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FINAL REPORT

SOLAR-TRACKER BALLOON FLIGHTS 3048, 3049, AND 3050

APPLIED SCIENCE DIVISION
LITTON SYSTEMS, INC.
LITTON INDUSTRIES

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SOLAR-TRACKER BALLOON FLIGHTS 3048, 3049, AND 3050

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TECHNICAL CONTENT STATEMENT

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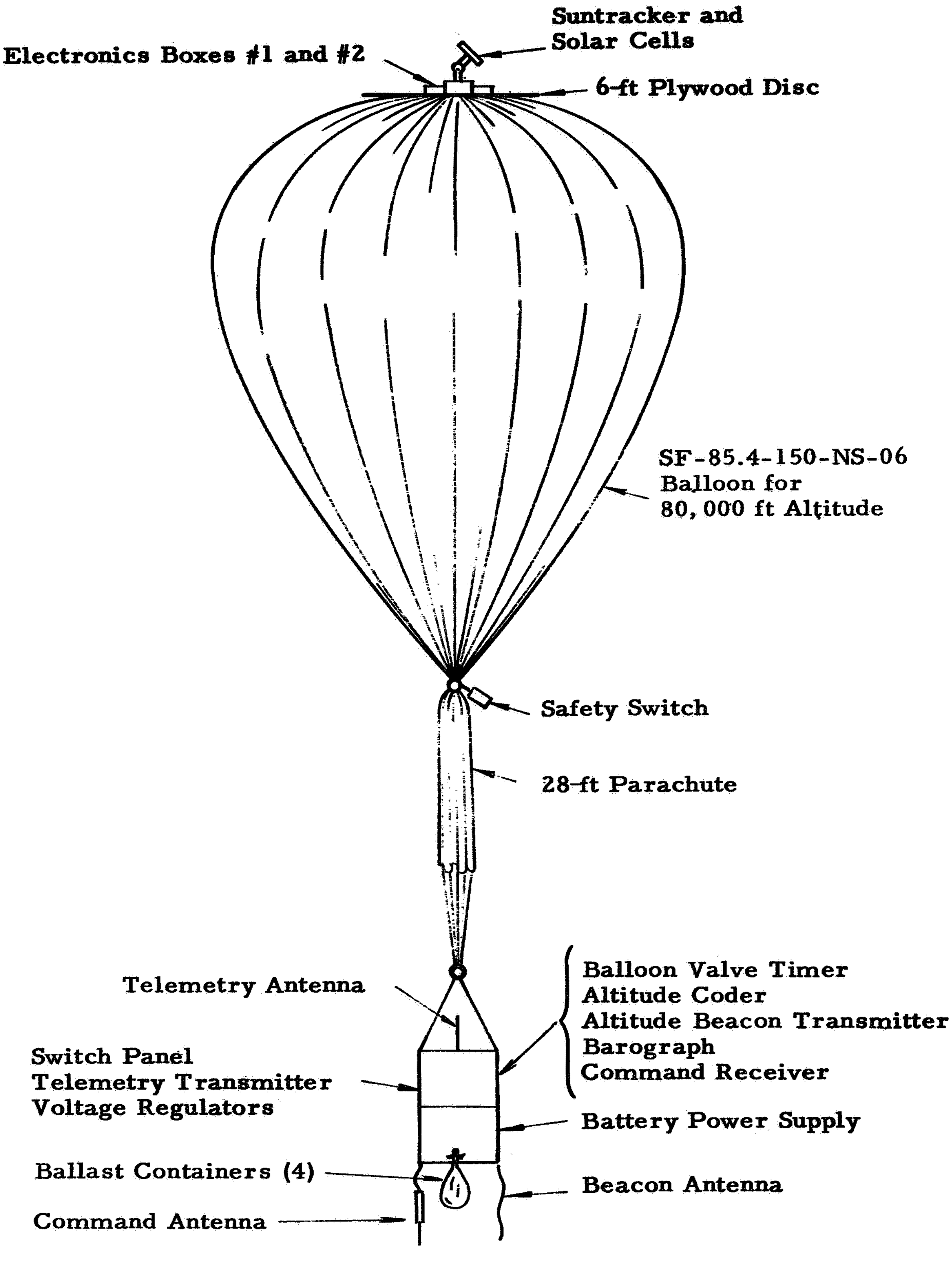
ABSTRACT

High altitude, solar-cell calibrations were accomplished during July and August 1968, using balloon techniques. Solar-cell modules, supplied by Jet Propulsion Laboratories, were flown on Litton-designed, balloon-mounted solar trackers at a nominal 80,000-foot altitude to obtain zero-air-mass performance data. Fifty-two solar cells were calibrated on two flights. The third and final flight of this program contained five solar cells and a special JPL radiometer. Accurate data were telemetered and recorded during each flight and reduced to computer-compatible punch cards before delivery to JPL. This report contains the operational details of the flights, discussion of instrumentation changes made during the program, and a tabulation of secondary temperature and calibration data recorded during the program.



BALLOON FLIGHT CONFIGURATION

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FINAL REPORT

SOLAR-TRACKER BALLOON FLIGHTS
3048, 3049, AND 3050

1. INTRODUCTION

1.1 General

Flights 3048, 3049, and 3050 were a planned series of three balloon flights conducted during July and August 1968 for Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under Subcontract 952223 to JPL. This contract provided for all necessary balloon flight services, including those required for flight preparation, functional verification of the flights 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 were included in this contract. Balloons, helium, power supplies, antennas, and other equipment required for the flights were supplied separately under Purchase Order EU 471750. Reduction of the primary telemetry data to computer-compatible punch cards was included as a task on this program for the first time.

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 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 80, 000 feet ±4000 feet, three 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 altitude, temperature and solar cell or radiometer output data during ascent and during a floating period of 4 hours, minimum. The floating period shall commence before 1100 CDT (Central Daylight Time) and shall be maintained until 1500.

3) To descent 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 balloon to Litton.

2. TECHNICAL DISCUSSION

2.1 Flight 3048 (JPL 68-1)

2.1.1 Flight Preparations

2.1.1.1 Project Personnel Assignments

Litton personnel responsible for preparations and flight operations on Flight 3048 were:

Project Engineer:	R. Conlon
Flight Leader:	M. Leuders
Instrumentation:	E. Minnich L. Nelson
Additional Launch, Tracking and Recovery Crew:	V. Schwalbe R. Olson D. Harshman

The same personnel conducted all flights on this program.

2.1.1.2 Pre-Flight Checkout

Required repairs and preventative maintenance were performed on all ground-station electronic support equipment within the air-conditioned telemetry van outfitted to house this equipment.

Significant revisions were made in the solar-tracker payload, the instrumentation, and the balloon, preceding the flight program:

1) A redesigned solar-tracker mounting plate
2) A new primary data commutator
3) A commutator device circuit modification
4) A new balloon design
5) A redesigned balloon cable.

The tracker solar cell mounting plate previously used on this program provided space for fourteen active solar cells and two temperature monitoring cells. Including calibration channels, the total system capacity was twenty-four data channels. It was desired to increase the data channel capacity to a total of thirty-six channels for the current series of flights. The size of the tracker mounting plate was increased from 5-1/8 x 9-5/8 inches to 8-3/4 x 16 inches to accommodate a terminal strip and a maximum of twenty-eight modules, each module capable of holding one or two individual solar cells. In addition to the base plate, new shade-seeking tracker drive sensor mounting brackets, a new sub-module plate, a new stepping switch, a new sun shield, and a modified timing circuit were required to complete the system expansion. Both the base plate and the sub-module plate were manufactured of aluminum to conserve tracker weight. To improve system thermal characteristics, a silicone heat conduction compound was liberally spread between the solar cell modules, the module mounting plate and the base plate.

A thirty-six channel stepping switch was selected to handle the twenty-six active solar cell outputs, three thermistor voltages, and seven calibration voltages. A high reliability electromechanical stepper was selected as the data commutator. This unit replaced the twenty-four position switch within the same physical location. The increased channel capacity necessitated additional wiring within the commutator case and the solar tracker. An external cable was required between these units.

The solid-state commutator drive circuit had been designed to advance the twenty-four position stepper every 15 seconds for a total cycle time of 6 minutes. With the increased system capacity, it was necessary to adjust the timing circuit, providing only 10 seconds per channel data sampling so that the complete cycle of 6 minutes could be held constant. The Unijunction transistor circuit time constant was changed by adjusting the timing potentiometer for a precise 10-second switching period.

The balloons built for the 1968 flight program were slightly larger than those previously used for the 80,000-foot lifting task. Balloon inflated diameter increased from 77 to 85.4 feet with a filled volume increase of 53,887 cubic feet. This revised design is theoretically capable of carrying an additional weight of 75 pounds to the 80,000-foot altitude level providing a significant safety factor to handle inevitable system weight increases while maintaining specified altitudes. An operational specification sheet and a load-altitude curve of this balloon are contained in the Appendix of this report.

The balloon-mounted electrical cable, carrying power to the top-mounted load and telemetry signal information to the transmitter below, was redesigned during initial flight preparation. The cable was lengthened to accommodate the larger balloon, and wire sizes were modified to handle the changed current drains. Individual wires were each AWG #22 stranded copper with double-cotton-covered insulation. A total of twenty-four wires was used; several strands of these size were paralleled for higher current capacity. The total number of individual circuit leads was eleven; a separate two-wire cable was used to open the squib-actuated descent valve.

A cover bracket was added to the lower payload instrumentation panel to protect the external control switches from accidental actuation during launch. The bracket was designed to clamp over the switches, holding them in only one possible position. This cover is installed prior to launch and will fit only if all switches are in the proper flight position.

The 100-mv (millivolt) on-board voltage 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 of 0, 20 and 40°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. Again, this year, a motor-driven timer and a pressure switch were installed in the power lead of the barotransmitter so that altitude data transmission would be on continuously below 75,000 feet and be turned off above this altitude, except for a 2-1/2-minute on-period every 10 minutes. The 7-1/2-minute off-time would allow noise-free data recording at least 75 percent of the time; the on-time is required to monitor float altitude and obtain a radio direction fix on the system, if necessary.

As a final system check, the entire top-mounted payload was attached with the tracker-mounting disc to the balloon top end fitting. Actual balloon and parachute cables were connected and the system put into operation while in the sun. System performance was monitored with no sign of noise or instability.

2.1.2 Field Operation

2.1.2.1 Launch

Flight 3048 was delayed a full week due to weather conditions that prevented solar-tracker checkout and flight operations. Launch preparation began at 0600 CDT on 19 July 1968, with the flight instrumentation on auxiliary power. Wind velocity was 3 mph from the north at the time layout began and had decreased to 2 mph by launch time. Inflation and final checkout were completed on schedule. Actual launch was delayed momentarily when the explosive release bolt did not automatically detach the payload from the launch arm as it was fired.

The upward force of the system, due to its free lift, was not sufficient to pull the exploded bolt free of the launch arm under the light wind conditions encountered. Thus, it was necessary to knock the bolt free. As this was done, the system rose smoothly from the launch arm.

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 truck driver and an assistant driver/radioman, handled the tracking and recovery. Operations were directed by the telemetry-control base station. Flight 3048 ascended on a southeasterly course to a point 1 mile east of Spring Valley, Wisconsin, at an altitude of 70,000 feet. From that position, the balloon swung 180 degrees back to the northwest and remained on that course for the duration of float, reaching a maximum altitude of 82,800 feet. The descent course was southeastward, from a position 5 miles south of Monticello, Minnesota, at the time the valve was opened to an impact 5 miles east of Ellsworth, Wisconsin. Impact was in an oats field. The impact switches caused the immediate firing of the balloon destruct device, and under the light wind conditions the lower payload was dragged only 50 feet before the balloon collapsed. The recovery crew arrived within a matter of minutes, discovered only minor damage to the upper payload, and returned all equipment to the plant that evening. There was no damage to the solar cells.

2.1.3 Flight Results

2.1.3.1 Balloon

The larger, redesigned balloon used on this year's program performed perfectly. Using 8 percent free lift, the average rate of rise was 856 fpm (feet per minute) to a float altitude of 82,800 feet. Altitude was stable during the floating period and the system remained above 80,800 feet throughout the required float period. The descent valve opened as programmed at 1500 CDT. The descent rate increased to approximately 670 fpm at 60,000 feet, but decreased slightly below that level. The average rate of descent was 587 fpm to the surface.

2.1.3.2 Instrumentation

A below-zero voltage reading was obtained on data commutator position #2 just prior to balloon inflation. This reading indicated an open circuit which was quickly located on a tracker terminal strip. A terminal had loosened from vibration of the truck used to transport it to the launch site. The terminal was tightened and the data rechecked, delaying launch only a few minutes.

All components of the tracking and telemetering systems performed with high stability throughout the entire flight period. The solar tracker turned on as programmed at 19,000 feet and immediately locked on the sun. Tracker corrections and rewinds were normal at the lower altitudes; at higher altitude, the tracker stabilized more quickly than on previous flights. There were no tracker rewinds between 75,000 feet on ascent throughout the float period and the descent phase until the tracker was de-energized at 17,000 feet. During system ascent, there was evidence of radio frequency interference on several data channels. The interference was correlated with beacon transmitter keying as encountered on some previous flights. Fortunately, the interference decreased at high altitudes and had no effect on the recorded data even during the brief beacon-on periods during float.

The new data commutation switch appeared to operate without fault throughout the flight; later data analysis revealed that a single data step was skipped during the float period. A transient voltage pulse from a tracker drive motor may have caused this one to miss. The 100-mv full-scale reference remained stable within +0.2 and -0.1 mv during the significant data-taking portion of the flight. The lower voltage reference points exhibited proportionally less drift.

The results of the telemetered secondary temperatures are found in the Appendix, page A-4, while the lower payload instrumentation temperatures of all three flights have been plotted as shown in the Appendix, page A-7. All temperature values were completely nominal on this flight.

The raw primary telemetry data, recorded during the flight in the form of printed frequency readings on paper tape, were later processed as an additional step. Following the flight, extraneous frequency readings were eliminated and channel identification manually added to the data tape. A punch card format was selected for logical identification and presentation of these data to a digital computer. A key punch operator manually transferred the frequency readings to standard punch cards. Each six-minute, thirty-six step, data scan was transferred to a three-card set. Fifty-four scans were reduced to 162 punch cards; the key punch operator accomplished the data reduction from this flight in approximately two hours. The reduced data on cards were sorted and then listed in sequential channel columns for ease of error checking and data review before being submitted to JPL personnel.

2.2 Flight 3049 (JPL 68-2)

2.2.1 Flight Preparations

The same solar tracker and telemetry system components used on Flight 3048 were set up for this flight. Shear pins in the tracker elevation drive mechanism were replaced in order to reduce mechanical hysteresis. After the solar cell modules were replaced with cells prepared for the second flight, the tracker was given a preliminary on-sun test. Modulation levels, thermistor channel voltages and reference voltages were checked and found unchanged from previous readings. The primary temperature reference channel, designated Bl, was used as an additional solar cell thermistor channel on this flight.

The main wet-cell battery pack was recharged and load-checked. All dry-cell battery packs were replaced with new cells, and these units were each tested under loaded conditions. The beacon-altitude transmitter, coder and timer were calibration checked for reuse as were all pressure-actuated switches. After a recheck of the primary temperature channels and an on-sun test of the entire system, it was judged ready for flight.

2.2.2 Field Operation

2.2.2.1 Launch

The launch crew had been called and preparations were underway for Flight 3049 by 0500 CDT on 29 July 1968. All pre-flight preparations and checks were normal. Wind conditions at the time layout began were 3 mph from the southeast with no appreciable change by launch time. Operational preparations were completed ahead of schedule so an extra cycle of telemetry data was taken prior to launch. The balloon was launched at 0836 CDT from the Litton flight center at New Brighton, Minnesota. It rose smoothly from the launch platform and was released perfectly from the truck.

2.2.2.2 Tracking and Recovery

Flight 3049 ascended on a southeasterly heading to a position 3 miles southwest of Plum City, Wisconsin, at an altitude of 70,000 feet. The system then took a westerly heading from 1000 to 1140 CDT, reaching a float altitude of 82,800 feet. After a 1-hour period, the balloon began to lose altitude and took a north-northeasterly heading to a point 5 miles northeast of Ellsworth, Wisconsin, at 1500 CDT, when the valve opened. From the time the valve opened at 66,200 feet until the safety timer terminated the flight, the system was on an east-southeasterly heading. At 1905 CDT, when the safety timer cut the balloon down, the system was over Ackerville, Wisconsin, at an altitude of 34,500 feet. The balloon and upper payload impacted in a cornfield 2 miles southeast of Jackson, Wisconsin, while the lower payload impacted in a cornfield 3 miles southwest of Cederburg, Wisconsin. The tracking crew landed at Timmerman Airport in Milwaukee, Wisconsin, rented a car and recovered the lower payload that evening. There was only minor damage to the lower payload. The recovery crew arrived in Milwaukee late that night and was unable to recover the upper payload until the following morning. The solar tracker was severely damaged by the free fall, but the solar cells appeared to be only slightly damaged. All the equipment, with the exception of the upper payload, was then loaded on the truck and returned to Minneapolis, The solar tracker was returned to Minneapolis by the JPL representative.

2.2.3 Flight Results

2.2.3.1 Balloon

The balloon design, material and valve location were identical to that used on the previous flight. Average rate of rise was 836 fpm using the usual 8 percent free lift. The system floated at a constant 82,800-foot altitude for a one-hour period. During the second hour of the floating period, the system descended to 80,000 feet. The system descended below 76,000 feet at 1300 CDT and reached 66,200 feet by the end of the normal floating period (1500 CDT) when the descent valve was actuated.

Cloud conditions correlated quite closely to altitude loss during float, but the amount of balloon descent due to this effect was greater than had been previously experienced. During the initial floating period, sky conditions below the system were clear. Light clouds moved in between the balloon and the surface during the second hour of float. Cloudiness increased to solid overcast during the last two hours of the float, and rain was experienced on the surface.

The balloon descent rate increased to only 300 fpm after the valve was opened. Between 60,000 and 40,000 feet, the descent slowed until the system achieved a nearly stable float equilibrium. At 1730 CDT, the balloon was still at 40,000 feet and descending at less than 60 fpm. At 1905 CDT, the backup safety control unit actuated the balloon release squibs, separating the lower payload and safety parachute from the balloon and top-mounted load. The estimated release altitude was 34,500 feet.

The basic altitude instability problem on this flight was due entirely to the loss of earth heat radiation on the balloon because of the cloud cover between the balloon and the surface. The high ascent rate and initially stable float period rules out the possibility of helium loss due to a leak. During the first hour of the float period, the system achieved thermal equilibrium. After self-valving the excess helium (free lift), the balloon reached a stable pressure, volume, and temperature condition. The temperature is primarily determined by the effect of direct solar radiation, radiation from the earth below, and the absorptivity of the balloon skin. The helium derives its temperature from the balloon skin since it is a diatomic gas transparent to radiation heat transfer. As a cloud layer moves between the balloon and earth, even a very thin cirrus layer, the radiation from the earth (mostly long-wave infrared energy converted by the earth's reception of direct solar energy) is greatly diminished. The surface temperature as seen by the balloon under clear conditions is approximately +12°C; under cloudy conditions the balloon may see a temperature of the cloud deck of, say, -55°C. This approximate 67-degree drop in temperature of the earth's radiation source cools the balloon skin and, ultimately, the enclosed gas. The resultant loss of lift initiates a descent. As the system descends, the gas is warmed somewhat by adiabatic compression. Depending on the ambient temperature lapse rate at that altitude, the balloon may continue to descend or may reach equilibrium at a lower altitude. When thermal equilibrium is reached, and as long as atmospheric conditions remain constant, the system will float at this lower altitude. On this flight, the cloud deck became progressively heavier, cutting off additional heating from below. The slow descent nearly stabilized at 66, 200 feet just prior to programmed float termination.

The descent valve on the balloons used on this year's program was placed in a lower position than on previously used balloons. Valve position can vary with the balloon shape, the valve size, and the desired descent rate. It is obvious from the time altitude profile of Flight 3048 that the particular size and position selected from this balloon produced an ideal descent rate from an 80, 000-foot float level. It was equally obvious that this design provides an unsatisfactory descent when the valve is opened at only 66, 200 foot altitude. The extremely slow descent was due to the fact that at this low altitude the helium level in the balloon does not extend to the lower portion of envelope as it does at float altitude. Between the altitude range of 55, 000 to 65, 000 feet, the helium level actually passes the descent valve position and is above this opening at all lower altitudes. When the valve is opened at 80, 000 feet, enough helium is valved by the time the 60, 000-foot level is reached to maintain system descent. When the valve is opened at the 66, 000-foot level, there is insufficient time to valve off enough helium to maintain system descent. On this flight, the system would have floated at approximately 40, 000 feet with the valve in the open position. Cooling due to the diminishing solar radiation from the setting sun brought the system down to 34, 500 feet by 1905 CDT, the release time.

2.2.3.2 Instrumentation

The secondary temperature commutator malfunctioned shortly after launch. It initially stopped on the box #1 temperature position for a one-hour period, then advanced to the VCO (voltage-controlled oscillator) temperature position for several minutes. At 0924 CDT, the commutator resumed operation and continued normally throughout the flight. The temperature data were practically identical to the data from Flight 3048.

The solar tracker was actuated at 19,000 feet as programmed. Sun acquisition was immediate and the tracker remained locked on the sun through ascent, float and descent to 60,000 feet before a rewind cycle occurred. Evidently this balloon configuration exhibits practically no rotation at high altitudes.

The commutated primary data were stable and accurate except for a small deviation of the reference frequencies for about three data scans. During this period, the 100-mv reference frequency shifted to a reading 3 Hz above the normal reference value. This discrepancy was thought to be caused by failure of the temperature control thermostat within the VCO module. The data shift indicated that the thermostat was temporarily stuck in the heater-on position causing the module to overheat. Close examination of the secondary temperature monitored between the half-hour recording points verified this temperature increase. As the flight progressed, the thermostat opened and the reference frequency and temperature returned to normal. Evidence of beacon radio frequency interference was seen on three data channels at altitudes below 75,000 feet. The amount of interference was small and caused no inaccuracy in the printed data. Following the flight, the data were reduced to a quantity of 159 computer punch cards and a three-page listing using the same format as used on the previous flight.

The solar tracker was the only component severely damaged on this flight. The near free fall did not damage electronic boxes #1 or #2 except for cover dents. The solar cells were not tested, but visually appeared to be intact with some surface scratches. The elevation drive assembly, mounting plates, sun shield and microswitches were destroyed; the azimuth drive and internal electrical components apparently survived the impact. This unit was not repaired on this program.

2.3 Flight 3050 (JPL 68-3)

2.3.1 Flight Preparations

For the first time during this program, the primary payload was not a group of solar cells. A special JPL-designed payload consisting of two evacuated radiometers with a filter and shutter assembly was prepared for testing on the solar tracker atop the balloon. The assembly provided space for four silicon solar cells below the rotating filter and chopper assembly. Three insulated and temperature-controlled electronic containers were required with this system, as well as a liquid nitrogen container for the purpose of maintaining an ultra-high vacuum within the radiometer case.

Many upper payload system modifications were necessary in order to accommodate this device. Major modifications of the tracker test plate and elevation drive mechanism were required to handle the weight and volume of all components. Weight size and center of gravity of individual components were checked and the components logically arranged about the center of rotation of the redesigned plate and drive mechanism. The three electronic boxes were positioned as counterbalance below the plate with the radiometer, inverter power supply, a standard solar cell module, five sun position sensors, and two terminal strips mounted above the plate. The drive shaft was also mounted above the plate to balance this considerable weight. A wider and higher yoke assembly was machined to mount the drive motor and the equipment. This equipment was designed and fabricated in a period of only a few days.

Simultaneously with this effort, electrical system modifications were made in order to efficiently power, monitor and control this special payload. Main power was provided to the radiometer heaters and circuitry through a pair of isolated leads from the lead-acid wet-cell battery pack in the lower payload. Two additional cells were added to this battery to boost voltage to the required 30 volts, nominal. A large filter capacitor (500 microfarads) was added to the input of the lower payload inverter to reduce switching noise on the line to the payload. The isolated leads were obtained, without modification of the existing balloon cable, by paralleling stepping switch power with telemetry system heater power leads. A stepper interrupt switch and a 200-μf (microfarad) transient filter capacitor were added to box #1 at the stepper input leads to prevent heater transients from advancing the stepper. Two 20,000-foot pressure switches were calibrated and installed to actuate the radiometer instrumentation after launch. The switches were paralleled for redundant considerations.

The data stepping switch (commutator) was rewired to handle the special radiometer requirements. The high, medium and low output scales of each radiometer were connected to the switch so that each range was interrogated twice during a complete scan. A single switch position was used to advance the filter wheel once each scan, while the chopper wheel was advanced twice each complete cycle. The seven calibration reference voltage and three thermistor channels monitored each scan were retained. Short circuit currents of the four solar cells mounted on the radiometer assembly were readout twice each scan. A separate "standard cell," mounted directly on the tracker plate with an individual sun shield, was telemetered once each cycle. The remaining channel, of the 36 available, was used for filter wheel position readout.

Close-tolerance bead thermistors were used with the primary temperature telemetry channels. One bead was embedded in a thermistor mount and readout twice per data scan. A second thermistor was mounted on the radiometer case, while a third was installed within the radiometer circuitry to monitor a critical circuit board component temperature. Temperature versus frequency calibration data were extended to cover a range from -40 to +80°C. The individual channel dwell time was changed from 10 to 20 seconds for this flight by increasing the timing circuit capacitance from 47 to 69 µf.

An auxiliary cable between electronic box #1 and the tracker was needed to handle the added wiring. By separating some previously paralleled leads, the internal tracker rotating ribbon cable accommodated all circuits. Wiring was tied to each side of the elevation yoke with the previously used terminal strips placed on the side of the yoke and on the main plate for convenient attachments. The newly designed elevation drive could not accommodate a slip clutch as previously incorporated so motor cut-off limit switches were installed as a backup to the normal sensor limit switches. Reverse diodes were placed across each switch to prevent lockup should they be actuated during flight. Separate ground circuits were maintained for the radiometer electronics, the solar cell common leads, and the main power return to reduce chances of interfering ground loop currents in the redesigned system.

The modified system was bench tested for many hours in order to work out compatibility problems such as frequency interference between systems, voltage offsets and off-scale data readings. The reference voltages were recalibrated with the entire system operating and, as shown on page A-3 of the Appendix, they were within microvolts of the optimum value requiring no readjustment. The secondary temperature data switch that malfunctioned intermittently on the previous flight was replaced with a new unit prior to launch.

A radio-command controlled ballast system was devised for this flight to prevent the altitude loss and subsequently altitude control problem experienced during Flight 3049. A Litton model R-16, five-channel VHF receiver and a separate battery were checked out and installed in the lower payload instrument container. A coaxial receiving antenna was suspended from one corner of the gondola with four 7-lb plastic bags of steel shot tied on each side and suspended just below the crash pad. An electrically actuated squib cutter was used to open each bag on command. The total amount of ballast was estimated to be sufficient to compensate for any conceivable loss of lift due to cloud cover so that a desired float altitude could be maintained.

The modified solar tracker with its radiometer payload was tested 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. All airborne and ground station components checked properly during this period and the system was judged ready to fly. The vacuum and test stand for the radiometers was installed in the telemetry van and the upper unit connected to this stand while on standby for this flight.

2.3.2 Field Operation

2.3.2.1 Launch

Preparations for Flight 3050 were cancelled at 0330 CDT on 12 August 1968 due to wind conditions and cloud cover in the launch area. The flight was rescheduled for the 14th because of bad weather conditions predicted for the 13th. On 14 August 1968, pre-launch preparations were being carried out under calm wind conditions until just prior to inflation when winds increased to above 8 mph with gusts to 14 mph. The flight was cancelled at 0850 CDT, the balloon was repacked, and all equipment was removed from the flight line. Five consecutive days of bad weather further delayed the flight until 20 August 1968. Preparations began at 0500 CDT with helium gauging and the warm-up of telemetry instruments. Layout was completed by 0800 CDT and inflation began at 0810 CDT with the wind out of the southwest at 3 mph. Launch was completed at 0841 CDT with no change in wind conditions.

2.3.2.2 Tracking and Recovery

The balloon ascended on an easterly heading to a position over Boyceville, Wisconsin, at 71,000 feet. The system remained in the vicinity of Boyceville and Knapp, Wisconsin, from 1000 to 1608 CDT, when at 43,000 feet during descent it again took an easterly heading. Impact was at 1722 CDT, 50 yards into a woods, 3 miles southwest of Boyd, Wisconsin. The lower payload came down through the trees, actuating the impact switches when it struck the ground. The lower payload did not move from that position. When the recovery crew arrived at the site of impact, the balloon was still standing and wind conditions were calm. The crew then pulled the upper payload gently to the ground by means of the balloon. All the equipment was recovered from the woods that afternoon and returned to the plant late that night.

2.3.3 Flight Results

2.3.3.1 Balloon

The balloon was identical to those used on the preceding two flights. The rate of rise averaged 856 fpm to achieve a float altitude of 80,800 feet. A maximum altitude reading of 81,300 feet was recorded after reaching float. At 1257 CDT, a slight altitude drop to 80,400 feet was noted and the first ballast bag was commanded open. The next altitude check showed an increase to 81,300 feet. At 1437 CDT, nearing the end of the float period with the altitude holding steady at 81,300 feet, the remaining three ballast drops were initiated. The altitude increased to 81,800 feet during the remaining float period. Descent was commenced on schedule and the average drop was 590 fpm to the surface.

2.3.3.2 Instrumentation

Power was automatically applied to both the solar tracker and the radiometer payload during system ascent. The tracker locked on-sun immediately and operated with stability throughout the flight; the first rewind noted was at 22,000 feet on descent. Preliminary data analysis indicated that the radiometers also performed properly for the entire period.

All primary and secondary telemetry components operated properly, except for a slight shift in reference frequencies from the pre-flight calibration values. Average reference frequencies for the 25-mv through 100-mv values were 3 Hz higher than pre-flight data. This variation is only 0.33% full scale and is thought to be primarily due to calibration frequencies being recorded at an internal instrument box temperature different than that encountered during flight. Actual upper payload instrumentation temperatures from this flight are listed in the Appendix, page A-6. The recorded VCO temperature during the float period is approximately 4 degrees above the average float readings from the preceding flights as shown on pages A-4 and A-5 of the Appendix. The temperature control thermostat within the potted VCO module that exhibited a short term fault on the previous flight, apparently caused an abnormal temperature increase during the float period of this flight. This thermostat exhibits a higher temperature control point and/or a wider differential control range than normal. Shock from system impacts and/or "old age" were the possible causes of this variation.

Battery power and voltage decay were apparently satisfactory in maintaining radiometer characteristics throughout the ascent, float and descent periods. Radio noise interference was not a problem on this flight. Post-flight examination indicates no visible damage to any of the system components, including the delicate radiometers.

The digitally printed primary data were reduced to punch cards using the usual format. The expanded scale readout of the radiometers, covering three data channels twice each scan for each unit, resulted in a large number of above or below scale readings. These extraneous readings were manually converted to zero millivolt frequency numbers before reduction to avoid confusing the computer during subsequent data analysis. The 20 seconds per channel sampling time generated only half the number of data samples during the float period, but additional data were reduced for the ascent and descent periods. Flight 3050 data recorded between 0910 and 1633 CDT reduced to 114 punch cards which were submitted to JPL.

3. CONCLUSIONS

All major objectives of this program were fulfilled. Each of the three balloons were successfully launched and each reached the required altitude in the desired time. The telemetry system, solar trackers and control instrumentation operated continuously through all flights. Although a solar tracker was severely damaged on one flight, all equipment and JPL payloads were recovered without loss. A low-cost punch card data reduction method was devised to simplify and further automate JPL's data analysis. For the fourth consecutive year, this program has achieved 100 percent balloon success (balloon successfully launched and attained specified altitude).

The system modifications incorporated on this year's flights proved completely satisfactory. The enlarged solar cell mounting panel required many upper instrumentation modifications but, in turn, provided sufficient space and system capacity during only two flights to calibrate 52 individual solar cells. Previously, between three and four flights were required to calibrate this quantity.

The redesigned balloon meets all normal flight requirements. It provided greatly improved load capacity, lifting considerably heavier payloads above 80,000 feet. Ascent rates were very good and quite consistent, indicating accurate helium handling. Descent rates on the first and third flights were similar and comparatively steady, which indicates proper descent valve size and position. The second flight's float and descent characteristics were unsatisfactory, but as explained in the text, this was not a balloon defect. Because of the possibility of meteorological conditions affecting the balloon in the same manner on the third flight, a radio-controlled ballast system was used. Although cloud cover was not a problem on this flight, the ballast was expended and provided effective altitude control.

The numerous tracker and electronic system modifications necessary to accommodate the radiometer payload on the final flight were justified by the satisfactory results obtained. Continuous and stable payload operation, with the preliminary data analysis indicating proper readout, verified all engineering changes. This flight demonstrated the feasibility of obtaining highly accurate solar intensity data from a radiometer using a balloon as a lifting device and test platform.

4. RECOMMENDATIONS

Further effort toward eliminating some of the minor problems experienced on solar cell calibration flights is recommended. Radio frequency data interference, faulty VCO heater control, poor altitude stability over clouds, and excessive tracker impact damage are problems that can be solved with efforts directed toward them.

Radio noise has been reduced so that it is not a major annoyance. Elimination of this interference is desirable, however, and may be accomplished by selection of an alternate beacon transmitting frequency, redesign of the beacon antenna, or by removing this transmitter from the payload if another means of balloon locating from the tracking aircraft can be devised. The thermostat within the VCO can be replaced, and temperature control can be improved at the same time. Either a close differential bimetal thermostat or a small solid-state temperature controller can be incorporated in the VCO module to accomplish accurate temperature control which will, in turn, directly improve telemetry system accuracy.

Undesirable altitude variations can be practically eliminated by carrying releasable ballast on all flights. A radio-controlled ballast system, using four separate bags of steel shot weighing 7 pounds each, flown on Flight 3050, demonstrated a practical method of altitude control. The total ballast weight of 28 pounds plus the control equipment weighing approximately 8 pounds reduced initial maximum altitude by 1300 feet. Experience has shown that this amount of ballast is capable of offsetting the amount of system free lift loss due to heavy cloud cover below the balloon. Other benefits are that it would offset altitude loss due to a balloon envelope leak and, by maintaining altitude, prevent the valve-open float condition encountered on Flight 3049. Ballast release can be accomplished by using internal timers, by automatic release from an altitude drop sensing device, or by radio command. The radio command system is recommended for all future flights because of its versatility, reliability and availability.

Additional versatility may be obtained by using one channel of the Litton model R16, five-channel receiver as a second means of opening the main descent valve. This feature would be useful as a backup to the flight programmer, and to initiate early descent in case of telemetry system or tracker failure, or in case the system approaches an unfavorable impact area (such as Lake Michigan).

The method of backup cutdown of the system might be questioned at this time. It is an absolute necessity to have this system out of the airlanes before dark, however, it may not be absolute necessary to separate the balloon and upper-payload from the lower payload and parachute to accomplish this task. Separating the system always results in severe solar tracker damage and the odds are high that the solar cells may be damaged or completely lost. A method of reliable and fast descent with the flight train intact is desired. A near-top mounted gas port, squib actuated by the backup safety timing switch, may satisfy this requirement. The top placement of the one-way valve would insure continuous descent; the size of the valve would be calculated to obtain a rapid descent, but not so large that the balloon might come apart before impact. The timer controlling this port would be mounted at the base of the balloon, powered by a separate battery and employing a separate cable on the balloon for complete redundancy.

The Applied Science Division of Litton Systems, Inc., looks forward to the opportunity to not only improve the 80,000-foot solar cell calibration flights, but to offer much higher altitude test platforms for radiometer solar investigations. Float altitudes of 140,000 feet or higher are practical with available equipment. Specialized instrumentation may be desirable to satisfy radiometer requirements at extreme altitudes. Litton stands ready to satisfy JPL's stringent requirements.

5. NEW TECHNOLOGY

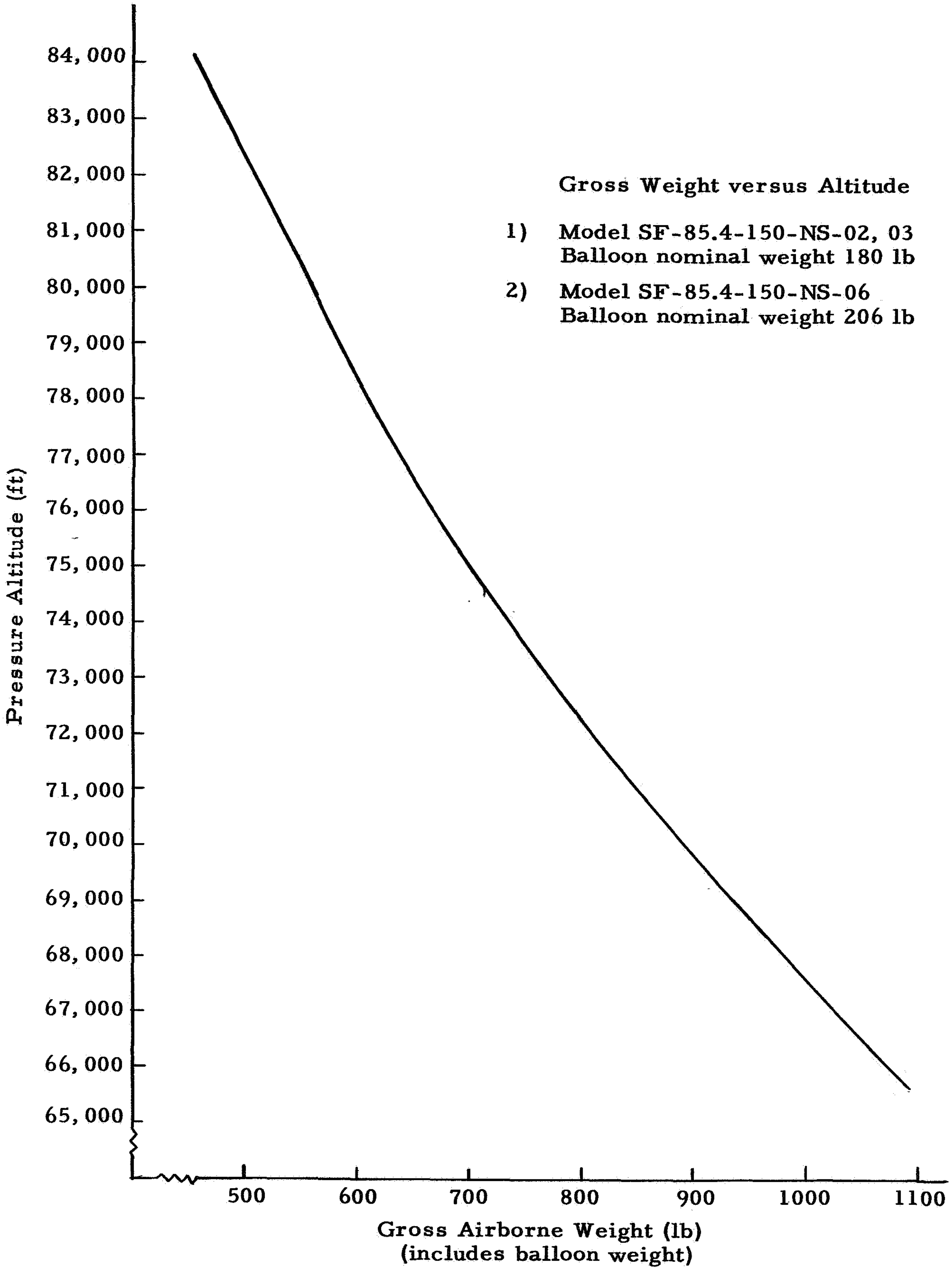
No items of new technology have been identified or reported during the course of this contract.

APPENDIX

FLIGHT DATA

OPERATIONAL SPECIFICATION SHEET
(for SF-85.4-150-NS-06 balloon)

Fabric Parameter (Σ)	0.20
Payload (design)	260 lb
Nominal Altitude	83,300 ft
Material (balloon wall and duct)	1.5-mil Polyethylene
Volume (theoretical)	243,000 ft^3
Inflated Diameter	85.4 ft
Inflated Height	72.6 ft
Deflated Length (gore length)	120.8 ft
Load Tapes	150 lb
Fittings; top	Plate Hoop and Ring; 21 in. I. D. with EV-13 mounting configuration
Fittings; bottom	Wedges and Collar; 5 in. O. D.
Number of Ducts	Two; each 10 ft^2 area
Location of Ducts	70 ft from bottom end fitting
Inflation Tube	12.75 in. dia. x 3 mil x 80 ft long
Inflation Attachment	25 ft from top apex
Destruction Device	Prima cord and rip panel
Descent Valve	One, located on duct
Estimated Balloon Weight	219 lb (incl. 16 lb of cable)
Engineering Specification Sheet	CO-1547
Load Altitude Curve	100201


Gross Weight versus Altitude
1) Model SF-85.4-150-NS-02, 03
Balloon nominal weight 180 lb
2) Model SF-85.4-150-NS-06
Balloon nominal weight 206 lb
Pressure Altitude (ft)
84,000
83,000
82,000
81,000
80,000
79,000
78,000
77,000
76,000
75,000
74,000
73,000
72,000
71,000
70,000
69,000
68,000
67,000
66,000
65,000
500
600
700
800
900
1000
1100
Gross Airborne Weight (lb)
(includes balloon weight)

FINAL SYSTEM CALIBRATION DATA

Reference Calibration Levels (mv)	Flight 3048		Flight 3050		Flight 3050	
	Voltage (mv)	Frequency (cps)	Voltage (mv)	Frequency (cps)	Voltage (mv)	Frequency (cps)
100	100.015	6847	99.992	6847	100.014	6847
80	80.017	7071	80.003	7070	80.017	7070
70	70.013	7181	69.998	7181	70.009	7181
60	60.004	7292	59.988	7292	60.002	7291
50	50.006	7401	49.992	7401	50.003	7400
25	24.966	7671	24.964	7672	24.967	7671
0	00.003	7938	00.001	7938	00.000	7937

TELEMETERED SECONDARY TEMPERATURE DATA

Flight 3048, 19 July 1968

Time from Launch	Temperature (°C)				
	V. C. O.	Disc	Box #1	Tracker	Box #2
L-1/2 hr	+49	+19	+28	+25	+32
L (09:12 CDT)	49	15	29	25	36
L+1/2	48	-13	24	11	35
L+1	47	-31	15	1	28
L+1-1/2	47	2	11	9	24
L+2	47	23	14	21	26
L+2-1/2	47	25	19	33	31
L+3	47	22	21	36	33
L+3-1/2	47	22	22	37	33
L+4	49	24	21	39	37
L+4-1/2	48	24	21	39	36
L+5	49	24	22	40	36
L+5-1/2	47	26	29	40	34
L+6	47	14	33	39	33
L+6-1/2	47	-18	23	18	35
L+7	47	-32	13	-6	28
L+7-1/2	46	-10	6	-5	22
L+8	+46	+8	+11	+11	+22

TELEMETERED SECONDARY TEMPERATURE DATA

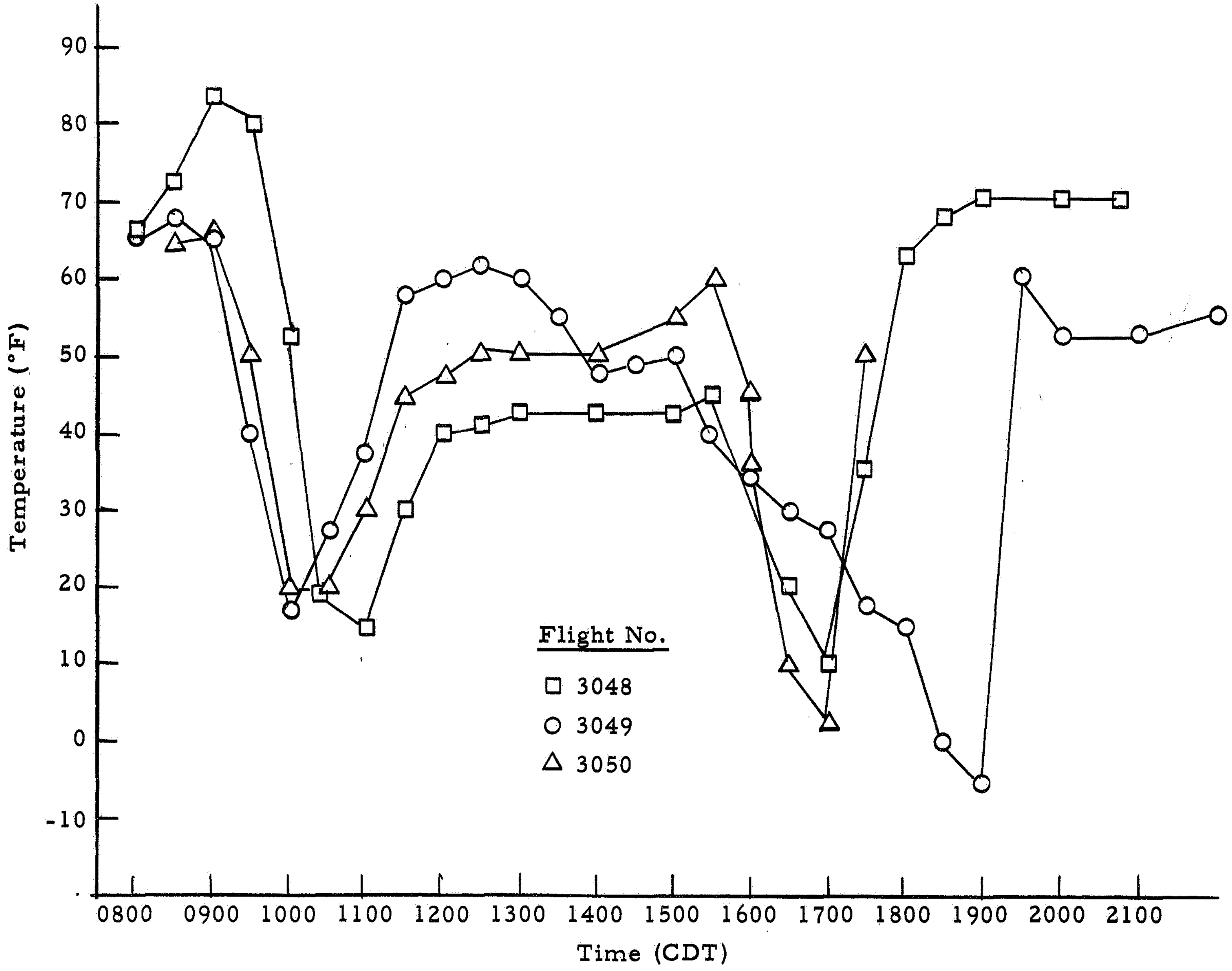
Flight 3049, 29 July 1968

Time from Launch	Temperature (°C)				
	V.C.O.	Disc	Box #1	Tracker	Box #2
L-1/2 hr	+47	+18	+22	+21	+31
L (08:37 CDT)	47	18	23	18	32
L+1/2	---	---	21	---	---
L+1	---	-33	---	---	---
L+1-1/2	46	-2	9	10	22
L+2	46	18	13	22	24
L+2-1/2	47	24	19	32	28
L+3	47	24	22	36	32
L+3-1/2	47	22	26	37	33
L+4	47	24	27	40	34
L+4-1/2	48	26	29	40	36
L+5	48	26	24	42	40
L+5-1/2	48	21	26	37	37
L+6	47	9	29	34	34
L+6-1/2	47	+6	31	29	30
L+7	47	-6	23	22	32
L+7-1/2	47	-19	18	14	30
L+8	46	-36	16	7	22
L+8-1/2	46	-32	14	+3	22
L+9	+45	-33	+9	-2	+22

TELEMETERED SECONDARY TEMPERATURE DATA

Flight 3050, 20 August 1968

Time from Launch	Temperature (°C)				
	V. C. O.	Disc	Box #1	Tracker	Box #2
L-1/2 hr	+49	+18	+25	+21	+34
L (08:41 CDT)	50	15	26	21	36
L+1/2	49	-9	25	17	36
L+1	48	-33	16	10	27
L+1-1/2	49	-9	13	17	23
L+2	49	5	14	26	26
L+2-1/2	50	8	15	33	34
L+3	51	9	15	37	37
L+3-1/2	51	11	15	40	40
L+4	51	13	17	41	40
L+4-1/2	51	14	18	44	41
L+5	51	16	22	43	36
L+5-1/2	51	14	22	44	39
L+6	51	9	24	44	37
L+6-1/2	51	-4	26	41	37
L+7	51	-25	20	28	39
L+7-1/2	50	-40	15	3	30
L+8	48	-15	7	-2	22
L+8-1/2	+48	-7	+7	+4	+22



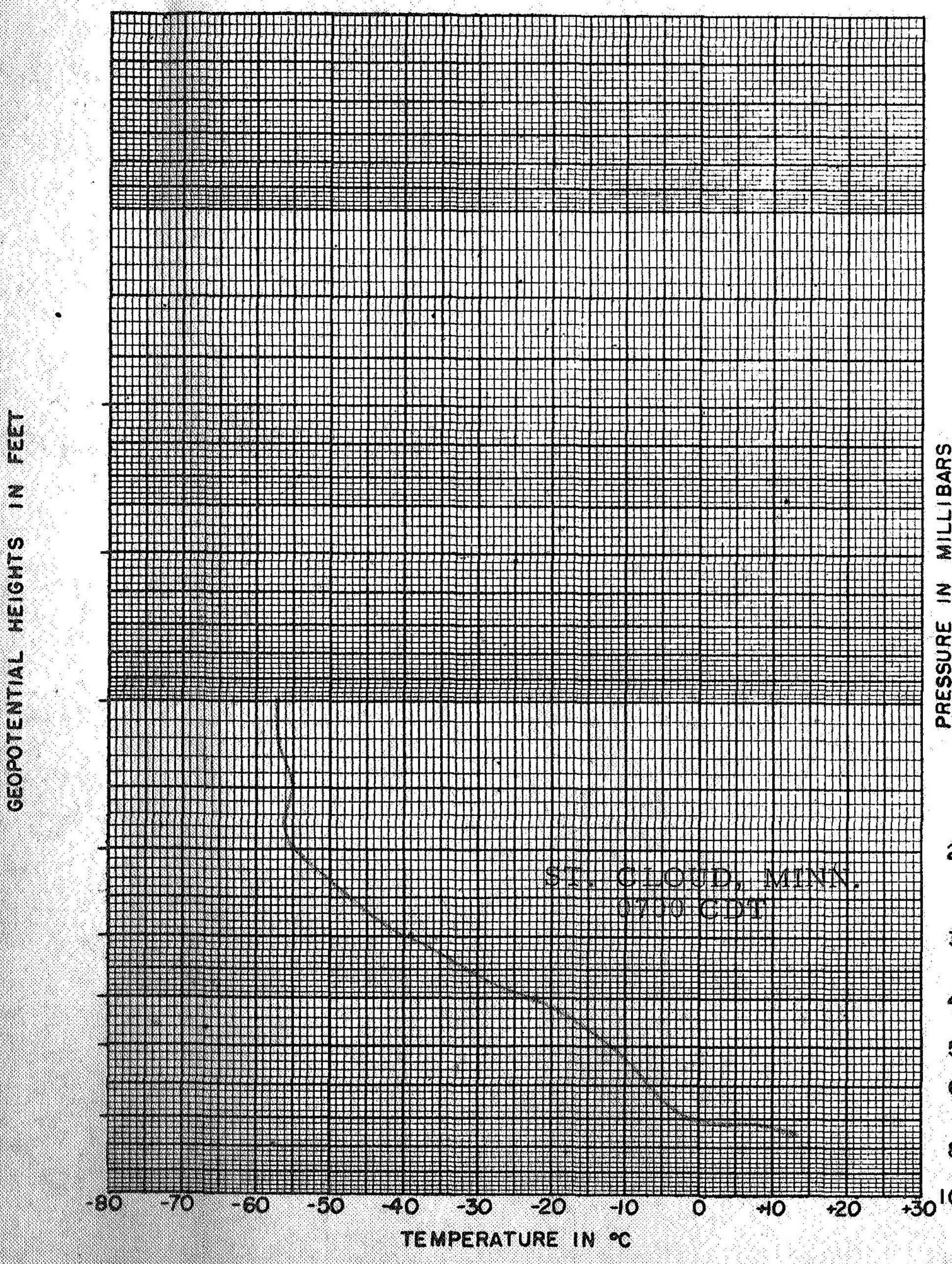
PAYLOAD TEMPERATURE PROFILES

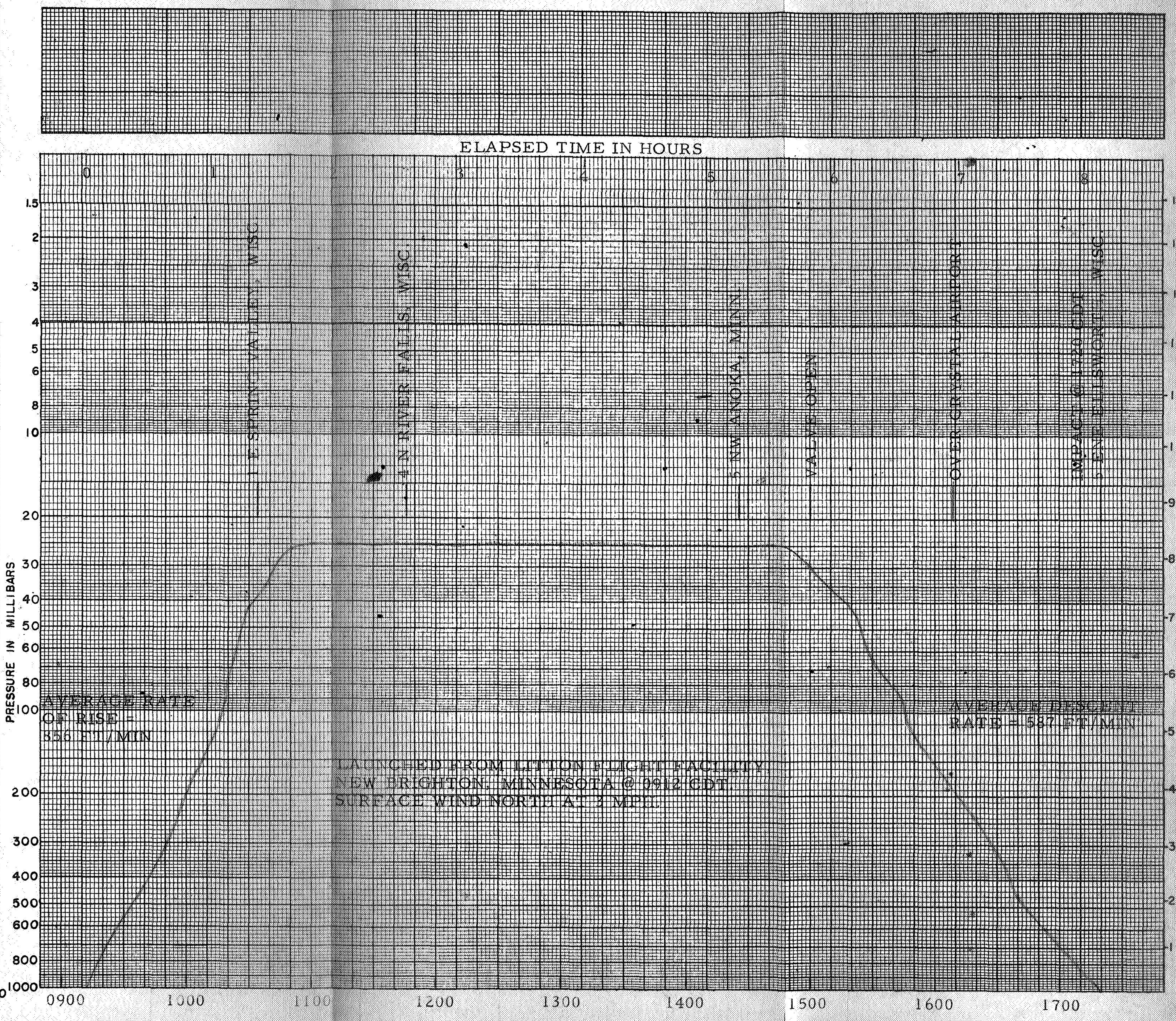
FLIGHT NO. 3048 **DATE** 19 July 1968
FOR JPL 59684
LOAD ON BALLOON 262 lbs
FREE LIFT 38.4 **LBS=** 8**%**

BALLOON TYPE	**NUMBER**	**MATERIAL**	**WEIGHT**
SF-84.5-150-NS-06	CO-1547-S/N-43	1.5 mil	218 **LBS.**

ALTITUDE DATA

TEMPERATURE DATA



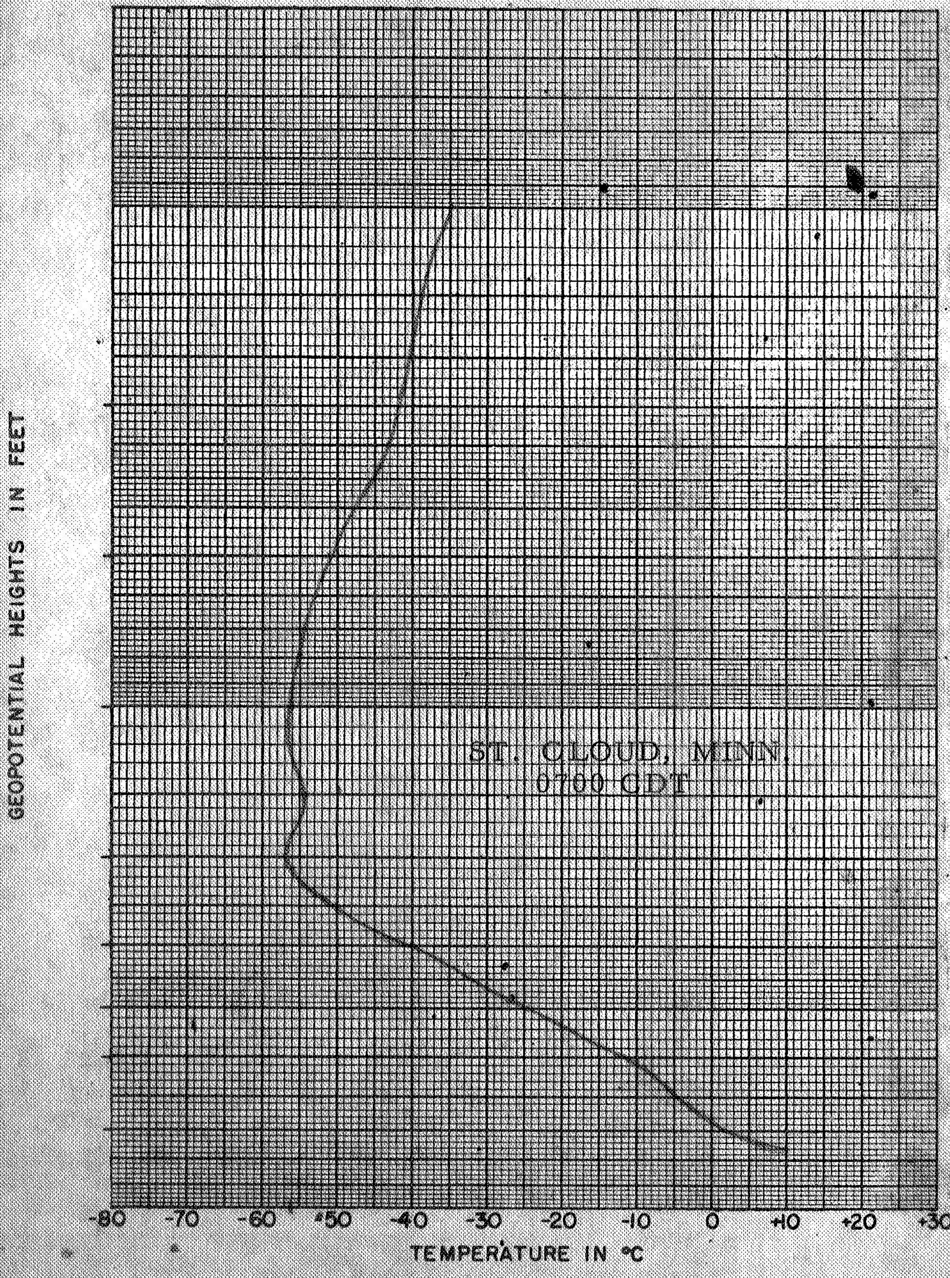


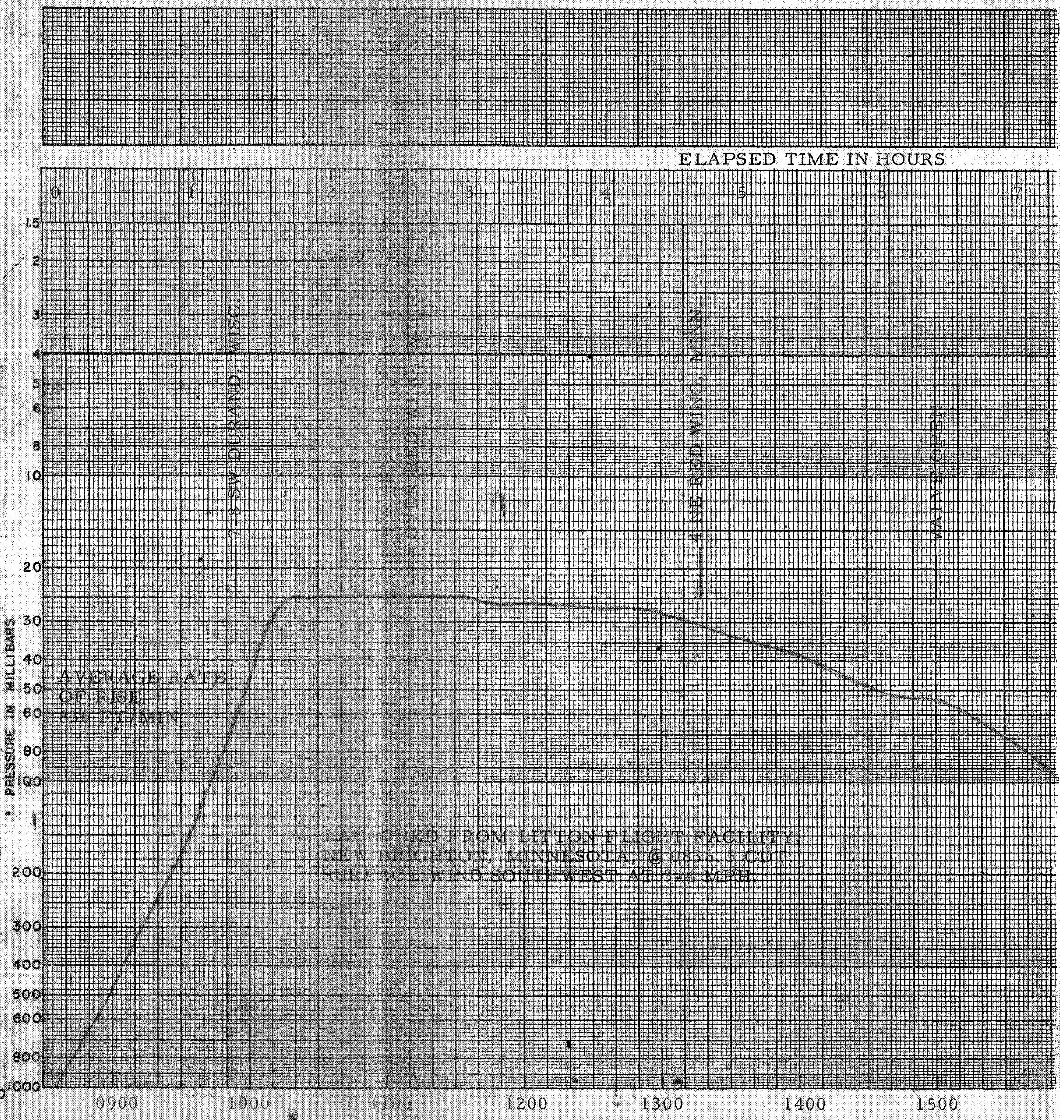
FLIGHT NO. 3049 **DATE** 29 July 1968
FOR JPL 59684
LOAD ON BALLOON 263 lbs
FREE LIFT 38.4 **LBS=** 8**%**

BALLOON TYPE	**NUMBER**	**MATERIAL**	**WEIGHT**
SF-84.5-150-NS-06	CO-1547-S/N-42	1.5 mil	217 **LBS.**

ALTITUDE DATA

TEMPERATURE DATA





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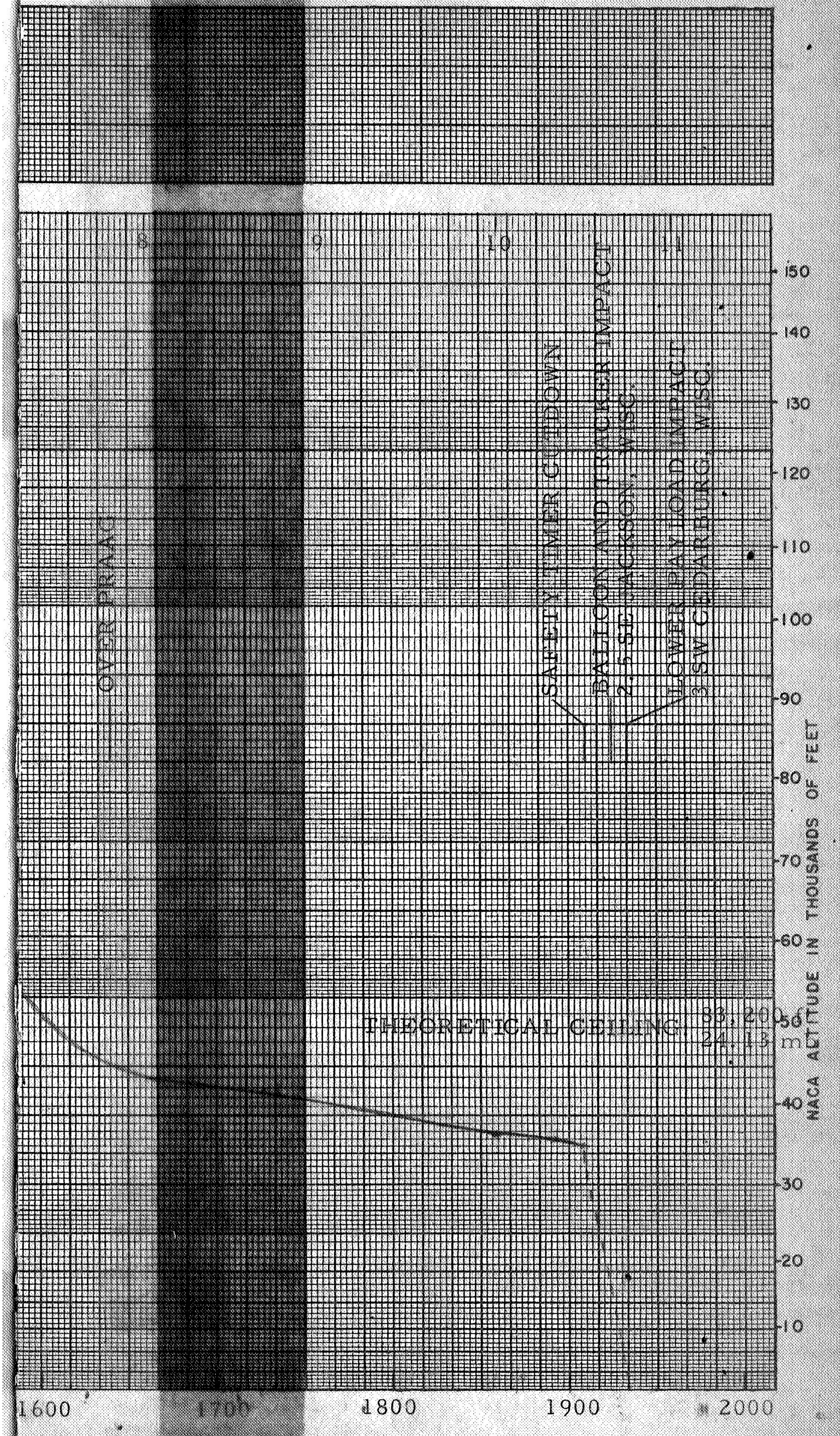
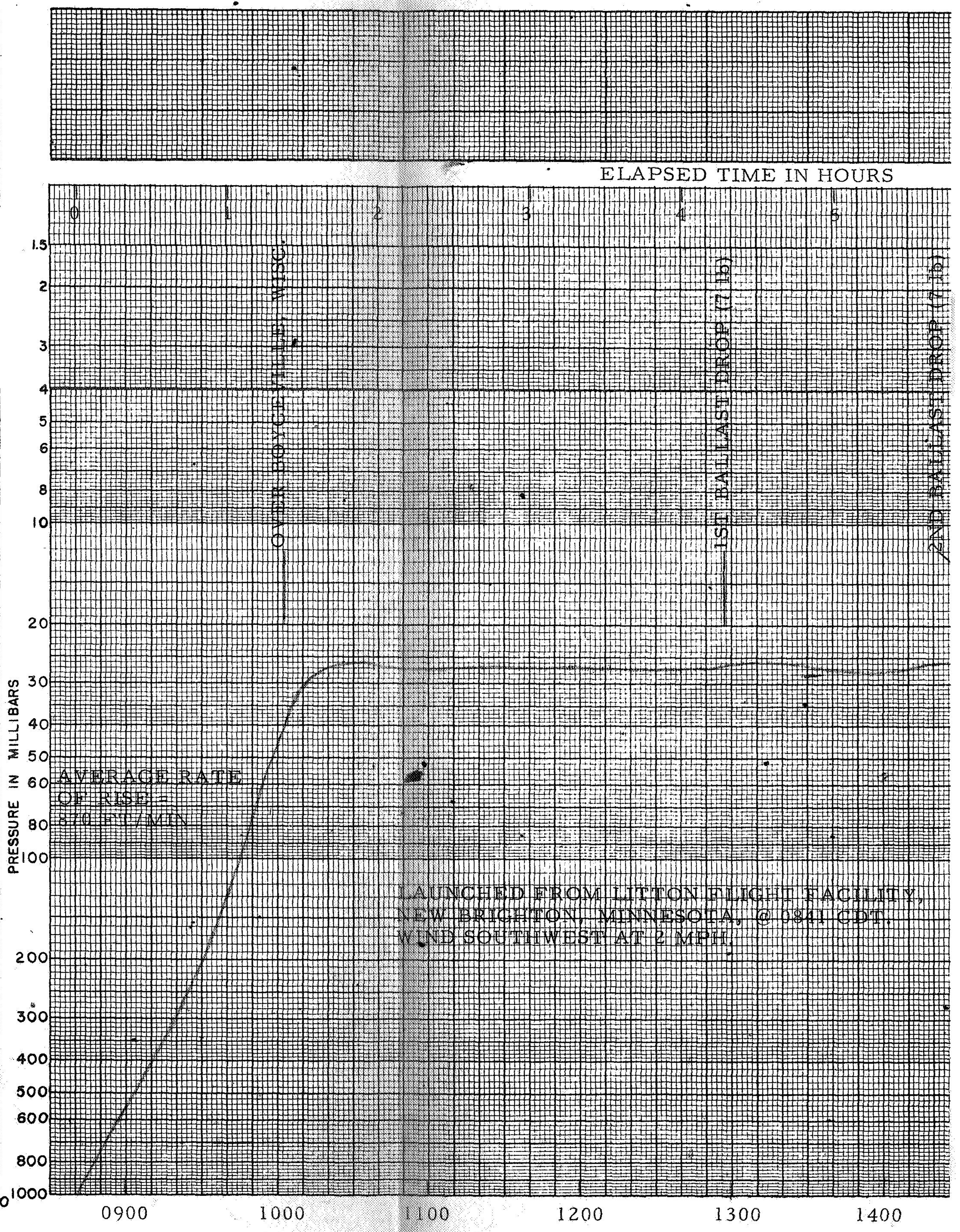

NACA ALTITUDE IN THOUSANDS OF FEET
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
1600
1700
1800
1900
2000
8
9
10
11
OVER PRAAG
SAFETY TIMER CUTDOWN
BALLOON AND TRACKER IMPACT
2.5 SE JACKSON, WISC.
LOWER PAYLOAD IMPACT
3 SW CEDARBURG, WISC.
THEORETICAL CEILING 83,200 ft
24.13 m

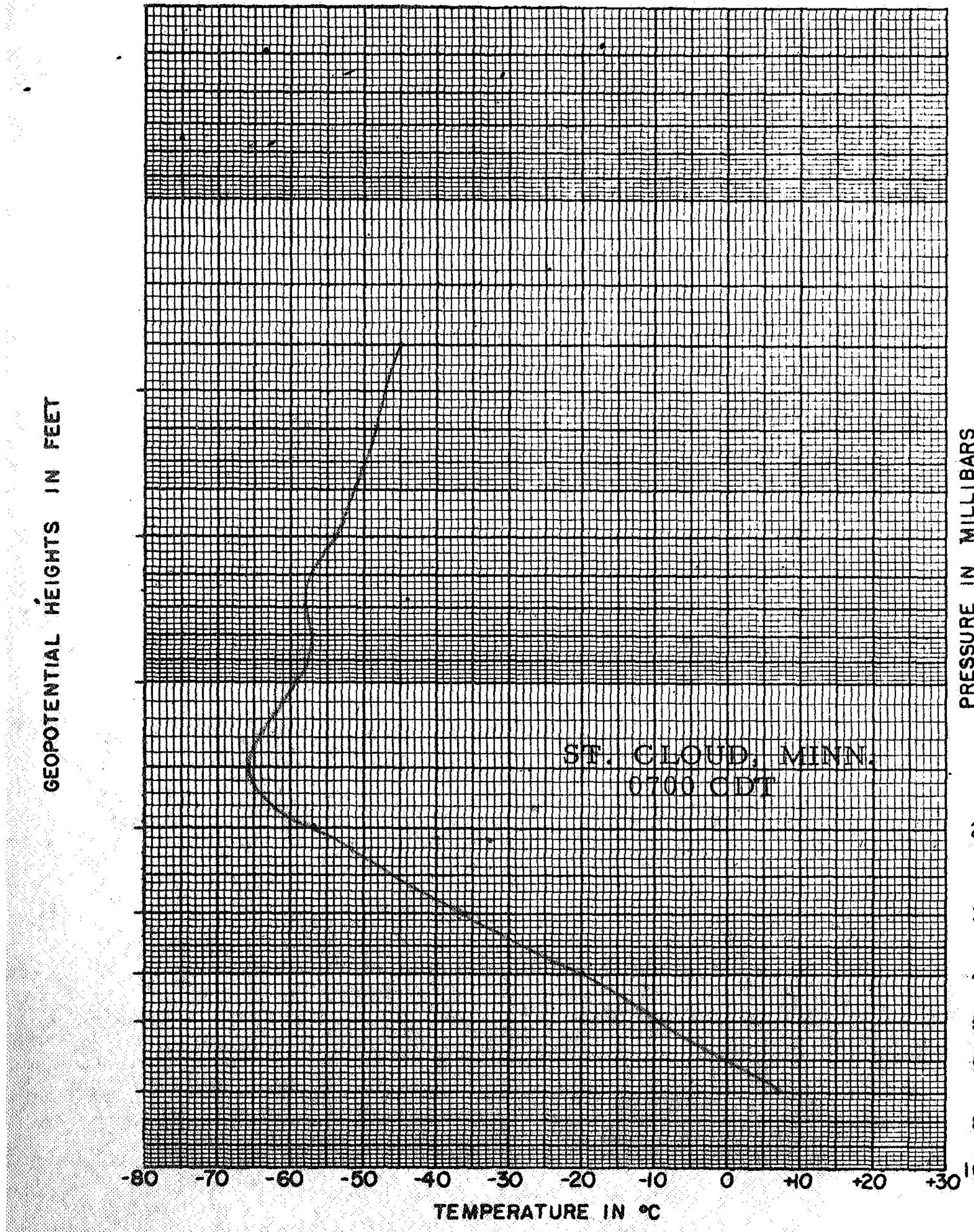
FLIGHT NO. 3050 **DATE** 20 August 1968
FOR JPL 59684 (Radiometer Payload)
LOAD ON BALLOON 314 lbs
FREE LIFT 42.6 **LBS=** 8**%**

BALLOON TYPE	**NUMBER**	**MATERIAL**	**WEIGHT**
SF-84.5-150-NS-06	CU-1547-S/N-41	1.5 mil	219 **LBS.**

ALTITUDE DATA



TEMPERATURE DATA



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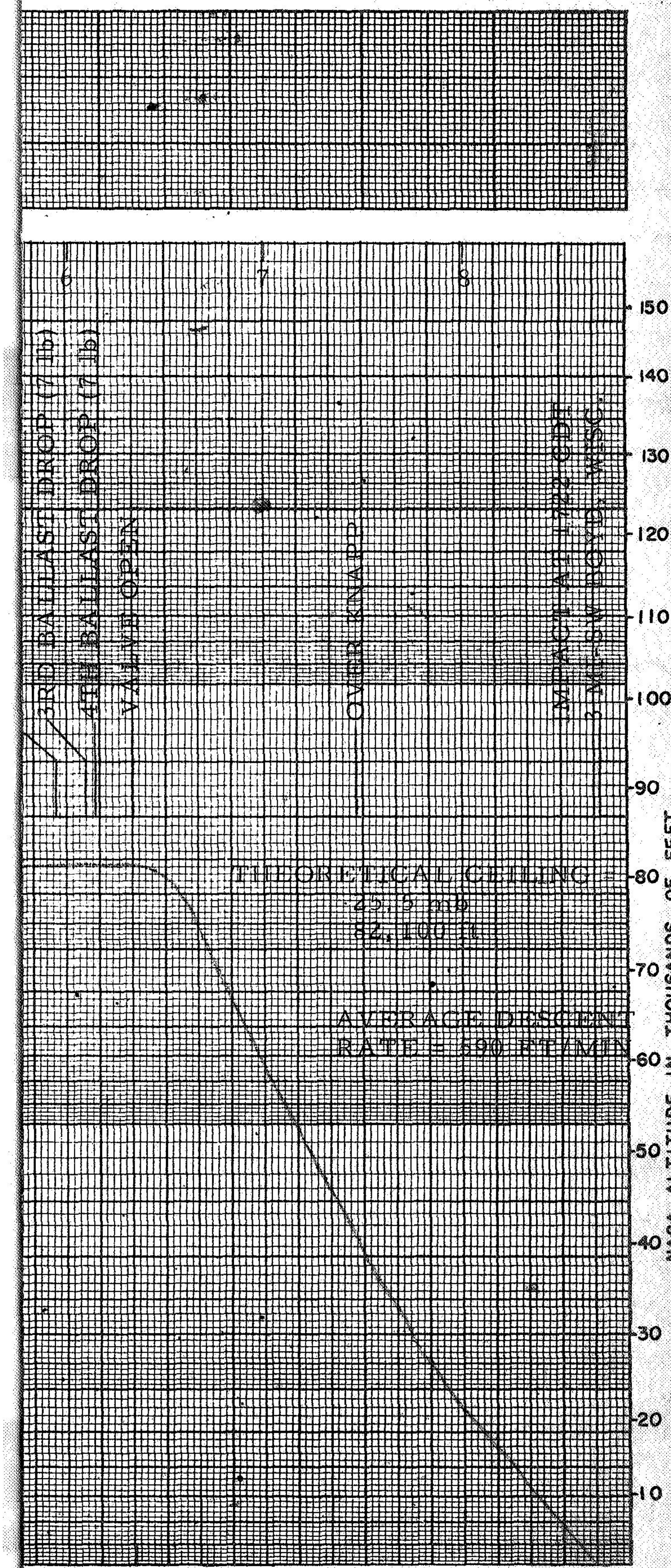
6
7
8
3RD BALLAST DROP (7 lb)
4TH BALLAST DROP (7 lb)
VALVE OPEN
OVER KNAPP
IMPACT AT 1722 CDT
3 MI. SW BOYD, WISC.
THEORETICAL CEILING =
25.5 mb
82,100 ft
AVERAGE DESCENT
RATE = 590 FT/MIN
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
NACA ALTITUDE IN THOUSANDS OF FEET
1500
1600
1700