AS&E

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ASE-3268

FINAL REPORT FOR CONTRACT NASW-2347

HIGH RESOLUTION STUDIES OF THE SOLAR X-RAY CORONA FROM AEROBEE ROCKETS

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PERIOD OF PERFORMANCE: 15 DECEMBER 1971-30 APRIL 1973

PREPARED FOR:

AMES RESEARCH CENTER
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MOFFETT FIELD, CALIFORNIA 94035

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Approved by: ____________________

G. S. Vaiana
Principal Investigator

FOREWORD

This document is the Final Report for NASA Contract NASW-2347. The period of performance of the contract was 15 December 1971 to 30 April 1973. The contract provided for completion of the construction of an imaging spectrometer payload designed for launch by an Aerobee 170 rocket and two flights of the payload.

The final quarterly report (period of performance 15 December 1972 to 14 March 1973) and the Final Report became due at the same time; consequently we have included the information for the quarterly report in this document.

The Principal Investigator for this contract was Dr. Giuseppe S. Vaiana.

CONTENTS

ILLUSTRATIONS

1.0 INTRODUCTION

This report describes the continuing effort performed by AS&E in the field of high resolution solar X-ray astronomy. This endeavor was begun in 1960 with the demonstration of the feasibility of cylindrically symmetric double reflection optics. Since that time we have developed a series of instruments of increasingly sophisticated design which have expanded the knowledge of the solar corona. The main results of this program were obtained with a payload which was designed for an Aerobee 150 launch vehicle. This instrument contained a 23 cm diameter mirror whose polished surface was a nickel phosphorous alloy. This payload was flown six times between March 1968 and November 1970. The results of these flights have been described elsewhere; however, during this period continuing laboratory testing indicated that areas of improvement existed and a proposal was made to NASA for the construction of a new and improved mirror which would form the nucleus of a new payload. This proporal was accepted and work was commenced on the new mirror and payload under contract NASW-2027 and continued under contract NASW-2240.

The mirror was finally accepted and the payload completed during the initial phase of the present contract. Since that time the payload has been launched and recovered twice on July 10, 1972 and March 8, 1973. No scientific data was obtained on the first occasion owing to the failure of solar pointing system to acquire the sun. The second flight was successful, although not completely, and high quality images of the sun were obtained.

Between the two flights the payload was involved in an aircraft accident which resulted in the payload being submerged in San Francisco Bay. The subsequent repair of the payload was handled under a modification to this contract, which had by this time been transferred to NASA, Ames Research Center from NASA Headquarters.

The statement of work for this contract is summarized below.

The contractor shall provide NASA with continuing studies of X-ray emission from the solar corona at high resolution from sounding rockets. This will include the following specific tasks:

(i) Integrate the components into the Aerobee 170 payload and calibrate the completed payload to ensure that the scientific objectives of the proposed rocket flights will be met. This will include a scientific evaluation of the grazing incidence mirror, selection of crystals for the spectrometer and design and fabrication of a computer interface for checkout of the experiment.

(ii) Make a first flight of the Aerobee 170 payload. This will include providing the necessary field support for integration and launch and analysis of the engineering data for improving the performance of the second flight.

(iii) Refurbish the payload and make a second flight of the payload.

(iv) Analyze the scientific data from both flights and, where appropriate, publish the data in the scientific literature.

(v) Perform a preliminary design of a grazing incidence grating X-ray spectrometer for inclusion in an Aerobee 170 payload.

After the plane crash a supplemental agreement was entered into which provided for the repair of the payload.

These activities will be described in greater detail in the following sections of this report.

2.0 SCIENTIFIC EVALUATION OF THE GRAZING INCIDENCE MIRROR

As previously mentioned in Section 1.0, AS&E has been committed to a program for the development of optical imaging systems for X-ray astronomy. The new mirror combines two improvements which have resulted from this study. The first involves the figure of the surfaces and the second the smoothness of the reflecting surface.

2.1 Surface Figure

Our previous mirrors have consisted of two co-axial surfaces, the first surface being a paraboloid and the second a hyperboloid. The disadvantage of systems of this type is that they do not satisfy the Abbé sine condition and the resulting image suffers from coma. This defect can be removed by a proper configuration of the surfaces. In this case, they are no longer paraboloid-hyperboloids but are parametric surfaces which are called Wolter-Schwarzschild surfaces.

Monte Carlo ray tracing techniques have shown that improvements at the arc-second level are to be expected. A disadvantage is that the surfaces are more difficult to construct and greater care has to be exercised.

2.2 Surface Finish

The geometrical criteria for specifying the tolerances on the slopes of the mirror surfaces break down at scales small enough for diffraction effects to become important. We can specify the requirements for the surface finish in terms of the traditional Rayleigh criterion for a perfect reflecting surface which is satisfied if surface irregularities introduce errors in the reflected wavefront of less than a quarter of a wavelength. For radiation incident at grazing angle θ , the height of a surface deviation corresponding to a $\lambda/4$ wavefront error is

$$h = \frac{\lambda}{8\theta} \text{ (radians)}$$

For a wavelength of 8.3 Å and a grazing angle of 1°, the resulting scale height is 60 Å. Irregularities of this scale and greater will modify the intensity distribution in the image plane on a scale of tens of arc seconds, resulting in a poor point response function. That is, mirrors with somewhat poor surface finish, although having high resolution, will exhibit relatively poor acutance since a substantial fraction of the reflected power lies in the wings of the distribution. This has been perhaps the most severe limitation on the high resolution mirrors we have built so far.

Scattering tests performed at AS&E have shown that fused silica produces less scatter than other available materials and consequently we chose to manufacture the mirror from this material.

The X-ray mirror was constructed by the Perkin-Elmer Corporation of Norwalk, Connecticut and was delivered to AS&E on 3 May 1972.

2.3 Visible Light Tests

The visible light resolution was obtained using the apparatus shown in Figure 2-1 and the procedure summarized below. The resolution was determined using a standard U. S. Air Force resolution target and Kodak High Contrast Copy Film (5069).

(i) The optical axis of the parabolic reflecting mirror is determined using a laser and the target is placed on, and normal to this axis.

(ii) The target is placed at the focus of the paraboloid. For this, the target is replaced with a pin-hole and the focal position determined using a Focault Knife edge test.

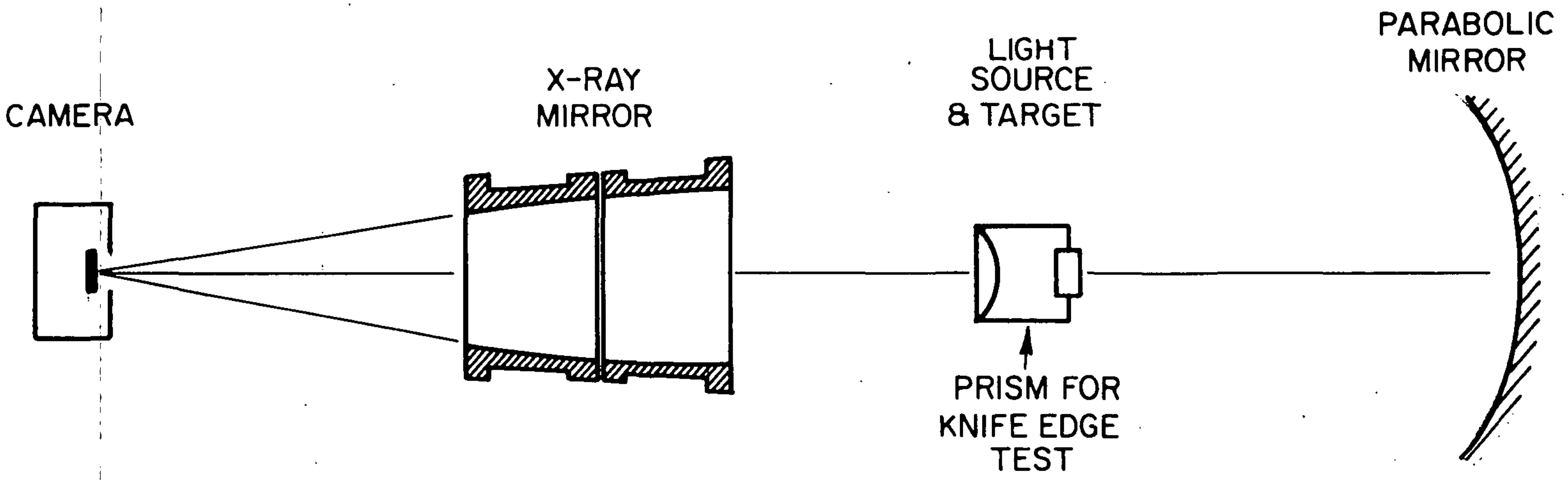

Figure 2-1. The Apparatus Used for the Resolution Test.

(iii) The axis of the X-ray mirror is co-aligned with the axis of the parabolic mirror by adjusting its position until the images produced by rays which are reflected from both mirror surfaces and from the rear surface alone are concentric.

(iv) The resolution target is replaced and a series of exposures are made at various focal positions. These exposures are made by illuminating the target with a brief light flash ($\sim$ few milliseconds).

(v) The off-axis resolution is obtained by displacing the target from the optical axis and repeating the focus plates.

An enlargement of one of the on-axis resolution charts is shown in Figure 2-2 and the variation of the resolution with focal position is shown in Figure 2-3.

In conclusion, our tests have shown that in visible light the X-ray mirrors have a resolution on the order of one arc second.

2.4 X-Ray Tests

The main X-ray tests have consisted in a measurement of the point response function of the mirrors for various wavelengths. The point-spread function is defined as the number of photons per unit area as a function of position in the plane of the image resulting from a point source. The X-rays focused by a grazing-incidence telescope strike the focal plane outside the geometrical image of the source primarily because of scattering at the mirror surfaces. The scattering depends on conditions at the reflecting surfaces which are not known in detail. Consequently, the point-spread function cannot be computed reliably and must be determined experimentally.

Knowledge of the point-spread function is essential for the interpretation of flight data obtained with the telescope. The focal plane energy distribution for an extended source can be calculated by convoluting the point-spread function with the form of the source.

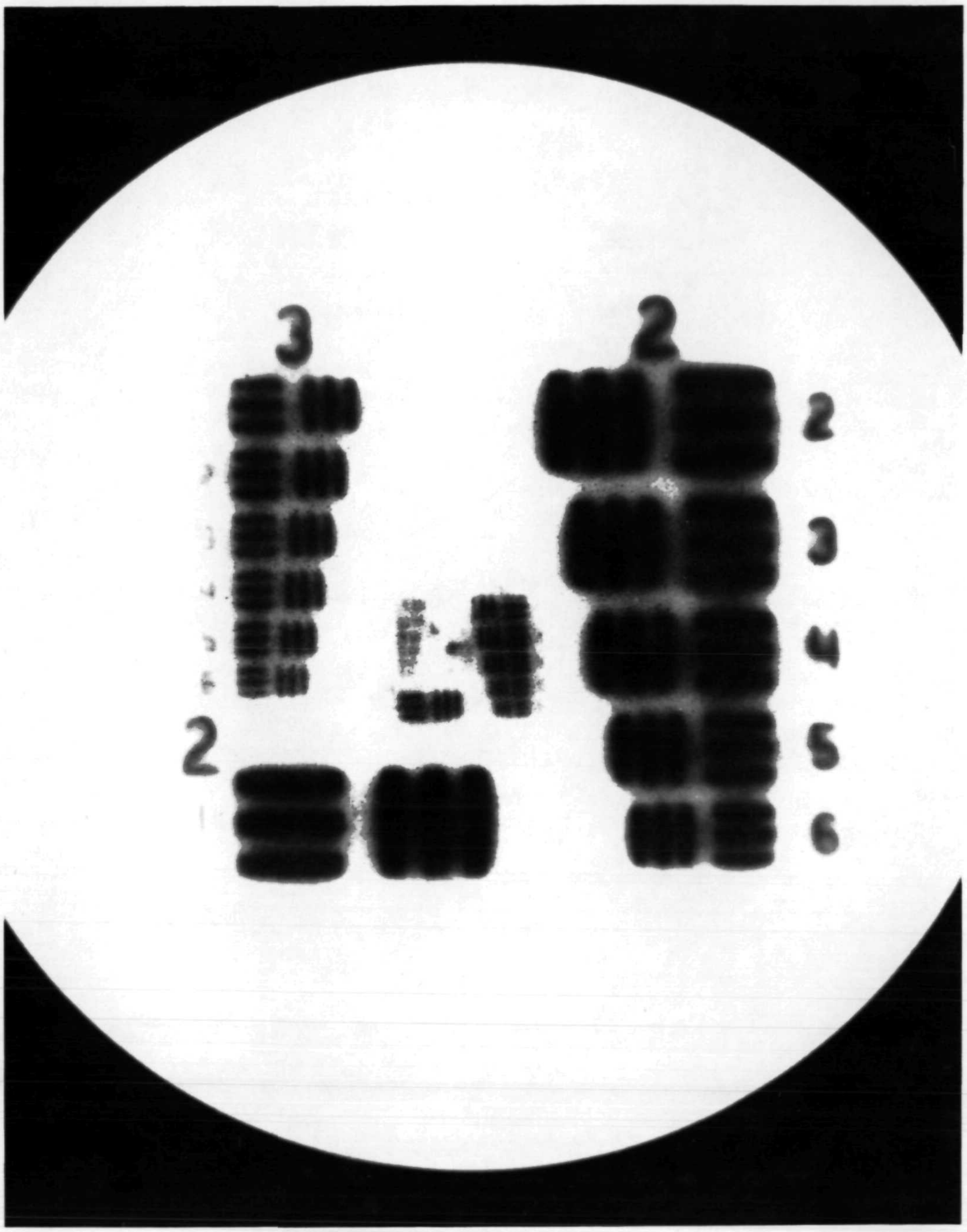

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Figure 2-2. Air Force 3-Bar Resolution Chart Imaged by the Mirror. The 5-2 Group on the Chart is Resolved, Illustrating a Spatial Resolution of Less Than One Arc Second for Visible Light.

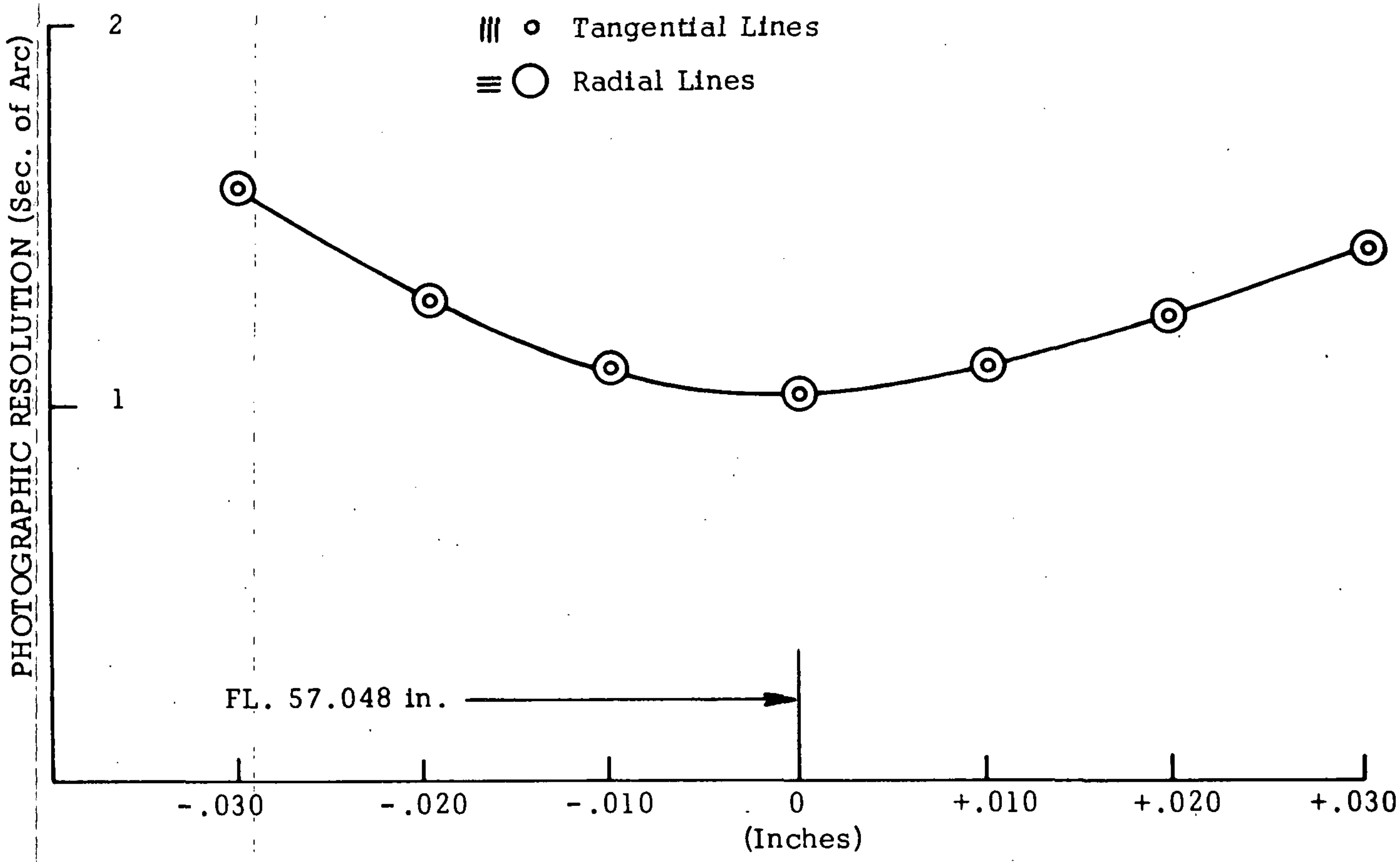


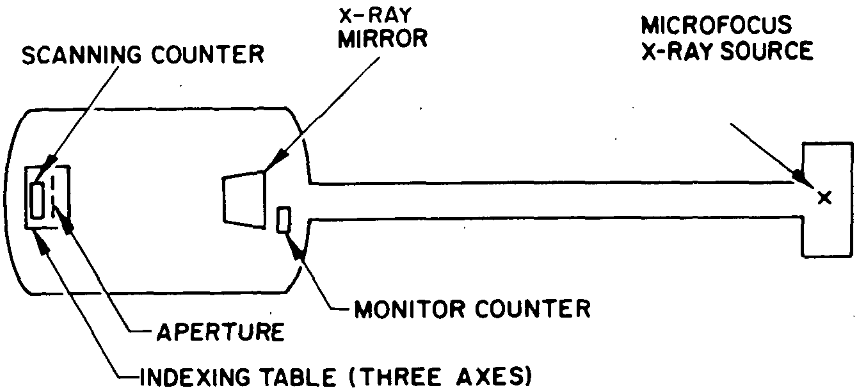
Figure 2-3. Photographic Resolution as a Function of Axial Focus of the 12 Inch Mirror. This is a Result of Tests Run at Perkin-Elmer Corporation

Conversely, the structure of an unknown source can be determined by unfolding the observed energy distribution with the point-spread function.

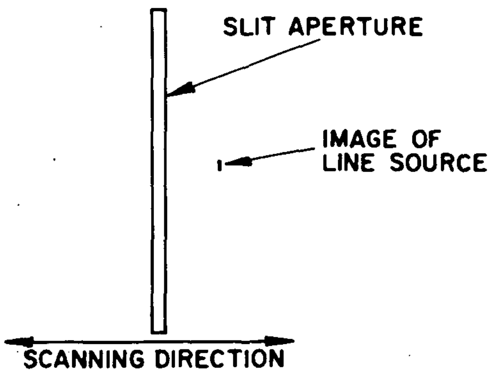
2.4.1 Experimental Measurements

The point-spread function of the mirror was studied using a micro-focus source of X-rays situated approximately 67 meters from the mirror. The arrangement is shown in Figure 2-4a . Various targets and operating potentials for the X-ray source were used to generate X-rays with wavelengths characteristic of the K and L lines of magnesium, carbon, copper and iron. For most measurements, the source was a line 10 arc-seconds long by 1-2 arc-seconds wide. The image was scanned by a proportional counter masked with a slit 1.5 arc minutes long by 1.8 arc seconds wide, the long dimension being parallel to the long dimension of the line image. The scan direction was across the narrow dimension of the image, as shown in Figure 2-4b . The line source gave the same result as a point source for this scanning geometry since the length of the line was much less than the length of the slit.

The proportional counter had a mylar window 0.0003 cm thick and was filled with methane at a pressure of 21 cm of Hg which was allowed to flow continuously. The position of the scanning counter along the optical axis was adjusted for minimum profile width after preliminary scans at several longitudinal positions. The flux incident on the telescope was monitored by a second proportional counter masked with a 0.95 cm diameter aperture (0.7 cm^2 area). Each point in the profile was measured by recording the number of incident counts required for 1000 counts at the scanning counter. The relative efficiency of the two counters was measured with both masking apertures removed. They were identical to within a few percent. It was verified that the



a. OVERALL VIEW



b. GEOMETRY FOR SLIT SCAN OF LINE IMAGE

Figure 2-4. Experimental Arrangement for the X-ray Measurements flux incident on the telescope was uniform over its aperture to better than ± 5%. The motion of the scanning table was controlled with an indexing stepping motor and was checked with a dial indicator during the scans.

Typical experimental data are shown in Figure 2-5 where they have been compared with the S-054 ATM mirrors. The improvement clearly demonstrates the better surface quality of this mirror.

2.5 A Computer Interface for Hardware Evaluation

In order to evaluate the payload performance, an interface was constructed to connect the payload data outputs to a Nova type computer. The interface consists of interrupt logic, plus data gates for the crystal shaft encoder and scalers and 2 digital to analog converters. The construction was based on the design suggested by Data General, the Nova manufacturers ("How to Use the Nova Computers", DG NM-5, April 1971, PG A19).

The interrupt logic signals the computer when data is ready to be transferred. The usual signal for driving the interrupt logic is the clock pulse. The computer can then read in under program control the shaft encoder output and the scalar data. This data can then be arranged in the memory in several different ways. The most useful is to use the shaft encoder as the address for storage of the scaler counts. This enables a distribution of counts vs. Bragg angle to be obtained. This digital data is converted to an analog signal and displayed on an oscilloscope (Figure 2-6). The software also permits detailed examination of smaller regions of interest.

Several other software programs have been written to enable the performance of the hardware to be evaluated.

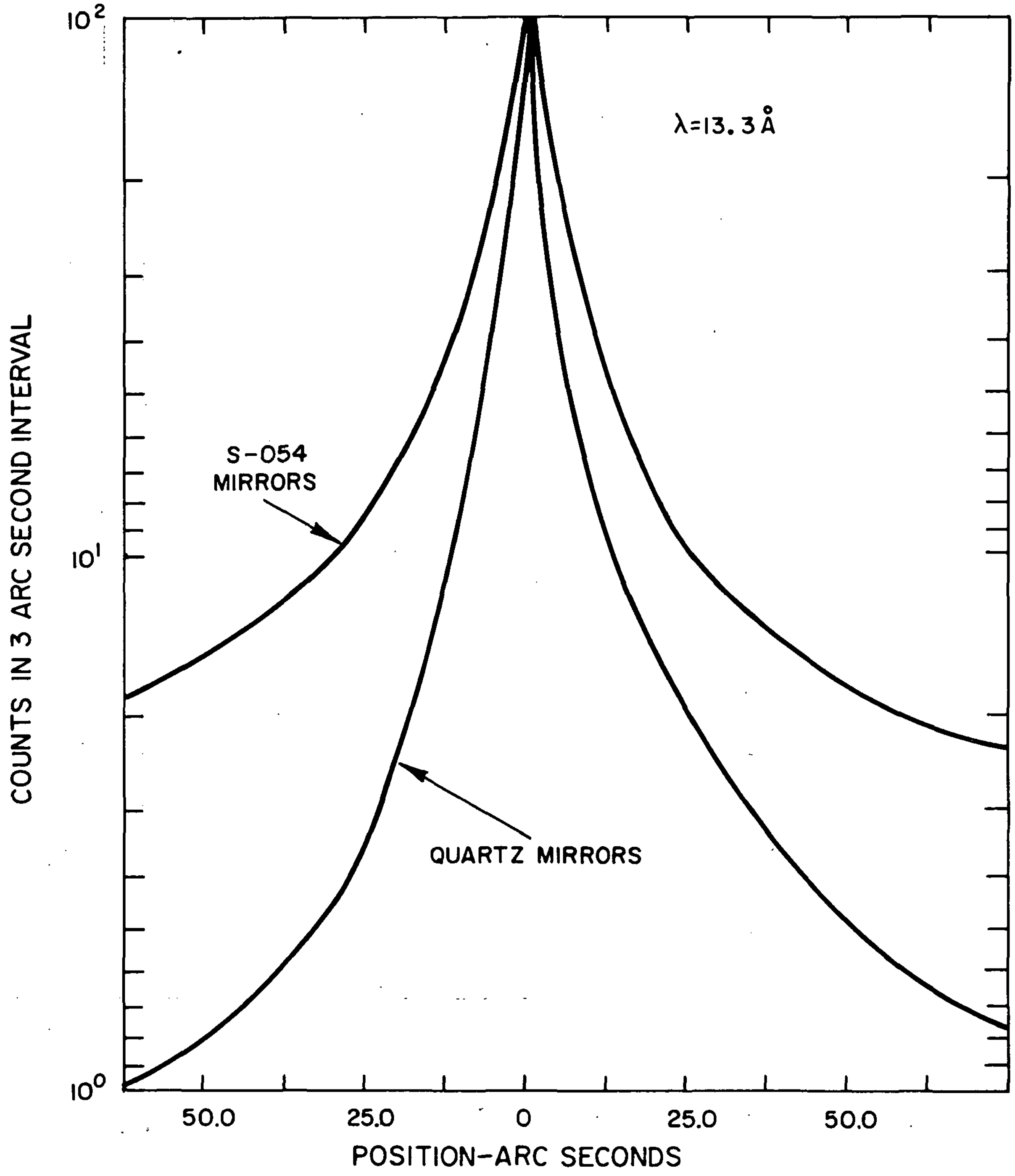


Figure 2-5. Comparison of the Point Response Function of the S-054 and the Quartz Rocket Mirror at the Wavelength of Copper L Radiation.

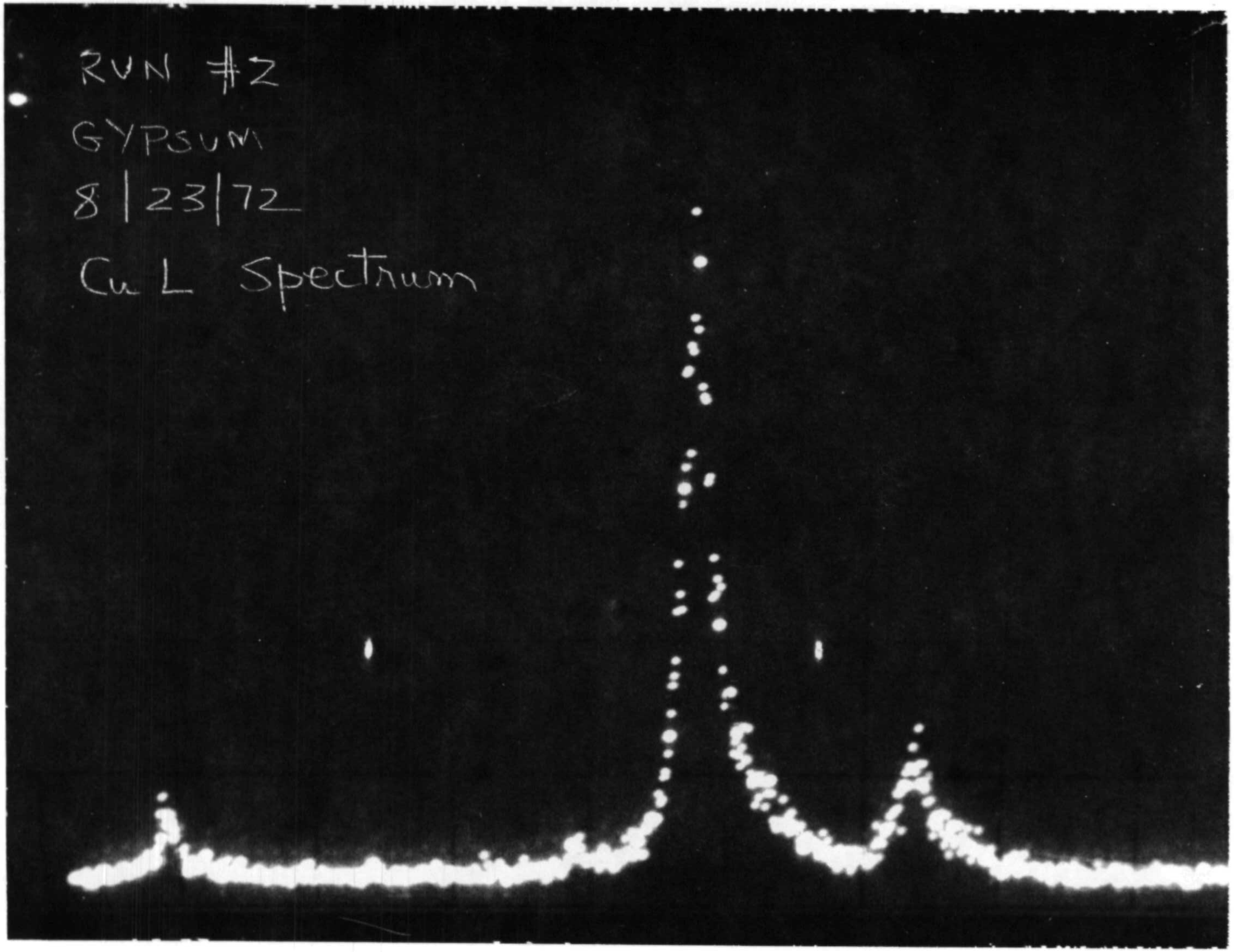


Figure 2-6. Photograph of the Oscilloscope Display of the Spectrometer Output. The Spectrum is from Copper near the L Transitions.

3.0 THE FLIGHT OF 13.028CS

3.1 Scientific Objectives

High resolution measurements of the temperature and density structure of the lower corona, and particularly the radial dependence of these quantities, provide extremely valuable information for understanding the heating mechanisms and energy balance of this portion of the solar atmosphere. This flight was the first one involving the new payload, which contains two separate but complementary experiments: the imaging and spectrometer systems. High resolution spectroscopy is required to supplement the broad band imaging data in order to determine details of the coronal structure, especially the electron density.

The vertical scale of the important coronal phenomena is less than the effective resolution of our former solar X-ray telescope, and may be less than the resolution of the new mirror. This difficulty can be overcome by using the limb of the moon as a moving shutter, and thus determining altitude structure by the temporal dependence of the emission. It was this experiment which was attempted at the fourth contact of the 7 March 1970 eclipse, but unfortunately a partial failure of the rocket pointing system severely degraded the data. The new flight was timed to observe fourth contact; the X-ray background from the rest of the sun is low enough so that a total eclipse is not required. This permits observations of the entire solar disc during a portion of the flight.

3.2 Mission Success Criteria

The following criteria were established for a completely successful mission:

1. To achieve the scientific objectives of the eclipse-related portion of the flight the launch must take place

within ± 20 seconds of T = 0. Fourth contact will then occur at T + 130 (± 20) sec into the flight.

2. Acquisition of the sun by SPARCS, followed by a period of fine pointing lasting for at least 200 seconds. During this 200 second period, the peak-to-peak motion during any 1 second exposure period must not exceed 10 arc-sec in pitch and yaw and $1/2^{o}$ in roll.

3. Successful operation of the experiment camera for at least 200 seconds of the period when fine pointing is maintained.

4. Successful operation of the spectrometer both before and after the roll maneuver occurring at T + 220 seconds.

5. Successful completion of the roll maneuver. Final position should be within $1/2^{o}$ of the predicted position.

6. Recovery, intact and unfogged by visible light, of the film from most of the exposures made during the period mentioned under item 2.

7. Successful operation of the PPM/FM and FM/FM transmitters during the period of fine pointing and recovery of the scientific data.

3.3 Launch Window Requirements

The scientific objectives of 13.028 CS require that it be launched to coincide with the fourth circumstance of the solar eclipse of 10 July 1972. The actual launch time had to be chosen so that the fourth circumstance occurs at T + 130 ± 20 secs into the flight. Our calculations indicate that the requested launch window would be 1500 hours +30 $^{+15}_{-20}$ secs. This time is Mountain Daylight Saving Time (MDST).

Unless the launch occurred within this window, the primary objective of the eclipse measurements would not be met. However, the secondary objectives would be satisfied for a flight later the same day or the following day. The requirement for the launch window was established by a computer study of possible trajectories available for different launch times. Figure 3-1 illustrates the results of this analysis. The curves show the angular separation of the solar and lunar discs as a function of time from launch.

The rocket is fired approximately due North from White Sands and as the apparent angular size of the Moon increases with altitude above the Earth's surface, the sequence of events seen in the frame of reference of the rocket, as it ascends, is as follows.

At T = 0 the sun and moon are separated, i.e., 4th circumstance has occurred on the surface of the Earth. As the rocket ascends the sun and moon appear to converge, overlap and finally diverge. The launch time is chosen so that the divergence occurs between T + 110 sec and T + 230 sec. During this period X-ray images were to be taken at 2 sec intervals with 1.5 sec exposures. The rate of separation of the sun and the moon is approximately 0.2 arc seconds/sec during this time and consequently the effective resolution of each image at this boundary is approximately 0.3 arc seconds.

3.4 Launch of 13.028 CS

A summary of the events associated with the launch of 13.028 CS from the White Sands Missile Range (WSMR) is given below:

26 June -- Payload integration was completed at ARC, with the spin balance, weight and center of gravity measurements. The payload was shipped directly to WSMR following these tests.

27 June - 4 July -- The payload was assembled for flight at WSMR. The optical system underwent final alignment and the precise focal position was obtained. The

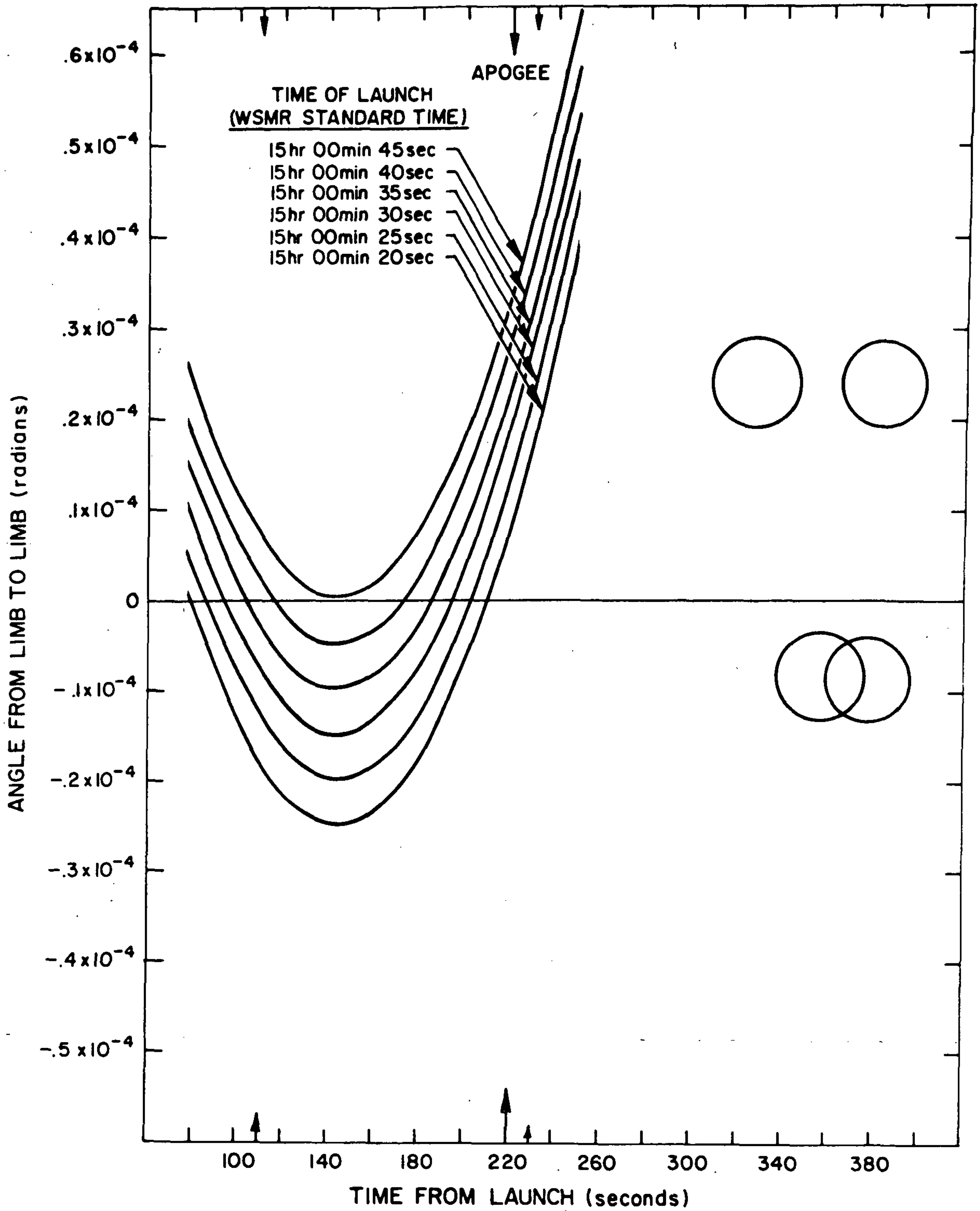


Figure 3-1. Calculated Trajectories Available for Different Launch Times from WSMR on 10 July 1972. The Small Arrows on the Abcissa Indicate the Period of 2 Sec. X-ray Exposures. The Circles Indicate the Geometry of the Sun and Moon Around 4th Circumstance (the "0" line on the ordinate).

spectrometer flight program was chosen and wired into the experiment. The final calibrations of the proportional counters were made. On 6 July a visit was made to the Sacramento Peak Observatory to select the best active region for study. The help of the observatory staff and in particular of Dr. D. M. Rust is acknowledged. Active region SPO 3128 was selected as the best candidate.

5 July -- The Pre-flight Conference for 13.028 CS was held and the launch time and window were defined and the range scheduled. The horizontal test was held in the afternoon. This was the first time that the SPARCS unit S/N 207 had been mated to the payload. During integration at GSFC, a SPARCS IV unit S/N 402 had been used. However, all SPARCS IV units were grounded after integration of 13.028 due to various problems and a SPARCS II unit had to be substituted. This unit was not ready until 5 July at which time it was shipped to WSMR for integration on the payload. The spin balance had been performed with S/N 206 which was used for 13.080. During the horizontal test it was found that the SPARCS can and the scientific payload were rotated one to another by 180°. The spin balance had also been performed in this condition. This meant that the gas jets controlled by the ISS in the fine mode would be 180° out of phase. Two options were available to overcome this difficulty. These were:

1. Rotate the SPARCS can through 180°. This would require a new spin balance.
2. Rotate the fine eyes through 180°. This would require realigning the science to the fine eyes.

Both of these alternatives would be fairly time consuming. However, as the latter would not require the use of additional facilities, it was chosen.

After the horizontal test, the tone ranging command was exercised. This was a failure mode command and is not exercised during the flight plan. At this time problems were encountered with the tone ranging and it was decided before launch to de-activate the tone-ranging command capability.

6-7 July -- The re-alignment of the fine eyes was completed and the necessary offset for the collimators was set in. A serious disagreement occurred between GSFC and Space General regarding the stability of the payload with the bulbous section. The area of concern was the correct angle for the trailing edge of the bulbous section. It was eventually agreed that the 10° chosen by AS&E was acceptable.

8 July -- The system was installed in the tower. The vertical check was scheduled for 1100 hrs.; however, the TM could not be turned on owing to a faulty jumper cable in the blockhouse. This caused the vertical to be postponed and the radar illumination check to be cancelled. The vertical check was held successfully approximately two hours later.

9 July -- Final preparation for flight following the vertical check was made. The precise launch time based on the final trajectory data was selected.

10 July -- The final countdown proceeded smoothly. The only problem resulted from a leaking valve in the proportional counter gas flow system. This was fixed and the counter gas reservoir was loaded. At T-60 sec, the SPARCS pneumatics umbilical line was released. This operation is performed remotely from the blockhouse. However, the indication lights for this operation showed

that separation had not occurred. Consequently SPARCS initiated a hold at T-30 sec in order to make a visual observation to see if the umbilical had released correctly. It had. However, the launch window for the de-occultation experiment had passed and the secondary objectives would be met by launching at any time during the rest of the day. However, as the weather conditions in the recovery area were deteriorating, it was decided to continue the countdown without an additional hold. The count was set back to T-180 sec and restarted. This final countdown was completed and 13.028 CS was launched at 1305:10.9 MDT. The rocket and Yo-Yo performed as anticipated; however, the SPARCS unit after completing the de-spin failed to point the payload to within 10° of the sun. The cause of the failure is not known at this time. However, the result was that no useful scientific data was obtained.

In retrospect, the procedures followed for the launch of 13.028 CS seem to have been inadequate to handle satisfactorily the problems associated with an unexpected hold. The major difficulties are listed below:

(i) Although the umbilical problem occurred at T-60 sec, the hold was not called until T-30 sec.

(ii) As there was only a single SPARCS engineer present, he had to go out to the tower and ascertain the umbilical was clear, and return to the blockhouse and then recheck the SPARCS monitors before allowing the count to proceed.

(iii) The count was recycled to T-180 sec instead of being re-started at T-30 sec. No reason was given at the time for this procedure and it probably arose from the fact that the Experimenter had informed the Navy that if a hold was necessary, it should take place before T-180 sec. At this time the gas flow to the counters would start and, as the supply would last for only 30 minutes, it is better to hold before this event has occurred. However, once the count has passed this point, nothing is gained by recycling to this time.

(iv) The launch finally took place 4 mins. and 41 secs. after T-0 and, if the count had been restarted, at T-30 sec, and if the delay associated with determining this time had been eliminated, it should have been possible to have launched with a delay of one minute or perhaps a little longer. In this event, 50% of the scientific objectives of the de-occultation experiment would have been met.

We understand that a TV camera will be placed in the tower during SPARCS launches to view the umbilical separation; we also recommend that:

(i) the procedure for initiating holds be made clearer;

(ii) the sequence of events after a hold has been initiated, and which must be followed in order to pick up the count after the hold, be discussed at the pre-shoot conference.

3.5 Recovery of 13.028 CS

The rocket payload contained a fused silica mirror which was being flown for the first time and several features had been designed into the payload to ensure the survival of the mirror at impact. These features included a crushable buffer forward of the mirror and a protective pad, which formed a bulbous section, around the mirror. The recovery took place in the Rhodes Canyon area without any problems. The actual landing was in sand and very little damage to the buffer occurred. The fused silica mirror was undamaged.

3.6 Conclusions

The pre-launch and launch activities for 13.028 CS were beset by a continuous series of problems. These were in many cases the result of:

(i) the experimenter's inexperience with his payload, which was being flown for the first time;

(ii) the pressure of launching on an unflexible schedule set by the solar eclipse of July 10;

(iii) the problems associated with the grounding of various SPARCS systems which resulted in the unit for 13.028 not becoming available until the day of the Horizontal Test.

Notwithstanding these problems, had the rocket been launched on time and acquired the sun, we feel that at the very least, the minimum success criteria for the mission would have been satisfied.

Finally, the cause of the SPARCS failure to acquire the sun is still unknown. The tentative conclusion is that the coarse eyes were confused by the high albedo from the cloud covered earth. In these circumstances the rate of acquisition is very low and it is believed that the gas supply was exhausted before the sun was acquired.

Following a design review held during August, 1972 to discuss this and other failures, several modifications to the system have been made. The two most important are:

(i) the replacement of the coarse sun sensors with low profile quartz sensors with superior output which allows for a return to the proven SPARCS I albedo compensation scheme.

(ii) the addition of rate sensors to the pitch and roll channels which will eliminate the possibility of low-quality rate information permitting SPARCS to "cone" around the sun.

4.0 AIR CRASH AND REFURBISHMENT

In an attempt to determine the nature of the SPARCS failure on 13.028 CS, the payload was shipped to NASA Ames for failure testing. On its return, the payload was aboard TWA Flight 604 which had an aborted take-off from San Francisco airport. The airplane overran the runway and ended up in the Bay. The result was that the payload spent a period of 50 hours in a salt water environment. In order to complete this refurbishment, a change of scope to the contract was negotiated with NASA Ames. The technical section of this porposal which contains details of the damage will be found in Appendix A of this report.

5.0 FLIGHT OF 13.029 CS

5.1 Scientific Objectives

This flight of the ASE Imaging Spectrometer was devoted to the spectroscopy and imaging of an active region. High resolution spectroscopy is required to supplement broad band imaging instruments to obtain the detailed temperature, density and chemical composition of the coronal plasma. The solar X-ray spectrum although quite complex can be divided into three wavelengths regimes. The strong emission lines present in these regimes are thus characteristic of three different types of process occurring in the corona. In general, most of the lines beyond 20 Å are produced in the general corona, most of the lines between 6 and 20 Å are associated with active regions and the strongest lines below 6 Å with solar flares. The wavelength region above 6 Å is of particular interest for it contains the resonance lines of the helium and hydrogen-like ions of the intermediate elements from carbon to silicon. The atomic parameters of these ions are relatively well known, thus simplifying the spectrum analysis which compares the measured line intensities with those predicted by ionization and excitation theory applied to the coronal plasma. The intensity of a particular line depends on the electron temperature, the element abundance and the emission integral over the region where the electron temperature has the value at which the particular ionization stage occurs. The elemental abundance of the element can be eliminated by comparing the intensities of two lines of a single element or ion. Combining this information with knowledge of the volume of the emitting region obtained from an imaging system enables the electron density to be determined. These results can then be compared with models of the physical processes present in active regions.

This experiment was designed to scan the principal lines of the helium-like spectra of silicon, magnesium, neon and oxygen and the hydrogen-like spectra of neon and oxygen. These lines are sufficient to construct a model of the active region under observation. In addition, lines from the spectra of nickel and iron will be observed.

In addition, these intervals will be searched for evidence of the satellite lines which have been attributed to dielectronic recombination. Evidence for this process is of great interest, since one of our basic problems is to establish the relative importance of all the atomic emission processes in determining the ionization balance in the corona. In fact, dielectronic recombination may be competitive with collisional excitation in producing the observed fluxes at the position of the resonance lines of the heavier coronal ions. This information can only be obtained with high resolution spectral scans of individual solar features, for which the experiment has been designed.

Finally, high resolution broad band X-ray images of the whole sun will be made. These images will show both the general morphology of the solar corona and the framework of the active region from which the spectral data has been obtained.

5.2 Mission Success Criteria

The mission success criteria for this flight were essentially identical to those for 13.028 CS described in Section 3.2 of this report.

5.3 Launch of 13.029 CS

13.029 CS was launched from WSMR, New Mexico at 1100 MDT on 8 March 1973. The payload acquired the sun and useful scientific data were obtained. A description of the flight and the problems encountered are contained within the flight report which will be found as Appendix B of this report.

5.4 Scientific Data Obtained with 13.029 CS

Scientific data from both experiments was recovered and is under analysis. As the spectrometers were pointed at a weakly emitting area of the sun, rather than at an active region, the analysis of this data will be more difficult than expected, but can still be expected to yield substantial scientific information.

The photographs from the imaging system have been developed and are being studied. A 58 sec exposure through an aluminized polypropylene filter with a nominal passband of 8-37 and 44-60 Å is reproduced as Figure 5-1 . It contains views of coronal structures never previously seen. A publication containing the preliminary information from this flight is in preparation.

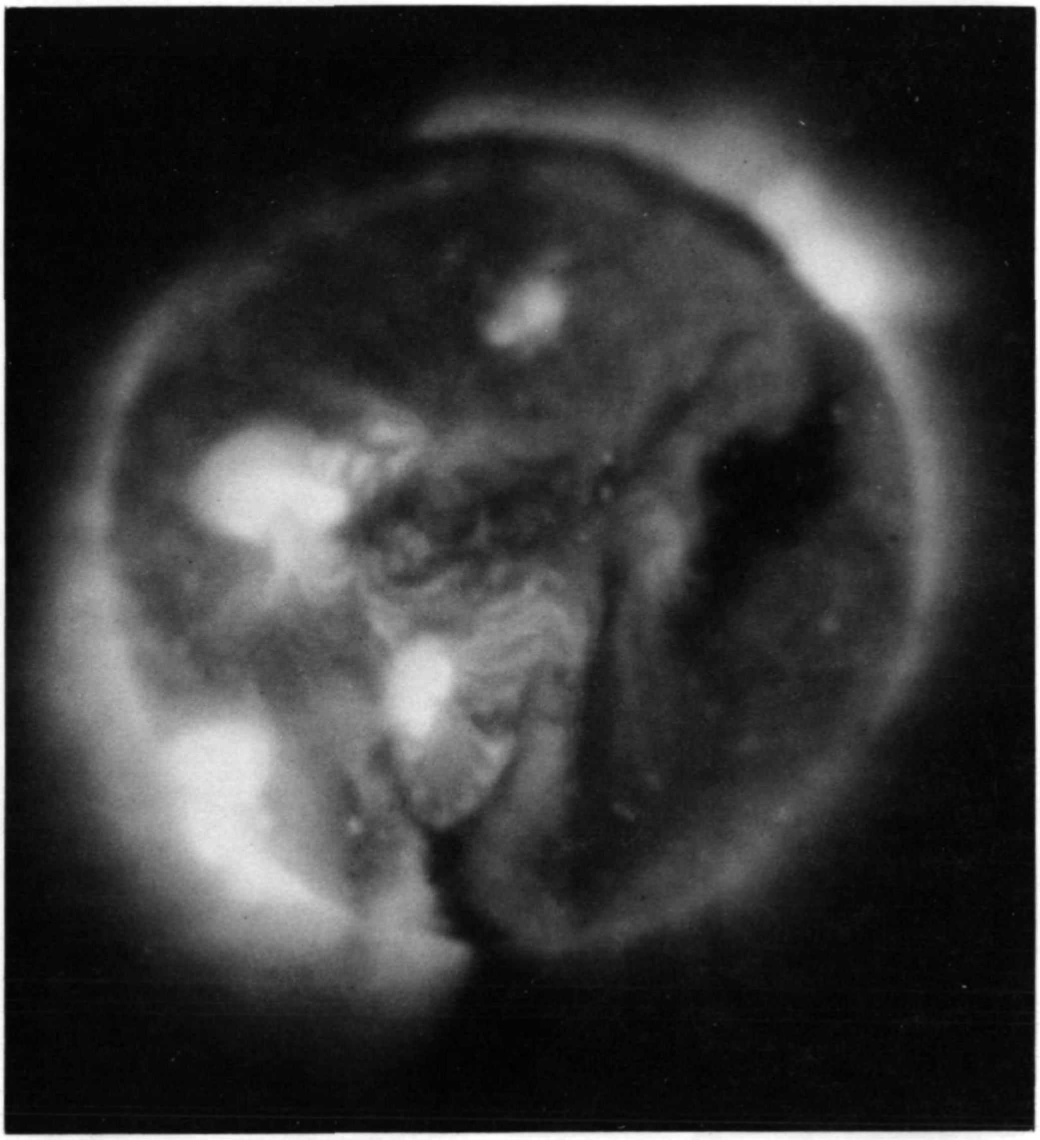


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Figure 5-1. An X-Ray Photograph of the Sun Taken on March 8, 1973 through a One Micron Aluminized Polypropylene Filter with a Nominal Bandpass of 8-37 and 44 to 60 Å.

6.0 A GRATING SPECTROMETER PAYLOAD

A design study has been undertaken to show how the crystal spectrometer in the present payload could be replaced by a grating spectrometer. The spectrometer consists of a plane parabolic reflection which concentrates X-rays from the sun onto a slit. The slit will allow X-rays from a linear region to be accepted. A one dimensional multi-grid collimator restricts the perpendicular field of view. The radiation passing through the slit is analyzed by a reflection grating and is detected by a matrix detector placed along the Rowland circle. This allows the entire diffracted spectrum to be recorded simultaneously.

An engineering layout of the instrument is shown in Figure 6-1.

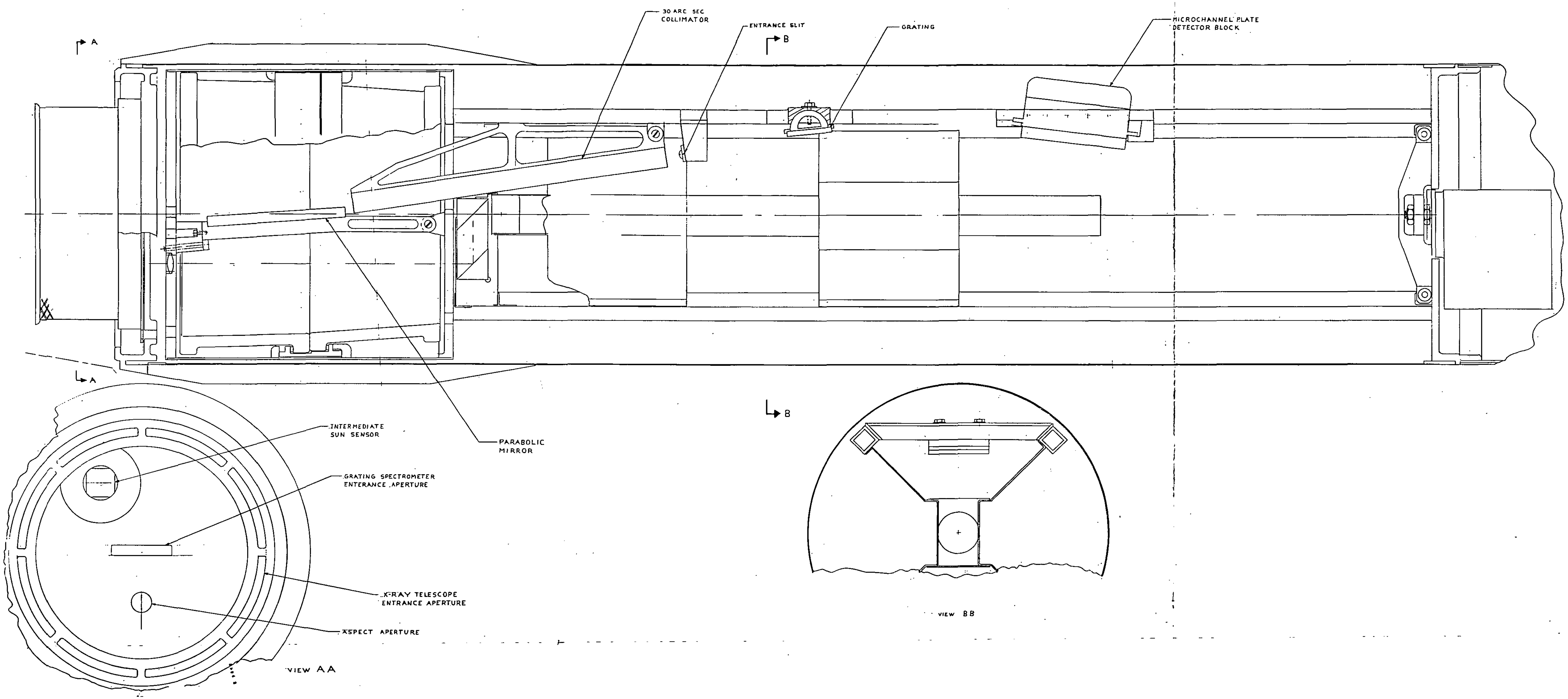

Figure 6-1. An Engineering Layout of the Imaging-Grating Spectrometer Payload.

7.0 PERSONNEL

The design and construction of the payload has involved many individuals at AS&E and has stretched over several contracts.

The overall scientific concept was developed by Giuseppe Vaiana with the aid of Allen Krieger and Leon Van Speybroeck. The latter, with the assistance of Richard Chase, had primary responsibility for the initial design of the mirror.

The payload was constructed under the direction of John Davis, by Heinz Manko, George Sherman and Joseph Ting, who had responsibility for systems, mechanical and electronic engineering respectively. They were aided by Robert Haggerty in areas concerning photography and film handling. These individuals, together with William Brymer, comprised the field crew for both launches.

The mechanical and electronic fabrication was performed at AS&E by many individuals, whose assistance is gratefully acknowledged.

The X-ray collimators were assembled by Edward Leiblein and Paul Hooban.

The computer interface and software was designed with the assistance of Henry Wilson.

The overall technical performance of the contract was supervised by Allen Krieger in his position as Acting Director of the Solar Physics Group.

APPENDIX A

Change of Scope of Contract NASW-2347 as a Result of the Crash of TWA Flight 604.

This proposal was submitted to NASA Ames on 24 October, 1972 as ASE document 3109. Reproduced here is the technical section of the proposal which describes the damage to the payload.

INTRODUCTION

This report describes the circumstances surrounding the accident that occurred to the AS&E payload which is to be flown on Aerobee 13.029CS. We have also outlined the steps already taken and those which still remain in order to ready the payload for flight. A brief outline of the added costs which have resulted from this accident are included.

PROBLEM HISTORY

As a result of the design review held during August to determine the causes of recent SPARCS failures, the AS&E payload flown on 13.028CS was sent to Ames Research Center in order to conduct a series of tests on the susceptibility of the SPARCS unit S/N 207 to radio frequency interference. These tests were completed without demonstrating any effects that could explain the failure of the unit to acquire the sun and the payload was shipped back to AS&E on YWA Flight 604. Unfortunately engine trouble occurred during the take-off and the flight was aborted. However, there was insufficient runway to bring the plane to a standstill and as a result the plane overran the end of the field and ended up in San Francisco Bay in approximately 20 feet of water. The accident occurred at 10:30 PM (P.S.T.) on 9/13/72. AS&E was notified of the accident by ARC the next morning. AS&E personnel were sent out to San Francisco and arrived at the accident scene that evening. During the day TWA personnel had attempted to remove the payload box from the hold, but it had jammed in the doorway. Various attempts were made to free the box, but it proved necessary to unload much of the cargo first and it was eventually freed at 1:00 AM.

The payload box and GSE were washed down to remove mud and were transferred to a TWA hangar where the payload box was weighed. It was found to be 100 lbs. overweight and this indicated that a leak had occurred. Consequently the box was opened and the payload removed. Most of the water had been absorbed by the foam cushions which hold the payload in position. These were removed and the excess water drained off. The payload was then transported to Ames Research Center where the most seriously affected assemblies were washed and dried in a thermal vacuum system. The payload was shipped back to AS&E on September 20.

On arrival at AS&E the payload has been completely disassembled and all the components have been thoroughly cleaned to remove all the salt deposits.

FINDINGS

In general, the payload has escaped without too much serious damage. The areas where replacement and additional work are required are outlined below.

1. Mechanical Structure

(i) The majority of the mechanical structure was made of aluminum and has survived with only limited apparent damage and will not have to be replaced. However, it has been necessary to strip and re-iridite many of the pieces including the extension can.

(ii) The mirror aperture plates, the filter wheel, and the spectrometer base plate were made from magnesium; these were badly corroded and will have to be replaced.

(iii) The battery box suffered severe damage as water entered and shorted out the batteries.

(iv) Part of the pre-filter mechanism was also damaged and will have to be replaced.

(v) The camera is located on a ball slide positioning fixture. The slides were badly corroded and have had to be replaced.

(vi) In addition to the above major items, most of the smaller hardware (e.g., bolts, clamps, etc.) has had to be replaced.

2. Electronic Equipment

The majority of the electronic equipment appears to have survived intact. This is attributed to the fact that most of the circuit boards are conformally coated. However, this conclusion is only preliminary and further functional testing, after the payload is reassembled, is required to ensure its validity.

The most serious areas of concern are:

(i) The shaft encoder - This has suffered a severe loss of gain in the least significant bits which may be a result of corrosion on the optical disk. The unit has been returned to the manufacturer for a failure analysis and we are awaiting the results.

(ii) One of the two high voltage power supplies has developed a breakdown problem probably associated with contamination and may have to be replaced.

(iii) Harnessing - The harnessing has been cleaned and examined and our initial belief that it would have to be replaced entirely seems to be unduly pessimistic. It is presently believed that only minimal replacement of cables and connectors will be required.

(iv) The proportional counters suffered corrosion which has affected their scientific performance and they will have to be replaced.

3. Scientific Equipment

Fortunately, the major scientific items, namely the X-ray mirror and the collimators, were not in the payload at the time of the accident and were undamaged.

The crystals were present and their surfaces have been affected by the salt water environment and will have to be replaced.

APPENDIX B

This report was submitted to NASA Ames on 29 March 1973 and describes the pre-launch, launch and flight of 13.029CS.

1.0 INTRODUCTION

Aerobee 170, Flight 13.029CS, was launched from the White Sands Test Facility "B" Tower on March 8, 1973 at 1100 MDT. The launch vehicle performed correctly. The SPARCS system acquired the sun and the experiment obtained significant scientific data. The minimum success criteria adopted at the FR[2] (22 January 1973) were met. The full mission success criteria were not completely satisfied because of out of specification performance of the yaw and roll controls. The payload was recovered in good condition.

2.0 SCIENTIFIC DATA

2.1 Experiment Description

The payload contained two semi-independent experiments. These were:

(i) A grazing incidence high resolution X-ray telescope to obtain full sun X-ray images with arc second resolution;

(ii) A collimated plane crystal Bragg spectrometer containing two crystals to obtain detailed spectra of an active region.

2.2 Results

The imaging system was programmed to take 12 exposures of varying duration. Of these the first 3 exposures were degraded as the rocket continued to roll until T + 121 sec. After roll stabilization was achieved, the remaining photographs were of very high quality. The stability of the pointing system in pitch, yaw and roll appears from the photographs to have been excellent, and considerably better than previously achieved. This has enabled us to record features down to the limit of our telescope resolution ($\sim$1 arc second).

The spectroscopy experiment was less successful due to the following factors:

(i) Orientation. The spectrometer collimators have a field of view of 3/4 arc minute (FWHM) and consequently must be accurately pointed at the active region of interest. This is achieved by determining the (r, θ) coordinates of the region. The payload is aligned with the center of the sun and the collimators are mechanically offset along the YAW axis to define r , and the payload is rolled around its pointing axis to define θ. For 13.029 the required coordinates were

$$r = 0.441 \text{ solar radii}$$
$$\theta = 242.6^{\circ}; \quad \phi_D = 332.9^{\circ}$$

The values we obtained were

$$r = 0.677 \text{ solar radii}$$
$$\theta = 215^{\circ}, \ \phi_D = 305.3^{\circ}$$

We believe that there were offsets in both pitch and yaw amounting to $0.5'$ and $3.5'$ respectively. (These values are obtained by determining the offset of the center of the full sun image from the payload axis.) The pitch error is within the tolerances of the ISS ($\pm 1'$); however, the yaw error is well outside. The magnitude of this offset is probably a result of the incorrect biassing of the ISS (see Section 4.0). Allowing for these offsets, the collimator axis would have pointed at

$$r = 0.45 \text{ solar radii}$$
and $$\theta = 219.6^{\circ}; \phi_D = 309.9^{\circ}$$

This indicates that the roll error was 23°.

The net effect of these offsets was that the collimators pointed at a region of the sun from which the X-ray emission was very weak. Consequently the counting rates were low and the data will require rather extensive analysis to determine its scientific usefulness.

3.0 FLIGHT PROBLEMS

1. During the flight one of the proportional counters developed a leak through its window. This occurred at approximately T + 294 sec. As the leak was severe, the flow restrictors operated and cut-off the gas supply to this counter. No data was recovered from this counter during the remainder of the flight.
2. The experiment was shut-off at T + 373 sec but turned on again at about T + 401 sec.
3. The mirror protection device monitor indicated non-closure although the current monitors indicated the squibs had fired.
4. The External-Internal/Lockout monitor went to zero volts at about 401 seconds.
5. The Shut Off. Cmd. monitor and the Time Delay Relays (TDR) monitor indicated that the TDR's had dropped out and the experiment was not shut off.
6. The 5V Reg. #1-5 and 6V Reg indicated that one of the regulators had failed.

Visual inspection of the payload after recovery and systems checks provided the following information:

A. Ledex switch (S1) had apparently shorted to the skin which was about 1" away, burning two terminals. A wire connected to one of the terminals was found broken off.

B. The following fuses were found blown:

(a) F45-3AMP, 8.5V Power to +6V regulator for Encoder Logic;

(b) F32-4AMP, 27V Power to Counter Drive Electronics and Motor;

(c) F29-1/2 AMP, 27V Power to Time Delay Relay Circuit for Exp. Shut Off;

(d) F26-2AMP, 27V Power for Beacon.

C. The protective device mechanism was being held open by the front bumper (shock absorver) due to the addition of an air baffle for the I. S. S. which was added after integration.

The reason for the short between the ledex switch and the skin is unknown, a metallic foreign object between the two is suspected but none has been discovered.

The short grounded the 27V instrument power causing the TDR's to reset and restart the experiment. It also explains the Ext-Int/Lockout monitor going to zero as this was the lead that had shorted and broken off.

The reason for the blown fuses is not readily apparent because the fuses are located in the circuit after the section where the short occurred. High surge currents due to the short may have been responsible. The Beacon fuse could have blown when the Beacon was ejected with the nose cone at T + 65 seconds.

A second shut off of the experiment would have occurred except that the TDR circuit fuse was blown and this explains why the experiment was still running on recovery of the payload.

The air baffle was added to the bumper between integration and arrival at W. S. M. R. and a complete systems test where the squibs actually released the mechanism was not made; only the squibs were fired in two separate tests to check the redundancy of the system.

4.0 PRE-FLIGHT PROBLEMS

The only major problem concerned the biassing of the ISS. Tests in the field indicated that the bias of the yaw sensors had been applied in reverse. This would have resulted in the payload being pointed 17.2 arc minutes away from the center of the sun. Experiments performed in the field by AS&E and SPARCS personnel indicated the problem and an additional bias of twice the magnitude and the opposite sign was applied. In flight the payload was offset in pitch by 3.5 arc minutes indicating that not only the sign of the bias, but also its magnitude, was correct. These tests are described in detail in a memorandum from J. M. Davis to G. Vaiana dated 29 March 1973.

5.0 RECOMMENDATIONS AND ACTIONS

5.1 Proportional Counter Window

The window was made from 1 micron polypropylene. It was deliberately made as thin as possible to allow the transmission of X-rays. Window failures from time to time are expected. The loss of observing time which resulted was less than 10% of the total for this counter. As the failure occurred within $\pm$ 1 sec of the opening of the prefilter, we are investigating the possibility that it was caused by an increased heat load.

5.2 Closure Mechanism

The failure of the closure mechanism is easily corrected and a procedural change will be instituted so that the Horizontal Test will be run in flight configuration and the redundant squib tests will be performed before the Horizontal.

5.3 The Ledex Short

No design changes are envisioned at this time; the failure was considered to be a random event and did not produce any ill effects on the payload.

5.4 ISS

The problems with the ISS are in SPARCS domain. We recommend that the biassing procedures be reviewed by cognizant personnel to see if this problem has occurred on other eyeblocks. In the future, the alignment tests, as performed for 13.029, will be a mandatory requirement.

6.0 This report was prepared by

J. M. Davis and H. Manko of AS&E, from whom additional information may be obtained if required.