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Results of the 1979 NASA/JPL Balloon Flight Solar Cell Calibration Program

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PREFACE

The work described in this report was performed by the Control and Energy Conversion Division of the Jet Propulsion Laboratory. The flight was conducted with the cooperation of the National Scientific Balloon Facility, located in Palestine, Texas. A summary of the data is presented.

ABSTRACT

The 1979 scheduled solar cell calibration balloon flight was successfully completed on August 8, meeting all objectives of the program. Thirty-eight modules were carried to an altitude of about 36 kilometers. These calibrated cells can be used as reference standards in simulator testing of cells and arrays.

ACKNOWLEDGMENT

The authors wish to extend appreciation for the cooperation and support provided by the entire staff of the National Scientific Balloon Facility.

Gratitude is also extended to assisting JPL personnel, especially B. E. Anspaugh, R. G. Downing and L. B. Sidwell.

The cooperation and patience extended by all participating organizations is greatly appreciated.

CONTENTS

SECTION I

INTRODUCTION

The primary source of electrical power for unmanned space vehicles is the direct conversion of solar energy through the use of solar cells. As advancing cell technology continues to modify the spectral range of solar cells to utilize more of the sun's spectrum, designers of solar arrays must have information detailing the impact of these modifications on cell conversion efficiency to be able to confidently minimize the active cell area required and hence the mass of the array structure.

Since laboratory simulation of extra-atmospheric solar radiation has not been accomplished on a practical scale with sufficient fidelity, high altitude exposure must be taken as the best representation of space itself. The error due to residual atmosphere may be computed using

$$\sum_{0}^{\infty} R_\lambda \; T_\lambda \; E_\lambda \; \Delta_\lambda = (1-\varepsilon) \sum_{0}^{\infty} R_\lambda \; E_\lambda \; \Delta_\lambda \qquad (1)$$

where R_λ = cell spectral response

E_λ = extra-atmospheric solar spectral irradiance (AMO)

T_λ = sky path spectral transmissivity

ε = fractional departure from true AMO response (error)

T_λ can be computed using

$$T_\lambda = \text{Exp} - (\tau_\lambda \sec Z)$$

where τ_λ = spectral extinction optical thickness (Reference 1)

Z = solar zenith angle

The actual limits in Eq. (1) will be determined by the cell spectral response, R_λ.

The values of these summations have been computed for transmissivities corresponding to an altitude of 36 kilometers (the altitude of this flight) and four solar zenith angles using available data (References 1 and 2). The spectral extinction optical thickness is plotted in Figure 1. Values of percent error (100ε) vs. solar zenith angle for two representative cell spectral responses (given in Figure 2) are shown in Figure 3. Data on this flight was taken for solar zenith angles between 25 degrees and 23 degrees. It is seen that the flight altitude used in these calibrations is such that the computed error due to residual atmosphere is negligible.

To reach and maintain the required altitude, the calibration program makes use of balloons provided and launched by the National Scientific Balloon Facility, Palestine, Texas.

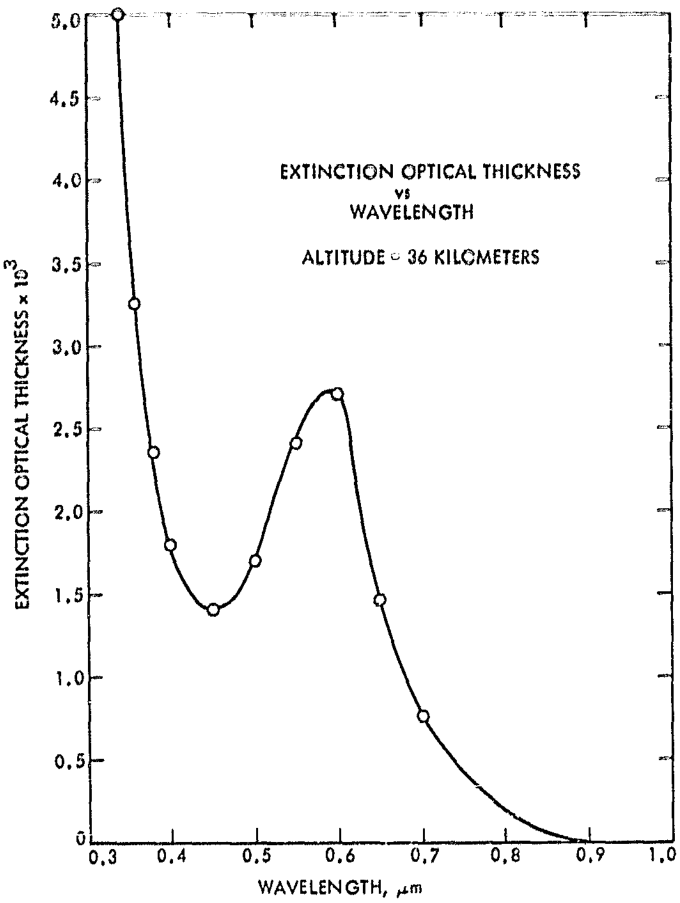

Figure 1. Extinction Optical Thickness

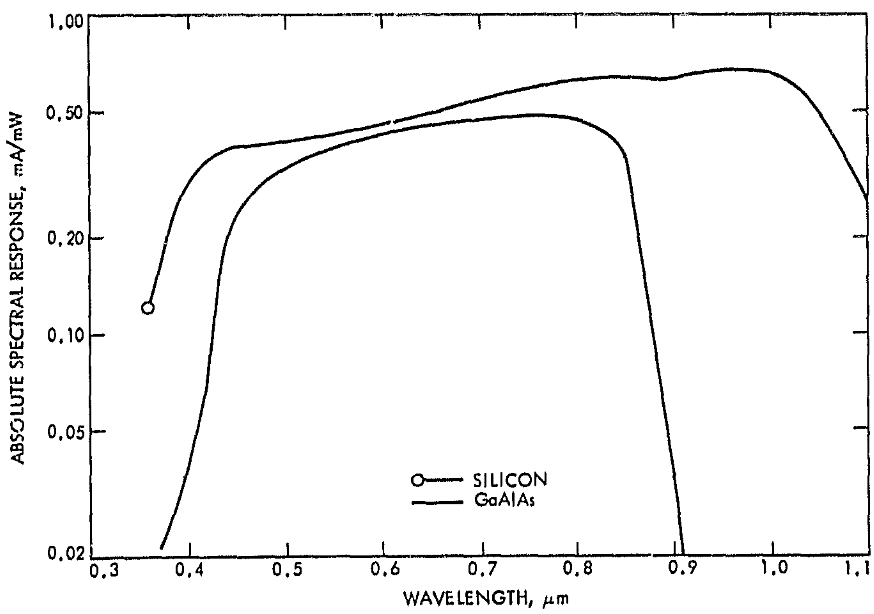

Figure 2. Cell Spectral Response

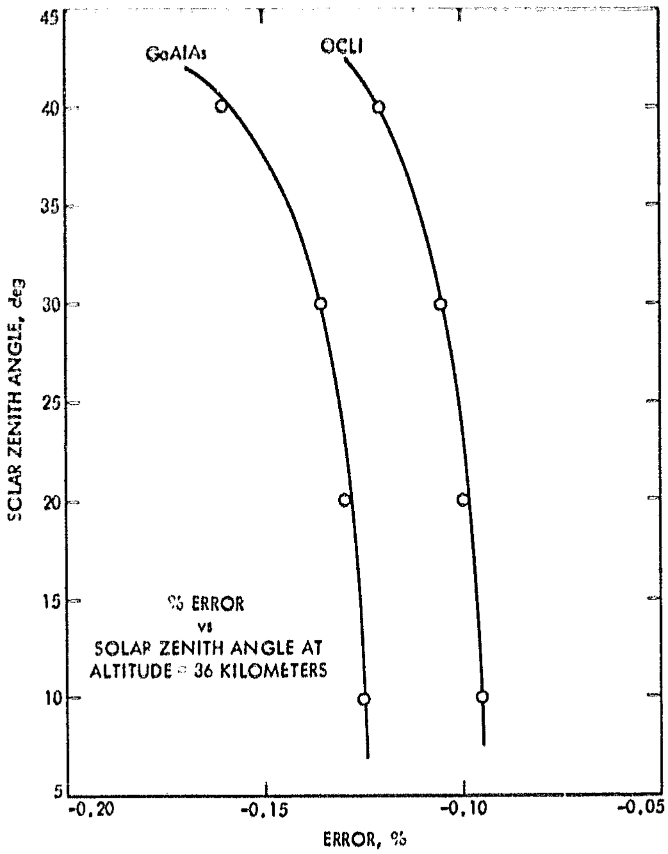

Figure 3. Error vs. Zenith Angle

SECTION II

PROCEDURE

To insure electrical and mechanical compatibility with other components of the flight system, the cells are mounted by the participants on JPL-supplied standard modules according to directions in Reference 3, which details materials, techniques, and workmanship standards for assembly. The JPL standard module is a machined copper block 3.7 cm x 4.8 cm x 0.3 cm thick, rimmed by 0.3 cm thick fiberglass, painted a high reflectance white, with insulated solder posts and is permanently provided with a precision (0.1 percent, 20 ppm/^{o}C) load resistor appropriate for scaling the cell output to the telemetry constraints. This load resistor, 0.5 ohm for a 2 cm x 2 cm cell, for example, also loads the cell in its short circuit current condition.

The mounted cells are then subjected to preflight measurements in the JPL X25L solar simulator. This measurement when compared to a postflight measurement under the same conditions may be used to detect cell damage or instabilities.

Prior to shipment to the launch facility, the modules are mounted on the sun tracker bed plate, Figure 4.

Upon arrival at the Palestine Facility, the tracker and module payload are checked for proper operation, the data acquisition and Pulse Code Modulation telemetry systems are calibrated, and mounting of the assembly onto the balloon is then accomplished, Figure 5.

At operating altitude the sun tracker bed plate is held pointed at the sun to within ±1 degree. The response of each module, temperatures of representative modules, sun lock information, and system calibration voltages are sampled twice each second and telemetered to the ground station where they are presented in teletype form for real time assessment and are also recorded on magnetic tape for later processing. Float altitude information is obtained from data supplied by the balloon facility.

SECTION III

SYSTEM DESCRIPTION

A solar tracker mounted in a frame on top of the balloon carries the module payload while the transmitter of the data link is located in the lower Gondola along with batteries for power and ballast for balloon control. At completion of the experiment, the upper payload and lower gondola are returned by parachutes and recovered. A more complete description of the system including the sun tracker can be found in Reference 4.

SECTION IV

DATA REDUCTION

The raw data as taken from the tape is corrected for temperature and sun-Earth distance according to the formula (Reference 5)

$$V_{28,1} = V_{T,R} \ (R^2) - \alpha(T-28)$$

where $V_{T,R}$ = measured module output voltage at temperature T and distance R

R = sun-Earth distance in astronomical units

α = module output voltage temperature coefficient

T = module temperature in ^oC

The value of α is supplied by the participant.

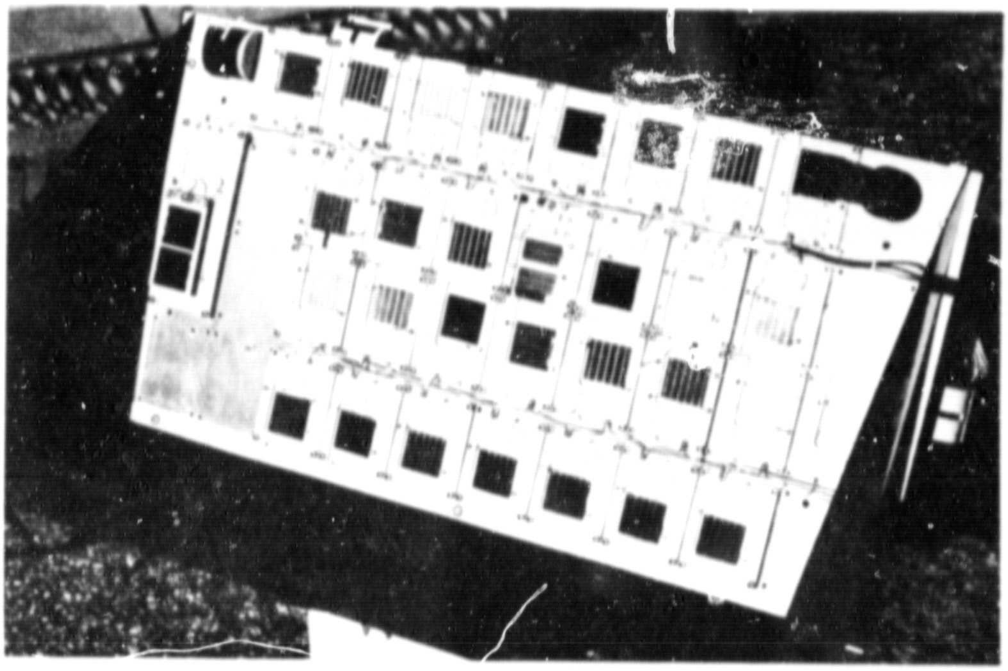

Figure 4. Typical Solar Module Payload

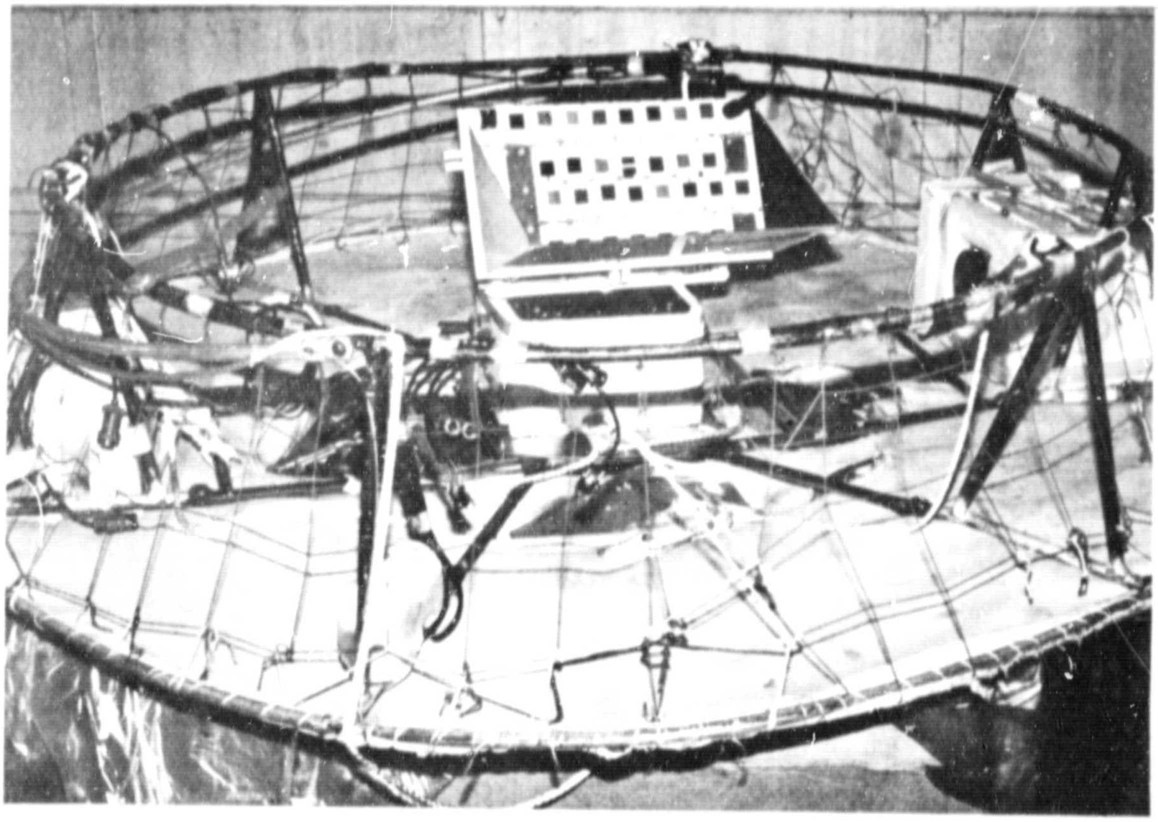

Figure 5. Balloon Mount

The calibration value is taken to be the average of 200 consecutive data points taken around the time of solar noon after indicated temperature stability.

The flight data were thus reduced and modules with their data and calibration values were returned to the participants. This information is collected in Table 1. The placement of modules on the field of the tracker bed for the 1979 flight is shown in Figure 6.

Table 1. Cell Calibration Data

BALLOON FLIGHT 79-1 DATE 8-8-79 ALTITUDE 117,000 RV=1.01392

CHANNEL NUMBER	MODULE NUMBER	ORGANIZATION CODE	TEMP. INTENSITY ADJ. AVERAGE MILLIVOLTS	STANDARD DEVIATION	AMO, SOLAR SIM. 1 AU, 28 DEG.C PRE-FLT	AMO, SOLAR SIM. 1 AU, 28 DEG.C POS-FLT	COMPARISON, SOLAR SIMULATOR & FLT PRE-FLT VS. POS-FLT (PERCENT)	COMPARISON, SOLAR SIMULATOR & FLT FLIGHT VS. PRE-FLT (PERCENT)
1	79-001	JPL	87.77	.09925	86.70	86.00	-.81	1.23
2	79-126	OCLI	81.49	.08063	80.90	81.10	.25	.73
3	79-113	HUGHES	56.43	.08701	56.00	55.95	-.09	.76
4	79-101	HUGHES	29.39	.08709	29.75	28.90	-2.86	-1.23
5	74-209	JPL	90.76	.09927	88.10	88.30	.23	3.02
6	79-115	HUGHES	56.77	.08353	56.70	56.70	.00	.13
7	79-132	TRW	73.54	.08357	73.85	73.83	-.03	-.42
8	79-002	JPL	84.30	.08978	83.60	83.20	-.48	.83
9	78-105	HUGHES	82.20	.09530	80.95	81.00	.06	1.54
10	79-134	TRW	75.07	.08434	75.10	74.80	-.40	-.04
11	79-107	HUGHES	49.42	.08959	31.50	30.70	-2.54	56.89
12	73-183	JPL	66.96	.09882	67.90	68.00	.15	-1.38
13	79-103	HUGHES	24.33	.08678	26.10	25.70	-1.53	-6.79
14	BFS-17A	JPL	60.14	.08071	60.40	61.00	.99	-.43
15	79-127	OCLI	82.07	.09412	81.75	81.30	-.55	.40
16	78-107	HUGHES	89.50	.10645	88.05	88.00	-.06	1.65
17	79-003	JPL	82.45	.07081	81.85	81.60	-.31	.73
18	79-122	OCLI	84.37	.19594	83.65	83.33	-.38	.86
19	73-182	JPL	67.83	.09426	68.65	68.85	.29	-1.19
20	78-110	HUGHES	95.02	.07924	93.95	93.75	-.21	1.14
21	79-133	TRW	73.58	.24430	73.85	73.40	-.61	-.36
22	79-109	HUGHES	21.04	.07746	20.90	20.90	.00	.65
23	79-136	TRW	75.22	.08212	75.10	75.20	.13	.15
24	79-004	JPL	83.43	.08756	83.05	82.75	-.36	.46
25	79-105	HUGHES	28.53	.08429	37.70	37.41	-.77	-24.33
26	76-001	JPL	67.32	.07523	68.40	68.65	.37	-1.58
27	79-005	JPL	76.39	.07775	76.30	75.70	-.79	.12
28	79-006	JPL	79.30	.11971	79.55	79.06	-.62	-.31
29	79-007	JPL	83.89	.07629	83.55	83.55	.00	.41
30	79-008	JPL	81.25	.09327	80.90	80.70	-.25	.44
31	79-009	JPL	79.33	.07772	78.95	78.90	-.06	.48
32	79-111	HUGHES	63.55	.10558	63.50	62.45	-1.65	.08
33	79-010	JPL	55.16	.07319	55.35	55.27	-.14	-.35
34	79-124A	OCLI	78.20	.09198	77.35	77.70	.45	1.10
35	79-124B	OCLI	77.93	.08796	76.90	77.37	.61	1.34
36	79-014	JPL	59.23	.09271	59.60	59.20	-.67	-.63
37	79-012	JPL	72.88	.07837	72.95	72.65	-.41	-.10
38	77-007	JPL	61.01	.09528	60.90	60.95	.08	.18

AVERAGE TEMPERATURE (DEG.C) AT FLOAT ALTITUDE = 45.95

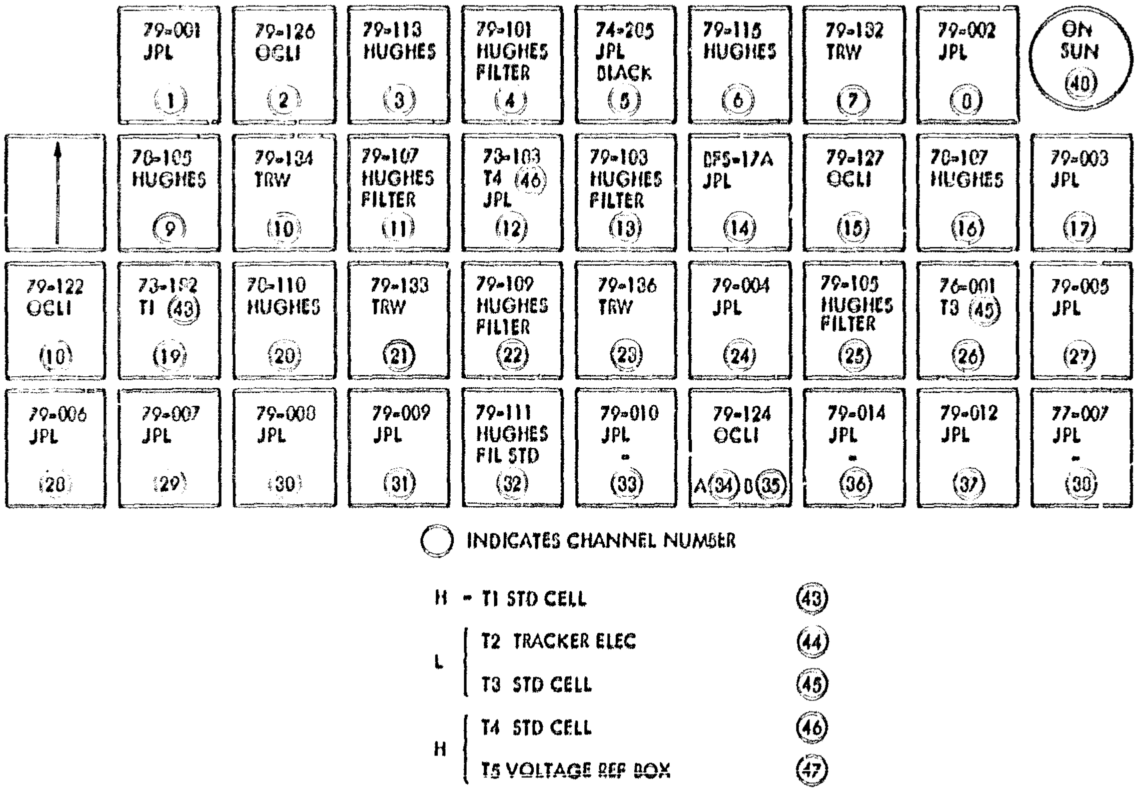

Figure 6. Module Location Chart

A detailed discussion of data reduction and an analysis of system error may be found in Reference 4.

SECTION V

MONITOR CELLS

Several standard modules have been flown repeatedly over the 16-year period of calibration flights. The record of the one with the longest history, BFS-17A, appears in Table 2. This data shows a standard deviation of 0.39 percent and a maximum deviation of 0.92 percent from the mean.

In addition, the uniformity of the solar irradiance (i.e. no spurious reflections, shadowing) over the field of the modules has been demonstrated since the location of this module was changed in that field from flight to flight.

Table 2. Repeatability of Standard Module BFS-17A
(31 Flights over a 17-Year Period)

Flight date	Output, mV	Flight data	Output, mV
9/5/63	60.07	8/5/70	60.32
8/3/64	60.43	4/5/74	60.37
8/8/64	60.17	4/23/74	60.37
7/28/65	59.90	5/8/74	60.36
8/9/65	59.90	10/12/74	60.80
8/13/65	59.93	10/24/74	60.56
7/29/65	60.67	6/6/75	60.20
8/4/66	60.25	6/27/75	60.21
8/12/66	60.15	6/10/77	60.35
8/26/66	60.02	8/11/77	60.46
7/14/67	60.06	7/20/78	60.49
7/25/67	60.02	7/8/79	60.14
8/4/67	59.83	Mean	60.25
8/10/67	60.02		
7/19/68	60.31	Std. Deviation	0.24
7/29/68	60.20		
8/26/69	60.37	Maximum deviation	0.55
9/8/69	60.17		
7/28/70	60.42		

Each data point is an average of 20 to 30 points per flight for period 9/5/63 to 8/5/70.

For flights on 4/5/74 through 7/1/75 each data point is an average of 100 or more flight data points.

For flights starting in September 1975, each data point is an average of 200 data points.

SECTION VI

FLIGHT PERFORMANCE

The launch at 0700 hours, CST, on August 8 was accomplished without incident as was the float phase. The tracker was energized at 1045 hours, CST, at an altitude of 35.7 kilometers with sun-lock occurring within 2 minutes. Data was taken for solar zenith angles between 25 degrees and 23 degrees. The flight was terminated at 1145 hours, CST. Although the parachute did not fully deploy and the tracking beacon failed, the payload was recovered the following afternoon undamaged.

SECTION VII

CONCLUSIONS

1. As emphasized by the history of repeatability of cell BFS-17A, viz ±1 percent (see Table 2), silicon cells when properly cared for are stable for long periods of time and may be used as standards with confidence.

2. The calculated error due to residual atmosphere on this flight is less than 0.10 percent for silicon cells and less than 0.13 percent for gallium arsenide cells.

3. As advancing technology continues to favorably modify cell spectral response, continued calibration of solar cells under AMO conditions is required to assure that solar panel performance with all its ramifications can be accurately predicted.

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