FINAL REPORT

1969 SOLAR-TRACKER BALLOON FLIGHTS 3051, 3052, 3053, 3054

APPLIED SCIENCE DIVISION
LITTON SYSTEMS, INC.
LITTON INDUSTRIES

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ABSTRACT

High-altitude solar cell and radiometer calibrations were accomplished during August and September 1969 using balloon techniques. Solar cell modules and radiometers supplied and installed by Jet Propulsion Laboratories were flown on Litton-designed, balloon-mounted, solar trackers at a nominal 120,000-foot altitude to obtain near zero-air-mass performance data. A total of four balloon flights were attempted in 1969. Two flights carried solar cell payloads and two flight attempts were made to obtain solar intensity measurements using JPL-designed radiometers. This report contains operational details of these flights, discussion of problems encountered and instrumentation changes accomplished during the program, and tabulations of secondary temperatures, calibration voltages, and time-altitude data recorded during the program.

SUMMARY

Four balloon flights were attempted on this year's solar calibration program. Two flights were flown for the primary purpose of obtaining accurate, near zero-air-mass short circuit current from a variety of types and manufacturers of photovoltaic solar cells. Solar cells calibrated in this manner are considered as "standard cells" and can serve as reference cells for subsequent intensity measurements. Two of the balloon flights were attempted with a dual radiometer payload for the purpose of obtaining accurate total solar intensity measurements under the stable, near zero-air-mass conditions encountered during the floating period of the balloon system. A float altitude of 120,000 feet was selected for these flights to minimize the affects of ozone and water vapor on the data.

The balloon flight system is essentially the same as used on eight previous programs of this nature sponsored by JPL. A solar tracker is mounted atop a helium-filled, polyethelene balloon to position the solar payload toward the sun, independent of balloon movements. A telemetry system, balloon control system, and battery power supply suspended below the balloon complete the basic system components. Solar intensity data and temperature data are telemetered to a ground-receiving station where they are recorded for future computer analysis. Altitude data and other housekeeping data are also telemetered for monitoring and control purposes.

Modifications were made to the system during this program to improve balloon control. A remotely controlled helium valve and a means of telemetering altitude information on the primary data transmitter were incorporated. A data interference problem was effectively eliminated by controlling and interfering beacon transmitter by pressure and time-activated controls backed up by the radio-command control system.

This report discusses the operational details of each flight and the problems encountered during the program. The flights with solar-cell payloads were generally successful, while the radiometer flights did not produce satisfactory results. Operationally, three of the four balloon flights were qualified successes. On the first flight flown with two radiometers as the payload, one radiometer malfunctioned early in the flight and the second unit had an erratic output. A second attempt to fly the radiometers was aborted before launch becuase of holes in the balloon material caused by the tracker during system erection. A section of the report details a list of recommendations for improvements in tracker and operations reliability, and in temperature control methods.

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1. INTRODUCTION

1.1 General

Flights 3051, 3052 and 3053 were a planned series of three balloon flights conducted during August and September 1969 for Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under Subcontract 952496 to JPL. Flight 3054 was an attempt to fly a fourth balloon during November 1969 under a unilateral contract modification (Mod. #1). This contract provided for all necessary balloon flight equipment and services. Balloons, helium, power supplies, antennas and other miscellaneous equipment required for the flights were supplied under this contract this year. Services include those required for flight preparation, functional verification of the flight control and data acquisition systems, tracking of the balloon aloft by aircraft, and the recovery and return of equipment after its descent to the surface. Meteorological services and reduction of the primary telemetry data on solar cell payloads to computer-compatible punch cards were also included.

This report discusses each flight in detail, describes system changes made preceding and during the flight operations, and provides analysis of the system discrepancies occurring during the program. Although the primary data were delivered to JPL at the conclusion of the final solar cell flight, the Appendix of this report contains secondary temperature data, calibration data, and flight time-altitude profiles of each flight.

1.2 Flight Objectives

Flight objectives were as follows:

1) To launch and ascend to an altitude of 120,000 ± 5000 feet, four balloon systems with solar tracker, solar cell and/or radiometer payloads, and instrumentation mounted atop the balloon; with telemetry and other instrumentation, and power supply mounted below the balloon.

2) To telemeter and record altitude, temperature and solar cell or radiometer output data during ascent and during a floating period of four hours, minimum. The floating period for the initial three flights shall commence before 1100 CDT (Central Daylight Time) and shall be maintained until 1500 CDT. The fourth flight shall float for two hours before and one hour after solar noon.

3) To descend to surface with balloon and payload intact.

4) To deflate balloon automatically upon impact by firing an explosive cord which opens the side of the helium-filled balloon bubble for the purpose of recovering the top-mounted solar tracker and solar cells with minimum damage.

5) To recover and return all equipment, except the expendable balloon, to Litton.

2. TECHNICAL DISCUSSION

2.1 Flight 3051 (JPL-69-1)

2.1.1 Flight Preparations

2.1.1.1 Project Personnel Assignments

Litton personnel responsible for preparations and flight operations on Flight 3051 were:

Project Engineer:	R. Conlon
Flight Leader:	M. Lueders
Instrumentation:	E. Minnich L. Nelson
Additional Launch, Tracking, and Recovery Crew:	V. Schwalbe D. Harshman J. Chesebro G. Benz G. Morri

The same key personnel conducted all flights on this program.

2.1.1.2 Pre-Flight Checkout

Required repairs and preventive maintenance were performed on all ground-station electronic support equipment to be housed within the Litton telemetry van. All airborne flight equipment was tested and recalibrated to insure both mechanical and electrical stability following the previous flight program. The airborne balloon control equipment selected for these 120,000-foot flights included a Litton Model R16 command receiver, a Model B58 high-altitude transmitter, a Model S12 timer for float-time control, a Model S15 timer for backup system cut-down, a beacon control programmer, a Model B17 recording barograph, and a recording thermograph for lower payload temperature monitoring.

The radio-command controlled ballast system was retained for this series of flights to prevent altitude loss during the float period. Four separate channels of the five-channel receiver were set up to open and release bags of steel shot attached to the lower payload. Three 15-lb bags plus one 20-lb bag were constructed for this flight.

The solar tracker for this flight was the same unit used on the previous year's radiometer flight (#3050). Although the radiometers and their instrumentation were redesigned, the mechanical arrangement previously used did not require modification. The only mechanical work necessary was the installation of stronger stainless steel gear pins and the removal of balancing weights from the payload to minimize the chance of mechanical oscillation in the elevation range of the tracker. The electrical modifications required to accommodate the new radiometer payload involves a complete re-wiring of the data commutating switch. The switching sequence and signal wiring arrangement used on Flight 3051 are presented on page 5 of this report.

Although radiometer power requirements were greatly reduced when the units were redesigned, the same power supply arrangement and capacity were used as on Flight 3050. This battery pack thus provided a high safety factor on voltage drop and power capacity. A new thermostat was installed in the voltage controlled oscillator (VCO) assembly to improve reference frequency stability over that experienced on the previous flight. The pressure-actuated switches used to turn on the solar tracker at 20, 000 feet on ascent were reset for 60, 000 feet to conserve power and reduce tracker operation time.

The 100-mv (millivolt) on-board reference circuitry was calibrated with a Leeds and Northrup Model K3 voltage potentiometer and Eppley standard cell. Voltages and corresponding subcarrier frequencies were similar in value to those recorded previously, so that the voltage divider did not require adjustment. A chart containing actual voltages and frequencies obtained in the final calibration is given in the Appendix, page A-3. Primary temperature channels were calibrated using a resistance decade to simulate temperature levels from -20 to +80°C. Secondary temperature circuitry was checked; the commutator was cleaned, and the output frequencies monitored and found nominal. Modulation voltage levels from the data subcarrier, temperature subcarriers, and on-sun sensor were checked and found nominal.

Switching Sequence

Channel No.	Description	Common Connection
1	100 mv calibrate	A*
2	Chopper wheel advance	B*
3	Solar cell #1	C*
4	Solar cell #2	C
5	Solar cell #3	C
6	80 mv calibrate	A
7	Solar cell temperature	A
8	Solar cell #4	C
9	Radiometer #1	B
10	Radiometer #2	B
11	Chopper wheel advance	B
12	70 mv calibrate	A
13	Solar cell #1	C
14	Solar cell #2	C
15	Solar cell #3	C
16	Solar cell #4	C
17	60 mv calibrate	A
18	Radiometer #1	B
19	Radiometer #2	B
20	Chopper wheel advance	B
21	Radiometer guard temperature	A
22	Radiometer circuit temperature	A
23	50 mv calibrate	A
24	Radiometer #1	B
25	Radiometer #2	B
26	Radiometer #1	B
27	Radiometer #2	B
28	25 mv calibrate	A
29	Chopper wheel advance	B
30	Solar cell temperature	A
31	Radiometer #1	B
32	Radiometer #2	B
33	Radiometer #1	B
34	Radiometer #2	B
35	Filter wheel advance	B
36	0 mv calibrate	A

*A = regulator voltage return
B = radiometer return
C = cell return

The beacon control timer was incorporated to minimize the possibility of radio-frequency interference on the primary telemetry data during the tracker-on portion of the flight. It was wired so that power would be removed from the output stage of the B58 transmitter when the system is above the 60,000-foot level (100,000-foot level on Flight 3051). The timer provides a 2-1/2-minute transmitter on time every 10 minutes for the purpose of altitude telemetry and direction determination.

The solar tracker with its radiometer payload was checked and adjusted in the sun and then the entire system was moved to the launch site for final checkout. With all components connected as they are in flight, using the balloon and parachute cabling to be flown, the system was actuated while in the sun for flight-simulation testing. After minor on-sun tracker adjustments and a thorough checkout for radio-frequency interference, all airborne and ground-station components checked properly and the system was judged ready to fly.

2.1.2 Field Operation

2.1.2.1 Launch

Flight 3051 was delayed two days due to poor weather conditions. Launch preparation began at 0430 CDT on 8 August 1969, with the attachment of auxiliary power to the truck-mounted system for warm-up. One of the two flight radiometers developed an oscillation during final checkout and the problem could not be corrected. The decision was made by JPL personnel to proceed with the flight because the other radiometer was operating normally. Balloon and system layout was completed at 0740 and inflation began at 0750. Surface winds averaged approximately six mph during the pre-launch period, but peaked at approximately 11 mph during the initial inflation period. The top payload was erected above the balloon without incident and launch was accomplished at 0829. The bubble downwind dynamic launch technique was used, with the lower payload mounted on the front of the launch vehicle. The same launch technique was used on all flights of this program.

2.1.2.2 Tracking and Recovery

As on previous programs, a four-man crew, consisting of a Cessna 170 pilot and observer/radioman, and on the ground, a trucker driver and an assistant driver/radioman, handled the tracking and recovery. Operations were directed by the telemetry-control base station. Flight 3051 ascended on a southeasterly course to a point over Maiden Rock, Wisconsin, at 80,000 feet altitude. At higher altitudes, the system was blown generally westward. The balloon reached its float altitude at 1045 above Miesville, Minnesota. During float, the system moved westward across Minnesota at a velocity of approximately 45 mph, reaching the Minnesota-South Dakota border at the end of the desired float period. The system continued west during a slow descent until the safety timer terminated the flight at 2043 at a point approximately 50 miles northwest of Pierre, South Dakota. The release was visually observed by the tracking aircraft crew at the Pierre airport, and the recovery truck crew 100 miles east of Pierre. The aircraft was grounded at Pierre during this period because of high winds and storm conditions in that area. Neither the parachuted lower payload or the free-falling balloon and tracker could be visually tracked after separation.

The following day (Saturday, 9 August), an aircraft search was conducted starting in the area where the balloon was last observed. The search was expanded when several pieces of balloon material were spotted from the air 20 miles southeast of Pierre. The payload and tracker could not be found during the Saturday airborne search. That evening, a telephone call was received by the Litton project engineer from a South Dakota rancher who had located the payload. The recovery force was notified and was able to recover the lower instrumentation, batteries and parachute by 1900 CDT. The location of the lower payload was 12 miles northwest of Pierre, just 9 feet from the edge of a cliff overlooking the Oahe Reservoir. The equipment had been dragged by surface winds until the parachute reached the edge of the cliff and collapsed. The rancher, on horseback, had neatly folded the chute to prevent further dragging. All equipment within the lower gondola was in good condition.

Using the lower payload as a reference, the tracking aircraft was able to spot the upper payload with a large portion of the balloon that same evening at 1915 CDT. Recovery was accomplished at 1100 CDT, Sunday morning, in a roadless area 35 miles northwest of Pierre. The tracker, one solar cell module, the radiometer housing and much interconnecting wiring were damaged by the free-fall. The upper payload was returned to the Litton facility by the aircraft by Sunday evening, 10 August. The lower payload was returned by Wednesday, 13 August.

2.1.3 Flight Results

2.1.3.1 Balloon

The balloons built for the 1969 flight program were slightly larger than those previously used for the 120,000-foot lifting task. The increase in payload required to handle the radiometers and the ballast system resulted in an increase of 15 feet in the balloon diameter, and 490,000 cubic feet in balloon volume. The enlarged design is capable of carrying a payload of 406 lb to 120,000 feet pressure-altitude. These balloons were ordered with specifications similar to those required on the slightly smaller 120,000-foot balloons used in 1966 and 1967, including the specification requiring that, "the gasports will be positioned by the manufacturer to provide an average descent rate of 700 to 1000 feet per minute."

The manufacturer made two modifications to the balloon designed for this program. One change was the addition of a high-slip reefing sleeve enclosing the lower 200 feet of the balloon to reduce wind effects during inflation, launch and low-altitude ascent. The sleeve is designed with a very thin tear panel and automatically opens as the balloon expands. The launch sequence shown in Figures 1 and 2 shows that the sleeve effectively retains the materials and is, therefore, a worthwhile design improvement. The second change was the use of a single gasport on the side of the balloon, in place of the three used on previously ordered balloons for the purpose of system descent. A query to the balloon manufacturer upon receipt of the balloon indicates that their calculations (through a computer) showed this valve size and placement would provide the specified system descent characteristics.

Figure 1. Launch Sequence Photos Showing Reefing Sleeve

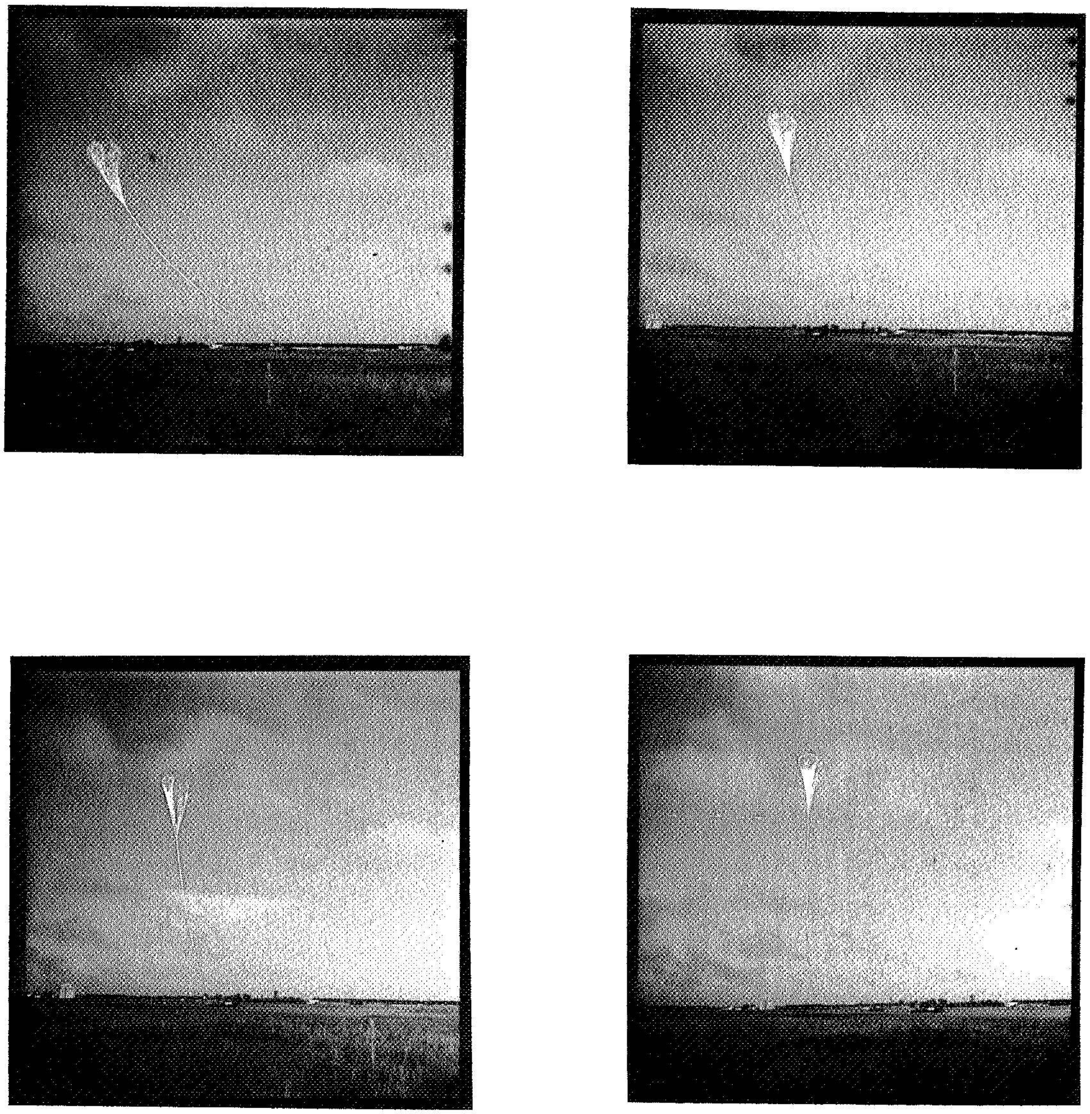


Figure 2. Launch Sequence Photos Showing Reefing Sleeve

Actual balloon performance revealed desired ascent and float characteristics. The average rate of ascent was 930 fpm (feet per minute) using 9% free lift. The balloon reached a height of 121,500 feet before 1100 CDT. By noon, the system dropped to 119,700 feet over some clouds. A 20-lb ballast drop increased altitude to 120,600 feet. Clouds increased and a second ballast drop of 15 lb at 1344 improved the float level from 119,200 feet back to 120,600 feet. Two additional 15-lb ballast releases at 1434 and 1444 boosted peak altitude of 121,800 feet at 1446. The timed opening of the descent gasport occurred at 1500, completing the four hours plus float period. The total time above the 115,000-foot level was five hours, 48 minutes.

The descent rate was extremely slow, reaching only 200 fpm at 105,000 feet at 1715 CDT. Below that level, the rate slowed as the balloon reached a nearly stable floating condition at approximately 96,000 feet. Timed payload separation occurred at 2044 CDT, a required safety procedure to clear airlanes prior to darkness. A time-altitude chart of this flight is contained in the Appendix, page A-9. From the descent characteristics obtained, it is obvious that the single gasport was too small and placed too low on the balloon envelope.

2.1.3.2 Instrumentation

All components of the tracking, control and telemetering systems performed throughout the longer-than-normal flight period. The solar tracker turned on as programmed at 60,000 feet and immediately locked on the sun. Balloon rotation was evidently very minimal, requiring the tracker to rewind only once during the entire 11-hour tracker-on period. Primary data reference frequencies recorded during the flight were quite stable, varying less than minus four cycles from the pre-flight reference. This error, amounting to approximately 0.4% of full-scale voltage, is correctable during data reduction. Considerable radio-frequency interference from the altitude beacon transmitter was evident on some of the data channels; however, above the 100,000-foot level, this transmitter was programmed off 75% of the time. During ascent, the radiometer that had not checked out properly ceased functioning completely. The second radiometer remained operative but was not as stable as desired. A preliminary analysis of the instability indicated that air currents (thermally induced) may have been entering the radiometer inlet chamber.

2.2 Flight 3052 (JPL-69-2)

2.2.1 Flight Preparations

The solar tracker damaged during the previous year's flight operations was rebuilt and prepared for this solar cell calibration flight.

Because of the descent characteristics experienced on the previous flight, the balloon manufacturer was immedicately consulted. Unfortunately, the second balloon was practically complete and to modify it at this state would possibly decrease reliability. The manufacturer suggested an alternate method of increasing the descent rate by use of a rip panel in the lower end of one of the vent ducts on the balloon. It was calculated that if a 54-foot section were ripped open, the proper descent rate could be quickly established. The panel was to be actuated by dropping a bag of steel shot that is cut free by a set of electric squibs fired at the conclusion of the float period. A small parachute is then used to prevent free-fall of the bag. The manufacturer agreed to install this duct on the balloon when it was laid out the morning of the next launch. As a backup to the rip panel, the manufacturer also was persuaded to supply an electrically actuated helium valve for this flight. This valve mounts on the opening at the apex fitting of the balloon and is contolled by one channel of the five-function, Litton command receiver. The tracker assembly was mounted on spacers approximately six inches above the valve.

After being plagued by radio-frequency interference on several past flights, a method was devised to turn off the beacon transmitter above 60,000 feet, yet still receive altitude information. Another subcarrier oscillator was added to the primary telemetry system for this purpose. A frequency of 30 KHz was chosen to avoid the possibility of harmonic frequencies interfering with the primary data channel at 7.5 KHz. The circuitry was arranged so that the new subcarrier was keyed continuously by the pulsed altitude data, but the normal beacon transmitter is turned completely off at altitudes above 60,000 feet. The beacon turn-on circuit was wired so that it could also be turned on via radio command in the event that the tracking aircraft lost visual contact with the balloon while it was above 60,000 feet. When actuating the beacon, the radio command operator has the option of turning the beacon on for only a 2-1/2-minute period or turning it on continuously. Requirements for a beacon turn-on command channel and a helium valve control channel reduced the number of possible ballast drops from four to three. Three 20-lb ballast bags were rigged for this flight.

The isolated leads used for radiometer power were routed to the electric helium valve below the tracker. The wet-cell main battery pack flown on the previous flight required replacement due to acid loss on impact and return shipment. The addition of new acid did not restore full capacity, so the power pack was retired to be used as a pre-flight test pack only. A new pack was cycled and all battery packs were checked under loaded conditions. The altitude sensor was recalibrated and all pressure-actuated switches were rechecked. Modulation levels were recalculated because of the additional subcarrier and then properly set up. Thermistor channel voltages and reference voltages were checked and found essentially unchanged from the previous flight. After adjusting the solar tracker during the preliminary on-sun test, the entire system was tested in the sun and judged ready for flight.

2.2.2 Field Operation

2.2.2.1 Launch

Launch preparations for Flight 3052 were underway before 0400 CDT on 26 August 1969. Balloon layout began at 0610 under near clam wind conditions. After layout, the rip panel was installed by the manufacturer's chief engineer without delaying launch preparations. The drop weight for the rip panel was carefully rigged above the chute. All instrumentation checks were normal, except that the VCO temperature was reading a lower value than normal. Inflation, final checkout and launch were completed without problems in winds of less than two mph. The lower payload left the launch vehicle at 0815 CDT.

2.2.2.2 Tracking and Recovery

This flight system ascended on an easterly course, but by 0928 moved to a position only two miles east of St. Paul at 65,000 feet altitude. By 1018, the system was moving west-northwesterly and was above Minneapolis at 113,000 feet. The ascent ceased at an altitude of 122,500 feet at 1032, and this was also the peak altitude experienced during the float period. The float course continued WNW, but cloud layers below the balloon caused an altitude loss to 120,000 feet by 1242 and then down to 118,500 feet by 1325. At this point, a 20-lb ballast bag was opened, and this was followed by an immediate increase in altitude. At 1410, the float level was 122,000 feet; at 1500, the end of the programmed float period, the altitude was 121,500 feet. During descent between 103,000 and 43,000 feet, the system remained near the Minnesota-North Dakota border in the vicinity of Fairmount, North Dakota. Descent below that level was easterly to impact of the lower payload five miles east of Nashua, Minnesota, at 2015. The balloon and top-mounted payload were separated from the lower section by the safety cutdown timer at 2003 at an altitude of only 13,000 feet. The top section held its tear-drop shape about five minutes after release, then it tipped and descended, but landed with very little tracker damage in a sunflower field one mile south of the lower package. Both sections were recoverable without difficulty and were returned before 1300 the following day.

2.2.3 Flight Results

2.2.3.1 Balloon

This balloon was identical to the unit used on the previous flight, except for the duct rip panel installed during launch preparations and the electric helium valve at the apex. Payload weight of 342 lb was 9 lb less, and the basic balloon weight of 745 lb was 12 lb less than component weights of the first flight. The ascent rate of 950 fpm and the peak altitude of 122,500 feet were precisely as expected. A single ballast drop maintained altitude within a total variation of 4000 feet, saving the remaining two drops for descent control, if needed. Following the valve and rip panel actuation time, a close watch on the altitude telemetry data was maintained to detect the effect of the rip panel actuation. After one hour, the slow descent rate was compared to previous data, which showed essentially no variation from Flight 3051. Helium valving through the top radio-controlled valve was initiated with four quick two-minute valve open commands. Short valve open periods were selected to minimize the chance of radio noise bursts closing the valve without operator knowledge. Some "off" time between opening periods was required to provide a safe cooling period for the transmitter.

The initial valve openings increased descent rate from less than 100 to 200 fpm. This rate diminished as soon as the valve was closed a short time. Another 16 minutes of intermittent valve open time increased the rate to 300 fpm, but showed the same undesirable deceleration characteristics. At 1803 CDT, the system was still at 91, 400 feet, and it could be seen from the data that time was quickly running out. Valving was continued with two, three and four minute valve open periods, followed by at least equal off times for transmitter cooling and altitude/descent rate monitoring. At 80, 000 feet, the rate was 500 fpm and by 70, 000 feet, it was up to approximately 600 fpm. Valve commanding continued and the descent rate continued to increase substantially. The rate was up to 800 fpm between 65, 000 and 35, 000 feet and averaged 920 fpm to the 13, 000-foot separation level. Interestingly, the descent rate of the lower payload below the parachute remained practically constant after release, indicating that the chute was causing a large part of the system drag in this altitude range, and demonstrating that balloon valving becomes ineffective at low altitudes. Indications were that additional valve open time at low altitude could have caused the balloon to lose all positive lift and it may have dropped over the chute, collapsed it, and caused a damaging near free-fall.

The electric helium valve was opened for 24 times and for a total of 49 minutes. Using curves that provide the electric valve's rate of flow versus altitude, the estimated loss of helium in terms of its lift was totalized through the descent. The total loss of lift was estimated at 268 lb on this flight.

Comparison of load altitude curves of this and the previous flight (see Appendix, pages A-10 and A-9) show that without valving, this balloon would have also reached a stabilized floating condition between 95,000 and 100,000 feet. Had it been determined earlier in the descent phase that the rip panel had not acutated, valving could have commenced earlier, and the system would have reached the surface before the safety termination time.

Examination of the system after impact revealed the rip panel problem. The rip panel drop weight was found, with a length of the rip line, tangled in the parachute. Instead of dropping free to pull out the panel, the weight fell only a few feet into the parachute rigging and was snagged.

2.2.3.2 Instrumentation

The solar tracker turned on at 60,000 feet and apparently remained stable and on-sun throughout the ascent, float and initial descent periods. The beacon transmitter was programmed off above 65,000 feet and the pulse rate information telemetered on the added subcarrier channel provided satisfactory altitude data throughout the flight. This modification effectively eliminated the radio-frequency interference visible on the analog data recordings on previous flights. The beacon transmitter was turned on for a 2-1/2-minute period twice during the high-level descent period by the tracking aircraft. Cloud cover and the fact that the aircraft was out of range of the base station communications necessitated these commands. The command system was exercised a total of 27 times on this flight.

The telemetered primary reference frequencies were not as stable during this flight as on previous flights. The 100-mv reference frequency varied ± 9 Hz, while the zero reference varied ± 3 Hz. A review of the VCO temperature profile (Appendix, page A-5) shows that temperature control was not maintained. Normally, the VCO temperature is well controlled within ±3°C. On this flight, the temperature held about 12°C below the 48°C nominal thermostatic set point until 3-1/2 hours after launch. At this point in the flight, the temperature rose to the 52°C range and was comparatively stable at that level through the remainder of the flight. Evidently, the thermostat which had been replaced this year was damaged on the previous flight's hard impact. The computer program used for transforming this frequency data into usable form automatically standardizes these reference frequencies, eliminating this drift as a source of error. Data recorded between 1032 and 1500 CDT were selected for further processing. These data were reduced to 114 punch cards and submitted to JPL.

2.3 Flight 3053 (JPL 69-3)

2.3.1 Flight Preparation

The solar tracker used on the second flight was prepared for this flight. In addition to necessary gear train, shaft and shear pin repairs, modifications were required to accommodate a hitch-hike solar panel from Lincoln Laboratory of the Massachusetts Institute of Technology. A compact (9.19 x 6.75 inches) module mounting plate was constructed for 18 JPL type solar modules. Since each module may accommodate up to two 1 x 2 cm solar cells, the full 26 data channel capacity was accommodated on the reduced area panel. The Lincoln Laboratory panel (5.76 x 5.96 inches) was mounted on a spacer next to the JPL panel. The back surface of the tracker mounting plate accommodates a 6.600 x 2.125 x 3.000 inch power converter box weighing 1.22 lb, and a 4.177 x 7.538 x 5.756 inch logic circuit box weighing 3.48 lb. Some filing was necessary to accommodate the height of the logic circuit case. The total weight of the Lincoln on-board equipment was approximately 5.5 lb. The two slip clutches used in the solar tracker's elevation drive train required considerable tightening to accommodate the increased payload weight.

The digital output of the Lincoln solar cell calibration panel instrumentation provides an accurate I-V curve of each cell plus panel temperature data. The pulse output signal was used to biphase modulate an 18 KHz subcarrier oscillator at the clock pulse rate. This subcarrier frequency was filtered, adjusted for proper level and mixed with 7.35 KHz primary data subcarrier, the 30 KHz altitude data subcarrier, the 250 Hz secondary temperature subcarrier and the 900 Hz off-sun subcarrier tone. Compatibility problems were encountered when the Lincoln Laboratory instrumentation was tested with the entire system in operation. The five watts input power at 28 volts required by this added equipment had no significant effect on the main power battery capacity. The modifications and additional effort required to set up and check out this system were funded separately by MIT-Lincoln Laboratory.

The balloon for this flight was manufactured with a duct rip panel installed at the factory. In all other respects, it was identical to the two balloons flown previously. The manufacturer asserted that the balloon would descend rapidly according to the original specifications if the rip panel could be properly actuated. Various duct rip panel opening schemes were analyzed. All schemes that involved dropping of a weight were eliminated from final consideration because of the possibility that the weight might be jarred loose at launch or might foul in the parachute, load line, or lower payload equipment when released at the end of the float period. A motor-driven reel was selected as the most reliable method of opening the balloon duct. A high torque miniature d-c motor directly drove a small reel. A microswitch on a strong, flexible bracket was used to limit motor operation after the reel was filled. This device, installed in a lightweight case, was mounted directly on the bottom metal fitting of the balloon to eliminate the possibility of line twisting and fouling. The reel assembly was tested with a simulated rip panel made from material stronger than the balloon duct material. The test indicated that the motor had more than sufficient torque to pull out the balloon panel.

A new thermostat was installed within the VCO module to improve temperature control. A new bead thermistor was installed near the thermostat and heater assembly to provide more accurate temperature telemetry from this module. All other telemetry and control equipment was set up and rechecked. All voltages and calibration frequencies were similar in value to those recorded previously so that system adjustments were not necessary. Page A-3 of the Appendix contains a listing of the primary voltages and reference frequencies obtained during final checkout for this flight. With all components operating as they are in flight, using the balloon and parachute cabling to be flown, the system was operated in the sun for flight simulation tests and, after final solar tracker adjustments, was considered ready for flight.

2.3.2 Field Operation

2.3.2.1 Launch

At 0530 CDT on 8 September 1969, balloon layout began for Flight 3053. Helium gauging, instrumentation warm-up, and preliminary system checkout had been completed by this time. Surface wind was 4 to 6 mph from the north-northwest with fair sky. By 0755, layout was complete, system setup and final telemetry system checkout complete, the flight battery pack was checked and permanently connected, and balloon inflation initiated. Inflation and final system checkout was completed at 0820. The balloon was launched at 0830 in 4 to 6 mph wind from the north-northeast. Because of the change in wind direction, the launch vehicle moved from the hard surfaced area into soft sand in order to align the lower payload properly under the rising balloon. Despite the poor surface, the launch was smoothly accomplished.

2.3.2.2 Tracking and Recovery

The balloon system headed to the southeast during the ascent period until reaching 80,000 feet. Between 80,000 feet and the 120,500-foot float level, the balloon circled above Goodhue, Minnesota, which is 60 miles from the launch site. During the floating period, the system nearly retraced its ascent course moving north-northwest and passing over a point approximately six miles east of the launch site. At 1500 CDT, the end of the specified float period, the balloon was ten miles northeast of the launch site. During initial descent, the course was easterly, then below 68,000 feet descent was southeasterly until impact at 1940 CDT. The system landed intact at the Durand, Wisconsin, airport. The explosive cord on the balloon envelope was actuated on impact but the system was dragged about 400 yards across and alongside the runway before deflating. Both the upper and lower payloads were recovered without problems. The solar panels and instrumentation were recovered in perfect condition. The balloon material was disposed of and the recovery crew returned the equipment to the plant the following day.

2.3.3 Flight Results

2.3.3.1 Balloon

The balloon used on this flight was identical to the two balloons flown previously except for the factory-installed duct rip panel and the reel method of actuating the panel. The average rate of rise of the balloon system was 850 fpm to a peak altitude of 120,800 feet. The system passed above the 115,000-foot level at 1048 CDT and remained above that level for four hours and 41 minutes. One 20-lb ballast drop was made at 1424 when the float level degraded to 118,500 feet. At 1455, five minutes before the valve and duct opening time, the altitude level had returned to 120,000 feet.

The altitude telemetry was monitored very carefully during the initial descent phase to determine the effect of the rip panel, if any. The initial descent rate during the first half hour period was 165 fpm; during the second half hour, the rate increased to 260 fpm. This first hour descent rate was considerably higher than that of the previous two flights, indicating the rip panel had been successfully actuated. Unfortunately, during the next 25-minute period, the descent rate slowed to 148 fpm. At this point, radio-controlled helium valving was initiated to increase the descent rate. Fifteen 2-minute valve openings were undertaken between 102,000 and 40,000 feet. The first opening was initiated at 1634, the final opening occurred at 1853 with the descent rate at 950 fpm. The overall descent rate averaged 430 fpm, enabling the system to reach the surface approximately 20 minutes prior to the safety cutdown initiation time.

Post-flight examination of the reel used to open the lower 54 feet of the balloon duct revealed that the nylon rip line was wound tightly and uniformly for a length of 68 feet. The remaining 25 feet were wound loosely over the initial length and the pull button and rip tape were at the end of the line. The evidence, including the time/altitude data plotted in the Appendix, indicated that the rip panel was actuated as programmed, and did result in an initial system descent.

2.3.3.2 Instrumentation

All components of the JPL and MIT instrumentation systems performed as desired throughout the flight. The MIT ground-station equipment recorded solar panel data on both magnetic tape and printed paper tape providing them with a large quantity of ascent, float, and descent data for later computer analysis. The JPL solar panel short circuit current data, temperatures, and reference frequencies were recorded in the usual manner on a single pack of printed paper tape with an analog recording as a backup. The printed data was later converted into a total of 138 punched computer cards which were submitted to JPL.

Improved temperature control of the primary JPL subcarrier oscillator was obtained compared to the previous flight. The new thermostat held reference frequencies very stable until the module temperature exceeded the set point temperature one hour before the end of the float period. Temperatures during the float period, especially in the area of the solar cells and the tracker mounting plate, were considerably higher than normal. Page A-6 of the Appendix lists the housekeeping temperature data from this flight.

Solar cell output parameters are generally compared and standardized at 28°C. Any variation from this temperature requires a correction; because of the temperature coefficients involved, a large temperature deviation increases the uncertainty of the actual corrected solar cell output. Telemetry from the MIT solar panel indicated that cell temperatures were near 80°C throughout the float period. Temperatures telemetered from a thermistor mounted on a JPL solar cell module indicated a temperature of 47°C one half hour after the beginning of float, increasing to a maximum of 63.5°C at the end of float. The temperature differences between solar panels are due to the dissimilarity in the thermal circuit of each panel. The thermal resistance of the MIT panel is high bebause the cells are mounted on a fiberglass circuit board with the only heat conduction paths through the wire leads and from the edges of the circuit board, through a metal spacer to the tracker mounting plate. On the other hand, the thermal resistance of the heat conduction path from the JPL solar cells to the mounting plate is very low. Each cell is mounted on a copper substrate. The copper substrate is bolted to an aluminum panel attached to the aluminum tracker mounting plate. Each metal-to-metal surface is coated with a thermal heat conducting compound to reduce thermal resistance. This mounting configuration helps to maintain all cells at a nearly identical temperature. In addition, the large thermal mass involved smooths out transient temperature variations, and causes a long thermal time constant which can be useful for temperature coefficient determinations.

The higher temperature of the solar cells and mounting plate compared to previous flight data can be explained by one or all of the three factors affecting thermal balance on this flight. The additional solar cells flown on this flight absorb more heat from the sun than the flat-white solar tracker plate front surface they replaced. The MIT power converter and logic circuitry mounted on the back surface of the tracker plate dissipated less than five watts of heating power into this area but this factor also contributes to the heat buildup during the long float period. The sun shade, which is painted flat-black, is mounted perpendicular to the sun and when properly aligned adds little to the heat rise of the panel. A slight misalignment of the sun shade may expose a large flat black surface area to the sun and the heat rise becomes substantial.

The solar tracker performed in a stable manner although its pointing accuracy during float may have been less than the plus or minus 1.5 degrees deviation obtained during ground checkout. The tracker was off-sun for a brief rewind at 1116 CDT, then did not rewind until descent at 1656 when it lost the sun for several minutes. One JPL solar cell was mounted closer to the bottom edge of the tracker mounting plate than all other cells. The tracker sun shade required pre-flight adjustment to avoid shadowing this cell during on-sun checkout. The telemetry data indicated some shading of this cell during the flight. The shading may have been caused by reduced pointing accuracy during flight but could also be attributed to sunshade misalignment caused during handling, inflation, or launch.

2.4 Flight 3054 (JPL 69-4)

2.4.1 Flight Preparation

The contract covering this program was modified on 9 October 1969 to include the effort necessary to conduct a fourth balloon flight. Meteorological conditions at this time of the year dictated changes in the JPL flight format. Upper altitude wind velocities are maximum during this season, and at 120,000 ft, may average over 100 knots out of the west. Launching from the usual Minneapolis site could result in an impact into the Great Lakes. A safer fall-season launch site was selected at the Mitchell airport, Mitchell, South Dakota; 300 miles west of Minneapolis. Another fall-season problem is the shortened daylight period. It was necessary to reduce the float period to three hours and reduce the descent time in order to bring the system down before dark.

Launching this system from a remote site and the lengthened flight distance caused many logistics problems. Launch and helium handling vehicles and equipment, the recovery vehicle, all flight components, all ground station antennas and instrumentation, and all operations personnel had to be moved to the launch site. Surface weather conditions such as ice and snow storms and below freezing temperatures increased the difficulty of the task. The uncertainty of long range weather forecasts during this period was another challenging factor. The anticipated extended range of the flight path meant that without a down-wind telemetry receiving station, data transmitted near the end of the flight could be lost. Receiving and recording equipment was assembled into a down-wind telemetry station located at the Litton-Minneapolis plant. Three antennas, including a two element Yagi antenna with azimuth and elevation rotators, were installed on the plant roof to handle this task.

The balloon obtained for this mission was identical in size and volume to the balloons flown on the previous three flights. This balloon, however, was manufactured with three helium gasports installed on a high duct instead of the single gasport placed on a lower duct of the previous balloons. Gasport No. 1 was located 252 ft from the base, No. 2 was located 174 ft from the base and No. 3 was located 144 ft from the base of this balloon. A duct rip panel was not installed on this balloon, but a radio-controlled helium valve was used at the balloon's top fitting as a backup descent controller. Three 20 lb ballast bags were again incorporated for additional altitude control.

In-plant instrumentation preparation consisted of solar tracker repair, radiometer payload assembly, data commutator rewiring, balloon control system rewiring, system recalibration and final testing. The tracker was severely damaged on impact of this year's first flight. The wiring, many internal gears, hubs, shafts and plates required repair and/or replacement. Practically all parts above the azimuth drive train were damaged beyond repair. After mechanical repair, two drive transistors required replacement before the tracker checked out properly with simulated sun conditions.

The dual radiometer payload was mechanically and electrically similar to the unit flown earlier during the program except that the inlet was redesigned to minimize the effects of air currents, and the four solar cells formerly mounted on the radiometer assembly had been eliminated. A single JPL solar cell was mounted on the tracker plate in a shielded housing. The resedigned radiometer required rewiring of the commutator. Four separate common connections were maintained to minimize potential electrical interference. The following switching sequence and signal wiring arrangement was selected for flight 3054:

Switching Sequence

Channel No.	Description	Common Connection
1	100 mv calibrate	A*
2	Radiometer #3	B*
3	Radiometer #6	B
4	Chopper wheel advance	C*
5	Radiometer #6	B
6	80 mv calibrate	A
7	Temperature 1 (thermistor)	A
8	Radiometer #3	B
9	Radiometer #6	B
10	Chopper wheel advance	C
11	Temperature 2 (thermistor)	A
12	70 mv calibrate volt	A
13	Radiometer #3	B
14	Radiometer #3	B
15	Radiometer #6	B
16	Chopper wheel advance	C
17	Radiometer #3	B
18	60 mv calibrate	A
19	Solar cell	D*
20	Radiometer #3	B
21	Radiometer #6	B
22	Chopper wheel advance	C
23	Radiometer #3	B
24	50 mv calibrate voltage	A
25	Radiometer #3	B
26	Radiometer #3	B
27	Radiometer #6	B
28	Chopper wheel advance	C
29	Radiometer #6	B
30	25 mv calibrate	A
31	Temperature 3 (thermistor)	A
32	Radiometer #3	B
33	Radiometer #6	B
34	Chopper wheel advance	C
35	Radiometer #6	B
36	0 mv calibrate	A

*A = regulator voltage return
B = radiometer return
C = chopper return
D = cell return

Several modifications were made to the balloon control instrumentation prior to this flight. Changes were made primarily to improve balloon altitude control from the tracking aircraft. It was anticipated that the tracking aircraft would monitor altitude and assume full control of the balloon descent when the launch site telemetry receiving range was exceeded during the long balloon track. To simplify operation of the backup radio-controlled helium valve, a two minute time-delay relay was used to hold the valve open for that time period when initiated by a momentary open command. This command signal also initiated a code keying relay within the beacon-altitude transmitter for verification of the valve opening command. For safety, another command channel (also used for high altitude beacon transmitter turn-on) was wired to release the open helium valve if the time delay circuitry failed or a shorter open period was desired. Another command channel was rewired to control flight termination (squib-actuated balloon separation) in the event the system had to be brought down before reaching an undesirable impact area such as a lake (i. e. Lake Michigan) or a large metropolitan area (i. e. Chicago). Another ten second time-delay relay was necessary to retain the normal three ballast drop command capability. One of the five command channels was revised to handle two ballast functions, differentiated by a momentary command for one ballast bag release, and a ten second hold for initiation of the second ballast bag release.

System checkout and final calibration was conducted at the Litton plant. All primary voltages and frequencies were stable and consistent with previous data. Reference resistances in the secondary temperature circuitry were changed to improve temperature telemetry stability. The high-reference resistance was changed to a stable 4.22 K ohms, which produced a 332 Hz reference tone; the low-reference resistance was 51K ohms for a 156 Hz reference frequency. Lack of suitable sun conditions delayed the usual preliminary on-sun solar tracker checkout conducted at the plant.

2.4.2 Field Operation

2.4.2.1 Pre-Launch

In-plant preparations were completed on Saturday, 15 November 1969, and plans were made to move to the Mitchell, South Dakota launch site on

Monday, 17 November. The move was delayed 24 hours when a winter storm moved through the area from west to east. By Tuesday morning, 18 November, the storm was still in the Minneapolis area but the area westward had cleared and it was predicted a large high-pressure weather system would remain in the launch area for several days. The launch vehicle, recovery vehicle and a station wagon were loaded with equipment and driven to the launch site on Tuesday. On Wednesday, the three Litton personnel at Mitchell began the telemetry station set-up and the solar tracker on-sun checkout. Meanwhile, the helium tractor-trailer and another station wagon were driven to the launch site by Litton and JPL personnel. By Wednesday afternoon, all equipment and personnel, except the tracking aircraft and pilot, were at the launch site and equipment set-up was progressing rapidly. A thin cloud cover prevented final tracker adjustments on Wednesday. The primary problem in tracker adjustment was the low sun angles at this latitude during this time of the year. The elevation low limit switches required remounting to obtain a minimum angle of 15 degrees to minimize tracker search time in the early morning and late afternoon.

On Thursday, final set-up of the launch equipment, telemetry station equipment, and solar tracker were completed. An on-sun system checkout was conducted for several hours to verify complete system operation and to allow JPL to conduct an on-sun radiometer ground calibration. The solar tracker exhibited excellent stability during this test and the system was judged ready for flight.

2.4.2.2 Launch

Launch preparations were initiated at 0330 CDT on 21 November 1969, under clear to scattered cloud conditions and a steady wind of 6 mph from the southeast. Preparation proceeded without problems until an Air Force balloon was monitored as flying a beacon transmitter on an identical frequency as the Litton beacon. A transmitting crystal was changed and the Litton transmitter re-tuned causing only a 20 minute delay. Balloon layout began at 0615. System checkout was accomplished and inflation began at 0730. Surface wind during inflation was 8 to 10 mph with occasional gusts up to 12 mph.

Initial inflation was conducted in the usual manner. The top payload was held by hand until the balloon bubble appeared to have sufficient lift to support the weight of the load. When the hand-held load begins to pull steadily upward, the load is released and normally, assumes a stable upright position at the apex of the balloon for the remaining inflation period. In this instance, however, because of the wind conditions, the balloon envelope extended around the six foot diameter plywood disc and came in contact with the solar tracker during the load erection. After the system assumed a vertical position, a hole could be seen in the balloon envelope. Inflation was halted and a plan was quickly devised to patch the balloon. The top helium valve was opened momentarily by the command system to rapidly reduce lift and allow the top load to settle and be held manually in a stable position while all visible holes and stretch marks were repaired with polyethylene tape.

Inflation was initiated for a second time. The top-mounted load was held down until the force was sufficient to lift the load plus approximately 150 lb. When released, the top load rose rapidly into position without problems. Although the second top load erection was successful, visual inspection revealed another hole in the material about 20 feet from the balloon's apex. Inflation was again halted and the valve opened to attempt another patching job. During deflation, just as the valve was being closed, a wind gust tipped the payload causing it to fall into the balloon and then onto the surface of the launch area. At this point, both the solar tracker and the balloon were beyond immediate repair and the flight had to be canceled.

2.4.2.3 Return

The tracking pilot was called during launch set-up and left the Minneapolis area at dawn for Mitchell. He arrived at 1015 CDT, helped the field crew disassemble the launch equipment, and returned to his home airport that afternoon.

The launch crew began disassembling and packing all equipment immediately following the aborted launch. This task was completed by early afternoon. Surface weather conditions were good for the return trip to

Minneapolis and all equipment and vehicles were returned by late evening, 21 November 1969.

In-plant visual inspection of the solar tracker indicated no damage to the radiometer components. Apparently, only minor damage had occurred to the tracking mechanism. Bent sensor brackets, a damaged elevation drive motor, and sheared azimuth drive gear pins appeared to be the extent of the trouble. The damaged balloon was shipped for repair. The upper 55 feet of the balloon, which is the length of material from the launching platform to the apex, will be completely inspected and all holes and stretch marks carefully repaired with a newly-developed, improved polyethylene tape. The gasports and material around the gasports will also be inspected and the balloon will be carefully repacked for use on a future flight program. Page A-8 of the Appendix contains a Property List describing the balloon, solar trackers, and other equipment owned by JPL in the contractor's possession at the conclusion of the 1969 flight program.

3. CONCLUSIONS

3.1 Balloons

Operationally, three of the four balloon flights attempted during this program were successfully accomplished. The three flights that were originally scheduled were prepared, launched, and reached the specified altitude for the specified time period. The data telemetry system and the balloon control instrumentation operated continuously during all flights. The 100% balloon success ratio which was maintained for a five-year period with 21 successful balloon flights ended when an attempt was made to launch a fourth balloon for this year's program.

The failure of the fourth flight attempt cannot be attributed to a faulty balloon, but to the high surface wind velocity during inflation and indirectly to the increased weight and size of the top-mounted payload. A combination of factors, including wind velocity, payload weight and size, and the timing of the erection of the top-mounted tracker system resulted in the failure as described in the previous section.

The design of the three balloons flown on this program was satisfactory since they lifted the increased system weight above the nominal 120,000 foot float altitude. However, the balloon design was not satisfactory in terms of descent characteristics. Improper gasport size and/or placement resulted in an extremely slow rate of descent, causing numerous recovery problems. Descent fixes suggested by the manufacturer were not effective for the second and third flights. The fourth balloon was redesigned with additional gasports; unfortunately, this design modification has not been checked out.

3.2 Control System

The many balloon control modifications incorporated into the system between flights were generally undertaken for the purpose of monitoring and controlling the descent rate. A helium valve was incorporated after the first flight and was used for all subsequent flights. Radio command control was used not only for ballast drops, but to control the valve, start and stop the beacon transmitter, and on the final flight attempt, to release the balloon in the event of an emergency. The data interference problem was effectively eliminated after the first flight by turning off the beacon above 60,000 feet and incorporating a subcarrier oscillator into the primary telemetry system for altitude monitoring. This change eliminated the need for an interfering transmitter during the normal data recording period. The beacon actuation command was provided as a back-up in cases of loss of primary telemetry altitude information or cloud cover problems. All control instrumentation modifications were completely successful during flight. The radio command system was exercised a total of 45 times without a miss during the three successfully launched flights.

3.3 Solar Tracking

The on-sun telemetry signal indicated proper solar tracker operation on all flights. Minor shadowing of a single cell was experienced on both solar cell flights. The shadowing noted on Flight No. 3052 was on a cell flown in a long tube for a sky brightness test. It was determined, the tube limited the view angle of this cell to an angle less than the tracker error or hysteresis angle. Actually, shadowing occurred on only five out of the thirty-eight data points. On Flight 3053, a non-standard solar cell module was mounted near the lower edge of the tracker mounting plate. The cell was then mounted close to the edge of the module. This caused some shading which was noted during pre-flight checkout. The tracker reflection shield was modified to minimize the shadow, but during the actual flight, shading occurred on 12 of the 38 data points. In both instances, shading was prevelant during the early or late stages of the float period but rarely occurred during the important solar noon-time period. By eliminating the few data points exhibiting shading seen on the analog recording, all remaining cell output data has on-sun accuracy.

3.4 Thermal Considerations

The comparatively high temperatures monitored at the solar cell mounts, the tracker mounting plate, and inside the electronic boxes during this year's flights were of great concern. Compared to the maximum temperatures noted at the 80,000-foot float level, the tracker mounting plate temperature averaged 24°C higher for the 120,000 foot level. The electronic boxes and the payload mounting disc temperatures were 12°C higher, while the controlled VCO (voltage controlled oscillator) temperature averaged five degrees higher on the 120,000 foot flights. High and variable solar cell temperatures during the float period increase the uncertainty of the data accuracy. The temperature coefficients of the cells are not necessarily linear over a wide temperature range and a large correction factor must be used to calculate the free-space, 28°C, output level. Similarly, the increased VCO and electronic box temperatures required telemetry data corrections to reference the data to preflight standards. Higher circuit temperatures require larger corrections, thus increasing data uncertainty.

The high temperatures experienced during 120,000 foot float compared to 80,000 foot float conditions occur for several reasons. For example, the absolute ambient temperature at 80,000 feet is minus 52°C, while at 120,000 feet it is 20 degrees warmer at minus 32°C. Another factor is the color of the surfaces perpendicular to the sun. A flat-black surface absorbs a large amount of the sun's energy compared to a white or reflective surface which remains comparatively cool in the sun. Usually, all sunny upper payload surfaces are painted flat white except for areas that might reflect onto the solar cells or sun sensor which are painted flat black. The cells are a variety of dark colors and may be covered with filters which absorb heat in varying degrees. The increased number of cells mounted on the tracker panel also contributes to the increase of panel temperature because they occupy a larger percentage of the surface area.

The following section of this report will present several solutions to the thermal problems.

4. RECOMMENDATIONS

4.1 Program Requirements and Options

The need for balloon-calibrated solar cells has increased with the advances in solar cell technology and the increased applications of solar cells. Flight system improvements are recommended on future balloon flights conducted for the purposes of calibrating solar cells and obtaining accurate radiometer measurements of solar constants above the significant water vapor and ozone atmospheric constituents. Solar tracker mechanical and thermal system modifications are desirable. Future tracker system improvements may take one of the following forms:

1) Same trackers, repaired; minor mechanical modifications made for ease of set-up and pointing improvement, and minor thermal control improvements made with shielding and painting.
2) Same trackers; thermal control accomplished with liquid cooling system.
3) New design top-mounted tracker; automatic liquid cooling system incorporated.
4) New design below the balloon tracker; automatic thermal control using thermoelectric elements or liquid cooling.

4.2 Top-Mounted Solar Tracker Options

4.2.1 Repair

Experience indicates that the two currently used solar trackers can be repaired numerous times without significant degradation of pointing accuracy or stability. Repair, no matter how substantial, has been and should continue to be the lowest cost option for flights. Existing trackers provide pointing accuracy of approximately ±1-1/2 to ±2-1/2 degrees. Minor mechanical design modifications may improve accuracy slightly. Improved sensor mounts could reduce set-up time considerably. New sensors and minor circuitry modifications would also reduce set-up time and improve stability. All relays should be replaced before reflight as a precautionary step.

4.2.2 Temperature Stabilization

Temperature stabilization of the solar cell modules could be attempted with the present trackers. Only minor thermal improvement can be made by improved painting and shielding techniques. A mechanical shielding scheme could be devised to shade all cells from solar radiation except those under current measurement. Disadvantages include weight, syncronization, and reliability problems. A pressurized liquid cooling system may be advantageous. For example, the system could consist of one or two self-pressurized and insulated tanks of Freon 12, a pressure regulator set to vent the tanks at approximately 105 PSI, copper cooling coils attached to the back of the tracker mounting plate, and a flexible hose between the tanks and the mounting plate. Temperatures above +28°C will vaporize the pressurized Freon, causing flow and resulting in heat transfer from the mounting plate to the Freon whenever its temperature exceeds the desired value. Assuming solar heating of 232 BTU's per square foot per hour and a 58 BTU's per hour Freon latent heat of vaporization, 4 lb of Freon would be consumed per hour for a one square foot area. At this rate, a four hour supply of Freon on a top-mounted tracker would be prohibitively heavy. A higher control temperature would considerably reduce the amount of coolant required. Consideration should be given to a simple system using approximately 4 lb of Freon with a pressure setting that provides a controlled temperature between 28 and 40°C for a minimum period of at least two hours.

Efficiency of this method may be enhanced by using the vented Freon vapor to power a miniature air ejector pump. The air pump has a mass augumentation ranging from 3 to 10, and with the use of lightweight honeycomb cooling fins on the back of the cell mounting plate, the airflow could aid the cooling capability significantly. An air pump powered by a tank of compressed gas could be used alone to reduce cell temperatures. This method would be simple but may weigh as much as the liquid cooling method and would not offer the automatic close temperature control feature.

4.2.3 New Design

A new solar tracker designed for top-of-the-balloon mounting could incorporate many improvements such as an externally-adjustable sun sensor module, a completely solid-state tracker motor control system, improved pointing accuracy, a built-in temperature control system, reduced height and volume, streamlined external surfaces to minimize balloon damage, and reduction in weight. Improved system reliability, increased data accuracy, and the continuation of a proven successful method solar cell calibration are the important advantages of this option.

4.3 Below-The-Balloon Tracker Option

4.3.1 Description

Changing the mounting position of the solar tracker from its current top-of-the-balloon location to a position on or just above the lower instrument and battery container requires a completely new design. As envisioned, the solar tracking mechanism is packaged about a vertical axle, allowing electrical leads to be connected from the lower gondola through the axle to the parachute. The azimuth gimbal is driven around the load-carrying shaft eliminating the need for support cables in the solar panel's view. The instrumentation and battery box serve as a reaction wheel for the azimuth drive to work against. The gondola components may require rearrangement into at least three horizontal spokes to provide the proper moment of inertia. Special bearings and universal joints are required to minimize friction and reduce undesirable angular momentum. A spreader bar or disc is mounted above the tracker for multipoint suspension of the parachute risers. This suspension helps dissipate any angular mementum without twisting the parachute. The disc or plate for parachute attachment may also serve as a balloon reflection shield for the solar panel. A 200 foot nylon load line must be used between the parachute and the base of the balloon to prevent balloon shading of the solar panel during the summer months at 45 degrees North latitude for a 214 foot diameter balloon.

The elevation drive mechanism, solar oriented payload, signal handling electronics, azimuth, elevation, and acquisition sensors, and the thermal control system components all mount on the driven azimuth mounting disc or beam. The elevation drive mechanism may be similar to that currently employed except for improved pointing accuracy. The cooling equipment can be mounted opposite the elevation drive as a counterbalance. Slip rings are required to couple input power and output signal leads to and from the azimuth mechanism. The limited travel of the elevation gimbal permits direct wiring to carry power and individual cell and thermistor signals between the azimuth platform and the solar-oriented panel.

4.3.2 Advantages and Disadvantages

A below-the-balloon solar calibration system offers many advantages but also some disadvantages compared to the existing top mounted system. These factors are summarized below:

Advantages

- Increased pointing accuracy
- Orientation of greater payload weight and volume
- More precise and longer duration temperature control system can be incorporated
- Total flight time can be significantly reduced
- Reduce probability of impact damage
- Reduce inflation time and probability of balloon damage during inflation
- Reduce balloon complexity and cost by elimination of gasports, electric valves and electrical wiring
- Reduce time of tracking and recovery

Disadvantages

- Long load line necessary to eliminate balloon shadow during the summer
- Long load line increases launch difficulty
- Load line length and launch area size limit future system growth

- Letdown reel mechanism may be necessary to overcome load line limitations
- Increased pendulous and oscillatory motions to overcome
- Slip rings necessary for some electrical leads
- A radar reflector and an independent balloon destruct system must be added on the balloon to meet FAA requirements

The Applied Science Division of Litton Industries again anticipates the opportunity and challenge of satisfying the stringent technical requirements of Jet Propulsion Laboratory in the areas of high performance airborne mechanical, fluidic, electronic and balloon systems.

5. NEW TECHNOLOGY

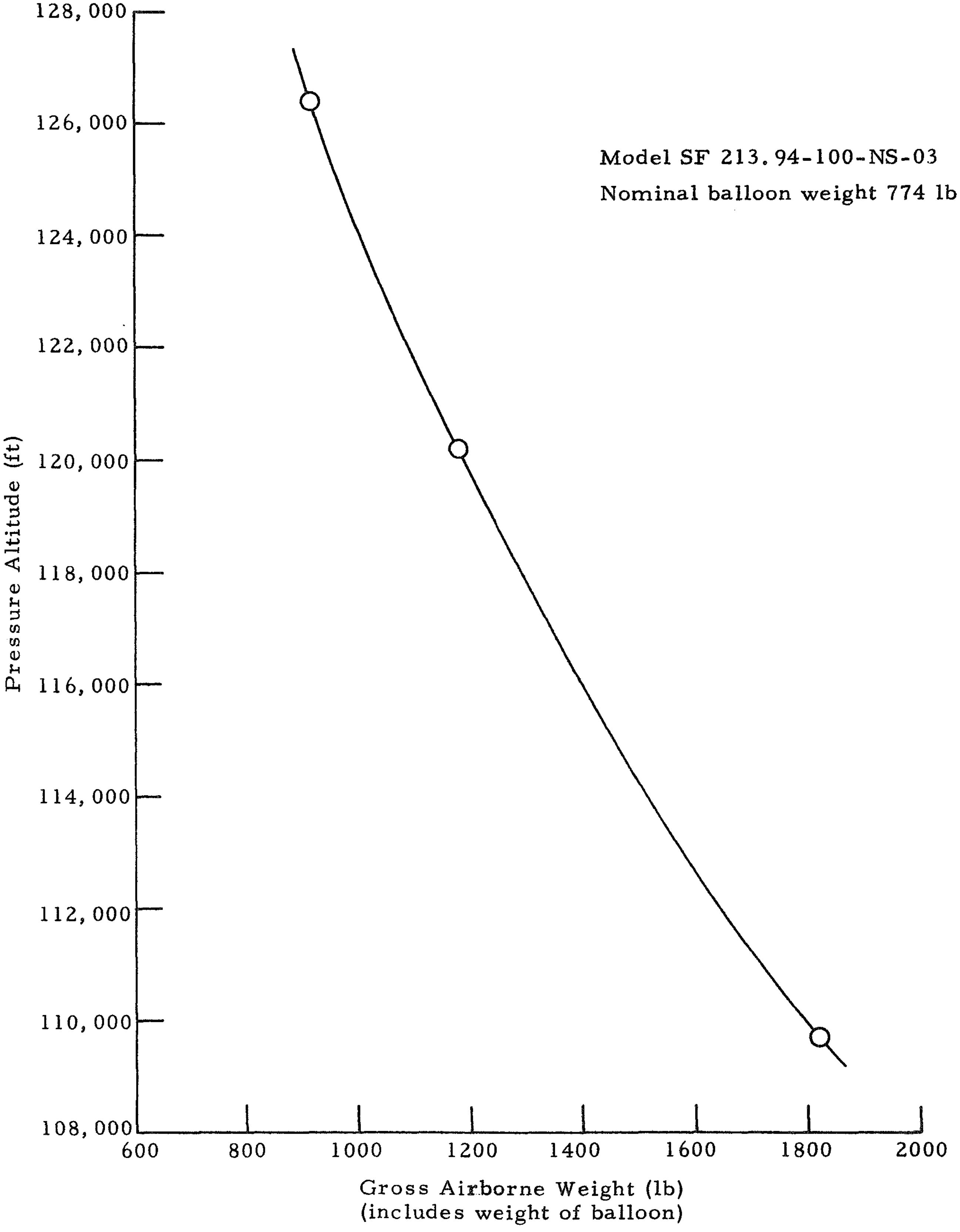
No items of new technology have been identified or reported during the course of this contract.

APPENDIX A

OPERATIONAL DATA

Operation Specification Sheet
(for SF-213.94-100-NS-01 balloon)

Fabric Parameter (Σ)		0.5
Payload (Design)		406 lb to 120,000 ft
Material (Balloon Wall and Duct)		0.7 mil S.F. Polyethylene
Volume (Theoretical)		3,432,400 ft^3
Surface Area (Estimated)		Not available
Inflated Height		138 ft
Deflated Length (Gore Length)		284 ft
Load Tapes		200 lb
Fittings; top		Plate Hoop and Ring - 25 in. O.D.
Fittings; bottom		5 in. I.D. Wedges and Collar
Number of Ducts		Two
Location of Duct - 25 sq ft each	Lo-Duct Hi-Duct	126 ft from base 248 ft from base
Inflation Tubes (Two)		12.75 in. Diam. x 3 mil x 100 ft long
Inflation Attachment		30 ft from top apex
Destruction Device		Prima Cord and Rip Panel
Descent Valves		Three in hi-duct
Estimated Balloon Weight		774 lb (incl. cable)
Engineering Specification Sheet		CO 9-311



GROSS WEIGHT VERSUS ALTITUDE

FINAL SYSTEM CALIBRATION DATA

Reference Calibration Levels (mv)	Flight 3051		Flight 3052		Flight 3053		Flight 3054	
	Voltage (mv)	Frequency (Hertz)	Voltage (mv)	Frequency (Hertz)	Voltage (mv)	Frequency (Hertz)	Voltage (mv)	Frequency (Hertz)
100	100.005	6848	99.992	6845	100.005	6849	100.004	6848
80	80.016	7071	80.003	7068	80.014	7073	80.013	7071
70	70.006	7182	69.995	7179	70.007	7184	70.010	7182
60	59.997	7292	59.987	7290	59.996	7294	59.997	7292
50	50.000	7401	49.989	7400	50.000	7403	50.000	7401
25	24.966	7672	24.961	7672	24.996	7675	24.964	7673
0	00.002	7938	00.001	7939	00.000	7941	00.001	7939

TELEMETERED SECONDARY TEMPERATURE DATA

Flight 3051, 8 August 1969

Time from Launch	Temperature (°C)				
	V.C.O.	Disc	Box #1	Tracker	Box #2
L-1/2 hr	+48	+18	+23	+21	+28
L (08:29 CDT)	48	19	25	21	30
L+1/2	48	-22	21	3	19
L+1	47	-11	14	-3	22
L+1-1/2	48	-13	13	8	22
L+2	47	1	18	24	24
L+2-1/2	49	7	24	35	32
L+3	49	9	28	41	36
L+3-1/2	49	14	32	47	39
L+4	48	16	36	50	37
L+4-1/2	49	17	36	55	41
L+5	49	18	39	60	42
L+5-1/2	50	19	39	60	42
L+6	49	18	40	60	42
L+6-1/2	51	21	39	62	47
L+7	53	21	42	65	48
L+7-1/2	52	18	50	65	45
L+8	52	0	52	65	48
L+8-1/2	55	11	55	67	54
L+9	+55	-12	+55	+62	+50

TELEMETRY SECONDARY TEMPERATURE DATA

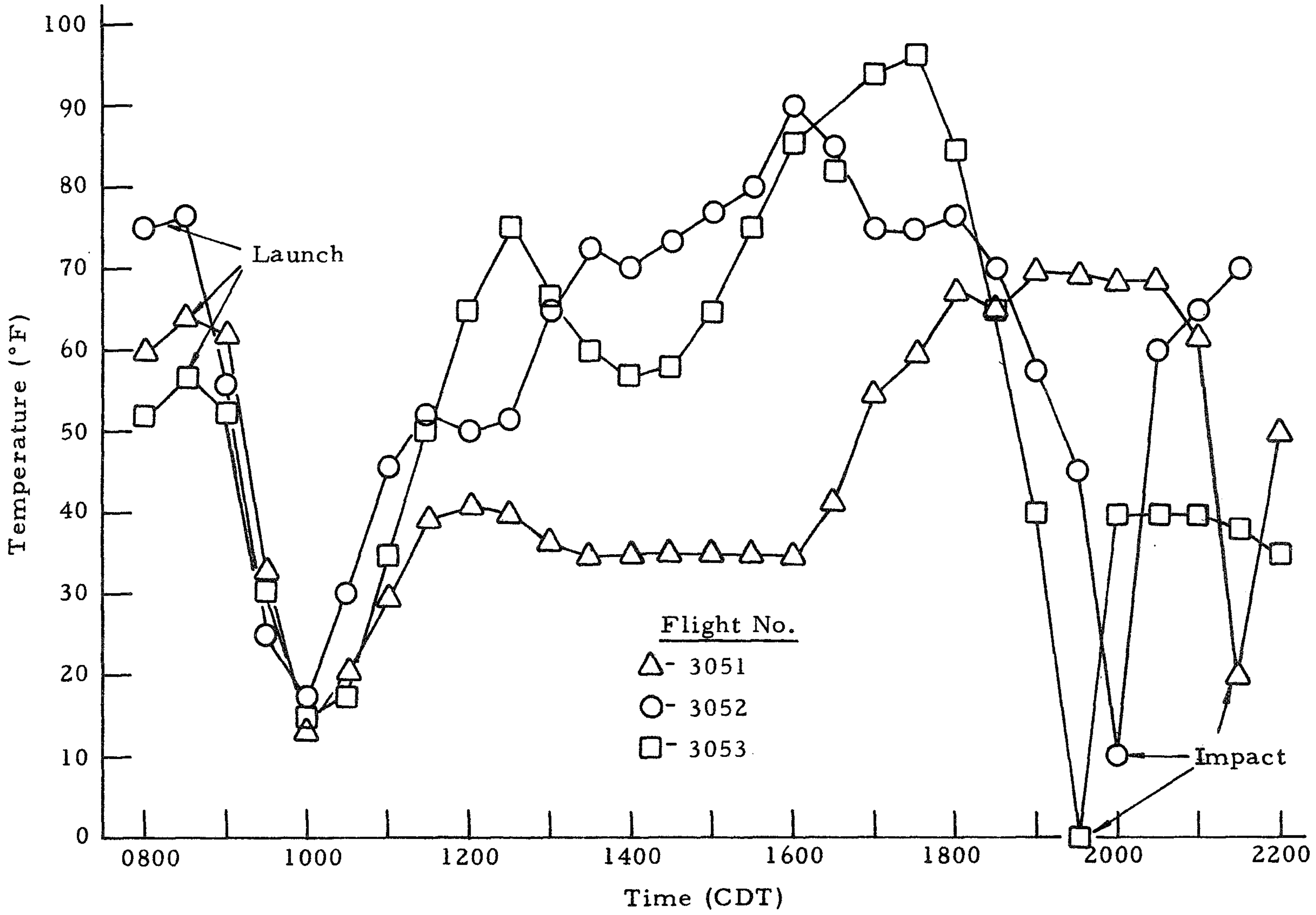
Flight 3052, 26 August 1969

Time from Launch	Temperature (°C)				
	V.C.O.	Disc	Box #1	Tracker	Box #2
L-1/2 hr	+39	+18	+21	+19	+26
L (08:14)	40	20	22	22	29
L+1/2	38	-18	20	15	27
L+1	39	-10	7	0	22
L+1-1/2	39	-7	5	12	22
L+2	36	3	9	26	22
L+2-1/2	36	10	17	36	26
L+3	36	19	27	47	29
L+3-1/2	38	23	34	52	35
L+4	47	21	34	54	44
L+4-1/2	51	26	35	55	48
L+5	52	26	36	60	50
L+5-1/2	54	29	36	62	52
L+6	52	24	44	57	48
L+6-1/2	51	27	47	60	47
L+7	52	26	45	57	48
L+7-1/2	51	18	48	55	47
L+8	52	9	47	54	50
L+8-1/2	51	3	39	48	45
L+11	34	-31	15	12	23

TELEMETRY SECONDARY TEMPERATURE DATA

Flight 3053, 8 September 1969

Time from Launch	Temperature (°C)				
	V.C.O.	Disc	Box #1	Tracker	Box #2
L+1/2 hr	+47	+9	+17	+12	+23
L (08:30)	47	10	17	12	24
L+1/2	46	-31	15	5	25
L+1	46	-22	5	0	24
L+1-1/2	46	-12	3	10	23
L+2	47	-5	7	26	24
L+2-1/2	47	11	15	37	28
L+3	48	-5	24	50	36
L+3-1/2	50	-24	27	55	44
L+4	51	22	35	65	47
L+4-1/2	53	23	41	65	48
L+5	56	22	42	70	57
L+5-1/2	59	29	48	70	60
L+6	59	11	55	73	54
L+6-1/2	59	23	55	73	54
L+7	59	15	57	70	54
L+7-1/2	60	7	52	67	57
L+8	60	5	52	65	54
L+8-1/2	57	-8	45	57	48
L+9	53	-28	35	45	41
L+9-1/2	48	-38	23	30	34
L+10-1/2	45	-18	3	-16	24



LOWER PAYLOAD TEMPERATURE PROFILES

JPL PROPERTY LIST

Item No.	Quantity	Description
*1	Two (2)	Sun Trackers (Contractor's Drawing No. ASD-236454 Rev. C)
2	Two (2)	Electronics Box No. 1 (Contractor's Drawing No. ASD-236456 Rev. A)
3	Two (2)	Electronics Box No. 2 (Contractor's Drawing No. ASD-236340 Rev. D)
4	One (1)	"T" cable with connectors (Contractor's Drawing No. ASD-236259 Rev. B)
5	One (1)	Gondola with Instrumentation and Battery Holder (Contractor's Drawing No. GMI-SK1569)
6	One (1)	Solid State UHF Telemetry Transmitter (5W., IERC445)
7	One (1)	UHF Antenna
8	One (1)	Balloon (120,000 ft altitude, #SF-213.94-100-NS-01)
*9	One (1)	Tracker Mounting Disc
10	One (1)	Set Main Power Batteries
11	One (1)	Beacon Antenna
12	One (1)	Set, Squibs, Nylon, One-shot relays, Primer cord, and Explosive bolt

*Repairs Required

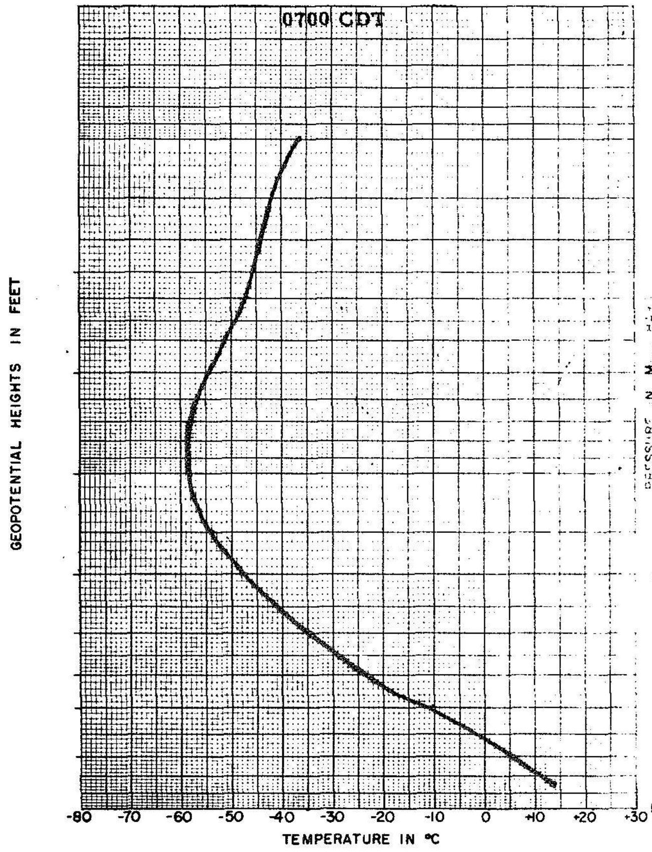
All other equipment is used but in good condition.

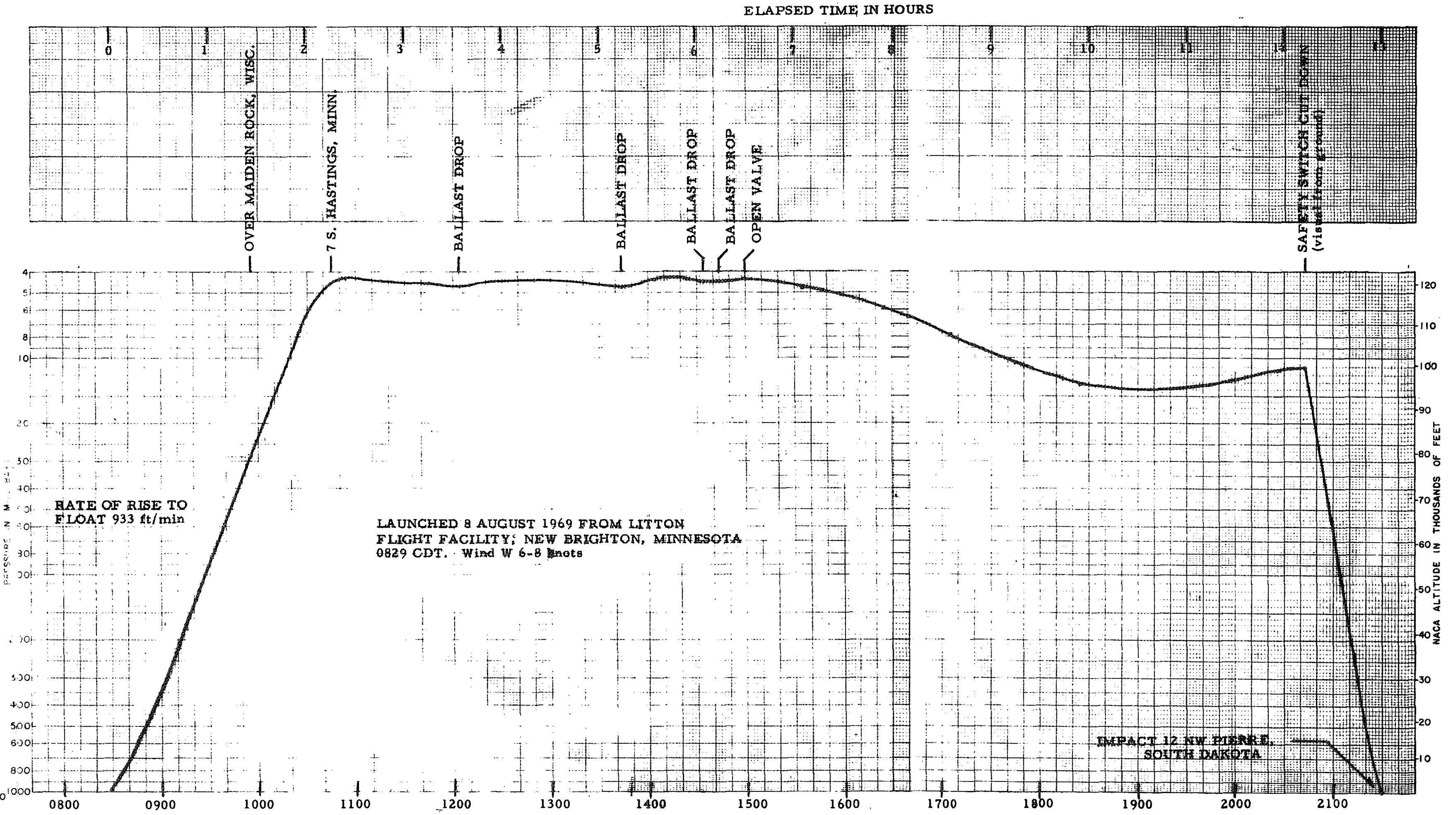
FLIGHT NO. 3051 DATE 8 August 1969
FOR JPL 59714
LOAD ON BALLOON 351 lb
FREE LIFT 100 LBS= 9%

BALLOON TYPE	NUMBER	MATERIAL	WEIGHT
SF-213.94-100-NS-01		0.7 mil	757 LBS.

ALTITUDE DATA

TEMPERATURE DATA



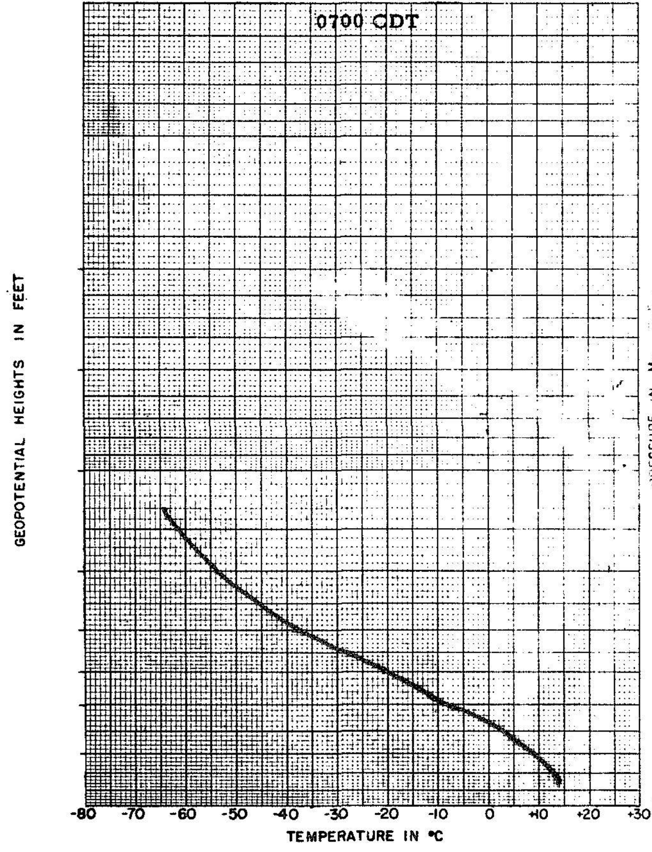


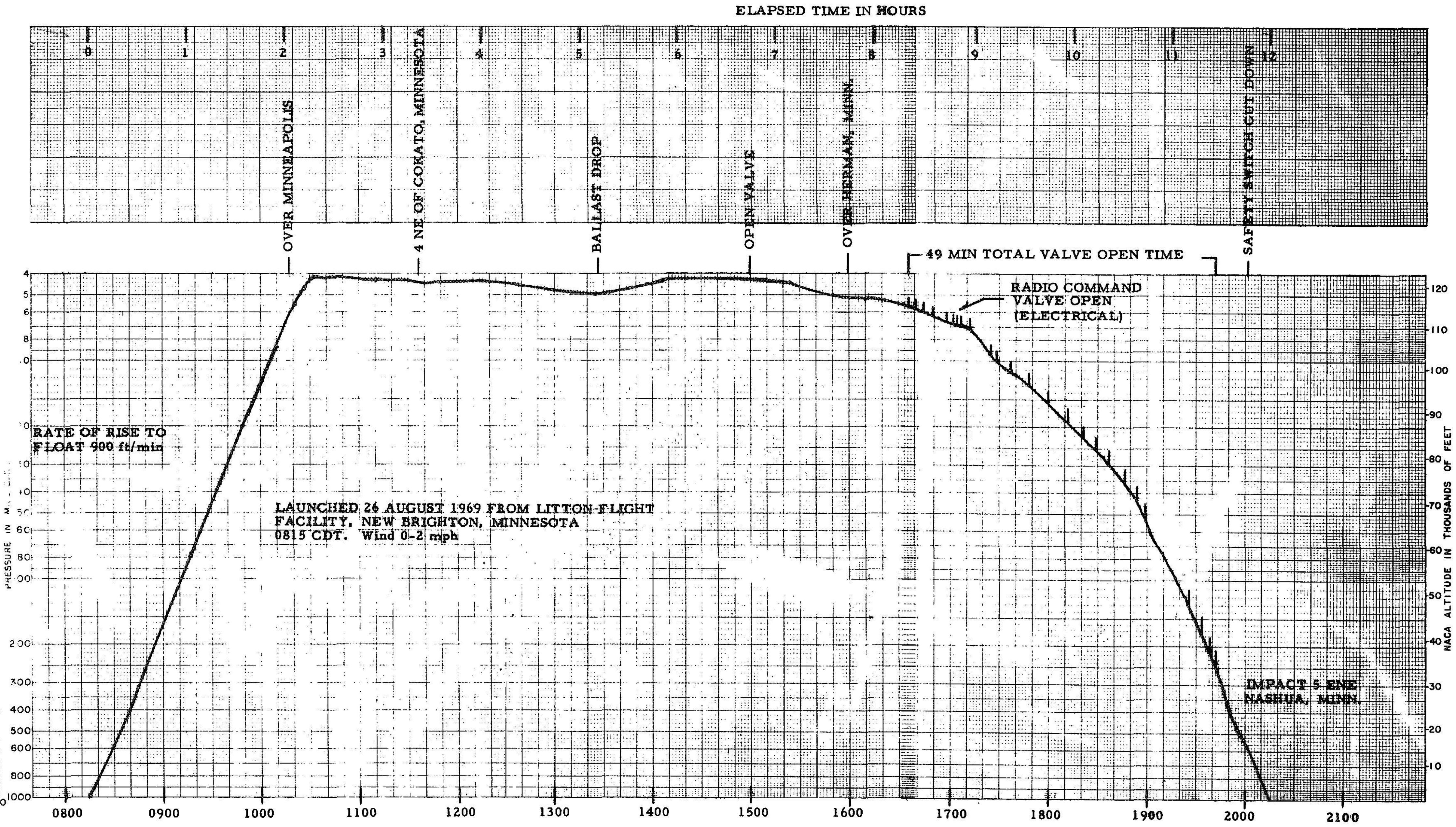
FLIGHT NO. 3052	DATE 26 August 1969
FOR JPL 59714	
LOAD ON BALLOON 342 lb	
FREE LIFT 98 LBS= 9 %	

BALLOON TYPE	NUMBER	MATERIAL	WEIGHT
SN-213.	94-100-NS-01	0.7 mil	745 LBS.

ALTITUDE DATA

TEMPERATURE DATA





FLIGHT NO. 3053 DATE 8 September 1969
FOR JPL 59714
LOAD ON BALLOON 336 lb
FREE LIFT 98 LBS= 9 %

BALLOON TYPE NUMBER	MATERIAL	WEIGHT
SF-213.94-100-NS-01	0.7 mil	750 LBS.

ALTITUDE DATA