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FINAL REPORT

STUDIES OF EXTRATERRESTRIAL DUST AT 40 KILOMETERS

(1967-1968)

APPLIED SCIENCE DIVISION

LITTON SYSTEMS, INC.

LITTON INDUSTRIES

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COP

FINAL REPORT

STUDIES OF EXTRATERRESTRIAL DUST AT 40 KILOMETERS

(1967-1968)

Prepared for:

National Aeronautics and Space Administration
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STUDIES OF EXTRATERRESTRIAL
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1. INTRODUCTION AND SUMMARY

The work performed under Contract NASw-1623 was a continuation of an effort begun in 1966 to investigate the nature and composition of extraterrestrial dust. This effort involved the development of a unique, high-volume particle sampler designed for balloon-borne operation at 40 km.

To date, four balloon flights of this sampler have been performed: one flight under the original contract, the other three under Contract NASw-1623. While these flights have demonstrated that the sampler is capable of achieving all performance objectives, we have not yet accomplished our primary goal: the acquisition and recovery of a sample of extraterrestrial dust.

In reviewing these attempts, we can point to no common cause of failure; each flight has presented an entirely different set of circumstances:

<u>Flight #1</u>: All systems performed well. Post-flight analyses revealed evidence of excessive contamination from explosive actuator fired at termination.

<u>Flight #2</u>: A normal flight until termination. Delayed opening (8 seconds) of parachute allowed the payload to reach excessive fall velocities; the resultant opening shock caused partial payload disintegration.

Flight #3: Premature separation of the sampler payload during ascent apparently caused by actuation of an emergency cutdown circuit--exact cause unknown.

Flight #4: Balloon failed to achieve sampling altitude due to an apparent helium leak.

Circumstances surrounding the flight attempts conducted under this contract (Flights 2 to 4) are discussed in greater detail in the following sections. Although the particle sampler has been described in a previous report,* a brief discussion of the system is included here for the sake of completeness.

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*Final Report, Contract NASw-1395.

2. CHARACTERISTICS OF THE COLLECTION SYSTEM

Design of a sampling system suitable for the collection of extraterrestrial dust has involved the application of principles and techniques developed over the past few years in connection with stratospheric sampling programs. These have been treated extensively in other scientific publications (Stern, et al., 1962; Chagnon and Junge, 1961; McFarland and Zeller, 1963; Wood, 1966), but it may be appropriate to include a brief description of the principles involved for completeness.

The sampler used in this program consists basically of a slit impactor coupled to an air-ejector pump. In operation, particle-laden air is pulled through an appropriately designed slit orifice as shown in Fig. 1. An impactor plate located downstream from the slit causes the air streamlines to bend sharply while the particle's inertia tends to keep moving it toward the plate. If the particle inertia is sufficiently high, it will impact on the collection plate.

The collection efficiency of a jet impaction system is characterized by the value of an inertial parameter K where

$$K = \frac{C\rho_p V_j D_p^2}{18\mu_j D_j} \tag{1}$$

and

C = Cunningham's slip correction

ρ_p = particle density

V_j = jet air velocity

D_p = particle diameter

μ_j = jet air viscosity

D_j = jet (slit) width.

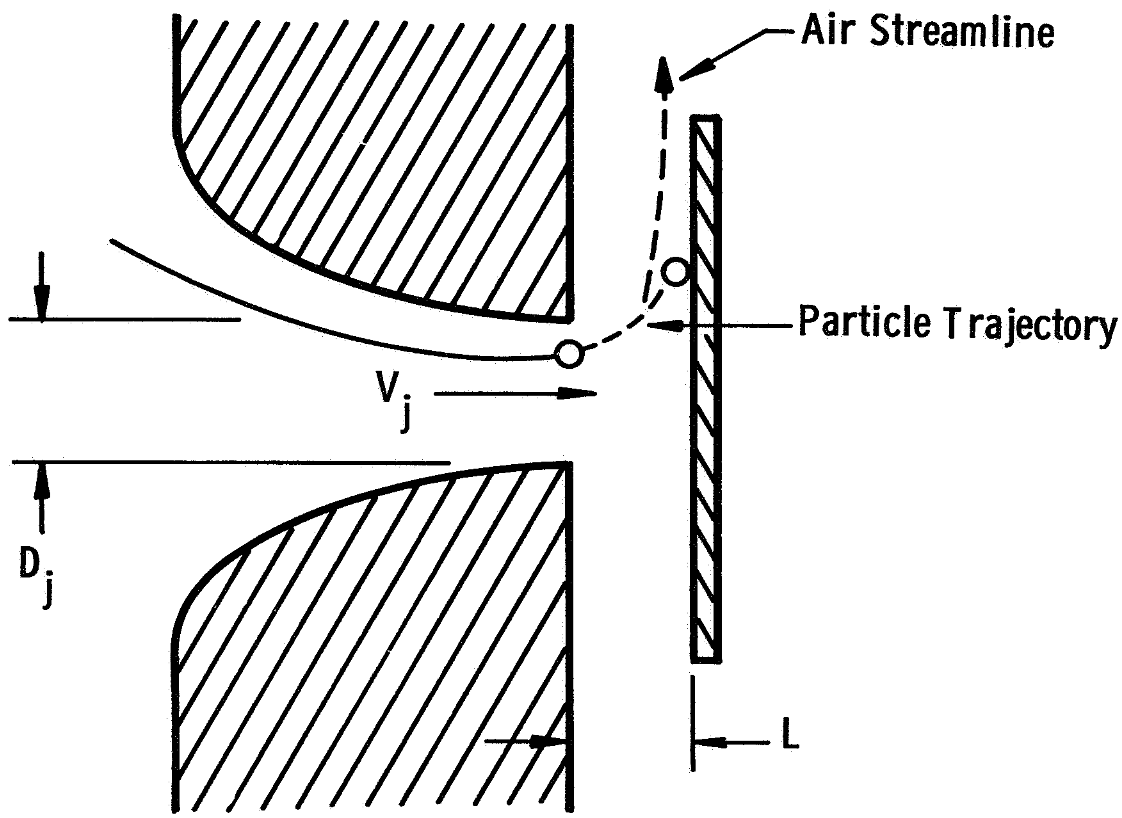

Fig. 1. Jet Impactor System

Other variables which must also be considered are the Jet Reynolds number, Re_j; the jet clearance, L, and the inlet shape. The collection efficiency, η, in functional notation, neglecting the shape factor, is then expressed by:

$$\eta = (K, Re_j, L/D_j) \qquad (2)$$

Theoretical solutions for this equation have been developed by a number of investigators (Ranz and Wong, 1952; Davies and Aylward, 1951). In general, however, experimental methods have been employed to obtain data from which performance characteristics may be accurately predicted.

Since impactor design involves factors which include air density, flow rate, and pressure drop, it is obvious that performance characteristics of the air mover must be considered. For this application, we have selected an air-ejector pump developed for the U. S. Atomic Energy Commission in connection with a program to sample radioactive, stratospheric debris. Basically, an air-ejector pump is a simple device. As illustrated in Fig. 2, 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.

Theoretical calculations supported by performance data acquired in operational use have indicated that an ejector pump-slit impactor combination could be designed to operate at 40 km. The system illustrated in Fig. 3 has the physical and performance characteristics given in Table 1.

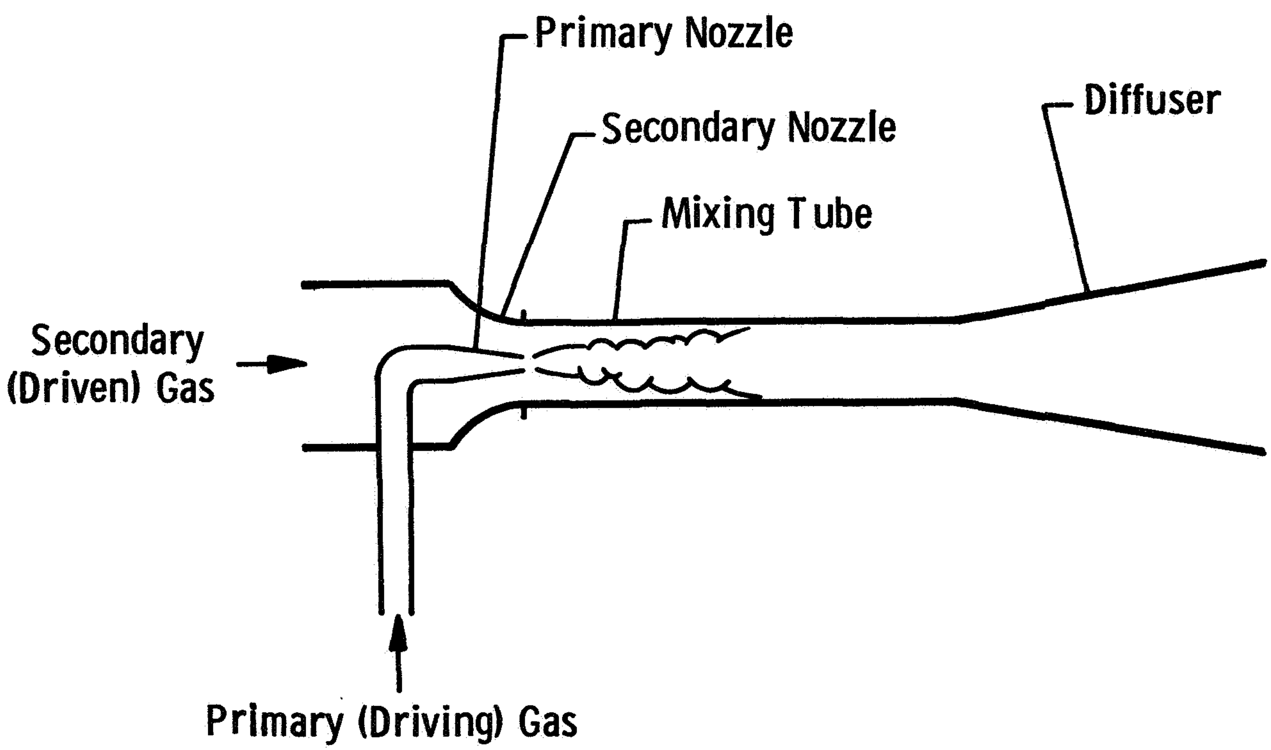

Fig. 2. Air Ejector Pump

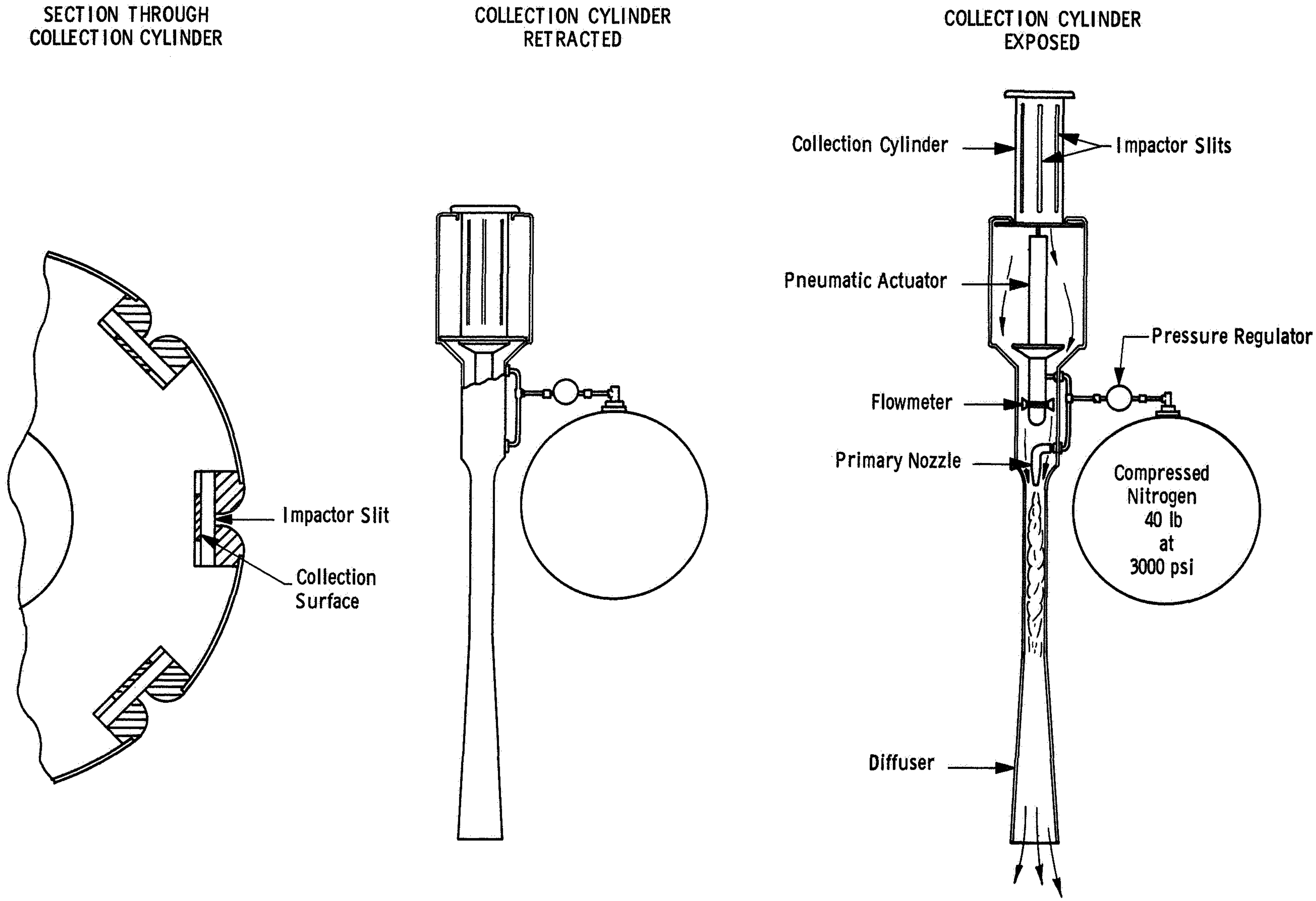

Fig. 3. Air Ejector Impactor Sampler

Table 1. Characteristics of the Large-Volume Impactor Sampler at 40 km (nominal)

Sampling rate	30 m^3/min
Particle size cutoff, diameter*	0.1 micron
Impactor slit width	3 mm
Impactor slit length	400 mm
Number of impactor slits	8
Total area, particle deposit	96 cm^2
Compressed nitrogen "fuel"	50 lb
System weight at launch**	350 lb

* Lower limit at which collection efficiency becomes 50% for spherical particles of unit density.

** Includes peripheral instrumentation, ballast, suspension cable.

As shown in the diagram (Fig. 3), the collection head consists of eight slit impactors arranged around the periphery of a 6-inch cylinder. This assembly is exposed and retracted by means of a linear pneumatic actuator. Because it is connected to the primary gas supply, the actuator (a spring-loaded piston) exposes the collector head automatically when the system programmer commands the air ejector to start the sampling period. The collector retracts when the sampler is turned off or the nitrogen becomes exhausted. Four spring-loaded latches, actuated at 90,000 feet by a pressure switch, serve to prevent the sample container from being jarred open at the landing impact.

Although the system incorporates very tight, secure closures, it is extremely difficult to achieve a true hermetic seal that would effectively prevent the entry of water vapor during descent. In view of this, a vent has been provided to allow pressure equalization through a small desiccant chamber backed up by two membrane filters.

Collection surfaces are mounted within the sampling head on eight aluminum backing strips. These numbered strips are positioned accurately behind each impactor slit and held firmly in place by locking pins. The prepared surfaces are installed and removed through the top of the sampler.

3. EXPERIMENTAL BALLOON FLIGHTS TO 40 KILOMETERS

3.1 Flight No. 3041

The second NASA balloon flight to sample extraterrestrial debris was launched Wednesday, 19 July 1967. Payload configuration is shown in Fig. 4.

After a successful launch, the system performed perfectly and achieved an average float altitude of 42 km.

During the sampling period of 6 hours and 50 minutes, the collector operated at a virtually constant sampling rate of 920 cfm. This was determined from telemetry data, and later confirmed by on-board recording tapes which agreed perfectly with the data telemetered.

The flight was terminated by radio command in advance of scheduled termination due to the inhospitable recovery area into which the payload was drifting and also because of the proximity of a cloud front advancing from the west. The recovery aircraft observed the destruction of the balloon vehicle, but was not able to locate the payload during parachute descent.

After an extensive search the following day, the payload gondola and instrumentation were located in a field of a few miles north of Buffalo, Wyoming. Examination of the payload revealed that the collection head had broken off and was missing. The collection head was subsequently located near the remnants of the balloon vehicle, about 10 miles west of the gondola impact position.

After an examination of the payload and on-board recorder data, we were able to draw rather definite conclusions as to the circumstances surrounding this failure:

1) All systems performed perfectly up to the time that command release was initiated.

Fig. 4. Auxiliary Lift Balloon and Sampler

2) At release, the payload was detached and a static line attached to the load line pulled the parachute free of its plastic container.

3) For an undetermined reason, the parachute did not open immediately. We know from the data recorded on-board that less than 8 seconds elapsed from cut-down to parachute opening, but this was evidently sufficient to allow the payload to reach an excessive fall velocity.

4) Inspection of the gondola indicated that it was subjected to a rather violent shock at the instant of parachute opening. In addition, there were indications that the gondola had rotated so that the initial opening shock was not along the vertical payload axis, but was to one side, resulting in a crack-the-whip effect which caused the bolts holding the sampler to shear. When found, the sampling head was jammed open in the fully extended position. This indicates to us that the gondola had probably rotated past 90° at the time the parachute opened, and that inertial forces were sufficient to jerk the sampler head outside of the protective cannister where it jammed. In the absence of such forces, retaining springs within the sampler would have kept the unit closed during free-fall. The fact that the rest of the gondola remained substantially intact is probably due to the steel aircraft cables anchored to the gondola base.

5) Detachment of the sampler head from the payload during the parachute opening shock was also confirmed by the on-board flow sensor recordings which indicated a high reverse flow through the ejector pump during descent. Normally, there would be no flow passage through the system with the closed sampling head attached.

Excessive contamination of the substrate fragments was confirmed by a cursory examination of a few electron microscope grids. It was our opinion that no useful information could be gained from further analyses.

3.2 Flight No. 3046

Balloon Flight 3046 launched at Mitchell, South Dakota, on 28 September 1967 was terminated by a premature separation of the balloon and payload.

3.2.1 General Background

Weather conditions at the time of launch on 28 September 1967 are summarized as follows:

Sky:	Clear
Surface Wind:	150 degrees, 4 knots
Winds Aloft:	28/1200 Z

Altitude (feet)	Bismark	Omaha
5,000	260/10	350/08
10,000	010/15	360/34
15,000	340/40	350/77
20,000	350/47	360/100

Under ideal surface weather conditions, the balloon and payload were launched at 0810 CDT. Subsequently, the following sequence of events were observed:

0811	Radio-command release, small payload balloon
0814	Main balloon reefing collar jettisoned
0817	Antenna drop, descent sensor armed
0818	Balloon enters apparent wind shear layer
0819	Payload separates from balloon
0845	Destruction of balloon observed

The payload descended by parachute to a relatively soft landing in a plowed field 2 miles west of Mitchell. The sampler and instrumentation were undamaged. Minor damage was sustained by the gondola frame.

Post-flight inspection of the payload indicated that the cutdown circuit had been actuated. This may be attributed to one of the following:

1) Radio interference on the command frequency

2) Turbulence-induced actuation of the balloon burst (descent) sensor

3) A filament short circuit in the descent sensor arming network.

With respect to (1) above, radio interference is admitted as a possible but improbable cause since all command functions involve the use of a complex code signal sequence that should rarely be duplicated by interference.

With respect to (2) above, we do know from visual observation of a trailing nylon line below the payload that the flight train encountered a shear layer just prior to cutdown. It should be noted, however, that the average ascent rate up to the time of cutdown was approximately 100 ft/min. In order for the descent sensor to actuate, the sensor would have to "see" a negative ascent (descent) amounting to 300 ft/min persisting for 2 seconds.

With respect to (3) above, we know that the descent sensor circuit was armed at 0817 CDT, about 2 minutes before separation. Inspection of the system wiring diagram indicates that a squib filament short to the brass squib case could have applied 28V to the cutdown firing circuit. If such a short did occur, however, it must have developed some 2 minutes after the arming squib fired and as a consequence of the payload reaction to the turbulence encountered. A post-flight inspection of the electrical circuit did not reveal evidence of such a condition.

3.2.2 Post-Flight Analysis of Microscope Grids

After return to Minneapolis, the sampling head was opened in a clean area and several electron microscope grids removed for examination. These grids proved to be exceptionally clean. At a magnification of 30,000, it was necessary to scan approximately 50 fields in order to find a contaminant particle. This level of contamination is lower than observed on laboratory controls prepared for previous flights, and indicative that negligible contamination was acquired at impact.

3.3 Flight No. 3047

The final flight attempts under this contract was conducted at the Litton flight center northeast of Minneapolis, Minnesota, on 13 June 1968.

The system was launched at 0630 CDT. Because of an initial low ascent rate, 30 lb of shot ballast was released at 0654. A radio command was transmitted at 0709 to release a second 30-lb supply.

One hour later, the balloon had reached an altitude of 31,300 ft; an average rate of rise for the first 60 minutes of flight of 520 ft/min. This was somewhat lower than programmed, but not an immediate cause for concern since 70 lb of additional ballast could be released after the balloon passed the 70,000-ft level.*

Unfortunately, the balloon never reached the 70,000-ft level. After passing 30,000 ft, the rate of ascent grew progressively slower and the leveled off at 63,500 ft. At 9:30 CDT, the balloon began a slow descent.

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* The third and fourth ballast drops (35 lb each) could not be actuated until armed by a pressure switch at 70,000 ft. Below that level, the same radio command channels performed other functions.

The decision to terminate the flight was made at approximately 1100 CDT, but it was decided to test the functioning of the radio command circuit and the sampler by commanding the sampler to turn on. The sampler was started successfully at 1123 CDT (59,000 ft) and turned off at 1217 CDT (58,500 ft). Evidence of sampler operation was provided by the flowmeter signal. It was also observed that the descent rate slowed as a few pounds of compressed nitrogen used to power the ejector pump were expended.

The balloon was cut loose at 1221 CDT and the payload impacted at 1247 CDT a few miles west of Fairchild, Wisconsin.

The time-altitude for Flight 3047 is shown in Fig. 5.

Inspection of the payload on recovery indicated that it had sustained what is considered normal impact damage; the sampler was in good condition, closed and latched.

In view of evidence presented by the time-altitude flight profile, it is our opinion that failure to reach sampling altitude was caused by a leak in the balloon. Such a leak might stem from any of several causes including 1) faulty balloon materials, 2) faults in construction, 3) damage incurred during inflation and launch, and 4) stresses produced by wind shears during ascent.

No direct evidence pointing to one or a combination of these possibilities as a probable cause of failure has been found.

As a final matter of interest, electron microscope examination of grids exposed during the short (55-minute) sampling period at 60,000 ft revealed no detectable evidence of particles. All surfaces including flight controls were virtually as particle-free as the laboratory controls. This is attributable to the fact that the ejector pump was adjusted to produce a high jet velocity at 140,000 ft. At 60,000 ft, the jet velocity would be much too low for efficient particle impaction.

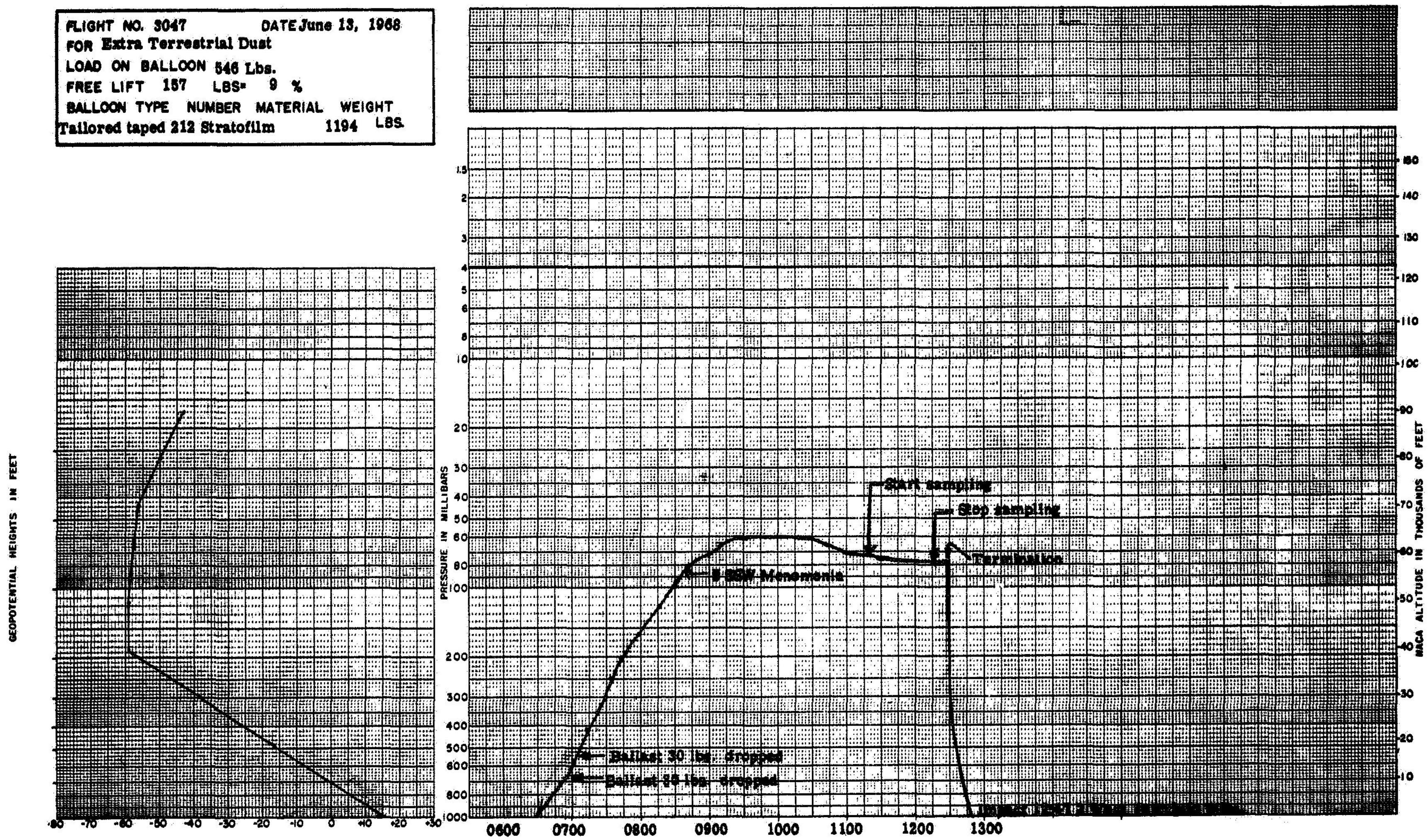

Fig. 5. Time Altitude for Flight 3047

4. RECOMMENDATIONS

The normal winter stratospheric reversal of winds will preclude any further balloon flight attempts until late spring, 1969. In the meantime, it is recommended that the sampler and associated residual NASA property be retained in Government Property Stores at the Applied Science Division, Litton Systems, Inc. This laboratory plans to review all program aspects and will outline recommendations for further work in a proposal to be submitted in early spring, 1969.

5. REFERENCES

Davies, C. N. and M. Aylward. The trajectories of heavy solid particles in a two-dimentional jet of ideal fluid impinging normally upon a plate. Proc. Phys. Soc. (London) 64B: 889-911 (1951).

Junge, C. E., C. W. Chagnon and J. E. Manson. Stratospheric aerosols. J. Meteorol. 18: 81-108 (1961).

McFarland, A. R. and H. W. Zeller. Study of a large volume impactor for high altitude aerosol collection. Final report, Contract AT(11-1)-401 (1963).

Ranz, W. E. and J. B. Wong. Impaction of dust and smoke particles on surface and body collectors. Ind. Eng. Chem. 44: 1371-81 (1952).

Stern, S. C., H. W. Zeller and A. I. Schekman. Collection efficiency of jet impactors at reduced pressures. Ind. Eng. Chem. Fundamentals 1: 273-77 (1962).

Wood, R. C., R. K. Olson and A. R. McFarland. Air ejector filter sampler: A balloon-borne collector of radioactive stratospheric debris. J. Appl. Met. 5: 866-71 (1966).