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FLIGHT REPORT INTERPLANETARY MONITORING PLATFORM IMP-I—EXPLORER XVIII

by Frank A. Carr

Goddard Space Flight Center
Greenbelt, Md.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1966

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FLIGHT REPORT

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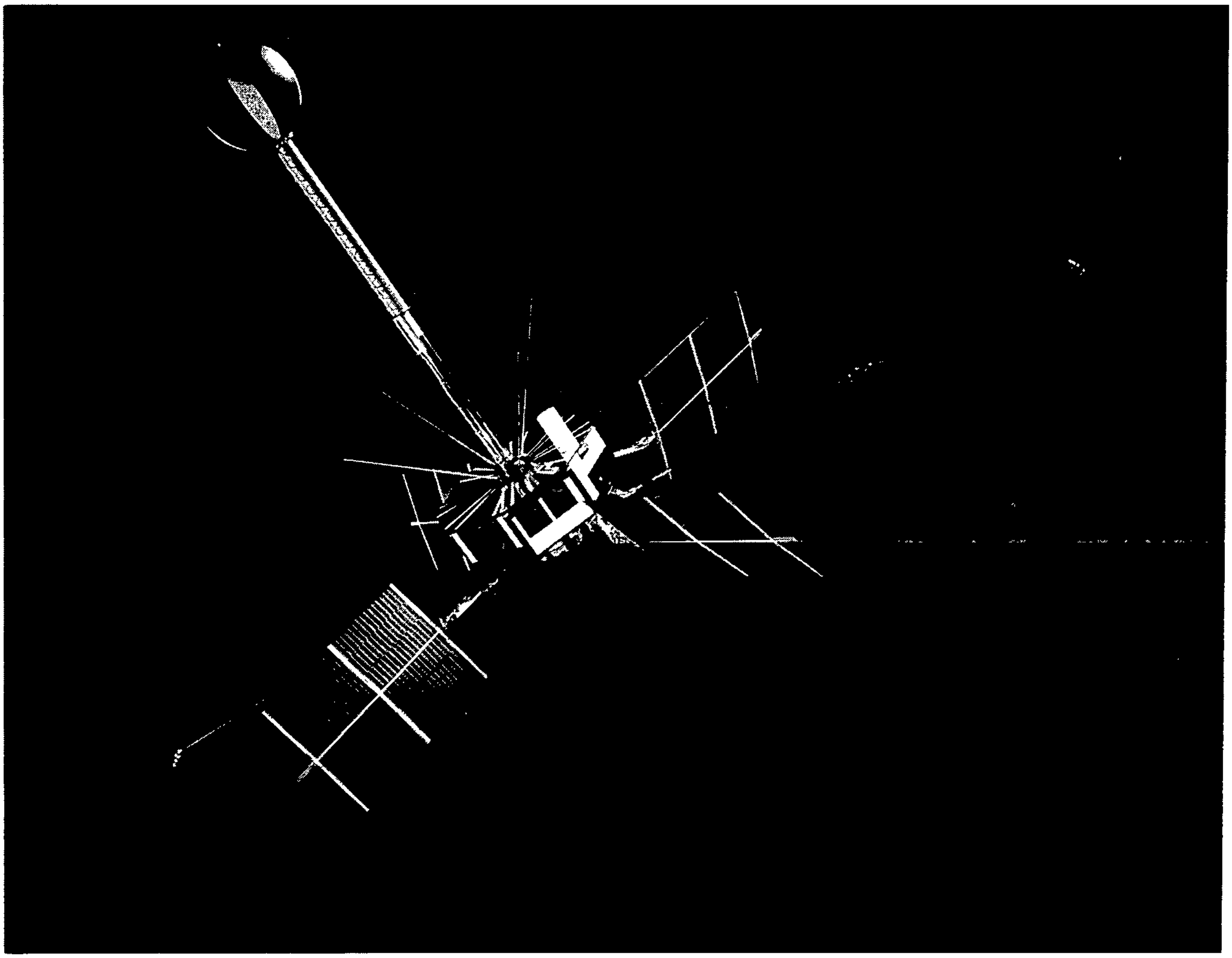
ABSTRACT

Following a successful launch, IMP-I operated successfully for six months. Thereafter performance levels decreased and only limited data was provided during the next 12 months. A total of nearly 6000 hours of data were obtained.

The elliptical orbit of IMP-I, reaching 106,000 nautical miles into cislunar space, provided the 9 scientific experiments with a unique opportunity to examine the outer limits of the Earth's magnetosphere, the transition region, and interplanetary space.

The performance of the spacecraft systems—telemetry, power, and thermal, was near nominal and is discussed based on telemetered performance parameter data. Some possible reasons for the degradation of the silver cadmium battery, which resulted in reduced operation, are discussed.

CONTENTS



IMP-I Spacecraft

FLIGHT REPORT
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IMP-I EXPLORER XVIII

by
Frank A. Carr
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INTRODUCTION

The IMP-I spacecraft was launched on 26 November 1963 (Figure 1) from the then Atlantic Missile Range. The Delta 21 launch vehicle performed satisfactorily (Reference 1)* placing the 138-pound spacecraft into an elliptical orbit ranging from 105 nautical miles to 105,600 nautical miles—or about half the distance to the moon.

The achieved apogee was about 50,000 nautical miles less than nominal. However, the spacecraft data showed that it traveled well beyond the earth's magnetosphere and transition region during the early months of its lifetime, and all scientific objectives were achieved despite the lowered apogee. Because of the eccentricity of the orbit, IMP-I spent about two-thirds of its time outside the earth's magnetosphere.

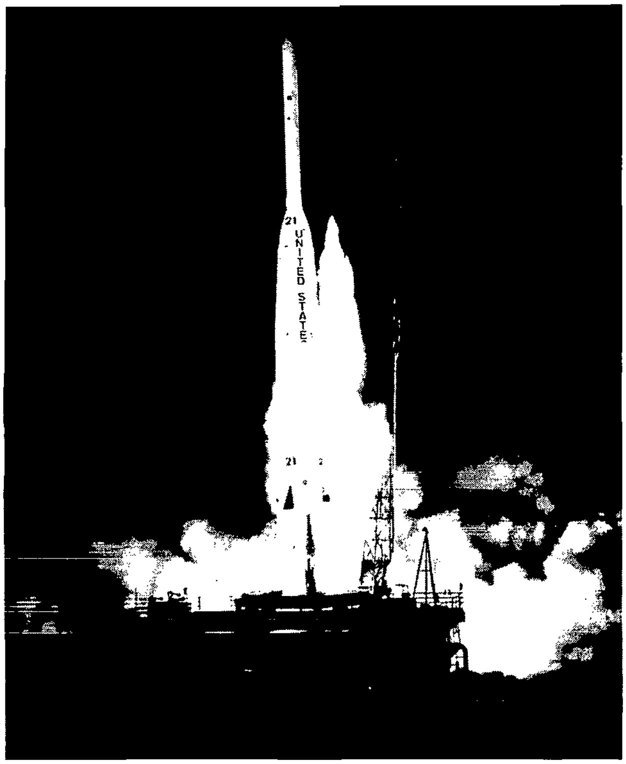

Figure 1-IMP-I launching.

The scientific experiments aboard IMP-I provided excellent data, including the first direct evidence for the existence of a collisionless magnetohydrodynamic shock wave in space enclosing the earth and its magnetosphere. The spacecraft also investigated in considerable detail the energy spectra, velocities, fluxes, and variations of cosmic rays, the solar wind, the magnitude and variations of magnetic fields in cislunar space, and the nature of the boundary or transition region between the earth's magnetosphere and the shock front (Reference 2).

*Delta 21 Field Flight Report, NASA Goddard Launch Operations, 15 February 1964.

ORBIT

The orbital parameters for the initial orbit are shown in Table 1.*

Table 1*

IMP-I Orbit

Apogee	195,552 km (105,598 n.m.)
Perigee	197 km (106 n.m.)
Period	5583.2 min (93.05 hrs.)
Inclination	33.34 deg
Eccentricity	0.937

*The elements for the initial conditions were computed and re-computed several times; those shown above were computed on 20 February 1964.

The orbital elements at selected times during the two years following launch are shown in Table 2.

Eighteen months after launch, the apogee position was 1000 n.m. lower while perigee had increased by about 1250 n.m. (Figure 2). The orbital period was 12 minutes longer than initially.

Table 2

IMP-I Orbital Elements at Selected Times After Launch

Date	Nominal	11/27/63	1/20/64	2/20/64	3/18/64	5/22/64	9/21/64	10/24/64	11/27/64	12/26/64	2/26/65	5/21/65	11/16/65
Days After Launch	-	0	55	86	113	178	299	333	365	396	459	542	721
Apogee Kilometers	277,184	195,552	194,134	193,832	193,894	194,068	192,461	192,764	192,839	192,349	192,182	193,721	187,075
Nautical Miles	149,700	105,598	104,832	104,669	104,703	104,797	103,929	104,092	104,133	103,868	103,778	104,609	101,020
Perigee Kilometers	190	197	1754	1993	1873	1911	3653	3249	3392	3747	3965	2494	162
Nautical Miles	103	106	947	1076	1011	1032	1973	1755	1832	2023	2141	1347	87.5
Period Minutes	9164	5583.2	5588.7	5586.2	5583.8	5592.4	5597.8	5593.7	5602.5	5597.1	5599.1	5601.9	5244.8
Hours	152.7	93.05	93.15	93.10	93.05	93.21	93.99	93.22	93.37	93.28	93.31	93.36	87.41
Inclination (degrees)	33.0	33.34	32.83	33.68	35.44	37.24	37.5	39.3	38.9	37.4	35.9	37.2	31.5
Eccentricity	0.955	0.937	0.922	0.920	0.921	0.921	0.904	0.908	0.906	0.903	0.901	0.915	0.935
Date Computed	-	2/23/64	3/14/64	4/14/64	5/2/64	6/4/64	12/23/64	12/23/64	12/23/64	12/23/64	12/23/64	12/23/64	12/23/64
Source	Delta 21 DTO	*	*	*	*	*	**	**	**	**	**	**	**

SOURCES *GSFC Operational Control Reports.
**IMP A Lifetime Study Per Tape 12/23/64.

NOTE: Re-Entry into Earth's Atmosphere Predicted for 11/20/65.

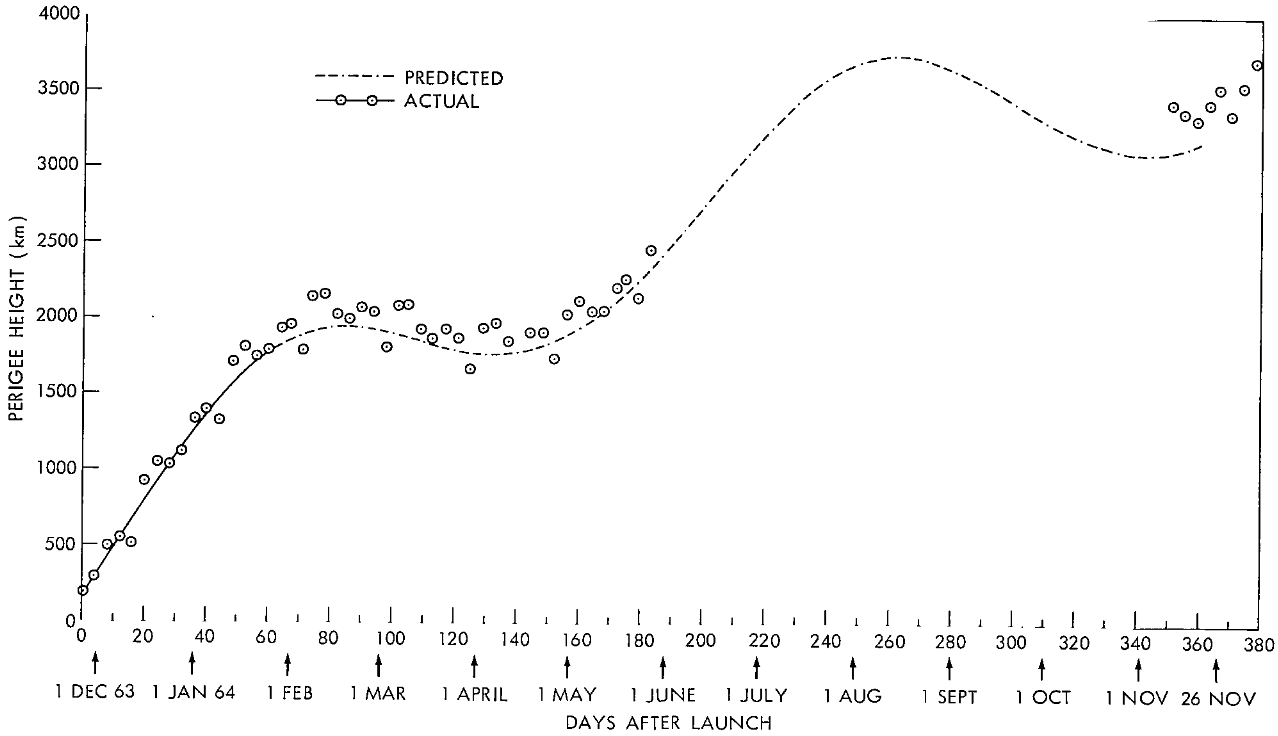

Figure 2-IMP-I perigee height versus time.

SPACECRAFT OPERATION SUMMARY

Following is a chronological summary of the performance of the spacecraft from launch through mid-May 1965 (Figure 3). Performance of all experiments and systems was satisfactory unless noted:

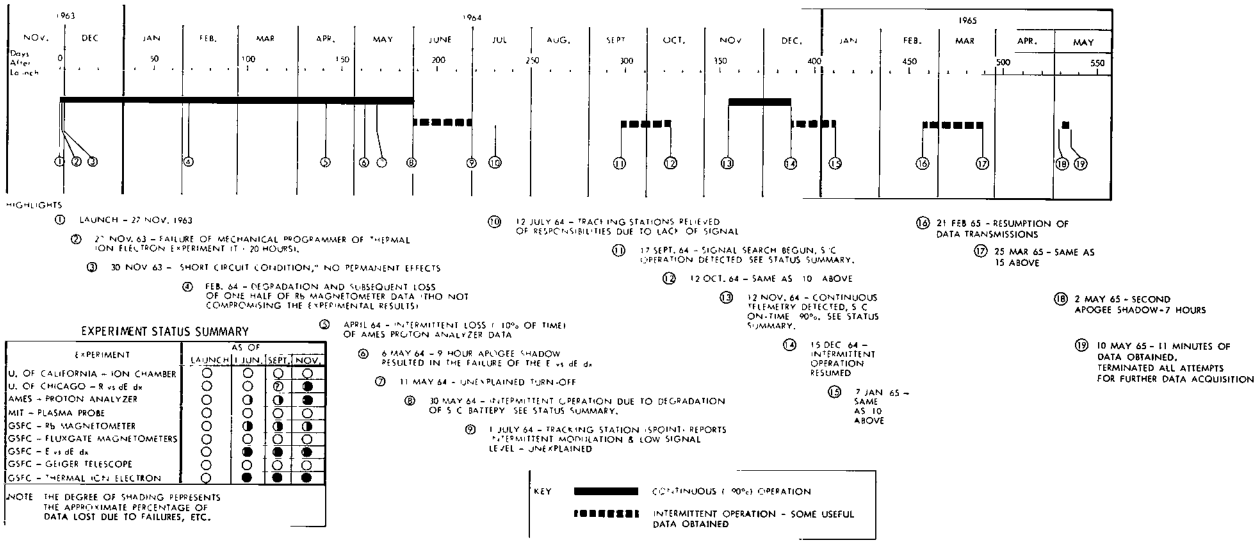

Figure 3-Life of the IMP-I satellite.

1. The mechanical programmer of the Thermal Ion-Electron experiment began erratic operation 20 hours after launch. Most of the data from this experiment were subsequently lost.

2. A temporary power system problem occurred three days after launch. A short circuit on the +12v output of the prime converter is suspected. No permanent damage, or reoccurrences were observed.

3. Beginning 3 February 1964, a failure in one of two redundant circuits in the Programmer Card 4 (gated telemetry amplifier) caused a gradual degradation and subsequent loss of data in alternate fourth sequences. This loss of one-half of the Rb magnetometer data continued but did not appreciably compromise the experimental results.

4. Beginning in mid-April 1964, the Ames Proton Analyzer data were intermittent. On occasion, the experiment data would read comb filter numbers of 108-109 representing a slightly negative input to the encoder. On these occasions, occurring from one to four days apart, the data were lost for periods of from several hours to several days. A possible cause could be voltage transients, internal to the experiment, occurring during the data storage mode.

5. In April, intermittent anomalies were observed in the range and range rate tracking messages. However, the data were usable and the problem was of no consequence.

6. On 6 May 1964, the spacecraft entered an extended apogee shadow (8-1/2 hours). As a result of the extreme cold, one channel of the E vs dE/dx was lost. The failure was probably due to the photomultiplier tube, although a number of other in-line items are possibilities. Future data from this experiment were of little value.

7. On 11 May 1964, several days after the IMP entered the shadow, the spacecraft turned off. Strip charts of the Joburg tape (#361) indicated that turn-off may not have been instantaneous. However, due to the quality of the recording, a definite conclusion cannot be reached. Normal spacecraft operation resumed 12 hours and 38 minutes later. Spacecraft data before and after this period give no indication of a possible cause.

8. On 30 May 1964, the spacecraft began a repetitive series of turn-offs and turn-ons. The duration of the on-times gradually decreased during the month of June from about 3/4 hours to a minute or less. On 14 July, Woomera, Australia claimed the acquisition of the IMP signal for two seconds. Thereafter, data acquisition efforts were substantially reduced and later temporarily abandoned. The cause of this problem has been attributed to the degradation of the spacecraft battery.* Proper operation would have continued except that the spin axis sun angle was such that the solar paddles were incapable of sustaining continuous operation without occasional assists from the battery. Based on the

*GSFC Memo from K. Sizemore, "Status of IMP Silver Cadmium Battery Leak Problem," 5 February 1965.

estimate of power output versus angle and the seasonal change of this angle, it was predicted that conditions would be favorable in mid-September and again in November to support continuous transmissions.

9. On 1 July 1964, the USAF Tracking Station at South Point, Hawaii, reported that it had acquired an intermittent, low level (-120dbm) signal during a 30-minute perigee pass; modulation was not detectable. This report is inconsistent with the presumed mode of operation of the spacecraft (i.e., off, with brief turn-ons every eight hours).

10. STADAN* began a search for the IMP signal on 17 September. The results were favorable: at 1245 UT, the Mojave (California) Station acquired and recorded an apparently normal signal. An on-off-on pattern was again evident. The duration of the on-periods varied from 30 minutes to several hours. During the following four weeks, over 200 hours of data were recorded. The status of the spacecraft and experiments was essentially unchanged from that in May, except that noise was causing problems with some of the MIT data, and the University of Chicago data were questionable.

11. After the first week of October, the duration of the operational periods decreased until only one minute was recorded on 15 October 1964. Tracking and data acquisition efforts were suspended until mid-November when the spin axis-sun angle was expected to be favorable once again.

12. On 12 November 1964, the Mojave Station acquired and recorded the IMP signal for nearly six hours. Thereafter, and until 15 December 1964, the satellite operated about 90 percent of the time providing over 600 hours of data. Status of the experiments was unchanged from the previous operational period, except that the University of Chicago experiment (R vs dE/dx) was not operating properly and their data were of little value.

13. A fourth period of operation from 21 February 1965 to 25 March 1965 provided intermittent and variable periods of operation. Small quantities of data were obtained. The operational status of experiments is not known at this time.

INFLIGHT TEMPERATURE DATA

The thermal control of the IMP spacecraft is a passive system consisting of varied geometrical patterns of white and black paints and polished aluminum surfaces. This configuration maintained internal temperatures from +15° to +50°C during the active lifetime of the satellite. For the IMP orbit, the temperatures of the internal electronic subsystems vary as functions of the impinging sunlight angle (since the IMP physical configuration is non-spherical) and the long-term characteristics of the external thermal coatings (Figure 4).

*Space Tracking and Data Acquisition Network.

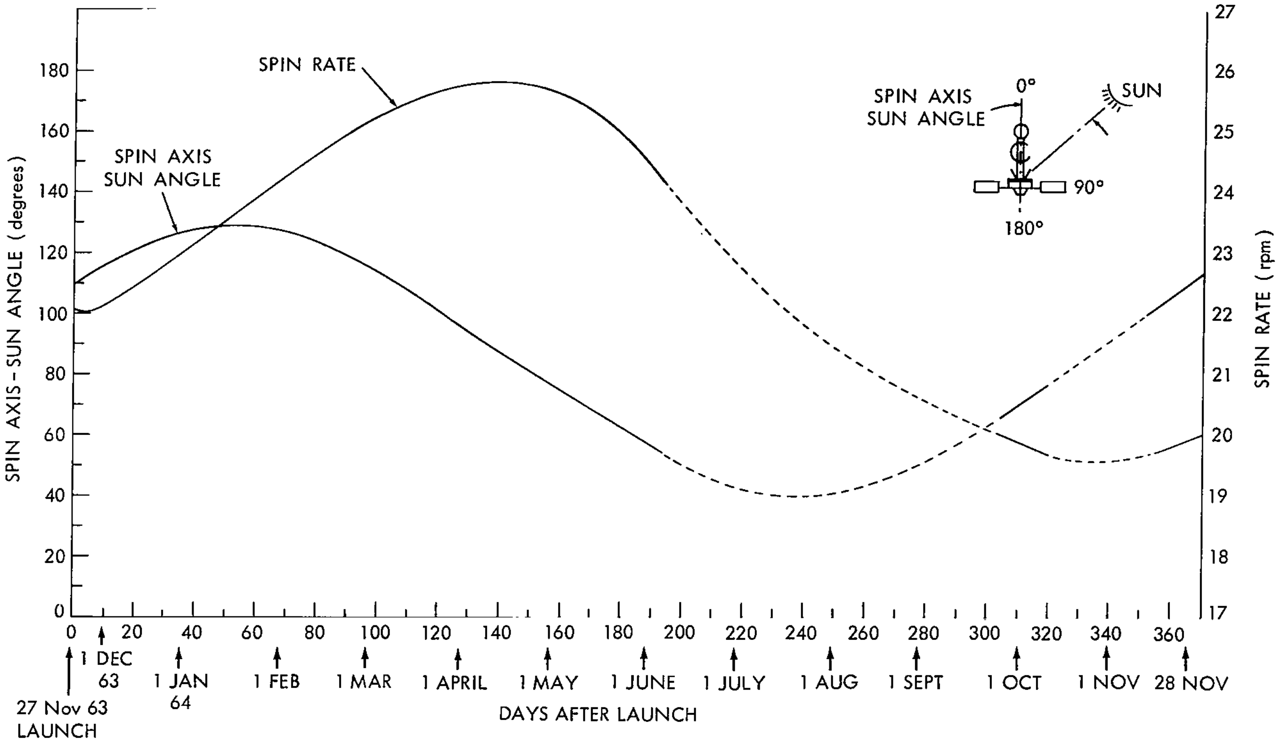

Figure 4-Spin axis-sun angle and spin rate versus time after launching of IMP-I.

The IMP performance parameter system (Reference 3) measured eight temperatures in addition to four voltages and three currents, and the telemetered data during the launch phase as well as the first six months of operation are plotted in Figures 5 and 6 respectively.

Comparisons of the in-flight data with pre-launch predictions are shown in Figures 7 through 11.*

The predicted temperature of the telemetry encoder, which is also representative of an average low power location, is shown in Figure 12.

Some comparisons of temperatures at identical sun angles but different times after launch are given in Table 3a, b and c. For example, it can be seen that the temperature of the prime converter is consistently higher at later times. This is probably due to an increase in the effective α/ϵ of the radiating tube. The thermal control system performed satisfactorily throughout the lifetime of the satellite.

Because of the intermittent operation of the spacecraft beginning 6 months after launch, it was possible to determine the non-operational (i.e., power off) temperatures. This was done by observing the temperature data immediately after the spacecraft turned on. Table 4 summarizes these data.

*Flight performance data mentioned in the text and graphs of this report have not been adjusted for any in-flight calibration drift (Appendix B).

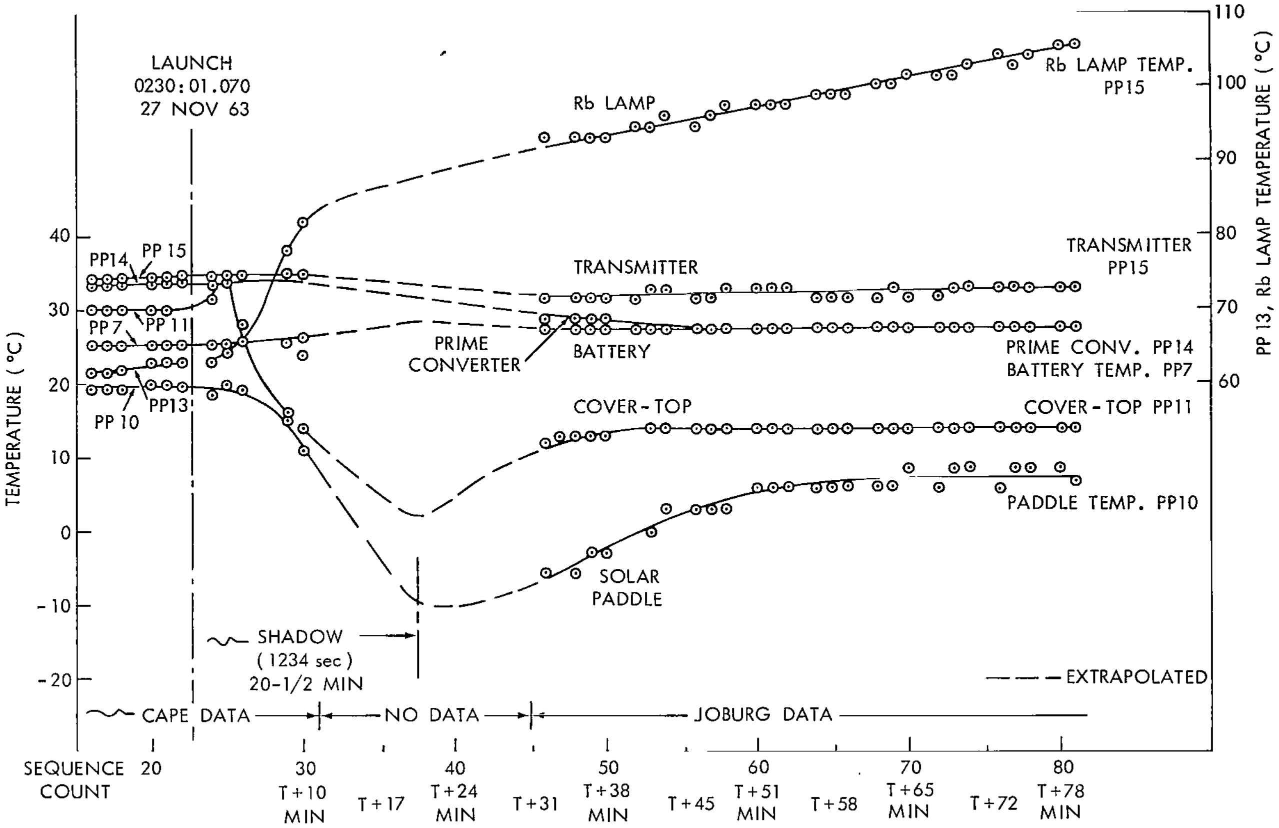

Figure 5-Temperature versus time after launch of IMP-I.

Table 3

Temperature Comparisons at Same Sun Angles But Different Times

Spin Axis-Sun Angle = 115°			
Location	Time After Launch		
	8 days	98 days	360 days
Skin 1	19°C	21°C	20°C
Skin 2	18	19	19
Paddle	10	12	15
Battery	37	40	34
Prime Conv	32	35	39
Transmitter	41	44	39

(a)

Spin Axis-Sun Angle = 120°		
Location	Time After Launch	
	17 days	88 days
Skin 1	20½°C	22°C
Skin 2	19	20
Paddle	7	10
Battery	39½	42
Prime Conv	33	35
Transmitter	45	47

(b)

Spin Axis-Sun Angle = 100°		
Location	Time After Launch	
	121 days	353 days
Skin 1	16°C	17½°C
Skin 2	15	17
Paddle	11	13
Battery	27	27½
Prime Conv	32	37
Transmitter	31	33

(c)

Table 4

Temperature Versus On-Off Condition

Spin Axis-Sun Angle = 65°	T On (°C)	T Off (°C)	ΔT (°C)
Skin Temp 1	+ 44	+39	- 5
Skin Temp 2	20	15	- 5
Rb Gas Cell	50	7	-43
Rb Lamp	105	50	-55
Battery	24	17	- 7
Prime Converter	46	18	-28
Transmitter	30	12	-18
Solar Paddle	6	6	0

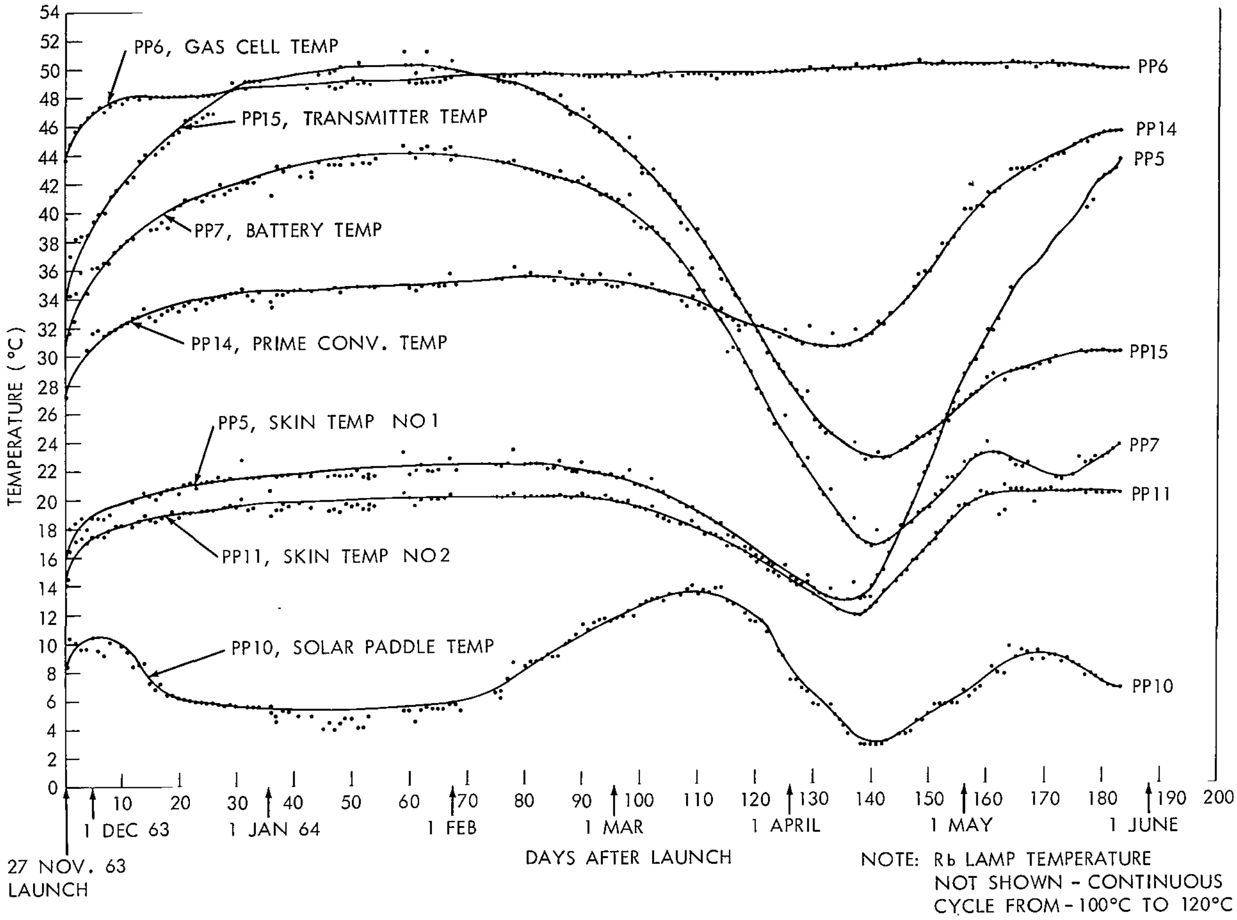

Figure 6-Performance parameter temperatures versus time after launch of IMP-I.

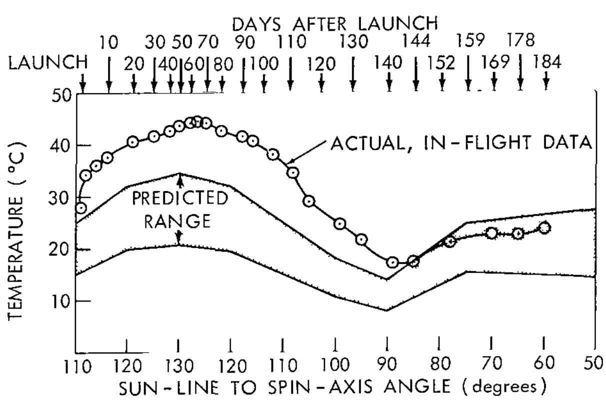

Figure 7-Battery temperature predicted and actual of IMP-I.

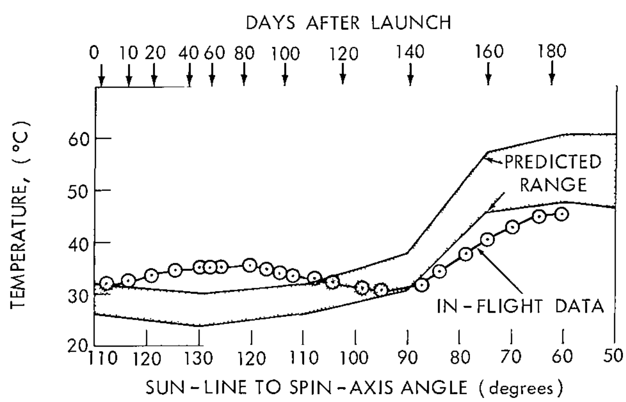

Figure 8-Prime converter temperature predicted and actual of IMP-I.

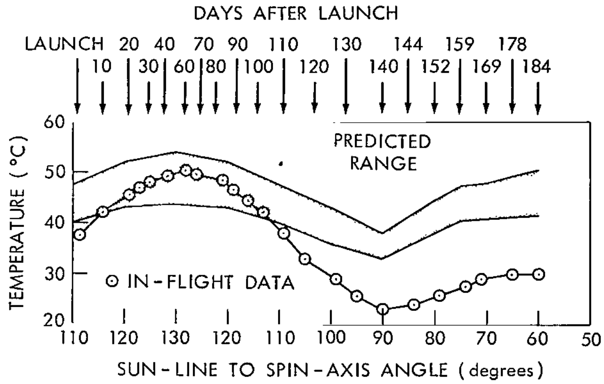

Figure 9–Transmitter temperature predicted and actual of IMP-I.

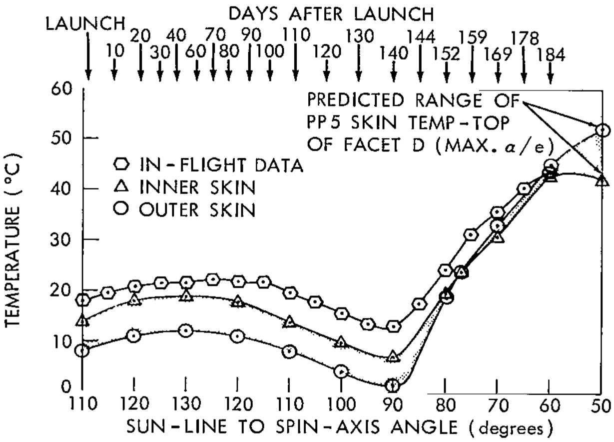

Figure 10–Skin temperature (PP5) of IMP-I.

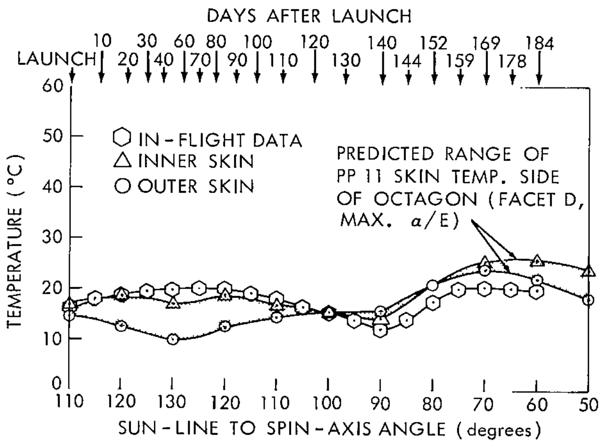

Figure 11–Skin temperature (PP11) of IMP-I.

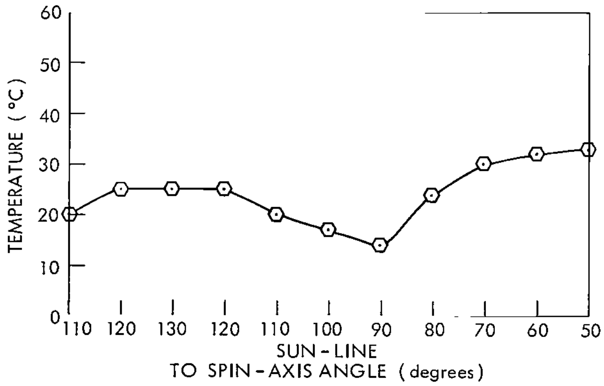

Figure 12–IMP-I predicted encoder temperature. No in-flight data available.

APOGEE SHADOW

One of the more interesting events in the life of IMP-I was the satellite's traversal through the shadow of the earth. On 6 May 1964, shortly after passing apogee at an altitude of about 191,000 km, the spacecraft entered the earth's shadow for a period of 8 hours and 39 minutes (exclusive of penumbra*).

Prior to launch, the possibility of an extended shadow was recognized. Because of the wide range of possible orbits, shadows from 6 to 10 or even 12 hours were forecast.

Of primary concern was the survivability of the spacecraft when exposed to extremely cold temperatures. Internal temperatures (experiments and electronics) were expected to fall to about -60°C while external locations (solar paddles, booms) would fall below -150°C.

*Region of partial illumination.

A mock-up of the IMP power system was subjected to a simulated shadow test in April 1964 to investigate the effects of such temperature extremes. The results indicated that survival was possible, if not probable.

Data (Figures 13, 14 and 15) indicated that the spacecraft entered the penumbra region at about 1521±2 UT, 6 May 1964. At that time the telemetered current from the solar paddles began to decrease. The penetration of the penumbra consumed approximately 55 minutes, during which time the solar paddle current decreased almost linearly from 2.8 to 0 amps.

Total darkness was encountered at 1616 UT (estimated) and spacecraft turn-off occurred at 1620:43.5 UT (during sequence 3, frame 6, channel 8). The STADAN tracking station at Woomera, Australia, recorded the spacecraft signal from several hours prior to the shadow through spacecraft turn-off. IMP-I carried redundant recycle clocks designed to re-start the spacecraft approximately eight hours after turn-off. Because of the extreme cold, it was anticipated that these clocks would probably slow down, or temporarily stop until re-warming occurred. The STADAN station at Santiago, Chile, reported that the spacecraft turned on at 0738 UT, 7 May 1964 (15 hours 17 minutes after turn-off).

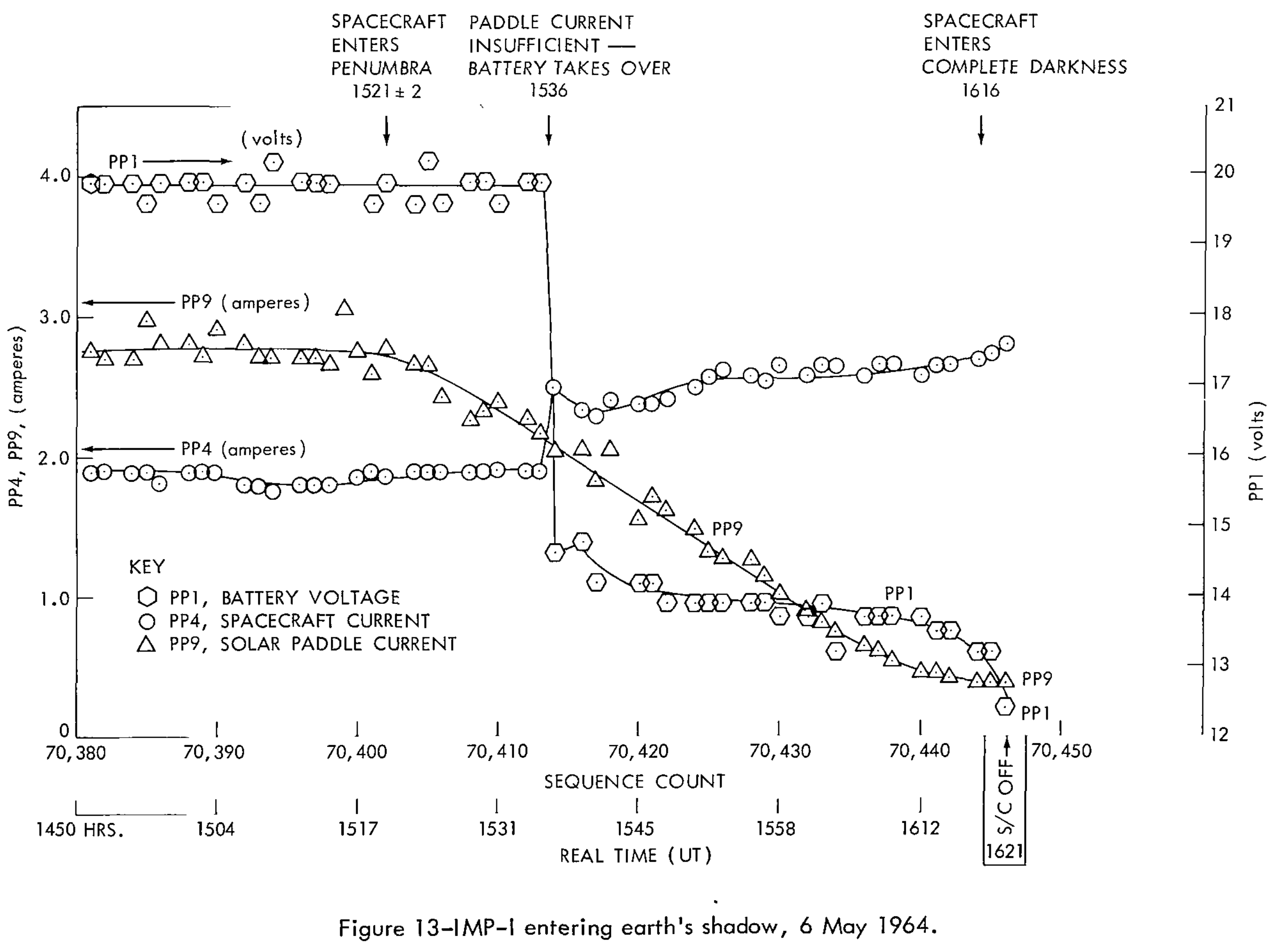

Figure 13-IMP-I entering earth's shadow, 6 May 1964.

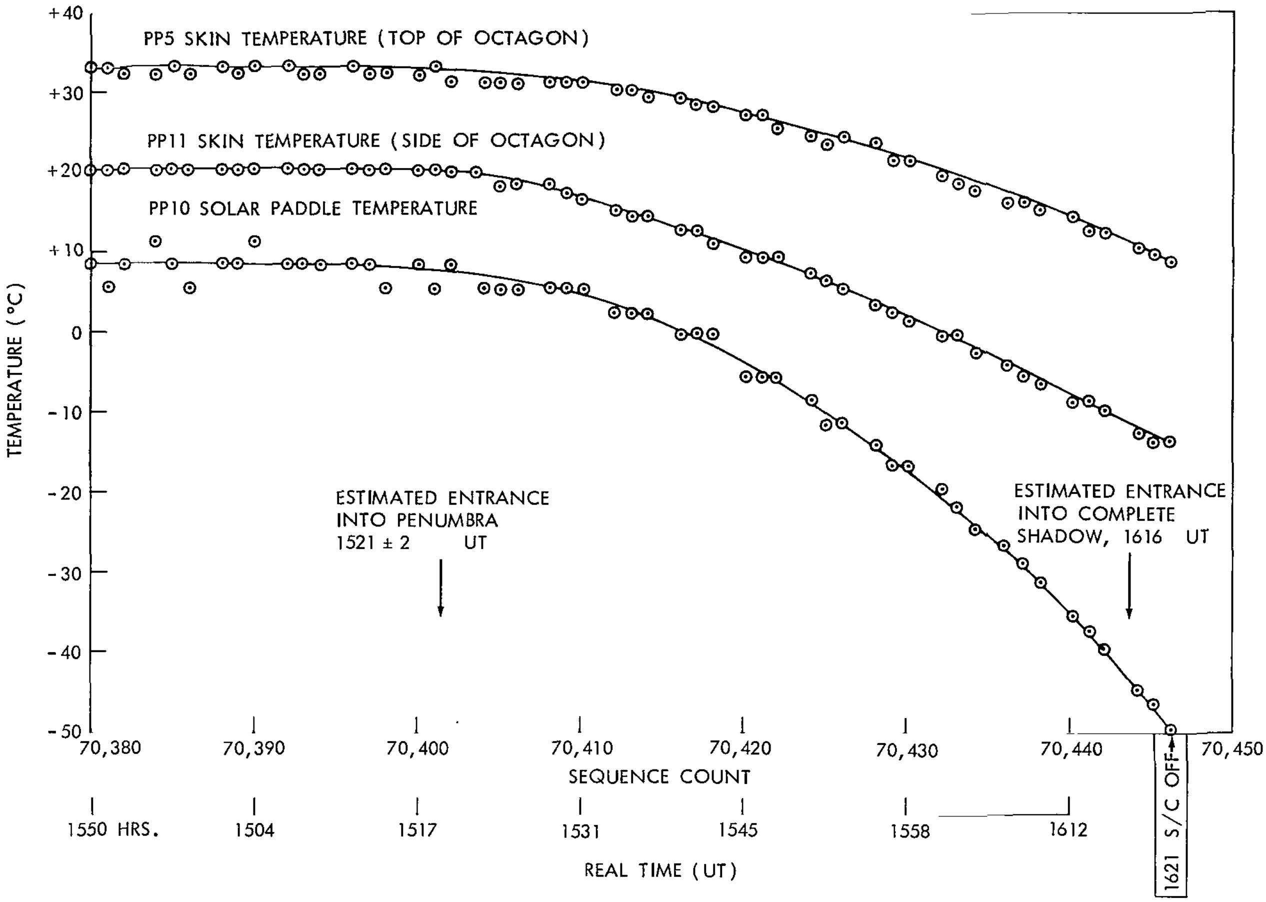

Figure 14-IMP-I entering earth's shadow, 6 May 1964, external temperature sensors.

Examination of the performance parameter data, Figure 13, as the spacecraft entered the shadow shows that the current from the solar paddles fell below the requirements of the spacecraft at approximately 1536 UT. The spacecraft continued to operate for only 45 minutes thereafter despite the fact that the nominal 5 ampere-hour battery should have been able to sustain at least 90 minutes of operation (longer with partial paddle current).

Taking into account the inaccuracies in the PP data (Appendix B), the area under the PP4 versus Time curve, Figure 13, (1535 to 1621 UT) indicates a spacecraft requirement of about 1.9 ampere-hours while the area under the PP9 versus Time curve (1535 to 1616 UT) indicates that the paddles supplied about 0.4 ampere-hours. The batteries then supplied only 1.5 ampere-hours.

Table 5

IMP-I Shadow Times

	Date (1964)	Time (UT)	Elapsed Time Hr:Min
Penumbra Entrance	6 May	1521	00:00
Complete Darkness	6 May	1616	00:55
Turn-Off	6 May	1621	01:00
Predicted Sunlight Entrance	7 May	0055	09:34
Turn-On	7 May	0738	16:17

Source: STADAN and IMP-I Data

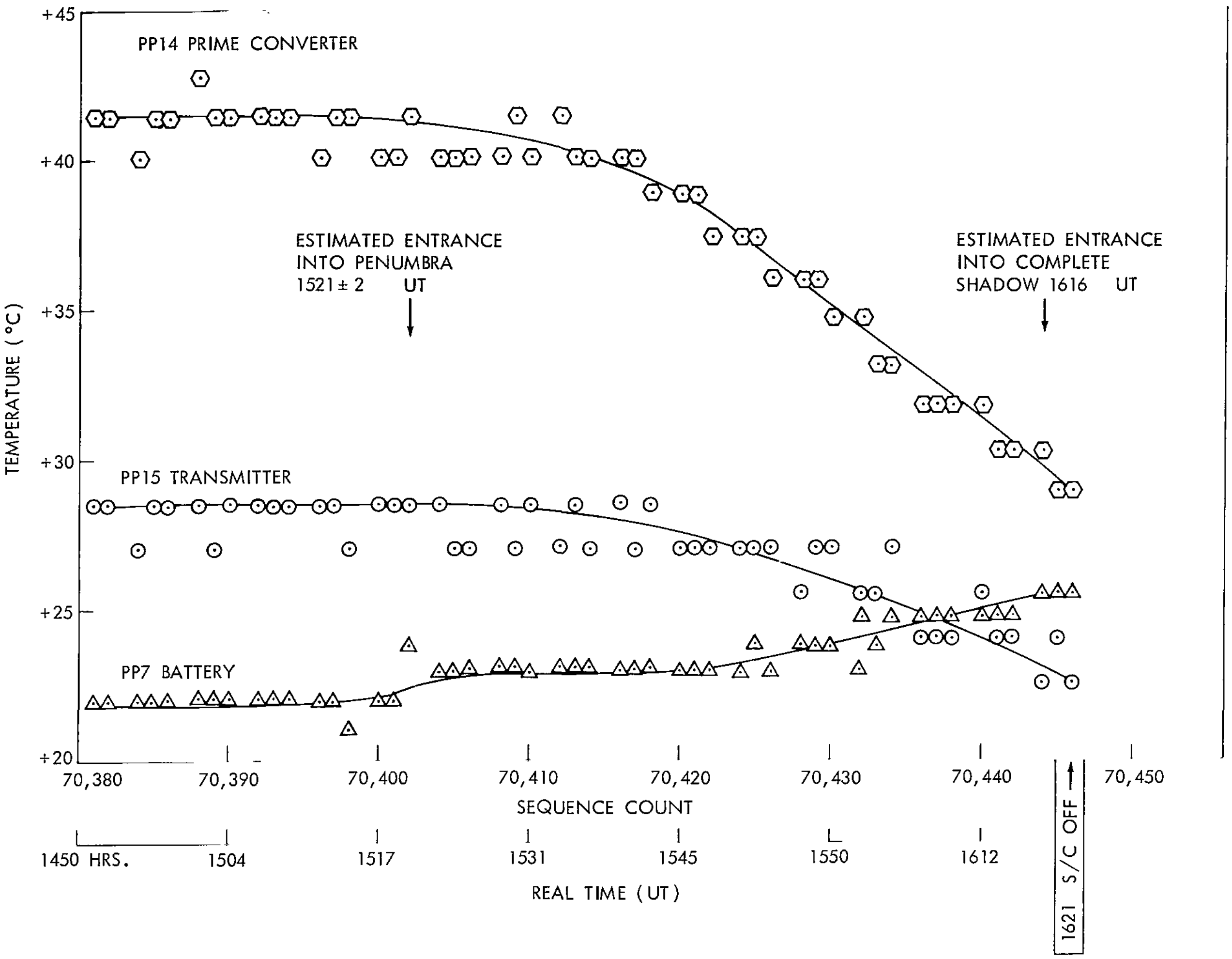

Figure 15-IMP-I entering earth's shadow, 6 May 1964, prime converter, transmitter and battery temperatures.

The silver cadmium battery used in IMP had a nominal capacity of about five ampere-hours. Ordinarily, this battery would be capable of operating the spacecraft for 1-1/2 to 2 hours. Since, at the entrance of this shadow, the effective or useful capacity of the IMP battery was calculated to be only 1-1/2 ampere-hours, it was concluded that the battery had degraded prior to this time. This problem is discussed at length in a later section.

A review of the immediate post-shadow data indicated that the only casualty of the big freeze was a failure in the GSFC, E vs dE/dx equipment. All other experiments and spacecraft systems returned to normal operation. From temperature and paddle output current data it appears that most if not all solar cells must have remained on the paddles, having survived close to liquid nitrogen temperatures.

As can be seen in Figures 14 and 15, the spacecraft temperatures begin to decrease rather rapidly even within the penumbra. Combining these data with the predicted cooling rates it appears that the battery temperature reached about -45 °C, the transmitter -80 °C, and the prime converter -90 °C (Figure 16). Experiments and other internal items probably reached temperatures of -45 °C to -80 °C.

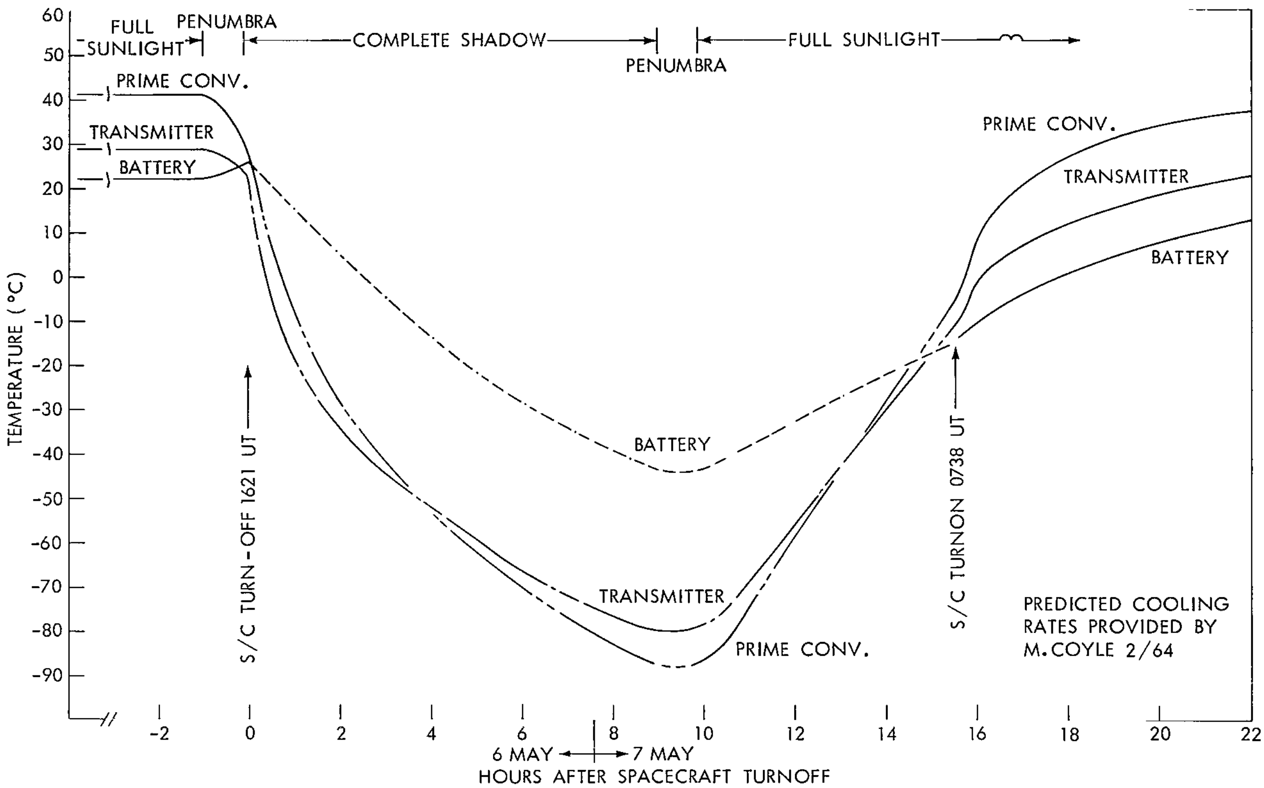

Figure 16-IMP-I temperatures during apogee shadow of 6-7 May 1964.

When the spacecraft resumed operation, after an estimated 6-3/4 hours in sunlight, the temperatures were as shown in Table 6.

This extended shadow is thought to be the longest such period ever encountered by a spacecraft. Not only did IMP survive and provide useful data thereafter, but it also traversed and survived a second shadow the following year (2, 3 May 1965, 7 hours and 4 minutes).

Table 6

IMP-I Temperatures

Performance Parameters, PP	Location	Temperature, °C ± 3°C
PP5	Top of Octagon	+13
PP6	Rb Gas Cell	- 5
PP7	Battery	-15
PP11	Side of Octagon	+ 4
PP13	Rb Lamp	+50
PP14	Prime Converter	- 7
PP15	Transmitter	-12

INFLIGHT POWER DATA

Seven parameters are telemetered which give an indication of the performance of the power system of the spacecraft. Included are the following voltages and currents (Figure 17):

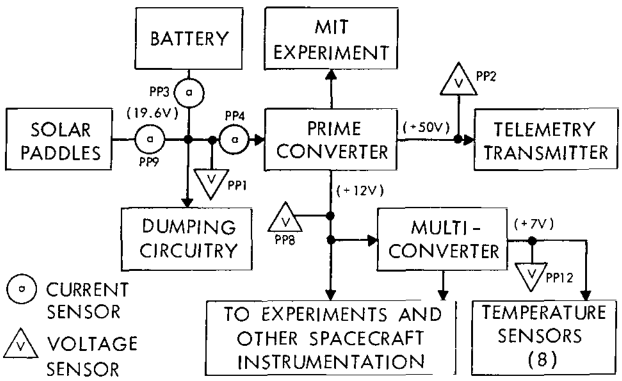

Figure 17-IMP-I primary power system simplified block diagram.

PP1	Primary system voltage
PP2	Prime converter +50v ±1% regulated output
PP8	Prime converter +12v ±1% regulated output
PP12	Multi-converter +7v ±1% regulated output
PP3	Battery charge current
PP4	Spacecraft load current
PP9	Solar array output current

Data for the six-month period following launch are plotted (daily averages) in Figure 18. There is a number of interesting items on this graph. For example, the four voltages appear to increase in value for some time after launch, reaching a plateau and remaining nearly constant thereafter. This upward drift has been attributed in most cases to telemetry calibration changes rather than out-of-tolerance performance of the converter-regulators.* The extreme stability of the multi-converter +7v output is evident from Figure 18. The solar array output current is also plotted and is discussed in a later paragraph.

The spacecraft load current is very uniform except for a slight discrepancy occurring three days after launch. At that time a power system problem developed (Item 2 of the SPACECRAFT OPERATION SUMMARY). A comparison of the load current before and after shows a net reduction of about 100 milliamperes. No known failures occurred which might have decreased the power consumption. This discrepancy remains unexplained.

The battery charge current PP3 shows an unusual and unexpected trend toward high charge rates. This may be symptomatic of the battery failure which became evident on 30 May 1964.

The solar paddle power supply flown on IMP-I consisted of four paddles with P/N cells. Each paddle produced about 33.6 watts per side at 1.0 Solar Constant and no radiation damage. Because of the geometrical placement of the paddles on the spacecraft, a variable power output is generated as the satellite spins and as the sun shines from different angles. The predicted power, averaged over a revolution, and the minimum during a revolution, is plotted as a function of spin axis-sun angle in Figure 19. These data are based on initial power output, i.e., before

*Appendix B gives a complete discussion of this problem.

radiation damage. The actual solar paddle output average is shown in Figure 20. For ease of comparison the predicted power is also shown on this graph.

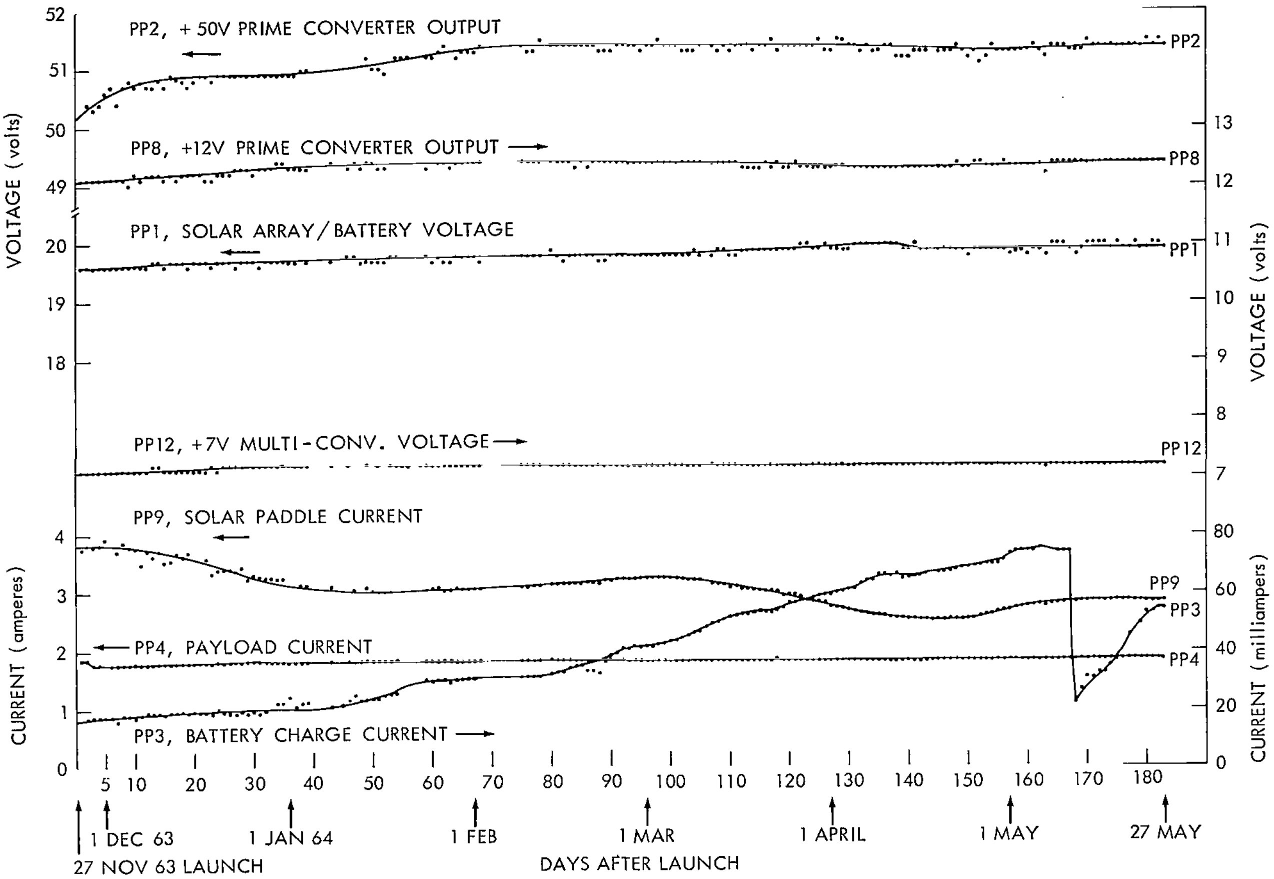

Figure 18-Performance parameter voltages and currents versus time after launch of IMP-1.

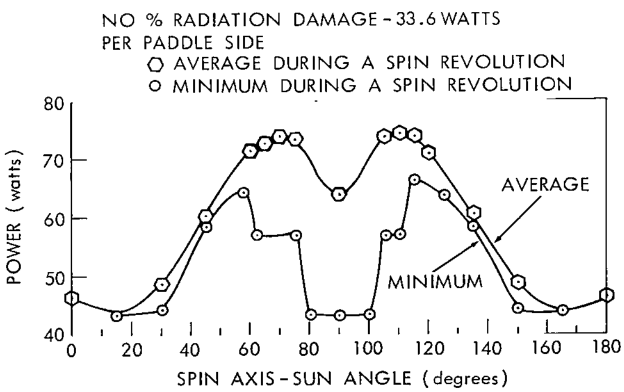

Figure 19-Predicted solar paddle power output versus spin axis-sun angle of IMP-1.

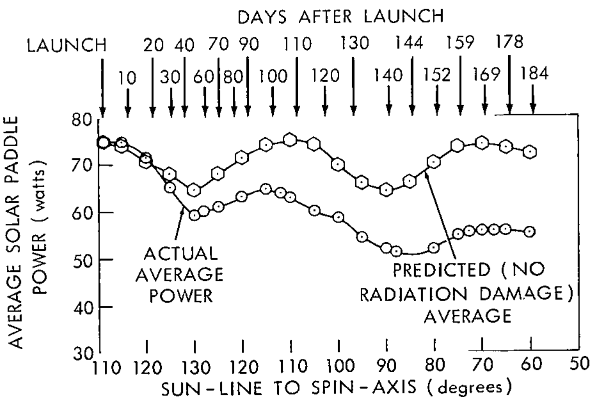

Figure 20-IMP-I solar paddle power output versus spin axis-sun angle.

Figure 21 presents some telemetered data which show the variation of paddle output due to the spin of the spacecraft. It is apparent from these curves that while the average paddle output over one revolution is consistently greater than that required by the spacecraft, the minimum output during a revolution sometimes falls below requirements. When this happens, the battery must supply the deficiency. If for some reason the battery is incapable of supplying power, the spacecraft will turn off for an eight hour recycle period. This was the mode of operation subsequent to 30 May 1964, whenever the impinging sunlight angle was such as to cause the minimum paddle output to fall below the spacecraft power requirement.

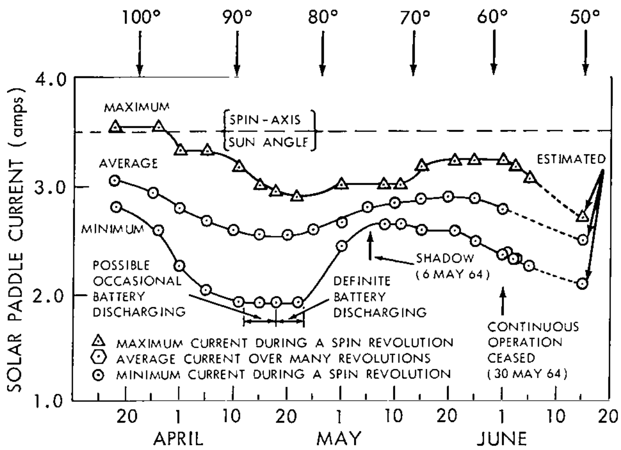

Figure 21-IMP-I solar paddle current for April to June 1964.

One year after launch, at the identical spin axis-sun angle which existed at launch, the solar paddles were producing exactly 75 percent of their initial capability. This 25 percent loss of capacity could be composed of failures such as open circuits of individual cells or strings of cells and degradation due to ultra-violet effects but the major portion is presumably due to energetic particle radiation damage.

BATTERY PROBLEM

As the IMP spacecraft entered the apogee shadow about 5-1/3 months after launch, the effective capacity of the battery was only 30 percent of its pre-launch nominal capacity of 5 ampere hours. After 6 months in orbit, the effective capacity was probably close to zero.

With regard to IMP there are four primary factors which could have either caused, contributed to, amplified, or accelerated battery degradation: temperature, pulsing (i.e., alternate charging and discharging as the satellite spins), the apogee shadow, and finally, excessive electrolyte in the battery cells.

High temperatures (in this case, +35°C and above) are known to substantially reduce the lifetime of silver cadmium batteries. From telemetered data (Figure 6), the IMP battery was exposed to temperatures in excess of +35°C for 110 days (60%) of its first six months in orbit. There is strong evidence in ground test data to indicate that this could contribute to a shortening of the IMP battery lifetime.

Pulsing of the battery occurs when the satellite spins and presents varying paddle areas to the impinging sunlight. At certain roll positions, the illuminated paddle area is insufficient to produce enough power to operate the spacecraft. At this instant, the battery is called upon to supply the deficiency. A few degrees later in the revolution, the area will increase providing the necessary power for the spacecraft as well as power to recharge the battery. Consequently, alternate discharging and charging of the battery occurs. Ground tests under this mode of operation indicate that the effective capacity may be, at least temporarily, decreased or increased depending on the amplitude and period of the pulsing. Pulsing of the battery is known to have existed during April. There is no generally accepted conclusion as to the effect of pulsing on the IMP battery.

The apogee shadow probably did not cause the battery problem (based on the data at shadow entrance discussed previously). However, if the battery was already degraded (for example, cracked) the shadow could have served to further aggravate the problem.

The electrolyte leakage problem has been intensely investigated by the Electrochemical Power Sources Section, GSFC, and has been reported in several documents including K. Sizemore's Memo:*

> "Leakage of electrolyte from silver cadmium batteries is caused by an excess of free electrolyte in the cells which prevents gas recombination resulting in an internal pressure rise.
>
> "The pressure buildup weakens the cell terminal-to-polystyrene interface eventually allowing the KOH electrolyte to leave the cell.
>
> "The KOH leak rate is accelerated because of the magnetic compensating loops which run adjacent to, and sometimes in direct contact with, the cell terminals and intercell connectors. In short, the loops act as a path for the electrolyte to follow after leaving the cell.
>
> "Epoxy cracks in high stress areas of the battery occurring during temperature cycling probably would not substantially increase the leak rate."

A review of the battery charge current history (PP3 data, Figure 18) shows a gradual upward trend for the five months after launch and preceding the May 1964 apogee shadow. Part of this increase is due to analog oscillator calibration drift (Appendix B). However, part of the observed data (about 2/3 to 3/4) is not due to oscillator drift and hence must be a measure of an increase of the trickle charge rate of the battery.

Silver cadmium batteries usually accept near zero current during long-term trickle charge. One battery (IMP battery 15) which was placed on test following the IMP-II launch began to degrade 75 days after the start of the test.** One of the cells developed an internal short causing a higher voltage to be impressed on the remaining good cells which resulted in an increase of the battery charge current. Eventually, some of the cells may rupture due to the internal gas pressure build-up and electrolyte leakage will occur.

*GSFC Memo from K. Sizemore, "Status of IMP Silver Cadmium Battery Leak Problem," 5 February 1965.
**GSFC Memo from K. Sizemore, "Life Test of IMP Battery No. 15," 20 April 1965.

The failure mode (life test of IMP battery 15) was attributed to +50°C operation which accelerates the reaction of silver oxide with the cellophane separators. The build-up of silver on the separator layers eventually results in a shorted cell.

In the case of IMP-I, it seems likely that a cell could have shorted due to the warm temperatures experienced during the early months in orbit causing a higher voltage to be impressed on the remaining cells and eventually causing rupture due to gas pressure. This, combined with excessive amounts of electrolyte in the cells and possible cracking of the epoxy due to the apogee shadow (battery reached -40°C), could well have resulted in total battery failure.

Many changes were incorporated into the IMP-B and C battery designs, including precise adjustment of electrolyte level, elimination of magnetic compensating loops, changes to the epoxy encapsulation techniques, and, for IMP-C, a battery over-charge protection circuit to preclude the possibility of internal pressure build-up and a thermal change to reduce the temperature of the battery.

CONCLUDING REMARKS

On 10 May 1965, 531 days after launch, STADAN recorded 11 minutes of IMP-I data. If the sun angle had been optimum, or if radiation damage had not reduced the array output by more than 25 percent, or if the battery had not failed, the spacecraft would have been operating full time.

Of course "if's" don't count, but the 10 May data do prove the hardiness of the basic spacecraft system. The RF system, programmers, encoder, power system (excluding battery) paddles, converters and regulators, optical aspect and performance parameters all are presumed to be functioning properly after 1-1/2 years in space. In addition, the University of California, Geiger telescope, magnetometers and possibly the MIT experiments would have provided useful scientific data. One further word about the under-voltage recycle system. From May 1964 to May 1965, this system operated properly for more than 900 cycles—a record.

IMP-I, the forerunner of a series of three launches, later expanded to seven, then eleven, successfully accomplished the following Mission Objectives:

1. To study in detail the radiation environment of cislunar space,
2. To study the properties of the interplanetary magnetic field and its dynamical relationship with solar particle fluxes,
3. To extend knowledge of solar-terrestrial relationships, and
4. To further the technological development of relatively inexpensive, spin-stabilized spacecraft for scientific investigations.

The value or successfulness of a satellite should not be measured in terms of days of operation or minutes or kilobits of telemetry recorded. Instead, one should ask the question "What has been learned?" Answers to this question can be found by referring to Appendix D - a bibliography of papers published by experimenters based on IMP-I data.

(Manuscript received September 29, 1965)

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Appendix A

IMP-I Performance Parameter System

The IMP-I performance parameter (PP) system consists of on-board instrumentation to telemeter 15 measurements of temperatures, voltages and currents. The design of the electronic instrumentation was the responsibility of the Flight Data Systems Branch, and thermistor networks were provided by the Thermal Systems Branch, GSFC.

Each of the 15 parameters presents an output voltage of 0 to 5vdc to the spacecraft encoder. The first seven parameters are encoded through one analog oscillator and the remainder through a second oscillator. The output of the oscillators is 5 to 15kc which is divided by 16 and telemetered during frame 2 of sequences 1, 2, and 3 of the IMP format. This permits about 33 samples of each of the 15 parameters during each hour of operation. The performance parameters are itemized in Table A1.

Table A1

Performance Parameter Measurements of IMP-I

Performance Parameter, PP	Measurement	Calibration	Nominal Spacecraft Operating Range
1	Solar Array/Battery Voltage	+10.5 to +21v	+11.8 to 19.6v
2	Prime Converter, +50v Output	+20 to +60v	+50.0v ± 1%
3	Battery Current	0 to 500 ma	$\lessapprox$ 50 ma
4	Spacecraft Current	0 to 4 amp.	~ 2 amp.
5	Skin Temp. 1 (Top of Facet D)	-34° to +73°C	
6	Rb Gas Cell Temperature	+6° to +82°C	+42° ± 5°C
7	Battery Temperature	-17° to +87°C	+10° to +30°C
8	Prime Converter, +12v Output	+9.5 to +13v	+12v ± 1%
9	Solar Array Current	0 to 5 amp.	~ 2 to 4 amp.
10	Solar Paddle (Arm 1) Temperature*	-138° to +80°C	
11	Skin Temp. 2 (Side Facet D)	-34° to +73°C	
12	Multi Converter, +7v Output	+4.0 to +8.5v	+7.0v ± 1%
13	Rb Lamp Temperature**	+53° to +148°C	+100° to +115°C
14	Prime Converter Temperature	-35° to +79°C	+45° to +60°C
15	Transmitter Temperature	-38° to +80°C	+40° to +55°C

*Also indicates spacecraft separation from X-258 third stage motor.
**Also indicates Rb magnetometer extension.
Note: Data from MIT experiment will confirm solar paddle erection.

The processing of the IMP analog data utilizes comb filters whose function is to improve the S/N ratio by reducing the noise band width.* There are 100 comb filters that cover the telemetered frequency range of 5kc/16 (312.5 cps) to 15kc/16 (937.5 cps). The bandwidth of each comb filter, in this application, is 6-1/4 cps.

*Ness, N. F., IMP Information Processing System, 29 June 1962.

Appendix B

Inflight Calibration Drift

An examination of the telemetered values of several performance parameters, especially the regulated voltage monitors, shows a gradual increase over a period of weeks (Figure 18 in body of report). These increases could be due to drifting of the regulated voltages or to calibration changes in the monitoring circuitry. Careful review of the telemetered data as well as test data on analog oscillators yields considerable evidence to indicate that the major portion of the apparent increases in flight is not due to out-of-tolerance operation of the regulators but rather to inaccuracies in the data due to long term drift of the analog oscillators.

The observed changes of the voltage monitors are summarized in Table B1.

Table B1

Observed Drift of PP Voltage Monitors

		T + 30 Min.	T + 180 Days	Change (Percent)*
PP1	System Voltage	19.5v	20.0v	2.7
PP2	Prime Conv. +50±1%v	50.2v	51.4v	2.7
PP8	Prime Conv. +12±1%v	12.06v	12.4v	3.6
PP12	Multi-Conv. + 7±1%v	7.07v	7.15v	2.6

*Percent change of telemetered frequency.

It is considered unlikely that the system voltage and the +50v output of the prime converter (PP1 and PP2 respectively) would actually drift upward to the values shown. Also, the drift rate (including the gradual leveling off) and percent frequency change is identical. This leads to the conclusion that the data are in error, probably due to aging characteristics of the analog oscillator which encodes these parameters.

The second two voltages, PP8 and PP12, drifted by different amounts and at different rates. To evaluate the portion due to oscillator drift, the data from another parameter, namely the solar paddle current (PP9), were reviewed. The PP9 frequency when the spacecraft was within the shadow of the earth, i.e., corresponding to 0 amperes, was noted to have changed by slightly more than 2 percent over the first six months. This change is attributed to analog oscillator drift and so it may be assumed that of the 3.6 percent change of the PP8, +12v±1 percent volt line, 2 percent is due to oscillator drift. The remainder (1.6 percent) is due to actual change of the regulated output and/or aging of the voltage divider network in the performance parameter electronics. Even if the +12v prime converter output did, in fact, exceed the ± 1 percent design tolerance, there was no adverse effect on the operation of the spacecraft or experiments.

The spacecraft current monitor (PP4) indicated 1.89 amps at 6 months after launch after having gradually increased from 1.75 amps at a few days after launch. This corresponds to a 2.7 percent frequency decrease lending additional support to the conclusions regarding analog oscillator drift noted.

The battery charge current, PP3, increased almost linearly until the extended shadow of 6 May. This increase cannot be attributed to data inaccuracies such as those mentioned. The total change corresponds to a 7 percent frequency decrease of which, perhaps 3 percent could be due to analog data drift (as discussed for PP1, PP2, and PP4). The remaining amount of increase of charge current is not understood fully at this time although it may be similar to the effect noticed on an IMP battery which was ground tested during 1964/1965.

In summary, the observed performance parameter data begin to drift shortly after launch until, six months later, they are about 2 to 3 percent in error. Table B2 compares the performance parameter data at May, 1964 (5 months after launch) before and after applying an appropriate correction factor (2 percent).

Table B2

Performance Parameter Data

Parameter	1 May 1964 Observed Data	Adjusted Data	Nominal
1. System Voltage, volts	20.0	19.5	19.6
2. +50v Regulated, volts	51.5	50.2	50.0
3. Battery Charge, ma	75	60	-
4. S/C Current, amps	1.89	1.80	~ 1.8
5. Skin Temp. 1, °C	43.5	41.0	-
6. Rb Gas Cell, °C	50.0	48.5	-
7. Battery, °C	23.5	22.0	-
8. +12v Regulated, volts	12.4	12.1	12.0
9. Paddle Current, amps	2.85	2.75	-
10. Paddle Temp., °C	+7.0	+1.5	-
11. Skin Temp. 2, °C	+20.0	+18.5	-
12. +7v Regulated, volts	7.2	7.0	7.0
13. Rb Lamp, °C	119 (max)	116 (max)	-
14. Prime Conv., °C	43	40.5	-
15. Transmitter, °C	30	27	-

It should be kept in mind that all curves appearing in the main text of this report are NOT corrected for the apparent analog oscillator drift but are based on the observed telemetered values.

Appendix C

IMP-I Performance Parameter Data – September 1964 to March 1965

Days After Launch	Date	PP1 (volts)	PP2 (volts)	PP3 (ma)	PP4 (amps)	PP5 (°C)	PP6 (°C)	PP7 (°C)	PP8 (volts)	PP9 Min (amps)	PP9 Ave (amps)	PP9 Max (amps)	PP10 (°C)	PP11 (°C)	PP12 (volts)	PP13 (°C)	PP14 (°C)	PP15 (°C)	SASA (deg)	Spin Rate (RPM)
302	9/23/64	19.7	50.9	12	1.85	41	49.5	20.8	12.2	2.37	2.70	2.97	+8	22	7.1	110	48	30	65	20.0
305	9/26/64	19.7	50.9	18	1.85	39.9	49.6	21.7	12.2	2.43	2.65	2.92	11	22.2	7.1	111	47.6	30		
309	9/30/64	19.7	50.9	18	1.87	35.4	49.5	18.8	12.2	2.43	2.64	2.92	10	21.3	7.1	112	45.1	27.4		
*312	10/3/64	19.7	50.9	14	1.82	35.3	49.6	21.0	12.2	2.43	2.59	2.92	9	21.8	7.1	110	45.4	29.2	72	19.8
*352	11/12/64	19.7	50.8	16	1.81	16.8	49.5	26.9	12.1	2.37	2.63	3.13	12	16.5	7.1	109	37.3	32.9	~103	19.7
*357	11/17/64	19.7	50.9	18	1.83	18.5	49.7	31.0	12.2	2.37	2.73	3.13	14	18.2	7.1	108	38	36.8	~105	19.72
*360	11/20/64	19.7	50.9	18	1.82	19.7	49.6	33.5	12.2	2.43	2.75	3.13	15	18.6	7.1	108	38.5	38.5	~108	19.75
*366	11/26/64	19.7	50.9	18.5	1.83	21.7	49.7	37.5	12.2	2.37	2.80	3.13	14.4	20.0	7.2	108	40.1	42.7		~19.8
*369	11/29/64	19.8	51.0	18	1.84	22.0	49.6	38.7	12.3	2.37	2.83	3.18	14.5	20.3	7.2	108	40.4	44	112	19.95
*372	12/2/64	19.7	50.9	18	1.84	22.6	49.6	39.4	12.2	2.37	2.82	3.13	14	20.5	7.2	107	40.7	46	115±2	20.0
*375	12/5/64	19.75	51.0	18	1.84	22.9	49.6	40.5	12.2	2.43	2.82	3.28	12	20.5	7.2	107	40.6	46.5	115±2	20.1
*379	12/9/64	19.8	51.1	18	1.85	23	49.6	42	12.2	2.37	-	3.07	11	22	7.15	~108	41	48	115±2	-
*385	12/15/64	19.8	51.0	18	1.85	24	49.7	43.3	12.3	2.32	2.72	3.02	11	22	7.2	~109	42.6	50.4	120	20.4
396	12/26/64	19.6	50.9	6	1.91	20	43	39.8	12.2	2.26	2.55	2.81	7	19	7.1	110	33	48	124	20.8
461	3/1/65	19.6	50.5	4	1.80	18	45	34	12.1	2.32	2.60	2.97	11	17	7.1	108	35	43	~115	23.2
475	3/15/65	19.6	50.2	4	1.89	14.5	25	26	12.1	2.26	-	2.81	12	14	7.1	-	18	30	~108	23.5
487	3/27/65	19.6	50.2	4	1.80	9	7	17	12.1	-	-	-	11	11	7.1	54	3	12	99	23.7
533	5/12/65 One minute of data recorded; thereafter, tracking efforts were terminated.																			

SASA is Spin Axis-Sun Angle.
Temperatures are not stabilized (due to intermittent operation) unless noted by an asterisk (*).
Uncorrected for analog oscillator drift.

Appendix D

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University of California, Ion Chamber:

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