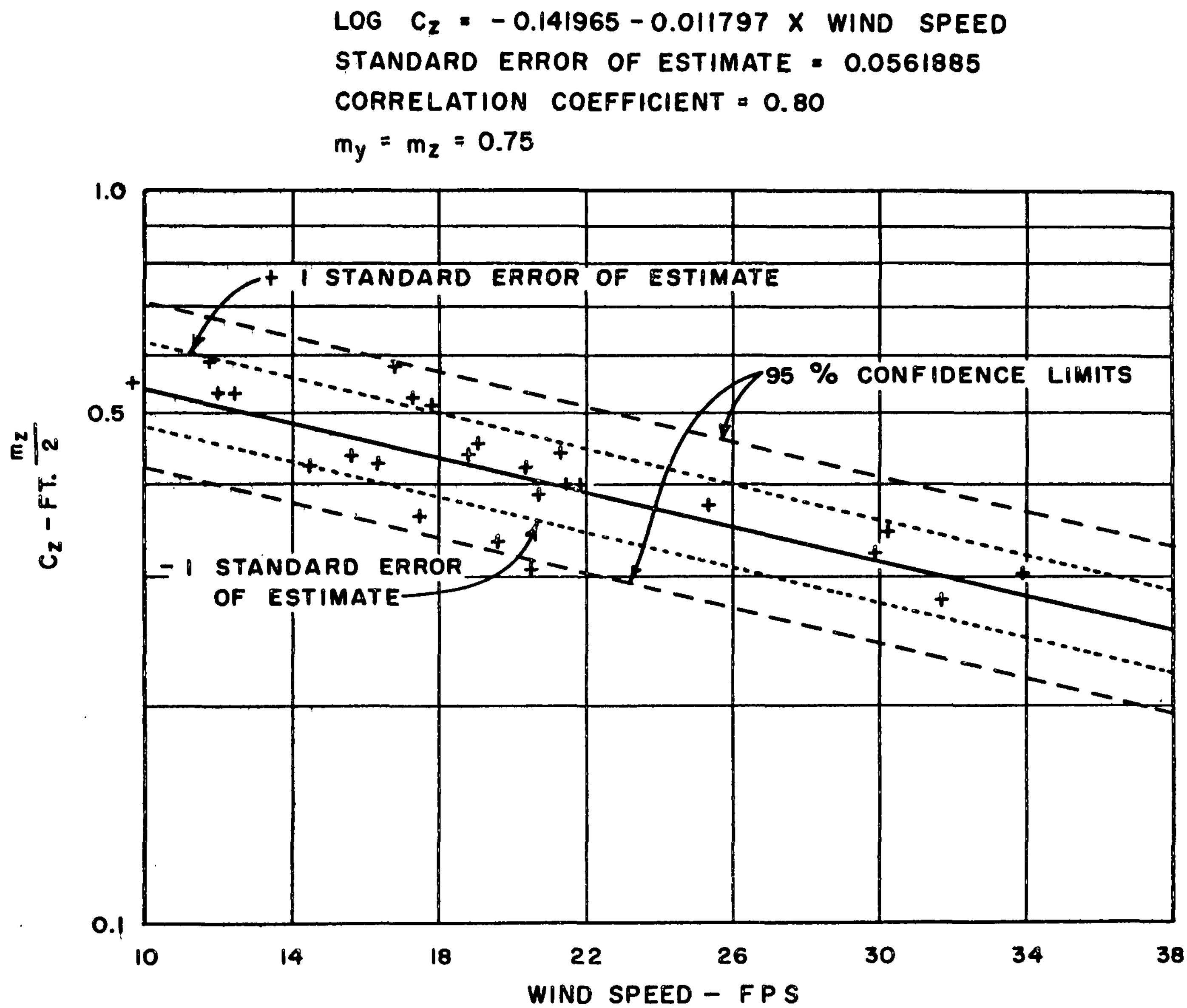


Figure 31. STATISTICAL ANALYSIS - RELATION C_z TO WIND SPEED

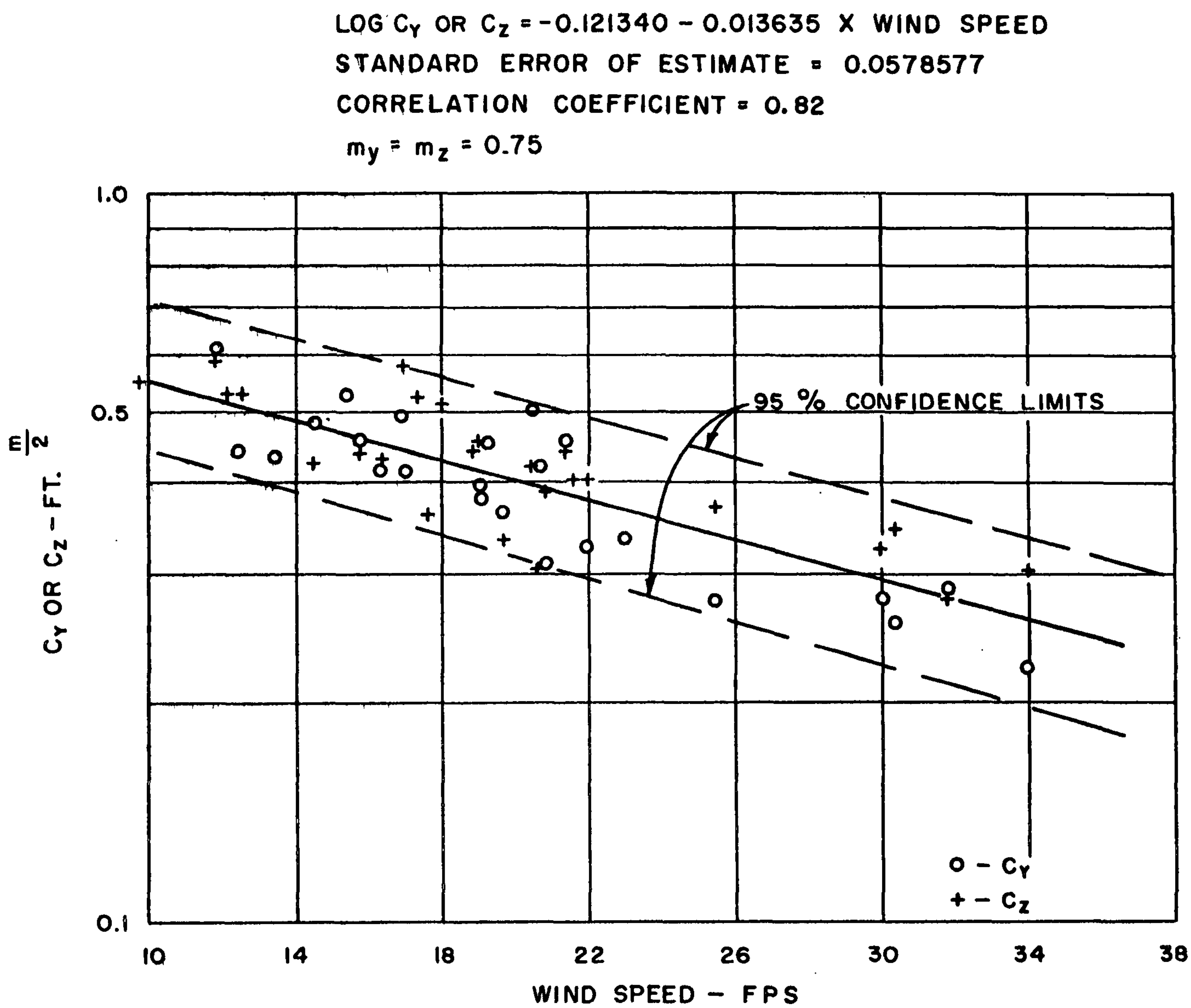


Figure 32. STATISTICAL ANALYSIS - RELATION C_y AND C_z TO WIND SPEED

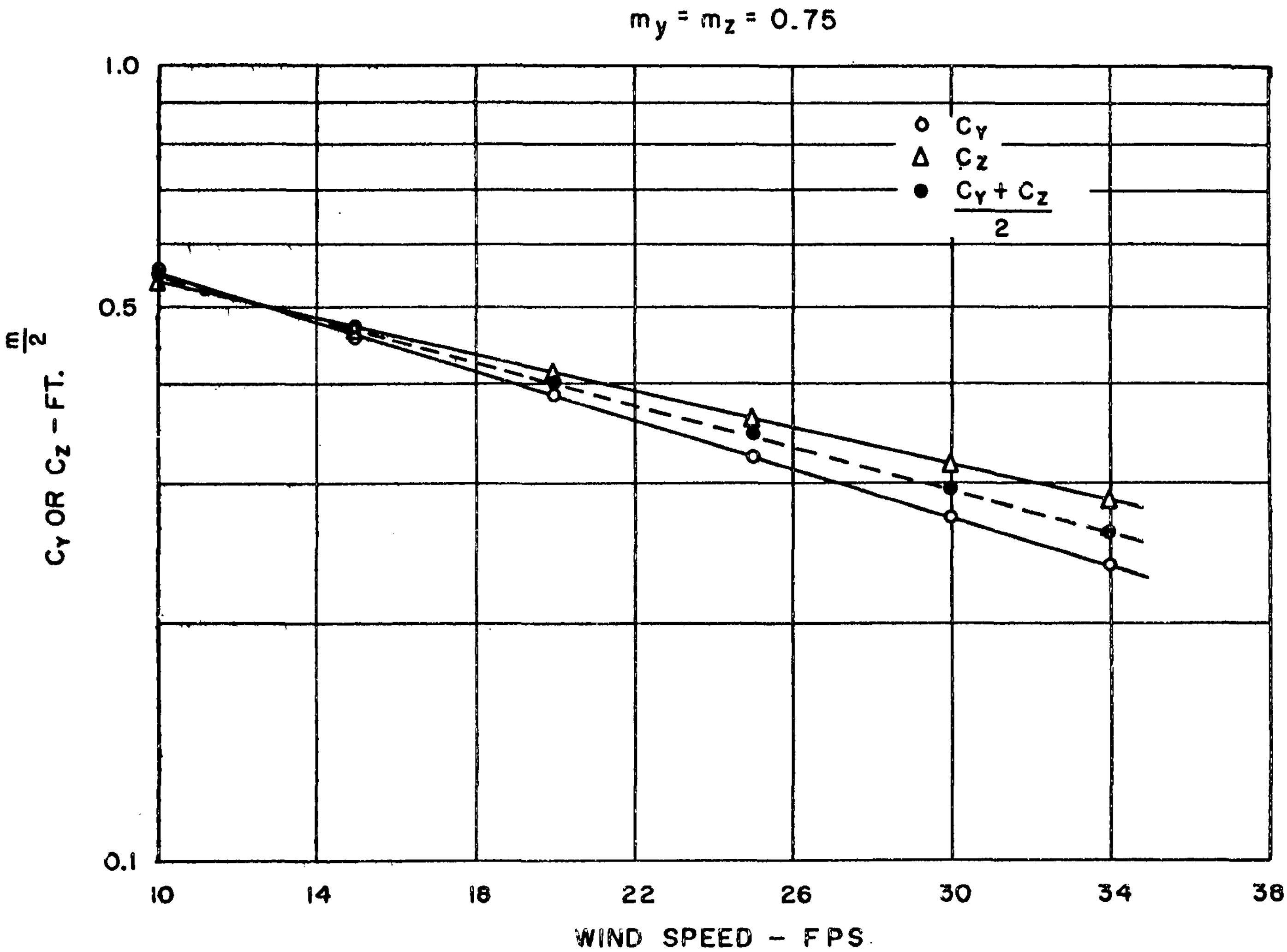


Figure 33. RELATION - C_y, C_z AND AVERAGE C, FT.$^{\frac{m}{2}}$, TO WIND SPEED

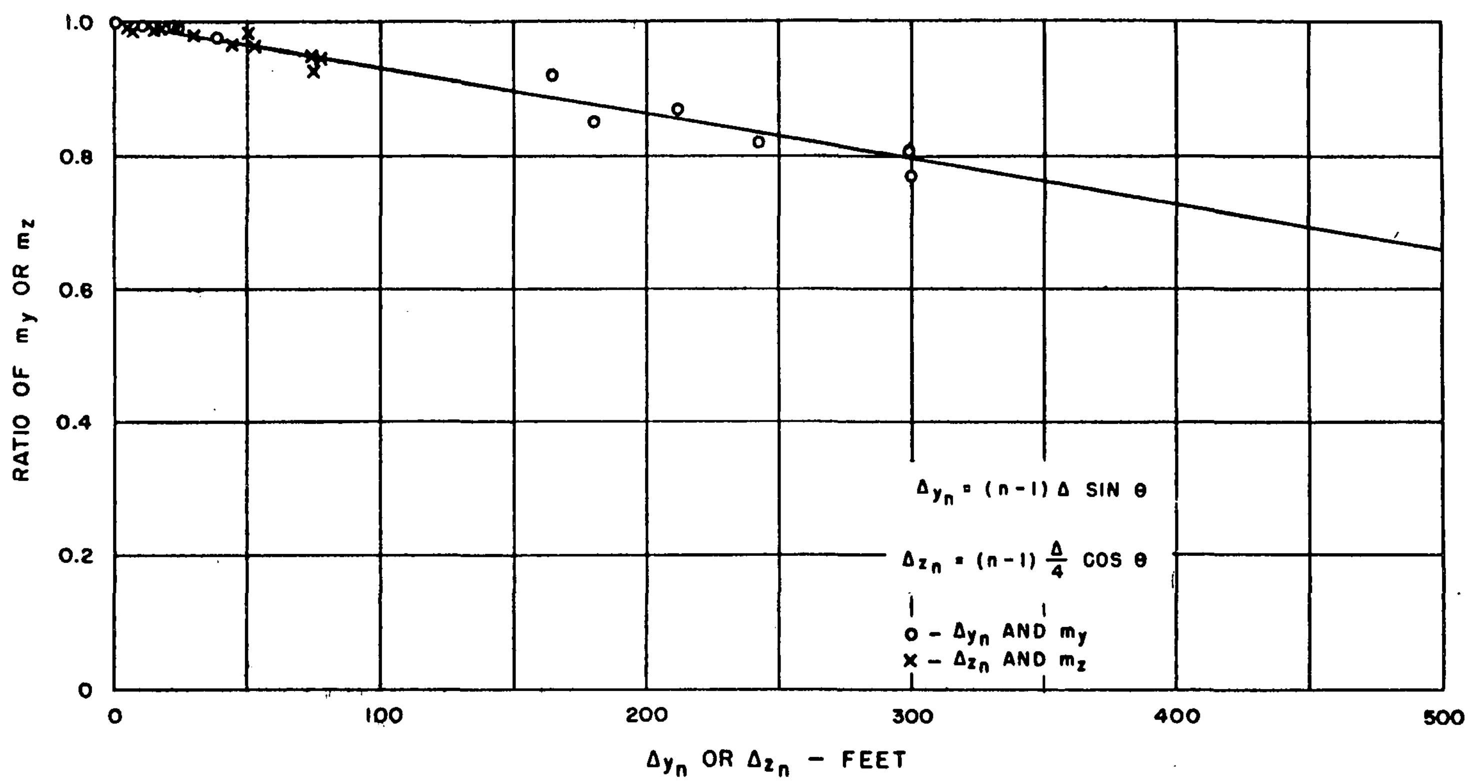


Figure 34. RELATION - RATIO OF m_y AND m_z FOR LINE AND POINT SOURCES TO Δy_n AND Δz_n

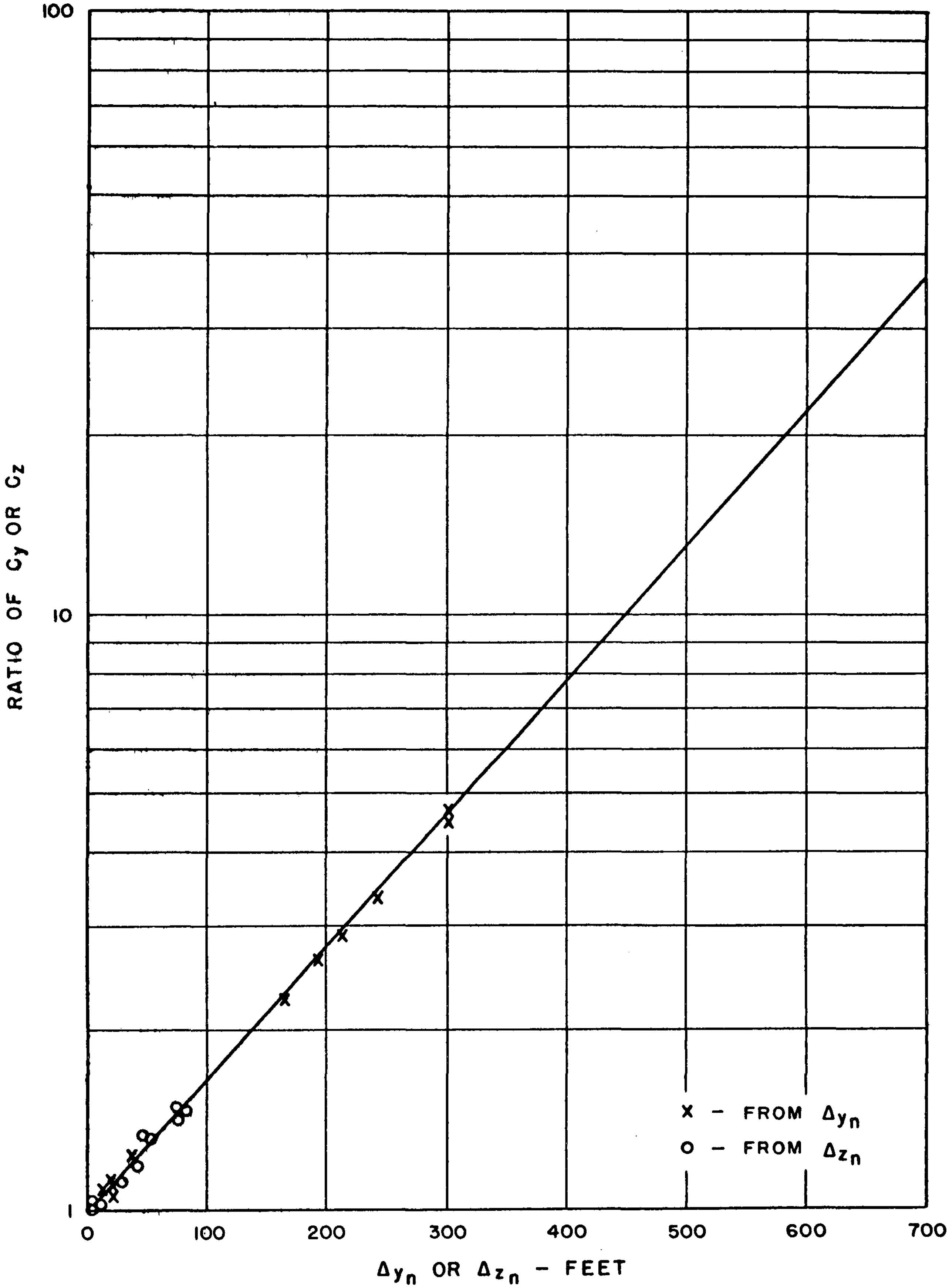


Figure 35. RELATION - RATIO OF C_y AND C_z FOR LINE AND POINT SOURCES TO Δy_n AND Δz_n

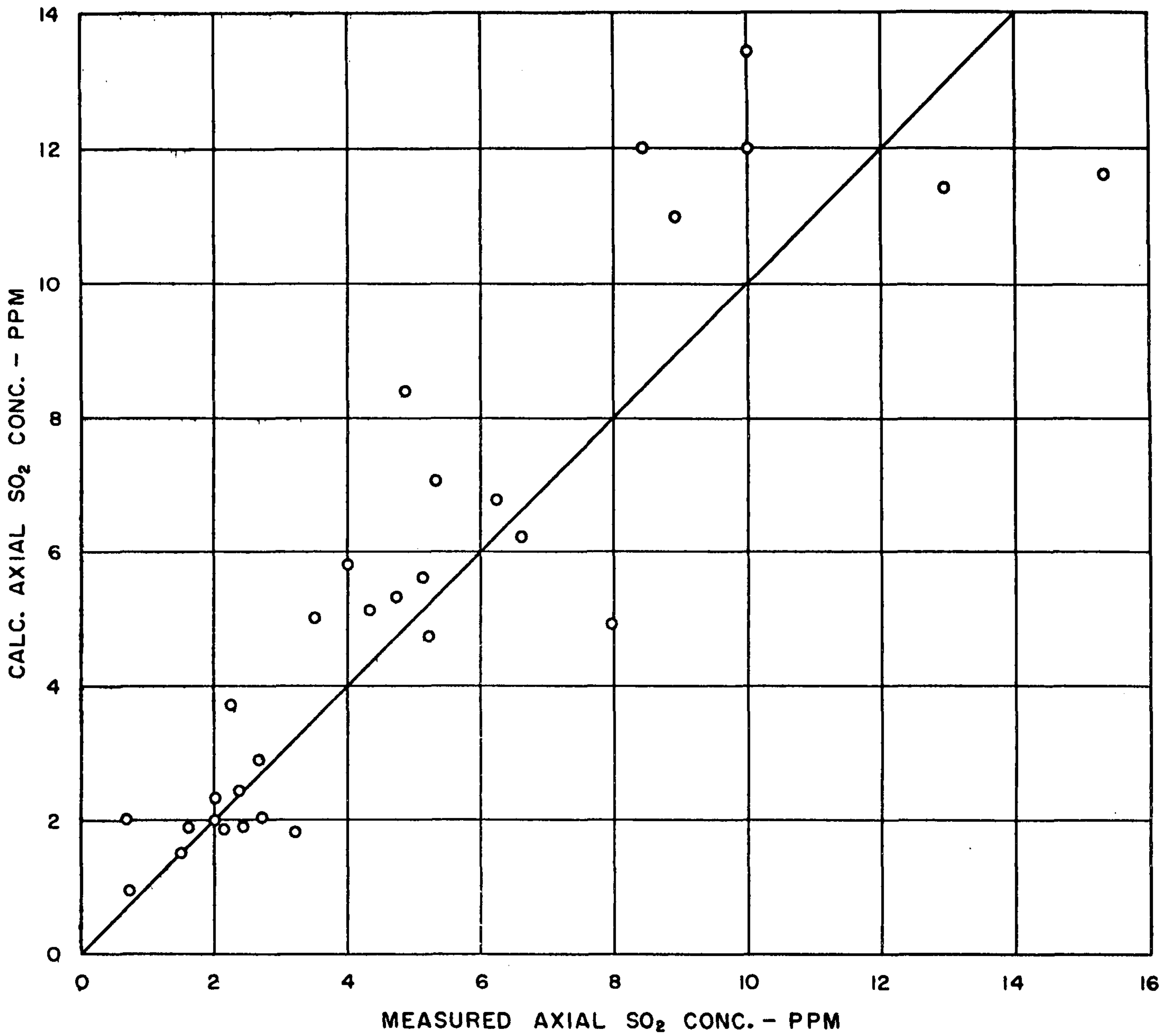


Figure 36. RELATION OF CALCULATED AXIAL SO_2 CONCENTRATION TO MEASURED AXIAL SO_2 CONCENTRATION

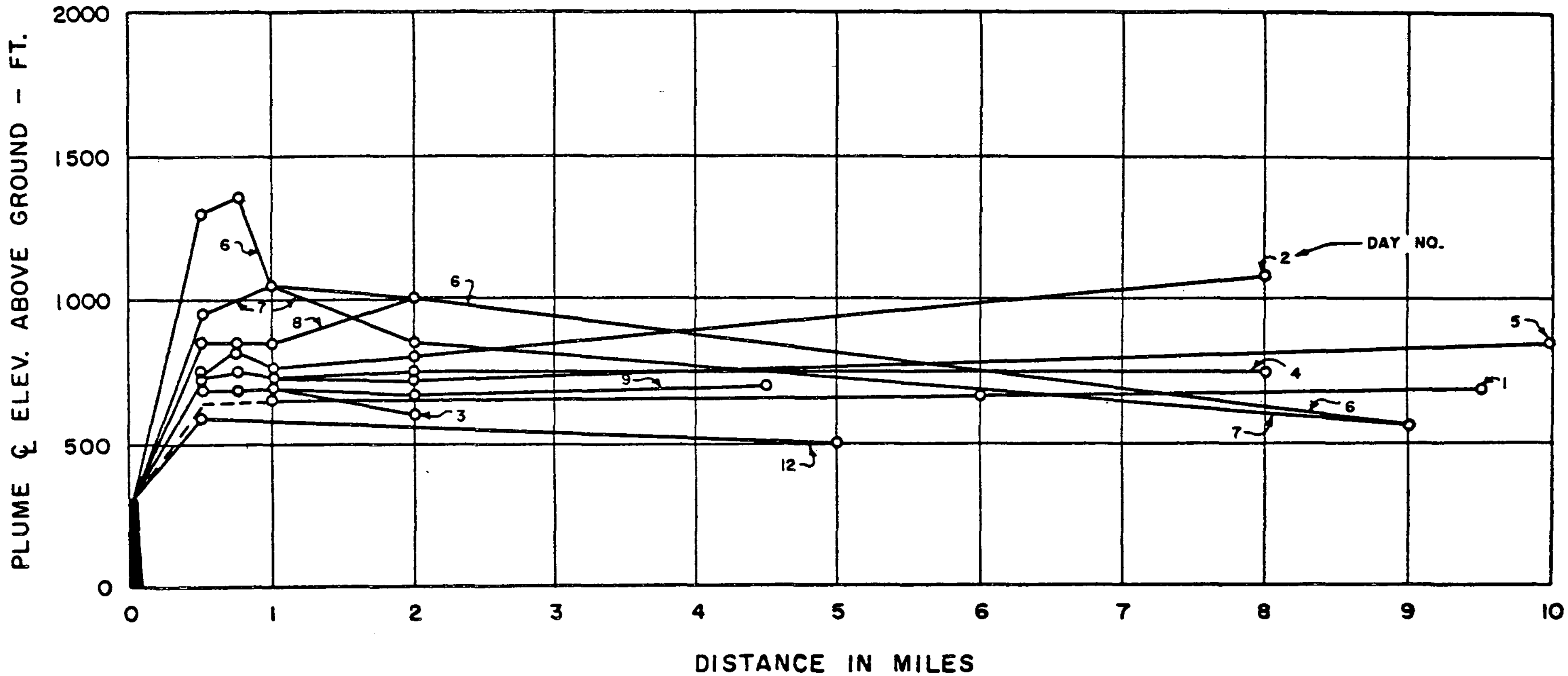


Figure 37. OBSERVED PLUME CENTERLINE ELEVATION WITH DISTANCE - INVERSION CONDITIONS

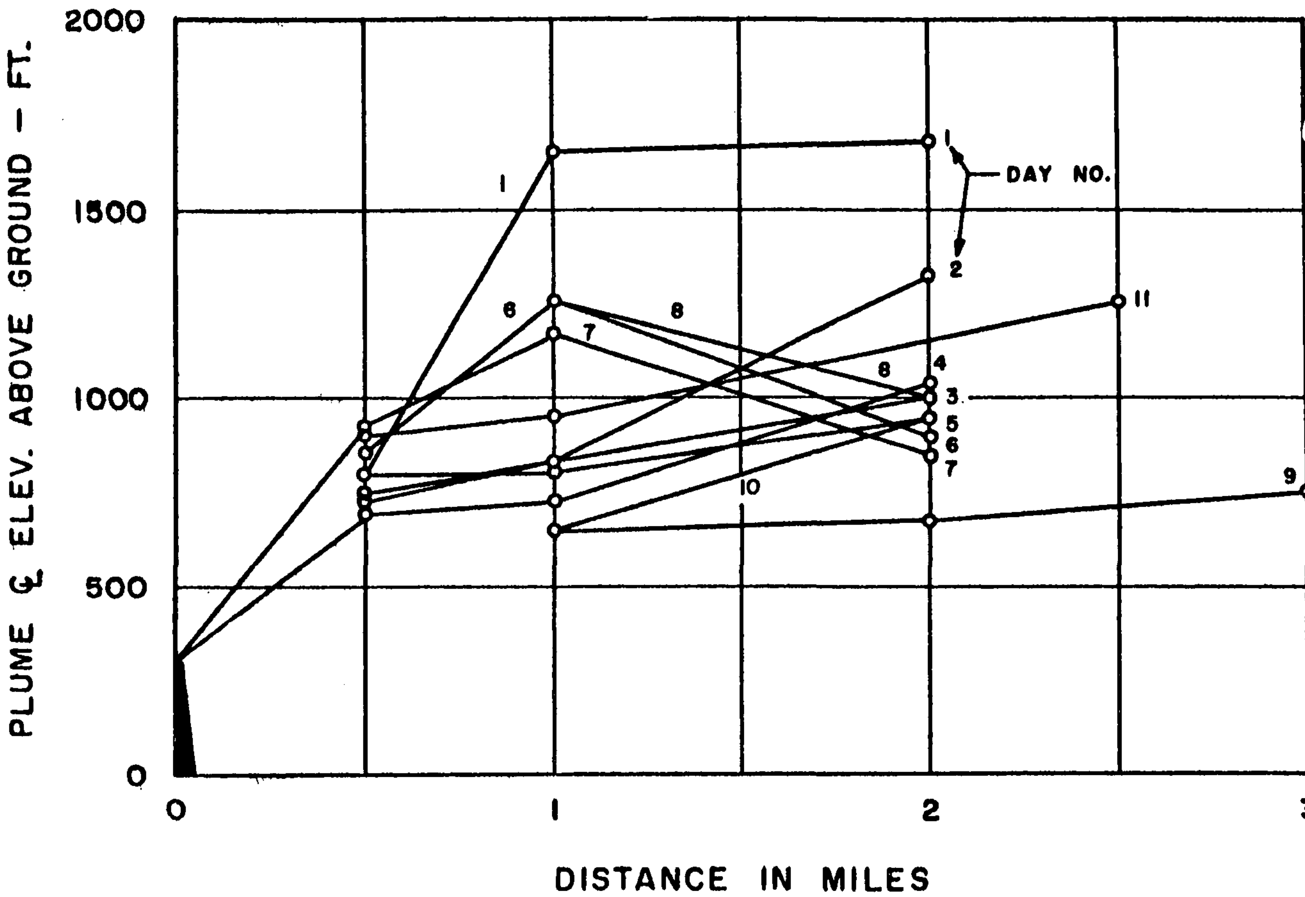


Figure 38. AVERAGE OBSERVED PLUME CENTERLINE ELEVATION WITH DISTANCE - LAPSE CONDITIONS

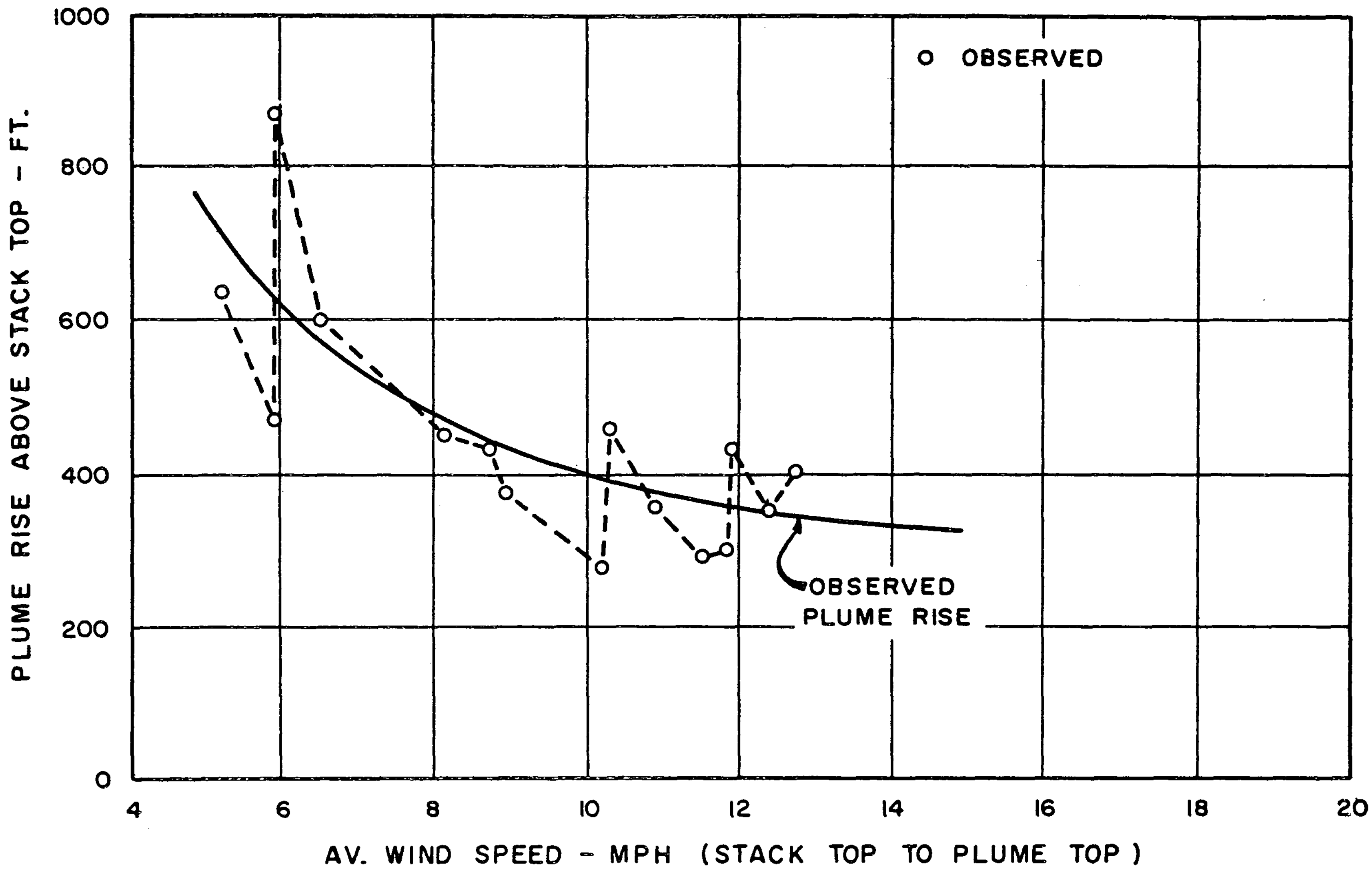


Figure 39. RELATION OF PLUME RISE TO WIND SPEED - INVERSION CONDITIONS

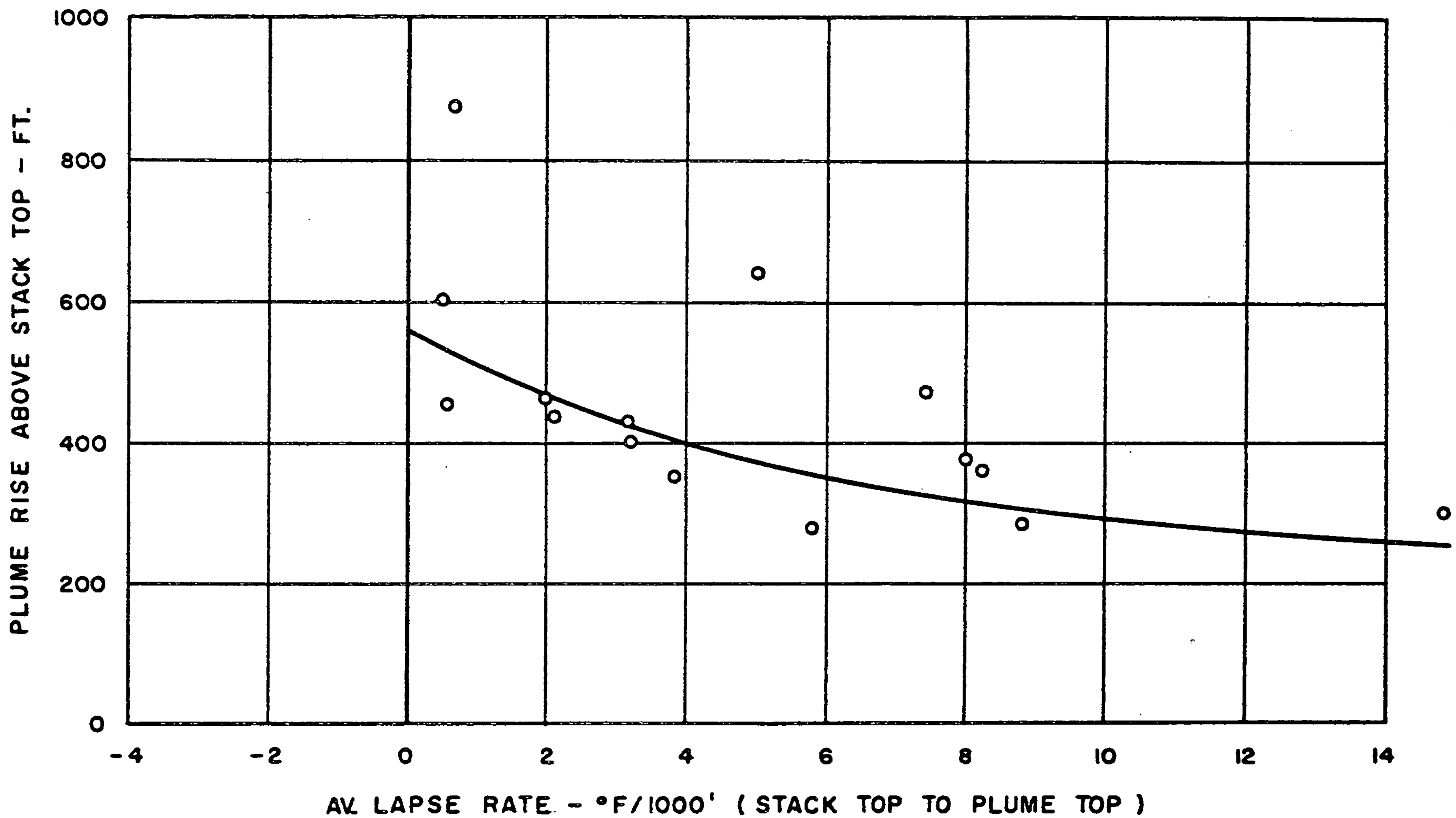


Figure 40. RELATION OF PLUME RISE TO TEMPERATURE GRADIENT, STACK TOP TO PLUME TOP - INVERSION CONDITIONS

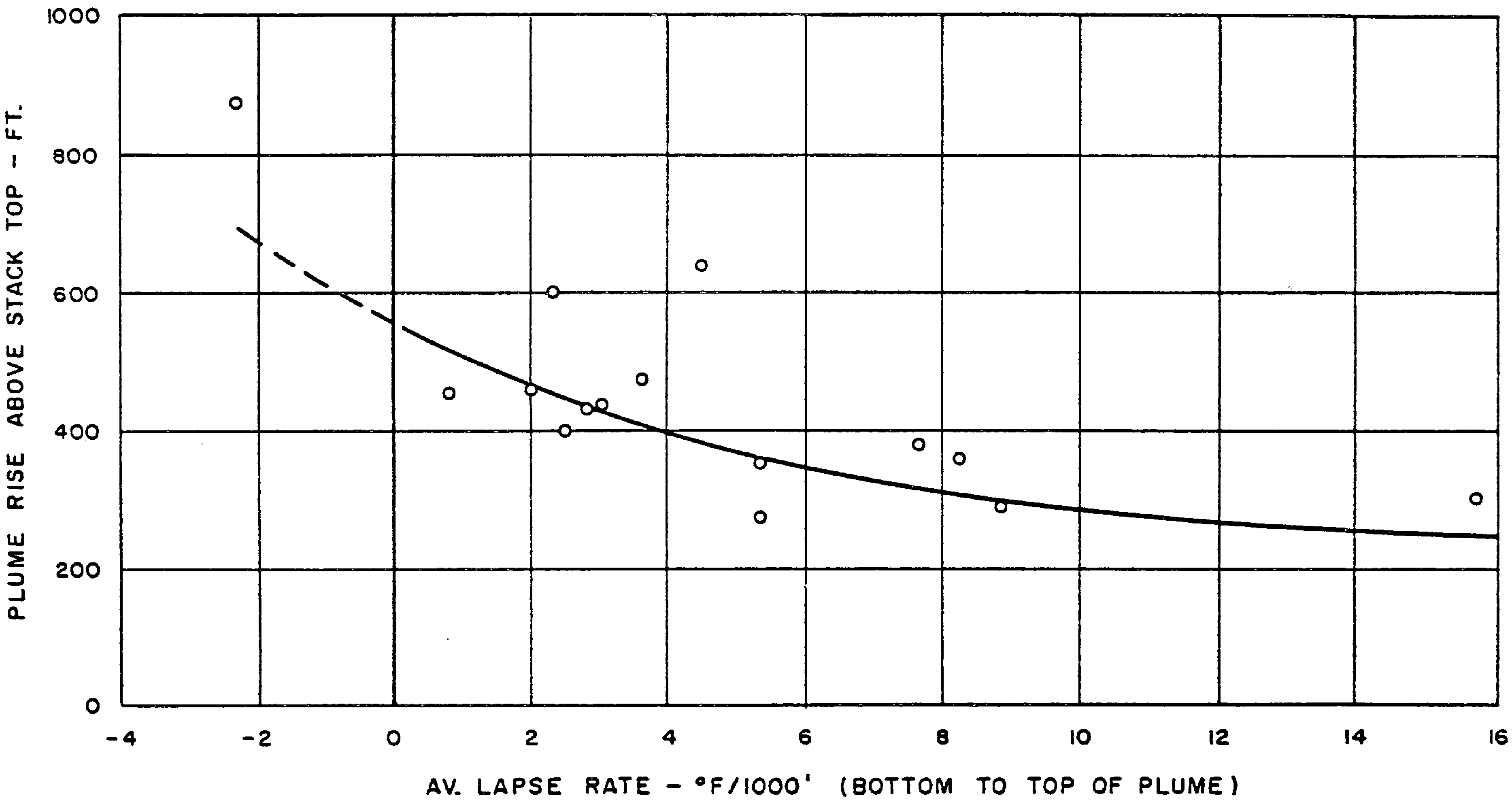


Figure 41. RELATION OF PLUME RISE TO TEMPERATURE GRADIENT, IN PLUME - INVERSION CONDITIONS

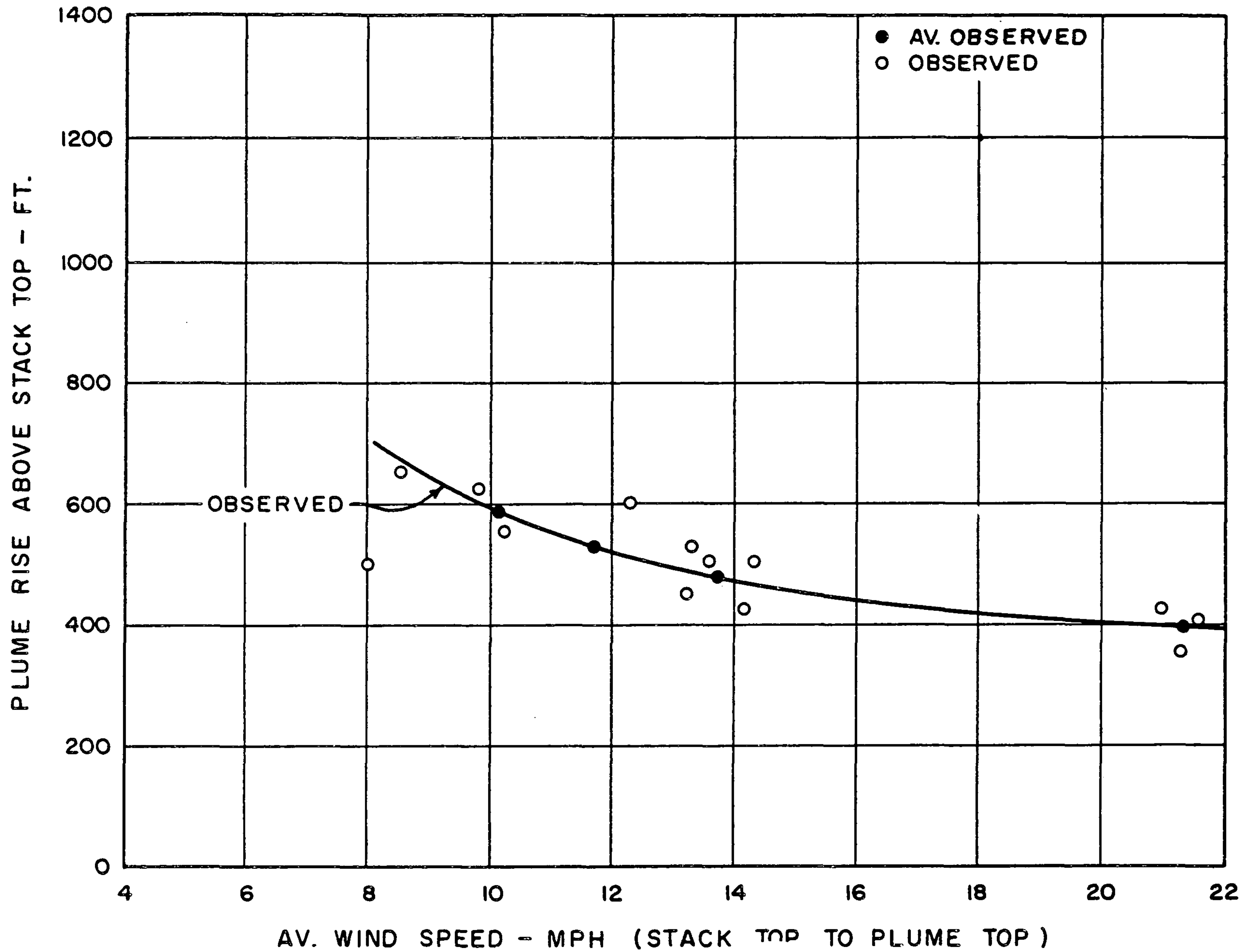


Figure 42. RELATION OF AVERAGE PLUME RISE TO WIND SPEED AT 1/2 AND 1 MILE FROM SOURCE - LAPSE CONDITIONS

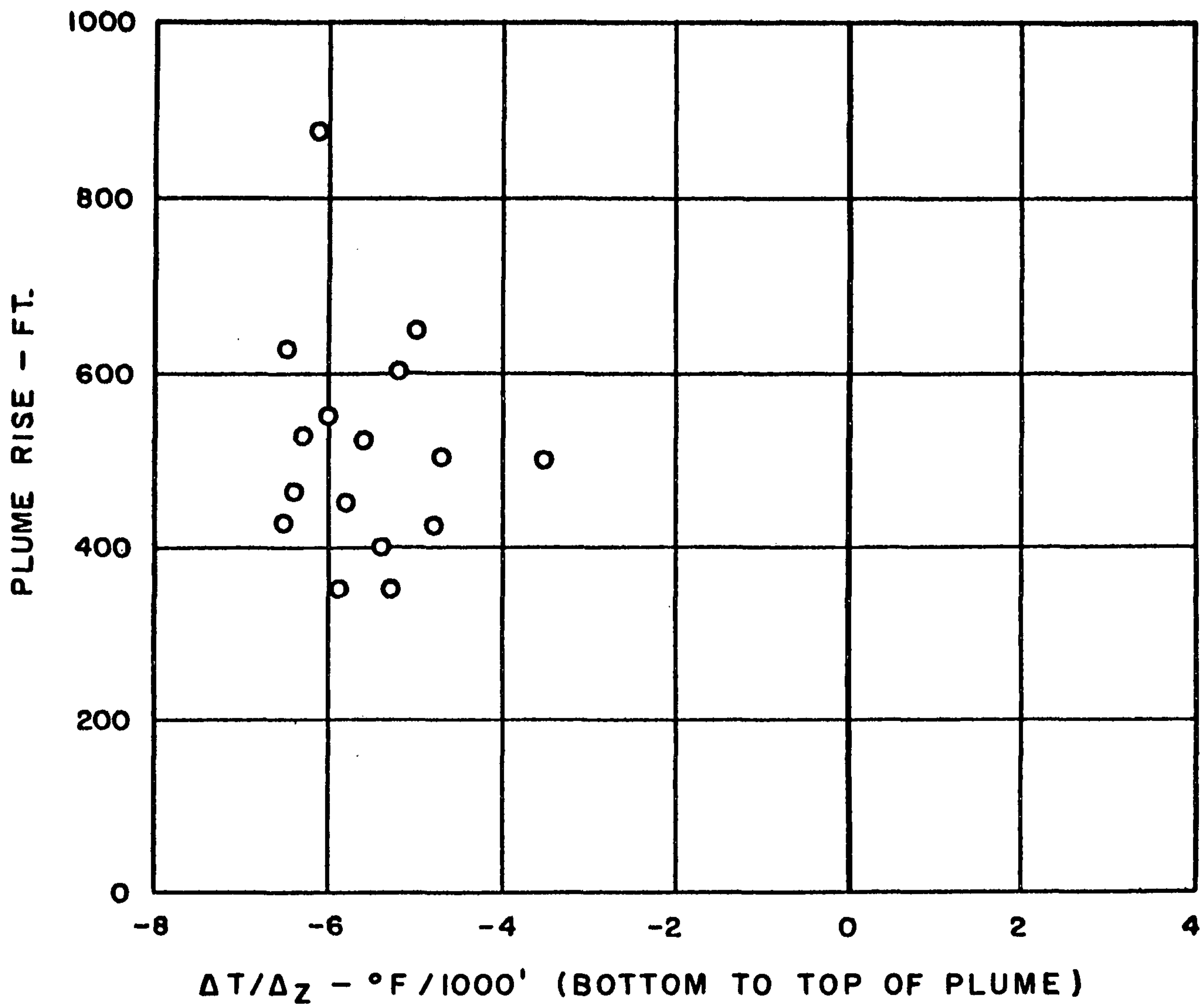


Figure 43. RELATION OF AVERAGE PLUME RISE AT 1/2 AND 1 MILE TO TEMPERATURE GRADIENT - LAPSE CONDITIONS

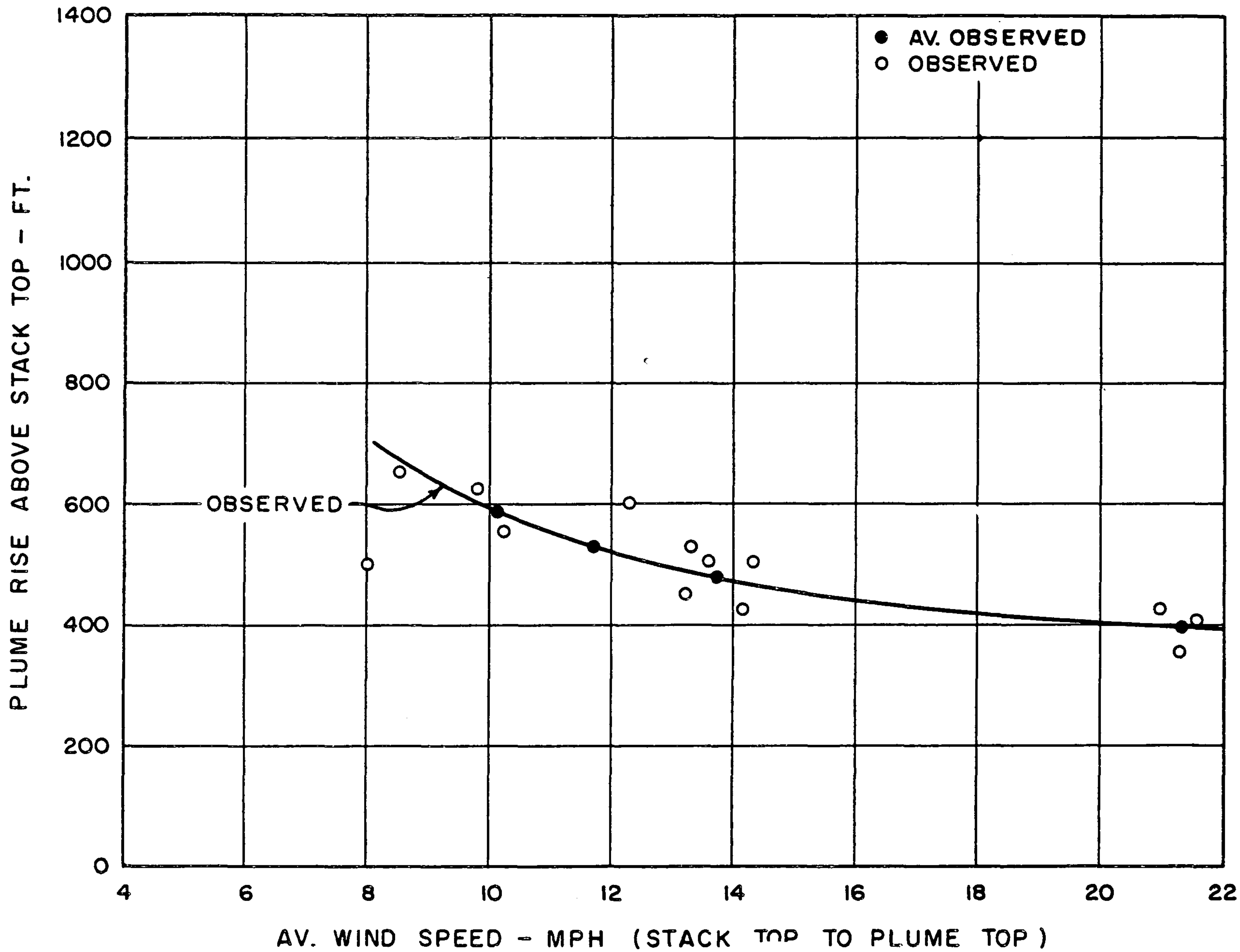


Figure 42. RELATION OF AVERAGE PLUME RISE TO WIND SPEED AT 1/2 AND 1 MILE FROM SOURCE - LAPSE CONDITIONS

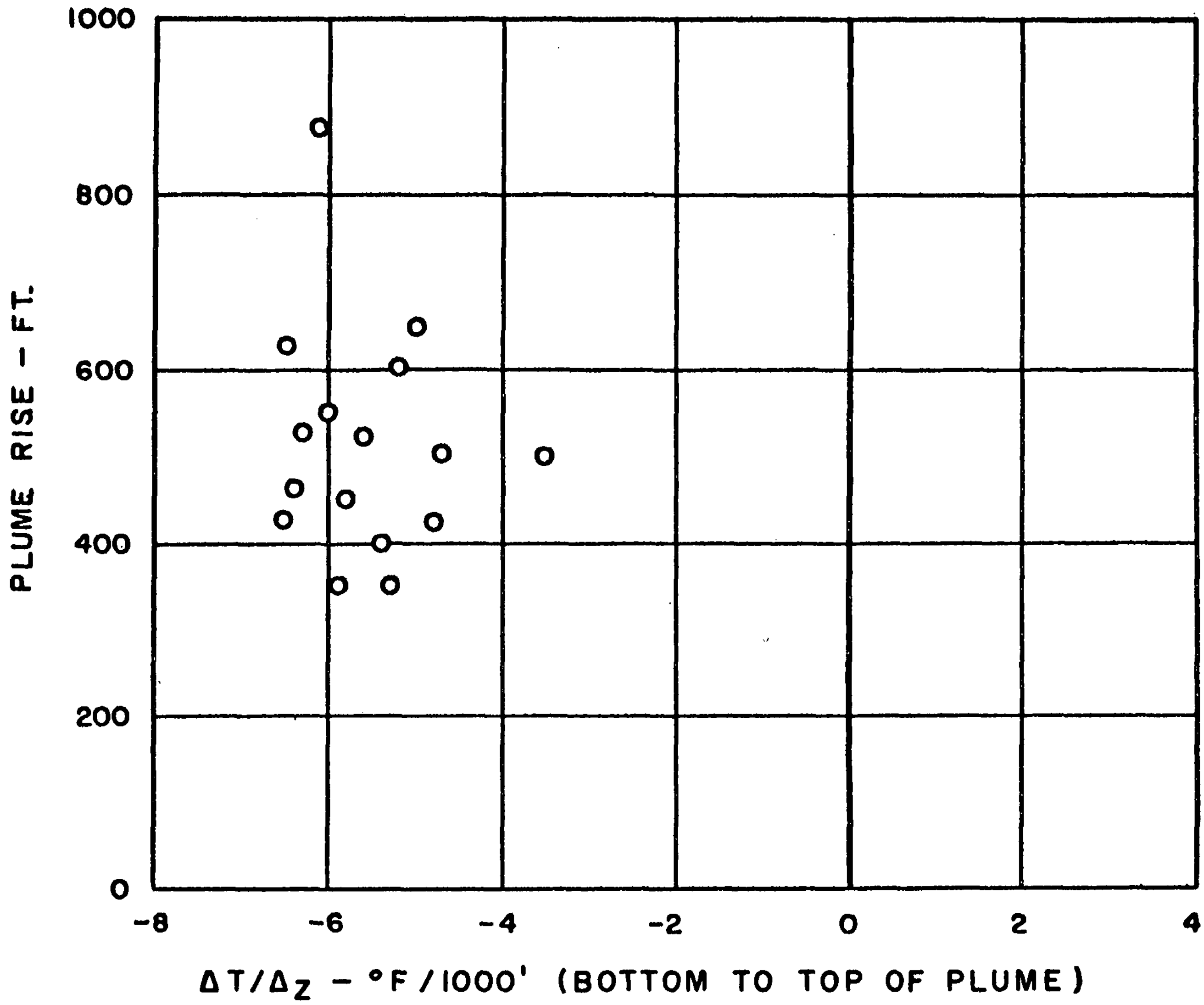


Figure 43. RELATION OF AVERAGE PLUME RISE AT 1/2 AND 1 MILE TO TEMPERATURE GRADIENT - LAPSE CONDITIONS

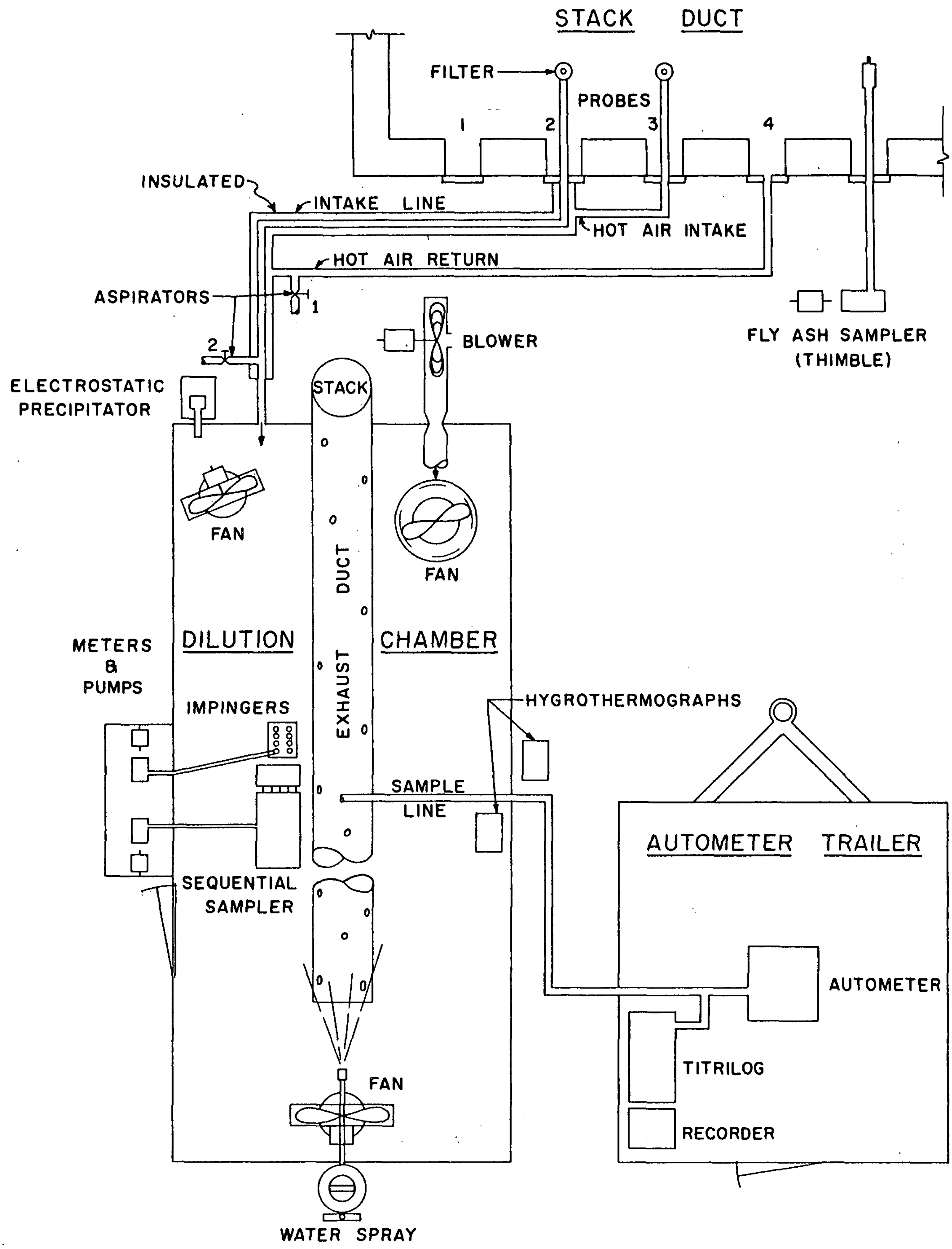
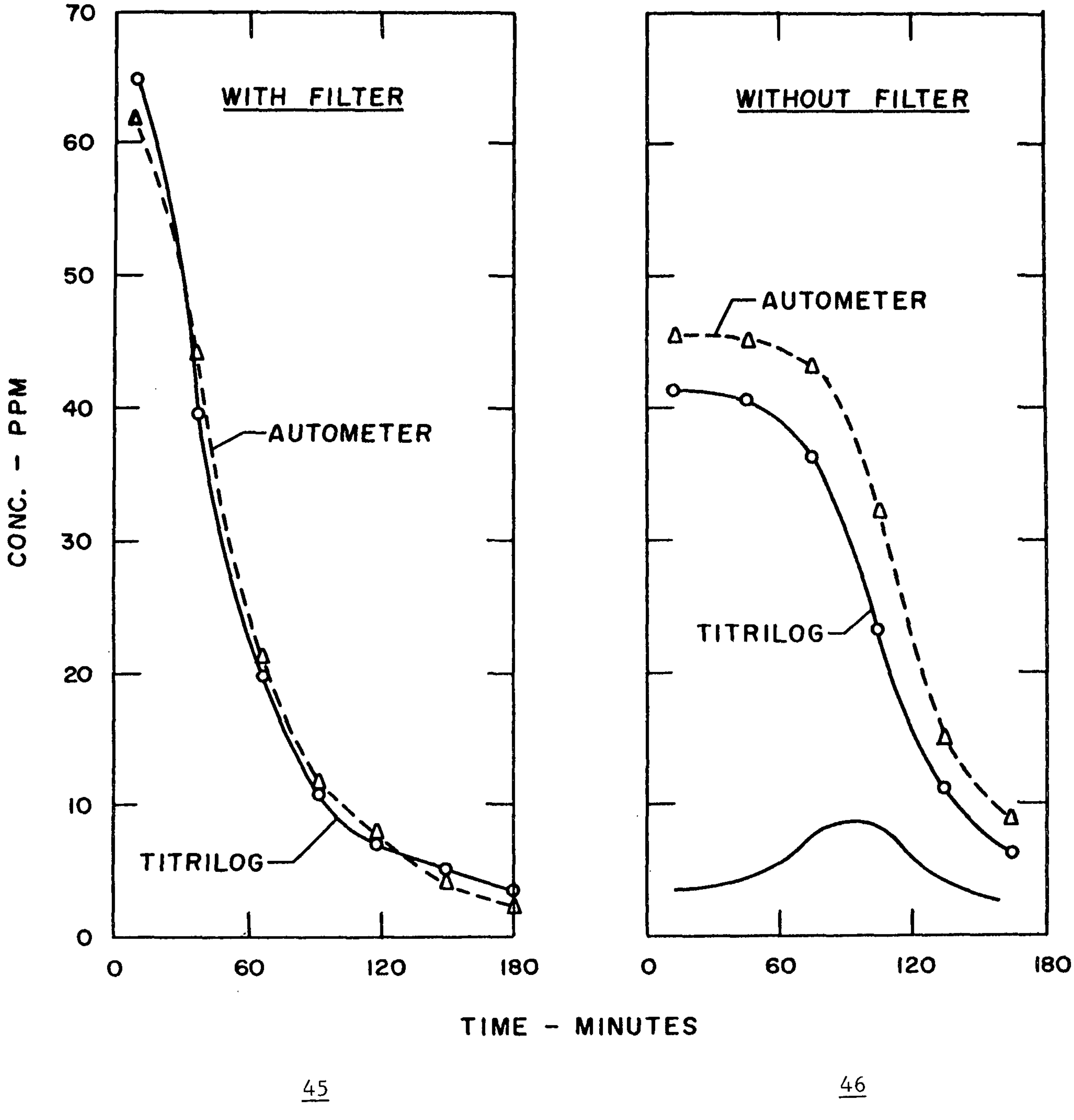


Figure 44. FLUE GAS DILUTION AND SAMPLING FACILITIES



Figures 45 and 46. RELATION OF AUTOMETER AND TITRILOG DATA FROM DILUTION CHAMBER

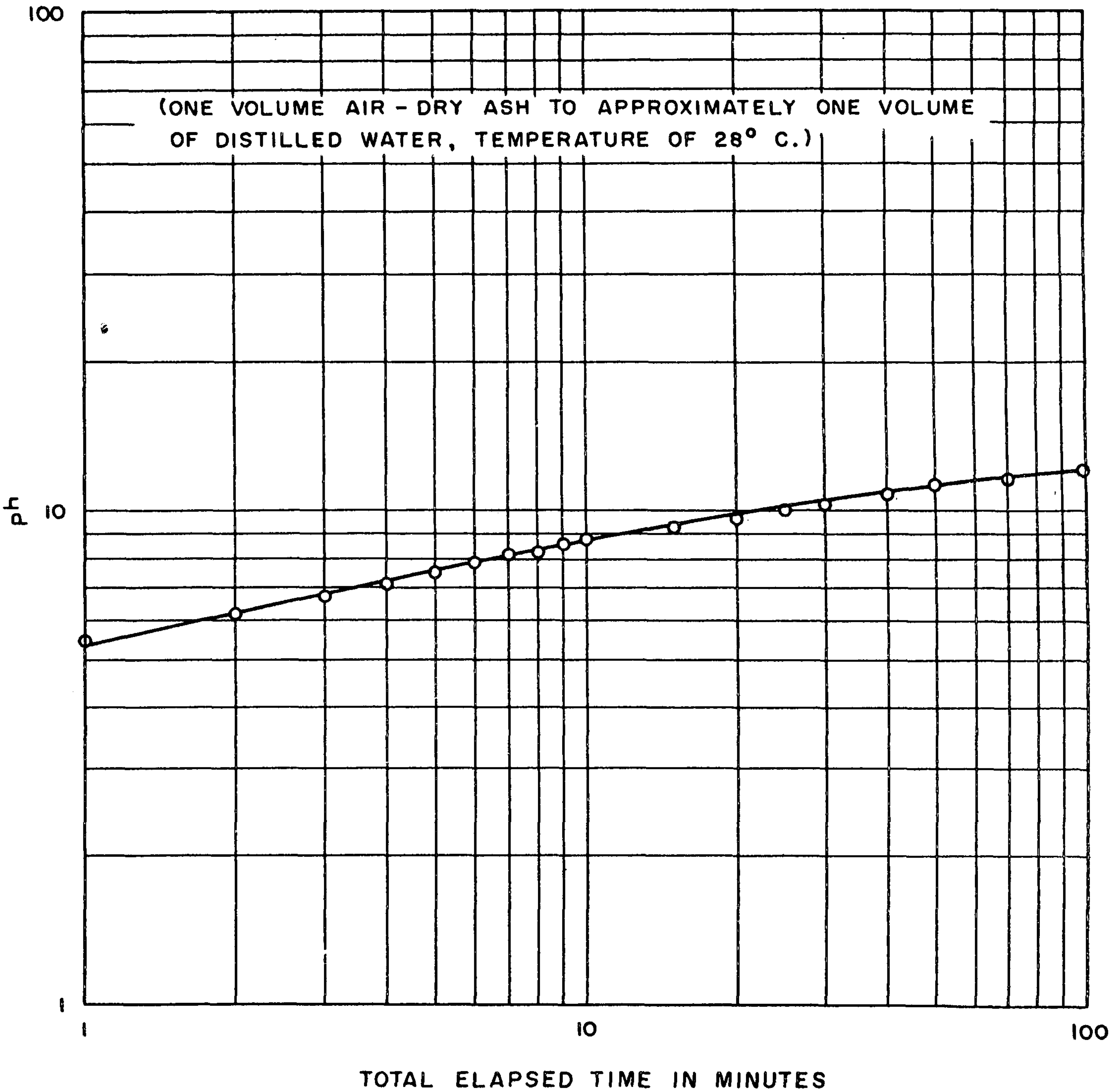


Figure 47. SHIFT IN pH OF FLY ASH WITH TIME

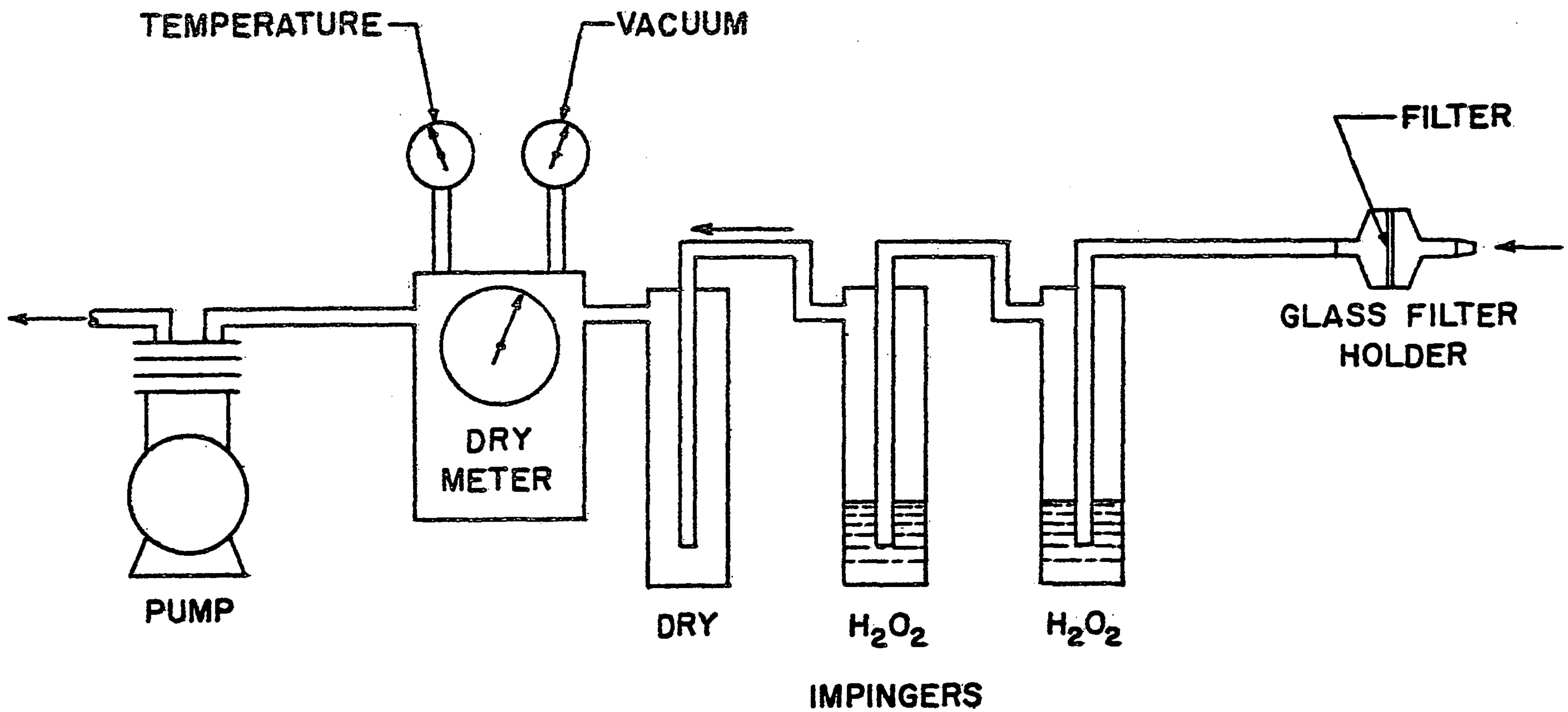


Figure 48. SAMPLE ASSEMBLY FOR SO_2 AND SO_3 PLUME COMPONENTS

NOMENCLATURE - DIFFUSION EQUATIONS

Symbol		System of Units
C_y	Diffusion coefficients along y axis	$ft.^{\frac{m}{2}}$ or $ft.^{\frac{m_y}{2}}$
C_z	Diffusion coefficients along z axis	$ft.^{\frac{m}{2}}$ or $ft.^{\frac{m_z}{2}}$
exp	The value e	2.718
m	Stability parameter	dimensionless
m_y	Stability parameter along y axis	dimensionless
m_z	Stability parameter along z axis	dimensionless
n	Number of stacks (equations 16 and 17)	-
Q	SO_2 emission rate	$ft.^3/sec.$
u	Wind speed	mph
$\bar{X}$	SO_2 concentration	ppm
$\bar{X}_{max}$	Maximum SO_2 concentration	ppm
x	Distance downwind from source	ft.
x_g	Distance from centerline along normal distribution curve (Gaussian)	ft.
y	Crosswind distance from centerline of plume	ft.
z	Vertical distance from centerline of plume	ft.
σ	Standard deviation of normal distribution curve (Gaussian)	ft.
σ_y	Standard deviation along y axis	ft.
σ_z	Standard deviation along z axis	ft.
θ	Angular difference between plume direction and stack alignment	degrees
Δ	Distance between stacks	ft.

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