NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Memorandum 33-615*

# *Mariner 9 Solar Array Design, Manufacture, and Performance*

*E. A. Sequeira*

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**JET PROPULSION LABORATORY**

**CALIFORNIA INSTITUTE OF TECHNOLOGY**

**PASADENA, CALIFORNIA**

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# PREFACE

The work described in this report was performed by the Guidance and Control Division of the Jet Propulsion Laboratory.

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ABSTRACT

The mission of Mariner 9, the first spacecraft to orbit another planet, was to make scientific observations of the surface of Mars. Throughout this unique mission, the Mariner 9 solar array successfully supported the power requirements of the spacecraft without experiencing anomalies. Basically, the design of the solar array was similar to those of Mariners 6 and 7; however, Mariner 9 had the additional flight operational requirement to perform in a Mars orbit environment mode. The array special tests provided unique information on the current-voltage characteristics and array space degradation. Tests indicated that total solar array current degradation was 3.5 percent, which could probably be attributed to the gradual degradation of the cover glass and/or the RTV 602 adhesive employed to cement the cover glass to the solar cell. Flight data also verified that the solar panels had successfully survived the Sun occultation periods without additional degradation or failures. Final array tests indicated very close correlation between predicted and actual flight array performance with no significant additional current degradation.

# I. INTRODUCTION

The Mariner '71 (Mariner 9, the first spacecraft to orbit another planet) had as its mission the scientific observations of the surface of Mars. The uniqueness of this mission required many of the spacecraft subsystem designs and/or operational modes to be different than previously experienced by earlier Mariner's. This report summarizes the design and operation of a part of the Mariner '71 power system, the solar array. Basically, the design of the solar array was similar to that successfully flown on the Mariner '69 (Mariner 6 and 7 spacecraft) mission; however, Mariner 9 had the additional flight operational requirement to perform in a Mars orbit environmental mode. Special inflight engineering tests were conducted during the latter part of the Mariner '71 flight that provided the JPL solar array design engineer with better information on solar array deep space performance than previously experienced. Detail study at this time was particularly interesting because of the small but unexpected array degradation noted during the flights of Mariners 6 and 7. There were indications that these earlier arrays may have lost approximately 3 to 5 percent solar array current output capability during transit to Mars and that the cause of this degradation could not be relegated to electron or proton impingement. The Mariner '71 mission provided an opportunity to use the same design and materials in the same deep space environment to gather further statistical information on this phenomenon.

Direct interrogation of the Mariner arrays through flight telemetry is normally restricted during missions because of the design of the power subsystem and the placement of the associated current and voltage output. The Mariner power subsystem employs zener diodes to shunt regulate the array voltage output during the colder portions of the mission. Array zener limiting begins approximately two days after launch. Past this point direct monitoring of the array can only be observed if serious array electrical performance degradation is experienced. During zener limiting only <u>indirect</u> array evaluation is normally possible through the monitoring of the special 3 solar cell "short circuit current - open circuit voltage (Isc-Voc) transducer." How well the Isc-Voc transducer served as a valid indicator of Mariner solar array capability after long term deep space exposure could only be hypothesized prior to Mariner 9. However, because of the opportunities provided by the three special engineering tests noted earlier, this information plus other important array design data were obtained. A summary of Mariner 9 solar array flight intelligence compiled by these inflight tests and discussed in this report include:

(1) The long term correlatibility of solar array and Isc-Voc transducer performance.

(2) Verification that adequate analytical tools exist to closely predict the electrical performance characteristics of a solar array in deep space.

(3) The development of data to support the contention that the Mariner '71 and probably the Mariner '69 solar arrays really experienced only 3 to 5 percent electrical degradation in transit to Mars. This data suggests that the degrading environment was not electron or proton degradation, but more likely the result of ultra-violet effects on the solar cell assemblies.

## II. SOLAR ARRAY DESIGN AND MANUFACTURE

### A. Solar Panel Structure

The Mariner 9 solar panels were similar in construction to Mariner 6 and 7 panels except for a minor modification of attachment hardware to accommodate extended outriggers that were required to extend the solar panels further from the spacecraft bus. Maintaining the basic Mariner 6 and 7 design permitted the Mariner '71 program to utilize solar array spare hardware remaining from the Mariner '69 program. A total of seven new solar panel substrates were fabricated by Zero Manufacturing Company of Los Angeles, California. Two Mariner 6 and 7 residual panels were refurbished and requalified for the Mariner 9 program. A photograph of the panel structure is shown in Fig. 1. The substrate consists of (0. 127 mm) aluminum alloy facing reinforced with lateral (0. 0762 mm) corrugations which provide rigidity across the panel. Two spar assemblies extended across the length of the panel along with cross members, which was required for increased torsional rigidity, make up the main structural support of the units. The face sheet and the corrugations are bonded to the spare assembly with Shell Epon 913 epoxy adhesive. The spar beams supported the zener diodes and provided the heat sink necessary for diode temperature dissipation. During launch the four panels of the Mariner 9 solar array are tip-latched together as shown in Fig. 2. After injection into space, the latches are released through pyrotechnic activation and the panels are deployed through a deployment damper mechanism located on the panel outrigger assembly.

The backside of the panel was painted with Cat-A-Lac white paint. The paint has a total normal emittance of 0.85 and a solar absorptance of 0.20 which was selected to minimize the solar array temperature during the early launch phase. The paint is an epoxy base, extremely durable and amenable to handling. Qualification testing of this paint included elevated temperature and outgassing tests. The results of these tests are shown in Table 1.

The cell surface of the substrate was coated with (0. 0508 mm) fiber glass cloth, impregnated and bonded to the surface by Epon 956 epoxy adhesive. This composite-fiber glass adhesive system was developed and qualified on the previous Mariner program and found to be an excellent dielectric insulating material for solar panel electrical components.

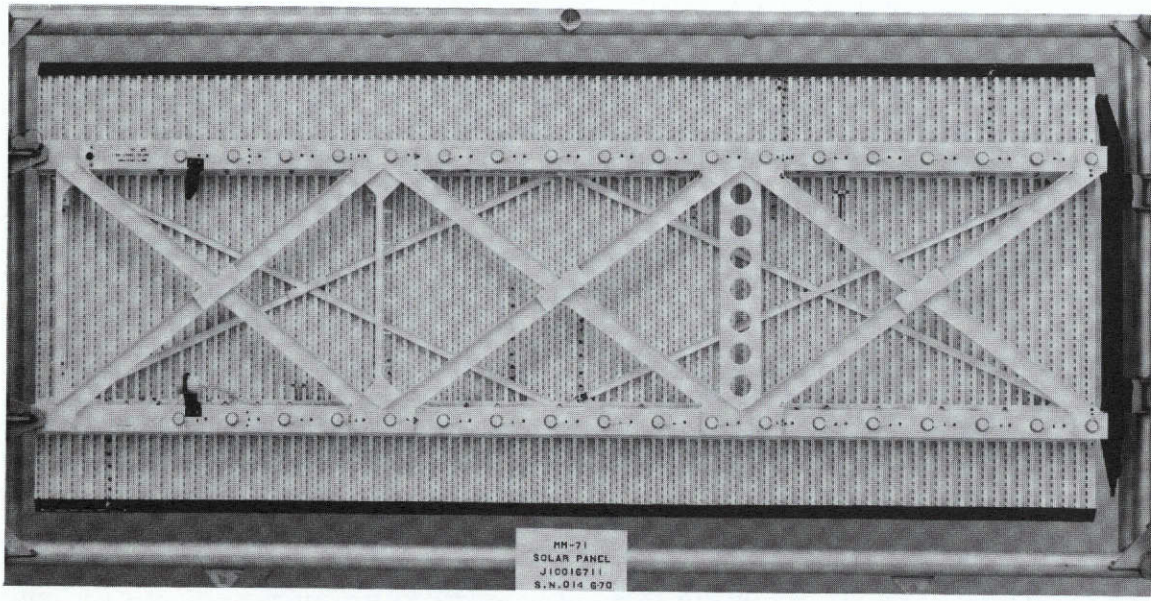



Fig. 1. MM-71 Solar Panel

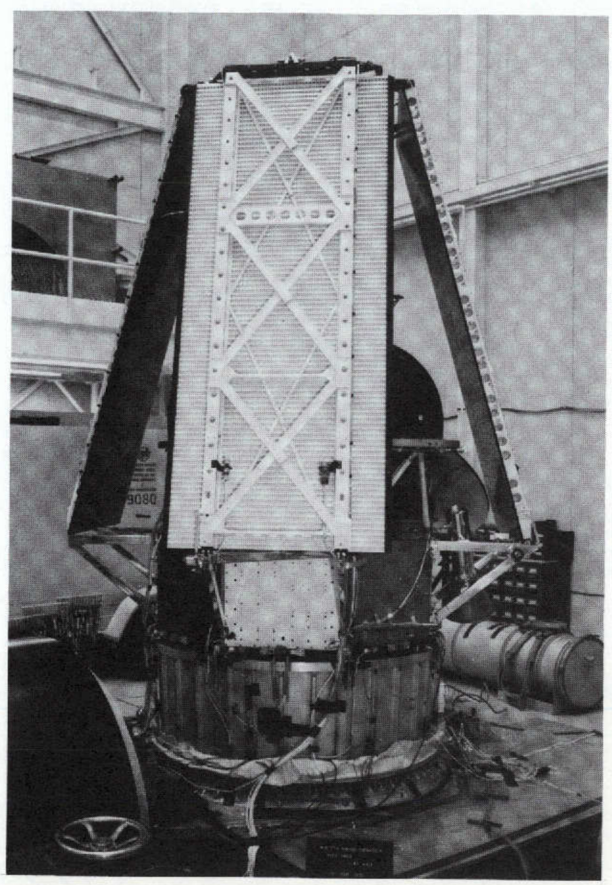


Fig. 2. Spacecraft With Solar Panels Tip-Latched

Table 1. Outgassing Characteristics of CAT-A-LAC White

| Sample No. | Time-Temperature Cycle in Air | Outgassing Characteristics | |
|---|---|---|---|
| | | Weight Loss (percent) | Volatile Condensible Material (VCM) (percent) |
| 1 | 24 hrs @ 93°C | 3.77 | 0.0004 |
| 2 | 1 hr @ 121°C | 2.96 | 0.0004 |
| 3 | 8 hrs @ 121°C | 1.43 | 0.0001 |
| 4 | 24 hrs @ 121°C | 1.05 | 0.0001 |

The solar panel substrate assembly was delivered to JPL painted and coated with the dielectric insulator. Acceptance of the substrate for assembly into a solar panel was based upon JPL visual inspection, dielectric insulation test and test results of adhesive and paint samples developed during the fabrication of each substrate. Upon fabrication completion, the substrates were subjected to a weight loading test to verify corrugation-spar bonding integrity.

## B. Solar Panel Components

1. Solar cells. The Mariner 9 solar array consists of 17,472 photovoltaic solar cells. The cells are 2 X 2 X 0.046 cm, N on P Phosphorous diffused silicon with a base resistivity of two ohm-centimeter. The ohmic contacts of the cells are solder coated silver-titanium. The cells were manufactured by Heliotek Corporation, Sylmar, California, in accordance with JPL specification SS500608. The selection and electrical matching of the cells were accomplished with an X-25L Solar Simulator at one AU sunlight intensity equivalent, using balloon flown standard solar cells to set the intensity. Power output requirement of the average solar cell was 59.0 milliwatts at 140 $mW/cm^2$ and 28°C and a minimum acceptable output of 54.3 milliwatts. MIL-STD-105D, normal for an Acceptance Quality Level (AQL) of 2.5 percent defective, was used for acceptance criteria. A total of 38,000 cells were procured for the program. Cell screening and acceptance was tied closely to cell manufacturing lots. 200 cells from each 5000-cell lots were selected at random and subjected

to a series of electrical and environmental tests. The tests were performed in accordance with JPL specification SS500608. The specified cell tests are briefly summarized below in the sequence they were conducted.

(1) Temperature and humidity

The cells were exposed in a humidity test chamber to 0° C and 95 percent humidity for a period of 4 hours. The temperature was raised to 65°C at the same humidity level and was left for a 48-hour period.

(2) Vacuum-temperature

The cells were placed in the vacuum chamber at a pressure of $10^{-5}$ mm of Hg and a temperature of -125° C for 4 hours and at +125° C for a 12-day period.

(3) High temperature

The cells were placed in a test chamber and exposed to a temperature of 145° C for a 36-hour period.

(4) High temperature soak

The cells were subjected to a high temperature of 215° C for a 2-minute period.

(5) Thermal shock

The cells were subjected to five temperature cycles between the extremes of +135 and -196° C. The cells remained at the high and low temperature extremes for a 1-hour period. The temperature rate change did not exceed 50° C per minute.

(6) Cell contact strength

Each cell of the AQL sample was tested for contact strength. The test requirements were for the cell to be capable to withstand a minimum 500-gram pull test on both "N" and "P" contacts when a wire is soldered to the contact and the force applied in a direction perpendicular to the cell surface. According to the AQL inspection criteria, a maximum of 10 failures of a sample size of 200 cells is considered acceptable. A contact strength of 1000 grams or greater was exhibited on 96 percent of the cells tested.

Prior to the cell contact strength test shown in (6) above, all solar cell AQL samples were electrically evaluated after each test to evaluate effective degradations due to environmental exposure. A change of cell performance greater than 5 percent was cause for solar cell rejection. The results of the electrical test following each environmental test is shown in Table 2.

2. Solar array submodules. A Mariner 9 solar array is an assembly of 4 or 5 matched solar cells electrically interconnected in parallel by 0.0762-mm tin plated kovar bus bars. The submodule design of a Mariner 9 solar array was developed during the Mariner 6 and 7 spacecraft program. This design had been developed to optimize the following array parameters: reliability, cost, ease of fabrication and the utilization of the maximum available area of the solar panel. Four and five-cell submodules were fabricated for the program. Interconnection of cells and bus bars was accomplished through soldering, using a tunnel oven soldering process. The cells and the kovar bus bars were assembled in a soldering fixture and the unit was processed through a tunnel oven which heated the fixture to temperatures above the melting point of solder. The soldering fixture and the resulting submodule assembly is shown in Fig. 3.

Table 2. Electrical Output Change Resulting from Environmental Tests (Percent from Previous Test)

| Lot Number | Temperature and Humidity | Vacuum Temperature | High Temperature | High Temperature Soak | Thermal Shock |
|---|---|---|---|---|---|
| 1 | 0 | -1.2 | +1.6 | -0.9 | -2.0 |
| 2 | +0.7 | -0.1 | -0.6 | +1.0 | -3.9 |
| 3 | -1.3 | +0.3 | +0.9 | -0.4 | -4.4 |
| 4 | -0.8 | +0.2 | +1.1 | +0.9 | -3.5 |
| 5A | -0.4 | +0.8 | +0.3 | 0 | -2.2 |
| 6 | +0.8 | -0.7 | +0.2 | +1.1 | -3.8 |
| 7 | -0.2 | -1.1 | +1.1 | -0.1 | -3.5 |
| 8 | +0.6 | -0.7 | +0.5 | +0.3 | -1.6 |
| AVERAGE CHANGE | -0.08 | -0.31 | +0.64 | +0.24 | -3.10 |

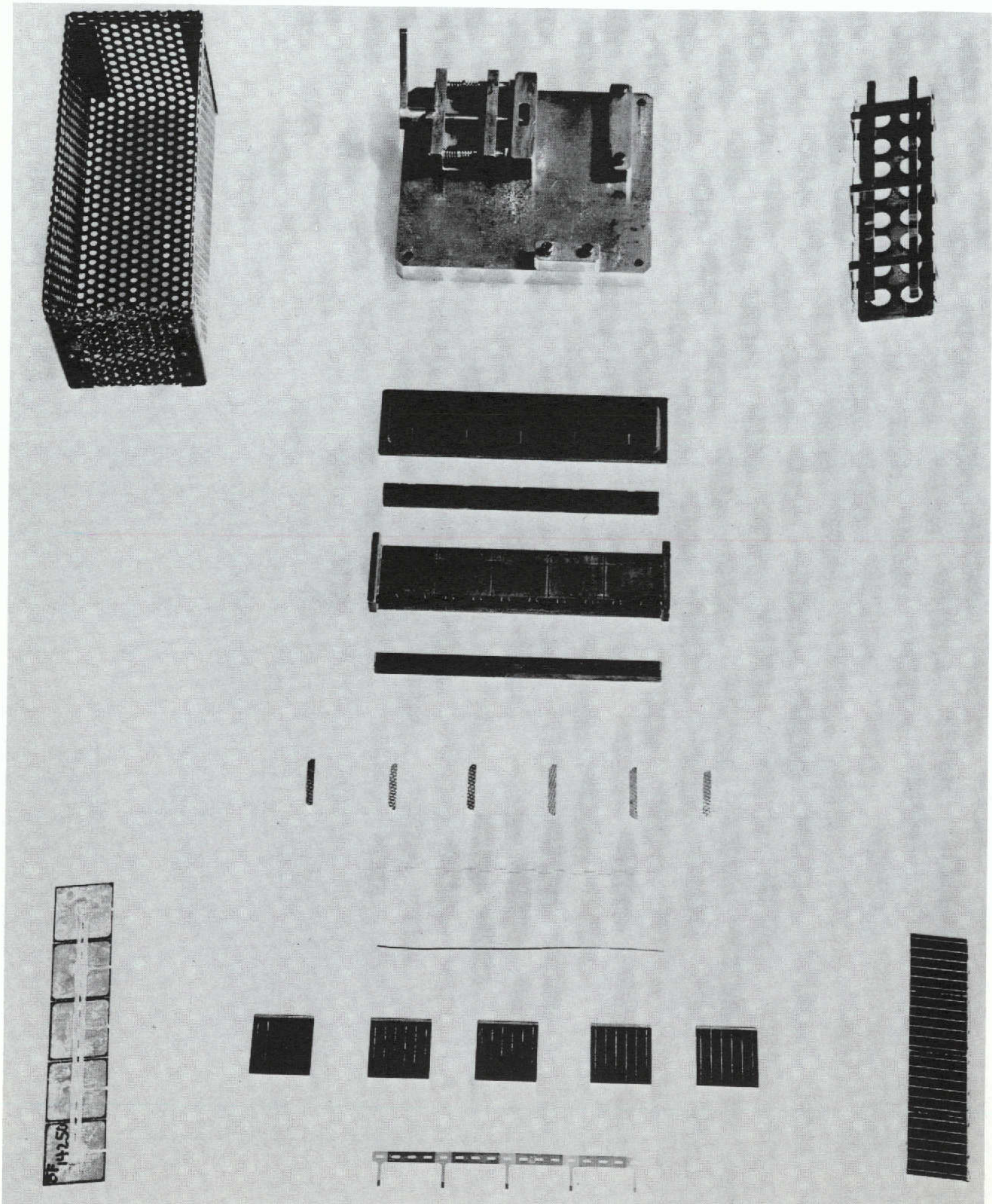


Fig. 3. Soldering Fixture and Submodule Assembly

One of the more significant differences between the Mariner 9 and the previous Mariner program was the redesign of the soldering fixture which was greatly improved and simplified. The following improvements were incorporated into the Mariner 9 tunnel oven submodule soldering fixture design:

(1) The soldering fixture rail was modified to prevent tooling marks from occurring in the n-contact solder fillet.

(2) The solar cell spacer height was reduced to prevent interference with the p-contact.

(3) The slot for the spacer associated with the No. 5 cell was enlarged to permit easy removal of the spacer.

(4) The alignment clips on the solder boat cage were reversed to permit meshing with the tunnel oven drive belt.

(5) The solder boat cage perimeter was enlarged slightly to permit ease of solder boat assembly.

(6) The p-contact tab alignment notch in the boat was relocated to the center position to reduce the buildup of tolerances.

A total of 7,049 submodules were fabricated for the solar panel program at a daily production rate of approximately 150 submodules. Table 3 shows the submodule fabrication yield. Two percent of all submodules fabricated were subjected to engineering evaluation tests which included electrical measurements, N and P contact peel strength test and thermal shock test. The thermal shock test consisted of three temperature cycles conducted in accordance with the following sequence:

(1) Visual inspection

(2) Electrical test

(3) Immerse in Liquid Nitrogen for 10 seconds

(4) Immerse in boiling water for 10 seconds

(5) Visual inspection

(6) Electrical test.

No electrical contact failures occurred during the submodule screening tests. The average electrical degradation of the submodule was 1.13 percent. The

Table 3. Submodule Fabrication Yield

| | |
|---|---|
| Total fabricated | 7,049 |
| 5-Cell fabricated | 4,715 |
| 4-Cell fabricated | 2,334 |
| Total submodules which contained marginal defects and were accepted by MRB decision | 353 |
| Total rejected submodules | 627 |

average p-contact peel strength was 1227 grams and the average n-contact peel strength was 3954 grams, which is significantly better than the minimum requirement specified of 500 grams. After the submodule soldering operation was complete, the submodules were identified by a serial number and processed for the application of cover glass filters.

The cover glass filters, procured from Optical Coating Laboratory, Santa Rosa, California, were similar to the type flown on Mariner 6 and 7 spacecraft. The cover glass consisted of 0.508-mm thick, 2 cm by 2 cm, 7940 fused silica substrate material coated with an anti-reflective coating and a multilayer interference filter with a cutoff at 410 millimicrons wavelength. Prior to assembly, the cover glass filters were subjected to screening tests on a 1-percent sampling basis. The tests included spectral characteristics measurements, humidity, durability and coating adhesion tests. The cover glasses were cemented to the solar cells with General Electric RTV 602 adhesive.

## C. Solar Panel Layout

The Mariner 9 solar panel was fabricated by Electro-Optical Systems of Pasadena, California. The solar panel layout is shown in Fig. 4. The layout is identical to the solar panel layout of Mariners 6 and 7. The selected configuration utilizes the maximum available panel area, provides increased reliability by employing the string folded concept and a decrease of magnetic fields by placing adjacent current paths to flow in opposite directions. The solar array

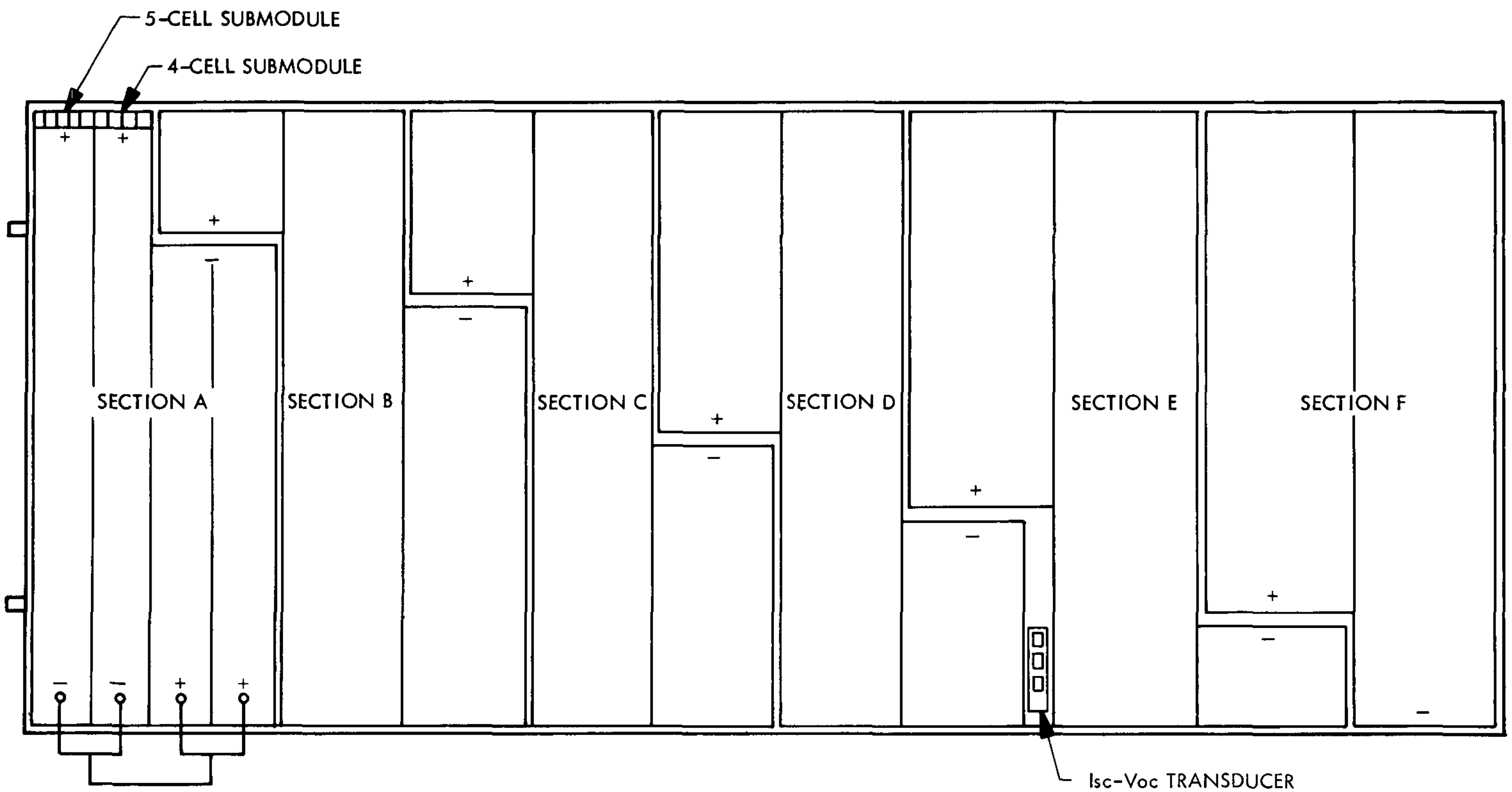



Fig. 4. Solar Panel Layout

of the four solar panels were designed into 24 isolated electrical sections. Connected in parallel were 224 cells and 78 cells connected in series. The individual panel was configured in six isolated electrical sections. Each section consisted of two strings made up of 4- or 5-cell submodules. Silicone rubber adhesive RTV-41 manufactured by the General Electric Company was used to bond the submodules to the substrate. The end wires of the electrical sections were soldered to specially designed terminal circuit boards. The boards consisted of a flat copper conductor produced by chemical etch, bonded to the fiber glass epoxy boards. Feedthrough holes in the substrate directed the wires to the backside of the panels and were routed to the Bendix type DS311-22-55S connector. The wiring harnesses of the solar panels were prefabricated on a mock-up board. This approach was used to reduce possible damage to the panel substrate. The harness was installed on the panel and secured to the main spars by cable clamps.

## D. Zener Diodes

The flight configuration of the Mariner 9 solar array shunt regulator required six Dickson DZ30808G zener diodes connected in series for each electrical section of a panel as shown in Fig. 5. Since there are six parallel sections per panel and four panels per array, there are a total of twenty-four parallel circuits of six series zeners per circuit or a total of 144 zeners per array. The diodes are mounted and torqued to the underside of the panel box beam spars that provide the heat sink for diode temperature control. The diodes are screened to provide a rated value of 8.25 volts plus or minus 2 percent at one ampere and 90°C stud temperature. A series string of 6 of these zeners was utilized to limit the voltage output of each panel electrical section to less than 51 volts. The thermal and electrical characteristics of each six zener diode series string, developed using composite I-V characteristics of the twenty-four parallel circuits of zeners as a function of spar temperature at one ampere, are seen to be 0.0213 volts/°C. Thermal analysis of the Mariner 9 solar panel design shunt has shown that the spar temperature (where the zener diodes are mounted) would be lower than the solar cell temperature by approximately 15 degrees and that the difference will vary as a function of solar intensity incident on the solar cells. This relationship is presented in Fig. 6.

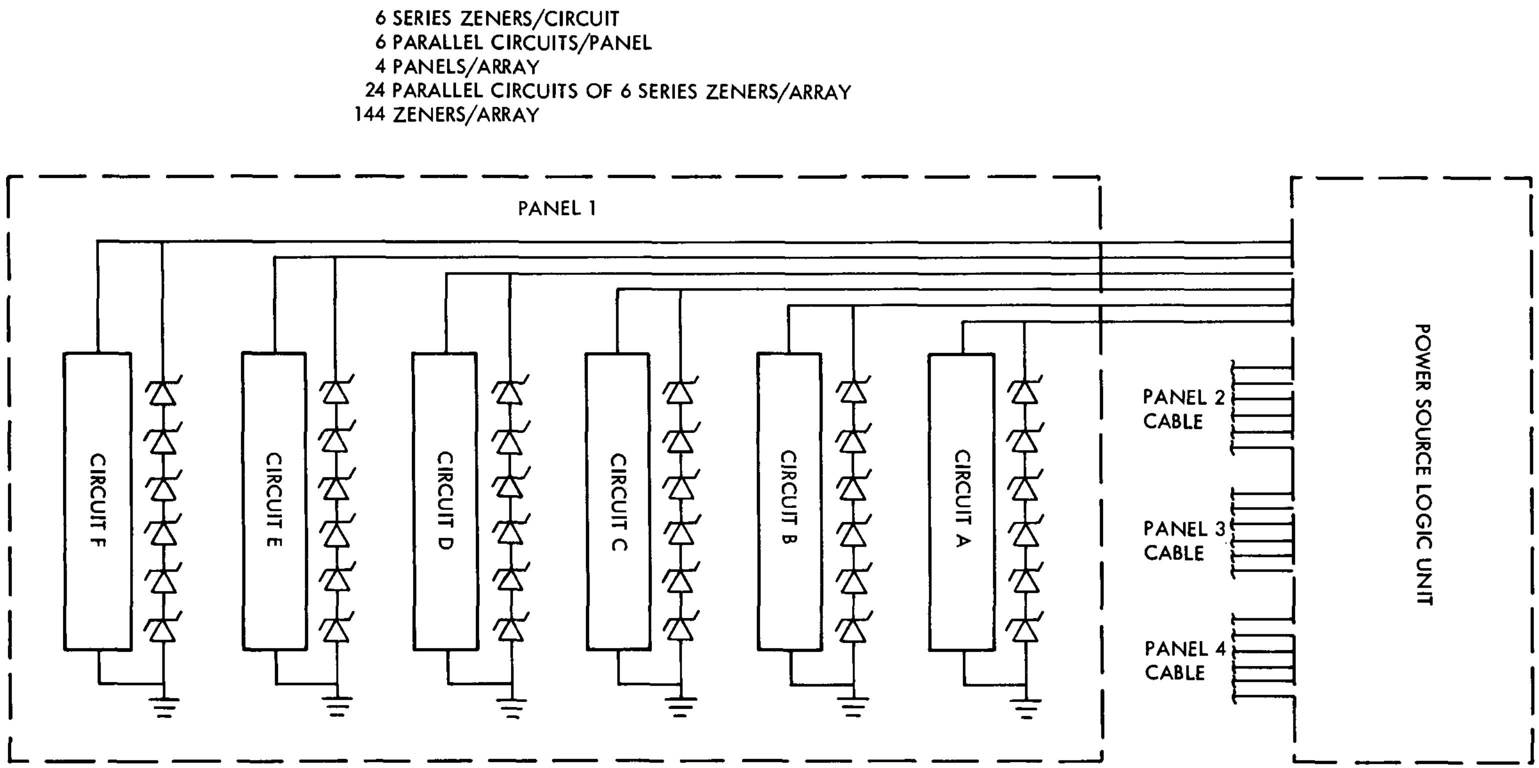



Fig. 5. Mariner 9 Solar Array-Zener Diodes Schematic

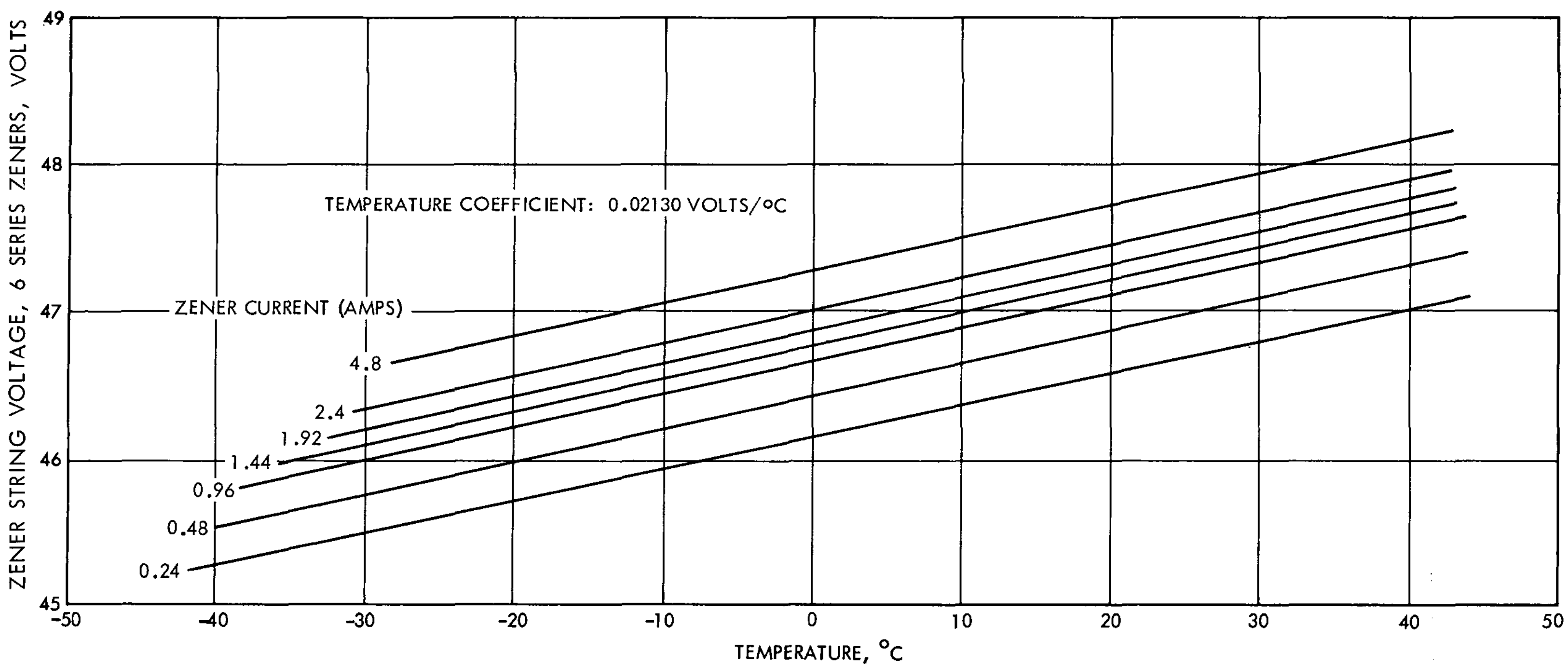



Fig. 6. Zener Diode String Voltage as a Function of Spar Temperature for Different Zener Currents

Figure 7 shows an example of the effects of zener regulation on the solar array I-V characteristics. This example would correspond to the anticipated electrical output characteristics of the Mariner 9 array on day 141 of the mission.

## E. Solar Array Transducers

Information on the Mariner 9 solar array performance during Mars mission is provided by the following on-board array temperature and Isc-Voc transducers:

(1) Temperature transducer. Transonic T-4242 transducer located on the backside of the plus Y solar panel provided information on the solar panel temperatures. The location of the transducer is shown in Fig. 8. Due to the similarity of Mariner 9 to Mariners 6 and 7 and the knowledge gained from Mariner 6 and 7 flight, the Mariner 9 solar array temperatures were predicted to within 2° C of actual flight data. Figure 9 shows predicted panel temperatures versus actual flight temperatures. The Mariner 7 solar panel had two transducers, one located on the inboard and the other on the outboard section of the panel. Measurements from the transducers indicated that the thermal excursion across the panel was approximately 2°C. It is assumed that Mariner 9 panels experienced the same type of temperature spread.

(2) Isc-Voc Transducer. The Isc-Voc transducer provided pertinent engineering information utilized in evaluating solar array performance during the mission. The utilization of Isc-Voc transducers on solar panels dates back to the Mariner 64 mission. The transducer consists of three standardized solar cells representative of the cells used to fabricate the solar panels. A number of improvements were made since Mariner 64 transducers, both in fabrication and calibration techniques. Prior to Mariners 6 and 7, the transducer resistive loads were located on the backside of the panels. Mariner 9 Isc-Voc transducer, like Mariners 6 and 7, incorporated all components on one fiberglass printed circuit board and the resistors were encapsulated in RTV 41 for protection against UV radiation damage. Figure 10 shows a photograph of this Isc-Voc transducer assembly.

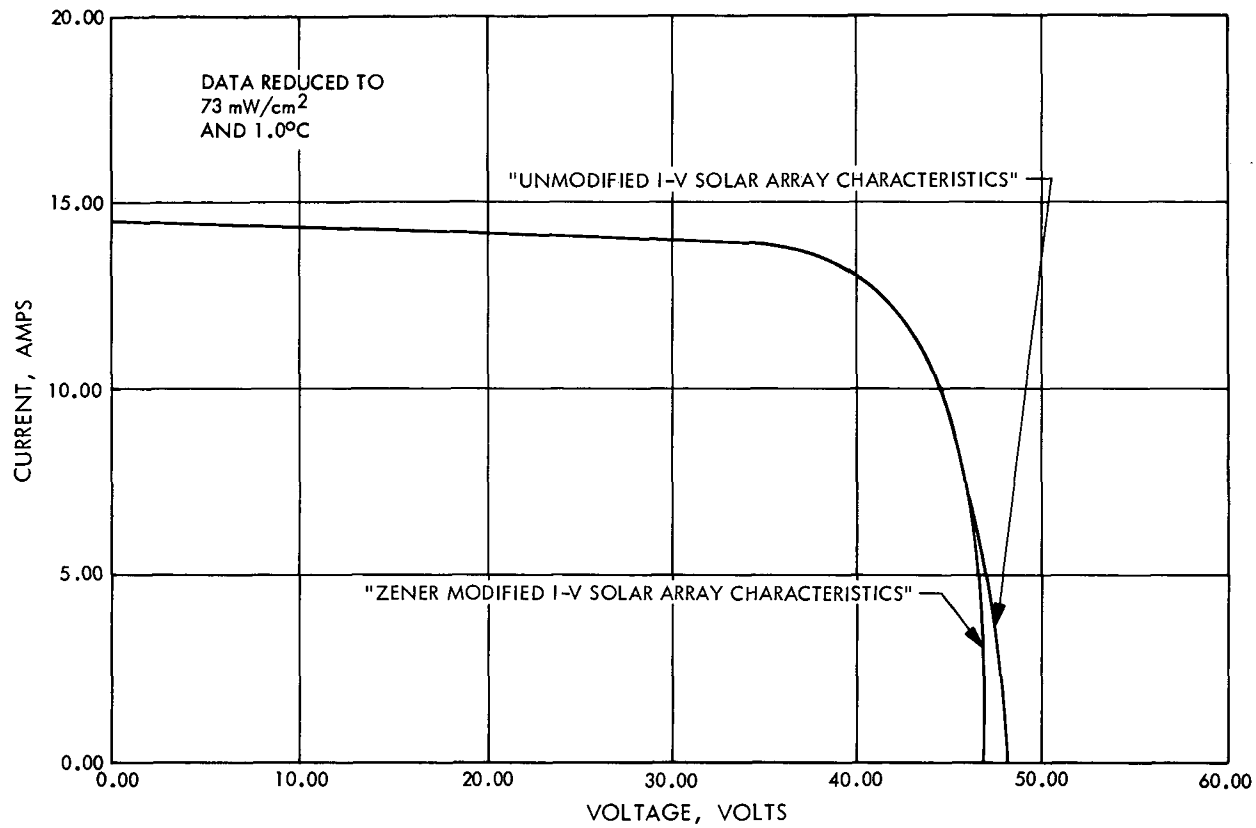



Fig. 7. Mariner 9 Anticipated Array Performance for Day 141 of Mission Showing Effects of Zener Regulation on I-V Characteristics

The cell resistors load two of the cells near their short circuit current (1.5 ohms) and one cell near its open circuit voltage point (1000 ohms). A schematic of the electrical connection is shown in Fig. 11. The two current cells differ in that before launch one cell is exposed to a dose of $1 \times 10^{16}$ e/cm$^2$ 1 MeV electrons which degraded the short circuit current output of the cell by approximately 50 percent and render it relatively impervious to further radiation damage as may be generated in flight by solar flares. Observation of the undegraded Isc and Voc cell then gives an indirect technique to aid in the assessment of the array short circuit currents and open circuit voltage. Comparison of performance between the degraded and the undegraded Isc cell provided information on space environments which may be degrading the array.

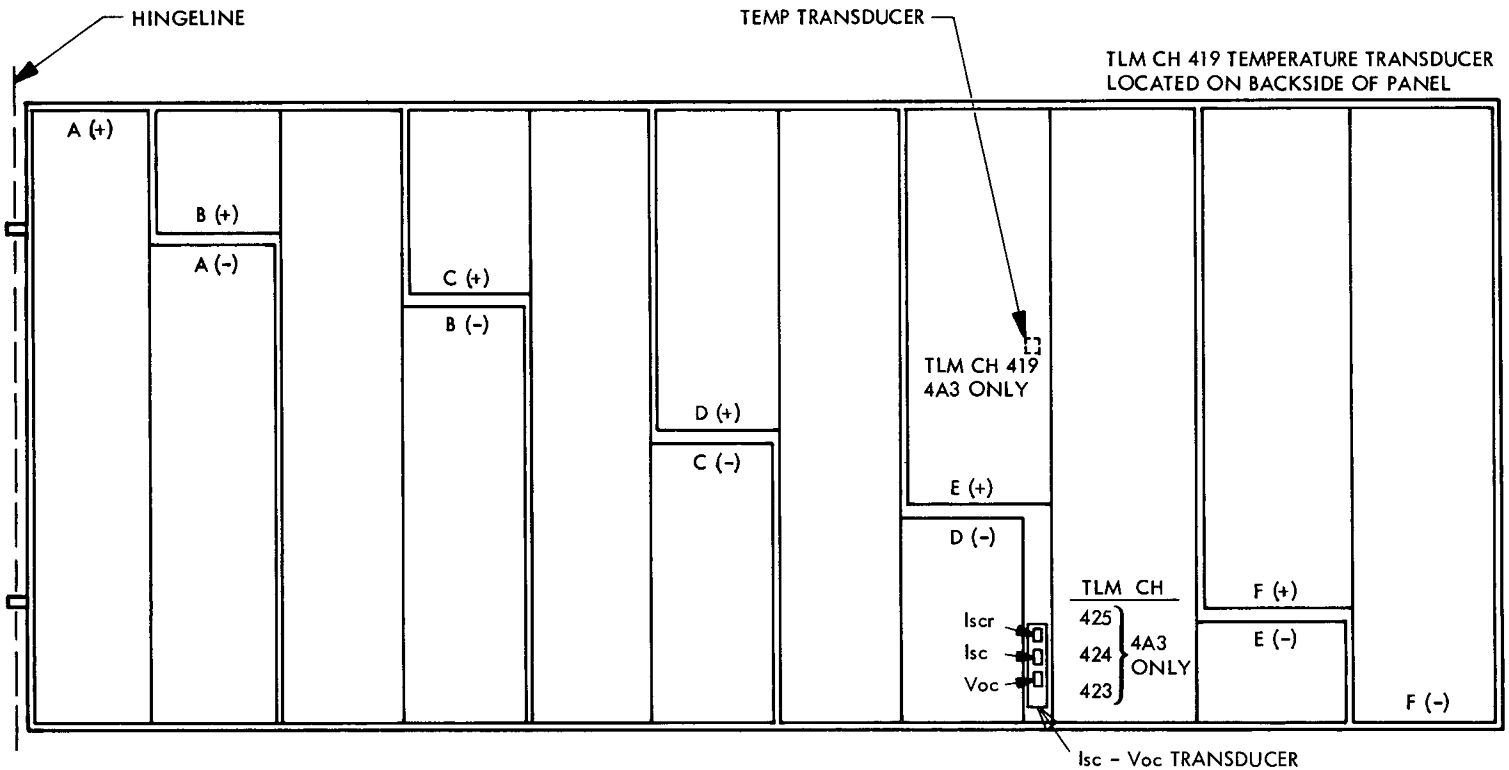



Fig. 8. Locations of Isc-Voc and Temperature Transducer on Mariner 9 Solar Panel

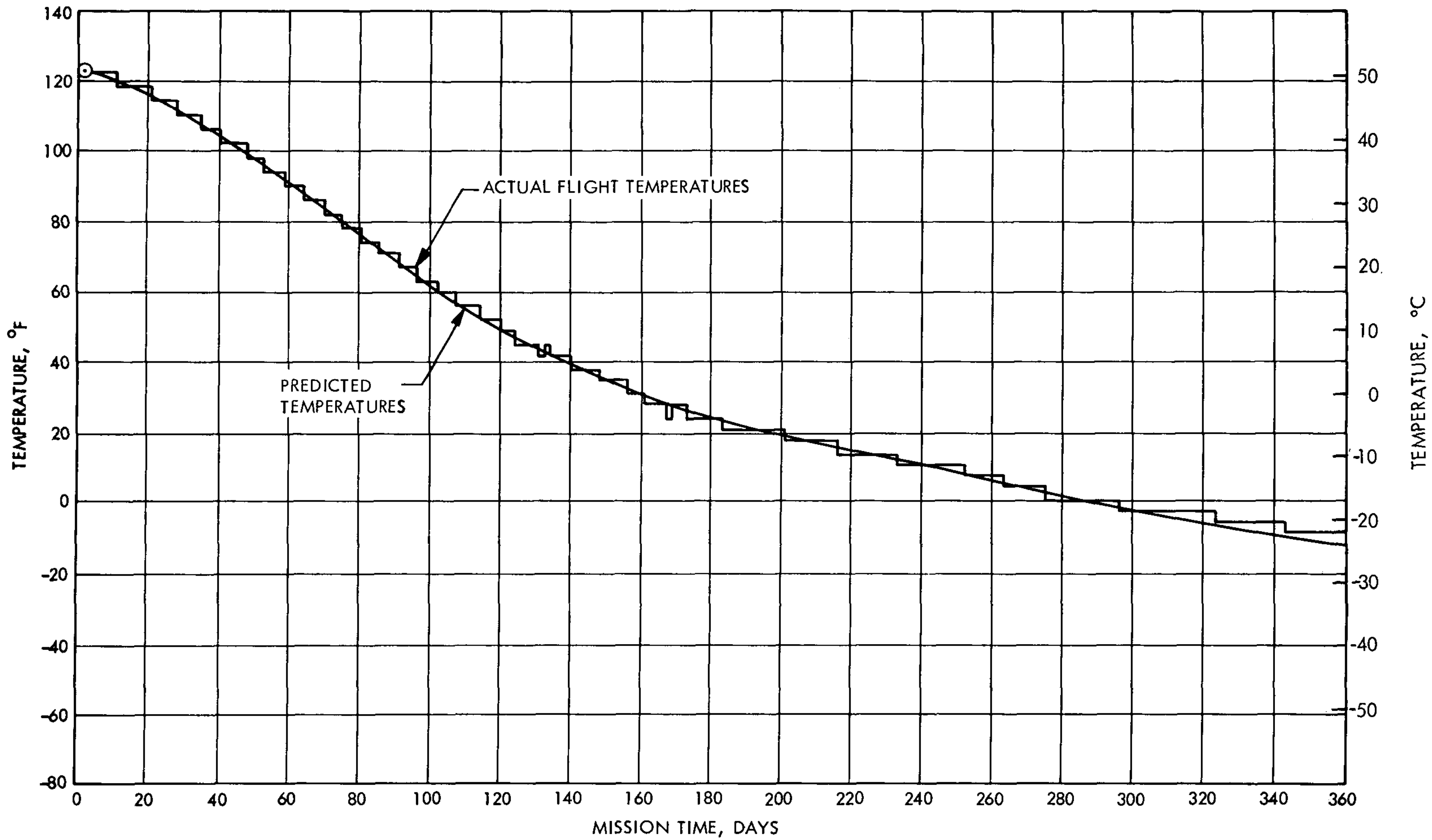



Fig. 9. Solar Panel Temperatures Recorded by Channel E419 Outboard Temperature Transducer

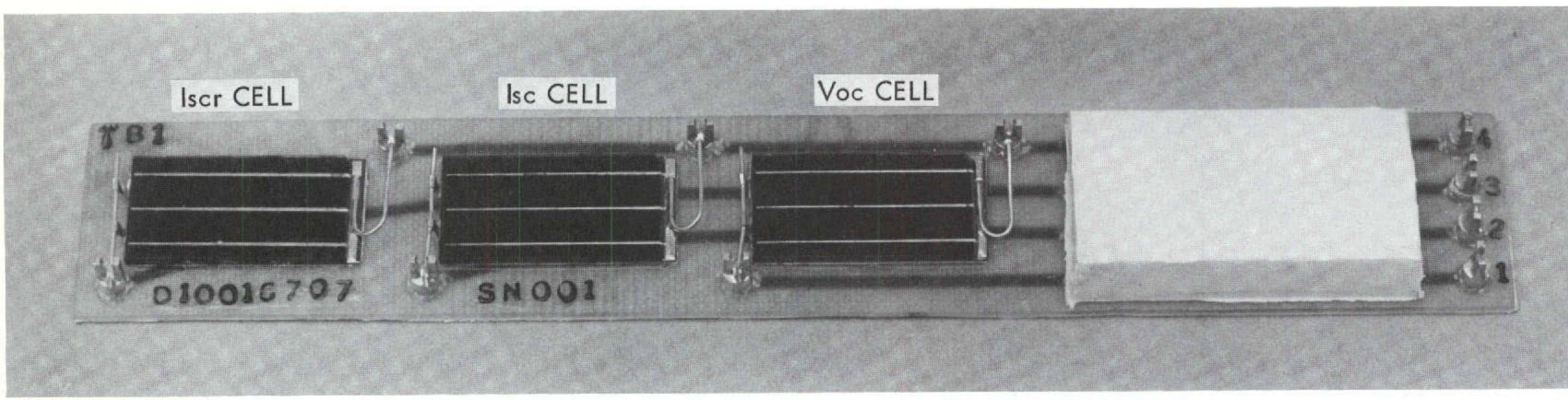



Fig. 10. Mariner 9 Isc-Vco Transducer Assembly

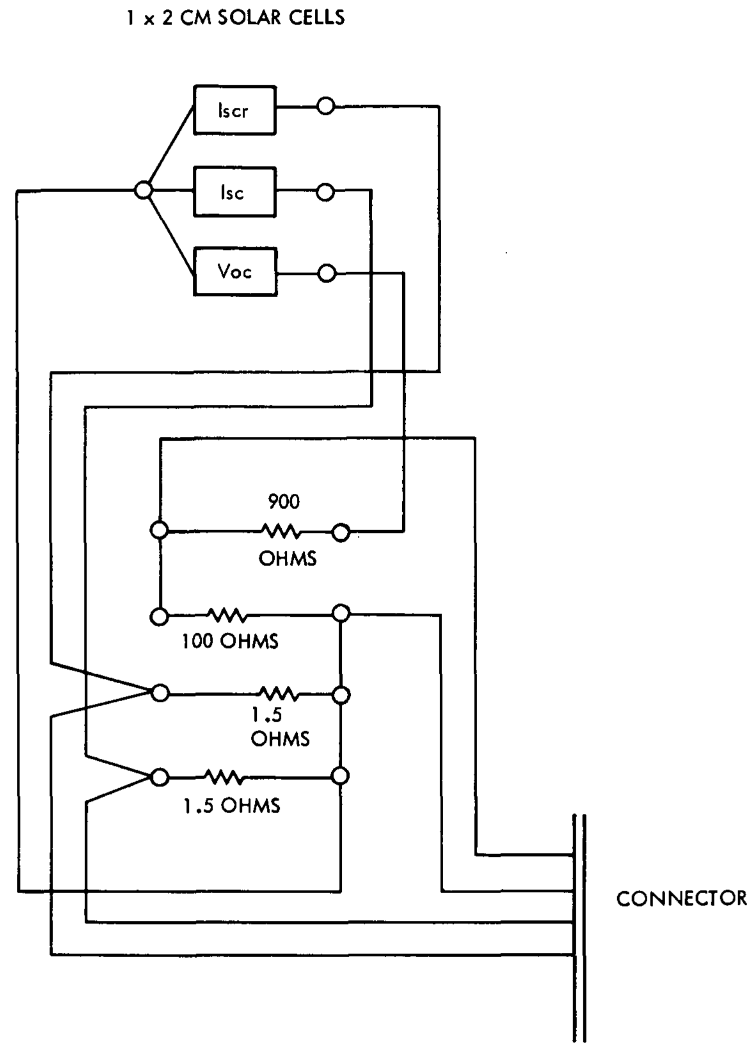



Fig. 11. Schematic Diagram of Isc-Voc Transducer

## III. SOLAR ARRAY ELECTRICAL CHARACTERISTICS ANALYTICAL MODELING AND PERFORMANCE PREDICTION TECHNIQUES

The solar array current and voltage performance characteristics are predicted for Mars encounter and during Mars mission using solar panel measurements made in sunlight at Table Mountain, Wrightwood, California, which are appropriately modified by Eqs. (1) and (2) below. Current-voltage characteristics of the electrical sections were measured. The relative solar intensity at the time of measurement was derived from balloon flight standardized solar cells that had spectral response characteristics similar to those of the solar cells on the panel. The solar panel temperature was determined from measurements of the open circuit voltage. The following equations were employed to extrapolate the data generated at Table Mountain to space conditions:

$$I_2 = I_1 + Isc_1 \left( \frac{x_2}{x_1} - 1 \right) + \alpha (T_2 - T_1) \tag{1}$$

$$V_2 = V_1 - \beta (T_2 - T_1) - \Delta I_{sc} R_s - K (T_2 - T_1) I_2 \tag{2}$$

$$\Delta I = \Delta Isc_1 \left( \frac{x_2}{x_1} - 1 \right) + \alpha (T_2 - T_1)$$

$$P_2 = I_2 V_2$$

where

$\alpha$ = Short circuit current temperature coefficient

$\beta$ = Open circuit voltage temperature coefficient

$I_1$ = Reference current coordinate

$V_1$ = Reference voltage coordinate

$Isc_1$ = Short circuit current of the reference data

$I_2$ = Extrapolated current coordinate

$V_2$ = Extrapolated voltage coordinate

$x_1$ = Reference span equivalent incident solar intensity

$x_2$ = Equivalent solar intensity to be investigated

$T_1$ = Reference cell temperature

$T_2$ = Cell temperature to be investigated

$R_s$ = Panel effective series resistance

K = Series resistance correction function for temperature

The primary design factors which were considered in the prelaunch evaluation of the Mariner 9 array anticipated performance were solar flares, temperature uncertainties, and environmental degradation resulting from long time UV and temperature exposure on the solar cells and other components. Other electrical design factors that needed to be considered during preflight performance prediction was the uncertainty in the extrapolating techniques used to predict power and temperature. The prelaunch performance design margins assigned to the Mariner 9 array included the following:

(1) Plus or minus 9°C temperature prediction uncertainty.

(2) Plus or minus 4 percent electrical measurement and prediction uncertainty.

(3) Minus 0.05 percent per day current degradation (based on early Mariner 6 flight experience).

(4) Minus 10 percent current degradation due to solar flares.

After launch, updated solar array performance predictions were made to reflect later performance of Mariners 6 and 7 and early flight characteristics of the Mariner 9 spacecraft.

The estimated solar panel outputs when measured at Table Mountain with the data reduced to launch, midcourse and Mars encounter conditions are shown in Fig. 12. The actual test results of the panels measured before and after the environmental qualification tests are presented in Table 4.

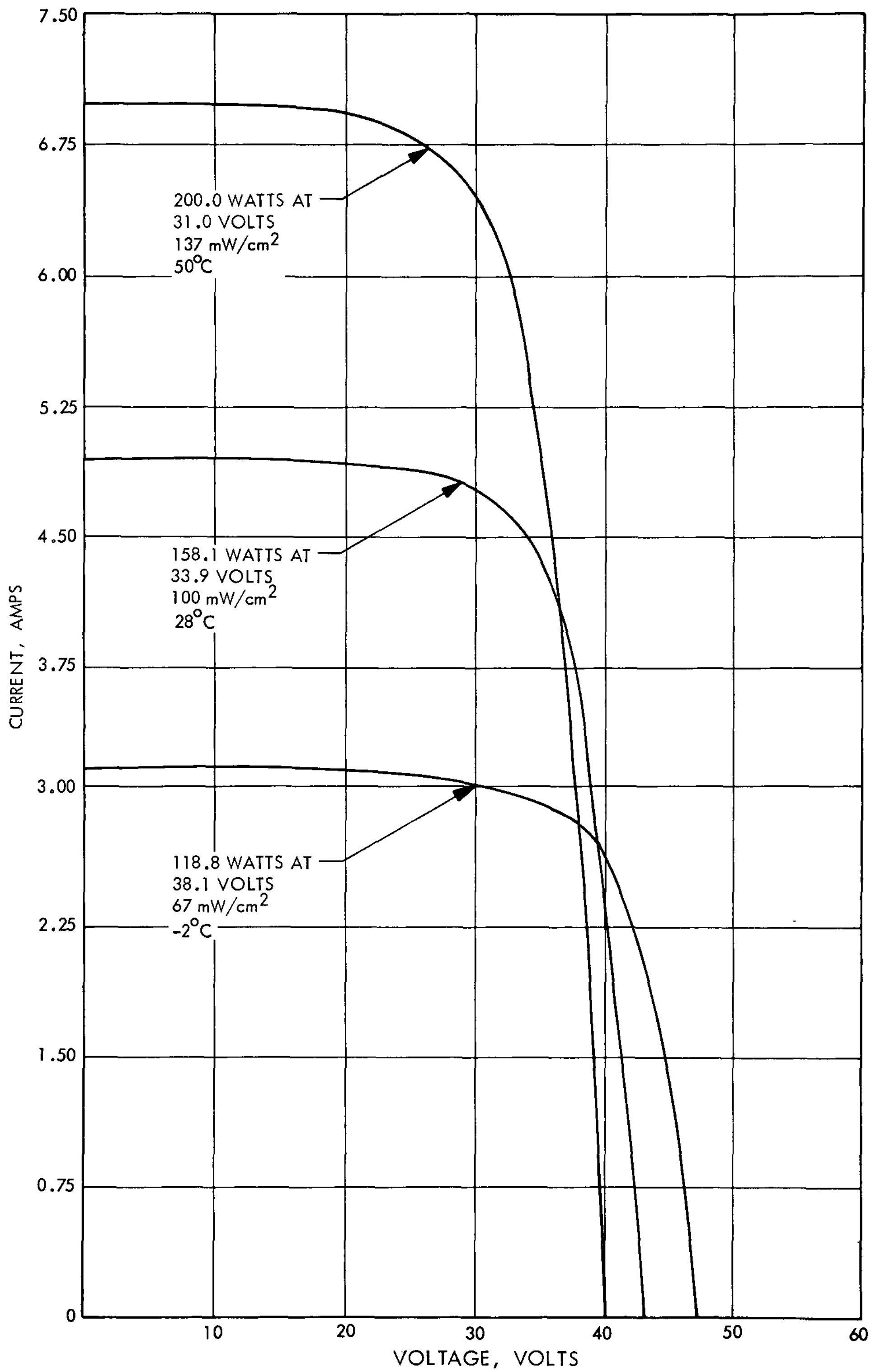



Fig. 12. Predicted Solar Panel Output for Launch, Midcourse and Mars Encounter

Table 4. Solar Panel Electrical Performance Before and After Environmental Tests

| Panel | Launch | | | |
|---|---|---|---|---|
| | Measured Output | | | |
| | Pre F/A | | Post F/A | |
| | Watts | Volts | Watts | Volts |
| 013 | 202.8 | 31.2 | 198.5 | 31.2 |
| 014 | 201.4 | 31.3 | 198.8 | 31.2 |
| 016 | 200.5 | 31.3 | 198.6 | 31.2 |
| 017 | 200.2 | 31.1 | 199.2 | 31.2 |
| ARRAY | 804.9 | 31.2 | 795.1 | 31.2 |
| **Panel** | **Encounter** | | | |
| | Measured Output | | | |
| | Pre F/A | | Post F/A | |
| | Watts | Volts | Watts | Volts |
| 013 | 120.7 | 39.3 | 117.7 | 38.9 |
| 014 | 119.5 | 39.5 | 117.6 | 39.0 |
| 016 | 119.3 | 39.2 | 117.8 | 39.0 |
| 017 | 119.0 | 38.9 | 118.2 | 39.0 |
| ARRAY | 478.5 | 39.2 | 471.3 | 39.0 |

## IV. ENVIRONMENTAL QUALIFICATION TESTS

The flight qualification tests of the solar panels were performed on one panel at a time and included thermal-vacuum, acoustic tests, sunlight stabilization tests and sunlight performance tests. Seven newly fabricated panels were subjected to the above tests and were conducted in accordance with JPL solar panel detail specification 504713. The thermal-vacuum test was conducted in the Environmental and Dynamic Test laboratory 2.13- X 4.27-m chamber. The test objectives were to:

(1) Evaluate fabrication quality of the flight panels and the mechanical integrity of related components.

(2) Complete outgassing and curing of the adhesive systems used on the panels.

(3) Evaluate the electrical performance of the solar panels after thermal-vacuum exposure.

The first phase of the program was to verify the adequacy of the applicable handling and operating procedures and establish appropriate thermal stabilization control temperatures. The solar panels were instrumented with thermocouples to monitor the temperatures during the test. The thermocouple locations on the panels are shown in Fig. 13. Prior to the start of the test, measurements of the zener diodes, the temperature transducer and the dielectric insulation were made to check for proper operation. Installation of the panels in the chamber prior to the start of the test is shown in Fig. 14. The panels were subjected to the following temperature cycles:

(1) Eight hours, or more, at low temperatures of -35°C plus or minus 2°C and a pressure of $10^{-5}$ torr, or less.

(2) Sixty hours, or more, at high temperature of plus 80°C plus or minus 2°C and a pressure of $10^{-5}$ torr, or less.

During the thermal cycle period the zener diodes voltage and current and the temperature transducers were measured both at the low and the high temperature periods. The temperature rate change was maintained within 5° C per minute. Heating and cooling of the solar panels was accomplished by the use of radiative heat transfer from the thermal shroud only.

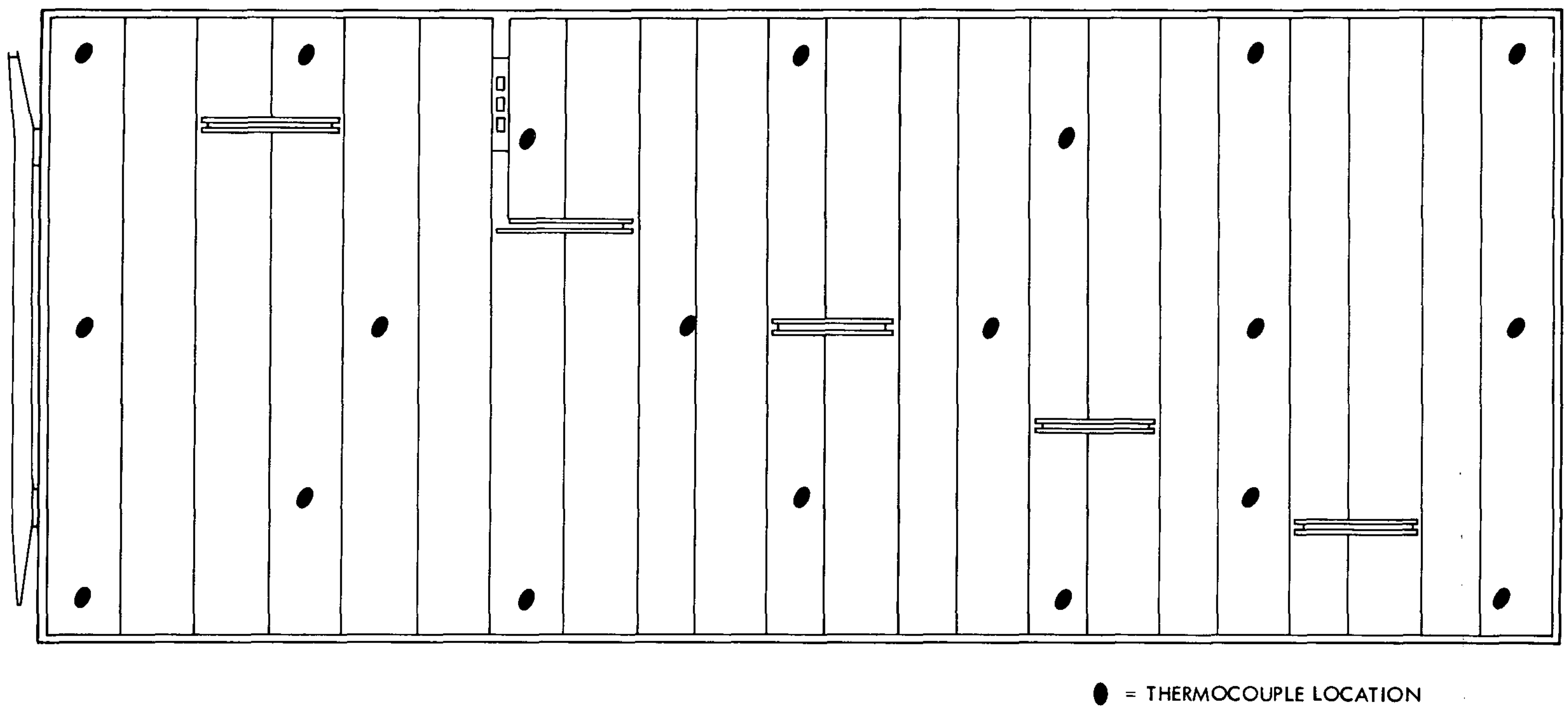



Fig. 13. Thermocouple Locations on Solar Panel

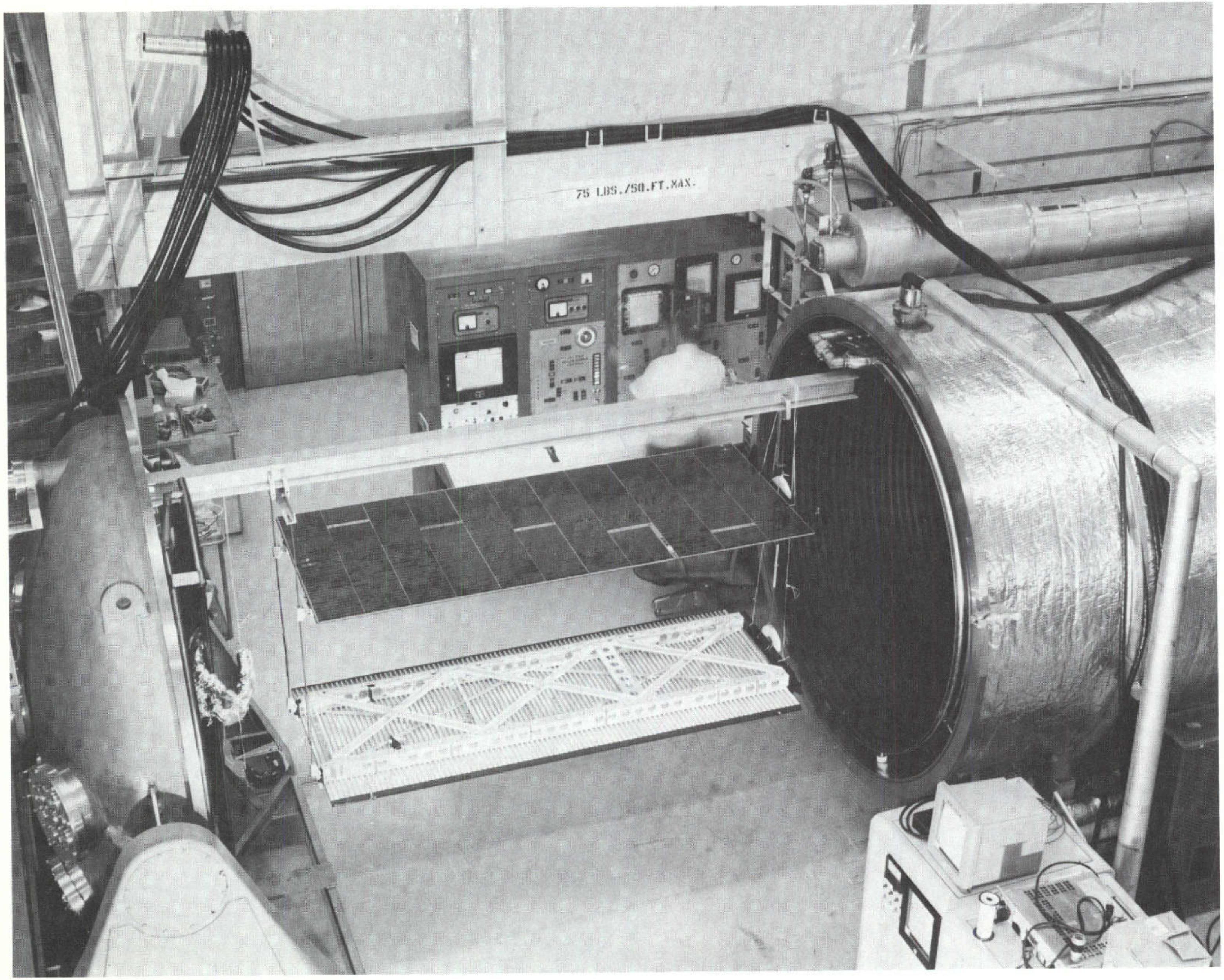
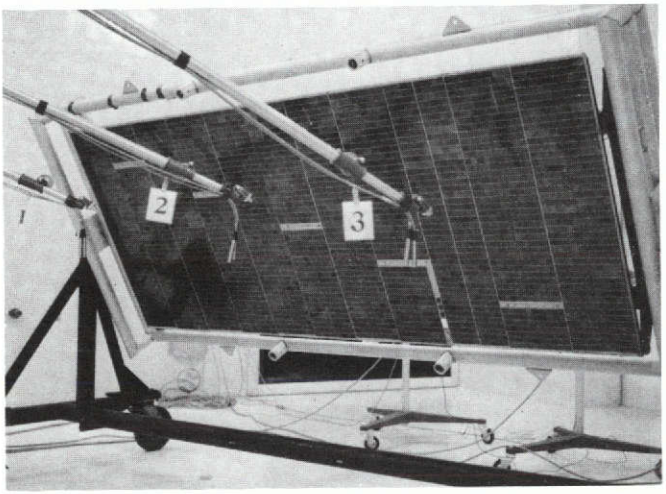


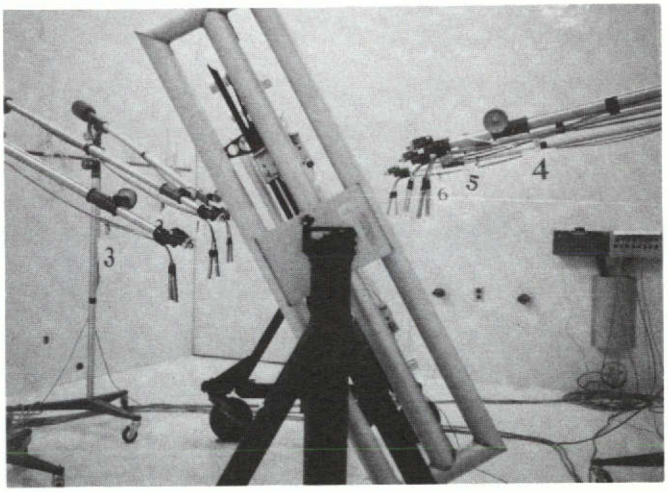

Fig. 14. Installation of Solar Panel in Thermal Vacuum Chamber

The second phase of the flight qualification test consisted of subjecting the flight panels to acoustic tests conducted in accordance with JPL detail specification 504713. On previous Mariner programs it was necessary to perform the test while the panels were suspended in a cage-like fixture. The Mariner 9 panels were placed in an acoustic chamber recently constructed which reduced the hazards associated with handling the fragile solar panels. Prior to test start, the chamber equilization test was performed using a Development Test Model. The locations of the microphones were identified so that they could be used in an identical manner during the tests of the flight panels. Six monitoring microphones were used during the flight panel tests to record the acoustic signals which were analyzed on a 1/3 octave analyzer after the test. The test was completed successfully. Figure 15 shows the locations of the microphones relative to the panel. The solar panels electrical performance was measured at Table Mountain before and after the environmental test program. A compilation of this data is presented in Table 4. The data is reduced to the anticipated performance conditions of post launch, cruise intensity-temperature conditions and the Mars encounter intensity-temperature conditions. The data suggests that the environmental testing program may have caused an array degradation of approximately one percent. However, since the repeatability of the Table Mountain test is estimated to have about the same uncertainty, there can not be confidence that this degradation number is correct.

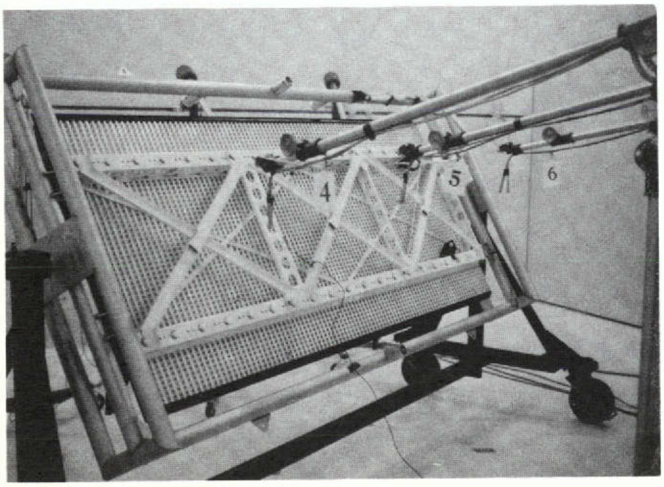
The qualified solar panels were shipped to the spacecraft assembly facility (SAF) at JPL for spacecraft assembly and subsequent system test. At this point in the operation at least one percent of the panels was sampled for microbiological contamination. This test indicated a requirement for recleaning the panels to reduce contamination to an acceptable level. This was accomplished by using Isopropyl alcohol.




FRONT OF PANEL




SIDE VIEW




BACK OF PANEL

Fig. 15. Location of Microphones for Acoustic Test

## V. LAUNCH READINESS TESTS

At the Eastern Test Range, at Cape Kennedy, the solar panels were subjected to the following operations to verify their readiness for launch:

(1) Mechanical inspection was performed on the panels upon arrival at the Cape to inspect for possible damage due to transportation.

(2) Two flight panels were sampled for microbiological contamination. The sampling was performed in accordance with supplemental procedure No. 1, M'71 PD 610. 18.

(3) The panels were cleaned and any deficiencies detected during the inspection were corrected.

(4) Solar panel electrical components were tested for proper operation. Components tested or tests performed, included the following:

 (a) Zener diodes.

 (b) Dielectric insulation.

 (c) Isc-Voc transducer.

 (d) Temperature transducers.

 (e) Verification of electrical connection of solar panel to the spacecraft.

 (f) Sunlight performance of the solar panels' individual electrical sections. This test was accomplished while the panels were placed in specially constructed clean boxes. The boxes were purged with nitrogen gas and wheeled outside for sunlight test. The boxes provided a clean environment and panel safety during the test.

## VI. SPECIAL STUDIES

### A. Solar Array Shading

During spacecraft maneuvers, the panels become misoriented from normal incident sunlight and the cell area of the panels can be shaded by the spacecraft structural elements. A study was conducted to evaluate the effects of shading on the solar array power.

The array power degradation is dependent upon the size of the shadow and the geometrical and electrical layout of the cells in the array. The loss in array power is not proportional to the shaded area of the panel, but greater. The effects of shading vary considerably, depending on which submodule in the string was shaded. This variance is due to the reverse characteristics of the individual submodules. Figure 16 shows the I-V characteristics of several individually shaded submodules. In general, because of the transient nature of shadowing and because of the difficulty of analysis in predicting Mariner 9 array space degradation because of shading, a worst case model was applied. This model considered that any shading of a string of solar cells effectively eliminate the electrical contribution of that string. The M'71 solar array cell layout minimized the effects of shadows in that the strings of cells were run normal to the solar panel length axis. Through this technique, the loss in solar array performance is directly correlated with shadow length. Whereas, if the strings of cells were run parallel to the length axis, relatively short shadows could cause a disproportionate amount of degradation.

### B. Solar Array "Hot Spots"

An open cell or a shaded cell in a submodule would generate localized heating because of power dissipation in that cell from power generated from the illuminated cells. Preliminary analysis was performed to evaluate the susceptibility to damage of the Mariner 9 solar array because of this potential failure mode. The study indicated that with heat loads generated because of power dissipations up to 2 watts per cell would not present problems to the solar panels. The submodule interconnections and the substrate would dissipate the heat over a large area; thus, the temperature would stay below 100° C.

Considering the physical configuration and diode isolation techniques designed into the array, it did not appear that conditions could exist to create power dissipations per cell greater than 2 watts.

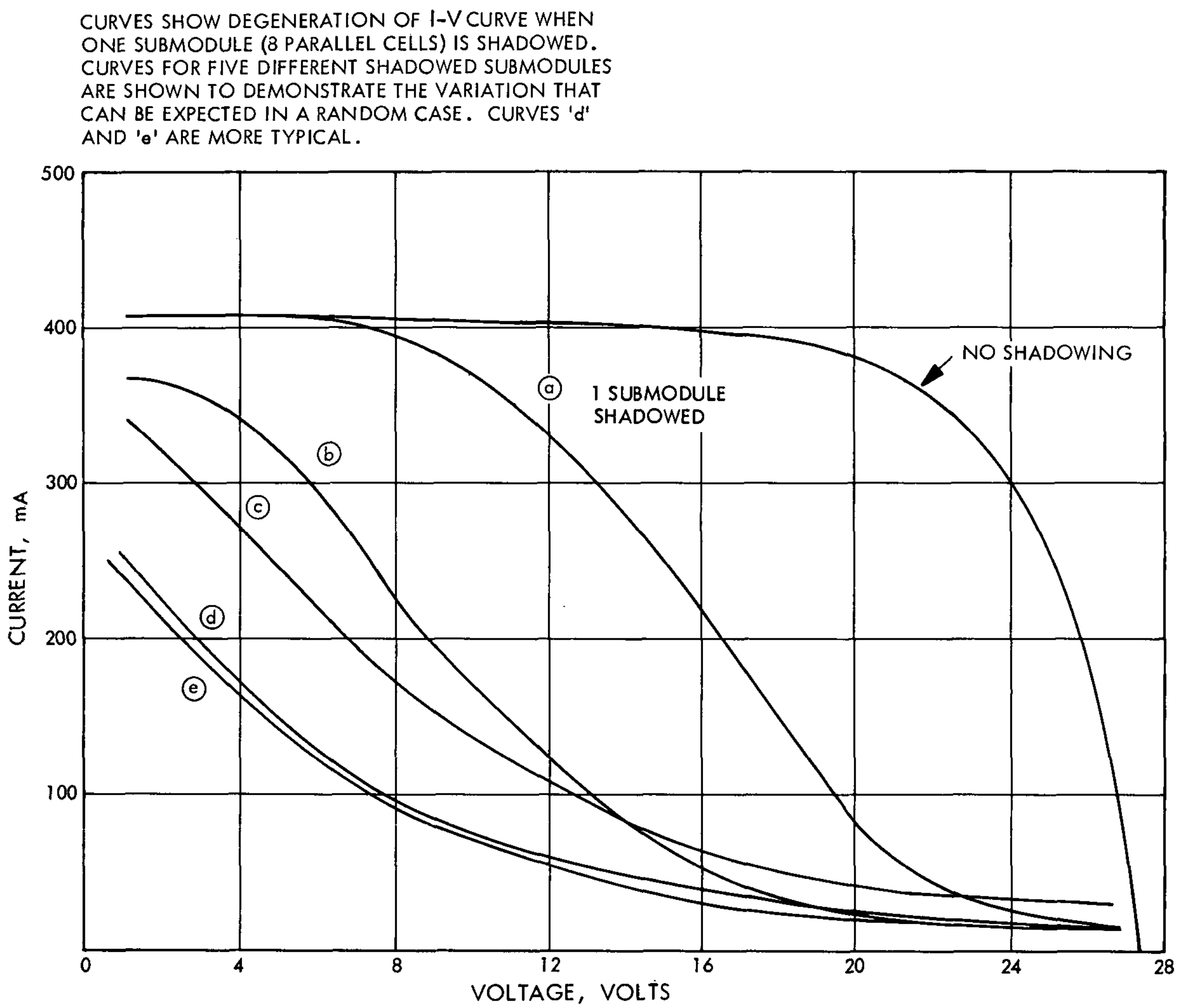



Fig. 16. Effect of Completely Shadowing Several Different Submodules (Rows of eight parallel cells)

# VII. FLIGHT PERFORMANCE SUMMARY

## A. Launch and Cruise Phase

The Mariner 9 spacecraft was launched on May 30, 1971. The solar panels were deployed and the spacecraft acquired the Sun 28 minutes after launch. The solar panel temperature derived from the temperature sensor, telemetry channel 419, located on the rear of the +Y solar panel, indicated an initial space panel temperature of 11.2° C. The temperature gradually increased and finally stabilized at 50.2° C and remained at this condition for approximately ten days from launch. Figure 17 shown estimated solar panel temperatures versus mission time from launch to Mars encounter. On the same curve actual flight temperatures are plotted versus data obtained from +Y temperature transducer, telemetry channel 419. Nominal temperature performance was recorded throughout the standard Mariner 9 mission.

The Isc-Voc transducer provided pertinent engineering information utilized to determine the status of the solar array performance capability. At day 0 it was observed that the Isc transducer cells indicated 1.0 percent lower output than had been predicted before launch. During this phase of the mission the array is operated near its open circuit voltage. This does not permit detailed evaluation of the current-voltage characteristics of the array. This operating point is relatively insensitive to intensity or current loss effects. Detailed analysis of the array at this time indicated array performance to be close to predicted, however, the accuracy of the analysis was limited because of the array performance resolution. The Isc-Voc transducer performance supported this analysis. The main deviation being the 1 percent lower current transducer performance than anticipated. Potential reasons for this deviation could include calibration accuracy, prediction uncertainty and telemetry accuracy.

Evaluation of the Isc-Voc transducers for day 51, day 79 and day 128 of the mission is presented in Table 5, showing a comparison of actual flight data of the Isc-Voc transducer with the prelaunch predicted output.

Evaluation of the array current and voltage output was also reviewed on the above mentioned days and the data indicated nominal array performance. The solar array operating voltage continued to increase with a decrease in array temperatures as anticipated and was eventually limited by the zener diodes at

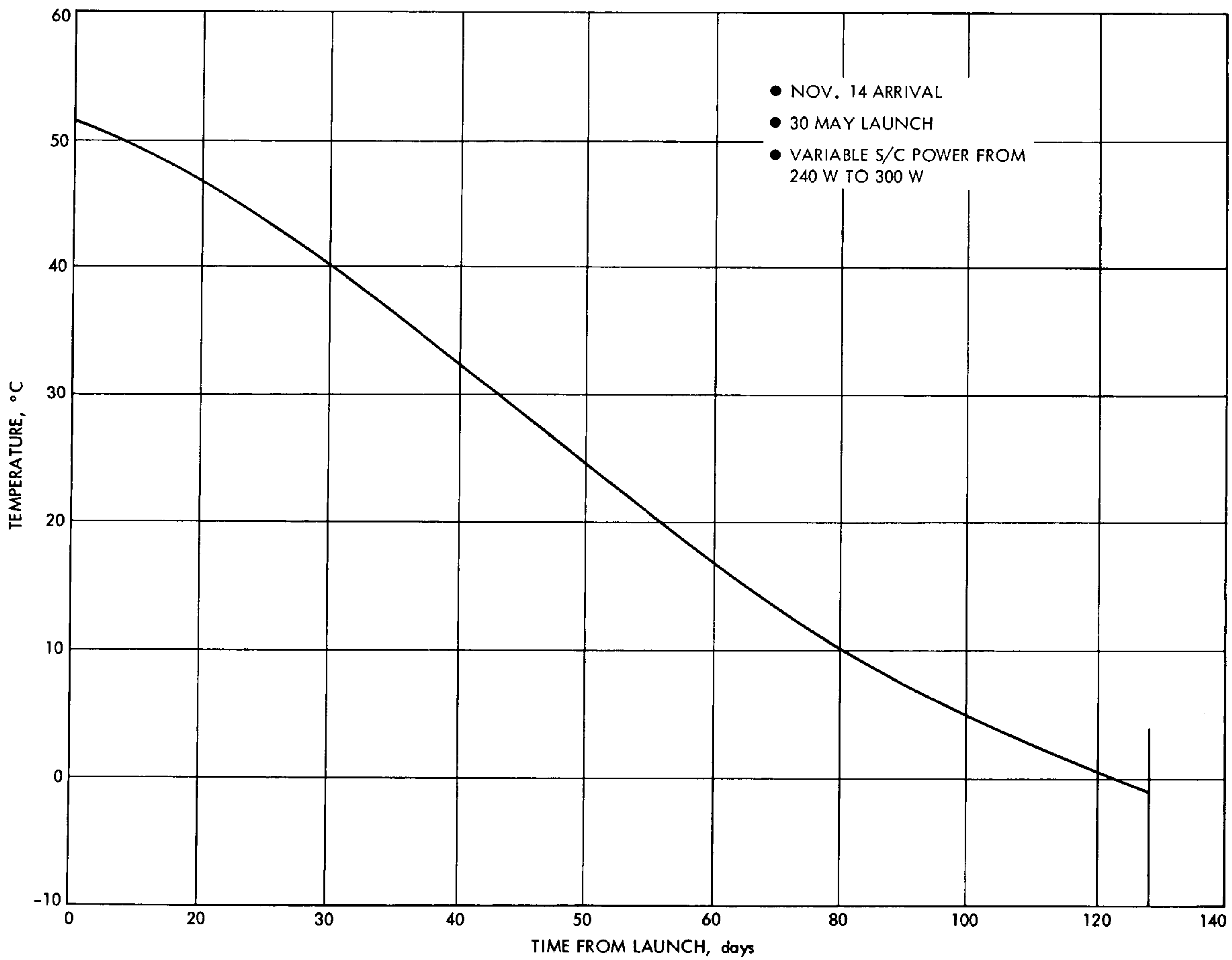



Fig. 17. Prelaunch Estimated Solar Panel Temperature Versus Mission Time

Table 5. Isc-Voc Transducer Predicted Output vs Actual Flight Data

| Day | Channel Number Telemetry | Transducer | Flight Output, mV | Prelaunch Predicted Output, mV |
|---|---|---|---|---|
| 51 | 423 | Voc | 557.0 | 547.0 |
| | 424 | Isc | 79.5 | 81.4 |
| | 425 | Iscr | 44.1 | 45.6 |
| 79 | 423 | Voc | 577.0 | 574.0 |
| | 424 | Isc | 68.2 | 69.3 |
| | 425 | Iscr | 36.7 | 37.0 |
| 128 | 423 | Voc | 607.0 | 602.0 |
| | 424 | Isc | 54.5 | 54.5 |
| | 425 | Iscr | 28.5 | 29.0 |

45.4 volts, approximately 140 days from launch and continued to be so limited except during maneuvers and special events. Figure 18 shows array actual flight operating voltage from launch to Mars encounter. Zener limitation of solar array output prevents direction evaluation of operating characteristics; hence, after day 140, more reliance had to be placed on the Isc-Voc transducer in evaluating the array performance. On day 140 the transducer indicated that the array had degraded approximately 1.5 percent from launch. This measurement is believed to be outside the limit of telemetry data resolution and hence confidence in this value is not justified. This amount of change, however, corresponds very well with the performance of the Isc-Voc transducers flown on Mariners 6 and 7. Extrapolation of this data to encounter suggested that this array would be only 3.5 percent lower than the prelaunch predicted performance curves developed, assuming no solar flare degradation. It appeared the array had not experienced great space degradation and was performing close to its predicted characteristics. The Isc-Voc transducer and the solar array performance appeared to be tracking each other and future estimates of array performance would reflect the Isc-Voc operation. Based on flight transducer data, a revised encounter prediction was made 27 days before encounter. Shown in Fig. 19 is a plot of the I-V characteristics of the array assuming 3.5 percent current degradation. Plotted in Fig. 20 is the degradation experienced by the Isc-Voc transducer from launch through Test No. 2. It illustrated the 1.5 percent current degradation noted on day 140 and shows the 3.5 percent current degradation at encounter.

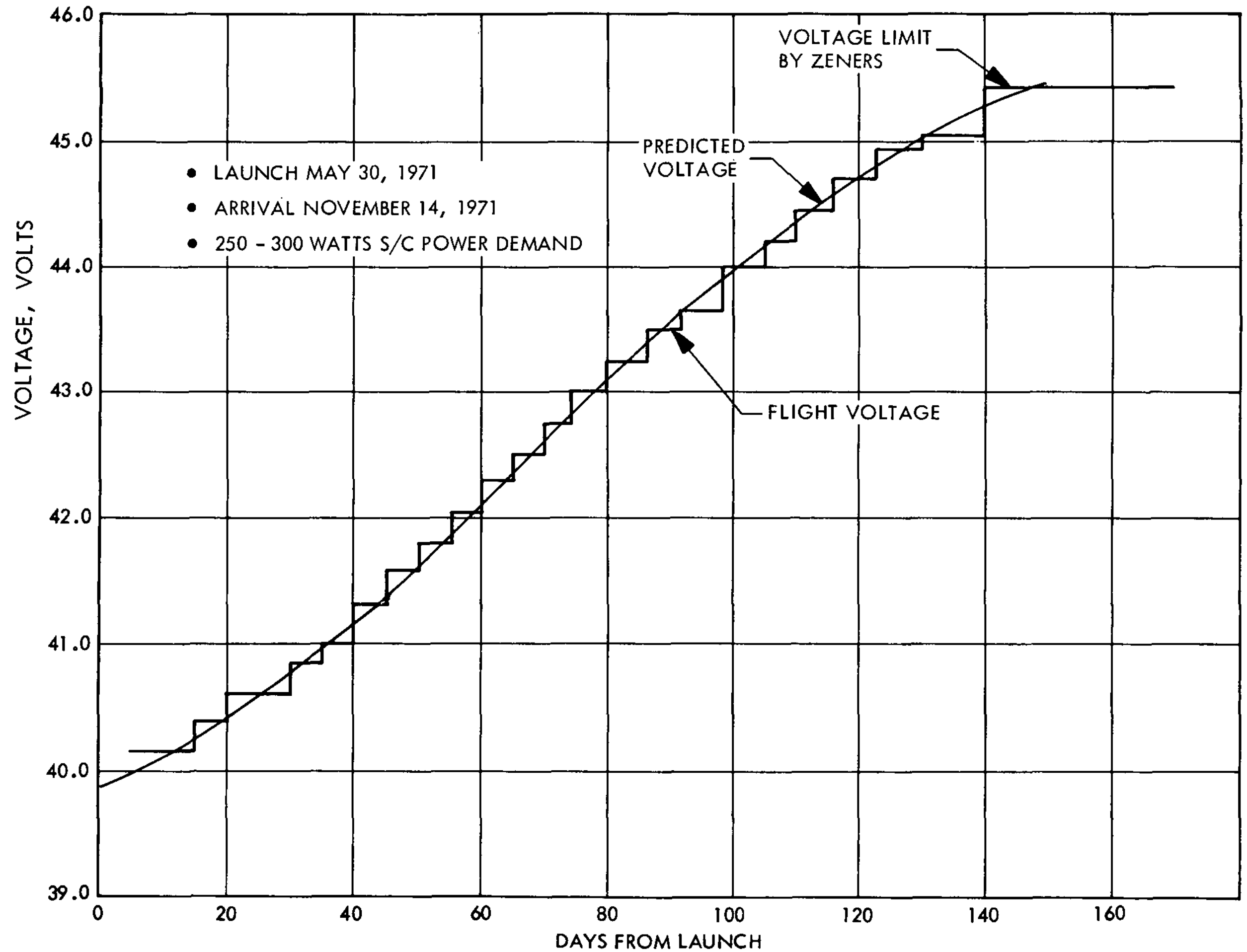



Fig. 18. Mariner 9 Solar Panel Performance Voltage Versus Time (PS and L, Channel 116)

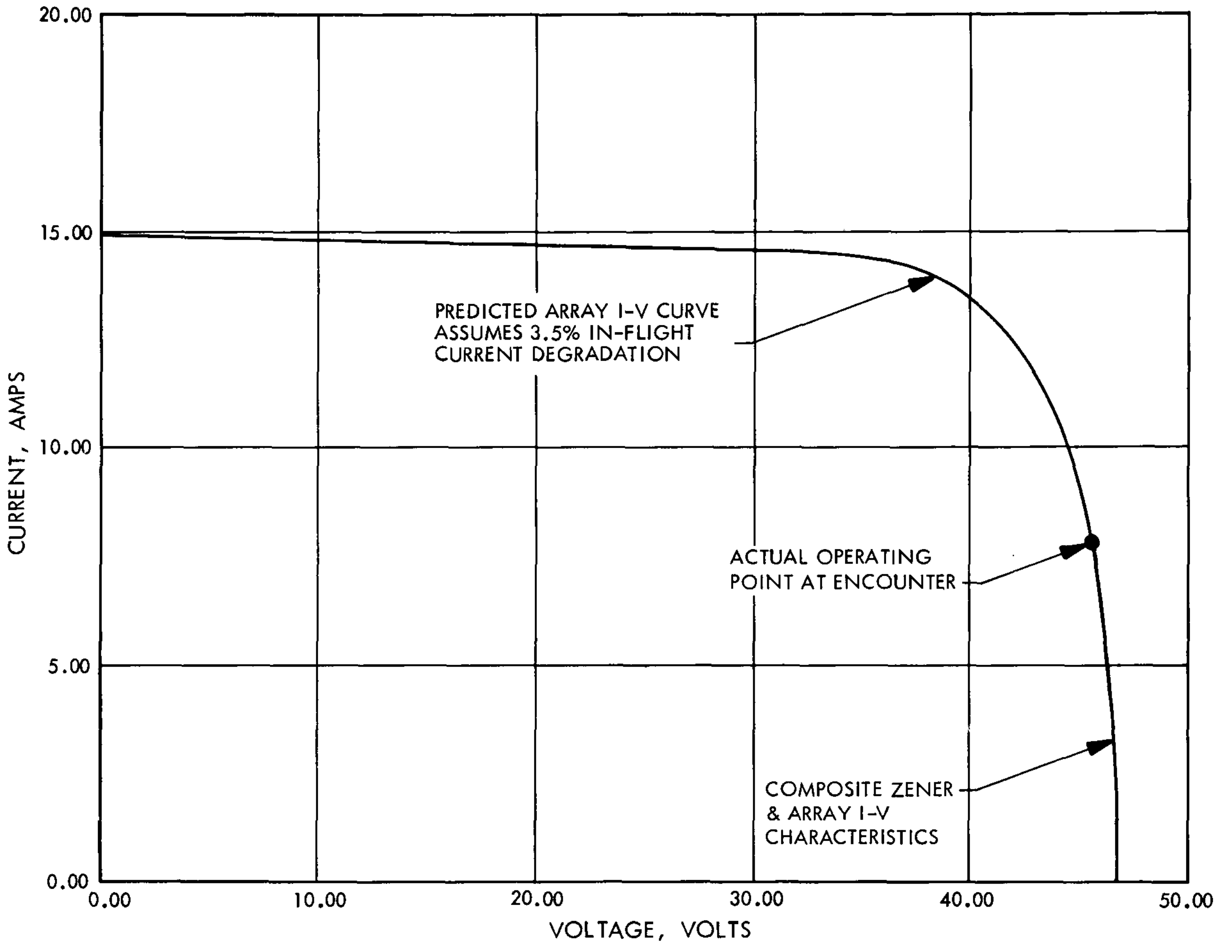



Fig. 19. Solar Array Predicted Performance at Encounter. Curve Degraded to Reflect Isc-Voc Transducer Telemetry Data (Prediction made 27 days before Encounter)

## B. Encounter and Orbital Phase

On November 14, 1971, the spacecraft was injected into orbit. The solar array current-voltage performance characteristics on November 14 are shown in Fig. 19. Solar array temperature was -2.3° C and the Sun intensity was 70.0 $mW/cm^2$. The first orbit trim maneuver was successfully conducted on November 15, 1971. On December 30, a second orbit trim was made to correct the orbital period coordinating the periapsis timing with the view period of the antenna at the Goldstone tracking station in California. The maneuver also changed the periapsis altitude from 1387 to 1650 kilometers. The spacecraft remained in that orbit for the rest of its operational life. The estimated array output power performance at orbital apoapsis and periapsis for the 90-day standard

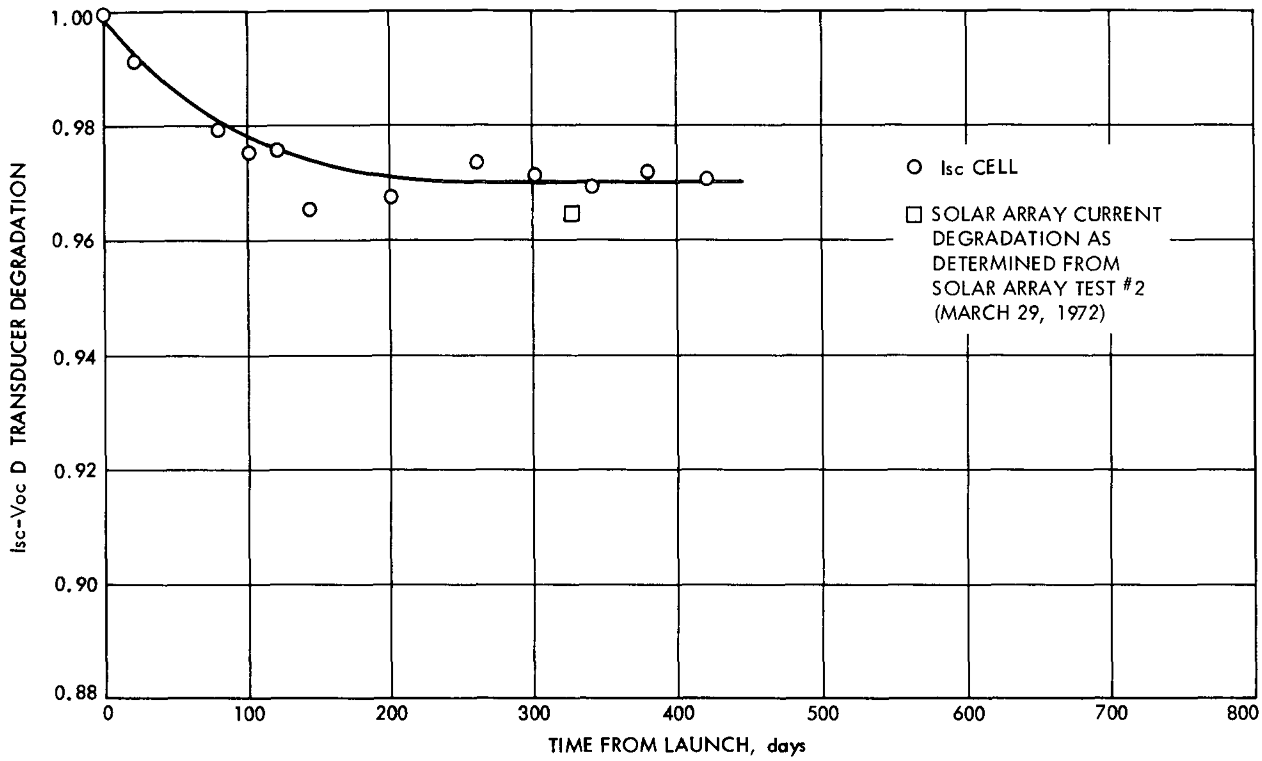



Fig. 20. Isc-Voc Transducer Degradation as a Function of Mission Time

mission is shown in Fig. 21. The solar array temperature profile for the initial mission orbits is shown in Fig. 22. The high array temperature is caused by planet albedo during the periapsis phase of the orbit point. The low array temperature at apoapsis was approximately at -2.2°C. At periapsis the array temperature is expected to rise to 5.6°C. This temperature profile continues to change as the planet moves further away from the Sun. The final orbit of the 90-day mission, orbit 180, is shown in Fig. 23 and indicates a low array temperature of -13.9°C, and rise to -1.1°C. Temperature telemetry data showed very good correlation with the temperature profiles indicated. During this orbital phase of the mission between April 2, 1972 and June 3, 1972, the spacecraft was subjected to 124 solar occultations created by the obscuration of the Sun by the planet. The longest of these occultations lasted 97 minutes and resulted in the array temperature decreasing to -158°C. As will be discussed later this occultation period occurred between the special array

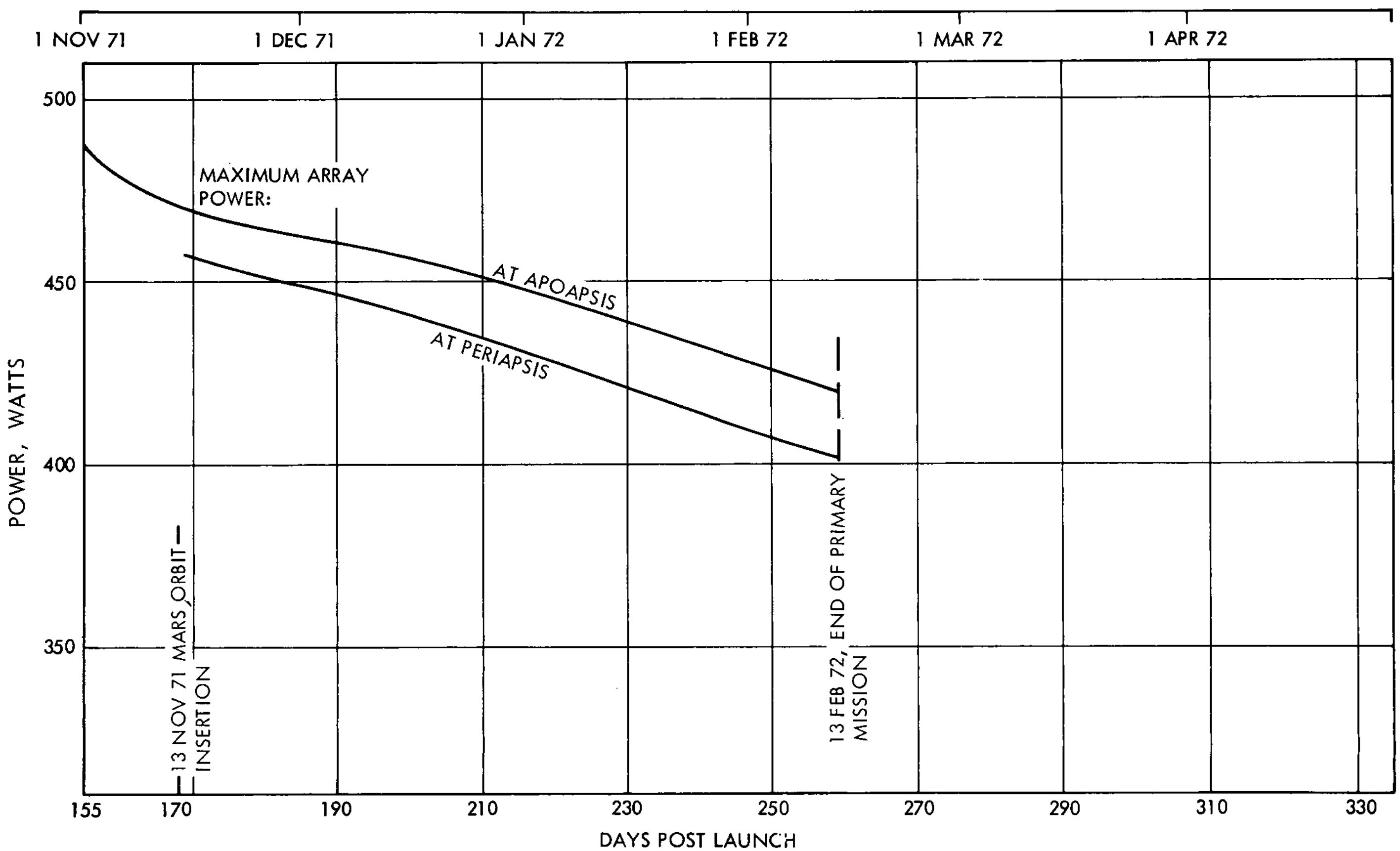



Fig. 21. Predicted Solar Array Performance for 90-Day Primary Mission

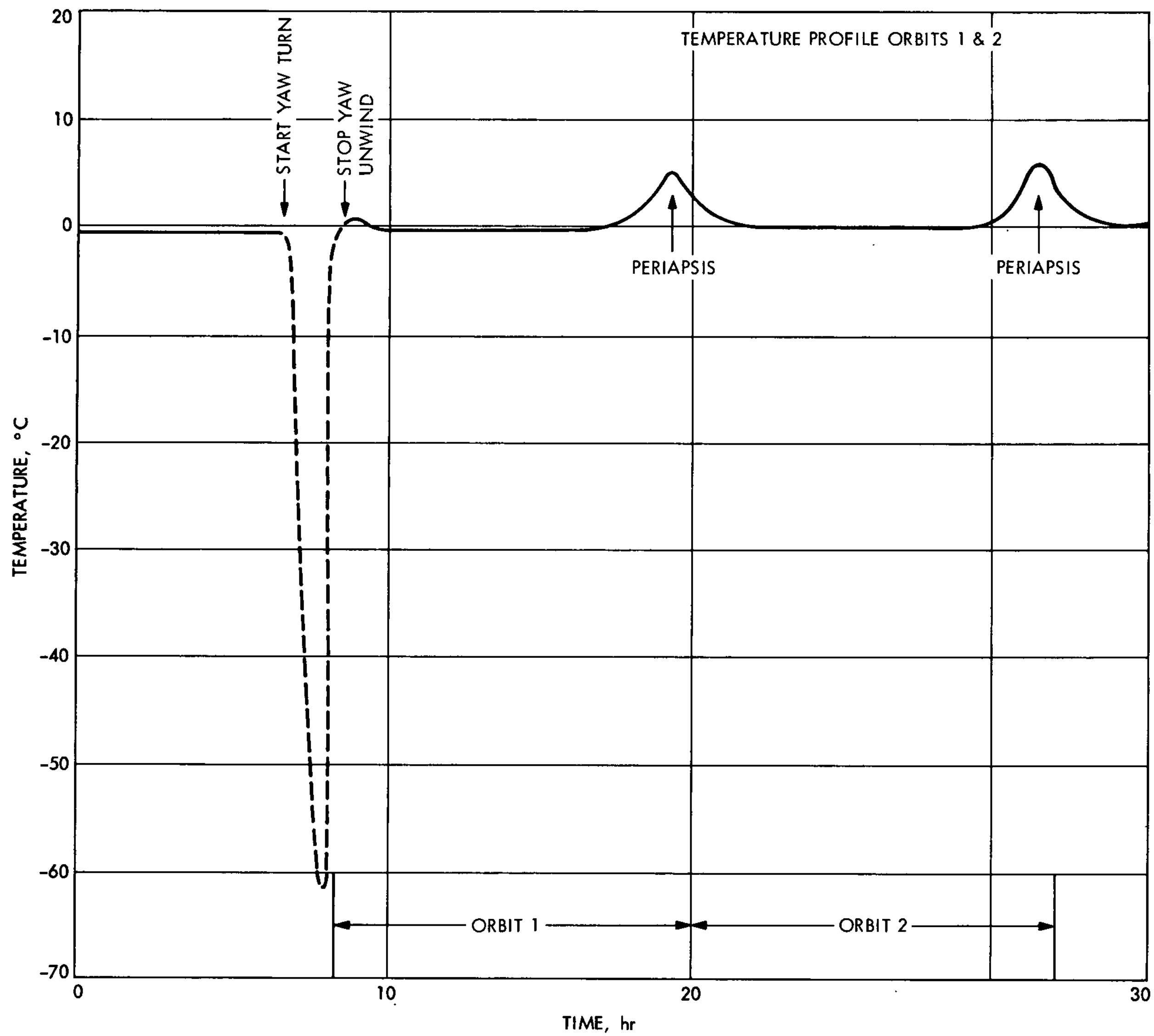



Fig. 22. Temperature Profile Orbits 1 and 2

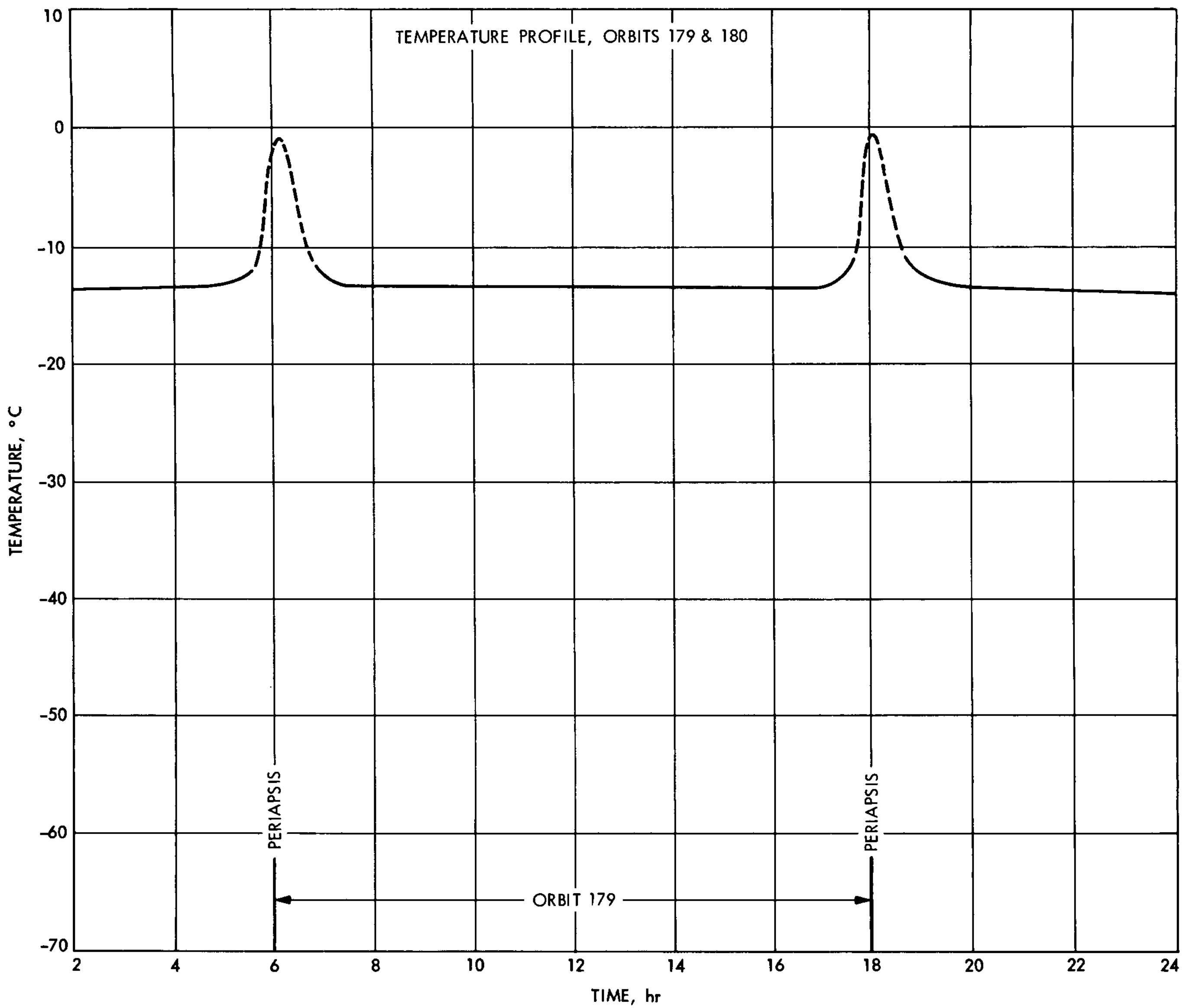



Fig. 23. Temperature Profile, Orbits 179 and 180

in-flight electrical test 2 and test 3. The tests indicated that no observable performance degradation resulted that could be attributed to thermal cycling. Later in the mission, starting on October 2, 1972 and lasting to mission termination on October 27, 1972, the spacecraft experienced 38 more occultations and hence thermal cycles. Although there was no detailed array performance measurement just prior to the end of the mission, it is not believed that these additional cycles did any damage to the solar array performance.

# VIII. SPECIAL SOLAR ARRAY TESTS

The solar array maximum performance capability cannot be directly monitored during the normal spacecraft operational modes. The power conversion subsystem operates the array on the voltage side of the maximum power point and the zener diodes limit the array voltage below 50 volts. Because of the above constraints, special tests were conducted on February 29 (Test No. 1), March 29 (Test No. 2), and June 5 (Test No. 3) to determine the maximum power output capability of the solar array. This was accomplished by gradually increasing the array electrical loads until the maximum power capability was exceeded and the spacecraft battery was required to support the loads. Additional data on array performance would be obtained by comparing the array operating voltage and current points near the maximum power point with the analytical predicted performance. Test No. 1 on February 29 did not establish the maximum power point of the solar array because of insufficient spacecraft loading capability to exceed the array available power. The array would have had to be degraded approximately 5 percent for the spacecraft loads to place the array in share with the battery. The fact that this did not happen supports the test results which indicated that the solar array experienced less than 5 percent degradation.

On March 29, the test was repeated. The spacecraft was now further away from the Sun and the power output capability was low enough to insure loading would eventually result in battery share. The test sequence is shown in Fig. 24. The effects of these commands and resulting loads on array voltage and panel current is shown as a function of time in Fig. 25. The highest power output produced by the array before it went into share with the battery was 430 watts. Review of the data in Fig. 25 indicates good correlation between the actual flight array voltage and current points and the array predicted I-V curve. Twenty-four pertinent current-voltage data points were obtained from the flight performance data during this test. These data points are shown in Fig. 26.

These points, plotted on Fig. 27, indicate an array maximum power capability of 434 watts. The I-V curve also displayed on Fig. 27 was obtained from the JPL solar array model program for these arrays with the proper temperature and intensities for the day, and for an assumed current

START OF TEST

SPACECRAFT CONDITION

1) BATTERY LOW CHARGE
2) HI TWT
3) SCIENCE ON
4) SCAN ON
5) DSS READY
6) PROPULSION HEATERS ON

ORBIT NO. 274

APOAPSIS START 16:41 08

PERIAPSIS START 22:41

| TIME | COMMAND | SPACECRAFT LOAD CHANGE | POWER SOURCE |
|---|---|---|---|
| 17:35:44 | DC-75/DC-18 | PROPULSION HEATERS OFF | ARRAY |
| 17:38:40 | 7 MI | P AND Y GYROS ON, A/P ON, 30V REGULATOR ON | ARRAY |
| 18:18:14 | DC-37 | BOOST CONVERTER INHIBITED | ARRAY |
| 18:23:14 | DC-75 | PROPULSION HEATERS ON | ARRAY |
| 18:25:05 | – | IRIS DC HEATERS CYCLE | ARRAY/BATTERY |
| 19:08:14 | DC-37 | B/C ENABLED | ARRAY/BATTERY |
| 19:48:14 | DC-37 | B/C INHIBITED | ARRAY/BATTERY |
| 19:53:14 | DC-75 | PROPULSION HEATERS OFF | ARRAY/BATTERY |
| 20:33:14 | DC-37 | B/C ENABLED | ARRAY |
| 20:43:14 | DC-37 | B/C INHIBITED | ARRAY |
| 20:53:14 | DC-3 | PLAYBACK MODE | ARRAY/BATTERY |
| 21:13:14 | DC-37 | B/C ENABLED | ARRAY |

SPACECRAFT AT END OF TEST OUT OF SHARE WITH THE BATTERY

Fig. 24. Sequence of Solar Array Test No. 2, March 29, 1972

| TELEMETRY DATA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TIME | PSL (116) VOLTS | | PANEL (203) AMPS | | PANEL (204) AMPS | | PANEL (223) AMPS | | PANEL (224) AMPS | | PANELS (ARRAY) AMPS |
| | DN | ENG | DN | ENG | DN | ENG | DN | ENG | DN | ENG | |
| 17/40/12 | 92 | 43.96 | 61 | 2.35 | 61 | 2.34 | 62 | 2.39 | 63 | 2.42 | 9.50 |
| 18/23/37 | 74/73 | ~39.52 | 67 | 2.59 | 67 | 2.58 | 67 | 2.59 | 68 | 2.62 | 10.38 |
| 18/24/19 | 73/72 | ~39.27 | 67 | 2.59 | 67 | 2.58 | 67 | 2.59 | 68 | 2.62 | 10.38 |
| 18/25/01 | 53 | 34.53 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 18/27/49 | 52 | 34.28 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 68 | 2.66 | 10.54 |
| 18/34/07 | 51 | 34.04 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 18/39/01 | 50 | 33.79 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 18/46/43 | 49 | 33.53 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 18/51/37 | 48 | 33.30 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 19/00/01 | 47 | 33.06 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 19/07/01 | 46 | 32.81 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 19/15/25 | 45 | 32.57 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 19/24/31 | 44 | 32.32 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 19/35/47 | 43 | 32.07 | 68 | 2.63 | 68 | 2.62 | 69 | 2.67 | 69 | 2.66 | 10.58 |
| 19/46/13 | 42 | 31.83 | 68 | 2.63 | 68 | 2.63 | 69 | 2.67 | 69 | 2.66 | 10.58 |
| 20/07/13 | 41 | 31.58 | 68 | 2.63 | 68 | 2.63 | 69 | 2.67 | 69 | 2.66 | 10.58 |
| 20/28/13 | 40 | 31.33 | 68 | 2.63 | 68 | 2.63 | 69 | 2.67 | 69 | 2.66 | 10.58 |
| 20/33/53 | 91 | 43.72 | 61 | 2.35 | 61 | 2.34 | 62 | 2.39 | 62 | 2.38 | 9.46 |
| 20/35/13 | 92/91 | ~43.84 | 61 | 2.35 | 61 | 2.34 | 62 | 2.39 | 62 | 2.38 | 9.46 |
| 20/36/37 | 92 | 43.97 | 61 | 2.35 | 61 | 2.34 | 62 | 2.39 | 62 | 2.38 | 9.46 |
| 20/40/44 | 92/93 | ~44.09 | 60 | 2.31 | 61 | 2.34 | 62 | 2.39 | 62 | 2.38 | 9.42 |
| 20/49/59 | 93 | 44.21 | 60 | 2.31 | 61 | 2.34 | 61 | 2.35 | 62 | 2.38 | 9.38 |
| 20/54/07 | 42 | 31.83 | 68 | 2.63 | 68 | 2.62 | 68 | 2.63 | 69 | 2.66 | 10.54 |
| 21/13/43 | 90/89 | 43.37 | 62 | 2.39 | 62 | 2.38 | 63 | 2.44 | 63 | 2.43 | 9.64 |
| 21/15/49 | 91/90 | ~43.61 | 62 | 2.39 | 62 | 2.38 | 63 | 2.44 | 63 | 2.43 | 9.64 |
| 21/20/01 | 87 | 42.78 | 64 | 2.47 | 64 | 2.46 | 65 | 2.51 | 64 | 2.46 | 9.90 |
| 21/20/43 | 91 | 43.72 | 61 | 2.35 | 62 | 2.38 | 62 | 2.39 | 63 | 2.43 | 9.55 |
| 21/21/29 | 87/88 | 42.90 | 64 | 2.47 | 64 | 2.46 | 65 | 2.51 | 64 | 2.47 | 9.91 |
| 21/29/07 | 92/91 | ~43.84 | 61 | 2.35 | 62 | 2.38 | 62 | 2.39 | 62 | 2.38 | 9.50 |
| 21/30/35 | 89 | 43.25 | 63 | 2.43 | 63 | 2.42 | 64 | 2.48 | 63 | 2.43 | 9.76 |
| 21/34/43 | 93 | 44.21 | 60 | 2.31 | 61 | 2.34 | 61 | 2.35 | 62 | 2.38 | 9.38 |

Fig. 25. Telemetry Data of Solar Array Test No. 2, March 29, 1972

| VOLTAGE – CURRENT POINTS DEVELOPED FROM TELEMETRY DATA | |
|---|---|
| ARRAY VOLTAGE (VOLTS) (PSL VOLTS +1.0 VOLT FOR DIODE DROP) | ARRAY CURRENT (AMPS) SUMMATION OF PANEL CURRENTS |
| 45.21 | 9.38 |
| 44.96 | 9.50 |
| 44.72 | 9.55 |
| 44.61 | 9.64 |
| 44.37 | 9.64 |
| 44.25 | 9.76 |
| 43.90 | 9.91 |
| 43.78 | 9.90 |
| 40.52 | 10.38 |
| 40.27 | 10.38 |
| 35.53 | 10.54 |
| 35.28 | 10.54 |
| 35.04 | 10.54 |
| 34.79 | 10.54 |
| 34.53 | 10.54 |
| 34.30 | 10.54 |
| 34.06 | 10.54 |
| 33.81 | 10.54 |
| 33.57 | 10.54 |
| 33.32 | 10.54 |
| 33.07 | 10.58 |
| 32.83 | 10.58 |
| 32.58 | 10.58 |
| 32.33 | 10.58 |

Fig. 26. Voltage-Current Points Developed from Telemetry Data of Solar Array Test No. 2, March 29, 1972

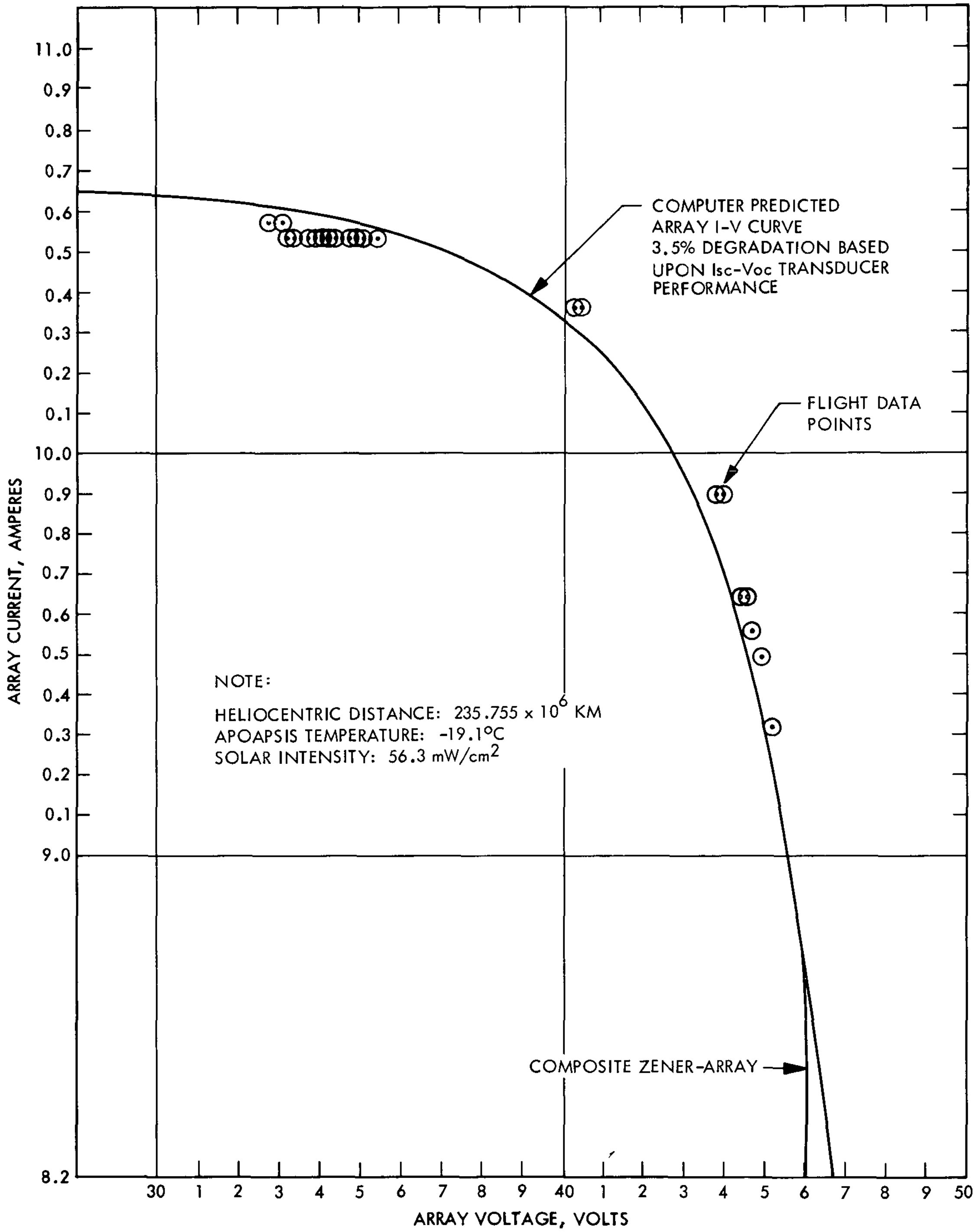



Fig. 27. Solar Array Performance During Array Test No. 2, March 29, 1972

degradation factor of 3.5 percent. The degradation of 3.5 percent is based on Isc-Voc transducer performance. The difference in maximum power determined from the flight data compared with the analytical model was 1.5 percent (Flight test indicated 434 watts vs analytical data of 427 watts).

On June 5, 1972, a third test was conducted to acquire more statistical data on the array and possibly to increase confidence in the array performance. The test was expected to require an array load of 371 watts and the maximum available array power was estimated to be about 400 watts. The same approach was used to develop the I-V characteristics of the solar array as was done during Test No. 2. The test sequence shown in Fig. 28 was commanded to force the solar array to exceed its capability and attain battery share. The results of the test as the loads are increased on the array voltage and current as a function of time is shown in Fig. 29. Distinct telemetry points of array operation during this third test are shown in Fig. 30 to bracket the array I-V characteristics. The best computer generated curve fit to the test data points was accomplished when a 3.5 percent degradation factor was applied as shown in Fig. 31.

The final special array test was conducted on October 2, 1972. The telemetry flight data as a function of time is shown in Fig. 32. Current-voltage points were selected to generate array I-V characteristics as shown in Fig. 33. The flight data in Fig. 33 were plotted on the predicted array performance curve as shown in Fig. 34. Again 3.5 percent current degradation factor was assumed from a study of the Isc-Voc transducer data. The resulting curve shows good agreement with the flight data.

The solar panels performed successfully throughout the remaining days of the mission. On October 27, 1972, the Attitude Control gas supply was depleted and the spacecraft went into a tumble. CC&S commands were issued to turn off the spacecraft.

| TEST SEQUENCE | | |
|---|---|---|
| DAY 158 TIME<br>H M S | FRAME | EVENT |
| 00/35/00 | 1 | SAT NO. 3 START. LOW RATE CHARGE, SCI ON. |
| 00/35/59 | 1 | B/C INHIBITED. |
| 00/37/59 | 11 | ROLL GYRO ON. SURVEY COMMAND START. |
| 01/07/59 | 13 | PROPULSION HEATER ON. |
| 01/17/59 | 17 | DSS ON. SHARE. |
| 01/28/00 | 20 | DSS PLAYBACK. SHARE CONTINUED. END SURVEY. |
| 02/09/00 | 32 | B/C ENABLED. SHARE CONTINUED START COMMAND BLOCK C |
| 02/11/00 | 34 | PROPULSION HEATER OFF. OUT OF SHARE |
| 02/16/00 | 35 | DSS READY. |
| 02/21/00 | 37 | DSS OFF. |
| 02/26/00 | 39 | B/C INHIBITED. |
| 02/28/00 | 41 | SCAN ON. |
| 02/38/00 | 43 | DSS ON. |
| 02/42/00 | 45 | DSS SLEW. SHARE. |
| 02/46/00 | 46 | DSS READY. SHARE CONTINUED. |
| 02/48/00 | 47 | SCAN OFF. SHARE CONTINUED. |
| 02/50/00 | 48 | DSS OFF. SHARE CONTINUED. |
| 02/52/00 | 48 | IRR/UVS OFF. SHARE CONTINUED. |
| 03/02/00 | 52 | IRIS OFF. OUT OF SHARE. |
| 03/12/00 | 57 | TV OFF. |
| 03/22/00 | 59 | BATTERY CHARGER OFF |
| 03/32/00 | 65 | TWTA LO. |

Fig. 28. Sequence of Solar Array Test No. 3, June 5, 1972

| TELEMETRY DATA | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAY 158 TIME H M S | PSL (CH 116) VOLTS | | CH 203 AMPS | | CH 204 AMPS | | CH 223 AMPS | | CH 224 AMPS | |
| | DN | ENG. | DN | ENG. | DN | ENG. | DN | ENG. | DN | ENG. |
| 00/35/29 | 96 | 44.93 | 53 | 2.02 | 49 | 1.87 | 53 | 2.02 | 52 | 1.98 |
| 00/38/17 | 95 | 44.69 | 55 | 2.11 | 54 | 2.06 | 56 | 2.15 | 55 | 2.11 |
| 00/41/05 | 95 | 44.69 | 55 | 2.11 | 53 | 2.02 | 55 | 2.11 | 55 | 2.11 |
| 00/43/53 | 95 | 44.69 | 56 | 2.15 | 54 | 2.06 | 56 | 2.15 | 56 | 2.15 |
| 00/46/41 | 95 | 44.69 | 56 | 2.15 | 54 | 2.06 | 56 | 2.15 | 55 | 2.11 |
| 00/49/29 | 95 | 44.69 | 56 | 2.15 | 54 | 2.06 | 56 | 2.15 | 56 | 2.11 |
| 00/52/17 | 95 | 44.69 | 56 | 2.15 | 54 | 2.06 | 56 | 2.15 | 56 | 2.11 |
| 00/55/05 | 95 | 44.69 | 55 | 2.11 | 53 | 2.02 | 55 | 2.11 | 56 | 2.15 |
| 00/57/53 | 95 | 44.69 | 56 | 2.15 | 53 | 2.02 | 56 | 2.15 | 55 | 2.11 |
| 01/00/41 | 95 | 44.69 | 55 | 2.11 | 53 | 2.02 | 55 | 2.11 | 55 | 2.11 |
| 01/03/29 | 95 | 44.69 | 55 | 2.11 | 54 | 2.06 | 55 | 2.11 | 55 | 2.11 |
| 01/06/17 | 95 | 44.69 | 55 | 2.11 | 53 | 2.02 | 55 | 2.11 | 55 | 2.11 |
| 01/09/05 | 94 | 44.45 | 57 | 2.19 | 56 | 2.15 | 57 | 2.19 | 57 | 2.19 |
| 01/11/53 | 94 | 44.45 | 57 | 2.19 | 56 | 2.15 | 57 | 2.19 | 57 | 2.19 |
| 01/14/41 | 94 | 44.45 | 57 | 2.19 | 56 | 2.15 | 57 | 2.19 | 57 | 2.19 |
| 01/17/29 | 94 | 44.45 | 57 | 2.19 | 56 | 2.15 | 57 | 2.19 | 57 | 2.19 |
| 01/20/17 | 48 | 33.30 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/23/05 | 48 | 33.30 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/25/53 | 48 | 33.30 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/28/41 | 47 | 33.06 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/31/29 | 47 | 33.06 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/34/17 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/37/05 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/39/53 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/48/17 | 45 | 32.57 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/51/05 | 44 | 32.32 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/53/53 | 44 | 32.32 | 63 | 2.43 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/56/41 | 44 | 32.32 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 01/59/29 | 44 | 32.32 | 63 | 2.43 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/02/17 | 44 | 32.32 | 63 | 2.43 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/05/05 | 43 | 32.07 | 63 | 2.43 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/07/53 | 43 | 32.07 | 63 | 2.43 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/10/41 | 43 | 32.07 | 63 | 2.43 | 62 | 2.39 | 63 | 2.43 | 57 | 2.19 |
| 02/13/29 | 94 | 44.45 | 58 | 2.23 | 56 | 2.15 | 57 | 2.19 | 57 | 2.19 |
| 02/16/17 | 95 | 44.69 | 56 | 2.15 | 55 | 2.11 | 56 | 2.15 | 56 | 2.15 |
| 02/19/05 | 95 | 44.69 | 56 | 2.15 | 55 | 2.11 | 56 | 2.15 | 56 | 2.15 |
| 02/21/53 | 95 | 44.69 | 55 | 2.15 | 54 | 2.06 | 55 | 2.15 | 55 | 2.15 |
| 02/24/41 | 95 | 44.69 | 55 | 2.15 | 54 | 2.06 | 55 | 2.15 | 55 | 2.15 |
| 02/27/29 | 95 | 44.69 | 56 | 2.15 | 53 | 2.02 | 56 | 2.15 | 55 | 2.15 |
| 02/30/17 | 95 | 44.69 | 56 | 2.15 | 55 | 2.11 | 56 | 2.15 | 56 | 2.15 |
| 02/33/05 | 95 | 44.69 | 56 | 2.15 | 55 | 2.11 | 56 | 2.15 | 57 | 2.19 |
| 02/35/53 | 95 | 44.69 | 56 | 2.15 | 55 | 2.11 | 56 | 2.15 | 57 | 2.19 |
| 02/38/41 | 94 | 44.45 | 57 | 2.19 | 56 | 2.15 | 57 | 2.19 | 58 | 2.23 |
| 02/41/29 | 94 | 44.45 | 57 | 2.19 | 56 | 2.15 | 58 | 2.23 | 57 | 2.19 |
| 02/44/17 | 45 | 32.57 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/47/05 | 45 | 32.57 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/49/53 | 45 | 32.57 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/52/41 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/55/29 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 02/58/17 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 03/01/05 | 46 | 32.81 | 62 | 2.39 | 62 | 2.39 | 63 | 2.43 | 63 | 2.43 |
| 03/03/53 | 96 | 44.93 | 54 | 2.06 | 52 | 1.98 | 54 | 2.06 | 54 | 2.06 |
| 03/06/41 | 96 | 44.93 | 54 | 2.06 | 52 | 1.98 | 54 | 2.06 | 54 | 2.06 |
| 03/09/29 | 96 | 44.93 | 54 | 2.06 | 52 | 1.98 | 54 | 2.06 | 54 | 2.06 |
| 03/12/17 | 97 | 45.17 | 52 | 1.98 | 47 | 1.79 | 51 | 1.94 | 50 | 1.91 |
| 03/015/05 | 97 | 45.17 | 52 | 1.98 | 47 | 1.79 | 51 | 1.94 | 50 | 1.91 |

Fig. 29. Telemetry Data of Solar Array Test No. 3, June 5, 1972

| TELEMETRY DATA | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAY 158 TIME H M S | PSL (CH 116) VOLTS | | CH 203 AMPS | | CH 204 AMPS | | CH 223 AMPS | | CH 224 AMPS | |
| | DN | ENG. | DN | ENG. | DN | ENG. | DN | ENG. | DN | ENG. |
| 03/17/53 | 97 | 45.17 | 51 | 1.94 | 47 | 1.79 | 51 | 1.94 | 50 | 1.91 |
| 03/20/41 | 97 | 45.17 | 51 | 1.94 | 47 | 1.79 | 51 | 1.94 | 50 | 1.91 |
| 03/23/29 | 97 | 45.17 | 48 | 1.83 | 42 | 1.57 | 48 | 1.83 | 45 | 1.69 |
| 03/26/17 | 97 | 45.17 | 48 | 1.83 | 42 | 1.57 | 47 | 1.79 | 45 | 1.69 |
| 03/29/05 | 97 | 45.17 | 48 | 1.83 | 42 | 1.57 | 48 | 1.83 | 46 | 1.75 |
| 03/32/27 | 98 | 45.41 | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/34/41 | 98 | 45.41 | 44 | 1.65 | 36 | -- | 43 | 1.61 | 40 | 1.50 |
| 03/37/29 | 98 | 45.41 | 43 | 1.61 | 36 | -- | 107 | -- | 40 | 1.50 |
| 03/43/05 | 98 | 45.41 | 44 | 1.65 | 37 | -- | 43 | 1.61 | 40 | 1.50 |
| 03/45/53 | 98 | 45.41 | 44 | 1.65 | -- | -- | 43 | 1.61 | -- | -- |
| 03/48/58 | 98 | 45.41 | -- | -- | 36 | -- | -- | -- | 40 | 1.50 |
| 03/51/29 | 98 | 45.41 | 45 | 1.69 | 39 | 1.46 | 45 | 1.69 | 43 | 1.61 |
| 03/54/17 | 97 | 45.17 | 49 | 1.87 | 44 | 1.65 | 48 | 1.83 | 47 | 1.79 |
| 03/57/05 | 97 | 45.17 | 49 | 1.87 | 44 | 1.65 | 49 | 1.87 | 47 | 1.79 |

Fig. 29 (contd)

| VOLTAGE – CURRENT POINTS DEVELOPED FROM TELEMETRY FLIGHT DATA | |
|---|---|
| ARRAY VOLTAGE (VOLTS) PSL VOLTS +1.0 VOLTS FOR DIODE DROP | ARRAY CURRENT (AMPS) |
| 45.93 | 7.89 |
| 45.69 | 8.43 |
| 45.69 | 8.35 |
| 45.69 | 8.51 |
| 45.69 | 8.39 |
| 45.45 | 8.72 |
| 34.30 | 9.64 |
| 33.07 | 9.68 |
| 46.17 | 6.92 |
| 46.17 | 6.98 |

Fig. 30. Voltage-Current Points Developed from Telemetry Flight Data of Solar Array Test No. 3, June 5, 1972

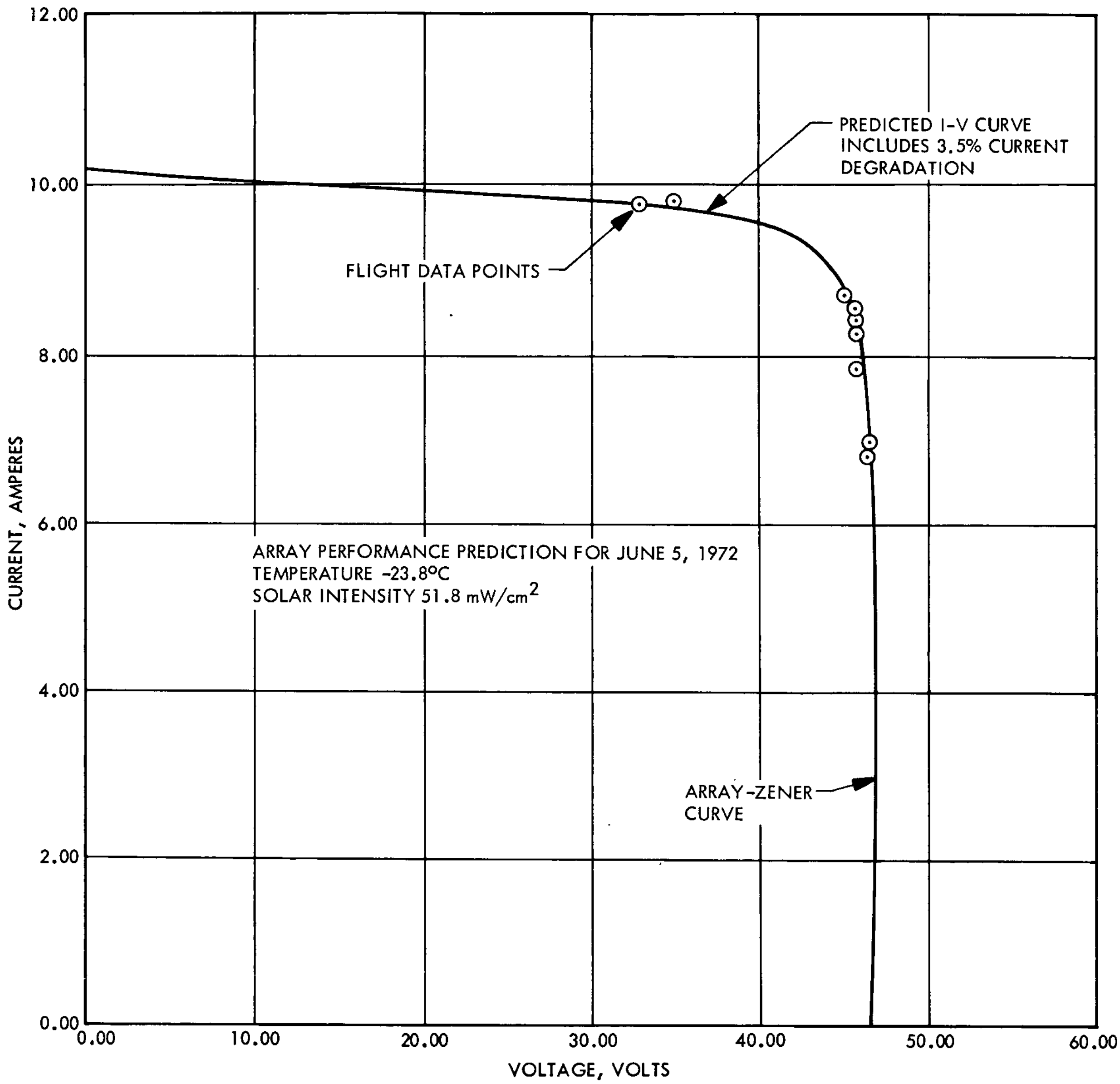



Fig. 31. Solar Array Performance During Test No. 3, June 5, 1972

| DAY 276 TIME H M S | PSL (CH 116) VOLTS | | CH 203 AMPS | | CH 204 AMPS | | CH 223 AMPS | | CH 224 AMPS | |
|---|---|---|---|---|---|---|---|---|---|---|
| | DN | ENG. | DN | ENG. | DN | ENG. | DN | ENG. | DN | ENG. |
| 14/54/33 | 97 | 45.17 | 47 | 1.79 | 42 | 1.57 | 47 | 1.79 | 45 | 1.69 |
| 14/157/04 | 97 | 45.17 | 47 | 1.79 | 42 | 1.57 | 47 | 1.79 | 47 | 1.79 |
| 15/08/33 | 97 | 45.17 | 48 | 1.83 | 44 | 1.65 | 48 | 1.83 | 47 | 1.79 |
| 15/14/09 | 97 | 45.17 | 48 | 1.83 | 44 | 1.65 | 48 | 1.83 | 47 | 1.79 |
| 15/22/33 | 97 | 45.17 | 48 | 1.83 | 44 | 1.65 | 48 | 1.83 | 47 | 1.79 |
| 15/33/50 | 97 | 45.17 | 48 | 1.83 | 42 | 1.57 | 48 | 1.83 | 45 | 1.69 |
| 15/36/21 | 97 | 45.17 | 47 | 1.79 | 42 | 1.57 | 47 | 1.79 | 45 | 1.69 |
| 15/41/57 | 97 | 45.17 | 47 | 1.79 | 44 | 1.65 | 46 | 1.75 | 47 | 1.79 |
| 15/55/57 | 96 | 44.93 | 51 | 1.94 | 48 | 1.83 | 51 | 1.94 | 51 | 1.94 |
| 18/44/01 | 96 | 44.93 | 52 | 1.98 | 50 | 1.91 | 52 | 1.98 | 52 | 1.98 |
| 18/57/45 | 97 | 45.17 | 46 | 1.75 | 41 | 1.53 | 46 | 1.75 | 44 | 1.65 |
| 19/03/21 | 97 | 45.17 | 46 | 1.75 | 41 | 1.53 | 46 | 1.75 | 44 | 1.65 |
| 20/30/08 | 98 | 45.41 | 43 | 1.61 | 36 | 1.34 | 42 | 1.57 | 40 | 1.50 |
| 20/32/56 | 98 | 45.41 | 43 | 1.61 | 36 | 1.34 | 42 | 1.57 | 40 | 1.50 |
| 20/41/20 | 99 | 45.65 | 38 | 1.42 | 31 | 1.14 | 38 | 1.42 | 35 | 1.30 |
| 20/46/56 | 99 | 45.65 | 37 | 1.38 | 31 | 1.14 | 37 | 1.38 | 35 | 1.30 |
| 16/09/45 | 50 | 33.78 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 16/15/21 | 49 | 33.54 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 16/23/45 | 48 | 33.30 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 16/29/21 | 47 | 33.06 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 16/34/57 | 46 | 32.81 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 16/43/04 | 45 | 32.57 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 17/00/09 | 44 | 32.32 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 17/30/57 | 43 | 32.07 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 17/44/57 | 42 | 31.83 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 18/01/45 | 41 | 31.59 | 60 | 2.31 | 60 | 2.31 | 61 | 2.35 | 61 | 2.35 |
| 21/14/56 | 93 | 44.21 | 52 | 1.98 | 54 | 2.06 | 53 | 2.02 | 55 | 2.15 |
| 21/28/56 | 94 | 44.45 | 54 | 2.06 | 54 | 2.06 | 55 | 2.15 | 55 | 2.15 |
| 21/34/32 | 95 | 44.69 | 54 | 2.06 | 51 | 1.94 | 55 | 2.15 | 53 | 2.02 |
| 21/01/13 | 93 | 44.21 | 54 | 2.06 | 54 | 2.06 | 55 | 2.15 | 55 | 2.15 |

Fig. 32. Telemetry Data of Solar Array Test No. 4, October 2, 1972

| ARRAY VOLTAGE (VOLTS) (PSL VOLTS +1.0 VOLT FOR DIODE DROP) | ARRAY CURRENT (AMPS) SUMMATION OF PANEL CURRENTS |
|---|---|
| 46.17 | 6.84 |
| 46.17 | 7.10 |
| 45.93 | 7.65 |
| 46.41 | 6.02 |
| 46.65 | 5.28 |
| 34.78 | 9.32 |
| 33.07 | 9.32 |
| 45.21 | 8.21 |
| 45.45 | 8.42 |
| 45.69 | 8.17 |
| 45.21 | 8.42 |

Fig. 33. Voltage-Current Points Developed from Telemetry Data of Solar Array Test No. 4, October 2, 1972

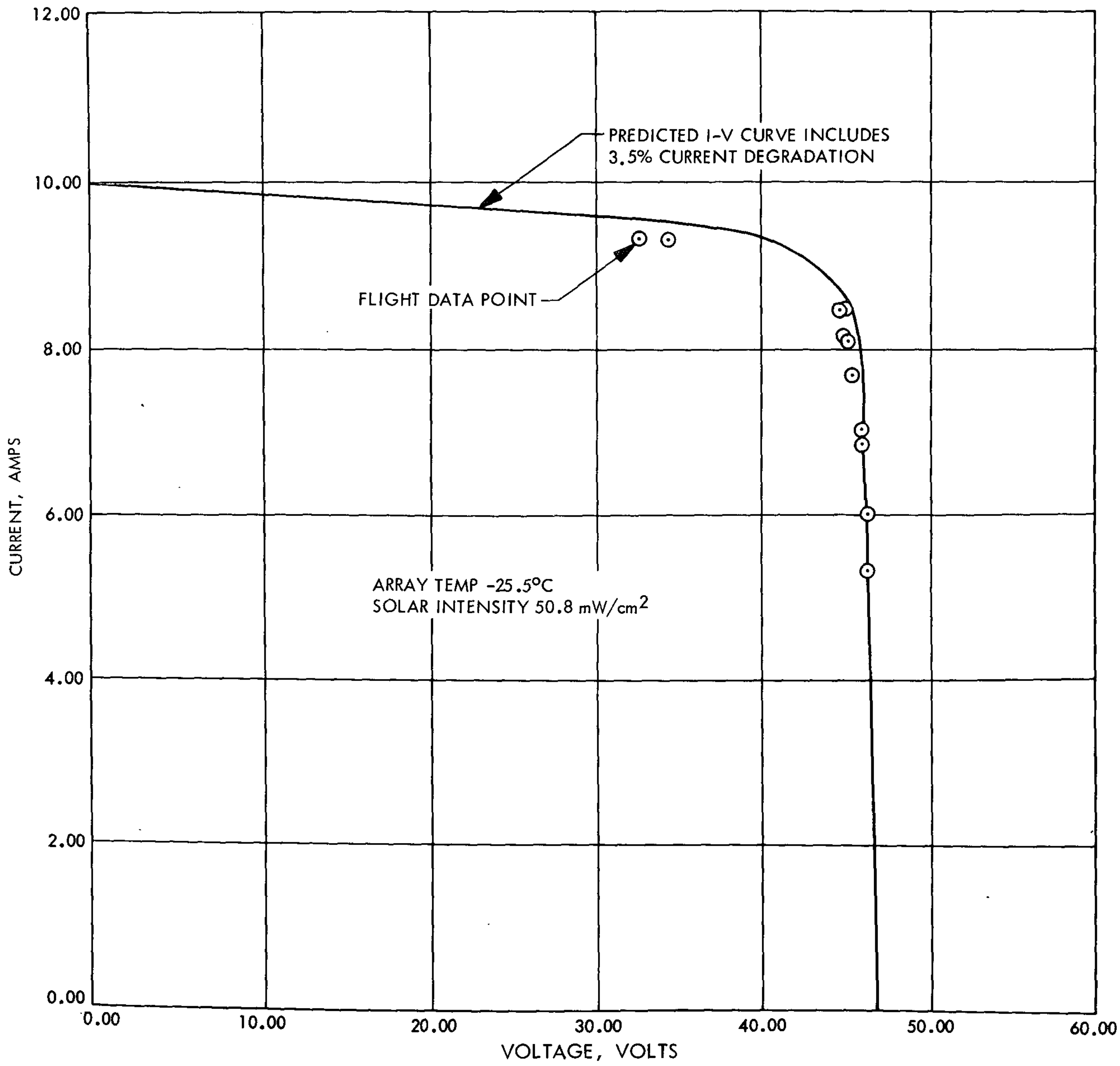



Fig. 34. Solar Array Performance During Test No. 4, October 2, 1972

## IX. COMMENTS AND CONCLUSIONS

The Mariner 9 solar array successfully supported the spacecraft power requirement during the Mariner standard and extended mission when the solar panels were normal to Sun. The panels did not experience anomalous behavior throughout the mission. The array special tests provided unique information on the current-voltage characteristics and array space degradation. The March 29 test indicated that the total solar array degradation was 3.5 percent. The degradation was current degradation and could probably be attributed to gradual degradation of the cover glass and/or the RTV 602 adhesive employed to cement the cover glass to the solar cell. Flight data generated during the June 5, 1972, special test confirmed the results obtained on March 29 and also verified that the solar panels had successfully survived the Sun occultation periods without additional degradation or failures. The final array test conducted on October 2, 1972, indicated very close correlation between predicted and actual flight array performance with no significant additional current degradation.

The accuracy of the analytical technique used to predict the array performance appears to be satisfactory. However, there appears to be a small difference of approximately one percent between the current-voltage characteristics of the flight data obtained during the special tests and the current-voltage characteristics of the computer predicted array performance. The difference may be related to the series resistance factor applied to the model for predicting solar array performance; however, the accuracy of data required to make this detailed an evaluation is believed to be outside the resolution of the flight telemetry data and modeling capability.

The Isc-Voc transducer performance output which was monitored during the mission and relied on for predicting solar array performance and degradation correlate closely with array performance data. For greater accuracy in predicting solar array performance, it is recommended for future missions that techniques be developed for direct monitoring of the array. If an Isc-Voc transducer must be relied upon, then more accurate telemetry data will be required and the complete I-V characteristics of the transducer monitored instead of only the open circuit voltage or the short circuit current.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