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The First Large Balloon Launch from Antarctica

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"This technical report has been reviewed and is approved for publication"

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This collection of five papers discusses the many practical problems, logistics, meteorlogical planning, flight history and recovery operations for the first very large (11.6M cu ft) stratospheric balloon launched from Antarctica. The on-board Gamma Ray Advanced Detector (GRAD) was flown successfully to detect gamma ray emissions from Supernova 1987A. The 2500-lb payload was recovered from a 12,500-ft plateau by LC-130 aircraft.

The instrumentation for command-control and telemetry, payload integration and testing, and the telemetry station installed aboard an LC-130 aircraft are described. An overview of the performance of the ARGOS satellite tracking and data-recovery system on this flight is included.

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Contents

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THE FIRST LARGE BALLOON LAUNCH FROM ANTARCTICA

1. A Large Balloon, Antarctica and Supernova 1987A

by

John Ground

Abstract

The first very large, helium-filled, single-cell, polyethylene, zero-pressure balloon was launched from Williams Field, Antarctica on 8 January 1988. Long-duration flight characteristics were demonstrated and unique methods of tracking and data retrieval were developed. Payload recovery from the Antarctic plateau was demonstrated. Valuable meteorological surface and stratospheric data were collected. Logistical and operational problems asssociated with working in an isolated polar environment were solved.

1. BACKGROUND

At the end of March 1987 the Space Astronomy Laboratory (SAL), University of Florida consulted the Air Force Geophysics Laboratory (AFGL) concerning the feasibility of flying a large zero pressure balloon from Amundsen-Scott Station (South Pole) Antarctica. This project, sponsored by Space Division (SD) and funded by the Defense Advanced Research Projects Agency (DARPA), would use an 11,800,000 cubic foot balloon floating at 130,000 feet to detect gamma ray emissions from Supernova 1987A, which had been detected in February 1987. These emissions, visible only in the southern hemisphere, could be best observed from the Antarctic continent. The ideal location was the South Pole. The sequence of events was such that the gamma ray emissions could be detected over Antarctica in January 1988. This coincided with the Antarctic summer, the only time testing of this nature could be accomplished. There was only one opportunity to collect these data. These unusual circumstances provided us a unique opportunity to demostrate the versatility and adaptability of balloons as near space test vehicles.

1.1 Gamma Ray Detector

The detector proposed for this experiment was developed for the Space Test Program (STP) and was initially intended to fly aboard the space shuttle. We agreed that this detector could be mated to an AFGL balloon electronics command, control, and telemetry package within the time available. The cost would be much less than a space shuttle experiment. The enviromental and logistical problems were the major constraints for this effort.

1.2 Launch Site

The feasibility of this proposal was investigated immediately. Very quickly, the idea of using Amundsen-Scott as an operational base was discarded because of logistical, operational, and meteorological constraints. McMurdo Station, operated by the National Science Foundation (NSF), was selected as the alternate site. Efforts were redirected to solving the problems associated with an operation from this location.

1.3 Balloon Launch Requirements

In the past helium-filled research balloons have been used in Antarctica. However, these balloons were small, generally 19,000 to 300,000 cu ft, with payloads 50 lb or less. This would be the first attempt to launch a very large, helium-filled, zero-pressure balloon carrying a payload weighing nearly 2500 pounds. An effort of this magnitude requires heavy equipment for the launch vehicle, launch arm, and helium storage. Approximately 150,000 standard cubic feet of helium would be required. All equipment would have to be airlifted to the site because of the short notice of this

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project. The logistical, operational, and meteorological problems was staggering; however, the successes with the smaller balloons indicated the task was manageable.

2. PLANNING DECISIONS

On 23 July 1987, a meeting was held at AFGL to review the progress of the investigations and to define the objectives and timetable for the Antarctica effort. Many problems and their solutions surfaced; time was the critical factor. We decided to proceed with the project until a problem arose that could not be solved within the time frame. A final Mission Readiness Review was scheduled for 10 November 1987. Other decisions made at this meeting were:

a) The launch site would be Williams Field, on the permanent ice shelf about 7 miles from McMurdo Station. The National Science Foundation would pack a snow covered area for use as a launch pad.

b) Gaseous helium would be the lifting gas, although investigations would continue for the use of liquid helium, because a source for the proper size helium cylinders that could be air-shipped from Christchurch, New Zealand to McMurdo Station, had not yet been identified.

c) Solar panels would provide long-duration power for the payload in lieu of a large weight of batteries.

d) Since it appeared certain that the balloon would drift beyond line-of-sight (out of range from the ground station) a mobile, telemetry/command station would be designed to go aboard the National Science Foundation's LC-130 aircraft.

e) The payload would include a sunseeker to point the platform so that the solar panels faced the sun and the gamma ray detector pointed toward the supernova.

f) The crews for the launch, telemetry, instrumentation, and data acquisition were chosen and their functions defined.

g) The launch vehicle would be the on-site Delta-3. AFGL would design the launch gantry and the NSF's on-site contractor, Antarctic Services (ANS) would construct it (see Figure 1).

h) Service ARGOS would provide balloon position when the balloon was beyond range of the base telemetry station.

i) Space Division (SD) would arrange a C-141 airlift to fly the gondola and support equipment from Holloman AFB, NM to McMurdo Station.

j) Upper air wind and temperature data would be obtained from on-site radiosonde soundings. Naval Support Forces Antarctica (NSFA) would provide the ground tracking unit, operator, radiosonde helium, and radiosondes. AFGL would provide other high-altitude radiosonde balloons and assist in launching them.

k) AFGL would provide and operate a tethersonde to obtain low level wind and temperature data.

l) The payload would be integrated and tested at AFGL, Det 1, Holloman AFB, NM. After integration and testing it would be shipped intact to McMurdo. The shipping date was set for 13 November 1987, three days after the Mission Readiness Review.

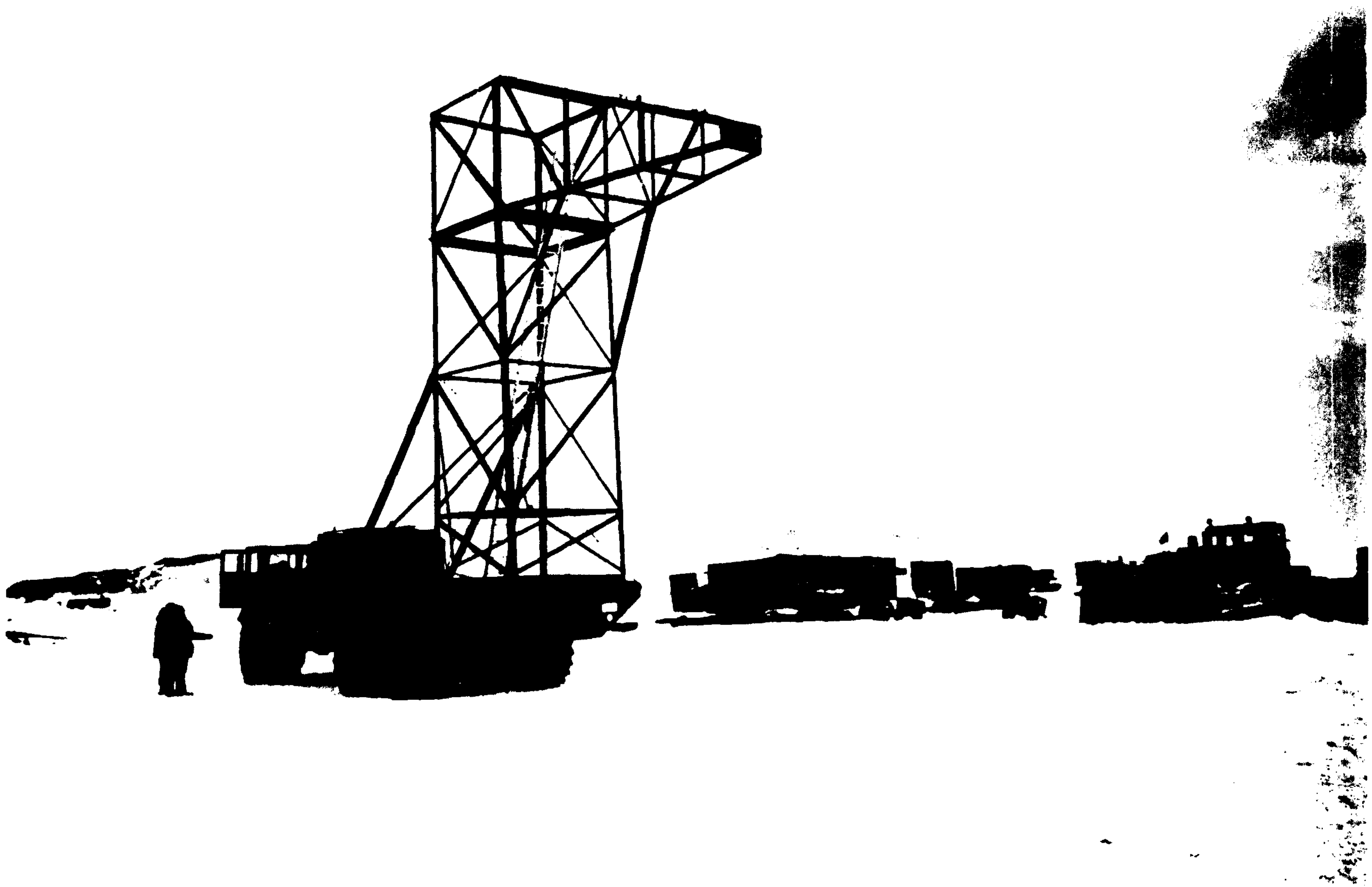

Figure 1. The Delta-3 launch vehicle with the balloon launch gantry, constructed by Antarctic Services, mounted on rear section. Williams Field, Antarctica.

m) The final flight preparations and testing would be done in the new Heavy Equipment Building at McMurdo.

n) The first launch atttempt was set for 6 January 1988.

3. FLIGHT OBJECTIVES

The main objective of this effort was to measure gamma ray emissions from Supernova 1987A for a minimum of 3, and a maximum of 21 days. An 11,820,000 cubic foot balloon floating at a constant altitude of 120,000 feet would be the platform for the gamma ray detector. It was desired but not required that the detector be recovered so that it could be analyzed for deterioration caused by the gamma ray strikes. Other objectives were to learn more about the surface, tropospheric, and stratospheric meteorology of Antarctica, to test the ARGOS tracking system, and to develop balloon launch techniques relevant to polar regions.

4. MILESTONES

Significant milestones, that is, major action items necessary to successfully accomplish the project on schedule, are listed below:

a) Aug 14,1987 AFGL Memorandum of Agreement (MOA) signed.
b) Aug 20,1987 AFSC/SD final approval.
c) Sep 22,1987 helium and balloons to Port Hueneme, CA for surface shipment.
d) Sep 29,1987 Solar panels delivered to Holloman AFB, NM.
e) Oct 8,1987 Test of the upwind launch system.
f) Oct 9,1987 Detector system delivered to Holloman AFB, NM.
g) Oct 21,1987 Gamma Ray Advanced Detector (GRAD) operations plan completed.
h) Oct 27,1987 Environmental chamber tests completed.
i) Nov 4,1987 Airborne telemetry station checks completed.
j) Nov 7,1987 Allup flight readiness tests completed.
k) Nov 10,1987 Mission Readiness Review. Approval granted to proceed to McMurdo.
l) Nov 13,1987 C-141 airlift shipment departed Holloman AFB, NM for McMurdo.
m) Dec 15,1987 All crews and equipment arrived at McMurdo.
n) Jan 3,1988 Allup launch, flight and telemetry tests completed at Williams Field.
o) Jan 6,1988 Launch minus two day tests completed. System ready for flight.
p) Jan 8, 1988 System launched.
q) Jan 11,1988 LC-130 data flight terminated.
r) Jan 13,1988 Payload recovery made using LC-130 aircraft.
s) Jan 29,1988 Last crew member left McMurdo.
t) Apr 27,1988 GRAD crew debriefed in Florida.
u) May 3,1988 Formal GRAD debriefing held in Washington, DC.

5. CLIMATIC INVESTIGATIONS

After the decision to launch the balloon from the Williams Field/McMurdo area rather than the Amundsen-Scott (South Pole) station, we investigated the geography and climatology of this area. It was immediately apparent that there was not a suitable launch site available at McMurdo Station (Figure 2). Therefore, by default the choice was Williams Field (Figure 3). A look at the climatology showed the mean January surface wind at McMurdo to be 10 knots while at Williams Field it was 6 knots. We made detailed analyses of the Williams Field surface wind data for January 1987 from records provided by LCDR Stewart, Naval Support Forces Antarctica (NSFA). These analyses are shown in Tables 1 and 2 below.

Table 1. WILLIAMS FIELD ANTARCTICA
January1987
Wind Distribution (% frequency)

Knots	0-2	3-5	6-8	9-11	12-14	15-17	18-20	>20
Percent	26.6	30.8	15.6	11.0	5.7	5.0	3.7	1.5

Percent frequency of wind speed by groups for Williams Field, Antarctica, January 1987
Source: NSFA Weather Observations, January 1987

Table 2. WILLIAMS FIELD ANTARCTICA
January 1987
Average Speed By Hour (LST)

Hour	00	01	02	03	04	05	06	07	08	09	10	11
Speed	6.0	5.6	4.3	6.0	5.5	5.6	6.0	5.4	5.0	4.7	5.6	6.0
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Speed	6.9	7.8	7.3	7.9	8.2	7.8	7.5	7.4	6.3	6.3	6.0	6.0

Figures are biased toward the low side as observations were discontinued during periods of very high winds.
Source: NSFA weather observations, January 1987.

The atmospheric structure was examined. The mean height of the tropopause in January was 25,000 feet MSL, with a mean temperature of -50° C. The mean temperature at float altitude, 120,000 feet was -15° C. This temperature profile is quite benign for balloon operations. However, from past ballooning experience in the Arctic there was a concern about the warm stratospheric temperatures and the ability to attain float altitude without expending a large amount of ballast. A free lift of 15 percent was planned to help compensate for the warm summer stratosphere.

Stratospheric wind data were collected from various sources and analyzed. These data, although sparse, led us to conclude that the summertime polar anticyclone would exist over Antarctica during January. From the limited data available, this system appeared to be weaker and shorter in duration

Figure 2. McMurdo Station, Antarctica. Note the absence of any large flat areas suitable for balloon launch.

Figure 3. Williams Field, Antarctica. Located on the permanent sea ice on the Ross Ice Shelf, about 7 miles from McMurdo Station.

than its northern hemisphere counterpart. We concluded that during the first half of January the winds at 120,000 feet at 78° south latitude would be blowing from east to west at a speed of 10-15 knots. During the latter half of the month the winds would remain easterly and decrease in speed. We also expected that the direction would reverse from east to west during the first half of February as the wintertime stratospheric polar cyclone began to be reestablished. There were strong indications that during the first half of January the balloon trajectory would be along the 78th parallel and that the balloon would return over the launch site in about 12-15 days (Nishimura, 1985)[1]. The actual flight experience showed these predictions to be reasonably accurate.

Although the mean cloud cover for McMurdo is 6 tenths, this was not expected to present a problem. It was desirable to launch in the absence of clouds but since the tracking would be done electronically it was not essential to the operation.

6. PRE-SHIPMENT ACTIVITIES

After the kickoff meeting in late July preparation activities began in many areas and moved at a rapid pace. Work began on the solar panels, logistics, gantry design, telemetry, helium procurement, pointing systems, and launch testing. Meetings and submeetings were held to assess the progress of the various aspects of the project. An AFGL instrumentation team travelled to the Space Astronomy Laboratory at the University of Florida to interface the AFGL flight instrumentation with the experiment package. These various activities continued through September when the various pieces of hardware were shipped to Detachment 1, AFGL, at Holloman AFB, NM for flight integration and testing.

With the arrival of the payload and crews at Holloman AFB, NM six distinct activities were scheduled to assure the flight readiness of the system. The objective was to assemble the total system into the operational configuration that would be used at McMurdo.

The integration phase of the operation consumed most of the month of October. The GRAD gondola complete with the AFGL instrumentation was mated with the solar panels, batteries and sunseeker/rotator system. The complete gondola was suspended from a crane; then data were received from the payload by the telemetry system to be used on the ice. Operating commands were sent to the payload to see that all systems responded properly. The ARGOS system was turned on and positioning data were received.

While the integration phase was in progress the launch crew was busy practicing the upwind launch technique. (For an upwind launch the wind is blowing toward the launch vehicle carrying the gondola. Thus the balloon at bubble release is blown toward the launch vehicle. This technique allows the launch vehicle to move more slowly, and over a shorter distance to release the payload directly beneath the rising balloon.) A partially inflated balloon attached to a launch vehicle was released and captured several times in wind conditions varying from calm to 10 knots. After two days of testing the launch crew was satisfied that this launch technique could be used at McMurdo in light

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1. Nishimura, J. (1985) Feasibility studies of "Polar Patrol Balloon", *Adv. Space Res.* **5** (No. 1): 87-90.

wind conditions. At this point we set the wind launch criterion that a mean launch wind, surface to bubble height, must not exceed 8 knots.

After the integration phase was complete the flight payload was environmentally tested in the thermovac altitude chamber at Holloman AFB. By varying the chamber air pressure and temperature to simulate the actual flight environment an altitude profile similar to the profile expected in Antarctica was "flown". Problems were encountered with the experiment's high voltage power supplies: these units failed during the simulated ascent when the pressure was changing rapidly. The solar panels could not be operated under flight conditions. However, the panels were temperature tested and shown to operate properly at the surface environment.

Immediately after the thermovac test the airborne telemetry was tested aboard a C-130 aircraft. These tests showed systems working. Aircraft vibration levels were found to be acceptable, but the telemetry reception was unsatisfactory. These tests and resolutions are discussed in detail by Thorn.

The last step in the testing phase was the all-up test conducted on 7 November 1987. The payload was rigged to the flight-ready mode, suspended from the launch vehicle and moved to the launch pad. Pad checkouts were made, the telemetry systems checked through the Oklahoma State University (OSU) tracking system, and all command functions were verified. All flight hardware was attached and the payload was shock tested by driving the launch vehicle through a launch run. At this point the system was flight ready and returned to the buildup area for packing and shipping.

On 10 November 1987 a Mission Readiness Review was held for review of all aspects of the project and for final go ahead approval for shipment. The uncertainties at this point were: a) the range of the C-130 telemetry system, b) the status of a backup high voltage power supply, and the unknowns associated with the meteorology. However, the risks were considered acceptable and the approval was given to proceed with shipment. On 13 November 1987 the C-141 departed Holloman AFB, NM enroute to McMurdo Station, Antarctica.

7. PREFLIGHT ACTIVITIES

After the crew and equipment arrived at McMurdo, operations were set up in the newly constructed Heavy Equipment building at McMurdo. Preflight calibrations and testing were made from here. Meanwhile, the control center and telemetry stations were being set up at Williams Field. All the launch support equipment was checked and readied and the helium racks were moved to the packed-snow launch pad at Williams Field. The Tufts launch arm was mounted on a sled and ice anchors were installed to hold it in position. The launch arm was installed in line with the prevailing easterly winds. Once in place it could not be moved to accommodate winds from other directions, but this did not become a problem because when the winds were light they were from a true easterly direction.

7.1 Wind Direction Nomenclature

A digression is necessary here to explain how wind directions are reported. Three methods are used, grid: magnetic and true. A grid wind references zero degree longitude as north and 180° longitude as south. The winds at Williams Field are usually reported in grid, which is 170 degrees from true.

Magnetic directions are seldom used in Antarctica. Upper-level winds are usually reported in true direction except at the Pole where, of necessity, grid is used. At Williams Field a grid west wind is a true east wind.

7.2 High Altitude Radiosondes

Whenever the surface winds at McMurdo permitted, we released 141,000 cubic foot polyethylene balloons to obtain wind data above 100,000 feet MSL. Ten launches were made and seven were successful. The other three were destroyed by winds during the launch process. The mean altitude for the successful launches was 138,000 feet MSL. Figure 4 shows a high-altitude radiosonde balloon being prepared for launch. The 5-mb level data for these launches are shown in Table 3.

Table 3. WILLIAMS FIELD ANTARCTICA
5 Millibar Data

Date	Height (meters)	Temperature (°C)	Direction (true)	Speed (knots)
17 Dec 1987	38230	-4.9*	070	17
20 Dec 1987	37988	-15.8	065	17
25 Dec 1987	37621	-6.3*	100	17
02 Jan 1988	37241	-17.5	110	12
03 Jan 1988	37379	-13.5	075	20
13 Jan 1988	37193	-15.8	105	15
16 Jan 1988	37319	-17.3	080	09

* The unusually warm temperature is due to the radiosonde's thermistor not being deployed properly. The anomaly on 25 Dec is valid data.

7.3 Telemetry Checkout

Another checkout of the airborne telemetry system was made from Williams Field. A small tethered balloon raised the flight package to 500 feet above ground level (AGL), and with the aircraft on the parking ramp the correct flight geometry was simulated. In the quiet environment, - absence of other radiators - good results were achieved.

7.4 Pre-Flight Preparations - Williams Field

On 31 December 1987 the payload and the operations were shifted to Williams Field. The gondola was housed in the garage at Williams Field. Operations were set up in a Quonset hut and the telemetry was housed in the mobile structure known as "Barney's Barn". Final calibrations were made and the systems assembled for the allup tests made on 3 Jan 1988. All checks proceeded normally and all systems checked Go. The launch-minus two-day test (L-2) was set for 6 Jan and the launch set

Figure 4. A 141,000 cubic foot radiosonde balloon inflated for launch at McMurdo Station, Antarctica. Facing camera, Mr. Joe Longshore, AFGL, Det 1. Away from camera, Mr. Joe Fumerola, PSL/NMSU.

for 0600 hours 8 Jan 1988. Figure 5 shows the layout at Williams Field.

The L-2 preparations began the morning of 6 Jan 1988. The temperature hovered near the 25° F mark most of the day. The winds were 6-8 knots and the sky was partly covered with low clouds. At 1130 hours the gondola was moved to the snow mound and attached to the gantry (see Figure 6). After attachment to the Delta-3 launch vehicle the system was transported to the pad for final flight checks. At 1700 hours all flight and experiment checks were complete and the system was flight ready. The launch was reconfirmed for 0600 hours 8 January 1988. The gondola was returned to the garage to await proper launch conditions.

8. LAUNCH ACTIVITIES

The launch activities began with the arrival of all crews at Williams Field at 0000 hours on 8 Jan 1988. The crews set about their various final flight preparations. Electronics, telemetry systems, experimenter packages and the flight hardware were checked.

8.1 Launch Arm Test

During the checkout of the launch arm we discovered that the launch arm would not activate because of the cold. The arm had been anchored to the ice for several days at below freezing temperatures. The temperature this morning was lower than usual, 12° F. We borrowed an aircraft heater to warm up the system and after about 2 hours of heating the arm would function well enough to launch.

8.2 Working Environment for Crews

Although the surface temperature was 12° F, because of the light winds and the bright sunshine and reflection from the snow covered surface, outdoor working conditions were not severe. As a matter of fact sunglasses were necessary and protection from sunburn was a concern. Layered clothing was an aid in maintaining comfort. When the wind would rise a parka was necessary and when calm, shirtsleeves were comfortable. Gloves were necessary when handling any exposed objects. Figure 7 shows the balloon laid out over the platform of the Tufts launch arm.

8.3 Tethersonde

The tethersonde balloon was inflated and positioned at 500 feet AGL. Periodically profiles were taken from the surface to 500 feet AGL to record temperature and wind data at 100 foot intervals. The wind data were averaged to give a mean wind for the 500 foot layer. The launch criterion was that this mean wind would not exceed 6 knots. The mean wind and surface temperature data are shown in Table 4.

Figure 5. "Barney's Barn", left, Control Center, center, garage, right. Williams Field, Antarctica.

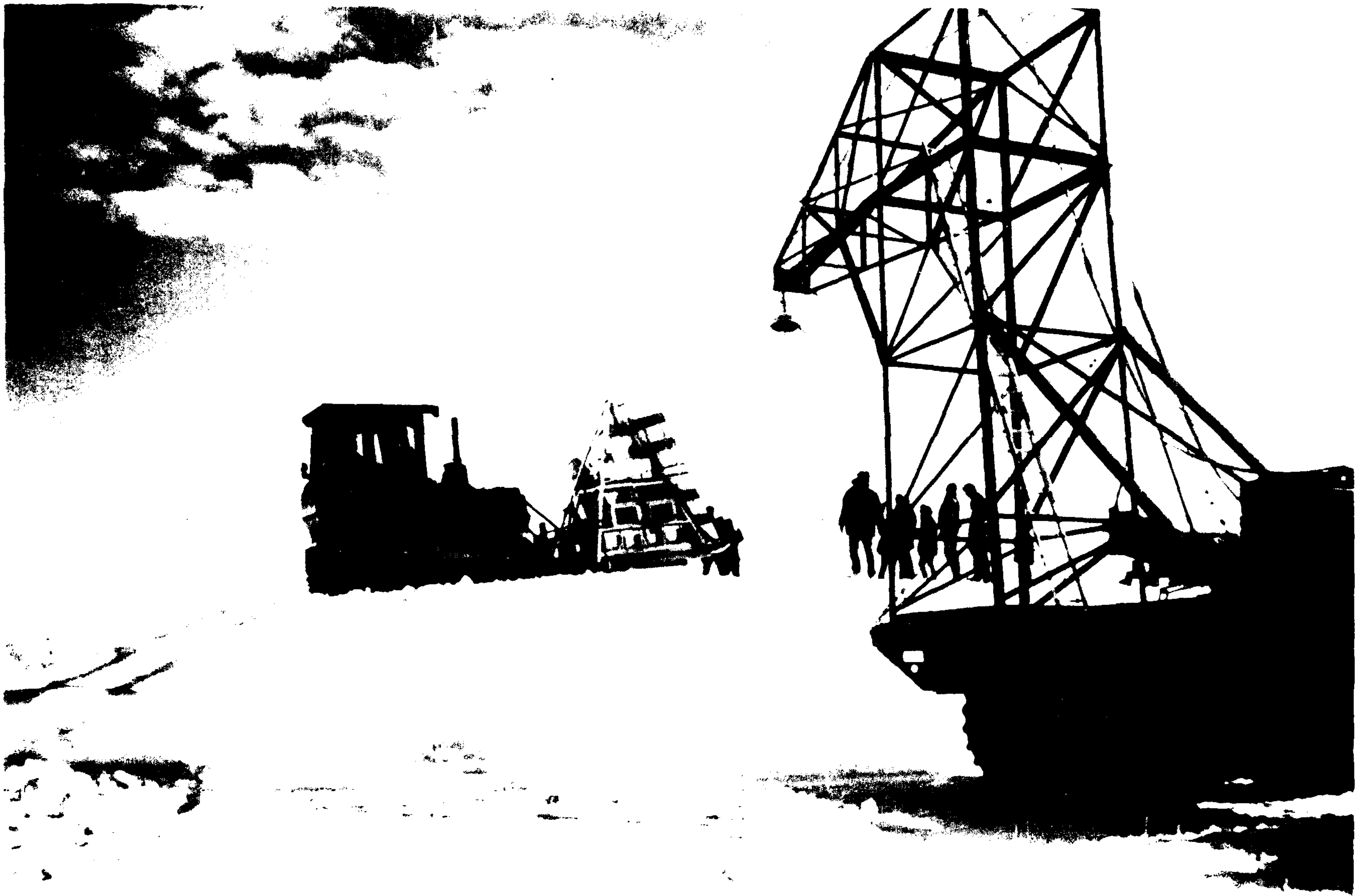

Figure 6. Payload being moved up the snow berm prior to attachment to the launch gantry. Williams Field, Antarctica.

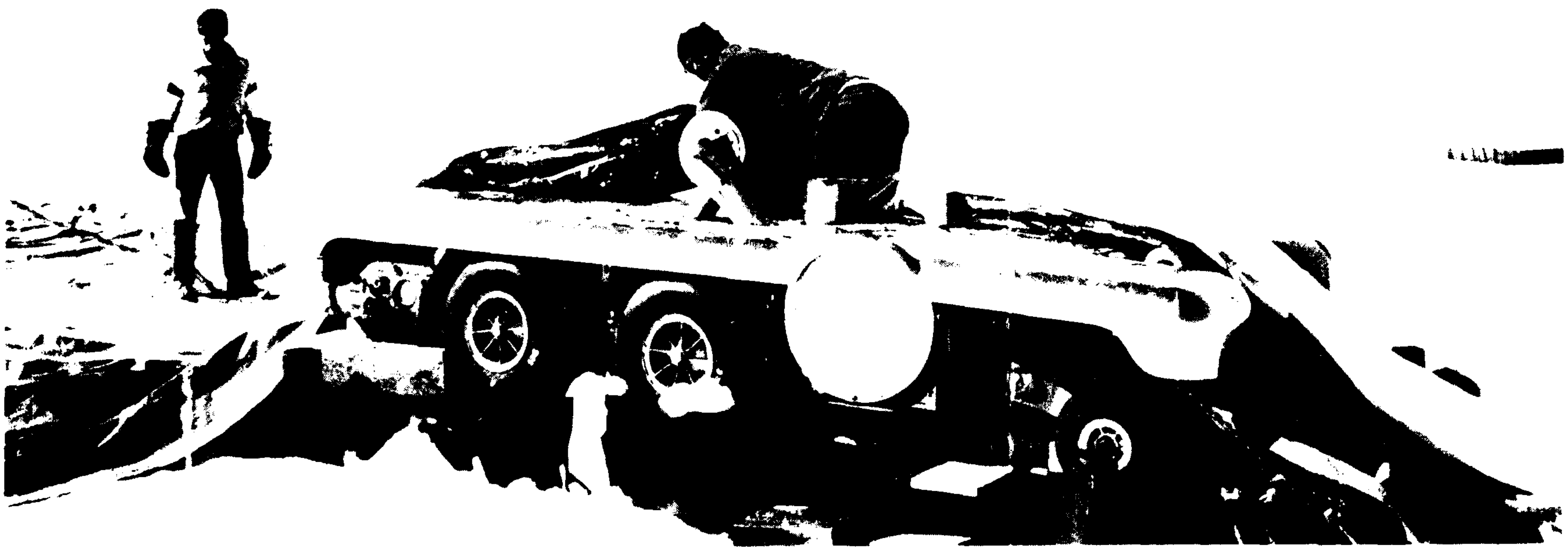

Figure 7. Tufts launch arm with balloon laid out over the platform.

Table 4. WILLIAMS FIELD Tethersonde Data
January 1988

Time (LST)	0000	0200	0500	0600	0730	0830	0930	1000	1200
Wind Speed (kt)	9.6	5.3	6.3	7.7	5.2	4.5	5.5	5.8	4.5
Temperature (°F)	12.3	13.8	11.8	15.2	19.0	17.8	20.8	19.0	24.8

Mean wind speed, surface to 500 feet AGL and surface temperature data for Williams Field, Antarctica, 77 deg 52 min S, 167 deg 05 min E.
Source: AFGL tethersonde data, January 1988.

8.4 Launch

At 0500 LST all systems were Go for launch configuration. The launch winds were just above the six knot launch criterion and showing a tendency to increase. However, at 0730 LST the wind dropped below six knots and the signal Go for launch was given. The payload was moved to the pad and final countdown checks were made (see Figure 8). Inflation began at 1105 LST. During inflation, the helium fittings developed leaks and the valves on the helium tanks did not feed evenly. Occasionally a valve would stop flowing. It could be freed by opening and closing the valve. Despite these problems the inflation process was completed in 55 minutes. After inflation was complete, lift computations were rechecked and the lift value compared with the weighoff scales to ensure that the system did have the planned 15 percent free lift. Figure 9 shows the inflated balloon just prior to launch. When assured that all was in order, at 1215 LST, I gave the signal to launch. The launch vehicle moved about 75 feet ahead and slightly to the right during the launch sequence. The upwind launch technique worked well and the balloon lifted off smoothly (see Figures 10, 11 and 12).

9. FLIGHT HISTORY

9.1 Ascent

The ascent portion of AFGL Flight H88-01 was nominal. The balloon climbed at a rate of 1393 fpm to the tropopause, 27,000 feet, and then averaged 721 fpm from the tropopause to float altitude. At float the altitude sensors indicated a pressure altitude of 114,400 feet. These sensors were calibrated using the 1976 Standard Atmosphere. The "D" value for this day was 4000 feet, giving a true altitude of 118,400 feet. The climbout profile and a temperature profile are shown in Figures 13 and 14. The 3 January data were used for the temperature profile as this was the last radiosonde sounding available that attained temperatures at float altitude prior to launch. When the balloon reached float altitude at 1435 LST it was 194° (true) at 16 nautical miles from the launch point.

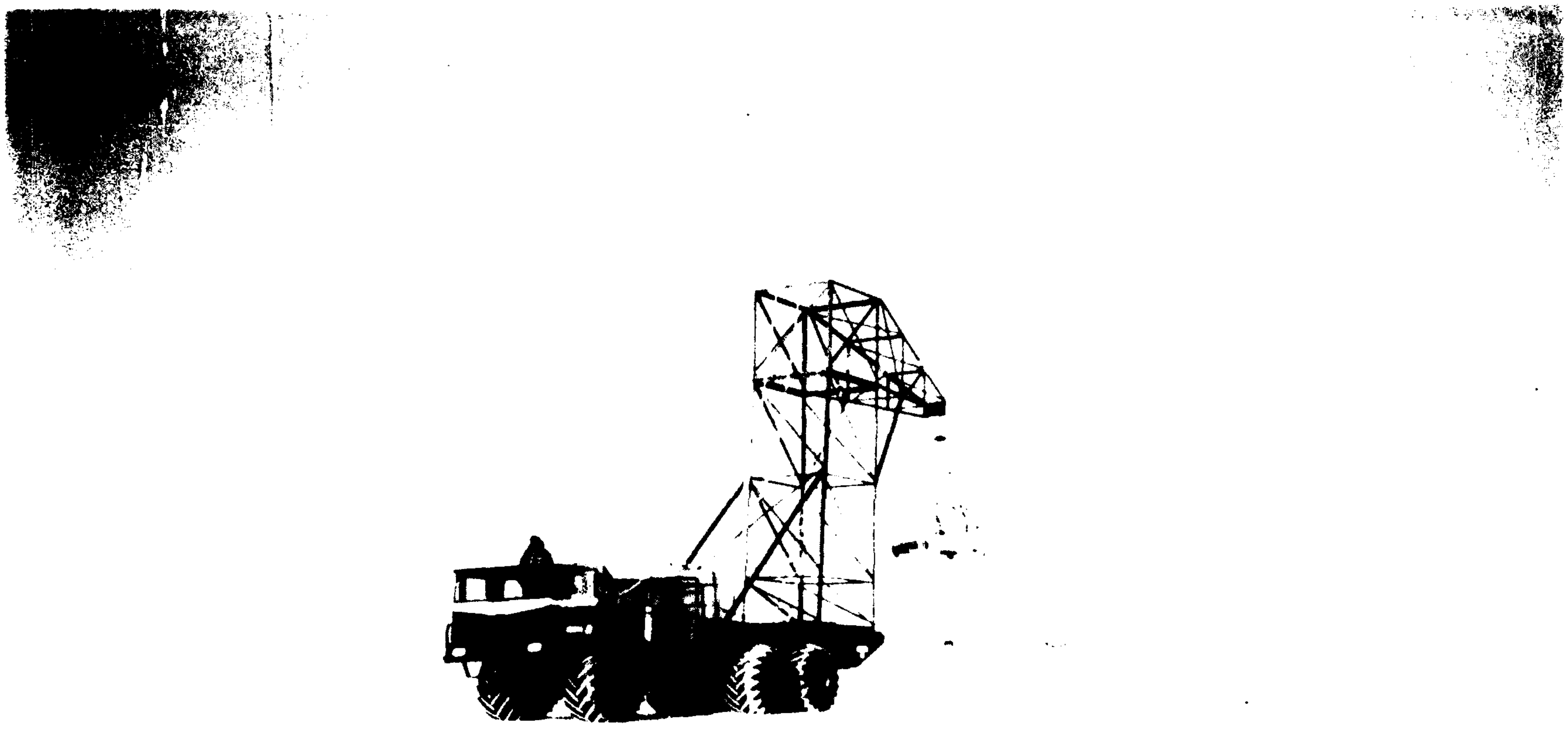

Figure 8. Payload attached to Delta-3, being moved to the launch site. Williams Field, Antarctica.

Figure 9. Inflated balloon just prior to launch. Williams Field, Antarctica.

Figure 10. Balloon just after bubble release. Williams Field, Antarctica.

Figure 11. Balloon rising just prior to payload release. Williams Field, Antarctica.

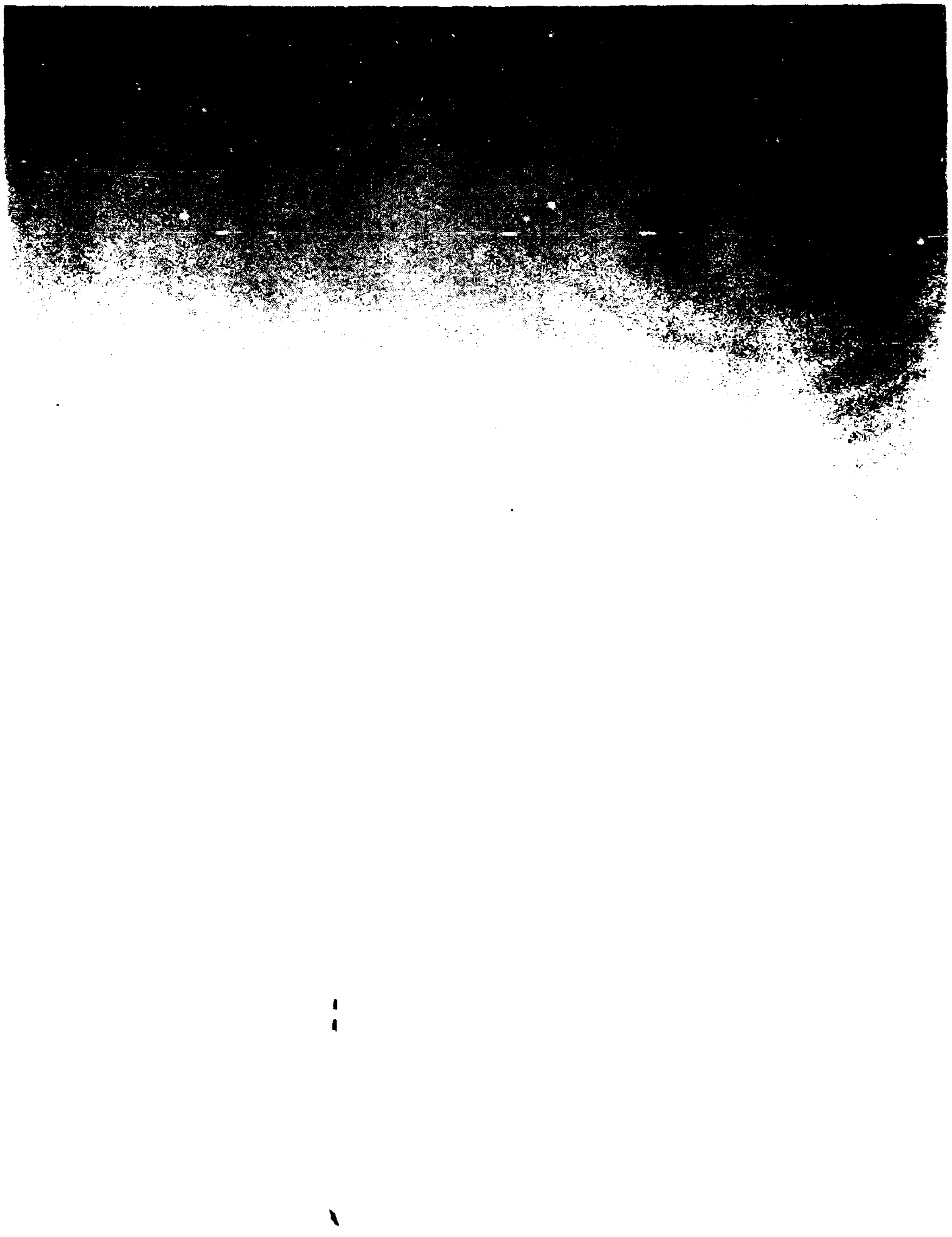

Figure 12. Balloon in flight. Williams Field, Antarctica.

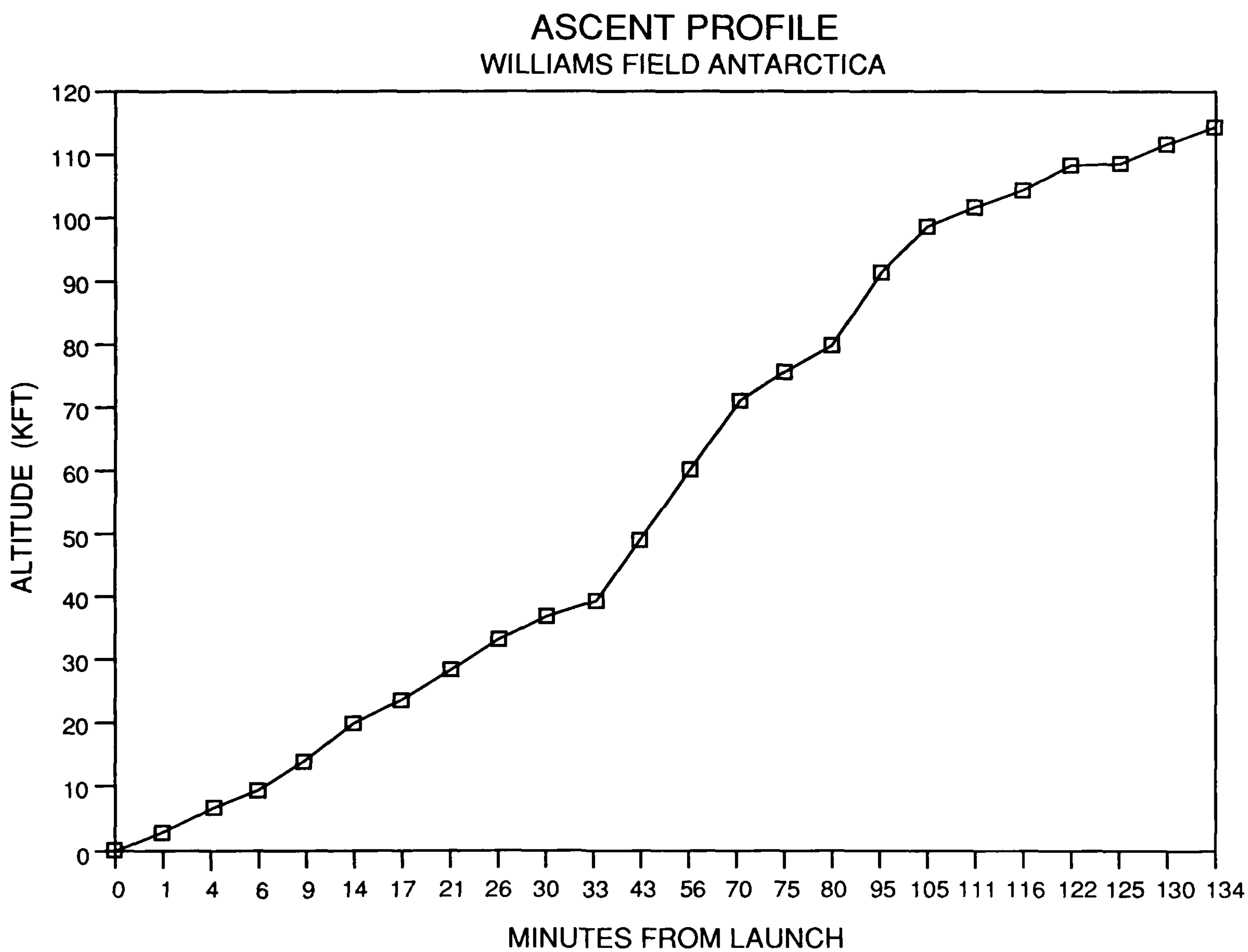

Figure 13. Ascent Profile

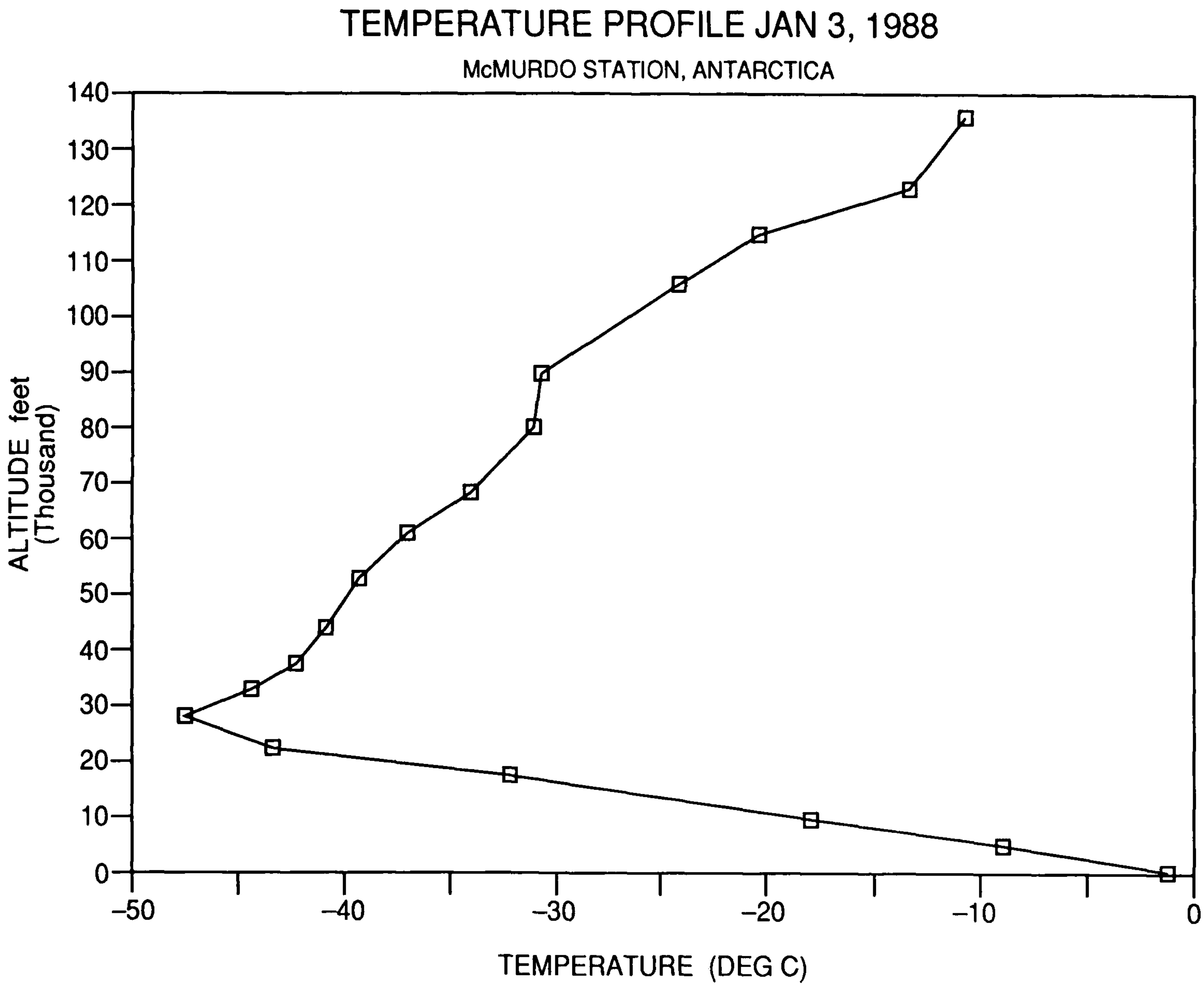

Figure 14. McMurdo Temperature Profile

9.2 Trajectory - Day 1

During the next 21 hours the balloon remained within line-of-sight-of the launch point. One hour after reaching float altitude experiment data were being received and recorded. Data collection continued until telemetry contact was lost on the following day at 1100 LST. During this time the balloon drifted to the west along the 78th parallel at a speed of 12-14 knots. Positions were recorded from the tracking station at Williams Field and from the ARGOS satellite system. The ground station positions are shown in Table 5.

Table 5. WILLIAMS FIELD ANTARCTICA
Tracking Data Balloon Flight H88-01

Date/Time (UT)	Elevation (deg)	Azimuth (deg)	Altitude (Kft)	HDO (nm)	Latitude (deg-min)	Longitude (deg-min)
081119	33.26	117.0	66.0	16.4	77° 57'	168° 13'
0142	43.00	132.0	85.0	14.9	78° 00'	167° 56'
0200	50.00	148.5	98.5	13.5	78° 02'	167° 34'
0222	56.80	169.8	110.0	11.8	78° 02'	167° 13'
0245	48.70	194.0	114.4	16.4	78° 06'	166° 44'
0300	42.90	197.3	114.4	20.1	78° 09'	166° 33'
0333	35.60	200.5	114.4	26.0	78° 13'	166° 19'
0403	32.30	203.3	114.4	29.4	78° 17'	166° 06'
0433	30.60	204.2	114.4	31.4	78° 19'	116° 00'
0508	29.80	204.3	114.1	32.3	78° 19'	165° 55'
0533	29.20	205.9	114.1	33.1	78° 20'	165° 53'
0603	28.51	208.2	113.7	33.9	78° 20'	165° 45'
0700	29.50	215.7	113.5	32.5	78° 16'	165° 31'
0730	29.65	220.6	113.3	32.3	78° 15'	165° 21'
0800	28.14	224.1	113.3	34.3	78° 15'	165° 07'
0830	27.17	229.8	113.0	35.7	78° 13'	164° 50'
0900	25.66	236.1	113.0	38.1	78° 11'	164° 29'
0930	23.66	241.7	113.0	41.6	78° 10'	164° 05'
1000	21.17	245.2	113.0	46.9	78° 10'	163° 36'
1030	18.83	248.6	113.0	53.0	78° 09'	163° 04'
1100	16.60	250.2	112.8	60.1	78° 10'	162° 29'
1130	15.34	250.1	112.6	64.9	78° 12'	162° 07'
1215	13.86	252.4	112.6	71.6	78° 14'	161° 38'
1300	12.45	256.4	112.4	79.2	78° 11'	160° 57'
1330	11.36	258.0	112.2	86.0	78° 10'	160° 22'
1400	10.39	260.1	112.2	93.2	78° 08'	159° 45'
1430	9.41	261.3	112.2	101.7	78° 08'	159° 04'
1500	9.40	262.4	112.0	101.6	78° 06'	159° 03'
1530	8.59	262.3	111.8	109.6	78° 07'	158° 25'
1600	8.29	261.2	111.8	112.9	78° 09'	158° 11'
1630	8.25	261.0	111.6	113.1	78° 10'	158° 10
1700	8.08	260.6	111.7	115.2	78° 11'	158° 00'
2000	5.32	262.4	113.5	159.7	78° 13'	154° 27'
2030	3.73	264.4	113.5	197.7	78° 11'	151° 22'
2100	4.12	263.6	113.5	187.2	78° 13'	152° 14'
2130	3.77	262.7	113.5	201.2	78° 18'	151° 09'

During the first day at float altitude the balloon maintained a relatively constant altitude, rising and sinking slightly with the rising and lowering of the sun. During the first low sun period small amounts of ballast were poured to maintain the highest float altitude possible. A total of two percent, 80 pounds, was poured before telemetry/command capability was lost.

9.3 Command Actions

The final command actions taken before the balloon was beyond line-of-sight were to set all safety and automatic controls. These actions were:

a) The 40,000 kft termination was activated.
b) The 100,000 ballast floor was activated.
c) The rotate feature was set to automatic.
d) The burst switch was armed.
e) The beacon was turned on.
f) The impact system was armed.

9.4 ARGOS Data

While waiting for an aircraft to become available for a telemetry run, the balloon position and its altitude were monitored through the ARGOS system. The balloon altitude and temperature data could be read out through the ARGOS receive station located in the NSFA building at McMurdo. Dr. Stearns, University of Wisconsin, had programed this station to receive the GRAD ARGOS data. Positions were received from Space Division (SD) twice daily via routine message traffic. This system worked quite well in updating the health and position of the balloon. However, just prior to the data run positions were received telephonically.

9.5 Flight Termination

On 9 January 1988 approval was received for the first data run via the LC-130 aircraft. The balloon at 102322 LST was located 77° 37' S, 104° 23' E, at an altitude of 114,500 feet MSL. This placed it about 800 nm west of the launch point. It was moving to the west at 10-12 knots. Immediately following the receipt of the ARGOS position at 0330 LST, 11 January, the LC-130 aircraft, XD04, was airborne enroute to intercept the balloon. When the aircraft was about 80 miles from the balloon the aircraft telemetry data readout indicated that the 3000-volt power supply for the experiment had failed. Since the aircraft was on station and the system was in an area where recovery was possible, the experimenters elected to terminate the flight. We issued the command and the payload separated from the balloon. The payload was tracked to the surface and the coordinates marked as 78.19° S, 88.53° E. After an inspection pass to assess surface conditions and the state of the payload, XD04 returned to McMurdo, landing at 2150 LST, 11 January.

10. RECOVERY

After reviewing the aerial photographs of the recovery area NSFA/VXE6 decided that a recovery attempt of the payload could be made. On 12 January 1988 at 1500 hours LST the LC-130 recovery aircraft, XD07, was enroute to the impact site. XD07 was able to land at the site and the payload was recovered (see Figure 15). (The recovery operation is covered in detail by Dallas.) The ground crew was allowed only one hour to make the recovery. Initially two hours had been planned but it had taken more time than was anticipated to relocate the payload. Because the snow at the impact location was much softer than expected the aircraft takeoff was very difficult. Two long-distance, time-consuming runs had to be made before the aircraft became airborne. XD07 landed at Williams Field with the payload at 0000 hours LST, 13 January. The payload was off-loaded and stored in the garage at Williams Field.

At this point the mission was complete except for the final wrapups and the logistical problems of returning all gear and supplies to the CONUS. Final detector testing was completed within a few days and items were prepared for shipment. The last person on the GRAD team, a logistics technician, left McMurdo on 29 January 1988.

11. DISCUSSION

11.1 ARGOS Tracking

The ARGOS system provided excellent tracking over the period of the flight. Although there was noise in the data the accuracy was acceptable for long-duration balloon flights. Also, by bringing back limited housekeeping data through this system we were able to monitor the health of the balloon in real time. A smoothed plot of the position data is shown in Figure 16.

The altitude data received from ARGOS were plotted and showed, as expected, the balloon responding to the rising and lowering of the sun. T he magnitude of this reaction was one of the unknowns at the onset of this flight effort. Excursions of 4000-6000 feet were noted between high sun and low sun. Each successive day the altitude dipped a little lower. It seems that eventually the balloon would have descended below 100,000 feet and the ballast valve would have been activated. This suggests that even at these high latitudes ballast is a necessity for long duration balloon flights, flights in excess of three days. The ARGOS atitude data are shown in Figures 17-1 to 17-4.

11.2 Communications

Various methods were used to communicate locally and between Antarctica and the CONUS. Around the launch site the primary mode of communications was by VHF radio operating on a frequency 138.125 Mhz. Telephone was used between McMurdo and Williams Field. The primary quick-response link bet.veeen McMurdo and the CONUS was the INMARSAT telephone link. Routine traffic was sent either normal message or E-mail. Mission Status Reports were sent daily via normal message, and ARGOS position reports were received twice daily. HF radio traffic was available but it was cumbersome to use and the reception was unpredictable. Other telephone service was available through the New Zealand station, Scott Base. Telephone calls through this system had to be scheduled

Figure 15. LC-130, XD07, and recovery crew at the impact site. Lat 78°S 89° E. Altitude 11,000 ft MSL

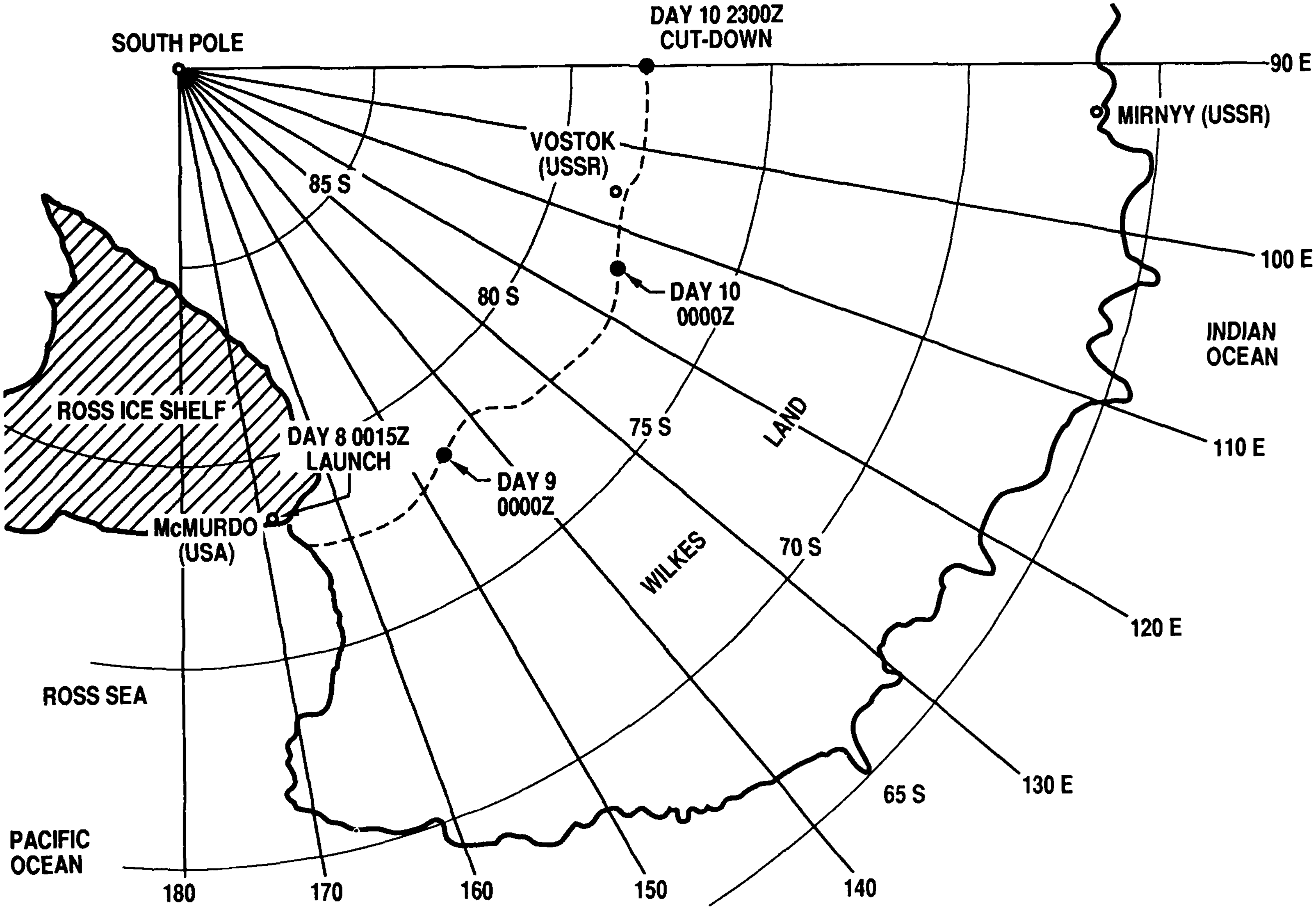

Figure 16. ARGOS Track

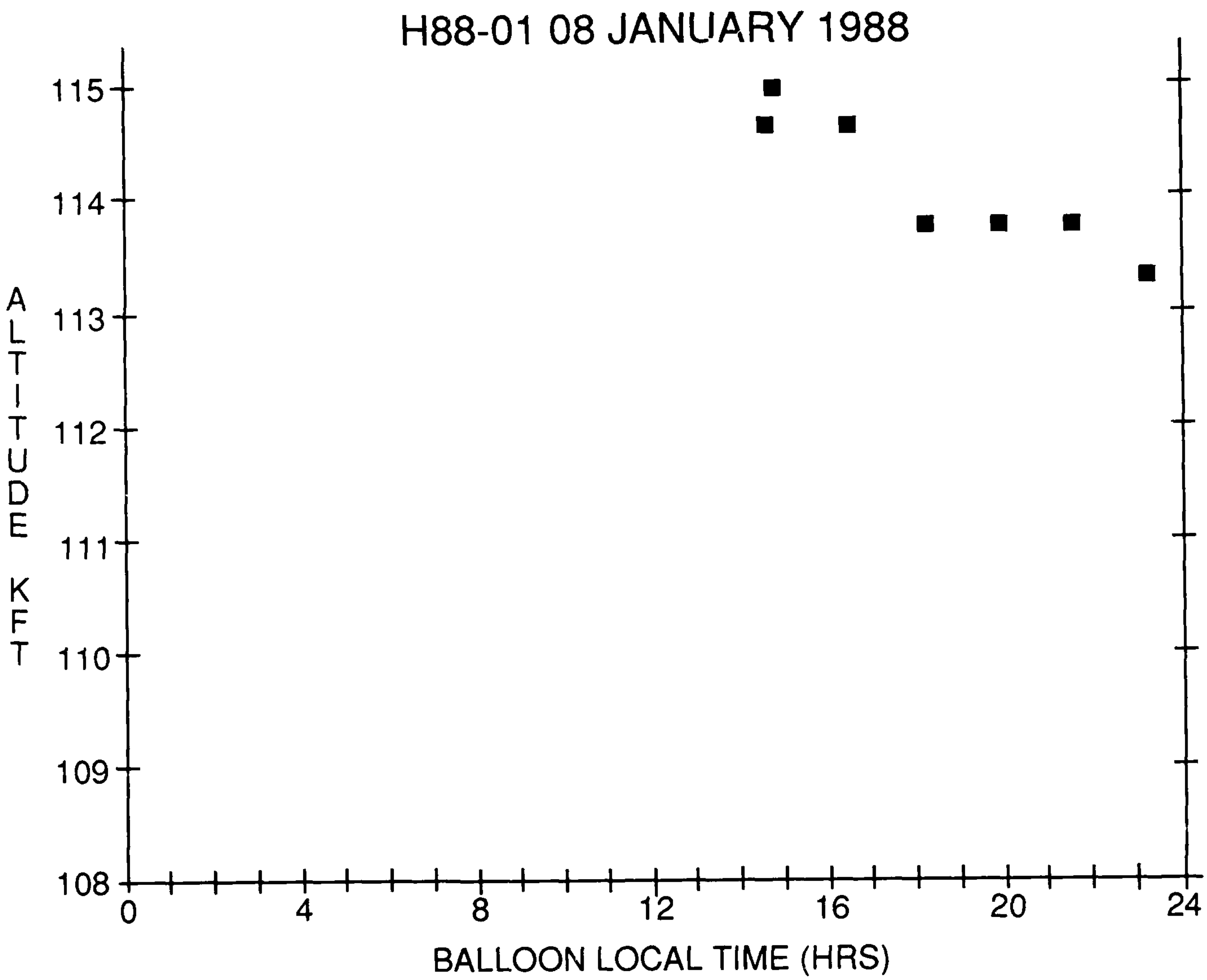

Figure 17-1. ARGOS Balloon Altitude Versus Time

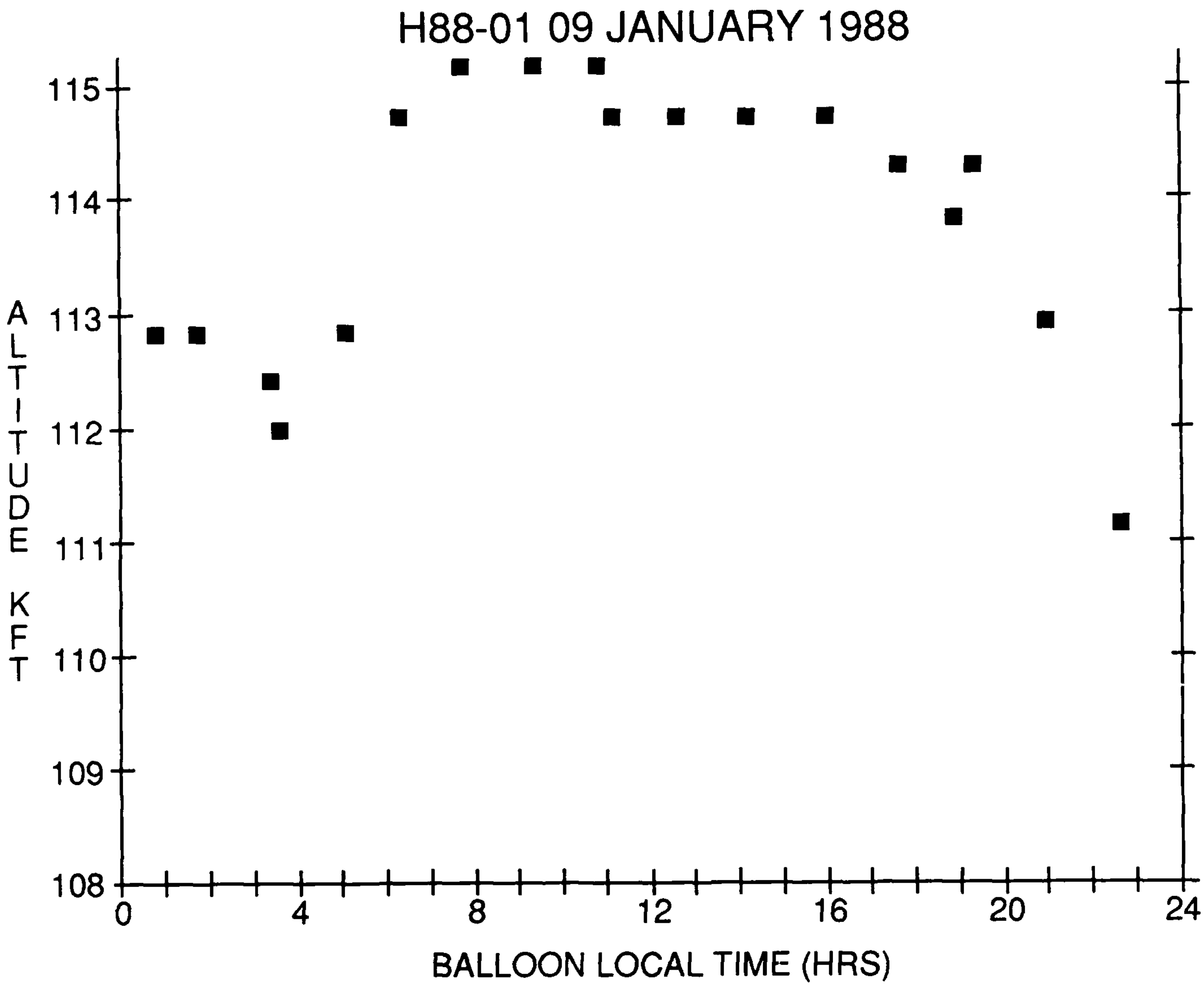

Figure 17-2. ARGOS Balloon Altitude Versus Time

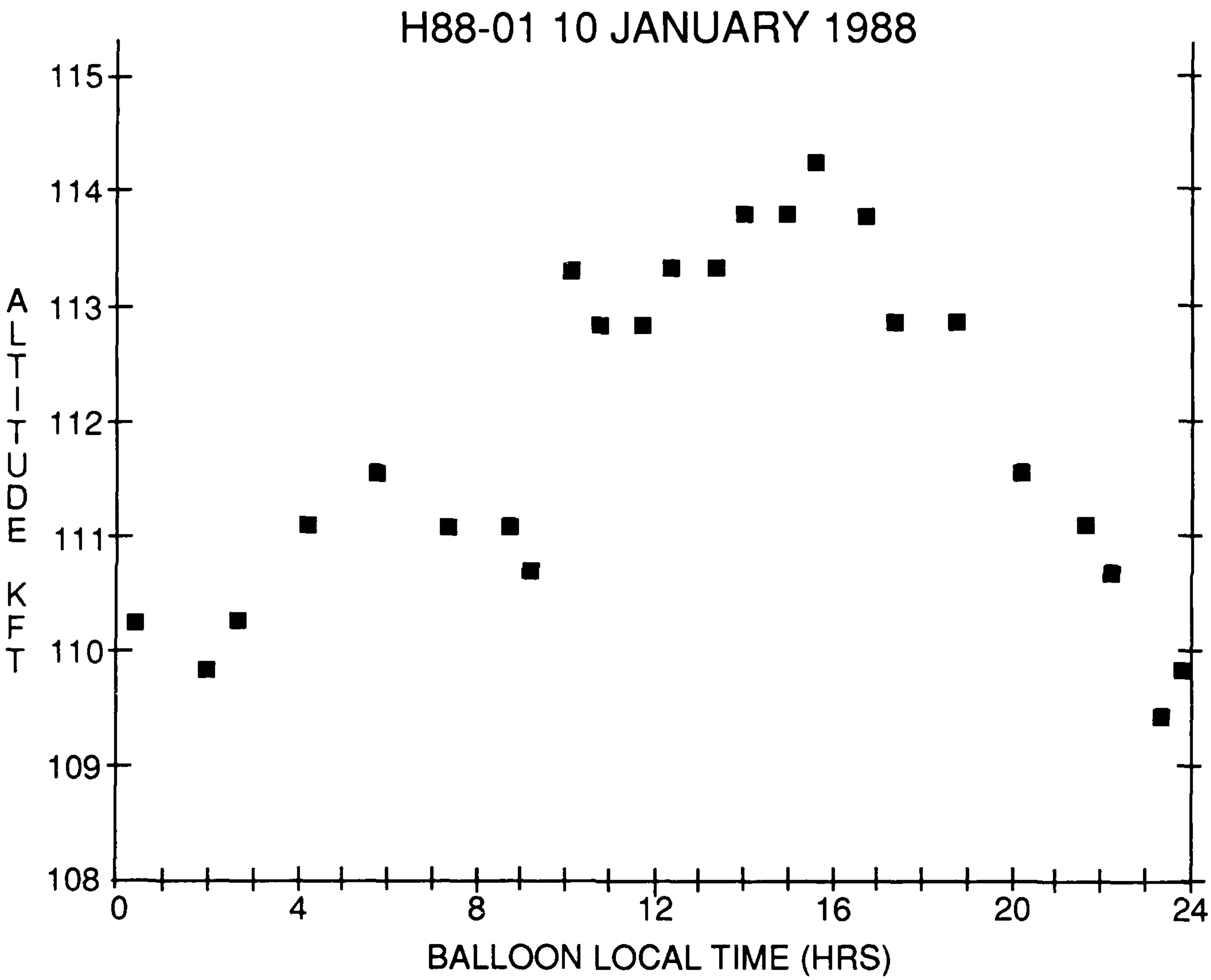

Figure 17-3. ARGOS Balloon Altitude Versus Time

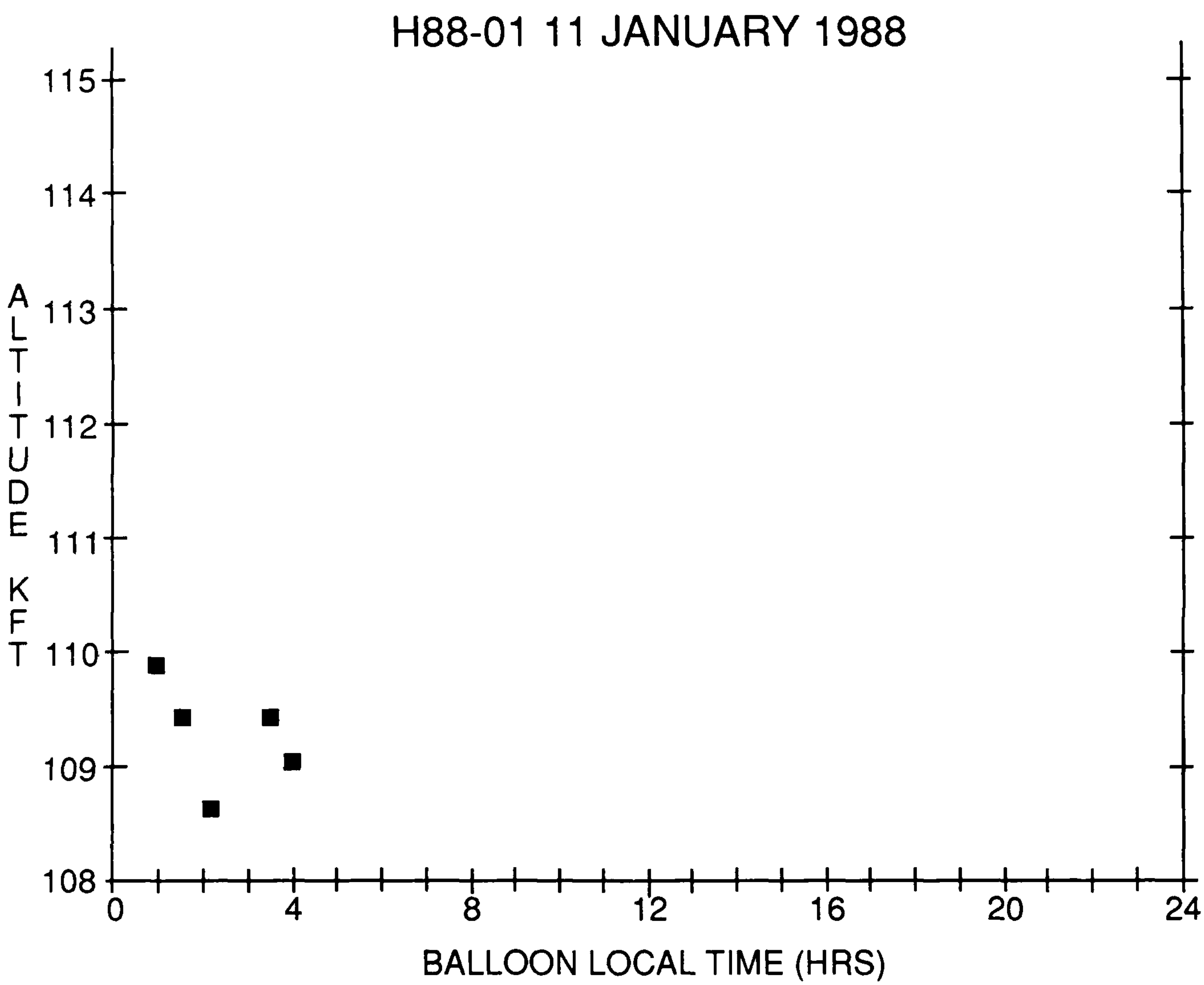

Figure 17-4. ARGOS Balloon Altitude Versus Time

days in advance. Mail service while available was extremely slow. Receipt time was ten to fourteen days.

12. CONCLUSIONS

After the return of the GRAD team to the CONUS two debriefings were held. The first of these was a technical and information workshop and the second was a formal debriefing to the sponsoring agencies.

The data presented showed that:

a) Excellent data were obtained concerning Supernova 1987A.

b) Large zero pressure balloons can be launched in the Antarctic environment.

c) The ARGOS tracking system provides an acceptable track for long-duration ballooning.

d) Solar panels are a viable alternative for batteries during the polar summer.

e) The S-band airborne telemetry/command system was an excellent method of data retrieval and balloon control.

f) New data were collected concerning the Antarctic stratosphere during the austral summer.

g) Long duration zero pressure balloon flights of several days are possible.

As a result of this highly successful venture, a community interest workshop, hosted by the National Science Foundation (NSF), was held to explore the use of this technology for those in the scientific community who are interested in long duration near space experiments from Antarctica.

Acknowledgements

Acknowledgements and credits are given to the organizations and the individual field team members that participated in project GRAD. The following listing in alphabetical order shows the organizations and their functions and the individual field team members and their roles.

Organizations:

Aerospace Corp	ARGOS setup and tracking support.
Air Force Geophysics Laboratory	Operations and Instrumentation
Antarctica Services	Support and Gantry Construction
Defense Advanced Research Projects Agency	Experiment Program Management and Science
Detachment 1, Air Force Geophysics Laboratory	Integration, Logistics and Launch
NASA Goddard	Science
National Science Foundation	Support
Naval Support Forces Antarctica	Ground, Meteorological and Flight Support
New Mexico State University	
Solar Energy Institute	Solar Panels
Physical Science Laboratory	Telemetry
Office of Naval Research	Accelerated Procurement and Money Transfers
Oklahoma State University	Data Acquisition and Tracking
USAF/AFSC Space Division	Sponsorship and Funding
University of Florida	Science and Gondola

The Field Team:

SrA D. Blair	AFGL	Flight Electronics
Dr. R. Coldwell	U of FL	Data Analysis
Mr. J. Cooper	NMSU/PSL	Telemetry
Mr. K. Dallas	AFGL	Engineering/Logistics
Dr. G. Eichorn	U of FL	Science
Mr. D. Ely	U of FL	Science Electronics
Mr. J. Fumerola	NMSU/PSL	Parachutes/Hardware
Mr. J. Ground	AFGL	Launch Director/Meteorology
SMS A. Hodges	Det 1, AFGL	Launch/Administration
Mr. B. Holloway	OSU	Data Acquisition
Dr. G. Lacshe	DARPA	Program Sponsor and Science
Mr. J. Longshore	Det 1, AFGL	Launch Crew Chief
TSG J. McDonald	AFGL	Flight Electronics
Mr. J. Mckisson	U of FL	Science Electronics
Dr. C. Rester	U of FL	Principal Investigator
Mr. B. Seagraves	NMSU/PSL	Telemetry
Mr. L. Skach	OSU	Data Acquisition
Dr. R. Starr	Catholic U	Data Analysis
Mr. W. Thorn	AFGL	Engineering/Flight Electronics
Dr. J. Trombka	NASA Goddard	Science

The AFGL Electronics Integration Team:

Mr. R. J. Cowie
SrA D. Blair
A1C C. Hice
TSG J. McDonald

A special acknowledgement is made to Mr. Hans Laping who died in March, 1988. Mr. Laping was one of the senior electronics design engineers for the GRAD project. Fortunately he lived to see the success of his efforts, which gave him great joy. He is sorely missed at AFGL.

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Abbreviations

AFGL	Air Force Geophysics Laboratory
AGL	Above ground level
ANS	Antarctic Services
DARPA	Defense Advanced Research Projects Agency
fpm	Feet per minute
GRAD	Gamma Ray Advanced Detector
MOA	Memorandum of Agreement
MSL	Mean Sea Level
NSF	National Science Foundation
NMSU	New Mexico State University
NSFA	Naval Support Forces Antarctica
OSU	Oklahoma State University
PSL	Physical Science Laboratory
SAL	Space Astromony Laboratory
SD	Space Division
WSMR	White Sands Missile Range

Contents

2. Logistics and Support for Balloon Flights from Antarctica

by

Kenneth Dallas

1. INTRODUCTION

In view of the remote location, exceptionally harsh climate, and limited facilities at Antarctica for large-scale balloon operations, the following description of our pioneering experience with GRAD is presented with emphasis on those details that should aid experimenters in planning similar programs.

2. SHIPMENTS

2.1 Scheduling

The December-January interval during summer is the only practicable time for stratospheric balloon operations from Antarctica. Proposals must be submitted by June 1 of the year prior to the projected field program. Moreover, it is imperative that experimenters allow sufficient time for pre-deployment of equipment up to one year in advance. This need arises from the fact that only one resupply ship arrives at McMurdo station per year, this at the end of the season (late January-early February).

2.2 Transportation Options

There are three methods of getting mission equipment to Antarctica: sealift, Kilo-air and SAAM:

Sealift is the preferred method for all equipment, especially heavy and bulky articles. The shipment must be at the embarkation point by December of the year before the projected field-party deployment. It will be loaded into standard Milvans (20-ft ISO Intermodal containers) by the National Science Foundation Contractor Representative Office and the Port Operations Department of the Naval Support Force Antarctica at Port Hueneme NCBC, CA, and sent directly to McMurdo by sea. Figure 1 shows the McMurdo staging area. Any item too large to fit in a container will be shipped as bulk load cargo in one of the ship's holds, but it is preferable to break any such item down: bulk loading reduces the number of containers shippable because the entire height of the hold will be lost to their use.

A less preferable mode of shipment is Kilo-air. Kilo-air is used for items that cannot be shipped a year in advance but will be ready for shipment prior to the start of airlift operations for the present Antarctic summer season. This method uses shipment by sea from Port Hueneme to Lyttleton Harbor (Christchurch), New Zealand, and trans-shipment, by military aircraft, from there to McMurdo. The

Figure 1. McMurdo Staging Area

least preferable method of shipment is by SAAM, Special Activity Air Mission, via military aircraft direct from the United States to the ice. This mode requires advanced planning with the Naval Support Force Antarctica and the Military Airlift Wing at Travis Air Force Base. The need to coordinate with the wing at Travis arises from the fact that they are the only C-141-equipped unit qualified to land on the Antarctic ice. These aircraft are only capable of landing on the ice until approximately the end of November, after which the ice no longer has the strength to support their weight.

The other aircraft used for support are C-130's - from the 40 Squadron, Royal New Zealand Air Force, who make wheeled landings on the ice until approximately mid-December, and from the Antarctic Development Squadron Six, United States Navy, who make ski-equipped landings throughout the season.

2.3 Packaging

Due to fuel requirements for the longest leg of a C-141 flight from the United States, maximum load weight must be kept below 55,000 lb. Also, the maximum number of standard air cargo pallets capable of being loaded on a C-141 is 14. Additional information such as maximum dimensions, floor loadings, loading restrictions, etc., can be obtained from Air Force Systems Command Handbook for Air Transportability, DH 1-11, written by the Aeronautical Systems Division (ASD) at Wright-Patterson AFB, OH. All equipment that must be floor-loaded, and some that is to be loaded on pallets needs to be certified for air transportability by ASD prior to shipment.

2.4 *Transport of Equipment to Antarctica*

Due to AFGL's short lead time, 6 months, to obtain gamma radiation from Supernova 1987A during January/Febuary 1988, the GRAD program used all three modes of transport. Kilo-air was used to ship four helium containers by sea to New Zealand and from there to the ice via C-130 and C-141 flights, as the schedule permitted. These containers are 8-ft wide × 4-ft high × 20-ft long and weigh 20,000 lb. Because the testing and systems integration activities were on-going into November 1987 it was necessary to ship the remainder of the support equipment via a SAMM mission directly from the AFGL Balloon R&D Test Facility at Holloman AFB, NM to the ice. This load included a 17,000-lb launch arm, the gondola with the experiment and balloon-control hardware installed, solar panels, telemetry stations and test/launch support equipment. The final packed load consisted of 9 1/2 pallets weighing approximately 44,000 lb. (Also on the plane were two turboprop engines which were later used by VXE to recover a C-130 aircraft that had been left on the polar plateau 12 years earlier with damage sustained during an accident on takeoff.)

2.5 Return Transport to the U.S.A

The GRAD shipment via sea lift from McMurdo to Port Hueneme, CA consisted of two 20-ft Milvans (ISO containers) containing all the ground support equipment and telemetry instrumentation, each with a gross weight of approximately 20,000 lb; one 20-ft ISO flat rack with the balloon launch arm, gross weight 19,000 lb; and the gondola with the detector in a 9 ft × 9 ft × 9 ft crate weighing 1200 lb which was loose-loaded in the hold of the ship while the three containers were deck-loaded. Also included in the return shipment were three of the four helium containers - the fourth was retained at Mc Murdo to test their applicability to year-round use instead of bottles. After completion of the program, space limitations on the C-130's (due to the number of people leaving the ice for station close-out) made it necessary to send by ship to New Zealand 10 small packing cases that were intended for return to the United States by air. (This load of electronic test equipment and computers was urgently needed to support other balloon-borne test programs.) It came from New Zealand by air freight to Hanscom AFB, MA and arrived about the 15th of April, 1988. The container shipment arrived at Holloman AFB, NM during the first week in May. The gondola was shipped to Hanscom by truck from the port and also arrived during the first week in May.

3. SUPPORT FACILITIES FOR FLIGHT PREPARATIONS

3.1 Shops, Tools and Equipment

Support facilities exist at McMurdo, with carpentry and welding shops, but it is advisable to bring anything that could possibly be needed since this support can be limited by resource non-availability. If, after arriving on the ice an unforeseen need arises for tools or equipment, the Berg Field Center at McMurdo can sometimes supply them. An exception is electronic test equipment which must be brought by the experimenter. Also, plan on bringing any spare parts that could possibly be needed - there is no supply service.

Work space is at a premium at McMurdo, and is even less available at Williams Field, therefore the minimum space requirements to accomplish the job should be carefully determined. Again, planning with the Polar Program Branch of NSF and their support contractor is vital, so that the program needs are known far enough in advance to allow time to set up facilities and ship in materials to support all the needs.

3.2 Housing for GRAD Payload Tests

We were extremely lucky to be able to use the new, heavy-vehicle maintenance building at McMurdo for final payload equipment tests. This building was available because it was still under construction and was not yet being used for vehicle repairs. This facility is a multi-bay building with overhead cranes and very large garage doors which greatly facilitated the handling of the gondola. A polyethylene-covered frame was erected inside the building to provide a clean room around the gondola, to preclude dust contamination of the radiation detector during the background-radiation calibrations. After the gondola was transported to the launch site at Williams Field it was housed temporarily in a garage for tracked-vehicle maintenance. This building did not have sufficient height to suspend the gondola for any further pointing-control tests, so only final electrical checks were performed there.

After the payload had been flown and recovered from the polar plateau it was again temporarily housed at Williams Field so that critical post-flight tests could be performed. All equipment was then returned to the heavy-vehicle maintenance building at McMurdo and packed for shipment back to the United States.

3.3 Materials-Handling Vehicles

Materials-handling forklifts in Antarctica are large, rough-terrain vehicles. In McMurdo they are articulated, wheeled loaders equipped with fork attachments. At Williams Field, all handling is done using tracked Caterpillar D6's. Figure 2 shows a typical vehicle. Experimenters must keep this in mind, because anything being transported by forklift will not receive a smooth ride!

Additional handling of the GRAD equipment in the heavy-vehicle building was provided by a small Bobcat with forks. Transport of the equipment between sites - McMurdo and Williams - was done on an all-terrain articulated truck known as Delta 3, manufactured by Formost in Canada. Unless this truck is driven very slowly it bounces, because it has high flotation tires and low tire pressures to allow travel on packed snow.

3.4 Local Transportation for Personnel

Transportation between McMurdo and Williams Field should be accomplished by using the hourly shuttle bus, if at all possible, since this keeps the amount of traffic on the snow road down to a volume that reduces wear. Tracked Sprites and large-tired pickups can be checked out from the NSF chalet as needed, but to have a vehicle dedicated for the program is difficult due to the limited number of vehicles that must be shared by all programs.

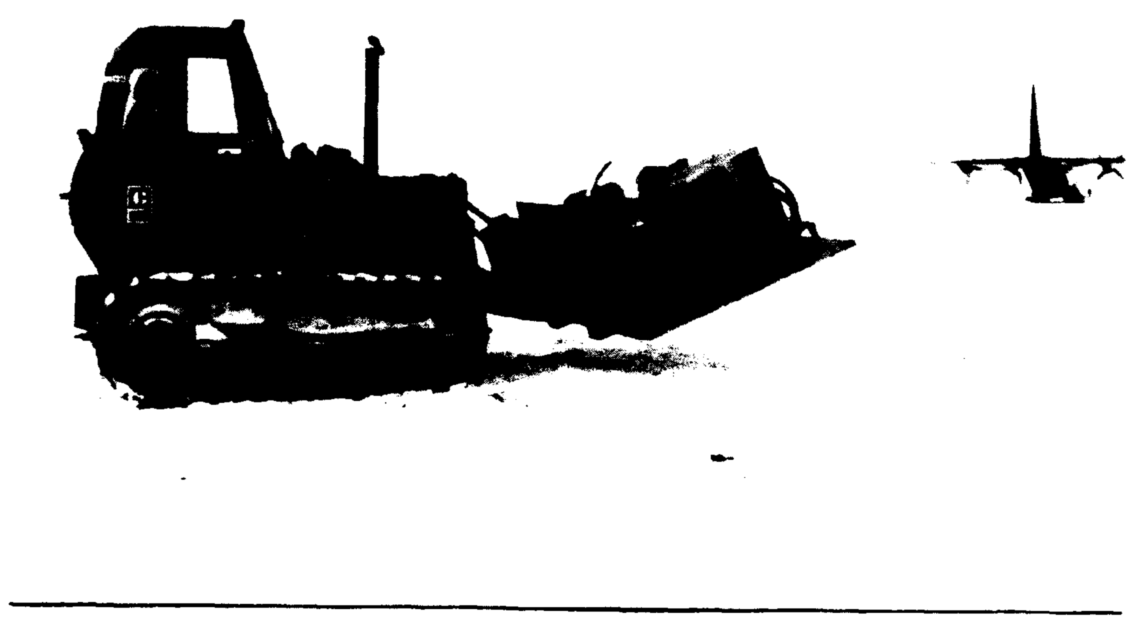


Figure 2. Forklift at Williams Field

4. LAUNCH-PAD OPERATIONS

4.1 Effects of Antarctic Environment on Launch Equipment

The helium racks were mounted on a 20-ton capacity sled which allowed movement on the packed snow of the launch pad. The launch arm was mounted on a smaller sled which was then prepositioned on the launch pad, and tied down to dead-man anchors made of buried telephone poles that controlled the jumping reaction caused by release of the balloon.

Problems due to the cold and snow occurred in both the launch arm and the helium racks:

The problems with the launch arm were caused by snow that had blown in under the frame and caked around the release arm catch and snubber brake. This was relieved by directing hot air from a Herman-Nelson heater under the vehicle for two hours, melting out the snow pack. In this way the launch arm was made usable. The release-arm motion was slow - apparently because the fluid in the snubber brake had stiffened up from the cold - but this did not affect the launch operation. Subsequent investigation revealed that there was an ice/snow pack in a guide-pin slot that engages the snubber brake, causing the brake to actuate early. For future operations it is recommended that the underside of the launch arm be enclosed to preclude the accumulation of snow and ice in these mechanisms. The problems with the helium racks were due to contraction of fittings from the cold. Pre-launch checks of the helium pressure found that two of the 32 cylinders had bled down to 300 psig from an average of 2700 psig. This did not seriously affect operations because sufficient volume remained to provide two balloon inflations if necessary. Also, a number of individual cylinder valve-cap shells needed tightening to stop the valves from leaking when open. The last problems occurred during inflation: leaks in the inflation-hose fittings were caused by additional cooling from pressure reduction and gas expansion, and one 4-cylinder manifold valve froze up for the same reason. In future operations, all valve shells should be tightened on arrival in Antarctica, and careful checks should be performed on setup for inflation to ensure that all open cylinders and manifolds are providing helium flow.

4.2 Substitute for Launch Crane

A special gantry to suspend the payload during launch was built by the NSF contractor representative, ITT Antarctic Services, at McMurdo. It is shown in Figure 3. The normal launch procedure using a 25-ton crane was impossible because the snow would not support a 25-ton crane. The gantry was mounted on the cargo bed of a Delta 3 vehicle with the gondola hanging off the rear. Balloon layout was accomplished using a Sprite towing a tracked trailer carrying the balloon box.

5. TELEMETRY GROUND STATION

The telemetry ground station was installed in a sled-mounted, 20 ×18 ft structure with a tracking antenna on its roof. Next to the telemetry station a Jamesway shelter was erected for work space, equipment storage, and crew shelter. (The Jamesway shown in Figure 4 is an insulated, fabric-covered-arch building similar to a Quonset hut.)

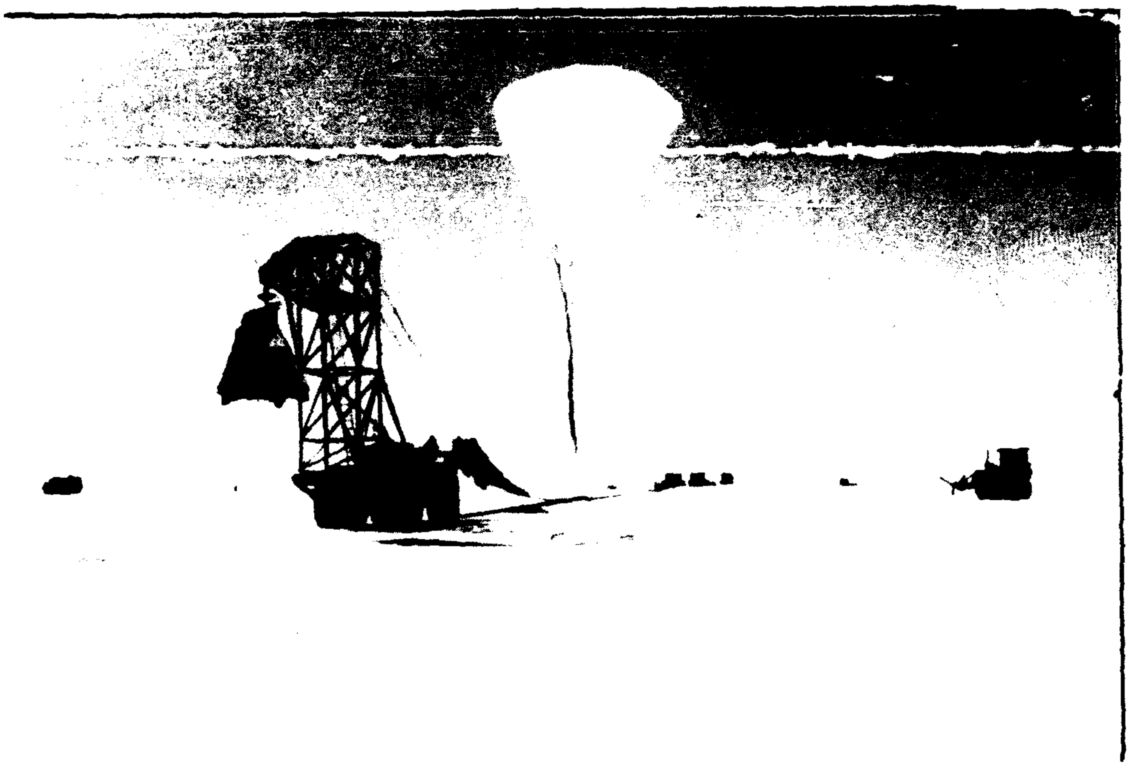


Figure 3. Delta 3 Gantry with GRAD Payload

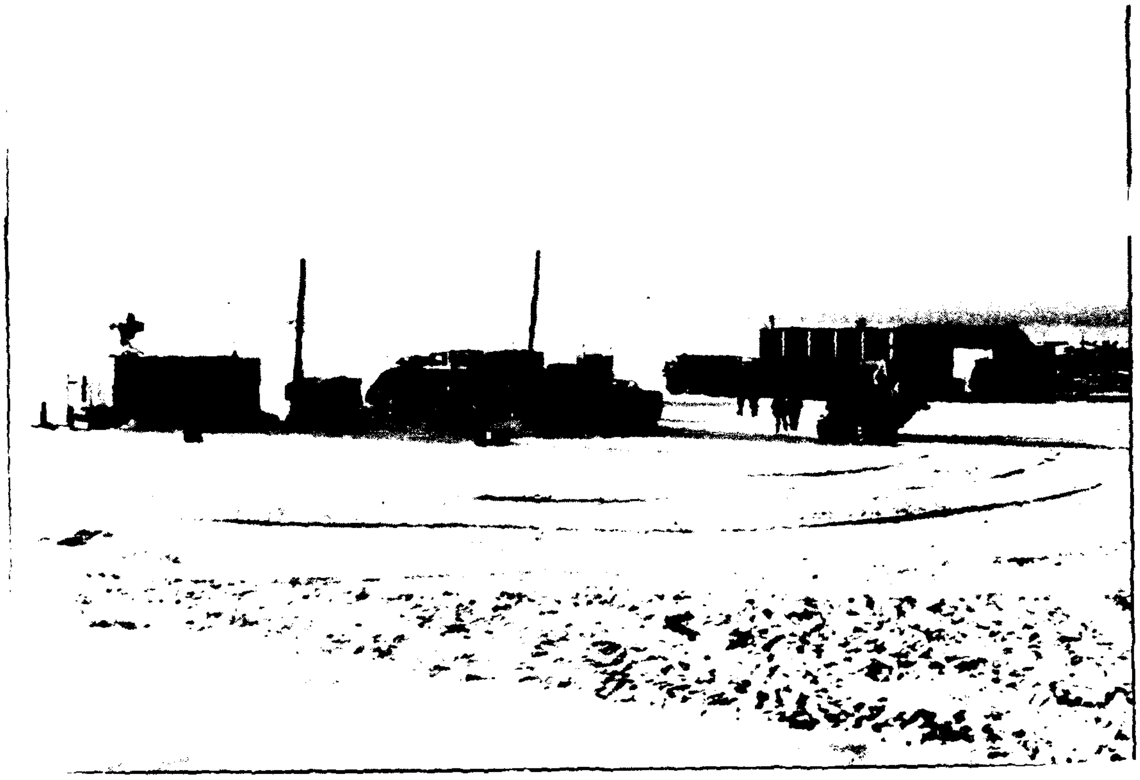


Figure 4. AFGL TM Station and Jamesway Shelter

6. PAYLOAD RECOVERY

6.1 Impact Location

Recovery of any balloon payload cannot be guaranteed, but all reasonable effort will be attempted to effect recovery. The primary factors that affect recovery are the snow conditions at the impact point and the location on the continent. Crevasse fields, soft, or exteremely ridged snow will preclude landing of C-130 aircraft on the polar plateau, and the distance from McMurdo or Pole and the payload weight will affect the range of the C-130's.

6.2 Planning and Rehearsal

The recovery operation should be planned in advance and actually rehearsed, because the time on the ground at the recovery site may be severely limited by aircraft fuel requirements. Recovery requires close attention to designing the payload, especially in the areas of dimensions, how equipment is mounted, and priorities of what parts are expendable.

The average altitude of the polar plateau is 10,000 feet above sea level: work is extremely fatiguing due to the lack of oxygen at those altitudes. One of the NSF requirements for GRAD recovery was that a Navy medical corpsman be on board whose only duty was to watch crew members for oxygen starvation. Also, it must be kept in mind that the recovery crew will be wearing bulky clothing; all equipment from the gondola should be designed to be manipulated while wearing mittens. Most important of all, don't design a gondola that won't fit through the doors of the aircraft! (Consult AFSC DH 1-11.)

6.3 Recovery of GRAD

Recovery of the GRAD gondola took place three days after termination of the flight. Figure 5 shows the payload as found by the recovery crew, with the aircraft in the background. The impact location was approximately 800 miles west of McMurdo. The recovery priority list was used since the time on the ground was limited to 1 hour due to unexpected soft snow at the recovery site. Recovery was accomplished by removing the battery packs, disconnecting the parachute and pointing system, and lifting the top end off the snow so that an air cargo pallet could be slipped under the down side of the gondola. The gondola was then strapped to the pallet and towed to the airplane by a snowmobile. At the airplane the gondola/pallet was winched up the cargo ramp into the plane and secured. Due to the soft snow conditions two takeoff runs were necessary. The first lasted 6 1/2 minutes; at that point the plane was turned around and the second run was made down along the tracks of the first run. This attempt finally succeeded after a takeoff run of nearly 15 miles.

Figure 5. GRAD Recovery - Aircraft and Gondola

Contents

3. GRAD Payload Integration and Flight System Integration

by

Ralph J. Cowie

1. INTRODUCTION

The AFGL balloon support requirements for the GRAD payload were first defined in detail at a meeting at the University of Florida Space Astronomy Laboratory in Gainesville, Florida on 19 August 1987. At that meeting personnel from the New Mexico State University Solar Institute presented three possible payload power system configurations for consideration. A joint decision was made to proceed with a solar-panel battery-charging system described in Sections 2.3 and 5.0. The "housekeeping" status monitors for the experiment and power systems and a command-control interface to the AFGL balloon control system for the GRAD experiment were defined. The AFGL data-acquisition encoder would be configured to provide as many monitors as all felt necessary for adequate in-flight assessment of flight-system health. It should also provide all data necessary to identify malfunctions and perhaps permit their correction via uplink radio command.

2. SYSTEM REQUIREMENTS

It was determined that apart from vehicle control, the GRAD experiment would need 28 individual command closures: 22 momentary, and 6 latching on/off functions. The experiment would also need 24 digital bits to indicate on/off status of experiment control, battery solar-charge controllers, dewar heaters, sun indicator, and rotator power. The experiment and balloon control commands are listed in the Appendix, Figures A-1 and A-2. Figure B-1 shows the digital subframe assignments.

2.1 Telemetry Channels

The telemetry analog channel requirement could be satisfied by 23 channels as follows:

Battery #1 - 3 To monitor temperature, voltage and current

Battery #4 - 3 Same as Battery #1

Solar Array - 11 For 3 temperature, 6 current, 1 voltage and 1 insolation measurements

GRAD experiment - 6 temperature measurements from National Semiconductor, solid state LM-335 devices that provide a 10-millivolt per degree Kelvin linear scale.

Figure B-2, Appendix B, lists the analog channel assignments.

2.2 Batteries

The payload power system was established as 4 battery packs made up of several silver-zinc batteries, Type BB-622/U, each capable of providing 80 ampere hours at a nominal 6 volts DC. Five of these batteries would be series connected to yield a nominal 28-volt DC power pack. Four such packs would be utilized. Battery Packs #1 and #4 would power the GRAD experiment and rotator, while battery packs #2 and #3 would power the AFGL primary and back-up flight-control and data-acquisition telemetry sytems, respectively.

2.3 Solar Array

Each of the four battery packs would have a charge controller fed from the solar panel array. For reliability and ease of handling, the solar array was divided into two sections. The upper array half would charge battery packs #1 and #3, while the lower array half would charge battery packs #2 and #4. Solar power was estimated to provide about 1250 to 1300 watts per square meter at balloon float altitude. The array was estimated to be about 70 square feet in area and weigh about 280 pounds. All four charge controllers would be identical and a total of six would be built; two would be spares.

2.4 Interface Wiring

The GRAD experiment consisted of several individual modules interconnected by cables. Integration of these modules with the AFGL balloon control and data acquisition/transmission system and to the power source batteries and solar array presented a difficult interface wiring problem.

3. GONDOLA CONFIGURATION

The gondola was configured as a pyramid, with a 3-shelf tier of platforms for mounting equipment (Figures 1 and 2). In this way, a specific weight and balance could be obtained to ensure that the gamma ray detector assembly would always have an unobstructed view to the incoming radiation from above. At the apex of the pyramid, a single point of suspension with specially designed fixtures allowed the payload rotator to provide a full 360 degree control of the payload in azimuth.

3.1 Recovery Parachute

Above the rotator, a torque-tube assembly was created using spreaders and stiffener rings in the risers and canopy of the 100-ft diameter, flat-circular canopy recovery parachute. The parachute was connected in line, directly from the top of the rotator to the base of the 11.6 million cu ft balloon which acted as a reaction mass for the rotator to torque against. Special consideration was paid to the design of all rigging to eliminate as much ferrous material as possible. In some cases titanium bolts were used and some standard balloon hardware devices were remanufactured.

3.2 Junction Boxes

To achieve a neat and serviceable design that allowed flexibility for testing and easy removal of sub-system components, we determined a junction box approach to be the best method to provide quick disconnect and replacement of major system modules. AFGL personnel implemented the junction-box concept on location at the Space Astronomy Laboratory on 26 September 1987. Junction box 450 contained 18 individual connectors with a wiring harness internal to the box. The 18 cables from various system components could be mated at the junction box and rerouted to the correct destination. The main gondola wiring consisted of some 30-odd multi-wire cables, exclusive of many coaxial cables for signal and radio frequency interconnections. Some split cables were unavoidable because of the various temperature sensor locations. Junction box 450 contained more than 300 wires and provided over 600 connections for telemetry and command.

A second junction box interconnected the rotator prime power source, the rotator electronics, the experiment dewar heaters and the sun indicator for telemetry and command. This unit, junction box 750, included the latching relays that switched power for the heaters and rotator. Figures 1, 2 and 3 show the relative size, shape and layout of the various gondola components.

The two solar array sections also required junction boxes for disassembly, power distribution and performance-monitor input to the AFGL encoder.

3.3 On-Board Instrumentation

Eighteen major flight-system components plus two ARGOS satellite system transmitters were mounted on the GRAD gondola. The ARGOS module had self-contained lithium batteries and a data interface that provided three pressure-altitude readings, three temperature readings and two azimuth orientation readings from the payload. Each ARGOS transmitter had its own antenna.

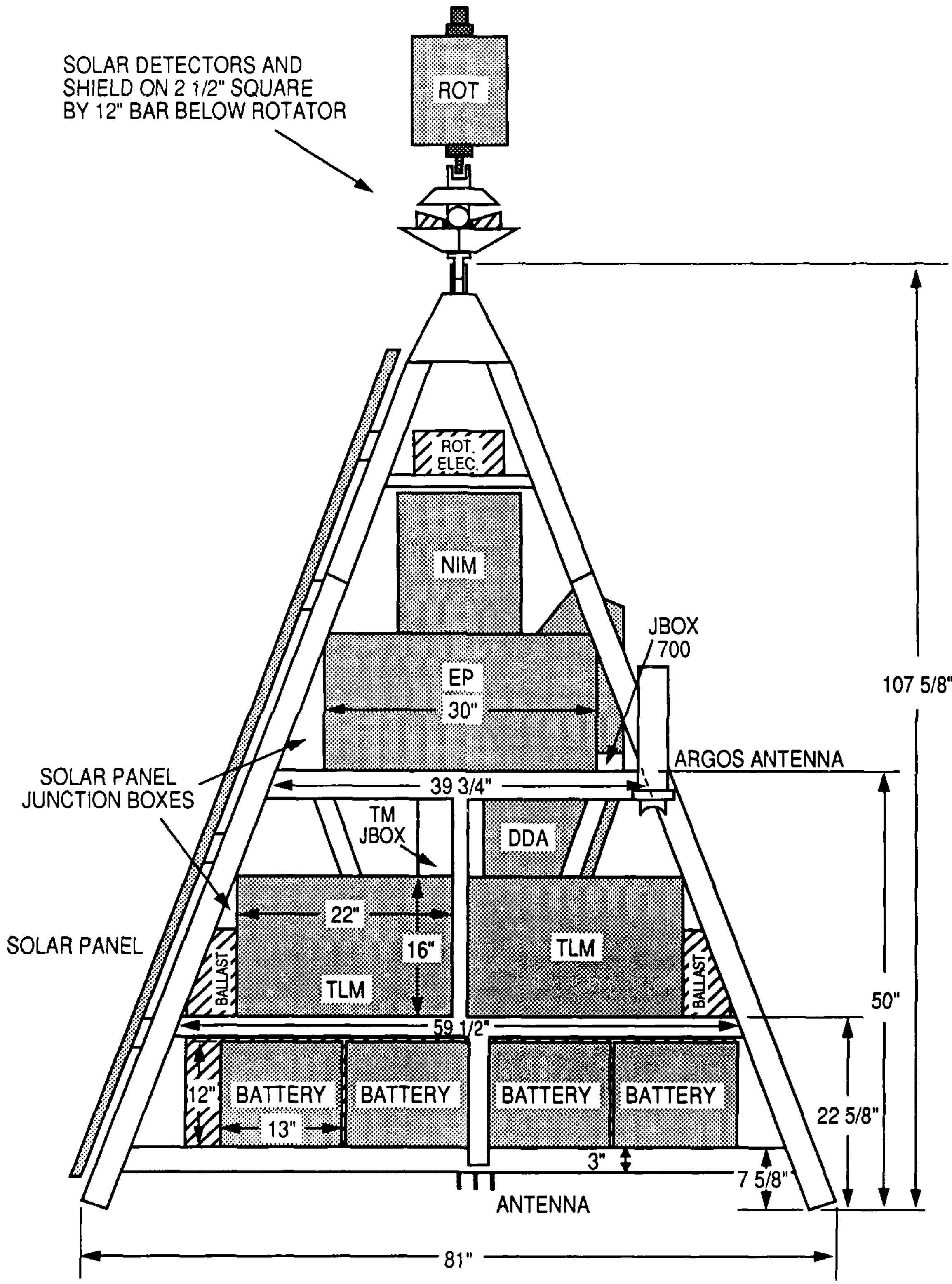


Figure 1. GRAD Gondola -X Side View.

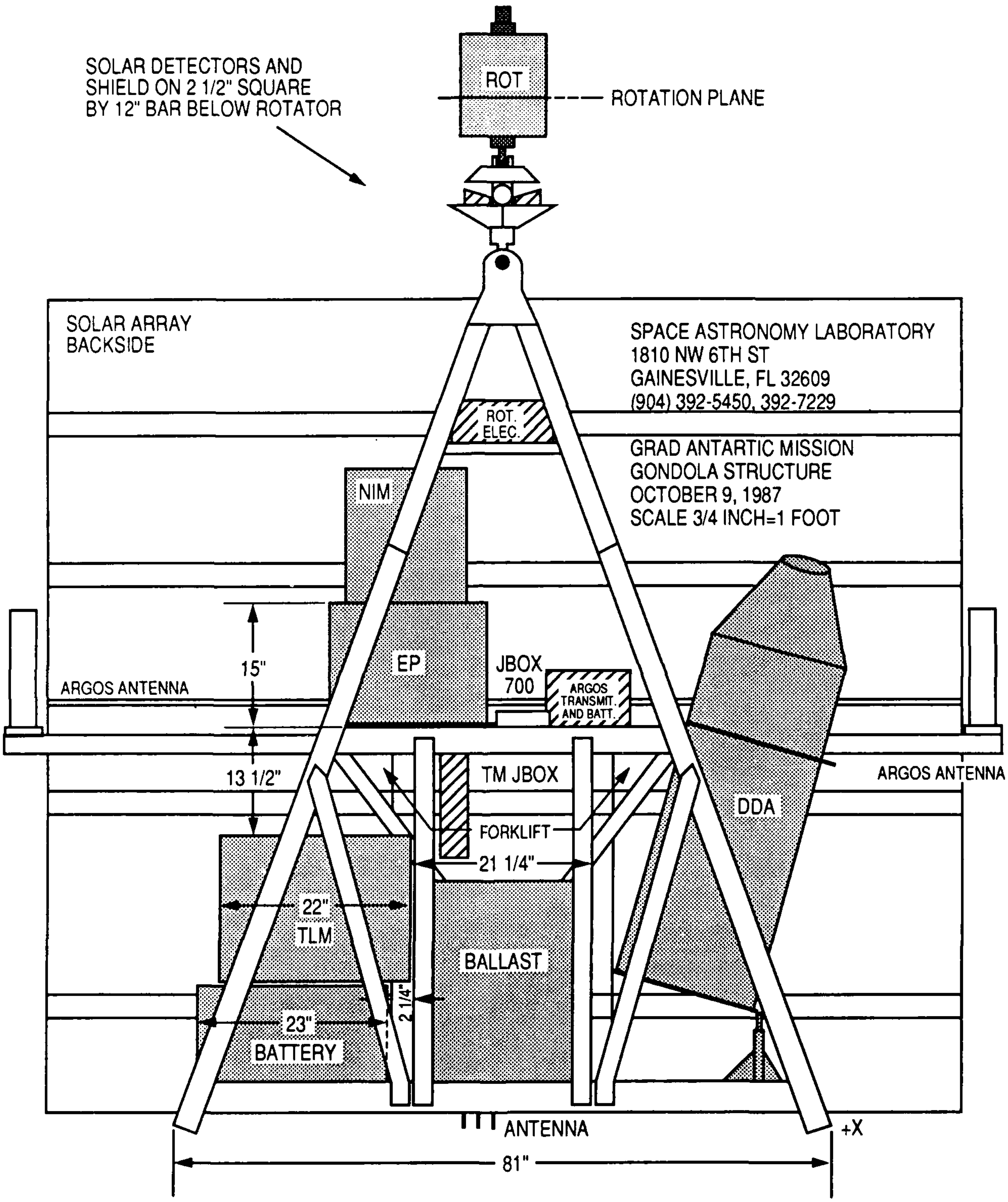


Figure 2. GRAD Gondola -Y Side View.

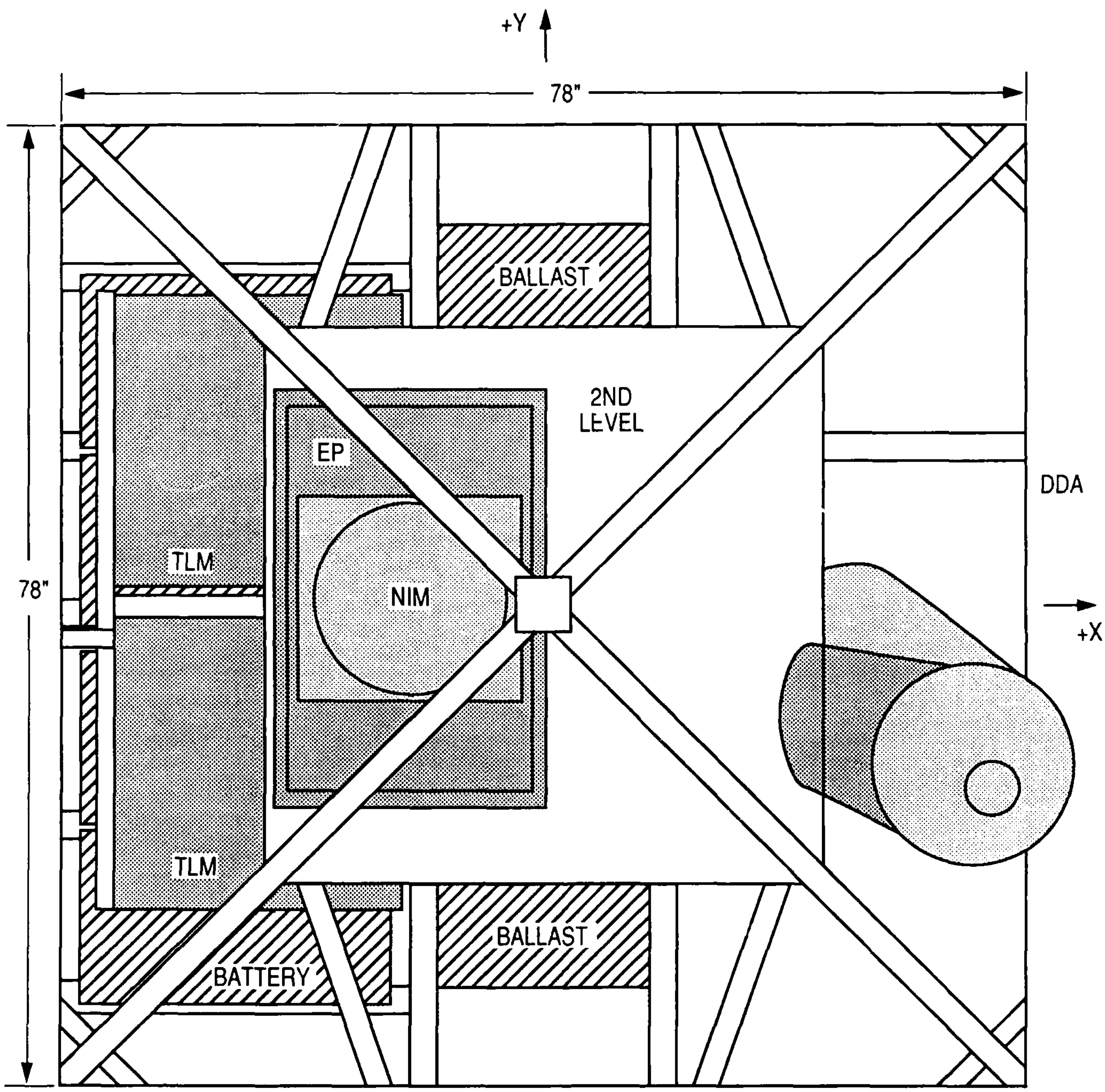


Figure 3. GRAD Gondola Top View.

3.3.1 ANTENNAS

The routing of rf cables and mounting of the 10 antennas necessary for the data transmitters, command receivers, UHF tracking beacon and the ARGOS tracking system were located so that signals received or transmitted were virtually unobstructed. The choice of position and the type of mounting provided for each antenna considered the shortest rf cable length, and reduced the likelihood of physical damage during balloon launching operations. The gondola overall size allowed adequate physical separation to minimize electrical interaction.

3.3.2 AFGL DATA TRANSMITTERS

The gondola carried four data transmitters, providing a primary and a back-up transmitter for each of the two downlinks, all switchable by command in case of failure or frequency interference. The data were transmitted using FM/PCM modulation in synchronous, serial-bitstream, standard IRIG (Inter Range Instrumentation Group) bi-phase level code, at 32 kilobits per second to conserve magnetic tape at the ground station.

4. COMMAND UPLINKS

The command uplinks for balloon flight-system control, primary and back-up, were digital frequency-shift-keyed (FSK) double scan, with selective address and parity FM serial bit streams at 360 baud. The experiment control uplinks were also FSK at 300 baud, using an RS-232 computer software-controlled, serial format. Both uplinks operated in the 430 MHz band. Three uhf command receivers were carried aboard the gondola, one in the primary instrumentation package and two in the back-up package. One receiver in the back-up package provided access to both the experiment control and the balloon flight-system control by utilizing special filters to discriminate between the different FSK audio frequency tones utilized for each. The experiment used 10.0 and 13.0 kHz while the AFGL command utilized 1440.0 and 1800.0 Hz. This approach provided full redundant back-up for control using two uplink frequencies with different addresses. Each control system could be reached by two independent transmission paths in case of component failure, antenna damage or frequency interference.

4.1 Rotator

The reference sensor normally used with the AFGL payload rotator is an Inland torque motor with a Develco, Inc., 2-axis, ring-core, fluxgate magnetometer, Model 9100. A magnetic reference would not be useable in the lower latitudes of Antarctica: For GRAD, the University of Florida converted the rotator magnetic reference to a solar reference made up of four sun sensors on a vertical axis, positioned 90 degrees apart in azimuth, and at a fixed elevation, with a unique sun-angle shade below the rotator slip-ring assembly. Using the sun as a reference, it was possible to command and hold a specific azimuth heading to within 2 degrees over the full 360 degrees of rotation capability.

5. SOLAR PANELS

The solar panels were SX-20 photovoltaic modules manufactured by the Solarex Corp., Rockville Maryland. Two sets of fifteen, 6-volt modules formed the array in the final flight configuration. Each section of the array had an insolation sensor (pyrometer) to measure the incident solar energy. A photocell sensor (sun indicator) with a very narrow field of view had a special mask (slit) that provided a voltage output whenever the solar panels faced the sun for optimum exposure within about 1 degree in azimuth. The solar-charging system was designed and built by the University of New Mexico Solar Energy Institute of Las Cruces, New Mexico.

6. AFGL INSTRUMENTATION PACKAGES

Figures 4 and 5 are block diagrams of the AFGL primary and back-up instrumentation packages. Because of the very tight schedule imposed by the logistics for the GRAD Antarctic expedition, it soon became obvious that considerable time would be saved if we could take an existing flight system and modify it to accomodate the GRAD requirements. We modified an AFGL flight system that had been flown to support a balloon-borne laser experiment, and fabricated a duplicate set of equipment as spares. This approach saved engineering time because most drawings already existed.

6.1 Flight Timers

A few unusual changes to the routine AFGL balloon system design concepts were necessary: The standard flight timer, which is normally settable to a maximum of 99 hours for flight duration, had to be modified to provide a maximum of 999 hours, and still retain all other standard features such as speed-up, add-time, and time-remaining status readout capability for telemetry. Circuitry and component changes were necessary, and additional testing was done to verify timer accuracy over the expected duration and anticipated ambient temperature cycle.

6.2 Independent Flight Termination Circuit

An independent, aneroid cell-controlled, last resort type, flight termination circuit was added to ensure that the mission would be properly terminated if the balloon with payload attached, should descend to the 40,000-ft pressure-altitude level. This independent flight termination circuit was added to the back-up balloon control unit and provided with an arm/disarm command and telemetry status indicator. For activation, it was independently powered by a long-life lithium battery with sufficient capacity to fire the squibs in the payload-separation-device under all anticipated environmental conditions. Activation of this circuit would prevent the possibility of a derelict balloon, floating aimlessly over the Antarctic, a potential hazard to aircraft.

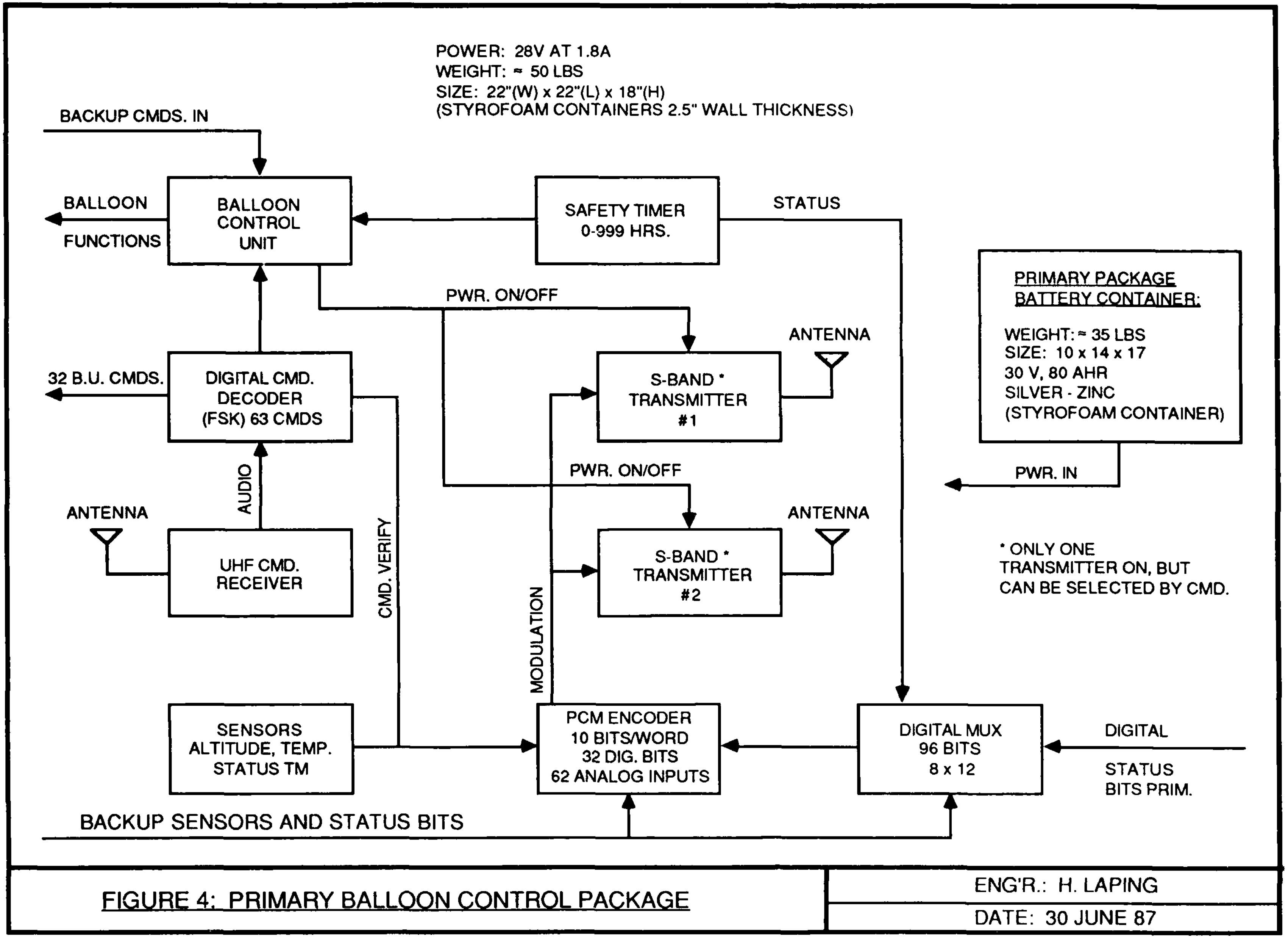


Figure 4. Primary Balloon Control Package

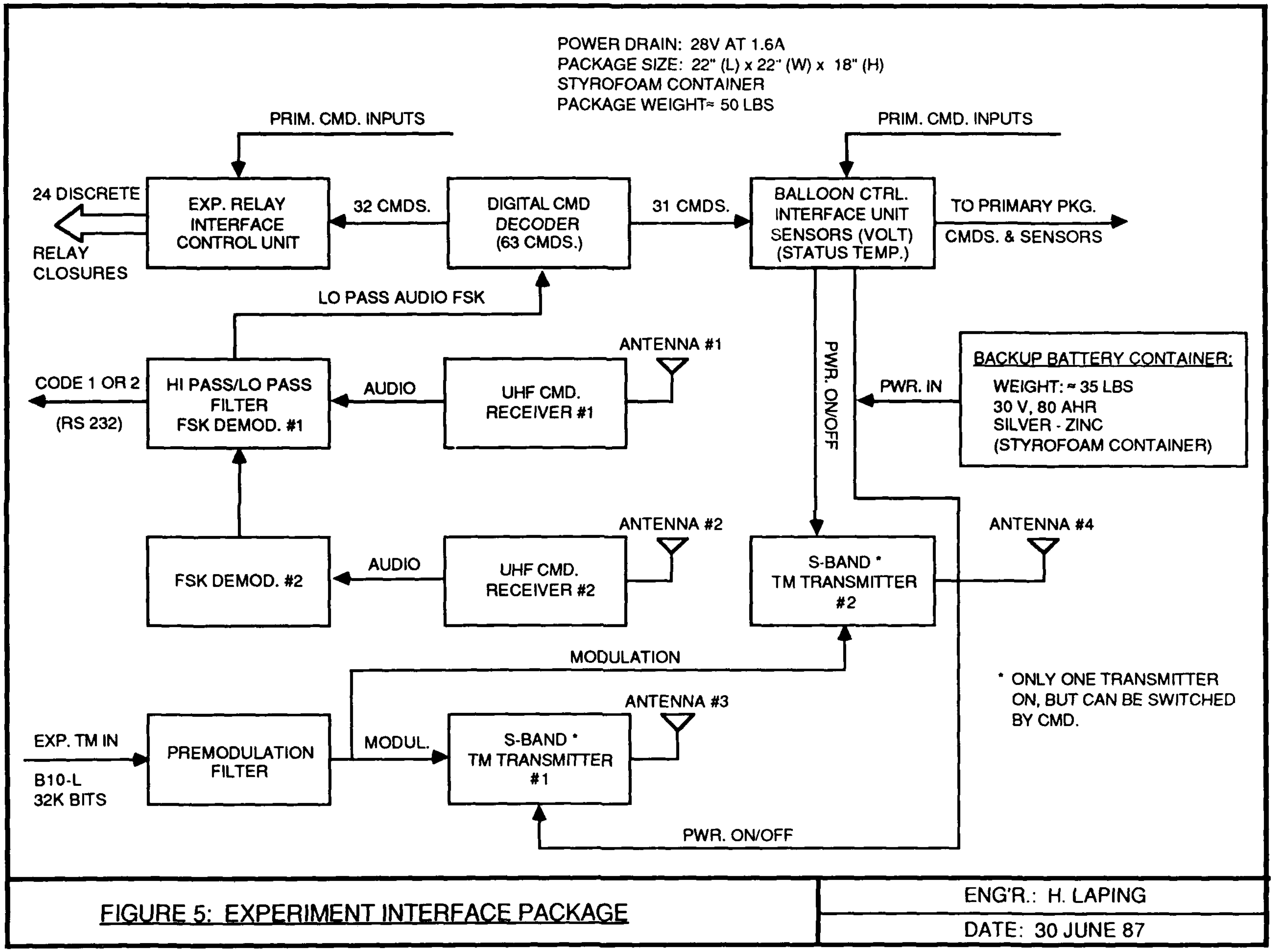


Figure 5. Experiment Interface Package

6.3 Automatic "Ballast Floor"

One additional change was made on location in Antarctica to provide an automatic "ballast floor", using the analog output voltage from the on-board high-altitude pressure transducer (0 to 0.5 psia) as a reference. A comparator circuit was installed and set that whenever the balloon descended below 100,000 feet, the ballast system was enabled for 1 minute out of 30 minutes. If at the end of 30 minutes, the balloon was below 100,000 feet, ballast would be poured for another minute, and so on. This circuit was also provided with an arm/disarm command and telemetry indicator. This change was implemented to ensure that the balloon system would stay aloft at least until all the pourable ballast was expended, or until the 40,000-ft, last resort termination circuit activated to end the mission.

6.4 Conclusions

The use of on-hand, flight-proven equipment with design modifications proved in the long run to have merit, as it allowed us to keep on schedule. Most of the changes occurred in harness wiring and in external cables. A special command interface relay control box was designed and built to match the GRAD requirements specifically. This new module was tailored to fit existing harness wiring and provided 31 redundant circuit closures. Two different command channels and independent relays were provided for each function to obviate the effects of component failure. All commands could be accessed via either primary or back-up command links, thus ensuring positive system control as long as the balloon was within line-of-sight range of either a tracking aircraft or a suitably equipped ground station.

7. SYSTEMS TESTS

On 21 October 1987, two complete sets of instruments were ready and available to begin altitude-chamber testing at the Holloman facility. Preliminary testing with the GRAD experiment had been fully successful and no serious rf interference had been noted. Successful open-loop telemetry checks had been completed and all systems fully integrated, including the solar panel arrangement. The altitude chamber tests were successfully completed between 26 and 30 October. The all-up, full-system test was completed successfully on 3 November. On 13 November the flight system with spares was on the way via C-141 special airlift to McMurdo Base, Antarctica - a little more than 60 days from the actual start of the GRAD payload integration effort.

Appendix A: Command Lists

Figures A-1 and A-2 show the command lists for the experiment and balloon control. The command numbers indicate individual channels and the first digit indicates the address code. This command system designed and built by AFGL can utilize address codes 1 through 9 for any uplink frequency.

EXPERIMENT COMMANDS

Project : GRAD Date : 17 Oct 87
Receiver Type: Vector / Conic
RX #1: 423.6 MHz RX #2: 437.5 MHz RX #3: 437.5 MHz

CMD	FUNCTION
132-232	GRAD Power ON
133-233	GRAD Power ON (R)
134-234	GRAD Power OFF
135-235	GRAD Power OFF (R)
136-236	SYSTEM RESET
137-237	SYSTEM RESET (R)
138-238	SWAP CPU
139-239	SWAP CPU (R)
140-240	ROTATOR ON
141-241	ROTATOR OFF
142-242	ROTATOR ON (R)
143-243	ROTATOR OFF (R)
144-244	HEATER ON
145-245	HEATER OFF
146-246	HEATER ON (R)
147-247	HEATER OFF (R)
148-248	HV STANDBY ON
149-249	HV STANDBY OFF
150-250	HV STANDBY ON (R)
151-251	HV STANDBY OFF (R)
152-252	BGO VETO DISABLE
153-253	BGO VETO ENABLE
154-254	BGO VETO DISABLE (R)
155-255	BGO VETO ENABLE (R)
156-256	SELECT FSK CODE #1 OUTPUT
157-257	SELECT FSK CODE #2 OUTPUT
158-258	SHUTDOWN OVERRIDE OFF
159-259	SHUTDOWN OVERRIDE ON
160-260	SHUTDOWN OVERRIDE OFF (R)
161-261	SHUTDOWN OVERRIDE ON (R)
162-262	40 Kft ANEROID ARM
163-263	40 Kft ANEROID DISARM

Figure A-1. Command List for Experiment

Balloon Control Commands

Project : GRAD Date : 17 Oct 87
Receiver Type: Vector / Conic
RX #1: 423.6 MHz RX #2: 437.5 MHz RX #3: 437.5 MHz

CMD	FUNCTION
101-201	TX #1 ON (in Prim, Bln TM)
102-202	TX #1 OFF
103-203	Add 10 hr to Flight Timer (in Prim)
104-204	BURST Switch ARM (Prim)
105-205	BURST Switch DISARM
106-206	IMPACT Feet ARM (Prim)
107-207	IMPACT Feet DISARM
108-208	BALLAST Blow (NOT USED FOR GRAD)
109-209	TX #3 ON (in BU, GRAD TM)
110-210	TX #3 OFF
111-211	TX #2 ON (on Plate Prim, Bln TM)
112-212	TX #2 OFF
113-213	
114-214	
115-215	
116-216	
117-217	LATCH He Valve OPEN
118-218	
119-219	He Valve OPEN Failsafe & UNLATCH Valve
120-220	TERMINATION-Valve
121-221	TERMINATION-Valve
122-222	
123-223	
124-224	BEACON ON (242.0 MHz)
125-225	BEACON OFF (242.0 MHz)
126-226	TX #4 ON (on plate BU GRAD TM)
127-227	TX #4 OFF
128-228	LATCH POUR Ballast
129-229	POUR Ballast OPEN Failsafe & UNLATCH
130-230	ARM AUTO BALLAST
131-231	DISARM AUTO BALLAST

Figure A-2. Command List for Balloon Control

Appendix B: Telemetry Channel Assignments

Figures B-1 and B-2 list the balloon down-link telemetry channel assignments. A digital multiplexer and PCM (pulse-code-modulation) data encoder designed and built by AFGL provided the 96 digital-bit status indicators for GRAD housekeeping monitors. This fully programmable encoder provided 60 analog data channels.

PCM ENCODER 1M-64 DATA	PROJECT: GRAD (BLN)
Bit Rate: 32 kbits/sec	Bits/Word: 10
Words/Frame: 65 (63 Data)	Code Type: BIO-L
Subframes: 1 (8X12 Digital)	TM Freq: ____________ MHz

ENCODER FORMAT (Analog & Digital Input Range is 0 to 5V)

Word No.	Function
000	Sync 11 11 00 11 01 MSBF
001	Sync 10 10 10 00 00 MSBF
	X= Q5 Q4 Q3 Q2 Q1 Q5=MSB
D1 002	SFID XX XX X0 00 00 (count UP start at 0)
D2 003	Digital subframe 10bits X 8 Frames
D3 004	Digital Subframe 2 bits X 8 Frames Remaining 8 bits are not subcommutated
A4-A63	Analog Inputs (Word 005-064)

Digital Subframe D2 and D3 (Word 003 & 004)

Bit/Frame		Function	
D2	1-0	0	Primary Cmd Reply
	2-0	0	
	3-0	0	
	4-0	64	
	5-0	32	
	6-0	16	
	7-0	8	
	8-0	4	
	9-0	2	
	10-0	1	
D3	1-0	Execute	
	2-0	0	
D2	1-1	0	Digital Timer Status
	2-1	0	
	3-1	0	10's of hours
	4-1	64	
	5-1	32	1's of hours
	6-1	16	
	7-1	8	
	8-1	4	
	9-1	2	
	10-1	1	
D3	1-1	Add Time ON	
	2-1	UNITS HOURS	

Figure B-1. Digital Bit/Subframe Assignments

PCM ENCODER 1M-64 DATA	PROJECT: GRAD (BLN)
Digital Subframe D2 and D3 (Word 003 & 004)	
Bit/Frame	Function
D2 1-2	0 Backup Digital Cmd Reply
2-2	0
3-2	0
4-2	64
5-2	32
6-2	16
7-2	8
8-2	4
9-2	2
10-2	1
D3 1-2	Execute
2-2	0
	GRAD housekeeping #1
D2 1-3	DATA Auto int ENABLE (MSB)
2-3	Manual aquire ON
3-3	ADC - 3 ENABLE
4-3	ADC - 2 ENABLE
5-3	ADC - 1 ENABLE
6-3	Auto rotation ENABLE
7-3	Long dump
8-3	BGO Veto ENABLE
9-3	0 (SPARE #1)
10-3	0 (SPARE #2) (LSB)
D3 1-3	TX #1 ON
2-3	TX #2 ON
	GRAD housekeeping #2
D2 1-4	Active CPU "B" ACTIVE (MSB)
2-4	System reset
3-4	Auto bias ON
4-4	Long data int ON
5-4	BGOB high voltage ON
6-4	BGOA high voltage ON
7-4	GE detector ON
8-4	HV standby ON
9-4	0 (SPARE #3)
10-4	0 (SPARE #4) (LSB)
D3 1-4	TX #3 ON
2-4	TX #4 ON
Note: All unused digital inputs are grounded by a pull down resistor in the encoder and Multiplexer.	

Figure B-1. Digital Bit/Subframe Assignments

PCM ENCODER 1M-64 DATA PROJECT: GRAD (BLN)

Bit/Frame	Function
D2 1-5	Ballast #1
2-5	Ballast #2
3-5	0
4-5	0
5-5	Impact ARM
6-5	10K Simulate ON
7-5	Burst Switch ARMED
8-5	Burst < 10K
9-5	Burst > 10K
10-5	HE Valve OPEN
D3 1-5	Prime TERMINATION
2-5	BU TERMINATION
	<u>GRAD housekeeping #3</u>
D2 1-6	0
2-6	ROTATOR POWER ON (MSB)
3-6	HEATER POWER ON
4-6	SUN INDICATOR SUN
5-6	GRAD BATTERY #1 CONN
6-6	PRIM BATTERY #2 CONN
7-6	BKUP BATTERY #3 CONN
8-6	HTRT BATTERY #4 CONN
9-6	0 (SPARE #5)
10-6	0 (SPARE #6) (LSB)
D3 1-6	40 Kft ANEROID ARM
2-6	BEACON POWER ON
D2 1-7	FSK #2 Code Selected
2-7	Auto Ballast Arm
3-7	Auto Ballast ON (Alt $\le$ 100 kft)
4-7	0
5-7	0
6-7	0
7-7	0
8-7	0
9-7	0
10-7	0
D3 1-7	0
2-7	0
3 *	0 * NOT SUBCOMMUTATED
4 *	0
5 *	0
6 *	0
7 *	0
8 *	0
9 *	0
10 *	0

Figure B-1. Digital Bit/Subframe Assignments

PCM ENCODER 1M-64 DATA	PROJECT: GRAD (BLN)	
	ANALOG INPUTS	
Word	Function	D-PAD
A 4	Ground Prim	005
A 5	Prim 28V (V/8)	006
A 6	12V (V/8)	007
A 7	5.2V (V/2)	008
A 8	Prim Current (0.5V = 1A) 0 TO 10 AMPS	009
A 9	BU 28V (V/8)	010
A10	12V (V/8)	011
A11	5.2V (V/2)	012
A12	BU Current (0.5V = 1A) 0 TO 10 AMPS	013
A13	RT #1 Prim Int Temp (YSI 10.25V 100K 100K)	014
A14	RT #2 TX #1 in Prim Pkg	015
A15	RT #3 TX #2 (on plate outside)	016
A16	RT #4 1M-64 Encoder	017
A17	RT #5 Prim Battery #2	018
A18	RT #6 GRAD Battery #1	019
A19	RT #7 Solar Array #1	020
A20	RT #8 BU Internal Temp (YSI 10.25V 100K 100K)	021
A21	RT #9 BU Battery #3	022
A22	RT #10 HTR/RTR Battery #4	023
A23	RT #11 TX #3 BU int GRAD TM	024
A24	RT #12 TX #4 (outside on BU plate GRAD TM)	025
A25	RT #13 Solar Array #2	026
A26	RT #14 Solar Array #3	027
A27	0-15 PSIA (Low Alt) See Tech Data	028
A28	0-2 PSIA (Med Alt)	029
A29	0-.5 PSIA (Hi Alt)	030
A30	X-Axis (+/- 2.5g)	031
A31	Y-Axis (+/- 2.5g)	032
A32	Z-Axis (+/- 2.5g)	033
A33	Z-Axis (+/- 7.5g)	034
A34	Prim Cmd Reply (50 mV/Cmd + 25mV Execute)	035
A35	BU Cmd Reply "	036

Figure B-2. Analog Word Assignments

PCM ENCODER 1M-64 DATA PROJECT: GRAD (BLN)		
ANALOG INPUTS		
Word	Function	D-PAD
A36	Timer (50 mV/hr + 25 mV Add 10 hr)	037
A37	RX #1 (Prim) Sig Strength	038
A38	RX #2 (BU) Sig Strength	039
A39	RX #3 (BU) Sig Strength	040
A40	UPPER ARRAY VOLTAGE (V/11)	041
A41	LOWER ARRAY VOLTAGE (V/11)	042
A42	SPARE (ARRAY TEMP #4 LM-335Z)	043
A43	SYSTEM ZERO CAL. (GND IN J-BOX 450)	044
A44	GRAD batt 1 current 0 TO 20 AMPS	045
A45	PRIM batt 2 current (0.25 VOLT/AMP)	046
A46	BKUP batt 3 current "	047
A47	RTHT batt 4 current "	048
A48	SOL ARR U 1 I to GRAD & batt 1 0-50 AMPS	049
A49	SOL ARR U 2 I to PRIM & batt 2 (0.1 V/A)	050
A50	SOL ARR L 1 I to BKUP & batt 3 "	051
A51	SOL ARR L 2 I to RTHT & batt 4 "	052
A52	Upper dewar temp 1 (LM335Z @ 5.2 V	053
A53	Lower dewar temp 2 2.2 K/100 K OHM)	054
A54	Elect box temp 3 V(100)-273 = TEMP C	055
A55	NIM box temp 4 10 mV/deg K	056
A56	RTR box temp 5 "	057
A57	Sun sen temp 6 "	058
A58	GRAD batt 1 + 27 Volt (V/11)	059
A59	PRIM batt 2 + 27 Volt "	060
A60	BKUP batt 3 + 27 Volt "	061
A61	RTHT batt 4 + 27 Volt (V/11)	062
A62	UPPER "Pyronometer"	063
A63	LOWER "Pyronometer"	064

Note: Word numbers such as 025 is the D-Pad Display.

D1 to A64 are the word numbers after Sync.
D = Digital. A = Analog

Figure B-2. Analog Word Assignments

Contents

4. Airborne Telemetry Station for GRAD

by

Willard F. Thorn

1. HISTORY

The GRAD balloon would, of course, drift with the wind. There were several theories as to where it would go. The first was that it would drift west, staying at a constant latitude. The second theory was that it would drift east, at a constant latitude. The third was: the path would be determined by the time when we launched in relation to when the upper air turnaround in the Antarctic actually occurred. Everyone agreed that the balloon would disappear over the horizon; depending on wind speed, the horizon would be 12 to 48 hours away.

The telemetry (TM) system flown on GRAD required line-of-sight between the balloon and the TM receiving station. After the balloon reached the horizon there would be no more data. One to two days data from a possible three-week flight were not acceptable. Several solutions were proposed. All but one were found to be impractical or impossible due, in part, to our lead-time constraints. The workable solution was to fly a TM station on board an LC-130 aircraft.

A TM station on board an LC-130 would allow the TM station to go to the balloon wherever it drifted. The National Science Foundation LC-130 aircraft had enough range and endurance to fly up to

1500 miles, circle for an hour and return to the starting point. This capability provided coverage to almost the entire Antarctic continent. See Figure 1.

2. IMPLEMENTATION

The most likely aircraft flight scenario was a flight of opportunity. We would be invited on a flight of opportunity only if we would have little or no impact on the original mission. This meant we had to be able to move our equipment in and set it up on a moment's notice - the entire system had to be as light and compact as posssible. By going on a flight of opportunity we would have minimal impact on the busy flight schedule.

2.1 TM Station Subsystems

Figure 2 is a block diagram of the TM system designed for the LC-130. The four subsystems are the receiving/transmitting equipment, the data-recording equipment, the antenna system, and the power source.

Modifications to the aircraft were against the rules. The only exception was that we might be able to mount antennas to a hatch cover. The hatch cover is not a structural part and therefore would not need so high a level of approval. In the past, other organizations had mounted antennas to hatch covers and had them approved. Mounting to a hatch cover also gave us the flexibility to move quickly from plane to plane by swapping hatch covers.

2.2 TM Station Setup

The best place in the aircraft to set up the station was against the forward bulkhead. See Figure 3. Freight was normally loaded aft, and passengers in the front. By stowing one set of seats we could install our station. This location had several other benefits: It was near the cargo-winch power plug; the hatch cover with the best access is over the cockpit, about 10 feet away; and finally, this location provided good communication with the flight crew.

The minimum equipment that would be needed to operate a TM station aboard the LC-130 included: an S-band receiver, two command transmitters; a power supply for the transmitters, a command generator and RS-232 Converter, a D-pad or a PCATS computer, the Florida computer, a 3500-watt inverter, and a bit synchronizer. For the most part, this is the same equipment used in the ground station, just less of it.

2.3 Equipment Racks

Almost all of the equipment was small enough to fit in two shock-mounted racks. See Figure 4. These racks, while heavy, could be carried by two people. The antennas were mounted to a hatch cover and two last-minute items, the power conditioner and cassette recorder, were strapped to the floor.

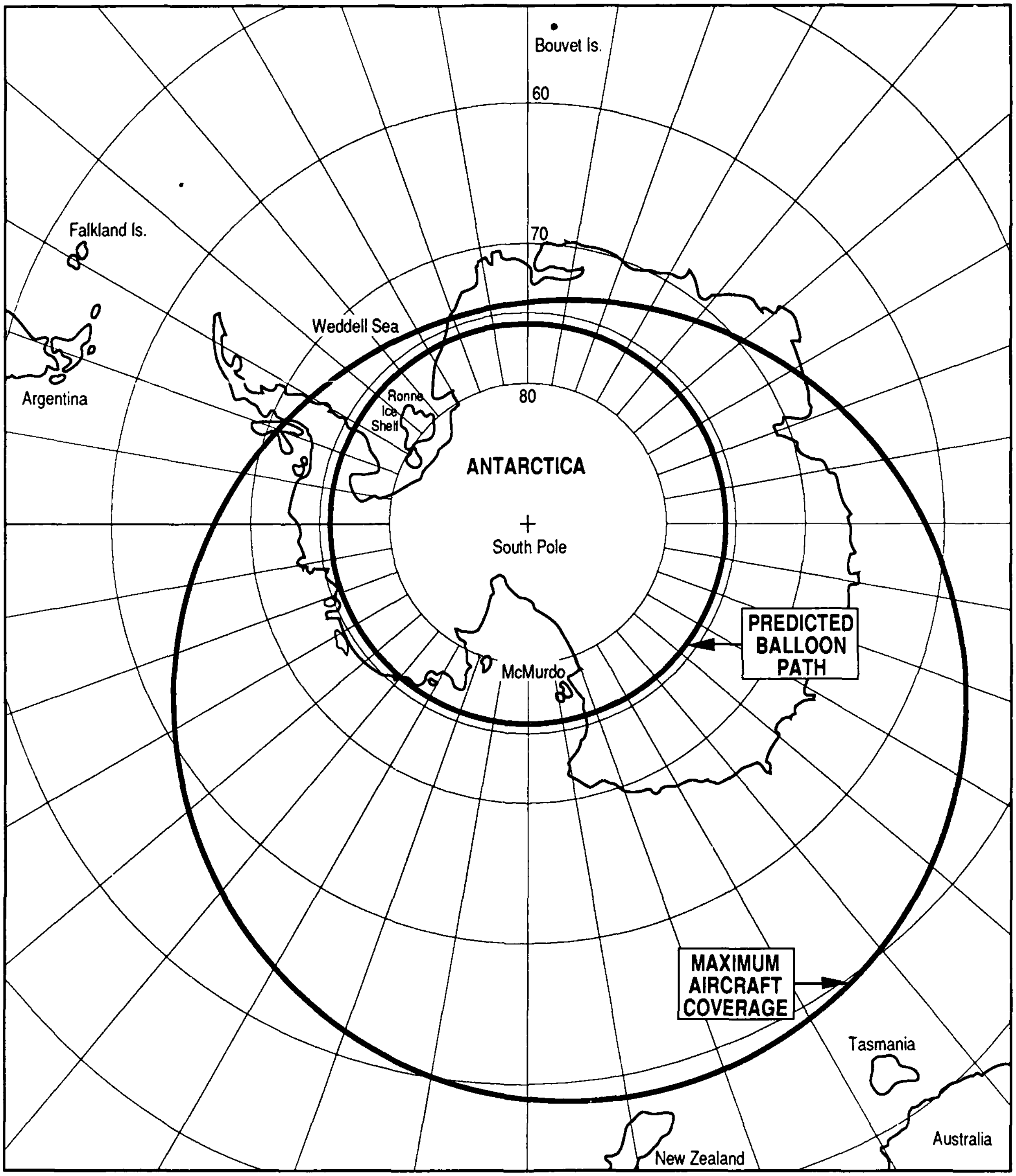


Figure 1. Aircraft TM Coverage

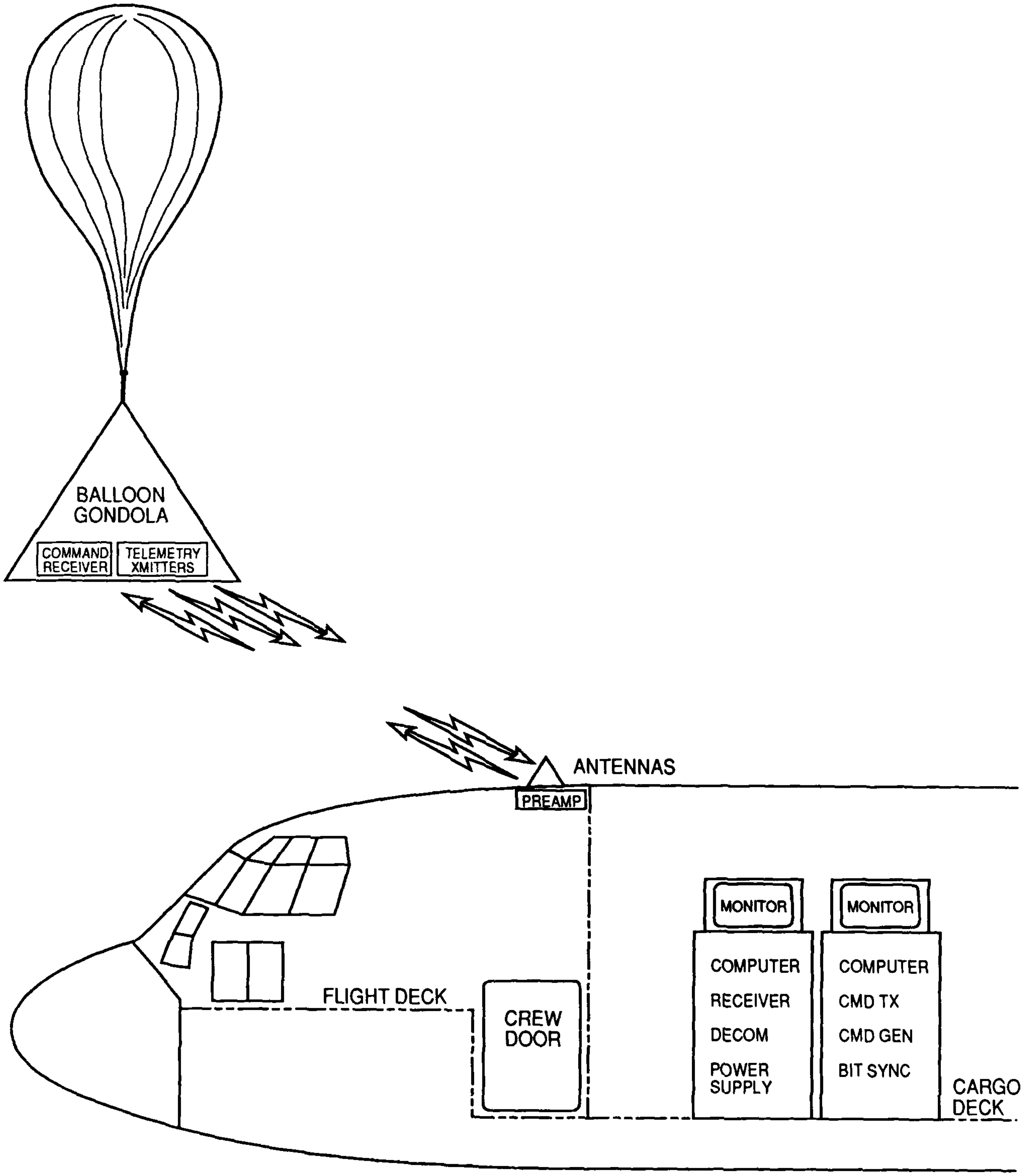


Figure 2. TM System Block Diagram

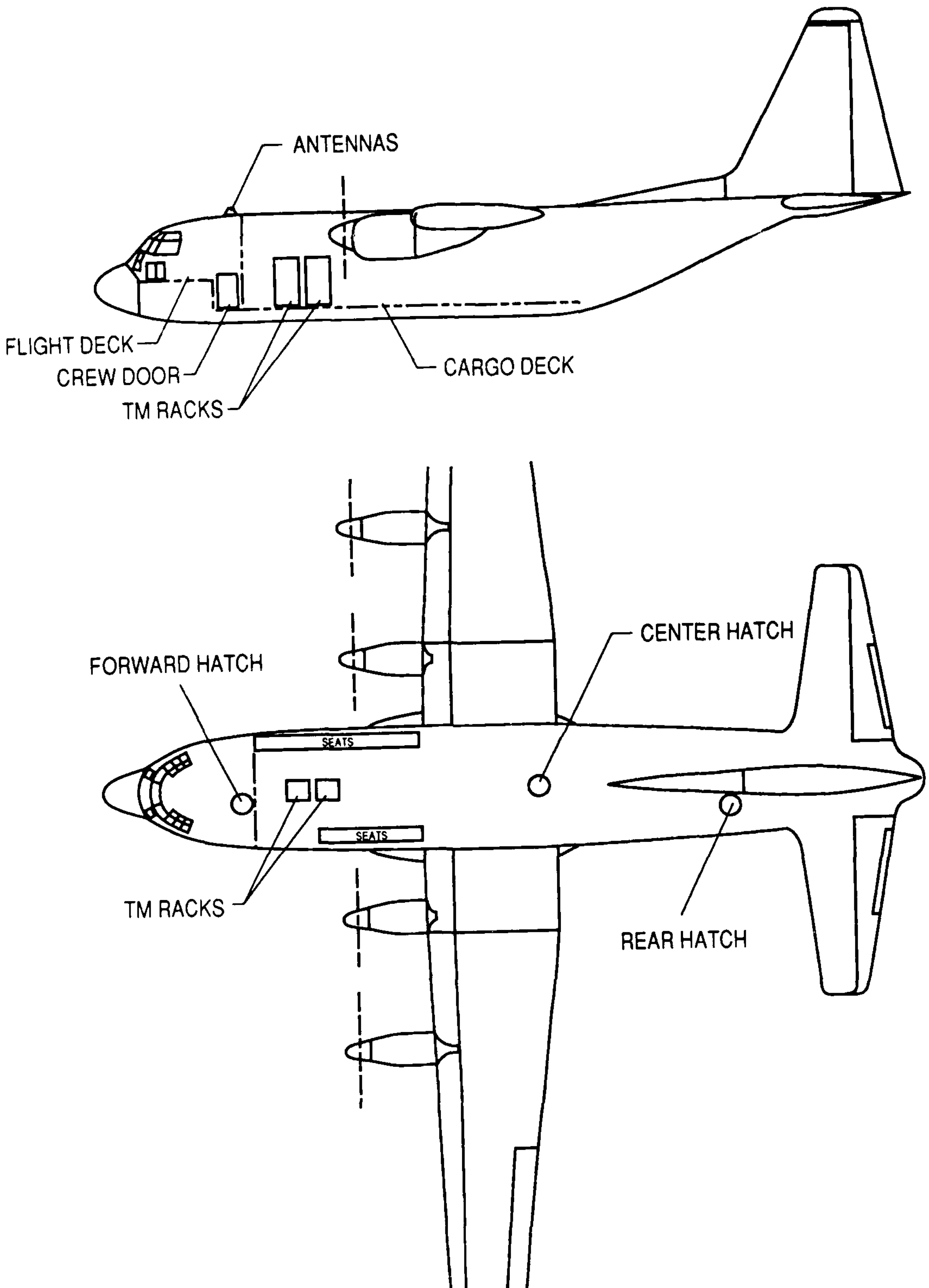


Figure 3. Aircraft Layout

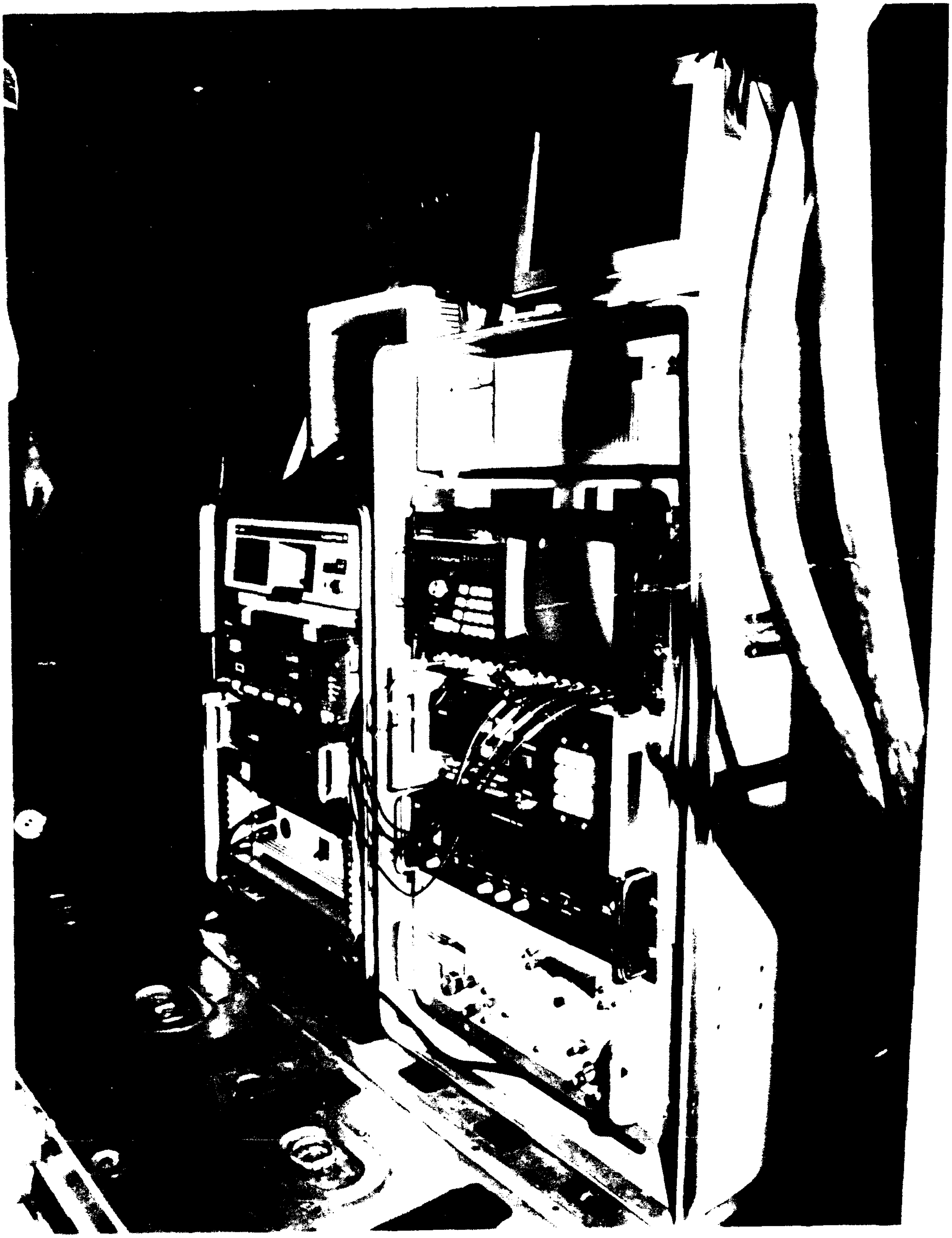


Figure 4. Equipment Racks

The racks were Fiberglas shipping containers. Nineteen-inch electronic-equipment racks were mounted in the containers using rubber vibration isolators. This arrangement cannot prevent vibration of the equipment, but it can provide a softer ride. The equipment was arranged in the racks to provide equal weight to each rack. Consideration was also given to minimizing wiring between the racks.

2.4 Power Supply

Power for the TM station was provided from the aircraft. The aircraft has a power outlet on the forward bulkhead for the cargo winch. The power outlet is rated for 28 volts DC at 300 amperes. A 3500-watt DC to AC converter was connected. The inverter could supply 30 amperes at 120 volts. We needed 12 to 14 amperes continuously, with surges up to 25 amperes during equipment turn-on.

The inverter output was 60 Hz at 120 volts. However, the output was not sinusoidal, but more like a square ware. This worked very well for most of the equipment, but the computers did not like it. A power-line conditioner was added to filter out power-line transients. The conditioner was not intended to make sine waves out of square wares. It did smooth the inverter output enough to keep the computers happy.

2.5 Antennas

The antennas provided the most challenge associated with the LC-130 TM station. There had to be two: one for receiving S-band telemetry on 2238 and 2258 MHz, and one for transmitting commands to the payload and balloon controls on 423.6 and 437.5 MHz. To cover a reasonably long balloon-to-aircraft distance on S-band, the receive antenna needed as much gain as possible.

The antennas had to be outside, on top of the aircraft. They had to be installed without modifying the aircraft, and they had to survive the flight environment. (That means they had to work during the flight and not endanger the aircraft.)

The only reasonable place to mount the antennas was on a hatch cover. The LC-130 has three hatch covers on top, located in the front, the center, and aft, as shown in Figure 3. The best choice was the front. The hatch cover is a 22-in diameter, pressure-tight door for emergency escape, shown in Figures 5 and 6. The pressure seal integrity had to be maintained. The outside skin is nearly flat. The inner, pressure-tight skin is a spherical section. The space between skins varies from 2 inches at the edge of the cover to 0.5 inch in the center.

The transmitting antenna was a simple blade. It is an approved aircraft antenna, but it had never been installed on a hatch cover before. It was mounted on the starboard edge of the cover. A doubler was used inside the outer skin. The feed was long enough to reach through the inner skin. The hole through the inner skin was sealed with RTV.

The antenna selected for the telemetry receive link was a 4-element phased array, diagrammed in Figure 7. Each element was tuned to a 1/4 wavelength and then mounted on a 1/8 inch thick aluminum plate 6 inches in diameter. The elements are in line, 1/4 wavelength apart. A second identical array was mounted to the same plate perpendicular to the first array.

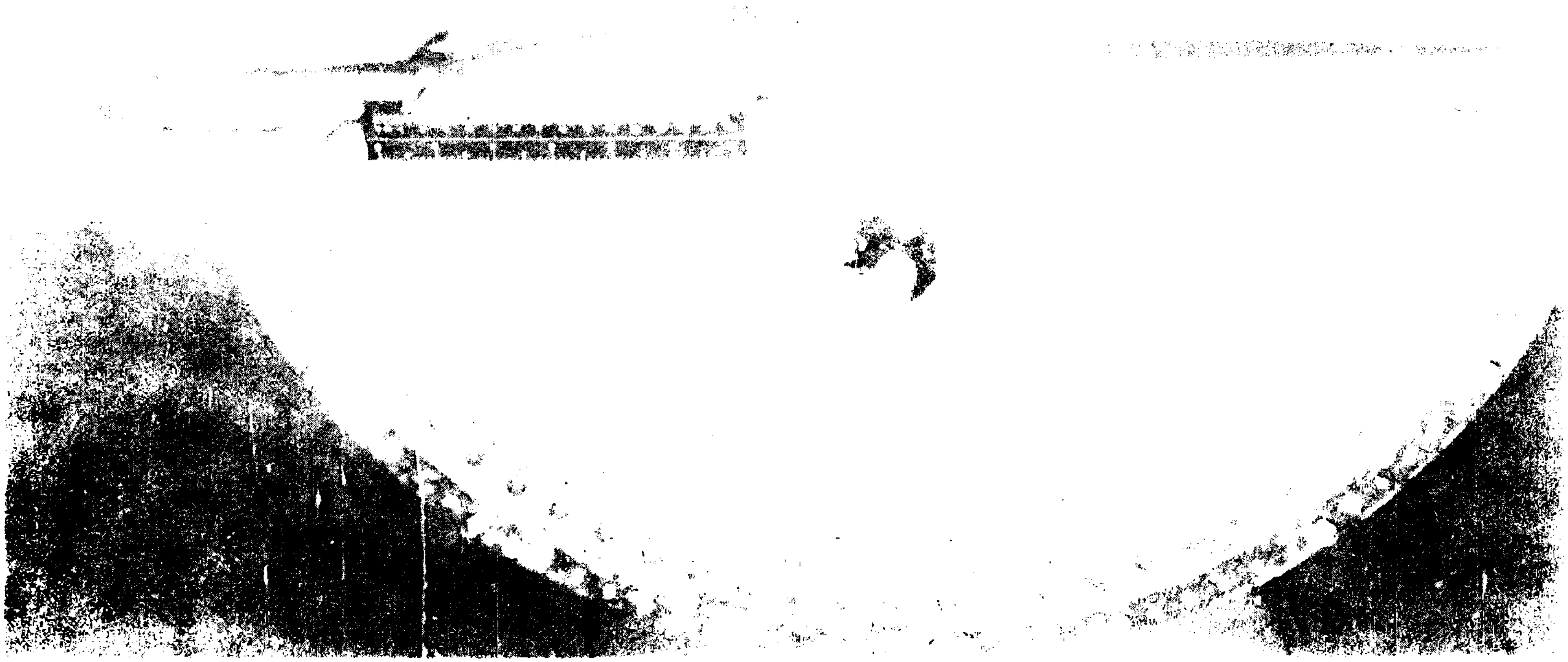


Figure 5. [illegible]

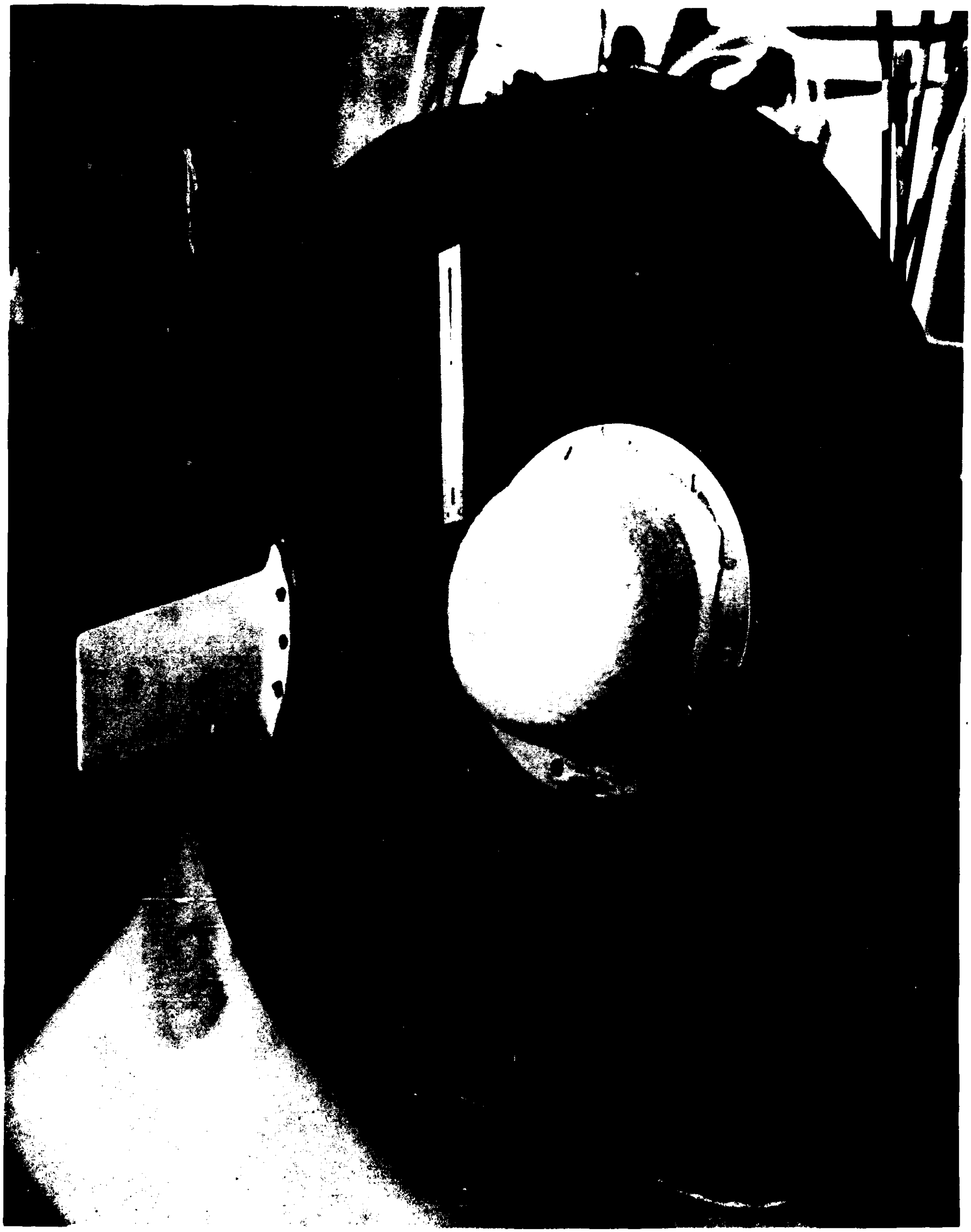


Figure 6. Hatch Cover Antenna, Outside

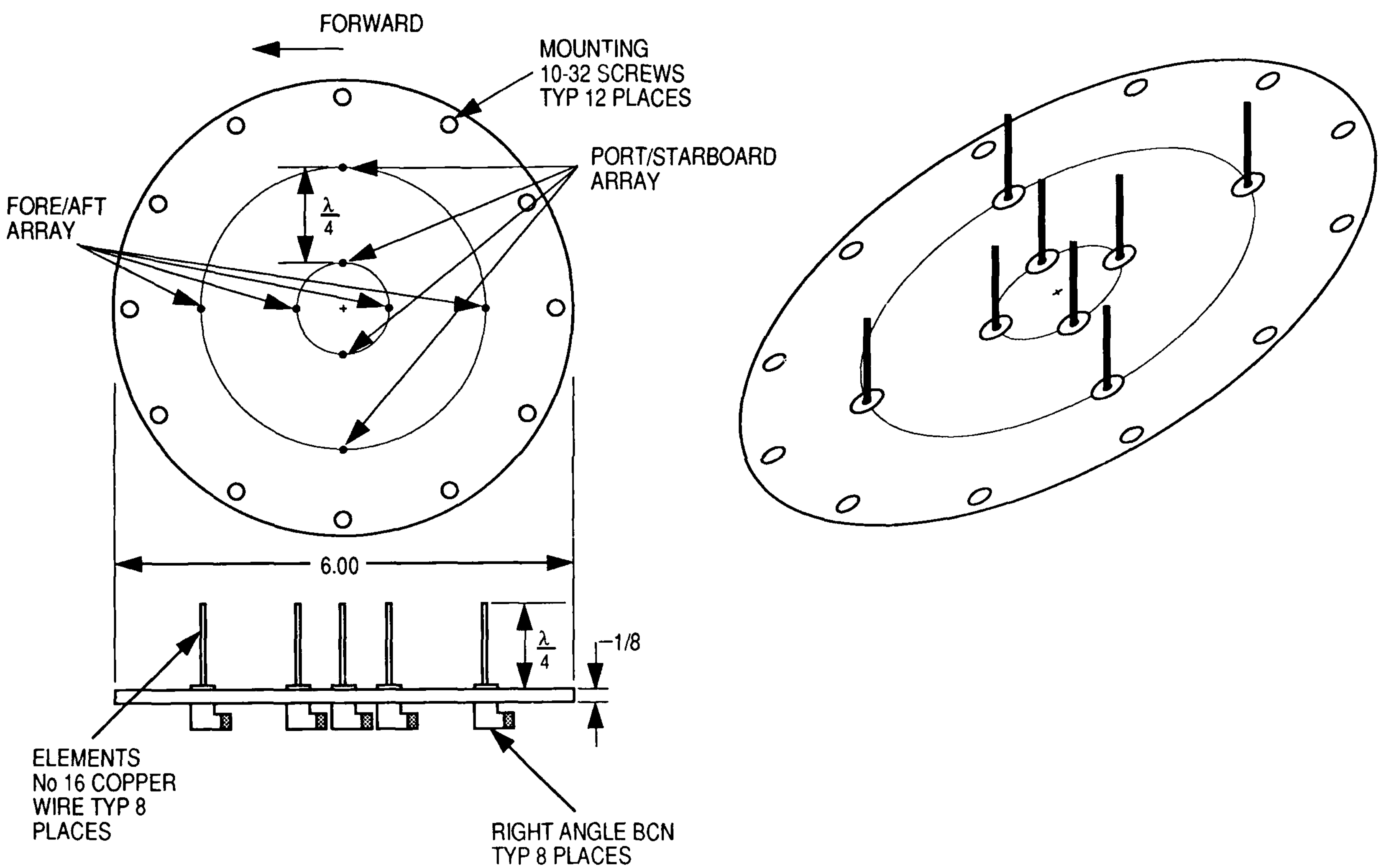


Figure 7. S-Band Array

A printed-circuit phasing device was used. It is diagrammed in Figure 8. The PC board was 6 inches square. OSM-type connectors were soldered directly to the PC board which was connected to the four elements with equal-length coaxial cables 12 inches long. By selecting an array and the order in which the elements were connected, the directional characteristics of the antenna could be adjusted to point to the balloon.

The antenna pattern looking at the horizontal plane covered about 80 degrees: 40 degrees either side of the line through the elements, as indicated in Figure 9.

Looking at a vertical plane through the elements, the pattern resembled a teardrop with its point at the antenna. The peak gain of the antenna was about 8 dB at elevation angles between 10 and 20 degrees.

The balloon range vs elevation angle is a fixed function for any particular height of balloon above the aircraft. As the balloon gets closer, less antenna gain is needed. The receiver antenna gain pattern coupled with the range versus elevation function provided a maximum range of 130 miles for data with a 16 dB signal-to-noise (SNR) ratio. The data could be received to about 220 miles if a 12-dB SNR could be tolerated. The balloon data link can get by with the lower SNR and the associated higher error rate. As a result, the balloon data link had a maximum range similar to the balloon command link.

A 20-dB gain, low-noise preamplifier mounted to the inside of the hatch cover gave good signal to the receiver even though it was located about 20 feet away from the antenna.

An S-band, band-pass filter was placed between the phasing PC board and the preamplifier. This prevented RF energy from the command link from getting into the receive system.

2.6 On-Board Data Recorder

Our AFGL data recorders are bigger, heavier, and draw more power than we could accept for use aboard the aircraft. The solution was a high-quality stereo cassette recorder. It had recording capability to 20 kHz frequency at the -3 dB point. Our two downlinks (for the balloon and experiment data) were encoded at 32 kilobits per second (kBPS) in BiO-L code. This code has a prime frequency of 32 kHz, too high for the recorder. A code converter was used to convert the BiO-L to NRZ-S code. The 32-kb NRZ code has a prime frequency of 16 kHz. The experiment data frequently had long strings of zeros. The S-code provided transitions for each zero thus maintaining the AC quality of the original code. This was necessary because the recorder will not record DC. After the flight the cassette tape was dubbed to the normal data recorders. The dubbed tapes were used for data play-back.

3. TESTING

The airborne telemetry station was sufficiently important to the GRAD program that a C-130 aircraft was flown to Holloman AFB for testing. (The only difference between a C-130 and an LC-130 are the skis on the LC-130.)

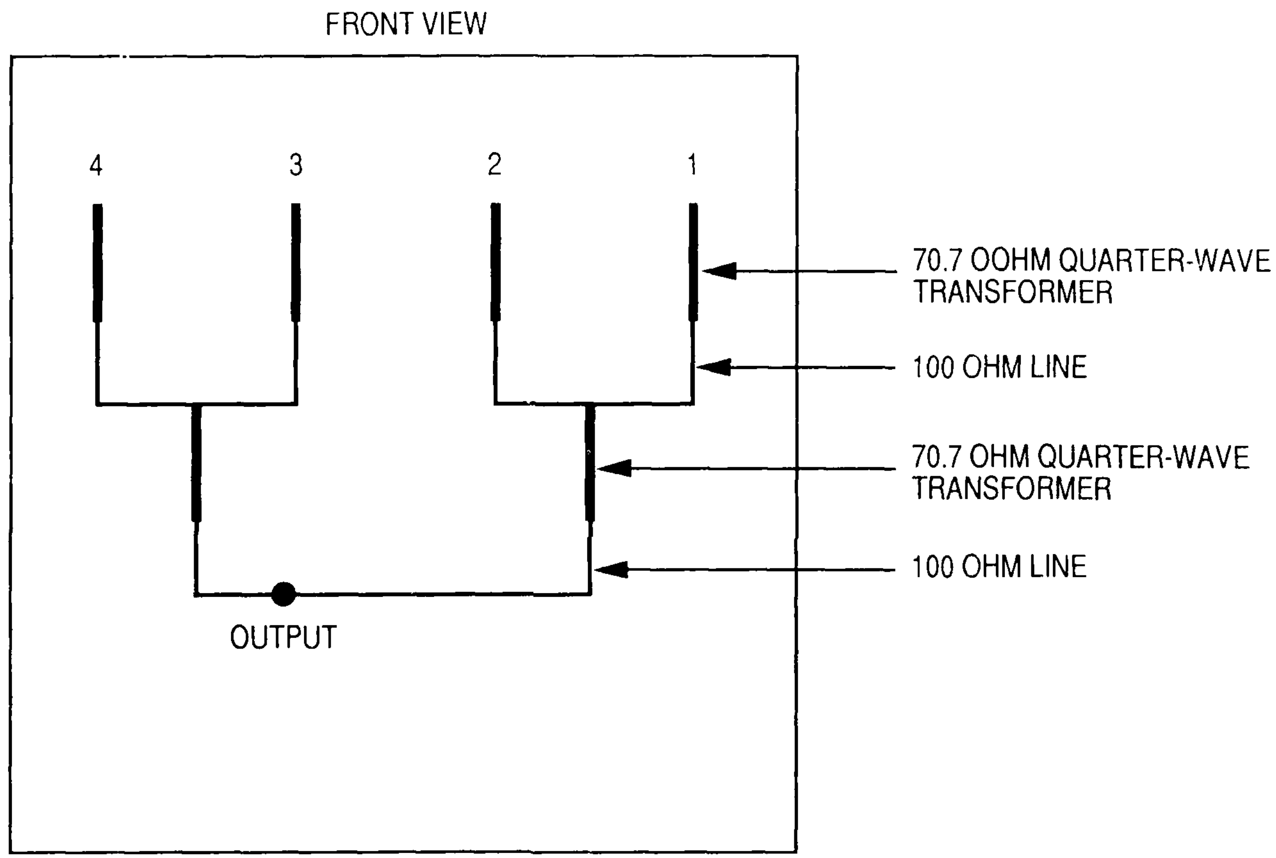
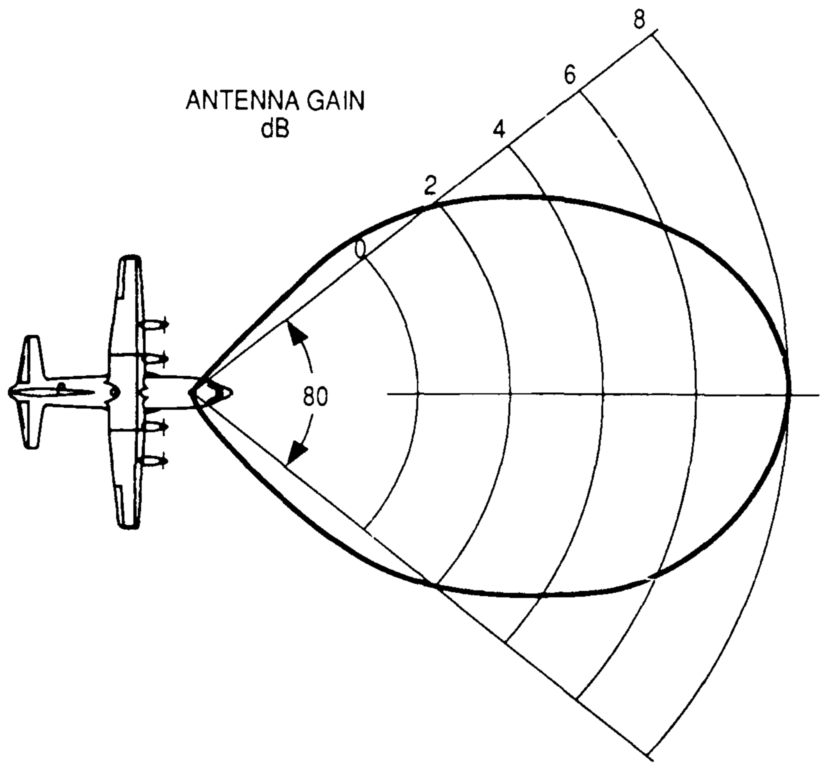


Figure 8. S-Band Phasing Array



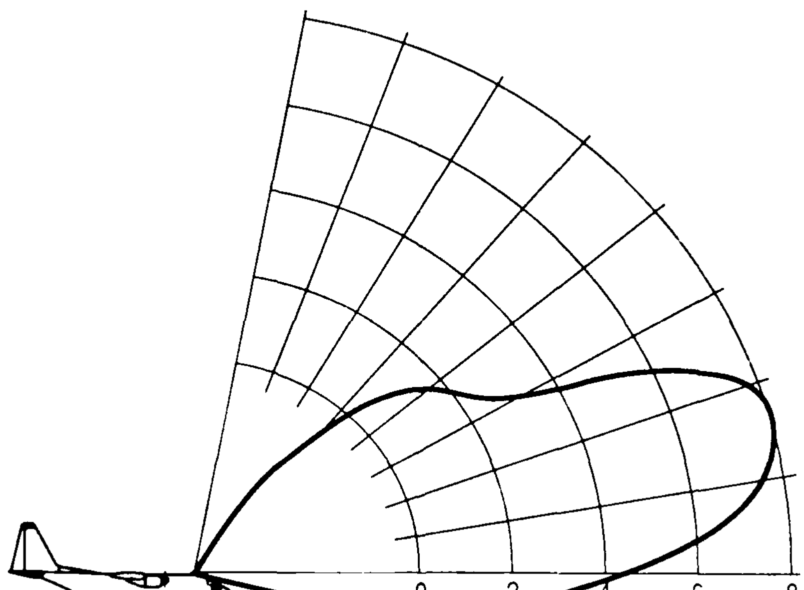


Figure 9. S-Band Antenna Gain Pattern

3.1 Ground Tests at Holloman AFB

The first ground tests were conducted with the aircraft placed about 500 yards from the building with the payload, as indicated in Figure 10. All the equipment fit in place in the aircraft as planned. See Figure 11. Ground testing was principally interference testing. Interference both with and from aircraft systems was of interest. (It was at this point we found the computers' sensitivity to the waveform output from the power inverter.) Our equipment created no interference with any aircraft system. The only interference with our system from the aircraft was from the radar transponder (IFF). This was no problem because there is no reason to have the transponder turned on in the Antarctic environment.

The hard disks had been removed from the computers because they are sensitive to vibration. Our PCATS computer was run during all testing with a test program that checks the floppy disk drive. This test program alternately wrote to, then read, the floppy disk and recorded any errors. This test showed no degradation due to the aircraft environment.

No aircraft versus TM system problems were found. However, we did discover a problem within our system. When a command transmitter was turned on, the receiving system was desensitized by up to 20 dB. This was a substantial problem because the experiment required commanding while data were being received. The solution was to add an S-band, pass-band filter between the receive antenna and the preamplifier. With the filter in place there was no detectable degradation of the receiving system by the transmitting system.

3.2 Flight Test at Holloman AFB, NM

The flight test at Holloman was very disappointing; it quickly became obvious that we were not going to get much data. The range with good signal was less than 5 miles. Part of the aircraft TM system was then taken to the top of a hill about 7 miles away, and in line-of-sight to the balloon payload, as indicated in Figure 12. Good data were received but the signal-to-noise ratio was poorer than expected. The TM system was then driven to the top of a mountain about 20 miles away, and still in line-of-sight of the payload. No useful data were received from this location.

Our range calculations indicated that the system should operate up to about 130 miles, as indicated in Figure 13. When our estimated correction factors were used for the test condition shortcomings at Holloman - noisy area, looking down, and reduced power - the predicted range dropped to 25 to 30 miles. During testing, however, 7 miles was marginal, and 20, unusable.

There were several very adverse conditions during these tests at Holloman AFB that would not be problems at Antarctica:

The Holloman/White Sands Missile Range area has many RF radiation sources and this makes a very noisy environment. Another factor was the test geometry. The balloon payload was on the ground, so that the aircraft antennas had to look down instead of up - the gain looking down is much lower than looking up; moreover, the aircraft wings and fuselage shield the antenna. A third factor was that the antennas for the balloon payload were remoted to the building roof through about 50 feet of coaxial cable. The coax attenuated the transmitter power, and thus reduced the transmitter range.

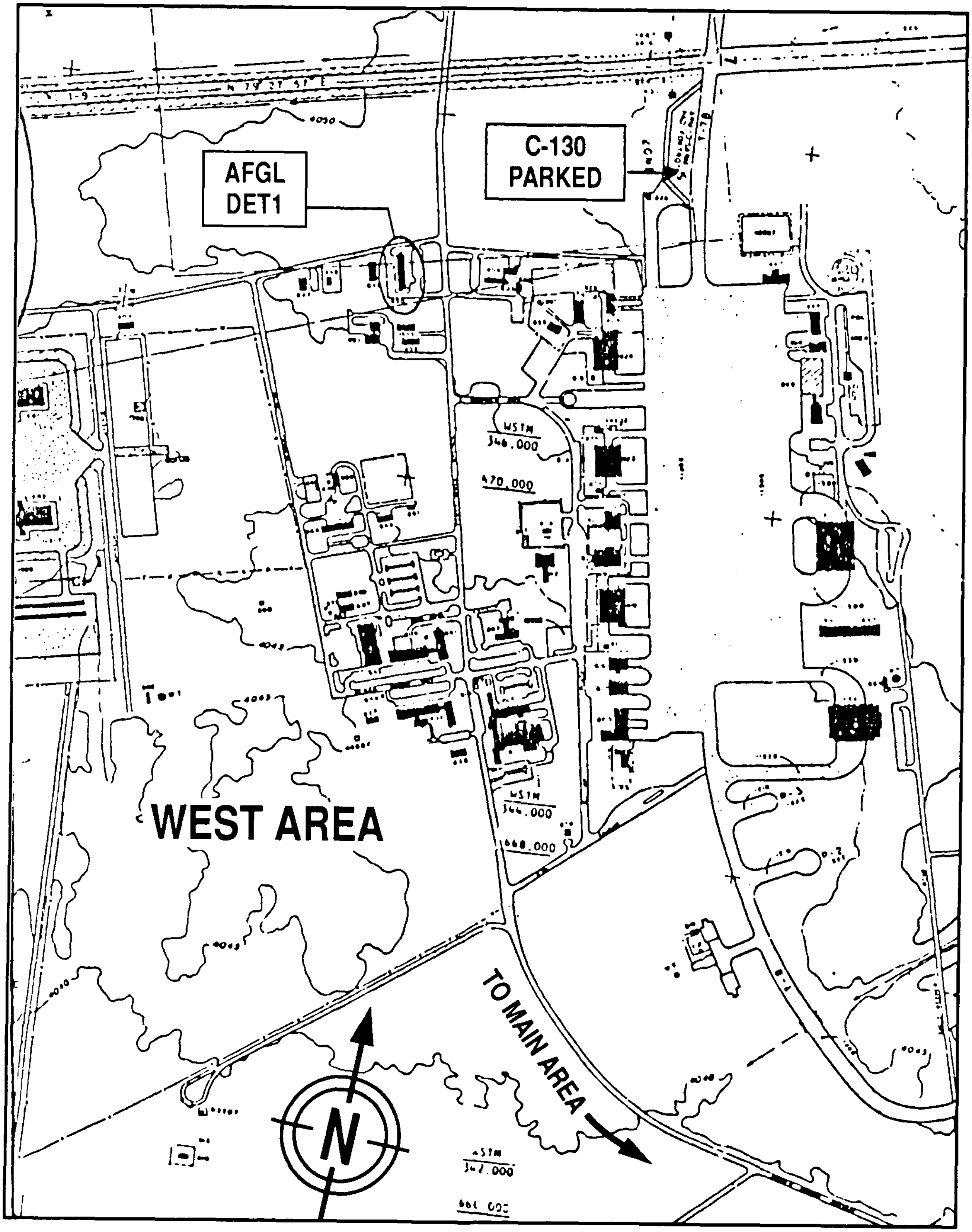


Figure 10. Holloman AFB Static Test Setup

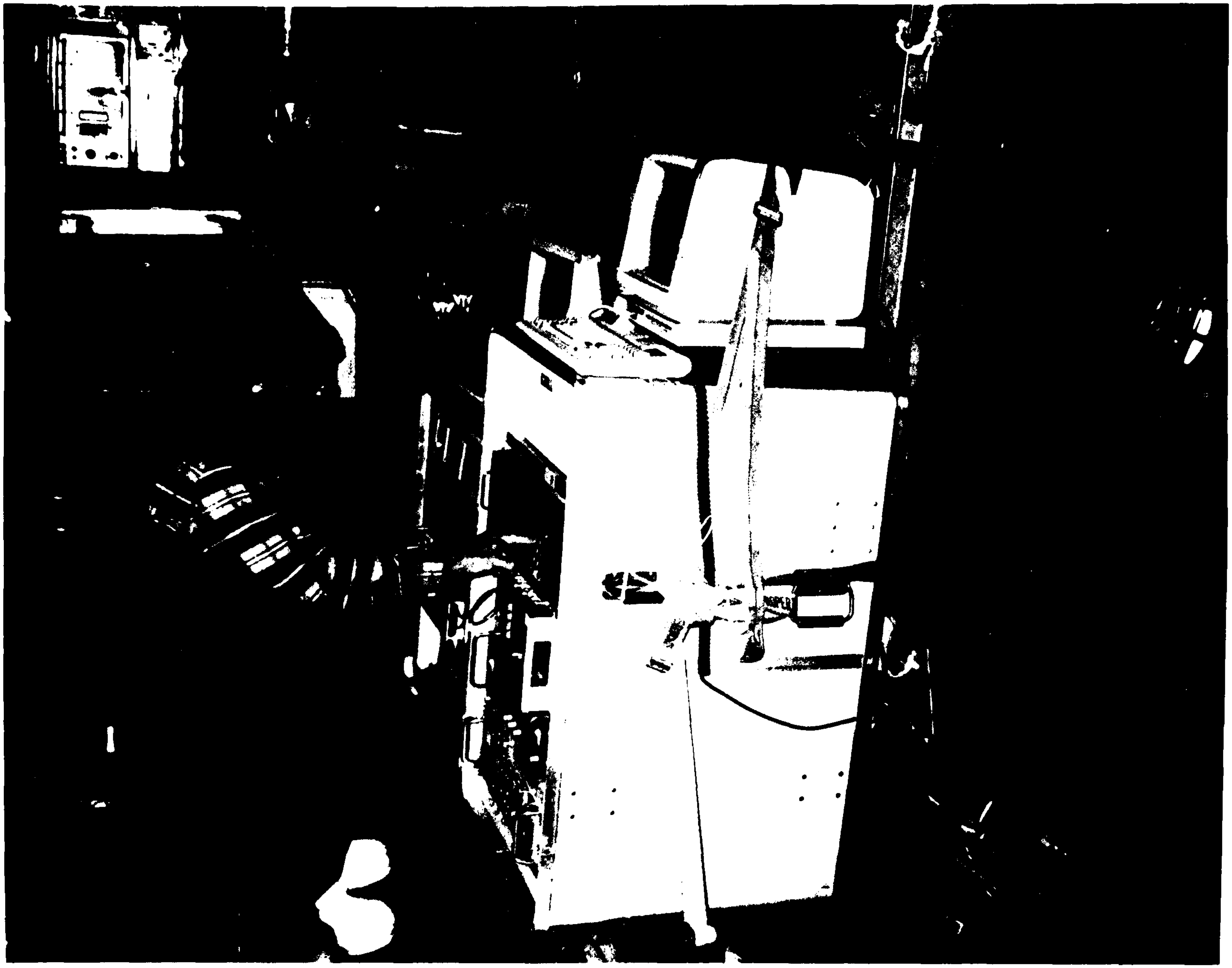


Figure 11. Aircraft Telemetry Station Installation

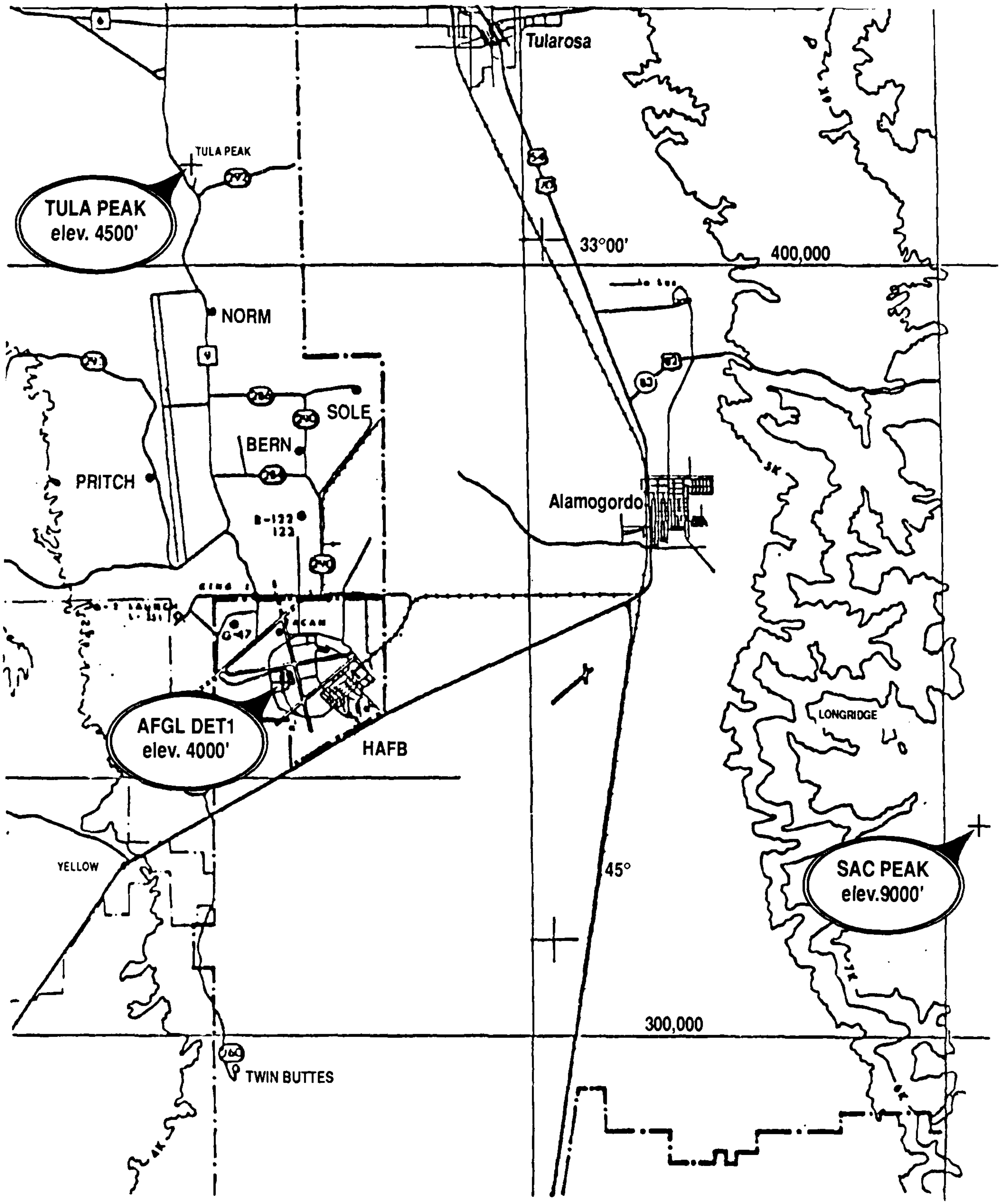


Figure 12. Holloman AFB Flight Test Configuration

RANGE EQUATION

$$S/N = \frac{Pt*Gt*Gr*W^2}{K*T*B*L*16*Pi^2*R^2}$$

DATA

Transmitter power	Pt	= 10 W
Tx antenna gain	Gt	= 3 dB
Rx antenna gain	Gr	= 7 dB at 7 deg elevation
	Gr	= 6 dB at 5 deg elevation
Wave length	W	= .429 ft
Boltzman's constant	K	= 1.38e-23
System noise temp	T	= 500 K
Bandwidth	B	= 500 kHz
Polarization loss	L	= 3 dB

SIGNAL TO NOISE RATIO FOR EXPERIMENT LINK

S/N = 16 at 124 miles

SIGNAL TO NOISE RATIO FOR BALLOON LINK

S/N = 12 at 155 miles

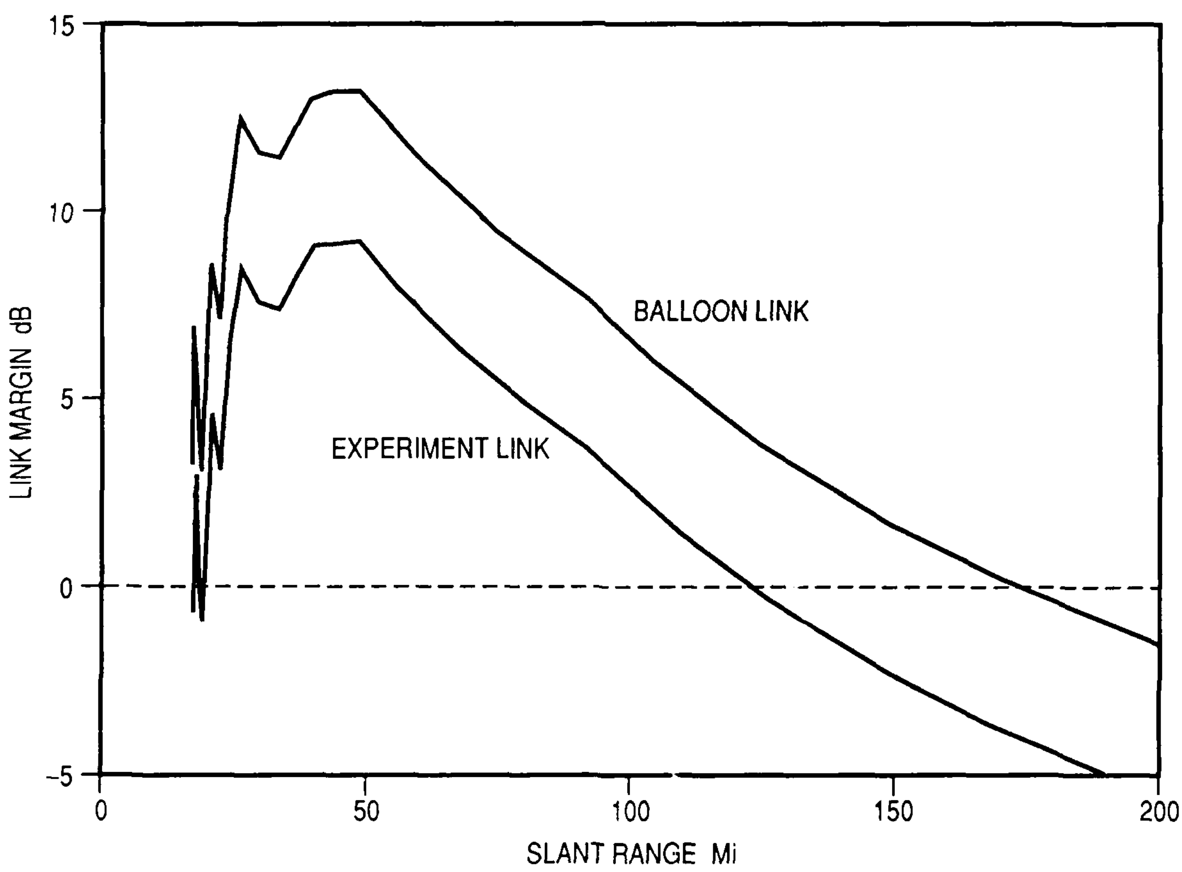


Figure 13. GRAD Link Calculations

With the shipping date imminent, time did not permit further testing at Holloman. From long experience in balloon operations at Holloman AFB we considered the limited range measurements attributable to our test conditions. Therefore the aircraft TM system was shipped, and testing deferred until arrival in Antarctica.

3.3 Tests at Antarctica

The first testing in Antarctica was at McMurdo Station, next to the buildng where the payload was built up. The aircraft TM system was set up on the ground and a transmitter and antenna were elevated to about 500 feet in the air, as diagrammed in Figure 14. The antenna was similar to those used for flight. With the transmitter output attenuated by 20 dB this test setup provided the same geometry and signal levels that were expected in flight with a range of 80 miles. This test provided very good signals. There are very few RF radiation sources in the McMurdo area, and all are known. The combination of proper geometry and low background noise provided results close to the calculated range.

The next step was to operate the system from an LC-130 at Williams Field. We arranged for time in an LC-130 that was grounded waiting for parts. As at Holloman, everything fit and operated properly. A transmitter was again lifted by the tethered balloon. This was the first test using the power conditioner; the computers worked properly. The results of this test supported our original estimate of at least 100-mile range for the airborne TM system.

4. THE GRAD FLIGHT

The balloon remained within line-of sight of the Williams Field launch site for 24 hours. Two and a half days after launch we set out in the aircraft in search of it. The last known position was 800 miles west, as indicated in Figure 15. We were given a dedicated flight, and since now there was no practical weight or size limit we took spares for everything we could.

After about three and a half hours we estimated range to the balloon to be under 200 miles. We commanded the payload transmitters on - the last command from Williams Field had been to turn the transmitters off - and the receivers immediately picked up the signal, although it was too weak to be useful. Useful balloon data began to come in at about 140 miles estimated range. This was all before anyone had a visual sighting of the balloon; we just kept flying toward where it should be. By the time we were about 80 miles away the balloon was in sight and we were getting good data from the experiment link.

The telemetry housekeeping data indicated that the balloon was performing well, but the experiment had a problem. We circled for over an hour recording data; then the decision was made to terminate the balloon flight. We issued the appropriate commands and the balloon separated from the payload. We continued to circle while the payload descended, taking data all the while. After payload impact we flew back to Williams Field, now 900 miles away.

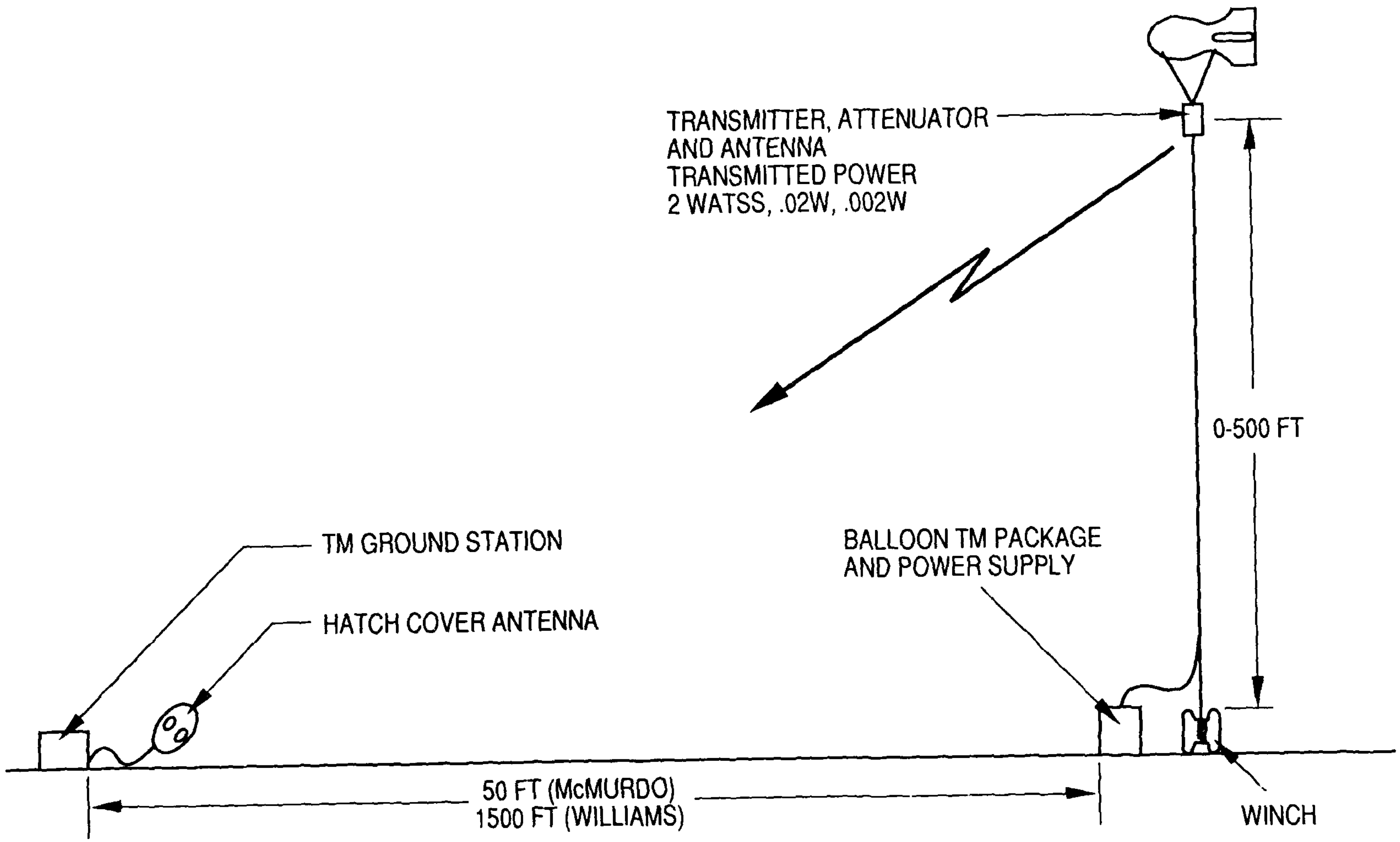


Figure 14. Antenna Test Setup

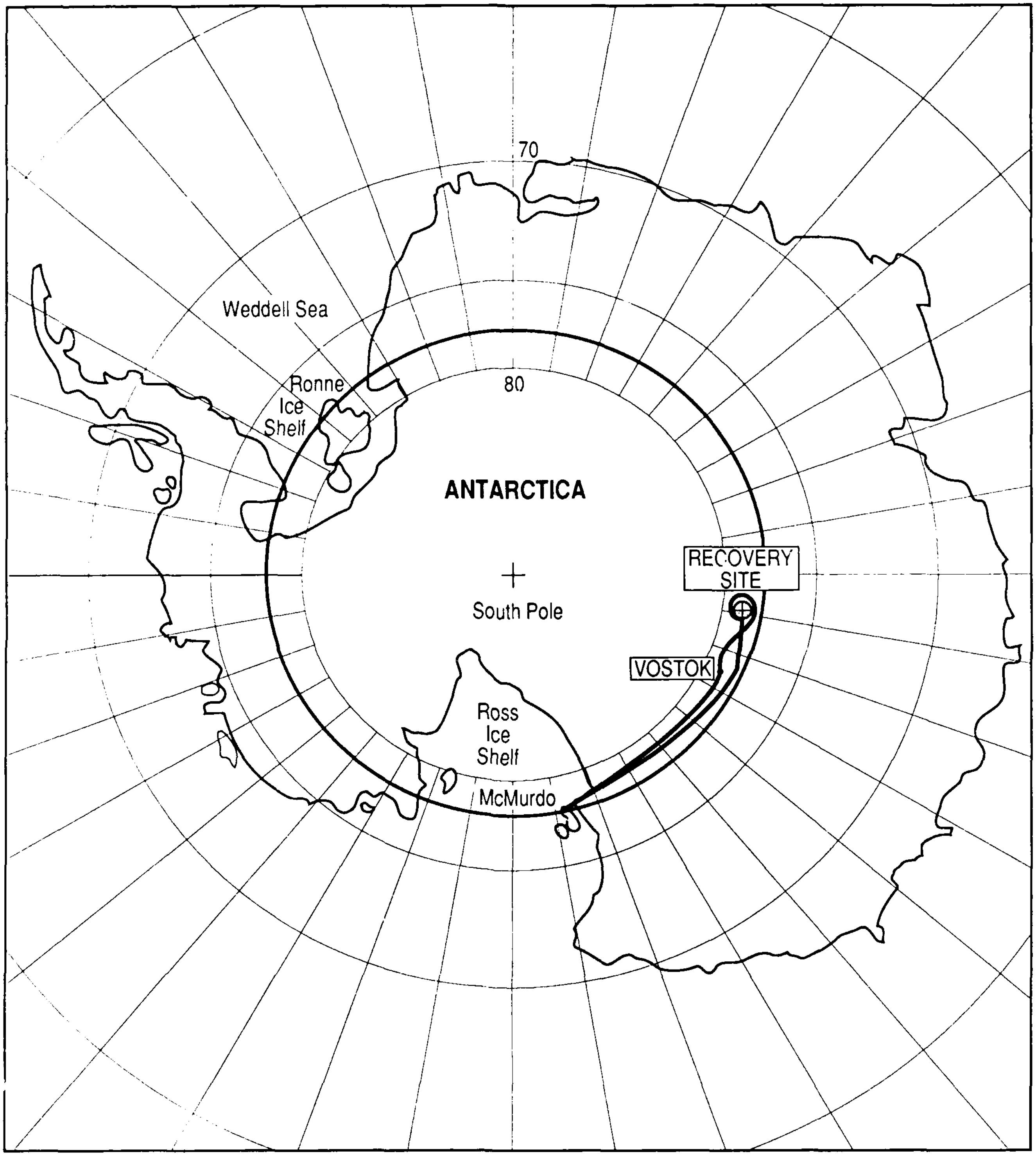


Figure 15. TM Flight Track and Recovery Location

5. CONCLUSIONS

The airborne telemetry system worked without a hitch for the entire flight. The balloon-to-aircraft range was at least as good as calculations indicated it should be. We had expected to have a limited flight of opportunity, but instead we got a much superior dedicated flight. The bottom line is that the airborne telemetry system filled a very necessary void for the GRAD program.

Acknowledgements

Credit for making this TM system possible must be given to many organizations and people. The Physical Sciences Laboratory, New Mexico State University, suggested the receive antenna design and built the antenna phasing PC board. They also provided the PCATS computer decommutator. The Oklahoma State University Electronics Laboratory supplied the S-band filter for the antenna. The TM racks were built up by AFGL. The antenna was also built and mounted to the hatch cover by AFGL. The hatch cover was borrowed from the 57-APS training aircraft at Hanscom AFB. The cassette tape recorder was purchased by Florida State University.

Most important of all was the cooperation from the National Science Foundation and the Navy VXE-6 in providing us the aircraft and superb air crew.

Contents

5. Performance of ARGOS Locating System in GRAD Flight*

by

Willard F. Thorn

1. INTRODUCTION

A tracking system was required for the major portion of the GRAD flight when it was expected to be floating far beyond the horizon in the Antarctic. The ARGOS system, while not ideal, promised to be the best for that application.

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* This paper is essentially a condensation of two unpublished papers by R. Koga, Space Sciences Laboratory, Aerospace Corporation:

(1987) ARGOS transmitter - GRAD tracking.

(1988) ARGOS monitoring of GRAD gondola during balloon flight in Antarctica.

2. THE ARGOS SYSTEM

The ARGOS system has three main parts (see Figure 1): satellites; flight systems on board the vehicle to be tracked; and ground stations. Two polar orbiting satellites pick up signals transmitted by the flight hardware and relay the information to the ground. The flight hardware, called the platform transmitter terminal (PTT), can encode data from on-board sensors and transmit this information on the same link as its locating signals. On the ground, telemetry-receiving stations and data-processing centers receive and process the data for distribution to the user.

The flight portion of an ARGOS system consists of a transmitter unit (PTT), an antenna (see Figure 2) and a power source. The PTT includes an analog input board, an RS232 input, a timer to control transmissions and the transmitter. The main features of the PTT are listed below:

Electrical:	
Transmission Frequency	401.650 MHz
Peak Transmission Power	2 W
Bit Rate	400 BPS
Repetition Rate	40-60 s *
Transmission Duration	360-920 ms *
Number of 8-bit Data Words	4-32 *
	*User programmable
Environmental:	
Operating Temperature	–40 to + 55 deg C
Storage Temperature	–55 to + 85 deg C
Mechanical	
Size	9.55 × 2.33 × 2.33 in
Weight	2.0 lb
Approx. Cost (PTT + antenna)	$2000

PTTs transmit their messages periodically, on the same frequency. They operate independently of each other, and without satellite interrogation. Messages from PTTs within the view of a satellite reach the onboard receiver at random. The duration of a transmission is always less than 1 second. The encoded analog data and the RS232 data are included in each message, with the PTT's identification code. The satellites record all messages as well as data about each message continuously. The recorded data are downlinked each time a satellite is within range of one of the three ground stations. The ARGOS data are forwarded to the data-processing centers in Landover, Maryland and Toulouse, France. PTT data and satellite data are then processed to obtain location of the PTT from the Doppler shift of the PTT carrier frequency. A minimum of five positions per day is obtained from a PTT in equatorial regions, and up to 17 per day in polar areas, with approximately 1 km accuracy.

Most users wait for their data to come out of the pipe line, but there is a way to get telemetry data from the ARGOS system immediately. There is a vhf repeater operating continuously, transmitting data as it is received. Data may be received directly with a vhf ground receiver. The satellite must be within line-of-sight of both the ground receiver and user's PTT to receive data in this manner.

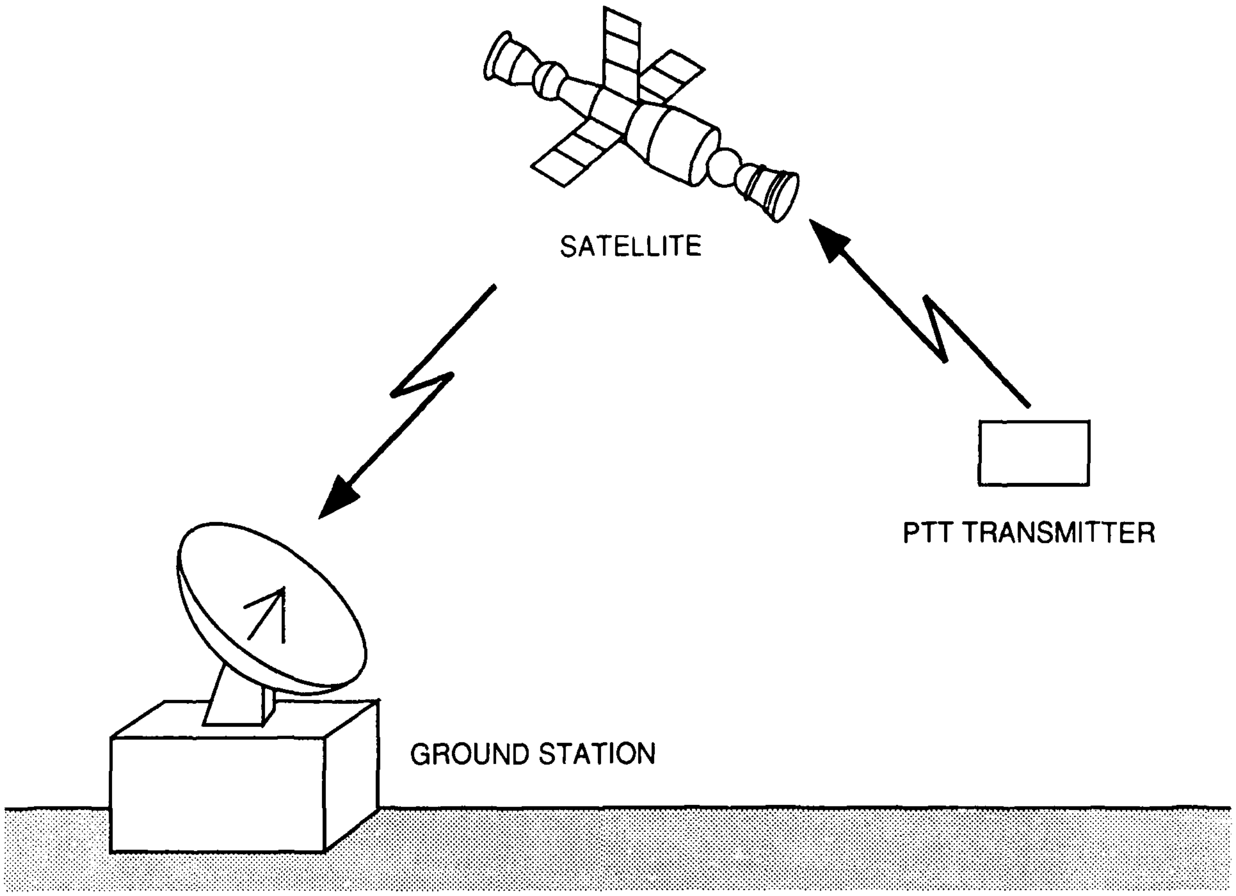

Figure 1. The ARGOS System

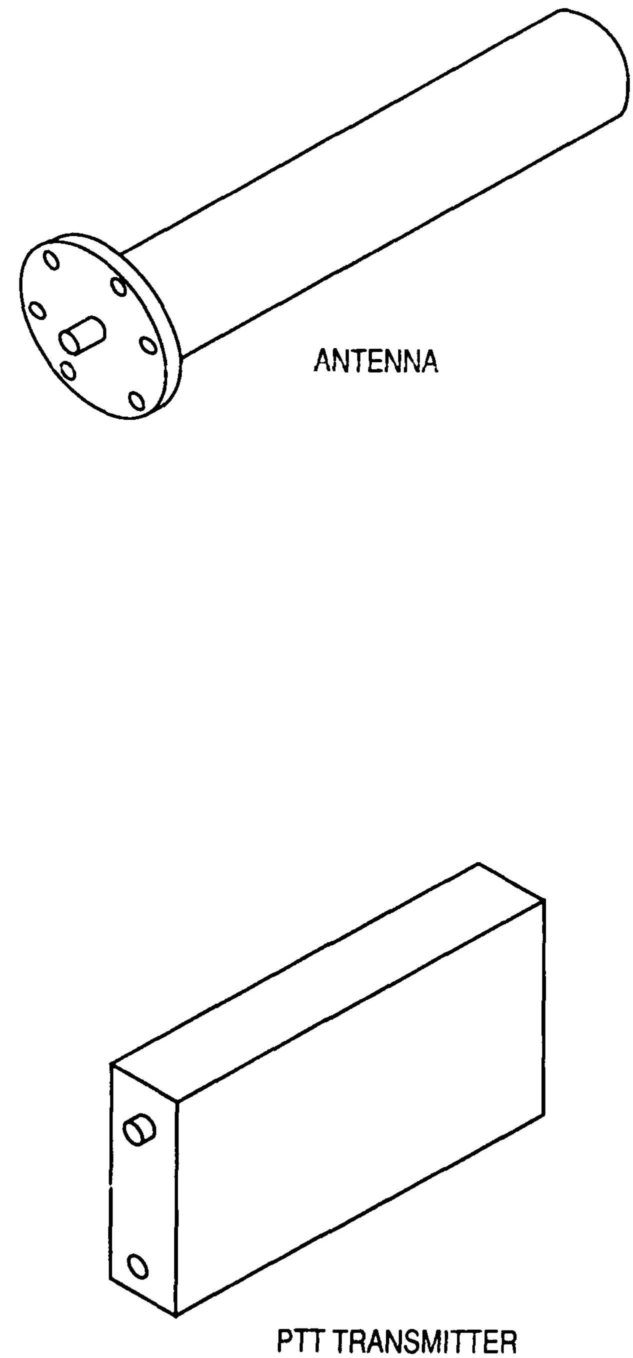

Figure 2. ARGOS Transmitter and Antenna

Position information is not available in this way; it must come from one of the data-processing centers.

3. THE GRAD/ARGOS SYSTEM

Three transmitters (PTTs) and accompanying helical antennas were ordered from Synergetics, Inc. Meanwhile, the loan of a PTT and antenna from Synergetics was a great help in developing the interface to GRAD. Two systems, one a backup for the other, were mounted on the GRAD gondola.

Each PTT had its own antenna and battery. An interface box fabricated by Aerospace Corp. was shared by both PTTs. The interface box accepted the analog data from GRAD and also provided the support circuits for three temperature probes. During testing it was discovered that between transmissions the PTT presented a low impedance load to the analog inputs, resulting in inaccurate readings. Resistors were added to buffer the analog channels (ADC). The PTTs, batteries and interface box were all packaged in a foam box 1 ft × 1.5 × 1 ft high, with 2-inch thick walls. The antennas were mounted on arms to provide clear transmission to the satellites. The analog input card of the PTT collected information through eight channels. Each channel was digitized into 8 bits, for a total of 64 bits. The channels were allocated as follows:

Channel	Transducer	Range
0	Temp. PTT box	–60.......+150 deg C
1	Temp. Solar Array	–60.......+150
2	Temp. Primary TM	–60.......+150
3	Rotator/SIN	0.........180 deg
4	Rotator/COS	0.........180 deg
5	Pressure Altitude	0...........15 PSIA
6	Pressure Altitude	0.............2 "
7	Prssure Altitude	0.............0.5 "

The last 128 bits of the GRAD rotator command data were transferred via RS-232 to the serial input port of the PTT for transmission. These 128 bits and the analog data (64 bits) provided a total ARGOS data transfer of 192 bits in addition to the ARGOS identification and other overhead bits.

4. TESTING

Our first ARGOS transmissions were from the gondola at the AFGL Detachment 1, Balloon Flight Facility at Holloman AFB during 20 - 23 October 1987. During the week of 26 October the gondola underwent a thermal/vacuum test in an environmental test chamber a few miles northeast of the AFGL Det. 1 building. For these tests - and most done in Antarctica - the antennas were remoted to the roof of the builiding containing the gondola.

A quick look at the ARGOS data from these two locations showed:

1) Lat: 32.846 N Long: 106.117 W
2) 32.894 N 106.093 W

These values were obtained by averaging several hours of data. On the earth's surface, along a line of latitude, the distance in nautical miles (nm) is approximately equal to the arc length in minutes times the cosine of the latitude; similarly, along longitude, distance in nm equals the arc length in minutes. The observed change, above, corresponds to movement of 2.8 nm to the north and 1.4 nm to the east - a reasonably accurate assessment.

For the tests in Antarctica, an ARGOS file receiving station (a Compaq computer with modem and phone) was set up at Aerospace Corporation in California. The information was disseminated via TYMNET from the Service ARGOS computer. The data was stored on floppy disks. No direct access was made from McMurdo Station. There was an existing ARGOS VHF receiving system in the weather station at McMurdo Station to gather data from unmanned weather monitors. Mr. G. Weidner, Univ. of Wisconsin, reprogrammed this system so that it would also print out data from the GRAD PTT's. We used it to check whether the satellite was receiving the PTT data, without having to rely on communications with the USA, and also to collect TM data (but not position) during the initial phase of the balloon flight while the balloon and the VHF receiving station were both within line-of-sight of the satellite.

PTTs were often exercised to make sure that nothing had gone wrong during transportation to Antarctica, and to check out the Aerospace Corp. data center. The ADC was calibrated by holding the input voltage to a fixed value and decoding the received signal at Aerospace. Most conversions were good to 0.01 volts. However, we noticed that channel 0 had a lower than usual input impedance and needed an added calibration to ascertain the deviation. The first order correction for this channel is made by adding 10 to the decimal value of the 8-bit word.

ARGOS positions with the gondola at McMurdo Station and at Williams Field place Williams Field about 4.1 nm east and 0.5 nm north of Mc Murdo, in good agreement with maps of the area.

5. GRAD FLIGHT DATA

Most files processed during the flight were "TX" files. (The "DS" files were accessed occasionally to search for more detailed information.)

For each passage of the satellite a data group was received. Each TX file also included the following information:

1. Identification code of the PTT
2. Latitude in degrees
3. Longitude in degrees
4. Quality of the transmission
5. Day the transmission was made
6. Time of the above day in UT
7. Day the position fix was made
8. Time of the above day in UT
9. Number of identical PTT information sets received by the satellite within one passage

6. DATA ANALYSIS AND DISCUSSION

6.1 Balloon Trajectory

The location data of the gondola were sorted using the quality factor of the transmission, and averaged over the information from both PTTs. The balloon traversed about 76 degrees of the arc along the 78 deg S latitude line, covering about 950 nm in about 3 days. Average speed was 13 knots.

6.2 Temperature Sensors

The ADC channel outputs were converted to temperature by the formula: Temp deg C = (ADC output (volts) - 2.73)*100. The temperature inside the ARGOS box varied between 2 and 48 deg C. The back side of the solar cell array reached temperatures as high as 60 and as low as 0 deg C. (The telemetry records indicated the array reached 90 deg C.) It is suspected that this temperature probe did not have good thermal contact with the array. The primary TM box was about 70 deg C at 12 hours after launch; then the temperature reading drastically dropped. (This is probably due to the transmitter being shut off.)

6.3 Rotator

The observed outputs varied between 1.5 and 3.5 volts, as expected. The flight data taken at McMurdo via S-band TM must be used to correlate this information.

6.4 Altitude Sensors

The data from the set of three AFGL pressure-altitude sensors were read out continuously. The ADC outputs are translated to altitude by the use of a table. Altitude values agreed well with other independent measurements when these were available.

6.5 GRAD Commands

The 128-bit command display was intended as a backup monitoring system to observe rotator command words. The PTTs transmitted the last 128 bits they received. This transmission was asynchronous to the commands and resulted in mostly 0's with occasional 1's. Time constraints did not allow checkout before the flight. This connection did confirm that commands were being sent, but interpretation of the data has not been possible.

7. CONCLUSIONS

The ARGOS system enabled us to monitor the location of the balloon gondola and to acquire some useful housekeeping information during the flight. When the flight was terminated, the gondola parachuted down to a plateau west of Vostok, the Russian station. Since the PTT's were still transmitting from the gondola on the ground, we could determine the location of the gondola and its altitude. The location was: Lat. 78.23 deg S, Long. 90.07 deg E, altitude 13,000 ft (pressure altitude based on 1976 Standard Atmosphere). After recovery of the gondola, it was reported that the location was correct but the correct altitude was 12,500 ft - an acceptable discrepancy. The ARGOS system worked well, with little impact on GRAD system operations.

Acknowledgements

R. Koga, Aerospace Corporation, designed the ARGOS system for GRAD and set up and operated the data-gathering station at Aeospace during the flight. AFGL provided the mounting and interface to the GRAD gondola. G. Weidner, University of Wisconsin, set up the VHF receiving station for GRAD at McMurdo station.

*U.S. GOVERNMENT PRINTING OFFICE: [illegible]-000/00005