NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1530

Results of the 1969 Balloon Flight Solar Cell Standardization Program

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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

High-altitude calibration of solar cells was accomplished during July and August of 1969 with the aid of free-flight balloons. Flights conducted were to an altitude of 36,576 m (120,000 ft), a 12,192-m (40,000-ft) altitude increase over the 1968 flights. Solar cells calibrated in this manner are recovered and used as intensity references in solar simulators and in terrestrial sunlight. Balloon-calibrated standard solar cells were made available to NASA centers and other government agencies through a cooperative effort with JPL.

Attempts to fly radiometers on two separate flights met with only partial success. The first flight was plagued with instrumentation troubles; the final flight never got off the ground because of balloon damage.

Comparison of solar cell data taken at altitudes of 24,384 m (80,000 ft) and 36,576 m (120,000 ft) was made. Solar cells with altered spectral response characteristics showed an approximate 1% increase in short-circuit current at the higher altitude. Normal, unaltered solar cells exhibited little if any change in output between the two altitudes.

A sky radiation experiment was also conducted as part of the 1969 balloon flights. Results indicate that there is no detectable sky radiation at 36,576 m (120,000 ft) when measured with the normal balloon instrumentation and telemetry techniques.

Results of the 1969 Balloon Flight Solar Cell Standardization Program

I. Introduction

Solar cells continue to play a leading role in unmanned space exploration. Thus there continues to be a need for space-calibrated standard solar cells. The JPL solar cell calibration program is fulfilling this need by calibrating solar cells on high-altitude balloon flights.

The altitude selected for the 1969 balloon flight series was 36,576 m (120,000 ft) instead of 24,384 m (80,000 ft). The higher altitude was chosen to provide a closer air-mass-zero calibration and eliminate, as much as possible, absorption layers in the atmosphere. Although this higher altitude attempt had been made several years ago and had met with success during a flight in 1966 and another in 1967, the larger balloons are more difficult to launch, require more time to ascend and descend, and are more costly. Notwithstanding the risks involved with a totally new balloon design and the extra effort and cost involved, it was felt that the added altitude would permit more accurate solar cell measurements. Thus all of the scheduled flights were programed for an altitude of 36,576 m (120,000 ft). This report discusses the results of the balloon flights conducted during the 1969 series in the vicinity of Minneapolis, Minnesota.

II. Balloon Flight System

The main components of the balloon flight system are a sun tracker, a helium-filled balloon, a telemetry system, and a battery power supply (Fig. 1). The sun tracker is mounted on the balloon apex, which is the most stable position of the balloon system. The telemetry transmitter and battery power supply together with several instruments for measuring altitude are suspended beneath the balloon. An electrical cable, incorporated into the balloon during manufacture, connects the top and bottom payloads. A parachute is provided in the event of balloon failure.

The solar tracker is used to position the solar cell payload toward the sun independently of balloon movements. The tracker is capable of movement in both elevation and azimuth to maintain an "on-sun" condition within ± 2 deg. A reflection shield attached to the solar tracker is used to prevent unwanted reflected light from reaching the solar cell payload.

The tracker and associated electronics boxes are mounted on a plywood disk 1.83 m (6 ft) in diameter which is bolted to the balloon top end fitting. The plywood disk permits the tracker to "float" on top of the helium bubble. Total weight of the upper payload is approximately 22.68 kg (50 lb).

The balloon used for flights of 36,576 m (120,000 ft) altitude is 65.23 m (214 ft) in diameter when fully inflated and has a volume of approximately 97,206 m^3 (3,432,400 ft^3). The balloon is fabricated from 17.78-μm (0.0007-in.) polyethylene material designed especially for balloon use. All flights except two prior to 1969 were made to an altitude of 24,384 m (80,000 ft). Balloon size

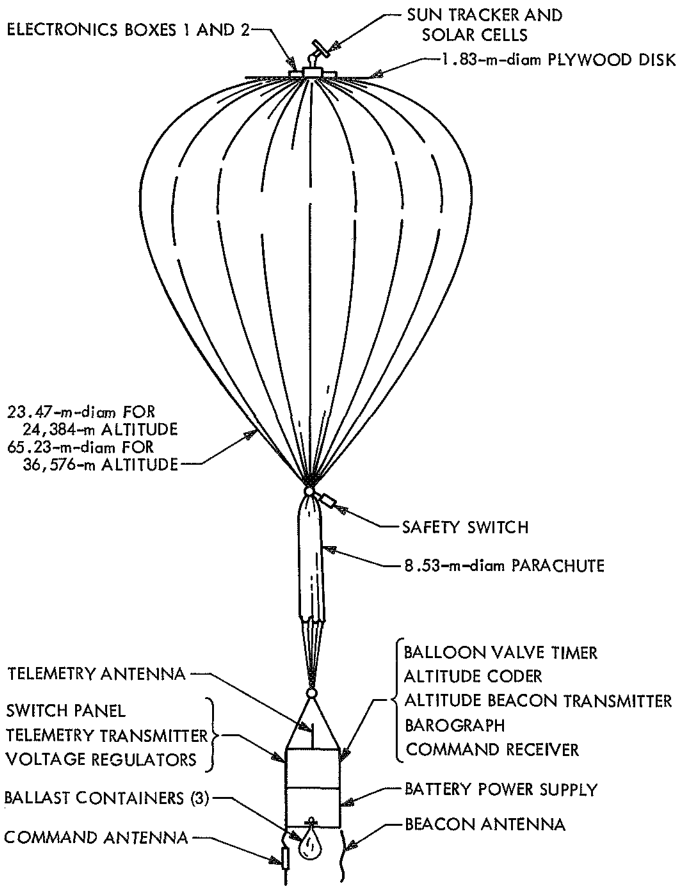

Fig. 1. Balloon flight configuration

and gross weight determine the float altitude. Table 1 gives a comparison of the balloons used to attain the float altitudes. During inflation, the helium is confined to the upper portion of the balloon by a launching mechanism to reduce problems associated with surface winds. The body of the balloon, protected by a polyethylene sheath, extends along the ground from the balloon launcher to a launch truck. The lower payload, containing the battery power supply and telemetry transmitter, is attached to the launch truck by an explosive bolt. The balloon is launched by releasing the upper portion of the balloon held by the launching mechanism. As the balloon rises, the launch truck is driven downwind to position the lower payload directly under the balloon body. At this point, the explosive bolt is fired by push-button controls within the launch truck and the balloon is free from ground constraint.

Table 1. Balloon characteristics

Parameters	24,384-m (80,000-ft) altitude	36,576-m (120,000-ft) altitude
Inflated diam, m (ft)	23.47 (77)	65.23 (214)
Volume (theoretical), m^3 (ft^3)	6,882 (243,000)	97,206 (3,432,400)
Material (thickness and type), μm (in.)	38.10 (0.0015), polyethylene	17.78 (0.0007), polyethylene
Payload (design), kg (lb)	120.2 (265)	184.2 (406)
Weight (including cable), kg (lb)	83.9 (185)	351.1 (774)
Cost, $	1700	4500

Several functions are performed by pressure switches and timing devices as the flight progresses. At 1524-m (5,000-ft) altitude, a pressure switch activates a circuit deploying a long dipole beacon antenna. At 18,288 m (60,000 ft), a second pressure switch activates the sun tracker, permitting it to lock on the sun. At the completion of the float period, a preset timer opens a set of valves in the side of the balloon, allowing helium to escape at a controlled rate and causing the balloon and its associated equipment to descend to the earth.

The heart of the telemetry system is the voltage-controlled oscillator. Solar cell voltages, interspersed with reference voltages and thermistor circuit voltages, are fed into the voltage-controlled oscillator, converted to frequencies, and transmitted to a ground station by a 5-W FM transmitter. At the ground station, telemetry data is recorded on printed paper tape in digital form and also displayed in analog form on a strip chart recorder. The solar cell data is then transferred from the printed tape to punch cards compatible with a JPL computer program.

The battery power supply provides adequate power for a normal flight while keeping weight to a minimum. Aircraft-type lead-acid batteries are used to provide main power for the telemetry transmitter, the stepping switch, and several temperature-controlling heaters. The solar tracker is electrically isolated from the main batteries and is powered by a separate alkaline-type dry battery. The total weight of the battery power supply is 35.4 kg (78 lb).

Accuracy of the balloon flight system has been determined by Zoutendyk (Ref. 1) to be ±0.73%. Over the years, small improvements were made to the solar tracker so that the pointing accuracy has been narrowed from ±4.3 to ±2.0 deg. No other improvements in the total accuracy have been made, but the tracking improvement brings the overall system accuracy to ±0.49%.

III. Balloon Flight Payloads

Solar cell modules comprising the payloads for the 1969 balloon flight series were supplied by seven different NASA and government agencies. The participating agencies are listed as follows:

(1) Ames Research Center, NASA, (2) Langley Research Center, NASA, (3) Goddard Space Flight Center, NASA, (4) Aero Propulsion Laboratory, Air Force, (5) Applied Physics Laboratory, Johns Hopkins University, (6) Lincoln Laboratory, Massachusetts Institute of Technology, (7) Jet Propulsion Laboratory, California Institute of Technology.

The first flight of the 1969 series had a radiometer payload (Fig. 2). Similar radiometers had been flown in the 1968 balloon flight series, but the instruments flown this year were of an improved design in that no vacuum housing was necessary. The radiometers were designed and built by the Instrumentation Section of JPL. The solar cell modules were divided into payloads for two flights as shown in Figs. 3–6.

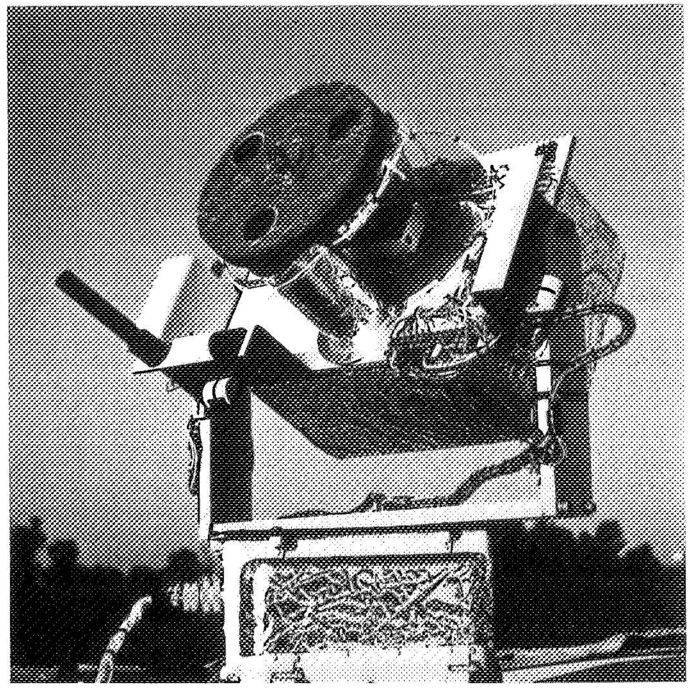

Fig. 2. Radiometer payload

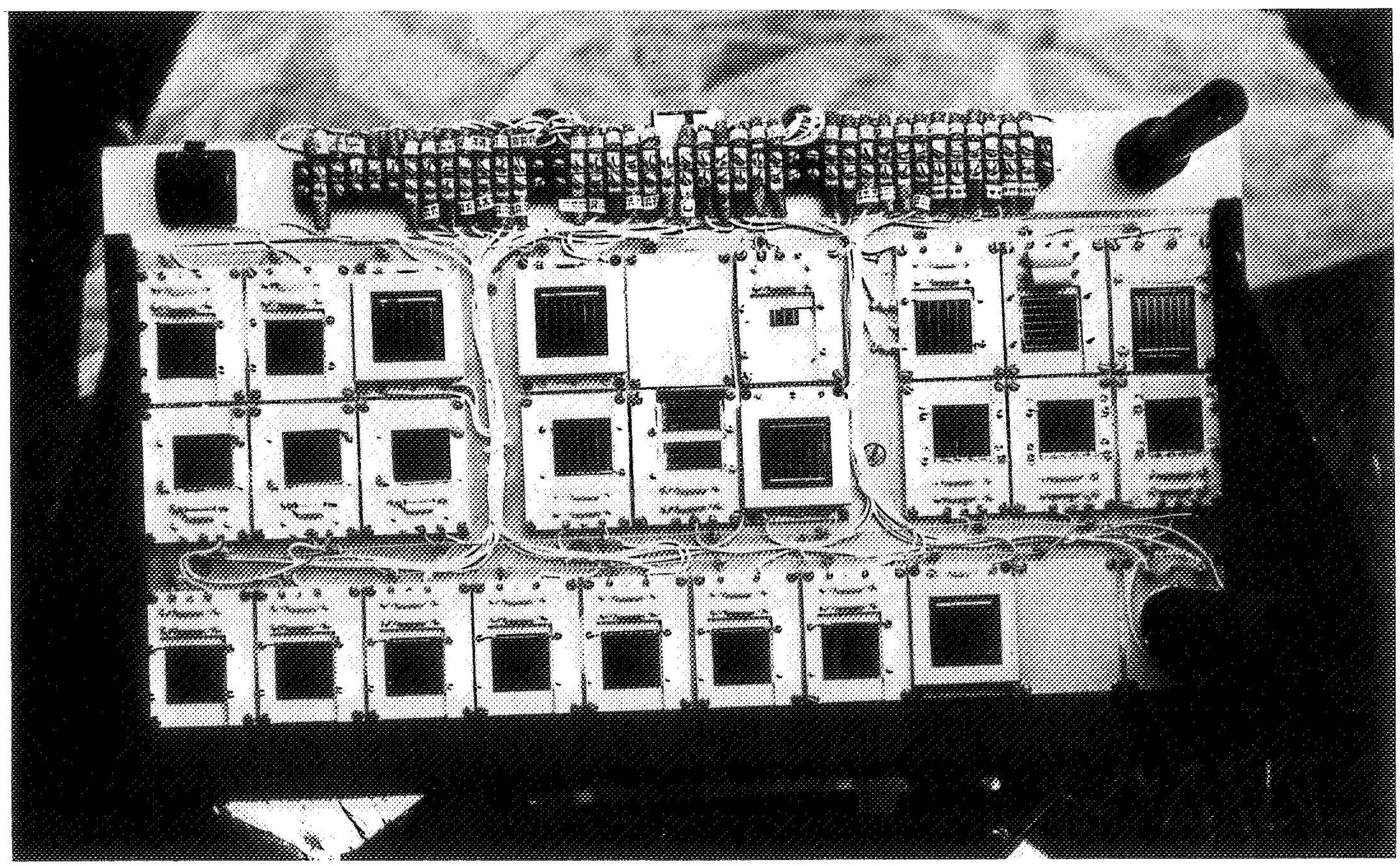

Fig. 3. Solar cell payload, flight 69-2

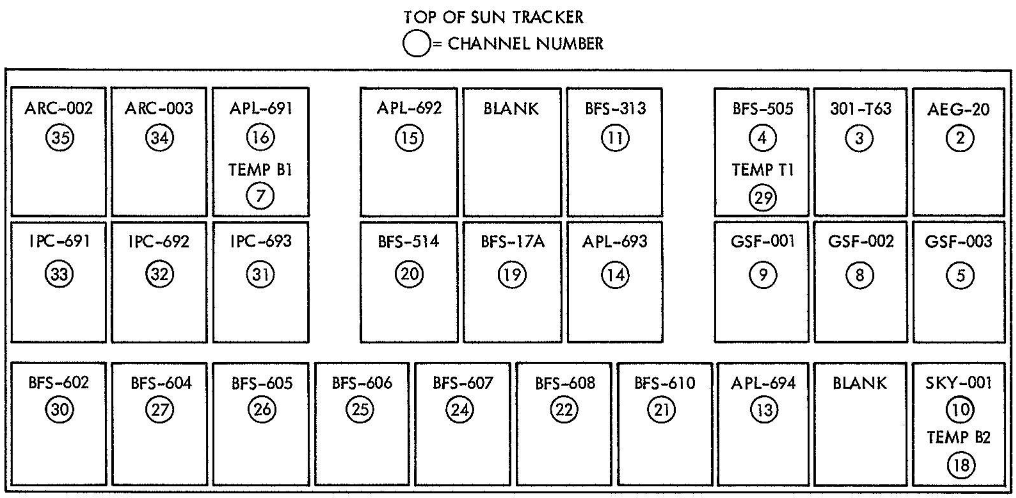

Fig. 4. Solar cell placement for flight 69-2

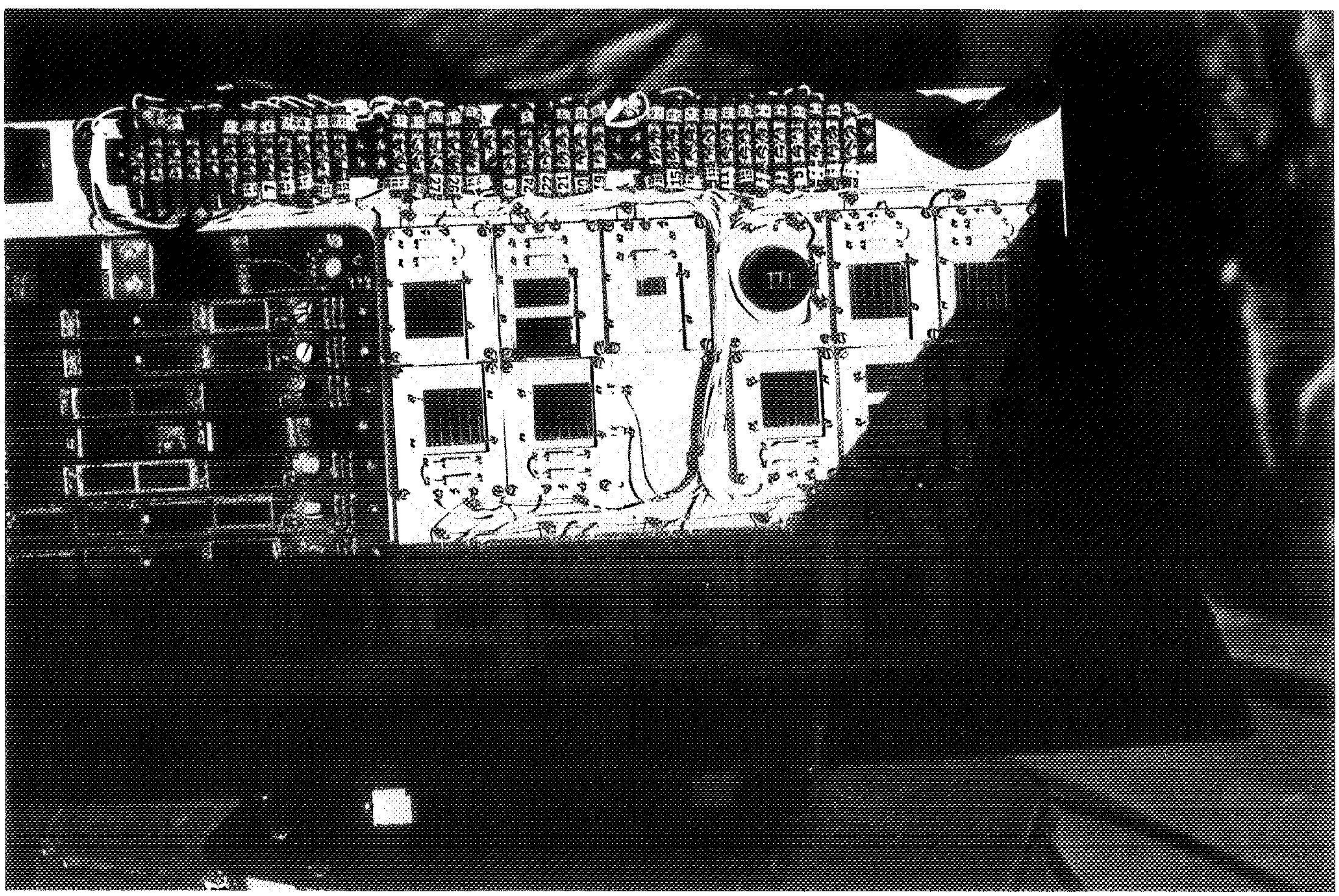

Fig. 5. Solar cell payload, flight 69-3

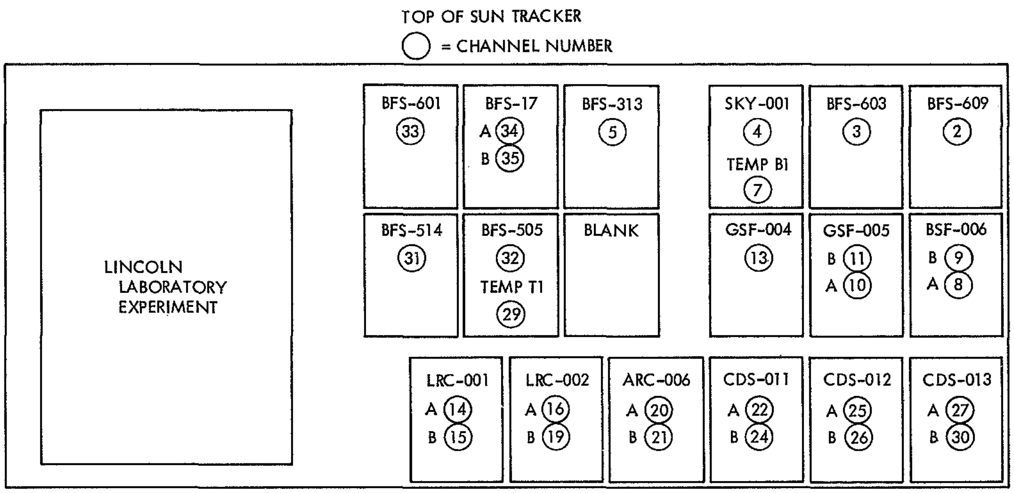

Fig. 6. Solar cell placement, flight 69-3

IV. Balloon Flight Performance

A. Flight 69-1

Balloon flight 69-1 was launched August 8, 1969, and reached a float altitude of 37,033 m (121,500 ft) at 1040 CDT. The balloon was equipped with a ballast system controlled by radio command, and the required altitude was maintained during the float period. The solar tracker performed in a normal manner with only one rewind required during the entire flight.

At the end of the float period, the preset timer opened the descent gasport, causing the balloon system to descend. However, the descent rate was not fast enough to bring the system to the ground prior to the safety switch activation which separates the balloon and the lower payload. When separation occurred at 2044 CDT, the balloon was still at 29,870 m (98,000 ft). This method of payload separation is necessary to clear airlanes prior to darkness. The lower payload descended by parachute, but the upper payload free-fell with the balloon material. The descent characteristics of this flight indicated that the gasport was too small and was placed too low on the balloon envelope. The sun tracker and radiometer payload were damaged considerably, as shown in Fig. 7.

In view of the descent problems experienced on the previous flight, a radio-controlled, electrically actuated helium valve was installed in the balloon apex fitting. The solar tracker was mounted on standoffs above the valve and was used with both flights 69-2 and 69-3. A photograph of the electric valve with the solar tracker above is shown in Fig. 8.

B. Flight 69-2

Balloon flight 69-2 was launched August 26, 1969, under nearly ideal conditions. Although the electric valve added approximately 2.72 kg (6.0 lb) to the top payload, no real difficulty was experienced during the launch. The balloon attained its float altitude at 1032 CDT and remained above 35,966 m (118,000 ft) throughout the float period. With the use of the radio-controlled, electrically activated helium valve, the balloon system was successfully brought to earth with only minimum damage to the solar tracker, while the solar cell payload remained completely undamaged.

C. Flight 69-3

Flight 69-3 also carried a solar cell payload and was launched from the Litton flight facility at New Brighton, Minnesota, on September 8, 1969. The system reached a peak float altitude of 36,820 m (120,800 ft) a few minutes before 1100 CDT and remained above 36,119 m (118,500 ft) throughout the float period. The balloon system was again brought to earth with the use of the electrically operated helium valve. Impact was at the Durrand, Wisconsin, airport, and although the balloon system used a nonconventional approach, no damage was inflicted to the payloads.

D. Flight 69-4

An attempt was made to launch a fourth balloon flight from Michell, South Dakota, on November 21, 1969, but a launch was not achieved. Because upper-altitude winds created the possibility of carrying the balloon into the Great Lakes region from a Minneapolis launch, the launch

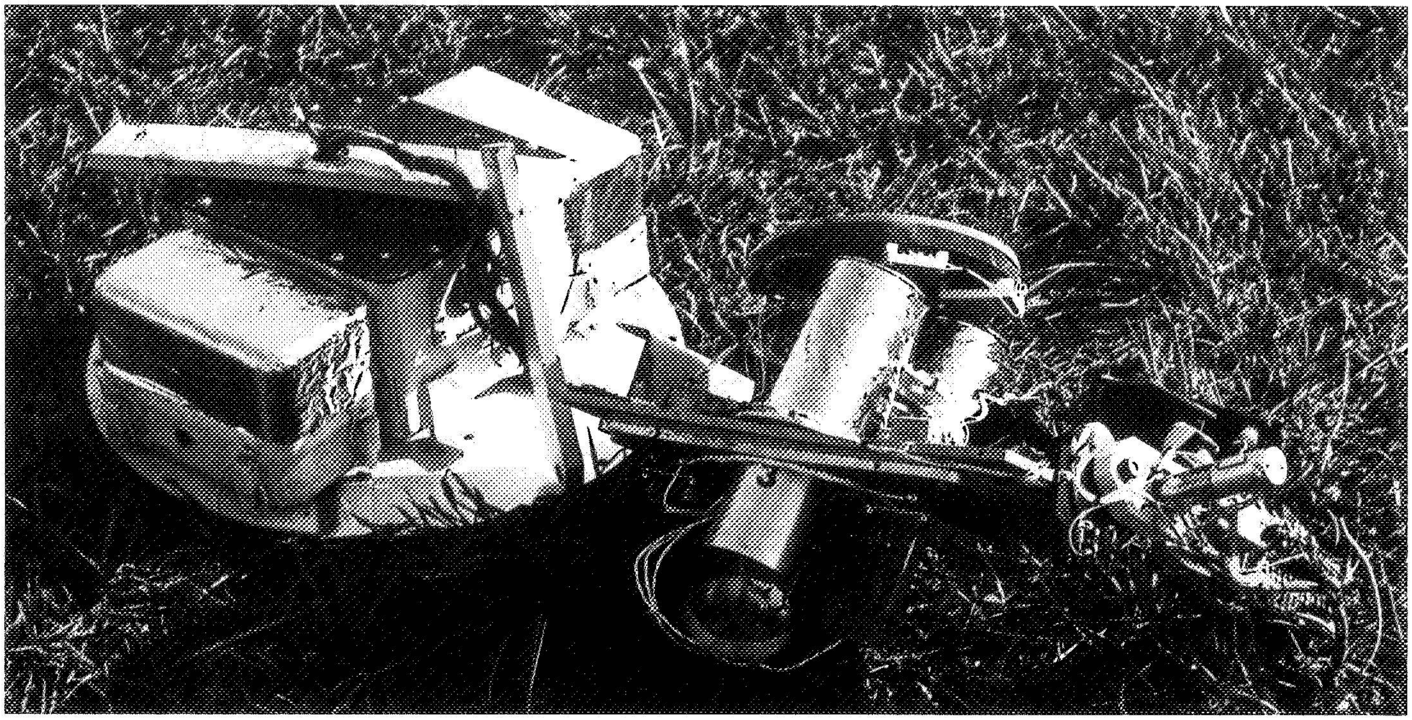

Fig. 7. Damage to radiometer payload, flight 69-1

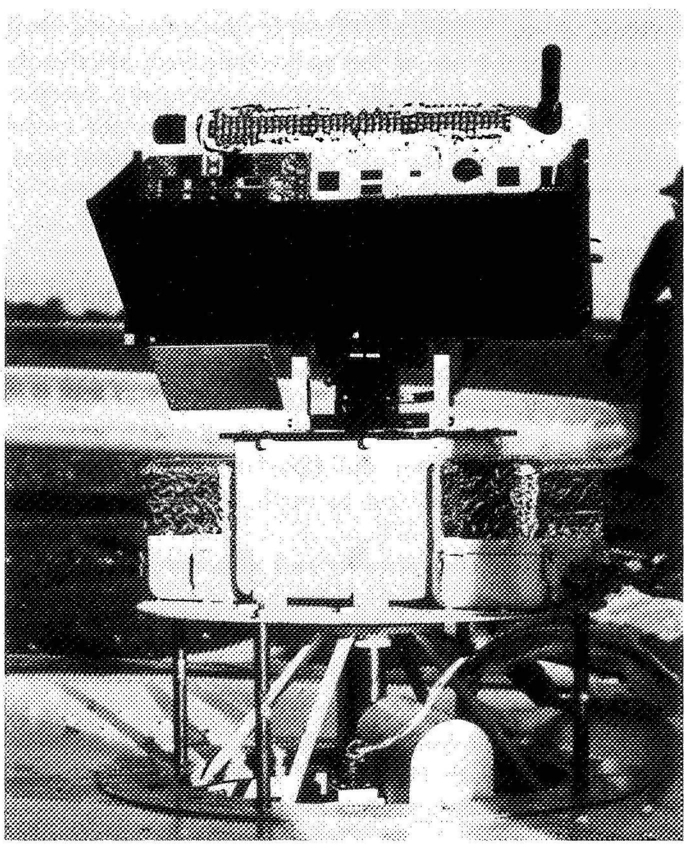

Fig. 8. Radio-controlled, electrically actuated helium valve

site of Mitchell, South Dakota, some 483 km (300 mi) west was chosen.

During inflation of the balloon and while the top payload was being erected, the balloon material came into contact with the solar tracker, creating tears in the material. The balloon was partially deflated and the upper payload hauled down while tape was applied to the tears. Inflation was resumed and the top payload again erected. This time an additional hole was seen in the balloon material about 6.1 m (20 ft) from the balloon apex. During the attempt to deflate the balloon and bring down the top payload the second time, a strong gust of wind tipped the payload onto the ground, damaging the solar tracker. At this point, the flight was cancelled, the balloon repacked for future repair, and all equipment and personnel returned to Minneapolis.

V. Discussion of Balloon Flight Data

A. Flight 69-1

Although there was interference from the radio beacon on flight 69-1, the beacon transmitter was programmed off 75% of the time, permitting a number of good data points to be obtained on the radiometers. One of the radiometers ceased functioning during the flight, but the other continued to give steady but lower-than-expected total intensity readings. At first it was believed that air currents were responsible for cooling the radiometer cavity, since these radiometers were not enclosed with a quartz window and vacuum housing as were the earlier radiometers. A fresh look at the data revealed that the radiometers were reradiating back into the circumsolar sky because of the large degree field of view necessary with the on-sun tolerance of the sun tracker.

The radiometer measurement, corrected for residual air mass above 36,576 m (120,000 ft) and for other conditions including sun distance, gave a 1-AU sunlight intensity of 136.8 mW/cm^2. While this value is lower than the presently accepted value of 139.6 mW/cm^2, measurements by other experimenters also differ with each other as well as with the presently accepted solar constant value. However, differences may well exist more in the scales used than in the actual values. More measurements and comparisons will undoubtedly be made in the future. Standard solar cell calibrations do not rely on any particular solar constant value expressed in mW/cm^2, but rather the short-circuit current output of a solar cell at 1 AU earth–space conditions.

B. Flight 69-2

For the second flight of the 1969 series, a method was devised to completely eliminate radio frequency interference on the data channels. This was done by routing the altitude information through a separate subcarrier oscillator and transmitting it through the main telemetry system.

The solar cell data on flight 2 was of high quality, and 27 data points at 36,576 m (120,000 ft) were averaged for each solar cell. Temperature of the modules at float altitude reached a maximum of 331.95°K (58.8°C) with an average temperature during the data gathering period of 329.65°K (56.5°C). Solar cell data corrected for intensity and also for temperature, when the cell's temperature coefficient was known, is shown in Table 2.

C. Flight 69-3

Data from the third flight of the 1969 series was again of high quality. Twenty-three data points at float altitude were averaged for each solar cell. Maximum temperature during float reached 336.65°K (63.5°C) while the average temperature during the data recording period was 331.85°K (58.7°C). Solar cell data corrected for intensity and also for temperature, when the cell's temperature coefficient was known, is shown in Table 3.

Data from the Lincoln Laboratory solar cell experiment was recorded separately and subsequently reduced by the Lincoln Laboratory and is therefore not included in this report.

D. Comparison of Solar Cell Data

Table 4 lists all the solar cell modules for which calibration data exists for both 24,384- and 36,576-m (80,000- and 120,000-ft) altitudes. Module BFS-17 has been flown repeatedly over a 7-yr period, which accounts for the high total number of flights at each altitude. Each flight to a particular altitude produces a calibration point corrected for intensity and temperature. When a cell has more than one flight at one altitude, the average calibration value is listed in the table. From Table 4 it can be shown that the average deviation of the cells from 24,384 to 36,576 m (80,000 to 120,000 ft) degraded by electron bombardment (BFS-120 and BFS-121) is +1.36%. The average deviation from 24,384 to 36,576 m (80,000 to 120,000 ft) of the normal, unaltered solar cells is only +0.11%. While the number of cells available for a statistical average is small, there is evidence that there is a change in the spectral distribution of sunlight between the two altitudes. However, this change does not appear to affect the short-circuit current output of normal, unaltered solar cells nearly as much as solar cells which have had their spectral response altered by electron bombardment. Since placing a bandpass filter over a solar cell has the same effect as changing the spectral distribution to a cell, it would be reasonable to assume that solar cells so covered would also show an increase in short-circuit current from 24,384 m (80,000 ft) to 36,576 m (120,000 ft).

E. Sky Radiation Experiment

In 1965, Ritchie (Ref. 2) made a sky radiation measurement on a balloon flight at 24,384 m (80,000 ft). His method employed a shading device above the solar cell detector to block out direct solar radiation. Results of the experiment indicated that radiation from the circumsolar sky was less than 0.5% of the total radiation, somewhat less than the ±0.5% accuracy of the balloon flight system.

It was realized that if the sky radiation was in actuality less than 0.5%, the accuracy of the balloon flight system would be the limiting element of a sky radiation measurement. With this limitation in mind it was decided to employ a more conventional measurement technique. Two subsequent attempts were made to measure the

Table 2. Flight 69-2, standard cell data summary[a]

Standard cell number	Manu-facturer	Type	Material	Cell dimensions, cm	Base resistivity, ohm-cm	Filter data	Temperature coefficient, mV/°K	Calibration data at 1 AU, 301.15°K, mV
AEG-20	AEG	*n-p*	Silicon	2 × 1 × 0.030	1	0.40-μm fused silica	—	61.16
301-T63	SIE			2 × 1 × 0.030	1	0.42-μm Suprasil	0.050	97.48
APL-691	HEK			2 × 2 × 0.030	2	Cover 7940	0.070	60.06
APL-692	HEK			2 × 2 × 0.030	2	Cover 7940	0.045	60.68
APL-693	HEK			2 × 2 × 0.030	2	Cover 7940	0.064	61.69
APL-694	HEK			2 × 2 × 0.030	2	Cover 7940	0.050	61.72
ARC-002	TI			2 × 2 × 0.030	10	None	—	74.49
ARC-003	TI	*n-p*		2 × 2 × 0.030	10	None	—	74.48
BFS-17A	HEK	*p-n*		1 × 2 × 0.046	1	0.41-μm 0211	0.036	60.37
SKY-001		*p-n*		0.6 × 1 × 0.046		None	0.041	30.77
BFS-313		*p-n*		0.6 × 1 × 0.046		None	0.031	33.06
BFS-505		*n-p*		2 × 2 × 0.046		0.41-μm 7940	0.060	65.54
BFS-514				2 × 2 × 0.046		7940		66.93
BFS-602				2 × 2 × 0.046	1	7940		67.22
BFS-604				2 × 2 × 0.046	10	0211		71.48
BFS-605				2 × 2 × 0.020	10	7940		68.90
BFS-606		*n-p*		2 × 2 × 0.020	10	0211		68.21
BFS-607		*p-n*		2 × 2 × 0.046	1	7940		63.97
BFS-608	HEK	*p-n*		2 × 2 × 0.046	1	0211		64.12
BFS-610	CRL	*n-p*		2 × 2 × 0.046	1	0211	0.060	63.28
GSF-001	HEK			2 × 2 × 0.036	10	7940	0.067	67.31
GSF-002	HEK			2 × 2 × 0.036		7940	0.070	67.09
GSF-003	CRL			2 × 2 × 0.036		0.41-μm 7940	0.031	70.16
IPC-691	IPC			2 × 2 × 0.039		Integral SiO_2	0.049	64.27
IPC-692	IPC			2 × 2 × 0.039		Integral SiO_2	0.049	62.64
IPC-693	IPC	*n-p*	Silicon	2 × 2 × 0.039	10	Integral SiO_2	0.049	63.65

[a]Flight date: Aug. 26, 1969; altitude: 36,576 m (120,000 ft); adjusted data: 139.6 mW/cm^2, 301.15°K. AEG = AEG Telefunken; APL = Applied Physics Laboratory; ARC = Ames Research Center; BFS = balloon flight standard; CRL = Centralab, Globe-Union, Inc.; GSF = Goddard Space Flight Center; HEK = Heliotek, a division of Textron, Inc.; IPC = Ion Physics Corp.; SIE = Siemens Aktiengesellschaft; SKY = sky radiation module; TI = Texas Instruments.

Table 3. Flight 69-3, standard cell data summary[a]

Standard cell number	Manufacturer	Type	Material	Cell dimensions, cm	Base resistivity, ohm-cm	Filter data	Temperature coefficient, mV/°K	Calibration data at 1 AU, 301.15°K, mV
ARC-006A	HEK	*n-p*	Silicon	1 × 2 × 0.025	1	None	—	60.22
ARC-006B		*n-p*		1 × 2 × 0.025		None	—	58.86
BFS-17A		*p-n*		1 × 2 × 0.046		0.41-μm 0211	0.036	60.17
BFS-17B		*p-n*		1 × 2 × 0.046		0.41-μm 0211	0.039	60.21
SKY-001		*p-n*		0.6 × 1 × 0.046		None	0.041	31.23
BFS-313		*p-n*		0.6 × 1 × 0.046		None	0.031	32.99
BFS-505		*n-p*		2 × 2 × 0.046		0.41-μm 7940	0.060	65.31
BFS-514				2 × 2 × 0.046			0.060	66.59
BFS-601				2 × 2 × 0.046	1		0.060	66.03
BFS-603	HEK			2 × 2 × 0.046	10		0.060	72.24
BFS-609	CRL	*n-p*	Silicon	2 × 2 × 0.046	1	0.41-μm 7940	0.060	65.45
CDS-011A	CLE	*p-n*	CDS	1 × 2 × 0.010	—	H-film	−0.085	30.98
CDS-011B				1 × 2 × 0.010	—		−0.042	28.98
CDS-012A				1 × 2 × 0.010	—		−0.075	33.43
CDS-012B				1 × 2 × 0.010	—		−0.040	30.82
CDS-013A				1 × 2 × 0.010	—		−0.088	33.14
CDS-013B	CLE	*p-n*	CDS	1 × 2 × 0.010	—	H-film	−0.093	31.40
GSF-004	CRL	*n-p*	Silicon	2 × 2 × 0.036	10	0.41-μm 7940	0.031	70.39
GSF-005A	HEK			1 × 2 × 0.036			0.017	70.98
GSF-005B				1 × 2 × 0.036			0.032	69.71
GSF-006A				1 × 2 × 0.036			0.063	53.81
GSF-006B				1 × 2 × 0.036	10	0.41-μm 7940	0.082	52.26
LRC-001A				1 × 2 × 0.030	1	None	0.023	67.12
LRC-001B				1 × 2 × 0.030	1	None	0.016	67.02
LRC-002A				1 × 2 × 0.036	10	0.41-μm 7940	0.017	68.63
LRC-002B	HEK	*n-p*	Silicon	1 × 2 × 0.036	10	0.41-μm 7940	0.019	68.14

[a]Flight date: Sep. 8, 1969; altitude: 36,576 m (120,000 ft); adjusted data: 139.6 mW/cm^2, 301.15°K. ARC = Ames Research Center; BFS = balloon flight standard; CDS = cadmium sulfide cell; CLE = Clevite; CRL = Centralab, Globe-Union, Inc.; GSF = Goddard Space Flight Center; HEK = Heliotek, a division of Textron, Inc.; LRC = Langley Research Center; SKY = sky radiation module.

Table 4. Comparison of solar cell data at 36,576 and 24,384 meters

Cell number	Cell type[a]	24,384-m (80,000-ft) altitude		36,576-m (120,000-ft) altitude		Deviation from 24,384 m (80,000 ft), %
		Number of flights	Average calibration value, mV	Number of flights	Average calibration value, mV	
BFS-01A	1	2	60.85	2	60.89	+0.07
BFS-01B	1	2	60.38	2	60.22	−0.26
BFS-17A	1	15	60.28	4	60.28	0.0
BFS-17B	1	14	60.56	3	60.41	−0.25
BFS-115A	2	2	57.55	1	57.95	+0.70
BFS-115B	2	2	57.94	1	58.24	+0.52
BFS-120A	3	1	38.73	1	39.16	+1.11
BFS-120B	3	1	37.37	1	37.67	+0.80
BFS-121A	3	2	40.18	1	40.95	+1.92
BFS-121B	3	2	42.57	1	43.26	+1.62
BFS-301	4	1	65.65	1	65.59	−0.09
BFS-302	4	1	64.82	1	65.19	+0.57
BFS-306	5	1	64.14	1	64.08	−0.09
BFS-311	6	1	69.73	1	69.67	−0.09

[a]1: HEK, *p-n*, 1 × 2 × 0.046 cm, 1 ohm-cm with 0.410-μm OCLI filter.
2: HEK, *n-p*, 1 × 2 × 0.046 cm, 10 ohm-cm without coverglass.
3: Same as 1 above except cells have been bombarded with 2×10^{14} e/cm^2 at 1 MeV.
4: HEK, *n-p*, 2 × 2 × 0.020 cm, 1 ohm-cm with 0.410-μm OCLI filter.
5: Same as 4 above except manufacturer is TI.
6: RCA, *n-p*, 2 × 2 × 0.020 cm, 1 ohm-cm with wraparound contacts, no coverglass.

amount of sky radiation, one at 24,384 m (80,000 ft) and the second at 36,576 m (120,000 ft), both using a collimation tube. The results were inconclusive, mainly because of radio interference on the telemetry channels. However, during the 1969 balloon flight series, a more accurate experiment was conducted. The results of the 1969 sky radiation experiment indicate that, with the measurement technique used, sky radiation is less than 0.5% of the total radiation at 36,576 m (120,000 ft), the accuracy again being limited by the accuracy of the balloon flight system.

The experiment was conducted in the following manner. Two solar cells having physical and electrical characteristics as nearly identical as practicable were selected as detectors. One of the solar cells was mounted as a standard module and designated BFS-313. The other cell was mounted on an especially machined aluminum block to accommodate a thermistor and a scaled-down version of a collimating tube. This second module was designated SKY-001.

The collimating tube had a length-to-width ratio of 8.7 to 1. The aperture angle had to be increased from the normal 5.7 deg to 6.6 deg to allow for the on-sun accuracy of the solar tracker. Instead of three baffles within the collimating tube, the scaled-down version had only one at the top which shaded the sides. The insides of the collimating tube were painted black with a 3-M velvet spray coating.

The two modules were flown together on flight 69-2 and placed as shown in Fig. 4 with the collimating tube in place on SKY-001. In order to establish a ratio for the two cells at a flight altitude of 36,576 m (120,000 ft), the cells were flown again on flight 69-3 and placed as shown in Fig. 6, this time with the collimating tube on SKY-001 removed. Temperature measurements for

SKY-001 were made with its own thermistor, while the temperature of BFS-313 was determined by a thermistor in an adjacent, similar module, BFS-505. Corrections for both temperature and solar intensity were made for each module and for each flight. The results of the measurements are summarized in Table 5.

Table 5. Collimated/uncollimated measurement comparison

Flight date	Altitude	BFS-313	SKY-001	Ratio
8-26-69	36,576 m (120,000 ft)	33.05 mV	31.29 mV[a]	0.9467
9-8-69	36,576 m (120,000 ft)	33.03 mV	31.27 mV[b]	0.9467

[a]Collimated reading.
[b]Uncollimated reading.

Since the ratio is the same for both a collimated and an uncollimated measurement, it follows that there is no detectable sky radiation at the 36,576 m (120,000 ft) altitude, the above method being used in conjunction with the balloon flight system. More refined measurements of the sky radiation must await a more accurate balloon flight telemetry system and should also employ a collimation tube having dimensions and features described in Ref. 3.

VI. Future Plans

Owing to the unsuccessful launch attempt of the radiometer flight, it was planned to have the balloon repaired and to use it for a radiometer flight in late June or early July of 1970. At the time of publication of this report the 1970 flights have been completed and the flight report is being prepared.

Shortly after the 1969 flights were complete, the Applied Science Division of Litton Industries, Inc., informed JPL that frequency allocations for use with the balloon flight operations could not be obtained since the allocations had been received through Navy contracts which had been terminated. As a result, JPL applied for the same or new frequencies within capabilities of the present telemetry equipment. Allocations were received from the Office of the Director of Telecommunications Management, Interdepartment Radio Advisory Committee. A frequency change to the main telemetry transmitter from the present 225.0 MHz to the new frequency of 217.5 MHz was required. The transmitter was returned to JPL and modified by a vendor prior to the 1970 scheduled balloon flight series.

VII. Summary

A balloon flight system for solar cell calibration has been employed successfully over a 7-yr period. Balloon flights have normally been made to an altitude of 24,384 m (80,000 ft); however, with improved materials and techniques, the risks of balloon failure have been minimized and, at present, flights are routinely made to a 36,576 m (120,000 ft) altitude.

The data presented in this report provides additional confidence in the balloon flight calibration technique. One standard silicon solar cell, BFS-17A, has been flown as a reference on nearly every flight over a 7-yr period. In Table 6, the measurements of this cell show repeatability to be within 1%. The data also shows that silicon

Table 6. Repeatability of standard solar cell BFS-17A for 18 flights over a 7-yr period

Flight date	Output, mA
9/5/63	60.07
8/3/64	60.43
8/8/64	60.17
7/28/65	59.90
8/9/65	59.90
8/13/65	59.93
7/29/66	60.67
8/4/66	60.25
8/12/66	60.15
8/26/66	60.02
7/14/67	60.06
7/25/67	60.02
8/4/67	59.83
8/10/67	60.02
7/19/68	60.31
7/29/68	60.20
8/26/69	60.37
9/8/69	60.17
Mean	60.14 mA
Maximum deviation from mean	0.88%
RMS deviation from mean	0.34%

Each data point is an average of 20–30 data points from each flight. All data is normalized to 139.6 mW/cm^2 and to a cell temperature of 301.15°K (28°C).

solar cells are reliable as standards over a long term if handled properly.

Standard solar cells calibrated by means of high-altitude balloon flights are maintained for use with JPL flight and advanced development programs. Standard solar cells provided by NASA centers and government agencies for balloon flight calibration are returned to the respective agencies, along with calibration data, for their control and use.

The solar cell standardization program is a continuing program designed to fill the need for standard solar cells. The use of high-altitude balloons has proven to be a feasible, reliable and economical method to obtain the needed standards.

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