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FLIGHT TEST OF A PRESSURIZATION SYSTEM USED TO MEASURE MINOR ATMOSPHERIC CONSTITUENTS FROM AN AIRCRAFT

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16. Abstract

A flight evaluation of an ambient air sample pressurization system was conducted at altitudes between 6 and 12 km. The system regulated the sample pressure to 10.15±0.1 N/cm^2 and provided sample flow to three gas analysis instruments included in the system. Ozone concentrations measured by two instruments employing different techniques varied from about 30 parts per billion by volume (ppbv) to over 350 ppbv, and the two ozone monitors agreed to within 20 ppbv. A carbon dioxide analyzer indicated modifications required for future installations.

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SUMMARY

An ambient air sample pressurization system proposed to measure the concentrations of minor atmospheric constituents from an aircraft was flight tested. Three gas analysis instruments measuring ozone and carbon dioxide were selected from a group of instruments and included in the system. The instruments assisted in evaluating the pressurization system, and the measurement techniques were examined for suitability to this application.

The pressure, temperature, and flow characteristics of the sample gas provided by the pressurization system were measured over a range of altitudes from 6 to 12 kilometers. The system provided adequate flow for the three instruments, and sample gas pressure was regulated to 10.15 ± 0.1 newtons per square centimeter.

Ambient altitude ozone concentrations were measured by using two instruments, an ultraviolet absorption ozone monitor and an electrochemical concentration cell ozone meter. Ozone concentrations measured by the two instruments varied from about 30 parts per billion by volume (ppbv) to over 350 ppbv during the flight series, and the two instruments showed agreement to within 20 ppbv. Ozone destruction in the sample pressurization system was measured after the flight series and was found to be less than 10 percent of the inlet concentration. A comparison was also made between ambient altitude ozone concentrations and cabin ozone concentrations and indicated that up to 60 percent of the measured ambient ozone concentration may be destroyed in the cabin air pressurization system and the cabin environment.

A nondispersed infrared carbon dioxide analyzer was included, although the instrument did not have sufficient sensitivity to detect the expected variations in carbon dioxide concentration. The flight tests indicated the need for (1) further evaluation of the zero and span characteristics of this analyzer in the aircraft environment and (2) inflight calibration checks.

INTRODUCTION

This report describes a flight evaluation of an ambient sample pressurization system proposed for operation on commercial jet airliners over a range of altitudes from 6 to 12 kilometers. The operation of three gas sampling instruments installed in the system to measure ambient concentrations of ozone and carbon dioxide is also examined.

A global atmospheric sampling program (GASP) is being implemented at the Lewis Research Center to measure particulate characteristics and background concentrations of a number of minor gas constituents in the troposphere and lower stratosphere on a global basis over a period of several years and to determine the contribution of jet aircraft to possible atmospheric contamination during this time period (ref. 1). Commercial airliners have been examined as a possible instrument platform for routinely collecting worldwide air-quality data (ref. 2). It is expected that flight versions of the complete GASP sampling system will be installed in a pressurized area of Boeing 747 aircraft. This system must be designed to operate unattended and may be inaccessible for periods ranging from several days to several weeks. These constraints as well as the aircraft environment place severe demands on the instruments required to measure background concentrations at high altitudes.

An essential element of the GASP sampling system is a provision for supplying a continuous flow of ambient sample air to the sampling instruments. The cabin air pressurization system can be used for this purpose; however, the cabin pressure is not constant, contamination of the sample gas can occur, and a variable degree of destruction of reactive gas constituents such as ozone may occur in the cabin ventilation system (ref. 3). Reference 4 suggests using a tetrafluoroethylene (TFE)-coated diaphragm pump to supply uncontaminated ambient air to a manifold which is vented to the cabin environment. A group of sampling instruments may be connected to the manifold. However, since several of the instruments proposed for inclusion in the GASP system require careful regulation of either sample pressure or sample flow, a sample pressurization system is needed which is capable of supplying a group of instruments with a constant flow of sample air at a constant pressure (near 1 atm) over a range of altitudes regardless of the cabin pressure.

To aid in developing the pressurization system design and also to evaluate several candidate instruments for the GASP system, a sample pressurization system was assembled and installed on the NASA CV-990 research aircraft based at the Ames Research Center (ref. 5). Three gas sampling instruments were included in the installation: (1) an ultraviolet absorption ozone monitor, (2) an electrochemical concentration cell ozone meter, and (3) a nondispersed infrared carbon dioxide analyzer. The installation was flown on the Ocean Color Expedition sponsored by NASA Goddard Space Flight Center during June and July of 1972. A flight test program was conducted to evaluate the sam-

ple pressurization system and to examine the operation of the gas analysis instruments in an aircraft environment.

SAMPLE PRESSURIZATION SYSTEM

Several means of providing an ambient gas sample for a group of gas sampling instruments are being considered for the GASP program. The differential between total pressure and static pressure at cruise speeds could be used to maintain a sample flow through an instrument. This approach would minimize the possibility of interference or contamination of the sample by pumps and regulators; however, the sensitivity of several of the proposed instruments is pressure-dependent, and sample pressures near altitude pressures would result in insufficient sensitivity. A second technique is to use a noncontaminating pump to pressurize a sample flow from altitude conditions to either cabin pressure or a fixed pressure. Operating with a pressurized sample flow (1) maintains the sensitivity of those instruments which show insufficient sensitivity with sample pressures near altitude pressures, (2) reduces the differential between sample pressure and cabin pressure which the instrument components must sustain, and (3) reduces the danger of sample contamination from small leaks since sample air will leak into the cabin. The pressurized sample system is examined in this report.

A schematic of the sample pressurization system used in the flight test program is shown in figure 1. A single-stage diaphragm pump was used to draw the sample gas from the inlet probe and supply the inlet manifold. The sample pump had a flow capacity at sea level of approximately 10^5 cubic centimeters per minute, but as the altitude increased, the sample pressure at the inlet probe decreased and the sample flow became smaller. The sample pump was driven at 105×10^3 hertz by an integral 185-watt, 115-volt, 60-hertz motor. The pump-motor assembly weighed approximately 8 kilograms.

The inlet manifold pressure was controlled at 10.15 newtons per square centimeter by a spring-loaded back-pressure regulator (labeled 1 in fig. 1). Each instrument drew its required flow from the inlet manifold, and any excess flow delivered by the pump was vented through the back-pressure regulator. Since the cabin pressure environment was not constant over the altitude range of interest, an absolute pressure regulator (2 in fig. 1) connected to the inlet manifold was used to supply a constant reference pressure of 8.20 newtons per square centimeter to the dome of the back-pressure regulator. Thus, the operation of the back-pressure regulator and consequently the inlet manifold pressure were independent of the cabin pressure. The absolute pressure regulator used a sealed, evacuated bellows reference and required a source of vacuum (simply a connection to the static discharge probe) to maintain the subatmospheric reference pressure. The inlet manifold pressure was changed when required by adjusting a manual control on the absolute pressure regulator.

The flows through the ultraviolet absorption ozone monitor and the carbon dioxide analyzer were ducted into a common exhaust manifold. The exhaust manifold pressure was maintained at 8.20 newtons per square centimeter by another back-pressure regulator (3 in fig. 1). This back-pressure regulator also used the reference pressure from the absolute pressure regulator to establish a constant exhaust manifold pressure. In this case, no spring load was used, and the exhaust manifold pressure was maintained at the same value as the reference pressure. Except for the spring, both back-pressure regulators were identical and weighed approximately 1 kilogram each. The regulator domes were sealed to prevent reference pressure leakage, and no manual adjustments of the regulators were made.

The sample flow rates through the carbon dioxide analyzer and the ultraviolet absorption ozone monitor were controlled by manual throttle valves downstream of each instrument. Since the differential pressure across these valves was constant, they were initially set to the desired flow and no further adjustment was required. Thus, both the instrument sample inlet pressure and the sample flow rate were maintained constant regardless of the aircraft pressure altitude or the cabin pressure environment.

The electrochemical concentration cell ozone meter required a different gas sample supply since this instrument could not sustain any significant differential between the sample gas pressure and the lower cabin pressure. The sample flow from the inlet manifold was throttled down to cabin pressure by means of a manual flow control valve and a vent to the cabin and then supplied to the ozone meter. A noncontaminant sample pump in the ozone meter drew the required sample flow through the instrument. The flow control valve was adjusted to supply sample flow to the instrument as well as approximately 1000 cubic centimeters per minute of excess flow which dumped into the cabin through the vent. Since the pressure drop across the control valve varied as the cabin pressure changed, a rotometer was installed in the cabin vent line to monitor the vent flow and to verify that the ozone meter was receiving sufficient flow. Occasional adjustment of the control valve was necessary during many flights.

An important consideration in the design of the sampling system was an attempt to minimize ozone destruction in the portions of the system upstream of the ozone measuring instruments. Two design guidelines were applied to achieve this goal: (1) minimize sample residence time in the system and (2) wherever possible, utilize ozone-compatible materials for components contacting the sample flow. The use of a back-pressure regulator to control the inlet manifold pressure rather than a standard pressure regulator which would restrict the sample flow at lower altitudes reduced the sample residence time in the inlet tubing and the inlet manifold. In addition, the sample gas did not pass through a regulator upstream of the sampling instruments. The sampling instruments were located as close as possible to the sampling pump in order to minimize sample residence time in the inlet manifold.

Reference 6 compares the ozone destruction characteristics of several materials and indicates that TFE is more compatible with ozone than stainless steel, aluminum, or several plastic materials which were examined, particularly when frequent conditioning of the system with high ozone concentrations is not feasible. As a result, wherever possible all components contacting the sample flow upstream of the instruments were either fabricated from TFE or TFE-coated. The only significant exceptions were the inlet probe and the mass flow meter located in the inlet manifold, both of which were stainless steel. The synthetic rubber sample pump diaphragm was covered with a sheet of TFE-coated fiberglass mesh, and the internal flow surfaces were TFE-coated. TFE tubing and fittings were used everywhere upstream of the instruments. Prior to the test flights the sample pressurization system including the inlet probe was cleaned with acetone and air-dried. The portion of the system not including the inlet probe or the instruments was conditioned before the flight series by connecting an ozone generator to the system inlet and flowing approximately a 1 percent by volume concentration of ozone through the system for 1 hour.

Pressure, temperature, and mass flow rate through the inlet manifold were measured by an absolute pressure transducer, a thermocouple, and a mass flow meter, respectively. These measurements were used to evaluate the performance of the pressurization system. Individual instrument flows were measured immediately downstream of the ultraviolet absorption ozone monitor and the carbon dioxide analyzer by rotameters. Absolute pressure transducers were used to monitor pressure at the pump inlet, exhaust manifold, and discharge line. A second thermocouple was used to measure the sample temperature at the inlet to the electrochemical concentration cell ozone meter.

GAS SAMPLING INSTRUMENTS

A number of gaseous atmospheric constituents and particulate characteristics associated with and affected by aircraft exhaust emissions will be monitored with the GASP sampling system. Figure 2 (from ref. 1) shows the approximate ranges of several constituents at altitude and ground level (nonurban) as well as the capability of certain available instrument measurement techniques. Table I, also taken from reference 1, shows some of the instrument operating principles being examined as candidates for the GASP application. Three instruments were selected from available candidate instruments and included in the sampling system to (1) assist in evaluating the sample pressurization system and (2) examine the measurement technique in an aircraft environment.

Electrochemical Concentration Cell Ozone Meter

The electrochemical concentration cell (ECC) ozone meter uses an iodine iodide redox electrode concentration cell sensor to measure the concentration of selected oxidants and reductants in the gas sample. The sensor is described in detail in reference 7. In this application, the instrument output is interpreted as ozone concentration. The instrument is also sensitive to sulfur dioxide; however, at the altitudes of interest the concentration of sulfur dioxide is assumed to be negligible with respect to the ozone concentration.

The instrument gives a continuous current output which is related to the ozone concentration in the sample and the gas sample temperature and pressure. Since the gas sample pressure is maintained at cabin altitude, which is variable up to 2.5 kilometers, the cabin pressure is recorded and used to correct the data. Variations in gas sample temperature are also recorded and used to correct the data.

The ECC meter is sensitive to ozone concentrations of 1 part per billion by volume (ppbv). The instrument will indicate 90 percent of a step change in ozone concentration in 1 minute. The flow rate through the instrument is maintained at 170 cubic centimeters per minute by a nonreactive gas sampling pump provided in the instrument. An ozone destruction filter is included in the meter to check the background current of the cell periodically.

Ultraviolet Absorption Ozone Monitor

The ultraviolet absorption ozone monitor utilizes the proportional intensity changes of an ultraviolet (uv) beam as it traverses a fixed path containing ozone to determine the concentration of ozone present in the gas sample. This instrument and its operation are described in reference 8. The sample flow is periodically passed through an ozone destruction filter inside the instrument which establishes a reference signal and is making the instrument relatively insensitive to changes in the source intensity, optical transmittance, or detector characteristics. In addition, this technique minimizes interference from other gaseous constituents which may be present in the sample flow. The sample pump in the instrument was disabled for these tests and the instrument flow was adjusted to 3000 cubic centimeters per minute by the throttle valve downstream of the instrument.

A direct readout of ozone concentration in parts per million by volume (ppmv) is given at approximately 20-second intervals. The instrument has a range of 0.003 to 20.000 ppmv. The monitor will indicate 90 percent of a step change in ozone concentration in approximately 30 seconds. Both zero and calibrate functions are provided on the instrument to check the electronic calibration.

Carbon Dioxide Analyzer

The nondispersed infrared technique employed in the carbon dioxide analyzer compares the infrared energy absorption of a column of the sample gas with the absorption of a similar column of a standard gas. A special detector cell translated the difference in infrared absorption by carbon dioxide (CO_2) in the two columns into a deflection of a thin metal diaphragm. This deflection is measured and related to the CO_2 concentration in the sample column. This technique is further described in reference 9.

The range of the CO_2 analyzer is from 0 to 500 ppmv with an accuracy of ±5 ppmv and a sensitivity of 2.5 ppmv. Although the ambient CO_2 concentration of approximately 320 ppmv falls well within the instrument range, the expected variation of CO_2 during a flight is smaller than the sensitivity of the instrument. The instrument was included only for the purpose of examining this technique in an aircraft environment and providing recommendations for future systems which may include this type of analyzer.

The minimum warmup time for this instrument is 1 hour, after which the instrument should be calibrated. Calibration includes passing both a zero gas and a span gas through the instrument. These gases were carried in 1000-cubic-centimeter low-pressure cylinders for the flight tests. Nitrogen was used as a zero gas, and span gas concentrations were 350 and 400 ppmv of CO_2 in nitrogen. Sample flow during the flights was maintained at 1000 cubic centimeters per minute by a valve downstream of the instrument.

TEST INSTALLATION

The ambient gas sampling equipment was installed aboard the NASA CV-990 research aircraft based at the Ames Research Center. The CV-990 is a four-engine jet passenger transport which has been modified with special view ports, power supplies, and other general use facilities and instrumentation to accommodate a wide variety of airborne research programs. The installation consisted essentially of two parts: (1) the sample probe, and (2) the pressurization system and gas sampling instruments. A schematic and photographs of the sample probe assembly and installation are shown in figure 3. Both inlet and discharge probes were mounted on a special window blank. Isolation valves and a bypass line allowed for purging of the inlet probe at altitudes below the test altitudes. The probe assembly was mounted with sufficient standoff of the probe inlet to avoid ingestion of boundary-layer air.

The sample pressurization system and instruments were installed in an equipment rack supplied by Ames for use aboard the CV-990 aircraft. The installation is shown in figure 4. The rack was located adjacent to the sample probe to minimize sample residence time. The inlet tubing connecting the probe to the rack was approximately 2 meters long. The sample pump was shock mounted; however, no attempt was made to vibration

isolate any of the remaining equipment.

Data from the pressure, temperature, and flow sensors in the pressurization system as well as from the three gas sampling instruments were recorded on the aircraft digital data acquisition system at 10-second intervals during the flights. The instrument outputs and the inlet manifold pressure were also recorded on strip chart recorders mounted in the equipment rack. A Greenwich mean time (G. m. t.) time code signal was recorded on a strip chart for correlation of flight events. Five-second updates of flight parameters and aircraft position information were processed by an onboard computer and displayed on a television monitor mounted on top of the equipment rack. The computer also provided a real-time correction of the ECC meter output for sample pressure and temperature and recorded preliminary calculations and data on an onboard printer. Reference 5 provides a more detailed description of the aircraft and its systems.

RESULTS AND DISCUSSION

Sample Pressurization System

A listing of the 15 CV-990 test flights on which the installation was flown is given in table II. Approximately 70 flight hours were flown during the expedition, although not all of that time was at altitudes above 6 kilometers.

The pressurization system performed well throughout the flight series, and no system component failures occurred. On each flight the sample pump was started at an altitude of approximately 6 kilometers and the instrument flows were set; no further adjustments were necessary. The sample pump delivered sufficient flow to supply the instruments at all test altitudes. Figure 5 shows the pump flow schedule recorded during three flights. Small variations in the flow schedule were likely because of variations in cruise Mach number, static air temperature, and inlet manifold pressure. The inlet manifold pressure was set at 10.15 newtons per square centimeter at an altitude of 9 kilometers by adjusting the absolute pressure regulator. Figure 6 shows the effect of altitude on the inlet manifold pressure for three flights. Since the flow rate through the instruments was nearly constant, any excess flow supplied by the pump was vented overboard through the inlet manifold back-pressure regulator. As the altitude increased and the pump flow rate decreased, the reduced flow through the regulator caused a small decrease in inlet manifold pressure. The largest variation in inlet manifold pressure observed during any of the test flights was less than ± 0.1 newton per square centimeter, which is considered an acceptable variation. No change was observed in the exhaust manifold pressure, which was set at 8.20 newtons per square centimeter. No variation was anticipated in this pressure since the flow rate through the exhaust manifold back pressure regulator was constant.

As the gas sample flowed through the inlet probe, inlet tubing and sample pump, it was heated by a combination of total-temperature recovery, heat transfer from system components, and temperature rise accompanying the pressure rise in the pump. As altitude increased, the static air temperature decreased; however, the temperature ratio across the pump increased as the pump pressure ratio became larger. Heat transfer upstream of the pump raised the gas temperature, but the pump discharge temperature was higher than the cabin air temperature and the gas was cooled as it passed through the inlet manifold.

Figure 7 shows data taken during several flights from a thermocouple located in the inlet manifold approximately 1.5 meters downstream of the pump. It is apparent that the difference in manifold temperature level between flights was often larger than the variation in temperature observed during a single flight. There was some indication that the variation in temperature level between flights could be related to static air temperature since flight 3, which showed low manifold temperatures, also recorded low static air temperatures (latitudes between 40° and 45° north), while flight 7 had higher static air temperatures (latitudes between 0° and 15° north) and showed higher manifold temperatures. However, this trend was not consistent throughout the flight series. It is likely that heat transfer in the inlet tubing and inlet manifold was an important factor in stabilizing the inlet manifold temperature.

After the flight series was completed, the pressurization system (not including the inlet probe) was tested to determine the extent of ozone destruction in the system at simulated flight conditions. A sketch of the test apparatus is shown in figure 8(a). The ozone generator consisted of an ultraviolet source mounted adjacent to a quartz tube carrying the sample flow. The ozone concentration supplied by the generator was a function of the sample flow rate. The throttle valve downstream of the generator was used to control the flow rate and simulate altitude pressures at the pump inlet.

The ozone generator was calibrated over a range of flow rates by using the ultraviolet absorption ozone monitor. The same monitor was then installed in the pressurization system, and the system was operated over a range of flow rates. The data obtained from these tests are shown in figure 8(b). It is expected that ozone destruction is related to sample residence time in the system, and the data indicate that the proportion of ozone destroyed decreases as the flow rate increases. At 5000 cubic centimeters per minute 17 percent of the ozone concentration is destroyed. However, the pump flow schedule shown in figure 5 indicates that the minimum sample flow rate occurring at the 12 kilometer altitude will be 7000 cubic centimeters per minute. If the data in figure 8(b) are extrapolated to a flow rate of 7000 cubic centimeters per minute, the proportion of ozone destroyed in the system is 10 percent of the inlet concentration.

Ozone. - The uV absorption ozone monitor was operated during the entire flight series with no problems. Both zero and calibrate output displays were stable. However, a problem was encountered with the ECC ozone meter during the first three flights when the instrument failed to indicate a normal positive background current. The instrument was replaced after flight 3, and the replacement analyzer performed well throughout the remainder of the flight series. The problem with the first ECC meter was apparently contamination of the sensing solution. The instrument functioned properly after it was cleaned and the solution was replaced.

Data from the uv absorption ozone monitor and the ECC meter are compared in figure 9 for flights 4, 5, 7, 8, and 9. Measured ambient ozone concentrations varied from about 30 ppbv to over 350 ppbv. The largest difference between ozone concentrations measured by the two instruments is 20 ppbv. During flights 8 and 9 agreement improved during the first hour of flight. Throughout most of the flights the two instruments agreed to within 10 ppbv.

Figure 10 shows ozone data from a portion of flight 6. During the period 1800 to 2000 G. m. t. the ECC meter was disconnected from the pressurization system and drew its gas sample directly from the aircraft cabin. The nearest cabin air ventilation duct was overhead, approximately $1\frac{1}{2}$ meters from the meter inlet. The uv absorption ozone monitor was not changed, so it continued to sample the altitude ambient air. Thus, the data shown in figure 10 indicate the extent of ozone destruction in the aircraft cabin pressurization system and the cabin environment. The difference in ozone concentration between the two instruments for the 23 data points shown varied from 41 to 59 percent of the measured ambient concentration at each point, with an average ozone destruction of 50 percent of the ambient level. The actual proportion of ozone destruction in the cabin air was even higher than indicated since ozone was also being destroyed in the sample pressurization system, and thus the measured ambient ozone concentration was made lower than the actual ambient concentration. At the 10.0-kilometer altitude, where the data in figure 10 were taken, the percent of ozone destruction in the pressurization system was less than 10 percent of the measured concentration, as shown previously.

High ozone concentrations were encountered on two flights. Data taken during flight 3 over the Great Lakes area are shown in figure 11. The high ozone concentrations correlated with changes in the static air temperature, wind speed and direction, and frost point, which indicated penetration of the tropopause at 1935 G. m. t. and sustained flight in stratospheric air until 2100 G. m. t. The second penetration of the tropopause at 2100 G. m. t. coincided with a jet stream encounter where wind speeds in excess of 56 meters per second were recorded and the ozone concentration decreased abruptly.

Figure 12 shows ozone data recorded during flight 10, when two peaks in ozone concentration were observed. The high ozone concentrations at the peaks indicate air of

stratospheric origin, although it is not clear that the tropopause was encountered. Reference 10 discusses the possible penetrations of the tropopause on this flight in more detail. Storm activity and light turbulence associated with both peaks suggested the possibility of downward mixing of stratospheric air. At 1331 G. m. t., when the first ozone peak was encountered, the ECC meter was again configured to sample cabin air ozone concentrations. On this occasion the proportion of ozone destroyed was not as large as on flight 6. The difference in ozone concentration between the two instruments was computed for 15 data points and expressed in percent of the measured ambient concentration. This yielded an average destruction of 34 percent of the measured ambient concentration.

Carbon dioxide. - As discussed previously, the carbon dioxide analyzer was included in the installation to examine the nondispersed infrared (NDIR) technique, although the analyzer was not sufficiently sensitive to detect the expected variations in CO_2 concentration. This problem was further complicated by the aircraft preflight procedure of shutting off the 60-hertz experiment power supplies for approximately 10 minutes during changeover from ground to aircraft power. Since there was not sufficient time for warm-up and recalibration prior to takeoff, when power was returned, the analyzer calibration was questionable. A further evaluation of the zero and span drift characteristics of this analyzer in the aircraft environment should be made. A means of calibrating the analyzer in flight is needed, and periodic calibration checks should be performed.

A problem with this type of analyzer did become apparent during the flight series. The detector cell in the analyzer contains a thin metal diaphragm which is susceptible to vibration. As the flight series progressed, the analyzer appeared to become more sensitive to vibration and flight turbulence. The detector must either be carefully isolated from vibration or replaced with another type of detector, possibly solid-state.

SUMMARY OF RESULTS

An altitude ambient sample gas pressurization system proposed for aircraft applications was flight tested for approximately 70 flight hours over a range of altitudes. Three gas sampling instruments were installed in the system to assist in evaluating the system and to examine the measuring techniques in a flight environment. Data on pressurization system flow parameters and ozone concentrations were recorded at altitudes between 6 and 12 kilometers on a number of test flights. The following results were obtained:

1. The sample gas pressurization system provided sufficient flow for the three gas analysis instruments and regulated the sample pressure to 10.15 ± 0.1 newtons per square centimeter over the altitude range from 6 to 12 kilometers. No system component failures occurred, and the system required a minimum of adjustment.

2. Two instruments, one using an ultraviolet absorption technique and the other using an electrochemical concentration cell, measured ozone concentrations over the range of

test altitudes and showed agreement to within 20 parts per billion by volume (ppbv). Measured ambient ozone concentrations ranged from approximately 30 ppbv to over 350 ppbv and indicated penetration of the tropopause on two occassions.

3. Ozone destruction in the sample pressurization system was measured after the flight series and was found to be less than 10 percent of the inlet ozone concentration with a sample flow rate of 7000 cubic centimeters per minute, corresponding to a 12-kilometer-pressure-altitude condition.

4. A nondispersed infrared carbon dioxide analyzer included in the flight package demonstrated the need for either vibration isolation or a detector modification to reduce the vibration sensitivity of the analyzer. A further evaluation of zero and span drift characteristics in the aircraft environment is needed, and periodic inflight calibration checks may be required.

5. The proportion of ozone destroyed in the aircraft cabin pressurization system and the cabin environment was measured on two flights and found to vary up to 60 percent of the measured altitude ambient ozone concentration.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 1, 1973,
501-04.

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TABLE I. - INSTRUMENT OPERATING PRINCIPLES EXAMINED

Atmosphere constituent	Sensitivity, ppbv	Operating principle
Ozone	1	Chemiluminescence (ethylene)
Ozone	3	Ultraviolet absorption (zero reference system)
Ozone	10	Ultraviolet absorption (second derivative, uv spectroscopy)
Ozone	5	Electrochemical (potassium iodide)
Carbon monoxide	200	Chemical-optical
Carbon monoxide	10	Chemical-optical (modified)
Carbon monoxide	200	Fluorescent nondispersed infrared
Carbon dioxide	1000	Nondispersed infrared
Water	1000	Aluminum adsorption
Oxides of nitrogen	1	Chemiluminescence
Oxides of nitrogen	.3	Chemiluminescence (modified)

TABLE II. - OCEAN COLOR EXPEDITION FLIGHT SERIES

Flight	Date	Origin	Destination
1	6/28/72	Moffett Field, Calif.	Moffett Field Calif.
2	6/30/72	Moffett Field, Calif.	Moffett Field, Calif.
3	7/5/72	Moffett Field, Calif.	Otis AFB, Mass.
4	7/7/72	Otis AFB, Mass.	Otis AFB, Mass.
5	7/8/72	Otis AFB, Mass.	Otis AFB, Mass.
6	7/9/72	Otis AFB, Mass.	Dakar, Senegal
7	7/11/72	Dakar, Senegal	Dakar, Senegal
8	7/12/72	Dakar, Senegal	Las Palmas, Canary Islands
9	7/13/72	Las Palmas, Canary Islands	Las Palmas, Canary Islands
10	7/15/72	Las Palmas, Canary Islands	Andrews AFB, Wash. D. C. [a]
11	7/17/72	Andrews AFB, Wash. D. C.	Andrews AFB, Wash. D. C.
12	7/18/72	Andrews AFB, Wash. D. C.	Miami, Fla.
13	7/20/72	Miami, Fla.	Miami, Fla.
14	7/21/72	Miami, Fla.	Miami, Fla.
15	7/24/72	Miami, Fla.	Moffett Field, Calif.

[a]Flight stopped in Bermuda for refueling.

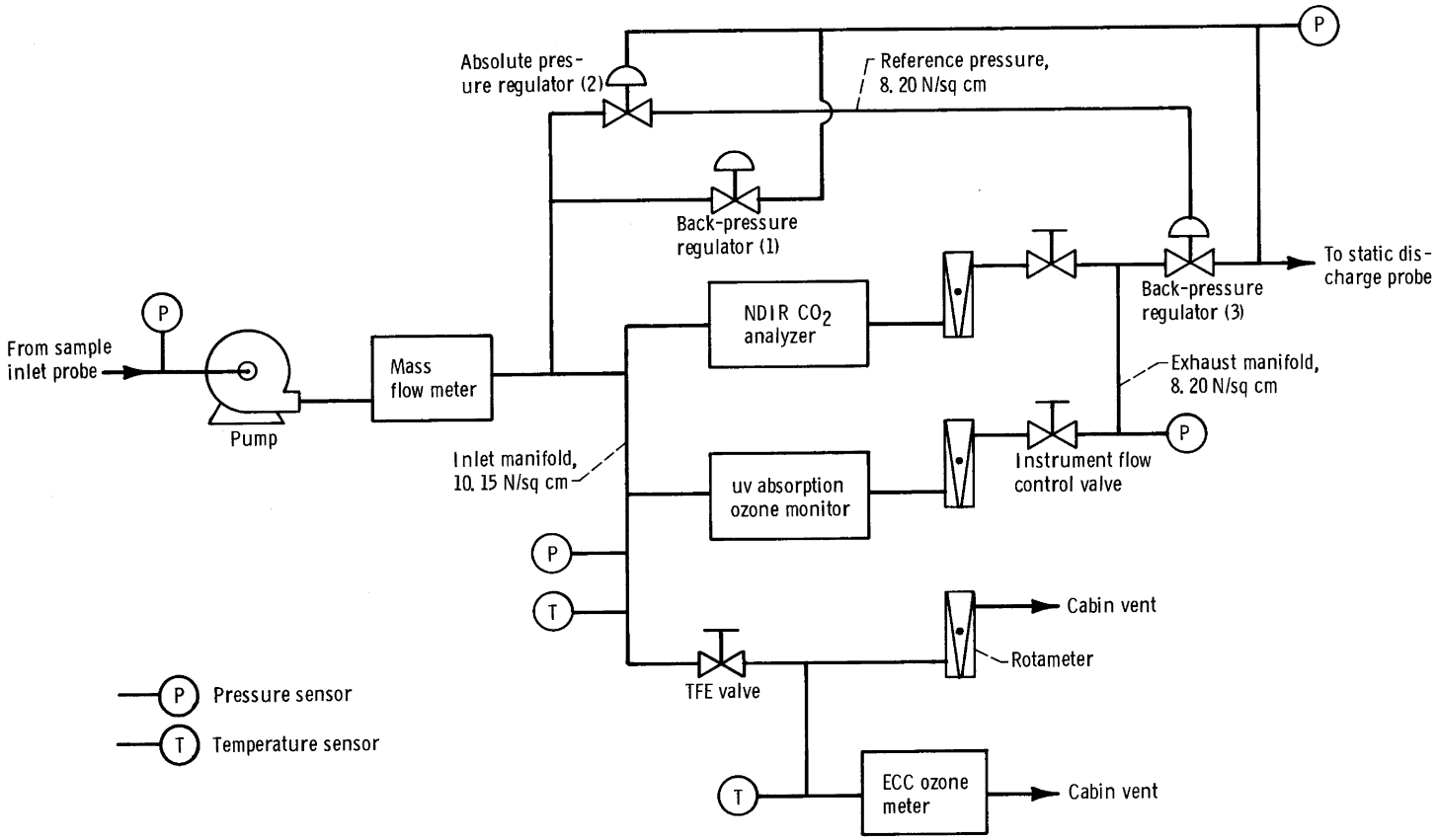


Figure 1. - Schematic of sample pressurization system.

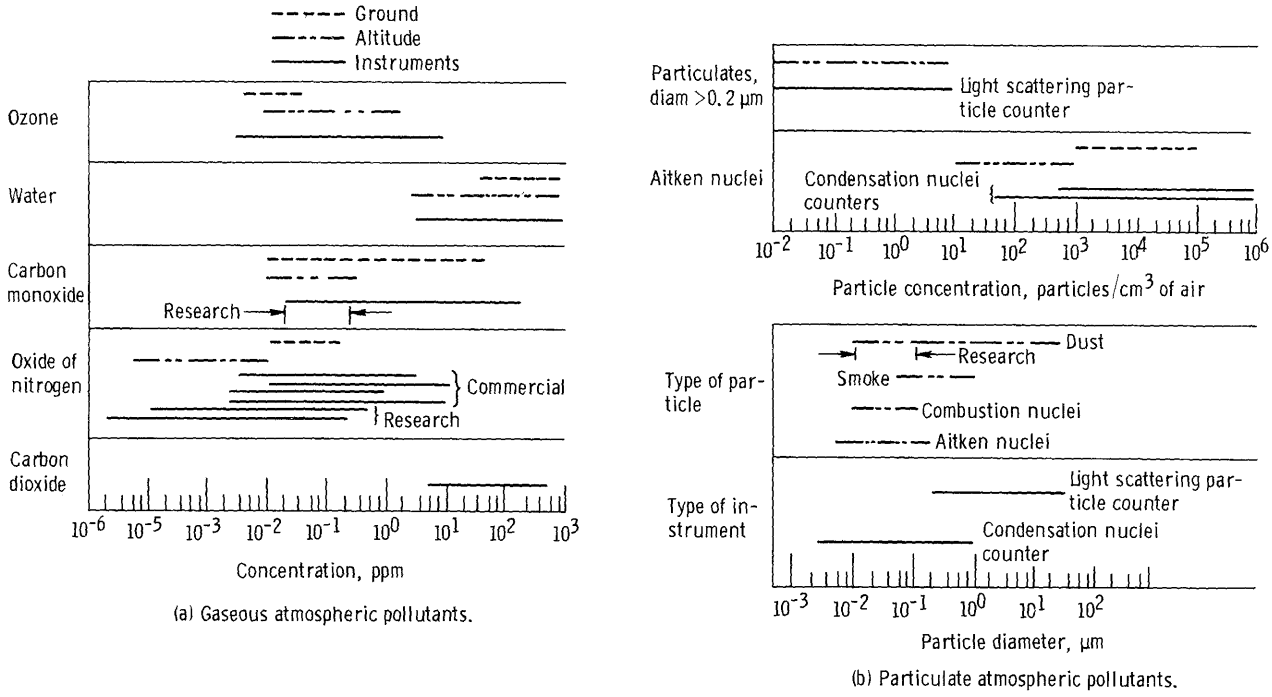
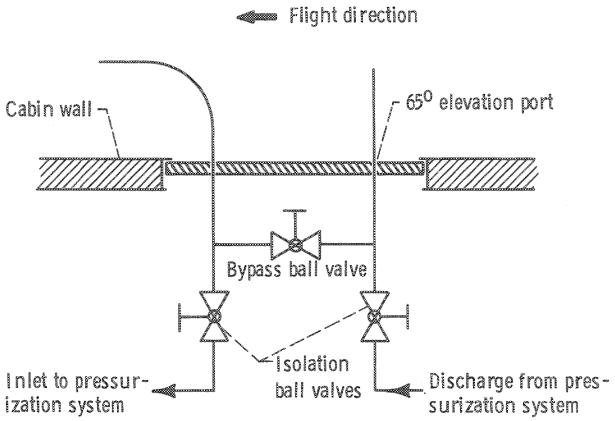
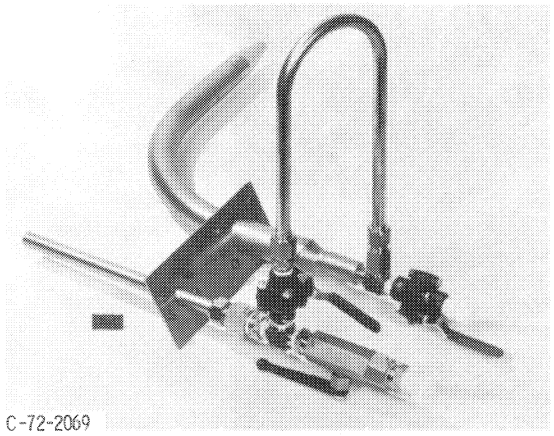


Figure 2. - Ranges of pollutant concentrations and capabilities of both research and commercial candidate instruments.



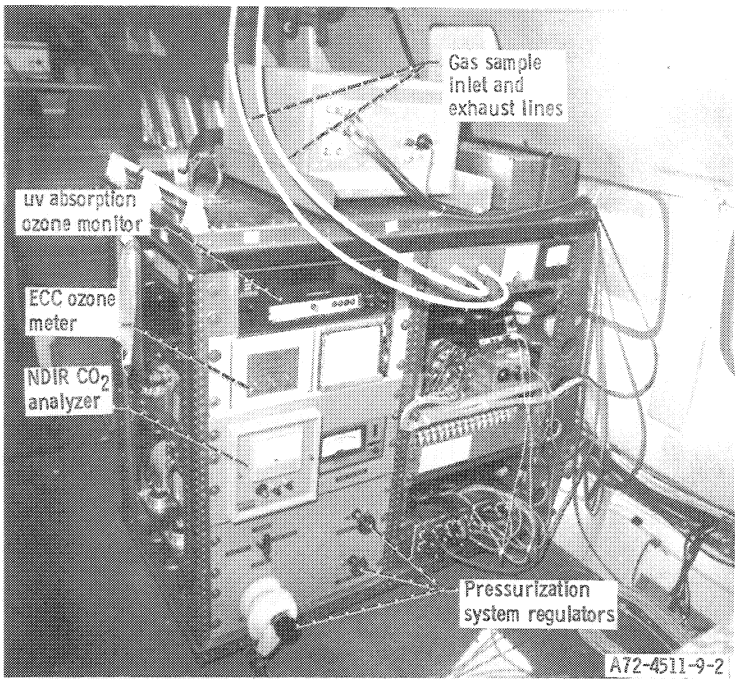
(a) Sample probe schematic.



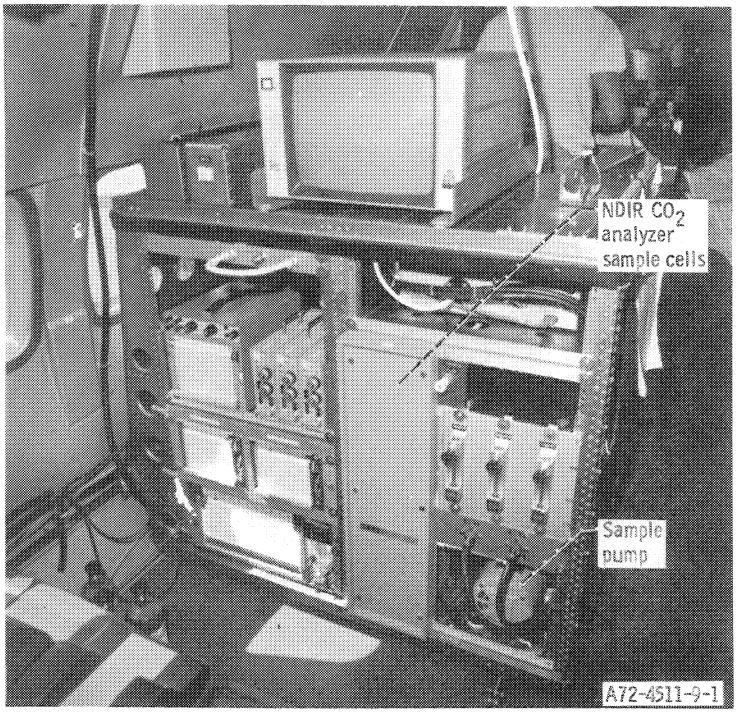
(b) Sample probe assembly.

(c) Sample probe installation.

Figure 3. - Sample probe assembly for CV-990 installation.



(a) View looking forward.



(b) View looking aft.

Figure 4. - Installation of sample pressurization system and gas sampling instruments in CV-990 equipment rack.

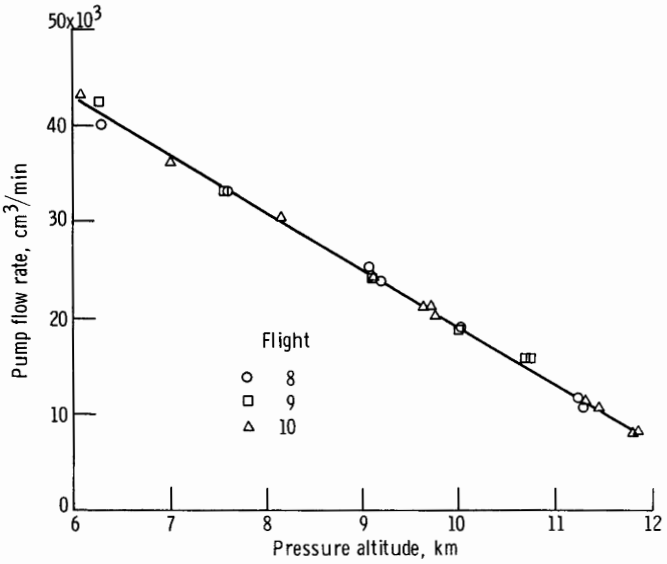


Figure 5. - Effect of pressure altitude on sample pump flow rate.

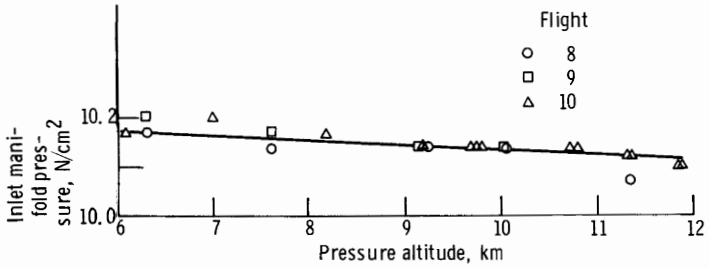


Figure 6. - Effect of pressure altitude on inlet manifold pressure.

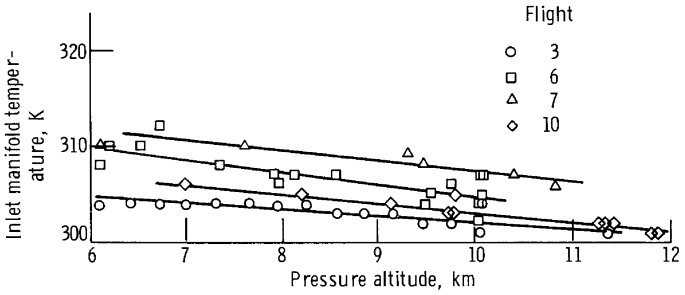
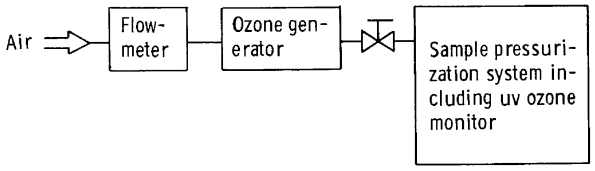
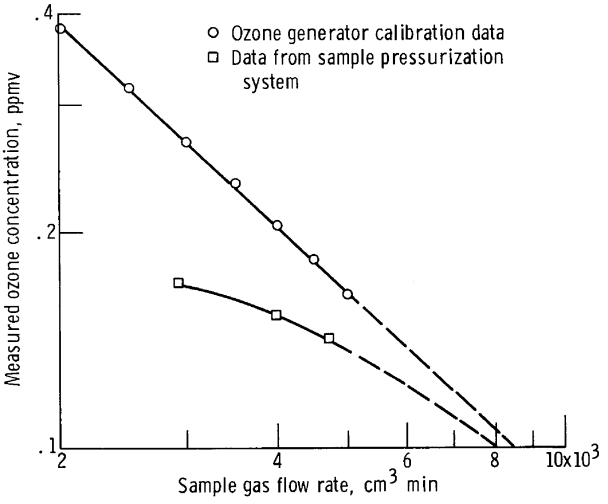


Figure 7. - Effect of pressure altitude on inlet manifold temperature.



(a) Test apparatus.



(b) Test data.

Figure 8. - Effect of sample pressurization system on ozone concentration.

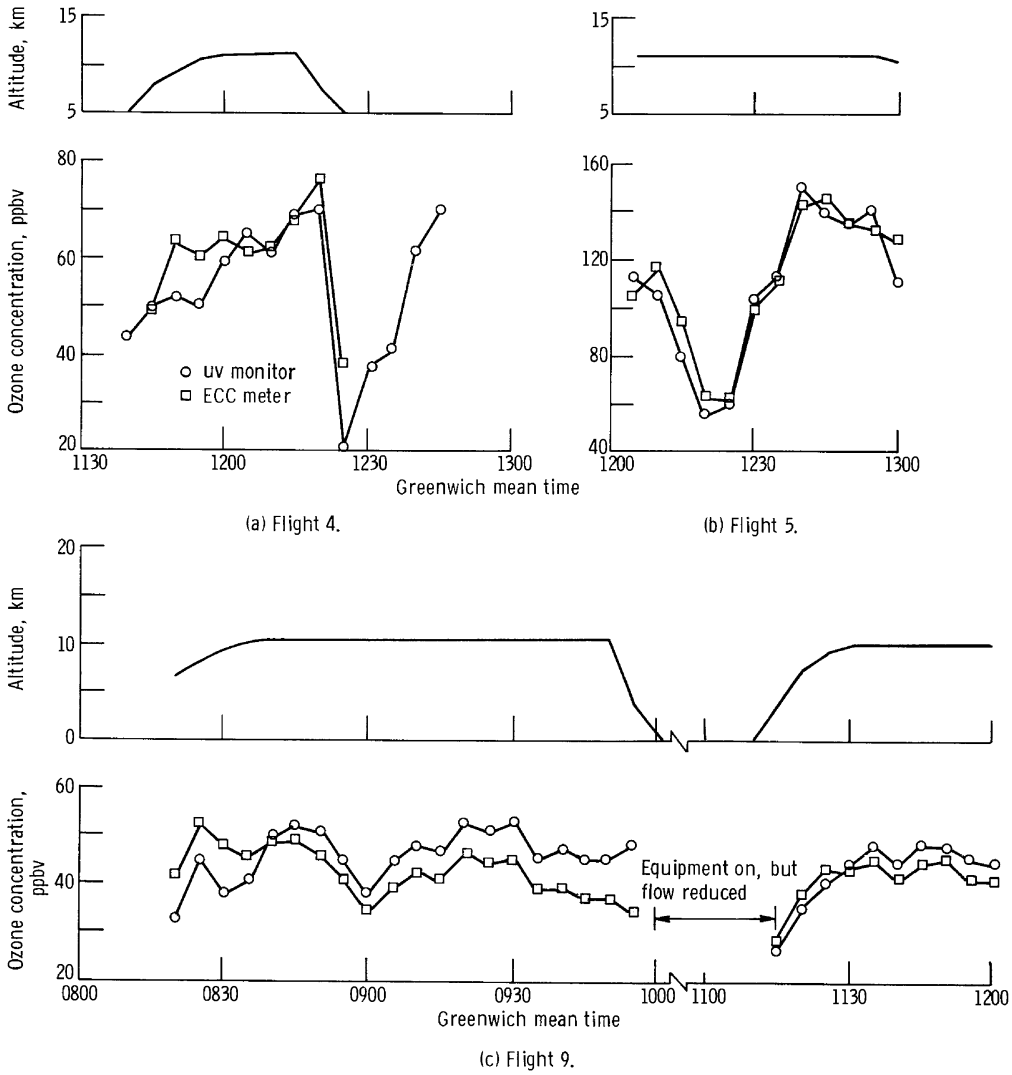
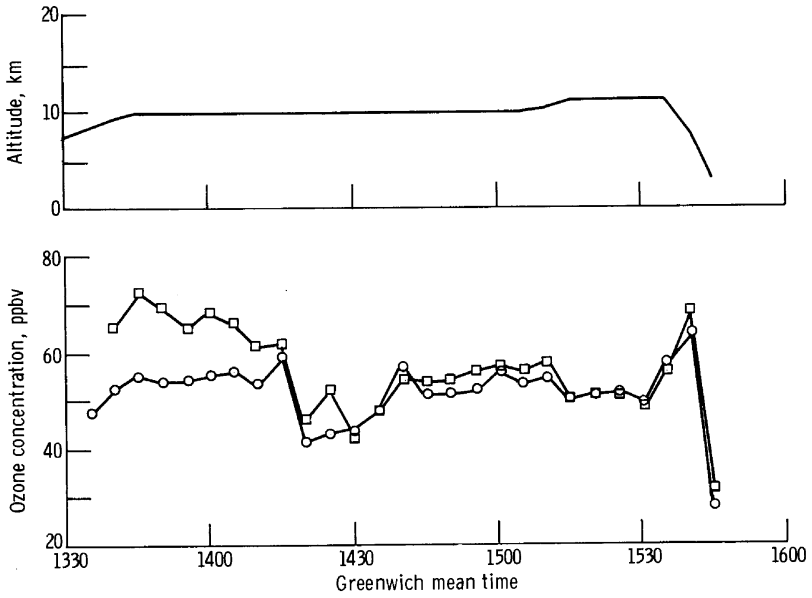
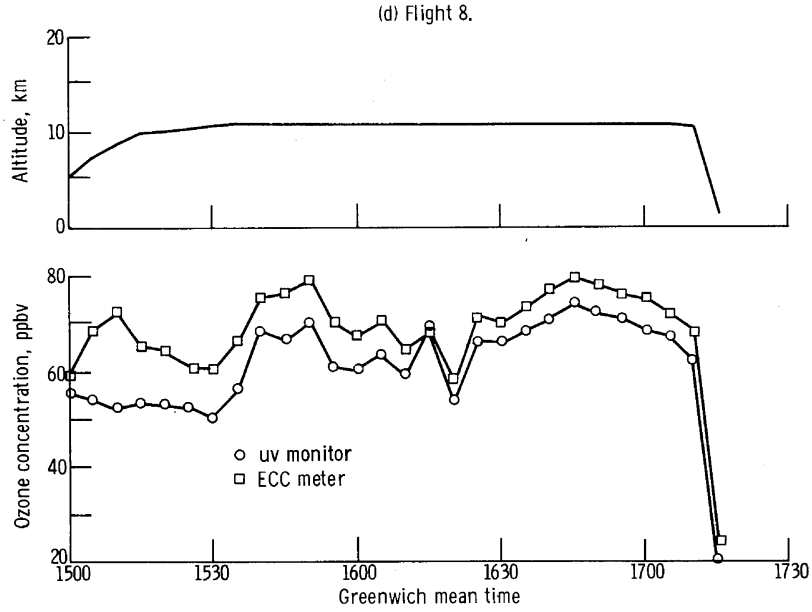


Figure 9. - Flight data comparison of ozone concentrations measured with ultraviolet absorption monitor and electrochemical concentration cell meter.



(d) Flight 8.



(e) Flight 9.

Figure 9. - Concluded.

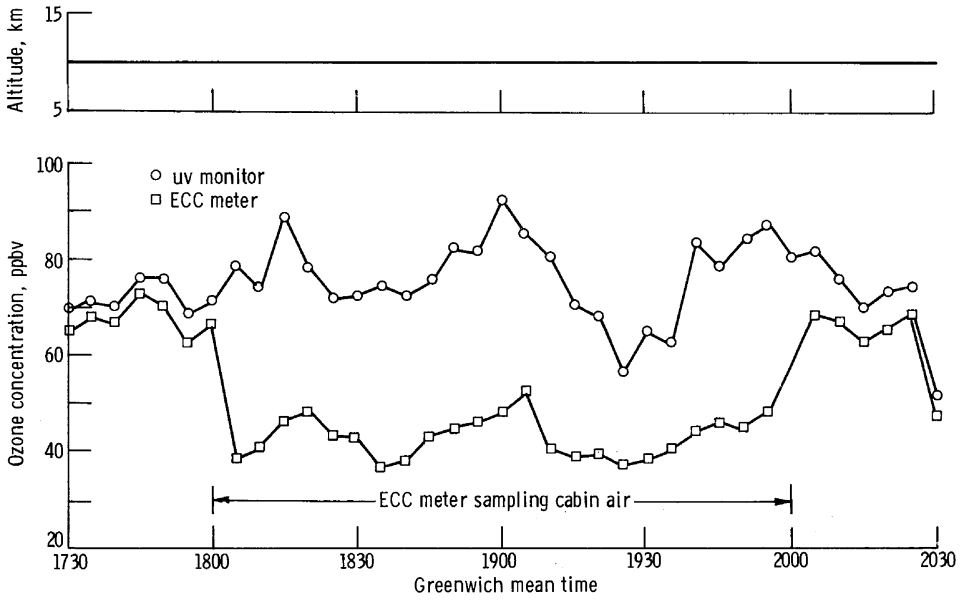


Figure 10. - Destruction of ozone in CV-990 cabin pressurization system measured during flight 6.

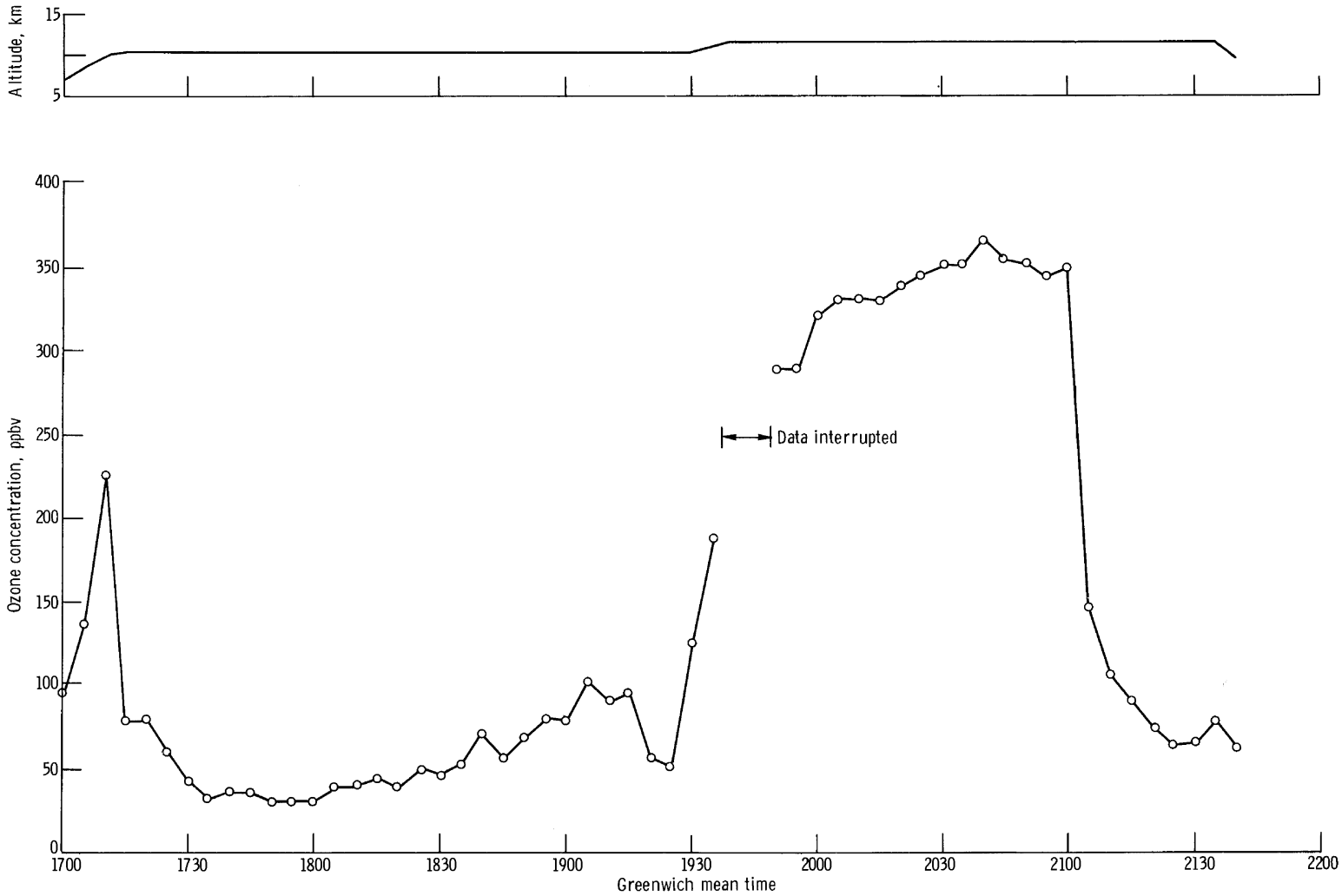


Figure 11. - Ozone concentrations measured during flight 3 with ultraviolet absorption ozone monitor.

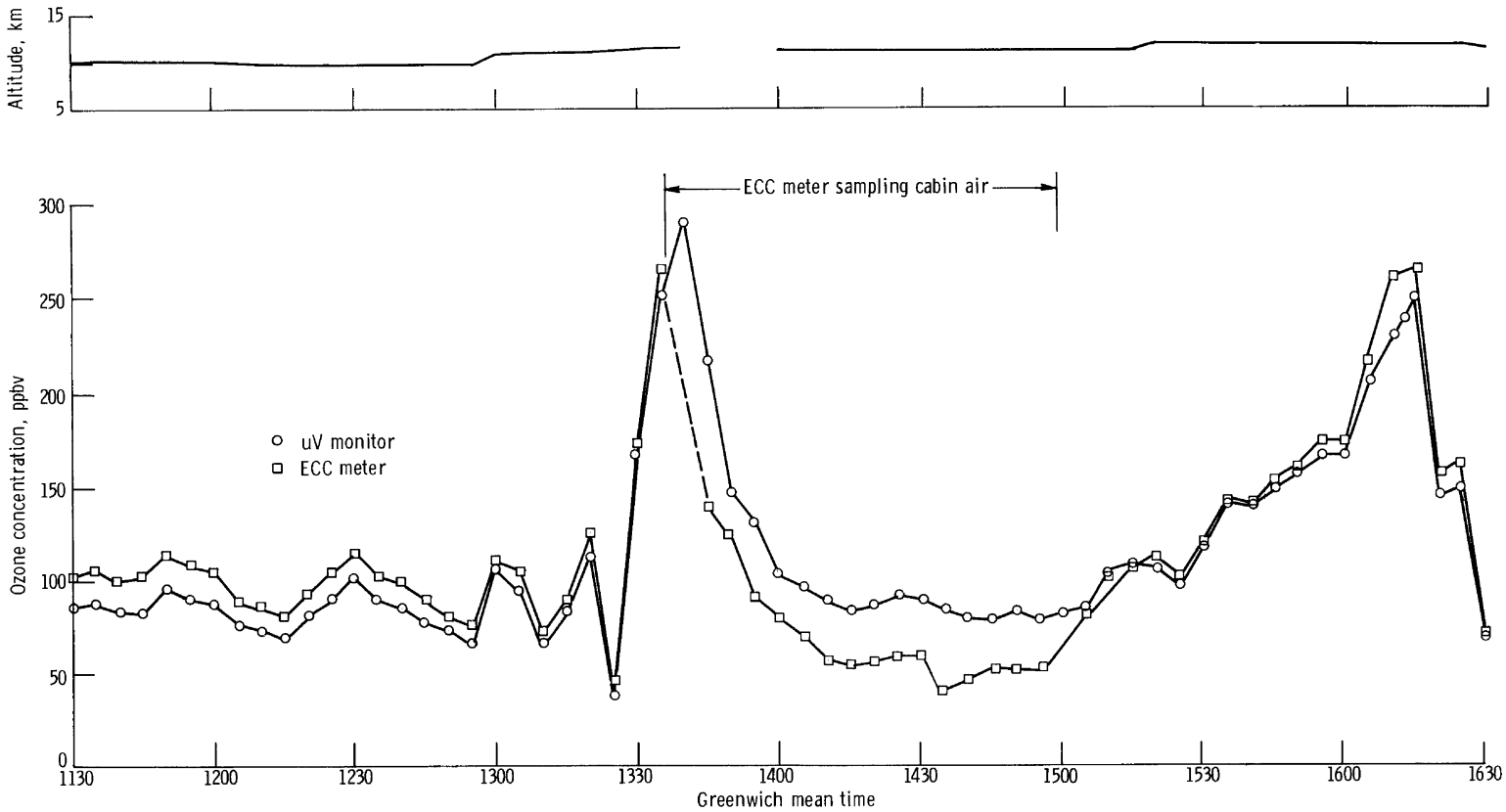


Figure 12. - Ozone concentrations measured during flight 10.