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Results of the 1980 NASA/JPL Balloon Flight Solar Cell Calibration Program

C.H. Seaman
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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.

ABSTRACT

The 1980 scheduled solar cell calibration balloon flight was successfully completed on July 24, meeting all objectives of the program. Thirty-eight modules were carried to an altitude of about 36 kilometers. In addition to the cell calibration program, an experiment to evaluate the calibration error versus altitude was performed. The calibrated cells can now 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 and R. G. Downing, for providing cell spectral response data. The cooperation and patience extended by all participating organizations are 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.

A computation (reported in the 1979 balloon flight results report (Reference 1)), using published atmospheric transmission data (Reference 2), the extraterrestrial solar spectrum (Reference 3), and typical cell spectral response data, found that the calibration error due to residual atmosphere at float altitude (36 km) was negligible. Figure 1 is reproduced from that report. Using the previously mentioned published data, the calibration error versus altitude was computed and is presented in Figure 2. To test the results of these computations, data was obtained during the ascent phase of the July 1980 flight. Starting at 18.5 km, a series of cell calibration data was taken on two silicon cells, which were also provided with temperature monitors. Simultaneous altitude information was available from radar and OMEGA measurements. During this series, the solar zenith angle varied from about 40 to about 20 deg. the temperature and zenith angle corrected "calibrations" of the cells during the ascent phase are compared to the "at float" values to obtain error versus altitude information. These results are also given in Figure 2 with a least squares fit indicated by the dashed curve. Considering the transient nature of the experimental process, the consistency of the measured values is good. While the final decision as to an adequate calibration altitude must await the results of the space shuttle solar cell calibration experiment, the substantial agreement between measured and computed errors suggests that the atmospheric absorption behavior is fairly well described. On the basis of this currently best available data, inference may be drawn with some confidence that an altitude above, say, 32 km is sufficient to obtain an accurate calibration of the more recent blue sensitive cells, while any calibration carried out below, say, 25 km should certainly be viewed with suspicion.

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.

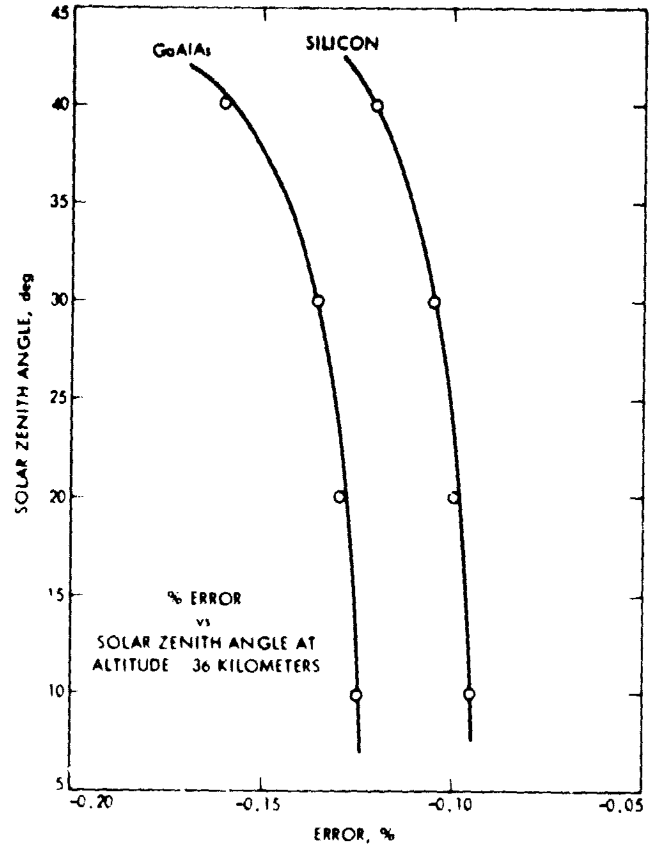

Figure 1. Percent Error vs Solar Zenith Angle

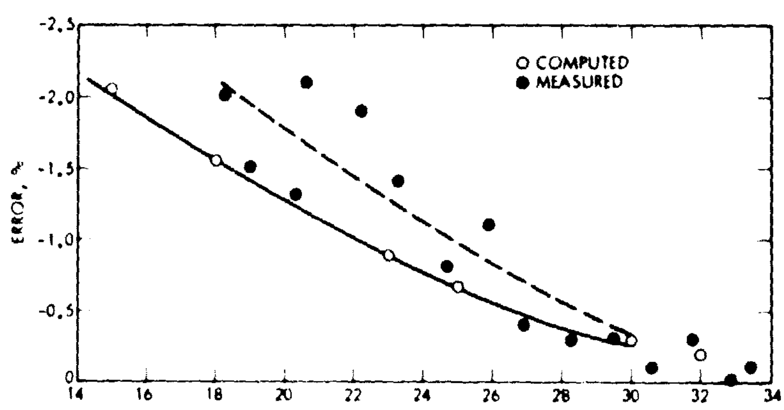

Figure 2. Calibration Error vs Altitude

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 4, 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/°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 3).

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 4).

At operating altitude the sun tracker bed plate is held pointed at the sun to within ±1 deg. 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 5.

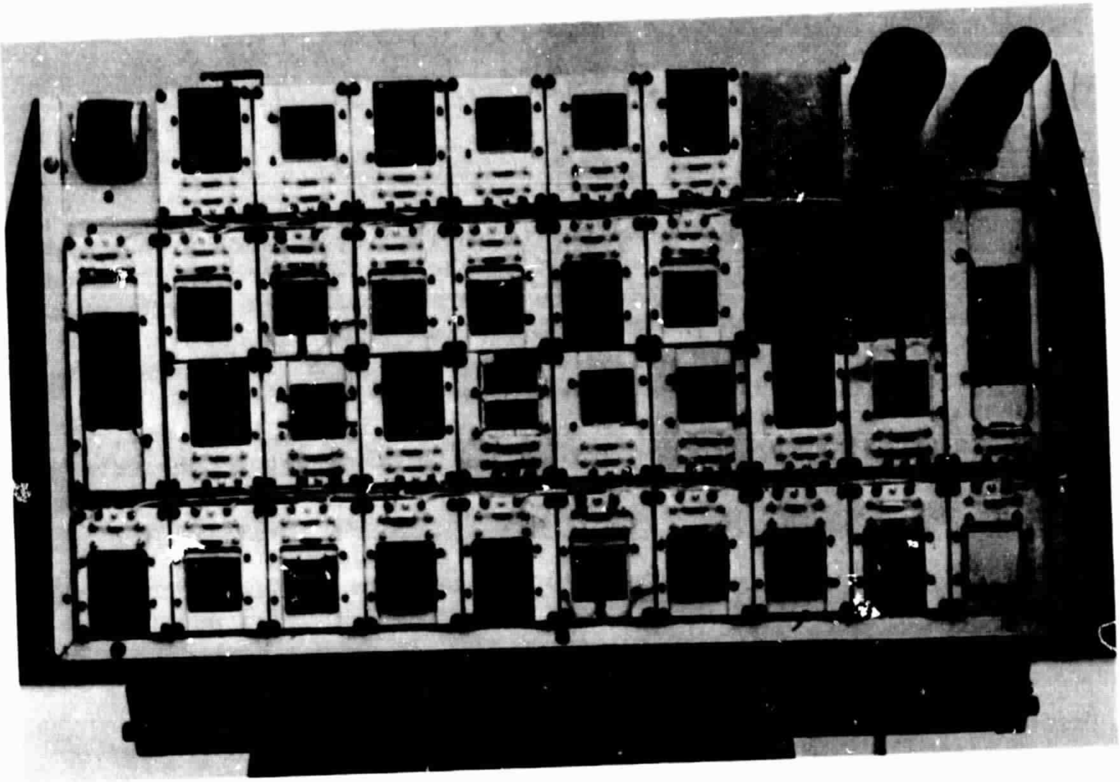

Figure 3. 1980 Solar Module Payload

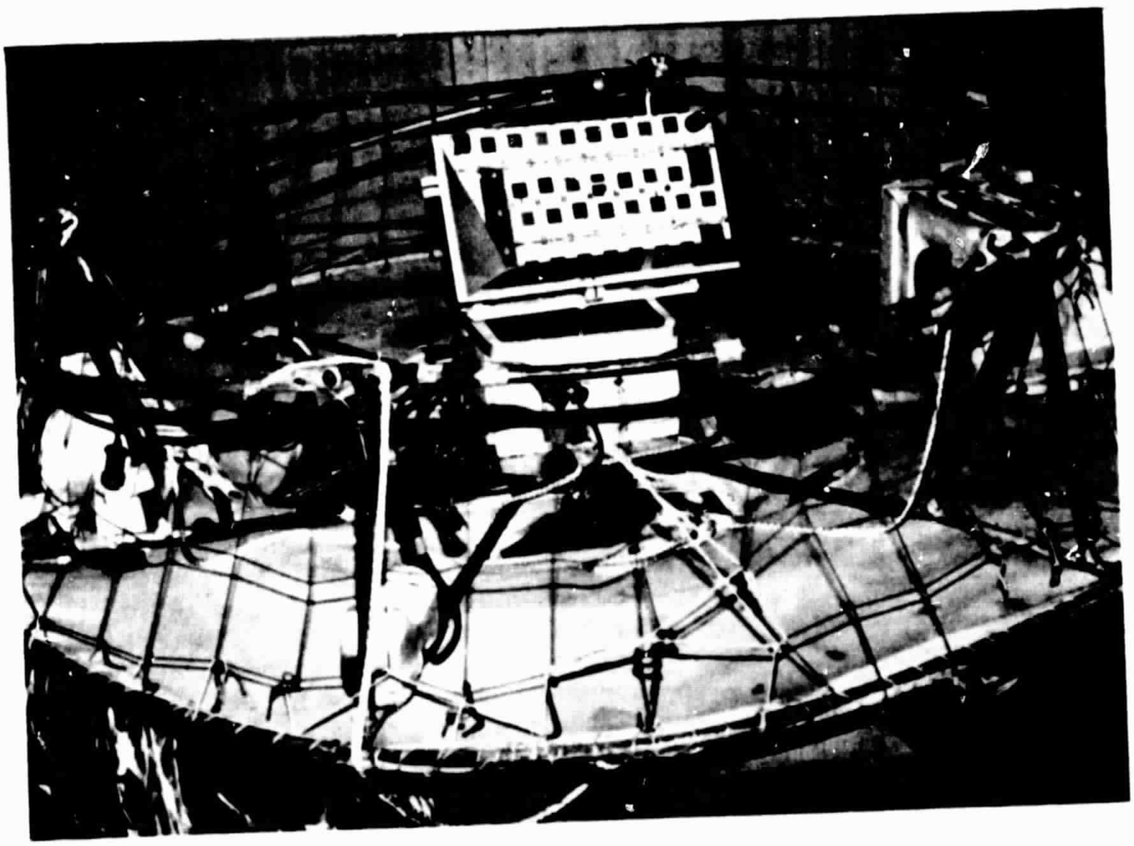

Figure 4. Balloon Mount

SECTION IV

DATA REDUCTION

The raw data as taken from the magnetic tape is corrected for temperature and sun-Earth distance according to the formula (Reference 6):

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

where

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

R = sun-Earth distance in astronomical units

α = module output temperature coefficient (supplied by participant)

T = module temperature in ^{o}C

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 1980 flight is shown in Figure 5.

A detailed discussion of data reduction and an analysis of system error may be found in Reference 5.

Table 1. Cell Calibration Data

BALLOON FLIGHT 80-1 DATE 7-24-80 ALTITUDE 35.40 KM RV=1.01585

CHANNEL NUMBER	MODULE NUMBER	ORGANIZATION CODE	TEMP. INTENSITY ADJ. AVERAGE	STANDARD DEVIATION	AMO, SOLAR SIM. 1 AU, 28 DEG.C PRE-FLT	POS-FLT	COMPARISON, SOLAR SIMULATOR & FLT PRE-FLT VS. POS-FLT (PERCENT)	FLIGHT VS. PRE-FLT (PERCENT)	COMMENTS
1	80-121	HUGHES	81.47	.05326	80.40	80.25	-.19	1.33	K6 3/4
2	80-003	JPL	78.69	.05423	77.75	77.80	.06	1.21	K6 3/4
3	80-123	HUGHES	75.19	.06628	74.26	74.10	-.22	1.29	K6 3/4
4	80-009	JPL	78.06	.05455	77.35	77.30	-.06	.91	K6 3/4
5	80-008	JPL	81.54	.04392	80.62	80.42	-.25	1.14	K6 1/2
6	80-134	HUGHES	56.72	.06252	56.33	56.60	.48	.69	GAALAS
8	[illegible]OU	JPL	73.63*	.06513	80.30	80.20	-.12	-8.31	
9	80-101	EUROSA	76.46	.07710	77.00	76.60	-.52	-.70	R=.25 2X4CM
10	80-006	JPL	80.82	.06996	80.00	79.20	-1.00	1.02	K6 1/2
11	76-001	JPL	67.83	.05765	68.68	68.70	.03	-1.24	THERM T3
12	80-002	JPL	84.10	.04912	83.10	83.30	.24	1.21	K6 3/4
13	80-173	SPECTRA	84.04	.05302	82.50	82.47	-.04	1.87	
14	80-125	HUGHES	84.24	.05416	83.30	83.15	-.18	1.13	MLAR
15	80-007	JPL	81.07	.04049	80.80	80.23	-.71	.33	K6 3/4
18	80-133	HUGHES	57.20	.05869	56.70	57.10	.71	.88	GAALAS
19	74-205	JPL	90.14	.06636	87.80	87.40	-.46	2.66	
20	80-132	HUGHES	57.05	.06837	56.70	56.80	.18	.61	GAALAS
21	BFS17A	JPL	60.05	.06161	61.00	60.85	-.25	-1.56	MONITOR
22	80-008	JPL	81.37	.07041	81.60	81.16	-.61	-.26	K6 3/4
23	78-003	JPL	88.44	.06392	85.50	86.70	1.40	3.43	
24	80-128	HUGHES	81.84	.07361	81.15	81.20	.06	.85	MLAR
25	73-102	JPL	68.00	.08119	68.85	68.63	-.32	-1.23	THERM T1
26	80-102	EUROSA	78.96	.07135	78.60	78.60	.00	.45	R=.25 2X4CM
27	80-138	HUGHES	21.91*	.05944	15.45	15.19	-2.27	41.84	R=10 400BP
28	80-501	JPL	83.72	.07678	82.88	82.50	-.46	1.02	K6 3/4
29	80-171	SPECTRA	84.57	.06268	84.10	83.87	-.27	.56	
30	78-009	JPL	58.50	.08308	36.10	35.70	-1.11	62.06	350NM B.P.
31	80-137	HUGHES	29.85*	.07400	31.87	32.15	.88	-6.32	R=4 600BP
32	73-103	JPL	66.87	.07657	67.70	68.00	.44	-1.23	THERM T4
33	78-008	JPL	30.80	.05017	30.20	30.18	-.07	1.99	[illegible]40NM H.P.
34	78-007	JPL	34.29	.08818	37.50	36.90	-1.60	-8.55	700NM B.P.
35	80-139	HUGHES	63.60	.05270	62.90	62.75	-.24	1.11	R=.33 K6 3/4
36	78-006	JPL	30.53*	.08346	29.05	28.95	-.34	5.11	500NM B.P.
39	100-MV		103.08*	.03268	.00	.00	.00	.00	
40	80-MV		82.40*	.05065	.00	.00	.00	.00	
41	50-MV		51.60*	.00004	.00	.00	.00	.00	
42	0-MV		.10*	.00000	.00	.00	.00	.00	

* INDICATES CHANNEL FOR WHICH NO TEMPERATURE COEFFICIENT WAS PROVIDED.

AVERAGE TEMPERATURE (DEG.C) AT FLOAT ALTITUDE = 50.17

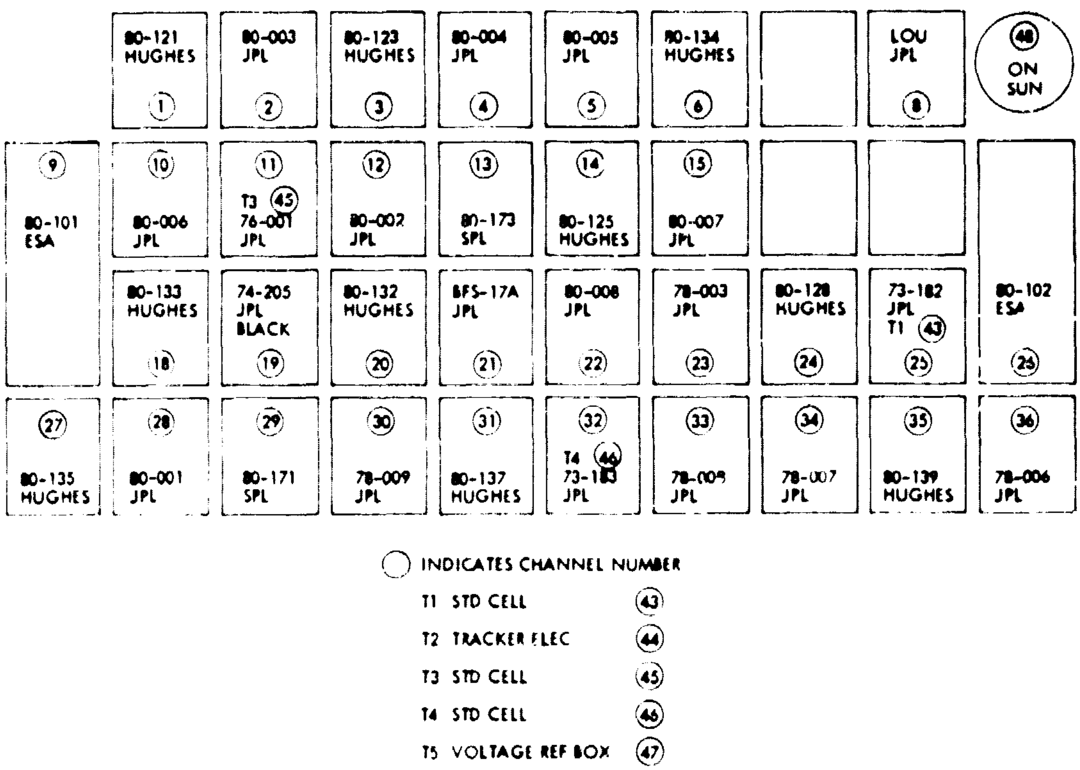

Figure 5. Module Location Chart

SECTION V

MONITOR CELLS

Several standard modules have been flown repeatedly over the 18-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 Solar Cell BFS-17A
(32 Flights over a 18-Year Period)

Flight date	Output, mV	Flight date	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	8/8/79	60.14
8/4/67	59.83	7/24/80	60.05
8/10/67	60.02		
7/19/68	60.31		
7/29/68	60.20		
8/26/69	60.37	Mean	60.25
9/8/69	60.17	Std. Deviation	0.24
7/28/70	60.42	Maximum deviation	0.55

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 0813 hours, CST, on July 24 was accomplished without incident as was the float phase. The tracker was energized at 0924 hours, CST, at an altitude of 16.7 km with sun lock occurring within 1 min. Data was taken starting at 18.5 km to provide data for the calibration error versus altitude experiment. Cell calibration data was obtained at a float altitude of about 35.5 km and a solar zenith angle of about 20 deg. The flight was terminated at about 1200 hours, CST. The payload was recovered the following morning.

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 calibration error due to residual atmosphere at float altitude (36 km) is negligible.

3. Altitudes lower than, say, 25 km are probably not adequate for reliable cell calibration.

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