X-440-66-322

NASA TM X- 55590

HISTORY OF ORBITING SOLAR OBSERVATORY OSO-2

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 3.00

Microfiche (MF) .75

ff 653 July 65

N67 11368 (ACCESSION NUMBER)

(THRU)

121 (PAGES)

1 (CODE)

TMX-55590 (NASA CR OR TMX OR AD NUMBER)

31 (CATEGORY)

FACILITY FORM 602

APRIL 1966

GODDARD SPACE FLIGHT CENTER

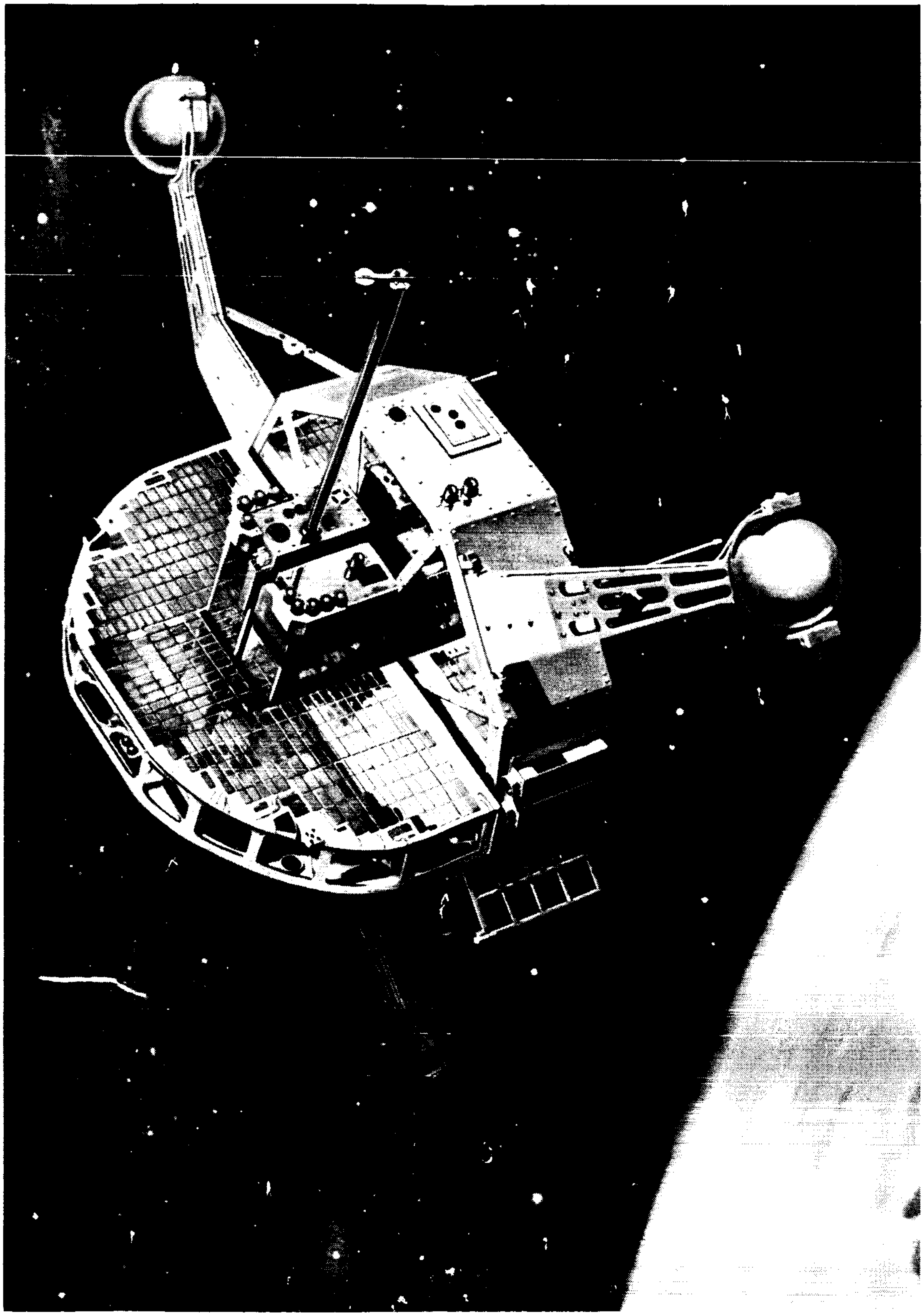
GREENBELT, MD.

X-440-66-322

HISTORY OF
ORBITING SOLAR OBSERVATORY
OSO-2

April 1966

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland



Frontispiece—OSO-2 Spacecraft

CONTENTS

Page

SECTION 1 - INTRODUCTION

1.1 INTRODUCTION 1-1
1.2 GENERAL DESCRIPTION OF OSO 1-2
1.2.1 SPACECRAFT 1-2
1.2.2 EXPERIMENTS 1-14
1.3 MISSION OBJECTIVES 1-14
1.3.1 OSO-2 MISSION OBJECTIVES 1-14
1.3.2 OSO-2 EXPERIMENTS 1-15

SECTION 2 - OSO-B DISASTER

2.1 EVENTS LEADING UP TO THE DISASTER 2-1
2.2 THE DISASTER 2-1
2.3 ACCIDENT INVESTIGATION 2-2
2.4 CONCLUSIONS AND RECOMMENDATIONS 2-5
2.5 SPIN BALANCE FACILITY REWORK 2-5

SECTION 3 - DEVELOPMENT OF OSO-2

3.1 SPACECRAFT 3-1
3.1.1 WHEEL STRUCTURE 3-1
3.1.2 SAIL STRUCTURE 3-2
3.1.3 BEARINGS 3-2
3.1.4 ATTITUDE CONTROL SYSTEM 3-2
3.1.5 COMMAND SYSTEM 3-3
3.1.6 TELEMETRY SYSTEM 3-3
3.1.7 ELECTRICAL POWER SYSTEM 3-4

CONTENTS

Page

SECTION 3 - DEVELOPMENT OF OSO-2 (Continued)

3.2 EXPERIMENTS 3-5

3.2.1 POINTED EXPERIMENTS 3-6

3.2.2 WHEEL EXPERIMENTS 3-6

3.3 OBSERVATORY 3-8

3.3.1 WEIGHT AND BALANCE 3-8

3.3.2 ACCEPTANCE TESTS 3-8

3.4 SHIPMENT TO CAPE KENNEDY 3-10

3.5 PRE-LAUNCH PREPARATIONS 3-12

3.5.1 HANGAR CHECKS 3-12

3.5.2 SPIN AND BALANCE CHECKS 3-15

3.5.3 LAUNCH TOWER CHECKS 3-16

SECTION 4 - LAUNCH AND EARLY ORBIT OPERATIONS

4.1 LIFT-OFF AND FIRST ORBIT 4-1

4.2 EXPERIMENT TURN-ON 4-3

SECTION 5 - NORMAL OPERATION

5.1 SPACECRAFT 5-1

5.1.1 ATTITUDE CONTROL SYSTEM 5-1

5.1.2 TELEMETRY SYSTEM 5-9

5.1.3 COMMAND SYSTEM 5-10

5.1.4 ELECTRICAL POWER SYSTEM 5-12

5.1.5 THERMAL MONITORING SYSTEM 5-12

5.2 EXPERIMENTS 5-16

5.2.1 NAVAL RESEARCH LABORATORY ULTRAVIOLET TELESCOPE AND CORONAGRAPH 5-16

CONTENTS

Page

SECTION 5 - NORMAL OPERATION (Continued)

5.2.2 NAVAL RESEARCH LABORATORY X-RAY TELESCOPE 5-26

5.2.3 HARVARD COLLEGE OBSERVATORY ULTRAVIOLET SPECTROHELIOGRAPH 5-27

5.2.4 GODDARD SPACE FLIGHT CENTER ULTRAVIOLET SPECTROPHOTOMETER 5-27

5.2.5 GODDARD SPACE FLIGHT CENTER LOW ENERGY GAMMA-RAY TELESCOPE 5-30

5.2.6 AMES RESEARCH CENTER EMISSIVITY DETECTORS 5-30

5.2.7 UNIVERSITY OF MINNESOTA ZODIACAL LIGHT TELESCOPES 5-31

5.2.8 UNIVERSITY OF NEW MEXICO HIGH ENERGY GAMMA-RAY TELESCOPE 5-32

5.3 TRACKING AND DATA 5-32

5.3.1 DATA ACQUISITION 5-32

5.3.2 DATA PROCESSING 5-34

SECTION 6 - TERMINAL OPERATION

6.1 GENERAL 6-1

6.2 TERMINAL OPERATION PLAN 6-1

6.3 TERMINAL OPERATION AND RESULTS 6-2

6.3.1 FIRST DAY - SEPTEMBER 24, 1965 6-2

6.3.2 SECOND DAY - SEPTEMBER 25, 1965 6-3

6.3.3 THIRD DAY - SEPTEMBER 26, 1965 6-3

6.3.4 FOURTH DAY - SEPTEMBER 27, 1965 6-4

6.3.5 SIXTH DAY - SEPTEMBER 29, 1965 6-4

6.3.6 SEVENTH DAY - SEPTEMBER 30, 1965 6-5

CONTENTS

Page

SECTION 6 - TERMINAL OPERATION (Continued)

6.3.7 EIGHTH DAY - OCTOBER 1, 1965 6-5

6.3.8 NINTH DAY - OCTOBER 2, 1965 6-6

6.3.9 FOURTEENTH DAY - OCTOBER 7, 1965 6-6

6.4 CONCLUSIONS 6-8

SECTION 7 - STOW OPERATION

7.1 PURPOSE 7-1

7.2 OPERATION 7-1

7.3 OPERATIONS AFTER OBSERVATORY STOW 7-1

7.4 RENEWED OSO-2 OPERATION, JUNE 1966 7-6

LIST OF ILLUSTRATIONS

Figure		Page
Frontispiece	OSO-2 Spacecraft	iii
1-1	Major Features of Wheel Structure	1-3
1-2	Major Features of Sail Structure	1-4
1-3	Azimuth Shaft Assembly	1-5
1-4	Launch Sequence Events	1-6
1-5	Gas Control Systems	1-7
1-6	Control System	1-8
1-7	Raster Scan	1-10
1-8	Nutation Damper	1-11
1-9	Oriented Experiments	1-17
1-10	Oriented Experiment Operational Modes	1-18
1-11	Wheel Experiments	1-21
3-1	OSO Observatory in Ball Brothers Balance Machine	3-9
3-2	OSO-2 Vibration Test Set-up	3-11
3-3	OSO-2 Loading at Lowry Air Force Base - 22 November 1964	3-13
4-1	Thor-Delta/OSO-2 Lift-off	4-2
5-1	OSO-2 Pitch Angle Drift	5-2
5-2	OSO-2 Spin Rate Decay	5-5
5-3	OSO-2 Spin Rate	5-6
5-4	Pointing Control Readout	5-8
5-5	Long Term Battery Charge Rate and Voltage	5-13
5-6	Battery Charge Rate and Voltage - Orbit 2435	5-14
5-7	Battery Charge Rate and Voltage - Orbit 3637	5-15
5-8	OSO-2 Hub Temperature	5-17
5-9	OSO-2 Rim Skin Temperature	5-18

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
5-10	OSO-2 Bottom Skin Temperature - Orbit 56	5-19
5-11	Azimuth Power Transistor Temperature - Orbit 2611	5-20
5-12	Solar Cell Panel Temperature - Orbit 3769	5-21
5-13	Solar Plot From OSO-2 Data During Orbit 194	5-22
5-14	Sun Photo Taken from Earth on 16 February 1965	5-23
5-15	Analog-to-Digital Processing Line	5-35
5-16	Quality Control and Edit Program	5-37
5-17	Quick-Look System, Fort Myers to GSFC	5-39

LIST OF TABLES

Table		Page
5-1	Successful "Playback-ON" Attempts	5-11
5-2	Analog Tape Track Assignments	5-33
7-1	OSO-2 Status - Orbit 4120	7-2
7-2	OSO-2 Temperatures - Orbit 4120	7-3
7-3	Transmitter RF ON Attempts	7-5
7-4	Spacecraft Battery Voltage	7-5
7-5	OSO-2 Temperatures (Degrees Centigrade) - March 1966	7-7

HISTORY OF ORBITING SOLAR OBSERVATORY OSO-2

SECTION 1 INTRODUCTION

1.1 INTRODUCTION

The sun is a seething sphere of atomic particles with temperatures and forces so great that they are almost incomprehensible to man. The surface of the sun is punctuated by sun spots, solar flares and prominences and massive emissions of radiation are associated with these solar phenomena.

Solar radiation and events have a definite effect on communications and climate on earth and are the determining factor in sustaining human life. If solar radiation decreased by as much as 5%, the earth would become a frigid ball and life, as we know it, would cease.

It is believed that the sun is responsible for magnetic-field and charged-particle phenomena beyond the earth's atmosphere. Therefore, if man is to venture into the reaches of space to explore our sister planets and beyond, information relative to the intensities of these magnetic fields and charged particles must be obtained to protect him adequately.

Man has been observing the sun and solar phenomena and gathering data about them for hundreds of years. However, his efforts have been hindered by being earth-bound and capable only of observing a small fraction of the total solar spectrum due to the earth's atmosphere. If man could take his instruments beyond the earth's atmosphere, he would be capable of studying the entire solar spectrum. Great strides toward this end have been made during recent years with the advent of balloon and rocket astronomy and man has increased his knowledge about his nearest star. However, only tiny bits and pieces of the solar puzzle could be fitted into place because of the limited equipment that could be carried aloft and the short durations they remained above the atmosphere.

With the development of NASA's Orbiting Solar Observatories, solar scientists, for the first time in history, have been afforded the opportunity to observe the sun, unobstructed by the earth's filtering atmosphere, for extended periods of time. Because of this, larger pieces of the solar puzzle are now falling into place and man is hopeful of being capable of accurate long-range weather prediction, development of more efficient communications systems, and gaining more information about magnetic-field and charged-particle phenomena.

1.2 GENERAL DESCRIPTION OF OSO

The OSO spacecraft, designed by Ball Brothers Research Corporation under contract to NASA, are earth-orbiting satellites used as stabilized platforms for solar-oriented scientific instruments. They are presently launched from the John F. Kennedy Space Center atop a modified Douglas Thor-Delta launch vehicle into a circular orbit 300 nautical miles above the earth. The inclination of the orbit to the equator is 33 degrees. The orbital period is approximately 95 minutes.

Observatory gross weight is approximately 600 pounds. Instrument weight capable of being carried aboard the spacecraft is approximately 40% of the gross weight of the observatory.

The total expected useful life of the observatory was six months and was limited only by the amount of high pressure nitrogen gas capable of being carried aboard to maintain pointing control of the instruments. However, on future spacecraft, a magnetic bias coil has been provided to reduce the effect of the earth's magnetic field on the spacecraft's pitch and roll attitudes. This should greatly increase the overall operational life of the OSO spacecraft.

1.2.1 SPACECRAFT

The main body of the spacecraft consists of a wheel of aluminum alloy separated into nine wedge-shaped compartments as illustrated in Figure 1-1. Five of these compartments contain apparatus for five experiments not requiring solar orientation. The remaining four compartments house the electronic controls, batteries, telemetry equipment, and radio-command equipment. Each wheel compartment provides approximately 1000 cubic inches of volume, and each wheel experiment can weigh up to approximately 45 pounds. Two compartments can be used by one experiment, and in this case, the maximum experiment weight is 90 pounds. The wheel also contains three extendable arms which are

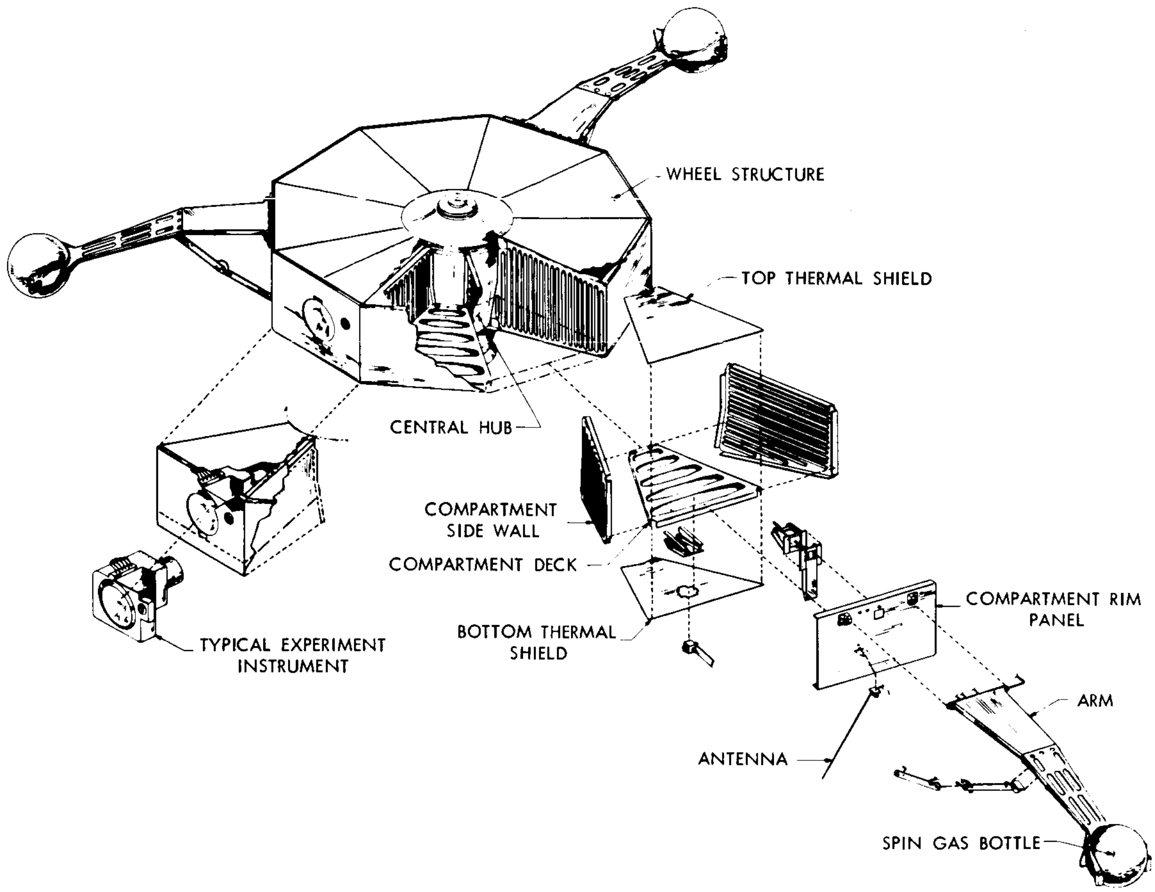


Figure 1-1. Major Features of Wheel Structure

folded down around the third stage of the launch vehicle during the launch phase. When the spacecraft is injected into orbit, the arms are extended which increases the effective diameter of the wheel from 44 inches to 96 inches.

A fan-shaped sail is mounted on top of the wheel by means of a rotating aluminum shaft and carries a solar array and pointed experiments. The solar array supplies the electrical power required for daylight operation, and it charges storage batteries for night-time operation. Space is provided in the sail section for two pointed experiments, each 4 inches wide by 8 inches high. The length was limited to 36 inches by the curvature of the Delta shroud, and the thickness of the eyes mounted on the pointed experiments. The length can now be expanded to 57 inches because of improvements to the Delta vehicle. A total instrument weight of approximately 88 pounds can be accommodated in the sail section. The radius of the sail is 22 inches which can also be increased due to Delta improvements. Figure 1-2 illustrates the major features of the sail structure.

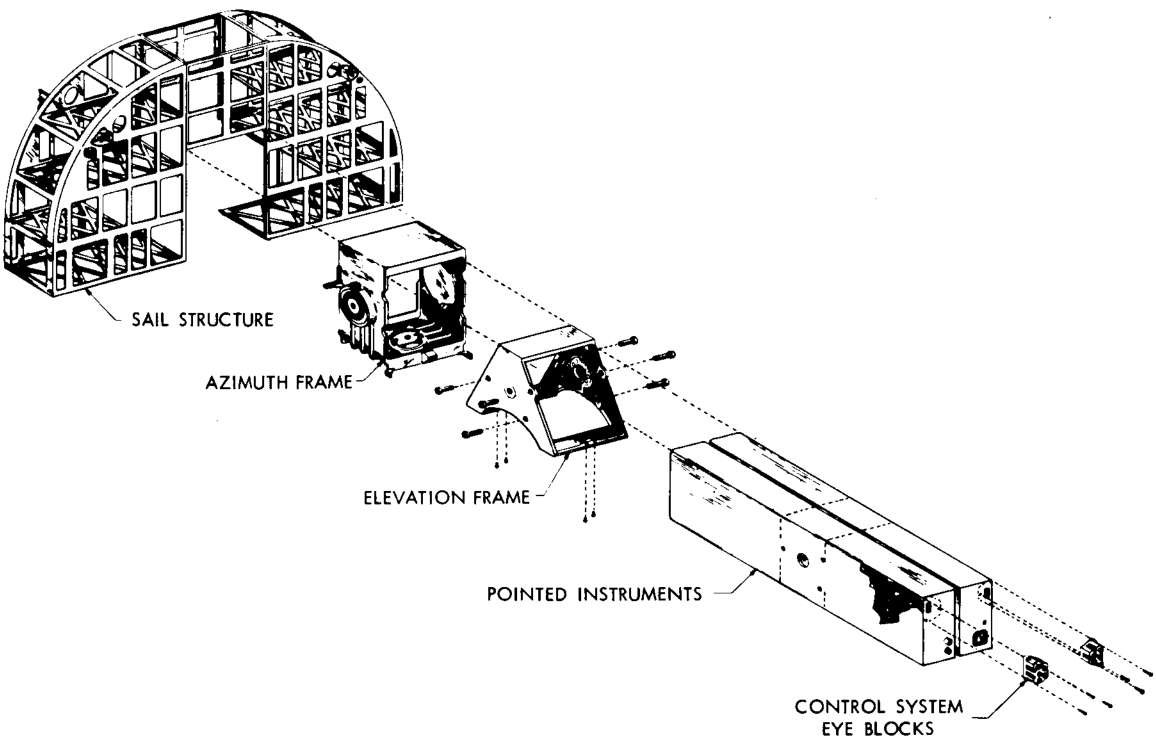


Figure 1-2. Major Features of Sail Structure

The two main structures are connected by an aluminum shaft which runs from the base of the sail, through the center of the wheel and terminates in a support ring structure on the underside of the wheel. This shaft is held in place by two bearings, one on top and one on the bottom of the wheel. Mounted on the shaft between the two bearings is a high pressure nitrogen gas tank for pitch precession jets located on the sail structure. A torque motor, mounted on the top of the shaft, controls the azimuth position of the sail while the spacecraft is in daylight. On the base of the shaft is a slip-ring assembly which allows transmission of power, telemetry signals, and control signals between the sail section and the wheel. Figure 1-3 illustrates the azimuth shaft assembly.

The inherent stability of the spacecraft is due to the gyroscopic spinning of the entire wheel structure. Figure 1-4 illustrates the sequence of events during launch. After second stage burnout, the entire third stage and spacecraft combination is spun up to approximately 120 rpm, activating an acceleration switch which starts the Launch Sequencer Timer. After third-stage burnout and 90 seconds after the spacecraft timer is started, squibs are fired in the spacecraft to release the three arms. Centrifugal force extends them. Extending the arms increases the gyroscopic stability of the wheel and decreases the spin rate to approximately 96 rpm. At the end of the arm is a high pressure nitrogen gas

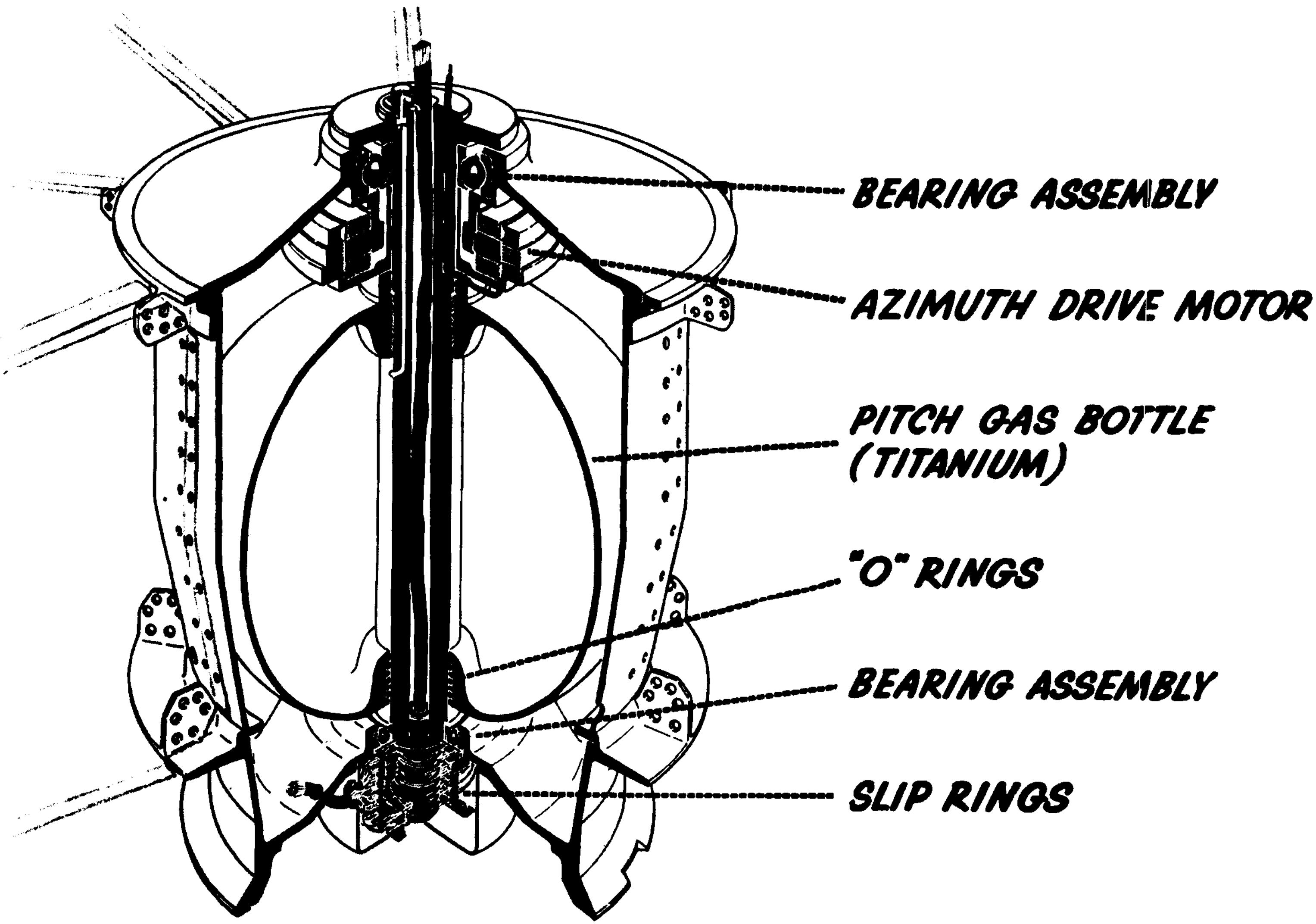


Figure 1-3. Azimuth Shaft Assembly

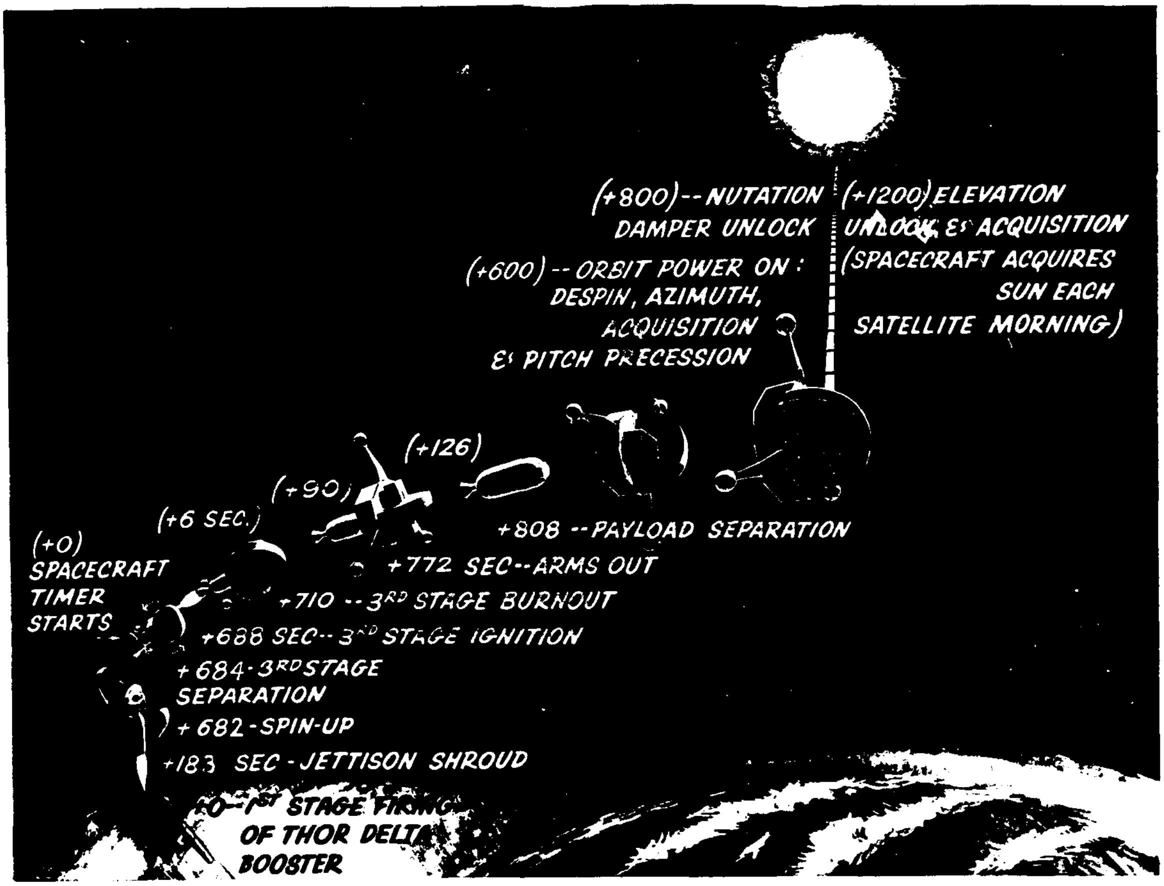


Figure 1-4. Launch Sequence Events

tank which supplies nitrogen gas to de-spin jets or spin-up jets, also located on the three arms. The wheel rotation is reduced by expelling nitrogen gas from the de-spin jets, thus slowing the wheel to 30 ±5% rpm. Photoelectric solar sensors (solar eyes) mounted on the rim of the wheel sense the sun once each revolution and electronic circuitry measures the period of rotation. When the measured rotational period drops below 28.5 rpm, nitrogen gas is expelled from the spin-up gas jets and the spin rate is increased to within 5% of nominal. Figure 1-5 illustrates the gas control systems.

The spacecraft is maintained in a position so that the spin axis is normal to the solar direction within ± 3 degrees. This is accomplished by expelling nitrogen gas from one of two precession jets mounted on the sail to gyroscopically precess the spacecraft about its pitch axis. A set of pitch control eyes, mounted on the sail, senses when the spin axis has drifted three degrees from normal to the solar direction, and electronic circuitry activates the proper precession jet to precess the spacecraft to one degree past normal in the opposite direction. Figures 1-5 and 1-6 illustrate the locations of the pitch gas control components and control system components, respectively.

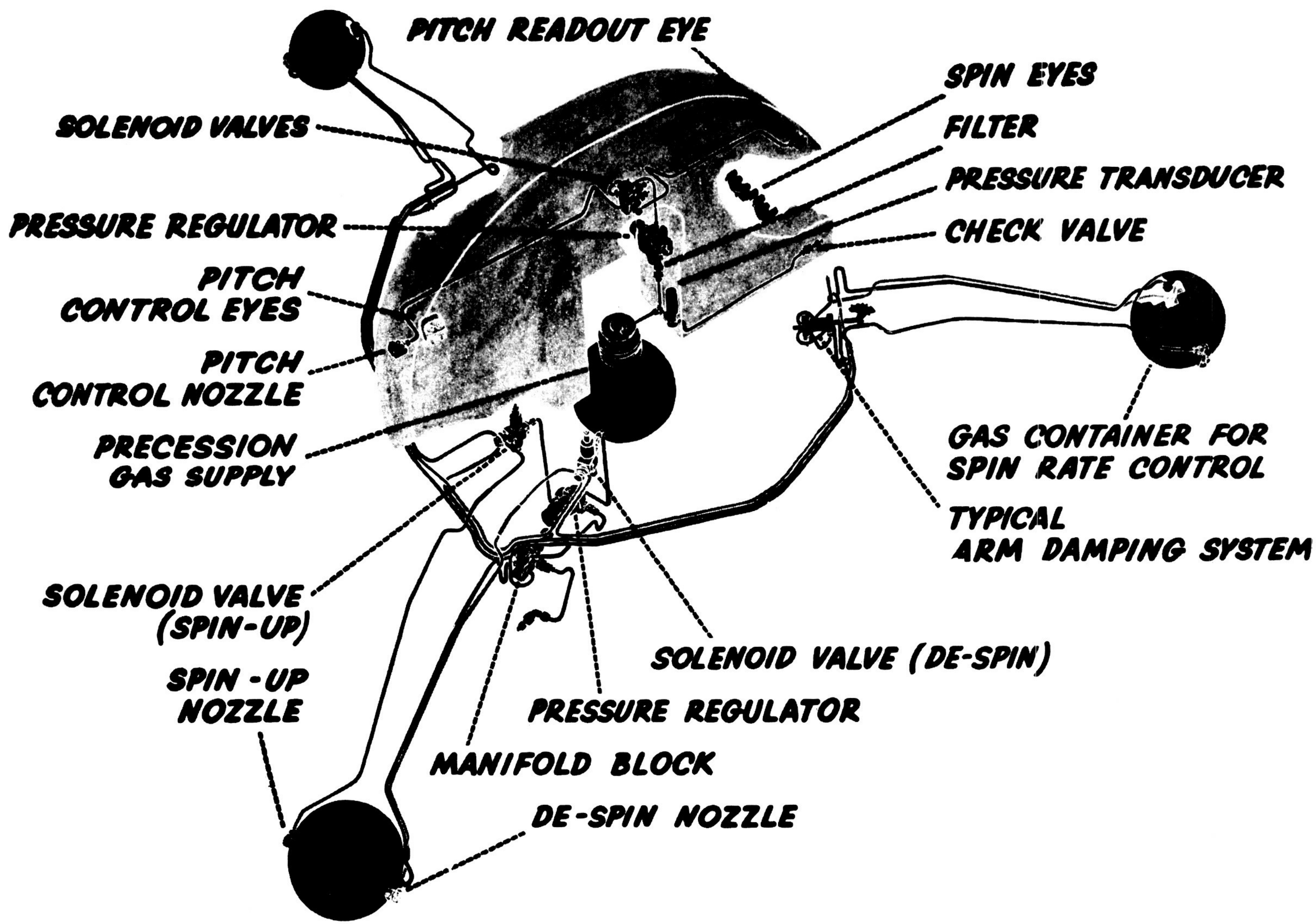


Figure 1-5. Gas Control Systems

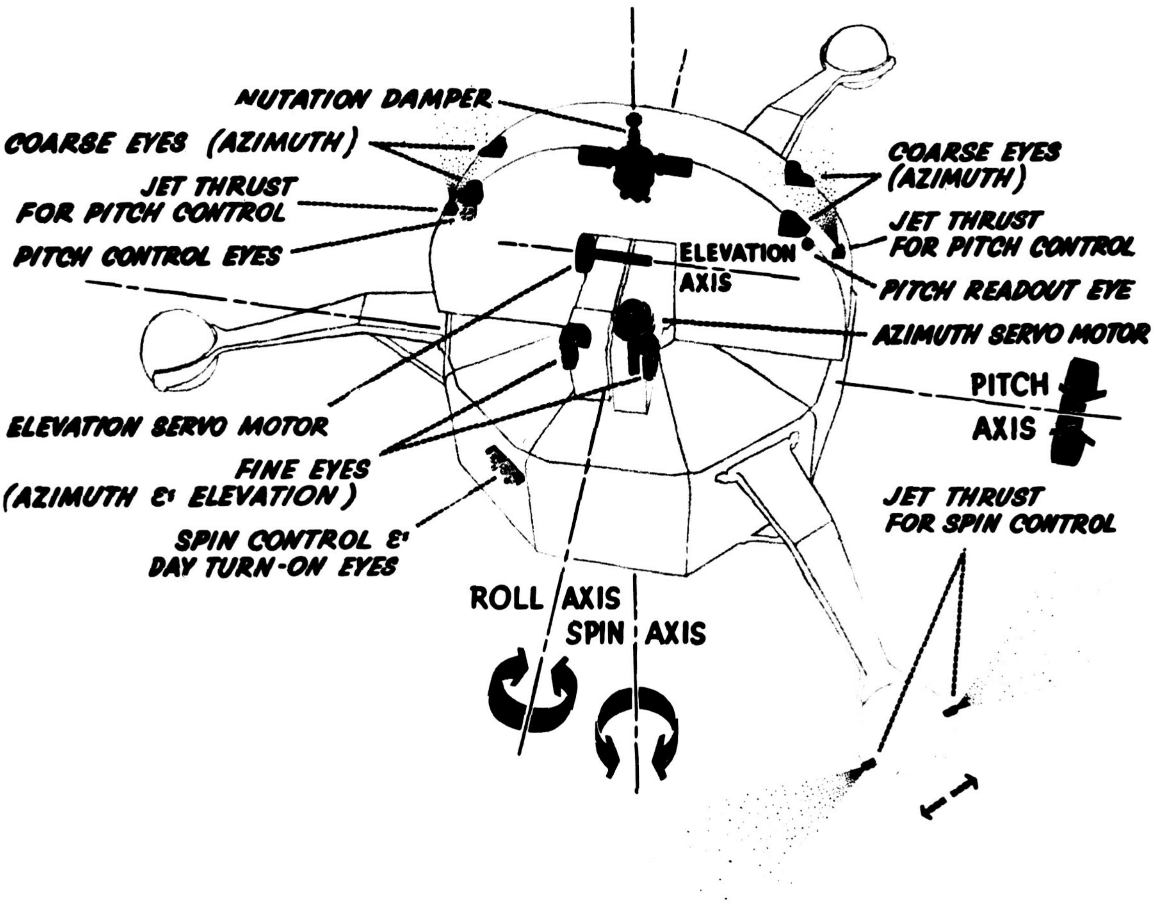


Figure 1-6. Control System

The OSO spacecraft rolls about the roll axis at approximately one degree per terrestrial day because of the precession of the observatory orbit and the earth orbit. The Aspect Measuring System provides a method of determining three-axis aspect with respect to the celestial sphere for the OSO. Aspect can be determined within three degrees. The measurement requires a magnetometer mounted on one arm of the spacecraft, with its sensitive axis in the plane of rotation. The Aspect Measurement System provides two sets of measured data which are read out directly by the OSO telemetry system. These two readouts are: (1) a measurement of the time interval which relates the wheel position in time to the spacecraft data word pulses for spin rate and spin angle determination, and (2) a measurement of the time interval between the magnetic field position and the solar direction for spacecraft roll angle determination. The magnetometer produces a sinusoidal output as the wheel rotates, except when the spin axis is parallel to the earth's magnetic field. The magnetometer output reaches its maximum positive value when the angle between the earth's magnetic field and the sensor axis is a minimum. Zero output occurs when the sensitive axis becomes perpendicular to the magnetic field. When the wheel has rotated 180 degrees and the sensor's sensitive axis is opposed to the field but forms the minimum angle between the sensitive axis and the lines of force, the magnetometer produces its maximum negative value. The zero output of the magnetometer is distinguished with electronic signal conditioning; therefore, the instantaneous time at which the magnetometer's axis is perpendicular to the magnetic field can be determined. This event is recorded from a pulse output which may be sent both to an experiment and to an on-board logic circuit. A second pulse, to locate the spin vector in the spin plane relative to the magnetometer sensitive axis, is generated from a sun sensor. The angle in the spin plane between the normal to the magnetic field and the sun vector is determined, for a known spin rate, by measuring the time interval between these two pulses with a counter circuit which counts the spacecraft 400 cps clock pulses. The roll angle of the spin axis, with respect to the ecliptic plane, is calculated by using this angle, the magnetic field characteristics and the earth-sun line at that point in space and time.

Azimuth control of the sail and pointed experiments is accomplished by a system of coarse and fine azimuth eyes and servo control. Each satellite night, with no sun as a reference, the torque motor is stopped and the sail structure rotates synchronously with the wheel. During satellite dawn, the azimuth coarse and fine eyes acquire the sun, and a servo control system and the azimuth torque motor drive the sail in a direction equal and opposite to the spinning wheel. When the pointed instruments are such that they are within 5 degrees of the center of the solar disc, the coarse eyes are switched out of the circuit, and only fine eyes are used to move the sail through the remaining 5 degrees. The fine control eyes then maintain the sail and pointed instruments to within ± 1 arc-minute of the center of the solar disc.

The elevation fine eyes develop error signals for control of the elevation servo in a manner similar to the azimuth control system. The pointed instruments are mounted on an elevation frame which is controlled by the elevation torque motor. The elevation servo is capable of moving the elevation frame and pointed instruments through an angle of ± 5 degrees in a plane containing the solar vector and the spin axis. It will maintain the pointed instruments in elevation to within ± 1 arc-minute of the center of the solar disc.

The azimuth and elevation systems of the OSO spacecraft can also be operated in a raster scan mode. Figure 1-7 illustrates the raster scan. This scan mode sweeps the pointed instruments in azimuth and elevation in such a way that the entire solar disc and part of its corona can be mapped by the experimental instruments. The scan consists of a square pattern 40 arc-minutes on a side, centered about the center of the maximum intensity of the solar disc. The scan

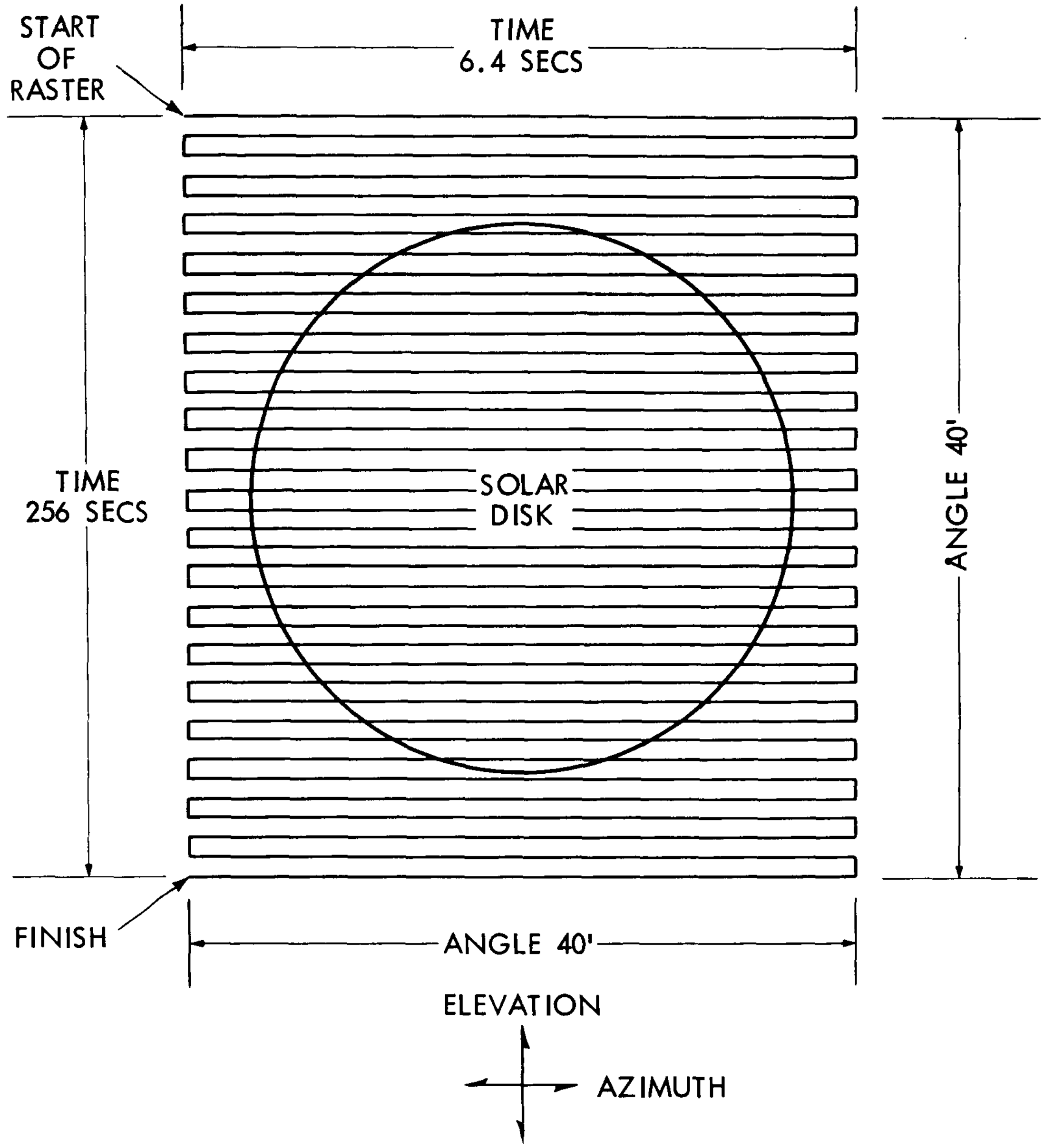


Figure 1-7. Raster Scan

starts at a point 20 arc-minutes in azimuth and elevation from the center and sweeps in azimuth. The azimuth sweep is accomplished in 6.4 seconds, and at the end of the sweep, the elevation steps down 1 arc-minute and the azimuth sweep is reversed. As seen in Figure 1-7, forty elevation steps are accomplished, presenting a complete picture of the sun every 256 seconds.

When the spacecraft is separated from the third stage rocket, it has a nutation due to wobble of the unbalanced burned-out third stage, the unsymmetrical

Telemetry is accomplished by a PCM/FM system containing two independent and parallel multiplexing systems. Each system has a multiplexer-encoder, digital tape recorder and a transmitter. Experiment measurements and spacecraft operating data (housekeeping data) are processed by the multiplexer-encoder into eight-bit words and 32-word main frames on a time shared basis. The multiplexed experiment and housekeeping data is simultaneously recorded by the tape recorder and transmitted to ground stations on a real time basis by the transmitter. Once during each orbit the tape recorder playback command is sent and the tape recorder is connected to the transmitter to transmit the data it recorded during the orbit. Playback of the orbital data is accomplished in approximately 5 minutes, and at the end of the playback period, the tape recorder automatically returns to the record mode and the transmitter again begins transmitting real time data.

The command system is a PCM/AM/AM tone-digital type capable of executing 70 commands. Two command receivers operate continuously for protection against a single receiver failure. The receiver outputs are a pulse-duration modulated audio tone and are fed to decoders which in turn actuate latch-type relays for command execution. The OSO command system enables ground controllers to: (1) control power (on or off) to experiments and various spacecraft system components; (2) select various spacecraft components by signal or power control; (3) operate the spacecraft control system by switching from automatic to manual control or vice versa; (4) control the real time and playback modes of operation; (5) control the pointing or raster modes of operation; (6) bypass the day-night control power system; and (7) bypass the automatic undervoltage and RF timer power circuits. The system uses digital tone techniques, and the commands are transmitted from STADAN (Satellite Tracking and Data Acquisition) stations. The spacecraft receives the coded RF command signal and decodes the digital information according to three possible addresses. Two addresses activate two redundant-output decoders in the wheel and the third activates a decoder in the sail. The command frame consists of two repeated address words and three repeated or different command words. An alternate command frame of one address word and one command word sent twice in succession can also be used. The command execution is performed if one of these command words activates the addressed decoder circuit. Commands are preprogrammed and automatically fed into the ground transmitting equipment by means of a punched paper tape. Emergency commands can be transmitted by means of a manual control panel in the ground equipment.

The spacecraft electrical power system consists of the solar array, the main battery pack, the squib battery pack, the undervoltage switch, and the turn-on circuitry. The solar array is mounted on the front face of the sail structure. There are approximately 1872 silicon solar cells arranged in 36 thrust of the separation spring and the unsymmetrical motion of the arms as they are extended. A further cause of nutation is unbalance of pointed instruments which have mechanical scanning devices. No nutation occurs when the instruments are pointed, but when the pointing control is turned off at night and the oriented section starts spinning, a dynamic unbalance occurs that causes a wobble of approximately 10 minutes. When the pointing control is turned on the following day, the wobble shows up as a nutation. A nutation damper is provided to remove these undesirable motions. It works on the principle that, if energy is removed from a freely rotating body, the body rotates about the axis of maximum moment of inertia. This axis is made to coincide with the azimuth shaft axis by careful balance before launch. The Nutation Damper is shown in Figure 1-8. It is mounted on the oriented section and consists of a tuned pendulum which moves in a silicone oil bath. The nutation energy is transmitted to the pendulum of the nutation damper and is dissipated by the oil. The damping constant is small so the bob moves through large amplitudes for small nutations.

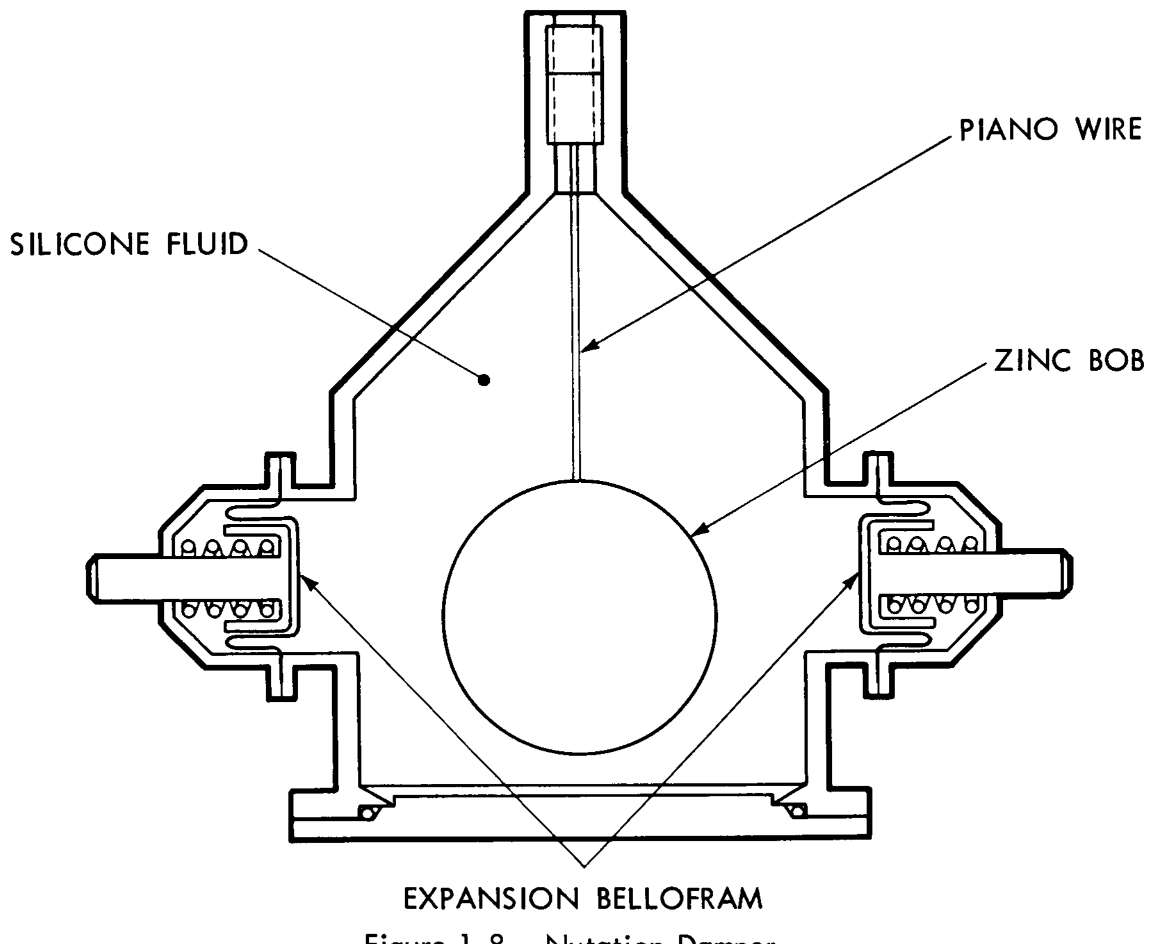


Figure 1-8. Nutation Damper

parallel strings of 52 each. The solar array converts solar energy into electrical power to furnish power for daytime operation and to charge the main batteries for night operation. The design power available from the solar array is approximately 27 watts. The main battery pack is made up of 42 nickle-cadmium type F cells. The 42 cells are distributed in six packs of seven cells each. To produce an 18.9 volt dc supply, 14 cells are connected in series, and the three packs of 14 cells each are connected in parallel to produce the necessary power capacity. The pack voltage range is 16 volts to 22 volts from a nearly discharged state to a fully charged state. To isolate the squib firing circuit from the main spacecraft power supply, firing energy for the various squibs is taken from separate batteries. The squib batteries are nickle-cadmium type C cells, and there are two battery packs in both the sail and the wheel structures. The sail packs supply energy to fire the azimuth, nutation damper and elevation squibs. The wheel battery packs fire the arm and compartment door squibs.

The spacecraft batteries have a rather flat discharge curve until they become almost fully discharged. Near the fully discharged state the voltage falls abruptly and the impedance rises so that very little power can be drawn from them. If the batteries were to become fully discharged, they would not be able to deliver the current necessary to allow the servo to catch and orient the sail toward the sun. This would cause the spacecraft to become disabled. Sections of the spacecraft can be turned off by the command system to conserve power. If the command system is not operative and the batteries discharged to the point where the voltage drops abruptly, an undervoltage switch is provided which shuts down the entire spacecraft and permits the batteries to charge from the rotating solar array. When the batteries are about 10 percent charged, the undervoltage switch turns on the spacecraft again.

During the dark portion of the orbit, certain of the components in the spacecraft do not need to operate. To conserve power, the pointing control, the pointed experiments and the spin-up system are turned off. A redundant pair of solar sensors located on the rim of the spacecraft wheel feed a circuit which actuates a relay. This relay turns the power on when the spacecraft comes into the sun and off when it goes into the shadow. These turn-on eyes are similar to fine eyes and also serve as sensors for determining wheel spin rate.

Thermal control of the OSO spacecraft is accomplished passively by use of surfaces with well controlled optical properties. All wheel compartments are thermally interconnected by the main frame and central casting, and heat generated and absorbed by the wheel is well distributed. Experiments are secured directly to the compartment deck and receive heat from and supply heat to the spacecraft structure. Instrument temperatures within the wheel vary from 7 degrees C at night to 13 degrees C during the day. The pointed instruments receive radiated heat from the elevation and azimuth frames, the front and rear of the solar array, the wheel top skin, the earth, direct sunlight on the front face, and internal heat sources. The external surfaces of the pointed instruments are highly polished to keep the heat inside during the observatory night. Temperatures in the pointed instruments range from 0 degrees C to 10 degrees C.

1.2.2 EXPERIMENTS

Experiments carried on board OSO spacecraft vary with each spacecraft and are determined by the objectives of each particular mission. They are all designed, however, to observe the sun and solar phenomena and to measure electromagnetic radiation produced by these phenomena in the ultraviolet, X-ray and gamma ray region of the spectrum which is absorbed or reflected by the earth's upper atmosphere. Experiments carried aboard OSO spacecraft also detect and measure celestial phenomena from other areas in space such as celestial ultraviolet energy; proton-electron energy; celestial neutron flux characteristics; zodiacal light intensity and direction; and interplanetary dust particle number, momentum and kinetic energy.

1.3 MISSION OBJECTIVES

With the OSO series of spacecraft, NASA has embarked upon a comprehensive space and astronomy program to study solar behavior affecting the structure and circulation of earth's atmosphere, the physical nature and origin of solar-surface phenomena, and the relation of this solar activity to terrestrial events. This is being accomplished by a unique combination of government and private solar research organizations over an eight year period from 1962 through 1970.

Solar activity follows a cycle averaging 11 years. The next period of maximum activity will occur in 1969 and 1970. Many solar physicists believe that if a complete study is made of radiation from the quiet sun, the incidence of transient solar phenomena should be predictable. The results of OSO-1, launched on 7 March 1962, give some support to this belief. When all the data has been reduced from OSO-2, launched 3 February 1965, it is believed that they too will support this theory. A total of eight OSO spacecraft are presently authorized and will be placed into earth orbit during the eight year period.

1.3.1 OSO-2 MISSION OBJECTIVES

OSO-2 was the second in this series of eight spacecraft which NASA will launch for the purpose of observing and investigating solar phenomena and effects. Its mission objectives were:

a. To study electromagnetic radiations from the sun in the ultraviolet and X-ray regions of the spectrum.

b. To map the solar disc in ultraviolet light and X-ray emissions.

c. To map the intensity of the white-light corona of the sun.

d. To monitor bursts of solar X-ray emissions.

e. To determine the origin of the polarization of zodiacal light.

f. To measure the direction of arrival and energies of primary cosmic gamma-ray radiation in the energy spectrum from 100 Mev to 1 Bev.

g. To detect gamma rays from the sun and from other sources in space in the energy spectrum from 0.1 to 0.7 Mev.

h. To measure ultraviolet radiation from nebular and stellar sources.

i. To measure the emissivity stability of spacecraft temperature control materials.

1.3.2 OSO-2 EXPERIMENTS

The OSO-2 mission objectives were accomplished by a complement of eight scientific instruments divided into two categories - solar oriented and non-oriented instruments. The oriented instruments were mounted in the sail section and required constant pointing in the solar direction. The non-oriented instruments were mounted in the wheel section and only required a quick-look at the sun once every two seconds or did not require a look at the sun at all.

Three of the eight instruments on board OSO-2 were provided by private solar research organizations and the remaining five were provided by various government research facilities.

1.3.2.1 Pointed Experiments

1.3.2.1.1 Naval Research Laboratory Ultraviolet Telescope and Coronagraph—Dr. R. Tousey, Investigator.

This portion of the NRL experiment package consisted of two experiments: a coronagraph experiment to map the intensity of the white light corona of the artificially eclipsed sun, operated during the pointing mode, and an ultraviolet scan experiment in which the sun was successively mapped in three ultraviolet wave-lengths during the spacecraft raster mode. (Lyman-Alpha, 1216 angstroms; 388 angstroms; and He II, 304 angstroms.)

The coronagraph experiment used an occulting disc to artificially eclipse the sun and a mechanical scanner to scan around the solar corona in a spiral motion. The coronal light was detected by an end-window type photomultiplier.

The ultraviolet scan experiment consisted of a dispersion grating followed by a set of three ultraviolet photomultipliers, each located at the focus of the three ultraviolet wave lengths. The high voltages required to operate the photomultipliers were obtained from separate high voltage power supplies, only one of which provided voltage at a given time. A voltage-selector energized each of the photomultipliers in sequence and in coincidence with signals generated at the end of each solar scan.

1.3.2.1.2 Naval Research Laboratory X-Ray Telescope—Dr. T. A. Chubb, Investigator.

This portion of the NRL experiment package was grouped into raster mode and point mode experiments. The purpose of the pointed experiments was to monitor bursts of solar X-ray emission in three wavelength bands and to search for X-ray emission from prominences at high altitudes above the solar disc. The purpose of the raster experiment was to repetitively map X-ray sources on the sun in two wavelength bands.

The pointed mode experiment utilized four Geiger counters: A 2 to 8 angstrom burst detector, an 8 to 20 angstrom background detector, a 44 to 60 angstrom burst detector, a background detector and a prominence detector. The burst detectors looked at the sun and recorded solar X-rays continuously during the point mode of operation. The background detector looked away from the sun and provided a basis for correcting the data for counts due to Van Allen or other particle radiation. The solar prominence detector looked at the region around the sun. During this observation, the sun was artificially eclipsed by an occulting disc which was extended approximately 24 inches in front of the X-ray counter.

Mapping by the raster experiment was accomplished by recording as a function of position responses of two very tightly collimated Geiger counter X-ray detectors. The pulse generated in these detectors was alternately switched to the data storage system during each sun raster, thereby permitting raster patterns at two wavelengths simultaneously.

1.3.2.1.3 Harvard College Observatory Ultraviolet Spectrometer and Spectroheliograph—Dr. L. Goldberg, Investigator.

This experiment consisted of a spectrometer which scanned over the long wavelength region of the ultraviolet spectrum between 300 and 1400 angstroms.

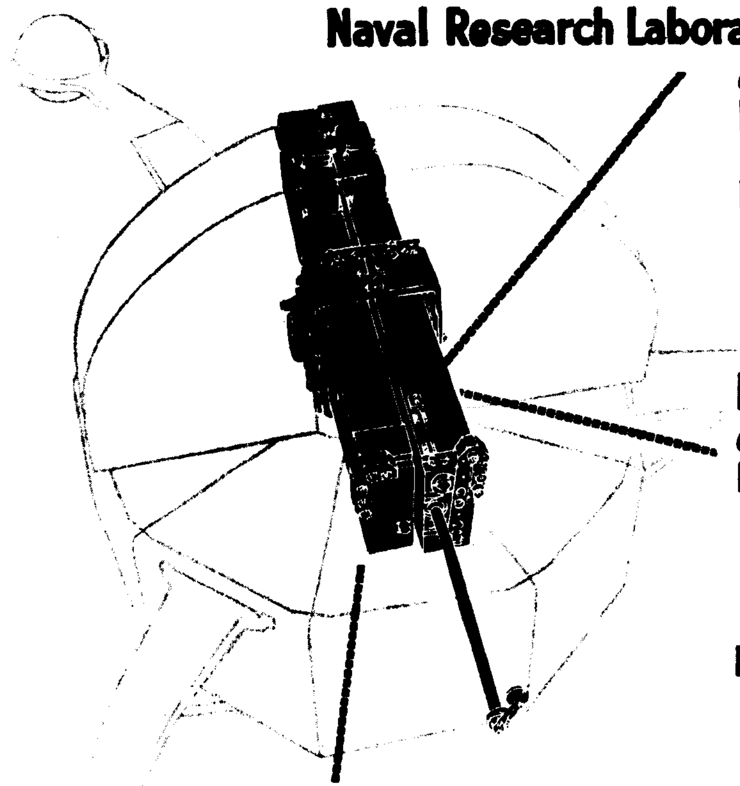


Figure 1-9. Oriented Experiments

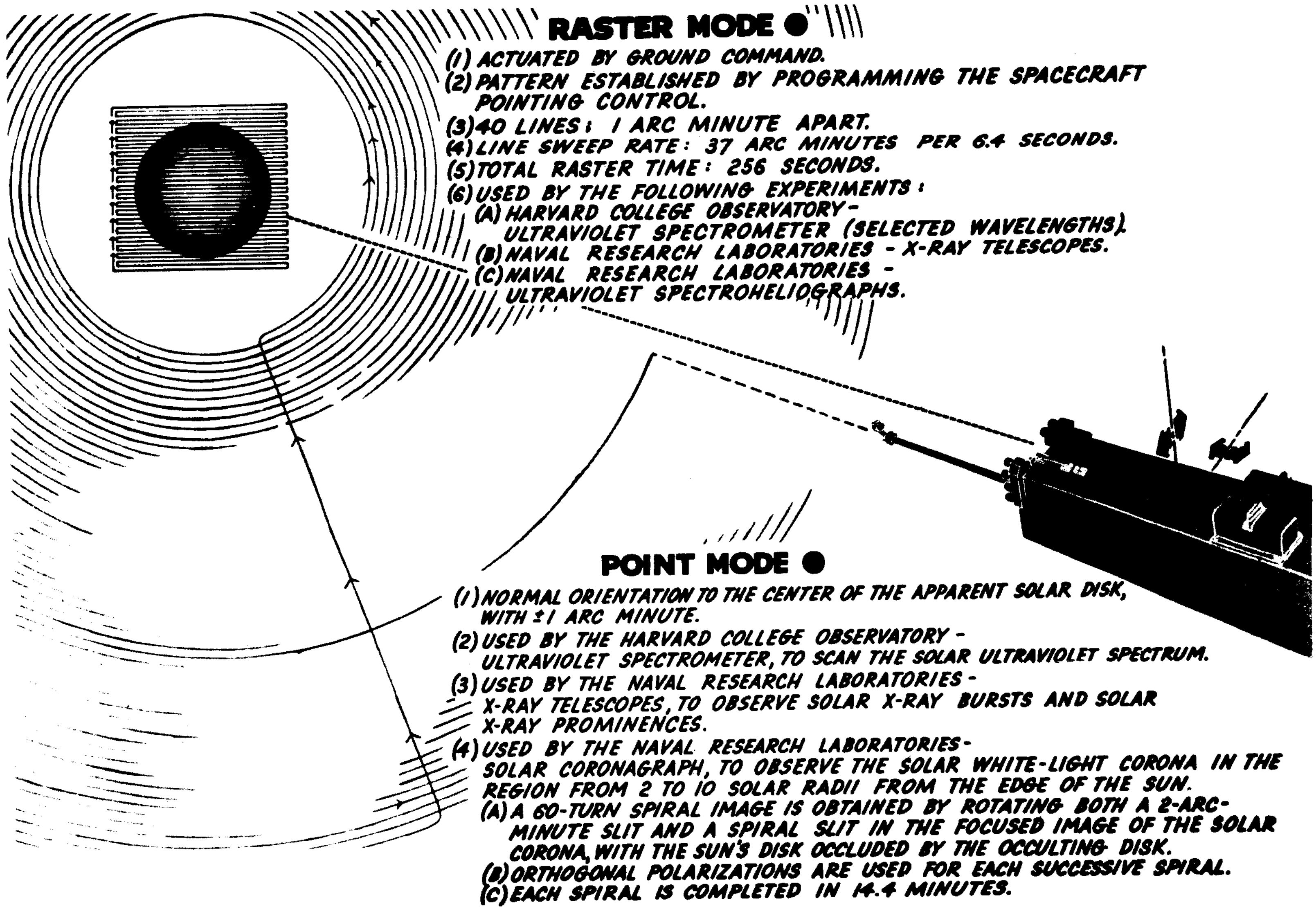


Figure 1-10. Oriented Experiment Operational Modes

The spectrometer used a windowless photomultiplier with a tungsten photo cathode as a detector which has a zero response to wavelengths longer than 1400 angstroms and a relatively flat response to shorter wavelengths.

Besides scanning the ultraviolet spectrum, a second type of observational procedure was available. Upon command from the ground, the spectrometer moved to any desired wavelength and a raster-type motion of the pointed experiments caused a monochromatic image of the sun to be constructed. The spectral range was covered with an approximate resolution of one angstrom. The spectrometer was designed to have an acceptable angle of about 1.8 minutes of arc in both the horizontal and vertical directions.

1.3.2.2 Wheel Experiments

1.3.2.2.1 Goddard Space Flight Center Ultraviolet Spectrophotometer—Dr. K. L. Hallam, Investigator.

Ultraviolet radiation from nebular and stellar sources were plotted in a wide-sky coverage of this light source in both the northern and southern hemispheres. The overall spectral coverage was from 1300 to 2600 angstroms. This experiment was expected to extend the knowledge of stellar atmospheres, interstellar atmospheres, interstellar gas, interstellar dust, and was to assist and complement the concurrent rocket astronomy programs by preliminary but comprehensive data about the brighter ultraviolet sources. The spectrophotometer had a field of view of 1/2 degree by 1 degree and was measured to an accuracy of 1 minute of arc. Intensities of the brighter sources were measured to an accuracy of 1 percent. The dynamic range of the instrument was six stellar magnitudes.

1.3.2.2.2 Goddard Space Flight Center Low Energy Gamma Ray Telescope—Mr. K. J. Frost, Investigator.

This experiment was designed to detect gamma-rays from the sun and from other sources in space, and to analyze their energy spectrum from 0.1 to 0.7 Mev. Of particular interest in this experiment was the ability to detect the 0.501 Mev electron-position annihilation line and to study any possible temporal variations.

1.3.2.2.3 Ames Research Center Emissivity Detectors—Mr. C. B. Neel, Investigator.

To support the Apollo project, it was necessary to determine the performance of spacecraft temperature-control coatings in the space environment.

Coatings to be tested for emissivity stability were applied to discs and exposed to solar energy and space environment during orbit. Measurements of thermal-radiation characteristics of the coatings versus time were thus obtained.

1.3.2.2.4 University of Minnesota Zodiacal Light Telescopes—Dr. E. P. Ney, Investigator.

The purpose of this experiment was to determine the origin of polarized zodiacal light, a nebulous light seen in the west after twilight and in the east before dawn. Experiment apparatus carried in the rotating wheel section measured the intensity of polarized zodiacal light along the spin axis. To do this, photomultipliers covered with sheets of polaroid were mounted on the top and bottom of the wheel section. The photomultipliers had a ten degree field of view and measured both visible and infrared light. Rotation of the polaroid sheet with the wheel section produced an alternating signal of 1/2 cps which was a direct measure of the intensity of the polarized light.

1.3.2.2.5 University of New Mexico High Energy Gamma Ray Telescope—Dr. C. P. Leavitt, Investigator.

This experiment measured the direction of arrival and energies of primary cosmic gamma-ray radiation in the energy range from approximately 100 Mev to 1 Bev. The primary purpose of this experiment was to locate discrete sources of radiation and to determine its energy spectrum in the range mentioned above. Energy resolution was expected to be about 30 percent and directional accuracies were measured to within ± 10 degrees.

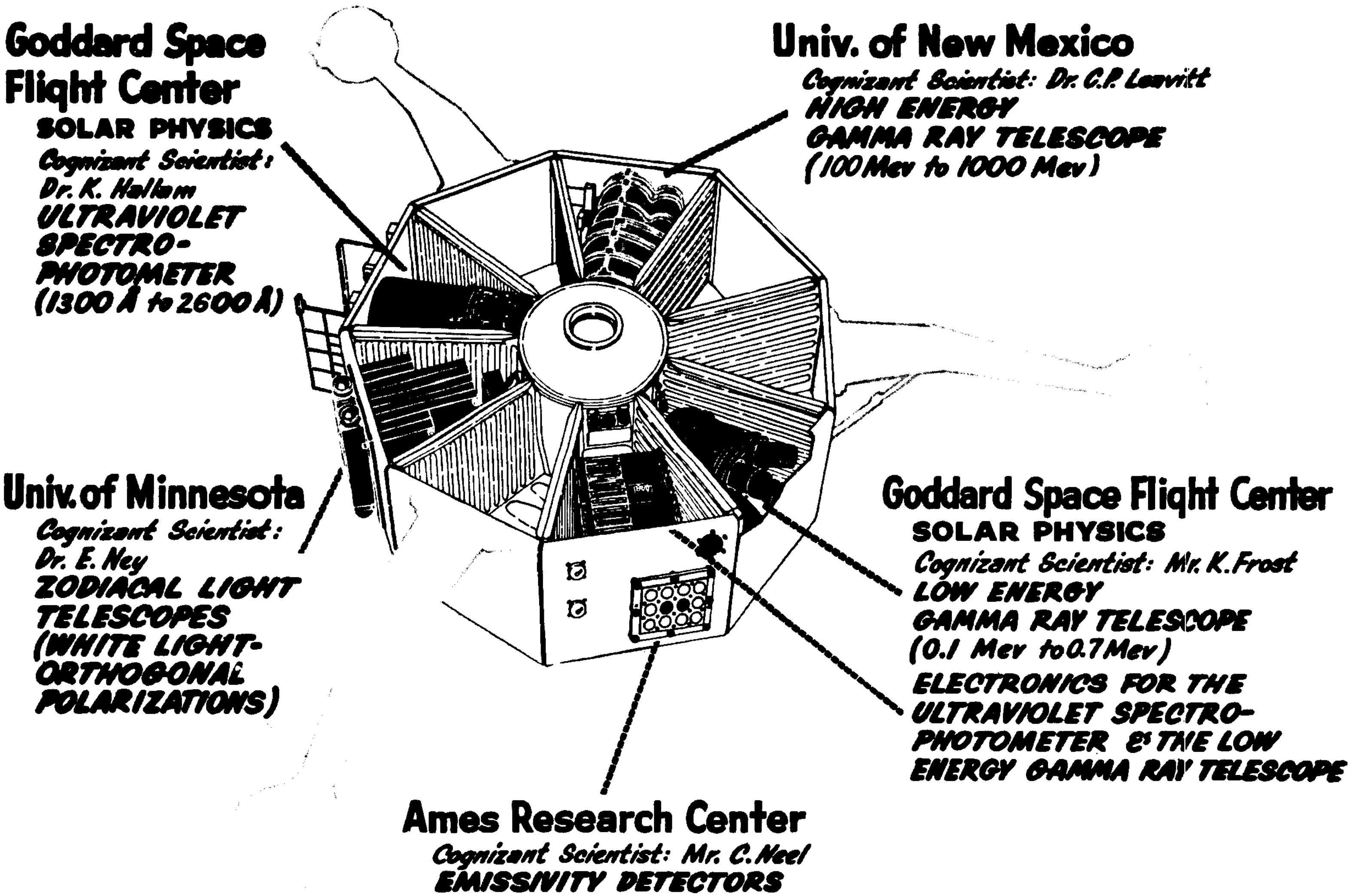


Figure 1-11. Wheel Experiments

SECTION 2
OSO-B DISASTER

2.1 EVENTS LEADING UP TO THE DISASTER

The OSO-B spacecraft arrived at Cape Kennedy on 12 March 1964. Routine checkout and preparation of the spacecraft and experiments took place until 9 April 1964, at which time the payload was covered with a polyethelene bag, purged with dry nitrogen and placed in its shipping container. The payload was stored in hangar AE to await the arrival of the Delta third stage rocket motor.

Because of its heavier weight, the OSO spacecraft uses a rocket motor with a thicker wall casing. When the motor arrived, it was given a receiving inspection, and it was discovered that there was a defect in the rocket motor casing. This motor was rejected, and a new X-248 A-6 rocket motor was flown down from Wallops Island, Virginia on 9 April 1964. The igniter paddle was removed from the rejected rocket motor to be installed in the new motor. During the removal of this paddle it was damaged and a new Delta paddle was built by the Naval Propellant Plant. The new Delta igniter paddle was flown to Cape Kennedy on 11 April 1964 and installed in the third stage rocket motor. The rocket motor was transported to the Spin Test Facility on 12 April 1964.

On 13 April the payload was removed from the shipping container, placed on a truck and, at approximately 0400 hours, it was moved to the Spin Test Facility.

2.2 THE DISASTER

Between 0930 and 0939 hours EST on 14 April 1964, the third stage X-248 A-6 solid propellant rocket motor inadvertently ignited and burned in the Spin Test Facility at Cape Kennedy. The rocket motor with the spacecraft attached tore loose from the alignment fixture in which it was mounted and shot to the ceiling of the facility. When it hit the ceiling, the spacecraft was torn loose from the third stage motor and fell to the floor. The rocket motor continued on to the corner of the building and burned until its fuel was expended. Eleven men were burned - three fatally and eight others suffered injuries ranging from critical to minor. The three men who died were not killed immediately but died as a result of their burns within a couple days to a couple weeks after the accident occurred.

Eye witness interviews after the accident indicated that the Douglas personnel had just completed their ordnance checks of the third stage/spacecraft combination. One of the Ball Brothers Research employees stepped over to the spacecraft to adjust the polyethelene shroud which was placed over the spacecraft and third stage as a dust protector and to purge them with nitrogen. As he touched the shroud a crackle was heard and the third stage ignited.

2.3 ACCIDENT INVESTIGATION

A Fact-Finding Committee was appointed by the NASA Goddard Space Flight Center Director. The committee was comprised of the following personnel:

D. G. Mazur, Chairman	NASA-GSFC
W. D. Baxter, Lt. Col	AFMTC
Dr. B. Bartocha	NPP
R. H. Gablehouse	Ball Brothers
E. E. Harton	NASA Headquarters
E. H. Helton	NASA-Wallops Island
L. T. Hogarth, Secretary	NASA-GSFC
R. J. Johnson	Douglas Aircraft Company
J. J. Nielon	NASA-GLOB
L. R. Piasechi	JPL
W. R. Schindler	NASA-GSFC
R. Steinberger	ABL
L. Swain	NASA-LRC

The committee investigated the following items at the Eastern Test Range (ETR) immediately after the accident to establish the circumstances surrounding the accident:

a. Hardware configuration at the time of the accident.

b. Eye witness testimony and reports.

c. Examination of the accident area including inspection and testing of significant items.

d. The time sequence of events leading up to the accident involving the rocket motor and the spacecraft.

e. Review of procedures.

f. Determination of possible causes.

g. Plans for tests to verify the possible causes.

The committee divided the investigation into four areas: (1) heat, (2) RF signal, (3) electricity and (4) mechanical shock and/or vibration. The committee also undertook the investigation of a similar accident which took place a few months earlier at the Oklahoma Ordnance Depot at Pryor, Oklahoma, to determine if the two accidents were related. In the Oklahoma accident, the Douglas Aircraft Company was preparing a destruct test of the X-248 rocket motor in order to test a new Delta third stage destruct system. No one was killed in this accident, but test equipment and a crane used for moving the rocket motor were considerably damaged. One person received minor injuries.

The first of the investigative courses of action taken was to investigate electrostatic discharge. This investigation was to determine possible modes by which an electrostatic charge could have caused ignition of the X-248 A-6 motor. It was divided into five tasks which were directed toward developing a comprehensive picutre of the electrostatic characteristics of the spacecraft/motor configuration and the motor/igniter assembly. The first of these tasks was to determine the electrostatic sensitivity of the X-248 squib. The second task was to determine the electrostatic sensitivity of all bulk explosives in the X-248 motor. Another task was to determine total and inter-element electrical characteristics (resistance, capacitance, and charge storage) of the spacecraft/motor and the motor/igniter under the application of both static and transient electrostatic voltages. This task was also to establish the critical inter-elemental breakdown voltages and paths. Task number four was to determine the electrostatic potentials and energies that could have been present under the circumstances prevailing at the time. The final task was to try to duplicate the X-248 inadvertant ignition in both the Eastern Test Range and Oklahoma accident configurations.

Electrostatic sensitivity tests of the Delta X-248 squib were conducted by the Franklin Institute. These tests consisted of discharging, through the squib, incremental voltages of a 500 pico-farad capacitor through a 5000 ohm resistance to simulate the capacity and resistance properties of a human being.

Measurements of the electrostatic sensitivity of the X-248 bulk explosives were conducted by the Naval Propellant Plant. It was determined from these measurements that the X-248 bulk explosives could not have been a factor in the accident.

Determination of the electrical characteristics of the spacecraft/motor and motor/igniter were conducted by Cornell Aeronautical Laboratory. They found that relatively weak sources of electrical current, such as electrostatic charging phenomena, are capable of building up large potentials between the dome and the nozzle of the motor with the igniter assembly in place. The squib is polarized and has the ability to store electrical energy. At voltages sufficiently high (250 to 1000 volts) to break down the dielectric in the squib, the squib could supply sufficient energy to ignite the lead styphnate primer.

Determination of electrostatic potentials and energies that could have been present under the circumstances at the time of the accident were investigated. The polyethelene shroud used over the spacecraft was found to be an electrostatic generator and had charge-concentrating areas that could charge the spacecraft to 15,000 volts if a mechanism was available to transfer the charge from the cover to the spacecraft fast enough. Rolling the cover up and down in a manner identical to the operation performed at Cape Kennedy generated voltages on the spacecraft as high as 2500 volts and averaged about 1200 volts. Wiping the plexiglass plate over the nozzle exit of the X-248 redistributed the charge on the plate and induced transient peak potentials up to approximately 5000 volts on the igniter firing lead. It was also found that a man with or without a Clean Room Suit ("bunny suit") could easily generate, just by normal activity, a charge sufficiently large that, if placed on the X-248 motor/spacecraft assembly, it could increase the spacecraft potential about 3000 volts on contact with the man.

The tests were conducted with an inert motor and a live initiator. Six ETR configuration firings were all produced by friction or movement of the polyethelene film identical to that used for the OSO-B shroud around the body of the rocket motor.

Cornel Aeronautical Laboratory proposed several modifications to the igniter assembly. A modified igniter assembly was fabricated and tested for the committee. The assembly withstood 60 kilovolts discharged directly to the squib without ignition, and subsequent tests were successful up to 100 kilovolts.

From the RF tests conducted by the Franklin Institute and the Picatinny Arsenal, together with the RF data supplied by Eastern Test Range, it was concluded that the accident was not caused by RF energy. It was also improbable that the accident was caused by incompatibility or instability of the chemical characteristics of any of the igniter or motor components.

2.4 CONCLUSIONS AND RECOMMENDATIONS

The committee concluded that the cause of the ignition of the third stage rocket motor at Cape Kennedy was an electrostatic discharge through the igniter squib. Cornell Aeronautical Laboratory recommended the following changes to the X-248 rocket motor: (1) use of a squib insensitive to electrostatic energies up to 25 kilovolts and 500 pico-farad, (2) use of a resistive plug between the squib case and the bridgewire, (3) use of a Faraday cage covering all sensitive parts of the squib assembly and (4) use of a conductive spray on electrostatic sensitive portions of the paddle. Cornell Aeronautical Laboratory demonstrated that the last three of the forementioned changes are adequate to insure against accidental squib initiation due to electrostatic discharges up to 100 kilovolts. In all subsequent Delta launches, an X-258 rocket motor was used instead of an X-248 because it used an igniter assembly less sensitive to electrostatic discharges, and the squib can be inserted on the launch tower.

Precautionary measures were also suggested which would apply to any solid propellant rocket motor: (1) to avoid the use of non-conductive materials, especially plastics, (2) to use squib arrangements which would permit installation as late in the operation as possible, (3) to check the conductivity of each igniter-motor system planned for usage to verify a low resistive path between all conductive components, (4) to strictly adhere to proper grounding procedures whenever a solid motor is to be handled with or without an igniter installed. It was also recommended that procedures for grounding personnel, spacecraft, motor and associated systems and components should be carefully considered for future rocket motor handling.

2.5 SPIN BALANCE FACILITY REWORK

The possibility of a new Spin Test Facility was investigated; however, a new facility could not be made ready until November 1965. It was decided to rework the damaged facility for use in the Delta program. During the rework of the Spin Test Facility, the following additional safety features were added to the building:

a. The pit in the southwest corner was floored over with portable decking which can be removed if the pit is required for future operations.

b. A new personnel door was placed in the center of the north wall.

c. Roll up doors on the east end of the building were replaced with two 6 by 10 feet swing-type doors. The remainder of the original opening was replaced with blast panels.

d. Panic hardware was improved on all personnel egress doors. Blank latch facings were installed on the door frames.

e. The interior of the west wall of the building was covered with gypsum wallboard to provide sealing and to retard fires.

f. The protruding tracks on the exterior of the west end of the building were removed.

g. An emergency audible warning system was installed.

h. A "Cone of Protection Lightning System" was installed around the facility.

i. The existing communication system was removed and replaced by an explosion proof intercom system.

j. Conductive plastic mats were supplied for use in areas where ordnance is handled.

k. A sprinkler system was installed in the high pay area.

l. Placards denoting explosive materials, classes, personnel limits, etc. were installed.

m. Personnel safety showers were installed at all personnel egress doors.

n. An additional closed circuit TV system was installed with cameras in the high bay area and monitors in the office trailer and control room. Personnel can now witness operations without being physically present in the bay. Procedures were changed so that all spacecraft testing necessary in the pit area is performed remotely.

o. The personnel trailer located at the west end of the building was removed to a more remote location.

p. The guard shack for the area was removed to approximately 350 feet from the facility.

q. The relative humidity inside the building was increased from 50% to 60%.

SECTION 3
DEVELOPMENT OF OSO-2

3.1 SPACECRAFT

After the OSO-B disaster OSO Project Management decided to rebuild the OSO-B spacecraft using prototype parts, OSO-B spare parts and new parts. The OSO-B prototype and flight spacecraft were returned to Ball Brothers Research Corporation in Boulder, Colorado. The experiments were removed and returned to their respective investigators for examination and testing to determine the extent of damage. When the damage to the spacecraft was surveyed, a schedule was set up to rework the OSO-B prototype spacecraft from existing flight spare components, updated prototype components, undamaged flight components and new procurement. All new procurement and OSO-B flight subassemblies were given a complete acceptance test. OSO-B flight spare units were only given thermal tests, whereas the prototype components were given functional and thermal tests. The go-ahead for OSO-2 was given on 17 June 1964.

The spacecraft was completely stripped of its components and the wheel and sail structures were separated. The flight subassemblies that were removed from the OSO-B spacecraft were inspected and tested to determine their usability. 35% of these subassemblies were determined to be suitable for use as OSO-2 flight subassemblies, 16% were suitable for use as flight spares and the remaining 49% were considered surplus and not suitable for OSO-2 usage.

When the OSO-2 spacecraft was delivered to Cape Kennedy, it was composed of 19% OSO-B flight subassemblies, 29% OSO-B flight spares, 22% OSO-B prototype subassemblies and 30% new procurement.

3.1.1 WHEEL STRUCTURE

The OSO-B prototype wheel structure was completely stripped of components, cleaned and used as the OSO-2 wheel structure. All the paint was removed from the interior of the compartments, and only the GSFC Ultraviolet and University of New Mexico experiment compartments were repainted black for flight. The paint was stripped from the rim panels, and the exterior of the spacecraft was left unpainted until after the testing program was complete. Epoxy radial strips painted with aluminum paint were installed on the wheel to replace those covered with aluminum foil. New upper and lower wheel covers had to be procured for the OSO-2 spacecraft.

OSO-B prototype arms, arm damper assemblies, azimuth shaft and spin gas bottles were installed on the wheel for OSO-2. A back-up slip ring assembly was assembled from OSO-B parts, and a new slip ring assembly was procured for the flight installation. The wiring of the wheel had to be updated to the OSO-2 flight configuration.

3.1.2 SAIL STRUCTURE

The OSO-B prototype sail structure was cleaned, painted and used as the structure for the OSO-2 spacecraft. A compatibility fit of the solar cell substrate indicated that relocation of several sail mounting holes was necessary. One of the mounting holes was damaged when the old dummy array was removed at Cape Kennedy prior to the accident. This was corrected by riveting a back-up piece of metal behind the torn hole.

The sail was mounted to the wheel structure on 3 September 1964. Integrated comprehensive testing of the spacecraft and experiments was conducted until 24 September at which time the observatory was installed on the balance machine and the observatory balance operation was begun.

3.1.3 BEARINGS

The top azimuth bearing, lower azimuth bearing and the elevation bearings that were installed in the OSO-2 spacecraft were the OSO-B flight spare units. The OSO-B prototype top azimuth bearing housing was also installed on OSO-2.

The OSO-B bearings experienced a grinding of surfaces because of a loss of lubricant. Part of the lubrication process was to place the bearings in a centrifuge, but this caused some of the lubrication to be forced from the bearings. Centrifuge operations were reduced, and as a result, the bearings used in OSO-2 were properly treated by a revised process. The quantity of lubricant impregnated into the retainer is now determined by weight.

3.1.4 ATTITUDE CONTROL SYSTEM

Fifty percent of the OSO-B2 spacecraft attitude control system was composed of OSO-B flight and prototype subassemblies. The remaining fifty percent consisted of OSO-B flight spares and new procurement.

The fine eyes used on OSO-1 contained a deposited knife edge. The vendor went out of business, and as a result, OSO-B fine eyes were provided by a film emulsion process. This was a better process, however, prolonged exposure to the sun caused a change and degraded the eyes. A deposited knife edge using aluminum was developed which proved to be three to four times smoother than the knife edge used on OSO-1.

New solenoid valves were procured for OSO-2 which incorporated in-line filters in addition to the regular filters. Leaks were encountered with the new valves, and as a result the specifications were tightened on the finishes of the seating surfaces. Acceptance tests were changed to assure that failures would not occur again. The Ball Brothers Research Corporation bench test fixture was also cleaned, and the specification was tightened on the allowable particle size.

The acceleration switches passed the acceptance tests, but later they were found to have a problem due to an increased bearing friction. It was determined that the switch problem was due to excessive bearing preload. The switches were modified by using a preload washer instead of the old method of adjusting the bearing spacing.

3.1.5 COMMAND SYSTEM

Practically the entire OSO-B command system was reusable for OSO-2. The only subassemblies from OSO-B that were not used were the hybrid circulator assembly and the VHF diplexer assembly. These two units were taken from OSO-B flight spares.

The OSO-B flight decoders were returned to the vendor for inspection and testing. The prototype decoders were installed in the spacecraft to check out the command system while the flight units were at the vendor being tested. The flight decoders were returned to Ball Brothers, given a receiving inspection and installed in the spacecraft.

A vendor representative conducted checks on the OSO-B flight and prototype command receivers. After the completion of these checks, it was found that all four of the receivers were suitable for flight usage. The OSO-B flight units were selected and installed in the spacecraft.

3.1.6 TELEMETRY SYSTEM

The telemetry system installed on OSO-2 consisted largely of OSO-B flight spare units. The OSO-2 telemetry system consisted of 57% OSO-B flight spares, 28% OSO-B flight components and 15% OSO-B prototype components. No new subassemblies had to be procured for OSO-2.

One of the OSO-B flight multiplexer-encoders had the epoxy cracked beyond repair and this unit was scrapped. The other OSO-B flight unit had an encoding error in one channel and a bad solder joint. This unit was later reworked and designated for use on OSO-C. The OSO-B flight spare and one prototype multiplexer-encoder were installed as OSO-2 flight components.

Five tape recorders were returned to the vendor with instructions to disassemble all mechanical modules. All modules were to be examined prior to replacement of bearings. The vendor was also instructed to pick three tape recorders that could be rebuilt - two for flight units and one for a flight spare. A complete check was made of all electrical components. A special lubricated tape was required for these tape recorders, and this was ordered from Minnesota Mining and Manufacturing Company on the same specification as earlier tapes. The tape that was delivered was not the same as earlier tapes and proved to be unsatisfactory. As a result, two year old tape was used to make up a reel for the tape recorders. One reel of tape had an extra drop-out which was not present in the other reels. End of tape and splice drop-outs were expected, so this reel was installed in the tape recorder originally designated as the alternate flight unit. During the testing program, this tape recorder had signal drop-outs at two tape positions. Preliminary investigation showed that the drop-out area in addition to the splice was approximately 20 bits long compared to about 7 bits for a splice. This amounted to a loss of less than 3 words per orbit. This unit was changed-out. However, later in the testing program, the primary tape recorder developed erratic drop-outs, and the tape recorder with the extra drop-out was installed in the primary position because of its predictable drop-out area.

During checkout, when the University of Minnesota experiment was turned on or off, the tape recorder went into a playback cycle. It was discovered that transients from the Minnesota experiment and other sources caused the Time Marker Generator to turn on. It normally took 0.75 volt to trigger the time marker. Modifications were made to the Time Marker Generator to increase the threshold voltage to 8 volts to trigger the time marker. A switching relay was also placed in the PCM Time Marker power line.

The transmitters installed on OSO-2 were originally an OSO-B flight and a flight spare unit. Transmitter current measurements were made after the observatory acceptance tests were completed. During these measurements it was noted that the transmitters operated in two discrete current modes that differed by 60 ma. The normal current with the arms down was 70 ma. The two currents measured were 70 ma and 130 ma. This was determined to be a normal condition for a bad mismatch such as occurs with the arms down. When the transmitters are operated with the arms up the normal current is 100 ma.

3.1.7 ELECTRICAL POWER SYSTEM

A new set of slip rings to the same specification as OSO-1 were procured for use in the OSO-2 spacecraft. The OSO-1 slip ring assembly exhibited a useful life span of two years. Its total life span included OSO-1 assembly, test and launch and orbital operation.

A new solar array had to be procured for the OSO-2 spacecraft. During vibration testing, an open circuit was detected in the center panel and a poor solder connection was found in one of the side panels. Vibration tests were continued with the open circuit still present. The array was returned to the vendor and the necessary remedial action was taken. While at the vendor's facility, a solder ball was also removed. Further tests revealed no more discrepancies, and the array was installed on the spacecraft.

Because of the long lead time in procuring new squib batteries, it was decided to use OSO-B flight batteries on the OSO-2 spacecraft. A set of squib batteries was assembled from cells on hand that were less than four months old. One pack of wheel squib batteries developed a shorted cell during vibration testing at Ball Brothers Research Corporation and was replaced with a new pack.

Ball Brothers Research Corporation originally proposed to use 45 main battery cells which they received for OSO-C. They also had 34 cells on hand that were several months old. Because of excessive loss of F cells in incoming inspection and acceptance tests, fabrication of flight batteries from new cells could not be accomplished consistent with the proposed launch schedule. It was necessary to use the reconditioned OSO-B main batteries. The pack wiring was updated and a deep discharge cycling of the batteries was accomplished. After deep cycling of the batteries it was found that the battery capacity was nearly the same as it was a year and a half before when they were originally acceptance tested.

3.2 EXPERIMENTS

All the experimental instruments were removed from the OSO-B spacecraft and returned to their respective investigators to determine the extent of damage as a result of the accident. All the experiments were physically and functionally checked and the necessary repairs were accomplished. Only the Harvard College and Ames Research Center experiments were replaced with the OSO-B flight spares. This was done because the damage incurred by these instruments could not be repaired in the time limit set by the established schedule. The OSO-B flight units were reworked, however, and were used as OSO-2 flight spares. The University of Minnesota flight experiment was initially installed in the OSO-2 spacecraft, but it was later replaced by the OSO-B flight spare which had been reworked to increase its sensitivity. All the experiment instruments were returned to Ball Brothers Research Corporation during August 1964 for incorporation into the OSO-2 spacecraft.

3.2.1 POINTED EXPERIMENTS

3.2.1.1 Naval Research Laboratory Instrument

The instrument installed on the OSO-2 spacecraft was basically the original OSO-B flight model. Only minor repairs had to be made to the ultraviolet telescope and coronagraph section such as straightening the bulkhead, replacement of a collar in the occulting support and replacement of the heat shields. The instrument was delivered to Ball Brothers on 31 August 1964 for incorporation into the OSO-2 spacecraft.

During the thermal-vacuum tests conducted on the observatory, it was noted that when the NRL instrument was turned on, it interfered excessively with the Harvard College data count. This condition was corrected by placing RF chokes in series with the common power line between the Naval Research Laboratory and Harvard instruments.

3.2.1.2 Harvard College Observatory Instrument

Harvard's flight spare unit was successfully qualified and delivered to Ball Brothers Research Corporation on 24 August 1964. It was essentially the same as the original flight model except for an additional command for wavelength selection.

Rework and test of this instrument went well up to the observatory acceptance test when a noise problem was detected during the thermal-vacuum testing. The noise was present in the Harvard data count whenever the spacecraft control system was operating or when the Naval Research Laboratory instrument was turned on. The noise problem was solved by installing RF chokes in series with the flexprints between the Harvard instrument and the spacecraft. New flexprints were provided which were made of mylar and not coated as usual, but were painted with aluminum paint instead. The noise generated as a result of the Naval Research Laboratory instrument operation was eliminated by placing RF chokes in series with the common power lines between the Naval Research Laboratory and Harvard instruments.

3.2.2 WHEEL EXPERIMENTS

3.2.2.1 GSFC Ultraviolet Spectrophotometer

The experiment installed on OSO-2 was the original OSO-B flight instrument. A checkout of the unit was performed and relatively little damage was found. Repairs consisted mainly of clean-up, readjustment and checkout of optics and electronics.

The instrument was delivered to Ball Brothers on 25 August 1964 for installation into the OSO-2 spacecraft. It performed well during integration and acceptance tests of the observatory with the exception that the Elgin Grating Stepper was off sequence. The grating continued to cycle, however, and would not cause loss of data during data reduction.

3.2.2.2 GSFC Low Energy Gamma Ray Telescope

The experimental instrument flown on OSO-2 was the original OSO-B flight model. Only minor repairs had to be made such as addition of magnetic shields and the installation of a new optical coupler. The instrument was delivered to Ball Brothers on 31 August 1964, and it performed well during integration and observatory acceptance testing. There was an indication of a loss of background data during thermal-vacuum testing, but it was found to be caused by a poorly collimated light source in the test setup. The experiment performed as expected when exposed to the sun.

3.2.2.3 Ames Research Center Emissivity Detectors

The Ames experiment installed on OSO-2 was the original OSO-B flight spare unit. A check of the OSO-B flight unit indicated the possibility of damage as a result of the accident. The OSO-2 experiment was delivered to Ball Brothers on 24 August 1964. No problems were encountered during the preparation of the instrument or during integration and acceptance testing.

3.2.2.4 University of Minnesota Zodiacal Light Telescopes

A check of the OSO-B flight instrument indicated no apparent defects as a result of the accident. This unit was delivered to Ball Brothers on 17 August 1964 and initially installed on the OSO-2 spacecraft. The OSO-B spare unit was reworked and updated to increase its sensitivity by replacing photomultiplier tubes and providing a better telescope protective device. This updated instrument was delivered to Ball Brothers on 12 October 1964 and was installed on the OSO-2 spacecraft. There were no significant problems with this experiment, and it performed well during the integration and acceptance tests.

3.2.2.5 University of New Mexico High Energy Gamma Ray Telescope

The University of New Mexico instrument flown on OSO-2 was the original OSO-B flight instrument. A complete check of the instrument was made and no serious difficulties were found as a result of the accident. The OSO-2 flight unit was delivered to Ball Brothers on 31 July 1964 and performed well during the integration and acceptance tests.

After arrival at Ball Brothers, the New Mexico experiment indicated a sector readout anomaly. This was known before the accident because their counter, when exceeding the maximum count rate of 31, did not reset to zero but consistently read out the sixteenth bit during ground test. Since the nominal spin rate is subject to only 5% variation and New Mexico can tolerate a 15% change without exceeding their maximum count rate, this situation was not considered a problem. If the spin rate should vary as much as 20% during flight, it would still be possible to determine the sector by looking at the spin rate housekeeping data. This anomaly could have always existed since the experiment was never exposed to more than a 15% spin rate change until just before the OSO-B accident.

3.3 OBSERVATORY

3.3.1 WEIGHT AND BALANCE

The OSO-2 spacecraft was buttoned up for the balance operation and mounted on the balance machine on 24 September 1964. A dummy solar array, dummy solenoid valves and a test set main battery were installed for the balance operation because the flight units were not yet ready for installation. The observatory pre-shake balance operation was completed the following day. The observatory was weighed after the balance operation, and the launch weight was computed to be 549.7 pounds. This included six pounds of weight for the flyable lifting lugs. Figure 3-1 shows the OSO spacecraft in the Ball Brothers Balance Machine.

3.3.2 ACCEPTANCE TESTS

Acceptance testing of the OSO-2 spacecraft consisted of vibration testing and thermal-vacuum testing. The observatory was prepared for the vibration testing and the sine sweep was completed on 5 October 1964. A brief mechanical inspection indicated no failures, but the solar array continuity check indicated an intermittent circuit. A poor solder joint was discovered and repaired which appeared to fix the discontinuity. The Z axis sinusoidal vibration was performed, and all spacecraft systems and experiments checked out satisfactorily. The random Z axis vibration test was completed on 6 October, and no problems were observed during a quick visual inspection of the observatory. The X axis vibration testing was performed and completed on 7 October. During these tests, the right hand panel of the solar array indicated discontinuities in both the sine and random vibration operations. All three solar array panels were returned to the vendor for failure analysis and repair. The solar array was returned from the vendor on 9 October, and they indicated that they could find nothing wrong with it. A receiving inspection was performed on the solar array, and by illuminating individual shingles, it was found that one shingle was

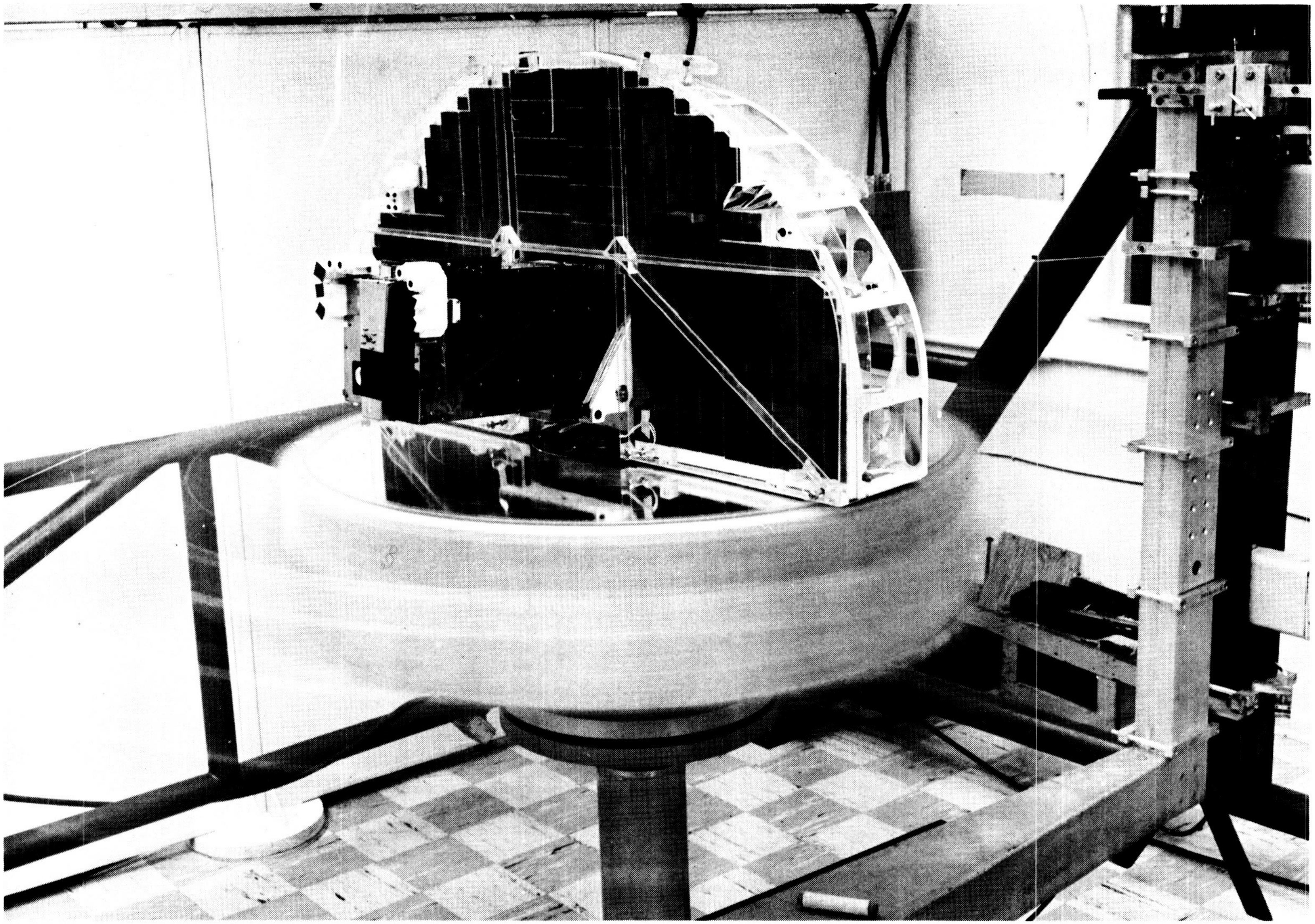


Figure 3-1. OSO Observatory in Ball Brothers Balance Machine

open in the center panel. The center panel was returned to the vendor for repair. The cause of the intermittent in the right hand panel was discovered to be a shorted solar cell caused by a minute solder ball. Both the right and left panels were returned to the vendor for comprehensive inspection. The solar array was returned from the vendor and installed on the spacecraft on 15 October 1964. The Y axis vibration was completed on 16 October, and no mechanical failures were found during a brief visual inspection. Figure 3-2 illustrates the vibration test set-up.

Thermal-Vacuum testing consisted of placing the observatory in a vacuum chamber and pumping it down to evacuate the air. The observatory was then operated, as it would be while in orbit, for a period of 72 hours at a temperature of 25 degrees Centigrade. After the "Hot Cycle" was completed, the observatory was operated for 72 hours in the "Cold Cycle" at a temperature of zero degrees Centigrade.

The observatory was installed in the vacuum chamber on 22 October 1964, and the Thermal-Vacuum testing was begun. During the "Hot Cycle" tests, the Harvard instrument recorded spurious noise at the servo transition points of the scan pattern. This noise was caused by the driving of the torque motors, and was a known phenomena. Filters were placed in series with the Harvard flexprint to reduce the noise. It was found that this would reduce the noise only if the metallic plating was not present over the flexprint. Because of this, the OSO-2 had to use aluminum painted flexprints instead of plated flexprints. Supplementary high temperature vacuum tests were run with the stripped flexprints, and no discernible noise effects were noted from the control system operation. However, operation of the Naval Research Laboratory experiment caused noise higher than desired by Harvard, and filter chokes had to be placed in the common power leads of the two experiments. The cold thermal-vacuum tests were begun on the morning of 31 October 1964. No serious problems were encountered with the "cold cycle," and the observatory was removed from the vacuum chamber on 3 November 1964.

3.4 SHIPMENT TO CAPE KENNEDY

The spacecraft was buttoned up for shipment to Cape Kennedy on 16 November 1964 and placed on the balance machine to check the alignment of the alignment nubbin. The alignment was not within the Douglas Aircraft Company specification and had to be corrected. On 17 November 1964, another balance operation was completed, and the alignment of the spin axis perpendicular to the separation plane was checked. The back of the solar array substrate was given a second coat of white paint which was necessary as indicated by emissivity measurements which were made.

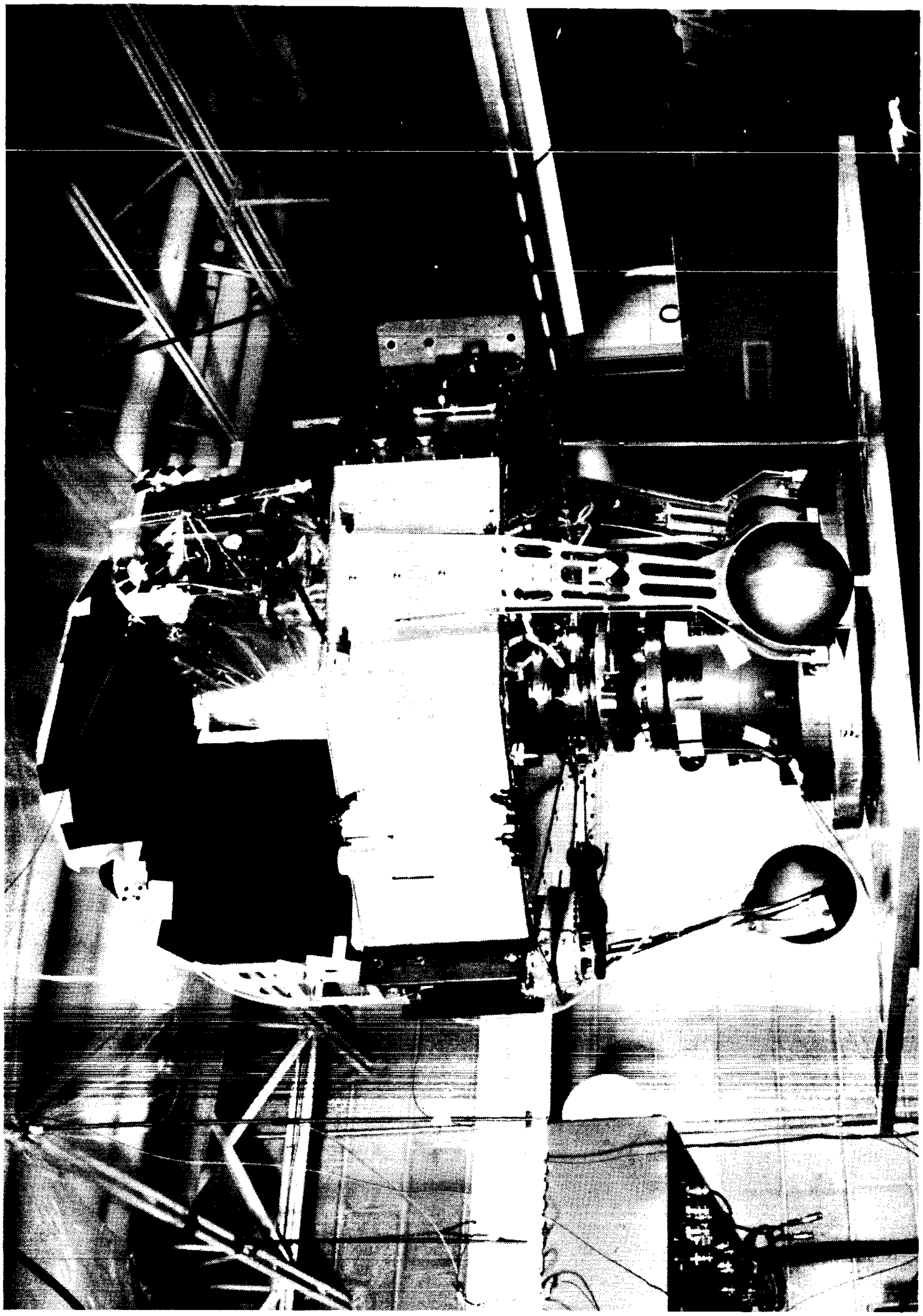


Figure 3-2. OSO-2 Vibration Test Set-up

The payload was installed in its shipping canister on 20 November 1964 and left by truck for Lowry Air Force Base together with its support equipment. The shipment was loaded aboard a Military Air Transport Service aircraft on 21 November 1964, but it had to be unloaded for transfer to another aircraft because of mechanical problems with the first airplane. Figure 3-3 shows the loading of the Military Air Transport Service aircraft. The second aircraft arrived at Lowry Air Force Base on 22 November 1964, but the shipment was reloaded on the first aircraft due to a development which made the second airplane unavailable. The airplane waited for departure on 23 November 1964 so that it would arrive at Cape Kennedy during the daylight hours. This was necessary because the landing strip at Cape Kennedy is not equipped with landing lights.

3.5 PRE-LAUNCH PREPARATIONS

The spacecraft arrived at Cape Kennedy at 0730 EST on 23 November 1964, only five months after the official go-ahead for OSO-2 development was given. A check of the external radioactive sources indicated that the University of Minnesota's Carbon 14 sources had leaked and were emitting beta rays. After decontamination activities had been accomplished, everything seemed all right. Some of the acceleration switches mounted on the spacecraft and container were found to be tripped when the spacecraft was uncanned at Cape Kennedy. It was determined that the switches were probably tripped due to handling during the loading operations at Lowry AFB.

3.5.1 HANGAR CHECKS

The spacecraft was removed from its shipping canister and placed in the clean tent in hangar AE on 25 November 1964. No visible damage was incurred by the spacecraft. Radio frequency checks were completed on the spacecraft except for voltage standing wave ratio measurements which could not be performed due to faulty test equipment. All eight experiments were given comprehensive checks and were found to be all right. The main batteries were placed in a deep discharge cycle to check their capacity. The battery discharge cycling tests were completed on 1 December 1964, and the measured capacity of 18 ampere-hours was far in excess of requirements. On 4 December 1964, the spacecraft was placed in its shipping canister and readied for extended storage in hangar AE to await the arrival of the Delta third stage. At this point, launch operations were suspended.

The Ball Brothers Research Corporation crew arrived again on 6 January 1965 and the spacecraft was again uncanned and installed in the clean tent.

Figure 3-3. OSO-2 Loading at Lowry Air Force Base - 22 November 1964

Comprehensive and sun pointing tests were conducted on the spacecraft and experiments. On 8 January 1965 the fairing compatibility fit checks were succesfully completed and the radio frequency interference tests were begun. RF spectrum measurements on transmitter number 1 with the arms down indicated multiple sidebands at approximately 2 Mc intervals. This phenomena had been observed during bench checks when a transmitter was connected to a severely mismatched reactive load.

The prime transmitter was being coupled into the command receivers, and this was discovered to be caused by a shift of the plastic sleeves on the ends of the antenna stubs. This prevented the stubs from touching the arms when the arms were down. When the sleeves were relocated to the correct position, the stubs touched the arms and transmitter operation was normal with no coupling into the command receivers.

It was determined that the compatibility between the transmitters and the arms down antennae was improved if the arms down antenna impedance was made slightly reactive. This was accomplished, without changing the arms up impedance, by changing the protective tip sleeving on the driven elements so that electrical contact was made with the spin bottle bracket. With this modification, the command and telemetry systems functioned normally with the arms down.

Later, it was discovered that spurious signals from the transmitters were still getting into the command system. Arms down impedance adjustments were made by changing the length of the RF cables. An attempt was made to adjust the length of the diplexer to "T" Power Divider coaxial cable to eliminate the spurious signals with the arms down and to match both transmitters with the arms up for optimum performance. The antenna stubs were insulated from the arm structure with heat-shrinkable tubing. Tests after changing the cable length indicated that neither transmitter could be made to generate spurious signals with the arms down. Transmitter number 2 was not delivering adequate power with the arms up, so the output coaxial relay cable was replaced with a new length cable. After this replacement, current into both transmitters was normal under all conditions, power into the matched load was normal and the standing wave ratio was normal at both frequencies.

On 13 January 1965, emissivity and absorptivity measurements on the thermal surfaces of the spacecraft were made. The wheel experiments were given a pre-comprehensive check-out on 14 January 1965. All but the GSFC Ultraviolet and Gamma-Ray experiments functioned normally. During the wheel pre-comprehensive checks, the GSFC Ultraviolet instrument was commanded "ON", but no data were observed at the telemetry ground station. However, the wavelength selector stepping was audible which indicated that the instrument was operating. An oscilloscope was connected to the rim panel test connector, and data were immediately received at the ground station. The data amplitude was 4.4 volts, further investigation disclosed no abnormalities. The instrument was turned on again at 16.2 volts to determine any possible voltage discrepancy, but normal operation was observed. On 20 January 1965, the instrument was turned on simultaneously with the spacecraft and data were received immediately. On 24 January 1965, the instrument buffer module was installed and a check revealed proper operation. Proper operation was again verified during checks made on 26 January 1965.

The GSFC Gamma-Ray experiment appeared to malfunction during pre-comprehensive checks on 14 January 1965. At that time, however, there was a data indication from the dead-time analog monitor. A two (2) microcurie Radium-226 source was substituted for the two Sodium-22 sources normally used, and a digital count was observed. A check of the digital numbers versus the source distance was made, and normal operation was observed. Later, checks were made using the two Sodium-22 sources once again, the the proper digital counts were observed.

The spacecraft was prepared for the balance operation on the Ball Brothers Balance Machine. The balance operation indicated a slight unbalance which was corrected. Perpendicularity measurement between the bearing axis and the plane of the attach fitting indicated a misalignment of approximately three quarters of an arc minute. This amount of misalignment would not affect the spacecraft performance, but it would result in the alignment nubbin having a run outside the Douglas Aircraft Company tolerance. The run out was not corrected, but Ball Brothers notified Douglas of the offset of the nubbin so that the effect could be taken into account upon mating.

3.5.2 SPIN AND BALANCE CHECKS

During the evening of 29 January 1965, all non-flight handling covers were removed from the OSO-2 observatory in hangar AE. The protective capsule was installed around the observatory and purged with nitrogen gas to provide an inert atmosphere. The observatory and the capsule were placed in the shipping container and transported to the Spin Test Area on a flat-bed truck at 2130 hours. Upon arrival at the Spin Test Area, the observatory and capsule were removed from the shipping container and weighed. The nitrogen purge line was connected to the capsule purge port. The payload was mated with the third stage and placed on the alignment fixture to check the alignment of the alignment nubbin. Upon completion of the nubbin alignment, the third stage and observatory were moved to the spin balance fixture, and the spin balance operation was performed by the Douglas Aircraft Corporation personnel.

3.5.3 LAUNCH TOWER CHECKS

When the spin balance operation was completed, the spacecraft was again installed in the shipping container and transported to the launch complex at 1800 hours on 31 January 1965. High winds delayed the mating of the second and third stages until approximately 1900 hours.

3.5.3.1 T-3 Day Checks

T-3 day checks were begun at 2200 hours on 31 January 1965 and were successfully completed approximately 0300 hours on 1 February 1965. After approximately 25 minutes of eqiupment set-up and observatory and equipment turn-on, remote communications checks were performed. Remote experiment status checks and control system checks were performed. The spin and pitch gas systems were tested for leaks and then each was pressurized to 2100 psi. The tape recorders were loaded with tape and operated in the playback mode to time the playback period. At the end of the tape recorder operation, all power was removed from the observatory and the T-3 day checks were secured.

3.5.3.2 T-1 Day Checks

T-1 day checks were initiated late in the evening of 2 February 1965 and were completed in the early morning of 3 February 1965. Countdown tasks performed on T-1 day were to verify the flight readiness of the launch vehicle, spacecraft and facilities equipment; to assure compatibility with Range Systems for launch; to install spacecraft fairings; and to install and electrically connect ordnance. Clearance to start the count was obtained from all systems, a communications check was performed and the necessary power was turned on. A check was made to verify that the engine sequencing and cut-off circuitry were performing properly. The vehicle tanks and bottles were pressurized, and the lubrication oil tank was filled. The second stage retro system was pressurized and topped.

Comprehensive performance tests by RF link were performed on the flight spacecraft and the third stage telemetry system. Performance measurements were made of the spacecraft systems and the third stage telemetry while operating. The vehicle electrical systems were checked for proper performance. The RF systems received an open loop composite test, first on external power and then on internal power, using the applicable Range ground transmitting and receiving systems. The flight batteries were secured and connected prior to the internal power checks.

Preparations were made for propellant flow and loading of the second stage. Samples were taken from the propellant trailers and tested. After a leak check of the system was completed, propellant lines were connected to the vehicle, and the second stage was loaded. During propellant processing and loading, all unnecessary personnel were cleared from the launch pad area.

All electrical power was turned on, and the complete ordnance wiring circuitry was checked for stray voltages in preparation for the ordnance installation. All ordnance not previously installed on T-2 day were installed and electrically connected. The payload compartment fairing and its separation bolt detonators were installed. During these tasks, personnel on the pad were kept to a minimum, and those working with ordnance had to wear the proper non-static producing clothing and had to be properly grounded at all times.

3.5.3.3 T-0 Day Checks

The T-0 day checks followed the T-1 day checks in the early morning hours of 3 February 1965. Final preparations prior to clearing the area were performed. This included capping or connecting all lines, installation of access doors, final inspections and cleaning up the pad area. The first stage fuel system was checked for leaks, fuel samples were tested and the first stage was loaded with fuel. The vehicle electronic systems were turned on, the RF systems were radiated and the engine slew checks were performed. Checks were made to verify that no interference existed between any of the vehicle systems. The vehicle gyros were tested for proper operation. The main vernier engine hypergolic igniters were installed. The first and second stage safe-and-arm mechanisms were installed and connected. Following these ordnance installations, an RF system test was performed by radiating C-band radars toward the vehicle to obtain beacon read-outs.

The first stage liquid oxygen (LOX) supply system was checked for leaks. The launch pad area was cleared of unnecessary personnel, and the first stage LOX tanks were filled. The second stage helium console was set up to supply the necessary helium to pressurize the second stage helium sphere.

All service areas of the launch tower were secured and cleared, and the tower was moved back to the tiedown area and secured. The complex area was cleared of all non-essential personnel and equipment, the blockhouse was sealed, all systems were armed and final checks were made to verify vehicle launch readiness.

SECTION 4
LAUNCH AND EARLY ORBIT OPERATIONS

4.1 LIFT-OFF AND FIRST ORBIT

OSO-B2 became OSO-2 at 1136 hours (EST) on 3 February 1965 when it lifted off launch complex 17 B at Cape Kennedy atop Thor-Delta 29. Figure 4-1 illustrates the Thor-Delta/OSO-2 lift-off. Figure 1-4 shows the general launch sequence of events for OSO launches. Telemetry data indicated that the actual OSO-2 launch events very closely followed the planned events as depicted in Figure 1-4.

The STADAN stations at Santiago, Chile; Lima, Peru; Quito, Ecuador and Fort Myers, Florida were designated as the primary stations and commanded playback of the spacecraft tape recorder. During the initial period of operation, the STADAN stations at Blossom Point, Maryland; Johannesburg, South Africa; Mojave, California and Woomera, Australia were designated as the secondary stations and were asked to acquire real-time data whenever possible.

During the launch and early orbit operations, various methods and agencies were employed to track the launch vehicle and the spacecraft. The Eastern Test Range (ETR) stations at Cape Kennedy, Patrick AFB, Grand Bahama Islands, San Salvador, and Antigua radar-tracked the launch vehicle's C-band beacon through the second stage burn-out. The ETR station at Ascension Island was used to track the C-band beacon during the launch and first orbit. The Smithsonian Astrophysical Observatory used Baker-Nunn cameras to optically track the spacecraft during the first 24 hours after launch. The North American Air Defense Command's (NORAD) Space Detection and Tracking System also tracked the spacecraft for the first 24 hours after launch. The Goddard Space Flight Center's Launch Operations Branch (LOB) at Cape Kennedy employed doppler techniques to track the launch vehicle and the spacecraft until the signal was lost.

The tracking data acquired indicated the following orbital elements: (1) apogee - 632.93 kilometers (393.3 statute miles), (2) perigee - 550.57 kilometers (342.1 statute miles), (3) period of orbit - 96.5 minutes and (4) equatorial inclination angle was 32.9 degrees.

During the first pass over the STADAN station at Johannesburg, South Africa, telemetry and housekeeping data were recorded on Sanborn charts. Digital counts of predetermined housekeeping channels were transmitted to the STADAN Control Center to help determine that all the spacecraft functions were correct. No commands were issued during the Johannesburg pass.

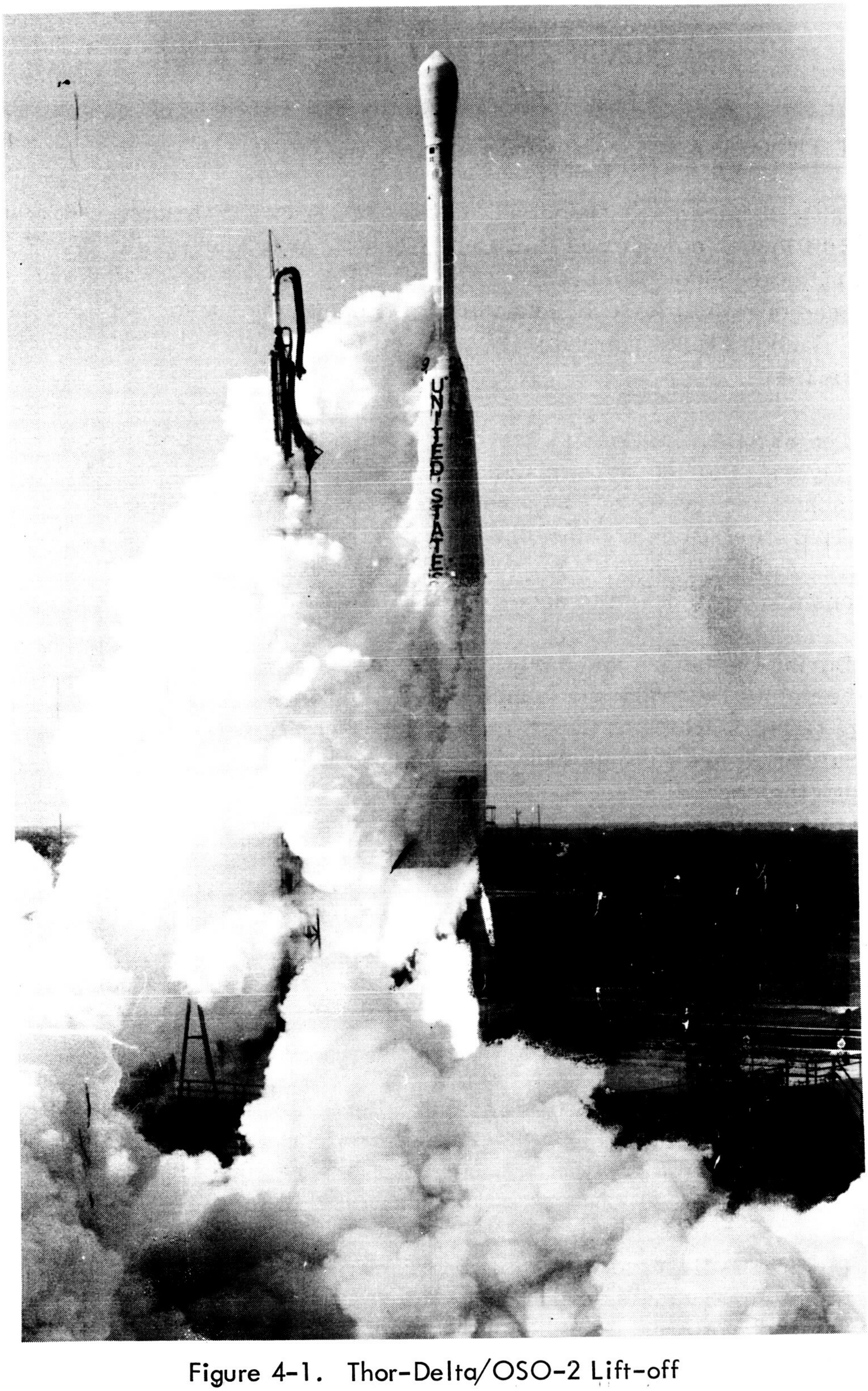


Figure 4-1. Thor-Delta/OSO-2 Lift-off

On the first pass over Mojave, California, telemetry and read-out housekeeping data were again recorded on Sanborn charts. Digital counts of certain predetermined housekeeping channels were again transmitted from Mojave to the STADAN Control Center. No commands were issued on this pass over the station.

When the OSO-2 was acquired on the first pass over the Fort Myers station, the tape recorder PLAYBACK ON command was transmitted, and the data that was accumulated by the observatory on the first orbit was recorded by Fort Myers. Approximately one minute after the playback cycle was completed, Fort Myers commanded the Ames Emissivity experiment to be turned on. No other commands were transmitted on this pass.

4.2 EXPERIMENT TURN-ON

Experiment turn-on was accomplished according to a predetermined schedule due to the outgassing requirements of the various experiments. The Ames Emissivity experiment was turned on after the tape recorder playback cycle of the first orbit. The University of New Mexico experiment was turned on by Fort Myers after playback in orbit eleven. The Goddard Space Flight Center Gamma-Ray experiment was turned on during orbit twelve. Naval Research Laboratory pointed experiments were commanded on during orbit thirteen.

The Harvard College Observatory pointed experiment was commanded on during orbit fourteen and after approximately one and one-half minutes of operation, it had to be commanded off due to internal problems in the experiment. During orbit 176, the Harvard experiment was again commanded on and after approximately two minutes of operation, it was commanded off. It appeared at that time that the experiment was not functioning properly, and later attempts at experiment turn-on confirmed this. The University of Minnesota Zodiacal Light Experiment was commanded on during orbit fifteen.

The Goddard Space Flight Center Ultraviolet experiment was commanded "ON" and, after six seconds, it was commanded "OFF" as planned during orbit 58. It was again commanded "ON" during orbit 59 and, after approximately twenty seconds of operation, it was commanded "OFF" as planned. During orbit 72, it was commanded "ON" and remained on until orbit 75 when it was commanded "OFF" due to possible problems with the experiment. During orbit 101, the GSFC Ultraviolet experiment was commanded "ON" and data indicated that the experiment was functioning properly.

SECTION 5
NORMAL OPERATION

5.1 SPACECRAFT

The spacecraft systems performed exceptionally well during the nine months and three days of the useful life of OSO-2. The original design objective of the OSO spacecraft was for a six months life. During the first few weeks there were indications that the life would be reduced to about half the design objective due to excessive pitch corrections and excessive usage of the pitch gas supply. However, by March 1965, a change in the pitch rate and the resulting changes in the pitch corrections indicated that this was no longer a problem. Based on an estimated pitch rate of 100 orbits per correction and an estimated 40 psi of gas per correction, it was determined that the pitch control would last through slightly more than 4000 orbits. It appeared that the observatory would be operational until about October or November 1965. As it turned out, this estimate was correct because the observatory was placed into a stowed condition on 6 November 1965.

5.1.1 ATTITUDE CONTROL SYSTEM

5.1.1.1 Pitch Control

The prime factors which determined the useful life of OSO-2 were the quantity of pitch gas on board the spacecraft and the consumption rate of the gas. There was 2100 psi of nitrogen gas loaded on board the spacecraft prior to launch on 3 February 1965. During the first few weeks of operation, pitch corrections were being made at the rate of approximately one correction every thirty orbits. This indicated that the useful life of OSO-2 would be a little more than three months. In March 1965, telemetry data showed that the interval had increased to approximately one correction every 100 orbits.

Figure 5-1 shows a plot of the pitch drift from 3 February through 30 September 1965. An automatic pitch correction is made by the pitch control system whenever the solar array has drifted three degrees from normal to the solar direction (solar vector). Pitch gas is expelled from nozzles on the sail structure to precess the spacecraft to one degree past normal in the opposite direction. The pitch drift plot of Figure 5-1 is made by plotting the pitch angle but subtracting the pitch corrections. The result is a smooth curve instead of the actual sawtooth wave of four degrees amplitude. It is interesting to note that the pitch drift curve was apparently made up of a downward sloping curve (average drift curve) plus a sinusoidal component of a period equal to approximately 48

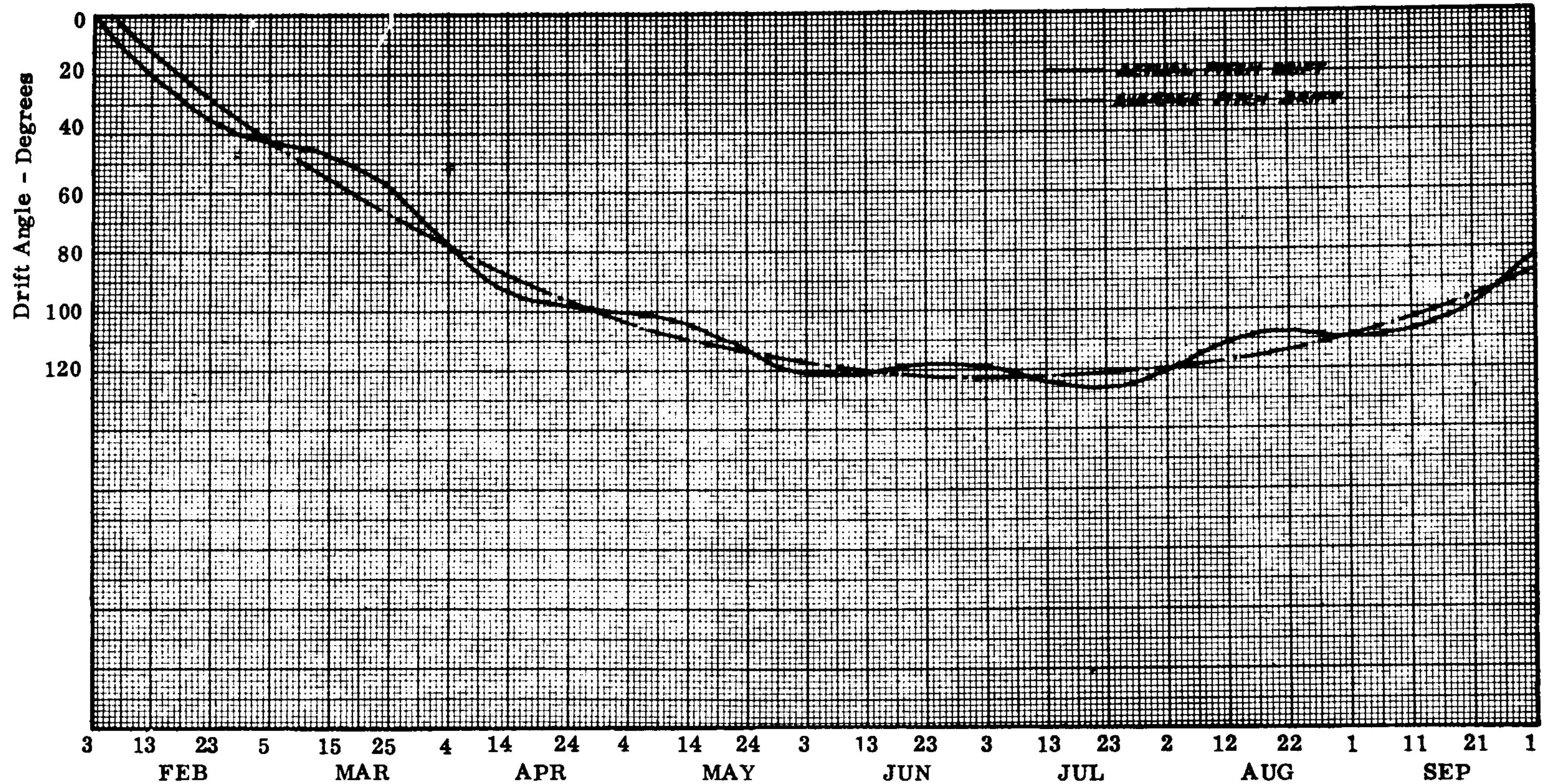


Figure 5-1. OSO-2 Pitch Angle Drift

days. This 48 day period was caused by the westerly precession of the spacecraft's orbital plane in reference to the solar direction. The orbital plane of any earth satellite will precess about the earth because of the perturbation of the earth. Since the earth is an oblate spheroid rather than a perfect sphere, a satellite approaching the equator from west to east is pulled from its orbital plane by the equatorial bulge. The result is that the satellite crosses the equator at a point west of where it would have crossed if the earth were a sphere.

The amplitude of the sinusoidal component was caused by the spacecraft changing its attitude in the earth's magnetic field due to the precession of the orbital plane. All electrical equipment set up an electromagnetic field around themselves, and the vector sum of these electromagnetic fields produces another electromagnetic field around the spacecraft. As the spacecraft's electromagnetic field alters its relationship to the earth's magnetic field due to orbital plane precession, the spacecraft field tries to align itself to the earth's field like a compass. This causes magnetic torques about the roll axis to precess the spacecraft in pitch which must be corrected by the pitch control system. Careful magnetic balance of the spacecraft prior to launch greatly reduces this effect by aligning the electromagnetic field of the spacecraft in a particular direction by using compensating permanent magnets.

The two main factors contributing to the downward slope of the average pitch drift curve of Figure 5-1 were the spacecraft's roll attitude referenced to the ecliptic plane and the earth's seasonal position about the sun. If the spacecraft were oriented with the spin axis located in, or parallel to, the ecliptic plane, this would require a pitch correction of approximately one degree per day because the earth travels almost one degree per day in its orbit around the sun. If the spin axis were oriented perpendicular to the ecliptic plane, no pitch correction would be required because, in this case, the solar array must rotate about the spin axis to be maintained normal to the solar vector. The spacecraft rolled about its roll axis at a nominal rate of one degree per terrestrial day because of the precession of the observatory orbital plane and the earth's orbit. It can be seen that the average pitch drift curve of Figure 5-1 had zero slope at approximately 1 July 1965. It was at this time during the OSO-2 useful life that the spin axis of the spacecraft was normal to the ecliptic plane. After 1 July, the spin axis of the spacecraft began to precess in the opposite direction, and the average pitch drift curve began its upward swing. As can be seen from the average pitch drift curve of Figure 5-1, the observatory drifted a maximum of 120 degrees in one direction and then drifted back approximately 90 more degrees for a total drift of 210 degrees. The spacecraft consumed approximately 10 psi of pitch gas for each degree of drift correction for a total of 2100 psi.

5.1.1.2 Spin Control

The OSO-2 spacecraft spin control system was designed to maintain the spacecraft's spin rate at 30 rpm. No automatic spin-up was provided on OSO-2; however, as shown in Figure 5-2, the spacecraft spin rate did change during the nine months that OSO-2 was in operation. The curve in Figure 5-2 was constructed in a similar manner as the pitch drift curve in Figure 5-1. Figure 5-2 is a plot of the spin decay rate minus the spin-up corrections made by the spin control system. It is interesting to observe that the rate of spin decay in Figure 5-2 very closely follows the pitch drift curve of Figure 5-1. Whenever the rate of pitch drift decreased, the rate of spin decay also decreased. The curve of Figure 5-2 also varies at the same cyclic rate of once every 48 days. In fact, if the two curves of Figures 5-1 and 5-2 were superimposed upon one another, they would show that they were almost a tracing of each other. These facts lead one to believe that the same factors causing the pitch angle drift of the spacecraft also caused the variation in the spin rate over the nine month period. It has been assumed that electrical apparatus and permanent magnets in the OSO-2 experiments produced a magnetic dipole effect in the plane of the spacecraft's wheel. As the spacecraft varied its attitude in the earth's magnetic field due to the precession of the orbital plane, the position of the spacecraft spin axis relative to the ecliptic plane and the earth's seasonal position about the sun; the magnetic dipole aided the spin of the wheel for 24 days and opposed it for the next 24 days.

Figure 5-3 is a plot of the spin rate for the period of 3 February 1965 through 30 September 1965. The reason for the varying pattern of the plot rather than a smooth sawtooth as spin-up corrections were made is because the spin rate readout was taken at varying times during each day. The large negative spike at approximately 24 September 1965 was due to a deliberate spin down command transmitted during the terminal operation. The terminal operation will be discussed in more detail in Section 6. It can be seen by Figure 5-3 that the spin rate of OSO-2 averaged 31 rpm during the nine months of its normal operation. This is within the design tolerance of $30 \pm 5\%$ rpm for the automatic spin control system. The seemingly large variation in spin rate from June 1965 on is due to the spacecraft spin axis passing through normal to the ecliptic plane at this time and continuing on in the same direction past normal.

5.1.1.3 Pointing Control

During the operational life of OSO-2, the pointing control system performed its function of maintaining the azimuth and elevation of the pointed instruments within plus or minus one arc-minute of the center of the solar disc in a very excellent manner. Figure 5-4 shows a plot of the azimuth and elevation read-out

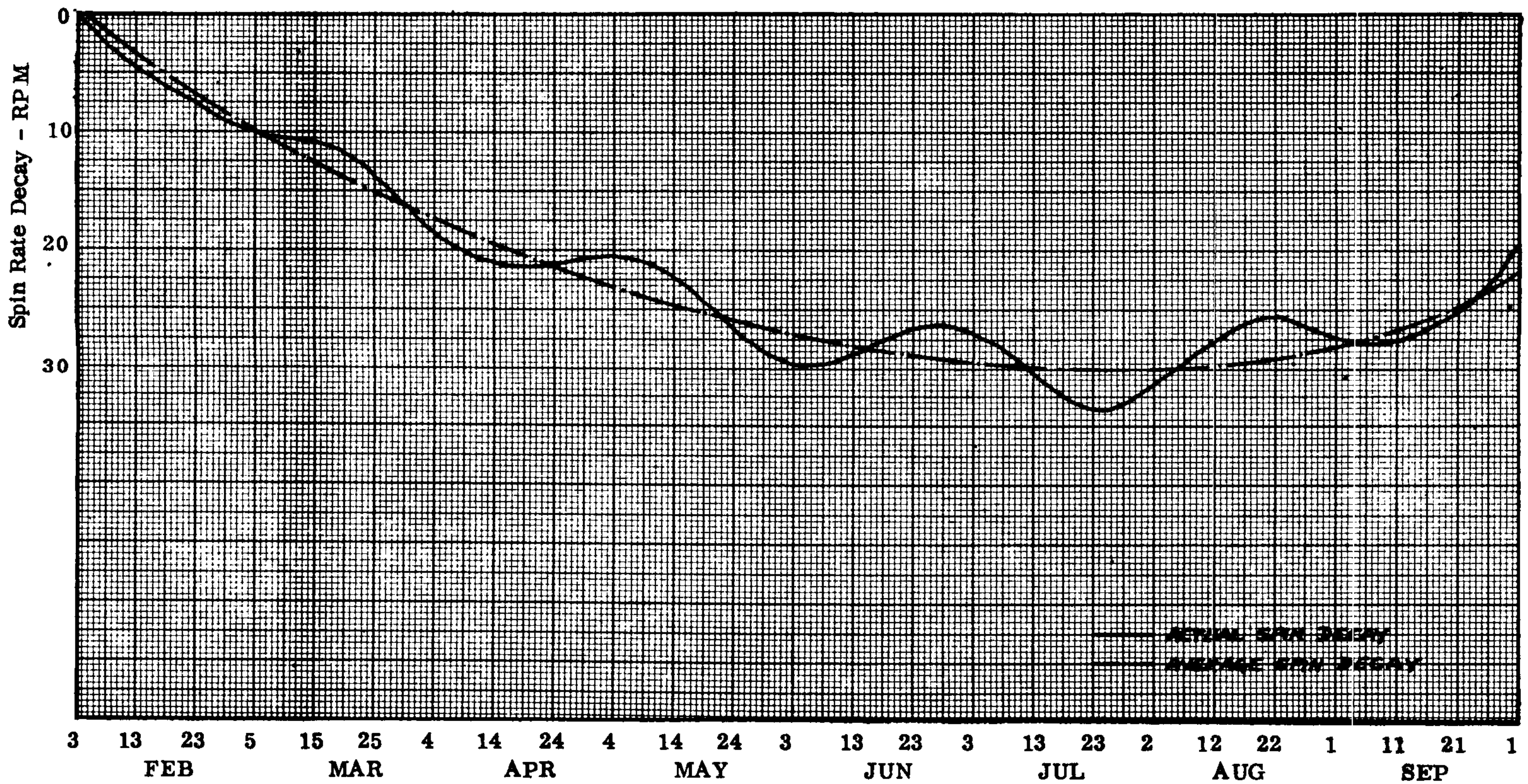


Figure 5-2. OSO-2 Spin Rate Decay

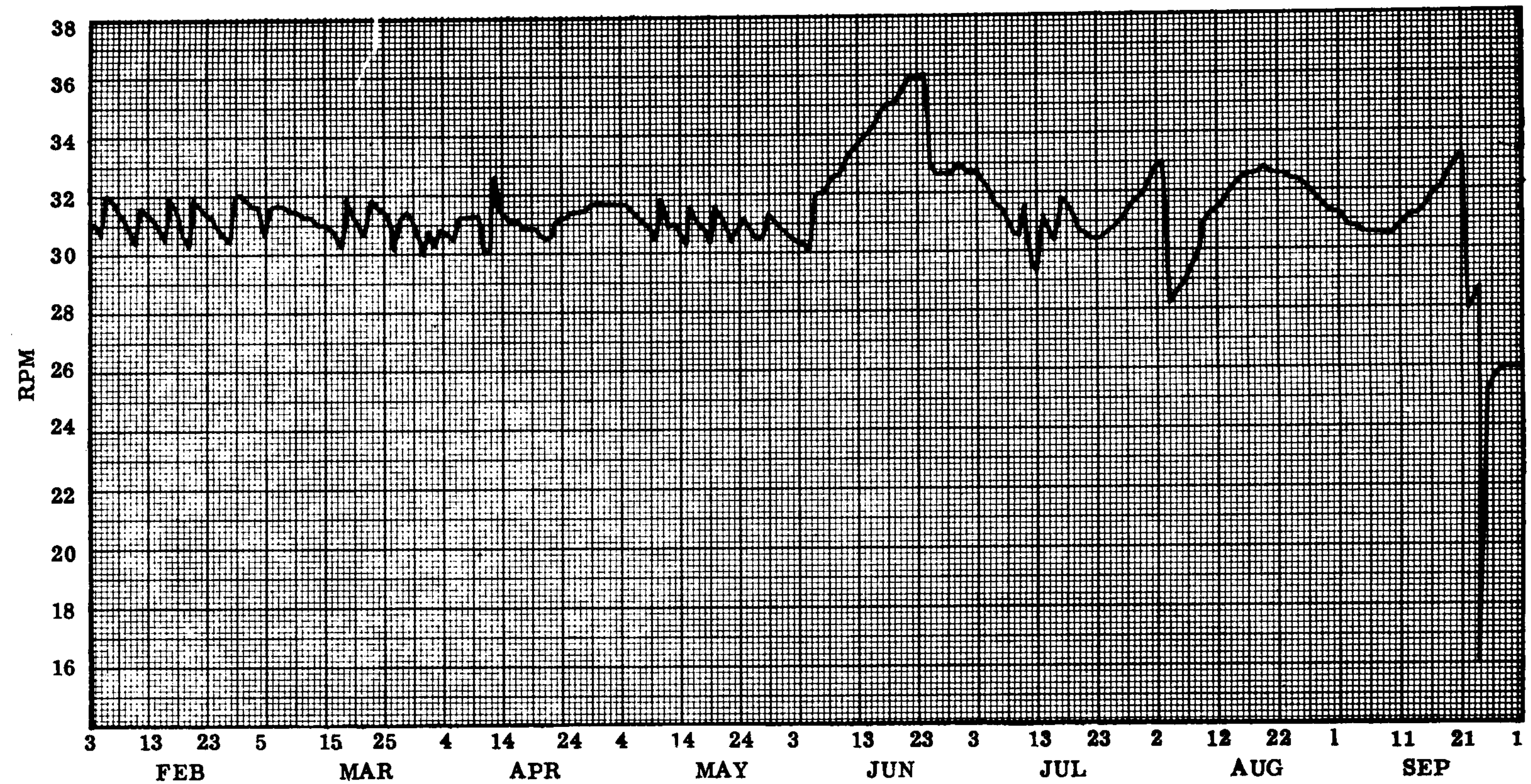


Figure 5-3. OSO-2 Spin Rate

for the period from 3 February 1965 through 30 September 1965. It can be seen from this figure that the long term pointing accuracy was well within one minute of arc in both azimuth and elevation. The pointing of the solar oriented experiments was slightly down and to the right of the center of the solar disc according to the plot of the position read-out in Figure 5-4. One must remember, however, that the OSO-2 read-out eye block was mounted on the Naval Research Laboratory pointed experiment, and the fine control eye block was mounted on the Harvard pointed experiment. This slight offset can easily be explained by a possible slight misalignment of the eye blocks to the pointed experiments, a slight misalignment of the pointed experiments in respect to one another, a slight difference in the overall characteristic curves of the eye blocks or a combination of any or all of these conditions.

Figure 5-4 shows a marked change in the pointing control of the OSO-2 spacecraft after approximately eleven days in orbit. A possible explanation for this is that during this period, the experiments were being turned on during various orbits, and the spacecraft had not yet reached a stable temperature. After eleven days, when all the experiments were turned on and operating, the temperature stabilized in the spacecraft, and the pointing control system settled down to a steady state.

OSO-2 raster mode operation was not as successful as was hoped. During orbit 189, the raster mode was commanded "ON" for nine orbits, but when the Naval Research Laboratory experiment was operated in the raster mode, telemetry sub-commutator synchronization slips were excessive. Raster mode operation was again commanded "ON" for three orbits in orbit 422 and again for two orbits in orbit 495 with the same results. As a result of the raster operation, it was determined that the spacecraft raster pattern was oriented with the center of the solar disc as planned. The Naval Research Laboratory experiment seemed to be pointing slightly off center (3 minutes in azimuth and 4 minutes in elevation), but it was close enough to get complete coverage of the solar disc. Interference with other experiments, the resulting loss of data, and the relatively poor quality of the data obtained during raster mode operation by the Naval Research Laboratory experiment made it undesirable to continue raster operation at that time.

Raster mode operations were again conducted for three orbits on 13 April 1965. On 15 April 1965, the raster command was again transmitted, but because of excessive sub-commutator synchronization slips and the apparent inability to obtain a complete raster picture, the point mode was commanded after two orbits. No full raster pictures were obtained during the first orbit. During the second orbit, two periods of slightly over four minutes of good data permitted two complete raster pictures to be printed.

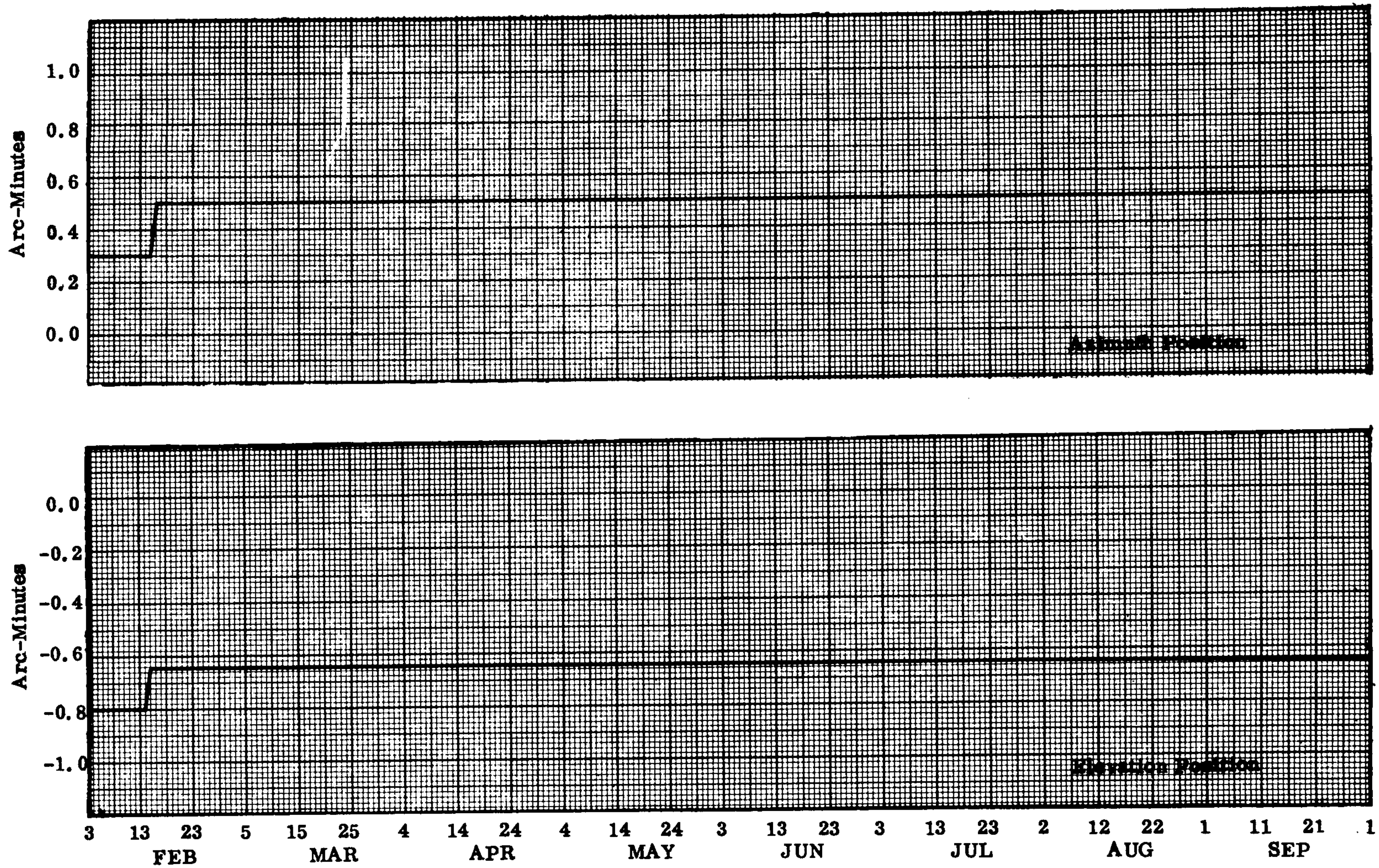


Figure 5-4. Pointing Control Readout

On 22 April 1965, the raster mode was again commanded "ON" from Quito, Ecuador which provided about 40 minutes of raster prior to the first pass over Fort Myers. Five orbits of raster mode operation were completed, and the spacecraft was commanded back into the point mode. Sub-commutator slips again occurred during these orbits, but there were few enough to obtain some raster data. As a result of the apparent "good" performance in the raster mode on 22 April 1965, it was decided to command the raster mode again the following day from Quito, Ecuador. At about this time, Dr. R. Tousey, of the Naval Research Laboratory, informed the OSO Project Office that his experiment was producing all ones which indicated full saturation. He requested that if all ones were detected in his data on the first pass over Fort Myers, that the observatory be commanded back into the point mode. Real time quick-look data from Fort Myers showed full saturation in Dr. Tousey's data, and the point mode command was transmitted.

The raster mode was again commanded "ON" for two orbits of operation on 19 May 1965. Dr. Tousey's experiment again indicated full saturation, and the observatory was returned to the point mode. It was decided at this time to repeat this two orbit raster operation each week to obtain data on the raster operation; however, the results remained the same.

5.1.2 TELEMETRY SYSTEM

The performance of the telemetry system during the operational life of OSO-2 was excellent. Real time and playback data were acquired regularly by the STADAN stations on each pass. The performance was so remarkable, in fact, that it was not necessary to switch to any of the secondary sub-systems during the normal operational phase of OSO-2. However, on 5 June 1965, an inadvertent switch from transmitter number 1 to transmitter number 2 did occur over Fort Myers during orbit 1818. On this pass, the observatory was acquired by Fort Myers and transmitted initial real time data on transmitter number 1. The spacecraft was then commanded into playback, and it transmitted the playback data on transmitter number 1. Within seconds after completing playback, and for reasons still unknown at this time, a switch was made to transmitter number 2. There was no apparent degradation in operation resulting from the switch, so transmitter number 2 was allowed to remain in operation. The data tapes from Fort Myers and Blossom Point were analyzed to determine the cause of the transmitter switch, but no definite conclusion could be reached.

One or two slips of the sub-commutator synchronization were expected during each orbit; however, it was noted that these sub-commutator slips were excessive whenever the Goddard Space Flight Center Ultraviolet experiment was operating, and whenever the Naval Research Laboratory experiment was operated in the spacecraft raster mode. It was believed that transient spikes in the line, generated by these experiments, were the cause of the sub-commutator slips. Very little data was lost as a result of the sub-commutator slips. It has been estimated that approximately 99 percent of the data during the sub-commutator slips were recoverable — 90 to 95 percent by computer and the rest by hand processing.

5.1.3 COMMAND SYSTEM

The OSO-2 command system performed very well during the operational life of the spacecraft. During the nine months and three days of observatory operation, there were 3970 "Playback ON" passes scheduled. Of these scheduled passes, 3930 orbits (99.04%) of complete playback data were recorded, and ten passes of partial playback data (approximately four minutes each) were recorded. There were 38 orbits of data lost due to the inability to command playback. Fifteen orbits of data were lost because playback could not be commanded due to ground station command equipment malfunction, 5 orbits of data were lost due to operator error, and 18 orbits of data were lost due to an unresponsive spacecraft.

There were several times during this period that commands were not executed on the first try and one or more commands had to be transmitted. Table 5-1 summarizes the successful "Playback ON" commands and the number of times the command had to be transmitted before it was executed. There were other spacecraft functional commands besides "Playback ON" which had to be repeated before they were executed; however, these unsuccessful commands were much fewer in number compared to the unsuccessful attempts at commanding recorder playback. There were many probable factors contributing to the large number of unsuccessful "Playback ON" commands. Possibly one of the greatest contributing factors was the increased number of playback commands in respect to the other spacecraft functional commands. Playback was commanded during each orbit, 14 times per day, for a total of 3970 playback commands. Some of the other functional commands were transmitted only once per day, if indeed that frequently. During the operational life of OSO-2, the spacecraft was continually changing its pitch, roll and spin attitude due to the orbital plane precession, the earth's magnetic field, and the earth's rotation about the sun. Because of the spacecraft's attitude in respect to the earth, there were probably many times when the first command did not get through because the antenna system was not in the proper orientation at the instant the command was transmitted. It is also possible that there were times when the spacecraft was at too shallow an elevation angle or at too great a distance when the first command was transmitted.

There were three still unexplained OSO-2 command anomalies experienced during the operational life of the spacecraft. The first of these occurred on 5

Table 5-1
Successful "Playback-ON" Attempts

Number of Attempts	Number of Orbits
First attempt	3685
Second attempt	138
Third attempt	68
Fourth attempt	24
Fifth attempt	12
Sixth attempt	5
Seventh attempt	1
Eighth attempt	3
Ninth attempt	1
Eleventh attempt	2
Twelfth attempt	1

June 1965 during orbit 1818. The Fort Myers STADAN station had commanded "Playback ON" using the standard command format of Address - Command - 1/2 second delay - Address - Command. When the Fort Myers data tape was analyzed, it indicated that the first "Playback ON" command caused the spacecraft to switch from transmitter number 1 to transmitter number 2, and the second playback command executed the tape recorder playback cycle.

The second of the command anomalies occurred on 24 June 1965 during orbit 2109. Fort Myers commanded "New Mexico Anticoincidence IN", "GSFC - UV Calibration IN" and "NRL - ON" during the real time period after the tape recorder playback cycle. Shortly after these commands were transmitted, the spacecraft housekeeping data indicated that the spacecraft had switched from the manual pitch control mode to the automatic pitch control mode. An automatic pitch correction occurred immediately because the pitch angle was past the limits of the automatic pitch control system. It was suspected that one of the "NRL - ON" commands caused the mode change because this was the only command during this pass which addressed the sail decoder. The "NRL - ON" command was transmitted twice using the standard command format. Prior to this pass, 15 "NRL - ON" commands were transmitted without any problems.

The third and final command anomaly occurred on 11 July 1965 during orbit 2358. Fort Myers commanded "New Mexico Anticoincidence IN" and "GSFC - UV Calibration IN" during the real time period following tape recorder playback. Shortly after these commands were transmitted, the spacecraft housekeeping data indicated that the Day/Night Relay bypass had been closed and the spacecraft had changed from the automatic spin control mode to the manual spin mode. A single command closes the Day/Night Relay bypass, activates manual spin control and disarms the spin back-up circuit. However, housekeeping data indicated that the spin back-up circuit remained armed. Upon further investigation, it was discovered that the spin rate had decreased from 31.38 rpm to 29.66 rpm. From this, it appeared that a manual de-spin command had also been executed during the transmission of the above mentioned commands. A manual de-spin command also arms the spin back-up circuit and closes the launch sequence timer back-up security relay. The launch sequence timer back-up security relay had to be commanded "OPEN".

5.1.4 ELECTRICAL POWER SYSTEM

The OSO-2 electrical power system performed very well during the nine months the spacecraft was in operation, and no problems were encountered. The spacecraft power system averaged approximately 20.5 volts for the entire period. Figure 5-5 shows a plot of the battery voltage and charge rate for the period of 3 February through 30 September 1965. It can be seen from the charge rate curve of Figure 5-5 that the charge rate of the spacecraft main batteries started at a maximum value and decreased to its minimum value at approximately 1 July 1965. From July through 6 November 1965, the time that the spacecraft was placed in a stowed condition, the charge rate increased. This pattern of charging was due to the increase in daylight hours and the corresponding decrease in the night-time hours as the summer months approached. With shorter periods of spacecraft night operation, there was less drain on the main batteries; therefore, there was a corresponding decrease in the battery charge rate. Figures 5-6 and 5-7 illustrate the battery charge rate and voltage for orbits 2435 and 3637, respectively. The dotted portions of these curves indicate the period that the spacecraft was in the earth's shadow.

5.1.5 THERMAL MONITORING SYSTEM

The thermal monitoring system consisted of numerous thermistor temperature sensors attached to various points on the observatory where it was desired

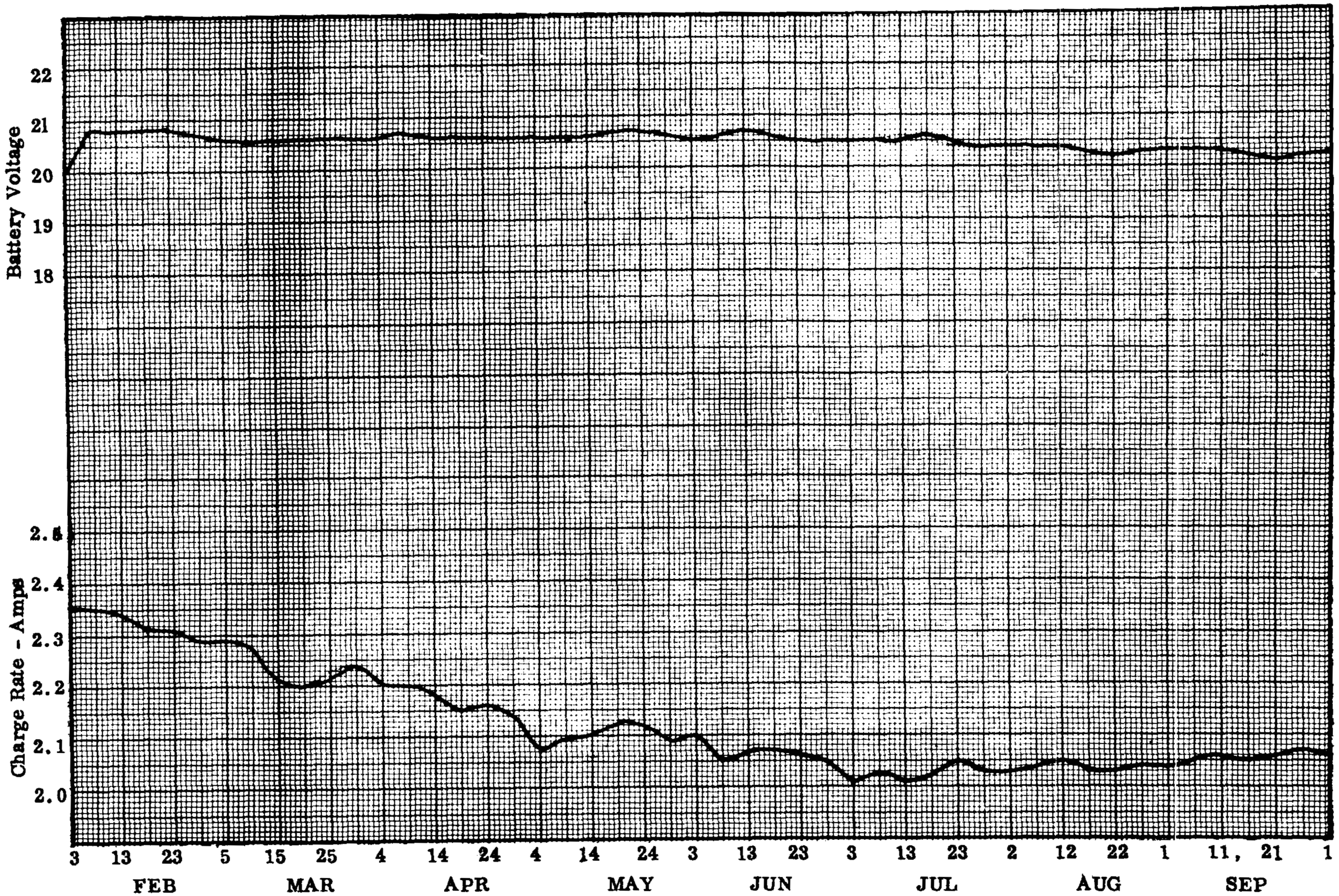


Figure 5-5. Long Term Battery Charge Rate and Voltage

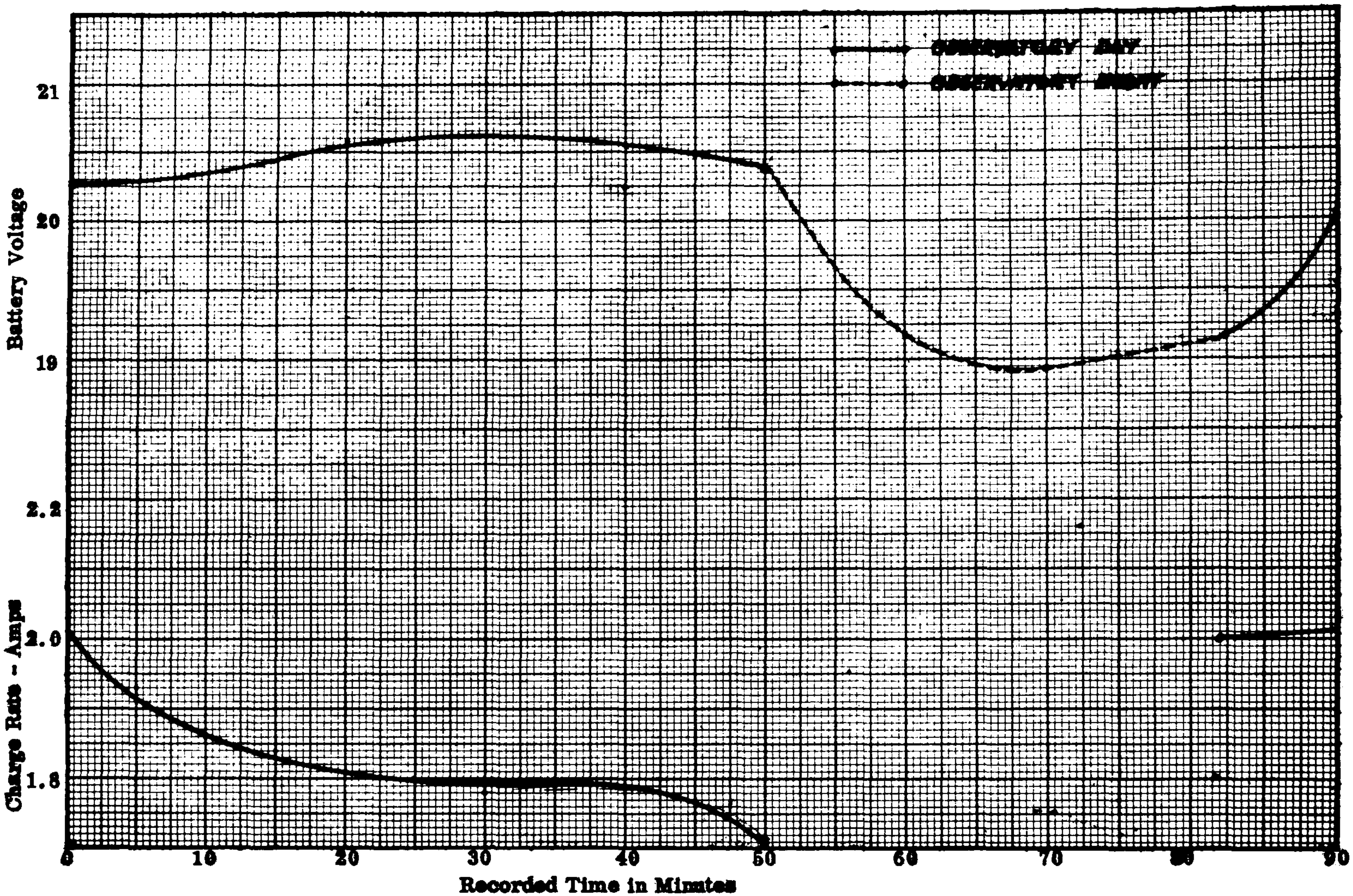


Figure 5-6. Battery Charge Rate and Voltage - Orbit 2435

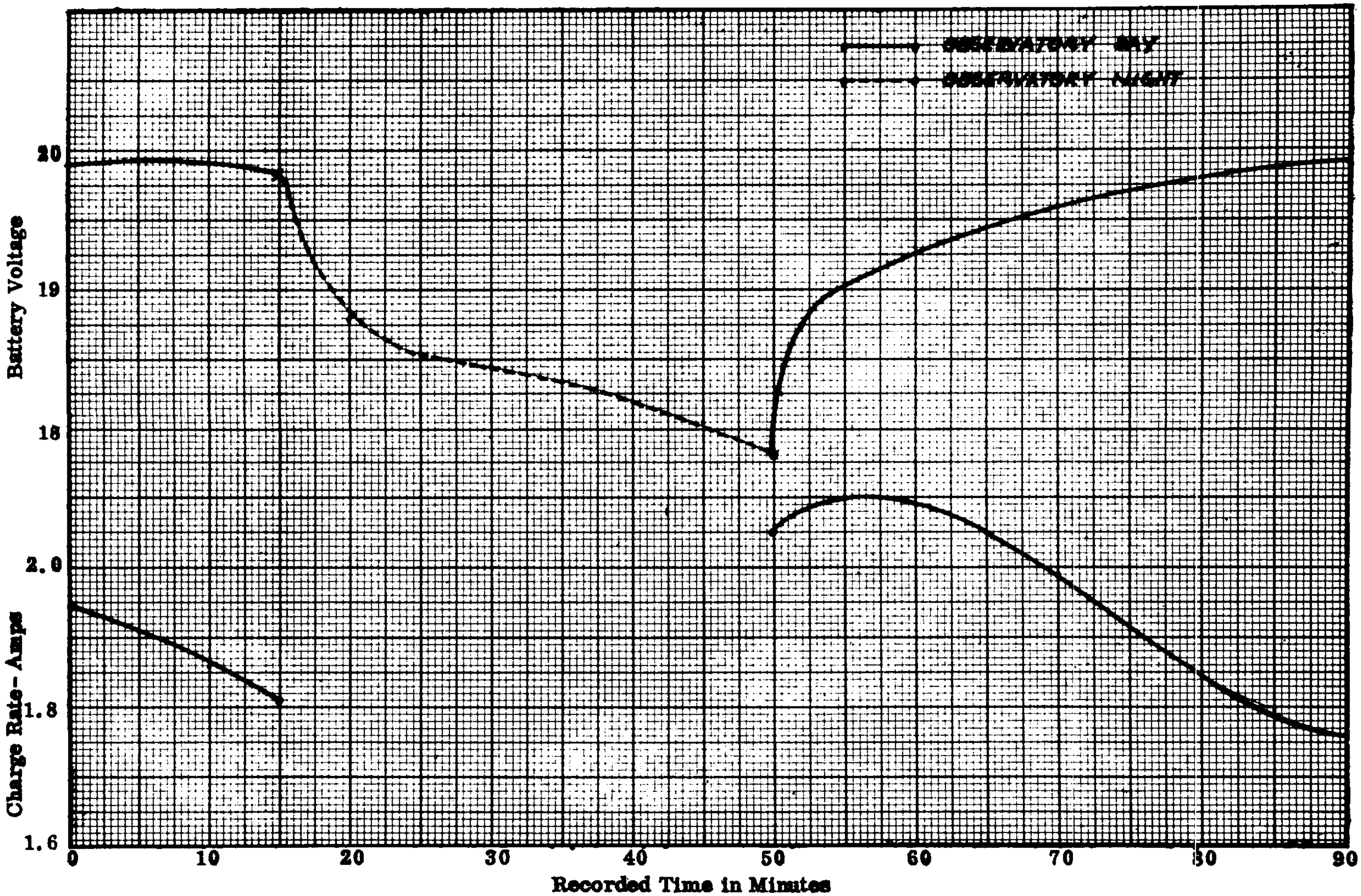


Figure 5-7. Battery Charge Rate and Voltage - Orbit 3637

to record the temperature. Electronic circuitry converted these temperatures into analog voltages, and these voltages were converted to digital form and transmitted back to ground stations by the telemetry system.

All the temperatures of the OSO-2 spacecraft were approximately as expected. The hub temperature averaged approximately +8 degrees centigrade, the arms averaged about -17 degrees centigrade, the batteries were approximately +7 degrees centigrade and the solar array varied from about +60 to -20 degrees centigrade.

Figure 5-8 is a plot of the hub temperature from 3 February through 30 September 1965. The lower curve of this figure is a plot of the minutes of sunlight per orbit. Comparing these two plots, it can be seen how drastically the hub temperature increased for increased periods of sunlight per orbit. It should also be noted that the increased periods of sunlight occurred at approximately the 48 day orbital plane precession period. These maximum periods of sunlight occurred whenever the orbital plane precessed such that the southernmost excursion of the orbital plane was in the solar direction. It can also be seen that the average hub temperature increased due to the days becoming longer as the summer months approached. Figure 5-9 is a plot of the rim skin temperature from 3 February through 30 September 1965. Figures 5-10, 5-11 and 5-12 illustrate typical temperature readings for selected orbits throughout the nine month period.

5.2 EXPERIMENTS

5.2.1 NAVAL RESEARCH LABORATORY ULTRAVIOLET TELESCOPE AND CORONAGRAPH

The Naval Research Laboratory experiment was commanded "ON" during orbit 13 on 4 February 1965. The observatory was operating in the point mode and all the Naval Research Laboratory instruments appeared to be performing normally and acquiring good data.

During orbit 189, the raster mode was commanded "ON". After nine orbits of operation in the raster mode, the point mode of operation was again commanded.

Figure 5-13 A shows the sun in 304 Å light on 4 March 1965. Figure 5-13 B shows the sun in 1216 Å light on 16 February 1965. Figure 5-13 B should be compared to Figure 5-14 which is a photo of the sun from the earth, also on 16 February 1965. Large sunspots can be seen in the lower left quadrant.

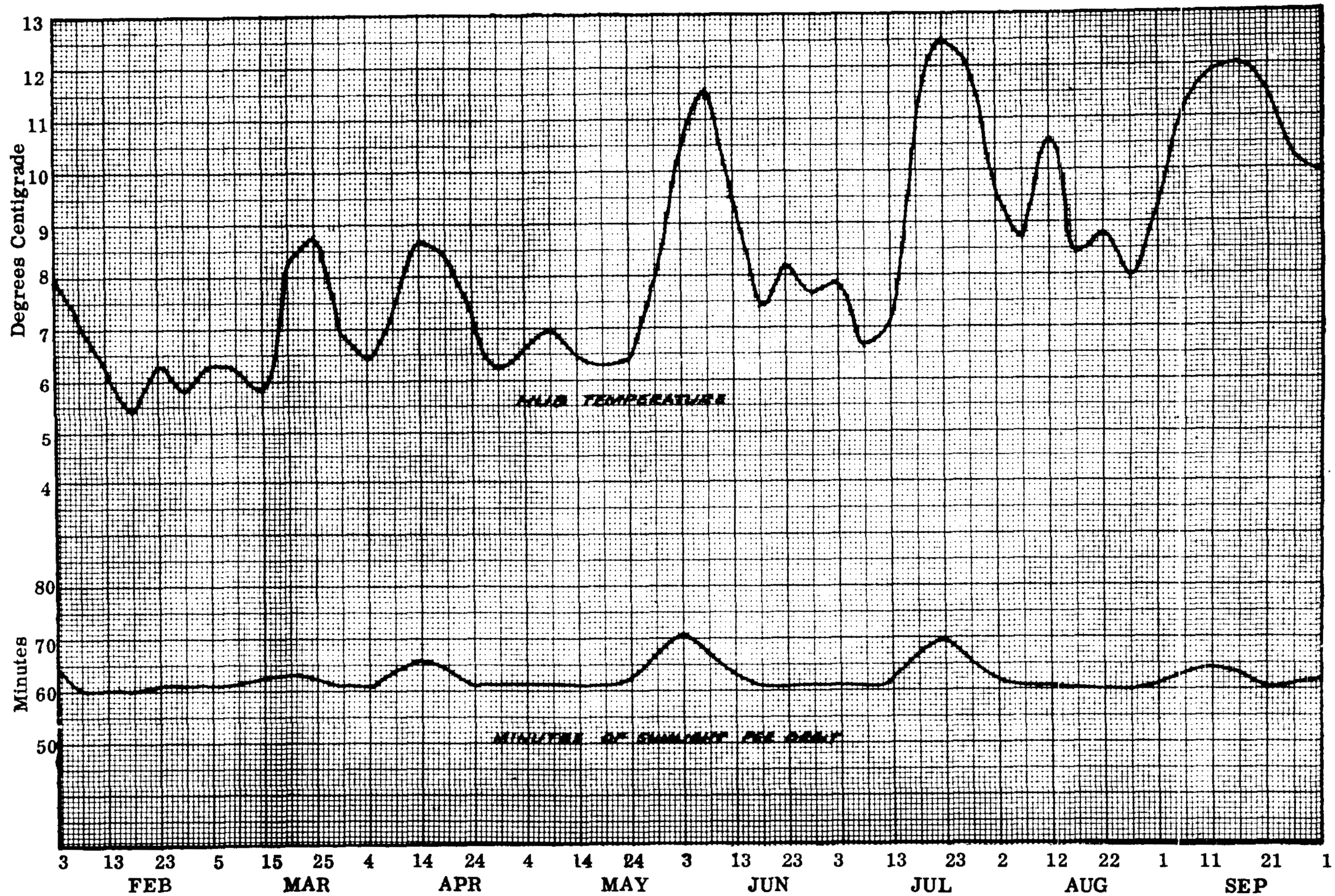


Figure 5-8. OSO-2 Hub Temperature

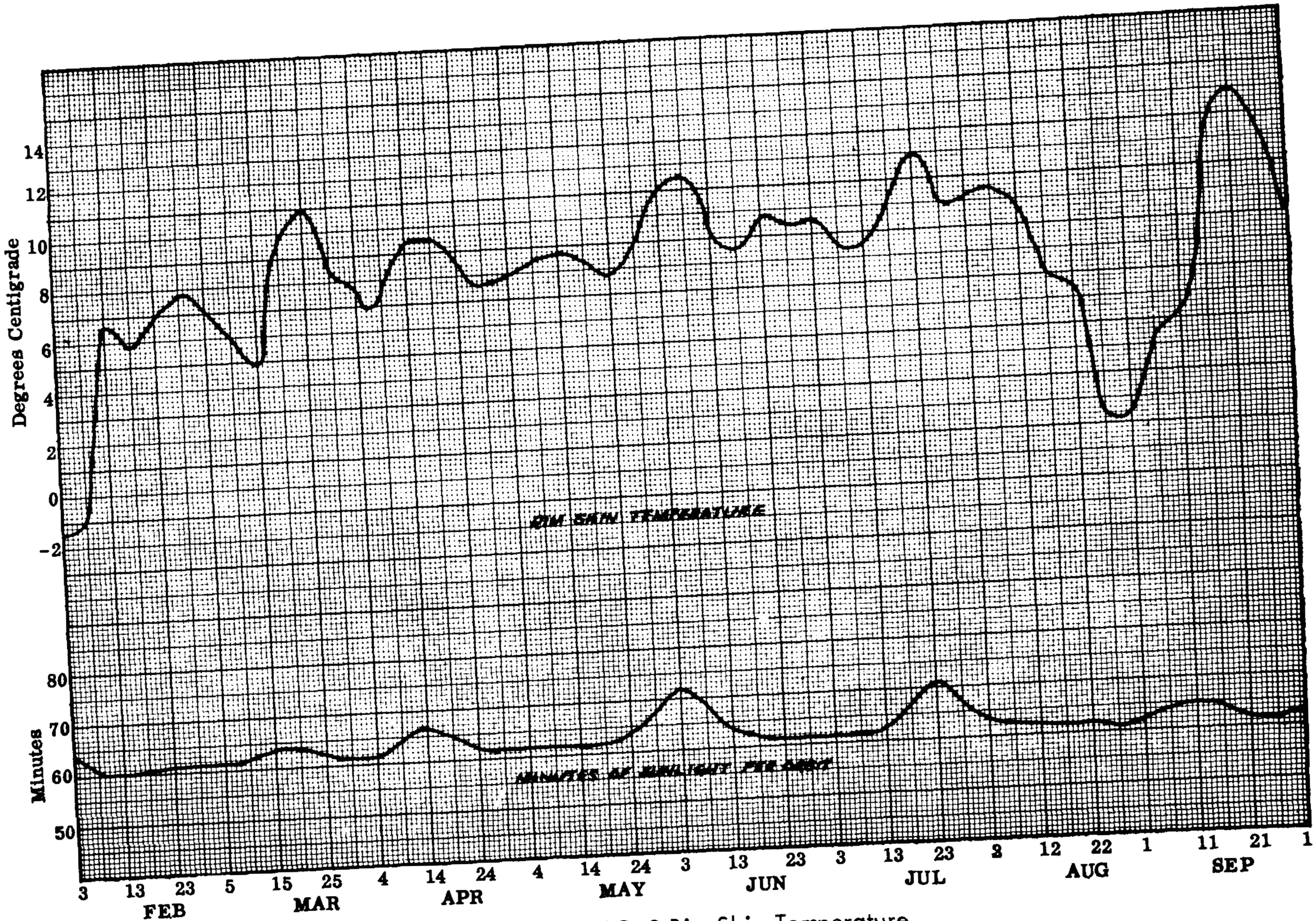


Figure 5-9. OSO-2 Rim Skin Temperature

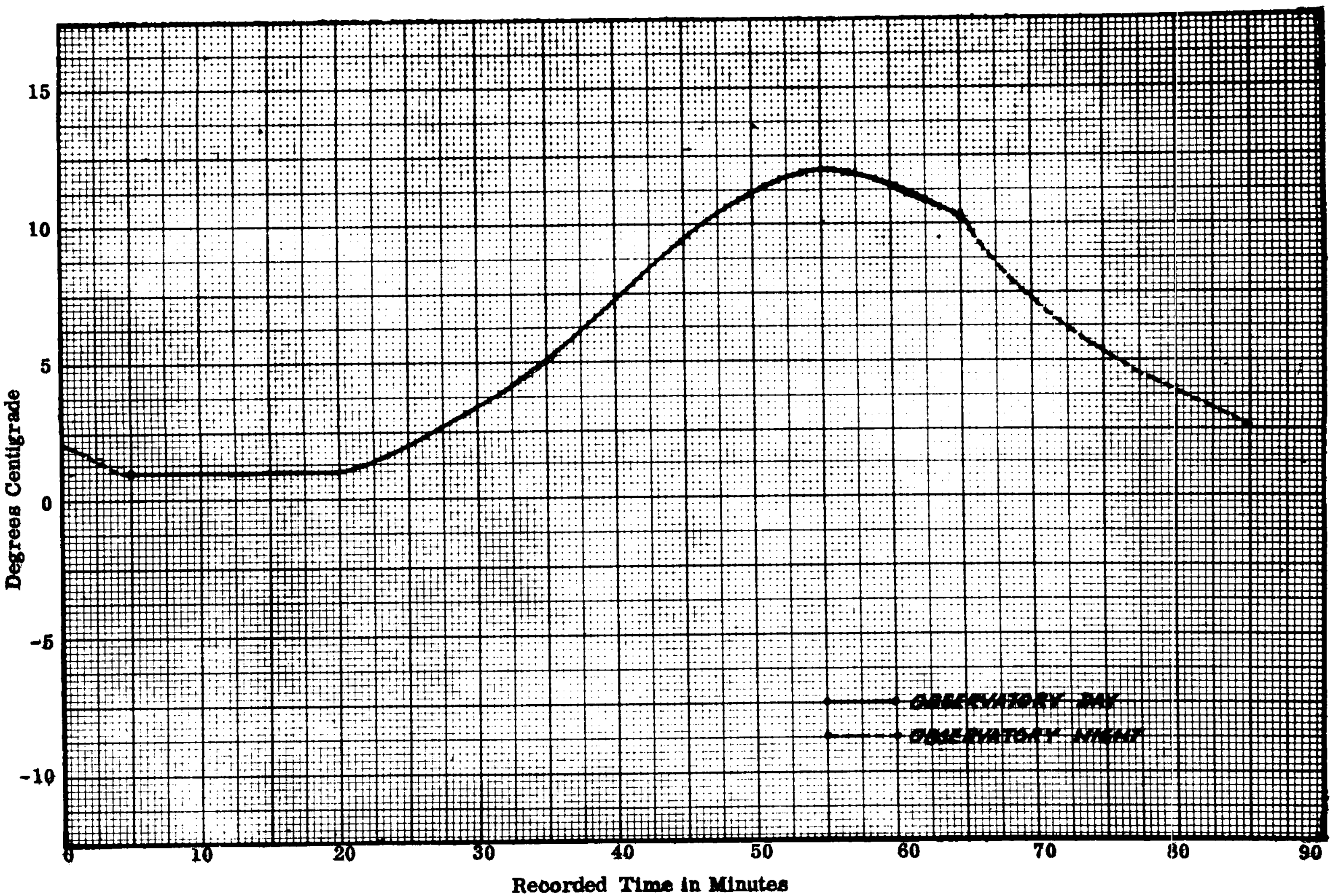


Figure 5-10. OSO-2 Bottom Skin Temperature - Orbit 56

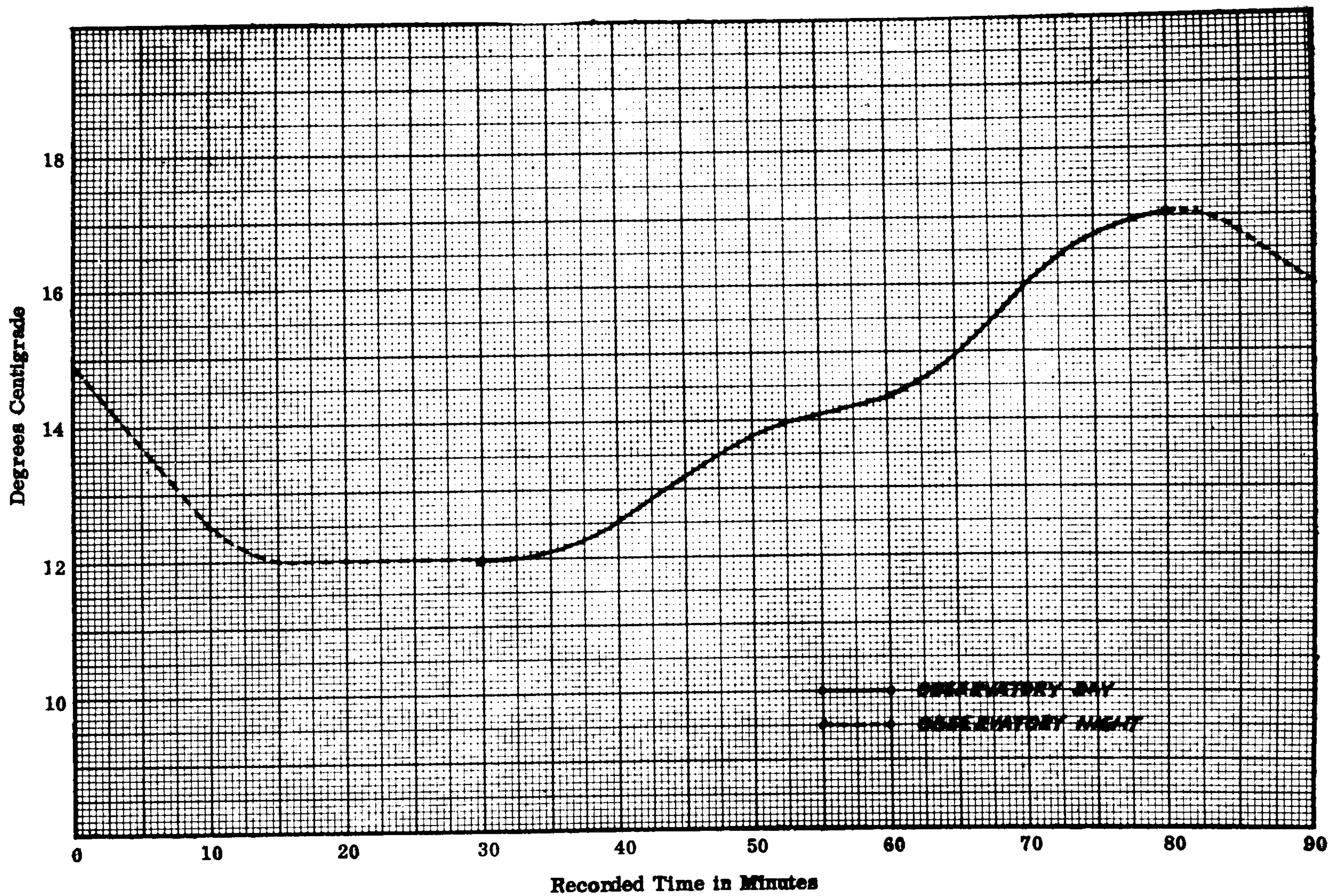


Figure 5-11. Azimuth Power Transistor Temperature - Orbit 2611

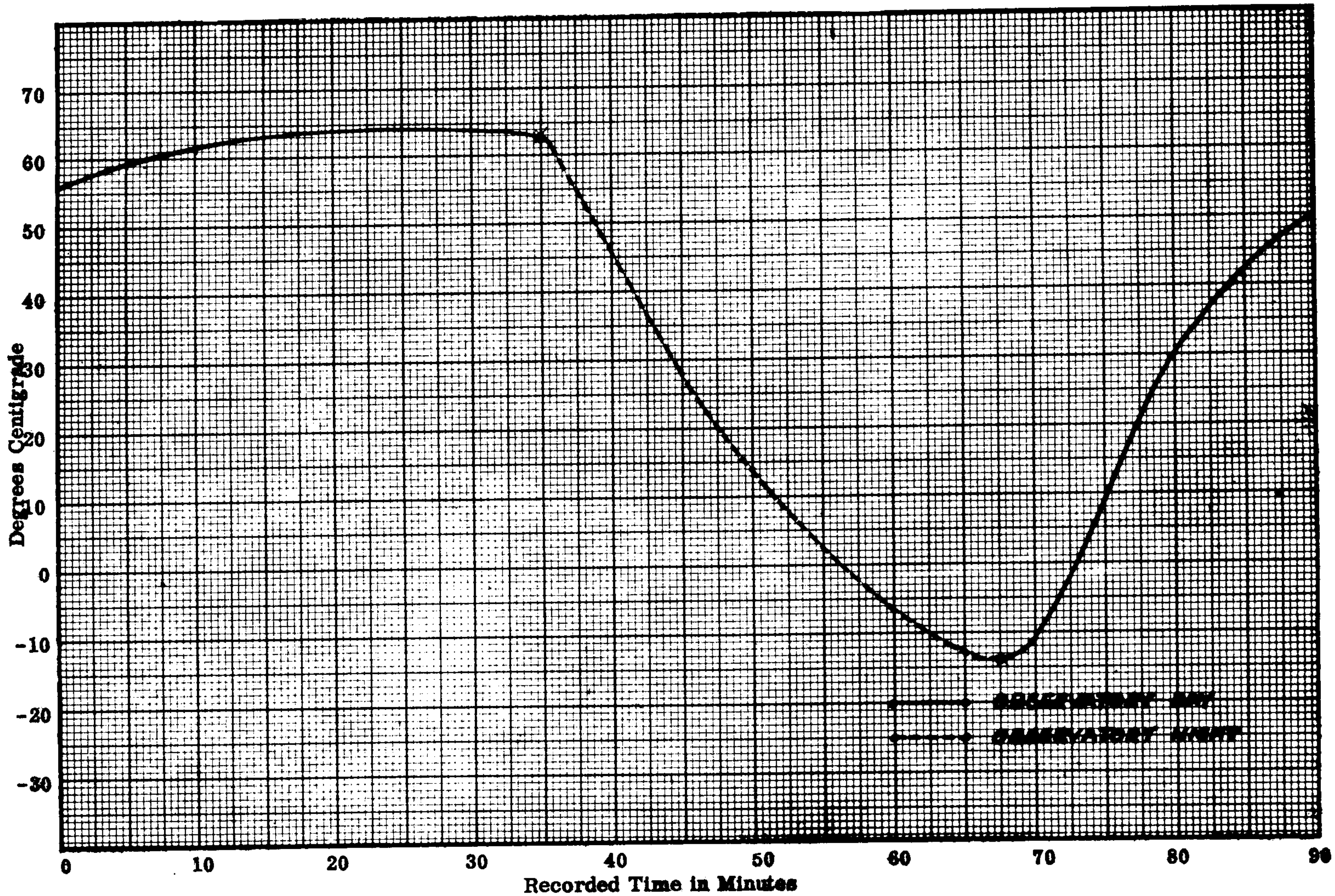


Figure 5-12. Solar Cell Panel Temperature - Orbit 3769

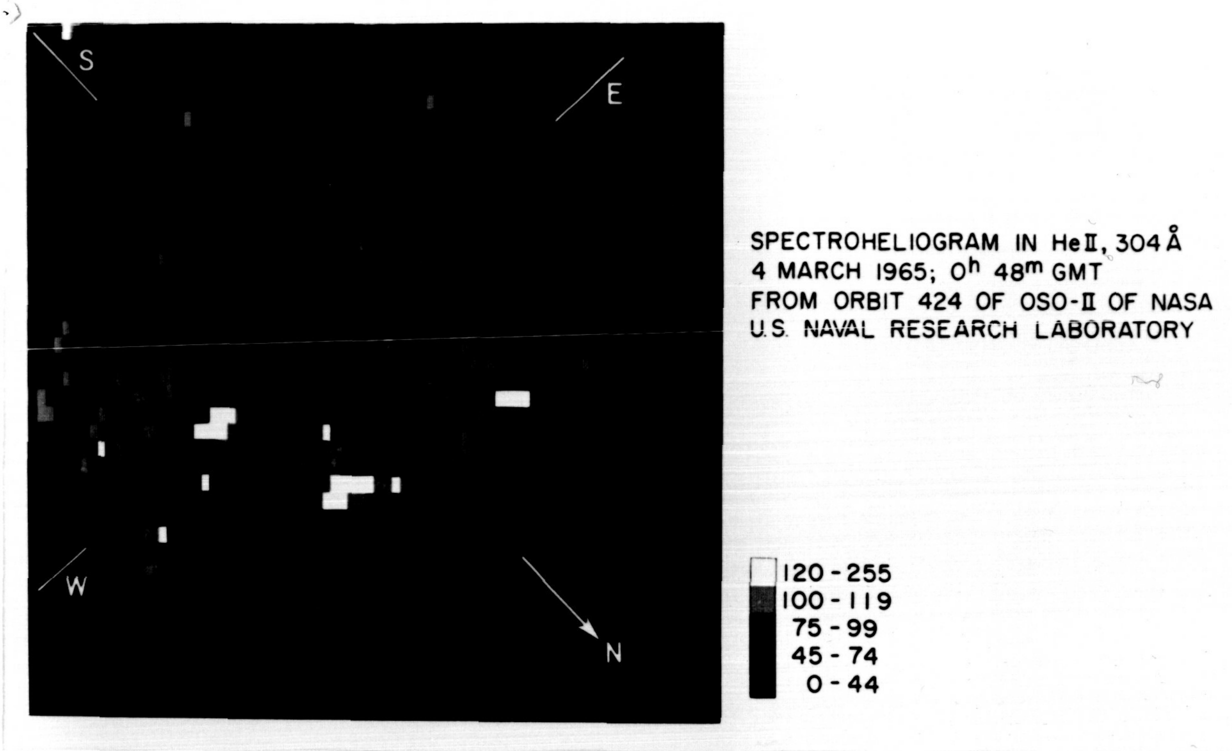


Figure 5-13 A. Solar Plot of OSO-2 Data—304 Å Light, 4 March 1965

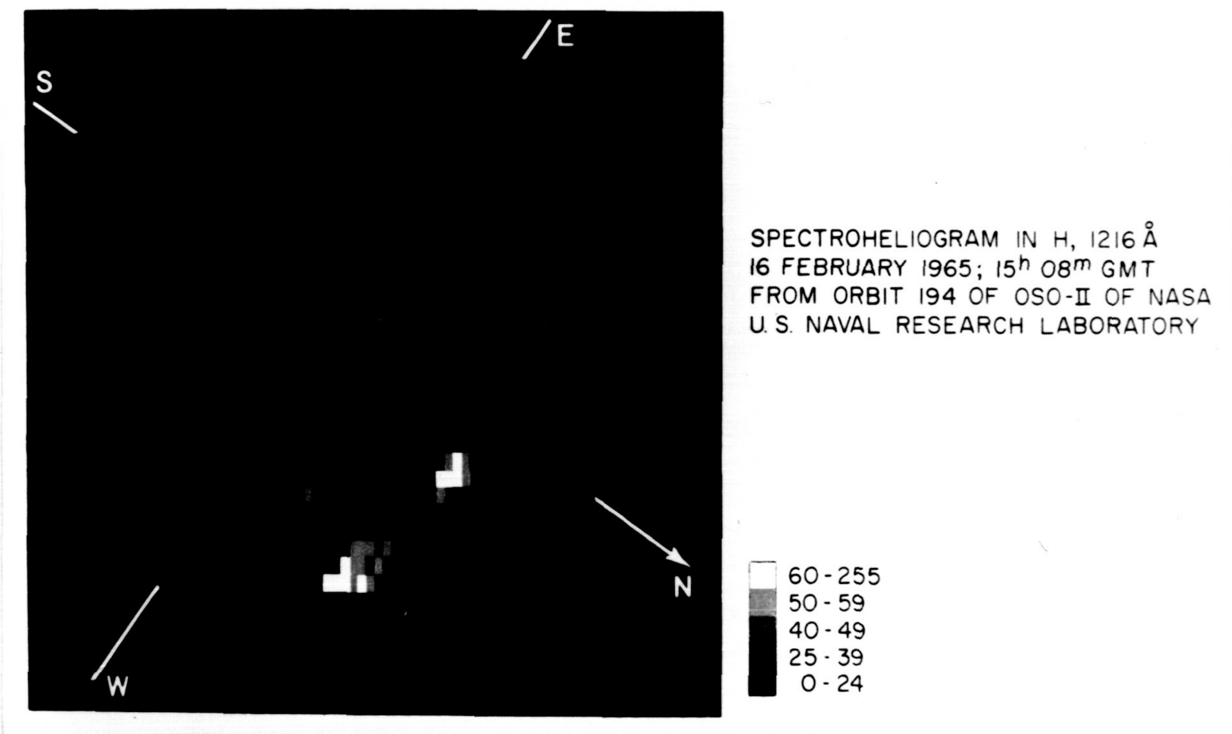


Figure 5-13 B. Solar Plot of OSO-2 Data—1216 Å Light, 16 February 1965

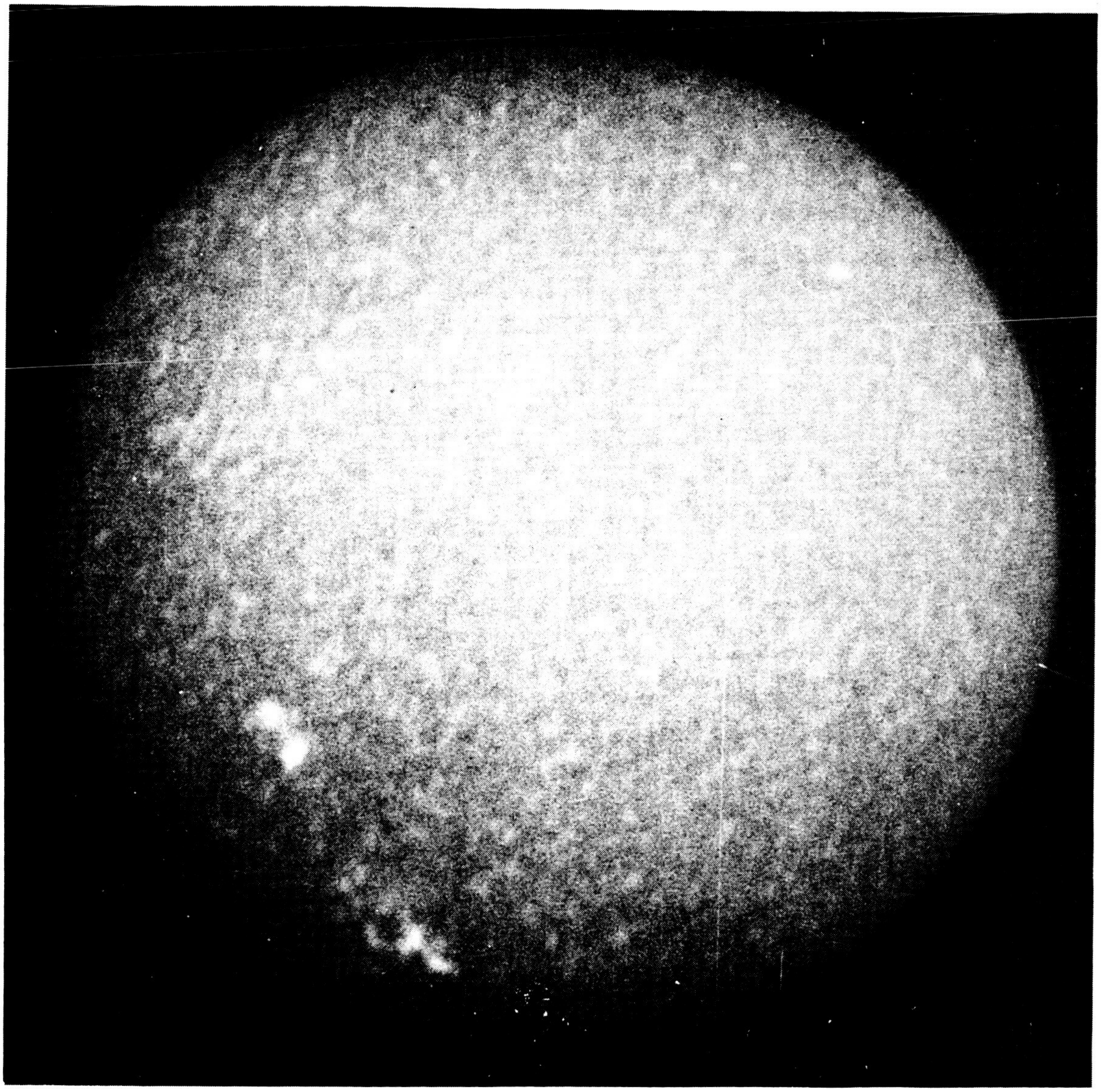


Figure 5-14. Sun Photo Taken from Earth on 16 February 1965

It was noted that when the Naval Research Laboratory experiment was operated in the raster mode, the sub-commutator slip counts became excessive. The experiment appeared to have little affect on sub-commutator synchronization in the point mode. During orbit 422, the raster mode was again commanded "ON" for three orbits with essentially the same results as the first time.

During orbit 495, the raster mode was commanded for the third time for two more orbits; however, the experiment was commanded "OFF" during orbit 499 due to a malfunction in the X-ray portion of the instrument. The experiment remained off until orbit 525 when it was commanded "ON" again in the point mode. It remained on until 13 April 1965.

The ultraviolet telescope and coronagraph experiment seemed to be working well and seemed stable except for interference from the Van Allen belt. There was a lot of stray light indicated and there was more noise in the signal than was expected. The source of the stray light and noise were not known at that time. The spectroheliograph had been switching detectors in the middle of the raster. It was believed that this was probably a result of arcing or noise in the instrument. The 304 angstroms detector was the only one which traced complete rasters, and a fairly good map of the solar disc was acquired with this detector.

More attempts at raster operation were conducted from 13 April through 18 April 1965 with very little success due to excessive sub-commutator slips. At about this time, Dr. Tousey of the Naval Research Laboratory reported that the experiment drive motor in the coronagraph had burned out. This left only the spectroheliograph in operation.

On approximately 23 April 1965, Dr. Tousey informed the OSO Project Office that the spectroheliograph was generating all ones during raster operation indicating full saturation. He requested that if all ones were detected in his data on the first pass over Fort Myers, the observatory be commanded back into the point mode. Quick-look data did indicate all ones in the data, and the point mode command was transmitted. On 19 May 1965, the spectroheliograph was again operated in the raster mode for two orbits. The results of this operation were that the detectors were still producing all ones. It was decided to repeat this operation each week to obtain data on raster operation. The spectroheliograph was operated in the point mode for the remainder of the observatory life except for two orbits per week when the raster mode was commanded.

5.2.2 NAVAL RESEARCH LABORATORY X-RAY TELESCOPE

The Naval Research Laboratory X-ray experiment operated normally from orbit 13 when it was initially commanded "ON" until orbit 495. Immediately upon acquisition at satellite dawn during orbit 495, the experiment began producing nothing else thereafter.

It was believed that the failure was probably caused by (1) a rupture of a window by a meteorite which in turn depleted the gas system, (2) high voltage power supply failure, or (3) multiple electronics failures. The Naval Research Laboratory performed tests to determine what would happen to the system when the gas supply was depleted.

5.2.3 HARVARD COLLEGE OBSERVATORY ULTRAVIOLET SPECTROHELIOGRAPH

The Harvard experiment was initially commanded "ON" during orbit 14. The experiment appeared to operate for approximately twenty seconds, but it had to be turned off after approximately one and one half minutes of operation due to apparent arcing within the instrument. (The experiment was reading out all zeros and then changed to all ones.) During orbit 27 the experiment was again commanded "ON" but had to be commanded "OFF" after five seconds of operation for the same reason as before. The experiment was commanded "ON" again during orbit 176. This time saturation was detected (all ones), and the experiment was commanded "OFF" after two minutes of operation.

No further attempts were made to activate the Harvard experiment until 11 May 1965. On 11 May 1965, the Harvard experiment was turned on for eight minutes during orbit 1450. It was commanded "ON" again during orbit 1451 and commanded "OFF" on orbit 1453. On 12 May 1965, the experiment was again commanded "ON" for four orbits in various modes of operation. All the commands issued on 11 May and 12 May 1965 were executed without difficulty. The results of this operation indicated that the Harvard high voltage was operating and there were no indications of arcing. Experiment data from the instrument indicated full saturation of the detectors. The experimenter believed that the trouble was in the shift register and was probably a burned out transistor.

In late June 1965, plans were made to turn on the Harvard experiment on a routine basis. At least twice a week the instrument would be turned on by Fort Myers in the slow wavelength scan mode after playback on an orbit for which the playback data could be received at the Goddard Space Flight Center via the quick-look system. At least once a week the instrument would be activated by Fort Myers after playback in the wavelength select Mode I and II options. The routine turn-on of the Harvard instrument was started on 29 June 1965. This Harvard experiment operation was scheduled for Tuesday and Thursday of each week, but no useful experiment data was obtained.

5.2.4 GODDARD SPACE FLIGHT CENTER ULTRAVIOLET SPECTROPHOTOMETER

The Goddard Space Flight Center Ultraviolet Spectrophotometer was initially turned on during orbit 58 for six seconds on 7 February 1965 as planned. It was again commanded "ON" for twenty seconds during orbit 59 with the Calibration Source Arm commanded into position. The experiment was again commanded "ON" with the Calibration Source Arm in position during orbit 72 on 8 February 1965. The experiment remained on until orbit 75 when it was commanded "OFF" because numerous wheel sub-commutator synchronization slips were occurring.

The data acquired during these orbits was evaluated at this point. It was found that the sync slips were intermittent, but in each instance, synchronization was recoverable for further useful data. The data counts of the instrument appeared to be six or more times larger than expected. The azimuth positions during these early orbits of approximately 20 to 40 degrees from the sun also seemed to indicate that some input of solar light could have been contributing to the high data count. It was also discovered that the ultraviolet radiation counts of the experiment increased when the spacecraft passed through the South Atlantic radiation anomaly. The problems associated with this radiation anamoly were greater than anticipated.

The experiment was again commanded "ON" in the calibrate mode on 10 February 1965 during orbit 101, and data indicated that the experiment was performing satisfactorily. The experiment remained in the calibrate mode until 12 February 1965 during orbit 131 when the command to retract the Calibration Source Arm was transmitted and the sky scanning was begun.

On approximately 23 February 1965, the Goddard Space Flight Center ultraviolet experiment appeared to be causing a loss of sub-commutator synchronization and was affecting other experiments—particularly the Ames Research Center Emissivity Experiment. It was decided at this time to turn the experiment off for one orbit per day to allow others to acquire good data. The experiment was turned off for a period of four days during orbits 263, 275, 290 and 306. The Ames Research Center evaluated their data for these orbits to determine whether or not continued turn-off of the Goddard Space Flight Center ultraviolet experiment would be necessary.

The sub-commutator slips appeared to be caused by a sequencing problem in the instrument. The instrument was designed to sequence by counting revolutions of the wheel section of the spacecraft. Every 80 revolutions of the spacecraft wheel, the azimuth indexer solar sensor, located on the bottom of the wheel section, would step one degree in azimuth. The purpose of this sensor was to control an electronic gate to allow the spectrophotometer photomultiplier output pulses to be gated into the counter for the period that the sensor saw the solar disc. Approximately 75% of each orbit was spent over water, and because of this, a phenomenon occurred which was not expected. As the plane of the spacecraft wheel swept across the ocean, the photomultiplier output was gated when the azimuth indexer viewed the sun. The output was again gated when the azimuth indexer saw the reflection on the sun in the ocean. Since the instrument was designed to sequence its azimuth indexer one degree every time it counted 80 sun pulses (spacecraft revolutions), when it was over water, it sequenced after only 40 revolutions due to sensing 40 sun images and 40 reflected sun images. Consequently, the indexer shifted at random. It appeared to step a few degrees in one direction and then got a reverse signal to step in the opposite direction.

On 30 May 1965 during two orbits, the observatory passed through a solar eclipse. It was expected that the maximum percentage of obscuration the observatory would experience would be approximately 70%. This did not cause night-time operation of the spacecraft. The Ames Research Center requested that the Goddard Space Flight Center ultraviolet experiment be commanded "OFF" during the eclipse to allow them to obtain good clear data for several consecutive orbits at that time.

It was expected that when the spectrophotometer was gated in the general direction of the sun, a problem in solar light rejection would have to be met. Baffle doors on either side of the entrance slit at the wheel rim and internally place light baffles, all painted with Parson's Optical Black Lacquer, were thought to give sufficient scattered light rejection. However, after examination of the data from orbits 73, 74 and 75, it was discovered that when the azimuth indexer moved closer to the solar disc, there was a proportionate increase in the data count. Where this light was leaking into the detector tube has not been pin-pointed; however, the locus appeared to be slightly off center of the solar index.

The data counts of the ultraviolet experiment read in binary coded scale from 0 to 255 counts. It was not believed that there would be data counts greater than 255 experienced by the instrument. Examination of the data from early orbits, however, indicated that the data was reading in such an extremely high range that frequently the counts filled up the counter once and overflowed and occasionally filled and overflowed the counter twice giving data readings of 514 and 518. These high readings have been attributed to the instrument reacting to scattered solar light and by a greater affect that anticipated from the Van Allen belt, the South Atlantic radiation anomaly and electron warm spots detected by a spectrometer carried aboard OSO-1.

The pitch angle of the spacecraft was limited to plus or minus 3 degrees from the solar vector when the spacecraft was in the automatic pitch control mode. In order to protect the photomultiplier tube of the spectrophotometer from being damaged by direct viewing of the solar disc, the spectrophotometer slit was canted -5 degrees. This allowed a safety factor of two degrees for the photo-multiplier tube. In mid-July 1965, the spacecraft was commanded into the manual pitch control mode to conserve pitch gas. On 21 August 1965 during orbit 2981, the pitch angle was allowed to reach +4.4 degrees. Meanwhile, the azimuth sensor of the spectrophotometer ranged from 50 degrees to 30 degrees toward the solar disc. At this time the detector tube was at the same elevation as the sun, and with the safety factor eliminated, the view path of the instrument swept past the solar disc. When orbit 2982 brought the spacecraft into sunlight, the pitch angle was still excessive. Four minutes of ultraviolet data were recorded followed by a five minute blackout and then a final burst of data counts for one minute. After this, the output data counts were all zero. Apparently the tube had been burned out. Several attempts to operate the experiment in the calibrate mode were made between 21 August 1965 and 24 August 1965, but the data count still indicated all zeros. The experiment was commanded "OFF" on 24 August 1965 during orbit 3020 and remained off until 2 October 1965 when it was turned on for the terminal operation.

5.2.5 GODDARD SPACE FLIGHT CENTER LOW ENERGY GAMMA-RAY TELESCOPE

The Goddard Space Flight Center gamma-ray experiment was initially commanded "ON" during orbit 12 on 4 February 1965. The experiment operated very well and there were no problems apparent with the detector. The data acquired was very good; although, the background count was approximately two times higher than expected. The experiment provided excellent data on the Van Allen belt.

On 22 July 1965, Mr. K. Frost of Goddard Space Flight Center, reported that he was getting garbled data. He indicated that his data was very erratic and that Harvard, which should have been reading zero, was actually reading 1028. Ball Brothers Research Corporation and the Goddard Space Flight Center Control Center were asked to investigate this problem. Investigation showed that a transistor had burned out in a piece of data processing equipment at the Goddard Control Center. This was corrected and the next data came through perfectly.

As the pitch angle drifted in a positive direction, there was an increase in the spin rate. On 28 July 1965 the spin rate was approximately 31.4 rpm. Mr. Frost was notified and he indicated that he started to loose data at 31.5 rpm. He said that he could adjust his data program to compensate for this, but that between 33 and 34 rpm his data would become garbled and it would be a complete loss. He agreed to monitor his data carefully, and when it got too bad, he would notify the OSO Project Office and a de-spin maneuver would be initiated. On 3 August 1965, the spin rate had reached 33.6 rpm. A de-spin command was executed, and the spin rate was reduced to 27.9 rpm.

5.2.6 AMES RESEARCH CENTER EMISSIVITY DETECTORS

The Ames Research Center emissivity experiment was turned on during orbit 1 on 3 February 1965. The operation of this experiment was as expected. A few Ames sub-commutator slips occurred, but this did not interfere with the acquisition of data. The data acquired was generally good, but it was significantly better when the Goddard Space Flight Center Ultraviolet experiment was not operating or the Naval Research Laboratory experiment was not operated in the raster mode.

5.2.7 UNIVERSITY OF MINNESOTA ZODIACAL LIGHT TELESCOPES

The University of Minnesota zodiacal light experiment was initially turned on during orbit 15 on 4 February 1965. Dr. E. P. Ney of the University of Minnesota Physics Department was very enthusiastic about the data they had acquired. He reported an occasional bad record from one of the South American stations, but he indicated that these could be reduced by "digging at it."

The main objective of the University of Minnesota experiment was to investigate the intensity and direction of polarized light from interplanetary space. Dr. Ney reported that approximately 1 out of 15 orbits passed close enough to the radiation anomaly in the South Atlantic, and that their standard calibrating telescope did show a definite profile of radiation. When the calibration telescope showed radiation effect of the anomaly, they could see a small effect in the photomultipliers, but they could compensate for this. Their original objective of measurement of the intensity and polarization of extra-terrestrial light was accomplished very successfully. As of 15 April 1965, they had not seen any large change in the zodiacal light, but Dr. Ney indicated that no large solar events which were expected to emit intense plasma clouds had as yet occurred. He expected that they might see some variations when they got all the data plotted chronologically. Dr. Ney also reported seeing lightning in one out of every three orbits. Dr. Ney indicated that the most interesting fact about the data they had acquired as of 15 April 1965, was the enormous variation in the brightness of the airglow layer which was scanned in profile by their experiment during each orbit. There appeared to be an indication that the airglow layer had maxima and minima separated by approximately 90 degrees in longitude as though there were some tidal effect in the excitation of this light. It was surprising to Dr. Ney to discover that the largest variations in the airglow may occur in a single terrestrial day. This was the first time to really get a global look at the brightness of the airglow. Because of the precession of the orbital plane, the University of Minnesota experiment was able to study the airglow at northern latitudes and southern latitudes in two month intervals. The ovservatory alternated between looking at southern latitude airglow one month and northern latitude airglow the next month.

The relatively dim portion of the sky at which they looked for the first 800 orbits made monitoring of the airglow and zodiacal light very good. They had not looked at a region of sky which contained a bright enough star to calibrate their equipment until the early 900 orbits. At this time, they discovered that the star Canopus was being seen by the telescopes looking in the direction of the sail. This allowed them to have absolute calibration of the equipment to compare with the calibration before launch.

The University of Minnesota zodiacal light experiment performed very well through the whole period in which the spacecraft was productive, and almost nine months of continuous data were acquired. Final results and conclusions have not yet been reached because the data acquired by this experiment is still in the process of being reduced and evaluated at this writing.

5.2.8 UNIVERSITY OF NEW MEXICO HIGH ENERGY GAMMA-RAY TELESCOPE

The University of New Mexico experiment was turned on during orbit 11. The data they acquired was reported as being very good. The rate of events was reported as being much higher than expected, and they were apparently responding to charged particles.

The University of New Mexico experiment was not disturbed by anything except the Van Allen belt. The experiment plotted the radiation anomaly over the South Atlantic very well. The pulse height spectrum showed no evidence of noise pulses, nor was it responding to noise pulses.

5.3 TRACKING AND DATA

5.3.1 DATA ACQUISITION

Acquisition and recording of telemetered data from OSO-2 was the responsibility of the prime STADAN stations at Fort Myers, Florida; Quito, Ecuador; Lima, Peru and Santiago, Chile. The secondary stations at Blossom Point, Maryland; Johannesburg, South Africa; Mojave, California and Woomera, Australia were used only during the early orbit phase or during those occasions where conflicts developed and no primary station was available to command playback and to record the telemetered data.

The standard analog tape reel used was 10 1/2 inches in diameter and contained 2400 feet of half inch wide magnetic tape. The analog tapes consisted of seven tracks. The normal track assignments are listed in Table 5-2. Two passes were recorded on each reel, and these passes were separated by approximately 60 seconds of running time to simplify later processing at the Goddard Space Flight Center. On each pass, two minutes of real-time data were recorded prior to sending the playback command, then the five-minute playback period was recorded followed by another two minutes of real-time data.

Table 5-2
Analog Tape Track Assignments

Track	Record Amplifier	Source	Signal
1	Direct	Multiplexed AGC and signal-conditioned clock signal from summary amplifier	D-C and 14,400 square wave
2	Direct	Minitrack time-standard control track generator	60 cps and binary time code 18.24 kc carrier
3	Direct	Output of signal conditioner	Conditioned PCM data
4	Direct	Minitrack time-standard	10 kc reference frequency
5	Direct	Output from Diversity Combiner	PCM data
6	FM	Minitrack time-standard	Serial decimal time
7	Direct	Audio amplifier or WWV, voice, commands	WWV, audio, code

The Fort Myers STADAN station was assigned the following additional responsibilities:

1. To command and record spacecraft telemetry as scheduled by Network Control.
2. To transmit to the Goddard Space Flight Center, via data link, all spacecraft real-time and tape recorded data.
3. To provide strip chart recordings of housekeeping data to the Spaceflight Branch representative on site.
4. To command the spacecraft, as scheduled, to provide complete observatory checkout during the first several days after launch.
5. To send those commands which were requested by the Ground Operations Manager during abnormal spacecraft operating conditions.

6. To provide simultaneously recorded duplicate magnetic tapes which were utilized in conjunction with Ball Brothers Research Corporation's ground station equipment for analyzing the spacecraft's tape recorded data.

5.3.2 DATA PROCESSING

All the analog tapes and the accompanying station logs were sent to the Analog Tape Library at the Goddard Space Flight Center via air mail. The last tape in each shipment from each station was evaluated for recording techniques and conformity to standards by the Tape Evaluation Group. The analog tapes were stored in the Central Processing Facility at the Goddard Space Flight Center until the data contained on them had been processed. One month after the processed data were released to the experimenters, the analog tapes were sent to the Federal archives for dead storage.

5.3.2.1 Analog-to-Digital Conversion

The analog tapes had to be converted into digital format for digital computer processing. The signal from the data track was fed into a PCM signal processor where the waveform was reconditioned. Figure 5-15 shows the analog-to-digital processing line. When bit synchronization was established in the bit synchronizer, the search was begun for the 16-bit frame sync word. After a 16-bit word conforming to the expected sync word was found, it had to be verified by appearing five consecutive times in the proper location with no more than one bit error per sync pattern. The proper location within the frame was established by starting a word counter, assuming the first appearance of the sync word was correct. If the 16-bit sync word was found at some location other than the expected one, the process was repeated using the most recently located sync word as the starting point. Once frame sync was established, a buffer record was written. Both time codes (binary-coded decimal and serial decimal) were decoded. A calibrated tracking oscillator was used to update the accumulator which in turn was compared periodically against both time standards. The input to this oscillator was the 10 kc reference frequency recorded on track 4. An elaborate system of flags was generated by the processing line which, if properly analyzed, indicated the quality of the time recorded on the buffer tape. In all the buffer records, the buffer frame was built by multiplexing: (1) the ground station recording time, (2) the first 30 channels from the telemetry main frame, (3) a special flag word and (4) the spacecraft frame-sync word, in that order. All the buffer tapes produced by the analog-to-decimal conversion processing line were chronological by station.

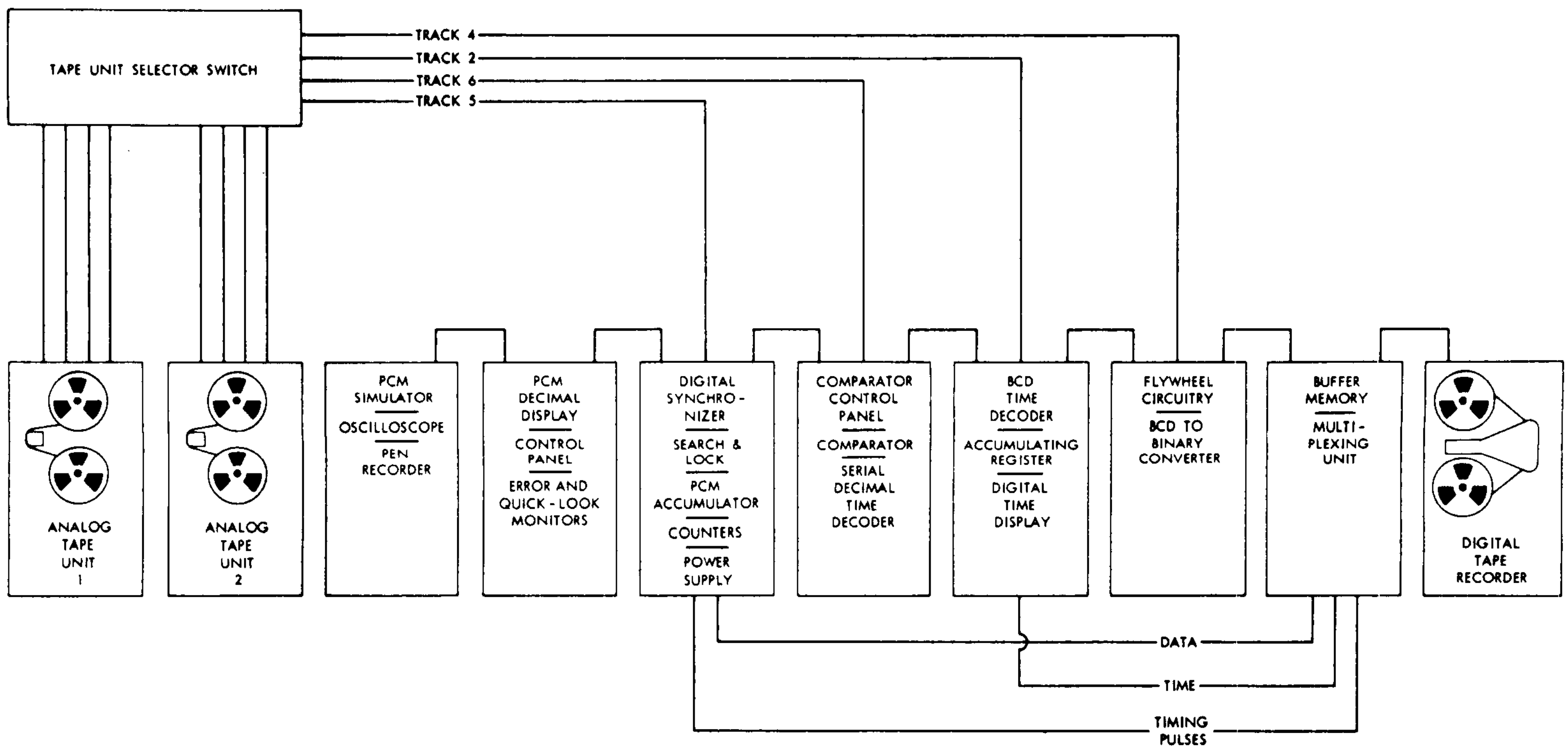


Figure 5-15. Analog-to-Digital Processing Line

5.3.2.2 Edit and Quality Control Operations

The edit and quality control operation divided the processing of the data into two major phases as shown in Figure 5-16. In Phase I, the proper file for input was selected, data and buffer-record formats were verified and the calculations were made which were necessary to determine the actual time of the first word in each telemetry frame. In Phase II, the data was formatted into 96-frame edit records, the sync word was inspected for bit errors, universal time was inserted and the edit tapes were written.

As can be seen from Figure 5-16, the buffer tapes from each STADAN station were placed into the computer in chronological order. The resulting edit tapes produced by the Edit and Quality Control Operation contained the data from all the STADAN stations arranged chronologically with universal time inserted for the entire nine month and three day period.

5.3.2.3 Decommutation Operation

The decommutation process produced chronological experimenter tapes from the edit tapes. The basic output was one data record for each experimenter from each 96-frame edit record. The experimenters could request any arrangement of both the experimenter data and the necessary sub-commutated data from each 96-frame edit record. In most cases, more than one of these experimenter records were written without the usual intervening gaps, thus producing longer tape records and achieving higher tape utilization.

Each reel of tape was mailed to the experimenter and was labeled with the spacecraft name, experimenter's name, decommutation run number, experimenter's tape-sequence number from this run, and the number of files written on the experimenter's tape.

5.3.2.4 Attitude Determination Program

In order that the attitude information would be as accurate as possible, the initial computations of the spacecraft attitude with respect to the celestial sphere were delayed. This permitted an accumulation of a large sample of magnetometer data from the spacecraft's aspect measurement system to be used in the attitude computation. Since the hour-by-hour variations in the spin axis orientation solution were large and ranged from a couple degrees to no solution at all when the sun vector and the local magnetic field vector were nearly parallel, the roll-angle error was computed and included on the tape. At the time of this writing, approximately 900 orbits of attitude data have been computed and mailed to the experimenters.

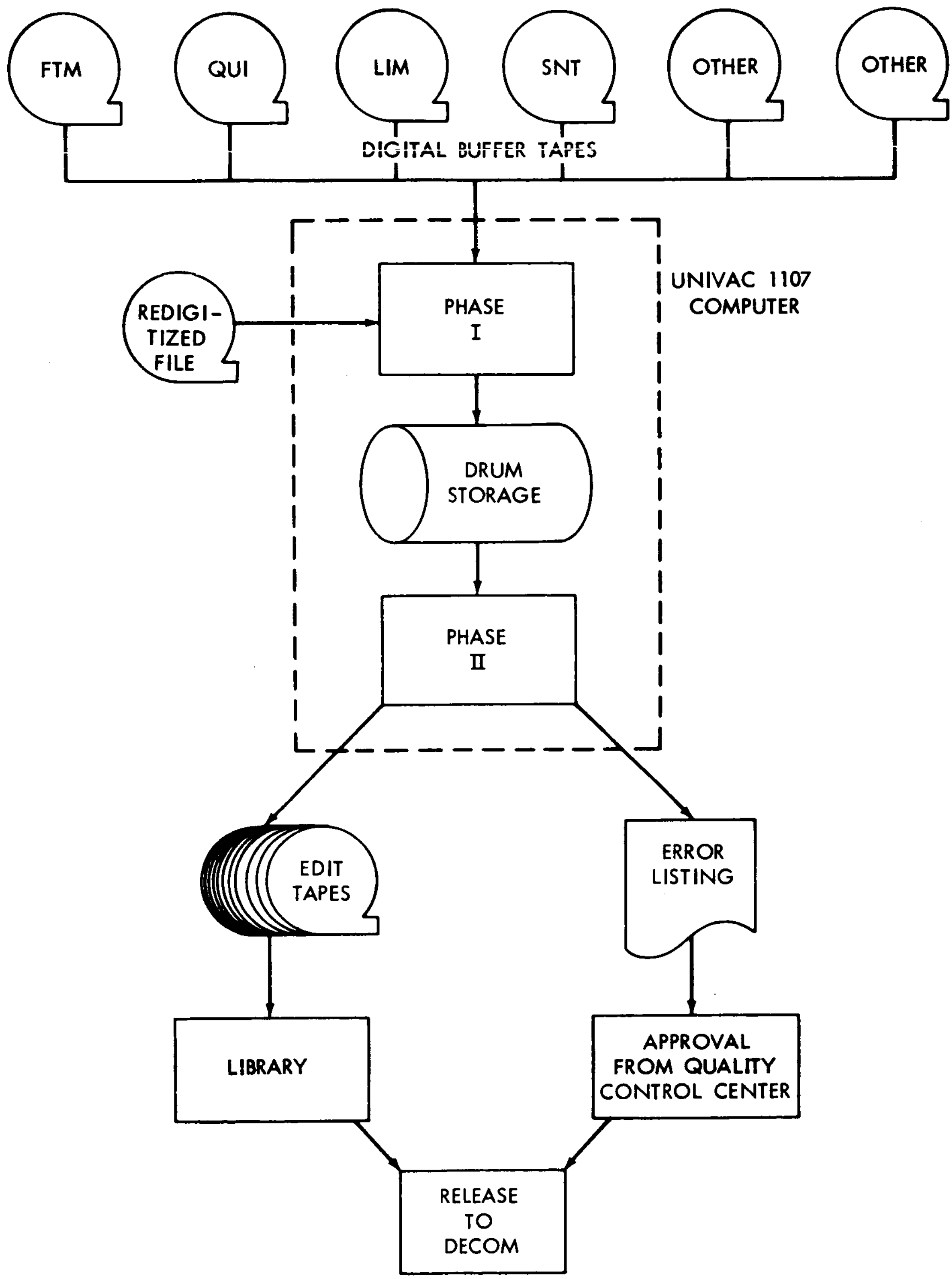


Figure 5-16. Quality Control and Edit Program

Because of the sub-commutator sync slips encountered, the data reduction process was slow and difficult. In order to produce buffer tapes in chronological order with the proper time correlation, the sub-commutator slip areas had to be reduced by hand so they could be inserted into their proper time relationship. The aspect data could not be reduced until the experiment data reduction was complete.

5.3.2.5 Quick-Look Operations

Spacecraft housekeeping data was sampled by two analog commutators. One commutator sampled data from the wheel section and another sampled data from the sail. Each commutator sampled a total of 48 data points.

Wheel commutator data was sub-commutated from main frame words 4 and 20. Because wheel commutator data was read-out twice per main frame, a total of 24 consecutive main frames were required to obtain one complete 48-channel cycle of wheel commutator data. Sail commutator data was sub-commutated from main frame words 10, 18 and 26. Since sail commutator data was read-out three times per main frame, a total of sixteen consecutive main frames were required to complete one 48-channel cycle of sail commutator data.

All STADAN stations which had data acquisition responsibilities were required to submit quick-look housekeeping reports to the OSO Operations Control Center via teletype as soon as possible after each pass.

Because of the location of the Fort Myers station, all OSO-2 telemetry data were transmitted to the Goddard Space Flight Center via data link. Real-time data was simultaneously recorded by Fort Myers on magnetic tape and transmitted to the Goddard Space Flight Center where it was decommutated and printed out by a CDC-160A computer. Figure 5-17 shows a block diagram of the Fort Myers to Goddard Space Flight Center Quick-look System. At the end of each pass, the magnetic tape containing the spacecraft's recorded data at 7200 bits per second was rewound immediately and played back at 1800 bits per second into the Rixon Data Tranceiver. The reason for the reduced data rate was due to the bandwidth limitations of the data link.

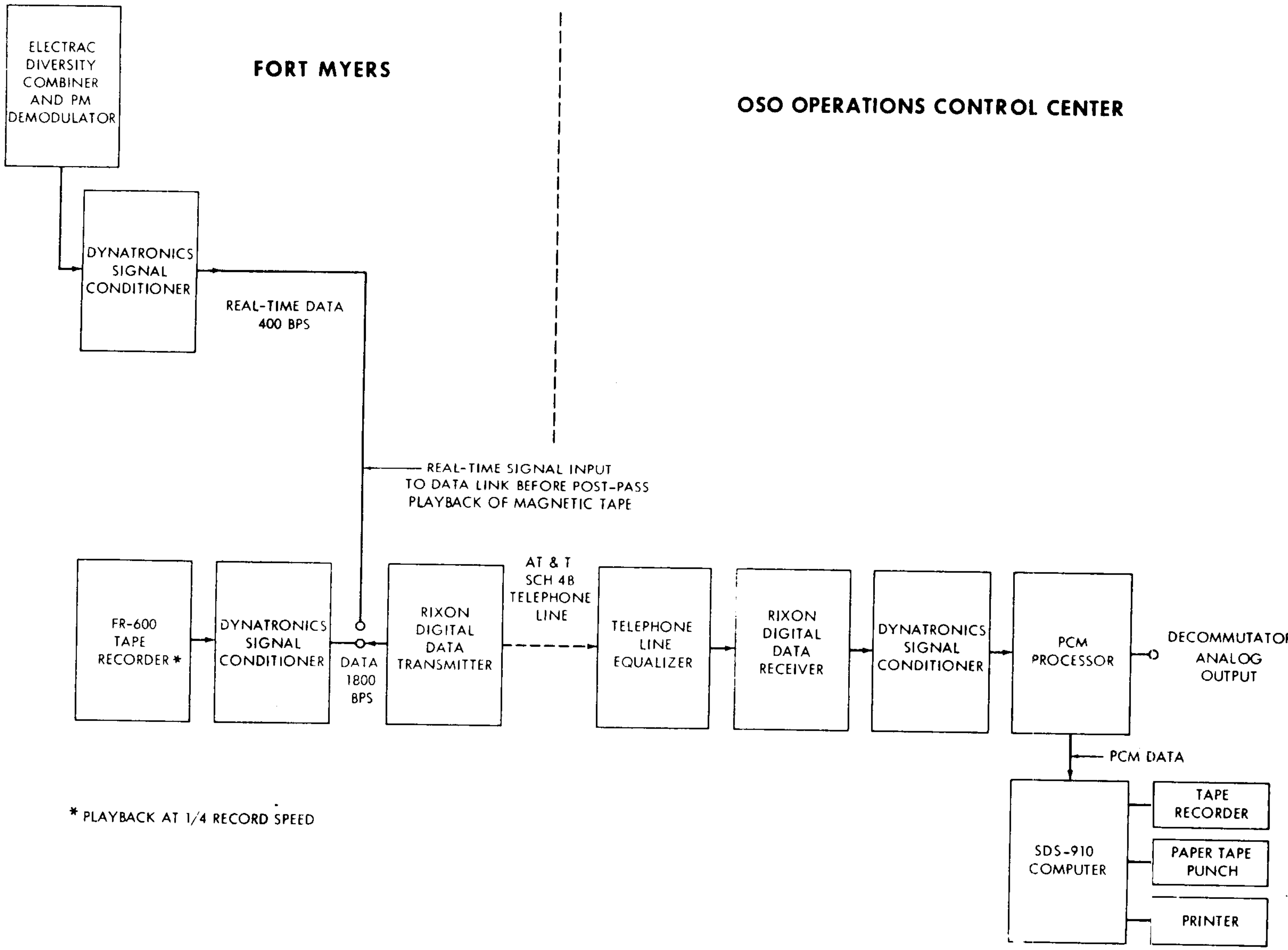


Figure 5-17. Quick-Look System, Fort Myers to GSFC

SECTION 6
TERMINAL OPERATION

6.1 GENERAL

During the latter part of June 1965, indications showed that the operational life of OSO-2 would soon be terminated due to depletion of the pitch control gas supply. Communications were sent from the OSO Project Office to Ball Brothers Research Corporation and to all investigators notifying them of this situation and asking for suggestions for a terminal operation.

On 3 July 1965, a reply from Dr. E. P. Ney, School of Physics, University of Minnesota, was received requesting that the following flight maneuvering program be performed: (1) de-spin to half the normal spin rate for fifteen orbits near the new moon, (2) de-spin to a quarter of the normal spin rate for fifteen orbits near the new moon.

About mid-July 1965, an unexpected upward swing of the average pitch drift curve occurred which indicated a reduction of the pitch control gas consumption rate and an extended life for the spacecraft. This resulted in a postponement of the terminal operation. In mid-September 1965, it again became apparent that the pitch control gas supply would soon be depleted, and a detailed terminal operation plan was prepared.

6.2 TERMINAL OPERATION PLAN

The terminal operation plan, consisting of inputs from Ball Brothers Research Corporation as well as all investigators, covered a two week period from 24 September 1965 through 7 October 1965.

First Day - Spin down to 0.25 rps (15 rpm) for fifteen orbits.

Second Day - Pitch down to -4 degrees. Spin up to approximately 0.4 rps (25 rpm). Turn on Harvard experiment for two orbits.

Third Day - Turn on raster mode for two orbits.

Fourth Day - Switch to transmitter number 1.

Fifth Day - Pitch correction to be made if necessary. Spin down to 0.25 rps (15 rpm). Spin up to 0.4 rps (25 rpm).

Sixth Day - Turn on Harvard experiment for six consecutive orbits in three different modes.

Tenth Day - Pitch correction if needed.

Eleventh Day - Switch tape recorders. Switch Digital Multiplexer-Encoder.

Twelfth Day - Verify command system.

Thirteenth Day - Naval Research Laboratory experiment operation. Spin down to 0.125 rps (7.5 rpm). Pitch correction.

Fourteenth Day - GSFC Ultraviolet experiment turn-on when pitch angle reaches +4.5 degrees. Go into stow operation.

6.3 TERMINAL OPERATION AND RESULTS

6.3.1 FIRST DAY - SEPTEMBER 24, 1965

The de-spin operation was initiated by Fort Myers on orbit 3486. The Day/Night Relay Bypass was commanded closed prior to spin-down to avoid automatic cycling of the Day/Night Relay which occurs at spin rates less than 21 rpm. Eight spin-down commands were transmitted at seven second intervals. Seven of these commands were successful, and the spin rate was reduced from 28.9 rpm to 16.4 rpm. There was no apparent explanation for the unsuccessful command. The spin gas pressure decreased from 840 psi to 752 psi. Manual spin commands produce four-second bursts of nitrogen gas and change the spin rate by approximately one and three-quarter rpm per command. The spin gas pressure is also reduced by approximately 12 psi per command.

The pitch angle remained steady at +2.25 degrees immediately following the spin-down commands. Beginning at the next satellite dawn, pitch angle readouts indicated the spacecraft was unstable and wobbling from +3.75 to +0.95 degrees. At approximately 16.5 minutes after observatory sunrise, the wobble damped out to less than 0.3 degrees peak-to-peak. The frequency of the wobble was approximately 0.04 to 0.05 cycles per second. The pitch angle appeared to be the primary factor controlling the magnitude of the wobble, whereas the period of the wobble was dependent on the spin rate. The pointed instruments balance out at a pitch angle of approximately -2 degrees, at which point the magnitude of the wobble should be minimum. On orbit 3489, Fort Myers commanded pitch down in an attempt to minimize the wobble. Six commands were transmitted at

15 second intervals. Four of these commands were successful and reduced the pitch angle from +2.72 to -1.02 degrees. There was again no apparent reason for the unsuccessful commands. For some unexplained reason, the pitch gas pressure read-out remained steady at 220 psi. Manual pitch corrections produce ten-second bursts of nitrogen gas and decrease the pitch gas pressure by approximately 6 psi per command. Based on previous OSO-2 experience, manual pitch commands changed the pitch angle by approximately 0.45 degrees per command at a spin rate of 32 rpm. At 16 rpm manual pitch commands should have changed the pitch angle by twice that much or approximately 0.9 degrees per command.

6.3.2 SECOND DAY - SEPTEMBER 25, 1965

On orbit 3501, after 24 hours of observatory operation at 16.4 rpm, operations were initiated by Fort Myers to return the spacecraft to normal operation. Five pitch down commands were transmitted at 20 to 25 second intervals prior to spin-up in order to take advantage of the smaller gas consumption at slower spin rates. All of these pitch commands were successful, and the pitch angle was reduced from +0.8 to -4.05 degrees. The pitch gas pressure decreased a normal amount from 220 psi to 187 psi. Four spin-up commands were transmitted at 10 second intervals in an attempt to increase the spin rate to 25 rpm. The spin gas pressure read-out remained steady at 740 psi. Real time automatic gain control readings from Fort Myers indicated that the spin rate had increased. Calculations made after the pass indicated that three of the four commands were successful, and the spin rate had increased from 16.6 rpm to 21.7 rpm. There was no apparent explanation for the unsuccessful command. The Day/Night Relay Bypass was successfully commanded open on the first attempt. On orbit 3502, the Rosman station successfully commanded spin-up twice, and the spin rate was increased to 25.2 rpm. The spin gas pressure decreased to 720 psi as a result of this operation. Rosman also transmitted the Harvard "ON" command, and Fort Myers issued the Harvard "OFF" command after two orbits. The Naval Research Laboratory experiment was commanded "ON" by Fort Myers. There were no difficulties experienced with these commands. There was an indication from telemetry data that the high voltage was on in the Harvard experiment, but there was no indication of arcing. There was also no indication of any useful data being produced by the Harvard experiment.

6.3.3 THIRD DAY - SEPTEMBER 26, 1965

The raster mode was to be turned on for two orbits to determine if there had been any degradation of the raster system after several months in orbit. The raster mode was commanded "ON" from Fort Myers, and two orbits later the point mode was commanded "ON". The Naval Research Laboratory instrument was commanded "OFF" for this operation. There were no difficulties experienced with these operations. The elevation and azimuth control systems operated excellently during the raster operation.

6.3.4 FOURTH DAY - SEPTEMBER 27, 1965

A switch to transmitter number 1 was to be accomplished to obtain another sample for reliability. A signal strength plot was to be made immediately before and after the switch to indicate any relative degradation in power output. The switch to transmitter number 1 was accomplished on the first command from Fort Myers. A 2 db increase in signal strength was noted in transmitter number 1 over transmitter number 2. This operation was accomplished without difficulty and transmitter number 1 was left on.

6.3.5 SIXTH DAY - SEPTEMBER 29, 1965

A pitch correction was to be made to maintain a pitch angle between the limits of +4 degrees and -4 degrees by manual control. The conditions to be met for this operation were a de-spin 0.25 rps, pitch down to -4 degrees, and the Day/Night Bypass was to be closed below 0.35 rps to avoid automatic cycling of the Day/Night Relay. At the beginning of this operation, the spacecraft status was as follows: (1) pitch angle +2.8 degrees, (2) pitch gas pressure 187 psi, (3) spin rate 26.2 rpm and (4) spin gas pressure 720 psi.

On the third and best pass over Fort Myers, the Day/Night Bypass "CLOSE" command was issued five times before it was executed. The spacecraft was despun to again take advantage of the reduced pitch gas consumption at slower spin rates. The spin down command was issued eight times but only executed twice. The pitch down command was issued two times, but it was only executed once. The spin up command was sent five times and executed three times. This operation resulted in a change in pitch angle to zero degrees.

On the next Fort Myers pass the spin down command was sent four times and executed twice. The pitch down command was issued four times and executed three times. Spin up commands were issued twice and executed twice. The Day/Night Bypass was closed after two attempts. This operation resulted in a pitch angle of -2.8 degrees. The spin rate during the pitch correction was approximately 17 rpm, and the final spin rate after the pitch correction was completed was 25.9 rpm. The pitch gas pressure was 150 psi and the spin gas pressure was 580 psi after this operation. The GSFC Ultraviolet experiment was turned off in preparation for the Harvard experiment operation on the following day because the GSFC Ultraviolet experiment was producing excessive sub-commutator sync slips.

6.3.6 SEVENTH DAY - SEPTEMBER 30, 1965

The Harvard instrument was to be turned on over Fort Myers for six consecutive orbits to check it while in three different operational modes. It was turned on in the wavelength scan mode by the Quito STADAN station. The first playback and Harvard "ON" commands were executed without difficulty. The optical wavelength select mode was commanded from Fort Myers two orbits later, and the mechanical wavelength select mode was commanded by Fort Myers two orbits after that. The Harvard "OFF" command had to be issued five times by Fort Myers before it was successfully executed. The GSFC Ultraviolet experiment was also commanded on by Fort Myers. No problems were experienced during this operation except for the repetition of commands to turn off the Harvard experiment. Indications showed that no useful data was received from the Harvard instrument.

6.3.7 EIGHTH DAY - OCTOBER 1, 1965

A switch to Digital Multiplexer-Encoder number 2 was to be made to obtain another sample for reliability. Because samples of DME were so small, the addition of one more in a limited group of statistics was quite important. A command system verification and switch to tape recorder number 2 were also planned.

The command system verification and switching of the Digital Multiplexer-Encoders were accomplished without difficulty. The command system was verified by sending and verifying the receipt of identical sail commands (Harvard "OFF-ON") via receiver number 1 and 2 and by identical commands through wheel decoder number 1 and 2 to switch from DME number 2 then back to DME number 1. DME number 2 was then switched back on.

The switch to tape recorder number 2 was to be made because it contained valuable launch data, and to determine if it would operate after several months storage in orbit. The amount of tape jitter due to pressure roller indentation was also to be determined.

The switch to tape recorder number 2 was performed on the third pass over Fort Myers because it was the first pass of the day over both Mojave and Fort Myers. On this orbit, tape recorder number 1 was dumped at Mojave, and shortly after acquisition at Fort Myers, the switch was made to recorder number 2. The tape recorder came on immediately and appeared to come up to speed without difficulty. During this playback, there were indications that the main frame lock was never achieved. Tape recorder number 2 was left on for the next complete orbit to see if this condition would clear up. During the playback of this orbit of data, the main frame lock was still unable to be obtained, and a switch back to tape recorder number 1 was accomplished. The switching operation was successful; however, the operation of the back-up tape recorder was not.

6.3.8 NINTH DAY - OCTOBER 2, 1965

The Naval Research Laboratory Spectroheliograph and Coronagraph were to be turned on during one complete orbit (day and night) to check their operation. On the first pass over Fort Myers, the GSFC Ultraviolet experiment and the NRL experiment were turned "OFF" and the raster mode was commanded "ON" to prepare for the NRL operation. On the second pass the Day/Night Bypass was closed to permit operation of the NRL instrument for the complete orbit, and the NRL instrument was commanded "ON". On the third pass the Day/Night Bypass was opened to permit normal operation of the NRL instrument (off at night - on during the day). On the fourth pass the point mode was commanded "ON", and the Day/Night Bypass was closed again to permit operation of the coronagraph during the complete orbit. The Day/Night Bypass was opened on the fifth pass, NRL was commanded "OFF", the raster mode was commanded "ON" and the GSFC Ultraviolet experiment was turned "ON".

This operation was successful with the following exceptions. The observatory had been maintained in manual pitch control for some time in an attempt to conserve pitch gas. During the NRL operation, switches were made to the automatic pitch control mode on three different orbits. Commands were issued on three different passes to return the observatory to manual pitch control. The pitch angle was near enough to zero on these switches so that no pitch corrections resulted. These switches to automatic pitch control occurred when the observatory was not over a station and when no commands were being issued from ground stations. Transients generated by the NRL instrument must have gotten into the command system causing the switch to automatic pitch control.

At the completion of the NRL instrument operation the raster mode was commanded "ON" to get a final check of the raster system. There were no indications that useful data was obtained from the NRL instrument during these operations except for that which was obtained from the coronagraph in the point mode.

6.3.9 FOURTEENTH DAY - OCTOBER 7, 1965

A spin down to 0.125 rps was planned to check the stability of the spacecraft and the University of Minnesota and GSFC Ultraviolet experiment calibrations were to be checked to obtain more data points for their sine curves.

The third pass over Fort Myers was selected because it was the longest and best pass. The tape recorder was dumped at Mojave, and shortly after acquisition at Fort Myers, commands were sent to close the Day/Night Bypass. Difficulty was experienced in getting this command through. It was determined that the command console at Fort Myers was not functioning properly, and no further attempts to command the observatory were made on this pass. On the next pass Rosman was set up to issue commands, and both Rosman and Fort Myers were set up to receive real time data. The tape recorder was again dumped over Mojave. Shortly after acquisition at Rosman, nine spin-down commands were issued. A check of the spin gas pressure showed that two of the commands did not get through, and two more spin down commands were issued.

The pitch angle fluctuated between +2 and +3 degrees indicating a slight instability. An attempt was made to improve the stability by commanding a single burst of pitch down gas. The pitch angle changed immediately to -4 degrees, and for a period of time it oscillated between zero and -4 degrees. Since this was more unstable, a single burst of pitch up gas was commanded, and the pitch angle finally settled down to approximately +2 degrees as the pass was completed.

A check of the spin rate was made as soon as possible using real time data from the pass. Data readings indicated that the observatory had possibly stopped spinning. It could not have come to a dead stop since there were indications of pitch fluctuations which probably could not occur if it were not spinning.

Since the true spin condition was unknown, immediate steps were taken to have the first station capable of commanding the spacecraft issue a spin up command. This turned out to be Australia, and they were instructed to obtain readings of automatic gain control and issued four spin up commands. The results of these automatic gain control readings indicated a spin rate of 3.9 rpm at the time of acquisition at Australia. When Fort Myers acquired the spacecraft, data showed the spin rate to be 7.8 rpm which indicated that the operation at Australia had been successful. It should be noted here that Australia set up and executed this operation in less than 13 minutes.

The observatory appeared quite steady with the pitch angle at approximately +2 degrees. After 15 orbits of operation at this spin rate, a pitch correction was made by commanding one burst of pitch down gas, and a correction of 2 degrees was achieved. There was no significant instability of the spacecraft, and it was decided to continue this mode of operation.

This completed the planned terminal operation except for the turn-on of the GSFC Ultraviolet experiment. Dr. Hallam requested that his experiment be turned on when the pitch angle reached +4.5 degrees. Since the observatory would eventually drift in that direction, this was accomplished just before the observatory was put into a stowed condition.

6.4 CONCLUSIONS

The terminal operation, in general, went very well. All back-up systems in the spacecraft performed as expected except for the back-up tape recorder. The majority of the data played back from this tape recorder could be recovered by hand processing. Its operation would not be satisfactory on a regular basis. It was not known if this condition would clear up with continued operation. The risk of losing a good operating tape recorder while trying to recover a poor one was considered too great. Because of the problem of the indented pressure roller on tape recorder number 2, a consideration to use a pressure belt drive instead of a pressure roller for future spacecraft was made.

The spacecraft command system appeared to function as planned and no problems were indicated during the verification tests. During the terminal operation and also at other times, there were a number of commands which had to be repeated many times before they were executed or sometimes never got through at all. At one time, during spin down operations, this was traced directly to the command console at Fort Myers. Just how many of these command malfunctions could be attributed to ground equipment was not known. Further investigation into this problem would be made and corrective action taken.

SECTION 7
STOW OPERATION

7.1 PURPOSE

The OSO-2 observatory was put into a stowed condition on 6 November 1965 to preserve it for periodic short-term or possible extended use whenever the pitch angle drifts within ±5 degrees. The stow current was computed to be less than 400 ma and the array output, at moderate pitch angles, should be greater than 600 ma. Thus, the net charge will allow periodic operation of the observatory wheel experiments for possibly 5 orbits or until the battery voltage drops to 17.2 volts.

7.2 OPERATION

The OSO-2 was placed in a "stow" condition by Fort Myers during orbit 4120 after 9 months and 3 days of operation. This was necessitated by the depletion of the pitch control gas supply.

Tape recorder #1 was successfully commanded to playback on the first attempt at the beginning of the pass. The spacecraft was in darkness during the entire pass which made it necessary to close the Day/Night Bypass Relay for command verification purposes. This was successfully accomplished after the tape recorder playback. Tape recorder power and the wheel experiments were successfully commanded off on the first attempts. The pointed experiments had been commanded off prior to this pass. Two commands were required to turn the pointing control system off, and there was no apparent explanation for the unsuccessful command. The Day/Night Bypass Relay was successfully commanded open after the Pointing Control System "OFF" Command had been verified. Transmitter #2 was turned off, and two commands were again required with no explanation for the unsuccessful command. Tables 7-1 and 7-2 show the status of the OSO-2 at the beginning of the stow operation.

7.3 OPERATIONS AFTER OBSERVATORY STOW

During periodic short-term operations, the transmitters were to be operated only over a ground station to conserve power. No operations were to be attempted unless the battery voltage was over 19 volts and stayed above 17.2 volts for at least two orbits. This would give a fair indication that the solar array was receiving sufficient light to produce an adequate charge to the batteries.

Table 7-1
OSO-2 Status - Orbit 4120

System	Function	Status
Telemetry	Transmitter #2 Encoder #2 Tape Recorder #1	On On On
Pitch Control	Pitch Angle Pitch Gas Pressure Pitch Control Pitch Backup 15 volt Reg.	+3.85 degrees 37.5 psi Manual Off
Spin Control	Spin Rate Spin Gas Pressure Spin Backup Circuit Spin Circuit 15 volt Reg. Spin Control	28.62 rpm (sail spinning) 24.5 psi Armed On Automatic
Power	Battery Voltage Battery Charge Rate (orbit 4119) Undervoltage Switch Bypass Control System Power Tape Recorder Power Auxiliary 15 volt Reg. Pointed Experiment Power Harvard High Voltage Pointed Experiments Wheel Experiments	19.04 volts 2.1 amp (Max) Open Off Off On On Off Off Off
Pointing Control	Position PWM Input Signal Motor Current Preamp Signal Target Eye Intensity Servo Amp 15 volt Reg. PWM 15 volt Reg. Raster Circuits 15 volt Reg.	Azimuth + 0.50 min Elevation - 0.65 min Azimuth 6.3 volts Elevation 7.0 volts Azimuth 60 ma Elevation 10 ma Azimuth 0.18 ma Elevation 0.10 ma 1.85 ma Off Off Off

Table 7-2
OSO-2 Temperatures - Orbit 4120

Section	Location	Temperatures (°C)
Wheel	GSFC Electronics	+7.4
	Battery #1	+17.0
	Battery #3	+11.0
	Battery #5	+11.5
	Top Skin	+13.5
	Bottom Skin	+10.3
	Rim Skin	+7.4
	Slip Ring	+9.2
	Hub	+12.7
	Spin Box	+25.5
	Arm	-10.9
	Spin Gas Bottle	+21.1
Sail	Power Amplifier Box	+20.8
	Servo Amplifier Box	+16.7
	Azimuth Casting	+12.4
	Azimuth Power Transistor	+14.9
	Solar Cell Array	
	Middle Right	+29.8
	Upper Right	+26.5
	Lower Right	+21.4
	Extreme Lower Right	+21.5
	Sail Commutator	+13.2
	Harvard Instrument	+6.1

If day power was found to be on during these interrogations, the sail control system was turned on until acquisition or for three minutes, whichever occurred first, so that the pitch angle could be read.

Whenever the pitch angle is between ±5 degrees, the OSO-2 can be operated normally. The limiting factors in these operations from the "stow condition" are: (1) proper operation of the experiments and equipment aboard the spacecraft, and (2) the pitch angle must be between ±5 degrees of normal to the solar direction.

Following the stow operation, daily attempts were made to turn the transmitter RF on for three minutes at a time in order to check spacecraft status. Table 7-3 summarizes these operations. The unsuccessful "RF ON" commands were transmitted using both spacecraft wheel decoders. It is assumed the spacecraft was in the under voltage condition at the times of the unsuccessful commands although there is no positive verification. "RF OFF" commands were transmitted following the "RF ON" commands on all passes for which there was no spacecraft response. During the passes on which successful "RF ON" commands were executed, the spacecraft battery voltage decreased as indicated in Table 7-4.

Examination of housekeeping data on pass 4161 indicated the spacecraft was in the manual spin control mode. All other spacecraft parameters were normal. The change in spin control mode occurred sometime between orbits 4121 and 4161. It was during this time that all attempts at commanding transmitter RF on were unsuccessful. The possibility of a false or spurious command causing the mode change has been ruled out. There are two manual spin mode commands which execute three functions: (1) Manual Spin Control/ UVS Bypass Security Closed/ Spin Backup Circuit Disarmed and (2) Manual Spin Control/ Day-Night Bypass Closed/ Spin Backup Circuit Disarmed. The UVS Bypass Security Relay, the Day-Night Relay Bypass, and the Spin Backup Circuit remained in their normal states after the spin mode change. The automatic spin control mode was commanded successfully on orbit 4176.

Additional "RF ON" commands were transmitted once daily from 11 November through 22 November with no success. The upward drift of the pitch angle is believed to be causing the shadow of the wheel to be cast on the solar array, thereby producing a net discharge and causing an under voltage condition. Predictions of the spacecraft attitude indicate that the solar array should begin receiving sufficient solar energy for full spacecraft operation for several weeks in March 1966.

On 23 November, Wheel Experiments "OFF"/UVS Switch Bypass Security "OPEN" and UVS Bypass "OPEN" commands were transmitted to assure a secure "stow" condition. No further attempts were made at commanding the spacecraft after 23 November 1965.

Table 7-3
Transmitter RF ON Attempts

Date	Orbit	Station	RF ON
6 Nov.	4121	Fort Myers	Successful first attempt
7 Nov.	4146	Fort Myers	Unsuccessful, seven attempts
8 Nov.	4147	Fort Myers	Unsuccessful, twelve attempts
8 Nov.	4148	Rosman	Unsuccessful, twelve attempts
8 Nov.	4149	Rosman	Unsuccessful, eight attempts
8 Nov.	4150	Rosman	Unsuccessful, eight attempts
8 Nov.	4161	Fort Myers	Successful first attempt
9 Nov.	4162	Fort Myers	Unsuccessful, eight attempts
9 Nov.	4176	Fort Myers	Successful first attempt
10 Nov.	4190	Fort Myers	Successful first attempt

Table 7-4
Spacecraft Battery Voltage

Orbit	Start of Pass	End of Pass
4121	18.45 volts	18.45 volts
4161	16.97 volts	16.75 volts
4176	17.07 volts	16.93 volts
4190	17.65 volts	17.53 volts

The OSO-2 spacecraft remained in this uncontrolled drifting condition from 23 November 1965 through 3 March 1966. During this period, predictions were made of the spacecraft's attitude relative to the sun by both Ball Brothers Research Corporation and the Goddard Space Flight Center. Ball Brothers predictions indicated a drift situation to permit acquisition of the sun for full observatory turn-on in March 1966. Later, the Goddard Space Flight Center predicted a turn-on situation in late February 1966. A decision was made to attempt turn-on of OSO-2 on 3 March 1966.

The observatory was commanded "ON" successfully on the first attempt during orbit 5877 on 3 March 1966 for four minutes of real-time operation. The maximum observed battery load voltage was 18.5 volts and the maximum charge rate was 1.72 amperes. The spin rate at that time was 27 rpm. The spin gas pressure was reading 236.35 psia and the pitch gas pressure was 37.019 psia. Transmitter number 2 and multiplexer-encoder number 2 were used for these operations. The transmitter modulation index was greater than when initially placed in the stowed condition. Fort Myers indicated that it was more difficult to "lock on" due to increased side band power. The transmitter may have been cold and could change modulation index after steady state operational conditions are obtained. This could improve real-time operations, but it might create difficulty during playback at an increased bit rate.

When the spacecraft was turned on, the Day/Night Relay indicated a night condition. This was probably due to the spacecraft not being within the 15-degree look angle of the day/night sensor. The spacecraft apparently was not in an attitude to obtain enough sunlight on the solar array to cause a day power situation.

The spacecraft was interrogated again briefly on 4 March 1966 and again on 7 March 1966 to obtain battery voltage and charge rate readings and temperature readings to try to establish the spacecraft's attitude in respect to the sun. These readings are summarized in Table 7-5. At this writing, it is planned to interrogate the spacecraft once weekly to try to catch it in a day power condition, so that it can be operated normally for a short period of time.

7.4 RENEWED OSO-2 OPERATION, JUNE 1966

The normal operating limits of an OSO observatory pointing control system in elevation are ±4 degrees of the sun vector. On 3 November 1965 the OSO-2 observatory was turned off (stowed) because it was drifting out of these limits. Its pitch gas supply, used to control this attitude within operating limits, was just about depleted. This gas system was designed for 6 months of operation and it had completed over 9 months of operation.

In stow condition the spacecraft would drift in pitch and make a complete somersault eventually coming back to an attitude where it would be pointing directly at the sun again. Predictions indicated that this attitude would be reached about February or March and again about May or June.

Interrogation of the spacecraft was begun early in March and data received indicated that the spacecraft was not in the proper attitude to try operation. Early in May interrogation revealed that conditions were improving. Temperatures and battery conditions indicated that more sunlight was reaching the solar cells. It was predicted that at about 1 June the observatory would be pointing at

Table 7-5
OSO-2 Temperatures (Degrees Centigrade) - March 1966

Temperature Sensor	3-3-66	3-3-66	3-4-66	3-4-66	3-7-66	3-7-66	3-7-66	3-15-66
Time in Sun in Min.	31	37	32	48	24	36	43	23
Orbit Number	5877	5878	5892	5895	5936	5938	5939	6057
WHEEL								
Battery #1 Temp.	15.0	15.0	15.0	16.0	16.0	16.0	16.0	15.0
Battery #3 Temp.	13.5	14.0	14.0	14.5	14.5	15.0	15.5	15.5
Battery #5 Temp.	13.0	13.5	13.0	14.5	14.0	14.5	14.5	13.5
Top Skin Temp.	43.0	45.5	45.5	48.0	44.0	46.0	47.0	43.0
Bottom Skin Temp.	13.5	17.5	13.5	23.0	13.5	18.5	21.5	16.0
Rim Skin Temp.	17.4	19.4	17.9	20.9	17.5	19.9	19.9	15.4
Slip Ring Temp.	10.7	11.2	11.7	12.7	12.2	12.7	13.2	11.7
Hub Temp.	15.2	15.2	15.2	16.7	16.7	16.7	16.7	15.2
Arm #4 Temp.	7.4	13.0	9.5	19.5	9.5	15.5	19.5	15.5
Spin Gas Bottle Temp.	37.5	42.5	40.0	48.0	37.0	44.0	47.0	42.0
Spin Box Temp.	25.0	25.0	25.0	25.5	25.5	26.0	26.0	24.0
SAIL								
Pwr. Amp. Box Temp.	27.8	27.8	28.4	29.4	29.4	29.4	29.4	26.2
Servo Amp. Box Temp.	25.6	25.6	26.0	27.3	26.7	26.7	27.3	24.0
Az. Casting Temp.	23.6	24.3	24.3	26.6	24.8	26.6	26.6	23.1
Az. Pwr. Transistor	24.1	25.2	25.2	26.8	25.7	26.8	26.8	23.5
Solar Cell (MR) Temp.	31.3	35.3	33.0	36.0	31.8	33.8	34.0	23.4
Solar Cell (UR) Temp.	27.4	32.1	31.0	33.2	26.7	31.6	32.0	22.2
Solar Cell (ELFR)	14.8	20.5	17.5	24.5	13.1	20.1	22.0	7.3
Solar Cell (LFR)	25.8	30.1	27.3	31.0	23.0	28.3	29.0	16.7
Sail Comm. Temp.	23.7	24.7	24.2	26.4	25.3	26.4	26.4	24.2
Harvard Temp.	47.0	47.1	48.0	50.0	49.0	51.0	51.0	48.0
Battery Voltage	18.65	18.65	19.81	19.83	19.83	19.86	19.86	17.77
Battery Charge Rate	1.46	1.71	1.13	1.34	1.13	1.59	1.63	0.08

the sun. On 25 May all conditions looked good and an attempt was made to turn on the control system to read the pitch angle. About 15 seconds after the control system command was issued the undervoltage switch turned off everything on the spacecraft. This is a safety valve which turns off all power on the spacecraft automatically when the battery voltage drops from its normal of 19 or 20 volts to 16.5 volts. This is done to prevent the batteries from becoming completely discharged in the event of a malfunction which drew excessive current. The spacecraft could not then be commanded. About one minute later the batteries had recharged enough to turn on the RF signal (transmitters) again.

On 26 May the turn on operation was tried again with the same results. Discussions were held between GSFC personnel and BBRC personnel and it was decided to take a gamble to get the control system on. The undervoltage switch would be bypassed, risking draining the batteries completely, if necessary, to try to get the control system on. If it came on and locked into the sun the batteries would be recharged and the observatory would be in good shape. If it did not lock on the batteries could drain completely and the observatory would be dead. June 1 was picked because it was the earliest date to provide reasonable good daylight passes over Fort Myers.

During the first pass over Fort Myers three of the wheel experiments were commanded on. This was done to get some experiment data in case the spacecraft turn on was not successful. These experiments were on for six minutes of the planned seven minutes when the undervoltage switch turned all systems off. All three experiments appeared to operate normally and it looked like good data was obtained. On the next pass over Fort Myers, the undervoltage switch bypass was closed and the control system was commanded on. It was immediately successful and the control system locked on. Data showed that the battery voltage was pulled down to 15.4 volts on acquisition but in about one minute was back up to about 19 volts. The pitch angle was readout at +2 degrees. All spacecraft data looked good.

On the third pass the undervoltage switch bypass was opened, the four experiments which were operating when the observatory was placed in stow were turned on (one of these operates only at night) and the tape recorder was turned on.

Initial data looked like the observatory had only been off for a matter of minutes rather than seven months. The spin rate was normal at 30.66 rpm, the battery voltage was about 20 volts, the charge rate was about 2 amps, pointing accuracy was within one minute of arc in azimuth and elevation, pitch gas pressure was 37.5 psi and spin gas pressure was 230 psi.

The first indication of malfunction was at tape recorder playback after the first orbit of operation. The tape recorder had apparently developed a flat spot from remaining idle for so long. This caused a periodic dropout of data. As a result this data cannot be reduced by computer and would have to be reduced by hand.

Discussions with the experimenters revealed they are very anxious to get more data. Although none have had an opportunity to analyze any data yet, Mr. K. Frost's (GSFC) Gamma Ray experiment indicated that the sequencing eyes of his experiment located on the wheel rim are working well after about 16 months in orbit environment. He is planning on using nine of these eyes on a future experiment and this is the first data on performance and life expectancy he has been able to gather. Also his detectors appear to be working. There had been some concern about the ability of this experiment to come on again once it had been turned off. The Ames Research Center has called and asked for specific data if possible. They will hand reduce any data that they can get from their emissivity experiment.