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Results of the 1983 NASA/JPL Balloon Flight Solar Cell Calibration Program

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ABSTRACT

The 1983 solar cell calibration balloon flight was successfully completed on July 12, meeting all objectives of the program. Thirty-four modules were carried to an altitude of 36.0 kilometers. 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 located in Palestine, Texas. Gratitude is also extended to assisting JPL personnel, especially B.E. Anspaugh, for providing cell spectral response information and data reduction assistance. The cooperation and patience extended by all participating organizations are greatly appreciated.

CONTENTS

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 response 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. While a theoretical prediction (Reference 1) and experimental evidence have suggested that an altitude greater than 30 kilometers is sufficient to give space-equivalent calibration, the final decision as to an adequate altitude must await the results of the space shuttle solar cell calibration experiment scheduled for May 1984.

To reach and maintain the chosen altitude of 36 kilometers, the calibration program makes use of balloons provided and launched by the National Scientific Balloon Facility of Palestine, Texas.

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 2, 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. These measurements, when compared to postflight measurements 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 1). Upon arrival at the Palestine facility, the tracker and module payload are checked for proper operation, and the data acquisition and Pulse Code Modulation telemetry systems are calibrated. Mounting of the assembly onto the balloon is then accomplished (Figure 2).

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

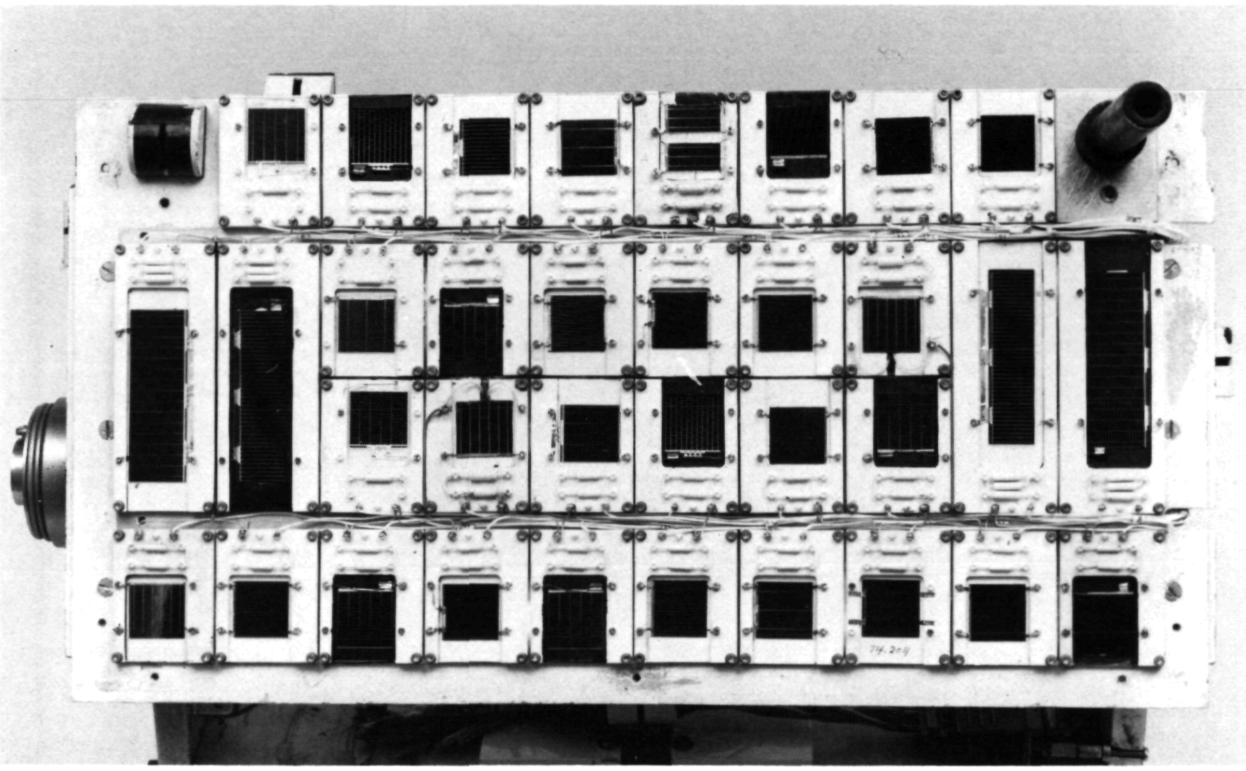

Figure 1. 1983 Solar Module Payload

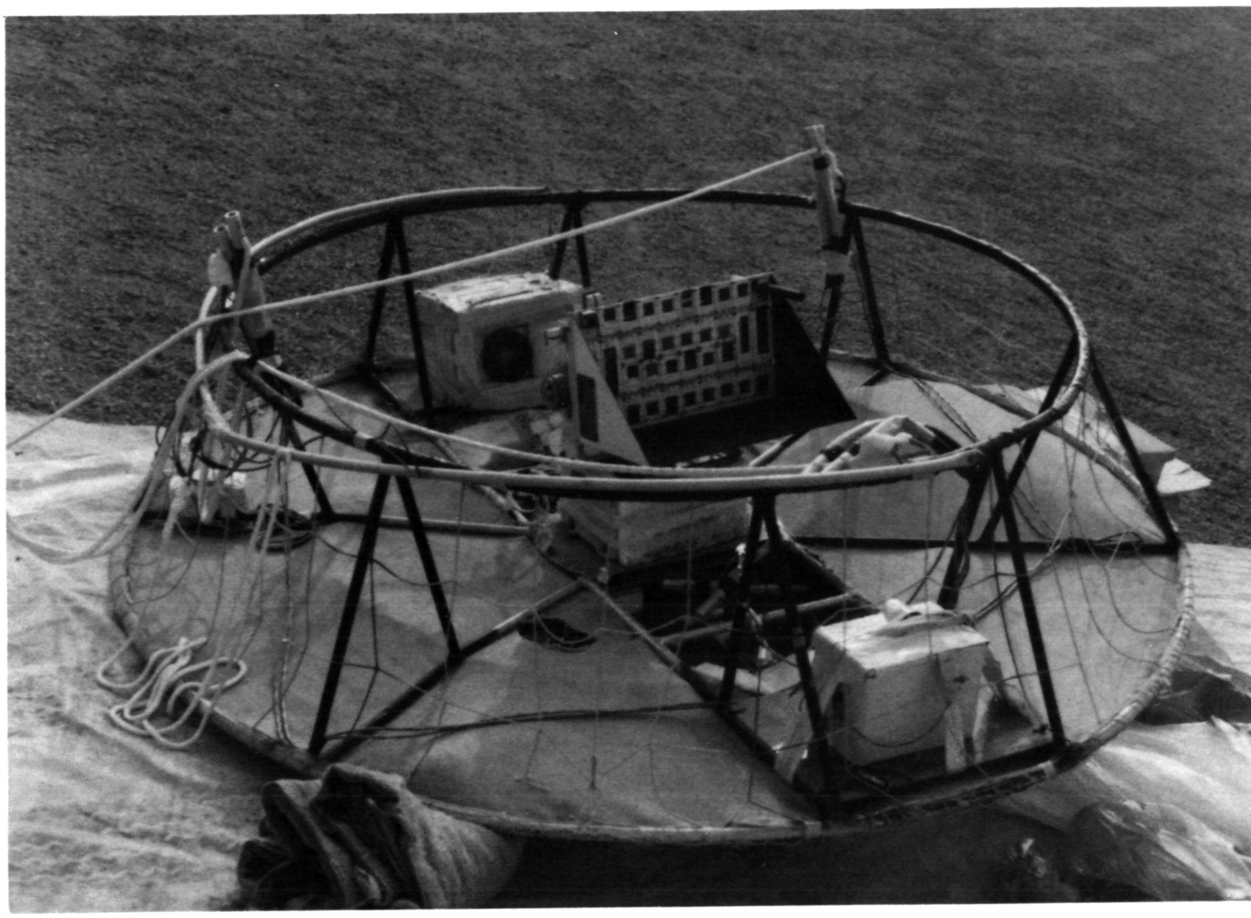

Figure 2. Balloon Mount

for later processing. Float altitude information is obtained from data supplied by the balloon facility. A plot of altitude in kilometers versus Central Daylight Time for the 1983 flight is shown in Figure 3.

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 3.

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 4):

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

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 participants)

T = module temperature in °C

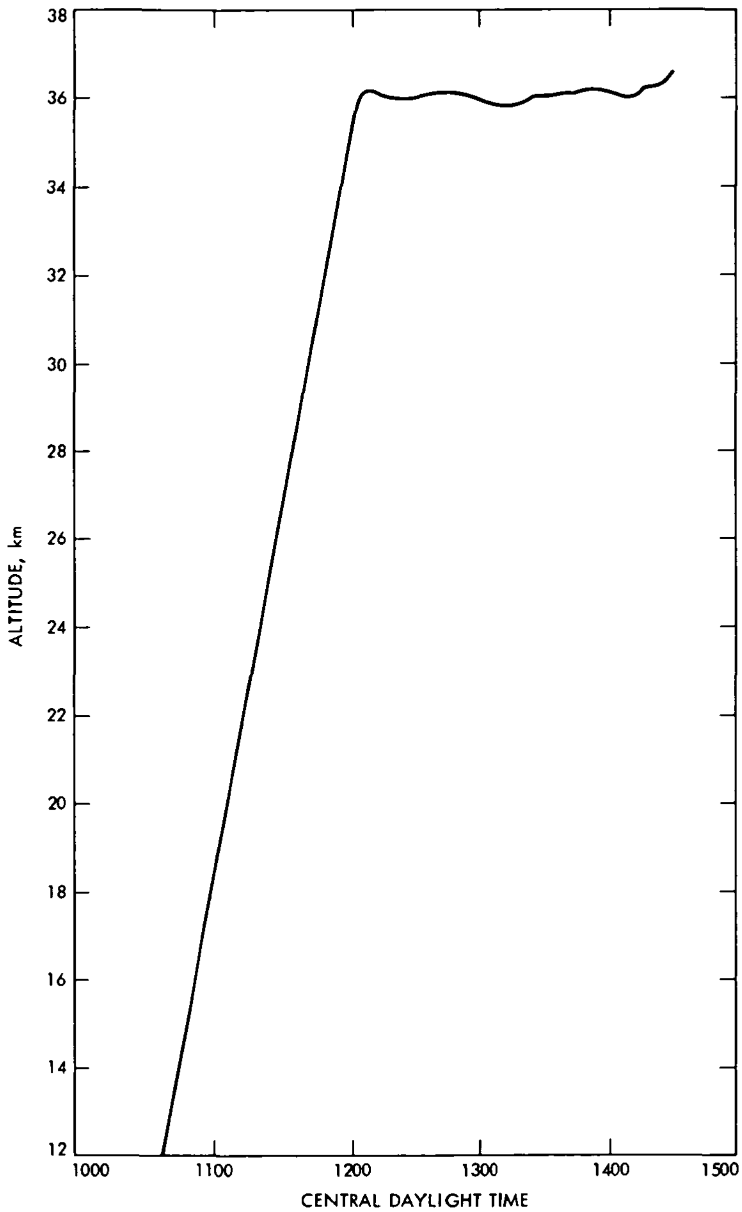

Figure 3. Flight 1983 Altitude Versus Time

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 1983 flight is shown in Figure 4.

A detailed discussion of data reduction and an analysis of system error may be found in Reference 3. The error in the calibration values due to radiation absorption and scattering by the residual atmosphere at float altitude is estimated to be less than 0.2 percent (Reference 1).

V. MONITOR CELLS

Several standard modules have been flown repeatedly over the 20-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 0.23 percent and a maximum deviation of 0.58 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 1. Cell Calibration Data

BALLOON FLIGHT 83-1 DATE 7-12-83 ALTITUDE 36.0 KM RV=1.0166

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	83-181	SPL	83.26	.06290	82.60	81.80	-.97	.80	K4
2	83-120	HUGHES	91.94	.05680	90.30	90.30	.00	1.81	K716
3	83-110	COMSAT	69.97	.04913	69.60	69.30	-.43	.54	AEG
4	83-151	ASEC	78.53	.06323	78.70	78.10	-.76	-.22	
5	BFS-17A	JPL	60.10	.04222	60.90	60.90	.00	-1.31	STANDARD
6	83-124	HUGHES	79.71	.04553	78.20	78.20	.00	1.93	AUSSAT
7	83-105	SHARP	80.08	.05038	79.60	79.50	-.13	.61	2 MIL
8	83-155	ASEC	79.55	.04982	78.60	78.80	.25	1.20	BENT BLOCK
9	83-115	COMSAT	96.62	.07774	94.60	94.60	.00	2.13	K7 2 BY 6
10	83-139	HUGHES	69.02	.05670	69.10	68.80	-.43	-.12	AEG 2 BY 6
11	83-170	SLRX	74.57	.05827	74.40	74.40	.00	.23	
12	83-126	HUGHES	77.34	.05392	77.10	77.20	.13	.31	K5
13	83-101	MELCO	61.85	.05392	61.10	61.30	.33	1.22	GA-AS
14	83-154	ASEC	87.74	.04121	86.50	86.70	.23	1.43	
15	83-160	ASEC	78.25	.02967	77.60	77.50	-.13	.84	
16	73-182	JPL	68.03	.05079	68.70	69.00	.44	-.97	TEMP MONITOR
17	83-180	SPL	86.83	.07637	85.40	85.10	-.35	1.67	K5
18	73-183	JPL	67.10	.07936	68.20	68.30	.15	-1.61	TEMP MONITOR
19	83-111	COMSAT	95.32	.06805	93.90	93.90	.00	1.51	K7
20	83-121	HUGHES	89.62	.07508	88.20	88.10	-.11	1.60	K716
21	83-106	SHARP	80.01	.07107	79.40	79.60	.25	.77	2 MIL
22	83-130	HUGHES	83.44	.07063	83.50	83.70	.24	-.07	K6.75
23	83-116	COMSAT	61.20	.06682	60.90	60.70	-.33	.49	AEG 2 BY 6
24	83-140	HUGHES	84.27	.08991	82.60	82.90	.36	2.02	K7 THIN
25	79-132	TRW	72.69	.07675	72.80	72.90	.14	-.15	REFLY
26	83-157	ASEC	76.28	.06245	75.90	75.90	.00	.50	
27	83-129	HUGHES	82.18	.06752	82.50	82.60	.12	-.39	K6.75
28	83-153	ASEC	86.78	.07338	85.90	86.00	.12	1.03	
29	83-133	HUGHES	76.56	.06633	77.00	77.20	.26	-.58	K4.75
30	83-103	MELCO	61.62	.07685	60.60	61.30	1.16	1.68	GA-AS
31	83-152	ASEC	79.74	.05917	80.00	79.70	-.38	-.32	
32	74-204	COMSAT	88.85	.11647	87.60	86.80	-.91	1.43	REFLY
33	83-159	ASEC	76.73	.05150	75.90	75.90	.00	1.10	
34	78-110	HUGHES	95.42	.07420	93.10	93.40	.32	2.49	REFLY K7
39	100-MV		99.80*	.02741	.00	.00	.00	.00	
40	80-MV		79.97*	.04688	.00	.00	.00	.00	
41	50-MV		50.21*	.03636	.00	.00	.00	.00	
42	0-MV		.00*	.00000	.00	.00	.00	.00	

* INDICATES CHANNEL FOR WHICH NO TEMPERATURE COEFFICIENT WAS PROVIDED.

AVERAGE TEMPERATURE (DEG.C) AT FLOAT ALTITUDE = 52.75

Table 2. Repeatability of Standard Solar Cell BFS-17A
(35 flights over a 21-year period)

Flight Date	Output, mW	Flight Date	Output, mW
9/5/63	60.07	4/5/74	60.37
8/3/64	60.43	4/23/74	60.37
8/8/64	60.17	5/8/74	60.36
7/28/65	59.90	10/12/74	60.80
8/9/65	59.90	10/24/74	60.56
8/13/65	59.93	6/6/75	60.20
7/29/65	60.67	6/27/75	60.21
8/4/66	60.25	6/10/77	60.35
8/12/66	60.15	8/11/77	60.46
8/26/66	60.02	7/20/78	60.49
7/14/67	60.06	8/8/79	60.14
7/25/67	60.02	7/24/80	60.05
8/4/67	59.83	7/25/81	60.07
8/10/67	60.02	7/21/82	59.86
7/19/68	60.31	7/12/83	60.10
7/29/68	60.20		
8/26/69	60.37		
9/8/69	60.17	Mean	60.22
7/28/70	60.42	Std. Deviation	0.23
8/5/70	60.32	Maximum Deviation	0.58

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.

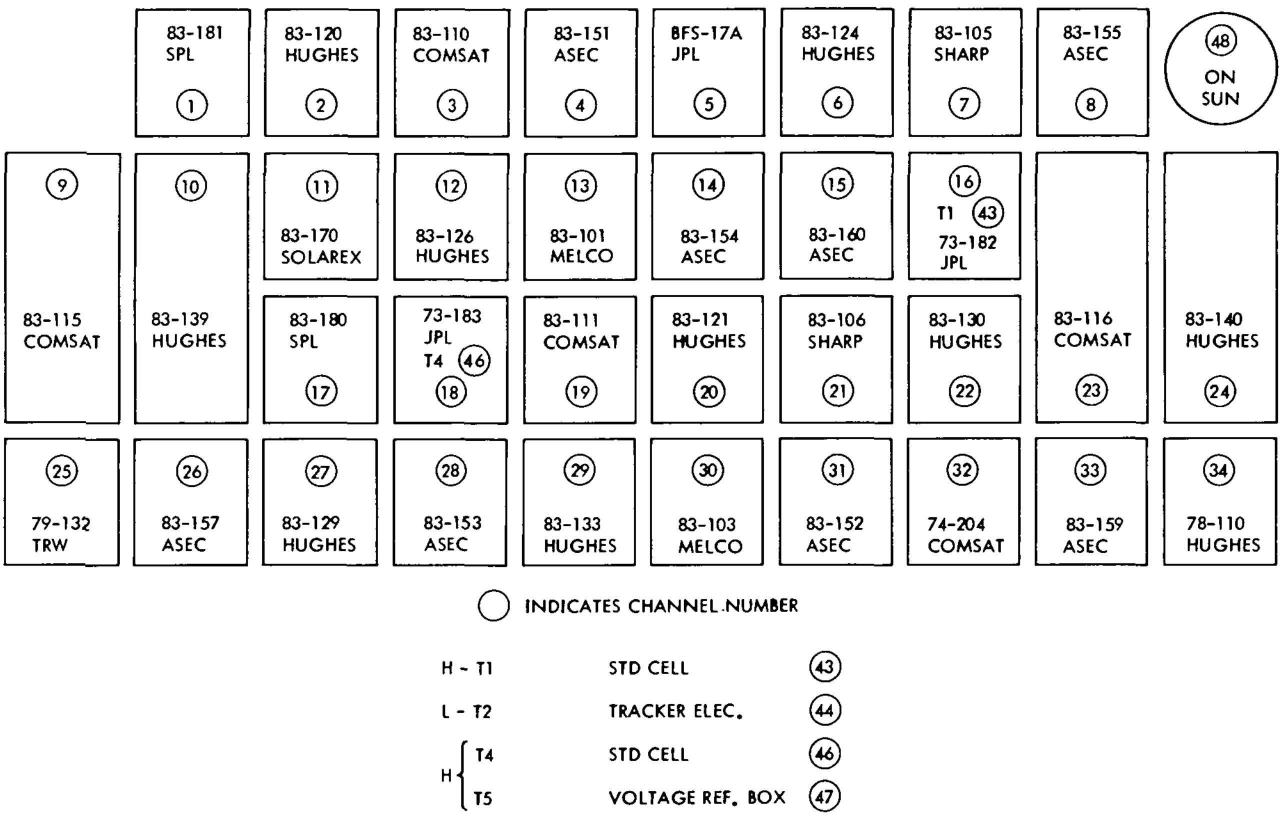

Figure 4. 1983 Module Location Chart

VI. CONCLUSIONS

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

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