MASTER

Air Ejector **PARTICLE SAMPLER**
A PROGRESS REPORT

PREPARED FOR

DIVISION OF BIOLOGY AND MEDICINE
U.S. ATOMIC ENERGY COMMISSION

BY

APPLIED SCIENCE DIVISION
LITTON SYSTEMS, INC.

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MASTER

AIR EJECTOR PARTICLE SAMPLER

A Progress Report

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September 1, 1964

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INTRODUCTION

At the present time there is a need for sampling systems capable of operating in the stratosphere at altitudes significantly above 100,000 feet. Aside from basic studies involving micrometeorites and naturally occurring debris, this requirement is of special importance because of the potential hazards to man arising out of the re-entry burnup of reactor-powered satellite vehicles and the need for information relative to high-altitude nuclear weapons tests.

Stratospheric sampling programs conducted by the U. S. Atomic Energy Commission, the Air Force, and others have made extensive use of balloon-borne dust collectors.¹ These sampling probes commonly use battery-powered pumps and blowers to pull air through a variety of particle collectors (impactors, filters and electrostatic precipitators). From the beginning, the electromechanical air movers have been a principal source of unreliability in all systems; carbon dust, oil and battery vapors introduce unwanted contamination, motors overheat easily in the thin atmosphere and burn out, and blowers do not operate efficiently.

These problems are compounded as operating altitude is increased. Although balloons are capable of ascending to altitudes above 140,000 feet, very few particulate samples have been obtained above 110,000 feet.

The air ejector pump offers an attractive approach to this dilemma. This relatively uncomplicated device utilizes no moving parts. Power is derived from a tank of compressed gas and batteries are needed only to actuate valves. There is nothing to wear out or burn out.

Under a contract with the Division of Biology and Medicine, U. S. Atomic Energy Commission, this laboratory has utilized theoretical and experimental studies to design a balloon-borne ejector powered filter sampler.*

*Initially proposed by R. K. Olson, Associate Engineer, Applied Science Division, Litton Systems, Inc.

During the past year this device has been tested in an altitude chamber and carried on three research balloon flights to sampling altitudes above 100,000 feet. The most recent of these (January 25, 1964) reached an altitude of 128,000 feet where 87,900 cubic feet of air were processed in 144 minutes. To date this is the highest level from which a large-volume sample has been obtained.

Although the ejector sampler is being developed primarily as a device capable of operating in the 100,000 to 150,000 foot region, preliminary calculations indicate that it may also be a competitive system at lower altitudes (60,000 feet) if comparisons include reliability factors.

LIST OF SYMBOLS

The following symbols are used in this report:

a	=	sound speed
A_1	=	area, primary nozzle exit
A_2	=	area, secondary nozzle exit
A_9	=	area, diffuser inlet (and mixing tube)
m_1	=	mass flow rate, primary (driving) gas
m_2	=	mass flow rate, secondary (driven) air
M_1	=	Mach number, primary nozzle exit
M_2	=	Mach number, secondary nozzle exit
M_9	=	Mach number, diffuser inlet
P_a	=	pressure, ambient (altitude) conditions
P_b	=	static pressure immediately downstream of filter collector
P_{o1}	=	total pressure, primary gas at primary nozzle exit
P_{o2}	=	total pressure, secondary air at secondary nozzle exit
Q_a	=	volume flow rate, air ingested at ambient (altitude) conditions
Q_2	=	volume flow rate, air at secondary nozzle conditions
T_o	=	stagnation temperature
V_2	=	velocity of air, secondary nozzle exit

- ϕ = mass ratio, mass of secondary air pumped per unit mass of primary (driving) gas used
- γ = isentropic exponent (air = 1.4)
- η_d = diffuser efficiency
- ρ_a = density, air at ambient (altitude) conditions
- ρ_2 = density, air at secondary nozzle conditions

DEVELOPMENT OF THE AIR EJECTOR PUMP

Review of Preliminary Studies

Design data for the high-altitude ejector pump have been obtained by McFarland in a feasibility study supported by the AEC.² This work, involving the theoretical development of continuity and momentum equations, supported by appropriate altitude chamber verification tests, is the subject of a paper being prepared for publication. Although a comprehensive discussion of ejector pump principles is not within the intended scope of this report, for the sake of completeness, some important relationships are presented here without proof.

Basically, an ejector pump is a simple device. As illustrated in Figure 1, a jet of high-velocity primary gas injected into a mixing tube will expand to entrain the surrounding secondary air. The resulting turbulent exchange of momentum between the driving (primary) gas and the driven (secondary) air produces a region of reduced pressure and a net flow through the system.

FIGURE 1. CONSTANT MIXING AREA EJECTOR PUMP

Two types of air ejectors have been described extensively in the literature. In the first type, primary and secondary streams mix in a tube of constant area; in the second, mixing occurs under constant pressure conditions in a diffuser. The constant-area ejector was chosen for this application because a large fraction of the pressure rise can be developed in the mixing section itself, whereas constant-pressure ejectors are entirely dependent upon the performance of a diffuser. This is felt to be an important consideration in this application because low air densities encountered at high altitudes tend to be detrimental to the performance of a diffuser.

In McFarland's analysis, which is patterned after that used by Chisholm,³ the flow is considered to be one-dimensional, steady, frictionless, and adiabatic. For the case in which the driving and driven gases are both air at the same total temperature, with sonic flow at the primary nozzle ($M = 1.0$), the continuity and momentum equations can be written in familiar thermodynamic notation:

(1) Continuity

$$\frac{P_{01}}{P_a} \frac{A_1}{A_9} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} + \frac{P_{02}}{P_a} \frac{A_2}{A_9} M_2 \left(1 + \frac{\gamma-1}{2} M_2^2 \right)^{\frac{-(\gamma+1)}{2(\gamma-1)}} \\ = M_9 \frac{\left(1 + \frac{\gamma-1}{2} M_9^2 \right)^{\frac{1}{2}}}{\left(1 + \frac{\gamma}{2} \eta_d M_9^2 \right)}$$

(2) Momentum

$$\frac{P_{01}}{P_a} \frac{A_1}{A_9} \frac{2 \frac{\gamma}{\gamma-1}}{\left(1 + \gamma \right)^{\frac{1}{\gamma-1}}} + \frac{P_{02}}{P_a} \frac{A_2}{A_9} \frac{\left(1 + \gamma M_2^2 \right)}{\left(1 + \frac{\gamma-1}{2} M_2^2 \right)^{\frac{\gamma}{\gamma-1}}} = \frac{1 + \gamma M_9^2}{1 + \frac{\gamma}{2} \eta_d M_9^2}$$

A useful measure of the performance of an air ejector pump is the ratio ϕ of the mass flow rate m_2 of air drawn into the air ejector per unit mass flow rate m_1 of primary gas expended. For the same conditions as assumed for the previous equations, this mass ratio can be expressed as:

$$\phi = \frac{m_2}{m_1} = \frac{P_{o2}}{P_{o1}} \frac{A_2}{A_1} M_2 \left[\frac{1 + \gamma}{2 \left(1 + \frac{\gamma - 1}{2} M_2^2 \right)} \right]^{\frac{\gamma + 1}{2(\gamma - 1)}} \quad (3)$$

Equations (1), (2) and (3) have been solved numerically on a Control Data Corporation Model G-15D digital computer using the Newton-Raphson iteration process. The ejector parameter values initially selected were those corresponding to an ejector model being evaluated experimentally:

$$\begin{aligned} \gamma &= 1.4 \quad (\text{air}) \\ A_1/A_9 &= 0.01 \\ A_2/A_9 &= 0.99 \\ \eta_d &= 0.50 \end{aligned}$$

Although diffuser efficiency η_d is a function of both altitude and Mach No. (M_9), it has been treated as a constant in solving the analytical equations. The value of 50% is suggested by Alves,⁴ and subsequent comparisons with experimental data indicate that this value was a good choice.

Plots of Equations (1) and (2) showing Mach No. (M_2) as a function of the secondary pressure ratio (P_a/P_{o2}) for constant values of primary pressure ratio (P_{o1}/P_a) are shown in Figure 2. Similarly, it is possible to solve Equation (3) and calculate the mass ratio ϕ as a function of P_a/P_{o2} for constant values of P_{o1}/P_a as displayed in Figure 3.

FIGURE 2. THEORETICAL PUMP PERFORMANCE--MACH NO. AT SECONDARY INLET

FIGURE 3. THEORETICAL PUMP PERFORMANCE--MASS RATIO

It will be noted that the family of curves in Figure 3 generate an envelope, the upper limit of which is indicated by a dashed line. For a particular pump configuration ($A_1/A_9 = 0.010$) this line defines the most favorable mass ratios ϕ that can be obtained with optimum combinations of primary pressure ratio P_{O1}/P_a^* and secondary pressure ratio P_a/P_{O2}^{**} . In order to determine the effect of changes in pump geometry, Equations (1), (2) and (3) have also been evaluated with respect to area ratios other than 0.010. In Figure 4 the dashed curve of Figure 3 ($A_1/A_9 = 0.010$) has been re-drawn in a comparison with similar curves corresponding to primary nozzle/mixing section area ratios (A_1/A_9) of 0.005 and 0.020. This presentation shows that the relationship between mass ratio ϕ and secondary pressure ratio P_a/P_{O2} is not a strong function of the area ratio.

FIGURE 4. OPTIMUM MASS RATIO FOR DIFFERENT PRIMARY NOZZLE/MIXING TUBE AREA RATIO

* Primary pressure ratio P_{O1}/P_a is a controllable parameter dependent upon the pressure at which the driving (primary) gas is injected.

** Secondary pressure ratio (P_a/P_{O2}) is essentially equal to the pressure ratio (P_a/P_b) developed across a filter or other resistance upstream of the pump as a consequence of the induced secondary air flow through the collector.

It is interesting to note the absence of scale factors in these relationships. All parameters are given in terms of dimensionless ratios. Performance of the ejector is substantially independent of size, provided geometric and dynamic similarity are observed.

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DESIGN OF THE EXPERIMENTAL EJECTOR POWERED SAMPLER

Basic Objectives

In order to minimize the number of variables involved and to facilitate subsequent comparisons with other operational particle collectors, the experimental sampler has been designed as a filter unit employing IPC 1478 paper in the direct-flow configuration shown in Figure 5. Stipulated performance goals emphasize the following:

- 1) Reliable operation in the stratosphere at altitudes up to 130,000 feet.
- 2) Ability to process large volumes of air (10^5 ft^3) at sampling rates approaching 1000 ft^3/min .

FIGURE 5. EJECTOR POWERED FILTER SAMPLER -- SCHEMATIC

Reliability is important because of the high cost of operational sampling missions; large samples are required for accurate radiochemical analyses; and high sampling rates reduce sampling time and minimize recovery costs.

FIGURE 6. RATIO OF PRESSURES ACROSS IPC 1478 FILTER

Design Features

● FILTER AREA

A filter area of 2 ft² was chosen for the sampler. This value represents a compromise between two opposing factors: 1) From the analysis standpoint, minimum filter area is desirable to reduce the amount of interfering background contamination present in the mat as introduced during manufacturing and handling; 2) From the sampler design standpoint, a large filter area is desirable to provide minimum resistance against which the pump must operate.

In previous work with other samplers using IPC 1478 filter media, the flow, pressure drop relationships have been established for an appropriate range of operating pressure altitudes. These relationships are summarized in Figure 6 with respect to an IPC collector having an area of 2 ft².

● PUMP DIMENSIONS

From Figure 4 it is evident that the mass ratio (pounds of air pumped per pound of driving gas) is not a sensitive function of the primary jet/mixing tube area ratio (A_1/A_0). As a result of this comparison and considerations involving other factors such as machining tolerances, an area ratio of 0.010 was selected for the experimental sampler. Since this area ratio is the same as used by McFarland in the preliminary study, much of his experimental altitude chamber data have been applied directly to the sampler design.

Dimensions of the pump are largely determined by flow-rate goals. Since we have specified a design flow rate of 1000 cfm at an operating altitude of 110,000 feet, the pressure ratio P_a/P_b across the filter as given by the curves of Figure 6 will be approximately 1.29. This is the pressure ratio that the pump must work against.

The primary pressure ratio required for most economical operation under these flow conditions (best mass ratio) is obtained from Figure 7, a replot of data defining the optimum relationship between primary and secondary pressure ratios. Noting again that at 1000 cfm, $P_a/P_b = 1.29 = P_a/P_{O_2}$, the corresponding primary pressure ratio is 38.

FIGURE 7. OPTIMUM RELATIONSHIP BETWEEN
PRIMARY AND SECONDARY PRESSURE

From Shapiro,⁵ the mass flow per unit area through the secondary nozzle (isentropic flow) may be expressed by the equation:

$$\frac{m_2}{A_2} = \frac{\sqrt{\gamma} P_{o2}}{\sqrt{R} \sqrt{T_o}} \frac{M_2}{\left(1 + \frac{\gamma-1}{2} M_2^2\right)^{\frac{\gamma+1}{2(\gamma-1)}}} \quad (4)$$

Since

$$m_2 = \frac{P_a Q_a}{R T_o},$$

and

$$\sqrt{\gamma R T_o} = a = \text{the velocity of sound,}$$

Equation (4) can be rearranged into a convenient form from which the ejector pump secondary nozzle area A_2 can be obtained:

$$A_2 = \frac{P_a Q_a}{P_{o2} M_2 a} \left(1 + \frac{\gamma-1}{2} M_2^2\right)^{\frac{\gamma+1}{2(\gamma-1)}} \quad (5)$$

Under 110,000 foot conditions, where:

$$a = 6.13 \times 10^4 \text{ ft/min} = \text{sound speed,}$$

$$Q_a = 1000 \text{ ft}^3/\text{min,}$$

$$P_a/P_{o2} = 1.29,$$

$$M_2 = 0.58,$$

and $\gamma = 1.4,$

Equation (5) yields an optimum value

$$A_2 = 0.044 \text{ ft}^2.$$

Because of a number of practical considerations, the area actually used for the secondary nozzle and mixing tube is 0.039 ft² (diameter = 2.68 inches).

Important features of the prototype ejector pump are shown in Figure 8. The primary nozzle has a 0.268 inch throat with an outside contour designed to permit the secondary air flowing over that surface to have a stable boundary layer. Gas from the primary nozzle discharges at the mixing tube entrance plane.

FIGURE 8. SCHEMATIC DIAGRAM OF PROTOTYPE EJECTOR PUMP

The interior contour of the secondary nozzle is an elliptical section similar to the ASME long-radius nozzles and it has a throat diameter of 2.68 inches.

The mixing tube has a 2.68 inch inside diameter and is 18.6 inches long. This length-to-diameter ratio ($L/D = 7$) is felt to represent the best compromise between a long length required for complete mixing and a short length minimizing frictional pressure losses. This value is also recommended by Keenan, et al.⁶

For pressure recovery the ejector is terminated by a 3-degree half-angle diffusing cone having an exit diameter of 5 inches.

● PRIMARY GAS RESERVOIR

A spherical titanium tank with an enclosed volume of 4655 cubic inches contains the primary driving gas. Weighing 50 pounds empty, this tank can hold up to 48 pounds of nitrogen compressed at 3600 psi.

Titanium is corrosion resistant and able to withstand severe thermal shock. Because of this and its exceptionally low thermal conductivity, we are able to use a convenient filling method in which the required weight of nitrogen is added as a liquid. Subsequent evaporation leaves the tank pressurized at the proper operating level without the use of high pressure pumps and gas-drying systems.

As a safety precaution, the vessel is subjected to a hydrostatic test at 4200 psi prior to each filling. This is done in order to insure that any damage sustained during previous landing impacts is detected. In this connection, it should be pointed out that no titanium reservoirs have been damaged or replaced in this program. One unit has survived four parachute landings, another, five landings. It is anticipated that the initial cost of a titanium reservoir will be distributed over many operations. The most promising alternative, the spun-filament fiberglass tank, is comparable in weight but higher in ultimate cost since it must be replaced after a limited number of filling cycles.

● PRIMARY SUPPLY REGULATION

In order to achieve the desired performance, primary gas must be expended at a selected constant rate, as dictated by the pumping speed required and the operating altitude. In the experimental sampling system, the flow of primary gas is controlled by an adjustable, single-stage pressure regulator and a pressure-dropping orifice as shown in Figure 8. In normal operation, the regulator maintains a constant downstream pressure on the order of 40 to 60 psi as the reservoir pressure bleeds down from 3000 psi. The orifice subsequently drops the pressure further to a value yielding the desired primary pressure ratio (P_{01}/P_a) at the nozzle exit. Substitution of various-size, calibrated orifices adjusts the primary pressure for operation at different sampling altitudes. Flow is initiated and stopped by two expendable explosive valves activated by an adjustable programmer.

● FLOWMETER

Meaningful interpretation of data from a sampling flight requires a determination of the total volume processed. On the ejector sampler, volume flow is measured by a low-drag propeller anemometer⁷ mounted between the filter collector and the pump. Appropriate corrections applied after the flight compensate for the fact that air density at the flowmeter is somewhat less than ambient (altitude) density. The total corrected volume is ultimately reduced to the volume of an equivalent mass at STP (0°C, 760 mm Hg).

System Operating Parameters

An important operating variable is the pressure P_{01} of primary gas at the nozzle exit. For a given operating altitude and filter area, this pressure setting will determine the sampling rate Q_a and the volume of ambient air pumped by each pound of primary gas. Figure 9 presents characteristic performance curves of the prototype ejector, showing the relationship of sampling rate Q_a and secondary pressure ratio P_a/P_{02} for different settings of primary gas pressure (expressed as the primary pressure ratio P_{01}/P_a).

FIGURE 9. OPERATING CHARACTERISTICS OF THE PROTOTYPE SAMPLER

Superimposed upon the pump curves of Figure 9 are the experimentally determined load characteristics of an IPC filter collector with area of two square feet. Since the pressure ratio P_a/P_{02} across the pump = P_a/P_b , the pressure ratio across the filter, the intersection of the appropriate filter load curve, and a selected pump primary pressure ratio defines an operating point of the pump-filter combination.

The curves shown in Figure 9 can be used in a number of ways. If, for example, we choose to run the pump at a primary pressure ratio of 20, the operating point defined by the intersection of appropriate filter and pump curves yields a sampling rate of 650 cfm at 110,000 feet (solid lines) or 570 cfm at 130,000 feet (dashed lines). If we wish to increase the sampling rate at 110,000 feet to 1000 cfm in order to shorten the sampling time, the curves show that this can be achieved by increasing the primary gas pressure to obtain a ratio, $P_{01}/P_a = 49$.

Not immediately evident from the curves of Figure 9 is the fact that an increase in sampling rate obtained by raising the primary gas pressure may incur a penalty in the form of a lower mass ratio, i. e., less air will be pumped by each pound of primary gas. This fact can be expressed in another way by stating that for a given pump-collector configuration, it generally takes more primary "fuel" to sample a given volume of stratospheric air in a short time than would be required over a longer time.

Noting from Figure 9 that 650 cfm and 1000 cfm (at 110,000 feet) generate pressure ratios (P_a/P_{02}) of 1.17 and 1.29 across the pump, respectively, the corresponding mass ratios (pounds of air pumped per pound of compressed nitrogen) may be found by referring back to the appropriate curves of Figure 3. At 650 cfm, $\phi = 2.4$ lb air/lb nitrogen; at 1000 cfm, $\phi = 1.7$ lb air/lb nitrogen.

ALTITUDE CHAMBER TESTS

Pre-flight tests have involved the assembly and operation of a complete sampling system in an altitude chamber. In these tests we have not been able to evaluate the system at full flow rates (1000 cfm) due to limitations of the chamber pumping system. (At full flow rates the primary gas is injected faster than the chamber pumps can dispose of it, and chamber pressure rises.)

It has, however, been possible to check out the integrated flight system functionally, and compare performance actually achieved with a computed performance derived from theoretical relationships.

The Test Setup

One sampling unit (Figure 10) was suspended in the altitude chamber in a manner calculated to provide a free unobstructed flow of air at the inlet and exhaust. Calibrated differential pressure gauges monitored pressure drop across the filter collector, and the PR-2 propeller anemometer provided a measurement of the volume pumped. Pressure altitude was telemetered by the B-58 altitude transmitter, and was also indicated by oil manometers. In order to simulate an actual flight, all functions, i.e., recorder start, timer start, ejector pump start, and pump stop, were initiated by the programmer used on balloon test flights.

FIGURE 10. PROTOTYPE AIR EJECTOR SAMPLER, ASSEMBLED

Test No. 1 - Operation at 90,000 Feet

In the first test, the pressure regulator was set at a value which would give a primary mass flow which the environmental chamber pumps could handle while maintaining a density altitude of 90,000 feet. After the chamber was pumped down, the unit automatically went through its program. Results are summarized in Table 1 and data are tabulated in Appendix A.

TABLE 1

Summary of Altitude Chamber Results for 90,000 Foot Test Altitude	
Altitude* (ft)	90,000
Regulator pressure (psia)	73
Primary pressure ratio (P_{01}/P_a)	18.6
Secondary pressure ratio (P_a/P_{02})	1.11
Ambient volume sampled (ft^3)**	66,127
Predicted sampling rate (ft^3/min)	855
Observed sampling rate (ft^3/min)	882

* Density equivalent altitude based upon 1958 ICAO Standard Atmosphere.

** Total volume during first 75 minutes of operation.

In this test the single stage pressure regulator operated at a set pressure near 73 psi. Figure 11 displays the observed flow rate and regulator pressure graphically as a function of time during the 75-minute run.

FIGURE 11. OBSERVED FLOW RATE AND GAUGE PRESSURE, ALTITUDE CHAMBER TEST

Test No. 2 - Operation at 105,000 and 108,400 Feet

In order to maintain a density equivalent chamber altitude of 105,000 feet for the second test, it was necessary to operate the sampler at a lower primary mass-flow rate. This was accomplished by reducing the regulator set pressure to 45 psi. The combined effect of this adjustment, plus the drop across the throttling orifice, yielded a primary pressure ratio (P_{O1}/P_a) of 14.5.

During this run, it was found that the altitude chamber pumps were operating slightly below their capacity, so after all data pertaining to operation at 105,000 feet had been recorded, and without stopping the run, the operating altitude was increased to the maximum value the chamber could sustain. Operating data at this density altitude (108,500 feet) were then recorded. Results of operation at 105,000 feet and 108,500 feet are summarized in Table 2.

TABLE 2

Summary of Altitude Chamber Results for 105,000 and 108,500 Foot Operation		
Altitude (ft)	105,000	108,500
Regulator pressure (psia)	46	47
Primary pressure ratio (P_{O1}/P_a)	14.5	16.9
Secondary pressure ratio (P_a/P_{O2})	1.12	1.14
Predicted sampling rate (ft^3/min)	585	630
Observed sampling rate (ft^3/min)	617	666

FIGURE 12. COMPARISON OF THEORETICAL AND OBSERVED PERFORMANCE, ALTITUDE CHAMBER TESTS

In Figure 12 sampler performance as predicted from theory is compared graphically with performance observed in the altitude chamber. The three curves display the functional relationship between primary pressure ratio and pumping speed for the three test conditions as computed from the theoretical model. Superimposed on these curves are the three test points for 90,000 feet, 105,000 feet, and 108,500 feet at the flow rates actually observed.

Conclusions - Altitude Chamber Tests

Within the limitations imposed by the altitude chamber, the agreement between theoretical and experimental data is good. In fact, the correlation is much better than would normally be expected in view of the number of simplifying assumptions incorporated into the theoretical treatment.* Although we could not verify performance at full flow rates (1000 cfm) or at the higher operating altitudes (130,000 feet) the tests tend to indicate that, within limits, theory may be used to obtain reasonable estimates of performance. It should be pointed out that the present theory does not take into account frictional effects that may become significant at higher mixing tube Mach numbers.

* We have, for example, assumed a diffuser efficiency $\eta = 0.5$.

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FLIGHT TESTS

To date, three flight tests of the prototype sampling system have been performed:

Flight No.	Date	Altitude (ft)	Launch Site
2618	June 7, 1963	105,800	Minneapolis, Minn.
2639	Oct. 24, 1963	106,800	San Angelo, Texas
2641	Jan. 25, 1964	128,000	San Angelo, Texas

Flight 2618 was conducted at Minneapolis, Minnesota, using Litton's ASD launch facilities. Flights 2639 and 2641 were cooperative ventures at San Angelo, Texas, in which ASD prepared the balloon payload, and the Air Force's 59th Weather Reconnaissance Squadron personnel conducted launch and recovery operations. These research flights had the following common objectives:

- 1) Evaluation of the prototype sampler with respect to ease of handling during preparation, launch and recovery.
- 2) Evaluation of the sampler's performance with respect to operation at 110,000 and 130,000 feet in the stratospheric environment.
- 3) Collection of large particulate samples for radiochemical analyses.
- 4) Determination of temperature profiles in and around the sampling equipment.

FIGURE 13. PAYLOAD CONFIGURATION, FLIGHT 2618

Flight 2618, June 7, 1963

Two identical prototype samplers in the configuration shown in Figure 13 were launched at 0430 CST on June 7, 1963. One objective of this flight was to evaluate sampler performance at different sampling rates.

Sampler No. 1 was fitted with the proper inlet orifice to induce a secondary flow of $1000 \text{ ft}^3/\text{min}$ at 40 psia inlet pressure at an altitude of 110,000 feet. Sampler No. 2 was set up to achieve an operating point of $500 \text{ ft}^3/\text{min}$ secondary air flow at 110,000 feet. The sampling times were established as 90 minutes for Sampler No. 1 and 240 minutes for Sampler No. 2.

The weights of primary gas required to fulfill the sampling mission described were 40 pounds for Sampler No. 1 and 32 pounds for Sampler No. 2. This corresponds to storage pressures of 3000 and 2400 psig.

Flight 2618 was launched at 0430 CST on June 7, 1963. Surface winds were moderate, but shifted approximately 15 degrees to the west after layout and during inflation. As a consequence of the wind shift, the launch vehicle was forced to leave the runway on the take-off run. Release and separation of the payload from the truck were normal and smooth; but Sampler No. 1 was observed to have suffered damage to the mixing section when the launch vehicle encountered a large bump just after leaving the runway. Misalignment of the mixing tube was evident visually, and subsequent examination revealed that the bump had thrown the sampler upward off its cushioning support, allowing the mixing tube to hit the launch platform and to be partially separated from its juncture with the secondary nozzle.

The rate of rise to float altitude of 105,800 feet was approximately $1000 \text{ ft}/\text{min}$. Shortly after launch, a fast-moving line of squalls entered the area. The balloon floated over heavy cloud cover for the duration of the flight, during which loss of ground radiation apparently caused a reduction in float altitude.

FIGURE 14. PAYLOAD CONFIGURATION, FLIGHT 2639

Sampling began, as indicated by double keying of the transmitter, at 6:42 CST. Sampler No. 1 shut off as programmed at 8:12 CST, and Sampler No. 2 stopped sampling at 10:40 CST.

Flight termination occurred at 10:52 CST, and impact occurred at approximately 11:35 CST in an open field near Clearwater, Minnesota. Surface winds at impact were high, about 20 knots. This provided an excellent test of the impact characteristics of the system. Inspection at the landing site revealed that impact had occurred directly on the fiberglass shield with no subsequent dragging. No part of the apparatus was damaged by impact.

Performance of samplers on Flight 2618 is included in the Summary, Table 3, page 39.

Flight 2639, October 24, 1963

In addition to the general objectives listed previously, this flight was a comparison between the prototype air ejector samplers and a conventional blower-powered direct-flow sampler at an operating altitude near 110,000 feet. The intended operation conditions for the three sampling units were as follows:

Sampler	Type	Sampling Rate (cfm)	Sampling Time (min)
1	Air Ejector	1000	85
2	Air Ejector	550	220
3	Direct Flow	275	220

It was desired that air ejector Sampler No. 2 (2 ft² filter area) be adjusted for a filter face velocity comparable to that usually achieved with the direct flow sampler (1 ft² filter area).

The payload, Figure 14, consisting of two ejector samplers and one DFS-2B direct flow sampler with associated instrumentation, parachute, etc., weighed 580 pounds. This system was flown on a 173-foot diameter, tailored-taped balloon.

Flight No. 2639 was launched successfully at San Angelo, Texas, 0630 CST on October 24, 1963. A dynamic launch method was used in which the payload was suspended from a frame on the rear end of a truck. The balloon bubble was placed downwind of the payload. After release of the bubble the truck moved forward until it was beneath the balloon, at which time the payload was released. Winds at the time of the launch were light and the launch was accomplished smoothly.

As indicated by the flight profile in Appendix B, the flight progressed according to the program except for an unusually slow rate of rise averaging 354 ft/min. Because of the slow ascent rate and the resulting increase in total flight time, two complicating factors were introduced:

- 1) The data-recording camera ran out of film approximately 15 minutes before the end of the programmed sampling period.
- 2) The emergency cut-down timer detached the parachute and load about 10 minutes before the end of the programmed 220-minute sampling period of ejector Sampler No. 2.

All samplers were recovered in good condition. It was observed in removing filters that the filter from Sampler No. 2 was still operating during part of the descent, it is possible that ice crystals or liquid droplets were ingested. Analysis of flowmeter data indicates that the two ejectors functioned properly throughout their programmed sampling periods. The direct-flow sampler sampled at a rate higher than programmed and stopped after 62 minutes.

Volume data for all three samplers are included in the Summary, Table 3, page 39.

Flight 2641, January 25, 1964

This flight was intended as a test of the prototype sampler at 130,000 feet. An electrostatic precipitator being developed by Del Electronics for the AEC was also carried. Performance of the precipitator will be reported separately.

The payload, consisting of the air ejector sampler, electrostatic precipitator, flight instrumentation, parachute, antennas, etc., weighed 459 pounds. This system was flown on a 229-foot diameter, tailored-taped balloon of 0.75-mil polyethylene. The assembled flight package is shown in Figure 15 on page 38.

In analyzing data from the two previous flights, it was noted that air being drawn into the sampler was much warmer than ambient, due to heating of load surfaces by solar radiation. In addition to reducing the mass flow rate through the system, this effect introduced uncertainties into the volume computations. On Flight 2641, solar heating was reduced by inverting the samplers to place the intake at the bottom of the payload and adding supplementary radiation shields. This is discussed further in the Summary.

Flight 2641 was launched successfully at San Angelo, Texas after a one-hour delay caused by winds gusting to 18 knots at the planned launch time. The flight ultimately reached a float altitude of 128,000 feet as indicated by the time-altitude profile (Appendix B). Sampler performance for Flight 2641 is included in the Summary, Table 3, page 39.

FIGURE 15. PAYLOAD CONFIGURATION, FLIGHT 2641

Summary of Flight Test Results

● SAMPLER PERFORMANCE

Table 3 summarizes volume data for the three evaluation flights. In the last two columns, the observed sampling rate derived from flowmeter readings is compared with a "theoretical" sampling rate. The theoretical rate is derived from equations and curves previously discussed, taking into account pressure and temperature conditions measured during flight.

Table 3 SUMMARY OF VOLUMES SAMPLED

Flight No.	Date	Sampler	AES = Air Ejector Sampler		DFS = Direct Flow Sampler			
			Average Altitude (ft)	Sampling Interval (min)	Volume Sampled (amb. ft ³)	Equiv. Vol. at STP (ft ³)	Theoretical Rate (ft ³ /min)	Observed Rate (ft ³ /min)
2618	6/7/63	AES (1)*	105,800	90	51,200	498	≈ 1000	568
		AES (2)	105,800	240	105,000	995	435	426
2639	10/24/63	AES (1)	105,700	84	69,900	538	911	832
		AES (2)**	106,800	210	110,700	806	485	527
		DFS (3)	105,400	63	23,000	176	≈ 300	365
2641	1/25/64	AES***	127,000	143	87,880	333	≈ 969	615

* Damaged on launch.

** Sampled approximately 10 minutes after shutdown, during descent. Volumes given do not include this fraction. Estimates indicate that the STP volume fraction sampled during descent would amount to 10 to 20 percent of the total.

*** Defective pressure regulator replaced with substitute obtained locally.

In three cases, the theoretical and observed sampling rates are in reasonable agreement (+10 percent). In the other two cases where the difference between observed and theoretical rates is substantial, mechanical problems may have rendered the comparisons invalid. On Flight 2618, for example, the mixing tube of Sampler No. 1 was broken during launch. On Flight 2641 a damaged pressure regulator was replaced at San Angelo with a substitute regulator of different type purchased locally.

● EASE OF HANDLING AND PREPARATION

The prototype sampler has presented no unusual or difficult problems in connection with flight preparation. If we consider only those aspects of preparation which would be necessary in operational flights and disregard the special research instrumentation carried, the ejector sampler appears to offer attractive advantages in field use.

One of the most important of these is the elimination of the heavy duty, wet battery pack and problems incident to transportation, filling, charging, and standby maintenance. Because liquid nitrogen is available at low cost within the continental U. S. and at many overseas military installations, filling of the ejector pressure reservoir has been accomplished easily and quickly. The required mass of nitrogen is added as a liquid, the reservoir is sealed, and subsequent vaporization pressurizes the sphere to 3000 psi. Because the vessel is titanium, thermal shock does not pose problems, and its very low thermal conductivity has permitted charging with little nitrogen loss, even though the sphere is uninsulated.

It is possible that the logistics of operation at some remote site may make it impractical to use the liquid nitrogen filling method. In this case, air supplied by a suitable compressor can be used as the primary gas if a dryer and filter are employed to remove water vapor and particulate contamination. To date this method has not been used.

Since the ejector pump has no moving parts, preflight checkout has involved mainly a visual inspection of the jet nozzle, connecting gas line, and an electrical continuity check of the explosive valves and timer-programmer.

With respect to ease of handling, the sampler has presented no difficult problems but, because of its unusual shape, the present version is slightly more vulnerable to accidental damage during launch than the conventional direct-flow sampler.

● THE EFFECT OF SOLAR RADIATION

Solar radiation incident on the sampler surfaces at altitude has been found to produce local temperature rises of significant magnitude. This factor introduces two undesirable effects: 1) the expansion of air in contact with warm sampler surfaces reduces the mass flow rate through the pump, and 2) it complicates the problem of converting flowmeter indicated volumes to equivalent volumes at ambient and STP conditions.

On the first two flights of the test series, the samplers were operated in a vertical position with the air inlet at the top. Analysis of temperature data indicates that this orientation favors the ingestion of warm air rising from heated load surfaces.

On Flight 2639 (106,800 feet), the observed air temperature rise as measured in the flowmeter duct of Sampler No. 2 was 27°C.

Because radiation effects are apt to be much more pronounced at 130,000 feet (the target altitude of the final flight), two basic changes were made on Flight 2641 to minimize solar heating: 1) sampler orientation was reversed to place the inlet below the payload, and 2) radiation shields were attached to shade sampler surfaces from the sun's direct rays.

In this configuration, ingestion of heated, boundary-layer air was minimized, the filtered exhaust being directed upward into the ascending column of warm air above the payload.

Post flight analysis of temperature data for Flight 2641 indicates that these measures were effective. Figure 16 is a sketch of the air ejector filter collector showing placement of thermistors. Figures 17 and 18 are graphical presentations of significant temperatures measured during Flight 2641.

T₁, an unshielded thermistor suspended approximately 2 feet below the sampling package, was exposed to the effects of downwash from the cold pressure vessel surfaces and was also exposed to direct solar radiation. Fluctuations indicated by T₁ and other thermistors are at the same frequency but out of phase with T₈; this is indicative of slow vertical oscillations of the balloon and load while sampling.

- T₁ - 2 ft Below Sampler Inlet
- T₂ - In Front of Filter
- T₃ - Surface of Inlet Cone
- T₄ - In Behind Filter
- T₅ - In Flow Meter
- T₆ - Primary Nozzle
- T₇ - Diffuser Outlet
- T₈ - At Top of Sampling Package
- T₉ - Surface of Pressure Vessel
- T₁₀ - Air in Instrument Box

- P₁ - Pressure Tap (Original Position)
- P₂ - Pressure Tap (New Probe)

FIGURE 16. PLACEMENT OF THERMISTORS ON FLIGHT 2641

FIGURE 17. TEMPERATURES MEASURED ON FLIGHT 2641

FIGURE 18. TEMPERATURES MEASURED ON FLIGHT 2641

REFERENCES

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5. Shapiro, A. H. Dynamics and thermodynamics of compressible fluid flow, vol. 1. N.Y., Ronald Press, 1953. p. 84.
6. Keenan, J. H., E. P. Neumann and F. Lustwerk. An investigation of ejector design by analysis and experiment. J. Appl. Mech. 17: 229-309 (1950).
7. Wood, R. C. Direct flow filter sampler: an improved large-volume collector of radioactive stratospheric debris. J. Appl. Meteorol. 3: 194-97 (1964).

* Personnel and facilities necessary for the performance of this contract were acquired by Litton Industries, Inc. on 11 September 1963. Information regarding this report may be obtained by contacting the Applied Science Division, Litton Systems, Inc., 2295 Walnut Street, St. Paul, Minnesota 55113.

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APPENDIX A

ENVIRONMENTAL CHAMBER TESTS DATA TABULATION

Sampler Parameters

- (a) Primary jet, mixing tube area ratio
 $A_1/A_9 = 0.010$
- (b) Diffuser efficiency assumed $\eta_d = 0.50$
- (c) Diameter of mixing tube (inches) = 2.68
- (d) Diameter of primary jet (inches) = .268
- (e) Filter area (ft^2) = 2
- (f) Primary gas = nitrogen

Tabulated Data

- t = time (min)
- P_a = chamber pressure (mm Hg)
- N = flowmeter count rate (counts/min)
- R = flowmeter calibration constant (ft^3/count)
- Q_f = flowmeter indicated volume flow rate
(ft^3/min)
- P = pressure drop measured across filter
(mm Hg)
- P_a/P_b = ratio of pressures across filter
- Q_a = computed volume flow rate into sampler
at chamber density (ft^3/min)
- P_r = regulator set pressure (psi)

Test #1

Test Altitude = 89,000 ft (ICAO density equivalent)

Chamber Temperature = 73°F

t (min)	P _a (mm Hg)	N (cpm)	R (ft ³)	Q _f ³ (ft ³ /min)	ΔP (mm Hg)	P _a /P _b	Q _a ³ (ft ³ /min)	P _r (psi)
0	21.0	-	9.7	-	-	-	-	-
2	21.0	99.0		960	1.80	1.094	877	71
5	21.0	94.7		919	1.80	1.094	840	71
8	17.8	101.0		979	1.80	1.113	880	71
12	17.8	100.2		972	1.80	1.113	874	72
16	17.8	101.9		987	1.80	1.113	887	72
22	17.9	100.0		970	1.81	1.112	872	72
27	18.0	101.0		979	1.82	1.111	881	73
33	18.1	101.5		985	1.83	1.112	886	74
39	18.0	101.9		987	1.84	1.113	887	74
48	18.0	102.3		993	1.84	1.113	891	74
53	18.0	102.2		991	1.84	1.113	890	74
58	18.0	102.2		991	1.84	1.113	890	74
63	18.0	102.2		991	1.84	1.113	890	74
68	18.0	101.6		986	1.82	1.111	887	73
75	18.5	99.4		964	1.80	1.108	870	72
78	18.5	94.3		915	1.60	1.094	836	58
86	18.0	61.4		595	0.93	1.054	564	35

Test #2

Test Altitude = 105,000 ft and 108,500 ft

Chamber Temperature = 80°F

t (min)	P _a (mm Hg)	N (cpm)	R (ft ³)	Q _f ³ (ft ³ /min)	ΔP (mm Hg)	P _a /P _b	Q _a ³ (ft ³ /min)	P _r (psi)
19	8.25	68.9	668	0.46	0.86	1.115	617	46
75	7.13	76.1	738	0.46	0.86	1.137	666	47

APPENDIX B

FLIGHT TEST DATA TABULATION AND FLIGHT PROFILES

Flight No. 2618, June 7, 1963

Due to a malfunction of the camera, no photopanel data are available for this flight. Data used in volume determinations are derived from information telemetered during flight and from the flowmeter counters as read before and after the flight. The flight profile is shown in Figure B-1, page 51.

● SAMPLER #1

Sampling altitude - 105,800 ft (pressure altitude)	
Sampling duration - 90 min	
Collector - 2 ft ² IPC No. 1478 filter paper	
Final flowmeter reading	09881
Initial flowmeter reading	<u>04061</u>
Accumulated count (N)	5820
Flowmeter constant (R) x N = 9.7 x 5820	56,400 ft ³
Flowmeter altitude correction = 21t = 21 x 90 min =	<u>1,890 ft³</u>
Volume measured by flowmeter =	58,290 ft ³
Downstream flow rate, $Q_f = 58,290 \text{ ft}^3 / 90 \text{ min} =$	647 ft ³ /min
Pressure ratio across filter (from filter characteristics) =	1.135
Upstream (ambient) flow rate, $Q_a = Q_f / 1.135$	568 ft ³ /min
Total volume ambient air sampled = 570 ft ³ /min x 90 min =	51,200 ft ³
Equivalent volume @ 0°C, 760 mm Hg =	498 ft ³

● SAMPLER #2

Sampling altitude - 105,800 ft (pressure altitude)

Sampling duration - 240 min

Collector - 2 ft² IPC No. 1478 filter paper

Final flowmeter reading = 27424

Initial flowmeter reading = 16364

Accumulated count (N) = 11060

Flowmeter constant (R) $\times$ N = $9.7 \times 11060 =$ 107,200 ft³

Flowmeter altitude correction = $21t = 21 \times 240 =$ 5,040 ft³

Volume measured by flowmeter = 112,240 ft³

Downstream flow rate, $Q_f = 112,240/240 =$ 468 ft³/min

Pressure ratio across filter (from filter characteristics) = 1.10

Upstream (ambient) flow rate, $Q_a = Q_f/1.1 =$ 426 ft³/min

Total ambient volume sampled = $Q_a t = 426 \times 240 =$ 102,200 ft³

Equivalent volume @ 0°C, 760 mm Hg = 995 ft³

FLIGHT NO. 2618 DATE June 7, 1963
 FOR USAEC
 LOAD ON BALLOON 492# Launch 420# Outdown
 FREE LIFT 98 LBS* 10%
 BALLOON TYPE NUMBER MATERIAL WEIGHT
 Tailored Tapeless 167-1-2 1-mil. 485 LBS.
 Poly

ALTITUDE DATA

B-58 Barotransmitter

FIGURE B-1. TIME-ALTITUDE PROFILE, FLIGHT 2618

Flight No. 2639, October 24, 1963

(See Figure B-2, page 58.)

Explanation (by column) of Data Tabulated in Tables B-1, B-2 and B-3.

- (1) Elapsed Time (min) - From chronometrically controlled camera-framing rate, backed up by time piece on photopanel.
- (2) Ambient Pressure (mb) - This value obtained from an aneroid barograph recorder backing up the B-58 ion density gauge which did not function properly. Possible error of this device is ± 1 mb.
- (3) Ambient Temperature ($^{\circ}\text{C}$) - From white unshielded radiosonde thermistor on an outrigger set, 6 feet horizontally from the end of support frame.
- (4) Pressure Altitude (ft) - From ICAO standard atmosphere tables corresponding to pressure in Column (2).
- (5) Flowmeter Reading - Value of totalizing counter obtained from film records of photopanel.
- (6) Flowmeter Count Rate (cpm) - The average count rate (cpm) for the preceding 5 minutes. The first entry (*) is an adjusted value because the flowmeter cannot come up to equilibrium speed instantaneously.
- (7) Flowmeter Constant (ft^3/count) - This represents the volume of air passing through the flowmeter each 100 revolutions (one count), uncorrected for altitude.
- (8) Flowmeter Flow Rate, Uncorrected ($\text{ft}^3/\text{min.}$) - This represents the volume rate of air passing through the flowmeter, uncorrected for altitude (Column 6 times Column 7).
- (9) Flowmeter Altitude Correction ($\text{ft}^3/\text{min.}$) - Above 100,000 feet, friction in the flowmeter gear train and bearings introduces a flowmeter error. This value, as experimentally determined, has been entered as a correction factor.

- (10) Flowmeter Flow Rate, Corrected (ft³/min) - This value, with the altitude correction applied (Column 8 plus Column 9), represents the volume rate of flow through the flowmeter at flowmeter pressure and temperature.
- (11) Flowmeter Temperature (°C) - This temperature, as sensed by a thermistor mounted in the flowmeter, represents an average value for the entire sampling period.
- (12) Temperature Expansion Factor - The flowmeter reading corrected for altitude represents a volume that has undergone expansion due to energy exchange from sampler surfaces heated by solar radiation. For these volume calculations we have arbitrarily assumed that this temperature rise occurs between the collecting filter and the flowmeter. This expansion factor is the ratio of measured flowmeter temperature (°K) to ambient temperature (°K); Column 11 divided by Column 3.
- (13) Downstream Flow Rate (ft³/min) - The flowmeter corrected rate (10) divided by the expansion factor due to temperature yields a flow rate downstream of the filter adjusted to ambient temperature conditions.
- (14) Filter Pressure Ratio - The ratio of pressure across the filter collector is a function of flow rate and sampling altitude. Since filter pressure-drop measurements attempted on this flight are believed to be invalid, pressure ratio is based upon the experimentally derived characteristics of IPC 1478 paper as given by the curves of Figure B-3.
- (15) Ambient Sampling Rate (ft³/min) - Obtained by dividing the downstream flow rate (13) by the filter pressure ratio (14).
- (16) Density Ratio - This is the ratio of ambient air density at sampling altitude ρ_a to the density of air at STP (0°C, 1013 mb) conditions, ρ_{STP} . It is derived from the relation:

$$\frac{\rho_a}{\rho_{STP}} = \frac{P_a}{1013} \times \frac{273}{T_a}$$

where P_a is the ambient pressure in millibars as given in Column 1, and T_a is the ambient temperature in degrees Kelvin from Column 2.

TABLE B-1. Data Reduction for Air Ejector Sampler No. 1 - Flight No. 2639

Elapsed Sampling Time (minutes)	Ambient Pressure (mb)	Ambient Temperature (°C)	Pressure Altitude (ft)	Flowmeter Reading	Flowmeter Count Rate N (CPM)	Flowmeter Constant R (ft ³ /count)	Flowmeter Flow Rate Uncorrected (CFM)	Flowmeter Altitude Correction (ft ³ /min)	Flowmeter Flow Rate Corrected (ft ³ /min)	Flowmeter Temperature (°C)	Temperature Expansion Factor	Downstream Flow Rate (ft ³ /min)	Filter Pressure Ratio	Ambient Sampling Rate (ft ³ /min)	Density Ratio	STP Flow Rate (ft ³ /min)	Filter Pressure Differential (mb)
0	9.6	-32	102,700	10024	116*	9.7	1125	20	1145	-15	1.07	1070	1.220	877	8.05	7.05	1.17
5	9.0		104,500	10583	116*		1125	20	1145			1070	1.220	877	7.87	6.90	1.17
10	8.8		105,000	11164	116		1115	20	1135			1060	1.215	873	7.87	6.87	1.20
15	8.8		105,000	11741	115		1115	20	1135			1060	1.215	873	7.87	6.87	1.20
20	8.8		105,000	12314	115		1109	20	1125			1050	1.215	865	7.87	6.81	1.20
25	8.8		105,000	12885	114		1105	20	1125			1050	1.215	865	7.78	6.73	1.20
30	8.7		105,400	13453	114		1096	21	1117			1044	1.215	860	7.68	6.61	1.17
35	8.6		105,600	14020	113		1095	21	1126			1052	1.220	864	7.65	6.61	1.17
40	8.5		105,800	14588	114		1105	21	1126			1062	1.220	867	7.52	6.52	1.20
45	8.5		105,900	15156	114		1115	21	1136			1062	1.225	867	7.52	6.52	1.20
50	8.4		106,200	15729	115		1125	21	1146			1070	1.225	873	7.52	6.57	1.17
55	8.4		106,700	16380	116		1085	22	1107			1034	1.220	848	7.42	6.28	1.12
60	8.3		106,500	16867	112		1009	22	1031			963	1.200	803	7.42	5.96	1.07
65	8.3		106,500	17389	104		970	22	992			927	1.200	773	7.33	5.67	1.07
70	8.2		106,800	17888	100		911	22	933			872	1.185	735	7.33	5.39	1.07
75	8.2		106,800	18360	94		873	22	895			836	1.175	712	7.33	5.22	1.00
80	8.2		106,800	18811	90		854	22	876			818	1.175	696	7.33	5.10	1.02
84	8.2		106,800	19163	88												

Avg. Flow @ STP = 6.4 ft³/min.
Avg. Ambient Flow = 832 ft³/min.

TABLE B-2. Data Reduction for Air Ejector Sampler No. 2 - Flight No. 2639

Sample No.	Altitude (ft)	Ambient Temperature (°C)	Pressure Altitude (ft)	Flowmeter Reading	Flowmeter Count Rate N (CPM)	Flowmeter Constant R (ft ³ /count)	Flowmeter Flow Rate Uncorrected (CPM)	Flowmeter Altitude Correction (ft ³ /min)	Flowmeter Flow Rate Corrected (ft ³ /min)	Flowmeter Temperature (°C)	Temperature Expansion Factor	Downstream Flow Rate (ft ³ /min)	Filter Pressure Ratio	Ambient Sampling Rate (ft ³ /min)	Density Ratio	STP Flow Rate (ft ³ /min)	Filter Pressure Differential (mb)
0	7.6	-32*	102,700	27293	62*	9.7	601	19	610	-5*	1.11	556	1.100	503	8.05	4.05	0.57
5	9.0		104,500	27566	62		601	20	621			558	1.110	503	7.87	3.96	0.65
10	8.6		105,000	27874	62		601	20	621			558	1.110	503	7.87	3.96	0.72
15	8.8			28183	62		601	20	621			558	1.110	503	7.87	3.96	0.70
20	8.8			28495	62		601	20	621			558	1.110	509	7.87	4.01	0.70
25	8.8			28808	61		611	20	631			568	1.115	509	7.87	4.01	0.70
30	8.7		105,400	29120	62		601	20	621			558	1.110	503	7.78	3.92	0.72
35	8.6		105,600	29435	63		611	21	632			569	1.115	510	7.68	3.92	0.72
40	8.5		105,800	29751	63		611	21	632			569	1.115	510	7.65	3.90	0.70
45	8.5		105,800	30063	62		601	21	622			561	1.115	503	7.60	3.83	0.72
50	8.4		106,200	30382	64		621	21	642			578	1.120	516	7.52	3.88	0.72
55	8.4		106,200	30701	64		621	21	642			578	1.120	516	7.52	3.88	0.70
60	8.1		106,500	31023	64		621	21	642			578	1.120	516	7.42	3.83	0.70
65	8.3		106,500	31347	65		630	21	651			586	1.120	523	7.42	3.88	0.70
70	8.2	32*	106,800	31670	65	9.7	630	22	652	-5*	1.11	586	1.125	521	7.31	3.82	0.70
75	8.2			31997	65		630	22	652			586	1.125	521	7.33	3.82	0.70
80	8.2			32324	65		630	22	652			586	1.125	521	7.33	3.82	0.70
85	8.2			32649	65		630	22	652			586	1.125	521	7.33	3.82	0.72
90	8.1		107,100	32974	65		630	22	652			586	1.125	521	7.24	3.77	0.72
95	8.0		107,400	33300	65		630	22	652			586	1.125	521	7.15	3.73	0.72
100	8.0			33626	66		640	22	662			596	1.125	530	7.15	3.79	0.70
105	8.0			33957	66		640	22	662			596	1.125	530	7.15	3.79	0.72

Data Reduction for AES No. 2 - Flight No. 2639 (continued)

Elapsed Sampling Time (minutes)	Ambient Pressure (mb)	Ambient Temperature (°C)	Pressure Altitude (ft)	Flowmeter Reading	Flowmeter Count Rate N (CFM)	Flowmeter Constant R (ft ³ /count)	Flowmeter Flow Rate Uncorrected (CFM)	Flowmeter Altitude Correction (ft ³ /min)	Flowmeter Flow Rate Corrected (ft ³ /min)	Flowmeter Temperature (°C)	Temperature Expansion Factor	Downstream Flow Rate (ft ³ /min)	Filter Pressure Ratio	Ambient Sampling Rate (ft ³ /min)	Density Ratio	STP Flow Rate (ft ³ /min)	Filter Pressure Differential (mb)
110	8.0	32.4	107,400	34287	66	9.7	640	22	662	-5.7	1.11	596	1.125	530	7.15	3.79	0.70
115	8.0		107,400	34618	66		640	22	662			596	1.125	530	7.15	3.79	0.70
120	8.0		107,400	34951	67		650	22	672			605	1.130	535	7.15	3.82	0.70
125	8.0		107,400	35286	67		650	22	672			605		535	7.15	3.82	0.70
130	7.9		107,600	35621	67		650	23	673			606		536	7.07	3.80	0.70
135	7.9		107,600	35957	67		650	23	673			606		536	7.07	3.80	0.70
140	7.8		108,000	36292	67		650		673			606		536	6.98	3.75	0.70
145	7.8		108,000	36620	68		660		683			615		544		3.80	0.70
150				36957	67		650		673			606		536		3.75	0.70
155				37303	67		650		673			606		536		3.75	0.70
160				37642	68		660		683			615		544		3.80	0.70
165				37984	68		660		683			615		544		3.80	0.70
170				38326	68		660		683			615		544		3.80	0.70
175				38665	68		660		683			615		544		3.80	0.70
180				39009	69		669		692			624	1.135	549		3.83	0.70
185				39356	69		669		692			624	1.135	549		3.83	0.70
190				39696	68		660		683			615	1.130	544		3.80	0.70
195				40037	68		660		683			615	1.130	544	6.98	3.80	0.70
200	7.9		107,600	40381	69		669		692			624	1.135	549	7.07	3.88	0.72
205	8.0		107,400	40721	68		660	22	682			614	1.130	544	7.15	3.99	0.72

Avg. Flow @ STP = 3.84 ft³/min
Avg. Ambient Flow = 527 ft³/min

TABLE B-3. Data Reduction for Direct Flow Sampler No. 3 - Flight No. 2639

Elapsed Sampling Time (minutes)	Ambient Pressure (mb)	Ambient Temperature ($^{\circ}$ C)	Pressure Altitude (ft)	Flowmeter Reading	Flowmeter Count Rate N (CPM)	Flowmeter Constant R (ft ³ /count)	Flowmeter Flow Rate Uncorrected (CFM)	Flowmeter Altitude Correction (ft ³ /min)	Flowmeter Flow Rate Corrected (ft ³ /min)	Flowmeter Temperature ($^{\circ}$ C)	Temperature Expansion Factor	Downstream Flow Rate (ft ³ /min)	Filter Pressure Ratio	Ambient Sampling Rate (ft ³ /min)	Density Ratio	STP Flow Rate (ft ³ /min)
0	9.6	-32	102,700	1483	47*	9.7	456	20	476	30	1.26			378	8.05	3.00
5	9.0		104,500	1612	47*		456	20	476	31	1.26			378	7.87	2.94
10	8.8		105,000	1848	47		456	20	476	31	1.26			382	7.87	3.01
15	8.8		105,000	2088	48		466	20	486	33	1.27			376	7.87	2.96
20	8.8		105,000	2324	47		456	20	476	34	1.27			372	7.87	2.93
25	8.8		105,000	2560	47		456	20	476	36	1.28			372	7.78	2.90
30	8.7		105,400	2791	46		446	20	466	36	1.28			363	7.68	2.79
35	8.6		105,600	3021	46		446	21	467	39	1.29			363	7.65	2.78
40	8.5		105,800	3250	46		446	21	467	39	1.29			352	7.52	2.65
45	8.5		105,800	3476	46		446	21	467	41	1.30			352	7.52	2.65
50	8.4		106,200	3703	45		437	21	458	41	1.30			343	7.42	2.55
55	8.4		106,200	3928	45		437	21	458	41	1.30			345	7.42	2.56
60	8.3		106,500	4149	44		427	22	449	42	1.31					
65	8.3		106,500	4340	38**		427	22	449	41	1.31					

Not Applicable

Not Applicable

Avg. Flow @ STP = 2.80 ft³/min
 Avg. Ambient Flow = 365 ft³/min

ALTITUDE DATA
BAROGRAPH

FIGURE B-2. TIME-ALTITUDE PROFILE, FLIGHT 2639

- (17) STP Flow Rate (ft^3/min) - The equivalent flow rate in terms of ambient volumes reduced to STP (0°C , 1013 mb) conditions is obtained by multiplying the ambient sampling rate (15) by the density ratio (16).
- (19) Filter Pressure Drop (mb) - The pressure drop across the filter collector as measured by gauges mounted on the photopanel. These data are in doubt but have been included for completeness.

Flight No. 2641, January 25, 1964

(See Figure B-3, page 64.)

Explanation (by column) of Data Tabulated in Table B-4.

- (1) Elapsed Time (min) - From chronometrically controlled camera-framing rate, backed up by time piece on photopanel.
- (2) Ambient Pressure (mb) - From B-58 barotransmitter.
- (3) Ambient Temperature ($^\circ\text{C}$) - From radiosonde ascents performed by 59th Weather Reconnaissance Squadron.
- (4) Pressure Altitude (ft) - From ICAO standard atmosphere tables corresponding to pressure in Column 2.
- (5) Flowmeter Reading - Value of totalizing counter obtained from film records of photopanel).
- (6) Flowmeter Count Rate (cpm) - The average count rate (cpm) for the preceding 5 minutes. The first entry is an adjusted value because the flowmeter cannot come up to equilibrium speed instantaneously.
- (7) Flowmeter Constant (ft^3/count) - This represents the volume of air passing through the flowmeter each 100 revolutions (one count), uncorrected for altitude.

- (8) Flowmeter Flow Rate, Uncorrected (ft^3/min) - This represents the volume rate of air passing through the flowmeter (Column 6 times Column 7) uncorrected for altitude.
- (9) Flowmeter Altitude Correction (ft^3/min) - Above 100,000 feet, friction in the flowmeter gear train and bearings introduces a flowmeter error. This value, as experimentally determined, has been entered as a correction factor.
- (10) Flowmeter Flow Rate, Corrected (ft^3/min) - This value, with the altitude correction applied (Column 8 plus Column 9), represents the volume rate of flow through the flowmeter at flowmeter pressure and temperature.
- (11) Flowmeter Temperature ($^{\circ}\text{C}$) - This is the temperature of air passing through the flowmeter as sensed by a thermistor mounted in the flowmeter duct.
- (12) Temperature Expansion Factor - The flowmeter reading corrected for altitude represents a volume that has undergone expansion due to energy exchange from sampler surfaces heated by solar radiation. For these volume calculations we have arbitrarily assumed that this temperature rise occurs between the collecting filter and the flowmeter. This expansion factor is the ratio of measured flowmeter temperature ($^{\circ}\text{K}$) to ambient temperature ($^{\circ}\text{K}$).
- (13) Downstream Flow Rate (ft^3/min) - The flowmeter corrected rate (10), divided by the expansion factor due to temperature, yields a flow rate downstream of the filter, adjusted to ambient temperature conditions.
- (14) Filter Pressure Ratio - The value recorded in this column is based on the experimentally derived characteristics of IPC 1478 paper as given by the curves of Figure 8.
- (15) Ambient Sampling Rate (ft^3/min) - Obtained by dividing the downstream flow rate (13) by the filter pressure ratio (14).

- (16) Density Ratio - This is the ratio of ambient air density at sampling altitude ρ_a to the density of air at STP (0°C, 1013 mb) conditions, ρ_{STP} . It is derived from the relation:

$$\frac{\rho_a}{\rho_{STP}} = \frac{P_a}{1013} \times \frac{273}{T_a}$$

where P_a is the ambient pressure in millibars as given in Column 1 and T_a is the ambient temperature in degrees Kelvin from Column 3.

- (17) STP Flow Rate (ft³/min) - The equivalent flow rate in terms of ambient volumes reduced to STP (0°C, 1013 mb) conditions is obtained by multiplying the ambient sampling rate (15) by the density ratio (16).
- (18) Filter Pressure Drop (in. H₂O) - Pressure drop across the filter is measured by gauges located on the photopanel.

During the first part of the flight, gauge readings were low as compared with pressures derived from average filter characteristics and the observed flow rate. As sampling progressed, the measured pressure drop rose gradually, and readings near the end of the sampling period became consistent with values calculated from flow rate.

Post flight tests of the pressure gauges indicate that a new diaphragm material being used by the gauge manufacturer is subject to hysteresis or lag effects at low temperatures.

- (19) Filter Pressure Ratio - Same parameter as (14) but derived from measured pressure readings (18). Because of gauge errors these values have not been used in computing volumes.

TABLE B-4. Data Reduction for Air Ejector Sampler No. 1 - Flight No. 2641

Elapsed Sampling Time (minutes)	Ambient Pressure (mb)	Ambient Temperature ($^{\circ}\text{C}$)	Pressure Altitude K (ft)	Flowmeter Reading	Flowmeter Count Rate N (CPM)	Flowmeter Constant K (ft^3/count)	Flowmeter Flow Rate Uncorrected (CFM)	Flowmeter Altitude Correction (ft^3/min)	Flowmeter Flow Rate Corrected (ft^3/min)	Flowmeter Temperature ($^{\circ}\text{C}$)	Temperature Expansion Factor	Downstream Flow Rate (ft^3/min)	Filter Pressure Ratio	Ambient Sampling Rate (ft^3/min)	Density Ratio ($\times 10^{-3}$)	STP Flow Rate (ft^3/min)	Filter Pressure Drop ($P_{\text{in}}/P_{\text{H}_2\text{O}}$)
0	4.58	-27	126.8	41553	-	9.7	706	73	779	-2	1.10	732	1.190	615	4.82	2.96	0.180
5	4.40	-26	121.6	41845	72.8		706	73	779	-11	1.06	732	1.190	615	4.82	2.96	0.180
10	4.18	-25.5	122.8	42188	72.4		702	73	775	-11	1.05	736	1.195	616	4.55	2.80	0.180
15	4.00	-24.5	124.0	42352	72.0		706	74	780	-11	1.05	741	1.200	617	4.37	2.69	0.190
20	3.80	-24	125.3	42981	73.2		710	74	784	-11	1.04	752	1.206	624	4.11	2.56	0.195
25	3.65	-23	126.4	43197	74.0		717	74	791	-11	1.04	760	1.210	628	3.99	2.49	0.200
30	3.50	-22	127.3	43640	73.6		714	75	789	-11	1.04	757	1.212	624	3.76	2.34	0.200
35	3.47	-22	127.5	44000	74.0		717	75	792	-11	1.04	760	1.213	626	3.72	2.33	0.200
40	3.47	-22	127.5	44367	73.4		711	75	786	-11	1.04	755	1.212	622	3.72	2.32	0.200
45	3.45	-21.5	127.65	44736	74.2		719	75	794	-11	1.03	760	1.215	634	3.00	2.34	0.200
50	3.45	-21.5	127.65	45094	73.6		714	75	789	-11	1.03	755	1.214	630	3.70	2.33	0.205
55	3.45	-21.5	127.65	45464	73.6		714	75	789	-11	1.03	755	1.214	630	3.70	2.33	0.210
60	3.44	-21.5	127.7	45831	73.0		715	75	790	-8	1.04	758	1.213	625	3.68	2.30	0.210
65	3.44	-21.5	127.7	46104	73.0		708	75	783	-8	1.04	752	1.213	620	3.60	2.26	0.220
70	3.43	-21	127.8	46549	73.0		708	75	783	-2	1.07	758	1.203	605	3.64	2.20	0.220
75	3.42	-21	127.8	46913	72.8		706	75	781	-2	1.07	756	1.203	603	3.65	2.20	0.230
80	3.42	-21	127.8	47265	72.6		704	75	779	-2	1.07	754	1.202	601	3.65	2.19	0.220
85	3.42	-21	127.8	47628	72.8		706	75	781	-5	1.06	755	1.202	602	3.65	2.20	0.220
90	3.41	-21	127.9	47990	72.4		702	75	777	-8	1.05	756	1.211	616	3.64	2.24	0.225
95	3.41	-21	127.9	48341	72.0		698	75	773	-11	1.04	742	1.210	614	3.64	2.24	0.210
100	3.40	-21	128.0	48701	72.0		698	76	774	-9	1.04	743	1.210	615	3.64	2.24	0.210
105	3.41	-21	128.0	49048	71.4		692	76	768	-5	1.06	723	1.203	601	3.64	2.19	0.210

Data Reduction for AES No. 1 - Flight No. 2641 (continued)

Elapsed Sampling Time (minutes)	Ambient Pressure (mb)	Ambient Temperature (°C)	Pressure Altitude K (ft)	Flowmeter Reading	Flowmeter Count Rate N (CPM)	Flowmeter Constant R (ft ³ /count)	Flowmeter Flow Rate Uncorrected (CFM)	Flowmeter Altitude Correction (ft ³ /min)	Flowmeter Flow Rate Corrected (ft ³ /min)	Flowmeter Temperature (°C)	Temperature Expansion Factor	Downstream Flow Rate (ft ³ /min)	Filter Pressure Ratio	Ambient Sampling Rate (ft ³ /min)	Density Ratio	STP Flow Rate (ft ³ /min)	Filter Pressure Drop (p in/H ₂ O)
110	3.41	-21	127.9	49405	71.4	9.7	692	75	767	-5	1.06	722	1.203	600	3.64	2.18	0.220
115	3.42	-21	127.8	49765	72.0		698	75	773	-2	1.07	719	1.202	599	3.65	2.18	0.220
120	3.43	-21	127.8	50111	71.4	9.7	692	75	767	-5	1.06	722	1.203	600	3.64	2.18	0.220
125	3.44	-21.5	127.7	50471	72.0		698	75	773	-5	1.06	727	1.204	604	3.68	2.22	0.220
130	3.45	-21.5	127.65	50830	71.8		696	75	771	-8	1.05	733	1.206	607	3.70	2.24	0.240
135	3.46	-22	127.6	51183	72.0		698	74	772	-5	1.05	734	1.206	608	3.71	2.26	*0.240 1.207
140	3.47	-22	127.5	51543	72.0		698	74	772	-5	1.05	734	1.205	608	3.72	2.26	*0.240 1.207
144	3.47	-22	127.5	51831	72.0		698	74	772	-5	1.05	734	1.205	608	3.72	2.26	*2.240 1.207

Total Ambient Vol. = 87,880
Av. Sampling Rate = 615

Total Vol. STP = 33
Av. Sampling Rate STP = 2.33

*These values are corrected for zero shift

FLIGHT NO. 2641 DATE 25 JAN 64
 FOR 86125
 LOAD ON BALLOON 453 LBS
 FREE LIFT LBS* %
 BALLOON TYPE NUMBER MATERIAL WEIGHT
 229 -1-1 2MIL 236 LBS.

ALTITUDE DATA

CODESONDE

FIGURE B-3. TIME-ALTITUDE PROFILE, FLIGHT 2641

APPENDIX C

ELECTRON MICROGRAPHS OF PARTICLES OBTAINED ON FLIGHT NO. 2641

A small (Casella)* impactor was flown, hitch-hike fashion, on the 25 January 1964 test of the ejector filter sampler for the purpose of obtaining particles for electron microscope analysis. This experiment was not conducted as a part of this contract and time has permitted only a preliminary examination of the samples obtained.

*C. F. Casella and Co., Ltd., London.

Description of Apparatus

A diagram of the connections used to obtain airflow through the impactor is shown in Figure C-1. Based on the pressure head available and on laboratory tests, the resulting volume airflow rate through the impactor at the flight altitude of 127,000 feet was about 500 cc/min. At this flow rate, the fourth stage jet velocity is only 200 cm/sec and the jet velocities of the first three stages are considerably lower. Because of this low flow rate and the fixed jet dimensions of the Casella impactor, it was expected prior to the flight that little, if any, material would be collected on the first three stages. Based on May's* data, the fourth stage (with a jet width, D_j , of 0.3 mm) has a particle size cutoff of approximately 0.050 microns for material of density 2.0 g/cc.

FIGURE C-1. LOCATION OF CASELLA IMPACTOR ON FLIGHT 2641

* May, K. R. J. Sci. Insts. 22: 187 (1945).

Results of Electron Microscope Examination

Prior to examination, all grids were shadowed with chromium to improve particle contrast. Grids from the Casella first stage were found to be uniformly coated with particles over the entire surface. These grids were not protected from contamination since they are centered in the impactor inlet and were therefore directly exposed to the atmosphere during a period beginning prior to launch and continuing throughout the flight until the recovery personnel sealed the inlet.

In contrast with the first stage and as expected, little material was observed on the second and third stages. The degree of deposition was judged to be only slightly greater than that usually observed on freshly prepared grids.

A relatively dense concentration of particles was observed on grids from the fourth stage. This material was concentrated in a thin line directly under the jet opening, 60 to 80 percent being deposited in a strip about the same width as the impactor jet (approximately 0.3 mm). The total apparent width of the deposit was approximately 6 or 7 grid windows (0.8 mm). Outside this strip, particle concentration was low--on the order of that seen on the second and third stage grids.

Electron micrographs on the following pages have been selected to show the various types and sizes of particles observed. Although we have made no quantitative estimates, observed particles can be grouped into four general types:

- 1) Large numbers of discrete particles ranging in size from 0.25 to 0.2 microns.
- 2) Very large clusters.
- 3) Fluffy particles with open, irregular structures.
- 4) Numerous particles with smaller, surrounding satellites.

It should be emphasized that particle types 2, 3, and 4 were found only in the deposit strip directly under the fourth stage jet.

FIGURE C-2. FOURTH STAGE OF CASELLA IMPACTOR EXPOSED AT 127,000 FEET
Particles impacted on Formvar substrate have been shadowed with chromium to improve contrast. Rings of small satellites around some particles may be residue from small liquid droplets.

FIGURE C-3. FOURTH STAGE OF CASELLA IMPACTOR EXPOSED AT 127,000 FEET
Typical large fluffy particle with open, irregular structure.

FIGURE C-4. FOURTH STAGE OF CASELLA IMPACTOR EXPOSED AT 127,000 FEET
Large circular pattern indicates possible liquid evaporation.

FIGURE C-5. FOURTH STAGE OF CASELLA IMPACTOR EXPOSED AT 127,000 FEET
This photomicrograph shows a variety of the particle types observed.

Although there is no question that the material observed on the fourth stage grids was collected at altitude, there is also no reason to exclude the possibility that an unknown fraction is contamination either from the balloon or the sampling equipment.

A more sophisticated, large-volume, impactor collector-classified will be evaluated at 110,000 feet and 130,000 feet in flight tests scheduled for May or June 1964. Samples will be collected in three size fractions on two cascaded impactor stages and a backup filter. In addition to radiochemical analyses, studies will include examination of 72 microscope grids with respect to particle morphology, size, and distribution.

APPENDIX D

GROSS GAMMA ACTIVITY IN SAMPLES RECOVERED FROM THE FLIGHT TEST PROGRAM

Measurements of the gross gamma activity on filters from the three flight tests of the air ejector sampler were performed at the Health and Safety Laboratory, U. S. Atomic Energy Commission. The following data have been extracted from memoranda issued by Dr. Leonard P. Salter of the Radiochemistry Division.

Flight No. 2618 (Minneapolis, Minnesota)

Flight Date: June 7, 1963

Altitude: 105,800 ft

HASL No.	A0794	A0795	A0796
Sampler	AES(1)	AES(2)	Control
Volume (kscf)	0.498	0.995	---
Analysis Date	June 27	June 27	June 27
cpm	2686*	6609*	9 ± 7
cpm/kscf	5390**	6640**	---
Analysis Date	July 9	July 11	July 9
cpm	2563*	5927*	9 ± 7
cpm/kscf	5140**	5960**	---

*Standard deviation due to counting less than 1/2 percent.

** These specific activity values are somewhat higher than those given in the original memo because of adjustments in computed volumes.

Flight No. 2639 (San Angelo, Texas)

Flight Date: October 24, 1963

Altitude: 106,800 ft

HASL No.	A0951	A0952	A0953
Sampler	AES(1)	AES(2)*	DFS
Volume (kscf)	0.538	0.806	0.176
Analysis Date	November 7	November 7	November 7
cpm	254 ± 8	460 ± 9	108 ± 8
cpm/kscf	472 ± 15	571 ± 11	614 ± 45
Analysis Date	January 7	January 7	January 7
cpm	215 ± 8	371 ± 8	81 ± 8
cpm/kscf	400 ± 15	460 ± 10	460 ± 45

Flight No. 2641 (San Angelo, Texas)

Flight Date: January 25, 1964

Altitude: 127,000 ft (average)

HASL No.		
Sampler	AES	Control
Volume (kscf)	0.333	---
Analysis Date	February 4	February 6
cpm	80 ± 5	5 ± 4
cpm/kscf	240 ± 15	---
Analysis Date	March 3	February 26
cpm	74 ± 5	6 ± 5
cpm/kscf	222 ± 15	---

* AES(2) sampled approximately 10 minutes after shutdown, during descent. The volume used in computing specific activity does not include this fraction. Since it is estimated that the additional volume sampled during descent was 10 to 20 percent of the total, it is probable that the true specific activity is lower than indicated.

Because of weight considerations, no attempt was made to include a direct flow filter sampler on Flight 2641. The computed concentrations are comparable, however, with values at 104,000 feet as obtained with direct flow samplers on January 16 and February 11 operational flights:

Flight Date	January 16, 1964		February 11, 1964	
Sampler	DFS #1	DFS #2	DFS #1	DFS #2
Altitude (10^3 ft)	104	104	104	104
Analysis Date	1/28	1/29	2/18	2/19
cpm/kscf	333 ± 8	327 ± 8	174 ± 9	182 ± 9
Analysis Date		2/27		
cpm/kscf		285 ± 8		

Note abbreviations:

- AES = Air Ejector Filter Sampler
- DFS = Direct Flow Filter Sampler
- kscf = Thousands of standard cubic feet
(volume at 760 mm Hg, 0°C)