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PEGASUS SATELLITE MEASUREMENTS OF METEOROID PENETRATION
(Feb. 16 - July 20, 1965)

by Robert J. Naumann

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20060516207

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION - WASHINGTON, D. C. - DECEMBER 1965

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SUMMARY

The Pegasus satellites deploy 200 m^2 of three thicknesses of Al instrumented to detect punctures resulting from meteoroid impingement. The determination of three points on a frequency of penetration vs. thickness of aluminum curve for thicknesses approaching useful spacecraft skin is directly applicable to spacecraft design problems.

The design and operation of the meteoroid experiment is discussed briefly. The results are seen to essentially agree with ground-based predictions for the thicker materials, and with other satellite measurements for the thinnest material. Also, some temporal variations in frequency are observed and possible correlations of these variations with known showers are investigated.

INTRODUCTION

The primary mission of the Pegasus spacecraft is the measurement of the frequency of meteoroid penetrations in various materials ranging from 40 micron 1100-0 Al to 400 micron 2024 T-3 Al . The penetration detectors consist of parallel plate capacitors which are formed by backing target sheets with a 12-micron mylar trilaminate which, in turn, is backed by a vapor-deposited Cu layer. The capacitors are made in 50 x 100 cm sheets which are bonded to both sides of a 2.54-cm foam core, as shown in Figure 1. The erectable wing-like structure of the Pegasus spacecraft supports 208 such detector panels. This provides 194.5 m^2 of instrumented area of which 171 m^2 is allocated to 400 micron 2024 T-3, 16 m^2 to 200 micron 2024 T-3, and 7.5 m^2 to 40 micron 1100-0 aluminum.‡ Figure 2 shows the Pegasus spacecraft with the sensors deployed.

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† Presented at the International Symposium on Meteoroid Orbits and Dust, Smithsonian Astrophysical Observatory, Cambridge, Mass. 9-13 Aug. 1965.

‡ Actual thicknesses are 406 $\pm$ 50μ, 203 $\pm$ 25 μ, and 38 $\pm$ 3 μ , respectively.

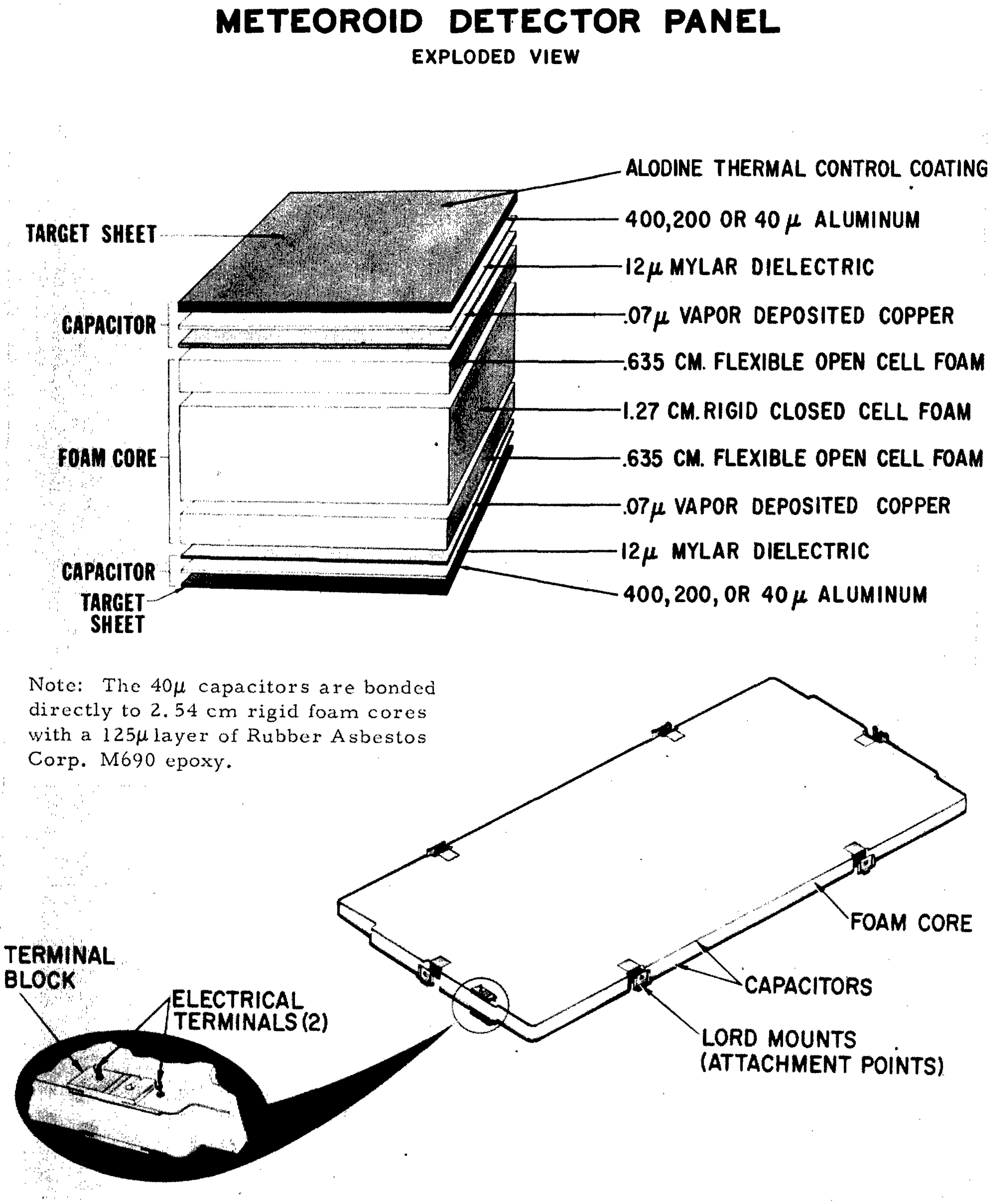

Figure 1 - Capacitor-type meteoroid penetration detector flown on Pegasus.

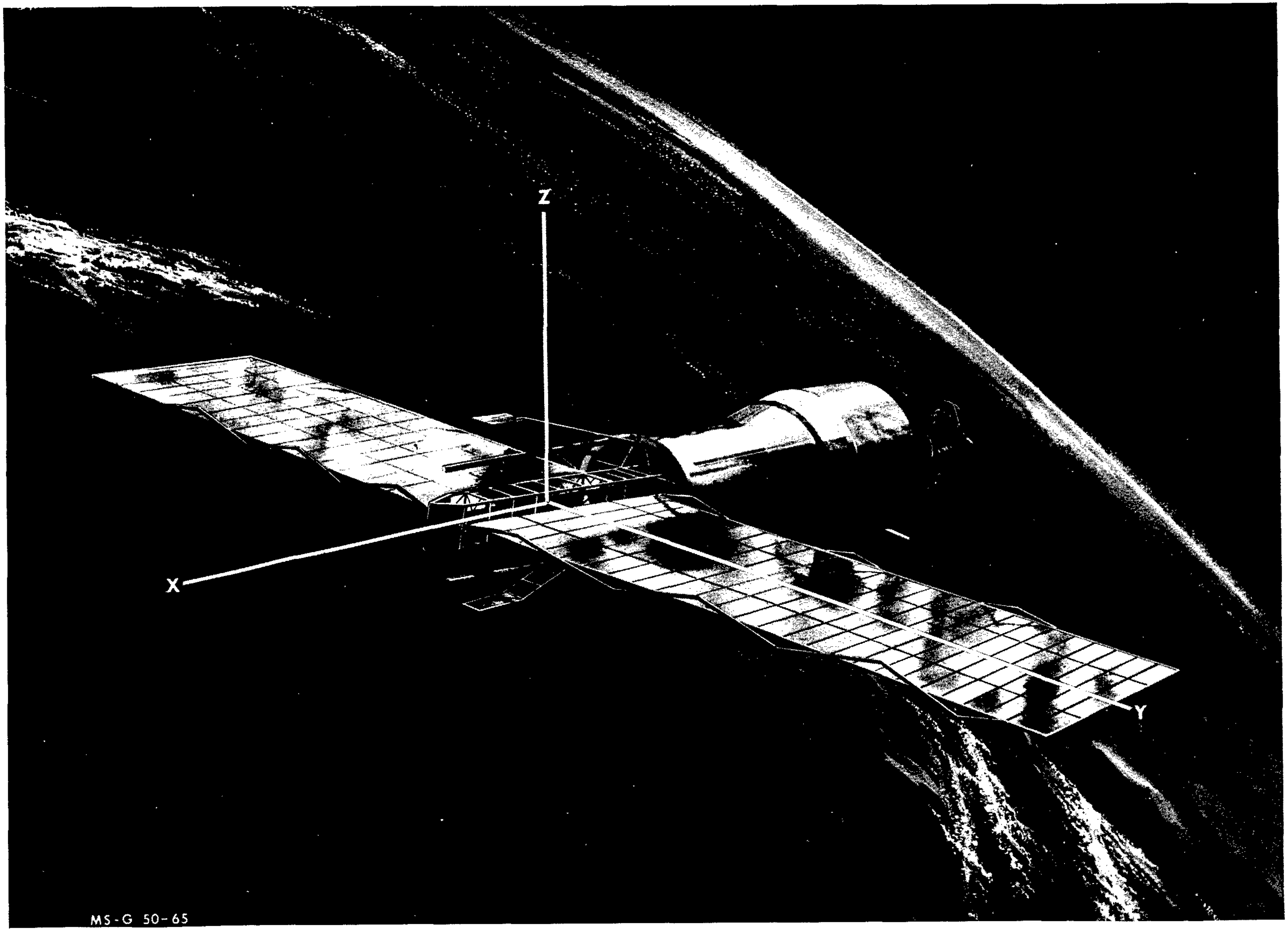

Figure 2 - Pegasus satellite configuration with body-fixed coordinate axes indicated.

The 400μ area is subdivided into 48 identifiable logic groups, each containing 5, 6, or 8 individual detector sheets; the 200μ area has 6 logic groups, each containing 3, 6, or 8 individual detectors; the 40μ area has 8 logic groups, each with 2 detectors. Figure 3 shows the location of the various panel logic groups.

A penetration through the detector target sheet and mylar dielectric momentarily shorts the capacitor detector which is normally maintained at a 40-volt potential by a network of current recharge amplifiers (CRA). The energy stored in the capacitor is dumped into the shorted area which burns away the Cu vapor deposit and clears the detector in approximately 1μ sec. The initial voltage drop across the capacitor starts an integrator in the Hit Detector which integrates the voltage across the detector panel for 250μ sec. If the integrated voltage-time product is greater than a certain predetermined value, a hit word is written in the memory and a cumulative counter is incremented.

The recharge of the panel is accomplished by 3 CRA's which are selected by a diode-resistor logic matrix in a unique pattern for each logic group. This pattern also is written into the hit-word and provides panel identification and location. The recharge time is also measured and written into the hit word.

In laboratory testing of the detectors, it was found that the discharge voltage produced by a high velocity particle ranges from fractions of volts to full discharge. No direct correlation between discharge level and any projectile property could be found, although there was some indication that the signal levels increased somewhat at higher velocities. The voltage-time product required to record a hit word was selected so that a typical discharge of 4 volts would be registered on Pegasus II and III, 3 volts on the 40μ panels on Pegasus I, and 5 volts on the remainder of the Pegasus I panels. Laboratory tests indicate that these settings would accept 80 to 90% of the signals resulting from meteoroid penetrations.

ANALYSIS OF PEGASUS FLIGHT DATA

As is often the case with a first flight test of a system such as the capacitor detector, there were several unforeseen problems not evidenced in the ground testing. Fortunately, these problems showed up soon enough in the operation of Pegasus I to be dealt with satisfactorily on Pegasus II. The problems encountered, the effect of the problems on data analysis, and the improvements on Pegasus II follow.

PEGASUS DETECTOR PANELS

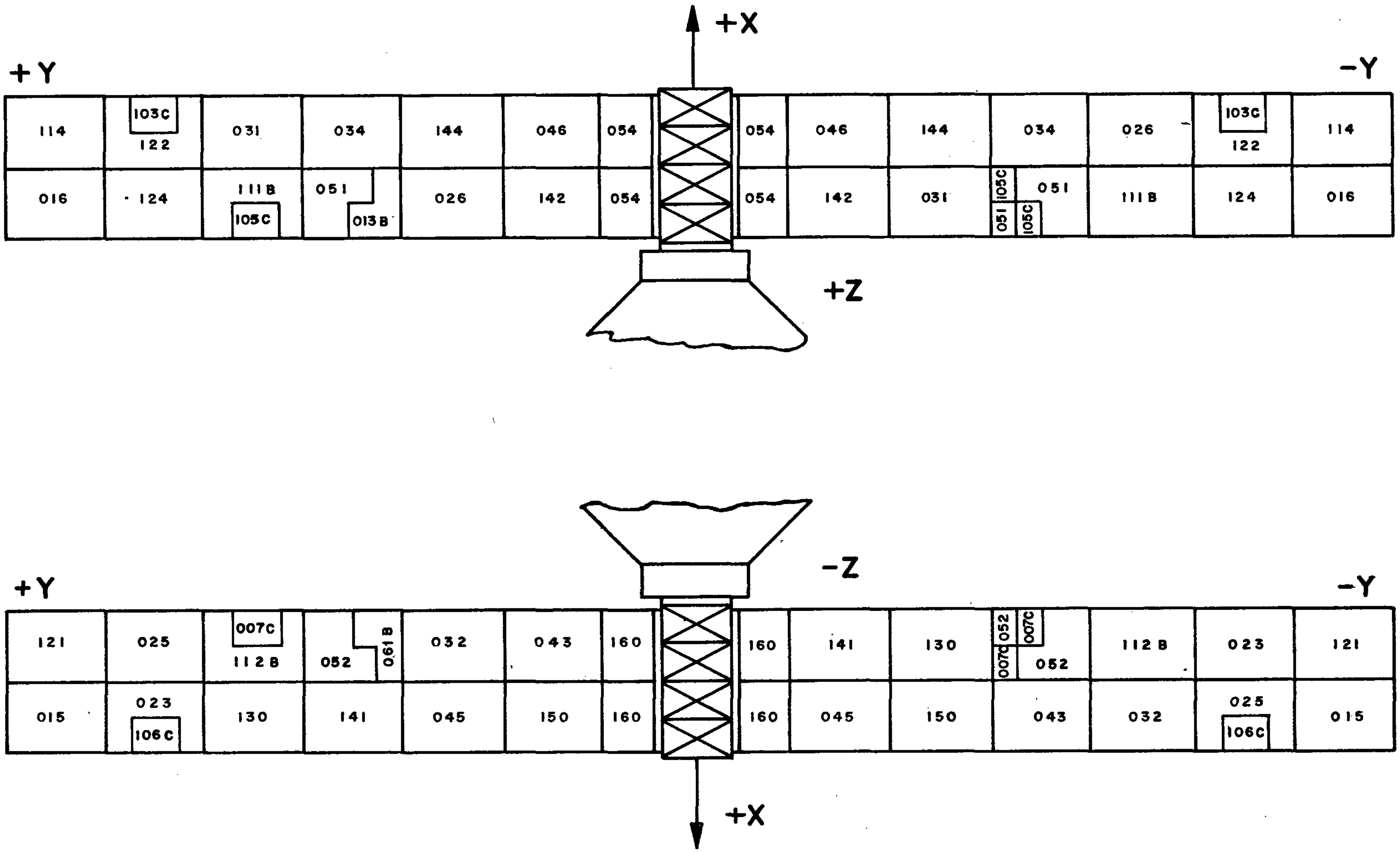

Figure 3 - Wing panel schematic showing location of various logic groups. The letter B after the logic group identification denotes 200μ panels, C denotes 40μ panels, and no letter denotes 400μ panels.

1. Isolation between capacitors in a logic group and sensitivity of the CRA's were not sufficient to generate panel identification and recharge time for hits occurring in logic groups containing more than 2 capacitors. Since the three different thicknesses on each wing are serviced by separate Hit Detectors, which are identified in the hit word, one could identify the thickness and the wing, but not the logic group of 400 or 200μ panels in which the discharge occurred. The detector isolation and CRA sensitivity were increased for Pegasus II, and all hits give complete information.

2. It was found that some 200 and 400μ panels become intermittent, presumably after damage from a meteoroid impact. It has been postulated that the Cu-coated mylar in the vicinity of a ragged hole in the target sheet could, through thermal expansion or contraction, result in a mechanical short. Such a short would be quickly burned away by the energy stored in the capacitor. However, the process can apparently repeat itself a large number of times, generally one or more times during each thermal cycle. Since each short writes a hit word, this situation was fatal to the 400μ experiment on Pegasus I where no panel identification was available. Time did not permit the investigation necessary to completely understand the behavior of such panels or the determination of whether this problem could be elmininated by a change in sensor construction. However, with the ability to identify the logic group for every hit indication, plus the fact that the average hit rate is about 1 per 100 days on a particular 400μ logic group, it becomes obvious that a logic group that registers several hits in a short time is intermittent. The procedure in such a case has been to accept the first hit as valid and ignore the remainder of the hit indications, as well as the area of the particular logic group from the time of the first hit. The offending logic group is then disconnected by ground command.

3. Detector shorting was found to be a more frequent occurrence on Pegasus I than had been indicated from laboratory tests of the detector panels, particularly at higher temperatures. When a short occurred on one of the capacitors on Pegasus I, the entire logic group was disabled. Obviously, several shorts could cause a severe degradation of instrumented area. It was not clear whether such shorting was caused by damage resulting from meteoroid impact or from inclusions or conductive spots in the mylar. A "burning-in" procedure was used on the panels to be flown on Pegasus II which may have eliminated potential trouble spots in the dielectric. The shorting rate observed on Pegasus II is substantially lower than on Pegasus I, but the peak temperatures have not been as high. Also, the ratio of shorts to observed penetrations

is still somewhat higher than laboratory results would indicate. Pegasus II and III also have a defusing capability for each individual capacitor which allows removal of a shorted panel from a logic group. Thus far, this feature has been used to good advantage in that 10 logic groups have been saved that otherwise would have been lost.

It had been feared prior to Pegasus I launch that trapped electron radiation in the South Atlantic magnetic anomaly might interfere with the experiment by inducing false counts in the meteoroid detector. Such events could occur in two different ways. Charge accumulation in the capacitor dielectric or in the foam behind the capacitor detector could conceivably build up and discharge spontaneously into the rear capacitor plate. This sudden charge deposition would change the potential of the capacitor and would cause the CRA's to deliver current to restore the original potential. This would be interpreted by the detection circuitry as a meteoroid hit. Such an effect was demonstrated in the laboratory, but at much higher dose rates than would be encountered in the Pegasus orbit. It was apparent that such an effect should depend on the total dose and was analogous to the "leaky-bucket" problem. The leakage rate, however, is one of the unknowns. Irradiation of the sensors at a realistic rate was prohibitive time-wise, so the question was largely unsettled. However, laboratory tests did indicate that such discharges required a substantial dose and were generally much less than the 4-volt threshold. One logic group in each detector thickness was debiased and coupled to the CRA through a $10\mu f$ capacitor. Such a panel could not detect a meteoroid-induced short, but could detect a sudden charge deposition; thus would serve to indicate if an appreciable number of such events would be detected.

The second possible mode of interference arises from radiation discharges in the mylar insulation of the printed cables that run from the spacecraft center section to the various panels. Such discharges may result in high-amplitude, high-frequency pulses. Such pulses could conceivably provide sufficient area-time product to pass the discriminator, but since there would be no actual discharge of the capacitor detector, the CRA's would only deliver current to recharge the cable which is insufficient to cause a panel identification or pulse verify to be written. One such event has been observed in Pegasus II.

On Pegasus II, it was found that the transient caused by commanding the fuse relay "ON" fires all the Hit Detectors and writes a spurious hit word with an illegitimate panel identification. The exact reason for this is not yet known, but such an event is easily recognizable.

Hits can be commanded into a specific logic group by commanding a panel disconnect, which bleeds the charge on the detector group to ground, and then reconnecting. Such an event is identifiable by the long recharge time since all capacitors in a logic group must be recharged from ground potential. Such commands are useful for checking the number of capacitors active in a logic group in which fuses may have been blown.

The cumulative counters respond to every Hit Detector output and are used only to ascertain that all the hit words in the memory have been found.† These words are sorted out and classified in the following manner:

1. Command Events - knowledge that a disconnect - connect command was sent to specified panel at specified time; recharge time corresponds to all active panels being recharged from ground potential.

2. Spurious Events - knowledge that Fuse Relay was commanded "ON" at specified time; generally all Hit Detectors and CRA's fire.

3. Intermittent Event - same panel produces more than one hit word in a time which is very short compared to the average interval between two valid hits in a single logic group.

4. Radiation Events - either a hit word on a debiased panel, or a hit word containing no panel identification or pulse verify; probability of such an occurrence is greater in periods of high radiation dose rate.

5. Valid Hit Resulting in Shorted Panel - hit word with the proper form which shows a full-time count in the recharge time register; also continuous current indications in the 3 CRA's that supply that logic group.

6. Normal Valid Hit - hit word that fulfills all tests for a normal hit word, i. e., proper panel identification and pulse verify count corresponding to a single detector panel recharging from a 4- to 40-volt discharge.

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†In retrospect it was indeed fortunate that sufficient diagnostic data was telemetered with each event to allow a ground-based analysis of each counter increment. One would certainly have a very distorted and false picture of the meteoroid environment if cumulative counts were the only data available.

In a very few cases the events counted by the cumulative counters exceeded the number of words. This has always happened during a time in which a panel was intermittent and rapidly shorting. Since the counter is incremented every time the integrator in the hit detector receives a certain voltage-time product in 250μ sec, and since 1.25 seconds are required to write a hit word into memory, it is quite understandable that a rapidly shorting panel can write more events in the cumulative counter than hit words in the memory. In these cases, such counts were disregarded as intermittencies.

Other rare cases have occurred in which too many or too few CRA's identify the discharged panel. This is understandable in terms of slight changes in values of various electronic components which may alter the CRA sensitivities. In such cases an educated guess can usually be made as to which panel is being recharged.

It is felt that radiation does not significantly affect the data from the meteoroid experiment, since no increase in counting rate with time has been observed on either Pegasus I or II which could be attributed to accumulated radiation dose, no disproportionate number of hits has occurred in the high radiation region in the South Atlantic anomaly, no debiased panels have indicated hits on Pegasus II,† and only one event typical of a cable pulse induced by radiation has been observed on Pegasus II. The largest uncertainity seems to be whether or not it is correct to attribute events that result in panel shorting or intermittency to meteoroid penetration, partial penetration, or damage, or whether such events occur spontaneously through prolonged vacuum soak, thermal cycling, and possibly other aspects of exposure to space environment. Laboratory tests to decide such questions are planned, but in any case the number of such events is less than 30% of the total observations in the 200 and 400μ detectors. No shorting or intermittent problems have been encountered in any of the 40μ panels on either Pegasus I or II, except for one panel on Pegasus I which may have been inadvertently disconnected and impacted with no applied voltage.

Pegasus I Results

Pegasus I received 4 hit indications on the 400μ panels in the first 11 days. However, several panels became intermittent at that time, and the lack of panel identity precluded separating valid hits from the intermittent

† The lack of panel identification on Pegasus I precluded observation of hit words orginating from debiased panels.

events after that time. Based on 4 events in 1925 m^2 day, the penetration frequency is .0021/m^2 days.

For some reason, a very high fraction of the penetrations on the 200μ panels resulted in shorts (assuming that shorts result from a meteoroid impact), and since there are only 6 logic groups, the 200μ area very quickly became lost. There were 9 hit indications in 248 m^2 days exposure which resulted in a penetration frequency of .036/m^2 days. Again it should be pointed out that the 200 and 400μ hit words did not contain panel identity or recharge time unless a short resulted. Therefore, some of the tests for validity could not be made.

The 40μ panels gave panel identification about 70% of the time and are still functioning extremely well. A total of 104 penetrations has been recorded in 858 m^2 day for a flux of .121/m^2 day. A time history of the cumulative events is shown in Figure 4.

Pegasus II Results

The number of penetrations, area-time exposure, and puncture frequency observed by Pegasus I and II (as of July 20, 1965) are summarized in Table I. Note that the few punctures observed in the 200 and 400μ Pegasus I detectors are in reasonably good agreement with Pegasus II results. The total 40μ events give a somewhat higher puncture rate for Pegasus II than for Pegasus I.

One possible explanation may be seen by comparing time history of the 40μ cumulative counts on Pegasus II (Figure 5) with Figure 4. There appears to be a significant increase in counts during the periods June 6 to June 12. It is interesting to note that this period corresponds with times of known meteor shower activity, i.e., the Arietids and the ζ - Perseids. Subtracting the shower events from the Pegasus II counts gives a sporadic background that is very close to the Pegasus I result. Of course a reasonable explanation must be found for the non-observation of the showers by Pegasus I.

One plausible explanation may be found in the difference of the rotational behavior of the two satellites. Angular momentum in the form of rotation about the x-axis was imparted to both spacecraft when the residual propellants were vented. Since the x-axis is a principal axis of least moment of inertia, such a rotational state is quasi-stable for a semi-rigid body. Pegasus I underwent a transition to the minimum rotational energy state (i.e., rotation about the z-axis, which is the axis of maximum moment of inertia) in 15 days. This rotation stabilized the

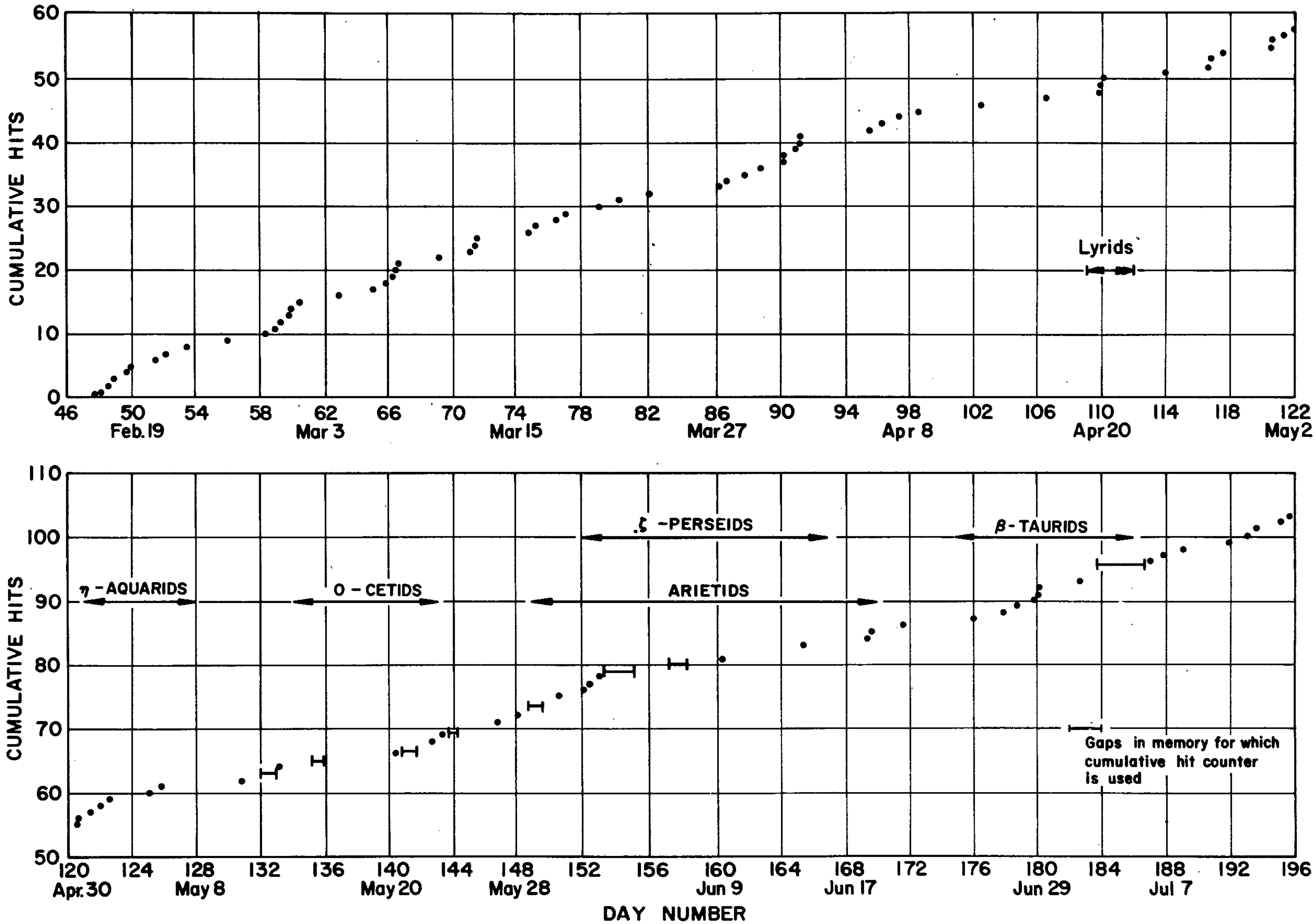

Figure 4 - Time history of accumulated penetrations for 40μ panels on Pegasus I.

TABLE I

	Number of Penetrations	Area-Time (m^2 day)	Frequency of Penetrations (No. /m^2sec)
Pegasus I			
400μ	4	1925	2.4×10^{-8}
200μ	9	248	4.2×10^{-7}
40μ	104	858	1.4×10^{-6}
Pegasus II			
400μ	30	8457	4.0×10^{-8}
200μ	14	734	2.2×10^{-7}
40μ (total)	61	357	2.0×10^{-6}
40μ (shower peak)	12	26	5.3×10^{-6}
40μ (sporadic)	40	299	1.5×10^{-6}

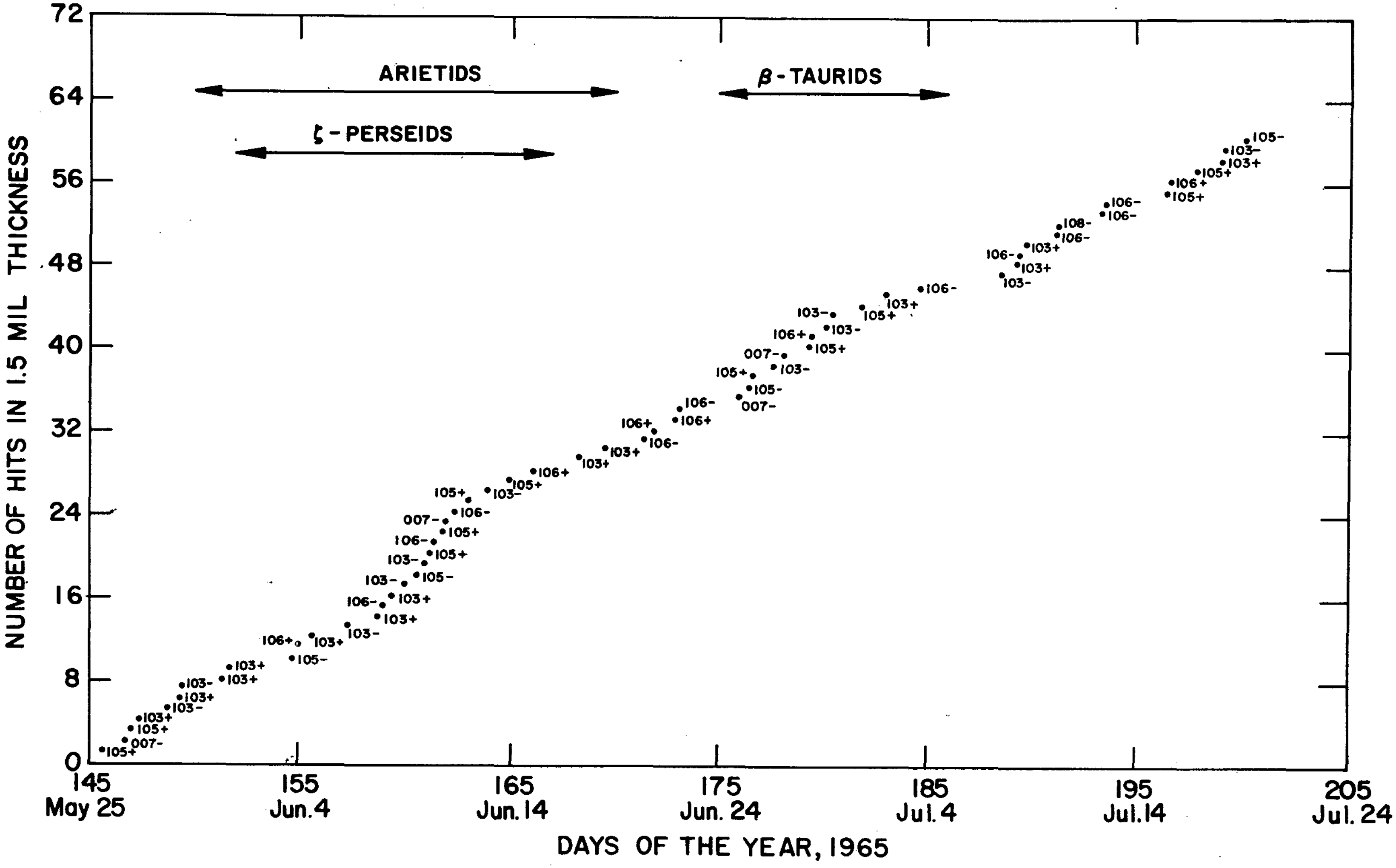

Figure 5 - Time history of accumulated penetrations for 40μ panels on Pegasus II.

sensor plane in space. Gravity gradient torque causes a precession of the rotational axis which provides a relatively slow scanning of the celestial sphere.

The result of this motion may be seen in terms of the angle the sun makes with the sensor plane shown in Figure 6. Preliminary analysis indicates that the normal to the sensor plane made angles of 50° and 65° with the radiants of the Arietids and ζ - Perseids, respectively, during the times of peak activity. Since the area presented to the shower direction is reduced by the cosine of the angle of incidence, and since the penetrating ability of an impacting meteoroid falls roughly as the 2/3 power of the cosine of the angle of incidence, it is understandable that these showers may be missed by Pegasus I. Of course the deviation that was attributed to shower events in Pegasus II data is small and may very well be nothing more than a coincidental statistical fluctuation.

Pegasus II, for reasons that are not yet completely clear, retained its rotation about the x-axis. This rotational configuration, together with the lower angular momentum imparted to it, results in a more rapid precession of the rotational axis as is evident in Figure 7 which shows the angle between the sun and the rotational axis. The motion is such that the entire celestial sphere is swept with the sensor axis in a period of a single day. Therefore the observation of showers having a population of detectable particles sufficiently above the sporadic background is virtually assured.

The time histories of the 200 and 400μ cumulative counts are shown in Figures 8 and 9. The sampling rates for these thicknesses are too low to see any shower effects.

COMPARISON WITH OTHER EXPERIMENTS

It is difficult to compare the Pegasus results with other experiments since calibrations of the detectors in terms of threshold masses have not been completed. Some preliminary comments may be appropriate, however. The capacitors are bonded to a foam backing which provides some acoustic impedance matching and reduces the severe rear surface reflection of shock waves that produces spallation damage. Therefore, these detectors probably behave more as semi-infinite targets than thin sheets. In fact, some qualification tests performed at NAA indicate that bonded sensors are much more difficult to perforate than the unbacked capacitors.

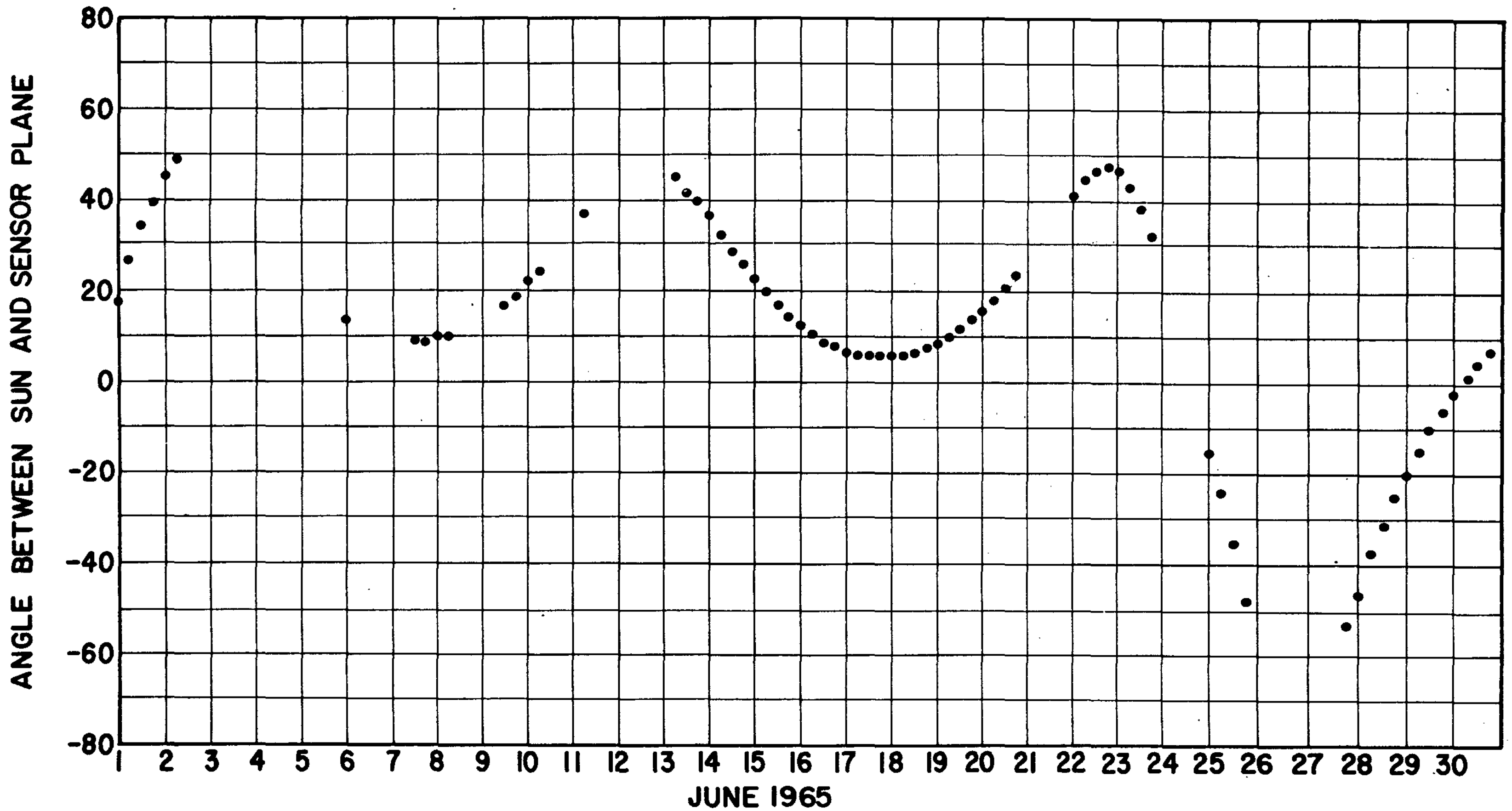

Figure 6 - Angle sun makes with Pegasus I sensor plane as a function of time.

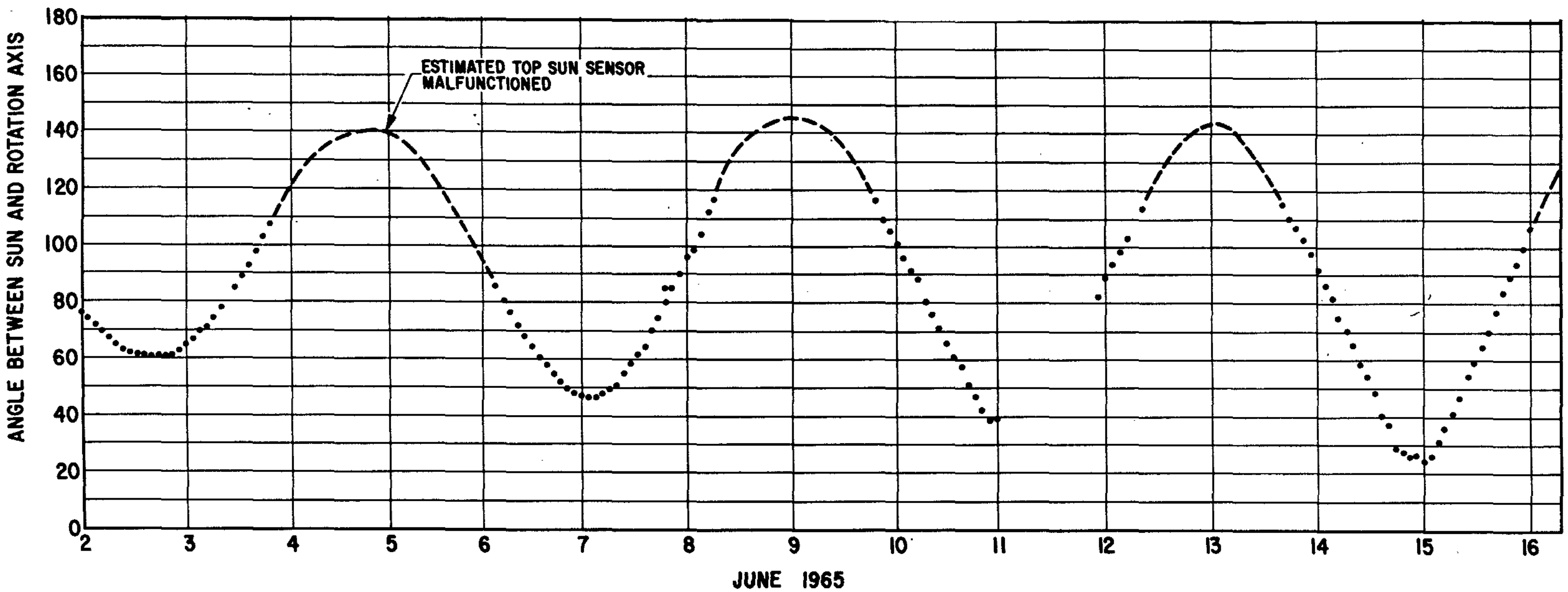

Figure 7 - Angle sun makes with Pegasus II rotational axis as a function of time.

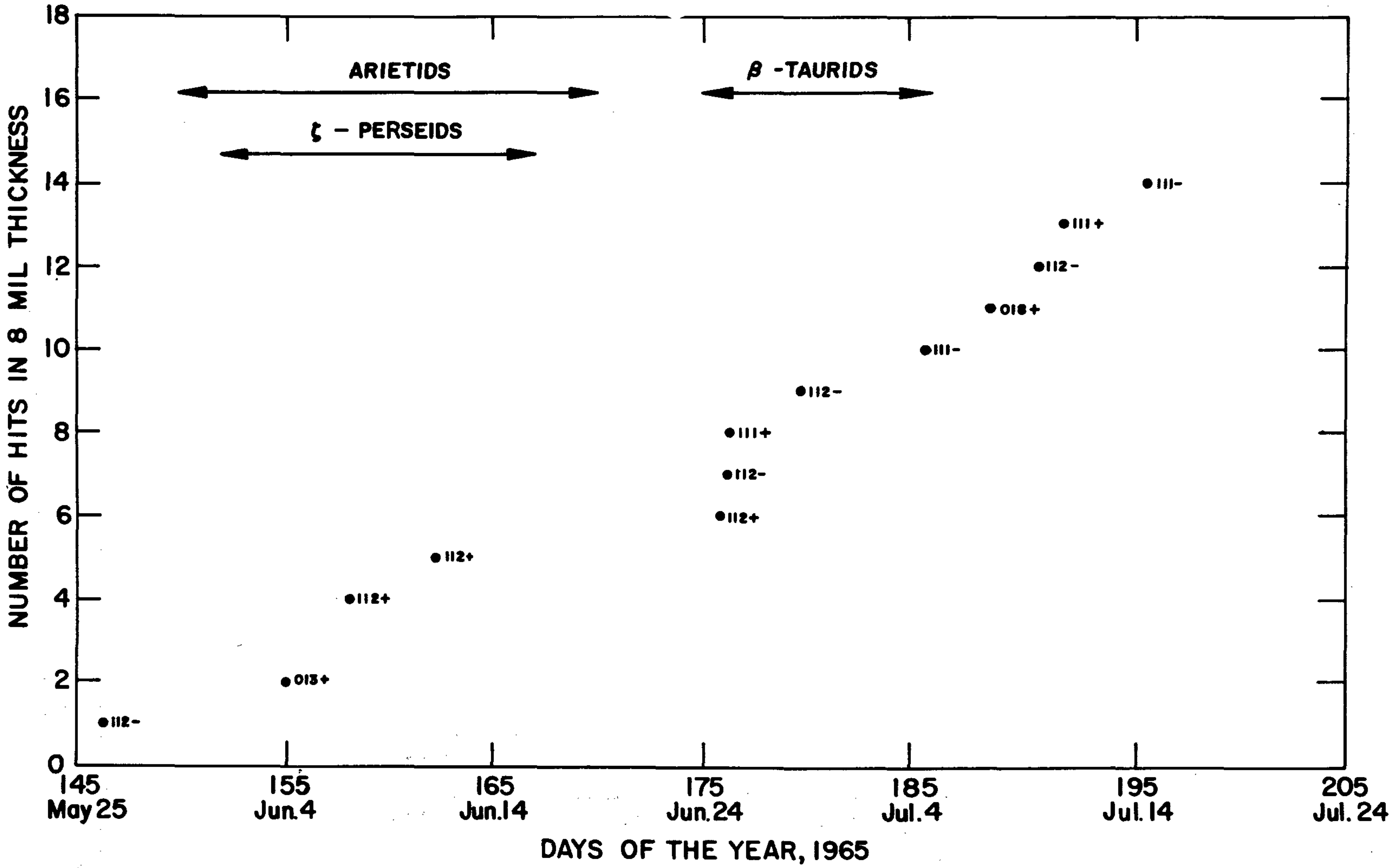

Figure 8 - Time history of accumulated penetrations for 200μ panels on Pegasus II.

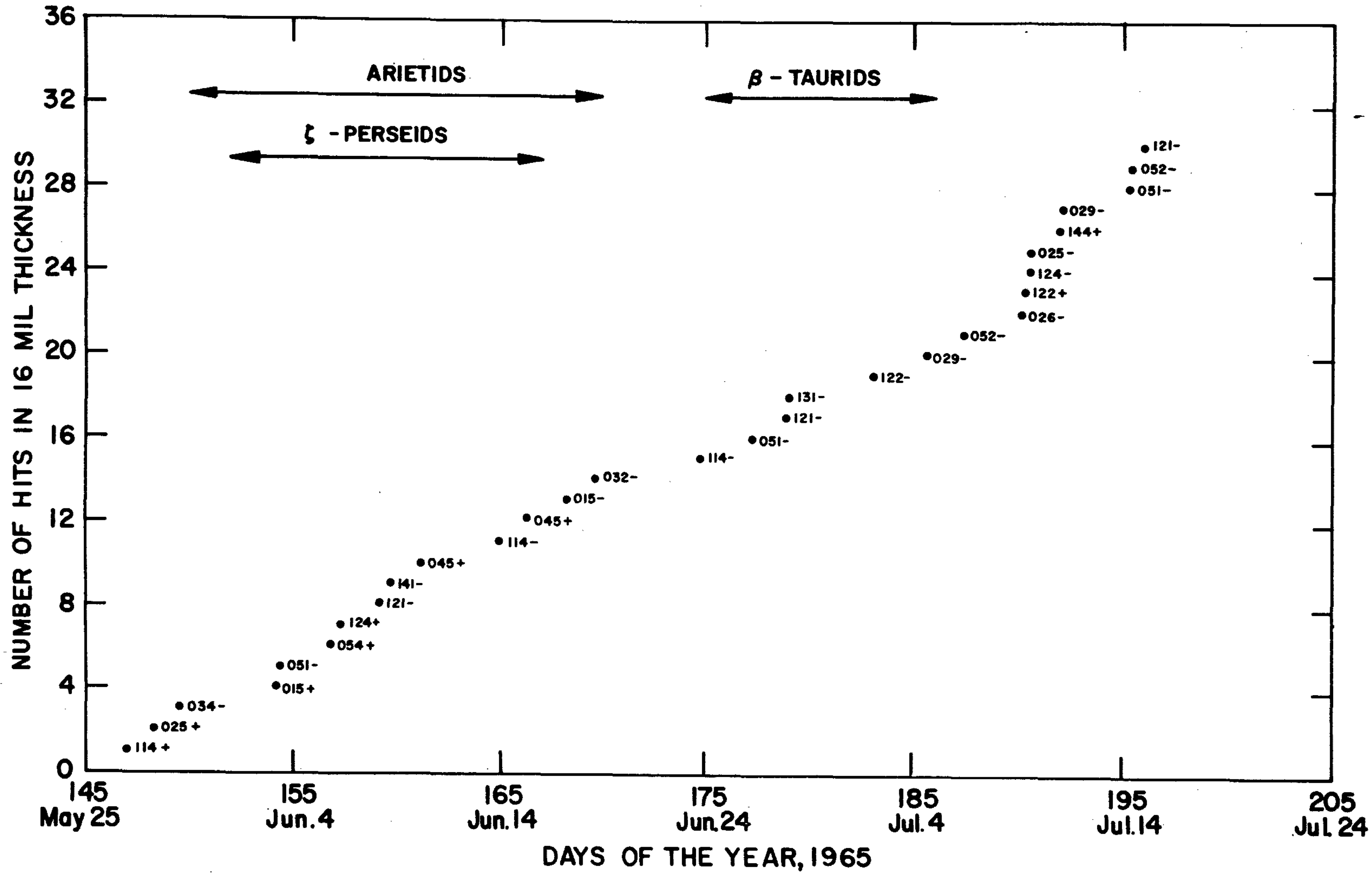

Figure 9 - Time history of accumulated penetrations for 400μ panels on Pegasus II.

The pressure cells, on the other hand, are under a hoop stress and have a free rear surface. A partial penetration can produce rear spallation and hairline cracks which can result in depressurization. It is not known whether or not this resulting decrease in penetration depth requirement for detection is compensated by the higher strength of the stainless steel. Also to be considered is the fact that the 40μ aluminum on Pegasus is 1100-0, which is known to be less resistant to penetration at lower velocities than the much stronger 2024-T3 used in the 200 and 400μ detectors. This may be partially offset by the fact that the 12μ of mylar that must also be penetrated represents an appreciable fraction of the 40μ sensor thickness.

Until such questions are settled by suitable calibrations, it does not appear justifiable to attempt to make corrections for material equivalence or detection mode. The penetration frequency vs. detector thickness for Pegasus I, II, and Explorer 23 is shown in Figure 10 along with the earlier predictions of Whipple[1].

It may be seen that the 40μ Pegasus points tend to confirm the Explorer 16 and 23 findings [2] that the penetrating flux, as well as the rate of decrease of puncture frequency with thickness, is much less than was originally estimated. As one proceeds to thicker materials, the penetration frequency and its rate of change appear to be in better agreement with the predictions based on astronomical measurements, although the slope is still not as steep as the astronomical measurements would indicate. There is still approximately 1 to 2 orders of magnitude between the mass range covered by Pegasus and the ground-based measurements. Obviously it would be desirable to make independent measurements in the same mass range.

George C. Marshall Space Flight Center,
National Aeronautics and Space Administration,
Huntsville, Alabama, September 13, 1965

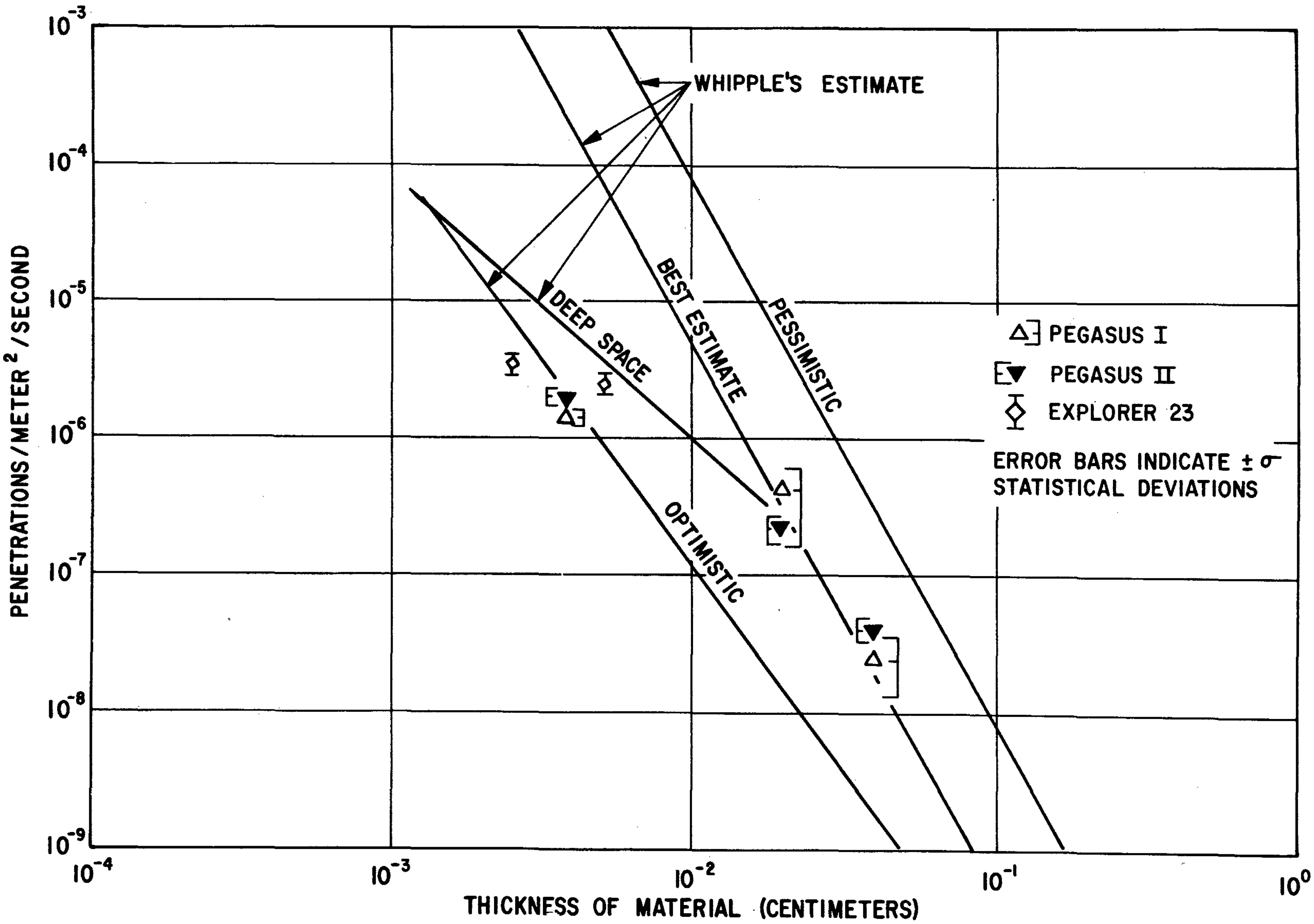

Figure 10 - Puncture frequency as a function of thickness.

REFERENCES

1. Whipple, Fred L., "On Meteoroids and Penetration," J. Geophys. Res., Vol. 68, No. 17, Sept. 1963, pp. 4929-39.

2. D'Aiutolo, C. T., "Review of Meteoroid Environment Based on Results from Explorer XIII and Explorer XVI Satellites," Space Research IV (Ed. P. Muller), Proceedings of the Fourth International Space Science Symposium, Warsaw, June 3-12, 1963. North-Holland Publishing Company, Amsterdam (1964).

NASA-Langley, 1965 M411