NSG-231
~~NSG-234~~
NSG-321

COSMIC DUST IN THE STRATOSPHERE

James R. Arnold, Narendra Bhandari* and David W. Parkin

University of California

San Diego, California, USA

Abstract

A balloon borne technique for stratospheric collection of micron size dust from up to a million cubic meters of air has been developed. The technique samples particles in size range of roughly 1-100 microns and thus the extraterrestrial particles in this size range which do not burn up during their entry in the earth's atmosphere are collected. The collection made during the maximum activity of early June meteor showers in 1966, indicates that the total terrestrial accretion in this size range certainly does not exceed 550 tons per day and is probably less than 50 tons per day over the whole earth.

---

* On leave from the Tata Institue of Fundamental Research,

1. INTRODUCTION

The observation of zodiacal light and of meteors has long made clear the existence of dust in interplanetary space. The measurement of the influx rate of this dust, and the collection of weighable amounts, have been active scientific problems for many years (Parkin and Hunter, 1962; Hemenway and Soberman 1962, 1965; Hodge and Wright, 1961-66; Crozier, 1965). None the less, there is presently no agreement on the amount or nature of the entering matter. The subject has been recently reviewed (Parkin and Tilles, 1967).

Particles below a certain size limit (which depends strongly on velocity, angle of entry, density, and composition) can be slowed down in the earth's atmosphere without being vaporized or even melted. The preservation of structure makes this size range especially interesting for laboratory study. This limit has been calculated (Öpik, 1961; Whipple, 1950) to be typically some tens of microns. Such particles fall through the atmosphere at very low speeds, $\sim$cm per sec, as compared to the 11-70 km/sec velocity of entry. Their concentration in the atmosphere is, therefore, higher than that in space by many orders of magnitude. The concentration increases further in the lower atmosphere as the speed of fall decreases. However, a maximum concentration is to be expected in the lower stratosphere since in the troposphere scavenging mechanisms remove the particles.

The extraterrestrial particles must be studied against a background of terrestrial material. This background is high and variable in the troposphere, though in some favored places (the open ocean or the Antarctic) it may be comparatively low. Above the tropopause, Junge and coworkers (1963) found a layer of fine "sulfate aerosol" in the size range below one micron. It is also well known that radioactive debris from atmospheric nuclear tests attaches itself to submicron particles, which remain in the stratosphere for periods ranging from months to years (Martell, 1966).

In the size range above one micron, however, Junge (1963) concluded that terrestrial contamination is very low in the stratosphere. This conclusion, of course, does not apply to periods soon after major volcanic events of the Krakatoa type. The most recent such event, which injected material into the stratosphere, was the eruption of Mt. Agung on Bali in 1963. Calculations show that $> 1\,\mu$ particles from this eruption will have long since fallen out of the stratosphere; and therefore for the present work, volcanic contamination in this size range can be ruled out.

The considerations given above led one of us (J. R. A.), several years ago, to begin development of a system for collection of particles above one micron from large volumes of air in the lower stratosphere. A balloon borne system adapting the "sticky-mesh" technique used by Parkin and coworkers (1962) for their surface air collections was developed. Its advantages include simplicity, ease of cleaning and large sampling capacity without heavy mechanical pumping devices and their associated contamination.

A fully successful flight of this system was made on June 10, 1966, at the peak of the early June meteor showers. In the following section we give a brief description of the apparatus and the flight.

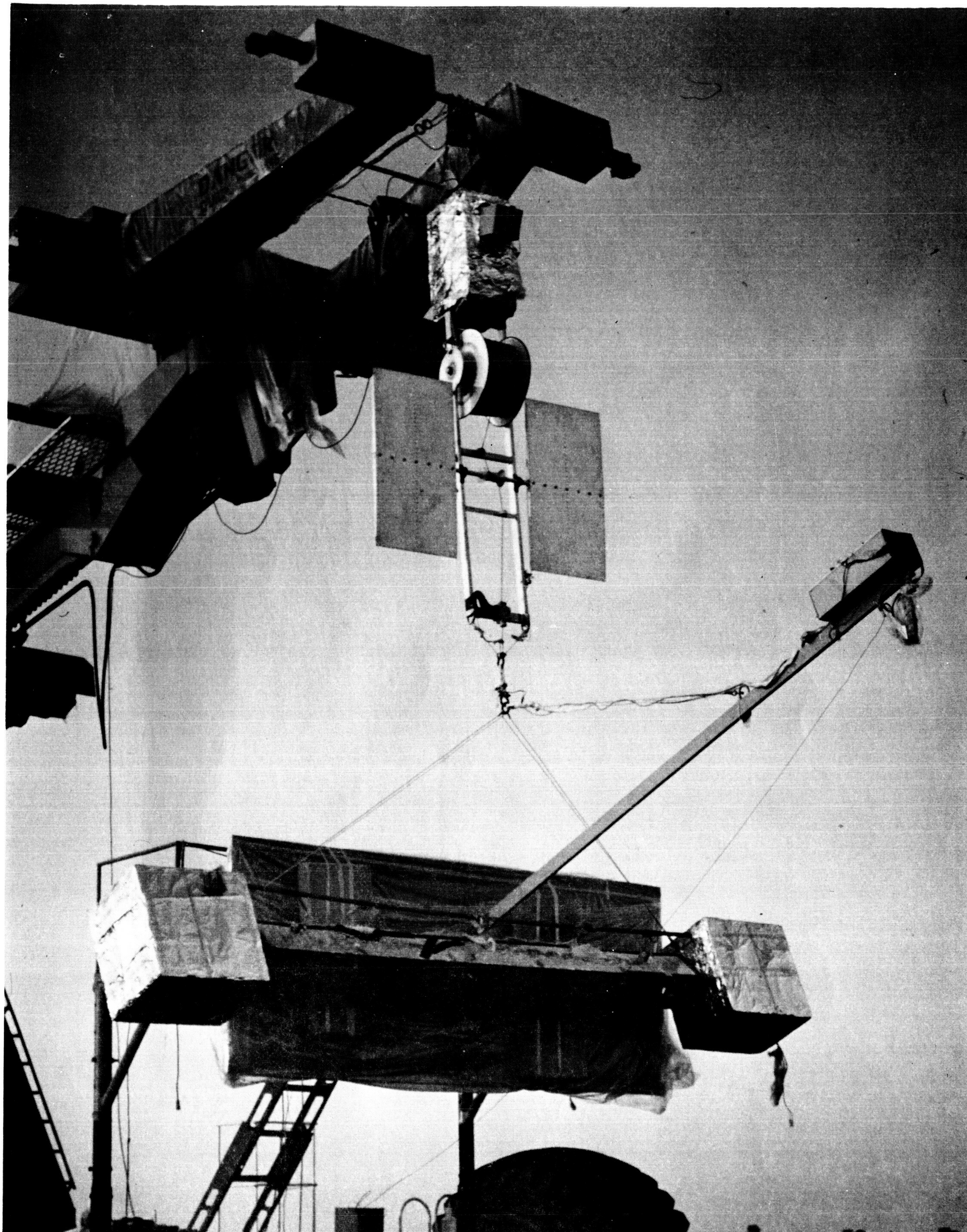
2. TECHNIQUE

The dust is collected by dragging a 10m^2 mesh impactor through the air by means of a balloon. The 2 km vertical separation of the balloon and collector ensures an ample wind shear, typically 15 km/hour at temperate latitudes, and over some 10-hour exposure, a sampling volume of the order of 10^6m^3 is expected.

Since for launching it is desirable to have a short flight line, a line release system was developed to effect the separation of the collector system from the balloon after the launch. The apparatus thus consists of two parts; the collector system and the line release system.

The collector system consists of two 6.5 meter long x 1 meter wide "Nitex" mesh panels made of 280 μ monofilament nylon fiber having 720 μ size holes. Each panel is divided into two separate sections with an intermediate 38 cm long "separation-cloth" made of tightly woven nylon. The upper section (0.9 m x 1 m), which is exposed to wind only momentarily before and after the collection, serves as our flight-blank while the rest of the screen serves as sample collector. A 50 cm long "cover-cloth" at the bottom of each panel protects the collector screen before and after the flight from any accidental exposure. The two panels are mounted side by side on a 5 cm diameter roller which can be operated by a motor from one end.

The rolled-up screens are encased in a 3-meter long cylindrical tube, which on its underside has a 5 cm wide slot along its length, through which the screen can be raised and lowered by motor control. The slot is closed immediately after the



collection by a door working by spring action. A 4-meter long boom is attached T-wise at the middle of this tube, permitting a three point suspension. This forces the screen to face the wind. (See figure 1)

FIG. 1

The tube containing the collection screens is encased in a precleaned protective foam box which is dropped off just after the system attains altitude. The metallic parts of the system exposed to the screens are made of gold-colored anodised aluminum or bronze.

This collector system is suspended below the line-release system (figure 1) which consists of the line reel and a friction spindle coupled to two paddles. When the system attains an altitude of 3 km, the brakes on the reel are released and line begins to pay out. The two paddles, 1.2 x 0.6 meters, rotate with the spindle and serve as a brake. The rate of fall is easily controlled at about 200 feet/minute. This let-down system may be applicable to other problems requiring the controlled payout of heavy loads.

3. FLIGHT DATA

The flight reported here was made on June 10, 1966, from the Balloon Base of NCAR at Palestine, Texas. The launch was

TABLE 1

Command Schedule for the 10th June 1966 Flight

Time	Command No.	Functions	Altitude (km.)	Mode of Action	Duration	Indication
0600	0	Launch	0			
0615	1	Paddle Release Line Let Down	3.5	Squib Squib	20 min.	Visual, 225.0 mc. Telemetry Recording
0700	2	Eject foam cover	16	Squib		Visual, Frequency Shift
0815	3	Screen Let Down	23.8	Motor (20 rev.)	3 min.	Frequency Shift
		Float			7 hrs. 30 min.	
1545	4	Screen Up	23.8	Motor (24 rev.)	30 min.	Frequency Shift
1555	5	Lock Lid	23.8	Squib		
1600	6	Termination Parachute Release	23.8	Squib		
(2 sec. delay)		Cutdown-Collector System				Decreasing Altitude
(5 sec. delay)		Cutdown-Line Release system				

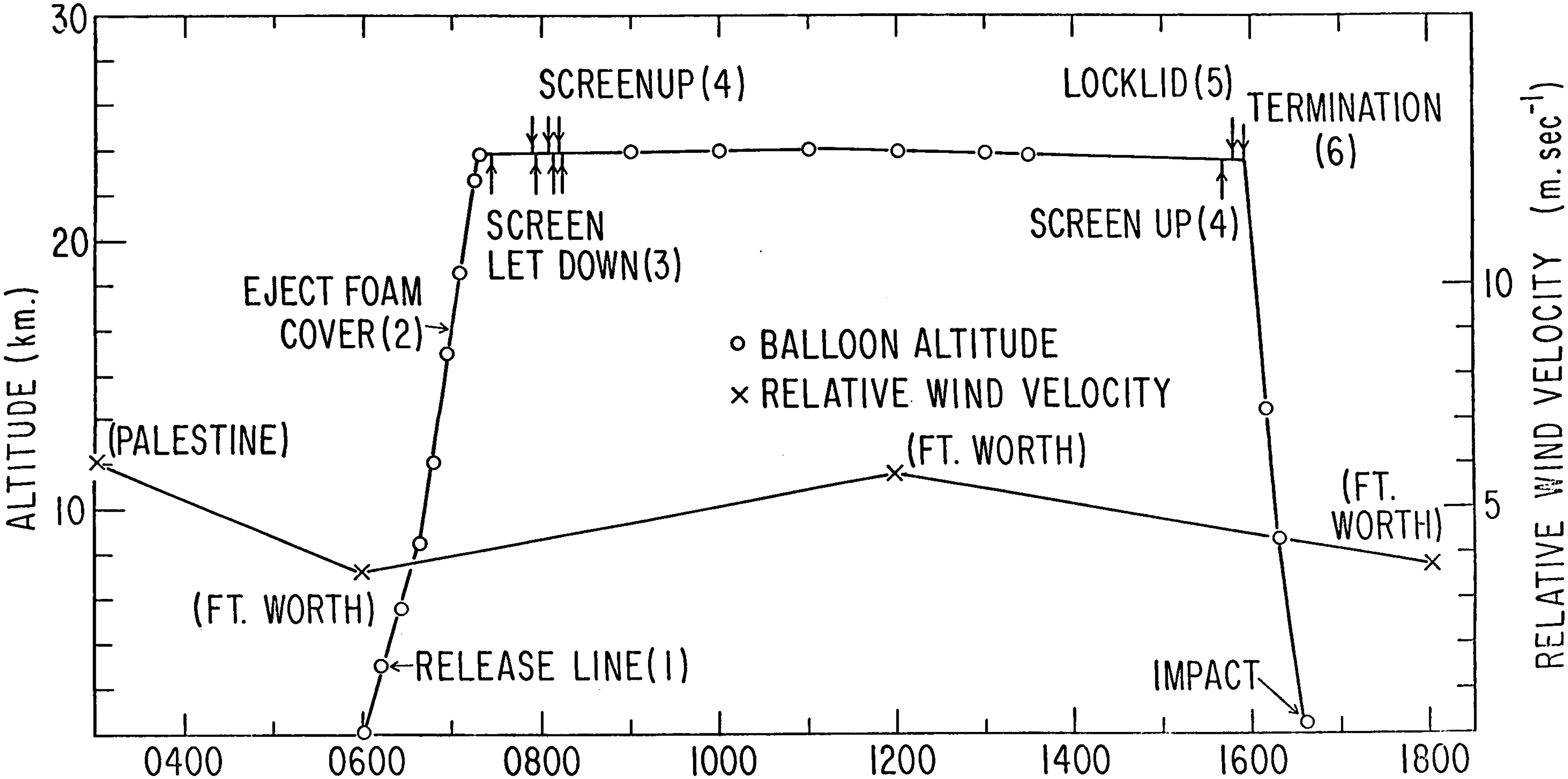

ALTITUDE (km.)
30
20
10
SCREENUP (4)
LOCKLID (5)
TERMINATION (6)
SCREEN LET DOWN (3)
SCREEN UP (4)
EJECT FOAM COVER (2)
BALLOON ALTITUDE
RELATIVE WIND VELOCITY
(PALESTINE)
(FT. WORTH)
(FT. WORTH)
(FT. WORTH)
RELEASE LINE (1)
IMPACT
0400
0600
0800
1000
1200
1400
1600
1800
TIME (C.D.T.)
RELATIVE WIND VELOCITY (m. sec⁻¹)
10
5

FIG. 2

made at 0600 hours CDT. The flight details are given in Table 1 and figure 2.

TABLE 1

For a few days before the flight, the wind pattern in the stratosphere was studied at two stations, Shreveport and Fort Worth, which were close to the expected trajectory. The balloon ceiling altitude was chosen for maximum and steady wind shear. The wind shear between the balloon and collector during the flight is also shown in figure 2, and on the average, was 17 km/hr. The integrated amount of wind is calculated to be 1.2×10^6 M^3 (ambient) (before corrections given below).

FIG. 2

4. CLEANING PROCEDURE

Previous to flight, the collector system is cleaned and assembled in a positive pressure clean room. The screen is washed in an ultrasonic bath by continuous cycling of detergent, methanol and Freon successively using a Randolph peristaltic pump which circulates the liquid through a plastic tubing by squeezing action, The wash is continuously filtered through a millipore filter which is connected with the pump and ultrasonic tank in a closed circuit. The particles collected on the millipore filter are transferred to a dish of water and a magnetic separation is made with a strong horeseshoe magnet. The magnetic and non-magnetic particles are then examined optically under a microscope.

Large amounts of nylon fibres from the screen are always present in the non-magnetic fraction and are easily recognized and rejected. The clean room and the handling procedures are controlled by blanks.

When the final washing is satisfactory, the screen is coated with silicone oil (Dow Corning 200 fluid; 10,000 centistokes) in Freon and run through a complete loading and unloading operation in the clean room. The particles from the screen are collected by soaking the screen in Freon for 24-48 hours and circulating the Freon through the millipore filter. A second recovery is made by giving an ultrasonic bath in Freon. This operational (laboratory) blank, after rejecting nylon fibers, was estimated for this flight to be less than 2 μg.

The recovery efficiency was determined by two experiments where a known number and kind of particles were put on the screen and was found to be 70 and 90 percent.

5. RESULTS

The results of particle analysis is given in Table 2. The magnetic fraction of screen S_1 consisted of five flakes [approximate dimensions in micons; 2 (66 x 120 x 20), 33 x 66 x 20, 14 x 17 x 10, 110 x 40 x 20 and one spherule, (γ = 7 μ)] ; no fine magnetic

TABLE 2

Results of Particle Analysis

Section	Particle Type	Density	Total	No. of Particles Radius* (microns) 5-12	12-20	20-28	28-35	35-45	45-50	50-60	100	Weight* (ug)
1. Blank panel 1 + 2 (Area 1.8 sqm)	Brown		87	66	21	x	x	x	x	x	x	1.3
	Black	1.5 - 2	17	11	5	x	1	x	x	x	x	0.3
	Metal	5A	3	x	1	1	x	x	x	x	1	12.0
	Magnetic		0	x	x	x	x	x	x	x	x	x
	Total		107	77	27	1	1	x	x	x	1	13.6
2. Screen panel 1 (Area 4.5 sqm)	Brown	2.6	326	285	29	9	3	x	x	x	x	5.3
	Black	2.2	91	63	21	4	3	x	x	x	x	2.3
	Metal	5A	24	14	6	4	x	x	x	x	x	3.5
	Magnetic	5A	6	x	x	x	x	x	x	x	x	1.5
	Total		457	362	56	17	6	x	x	x	x	12.6
3. Screen panel 2 (Area 4.5 sqm)	Brown	2.2-2.6	151	89	42	x	18	1	1	x	x	9.5
	Black	1.5-2	46	23	16	5	x	1	x	1	x	8.0
	Metal		x	x	x	x	x	x	x	x	x	x
	Magnetic	5A	3	2	x	x	x	x	x	x	x	1.0
	Total		200	114	58	5	18	2	1	1	x	18.5

* All particles have been approximated to a sphere. Where shape is better known, correction has been made in calculating the weight.

A: Assumed for the purpose of calculating the weight.

dust was present. On Screen S_2, three magnetic particles were recovered. Two were $\sim 5\,\mu$ size and the other one was lost during manipulation; no fine magnetic dust was present on this screen either. Electron microprobe analysis on three of the flakes from S_1 showed that their Fe, Mn, Ni composition (99% Fe, $\sim$1% Mn, $<$1%Ni) are similar to common steel.

The nonmagnetic fraction was separated into three groups from their appearance: brown, black and metallic. The density of a few particles was measured and is given in Table 2. A few brown particles were identified as feldspar by their polarization pattern. Most of the particles were irregular in shape; some of the black and metallic particles were also like thin flakes.

When the collector system was opened after the flight it was observed that a few insects and specks of dust had entered the inside of the case presumably during the landing of the package. Although the sample screens are protected by the cover screen, a small portion at one end of the panel S_1 had remained slightly exposed. The particles picked up from this part were similar to the brown particles in appearance. Therefore it is very likely that at least a part of the particles on screen S_1, and possibly on S_2 are contamination.

6. DISCUSSION

The collector system functions as an impactor, in a regime of low Reynolds number. Its behavior is in accord with laminar flow (Stokes' law) at high pressure and large particle diameter, approaching molecular flow as pressure and diameter decrease. In this regime the force on a spherical particle moving relative to a gas is given by a formula of Millikan (Kennard, p. 310).

$$F = 6\pi\eta\gamma V \left[1 + \frac{\lambda}{\gamma}\left(A + Be^{-\frac{Cr}{\lambda}}\right)\right]^{-1} \tag{1}$$

Where V is the relative velocity, η the viscosity of air, and the empirical constants A = 1.23, B = .41, c = 88. Using an approximation to the complex flow pattern in the mesh, and assuming that particles approaching the filaments will be captured if they are accelerated to less than 20 percent of the mean lateral velocity of the gas stream within one filament diameter in front of the mesh, we derive for the cutoff radius the rough formula

$$\gamma^2_{cutoff} = \frac{45}{2} \cdot \frac{\eta b \theta}{\rho v} \tag{2}$$

where b is the filament diameter, ρ the density of the particle, v the wind speed near the mesh, and θ the correction factor in parentheses of equation (1). For $(\frac{r}{\lambda})$ large, $\theta \sim 1$; for small $(\frac{r}{\lambda})$ equation (2) reduces to

$$\gamma_{cutoff} = \frac{14\eta b}{\rho v \lambda} \tag{2a}$$

For mesh of 700 μ sized holes and 280 μ fiber diameter as used, $\theta \sim 1$ at sea level; at the 30 mb level the full formula must be used. Of course, there is no sharp cutoff, but the values given by equation (2) are well enough confirmed by observation at both pressures to give confidence that the mechanism is correct. Some sample results of equation (2) are given in Table 3.

TABLE 3

Cutoff Radii for Various Mesh Impactors

Fiber diameter (microns)	Mesh hole size (microns)	Particle Density ($g.cm^{-3}$)	Pressure (mb)	r_{Cutoff} (microns)
280	700	1	1000	5
"	"	"	30	3.6
"	"	3	1000	3
"	"	"	30	1.3
40	100	"	1000	1.1
"	"	"	30	0.3

It is necessary to know approximately the resistance of the screen to air flow for two reasons: (1) to correct the total air volume calculated from the meteorological data, and (2) to use the proper value of v in equation (2) above. Again the flow equations must be laminar-molecular; since in the region of interest, the mesh hole size a $\gg \lambda$, the laminar regime prevails to a good approximation. Since the value of η, and hence the decrease in velocity in front of the screen, is almost the same at 30 mb as at sea level, it is safe to calibrate at sea level. This calibration, giving a flow decrement of $\sim$30 percent for our flight, has been used to determine sampling volume from the meteorological data and the cutoff values.

For particles above the minimum size the screen has an efficiency equal to the fractional area covered by filaments, in our case close to 0.5. Thus on the present flight the effective sample volume is $1.2 \cdot 10^6 \cdot 0.7 \cdot 0.5 = 4.2 \cdot 10^5$ cubic meters (ambient).

The efficiency of the screen was tested at sea level by estimating the amount of air borne radioactivity of Be^7, Cs^{137}, and Pb^{210} picked up by the screen for a known amount of air passed through it. These radioactivities are expected to be attached to particles close to 1 μ in size (Lockhart, et al, 1966). The activity found on the screen was similar to that expected indicating that the screen is fairly efficient for micron size particles. Laboratory tests also showed that the silicone oil coating remains fairly sticky at dry ice temperatures.

The screen collector will be efficient for extraterrestrial particles larger than the lower impactor cutoff, and up to the size at which the extraterrestrial particles are heated to vaporization in passing into the atmosphere. Particles above this size largely or entirely vaporize. The vapor so formed, distributed over a path length of many kilometers, is presumably to be found in the stratosphere in the sub-micron particle size range. It is inaccessible to our technique. The problem of heating on deceleration of a dust particle ($d \ll \lambda$) has been treated by Whipple (1950) and Öpik (1961). Whipple's formula may be given in the form

$$\frac{M}{B} = \frac{3e\beta D\sigma \ (T^4_{max} - T_o^{\,4})}{\alpha b V_\infty^3 \cos Z} \qquad (3)$$

Where for the particle M = mass, B = radiating area, β = emissivity, D = drag coefficient, α = accomodation coefficient. The other symbols are σ = Stefan-Boltzmann constant, b = inverse scale height of the atmosphere, V_∞ = velocity of the particle outside the atmosphere, and Z = zenith angle.

For spherical particles, setting $\alpha = \beta = 1$, D = 2 (reasonable values for most substances), this gives

$$d = \frac{36e\sigma \ (T_{max}^{\;4} - T_o^{\,4})}{b\rho_s \ V_\infty^{\,3} \ \mathrm{Cos}Z} \qquad (4)$$

Where ρ is the density of the particle. The proper value of T_{max} for survival is difficult to estimate. The melting point of chondritic iron-nickel and stone phases is $\sim$1700 ^{o}K. The vapor pressure curves are not well known and we adopt a value of 2000^{o}K (similar to Öpik's) as just sufficient to cause vaporization during the high temperature period, of the order of one second. Particles containing organic polymer or other volatile or reactive substances may be destroyed at a much lower temperature. Particles of about half the limiting diameter will melt, and become spherules. If they are originally of low bulk density, this meling and compaction will lead quickly to vaporization. For these reasons, and because the spherical approximation may cause errors for highly irregular particles the limiting values of d given are uncertain at least by a factor 2 for metal and silicate particles and perhaps systematically too large. Finally substituting

$b = 1.5 \times 10^{-6}$,

$$\rho_s d = \frac{5.9.10^5}{V_\infty^3 . \cos Z} \tag{5}$$

Where d is in microns, V is in km/sec and in gm^{-3}. This function d is tabulated for a few selected values in Table 4.

Assuming an isotropic entering flux, the value of sin Z tabulated gives the integral fraction entering at steeper angles than Z. For example, at V_{oo}= 11.2 km, 80 percent of particles have 720 while only 2 percent have 2200.

For silicate particles in near-circular orbits of low inclination the upper survival limit (as spherules) is then

TABLE 4

Maximum Density - radius Product ($\rho_s \delta$) as a Function of Entering Velocity and Zenith Angle
(ρ_s in g/cm^3, δ in microns)

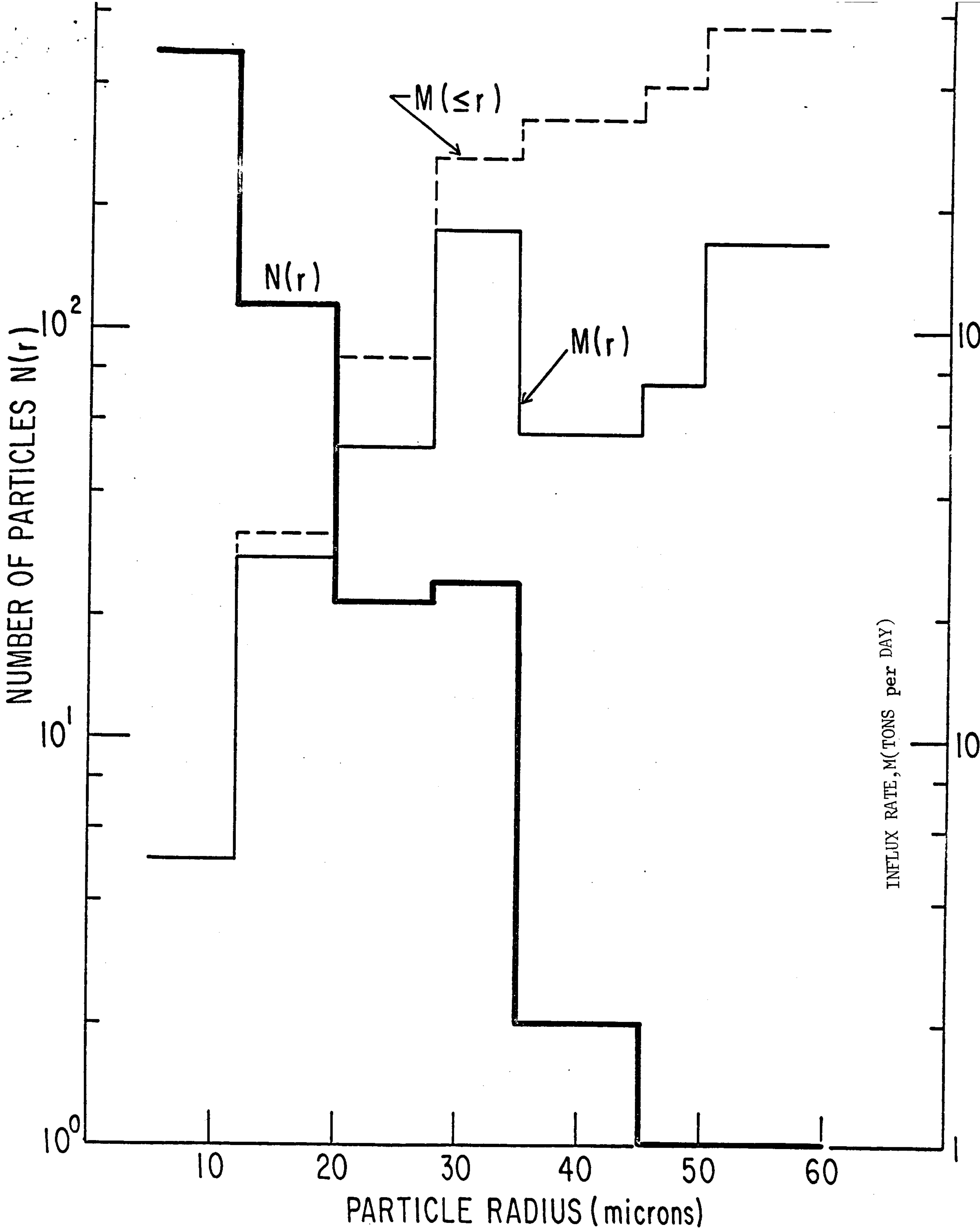
U km/sec	V km/sec								
	sin Z	0	0.2	0.4	0.6	0.8	0.9	0.96	0.98
	Cos Z	1	0.980	0.916	0.800	0.600	0.436	0.312	0.199
0	11.2	430	440	470	540	720	990	1400	2200
6	12.7	290	300	320	400	480	670	930	1500
12	16.4	130	130	140	180	220	300	420	650
24	26.5	32	33	35	40	53	73	100	160
60	61	2.6	2.7	2.8	3.3	4.3	6	8.3	13

around 100-150 microns or without fusion 50-70 microns. For particles entering at typical meteor velocities, above 24 km/sec, the limit drops to 10 μ or less for spherules and 5 μ or less for unfused particles. So far as this model of molecular deceleration applies, most meteor showers will contribute only a narrow range of surviving particles to balloon or rocket collections. The June showers have values of U_{∞} of 29 and 39 km/sec. Thus, if there are no special mechanisms of deceleration, such showers must contribute little in the micron range.

This model for deceleration yields the further conclusion that atmospheric deceleration cannot disrupt particles in this size range, however weak structurally they are, except by thermal effects. So long as collisions occur molecule by molecule, no appreciable relative forces can be created, even though the braking deceleration may reach 100 g or more. Such particles may however be disrupted on striking the collector.

FIG. 3

A comparison of the data obtained on screen S_1, screen S_2 and the blank shows no striking differences. The size distribution of particles on both screens is given in figure 3. Allowing for mesh collecting efficiency the conversion from number collected to the mass accretion rate, M, may be made through the formula



M(≤r)
N(r)
M(r)
NUMBER OF PARTICLES N(r)
10^2
10^1
10^0
10^2
10
1
INFLUX RATE, M(TONS per DAY)
10
20
30
40
50
60
PARTICLE RADIUS (microns)

FIG. 3

$$M_s = \frac{N_s m_s u}{V} \tag{6}$$

where the subscript s refers to particles of given size and density. N is the number of particles, m the mass of each, and u the settling (Stokes-Cunningham) velocity at the altitude of collection and V the effective sample volume. This equation has been used to obtain the histogram M(r) and the integral histogram $M (\leq r)$ of influx rate as given in figure 3. This gives an upper limit for the influx rate to the earth in early June 1966 of 550 tons/day in our size region on the unrealistic assumption of a zero blank and no terrestrial component.

However, the flight blank is in fact comparable to the sample in mass and, more important, in the identifiable characteristics of the particles. Our hope of finding particles of distinctive type on the exposed screens has not been realized. The largest particles on both sample and blank have been clearly identified as contaminants. In the case of the blank, a single particle contains most of the mass, which otherwise would be comparable to the laboratory blank of 2 ug. In the sample distribution, there happens not to be a single massive particle, but the four particles above 35 u still contribute 50 percent to the observed integral influx rate. This value, and these particles, are particularly suspect. The particles below 35 μ occur in statistically adequate numbers, on the sample screens. There are only two particles on the blank from 20-35 μ where nine would be expected on the hypothesis of equal numbers per unit area; as the most favorable single comparison this is not statistically impressive.

The only conclusion possible at present is that the mass influx rate to the earth in the size range between one micron and some tens of microns is (or was in June 1966) much lower than 550 tons/day. The flux of particles of distinctive type can hardly exceed 50 tons/day. The limits are not dependent on any assumed composition. The collection from the stratosphere is complete except for particles soluble in Freon and those indistinguishable from nylon fragments. Since large organic particles are unlikely to survive entry in any case, this does not seem to be a serious restriction.

This result is in sharp contrast to those of some other recent and older studies (Crozier, 1966; Hemenway and Soberman, 1962-65; Parkin and Hunter, 1962). It is, however, quite consistent with the Barbados data of Parkin, Delany and Delany (1967), and the recent Explorer XVI and Pegasus penetration experiments (Naumann, 1966).

Parkin, Delaney and Delaney give an upper limit of 0.2 tons/day earth for the ferro magnetic particles. Nauman finds that total influx rate is of the order of 10 tons/day (the satellite rates are limited by statistics to particles below $\sim 10^{-6}$g).

The results may also be compared with those of Shedlovsky and Paisley (1966), whose absolute filter technique samples particles of long residence time in the stratosphere: the submicron particles and the smoke condensed from the large ones. Their limit (assuming chondritic composition based on Iron content) is 250 tons/day.

The strongest present evidence for a higher mass influx rate (averaged over periods of $\sim 10^5$ years) is the Al^{26} data of Lal and Venkatavaradan (1966) and of Wasson, Alder and Oeschger (1967). Since their result depends on the product of the mass influx rate, exposure time in space and solar proton flux, there is no definite contradiction. Their data are compatible with influx rates of silicates as low as 10^3 tons/day. Assuming a solar rather than a chondritic composition (Fe/Si = 0.1-0.2) a total influx (stone and metal) of $1\text{-}2 \cdot 10^3$ tons/day in the meteor size range ($>100\mu$) is not excluded (Elford and Hawkins, 1964). The influx rate of unaltered particles in this size range is very small however. It remains true that the only certainly extraterrestrial particles are deep sea spherules (Murray, 1876) which however may well be meteoritic in origin

(Petersson and Fredriksson, 1958).

The present experimental system is capable of further improvement. The signal-to-noise ratio can be raised in a longer flight, and it is also desirable to lower the impactor cutoff by using a finer mesh. Some further improvements in cleanliness may be possible. Efforts are proceeding to this end.

Acknowledgments. The work reported here depended essentially on the efforts of Mr. Norman Fong, and also of Mr. Ronald LaBorde and Mr. Crispin Hollinshead. We are indebted to Dr. Arch Reid for microprobe analyses. The balloon operations were carried out by the staff of the NCAR Balloon Base, Palestine, Texas. Other support furnished by them included purchase of balloons and helium. The work was generally supported by NASA Grants NsG-~~734~~ 731 and NsG-321.

REFERENCES

Crozier, W. D., Nine years of continuous collection of black magnetic spherules from the atmosphere, Jour. Geophys. Res., 71, 603, 1966.

Elford, G. W., and G. S. Hawkins, Meteor echo rates and the fluxes of sporadic meteors, Harvard College Observatory Research Report 9, 1964.

Hemenway, C. L., and R. K. Soberman, Studies of micrometeorites obtained from a recoverable sounding rocket, The Astron. Jour., 67, 256-266, 1962.

Hodge, P. W., F. W. Wright, and C. C. Langway, Studies of particles for extraterrestrial origin, Parts 1 to 4, Jour. Geophys. Res., 68, No. 19, 5575, 1963, 69, No. 12, 2449, 1964, 69, No. 14, 2919, 1964, 70, No. 16, 3889, 1965.

Junge, C. E., Airchemistry and Radioactivity, Academic Press, New York, 1963.

Kennard, E. H., Kinetic Theory of Gases, McGraw Hill Book Co., New York, 1938.

Lal, D, and V. S. Venkatavaradan, Low energy protons: Average flux in interplanetary space during the last 100,000 years, Science, 151, 1381, 1966.

Lockhart, L. B, R. L. Patterson, Jr., and A. W. Saunders, The size distribution of radioactive atmospheric aerosols, Jour.

Geophys. Res., 70, No. 24, 6033, 1965.

Martell, E. A., The size distribution and interaction of radioactive aerosols in the stratosphere, Tellus, 18, 2-3, 486, 1966.

Murray, J., On the distribution of volcanic debris over the floor of the ocean, Proceedings Royal Society of Edinburgh, 9, 247-261, 1876.

Naumann, R. J., The near earth meteoroid environment, N.A.S.A. Technical Note D, 1966.

Öpik, E. J., Physics of meteor flight in the atmosphere, Interscience Publishers Inc., New York, 1958.

Parkin, D. W., A. C. Delany, and A. C. Delany, A search for air borne dust on Barbados, Geochim. Cosmochim Acta, to be published.

Parkin, D. W., and W. Hunter, Meteorites and cosmic dust, in Advances in Astronomy and Astrophysics, Academic Press, 1, 105-163, 1962.

Parkin, D. W., and D. Tilles, The influx of extraterrestrial material, to be published in Science.

Pettersson, H., and K. Fredriksson, Magnetic spherules in deep sea deposits, Pacific Science, XII, No. 1, 71-81, 1958.

Shedlovsky, J. P., and S. Paisley, On the meteoritic component of stratospheric aerosols, _Tellus_, _18_, 2-3, 499, 1966.

Soberman, R. K., and C. L. Hemenway, Meteoric dust in the upper atmosphere, _Jour. Geophys. Res._, _70_, 4943, 1965.

Wasson, J. T., Radioactivity in interplanetary dust, _ICARUS_, _2_, 54-87, 1963.

Wasson, J. T., B. Alder, and H. Oeschger, Al^{26} in Pacific sediments: Implications, _Science_, _155_, 446, 1967.

Whipple, F. L., The theory of micrometeorites, Part I. In an isothermal atmosphere, _Proceedings of National Academy of Sciences_, _36_, 12, 687, 1950.

Caption to Figures

Fig.1.Apparatus just before the launch.

Fig. 2. Balloon trajectory and the variation in relative round velocity between the balloon and the collector as a function of time. Figures within the paranthesis denote various command functions, Table 2.

Fig. 3. Size distribution. Mass accretion rate (tons per day over the whole earth) as a function of particle radius, r, uncorrected for blank is also shown.