Dr. E. Mercanti, 610

THE MICROMETEOROID EXPERIMENT ON THE OGO 2 SATELLITE

Report on Analysis of Experiment Data

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Smithsonian Institution
Astrophysical Observatory
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SUMMARY

This report describes the OGO 2 micrometeoroid experiment, including a brief description of the equipment and a detailed discussion of the data reduction and analysis.

The aim of this experiment was to measure the velocities, masses, and orbits of dust particles in the earth's dust cloud. The negative results obtained were instrumental in bringing about a reappraisal of the magnitude of this dust concentration. No orbits were determined, and it is questionable whether any micrometeoroids of mass $> 10^{-12}$ g impacted on the sensors during the 1300 hr in which good data were obtained. Two possible impacts were recorded, but these were more likely due to experiment noise. These two events give an upper limit to the flux of particles of mass $> 10^{-12}$ g of 3×10^{-2} particles/m^2 sec 2π ster. This figure is compared with data from other experiments.

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1. INTRODUCTION

An experiment designed to measure the velocities, masses, and orbits of impacting micrometeoroids was flown on the OGO 2 satellite, launched 14 October 1965. The experiment was designed (Alexander et al., 1962) on the basis of an expected flux consistent with previous microphone experiments (Alexander et al., 1963), the validity of which is now extremely doubtful (Nilsson, 1966; Shapiro et al., 1966; Konstantinov et al., 1968). Data were analyzed from launch through March 1966, after which no data were available until June 1966, when it appeared that experiment noise precluded further meaningful analysis. No velocity measures were made in the 1300 hr of good data; however, two possible, but not probable, impacts were recorded. This report describes how the early data were analyzed and how these two possible events were isolated.

2. EQUIPMENT

A complete detector is shown in Figure 1. A micrometeoroid would first be detected by its passage through the front two thin films, designated A. Each film consisted of 500 Å of Al_2O_3, on which 500 Å of Al was deposited front and back. An additional 325 Å of Mo was deposited on the front of the second film of the +X and +Y sensors. An amplifier detected the ionization resulting from the passage of the particle through the second film. If the angle of incidence and the composition of the particle were suitable, it then went on to impact destructively on the rear capacitor sensor, designated B. This consisted of a thin-film capacitor deposited on a glass disk. The velocity of the particle (after deceleration) was measured by the time of passage between the A and the B sensor outputs. A lead zirconate transducer, designated M, was bonded to the back of each capacitor plate to provide a measure of the impulse imparted to the plate by the particle impact.

Four of these detectors were arranged in the manner shown in Figure 2, where X, Y, Z refer to the spacecraft axes, such that when the spacecraft was properly stabilized, +X was normal to the earth-sun line and +Z pointed toward the earth's center. Each A sensor fed a separate amplifier, but the B and M sensors fed common amplifiers, as shown. Both the B and the M amplifiers fed pulse-height analyzers with logarithmic outputs divided into seven levels spanning two orders of magnitude. Each A amplifier operated a comparator, the output of which started the time-of-flight (TOF) clock and served to identify the detector. In the absence of an A signal, there were no means of identifying which detector gave rise to a B and/or an M signal. The flight unit and the individual sensors were laboratory tested by means of a NASA hypervelocity dust-particle accelerator. This machine, which could accelerate single carbonyl iron spheres of mass 10^{-10} to 10^{-12} g to speeds between 1 and 5 km sec^{-1}, was indispensable to the development of the OGO detectors. The amplitudes of the B output signals were somewhat erratic but appeared to be related to the energy of the impacting particle. The threshold of detection was less than 0.2 erg, corresponding to a 10^{-11} g particle impacting at 2 km sec^{-1}. Tests showed the outputs of the A sensors to be proportional to mv^3, with a threshold corresponding approximately to a 10^{-11} g particle impacting at about 3 km sec^{-1}. Deceleration for these particles through the A film was less than 5% at these speeds. The limiting sensitivity of each transducer input M was set at about 1×10^{-4} dyne sec, corresponding to a 2×10^{-10} g particle impacting at somewhat less than 5 km sec^{-1}, depending on the amount of material ejected on impact.

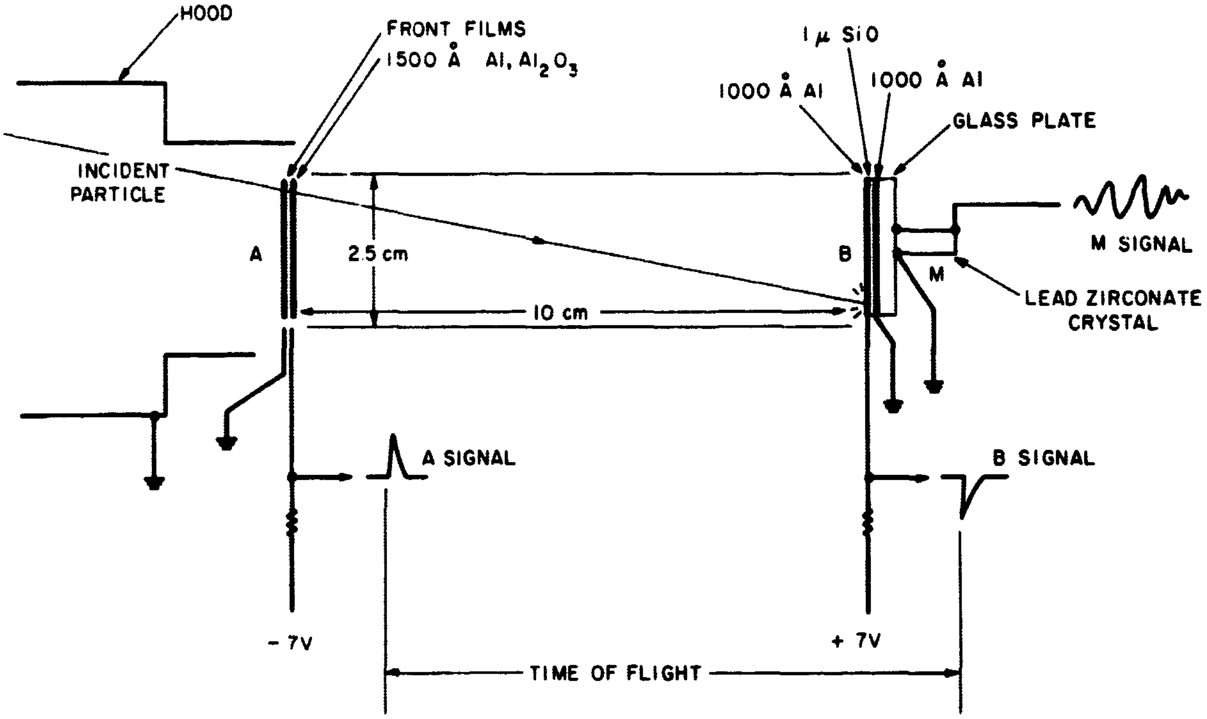

Figure 1. The OGO 2 micrometeoroid detector.

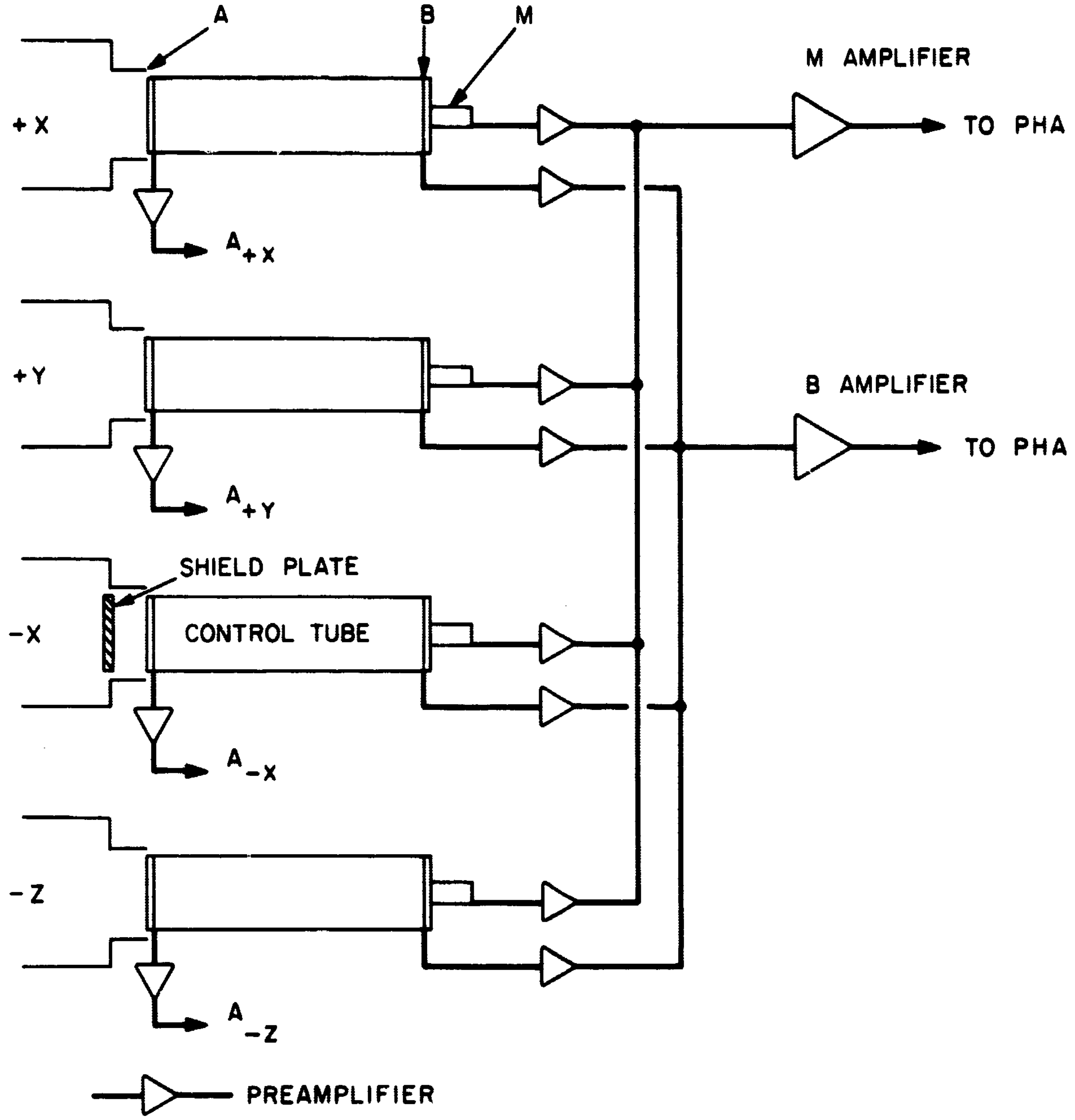

Figure 2. The OGO 2 detector system; X, Y, Z refer to the orientation of the detectors with respect to the spacecraft body axes.

The spacecraft velocity was between 6 and 8 km $\sec^{-1}$, so that given any reasonable orbital distribution, particle impact velocities would be at least ~10 km $\sec^{-1}$. A mass threshold of 10^{-12} g thus seems a reasonable estimate for both the A and the B sensors.

It is of interest at this point to return to the results from the OGO 1 experiment (Nilsson et al., 1965). Three "probable" impacts were recorded, and although the spacecraft was not properly stabilized, it was possible to calculate the most probable particle orbits. It now appears more likely that these three events were due to noise and not to micrometeoroid impact. Two assumptions made in assessing these data are no longer justified: first, that the B sensors failed under micrometeoroid bombardment when experiment power was turned off; and second, that experiment noise was unlikely, since there was no history of such noise in ground tests. Later experience with the OGO 2 and OGO 4 flight units has shown the second assumption to be naive. Both these units have responded to occasional noise from unknown sources.

The first assumption illustrates one of the main shortcomings of the OGO 1 unit: the fact that there was no explicit knowledge of whether the sensors survived in space or failed sometime during the flight. Additions were made to the OGO 2 unit to provide this knowledge. If a B capacitor shorted, this information was signaled in the telemetry data. In an attempt to prevent such a failure, a battery was installed such that the B sensor capacitors were kept charged even though the experiment power was turned off. However, this battery was not connected to the -Z sensor, which was left unprotected to test the first assumption made in analyzing the OGO 1 data. A metal plate shielded the -X detector from any particle impact. This detector thus served as a control against electrical interference

3. DATA ARRANGEMENT

3.1 Modes of Data

Data from the experiment were recorded in several different modes. "Real-time" data were taken directly from the satellite and recorded on the ground. These data were generally taken at either 64,000 or 16,000 bits/sec. These rates apply to the total data output from the spacecraft, which includes data from its 20 experiments, as well as spacecraft engineering data. Through a commutator system the micrometeoroid experiment was read out every 2.3 sec or 9 sec, respectively, in the above modes. The experiment also contained data registers that stored the sensor output data from the time of the event until such time as the registers were required to hold new data. Readout did not disturb the data storage. The manner in which data were changed in the data registers is discussed in Section 4.2.

In terms of elapsed time, most of the data were obtained in the "playback" mode. Two onboard tape recorders recorded experiment data, generally at a rate of 4,000 bits/sec, which were played back to ground stations at a much faster rate whenever the spacecraft was above the horizon. From the viewpoint of this experiment, the playback data have two advantages. First, the readout rate for this experiment was only once every 37 sec, more than adequate in view of the low event rate. Second, these data are much freer from command interference, since commands were generally transmitted to the spacecraft during real-time passes. Some of these commands resulted in electric transients that were recorded by the experiment sensors in much the same way as micrometeoroids would be recorded. The removal of these events from the data is discussed in Section 6.2.3.

3.2 Data Readout

3.2.1 Storage registers

Each readout frame or record consists of four 9-bit words. These total 36 binary bits, which are arranged in two independent groups of data of 18 bits each. These correspond to the two 18-bit storage registers in the experiment, labeled "hit 1" and "hit 2," respectively. This arrangement dates from the early planning stages for this experiment when it was thought that the impact rate might be such that more than one event would be recorded between readouts, i. e., within 37 sec. Thus, 18 bits are allotted to record all the sensor data from one event, and the information for two separate events can be stored at one time. The 18 bits are divided up as shown in Table 1. We shall now consider these bit allocations in functional detail.

Table 1. Bit allocation

Function	Allotment	Label
Sensor status	3 bits	CHG
Tube identification	2 bits	ID
Time-of-flight	7 bits	TOF
B amplitude	3 bits	B
M amplitude	3 bits	M

3.2.2 Tube identification

The A sensor of each detector fed an independent amplifier and comparator, resulting in either a 0- or 1-level output, depending on whether or not the input level reached a certain threshold value. These A sensors were to provide the information necessary to determine in which detector an impact had been recorded. Now, two bits would appear to be sufficient to specify which of four sensors has been triggered. The coded output is shown in Table 2.

Table 2. Detector identification

Tube	Bits	Dec. equivalent
+X	01	1
+Y	00	0
-X	10	2
-Z	11	3

The assumption inherent in the above arrangement, however, is that only one sensor at a time would be triggered, the case for a true micrometeoroid impact. Noise will generally trigger more than one sensor, and two bits are inadequate to describe such a situation. For example, if the +X and -X A sensors are triggered together, the circuitry was such as to produce the code 00, indistinguishable from an event in the +Y detector. This particular case was helped by also feeding the A output signal from the +Y detector to the charge amplifier, a procedure detailed in the next section. It should be noted from Table 2 that the presence or absence of a signal from the -Z A sensor in no way affected the identification code. No A signal at all still reads out as binary 11.

3.2.3 Sensor status

To interpret the data correctly (particularly a null result), it is necessary to be sure that the sensors, as well as the electronics, were functioning properly. This was undertaken by an Inflight Calibration (IFC) system, described in Section 4. As part of this system, the status of the A and B sensors of each detector in turn was read out in a 3-bit code in each 18-bit hit. Let us first consider the A sensors. The front films were very thin, and some concern was felt for their surviving the rigors of launch and spacecraft deployment. Ground tests showed that the only failure mode at all likely was a portion of one film detaching itself from the supporting grid and touching the neighboring film, thus shorting the input to that A amplifier. This was easily sensed by monitoring the bias voltage on the second film in each A sensor.

The B sensor capacitors occasionally developed short circuits, thus being rendered incapable of sensing impacts. A clearing circuit was provided that could be activated by ground command. This was sometimes successful in clearing minor short circuits in these capacitors. The state of each B capacitor was monitored by way of the 7-v bias voltage across each. If this voltage dropped below 1 v, the status was signaled as bad.

The 3 bits for the status code word were obtained by discarding the measurement of particle charge, for which the equipment was inadequate anyway, and modifying the logic circuits to read out as in Tables 3a and 3b.

Table 3a. Status code (+X, -X, -Z)

Sensor	Status	Dec. equivalent
AB	000	0
$A\overline{B}$	001	1
$\overline{A}B$	010	2
$\overline{AB}$	011	3

where AB = both good, $\overline{A}B$ = A bad, B good, etc.

Also, as mentioned previously, the A signal from the +Y detector was fed into the unused charge amplifier, resulting in a different code from that of Table 3a for the +Y detector status. This is given in Table 3b. It should be noted that the status bits are labeled "CHG" in the data records.

Table 3b. Status code (+Y)

Sensor	Status	Dec. equivalent
AB	101	5
$A\bar{B}$	001	1
$\bar{A}B$	110	6
$\overline{AB}$	011	3

3.2.4 Time-of-flight

Any A pulse started a 4-Mhz oscillator that was stopped on receipt of a B pulse or after 31.75 µsec, whichever occurred sooner. The number of oscillator cycles was counted and stored in a 7-bit register, thus providing a TOF measure in 0.25-µsec units up to a maximum of $2^7 - 1 = 127$.

3.2.5 Rear capacitor (B) signal

The four B sensors all fed a common amplifier with an analog output that passed to a pulse-height analyzer (PHA). The PHA covered a magnitude range of 50 in 7 levels, and the output was stored as a 3-bit binary number. The output from the common B amplifier was also used to stop the TOF clock.

3.2.6 Microphone (M) signal

The four microphone sensors fed a common amplifier with an analog output that went to a 7-level PHA covering a magnitude range of 50. The PHA output was stored as a 3-bit binary number.

4. INFLIGHT CALIBRATION

4.1 IFC Signal Inputs

The IFC system continuously generated electronic signals simulating micrometeoroid impacts; these signals were applied sequentially to the four detectors. The primary use of the IFC signals was to check continuously the status of the A and B sensors and to check the aliveness of the electronics following all the sensors. Pulses of certain amplitude and duration were used to stimulate the electronics and give rise to certain recognizable readout values for each detector. The actual input-pulse parameters varied with temperature, so that minor changes in the IFC output values during the flight more likely reflected changes in the input levels than changes in the sensor electronics. The nominal IFC values are shown in Table 4 for about 60°F. Figure 3 shows the variation of TOF with temperature for each detector.

Table 4. IFC values at 60°F

	CHG	ID	TOF	B	M
+X	0	1	95	3	2
+Y	5	0	107	3	3
-X	0	2	100	3	3
-Z	0	3	114	3	3

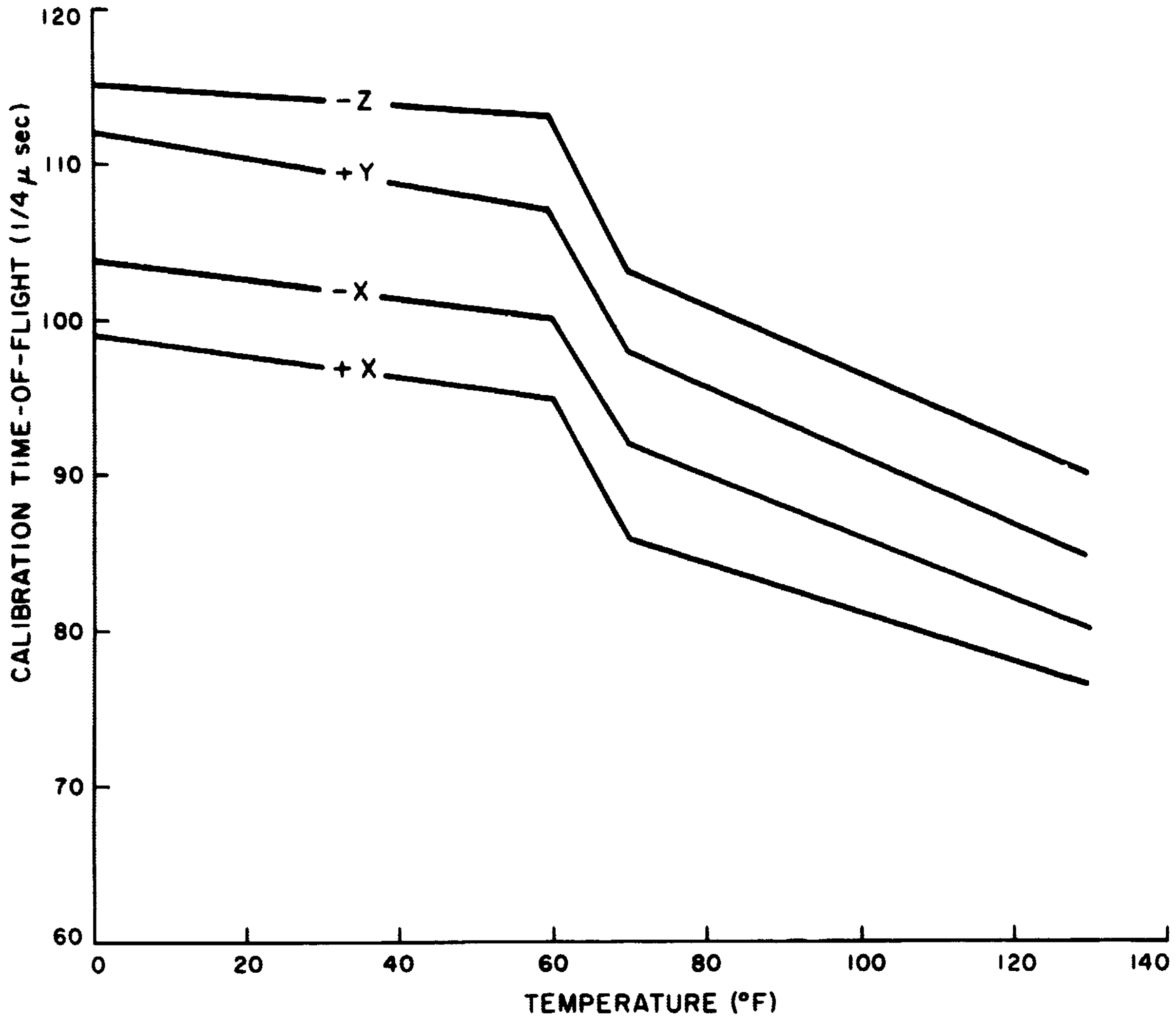

Figure 3. The IFC TOF as a function of experiment temperature.

4.2 Changes of Data

Before we proceed further with the IFC data, it is necessary to understand the manner in which changes of data were effected. As outlined in Section 3.2.1, each readout record of 36 bits is divided into two "hits" of 18 bits each. Readout of hit-1 and hit-2 data registers did not destroy the information held there, which remained held until new information (noise, IFC, or micrometeoroid impact) was transferred. Transfer was accomplished in the following way: If hit 2 was all clear (zero), the new information went into the hit-2 register. If, however, hit 2 already held nonzero information, both hit registers would be cleared and the new information would go into hit 1. For example, let us suppose the previous two events were called A and B, and event C came along. We could have:

$$\text{hit 1} = A \quad , \quad \text{hit 2} = B$$

$$\text{event } C \rightarrow \text{hit 1} = C \quad , \quad \text{hit 2} = 0$$

or

$$\text{hit 1} = B \quad , \quad \text{hit 2} = 0$$

$$\text{event } C \rightarrow \text{hit 1} = B \quad , \quad \text{hit 2} = C \quad .$$

New data were transferred only if the output from either the B or the M sensors was nonzero. Thus, at least one of B or M of hit 1 should always be nonzero. The length of time a given event remained in the data registers depended entirely on how much time elapsed before a new event came along. In general, those events recorded in hit 1 lasted longer than those recorded in hit 2. The IFC system was such that an event in hit 1 could not survive more than 30 readouts.

4.3 Appearance of IFC Data

A 4-step binary counter generated a single pulse, under quiet conditions, for each 15 times the data registers were read out. This pulse was used to trigger the IFC module. Each time the IFC module was triggered, it generated the signals given in Table 4 for one detector tube. The detectors were stimulated in the order +X, +Y, -X, -Z. Thus, under quiet conditions, each detector was stimulated once every 4 × 15 = 60 readouts. Accordingly, the readout information from each detector would repeat 30 or 15 times, depending on whether it went into hit 1 or hit 2, respectively. Any time data were transferred, the 4-step binary counter was returned to zero. Let us consider an event A, say, occurring when the +Y IFC data had repeated in the hit-1 register for 20 readouts, and the -X IFC data had repeated in the hit-2 register for 5 readouts. The new event would clear the IFC information and register in hit 1. The 4-step binary counter would start from zero again.

If no further events were transferred, event A would repeat in hit 1 for 15 readouts while hit 2 was zero, then the -Z IFC data would appear in hit 2. This combination would repeat another 15 times before both registers were cleared and the +X IFC data appeared in hit 1. Thus, if the event rate was low compared with the time for 15 readouts (= 9 min of playback data), each event was ensured of repeating in the data at least 15 times. If events occurred more often than that, the number of repetitions was reduced accordingly, and the IFC data were effectively locked out. Under quiet conditions, an event is easily recognized in the data by virtue of the interruption to the normal repetition sequence of IFC data. A sample of real data is shown in the Appendix.

5. OPERATION OF THE EXPERIMENT

The OGO 2 spacecraft was launched into a polar orbit (see Table 5) on 14 October 1965. The micrometeoroid experiment was turned on shortly thereafter and remained on most of the time until 8 April 1966, when it was turned off until 27 June 1966. It was then operated most of the time until May 1967. During operation, the IFC system checked the correct functioning of the three sensors in each detector and their accompanying electronics. No failure of the A films occurred. The B capacitor of the -X detector failed at the end of February 1966. The unprotected capacitor of the -Z detector did not fail, thus invalidating the assumption made in the previous analysis of the OGO 1 data that the sensors had failed. It should be noted that the -X detector was the one shielded from impact for control purposes; thus, the failure of this B sensor could be due only to an inherent defect in the capacitor itself. The experiment heater failed after about 1 week of operation, and the unit cooled below its optimum temperature range. Later, a more favorable spacecraft attitude to the sun brought the temperature up to normal. It was during this initial cooling period that the microphones emitted a lot of noise, which drew attention to the susceptibility of these sensors to thermal environment (Nilsson, 1966).

Table 5. Orbital elements of OGO 2

Launch date	14 October 1965
Epoch of table	19 January 1966
Semimajor axis	7340 km
Eccentricity	0. 0744
Inclination	$87\overset{\circ}{.}36$
Period	104. 3 min
Perigee height	415 km
Apogee height	1507 km
Perigee velocity	7. 94 km $\sec^{-1}$
Apogee velocity	6. 84 km $\sec^{-1}$

6. REDUCTION OF DATA

6.1 Type of Event

The electronics were such that a signal from either the B or the M amplifier was necessary for an event to appear in the telemetry. An event triggering an A sensor only would not appear in the data. It was no use searching for impacts that triggered only the M sensors, for if any existed, they were completely masked by the thousands of such events resulting from thermal noise. An M event accompanied by an A signal would have been of greater interest, but an electronic deficiency in the unit allowed some interaction between the A_{+X} and the M amplifiers. This became worse at low operating temperatures, and as a result of the heater failure and all the M noise, this combination of events had to be ignored. From these considerations, it can be seen that for an event to be accepted as a possible impact, it had to involve an output from the B sensors.

6.2 Processing of Data

The primary data given to the experimenters consisted of magnetic tapes listing each readout from the experiment, along with time, temperature, etc. (see Appendix). The vast majority of these readouts consisted of IFC information, and the principal job of data reduction was to isolate those events that might be due to micrometeoroid impact. This was done in three successive stages, illustrated in Figure 4.

6.2.1 First-level reduction

First-level reduction consisted of reducing the primary data to only those records (readouts) that represented changes. Under quiet conditions, the data in hit 1 and hit 2 remained unchanged for 15 records. By means of a computer, the data were scanned for only those records that inaugurated a change in either hit 1 or hit 2. In addition, to eliminate telemetry noise, only those changes that then repeated at least two more times in the original data were allowed as first-level data.

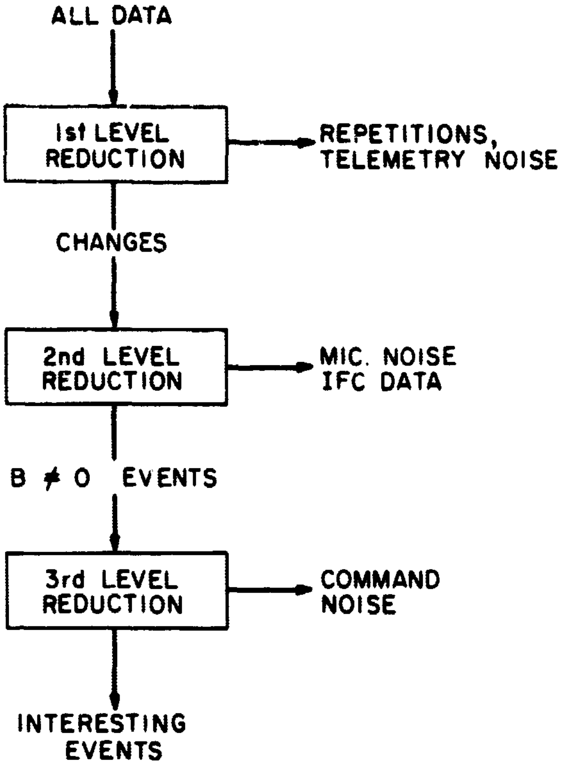

Figure 4. Successive stages of data reduction.

6.2.2 Second-level reduction

The first-level data consisted primarily of IFC records. The second-level program compared these records with the known values of IFC data and allowed through only those records that did not check out as genuine IFC records. Since the IFC data were a function of temperature, a minor difficulty was encountered here in that a number of genuine IFC records were passed on because the labeled temperature was incorrect. These records were later rejected by hand. Also, many of the first-level records consisted of microphone noise, i. e., M-only events. These were of no further interest and were rejected in the second-level reduction. The output of this level thus consisted of a few genuine IFC records and all the noise and other events with nonzero B data.

6. 2. 3 Third-level reduction

Commands sent to the spacecraft often caused electronic interference that resulted in events in the data with the appearance of genuine impacts. The times of these commands are known. Third-level reduction consisted of removing those events that occurred within an interval extending from 30 sec before a command to 210 sec following that command. Thus, 4 min around each command were eliminated from the data. This resulted in a reduction of the playback data time by 5% and a reduction of the real-time data time by 50%. This reduced data sample is termed "available" data.

6. 3 Results of Data Reduction

The three successive stages outlined above reduced about 1370 hr of playback data consisting of approximately 140,000 records to 98 records requiring closer attention. Many of these records consisted of events held in the experiment data registers at the start of a particular data sample. The first-level program was later modified to exclude these events on the grounds that a valid change had to appear in the data to be acceptable. One could not assign an accurate time to an event already held in the registers at the start of a sample, and in general such events were caused by command interference generated more than 210 sec before the start of the data sample. Many of the third-level records were, as previously mentioned, IFC records with incorrect values of temperature. Some of the records were invalid in the sense that no micrometeoroid impact could cause that particular arrangement of bits in the data registers. For example, a record having CHG = 0, ID = 0 had to be caused by noise, for the reasons explained in Section 3. 2. 3, even if the source of the noise was unknown. The final result of this hand reduction of the third-level playback data consisted of only two records that could reasonably be interpreted as possible impacts. These records are given in Table 6.

Table 6. Possible impact records

Time (UT)				Hit 1					Hit 2				
Day	HR	MN	Sec	CHG	ID	TOF	B	M	CHG	ID	TOF	B	M
64	18	23	56	1	2	85	3	3	0	3	0	1	0
66	10	27	21	0	3	0	0	2	0	3	0	3	0

At the time of the day-64 event (5 March 1966), hit 1 contained IFC data for the -X detector, and the B-only event was recorded in hit 2. It should be noted with reference to Table 3a that the IFC data indicate the B capacitor for the -X detector was shorted at the time of this event. This has a bearing on the possibility that the B event recorded was due to internal noise and not to micrometeoroid impact. At the time of the day-66 event (7 March 1966), hit 1 contained a microphone noise event (M-only), and the possible impact event was recorded in hit 2. As explained in Section 3.2.2, the values ID = 3 in Table 5 do not indicate that the events triggered the A_{-Z} sensor; rather, the TOF = 0 indicates that no A sensors were triggered.

7. ANALYSIS OF DATA

In the period from launch until 8 April 1966, the 1350 hr of available data (i. e., all data less those periods adjacent to command times) consisted of about 50 hr of real-time data and 1300 hr of playback data. In the previous section, we have described the reduction of the playback data and the finding of two events that may have resulted from micrometeoroid impacts. It is necessary to consider in more detail the possibility that these events were caused by noise. No electronic noise was noted on this or two other experiments specifically checked (50-01 and 50-02) at the two times in question, but the possibility of some unknown electrical transient occurring within the complex spacecraft still cannot be discounted. This possibility appears greater after an examination of the 50 hr of available real-time data. These data contain about 10 events that were obviously due to noise from some unknown transients. In addition, there are about 40 B events similar to the two found in the playback data. If these were due to real impacts, we would expect ~1000 rather than 2 events in the 1300 hr of playback data; hence, they must have been the result of noise. The fact that such noise exists in the real-time data throws considerable doubt on any assumption that the playback data are free of similar noise.

There was another source of noise within the experiment itself. The IFC data showed that the B capacitor of the -X detector started to fail around 27 February 1966. Such a failure would be expected to generate B events. After 11 June, when experiment data were again obtained, this capacitor was shorted or nearly so, and the B-event rate in the playback data was very much greater, at times ~10 events/hr. For this reason no more data were reduced beyond 23 November 1966, although the experiment remained on through May 1967. The useful period of operation of the experiment was thus limited to 16 October 1965 to 8 April 1966. The two unexplained B events in the playback data of this period represent an upper limit to the flux of particles larger than $\sim 10^{-12}$ g. The effective area (area × solid angle) of each of the B sensors was 0.27 cm^2 ster, so this corresponds to a flux of about 3×10^{-2} particles/m^2 sec 2π ster.

8. DISCUSSION OF THE OGO 2 EXPERIMENT

While this experiment was an improvement on that flown on OGO 1, there were still some obvious shortcomings. One of the more serious was that particles had to impact a B sensor in order to register in the data. Despite the thinness of the A films, the possibility still remained that the particles might be of such low density as to be unable to penetrate these films without suffering almost complete deceleration. This could be answered by enabling A-only events to register in the data, a change that was made on the OGO 4 unit (Nilsson *et al.*, 1969).

The effective area of the B sensors needed to be increased in order to expect to measure any particle velocities. Further, in view of the low event rate, better procedures for the recognition of noise were required. These changes were also implemented on the OGO 4 unit.

9. COMPARISON WITH OTHER DATA

Ferry et al. (1968) attempted to record the penetration of thin films by small particles (~3 μ) at satellite altitudes. They exposed a number of surfaces on Gemini 9 and 12 and concluded that they had found little or no evidence of penetration by extraterrestrial material. Contamination particles and microscopic defects in their films (which are rather analogous to the noise events in the OGO data reported above) prevented an actual determination of particle flux, but the data were sufficient to show that the flux was at least an order of magnitude lower than that predicted by Dubin (1963). The latter influx rate was based primarily on the early rocket and satellite microphone data (Alexander et al., 1963) and rocket-borne particle-collection experiments (Hemenway and Soberman, 1962), none of which we now consider reliable. Blanchard et al. (1967) have shown that contamination problems were not sufficiently well understood at the time of those early collection experiments. The conclusions of Ferry and his colleagues are supported by the Gemini 12 results of Brownlee et al. (1968). Other rocket experimenters, such as McDonnell (1967) and Carr and Gabe (1967), have also determined that the dust-particle densities at these altitudes must be much lower than previously indicated. Hemenway et al. (1968) recently reassessed the flux of interplanetary dust at a lower value. Their "model B" is shown in Figure 5.

The penetration results from the Pegasus (Naumann, 1966) and Explorer 16 (D'Aiutolo, 1964) satellites for particles in the range 10^{-9} to 10^{-6} g appear to fit perfectly the mass distribution calculated by van de Hulst (1947). The Explorer 16 data plotted in Figure 5 are from a recalculation of the mass threshold values by Naumann and are in good agreement with some recent microphone data from a satellite experiment. Konstantinov et al. (1968) used piezoelectric sensors on Kosmos 135 and, besides refuting the early microphone results, concluded that they had

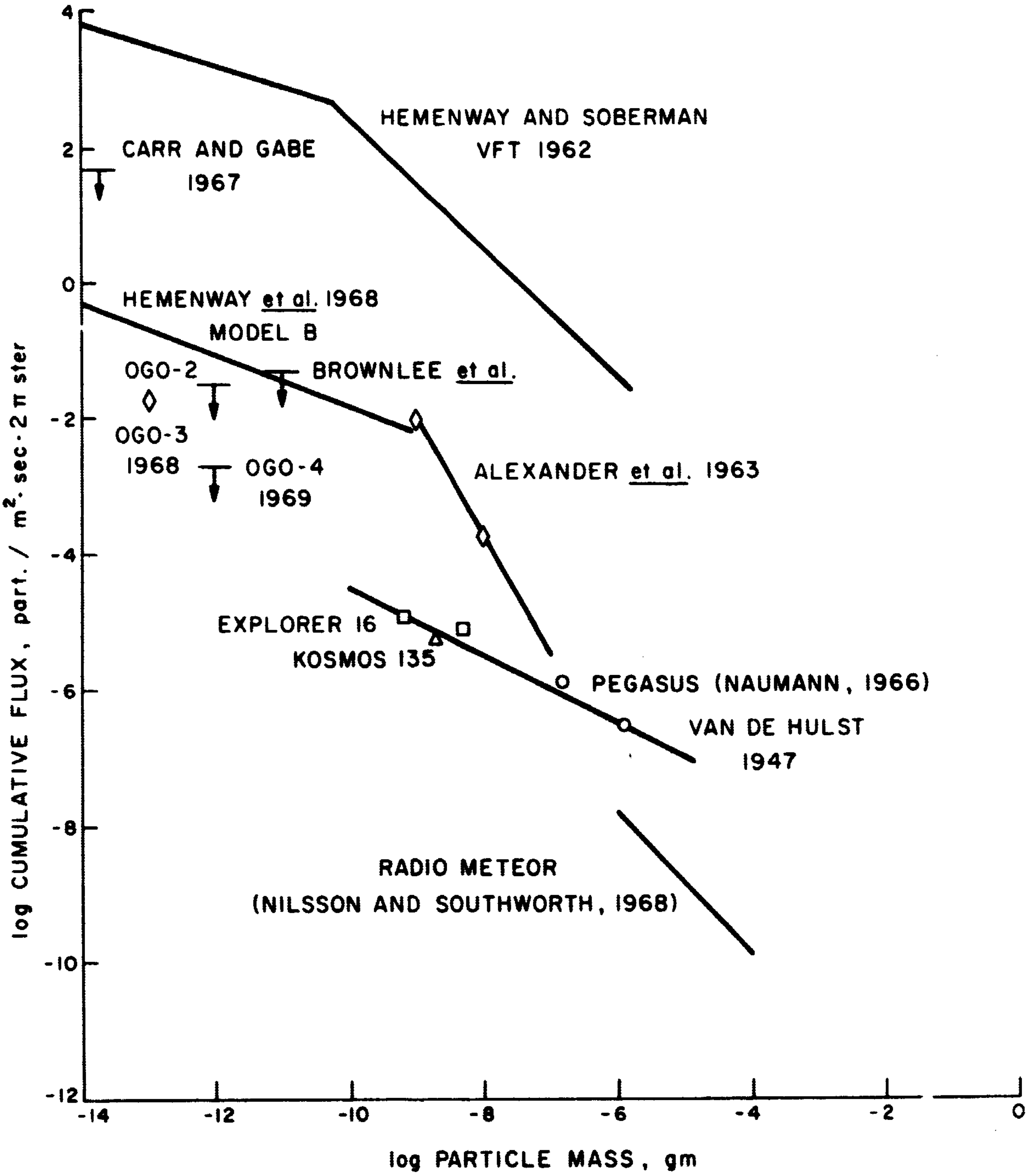

Figure 5. Cumulative flux versus mass plots for various data.

probably recorded four impacts of particles greater than 2×10^{-9} g. This is equivalent to a flux of 7×10^{-6} particles/m^2 sec 2π ster, in good agreement with the Explorer 16 penetration data.

From meteor (Nilsson and Southworth, 1968) and other data, it would appear that a constant mass per magnitude relation is a reasonable description of the flux as a function of mass for particles between 10^{-9} and 1 g. Extrapolation of the Explorer 16 data on this basis leads to a predicted flux of about 1×10^{-2} particles/m^2 sec 2π ster of mass greater than 10^{-12} g. This is quite consistent with our interpretation of the OGO 2 data.

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APPENDIX

A sample of playback data from tape DD7885. The primary data shown are part of file #8. The results of the three stages of data reduction are also shown.

```
OMETEORITE EXPERIMENT        ALEXANDER        DATA RATE   PLAYBK         DAY    66

TIME  TIME      TIME                  HIT NO 1                        HIT NO 2              EP 3     BUS
FLAG  MSEC    HR-MN-SC     CHG   ID     V     B     M     CHG   ID     V     B     M     TEMP     VOLT

      35355702   9 49 16     0     0     0     0     0      0     0     0     0     0     92.2    25.37

      35392566   9 49 53     0     0     0     0     0      0     0     0     0     0     92.2    25.51

      35429430   9 50 29     0     0     0     0     0      0     0     0     0     0     92.2    25.37

      35466294   9 51  6     0     0     0     0     0      0     0     0     0     0     92.2    25.51

      35503158   9 51 43     0     1    84     3     2      0     0     0     0     0     92.2    25.37

      35540022   9 52 20     0     1    84     3     2      0     0     0     0     0     92.2    25.51

      35576886   9 52 57     0     1    84     3     2      0     0     0     0     0     92.2    25.37

      35613750   9 53 34     0     1    84     3     2      0     0     0     0     0     92.2    25.37

      35650613   9 54 11     0     1    84     3     2      0     0     0     0     0     92.2    25.37

      35687477   9 54 47     0     1    84     3     2      0     0     0     0     0     92.2    25.51

      35724341   9 55 24     0     1    84     3     2      0     0     0     0     0     92.2    25.51

      35761205   9 56  1     0     1    84     3     2      0     0     0     0     0     92.2    25.51

      35798069   9 56 38     0     1    84     3     2      0     0     0     0     0     92.2    25.51

      35834933   9 57 15     0     1    84     3     2      5     0    95     3     3     92.2    25.37

      35871797   9 57 52     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      35908660   9 58 29     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      35945524   9 59  6     0     1    84     3     2      5     0    95     3     3     92.2    25.37

      35982388   9 59 42     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      36019252  10  0 19     0     1    84     3     2      5     0    95     3     3     92.2    25.37
      36056116  10  0 56     0     1    84     3     2      5     0    95     3     3     92.2    25.37

      36092980  10  1 33     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      36129844  10  2 10     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      36166707  10  2 47     0     1    84     3     2      5     0    95     3     3     92.2    25.37

      36203571  10  3 24     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      36240435  10  4  0     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      36277299  10  4 37     0     1    84     3     2      5     0    95     3     3     92.2    25.51

      36314163  10  5 14     0     1    84     3     2      5     0    95     3     3     92.2    25.37
```

:OMETEORITE EXPERIMENT ALEXANDER DATA RATE PLAYBK DAY 66

TIME FLAG	TIME MSEC	TIME HR-MN-SC	CHG	HIT NO 1 ID	V	B	M	CHG	HIT NO 2 ID	V	B	M	EP 3 TEMP	BUS VOLT
	36351027	10 5 51	0	1	84	3	2	5	0	95	3	3	92.2	25.37
	36387891	10 6 28	1	2	89	3	3	0	0	0	0	0	92.2	25.51
	36424754	10 7 5	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36461618	10 7 42	1	2	89	3	3	0	0	0	0	0	92.2	25.51
	36498482	10 8 18	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36535346	10 8 55	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36572210	10 9 32	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36609074	10 10 9	1	2	89	3	3	0	0	0	0	0	99.9	99.99
	36645938	10 10 46	1	2	89	3	3	0	0	0	0	0	92.2	25.51
	36682801	10 11 23	1	2	89	3	3	0	0	0	0	0	92.2	25.51
	36719665	10 12 0	1	2	89	3	3	0	0	0	0	0	8.8	25.51
	36756529	10 12 37	1	2	89	3	3	0	0	0	0	0	92.2	25.51
	36793393	10 13 13	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36830257	10 13 50	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36867121	10 14 27	1	2	89	3	3	0	0	0	0	0	99.9	25.51
	36903985	10 15 4	1	2	89	3	3	0	0	0	0	0	92.2	25.37
	36940848	10 15 41	999	999	999	999	999	999	999	999	999	999	92.2	25.51
	36977712	10 16 18	1	2	89	3	3	0	3	101	3	3	92.2	14.03
	37014576	10 16 55	1	2	89	3	3	0	3	101	3	3	92.2	25.37
	37051440	10 17 31	1	2	89	3	3	0	3	101	3	3	92.2	25.37
	37088304	10 18 8	1	2	89	3	3	0	3	101	3	3	92.2	25.51
	37125168	10 18 45	1	2	89	3	3	0	3	101	3	3	92.2	25.51
	37162032	10 19 22	1	2	89	3	3	0	3	101	3	3	92.2	25.51
	37198895	10 19 59	1	2	89	3	3	0	3	101	3	3	92.2	25.51
	37235759	10 20 36	1	2	89	3	3	0	3	101	3	3	92.2	25.51
	37272623	10 21 13	1	2	89	3	3	0	3	101	3	3	92.2	25.37
	37309467	10 21 49	1	2	89	3	3	0	3	101	3	3	92.2	25.51

```
(OMETEORITE EXPERIMENT      ALEXANDER      DATA RATE   PLAYBK        DAY   66

 TIME  TIME      TIME                HIT NO 1                  HIT NO 2          EP 3     BUS
 FLAG  MSEC     HR-MN-SC     CHG  ID     V     B    M    CHG  ID     V    B    M   TEMP     VOLT

      37346351 10 22 26       1     2    89    3    3      0    3   101    3    3    92.2    25.37

      37383215 10 23  3       1     2    89    3    3      0    3   101    3    3    92.2    25.37

      37420079 10 23 40     999   999   999  999  999    999  999   999  999  999    92.2    25.51

      37456942 10 24 17       0     3     0    0    2      0    0     0    0    0    92.2    25.37

      37493806 10 24 54       0     3     0    0    2      0    0     0    0    0    92.2    25.37

      37530670 10 25 31       0     3     0    0    2      0    0     0    0    0    92.2    25.37

      37567534 10 26  8       0     3     0    0    2      0    0     0    0    0    92.2    25.51

      37604398 10 26 44       0     3     0    0    2      0    0     0    0    0    92.2    25.51

      37641262 10 27 21       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      37678126 10 27 58       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      37714989 10 28 35       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      37751853 10 29 12       0     3     0    0    2      0    3     0    3    0    92.2    25.37

      37788717 10 29 49       0     3     0    0    2      0    3     0    3    0    92.2    25.37

      37825581 10 30 26       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      37862445 10 31  2       0     3     0    0    2      0    3     0    3    0    92.2    25.37

      37899309 10 31 39       0     3     0    0    2      0    3     0    3    0    92.2    25.37

      37936173 10 32 16       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      37973036 10 32 53       0     3     0    0    2      0    3     0    3    0    92.2    25.37

      38009900 10 33 30       0     3     0    0    2      0    3     0    3    0    92.2    25.37

      38046764 10 34  7       0     3     0    0    2      0    3     0    3    0    92.2    25.51
      38083628 10 34 44       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      38120492 10 35 20       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      38157356 10 35 57       0     3     0    0    2      0    3     0    3    0    92.2    25.51

      38194220 10 36 34       0     1    84    3    2      0    0     0    0    0    92.2    25.51

      38231083 10 37 11       0     1    84    3    2      0    0     0    0    0    92.2    25.37

      38267947 10 37 48       0     1    84    3    2      0    0     0    0    0    92.2    25.37

      38304811 10 38 25       0     1    84    3    2      0    0     0    0    0    92.2    25.51
```

```
OMETEORITE EXPERIMENT        ALEXANDER        DATA RATE   PLAYBK         DAY   66

TIME  TIME      TIME                HIT NO 1                        HIT NO 2            EP 3     BUS
FLAG  MSEC    HR-MN-SC      CHG  ID    V     B    M    CHG  ID    V     B    M    TEMP     VOLT

         38341675 10 39  2    0    1    84    3    2     0    0     0    0    0    92.2    25.37
         38378539 10 39 39    0    1    84    3    2     0    0     0    0    0    92.2    25.51
         38415403 10 40 15    0    1    84    3    2     0    0     0    0    0    92.2    25.37
         38452267 10 40 52    0    1    84    3    2     0    0     0    0    0    92.2    25.37
         38489130 10 41 29    0    1    84    3    2     0    0     0    0    0    92.2    25.37
         38525994 10 42  6    0    1    84    3    2     0    0     0    0    0    92.2    25.51
         38562858 10 42 43    0    1    84    3    2     0    0     0    0    0    92.2    25.51
         38599722 10 43 20    0    1    84    3    2     0    0     0    0    0    92.2    25.37
         38636586 10 43 57    0    1    84    3    2     0    0     0    0    0    92.2    25.51
         38673450 10 44 33    0    1    84    3    2     0    0     0    0    0    92.2    25.51
         38710314 10 45 10    0    1    84    3    2     0    0     0    0    0    92.2    25.37
         38747177 10 45 47    0    1    84    3    2     5    0    95    3    3    92.2    25.37
         38784041 10 46 24    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         38820905 10 47  1    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         38857769 10 47 38    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         38894633 10 48 15    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         38931497 10 48 51    0    1    84    3    2     5    0    95    3    3    92.2    25.37
         38968361 10 49 28    0    1    84    3    2     5    0    95    3    3    92.2    25.37
         39005224 10 50  5    0    1    84    3    2     5    0    95    3    3    92.2    25.37
         39042088 10 50 42    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         39078952 10 51 19    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         39115816 10 51 56    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         39152680 10 52 33    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         39189544 10 53 10    0    1    84    3    2     5    0    95    3    3    92.2    25.37
         39226407 10 53 46    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         39263271 10 54 23    0    1    84    3    2     5    0    95    3    3    92.2    25.51
         39300135 10 55  0    1    2    89    3    3     0    0     0    0    0    92.2    25.37
```

Level-1 data from file 8 of tape DD7885. These data contain the day-66 event.

```
FILE ID 18 65811    20    2    674     1  1637    1  2273   66   66  35355  3

     YR  DY                HIT 1                HIT 2          I     T       V

0    66  66    9 51 43     0 1  84 3 2     0 0    0 0 0   1   92.2   25.4  3    8
0    66  66    9 57 15     0 1  84 3 2     5 0   95 3 3   2   92.2   25.4  3    8
0    66  66   10  6 28     1 2  89 3 3     0 0    0 0 0   1   92.2   25.5  3    8
0    66  66   10 16 18     1 2  89 3 3     0 3  101 3 3   2   92.2   14.0  3    8
0    66  66   10 24 17     0 3   0 0 2     0 0    0 0 0   1   92.2   25.4  3    8
0    66  66   10 27 21     0 3   0 0 2     0 3    0 3 0   2   92.2   25.5  3    8
0    66  66   10 36 34     0 1  84 3 2     0 0    0 0 0   1   92.2   25.5  3    8
0    66  66   10 45 47     0 1  84 3 2     5 0   95 3 3   2   92.2   25.4  3    8
0    66  66   10 55 -0     1 2  89 3 3     0 0    0 0 0   1   92.2   25.4  3    8
0    66  66   11  4 13     1 2  89 3 3     0 3  100 3 3   2   92.2   25.5  3    8
0    66  66   11 13 26     0 1  84 3 2     0 0    0 0 0   1   92.2   25.4  3    8
0    66  66   11 22 39     0 1  84 3 2     5 0   95 3 3   2   92.2   25.5  3    8

154 FRAMES OF DATA AT  4 KB  PB  IS  1  34  37  HH  MM  SS
```

The format is essentially that of the primary (level 0) data; I is an index showing which "hit" brought about a "change" in the data, and T and V are temperature (°F) and power-input voltage, respectively.

The only frame to reach level-2 reduction was that of $10^h 27^m 21^s$. There were no commands at this time, so this record reached level 3 and was finally considered as a possible micrometeoroid event.