ASE-1987

FINAL REPORT

A CONTINUATION OF A PROGRAM OF HIGH ANGULAR RESOLUTION STUDIES OF CELESTIAL X-RAY SOURCES

CONTRACT NASW-1634, MODIFICATION No. 1

REPORT PERIOD 6 JULY-29 DECEMBER 1967

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

29 JULY 1968

AMERICAN SCIENCE AND ENGINEERING
11 Carleton Street, Cambridge, Massachusetts 02142

AS&E

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19 February 1968 to 1 August 1968

Prepared for

National Aeronautics and Space Administration

NASA Headquarters

Washington, D. C. 20546

Prepared by

American Science and Engineering

11 Carleton Street

Cambridge, Massachusetts 02142

Date: 29 July 1968

FOREWORD

This document is the final report on NASA Contract NASW-1634, Modification No. 1. This contract is part of a continuing program of X-ray astronomy by AS&E and calls for the refurbishment and reflight of an instrumented payload which was flown under Contract NASW-1634 but due to door malfunctions was not able to obtain useful data on cosmic X-ray sources.

The payload was recovered intact and the instrumentation, including the door, operated satisfactorily; but due to a timer malfunction in the NASA/GSFC ACS the original experimental objectives were not fulfilled. However, the experimental equipment functioned well, and X-rays were seen from a large portion of the sky. This payload is expected to be flown again in the Fall of 1968.

The authors of this report are R. Giacconi, H. Gursky, P. Gorenstein, and H. Manko.

ACKNOWLEDGMENTS

We wish to acknowledge the contributions of the following individuals at AS&E to this program. Mr. A. DeCaprio, the Project Senior Mechanical Engineer, and Mr. S. Mickiewicz, the Project Electronic Engineer, were responsible for the design, fabrication and testing of the payload in their respective areas. Additional engineering support was obtained from Mr. A. B. Johnson, Director of Engineering, Mr. W. Antrim, Director, Mechanical Engineering Department, and Mr. W. Sheehan, Electronics Technician. The contribution of Heidi Zmijewski to the calibration and preliminary data reduction effort is very much appreciated.

We also wish to thank personnel of the NASA/GSFC Sounding Rocket Branch who provided support for this payload in their respective areas, and the personnel of the USN MOTF, WSMR for their support during the launch phase.

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1.0 INTRODUCTION

This rocket flight was a second attempt at an experimental plan that has been described in the final report for Contract NASW-1634 (ASE-1825). In the first attempt (NASA 4.228) a thermal failure in a mechanism designed to open a door in the payload at a specified time after launch meant that none of the experimental objectives were completed. For the reflight, NASA 4.261, the problems that led to the thermal failure were corrected; the treatment was verified by a laboratory test simulating the thermal conditions of launch. For completeness, the introduction and experimental plan of document ASE-1825 are repeated here.

The objectives of this experimental program followed from the results we had obtained from the preceding rocket flight. The principal observations were as follows:

1. An identification of the X-ray source Cyg X-2 with a bluish, variable, visible object.

2. The absence of X-ray emission from Cygnus A, the extra-galactic radio source, at a level of intensity observable from rockets.

3. A distribution of X-ray sources that strongly suggested that they are associated with the spiral arm structure of the galaxy.

4. The existence of a deficiency in the number of photons in the low energy part of the spectrum for several of the X-ray sources.

The conclusion derived from observation (3) suggests a particular distribution for X-ray sources along that portion of the galactic equator which lies between $\ell^{II} = 100^{\circ}$ and $\ell^{II} = 260^{\circ}$. In particular, sources are expected in the Cepheus-Lacertus region because of the presence of the Perseus spiral arm and in the Orion region because of the Orion arm. Although this part of the galactic equator has not been observed with the same sensitivity as the part between $\ell^{II} = -15^{\circ}$ and $\ell^{II} = 100^{\circ}$, the NRL group has reported several sources in the former region. In addition, if observation (4) results from interstellar attenuation, then a correlation is expected between the low energy deficiency and the integrated mass density to the source which is related to its distance along a certain direction. Hence a measurement of the distribution and spectra of X-ray sources between 100° and 260° would test various hypotheses of the spiral arm model:

1. The presence of sources in certain regions along the galactic equator and not others.

2. General correlation of intensity at the earth with location based on distance to the relevant spiral arm and the assumption that groups of X-ray sources have the same average inherent intensity.

3. General correlation of low energy photon deficiency with location based on distance to spiral arm, and the assumption that interstellar attenuation is the reason for the deficiency.

Other objectives of this experiment include the following:

1. Determination of X-ray source locations precise enough (10 arc min x 10 arc min) to allow the possibility of making identifications with specific visible or radio objects. Of particular interest are the radio sources Cas A and SN 1572 which are believed to be remnants of supernova explosions.

2. A measurement of the spectrum of the Crab Nebula. The presence of a low energy deficiency would almost definitely be a result of interstellar attenuation because its large spatial extent (~1 pc) precludes self-absorption. Since the distance to that object is known (1300-1700 pc), the spectral measurement would determine the density of middle Z elements in the interstellar medium.

3. A measurement of the X-ray background along the galactic equator from $\ell^{II} = 100^{o}$ to $\ell^{II} = 260^{o}$ and perpendicular to the equator at $\ell^{II} = 115^{o}$ to look for any anisotropies.

2.0 EXPERIMENT PLAN

The X-ray detectors were to observe out the side of the payload (along - yaw axis) behind two slat collimators. Each collimator had a field of view of 2° by 45° full width half maximum. The two 2° fields of view were offset from the plane normal to the roll axis by $+30^{\circ}$ and -30°. Hence the location of an X-ray along two lines intersecting at a 60° angle could be attained in a single scan. The precise location (several arc minutes) of the X-ray field of view upon the celestial sphere was to be obtained by photographing the star field with an aspect camera located between the two collimators.

A standard ACS system controlled the aspect of the vehicle. The experimental program consisted of maneuvering the vehicle successively through a sequence of several targets. However, no time was spent actually pointing at the targets. The observation periods were the controlled rate of scan between pointing positions. In this manner certain regions along the galactic equator were scanned at a rate of 2°/sec, another at 1°/sec and parts of the Cassiopeia, Cepheus, and Lacertus constellations at $3/4^{\circ}$/sec in a series of maneuvers that included several scans at various angles to the equator. At the fastest rate of scan, 2°/sec, the minimum detectable source (each collimator) was to have been 0.035 counts/sec (2-5 keV) which is about 2×10^{-3} Sco X-1. At the slower rate of scan the location determination capability was about 10-20 arc minutes.

3.0 HARDWARE DESIGN

The payload for NASA Aerobee Rocket 4.261 CG came from refurbishment of Rockets 4.148, 4.149, and 4.228 CG. However, the instrumentation underwent considerable change after Rocket 4.148 CG was flown. After 4.228 the changes made on this payload consisted of a modification on the door pulley and cables which allowed the door to swing open with little or no drag due to the cables which are used to reel in the door. An additional monitor for the door control relay was also added with outputs going to both the AS&E commutator and the control console. The replacement of batteries, fuses, resistors, etc., if and when required, were the only other changes.

3.1 Aspect Camera

The camera which has now flown satisfactorily four (4) times was a 16 mm Milliken Model DBM-3C with an Angenieux f/.95, 25 mm focal length lens. Figure 1 is a picture of the camera and associated hardware.

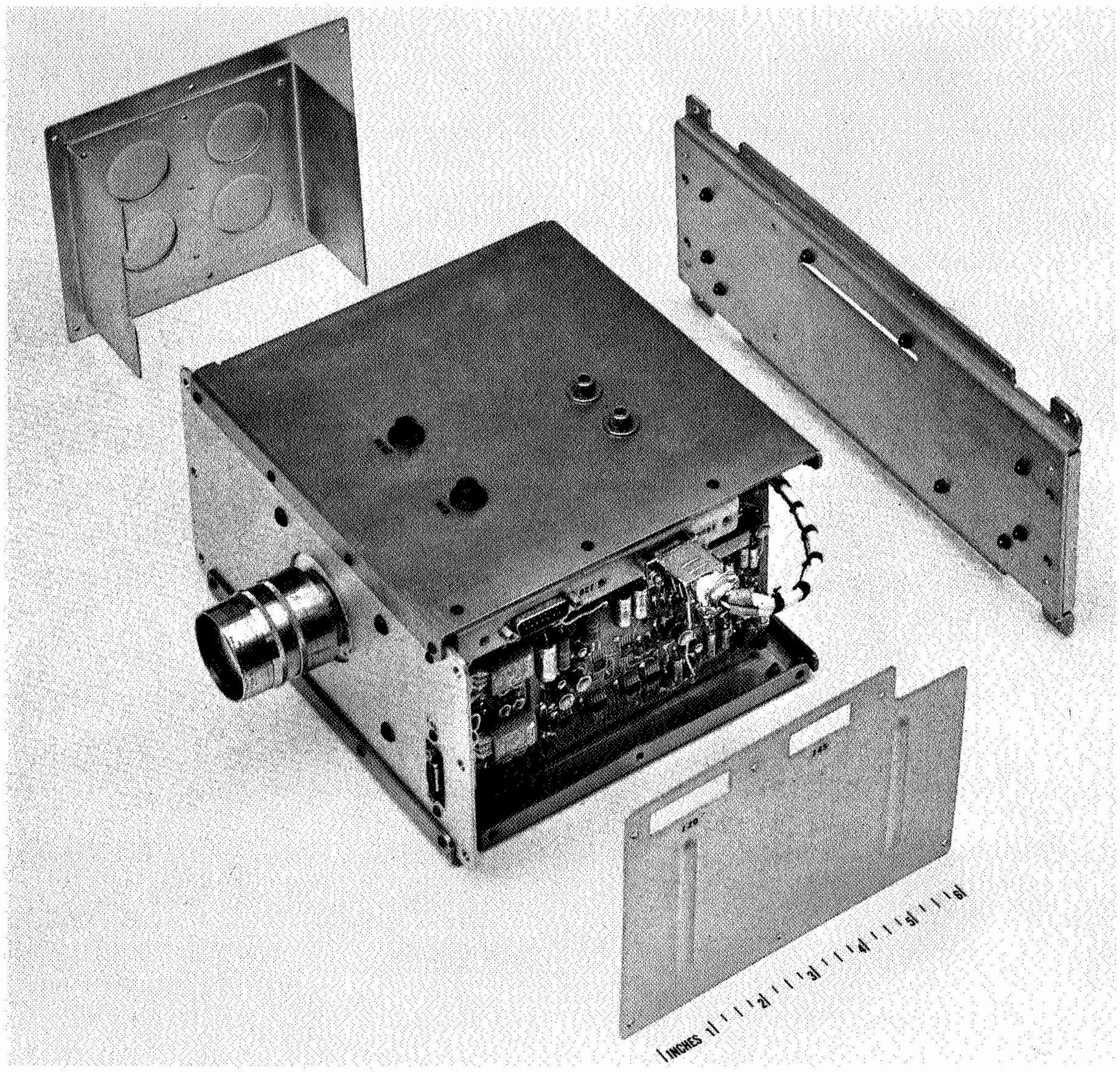
Due to some erratic operation at voltage above 27 VDC, the camera has been sent back to the factory for a complete overhaul in anticipation for further flights.

A new film which is twice as sensitive as film used previously was tested and installed on this flight. The film is Kodak 2485 High Speed Recording Film with an ESTAR-AH base.

3.2 Proportional Counters

Three types of proportional counters were used on this flight. Of the twenty counters flown, six had 2 mil beryllium windows, two had 1 mil beryllium windows, and 12 had thick aluminum windows. The beryllium window (active) counters were filled with P10 (90% Argon and 10% Methane) and had overall dimensions 16" x 2" x 2" with an effective window area of 14.81 x 1.75" minus a considerable loss due to the presence of a support

ASPECT CAMERA ASSEMBLY



DO-006

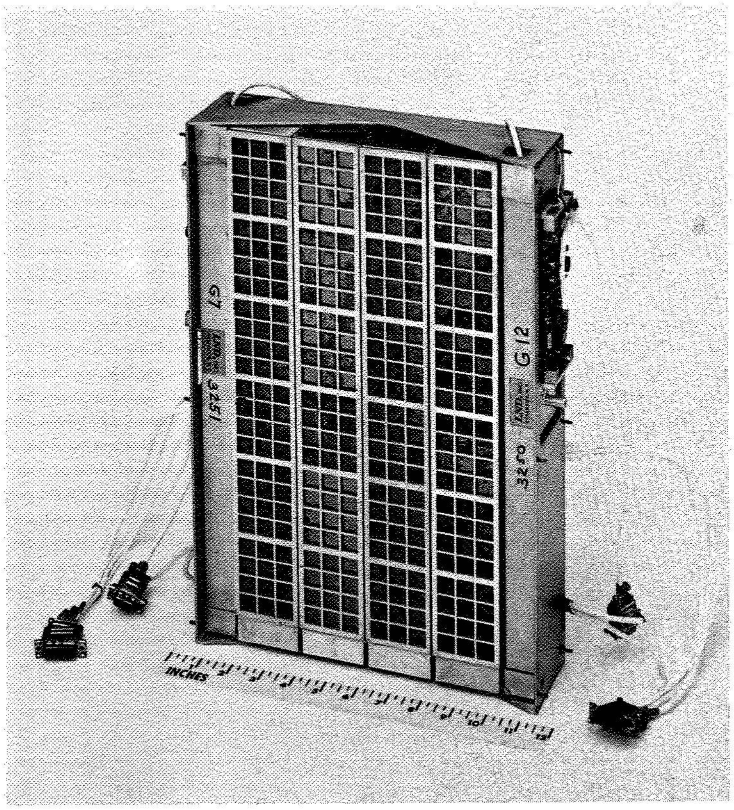
Figure 1

structure. The thick window (guard) counters were filled with Xenon and had overall dimensions of 16" x 2" x 1". The counters were set up in two banks with 4 active counters in front, enclosed by 6 guard counters on 3 sides in each bank. Figure 2 shows the layout of an active counter bank with a guard counter on each side. Figure 2 also shows the layout of the remaining guard counters which are mounted directly behind the active counters. Location of the preamp for each proportional counter can also be seen.

Any cosmic ray event which was able to penetrate the active counters and reach the guard counters would produce a veto signal which would block out the corresponding signals generated in the active counters. A 3μs delay line was added to the logic circuitry to compensate for any delays which might occur in the development of the veto signal in the guard counters. Figure 3 is a block diagram of the proportional counter logic used. Digital information was supplied by each active counter, and two active counters were combined for the pulse height information. Two scalers, one pulse height analog channel and two log count rate meter outputs were supplied by each of four separate logic circuits. Figure 4 is a block diagram of the preamp circuit used for each of the counters.

3.3 Collimators

Two slat-type collimators, one in front of each bank of counters, were used to limit the acceptance directions of the X-rays to a field of view of $2^{\circ} \times 45^{\circ}$ (full width half maximum). The two sets of slats were inclined $+30^{\circ}$ and -30° from a plane normal to the roll axis of the rocket. The overall dimension of each collimator bank was 15" x 8 1/2" x 5 1/2". The individual slats were made of iron and spaced a distance of .160". The collimators and their relation to the camera are seen in the fully assembled payload shown in Figure 5. A closeup view of the collimators is shown in Figure 6.



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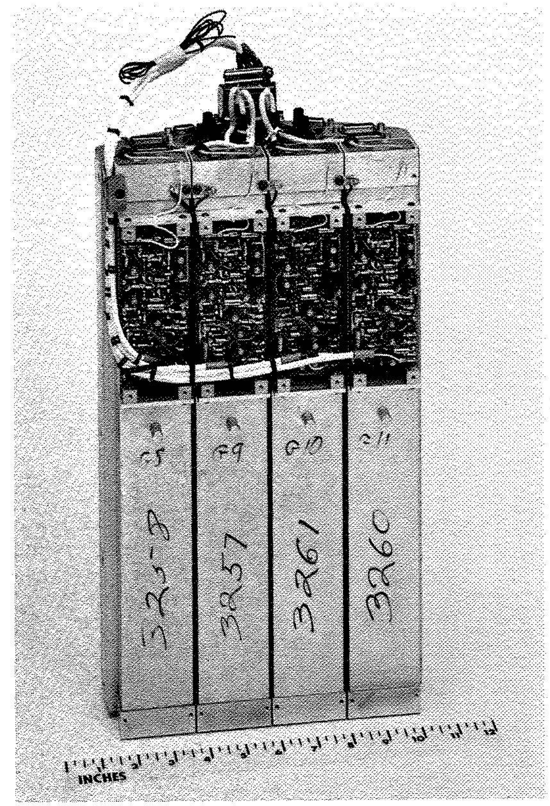

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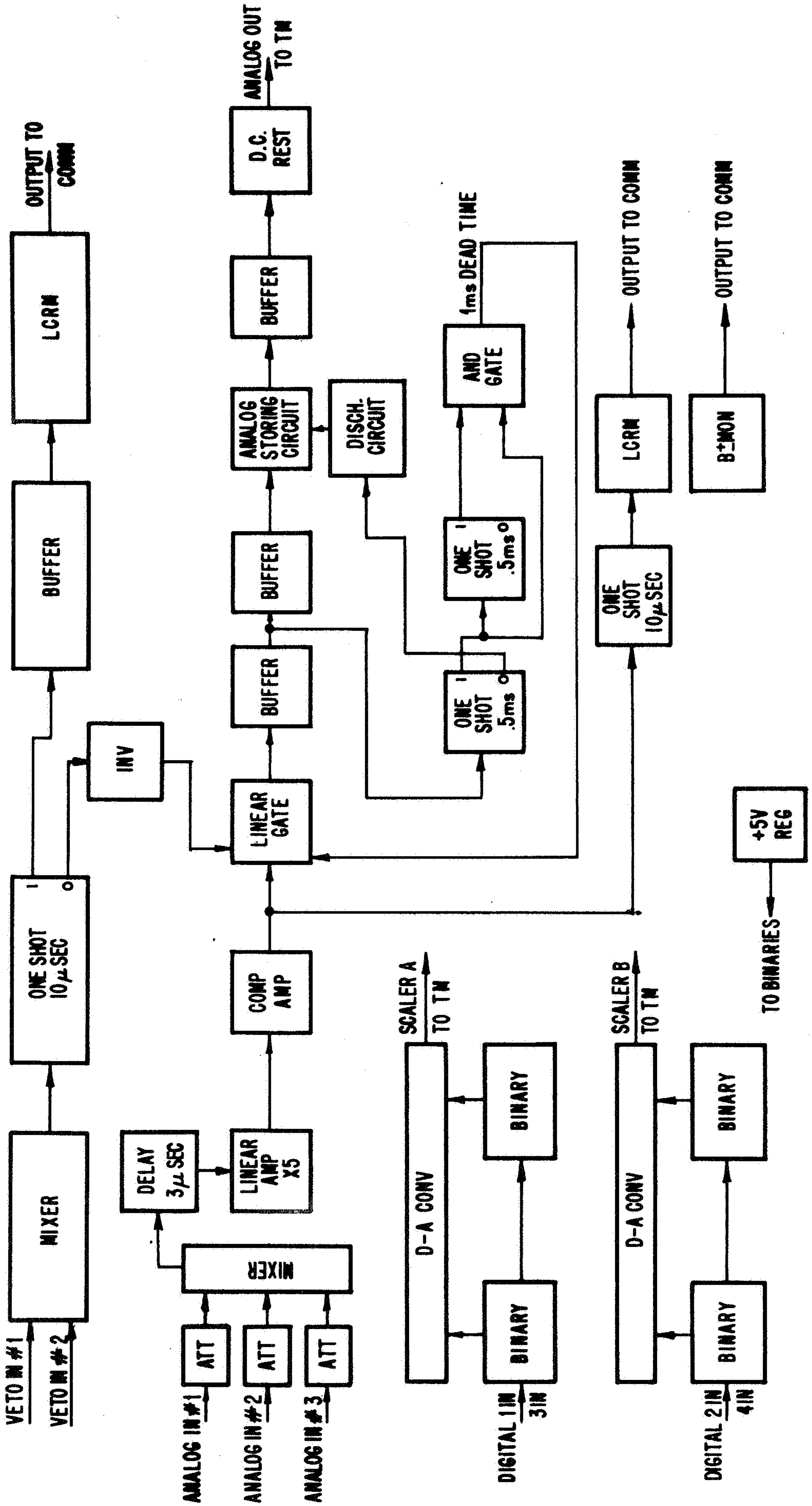
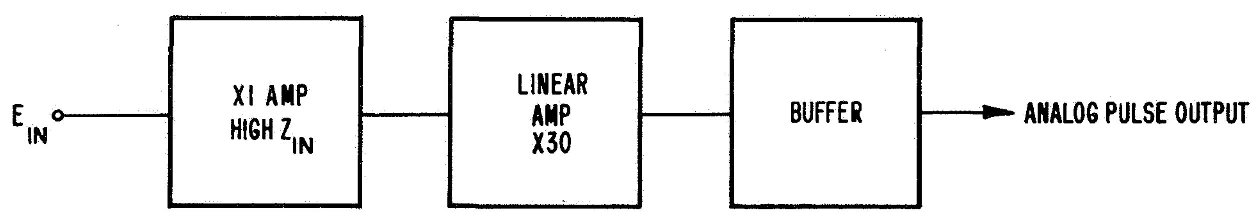
PROPORTIONAL COUNTER ASSEMBLIES

Figure 2



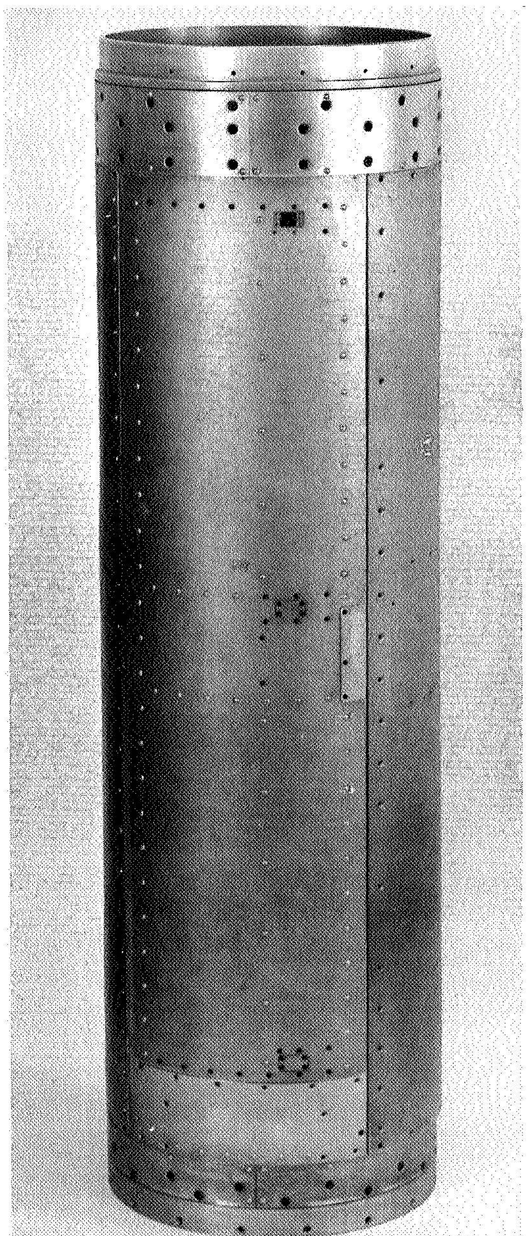
PROPORTIONAL COUNTER LOGIC



PROPORTIONAL COUNTER PREAMP

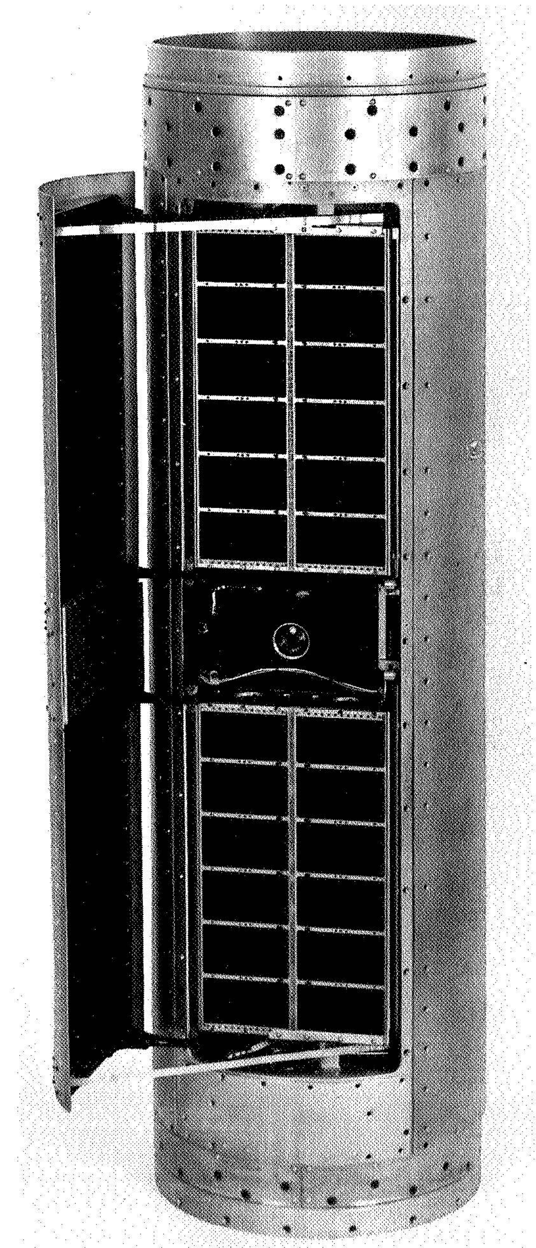
Figure 4

VIEWS OF ASSEMBLED PAYLOAD



DY-001

CLOSED

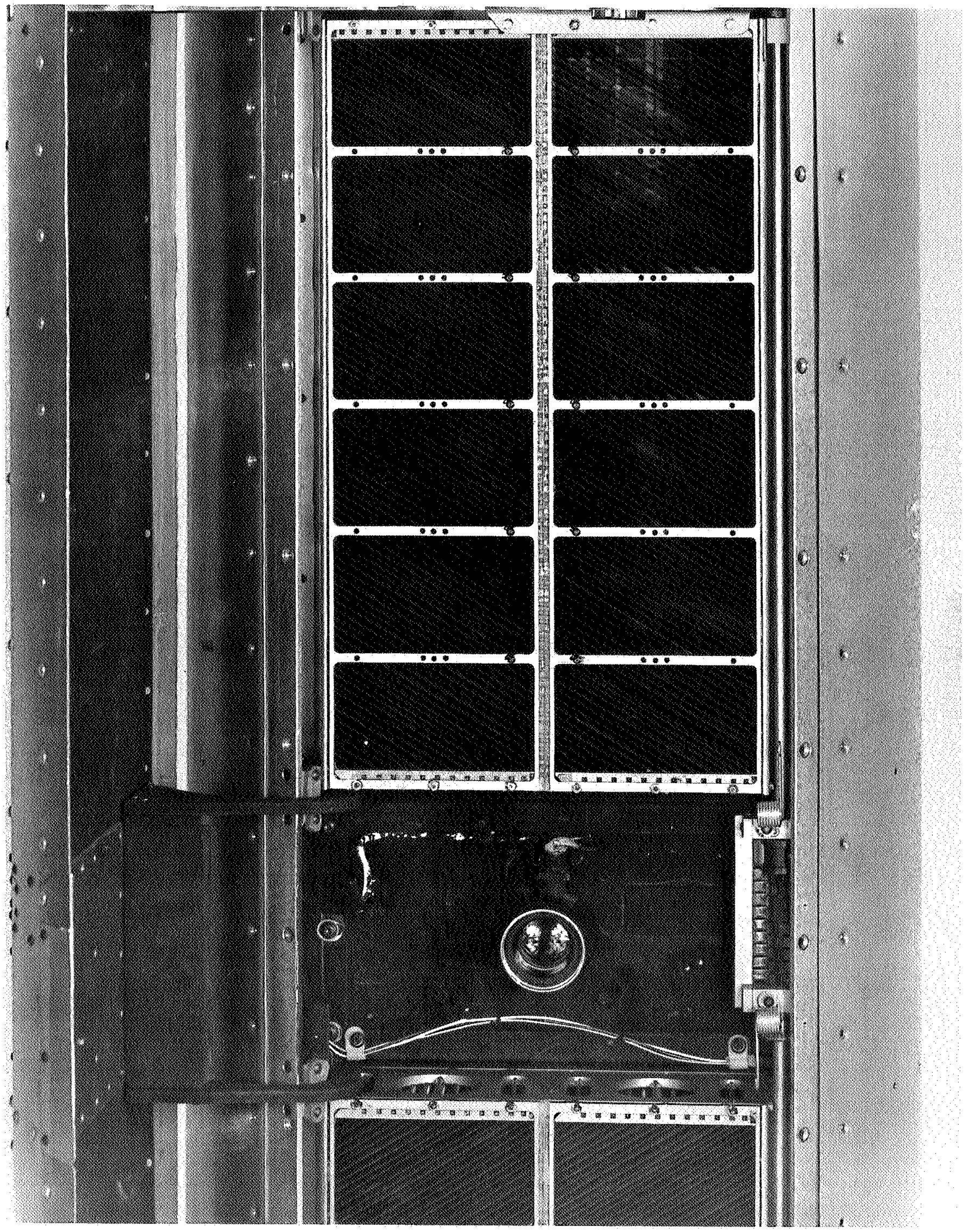


DY-002

OPEN

Figure 5

CLOSE-UP OF COLLIMATOR IN ASSEMBLED PAYLOAD



DY-003

Figure 6

3.4 Telemetry

The telemetry used in this payload consisted of two Model SST-3, PPM/AM systems operating at a 20 KCPS sampling rate and were developed and supplied by NASA/GSFC. The operating frequencies for the two transmitters were 234.0 MHz and 244.3 MHz, with the experiment section using 12 of the 15 channels available on each transmitter. Table I contains a list of the channels and the information transmitted on each channel. Four of the signals on each transmitter required increased frequency response, and therefore two channels were used on each of them.

Table II gives the function transmitted on each of the channels that carried the commutator data from the experiment.

3.5 ACS

The maneuvers programmed by the ACS are listed in Table III. Column 3 shows the programmed times in position, and Column 5 shows the actual times in position as deduced from the telemetry data.

The first nine maneuvers are involved in correcting for the actual launch attitude in order to line up the rocket axes at the desired starting point. At the ninth maneuver, ACS Ledex position 10, the vehicle was programmed to Roll CW 12.10° in 2.14 seconds; but due to the malfunction in the ACS digital timer, the actual time spent in Roll was 79.27 seconds. This caused the axes of the payload to be orientated to other than the required region of the sky. During that period the roll rate was 6°/sec, a rate which is generally too rapid for the X-ray detectors and aspect sensor to acquire good data. Also, during a considerable portion of the 79.27 seconds, the X-ray detectors were directed earthward.

When the roll maneuver finally ceased, the X-ray detectors were directed at the celestial coordinates of 2.8^{hr}, -6°, which was close to the horizon and off by about 90° from the first target position. Consequently, even though the subsequent maneuvers were properly executed

TABLE I

TELEMETRY CHANNEL ALLOCATIONS

Telemetry System #1 (234.0 MHz)

Data	Channel
Pha (c)	2 and 10
Psd (a)	3 and 11
Psd (c)	4 and 12
Pha (a)	5 and 13
Scaler (d)	6
Scaler (b)	7
ASE Commutator, Pole 1	8
Roll and despin valves	9
ACS Commutator	14
Accel./roll position	15
Fiducial light	16

Telemetry System #2 (244.3 MHz)

Data	Channel
Pha (b)	2 and 10
Psd (d)	3 and 11
Pha (d)	4 and 12
Psd (b)	5 and 13
Scaler (c)	6
Ledex and yaw valves	7
ASE Commutator, Pole 2	8
Clock	9
Pitch Valves	14
Pc/Yaw position	15
Scaler (a)	16

TABLE II

COMMUTATED CHANNEL

Transmitter #1 (234.0 MHz)

Segment	Data
1 - 9	Synchronization Pulses
10	Spare
11	7.5 V Internal Power Monitor
12	Door Open Monitor
13	Spare
14	Spare
15	Spare
16	Door Control Relay Mon.
17	Door Control Relay Mon.
18	Door Control Relay Mon.
19	Spare
20	Spare
21	P. C. LCRM-A
22	P. C. LCRM-C
23	P. C. HV Monitor B
24	P. C. HV Monitor D
25	Guard No. 1 HV Monitor
26	Guard LCRM-A
27	Guard LCRM-C
28	P. C. Cutoff Mon. No. 1
29	P. C. Cutoff Mon. No. 3
30	P. C. Cutoff Mon. No. 5
31	P. C. Cutoff Mon. No. 7
32	Spare
33	Spare
34	B+ Mon. A
35	B+ Mon. C
36	+6.75 V Monitor No. 1
37	Door Batt. No. 1 Mon.
38	+9 V Monitor
39	Timer No. 1 Operate Mon.
40	28 V Monitor No. 1
41	28 V Camera Batt. Mon.
42	+6.75 V Reg. No. 1 Monitor
43	5.0 V Calibrate
44	2.5 V Calibrate
45	0 V Calibrate

TABLE II - cont'd

COMMUTATED CHANNEL

Transmitter #2 (244.3 MHz)

Segment	Data
1 - 9	Synchronization Pulses
10	Spare
11	7.5 V Internal Power Monitor
12	Door Closed Monitor
13	Spare
14	Spare
15	Spare
16	Door Control Relay Mon.
17	Door Control Relay Mon.
18	Door Control Relay Mon.
19	Spare
20	Spare
21	P. C. LCRM-B
22	P. C. LCRM-D
23	P. C. HV Monitor A
24	P. C. HV Monitor C
25	Guard No. 2 HV Monitor
26	Guard LCRM-B
27	Guard LCRM-D
28	P. C. Cutoff Monitor #2
29	P. C. Cutoff Monitor #4
30	P. C. Cutoff Monitor #6
31	P. C. Cutoff Monitor #8
32	Spare
33	Camera Monitor
34	B+ Monitor B
35	B+ Monitor D
36	6.75 V Monitor #2
37	Door Batt. #2 Monitor
38	Not Used (2V)
39	Timer #2 Operate Monitor
40	28 V Monitor #2
41	28 V Instr. Batt. Mon.
42	+6.75 V Reg. #2 Monitor
43	5.0 V Calibrate
44	2.5 V Calibrate
45	0 V Calibrate

TABLE III

4.261 ACS PROGRAM

ACS Ledex Pos.	PROGRAMMED ACS Function	PROGRAMMED Time In Pos. (Sec.)	ACTUAL Flight Time (Sec.)	ACTUAL Time In Pos. (Sec.)
2	Coast	12.00	51.84	12.02
3	Despin	Adaptive	63.90	13.10
4	Erect	Adaptive	77.00	14.35
5	Coast	2.00	91.35	2.00
6	Roll R/A	2.578	93.35	2.58
7	Pitch R/A	2.179	95.93	2.18
8	Yaw R/A	3.105	98.11	1.00
9	Coast	1.00	99.11	10.31
10	Roll cw 12°.10	2.14	109.42	79.27
11	Pitch ccw 73°.725	37.50	188.69	17.58
12	Pitch ccw 14°.20	15.10	206.27	9.09
13	Pitch ccw 37°.675	19.00	215.36	85.64
14	Pitch ccw 40°.225	57.60	301.10	14.00
15	Yaw ccw 30°.050	4.80		
16	Pitch cw 26°.300	33.00		
17	Yaw ccw 30°.050	4.80		
18	Pitch ccw 15°.200	21.5		
19	Pitch ccw ∞	∞		

all the following pointing positions were greatly in error because of the loss of reference. The remainder of the observation consisted of three successive pitch maneuvers to celestial position 11.5^{hr}, $+47^{o}$. The maneuver continued somewhat beyond that, but the detectors were below the horizon by then. Good X-ray data was obtained during virtually all of this sequence, and good aspect information was derived from regions of sufficient star concentrations. However, the data bore little relation to the original experimental objectives.

4.0 TESTING AND CALIBRATION

4.1 Testing

Work was initiated on refurbishment of payload in December 1967. Rework and fabrication of parts was completed by 31 December 1967, and the assembled payload was ready for testing, alignment and calibration by 5 January 1968. The following schedule was adhered to for this phase:

1.	System Testing	8-11 January 1968
2.	Integration	7-8 January 1968
3.	Alignment	12-15 January 1968
4.	Calibration	16-19 January 1968

4.1.1 System Tests

A standard system test was performed on the payload to verify proper operation of (a) all instruments, (b) power and control system, (c) door operate mechanism, (d) TM data readout at the TM interface including commutated data, and (e) compatibility and operation of the ground control console. Satisfactory completion of this test was a prerequisite for any further testing.

4.1.2 Integration Tests

The payload/TM/ACS integration test was conducted at NASA/GSFC on 7 January 1968. There were no problems or difficulties encountered during the test and all systems operated satisfactorily. The equipment and personnel returned to AS&E the following day to prepare for and complete the alignment and calibration of the payload.

4.1.3 Environmental Tests

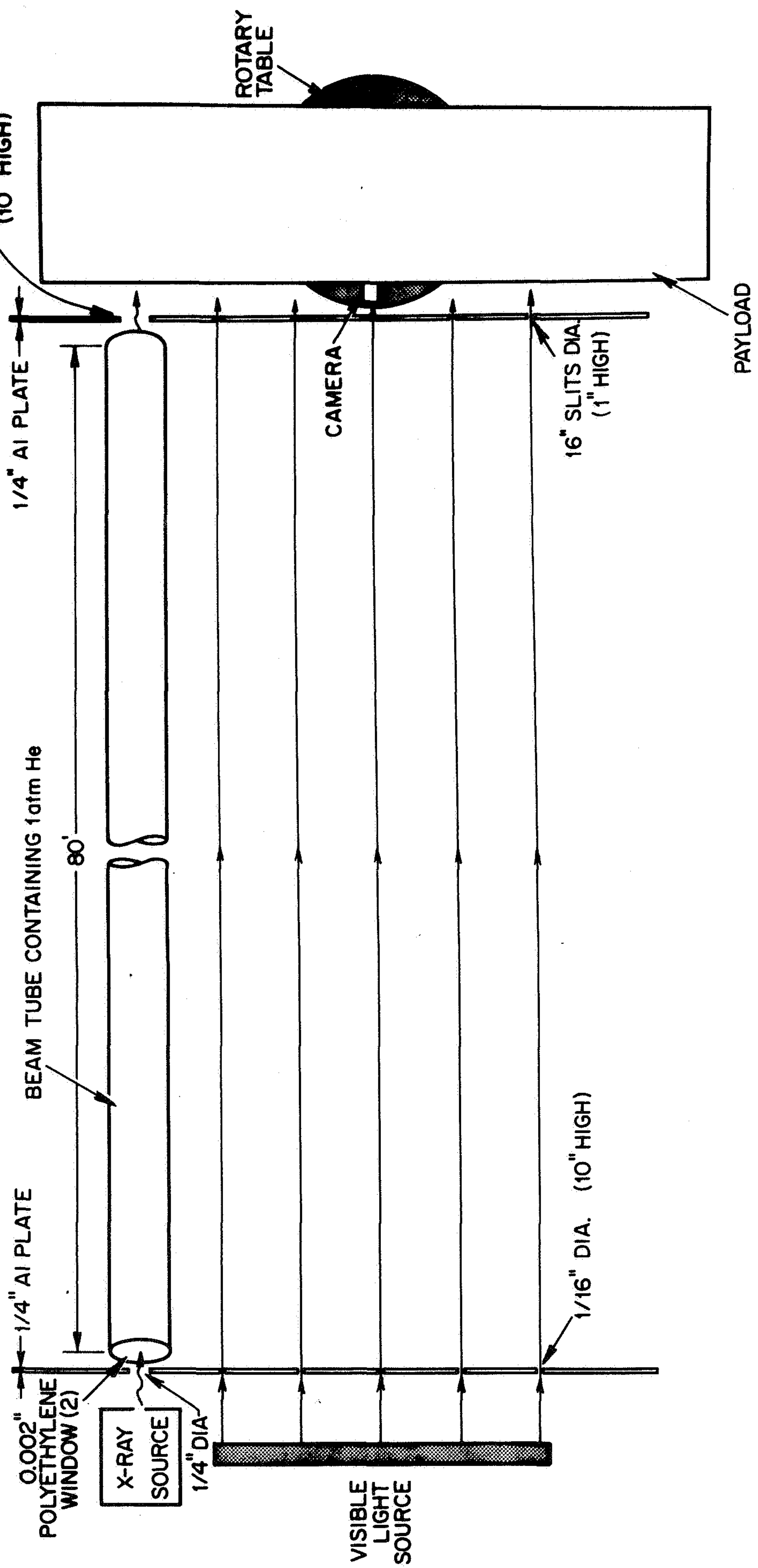
Since the payload was subjected to the standard Aerobee vibration test on its previous flight (4.228 CG) on 13 October 1967 and had performed satisfactorily, it was decided that another vibration test was not necessary. The need for another vacuum test was eliminated since there were no changes made since the last flight which would affect the operation at low pressure or vacuum.

4.2 Calibration and Alignment

Calibration of the X-ray proportional counters was carried out by exposing each detector to a series of radioactive X-ray sources ranging in photon energy from 1.5 to 22 keV. In this manner the overall response of the counters and amplifiers were measured, the desired gain and bias were established, and the energy resolution of the system was determined over that range of energy. In addition, a Co^{60} source was used to simulate cosmic background in the calibration of the rise time discrimination system.

The rigidity of the payload was such that the alignment of the aspect camera and the X-ray collimators would be maintained throughout the launch and duration of the flight. However, it was essential to measure their relative alignment in the laboratory prior to flight. Through knowledge of the alignment, the location of an X-ray source could be determined from the observance of a counting rate peak at a certain time and the aspect photographs. This was achieved by setting up an "X-ray" star in the laboratory. Several light beams and an X-ray beam were made parallel to each other by collimating each through the same two rigid plates. The entire payload was set upon a rotary table with both the aspect camera and X-ray detectors in operation, as shown in Figure 7. The payload is positioned such that the camera views one of the light beams. As the rotary table is turned, a maximum is observed in the counting rate. At exactly that point a photograph is taken. Inspection of the photograph reveals where on the photograph the X-ray star will appear. The camera registration was sufficiently precise, such that the sprocket holes of the film could be used as a reference. This technique enabled us to establish the alignment to within several arc minutes.

Collimator plate #1 consisted of a series of holes (1/4" dia for X-ray, 1/16" dia for visible light), spaced 3" apart. Collimator plate #2 was a



MEASUREMENT OF CAMERA-COLLIMATOR ALIGNMENT

1625

Figure 7

series of slits 1" high whose spacing matched that of plate #1. It contained a 4" opening for the X-rays and several 1/16" openings for the light.

The X-ray and light sources were removed 80' from the payload. Consequently, the X-ray beam was collimated to 17 arc min. by the 4" opening and the light beams were collimated to less than 1/2 arc min. Several passes were needed to sample the entire 32" of collimator length. As the low energy X-ray flux would be utterly attenuated by 80' of air, a beam tube containing 1 atmosphere of helium was used between the plates as the means of transmitting the X-rays.

5.0 FLIGHT 4.261 CG

On 24 January 1968 equipment and personnel arrived at WSMR for final testing and prelaunch preparation. A schedule of events for this period follows:

Preflight Conference	26 January 1968
Horizontal Check	29 January 1968
Rocket Installed in Tower A	30 January 1968
Vertical Check	31 January 1968
3 Hour Check	1 February 1968
Launch	1 February 1968

During this phase no problems occurred until after the vertical check. Missile Flight Safety requested another vertical check on the morning of 1 February 1968, and on applying external power for the experiment the +9.0 V DC power line was found to be shorted. The short was located at the pullaway connector by a screw which was installed when the pullaway cable was rigged. The short was removed, and on running the check the telemetry system was found to have a bad VCO which was replaced. No further problems were encountered.

The payload was launched at 2230 MST on 1 February 1968. Vehicle data was as follows:

Burnout	51.84 sec
Despin Start	63.90 sec
Despin Complete	77.00 sec
Erect Complete	91.355 sec
Severance	317.94 sec

Roll rate was 2.2 RPS at burnout, and an apogee of 86.5 statute miles was reached. Recovery of the payload the following day indicated very minor structural damage. The door had opened and closed properly, and further inspection and electrical testing at AS&E showed no further damage to the payload and that all systems were still operating.

A check of the recorded data did indicate that when the door opened during flight some RFI was apparent in the lower counter and logic banks and that some remedial shielding would be necessary for future flights.

6.0 DATA

The malfunction of the ACS system meant that the experimental objectives were missed for the second time. However, X-ray data of some interest was obtained from a large portion of the sky. The instrumentation functioned well, and expectations concerning the added X-ray detection sensitivity conferred by the rise time discrimination system were fulfilled. A certain amount of radio frequency interference from the telemetry transmitter did appear sporadically in two detectors. Nevertheless, there was no difficulty in separating the X-ray signals from the noise by virtue of the energy-rise time criteria that had been established. Two discrete X-ray sources were seen; the Crab Nebula plus a source from the direction of Vela during the 6^{o}/sec roll maneuver. A diffuse X-ray flux was observed for which it should be possible to derive a significant measure of the spectral distribution in the energy range 1-12 keV.