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SUMMARY

The airborne effluent measurements and cloud physical behavior for the May 12, 1977, Titan III launch are summarized. The Titan vehicle was launched at 1027 eastern daylight time (EDT) from launch complex 40 at the Air Force Eastern Test Range (AFETR), Florida. The measurement activity is but one of many conducted by the National Aeronautics and Space Administration (NASA) as part of its tropospheric program to study the effect of launch vehicle emissions on tropospheric air quality.

The monitoring program included airborne effluent measurements in situ in the launch cloud, visible and infrared photography of cloud growth and physical behavior, and limited surface collection of rain samples. Effluent measurements included concentrations of hydrogen chloride (HCl), nitrogen oxide (NO), nitrogen oxides NO_x, and aerosols as a function of time in the exhaust cloud. For the first time in situ particulate mass concentration and aerosol number density in the launch cloud were measured as a function of time and size in the range of 0.05- to 25-μm diameter.

Measurement results showed incloud gaseous effluent values to be similar to those measured at earlier launches. For example, maximum incloud HCl concentrations ranged from about 10 parts per million by volume (ppm) several minutes after launch to 1 to 2 ppm at 45 minutes after launch. Maximum NO_x concentration was about 500 parts per billion by volume (ppb) at several minutes after launch and about 100 ppb after 45 minutes. Integrating nephelometer measurements showed maximum incloud particle concentrations to be similar to those of earlier launches, namely about 1800 $\mu g/m^3$ several minutes after launch to about 400 $\mu g/m^3$ by 45 minutes. Particle sizing measurements showed the incloud particle distribution to be generally bimodal in the range of 0.05- to 25-μm diameter. Weather conditions were overcast and cloudy, resulting in difficulty in identifying the launch cloud from the ambient background. As a result, only about 10 minutes of usable cloud photography (visible and infrared) data were obtained. Rain samples (intermittent rain) collected at the surface showed no evidence of absorbed HCl from the exhaust cloud.

The format of the paper is data presentation.

INTRODUCTION

Since 1972 NASA has been conducting launch vehicle effluent (LVE) measurements at selected NASA and Air Force launches for the purpose of investigating the effect of launch vehicle emissions (mainly, solid rocket motor emissions) on tropospheric air quality. This tropospheric program is aimed at measuring and predicting the impact of ground clouds produced at launch on the surface air quality. The LVE monitoring program is conducted by the Langley Research Center (LaRC) with intercenter support from Marshall Space Flight Center (MSFC) and John F. Kennedy Space Center (KSC). The goal of the LVE program is to assess the applicability and accuracy of diffusion models for predicting the dispersion of exhaust effluents from NASA's current and future launch vehicles. The objectives of the program are to develop data to be used in the establishment of potential launch constraints and to develop inhouse expertise in the areas relating to the environmental impact of launch activities. The approach employed to meet these objectives is that of measuring rocket exhaust products (produced by large, solid, rocket motor launch vehicles) at surface level and within the stabilized ground cloud formed in the troposphere as the result of the launch. These exhaust products are mainly hydrogen chloride gas (HCl) and particulates (aluminum oxide and debris). These measurements are then used to make direct comparisons with the diffusion models and NASA plume codes that are used to predict effluent composition and concentrations.

From 1972 through midyear 1974, LaRC monitored six launches (refs. 1 to 5) for purposes of developing the measurement techniques and operational procedures for full-scale (land, sea, and airborne) monitoring of four targeted launches in late 1974 and 1975. The four target launches were selected for full-scale measurement and modeling programs in which model-measurement results would be intercompared. The HCl data obtained during the four launches are reported in reference 6, and the May 1975 launch results are discussed in detail in reference 7. Following the completion of the monitoring of the four full-scale launch monitoring activities, LaRC discontinued such large scale monitoring but has continued the airborne sampling at a rate of about two launches per year.

The measurement results for the May 12, 1977, Titan III launch are summarized herein. The purpose of the paper is data presentation. The Titan vehicle was launched from launch complex 40 (LC-40) at AFETR. Launch time was 1427 universal time (UT) (1027 EDT). The LVE monitoring experiment included airborne effluent measurements in situ in the launch cloud, visible and infrared photography of cloud growth and physical characteristics, and limited collection of rain samples at the surface.

SYMBOLS

t_0	reference time for concentration-time plots, min:sec after launch
Q	sample flow rate, m^3/min
V	air volume sampled in Δt, m^3
Δf	frequency change, Hz
Δt	transit time of aircraft through cloud, min

Abbreviations:

FSSP	forward scattering spectrometer probe
CS-27200	camera site, Air Force facility 27200
LC-40	launch complex 40
LVE	launch vehicle effluent
ppb	parts per billion by volume
ppm	parts per million by volume
QCM	quartz crystal microbalance cascade impactor
SRM	solid rocket motor
T	time relative to launch; T - 0 is launch
UCS	universal camera site
VAB	camera site, Vertical Assembly Building

EXHAUST CLOUD DESCRIPTION

A brief description of the ground cloud sampled by the aircraft is presented. Refer to reference 5, 7, 8, or 9 for a more detailed cloud discussion.

The Titan III launch vehicle consists of a three-stage core using a liquid propulsion system and two solid rocket motors (SRM) attached on opposite sides of the core. Only the SRM boosters (first 10 to 20 seconds of burn) contribute effluents to the ground cloud since the liquid propulsion system is ignited at altitude. Each SRM booster has a mass-flow rate at lift-off of about 4160 kg/sec, and remains relatively constant for the first 20 seconds of burn. This initial exhaust from the SRM boosters generates a ground cloud in the immediate vicinity of the launch pad and, as a result of its heat content, rises to a stabilization altitude where it then drifts and diffuses with the prevailing winds. Stabilization typically occurs within 15 minutes after launch at altitudes between 1000 and 2000 meters, depending upon cloud buoyancy, meteorology, and mixing layer height. Initially, the cloud is composed of species from the SRM engine exhaust, debris from the launch pad, and species generated during high-temperature afterburning reactions in the exhaust plume. However as the cloud rises, stabilizes, and drifts with the wind, it entrains large quantities of atmospheric air, and by stabilization less than 1 percent of the cloud mass is engine exhaust. Main constituents of the stabilized ground cloud are listed in table I. Incloud concentrations at about 10 to 15 minutes after launch and the sources for each specie are given.

MEASUREMENT PROGRAM

The airborne sampling strategy and instrumentation used in the LVE program have been discussed in previous reports. (See refs. 5, 7, and 10.) Descriptions of the visible photography and infrared imaging instrumentation are available in references 7 and 11. Therefore, only a brief summary of the measurement program is presented in this paper.

Airborne Sampling Plan

The sampling platform, a twin-engine light aircraft, was airborne at approximately T - 30 minutes. Range safety required the aircraft to be in a holding pattern at an altitude of approximately 1000 meters, approximately 8 km west of the launch pad. (See fig. 1.) Just before T - 0 the aircraft was released from the holding pattern and radar vectored to cross the range safety limit line at T + 1 minute to perform the sampling mission. The sampling plan used by the aircraft was a series of basic downwind and crosswind penetrations of the exhaust cloud, each through the center of the cloud as determined visually by the flight crew. (See fig. 2.) For this mission, 13 penetrations of the exhaust

cloud were made about T + 4 minutes to T + 48 minutes. After the 13th pass, the exhaust cloud could not be distinguished from the ambient cloud background and sampling was terminated. The flight parameters associated with each sampling pass are listed in table II.

Airborne Instrumentation

The sampling aircraft (ref. 10) was equipped to monitor HCl, suspended particulates, suspended aerosols, nitrogen oxide, nitrogen oxides, and chlorine (Cl_2). Routine flight parameters (altitude, heading, airspeed, etc.) were also measured. Aircraft position was obtained by ground radar track of the onboard S-band transmitter beacon. As discussed in reference 10, all effluent air samples are taken into the aircraft through specially designed sampling probes located in the nose of the aircraft. These probes extend forward of the flow-field disturbance created by the aircraft nose, thus collecting undisturbed, free-stream sampling air. Of the instrumentation, only the Cl_2 detector and the aircraft heading indicator failed to obtain data. The characteristics of the effluent monitoring instrumentation from which data were obtained for this mission are described in table III. The operation of each type of instrument is described in references 10, 12, 13, and 14. All but two instruments of table III, the 10-stage quartz crystal microbalance cascade impactor (QCM) and the forward scattering spectrometer probe (FSSP), have been flown on earlier LVE missions. The integrating nephelometer measures the total suspended (greater than 0.4-μm diameter) particulate mass concentration as a function of position (time) in the cloud. The 10-stage QCM measures suspended particulate mass concentration ($\mu g/m^3$) as a function of time in 10 particle size (aerodynamic) ranges from 0.05- to 25-μm diameter. Size separated elemental analyses were made postflight on particles collected in the cascade impactor by using scanning electron microscopy. The FSSP measures aerosol number density (nuclei/cm^3) as a function of time and size in a size range from 0.5- to 45-μm diameter. For this launch, the FSSP sizing range was selected to be from 0.5- to 7.5-μm diameter with 15 size increments. Discussion on the measuring principles of these three instruments in terms of the incloud measurements is given in appendix A. A thorough understanding of the LVE problem and the aerosol (nephelometer, QCM, and FSSP) instrumental techniques are required when interpreting the aerosol measurement data. The discussion of such an understanding is beyond the scope of this data paper.

Surface-Level Rain Collectors

Since the weather was overcast with a high probability of rain, 17 rain collectors were deployed at surface level around the launch pad and in the general area beneath the predicted path of the exhaust cloud. (See fig. 3.) These detectors were plastic containers,

each having a surface area of 160 cm^2, and each containing a water saturated solution of mineral oil for preservation of any collected raindrops. All detectors were collected within 30 minutes after launch. Samples were returned to LaRC for chloride (microcoulometric) and sodium (atomic absorption) analyses.

Cloud Imaging Systems

Metric tracking cameras (ref. 11) and time sequence cameras were located at sites UCS-9, UCS-2, and CS-27200 (see fig. 4) for purposes of obtaining records of cloud track, rise, growth, and volume. A motion-picture camera was located at site VAB. Infrared scanners (ref. 7) located at sites CS-27200 and VAB provided additional cloud physical data. Operational problems of identifying the exhaust cloud from ambient overcast and rain clouds were experienced at all cloud imaging sites. Typically only 10 to 11 minutes of usable data were obtained at each site.

DATA RESULTS

The data obtained during the May 12, 1977, LVE measurement operation are presented in this section. Where appropriate, similar data from earlier launches are shown for comparison.

Meteorology

Figure 5 shows the meteorological data for the launch. These data are from a rawinsonde released at T - 40 minutes (time nearest launch where sonde data are available) and T - 0 tower and surface data. Notable features of the data are the nearly constant wind direction (70^o to 80^o) and wind speed (10 to 12 m/s) from about 0.1- to 1-km altitude and the temperature inversion at about 2.3-km altitude.

Cloud Physical Parameters

As stated previously, overcast weather conditions were responsible for limited cloud imaging data at all tracking sites. Tracking data were obtained for about 11 minutes, and infrared data were limited to 8 to 10 minutes and with poor resolution because of signal attenuation by water droplets in the atmosphere. Usable still and motion-picture data were not obtained at a sufficient number of sites to allow data reduction for determination of cloud parameters. The data obtained by the imaging systems are discussed in the following paragraphs, and where appropriate the data are used to compare the aircraft radar tracked position (during each sampling pass) to the main exhaust cloud as tracked optically.

Figure 6 shows the 11 minutes of cloud trajectory data from the tracking cameras. The bars on the data indicate the uncertainties in the cloud location as determined from

the three tracking cameras. (See ref. 5 for a discussion of data analysis techniques.) Also shown is the aircraft location for sampling passes 4 and 5, the earliest passes for which aircraft location data are available. The aircraft location during these passes and the cloud location data at 11 minutes agree to within about 1.3 km, which is considered good agreement when considering the overcast conditions and the cloud identification problems. Figure 7 shows the cloud rise data for the launch and the error bars for each cloud altitude measurement. Cloud rise data from 6 to 10 minutes were not usable. The sampling altitudes for the first four airborne passes are also shown. Figure 8 is a comparison of the cloud trajectory data (fig. 6) and the aircraft location (table II) for each sampling pass. The following points are important for this comparison:

(1) Based on the effluent measurement data from the airborne instrumentation, all 13 sampling passes of table II were samplings of launch effluents.

(2) The cloud trajectory measurements are consistent with the meteorology data (fig. 5) and the residence time of the cloud at each altitude (fig. 7) and also agree with ground observer reports.

(3) Meteorological conditions of overcast and clouds caused difficulty for the surface and airborne measurement teams in cloud identification and tracking. Frequently the launch vehicle generates more than one cloud, but generally (with good observational conditions) one is easily identified as the main (largest) cloud. Also, as the main cloud drifts downwind, small cloud puffs can separate from the main cloud.

Based on the data of figures 6, 7, and 8, passes 1 to 5 are probably samples in the main cloud that was optically tracked. Sampling passes 6 and 7 are probably upper portions of the main cloud that broke away during the first 10 minutes and have drifted northwest after separation from the main cloud. The altitude of these passes, the location and time of the sampling passes, and the wind velocity at the sampling altitude support this conclusion. The lack of optical track data beyond 11 minutes and the poor exhaust cloud contrast as compared with the overcast, cloudy day makes it difficult to determine what portion of the exhaust cloud was sampled beyond pass 7. The location and time of passes 8 and 9 (6 to 7 km from the pad and T + 30 minutes) and passes 4 and 5, early samplings of the main cloud (5 to 6 km from the pad and T + 11 to 13 minutes), and the existing wind speeds indicate that the measurements from passes 8 and 9 are probably not from the same cloud sampled in the first five passes. Since location of pass 10 is not documented, no conclusion can be made. Location and time of passes 11 to 13 are consistent with the main cloud position at passes 4 and 5 and the projected trajectory of the cloud from T + 11 minutes to T + 40 to 50 minutes, using the meteorology data of figure 5. Thus, measurements from passes 11 to 13 are most likely samplings of that same cloud sampled in the first five passes.

Because of poor exhaust cloud contrast as compared to the overcast ambient background and some operational problems, cloud volume could not be calculated from the optical tracking data. However, cloud volume was calculated from the residence time of the aircraft in the cloud and the aircraft flight speed for successive crosswind and downwind. These calculations were made only for successive passes which were thought to be in the main cloud. The results are shown in figure 9. Comparison of these calculations with the conventional volume calculations (using the optical data) for launches where both techniques can be applied indicates that the aircraft determined cloud volumes are within a factor of 3 of those determined by the more accurate optical data.

Figures 10 and 11 show a comparison of the May 12, 1977, cloud data with those of other Titan III clouds (all at the Florida launch site). Figure 10 shows the cloud rise data where launch time is given in local time. As shown, the initial rise rate of the clouds, 4 to 5 m/s, is essentially the same and thus independent of the existing meteorology. However, cloud stabilization altitude is different among the launches and is a function of meteorology. Based on figure 10, stabilization altitudes range from 1 to 2 km with cloud stabilization occurring within 15 minutes after launch. Figure 11 shows the cloud volume comparison. Note the scale break in the time axis. All results except May 12, 1977, were obtained from optical tracking data. Considering the factor of 3 uncertainty in the May 1977 volume calculations and the different meteorological conditions for the launches, the volume agreement is reasonable.

Surface Rain Collection

Of the 17 rain collectors deployed (fig. 3), 14 contained one or more raindrops. Laboratory analysis showed the chloride content of these raindrops to be normal (ambient), thus indicating that the raindrops had no contact with the exhaust cloud or if in contact with the exhaust cloud, absorbed negligible HCl from the cloud.

Airborne Effluent Measurements

Concentration-time data.- Incloud effluent concentrations of HCl, particles (nephelometer), and NO_x measured during each sampling pass are shown in figure 12. The NO data are not shown because measurements indicate nearly all the NO_x are NO. Zero time on the abscissa of each plot is shown in the subtitles of the figure as t_0 given in minutes and seconds after launch. The following comments are to be considered in the interpretation of the data of figure 12:

(1) As a result of either operational or data-reduction difficulties, nephelometer data are not shown for pass 3, HCl data are not shown for pass 11, and for pass 1 the period of data reduction did not encompass NO_x concentration return to ambient values.

Passes 9 and 13 include data for a cloud penetration that included a small segment (a puff) separated from the main cloud. In each case the aircraft crew could visually separate the puff from the main cloud.

(2) No correction for sampling line time delay effects of the various instruments has been applied to the data. Generally the nephelometer and HCl instruments respond together, whereas the NO_x data lag by about 10 seconds. This lag is due to the NO_x instrument being located in the aft passenger cabin, whereas the other two instruments are located in the nose compartment of the aircraft.

(3) Beyond about 11 minutes after launch, overcast and cloudy weather made cloud identification and airborne sampling difficult to the extent that successive sampling passes were not always of the same exhaust cloud. Where possible, attempts to identify ambiguities associated with the sampling passes have been made.

For this mission, maximum observed HCl concentration was about 10 ppm, having occurred during passes 3 and 4 (T + 10 minutes). By passes 12 and 13 (T + 45 minutes), HCl had decayed to about 1 to 2 ppm. Maximum NO_x concentrations were of the order of 450 to 550 ppb, having occurred during the first four passes. By about T + 45 minutes, NO_x has decayed to 100 to 200 ppb. Maximum particulate concentration (nephelometer) was of the order of 1850 $\mu g/m^3$ (pass 4) and decayed to 400 to 500 $\mu g/m^3$ by passes 12 and 13.

Data from all 13 passes are plotted in figure 12, using 1-second data intervals. Appendix B shows the tabulated data at 2-second intervals. Tabulated times refer to the abscissa of figure 12.

The May 12, 1977, airborne data are compared with those of earlier Titan III launches in figure 13. The solid lines represent the envelope of maximum observed concentrations in each sampling pass for the earlier Titan III launches. As shown in the figure, the May 12, 1977, data are within the earlier data envelope.

Aerosol sizing data.- As discussed in appendix A, the size distribution (QCM and FSSP instruments) of the aerosols in the LVE cloud was determined on a per pass basis rather than as a function of time. Refer to appendix A for a discussion of the data reduction techniques. As noted in appendix A, the QCM instrument (like the nephelometer) is responsive to mainly the particulate portion of the aerosols in the LVE cloud. The heated sample inlet probe of the QCM vaporizes the liquid aerosols (including most of the water on the surface of the particulates) in the air sample prior to the sample air impaction on the QCM sensing crystals. The QCM data for each sampling pass are shown in table IV. As noted in the table, data are not shown for passes 1, 2, 3, 4, and 13 or for the 0.4-μm sizing stage during all passes. (See table IV footnotes as to cause.) The data show a bimodal size distribution with nodes at about 0.1-μm diameter and around 0.8- to

1.6-μm diameter. Few particles above 3-μm diameter were observed. Figure 14 is a plot of the data of table IV. The results of the elemental and morphological analyses of particles collected by the QCM are discussed in detail in reference 15 and are briefly summarized here. The analyses were performed postlaunch on those particles collected on each stage of the QCM. The particles from the QCM stages, which showed positive weight gains, were examined with a scanning electron microscope. The particles in the size range of 0.4 to 1.6 μm consist of aluminum oxide spheres and a few irregular shape particles containing sodium and chlorine. The particles in the smaller size nodes (0.05- to 0.2-μm range) consist of a few single particles and a large number of agglomerates. These particles had a more complex makeup consisting of sodium, aluminum, sulfur, chlorine, potassium, calcium, iron, and zinc.

As discussed in appendix A, the FSSP instrument, located external to the aircraft, is sensitive to both the solid and liquid aerosols in the LVE cloud. Figure 15 and table V show the FSSP data for each of the 13 sampling passes. The data are presented in aerosol percentage, defined as the number of aerosols present in a given size interval divided by the number of aerosols sampled in all size intervals, expressed as a percent. The following comments concerning the FSSP data are appropriate:

(1) For most passes, peak aerosol quantity occurs around 2- to 3-μm diameter. Passes 3, 4, and 6 show maximum aerosols at about 6-μm diameter. Note that passes 3, 4, and 6 along with pass 2 showed the highest incloud HCl data. The significance of this observation cannot be determined until additional data from other launches have been analyzed.

(2) The maximum aerosols present in any size interval is 20 percent (pass 12, 1.5 to 2 μm); generally, for a given pass the maximum aerosol percentage is only 10 to 12 percent.

(3) In most cases, when small diameter aerosols (0.5 to 2.5 μm) increase in number, the larger size aerosols (5.5 to 7 μm) decrease in number. Figure 16 illustrates this behavior. Likewise a decrease in small size aerosols occurs with an increase in large aerosols. Again additional launch data are required before any significance is placed on this observation.

CONCLUDING REMARKS

The data presented herein were obtained during the May 12, 1977, Titan III launch vehicle effluent (LVE) measurement program. Most data are presented in both tabular and graphical form, in a format easily used and referenced for applications. No data analyses are presented and data discussion is limited to only those instances where the

lack of such discussion would result in possible misuse or misinterpretation of the data (e.g., the cloud trajectory-aircraft position discussion is required to judge the relative importance of each airborne sampling pass). A comparison of the May 12, 1977, data with earlier LVE measurement data suggests that the data set is representative of that from a Titan III launch.

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APPENDIX A

OPERATING PRINCIPLES FOR PARTICLE INSTRUMENTATION

The three instruments used for measuring aerosols in the rocket exhaust cloud are briefly discussed.

Integrating Nephelometer

The integrating nephelometer measures the light scattering coefficient of suspended particulates. The inlet is heated so that the relative humidity of the air sample is below the deliquescent point of most aerosols; thus, the nephelometer is insensitive to most liquid aerosols. The integrating nephelometer has a mass concentration scale which was arrived at through the assumption of a linear relation between mass concentration and scattering coefficient (ref. 16). There are limitations on the validity of this assumption and therefore errors involved in relating scattering coefficients to mass concentration. These errors may be as large as a factor of 4, depending on the combination of refractive index and size distribution of the particles (ref. 17). The data obtained with the integrating nephelometer are therefore only an approximation for the mass concentration in the rocket exhaust cloud. However because of its fast response, the nephelometer provides information on the relative concentration of mass as a function of position (time) in the cloud. It also serves to indicate when the aircraft enters and exits the cloud and helps with the interpretation of data from the other instruments aboard the aircraft.

Quartz Crystal Microbalance Cascade Impactor

The quartz crystal microbalance (QCM) of reference 18 is a 10-stage cascade impactor which measures the concentration of particulates as a function of particle diameter covering a size range from 0.05- to 25-μm diameter. It is similar in concept to other cascade impactors in that the particles are separated inertially and classified according to aerodynamic size. The larger particles are collected in the first stage with each succeeding stage collecting progressively smaller particles.

Each stage of the cascade contains a microbalance consisting of two frequency matched quartz crystals in an oscillator circuit. One of the crystals (the sensing crystal) serves as a collecting surface on which the particles are impacted. It has an adhesive coating to prevent the particles from bouncing off. As particles are collected on the crystal's surface, the resonance frequency decreases in proportion to the amount of mass added. This frequency is mixed with the frequency provided by the second crystal (reference), thereby resulting in a beat frequency which is an indication of the mass of the particulates collected. Thus, the particles in each stage (size interval) are auto-

matically weighed as they are collected. The signals from the 10 cascade stages are independent and are recorded as data output.

For the airborne measurements the cascade was flown in the nose section of the aircraft. The particles were brought into the sensor through an inlet probe which was designed to provide isokinetic flow at the aircraft sampling speed of 51 m/s. The inlet air is heated to reduce the relative humidity and thus reduce the amount of moisture reaching the sensing crystals. During previous use of the QCM (single stage), deposits of moisture on the crystals could cause undesirable responses in the instrument, thereby resulting in uninterpretable data. The heating of the inlet air substantially reduces this problem and results in the QCM being relatively insensitive to liquid aerosols.

The mass concentration in each size interval (each stage of the cascade) was determined in the following manner for each sampling pass. At a time (determined from nephelometer data) just before the aircraft entered the cloud, a frequency reading was taken for each stage. A second frequency reading was taken just after exiting the cloud. The difference between the two frequencies Δf is proportional to the mass of the particles collected during that pass. The mass concentration is given by

$$C = 1.44 \times 10^{-3} \frac{\Delta f}{V} \tag{1}$$

where C is the mass concentration ($\mu g/m^3$), 1.44×10^{-3} $\mu g/Hz$ is the mass sensitivity of the crystal, and V is the volume of air sampled during the pass through the cloud. Thus,

$$V = Q\ \Delta t \tag{2}$$

where Q is the rate of air flowing through the cascade (2×10^{-4} m^3/min) and Δt is the transit time of the aircraft through the cloud as indicated by the response of the nephelometer. This data reduction is performed postlaunch from continuous time records of the frequency output for each stage. Any decrease in Δf between sampling passes is attributed to moisture or liquid aerosol evaporation from the sensor crystal. Thus, by monitoring Δf between sampling passes, the effectiveness of the heated inlet probe is determined.

Particles collected in a given stage are assigned an aerodynamic diameter equal to the 50-percent efficiency point (the diameter at which the impaction efficiency is 50 percent for particles with a mass density of 2). The 50-percent efficiency points for each stage in the cascade QCM as given by the instrument manufacturer are those listed in table IV.

APPENDIX A

Forward Scattering Spectrometer Probe

The forward scattering spectrometer probe (FSSP) measures the number of suspended aerosols as a function of aerosol diameter over a size range of 0.5 to 45 μm with four overlapping ranges. For the May 12, 1977, launch a range of 0.5 to 7.5 μm in fifteen 0.5-μm-wide intervals was used. Individual aerosol nuclei (solid and liquid) are counted and sized when they pass through the focused portion of a laser beam (the sampling volume). As each aerosol passes through the sampling volume, it scatters light from the incident laser beam. The light scattered in the near-forward direction is directed onto a photodiode which generates a pulse. There is one pulse for each nucleus that passes through the beam. The magnitude of the pulse depends on the amount of light scattered by the aerosol which is related to the size of the aerosol. The FSSP data are presented as the number of aerosols sampled in a given size interval divided by the total number sampled in all size ranges, expressed in percent.

Since the FSSP is flown external to the aircraft, aerosols are not altered in any way by the sampling process. If, for example, the sample consisted of solid particles, liquid particles, solid particles coated with liquid, or a combination of these three, all would be sampled and detected without changing their state.

APPENDIX B

TABULATION OF AIRBORNE HCl, NO_x, AND NEPHELOMETER PARTICULATE DATA

Tables VI to XVIII are tabulations of the airborne effluent data shown graphically in figure 12. Tabulations are for 2-second intervals. Some background data shown in figure 12 have been omitted from the tabulations.

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TABLE I.- GROUND CLOUD CONSTITUENTS

Specie	Source	Nominal maximum concentration
N_2	Ambient air	Ambient values
O_2	Ambient air	Ambient values
H_2O	Ambient air; launch pad cooling; exhaust	Ambient values
CO_2	Ambient air; exhaust plume afterburning	Ambient values
Particles	Exhaust; pad debris	[a]1000 to 3000 $\mu g/m^3$
HCl	Exhaust	[a]5 to 40 ppm
CO	Ambient air; exhaust	[a]<1 ppm
NO	Exhaust plume afterburning	[a]200 to 800 ppb
Cl_2	Exhaust plume afterburning	[b]20 to 40 ppb

[a]Measured values from earlier LVE.

[b]Measured in LVE activities since May 1977.

TABLE II.- AIRBORNE SAMPLING PARAMETERS

Pass	Sampling altitude, m (a)	Type of pass	Aircraft location from LC-40 (b)		Time of pass after launch, min (c)
			km	Azimuth, deg	
1	1076 ± 31	Downwind	(d)	(d)	4.8
2	1169 ± 30	Crosswind	(d)	(d)	6.1
3	1426 ± 26	Downwind	(d)	(d)	9.2
4	1440 ± 18	Crosswind	6.1	274	11.2
5	1565 ± 21	Downwind	4.2	270	13.8
6	1558 ± 11	Crosswind	4.0	290	16.1
7	1565 ± 13	Downwind	3.5	320	18.7
8	1460 ± 27	Skew	7.0	269	28.0
9	1509 ± 22	Crosswind	7.6	260	31.9
10	1407 ± 26	Upwind	(d)	(d)	39.6
11	1377 ± 32	Crosswind	15.4	255	43.0
12	1376 ± 27	Crosswind	15.3	260	45.0
13	1403 ± 26	Skew	16.4	261	48.4

[a]Sampling altitude ± Altitude variation during pass.

[b]Aircraft location at time of pass.

[c]Approximate time when aircraft was at center of cloud.

[d]Radar track data not available.

TABLE III.- INSTRUMENT CHARACTERISTICS

Instrument	Specie	Reference	Range (a)	Detection limit	Time to respond to 90 percent reading, sec
Chemiluminescent	HCl	10, 12, 13	0.5 to 200 ppm	0.5 ppm	1
Chemiluminescent	NO and NO_x	10	0.002 to 5 ppm	0.002 ppm	1
10-stage quartz crystal microbalance[b]	Aerosols	14	0.05- to 25-μm diameter	10 $\mu g/m^3$	2
Forward scattering spectrometer probe[c]	Aerosols	--------	0.5- to 7.5-μm diameter	1 nucleus	<1
Nephelometer	Aerosols	10	>0.4-μm diameter	100 neuclei	.2

[a]For aerosol instruments, range given in aerosol diameter.

[b]Mass concentration at 10 diameter ranges (0.05, 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.3, 12.5, and 25 μm).

[c]Aerosol number density in 15 diameter ranges (0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, and 7.5 μm).

TABLE IV.- PARTICULATE MASS CONCENTRATION ($\mu g/m^3$) AS FUNCTION OF PARTICLE DIAMETER (QCM DATA)

Pass	Particle diameter, μm										Σ stages
	0.05	0.1	0.2	0.4	0.8	1.6	3.2	6.3	12.5	25	
[a]1	---	---	--	--	--	--	--	--	---	--	---
[a]2	---	---	--	--	--	--	--	--	---	--	---
[a]3	---	---	--	--	--	--	--	--	---	--	---
[a]4	---	---	--	--	--	--	--	--	---	--	---
5	25	406	9	(b)	68	25	0	0	0	0	533
6	52	380	17	(b)	52	9	0	0	0	0	510
7	43	155	9	(b)	69	17	0	0	0	0	293
8	35	66	4	(b)	17	70	0	0	0	0	192
[c]9	72	72	23	(b)	12	40	0	0	0	0	219
10	27	54	10	(b)	3	14	0	0	0	0	108
11	25	108	11	(b)	22	14	0	0	0	0	180
12	62	88	26	(b)	11	18	0	0	0	0	205
[c]13	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)

[a]Instrument not warmed up. Data invalid.

[b]QCM stage for 0.4-μm particles inoperative for launch sampling.

[c]Data includes puff.

[d]No significant mass gain above background.

TABLE V.- PERCENT OF AEROSOL AS FUNCTION OF SIZE

(FSSP DATA)

Pass	Diameter, μm														
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
1	4.3	6.5	8.1	8.7	8.6	8.6	8.4	8.2	8.1	7.3	6.7	6.1	5.4	4.4	0.6
2	2.1	3.4	4.5	6.8	10.8	12.4	12.1	11.0	9.5	7.1	6.1	5.5	4.7	3.3	.7
3	2.0	3.5	5.0	7.4	9.4	7.7	6.4	6.2	7.2	7.4	9.3	10.4	9.7	7.5	.9
4	2.4	3.2	4.2	5.1	6.2	5.8	5.4	6.2	8.0	8.4	10.7	11.9	10.9	9.4	2.2
5	3.4	5.7	7.6	10.0	12.1	7.6	5.3	5.3	5.7	7.1	7.9	8.3	7.5	5.7	.8
6	2.9	4.2	5.6	7.6	9.0	6.7	5.5	6.4	7.9	7.6	9.3	10.0	9.0	7.8	.5
7	4.3	5.5	8.0	10.1	12.1	7.6	5.0	5.8	7.0	6.3	7.0	7.6	7.1	6.1	.5
8	3.5	6.5	10.3	12.8	14.2	9.1	5.9	5.7	6.2	6.1	6.9	5.8	3.8	2.6	.6
[a]9	4.7	7.2	9.9	12.5	13.9	7.9	5.2	5.6	6.3	5.8	6.5	6.2	4.6	3.0	.7
10	6.6	12.4	16.0	17.9	17.7	8.8	4.4	2.8	2.4	2.2	2.5	2.1	1.6	1.5	1.1
11	10.4	17.6	17.0	17.6	13.6	4.7	2.7	2.2	2.7	1.9	1.9	2.2	2.0	1.9	1.6
12	10.9	18.9	19.4	20.0	16.1	4.2	2.0	1.2	1.4	1.2	1.1	1.2	.9	.7	.8
[a]13	8.0	12.3	15.1	17.0	15.5	6.7	3.8	3.1	3.3	2.7	3.0	2.8	1.5	1.5	.9

[a]Data includes puff.

TABLE VI.- AIRBORNE DATA SAMPLING PASS 1

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
0	0.2	16	26
2	.2	16	27
4	.2	50	28
6	.2	10	29
8	.2	22	25
10	.2	-8	25
12	.2	25	27
14	.2	-34	28
16	.2	5	48
18	.2	29	110
20	.2	17	161
22	.2	20	185
24	.5	23	294
26	.6	32	331
28	.5	51	253
30	3.9	115	295
32	1.0	139	271
34	.6	192	144
36	.4	365	81
38	.3	337	53
40	.3	271	38
42	.2	516	34
44	.2	387	30

TABLE VII.- AIRBORNE DATA SAMPLING PASS 2

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
20	0.2	10	27
22	.2	41	27
24	.2	7	27
26	.2	33	36
28	.2	20	27
30	.2	21	28
32	.2	18	31
34	.2	42	27
36	.6	7	49
38	4.6	33	185
40	6.8	49	334
42	4.2	8	422
44	1.5	62	330
46	.9	63	178
48	.6	119	97
50	.5	296	60
52	1.1	464	53
54	.8	565	81
56	.6	389	63
58	.5	125	43
60	.4	24	33
62	.4	15	29
64	.4	53	28
66	.4	75	27
68	.3	39	25
70	.3	28	33

TABLE VIII.- AIRBORNE DATA SAMPLING PASS 3

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$ (a)
10	0.2	10	
12	.2	4	
14	.2	5	
16	1.0	-7	
18	1.3	-35	
20	1.3	20	
22	2.9	10	
24	4.4	7	
26	4.0	56	
28	4.3	43	
30	5.6	130	
32	6.5	139	
34	6.2	123	
36	6.5	198	
38	3.8	230	
40	4.0	229	
42	6.0	260	
44	8.7	343	
46	9.2	288	
48	7.7	334	
50	9.1	233	
52	9.6	174	
54	6.7	232	
56	6.3	362	
58	4.3	413	
60	3.2	445	
62	3.3	377	
64	2.8	410	
66	2.0	315	
68	1.7	275	
70	1.8	176	
72	1.9	87	
74	1.4	77	
76	1.1	81	
78	.9	0	
80	.8	22	
82	.7	36	
84	.6	75	
86	.6	39	
88	.5	3	
90	.5	35	
92	.5	3	
94	.5	0	
96	.5	-13	
98	.5	1	
100	.4	11	

[a]Malfunctioned during pass 3.

TABLE IX.- AIRBORNE DATA SAMPLING PASS 4

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
10	0.3	10	54
12	.3	19	46
14	.3	31	38
16	.3	60	23
18	.4	10	48
20	.4	50	89
22	1.2	18	185
24	1.4	22	272
26	1.8	4	383
28	4.1	19	468
30	3.4	27	784
32	4.8	84	1026
34	9.7	112	1292
36	8.4	110	1871
38	5.8	146	1663
40	4.7	169	1163
42	4.3	200	948
44	5.4	255	744
46	4.0	342	652
48	4.7	448	457
50	4.8	355	432
52	5.3	256	411
54	4.3	257	430
56	2.9	227	304
58	2.6	201	175
60	2.3	226	105
62	1.9	243	57
64	1.8	288	43
66	1.6	195	42
68	1.5	108	42
70	1.3	75	40
72	1.2	62	40
74	1.2	40	36
76	1.2	82	20
78	1.2	39	38
80	1.1	36	55
82	1.0	9	40
84	.9	45	59
86	.8	61	48
88	.7	23	57
90	.7	70	54
92	.6	37	56
94	.5	13	54
96	.5	33	58
98	.5	36	60
100	.4	47	66

TABLE X.- AIRBORNE DATA SAMPLING PASS 5

Reference time, sec	HCl concentration, ppb	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
10	0.3	44	22
12	.3	71	20
14	.3	21	38
16	1.3	36	32
18	1.9	42	88
20	2.0	10	113
22	2.3	52	106
24	2.1	41	97
26	1.9	47	87
28	1.5	73	54
30	1.2	147	25
32	1.3	135	39
34	1.0	162	21
36	.9	144	1
38	.9	103	-2
40	.8	73	5
42	.6	95	-25
44	.6	71	-45
46	.6	77	-11
48	.5	52	-16
50	.5	70	-15
52	.4	64	-30
54	.6	6	65
56	.9	20	156
58	.8	36	196
60	1.8	49	270
62	1.3	30	243
64	1.0	46	174
66	2.0	42	390
68	2.8	49	561
70	4.2	97	707
72	2.7	97	493
74	1.6	113	327
76	2.9	99	314
78	1.9	87	248
80	1.9	177	223
82	1.5	242	157
84	1.2	165	105
86	1.0	150	81
88	.9	113	32
90	.8	140	31
92	.8	82	40
94	.7	64	45
96	.9	36	131
98	1.4	31	178
100	1.4	48	183
102	1.2	52	85
104	.9	38	10
106	.7	71	1
108	.7	76	14
110	.6	108	39
112	.6	86	37
114	.5	107	35
116	.5	58	19
118	.5	-11	8
120	.5	33	24

TABLE XI.- AIRBORNE DATA SAMPLING PASS 6

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
10	0.3	22	-14
12	.3	64	1
14	.3	20	2
16	.2	-18	10
18	.3	11	0
20	.3	25	107
22	.4	25	146
24	.6	13	161
26	2.6	10	331
28	3.5	45	546
30	3.7	74	664
32	4.7	39	668
34	3.8	56	705
36	4.6	66	602
38	4.8	162	536
40	5.2	237	525
42	4.9	247	549
44	4.3	219	484
46	3.8	241	449
48	2.6	246	353
50	2.7	253	247
52	2.2	234	212
54	1.7	223	143
56	1.3	197	86
58	1.2	188	41
60	1.0	150	19
62	.9	120	12
64	.8	108	4
66	.8	65	-14
68	.7	59	-9
70	.6	74	-5

TABLE XII.- AIRBORNE DATA SAMPLING PASS 7

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
10	0.3	54	17
12	.3	30	22
14	.3	38	36
16	.3	25	26
18	.4	40	39
20	.4	15	79
22	.3	20	46
24	.5	26	39
26	.5	76	59
28	.5	48	63
30	.4	53	38
32	.5	81	55
34	.6	78	68
36	.6	45	77
38	1.1	28	82
40	1.4	82	82
42	2.2	67	86
44	1.3	48	111
46	.9	52	97
48	.7	44	77
50	.6	71	43
52	.6	70	18
54	.5	84	37
56	.6	135	24
58	.7	126	67
60	1.0	74	85
62	1.1	39	134
64	.7	70	117
66	.7	31	92
68	.7	2	83
70	.7	68	81
71	.6	68	67
74	.6	83	76
76	.5	86	50
78	.5	40	18

TABLE XIII.- AIRBORNE DATA SAMPLING PASS 8

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
20	0.4	40	13
22	.5	11	15
24	.4	39	20
26	.4	-9	52
28	.4	38	54
30	.4	35	167
32	.4	45	141
34	.4	-3	200
36	.4	-9	289
38	.5	37	246
40	.5	34	267
42	.7	70	326
44	.5	64	351
46	.8	70	445
48	.9	112	494
50	1.4	29	497
52	1.3	106	514
54	1.6	133	517
56	1.9	117	510
58	2.0	136	517
60	2.1	194	529
62	2.1	144	503
64	1.8	166	472
66	1.8	151	458
68	1.8	158	436
70	1.8	125	423
72	1.9	104	427
74	1.8	99	411
76	1.8	86	398
78	1.9	91	360
80	2.0	108	412
82	1.6	118	436
84	1.6	83	334
86	1.4	83	252
88	1.5	109	237
90	1.5	67	283
92	1.2	139	245
94	1.0	99	137
96	.8	60	92
98	.7	36	38
100	.6	76	19
102	.5	78	5
104	.6	23	18
106	.6	40	24
108	.5	0	12
110	.5	42	10

TABLE XIV.- AIRBORNE DATA SAMPLING PASS 9

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
20	0.3	8	-78
22	.3	23	-76
24	.3	8	-57
26	.3	29	-41
28	.3	20	-37
30	.4	35	-6
32	.3	-15	41
34	.5	37	95
36	.6	8	87
38	.6	41	111
40	.7	26	115
42	.6	56	82
44	.7	7	---
46	.9	23	107
48	1.0	76	137
50	1.2	69	188
52	1.3	62	202
54	1.4	53	255
56	1.6	68	265
58	1.8	96	287
60	1.7	74	278
62	1.7	78	294
64	1.6	69	280
66	1.6	63	253
68	1.9	79	257
70	2.0	130	303
72	2.0	137	311
74	2.4	114	309
76	2.6	79	318
78	2.6	108	283
80	2.3	129	290
82	2.6	82	268
84	2.9	149	237
86	2.2	110	235
88	2.0	88	185
90	3.0	106	183
92	2.6	136	239
94	2.5	124	194
96	2.8	112	187
98	2.0	111	177
100	1.7	81	111
102	1.5	94	68
104	1.3	113	82
106	1.2	61	54
108	1.1	126	55
110	1.1	82	40
112	1.0	53	12
114	1.0	43	21
116	1.0	30	42
118	.9	45	36

TABLE XIV.- Concluded

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
[a]120	0.9	66	44
122	.8	58	46
124	.8	44	49
126	.7	66	22
128	.7	59	21
130	1.8	10	52
132	1.6	52	189
134	.8	31	168
136	.9	61	103
138	1.0	73	80
140	1.5	58	112
142	1.8	104	166
144	1.7	79	227
146	1.1	48	234
148	1.3	19	176
150	1.5	51	107
152	2.1	85	60
154	2.8	114	29
156	2.4	107	14
158	1.9	121	118
160	1.9	23	212
162	1.5	77	227
164	1.4	11	220
166	1.5	41	141
168	1.9	35	190
170	1.8	45	281
172	1.5	75	238
174	2.2	41	129
176	2.4	49	69
178	2.5	66	31
180	2.2	92	-1
182	2.0	101	-15
184	1.8	-17	4
186	1.6	72	21
188	1.4	36	72
190	1.4	2	155
192	1.8	40	102
194	2.2	78	46
196	2.3	7	-2
198	2.3	31	-1
200	1.8	69	-19
202	1.4	46	33
204	1.2	66	91
206	1.1	23	75
208	.8	54	50
210	.9	34	51
212	.9	35	23
214	.9	56	27
216	.9	40	31
218	1.0	51	20
220	1.0	50	33

[a]Start of puff data.

TABLE XV.- AIRBORNE DATA SAMPLING PASS 10

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
20	0.3	42	-24
22	.3	60	-24
24	.3	51	8
26	.3	53	5
28	.3	38	23
30	.3	2	44
32	.3	-6	108
34	.3	39	192
36	.3	60	242
38	.2	23	274
40	.4	32	308
42	.6	28	314
44	.8	41	352
46	.9	37	378
48	1.0	81	375
50	1.4	48	403
52	1.7	27	473
54	1.6	51	534
56	1.8	124	543
58	1.9	93	532
60	1.9	101	516
62	2.0	93	484
64	1.9	88	479
66	2.4	180	501
68	2.3	154	494
70	2.4	116	508
72	2.4	131	531
74	2.2	100	549
76	2.4	79	560
78	2.2	112	524
80	2.3	117	488
82	2.2	121	428
84	2.2	112	396
86	2.0	117	400
88	2.1	115	397
90	2.0	125	425
92	1.9	104	454
94	1.8	104	477
96	1.8	102	530

TABLE XV.- Concluded

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
98	1.8	77	523
100	1.7	50	571
102	1.7	58	552
104	1.6	105	538
106	1.6	130	486
108	1.6	83	448
110	1.8	106	399
112	1.8	156	341
114	1.8	81	331
116	1.7	80	340
118	1.6	59	307
120	1.6	17	239
122	1.6	44	196
124	1.5	59	181
126	1.5	82	169
128	1.4	103	130
130	1.4	42	92
132	1.4	77	75
134	1.3	27	79
136	1.3	25	57
138	1.2	59	56
140	1.2	35	40
142	1.1	34	10
144	1.2	-10	11
146	1.1	39	29
148	1.0	15	37
150	.9	53	46
152	.9	-23	29
154	.9	19	11
156	.8	26	23
158	.8	54	11
160	.8	73	18
162	.7	49	36
164	.6	-3	45
166	.6	63	57
168	.6	56	47
170	.6	-3	33

TABLE XVI.- AIRBORNE DATA SAMPLING PASS 11

Reference time, sec	HCl concentration, ppm (a)	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
10		7	81
12		40	55
14		32	41
16		41	30
18		23	49
20		-6	68
22		31	131
24		55	223
26		60	286
28		23	328
30		18	356
32		14	332
34		46	298
36		73	261
38		108	250
40		58	239
42		33	232
44		55	201
46		63	178
48		13	166
50		42	149
52		0	169
54		32	210
56		33	221
58		27	194
60		13	185
62		45	189
64		44	179
66		21	165
68		72	162
70		97	179
72		55	188
74		50	196
76		31	203

[a]Malfunctioned during pass 11.

TABLE XVI.- Concluded

Reference time, sec	HCl concentration, ppm (a)	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
78		63	202
80		52	226
82		45	242
84		25	212
86		85	223
88		77	258
90		98	275
92		52	281
94		63	268
96		30	270
98		26	229
100		74	230
102		91	234
104		30	255
106		66	279
108		41	303
110		-9	300
112		74	310
114		49	303
116		47	335
118		27	367
120		6	371
122		53	440
124		-2	475
126		47	474
128		33	471
130		88	346
132		54	253
134		107	206
136		103	171
138		100	142
140		46	189
142		86	153
144		106	91
146		77	70

[a]Malfunctioned during pass 11.

TABLE XVII.- AIRBORNE DATA SAMPLING PASS 12

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
20	0.1	44	111
22	.1	20	170
24	.1	-35	188
26	.1	19	229
28	.2	41	271
30	.3	34	337
32	.7	89	372
34	.8	47	444
36	1.1	67	467
38	1.2	84	500
40	1.1	78	520
42	1.1	135	501
44	1.0	65	489
46	1.0	114	478
48	1.0	146	505
50	.8	162	464
52	.8	92	413
54	.7	95	407
56	.7	98	385
58	.5	86	346
60	.5	71	363
62	.5	118	362
64	.5	110	384
66	.5	53	389
68	.4	75	385
70	.4	69	379
72	.4	75	391
74	.4	66	407
76	.4	87	406
78	.4	38	398
80	.3	34	355
82	.3	43	313
84	.3	105	278
86	.3	95	280
88	.2	50	251
90	.2	78	231
92	.2	12	243
94	.1	47	240
96	.2	74	257
98	.1	27	252
100	.1	45	248
102	.1	37	231
104	.1	70	195
106	.1	60	140
108	.1	7	137
110	.1	16	118
112	.2	38	129
114	.1	100	137
116	.1	41	95
118	.1	46	62
120	0	27	51

TABLE XVIII.- AIRBORNE DATA SAMPLING PASS 13

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
20	0.4	-28	2
22	.5	45	7
24	.5	47	-1
26	.5	43	121
28	.5	22	296
30	.6	26	396
32	.5	26	364
34	.5	44	259
36	.5	2	151
38	.5	63	91
40	.4	100	61
42	.4	49	62
44	.4	37	80
46	.4	28	130
48	.4	34	155
50	.4	-19	178
52	.5	27	197
54	.5	72	218
56	.6	-9	252
58	.6	71	288
60	.7	56	306
62	.8	18	343
64	1.0	54	394
66	.9	96	385
68	.9	18	331
70	1.0	96	300
72	1.3	53	360
74	1.6	54	381
76	1.6	66	379
78	1.9	63	372
80	1.7	30	469
82	1.7	31	427
84	1.6	102	416
86	1.4	123	348
88	1.3	113	314
90	1.2	95	308
92	1.2	89	300
94	1.2	119	208
96	1.1	52	139
98	1.1	120	127

TABLE XVIII.- Concluded

Reference time, sec	HCl concentration, ppm	NO_x concentration, ppb	Particle concentration (nephelometer), $\mu g/m^3$
100	1.0	92	113
102	1.0	11	76
104	.9	40	64
106	1.0	78	64
108	.9	16	37
110	.8	40	40
112	.8	51	36
114	.8	51	10
116	.8	45	29
118	.8	62	31
[a]180	.6	75	2
182	.6	60	2
184	.6	10	3
186	.5	12	19
188	.5	46	42
190	.6	43	65
192	.6	19	98
194	.6	57	151
196	.5	55	223
198	.7	70	277
200	.7	107	297
202	1.2	58	337
204	1.7	65	485
206	1.3	78	539
208	1.4	37	498
210	1.3	48	365
212	1.2	116	260
214	1.2	72	232
216	1.1	89	192
218	1.0	133	153
220	1.0	54	144
222	1.0	39	135
224	1.0	44	133
226	.9	53	112
228	.9	18	50
230	.9	62	13
232	.8	29	-6
234	.8	51	0
236	.8	42	3
238	.8	51	1
240	.8	-23	10

[a]Puff data.

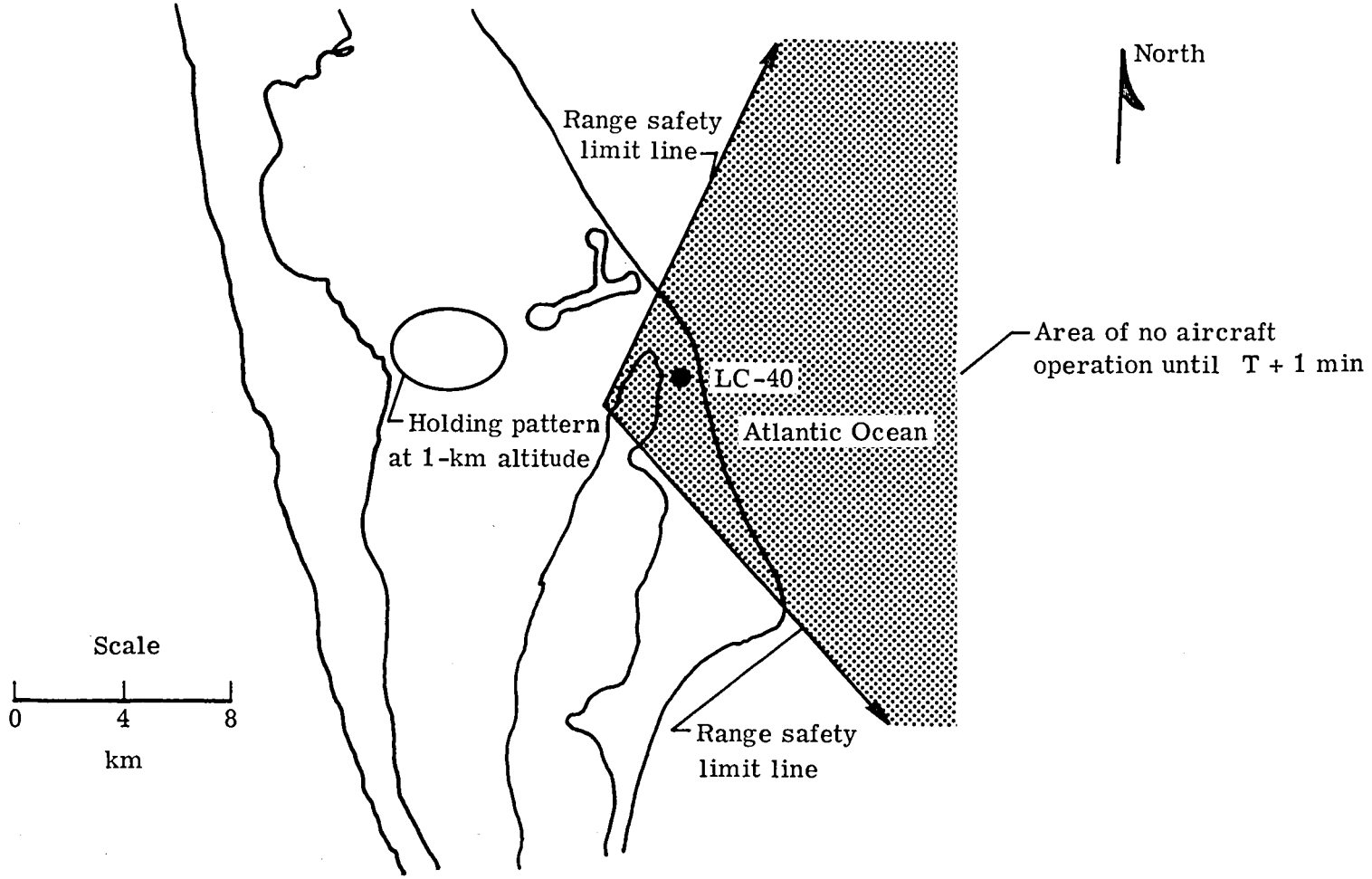


Figure 1.- Aircraft holding pattern.

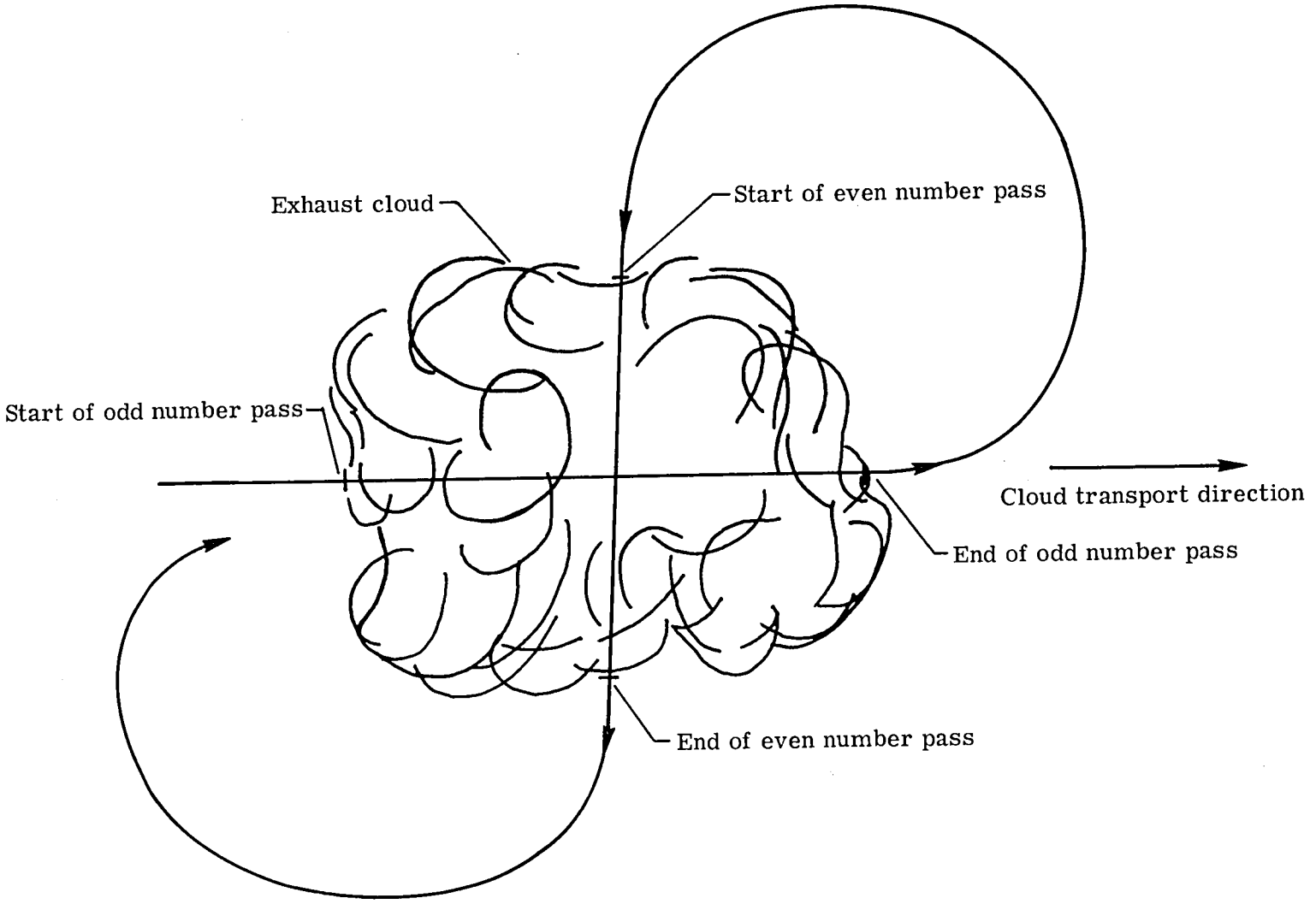


Figure 2.- Basic aircraft sampling plan, downwind and crosswind (plan view). Alternate odd and even number passes may be at varying altitudes.

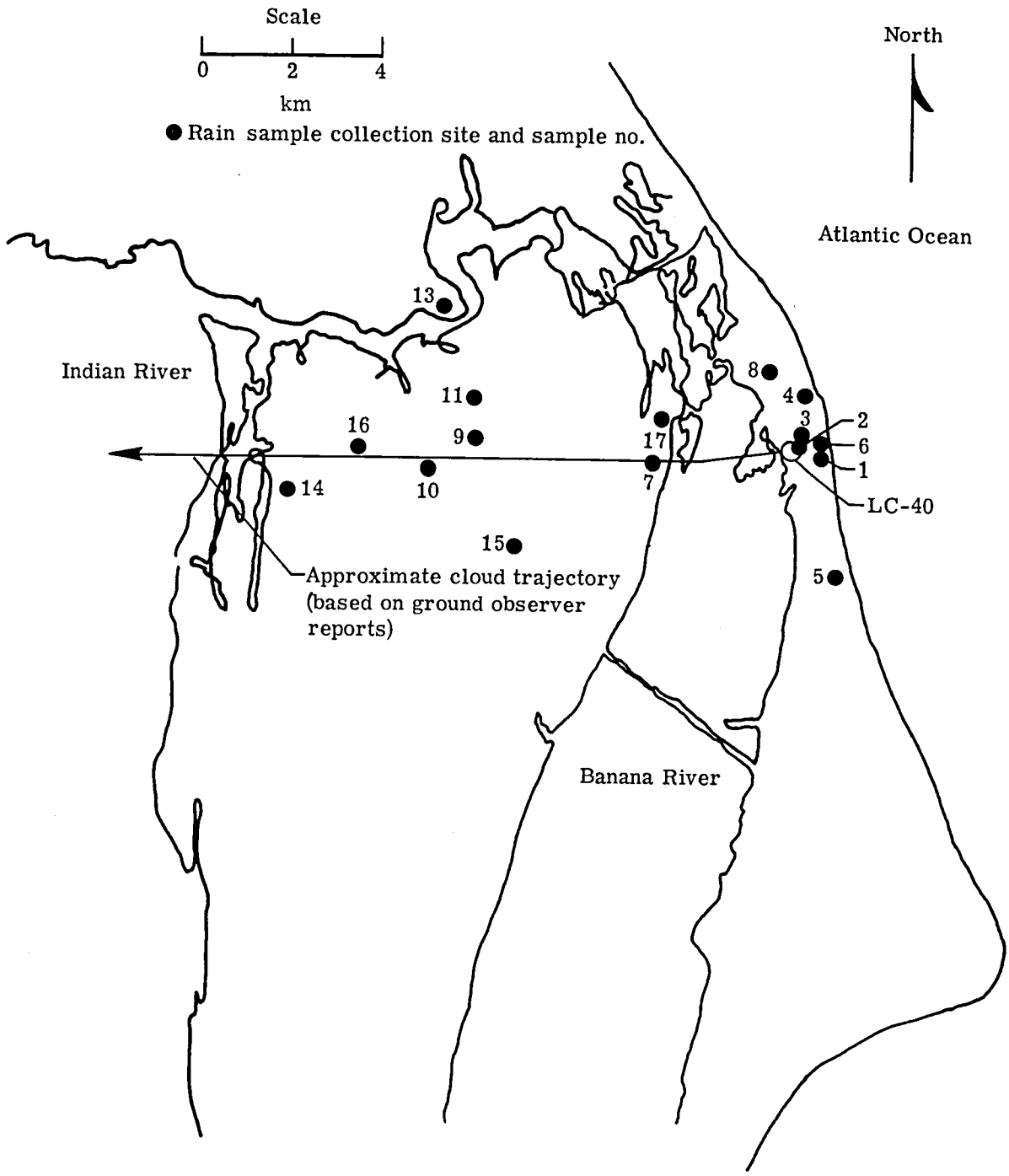


Figure 3.- Surface-rain-collector site plan.

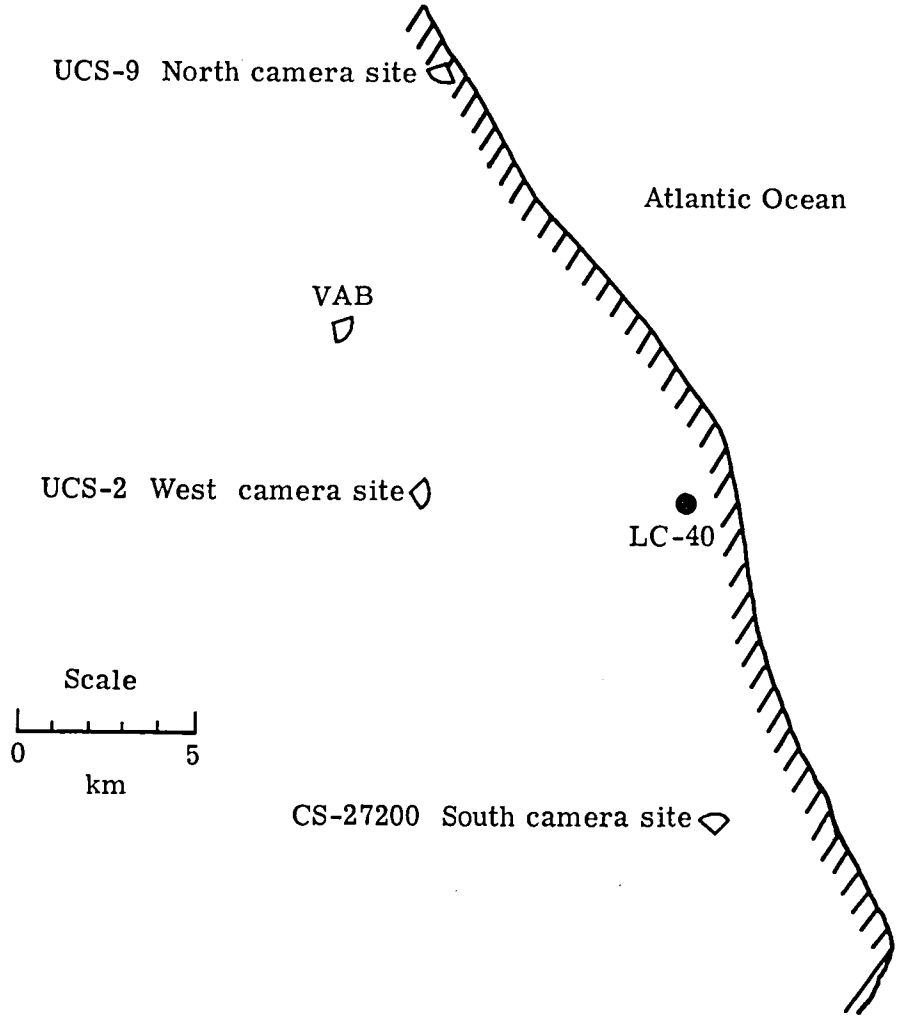


Figure 4.- Optical-instrumentation site locations.

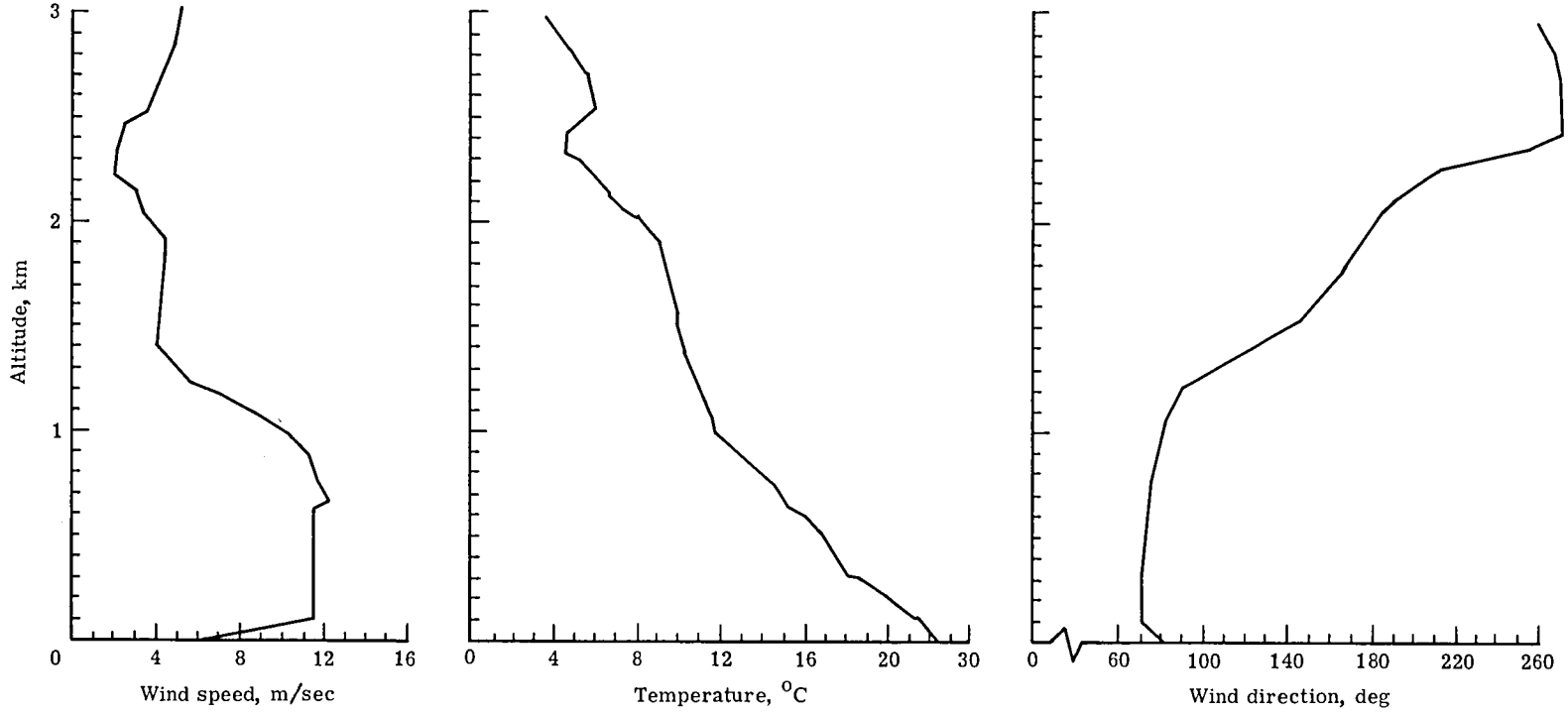


Figure 5.- Launch meteorology. T - 0 tower data; T - 40 min rawinsonde release.

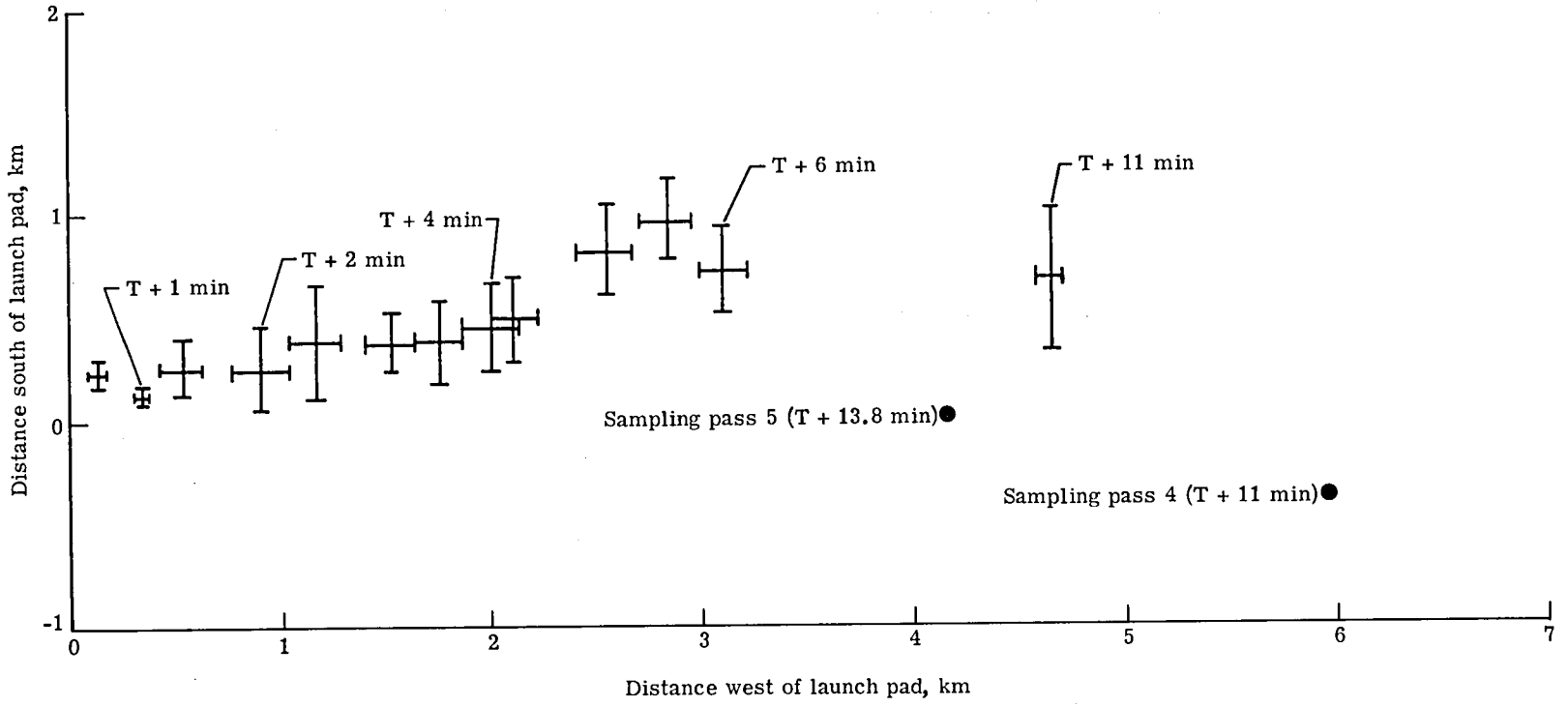


Figure 6.- Optical track of cloud trajectory.

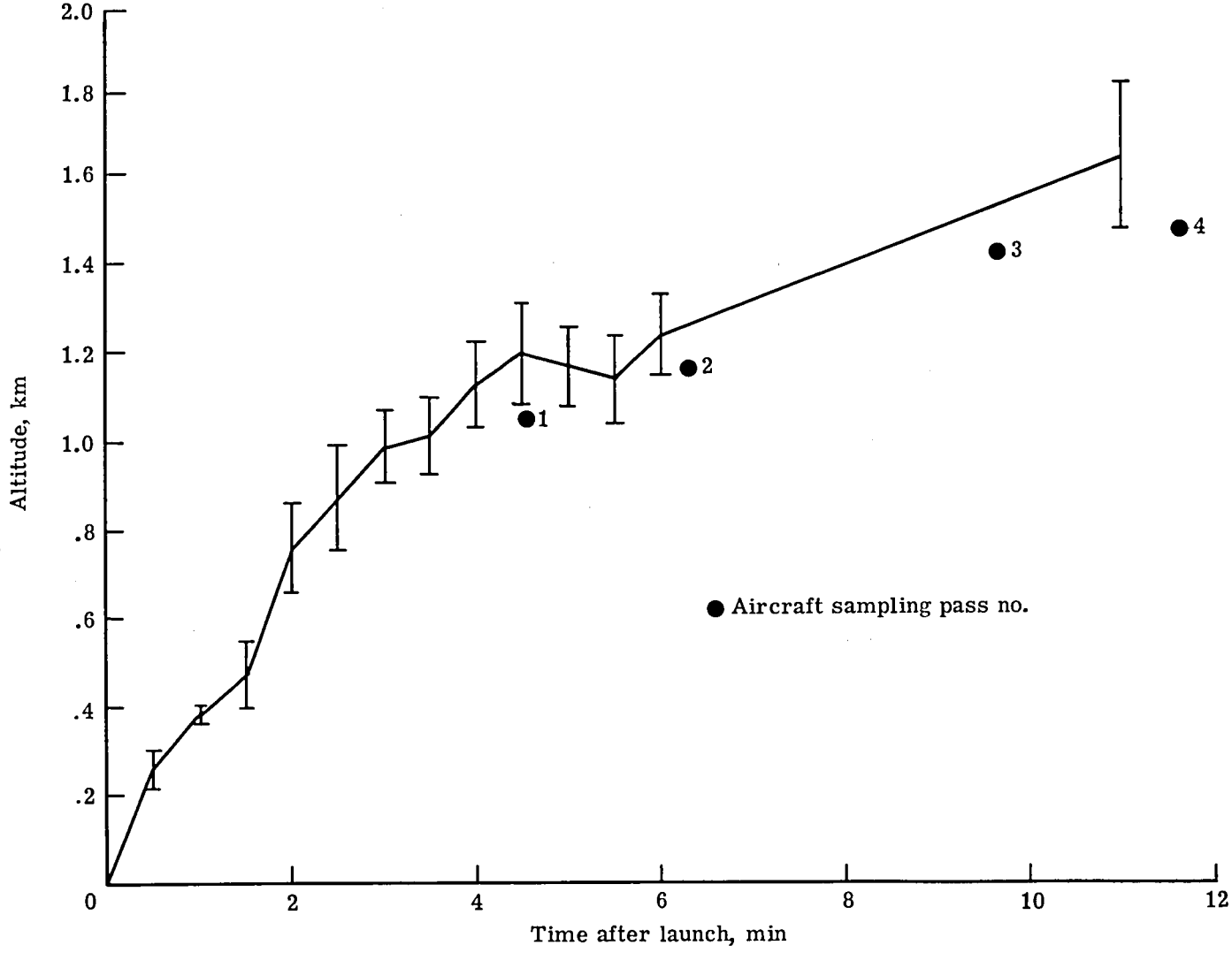


Figure 7.- Cloud-rise data.

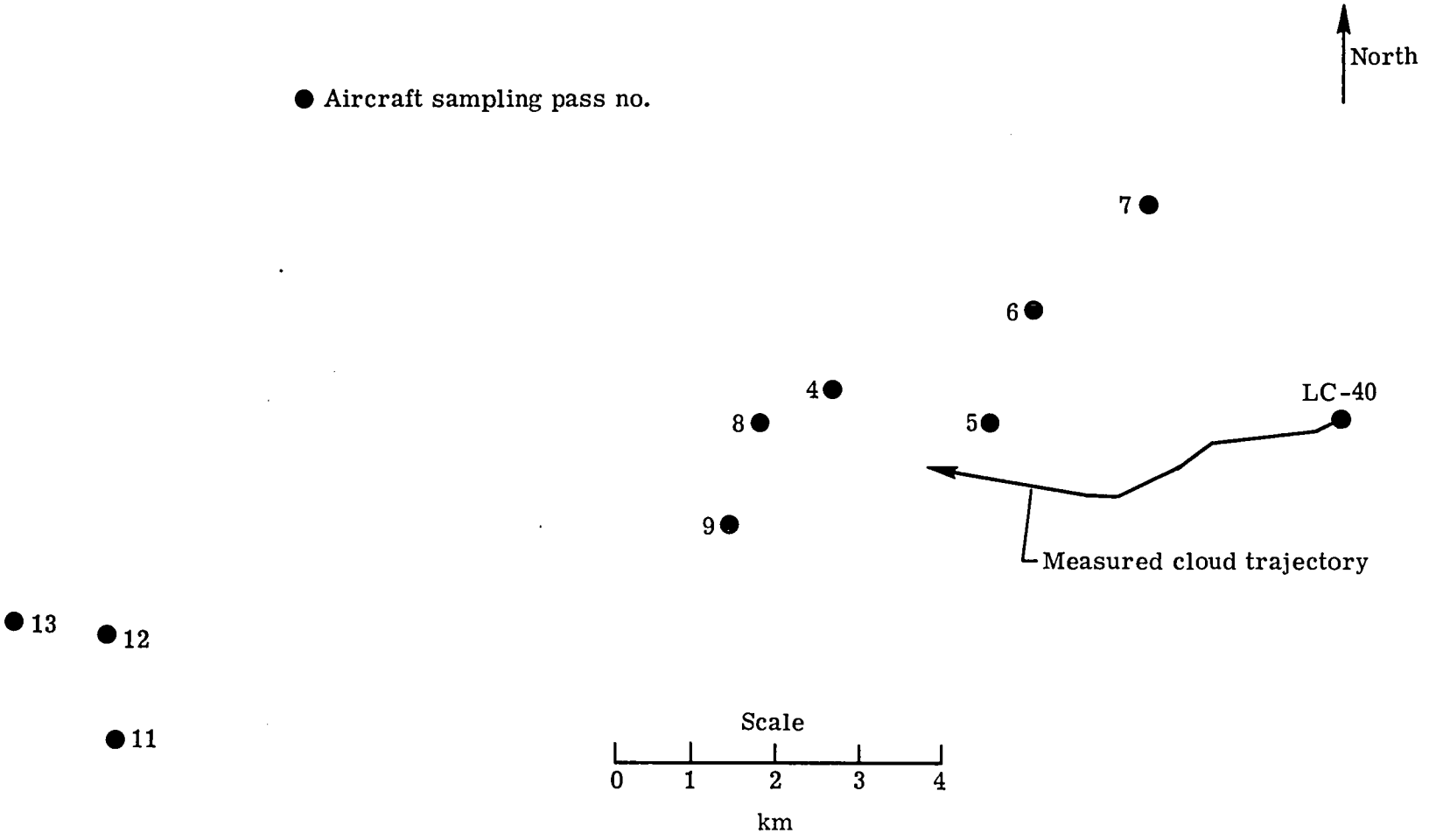


Figure 8.- Comparison of cloud trajectory and aircraft location.

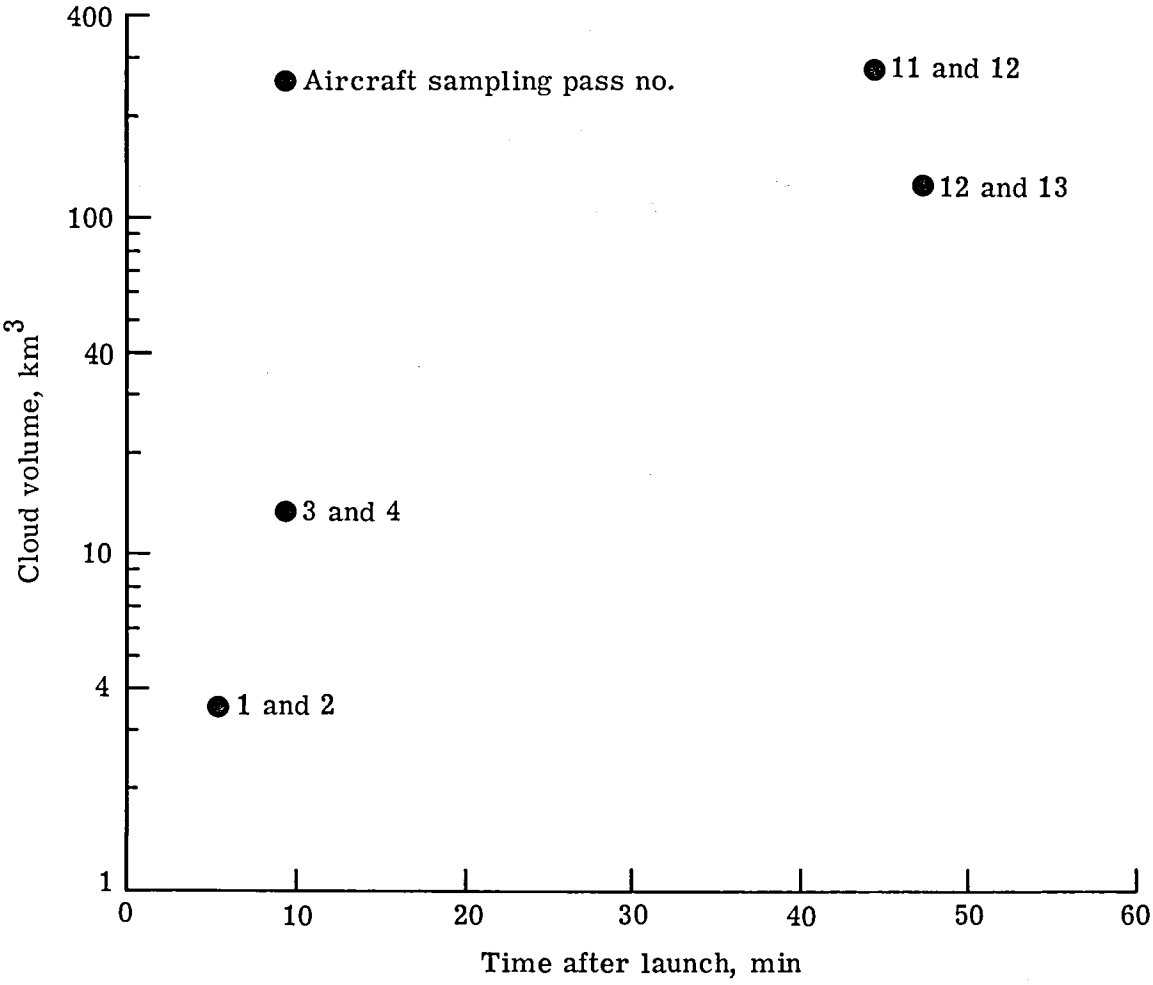


Figure 9.- Estimated cloud volume; aircraft data.

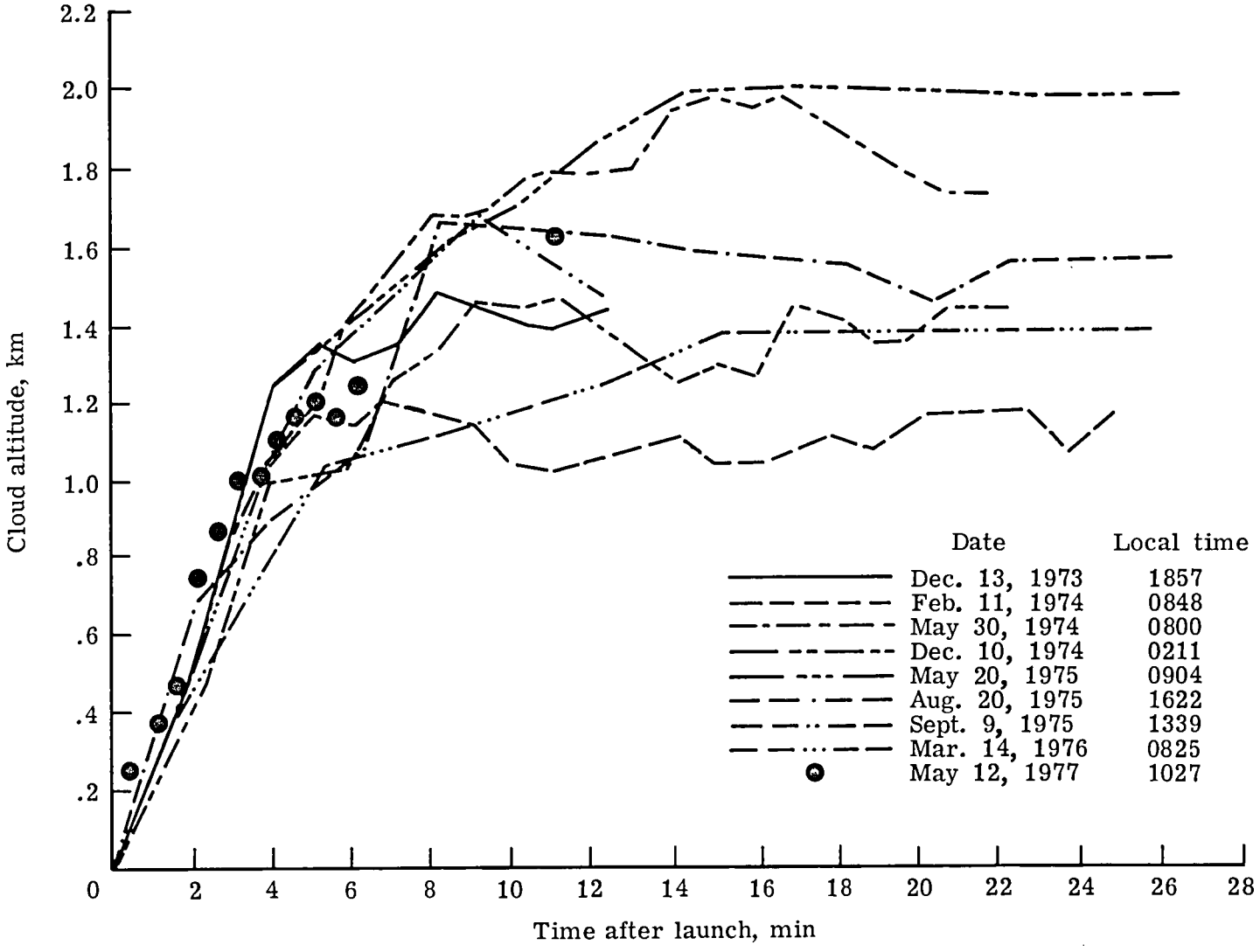


Figure 10.- Cloud rise and stabilization height. Titan III launches.

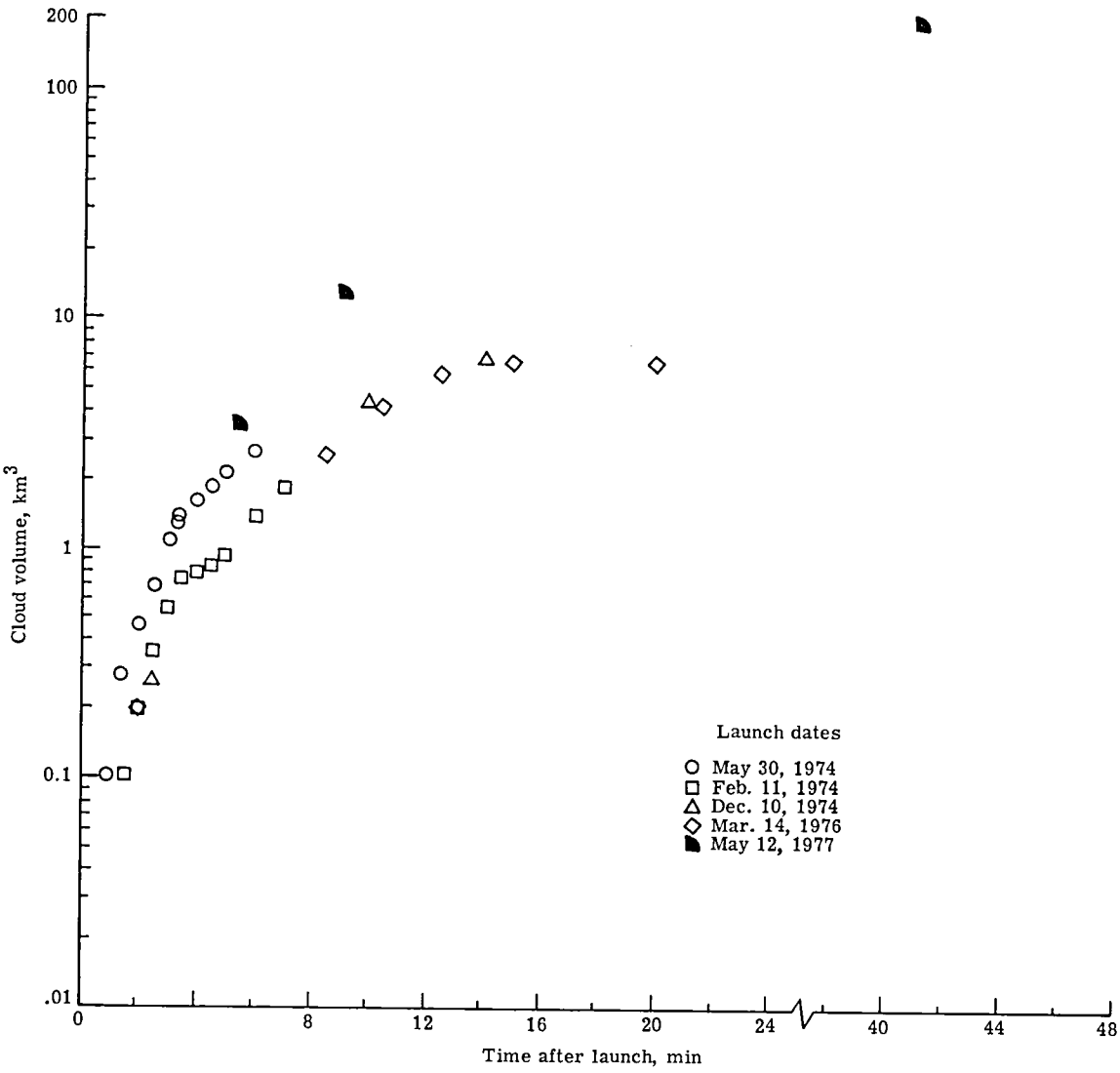
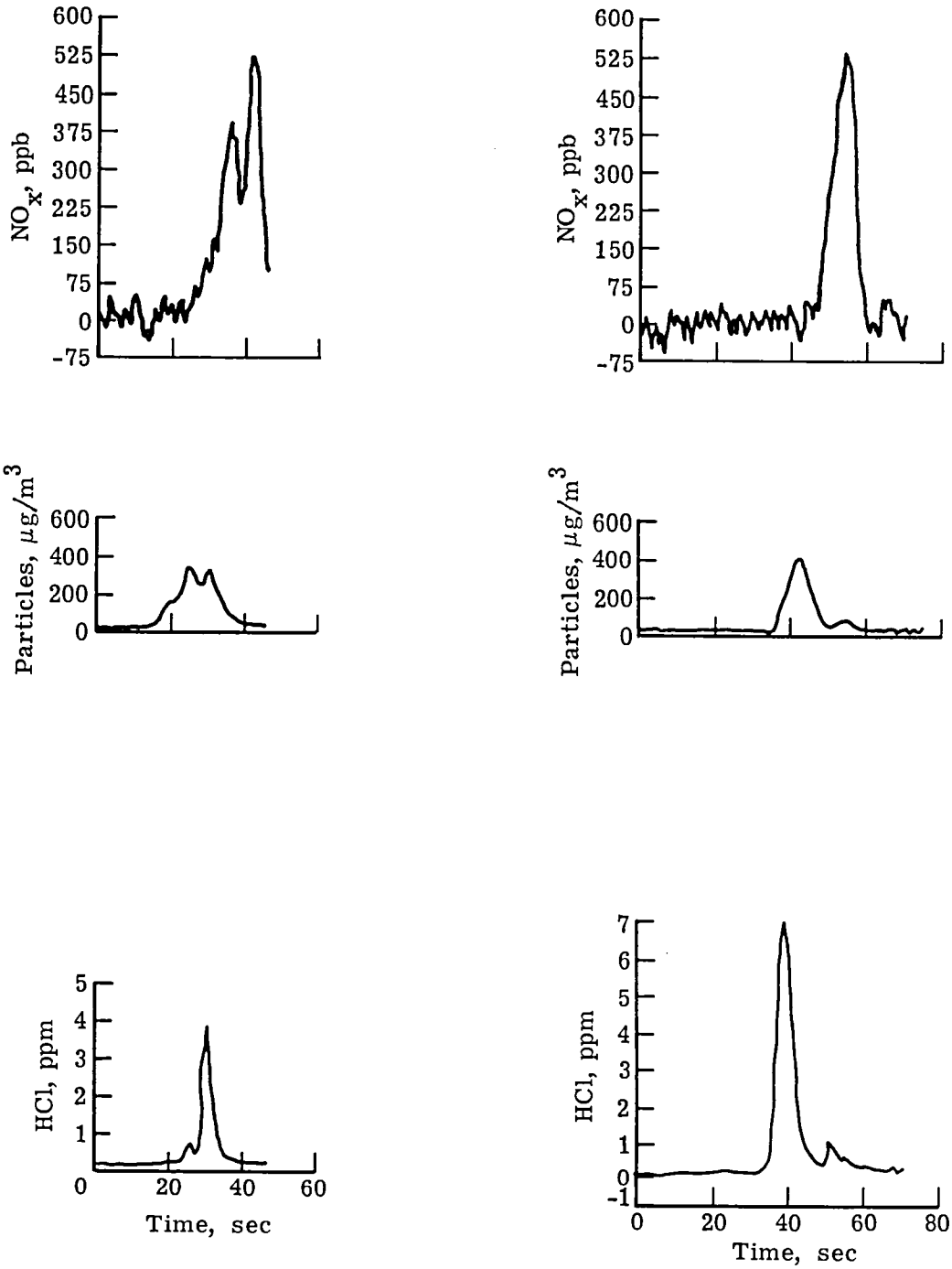


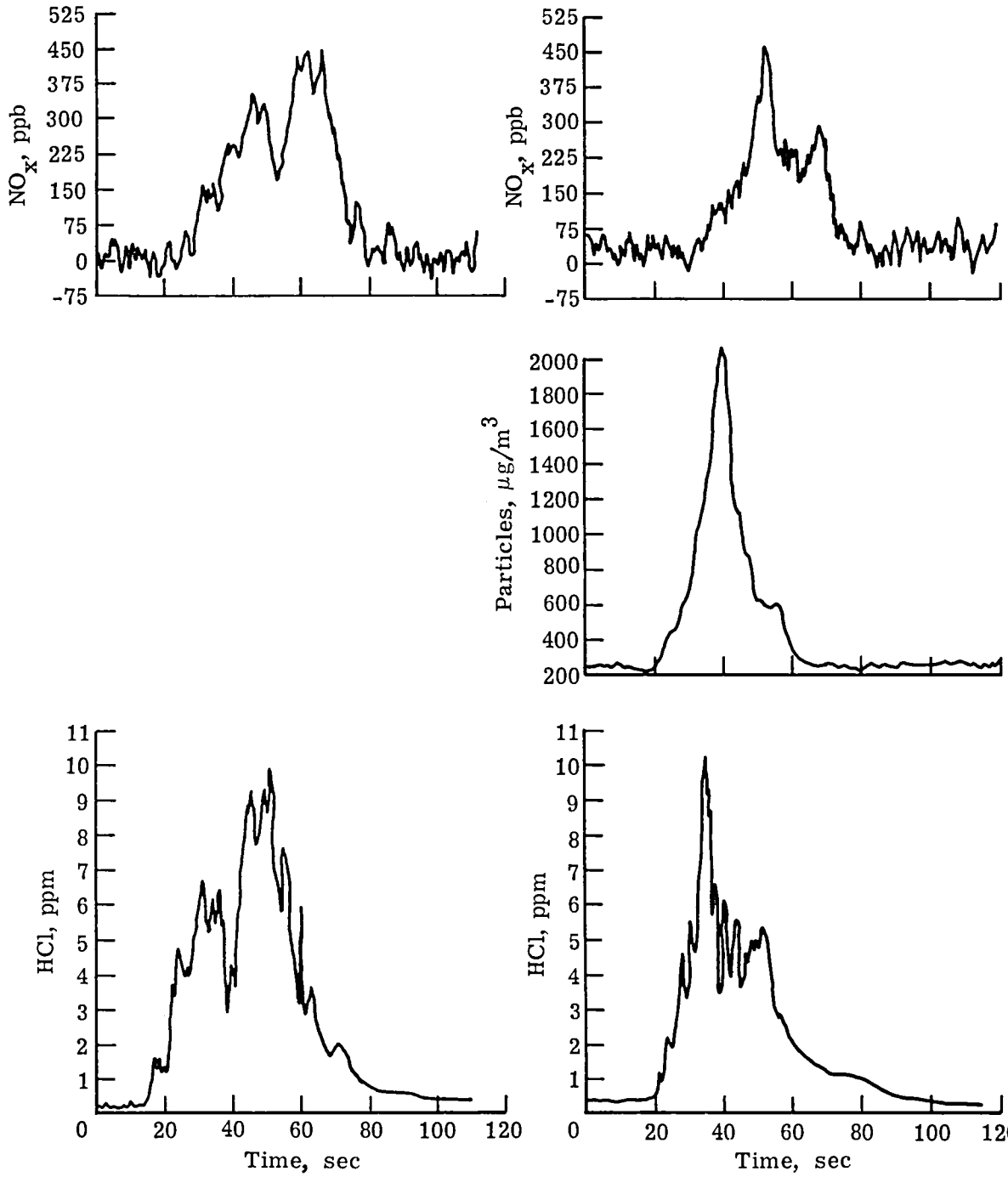
Figure 11.- Comparison of cloud volume data.



(a) Pass 1; t_0 = 4 min 18 sec.

(b) Pass 2; t_0 = 5 min 28 sec.

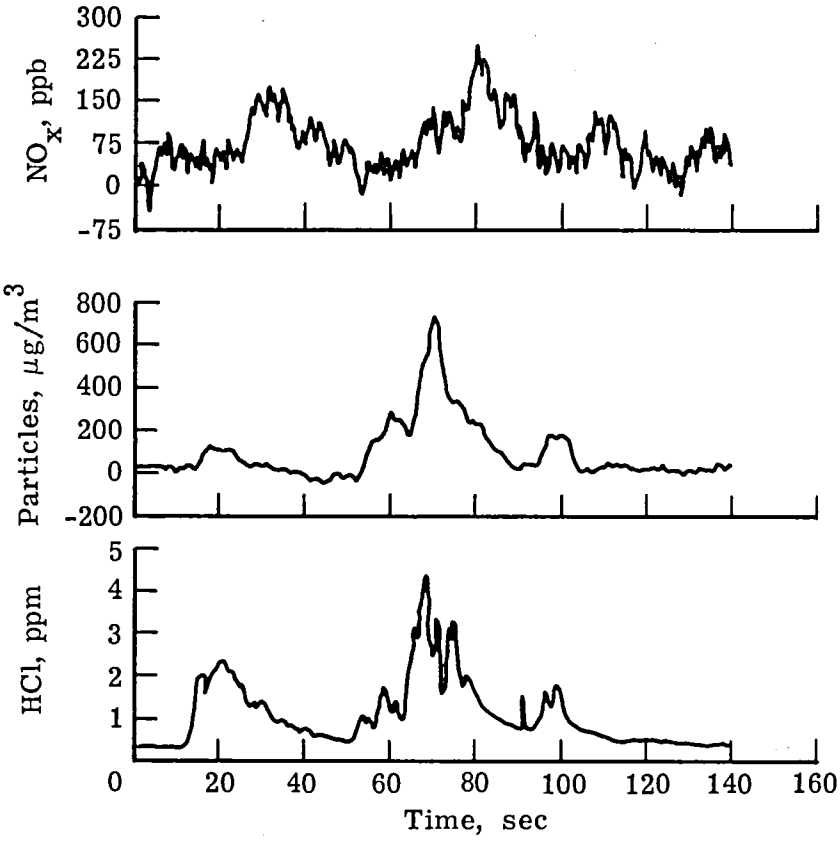
Figure 12.- Concentration-time data.



(c) Pass 3; t_0 = 8 min 19 sec.

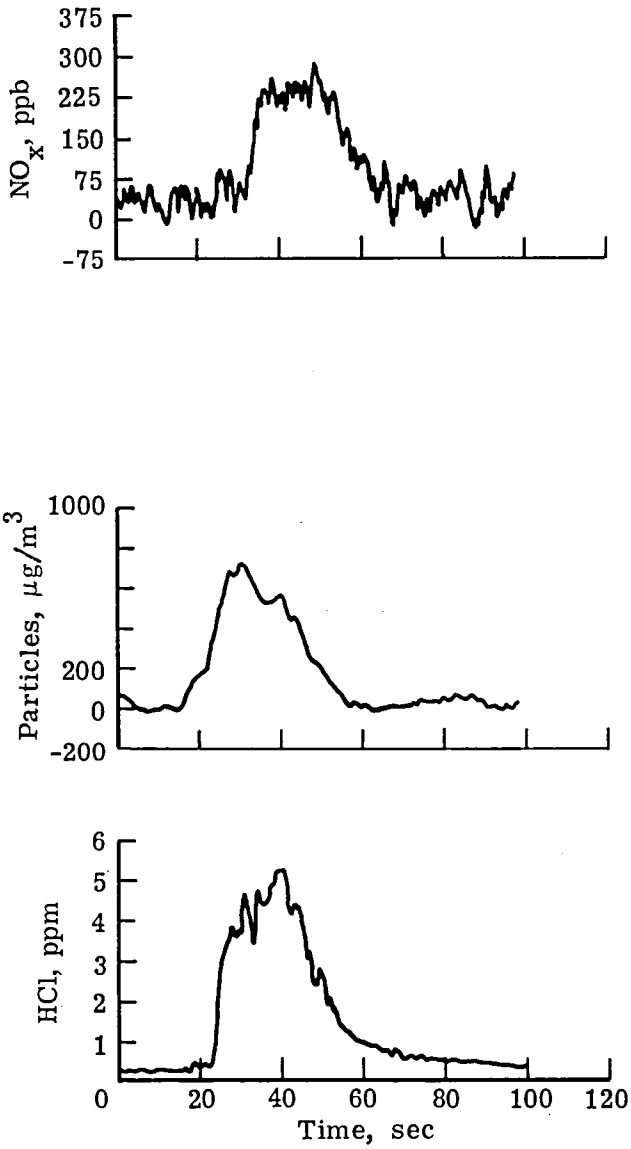
(d) Pass 4; t_0 = 10 min 29 sec.

Figure 12.- Continued.

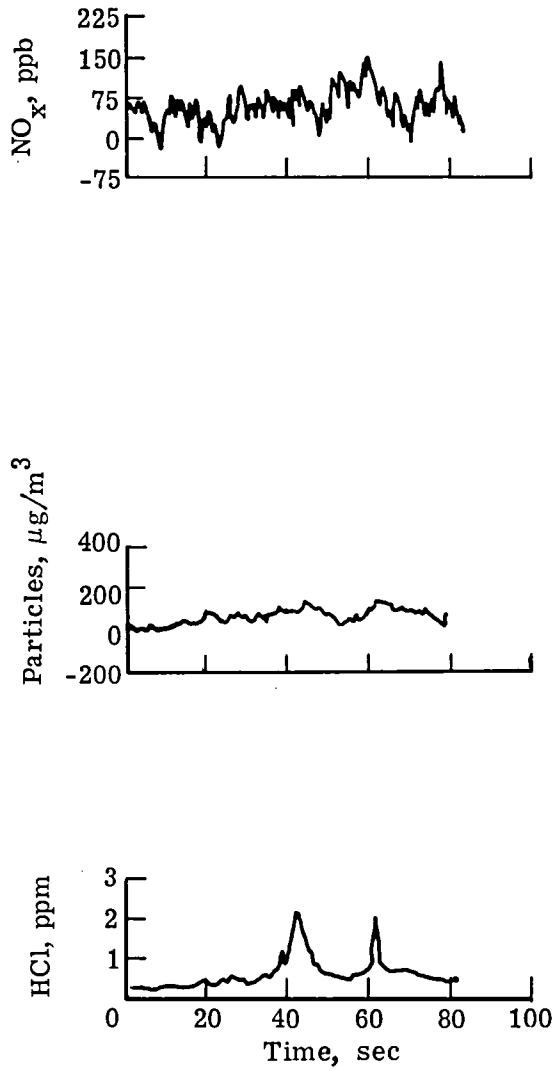


(e) Pass 5; t_0 = 12 min 29 sec.

Figure 12.- Continued.

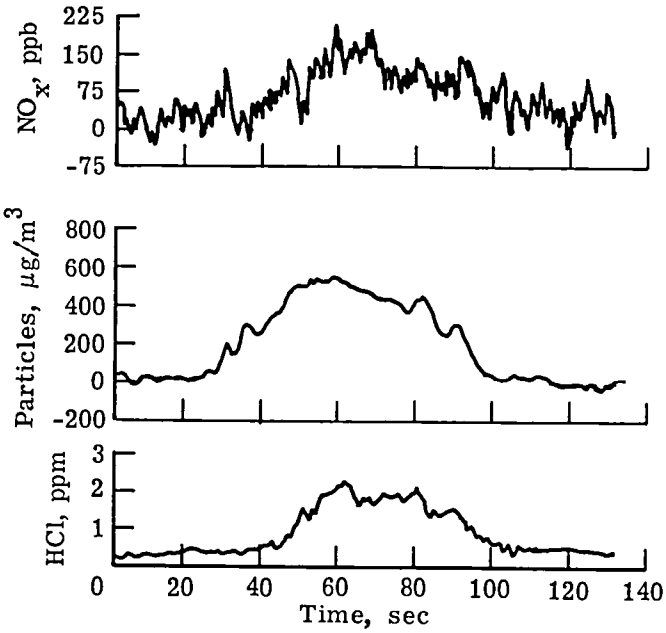


(f) Pass 6; t_0 = 15 min 29 sec.

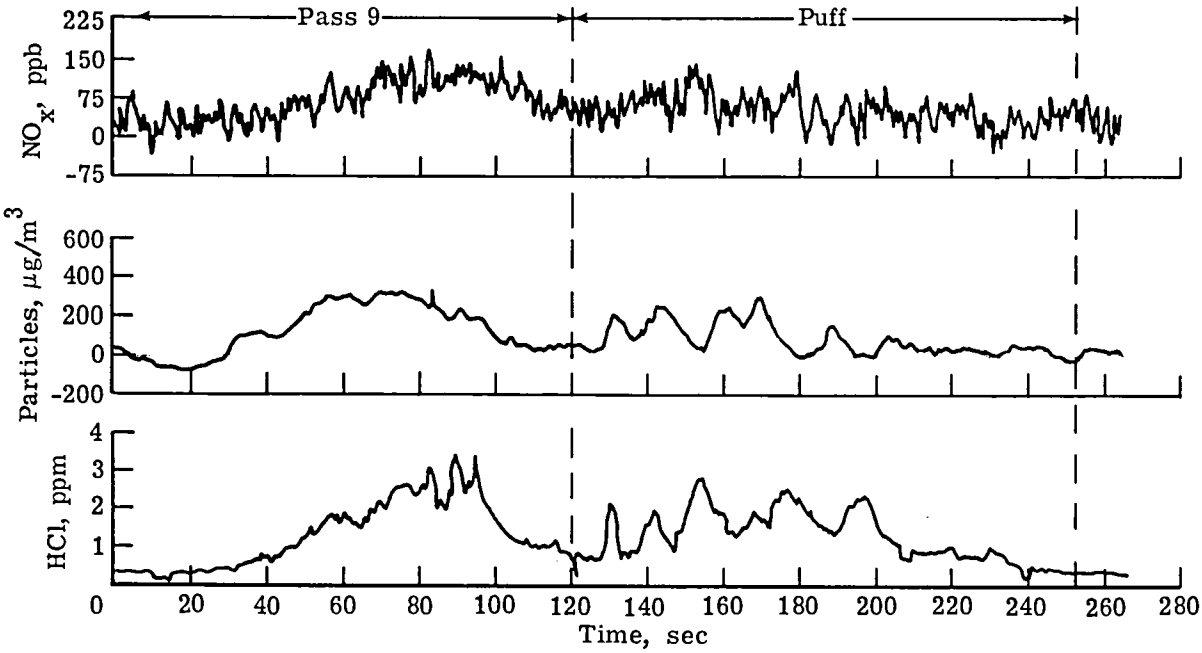


(g) Pass 7; t_0 = 17 min 59 sec.

Figure 12.- Continued.

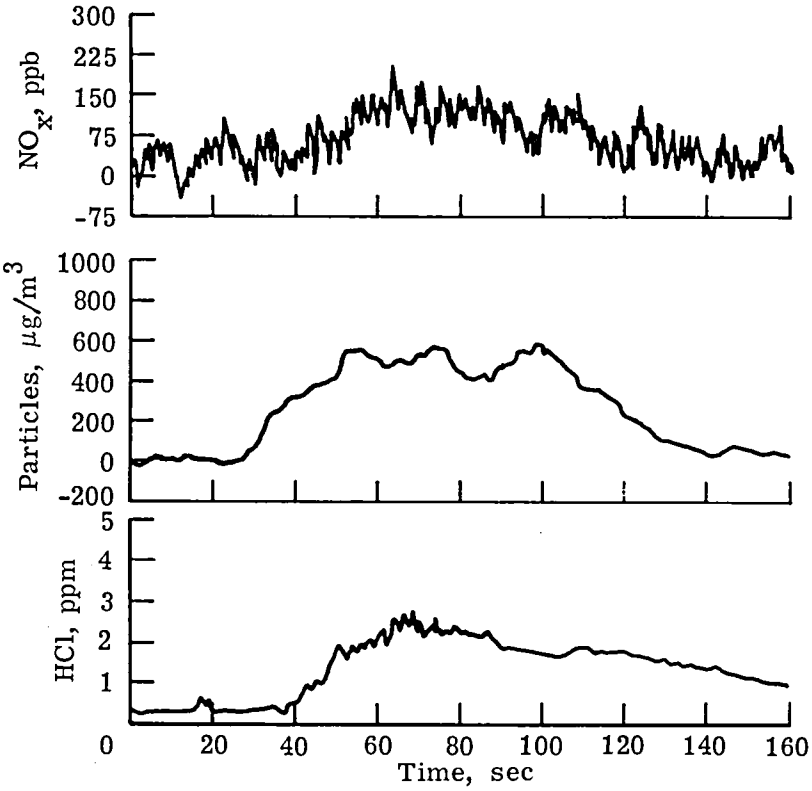


(h) Pass 8; t_0 = 26 min 59 sec.

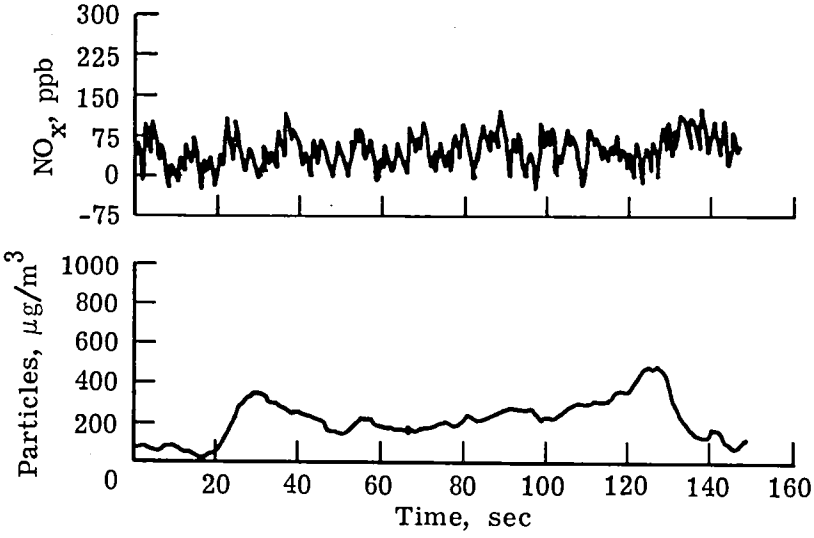


(i) Pass 9; t_0 = 30 min 39 sec.

Figure 12.- Continued.

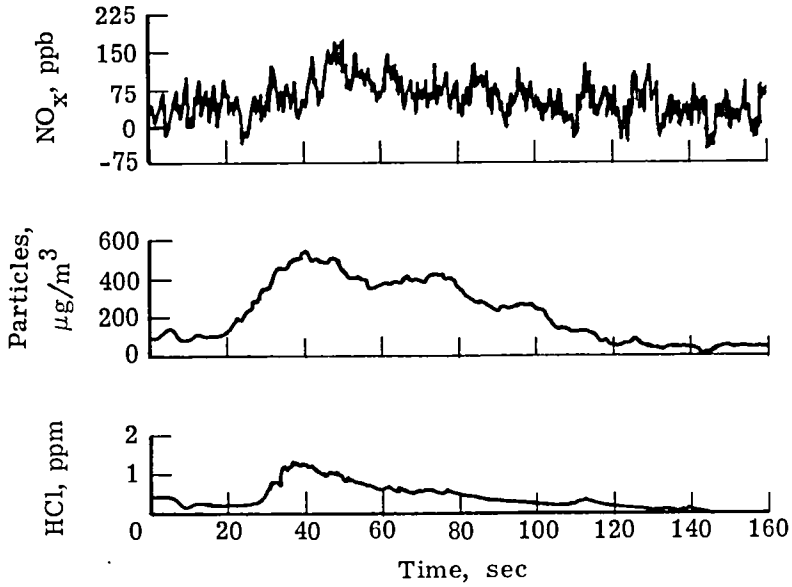


(j) Pass 10; t_0 = 38 min 14 sec.

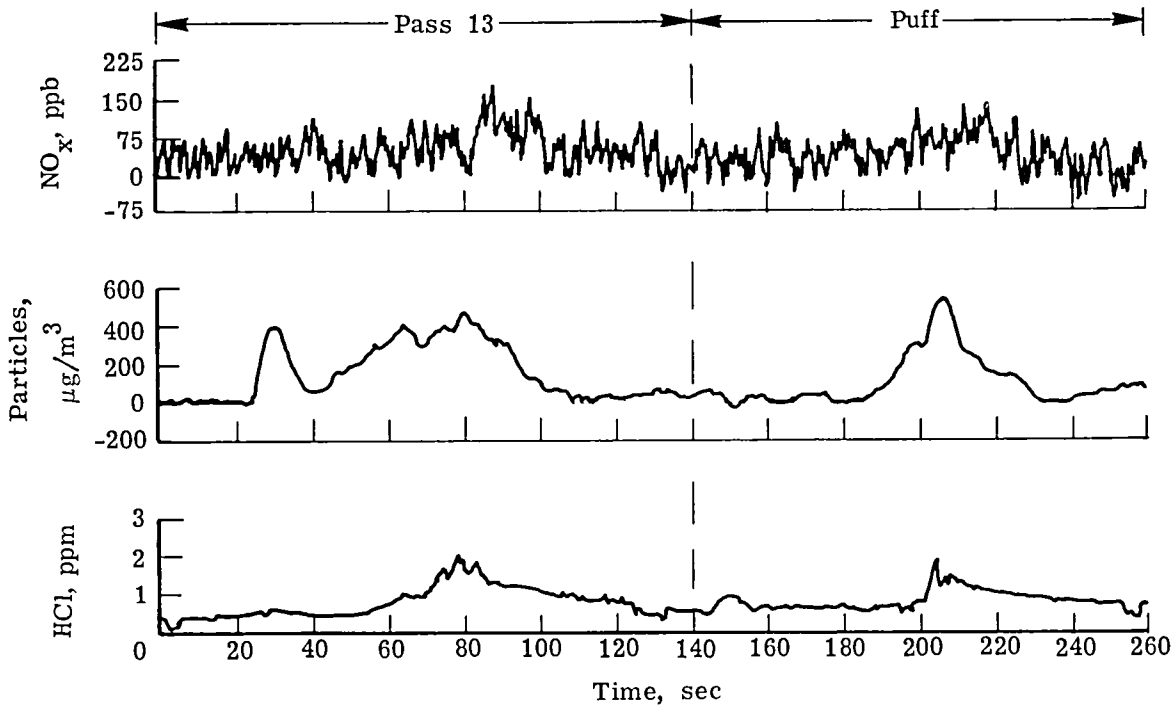


(k) Pass 11; t_0 = 41 min 43 sec.

Figure 12.- Continued.



(l) Pass 12; t_0 = 44 min 13 sec.



(m) Pass 13; t_0 = 47 min 14 sec.

Figure 12.- Concluded.

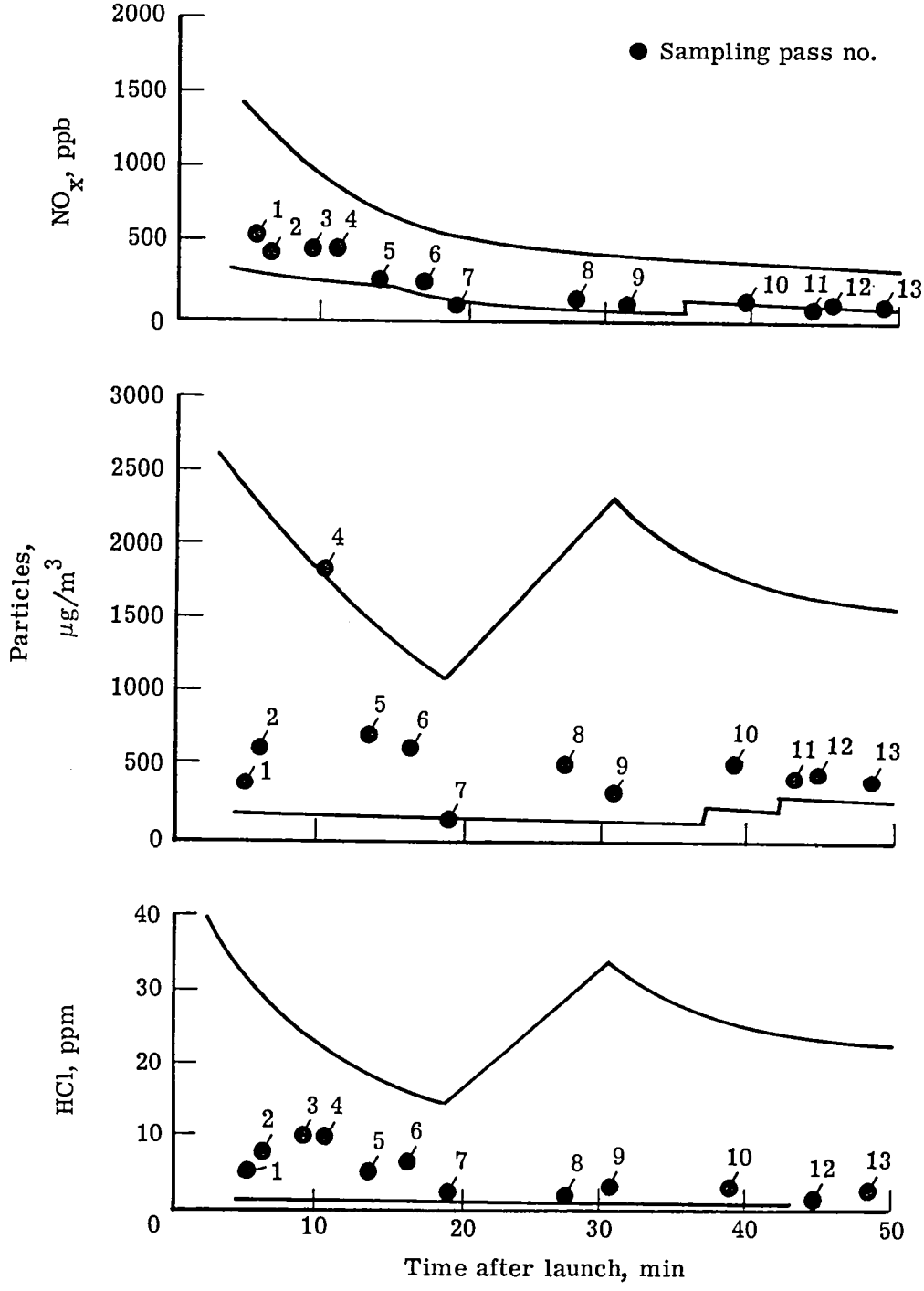


Figure 13.- Comparison of maximum incloud concentrations.

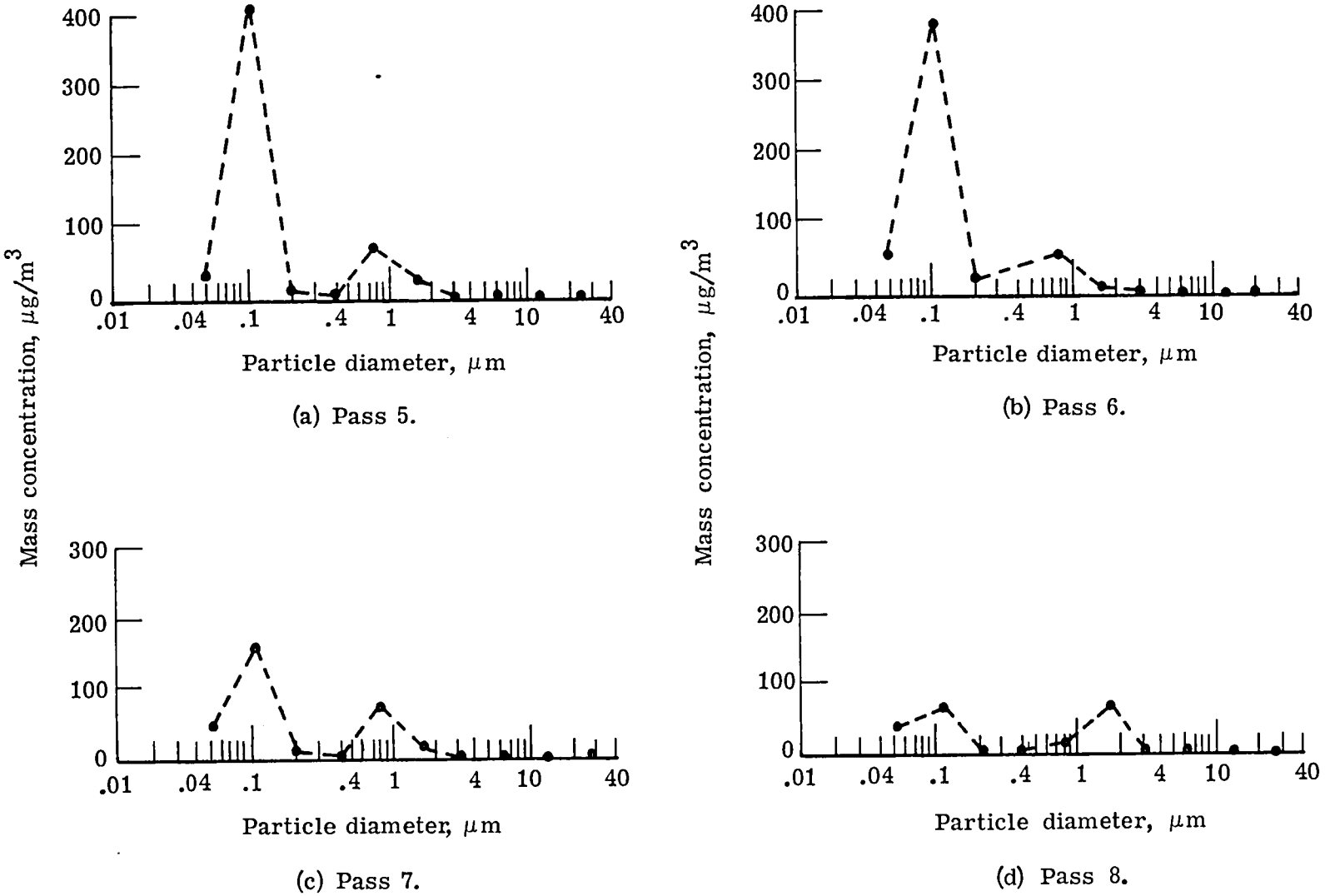
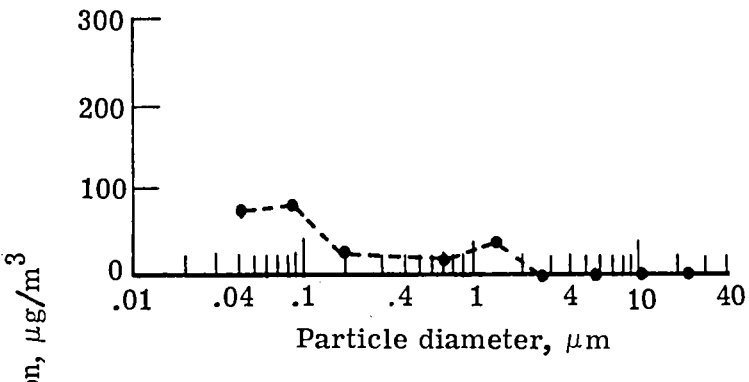
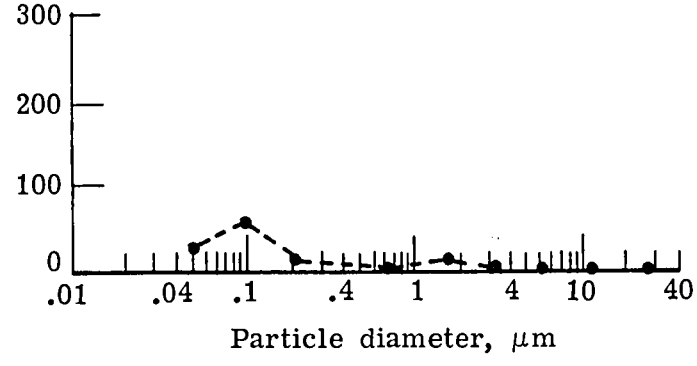


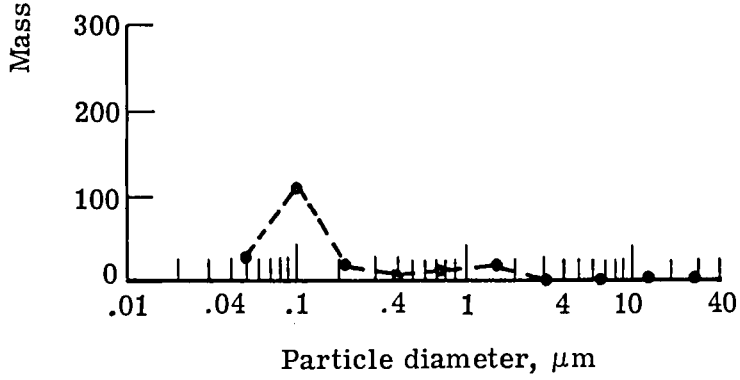
Figure 14.- QCM sizing data.



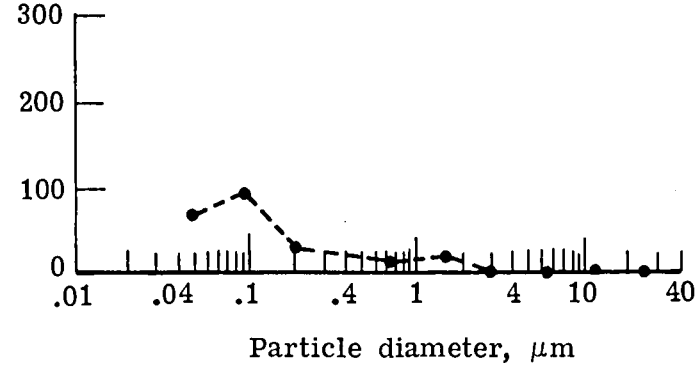
(e) Pass 9 plus puff.



(f) Pass 10.



(g) Pass 11.



(h) Pass 12.

Figure 14.- Concluded.

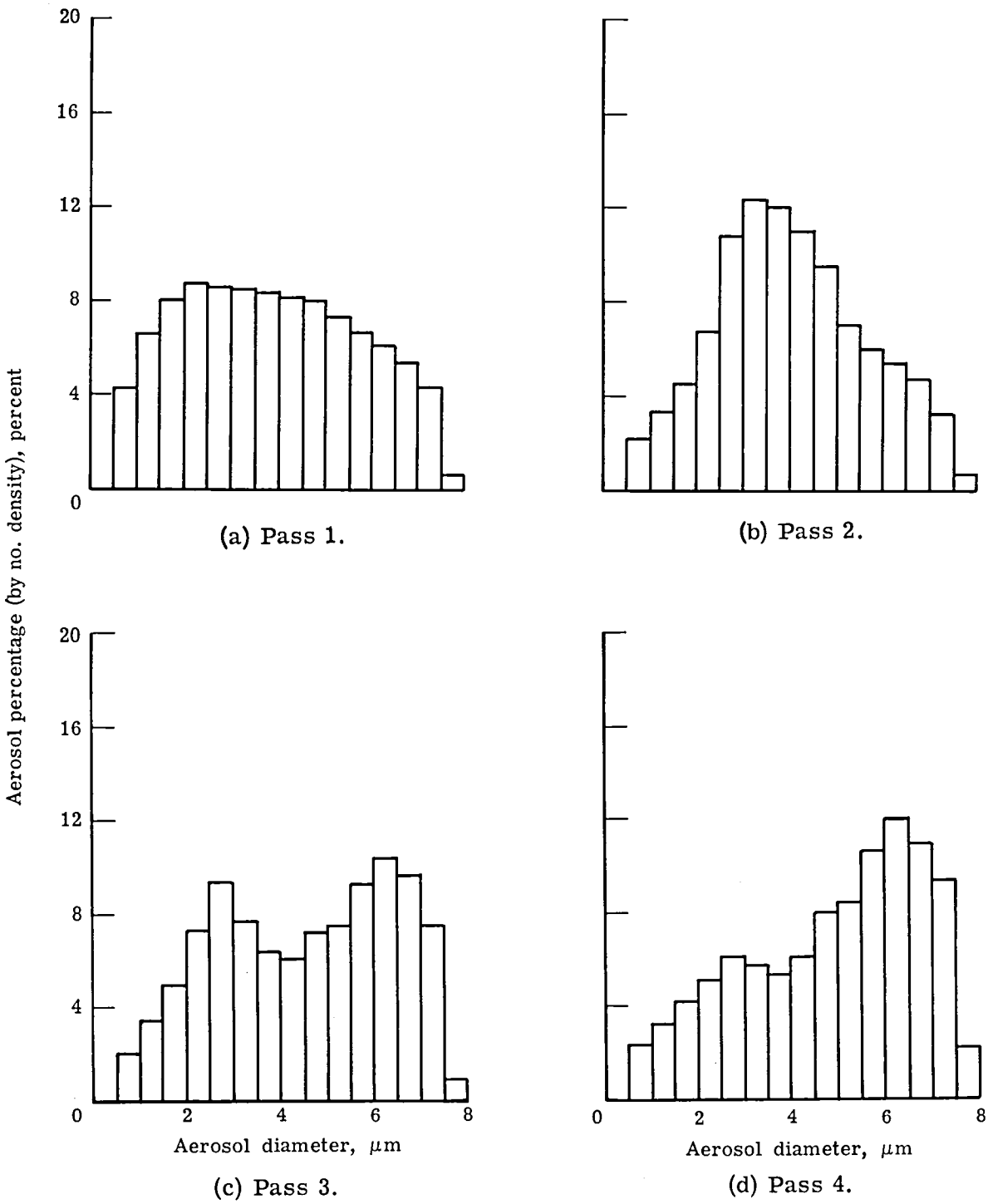


Figure 15.- Aerosol percentage as function of size (FSSP data).

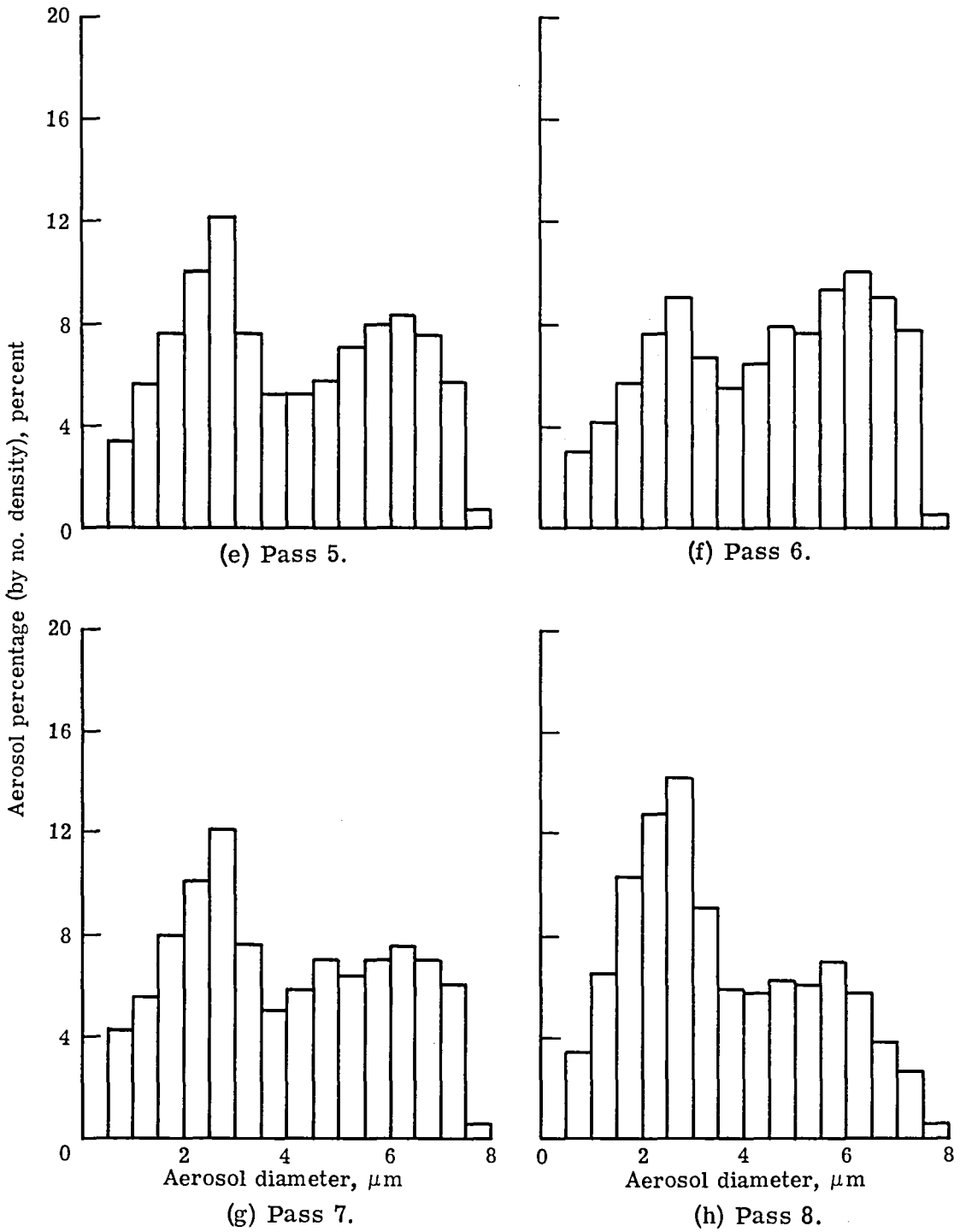
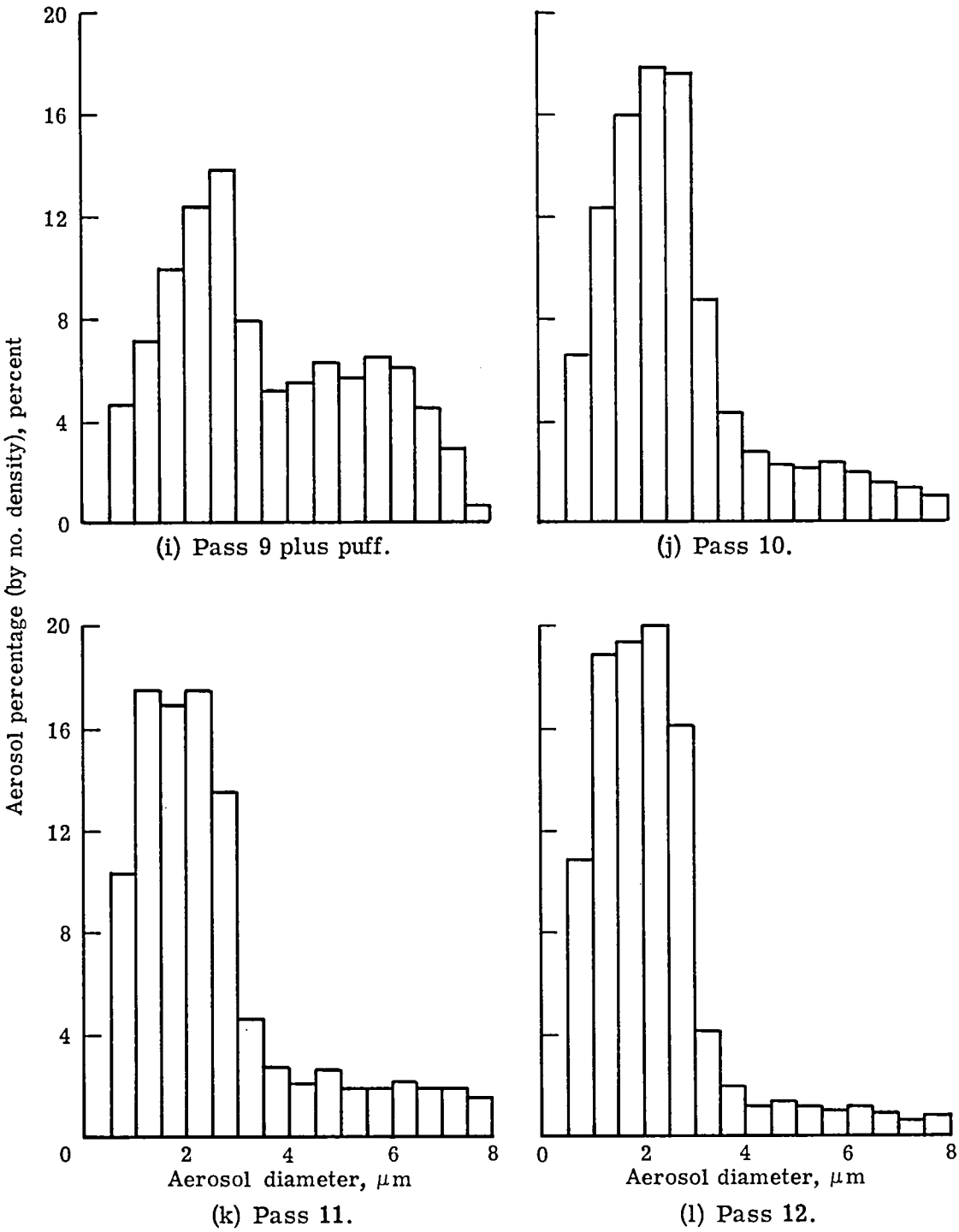


Figure 15.- Continued.



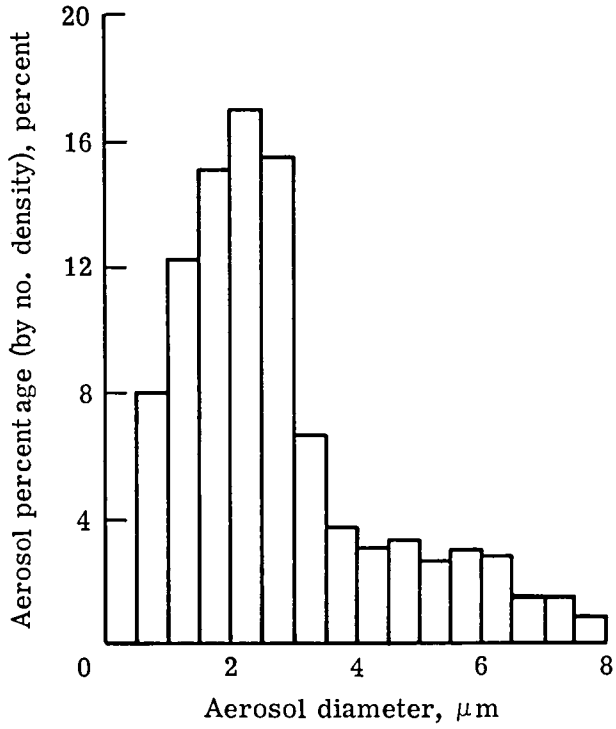
(i) Pass 9 plus puff.

(j) Pass 10.

(k) Pass 11.

(l) Pass 12.

Figure 15.- Continued.



(m) Pass 13 plus puff.

Figure 15.- Concluded.

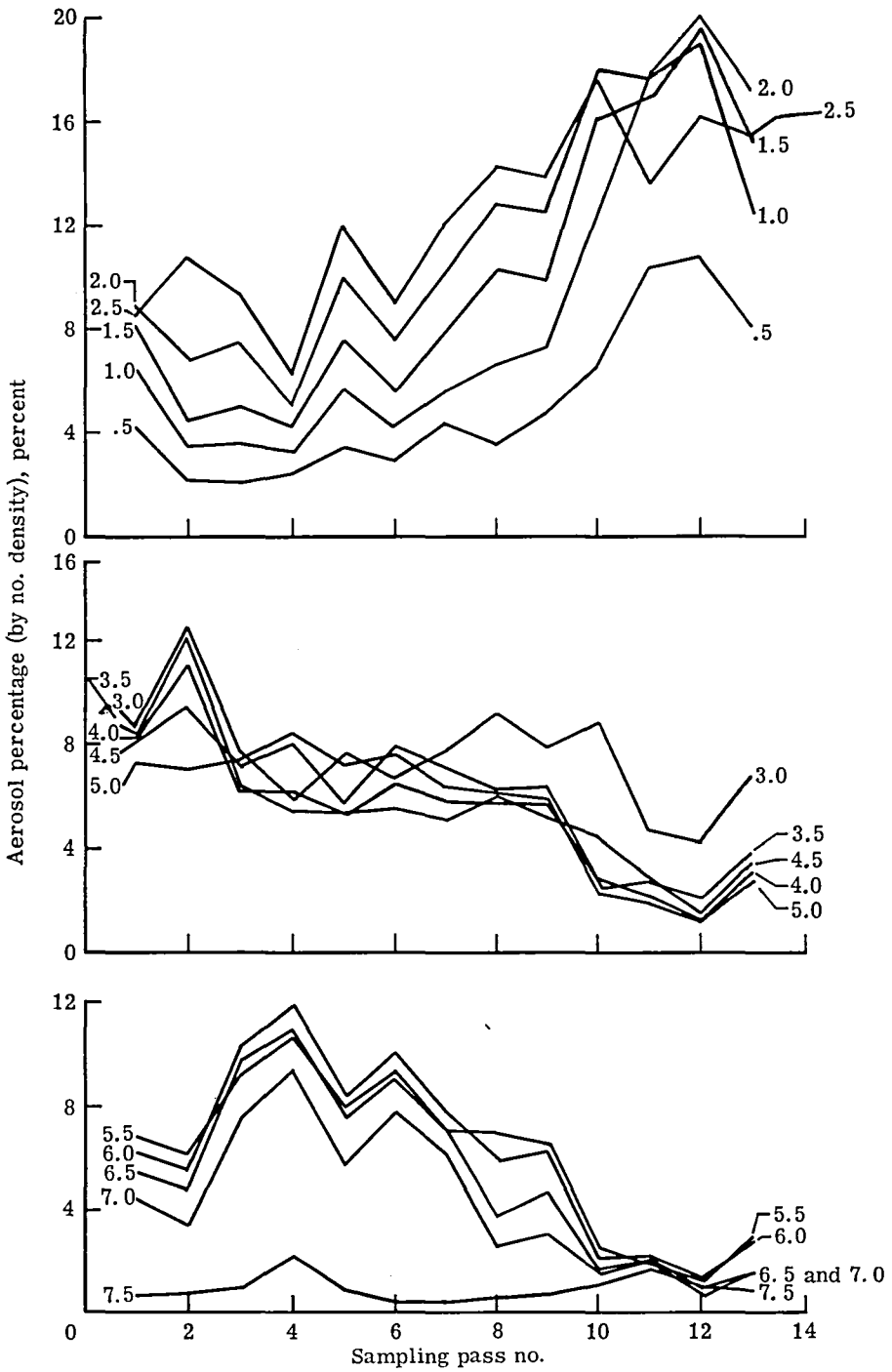


Figure 16.- Aerosol percentage as function of sampling pass (FSSP data).

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15. Supplementary Notes

16. Abstract

Airborne effluent measurements and cloud physical behavior for the May 21, 1977, Titan III launch from the Air Force Eastern Test Range, Fla. are presented. The monitoring program included airborne effluent measurements in situ in the launch cloud, visible and infrared photography of cloud growth and physical behavior, and limited surface collection of rain samples. Airborne effluent measurements included concentrations of HCl, NO, NO_x, and aerosols as a function of time in the exhaust cloud. For the first time in situ particulate mass concentration and aerosol number density were measured as a function of time and size in the size range of 0.05- to 25-μm diameter. Measurement results were similar to those of earlier launch monitorings. Maximum HCl and NO_x concentrations ranged from 10 ppm and 500 ppb, respectively, several minutes after launch to about 1 ppm and 100 ppb at 45 minutes after launch. Particulate results were somewhat dependent on the instrumental technique. A tabulated listing of the airborne data is given in the appendix. Overcast weather limited documentation of exhaust cloud growth and physical behavior.

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