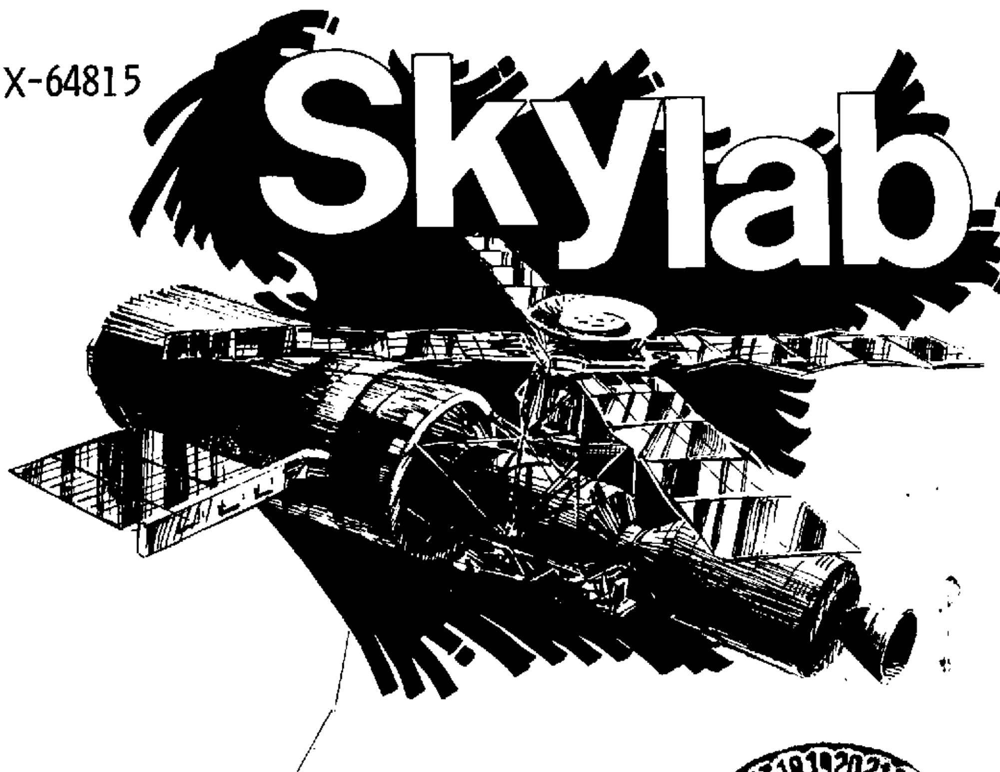
June 28, 1974

NASA TECHNICAL MEMORANDUM

NASA TM X-64815



MSFC SKYLAB APOLLO TELESCOPE MOUNT SUMMARY MISSION REPORT

Skylab Program Office

JUL 1974
NASA STI FACILITY
INPUT BRANCH

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

N74-28311

(NASA-TM-X-64815) MSFC SKYLAB APOLLO TELESCOPE MOUNT SUMMARY MISSION REPORT (NASA) 142 p HC $4.75 CSCL 22A

Unclas
G3/30 43135

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM X-64815	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE MSFC Skylab Apollo Telescope Mount Summary Mission Report		5. REPORT DATE June 28, 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) A.R. Morse		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by ATM Project Office

16. ABSTRACT

This report presents a summary of the Apollo Telescope Mount (ATM) performance during the 8.5-month Skylab mission. The report contains a brief description of each ATM system, system performance summaries, discussion of all significant ATM anomalies which occurred during the Skylab mission, and, in an appendix, a summary of the Skylab ATM Calibration Rocket Project (CALROC). The text is supplemented and amplified by photographs, drawings, curves, and tables.

The report shows that the ATM not only met, but exceeded premission performance criteria, and that participation of Man in space for this scientific investigation greatly enhanced the quality and quantity of the data attained.

17. KEY WORDS Skylab Apollo Telescope Mount	18. DISTRIBUTION STATEMENT Unclassified - Unlimited James D Ledbetter

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	142	NTIS

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

ACKNOWLEDGEMENT

This report was published by the Martin Marietta Corporation, Huntsville, Alabama. The editor wishes to acknowledge all the personnel who made technical contributions, suggestions, and comments in the formulation of this document. This summary mission report used much technical data and material evolved from conceptual design through the post mission testing. Acknowledgement is given to all personnel participating directly in the support of mission operations and the preparation of this document.

It is not possible to list all the persons contributing to this program. However, we are especially indebted to the significant contributions made by the George C. Marshall Space Flight Center Mission Support Groups:

John D. Hoverkamp, Mission Sequence Evaluation
William B. Chubb, Attitude and Pointing Control
Alvan P. Woosley, Electrical Power
Billy M. Adair, Instrumentation and Communication
George D. Hopson, Thermal and Environmental Control
Jerald L. Vaniman, ATM Thermal Control
Robert G. Eudy, Structures and Mechanical
Jimmy R. Thompson, Crew Systems
Charles M. Davis, Contamination Control

PRINCIPAL INVESTIGATORS

S052 White Light Coronagraph
Dr. R. MacQueen, High Altitude Observatory, Boulder, Colorado

S054 X-Ray Spectrographic Telescope
Dr. G. S. Vaiana, American Science & Engineering, Cambridge, Mass.

S055A Ultraviolet Scanning Polychrometer Spectroheliometer
Dr. E. Reeves, Harvard College Observatory, Cambridge, Mass.

S056 X-Ray Telescope
Mr. J. Milligan, Marshall Space Flight Center, Huntsville, Ala.

S082A Extreme Ultraviolet Spectroheliograph
S082B Spectrograph and Extreme Ultraviolet Monitor
Dr. R. Tousey, Naval Research Laboratory, Washington, D.C.

SKYLAB CREWS

SL-2

Charles (Pete) Conrad Jr.	Commander
Paul J. Weitz	Pilot
Joseph P. Kerwin	Scientist Pilot

SL-3

Alan L. Bean	Commander
Jack R. Lousma	Pilot
Owen K. Garriott	Scientist Pilot

SL-4

Gerald P. (Jerry) Carr	Commander
William R. (Bill) Pogue	Pilot
Edward G. (Ed) Gibson	Scientist Pilot

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

Section 1

INTRODUCTION

This report describes the performance of the Apollo Telescope Mount (ATM), figure 1-1, during the Skylab Mission and of the ATM Module contributions to the overall success of Skylab. This report contains a brief description of the ATM systems, the ATM systems performance, and a description of ATM anomalies.

The ATM performance not only met, but in many instances exceeded, both design requirements and premission objectives. The primary objectives delegated to the ATM in support of the Skylab Mission were:

1. Acquire high resolution observations of the structure and behavior of the Sun from above the Earth's atmosphere.

2. Evaluate the ability and desirability of man to operate complex scientific instruments in the space environment.

3. Obtain engineering and technological data needed for development of advanced astronomical systems.

The loss of the Orbital Workshop (OWS) meteoroid shield during Skylab 1 launch and the subsequent loss of the OWS electrical power generating capabilities seriously jeopardized the Skylab Mission. The exceptional performance of the ATM systems minimized the thermal and electrical stresses on Skylab during the early mission period and provided ground personnel with the necessary time to develop the equipment and procedures which subsequently made Skylab a habitable and useful space station.

During this early mission period, the ATM electrical power system was the only source of power generation. The ATM communication system provided the means for corrective ground commands while the ATM digital computer controlled the attitudes that optimized thermal and electrical balance. The ATM attitude and pointing control system control moment gyroscopes responding to the ATM digital computer commands effectively maintained Skylab attitudes.

The effectiveness of the ATM as a solar observation platform is proven by the quality of the transmitted and photographed solar data. A total number of 171,098 photographs and approximately 2,000 hours of photoelectric data was obtained. These data are superior to any previously evaluated and are expected to result in significant scientific discoveries which will revise many theories of solar physics. These discoveries will be identified

Section 1

INTRODUCTION

This report describes the performance of the Apollo Telescope Mount (ATM), figure 1-1, during the Skylab Mission and of the ATM Module contributions to the overall success of Skylab. This report contains a brief description of the ATM systems, the ATM systems performance, and a description of ATM anomalies.

The ATM performance not only met, but in many instances exceeded, both design requirements and premission objectives. The primary objectives delegated to the ATM in support of the Skylab Mission were:

1. Acquire high resolution observations of the structure and behavior of the Sun from above the Earth's atmosphere.

2. Evaluate the ability and desirability of man to operate complex scientific instruments in the space environment.

3. Obtain engineering and technological data needed for development of advanced astronomical systems.

The loss of the Orbital Workshop (OWS) meteoroid shield during Skylab 1 launch and the subsequent loss of the OWS electrical power generating capabilities seriously jeopardized the Skylab Mission. The exceptional performance of the ATM systems minimized the thermal and electrical stresses on Skylab during the early mission period and provided ground personnel with the necessary time to develop the equipment and procedures which subsequently made Skylab a habitable and useful space station.

During this early mission period, the ATM electrical power system was the only source of power generation. The ATM communication system provided the means for corrective ground commands while the ATM digital computer controlled the attitudes that optimized thermal and electrical balance. The ATM attitude and pointing control system control moment gyroscopes responding to the ATM digital computer commands effectively maintained Skylab attitudes.

The effectiveness of the ATM as a solar observation platform is proven by the quality of the transmitted and photographed solar data. A total number of 171,098 photographs and approximately 2,000 hours of photoelectric data was obtained. These data are superior to any previously evaluated and are expected to result in significant scientific discoveries which will revise many theories of solar physics. These discoveries will be identified

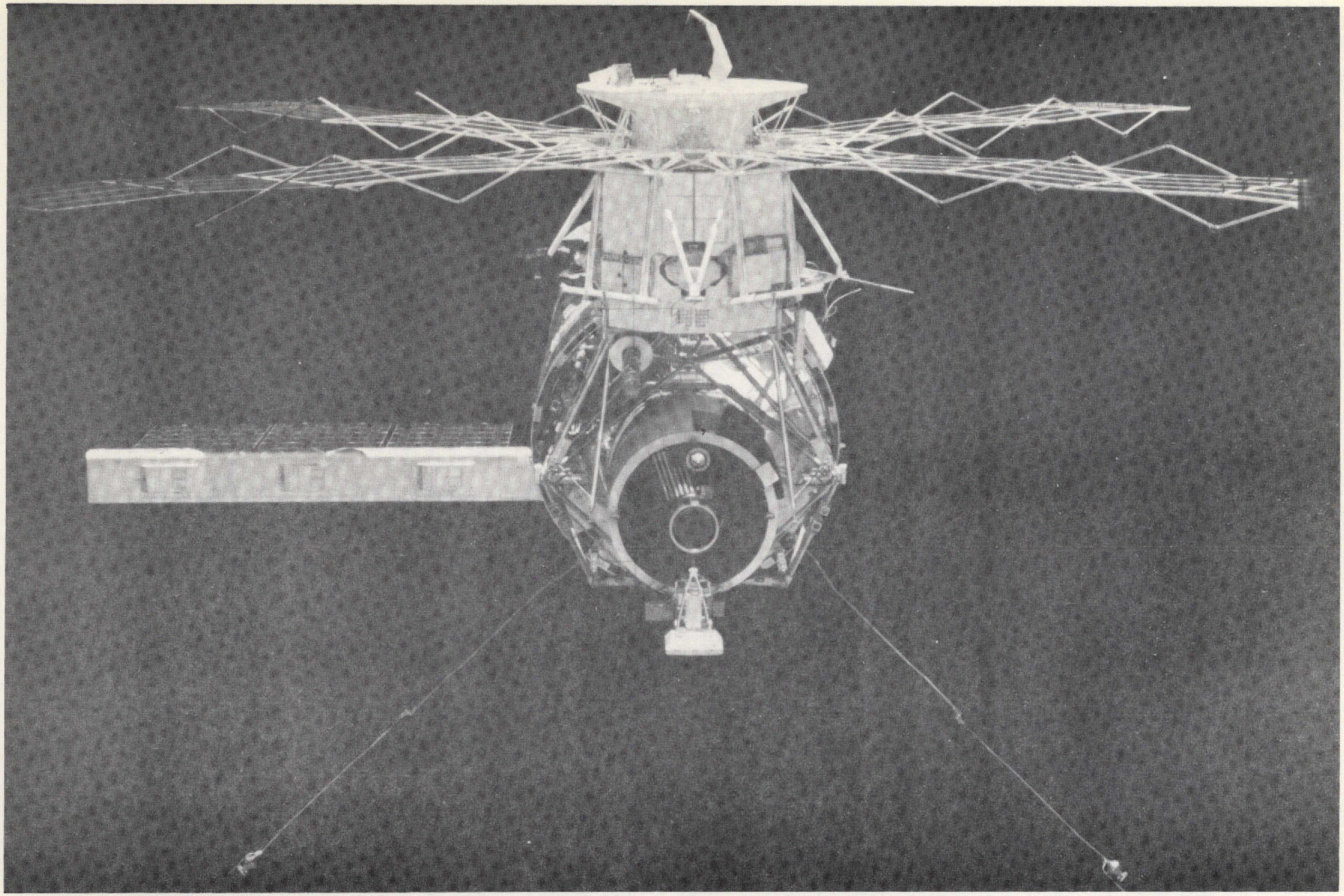


Figure 1-1. Apollo Telescope Mount in Orbital Skylab Configuration

by the Principal Investigators in their respective reports after completion of their evaluation.

This report provides the National Aeronautics and Space Administration Headquarters, Office of Space Science and other interested agencies with a summary of the ATM performance during the period from Skylab 1 launch through Skylab 4 splashdown.

The Skylab ATM systems technical memorandums are listed below:

1. TM X-64811 MSFC Skylab Apollo Telescope Mount Final Technical Report.

2. TM X-64817 MSFC Skylab Attitude & Pointing Control System Mission Evaluation Report.

3. TM X-64818 MSFC Skylab Electrical Power System Mission Evaluation Report.

4. TM X-64819 MSFC Skylab Instrumentation & Communication System Mission Evaluation Report.

5. TM X-64821 MSFC Skylab Apollo Telescope Mount Experiment Systems Mission Evaluation Report.

6. TM X-64823 MSFC Skylab Apollo Telescope Mount Thermal Control System Mission Evaluation Report.

7. TM X-64824 MSFC Skylab Structures & Mechanical Systems Mission Evaluation Report.

8. TM X-64825 MSFC Skylab Crew Systems Mission Evaluation Report.

9. TM X-64826 MSFC Skylab Contamination Control Systems Mission Evaluation Report.

SECTION II. CONFIGURATION

MISSION DESCRIPTION

The Skylab mission profile, figure 2-1, consisted of six distinct phases of operation: the placing of Skylab into Earth orbit, three manned periods, and two unmanned periods. Skylab, consisting of the Orbital Workshop, Airlock Module, Multiple Docking Adapter and Apollo Telescope Mount, figure 2-2, was launched as one unit with a two-stage Saturn V launch vehicle. Following orbital insertion the ATM and its solar arrays were successfully deployed, figure 2-3. After 10 days of maneuvers to maintain workshop thermal and electrical balance while ground support personnel developed the necessary solar shields and OWS solar array release equipment for OWS repairs, all systems were confirmed ready to support crew operations.

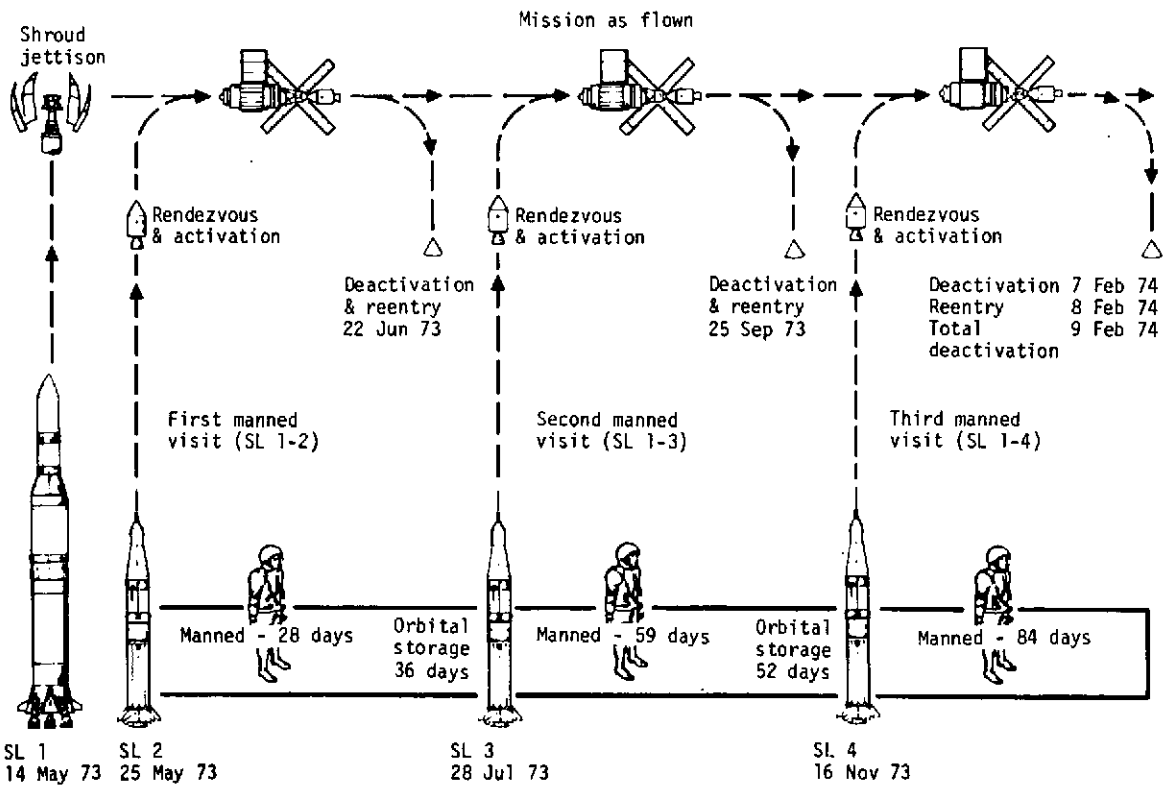


Figure 2-1. Skylab Mission Profile

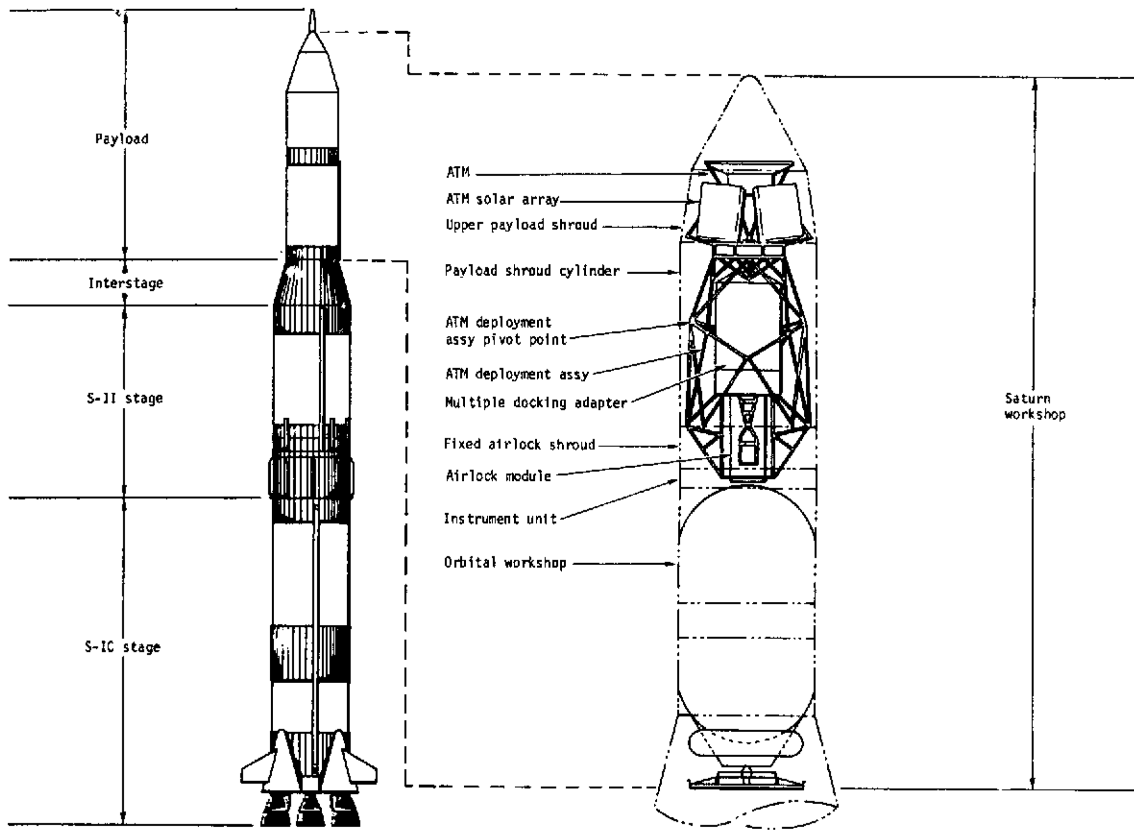


Figure 2-2. Skylab Launch Configuration

The first three-man crew was launched in the Command and Service Module by a Saturn IB vehicle. After docking with the Skylab, the crew proceeded with OWS repair activities which included deployment of the parasol solar shield and activation of systems in accordance with procedures and ground management criteria. After completion of the repair activities Skylab was ready for normal manned program activities. At the end of the first 28-day period, the crew returned to Earth in the Command Module and Skylab operated in an unmanned mode for a 36-day period. The second three-man crew was launched by another Saturn IB for a 59-day period of manned Skylab operations. After the return of the second crew to Earth, Skylab operated in an unmanned mode for a 52-day period. The third three-man crew was then launched with the third Saturn IB, for an 84-day period in orbit. Total Skylab mission activities covered a period of approximately 8.5 months.

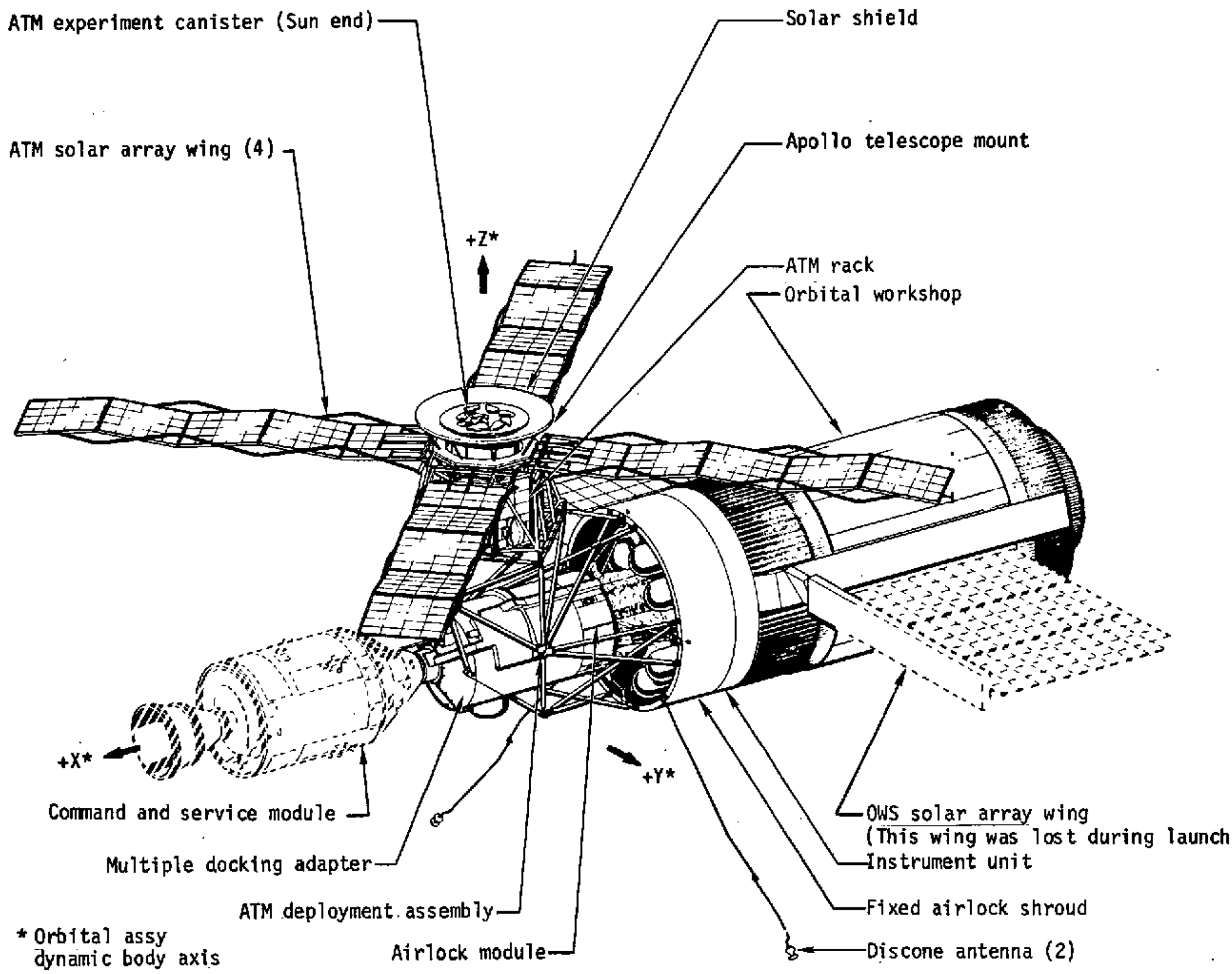


Figure 2-3. Saturn Workshop Configuration

ATM operations during Skylab 2 mission consisted of the crew conducting the ATM solar observatory experiment programs. The ATM activities of the Skylab 3 crew were similar to those of the previous mission; however, more emphasis was placed on solar astronomy and additional crew observation time was allocated for observing targets of opportunity. Skylab 4 crew activities were enhanced by initiating regular planning sessions between the Principal Investigators and the crew during the mission to closely coordinate targets of opportunity activities. In addition, Skylab 4 activities included observation of comet Kohoutek as well as additional time for observing targets of opportunity.

ATM SYSTEM DESCRIPTION

The ATM weighed approximately 11,200 kilograms, measured 6 meters across with the solar array folded, and 31 meters with the solar array extended. The solar array generated 10.5 kilowatts nominal power in the sunlight with an effective exposed area of about 110 square meters.

The ATM was designed to accommodate eight solar astronomy observation instruments and systems to provide attitude control for the entire Skylab and pointing control for the solar experiment canister. The ATM contained thermal control, telemetry, command receiving, and electrical power systems. The ATM electrical system was designed to share 2,500 watts with the Airlock Module power system. The controls and visual displays for the ATM systems and solar inscruments were located on the ATM control and display console mounted in the Multiple Docking Adapter.

The ATM structure was designed as a rack and canister. The rack was an octagonal truss-type structure supporting the canister and experiment support equipment. The rack was approximately 3.35 meters across and 3.66 meters high, with a 4.37 meter diameter solar shield at the Sun-end to protect the electronic components from the Sun's direct radiation. The rack was designed to accommodate the experiment canister internally with external attachment points for the solar array, deployment assembly, and the ATM subsystem equipment. The ATM experiments were mounted in the ATM canister, as shown in figure 2-4. The experiment canister was a cylinder approximately 2.13 meters in diameter, 3.05 meters long, and closed at both ends except for the solar experiment viewing and film retrieval doors. The canister incorporated an internal cruciform spar to provide mounting points for the eight experiments. The canister was attached to the rack by means of flex-pivot gimbal rings and a roll ring. The roll ring was supported by rollers mounted on the rack, permitting the canister rotation. The active thermal control system equipment was mounted externally on the lateral wall of the MDA end to provide thermal control for the experiment package.

ATM Experiments System

The ATM experiments were designed to provide high resolution data, in the spectral range from 2 to 7,000 angstroms, of the entire solar disk and corona or features of interest. The designs provided for

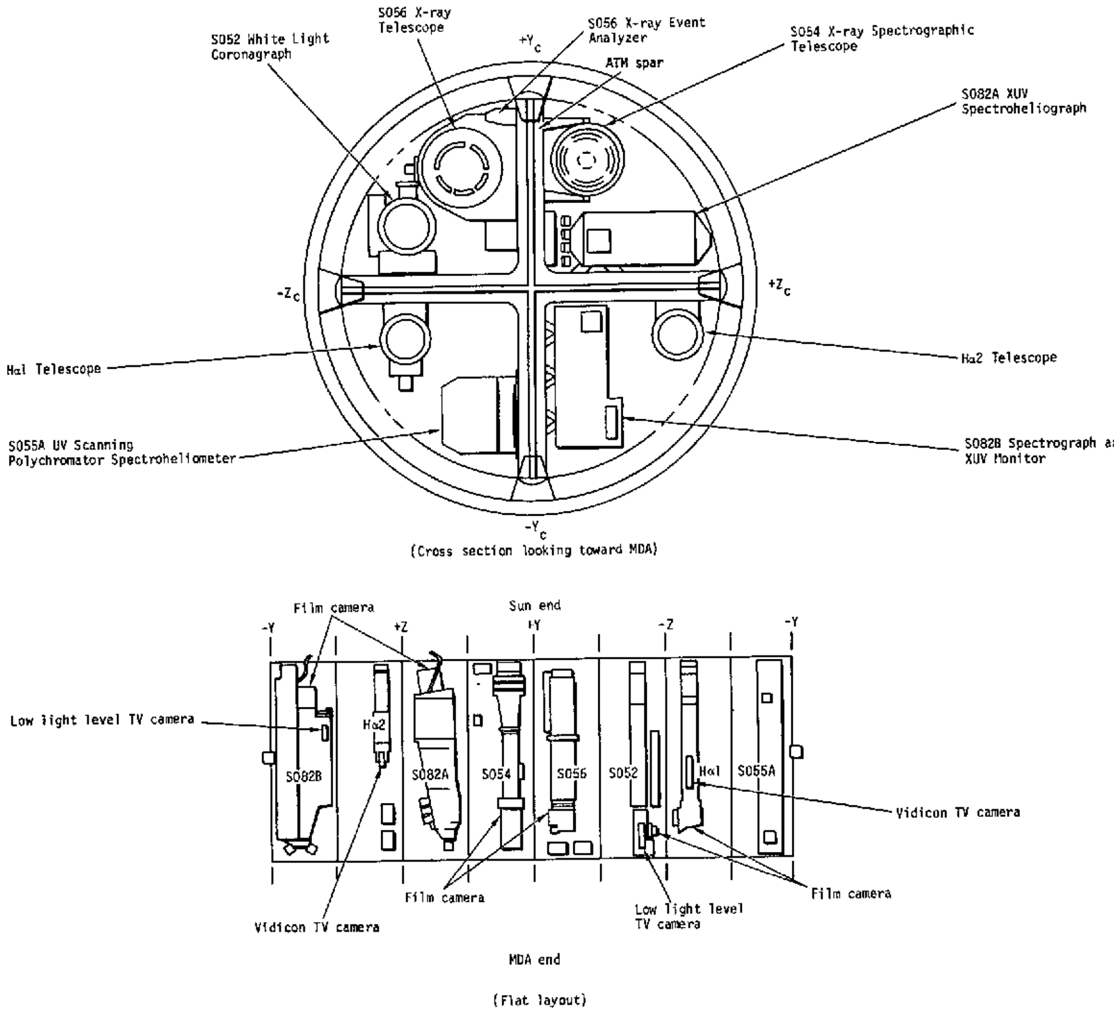
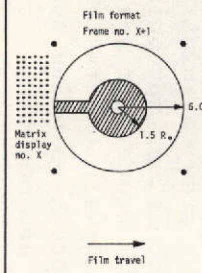
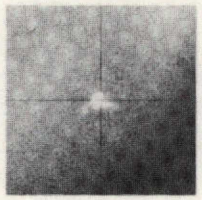
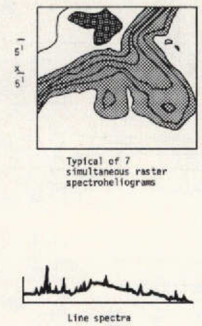
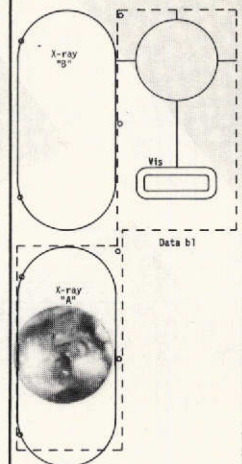
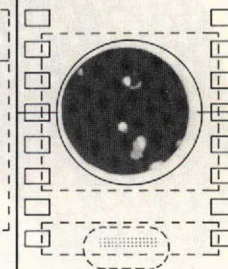
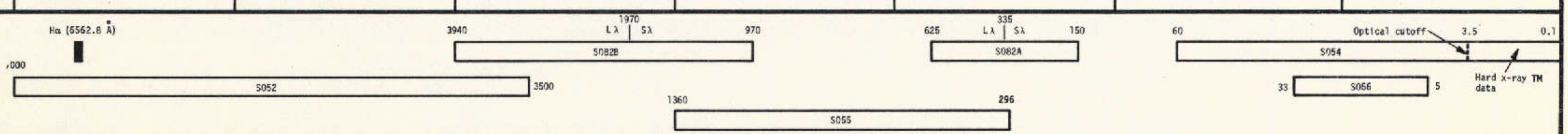


Figure 2-4. ATM Experiment Arrangement

data to be stored on film for crew return to Earth, telemetered real time, or stored on tape for delayed transmission to the Space Tracking Data Network. An integrated summary of the experiments including the overall wavelength coverage, type of data obtained, and selected design parameters is presented in table 2-1. The integrated canister design allowed the crew to point the canister, with an accuracy within 2.5 arc seconds, at any point on the solar disk or within 24 arc minutes of Sun center for solar phenomena data collection. The ATM interfaced with the instruments to provide electrical power, thermal control, pointing synchronization and timing signals, data downlink, and mounting.

Table 2-1. ATM Instrument Integrated Summary

	S052 WLC	Hα1 & 2	S082B XUV slit	S055 Scan spect	S082A XUV spect	S054 X-ray spect	S056 X-ray tele
Primary objective	Observations of solar corona	Provide and record ATM pointing	Record line spectra of chromosphere	Observations of chromosphere and lower corona	XUV images of chromosphere and lower corona	X-ray images and spectra of lower corona	X-ray images of lower corona
Prime scientific data	 Photographic	 Hα 1 only photographic	 'hotographic	 Photoelectric	 Photographic	 Photographic	 Photographic
Available film	8,025 Frames/cam 5 cameras	15,400 Frames/mag 5 magazines	1,608 Frames/cam 4 cameras	Data recorded on ATM tape recorder and telemetered to ground	201 Frames/cam 6 cameras	6,970 Frames/mag 5 magazines	6,000 frames/mag 5 magazines
Field of view	Film 1.5 to 6 D☉ (48 to 192 $\widehat{\text{min}}$) TV 1.5 to 4.5 D☉ (48 to 144 $\widehat{\text{min}}$)	Hα 1 Film - 35 $\widehat{\text{min}}$ TV: Zm (4.5 $\widehat{\text{min}}$-16 $\widehat{\text{min}}$) Hα 2 Zm (7 $\widehat{\text{min}}$-35 $\widehat{\text{min}}$)	2 $\widehat{\text{sec}}$ by 60 $\widehat{\text{sec}}$	5 $\widehat{\text{min}}$ by 5.5 $\widehat{\text{min}}$ (mirror raster scan) 5 $\widehat{\text{min}}$ by 5 $\widehat{\text{sec}}$ (mirror line scan) 5 $\widehat{\text{sec}}$ by 5 $\widehat{\text{sec}}$ (mirror fixed pos)	56 $\widehat{\text{min}}$	48 $\widehat{\text{min}}$	40 $\widehat{\text{min}}$
Spatial resolution	8 $\widehat{\text{sec}}$	1 $\widehat{\text{sec}}$ (Film) 1.5 $\widehat{\text{sec}}$ (TV zoom in)	≈3 $\widehat{\text{sec}}$	5 $\widehat{\text{sec}}$	5 $\widehat{\text{sec}}$	3 $\widehat{\text{sec}}$	2.5 $\widehat{\text{sec}}$
Spectral resolution	—	0.7Å	0.06 Å-short wavelength 0.12Å-long (design limits)	1.2Å	0.13Å for 10 $\widehat{\text{sec}}$ feature	.15Å at 7Å	2.5Å
Additional scientific data	—	—	XUV monitor (TV only)	Intensity data display	—	Hard x-ray TM data (pulse height analyzer)	X-rea data
Wavelength response in angstroms							

S052 - White Light Coronagraph - The White Light Coronagraph, figure 2-5, was designed to provide data on the solar corona in the visible region of the electromagnetic spectrum from 3,500 to 7,000 angstroms with a field of view from 1.5 to 6 solar diameters. The instrument contained three external disks for occulting the image of the solar disk to 1.5 solar radii. Data from S052 were recorded on film, provided as a video display for the crew, and transmitted to the ground for television observation.

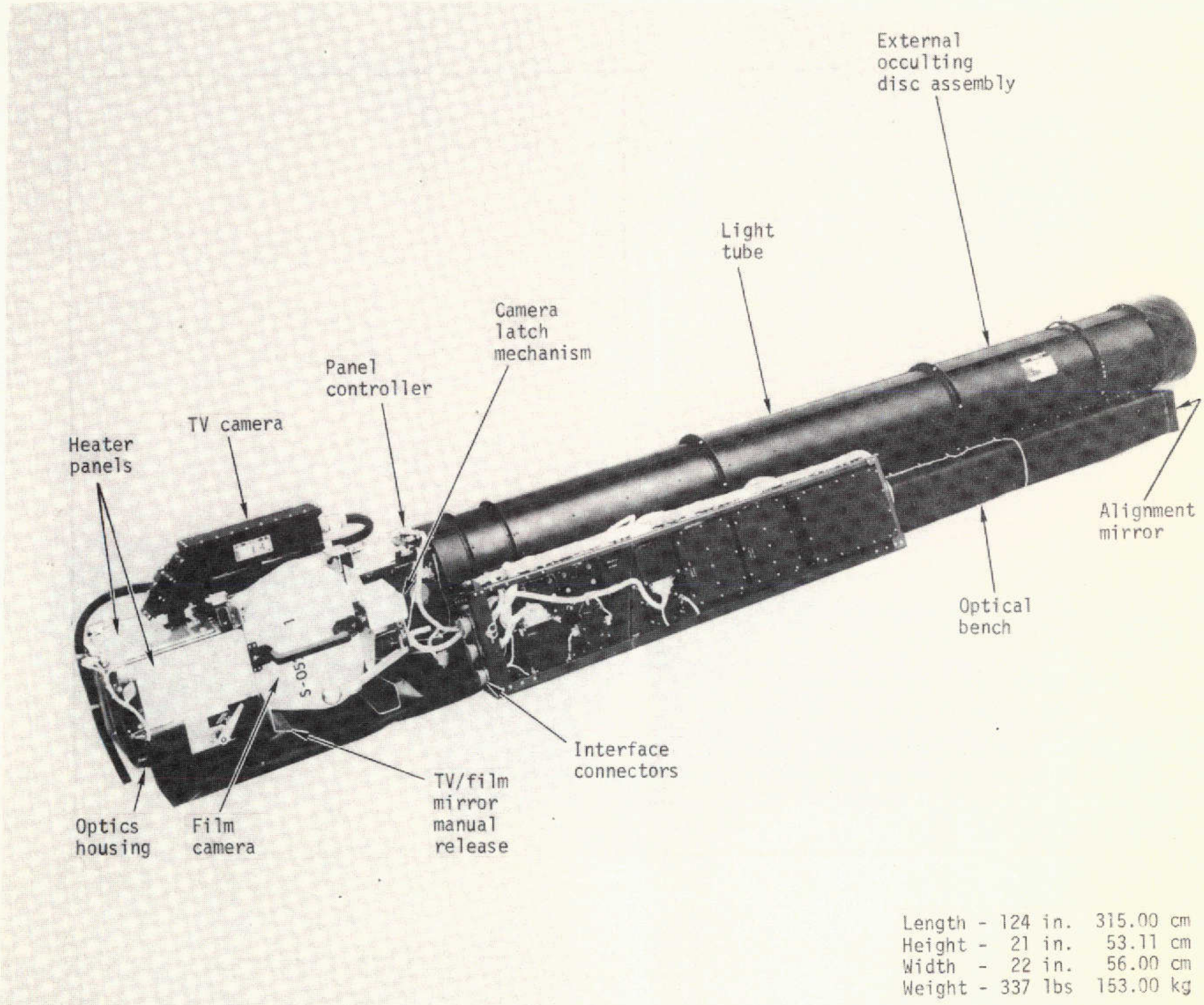
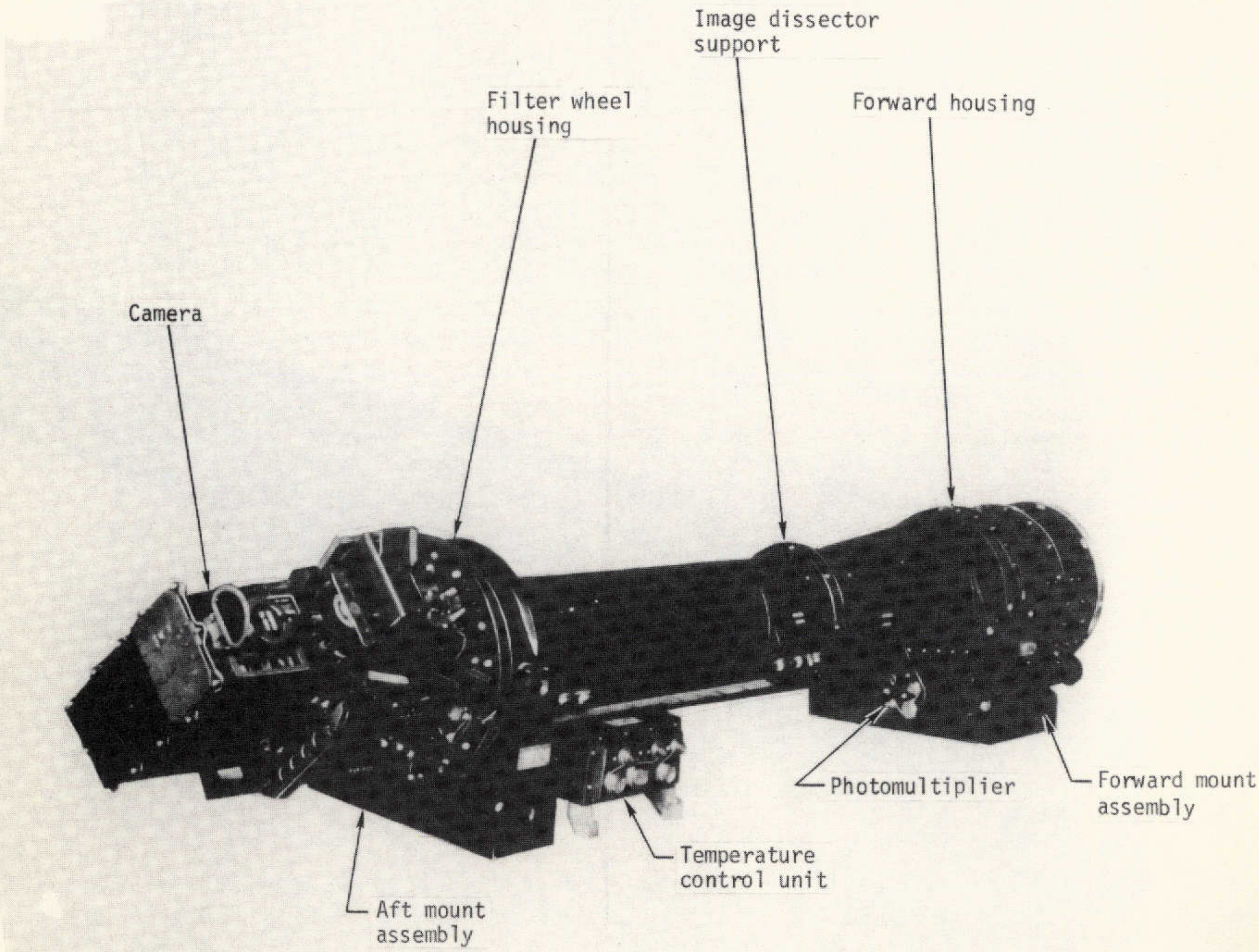


Figure 2-5. S052 White Light Coronagraph

S054 - X-Ray Spectrographic Telescope - The X-Ray Spectrographic Telescope, figure 2-6, was designed to study solar emissions in the soft X-ray spectrum, from 3 to 60 angstroms, with a field of view of 48 arc minutes covering the entire solar disk, and a spatial resolution of 2 arc seconds. The X-ray images were recorded on film and also displayed on the control and display console for the crew.



Length -	114.8 in.	291.6 cm	
Height -	19.4 in.	49.3 cm	
Width -	21.5 in.	54.6 cm	
Weight -	311.0 lbs	141.3 kg	

Figure 2-6. S054 X-Ray Spectrographic Telescope

S055A - Ultraviolet Scanning Polychromator Spectroheliometer - The Ultraviolet Scanning Polychromator Spectroheliometer, figure 2-7, was designed to measure the intensity of solar radiation from selected regions of the Sun in the extreme ultraviolet wavelength region of 1,350 to 296 angstroms with a 5 by 5 arc-second field of view. Simultaneous raster patterns of seven atomic lines were used to construct spectroheliograms. Unlike other instruments, this instrument carried no film. The data were recorded on the ATM tape recorder in digital form and transmitted via telemetry to the ground.

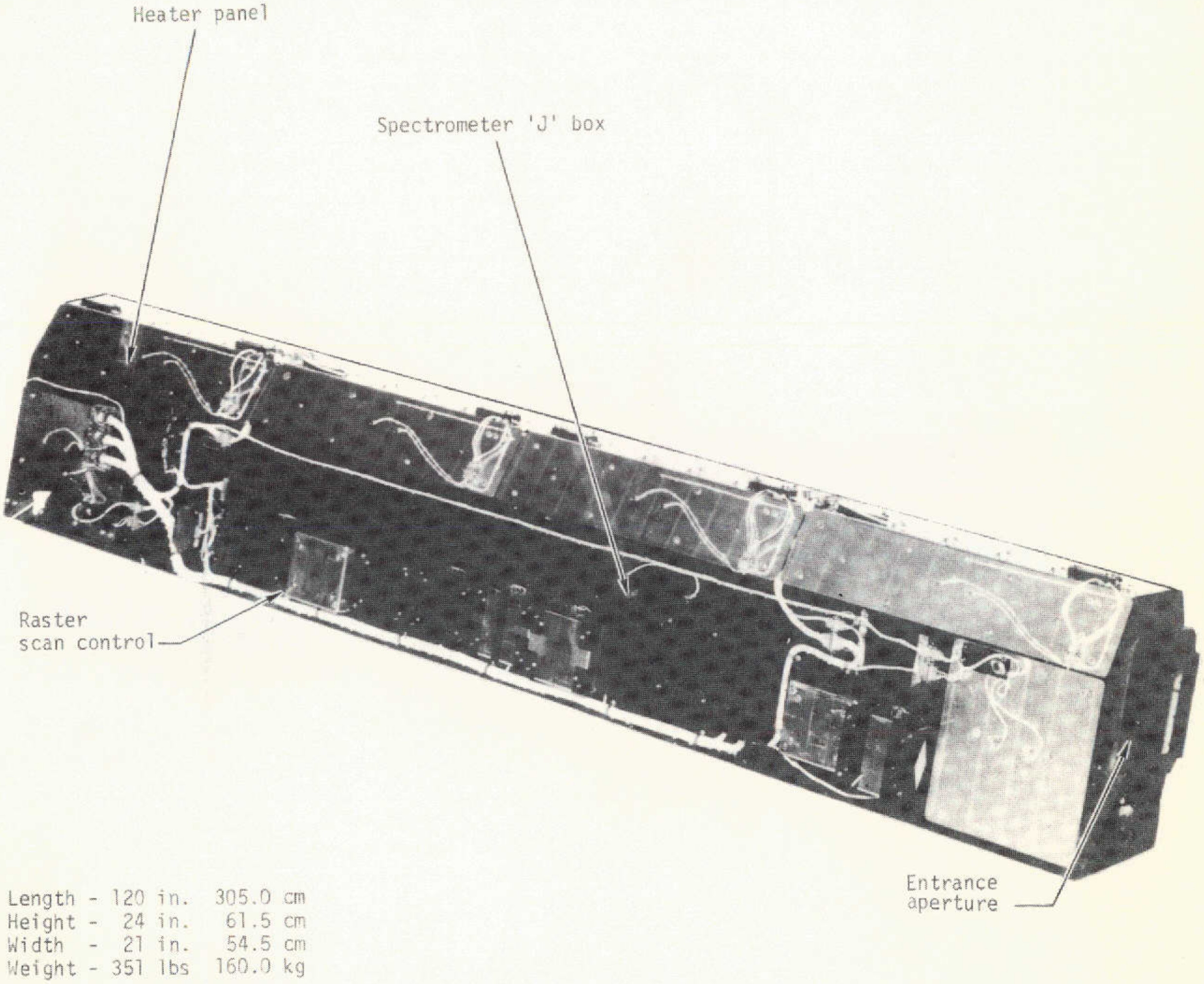
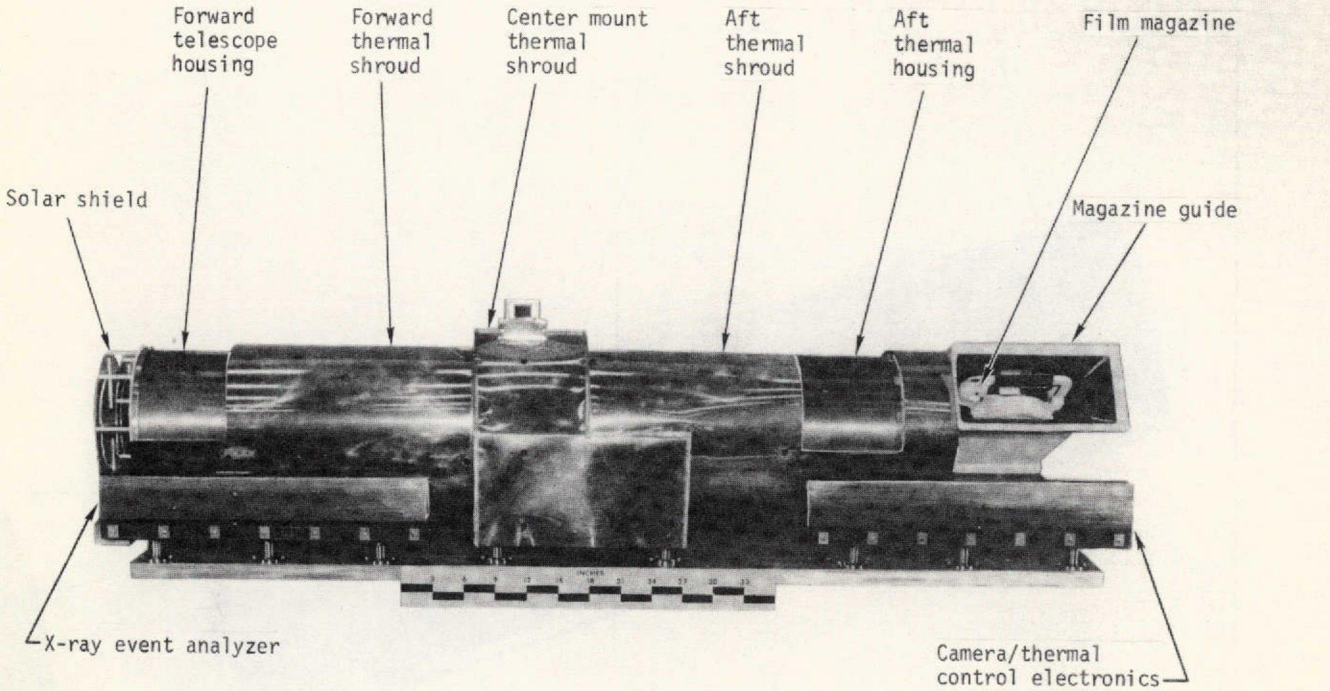


Figure 2-7. S055A Extreme Ultraviolet Scanning Polychromator Spectroheliometer

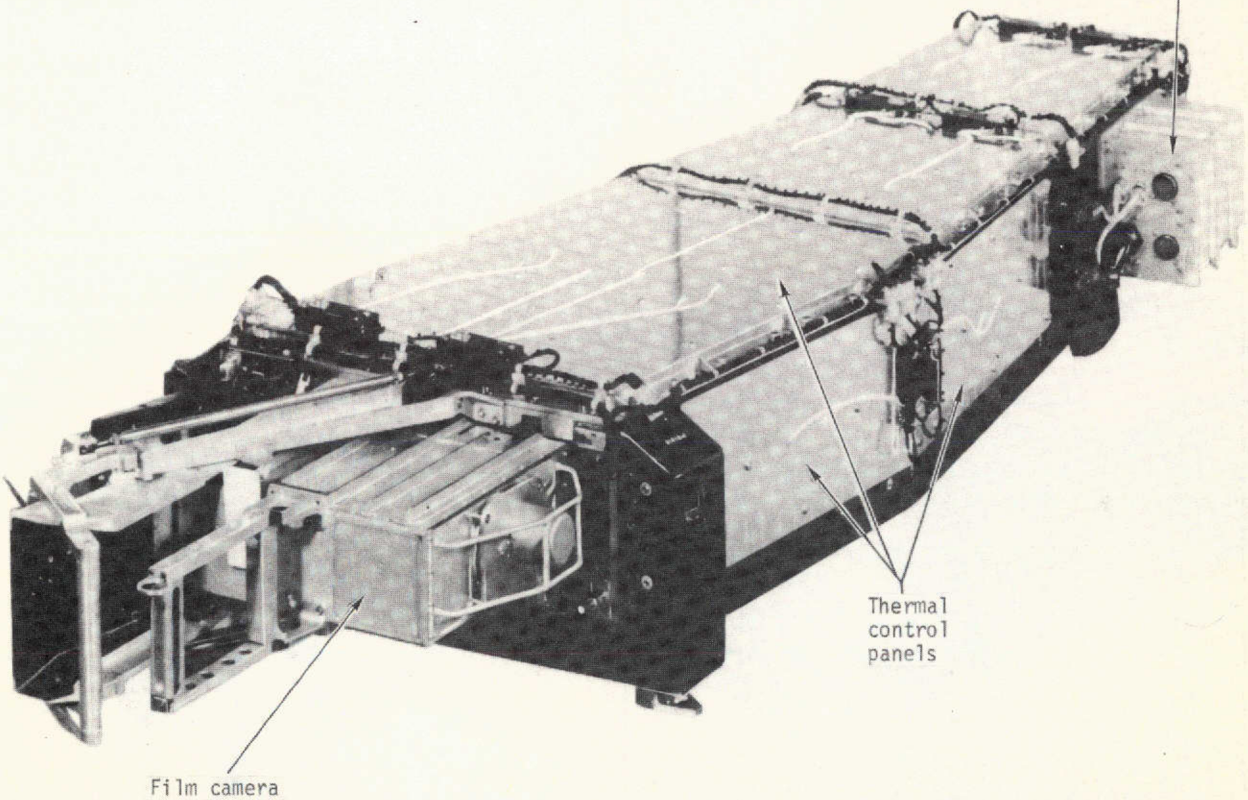
S056 - X-Ray Telescope - The X-Ray Telescope, figure 2-8, design provided for X-ray filtergrams (solar images of narrow wavelength intervals) in five bandwidths from 5 to 33 angstroms and one in visible light. The design provided for spectral data (intensity versus wavelength) in two adjacent channels of 10 wavelength bands from 2.5 to 20 angstroms. The filtergrams were recorded on film. The spectral data were displayed on the control and display console, transmitted real time to the ground, and recorded on the ATM tape recorder for delayed transmission to the ground.



Length -	105.0 in.	267.00 cm
Height -	24.5 in.	62.23 cm
Width -	23.0 in.	58.00 cm
Weight	354.0 lbs	161.00 kg

Figure 2-8. S056 X-Ray Telescope

S082A - Extreme Ultraviolet Spectroheliograph - The Extreme Ultraviolet Spectroheliograph, figure 2-9, was designed to record photographic images of the solar chromosphere and corona to 1.5 solar radii in the extreme ultraviolet wavelengths between 150 and 625 angstroms. S082A was used in conjunction with the television on S082B and S055A for data comparison.



Length -	122.6 in.	312.4 cm
Height -	16.0 in.	41.0 cm
Width -	35.0 in.	88.9 cm
Weight -	252.0 lbs	114.3 kg

Figure 2-9. S082A Extreme Ultraviolet Spectroheliograph

S082B - Spectrograph and Extreme Ultraviolet Monitor - The Spectrograph and Extreme Ultraviolet Monitor, figure 2-10, was used to photograph line spectra of small selected areas on and off the solar disk and across the limb in two wavelength bands; 970 to 1970 angstroms or 1940 to 3940 angstroms. The extreme ultraviolet monitor was used to observe the video image of the full solar disk in the wavelength band from 170 to 550 angstroms and to identify solar features of interest.

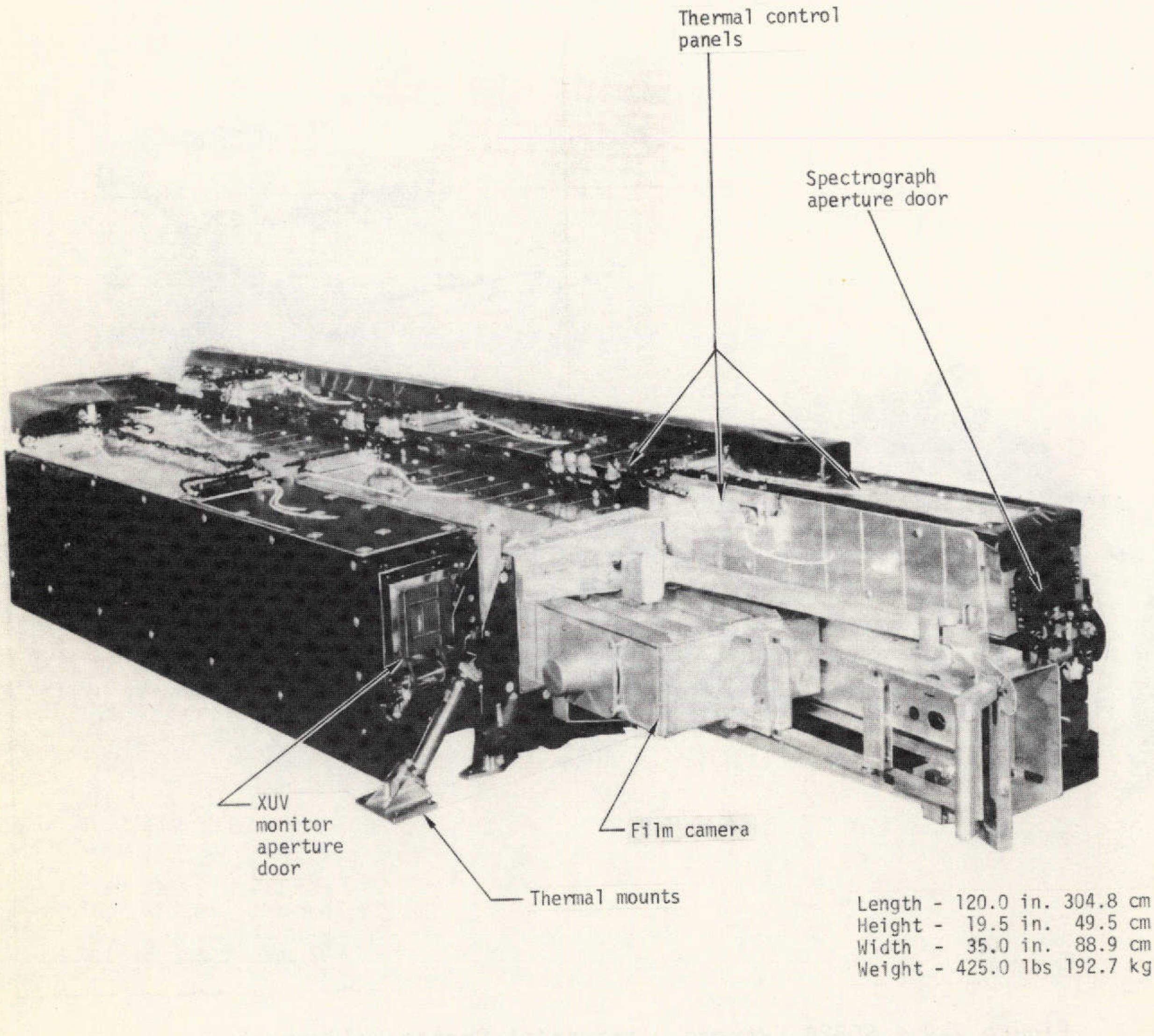


Figure 2-10. S082B Spectrograph and Extreme Ultraviolet Monitor

Hydrogen-Alpha Telescopes - The H-Alpha 1 and H-Alpha 2 telescopes, figures 2-11 and 2-12, provided a diffraction limited image of the Sun in hydrogen - alpha light (6,562.8 angstroms). Both telescopes were equipped with a vidicon, which displayed real time solar detail to the Skylab crew. The H-Alpha video images were used by the crew to observe the Sun, detect regions of scientific interest, and to point the ATM at specific features on the Sun for further study by S055A and S082B which were co-aligned with the H-Alpha telescopes. A film camera was also mounted on the H-Alpha 1 telescope to provide high resolution photographs of the solar disk and to provide a record of the ATM pointing.

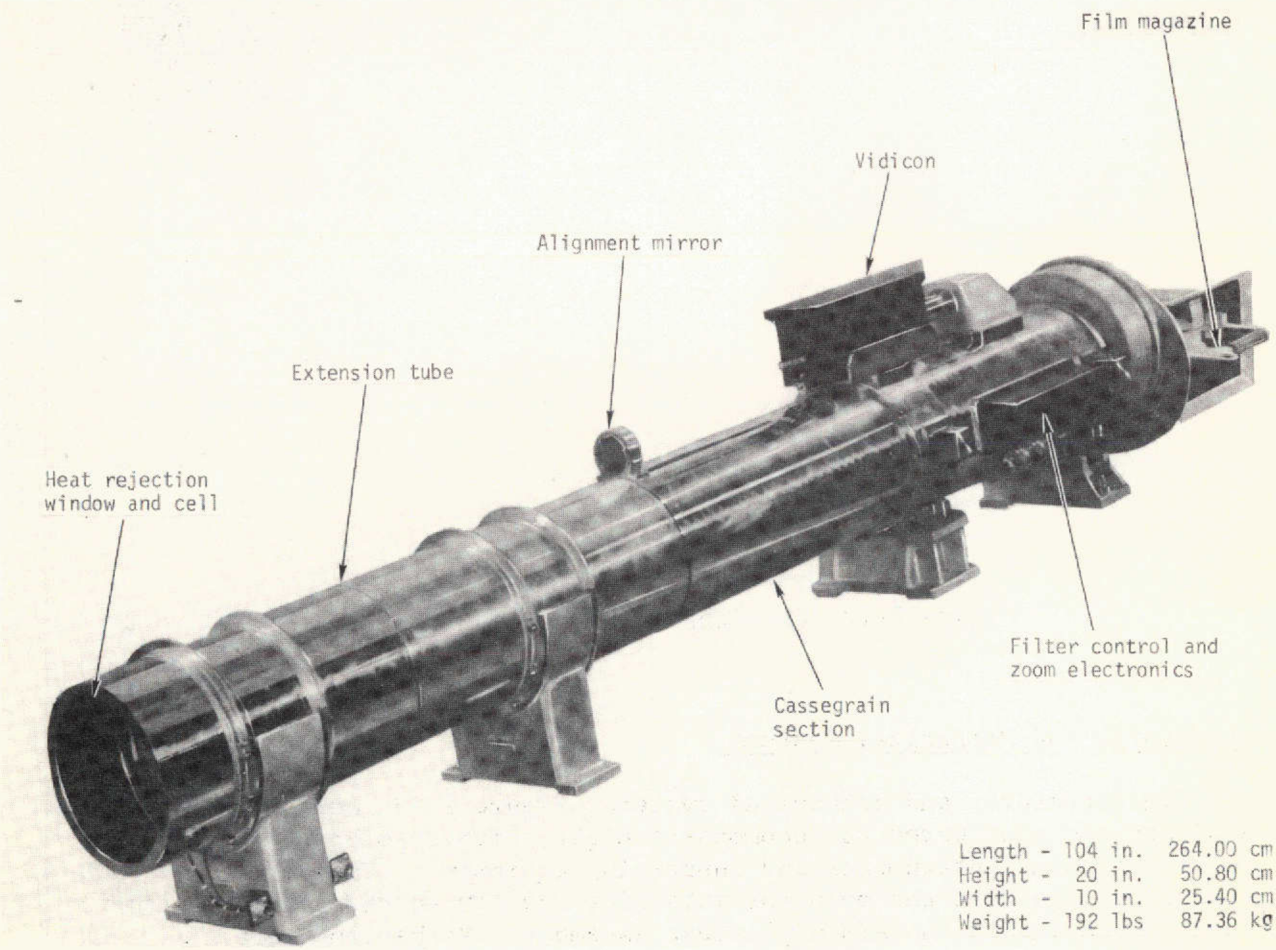
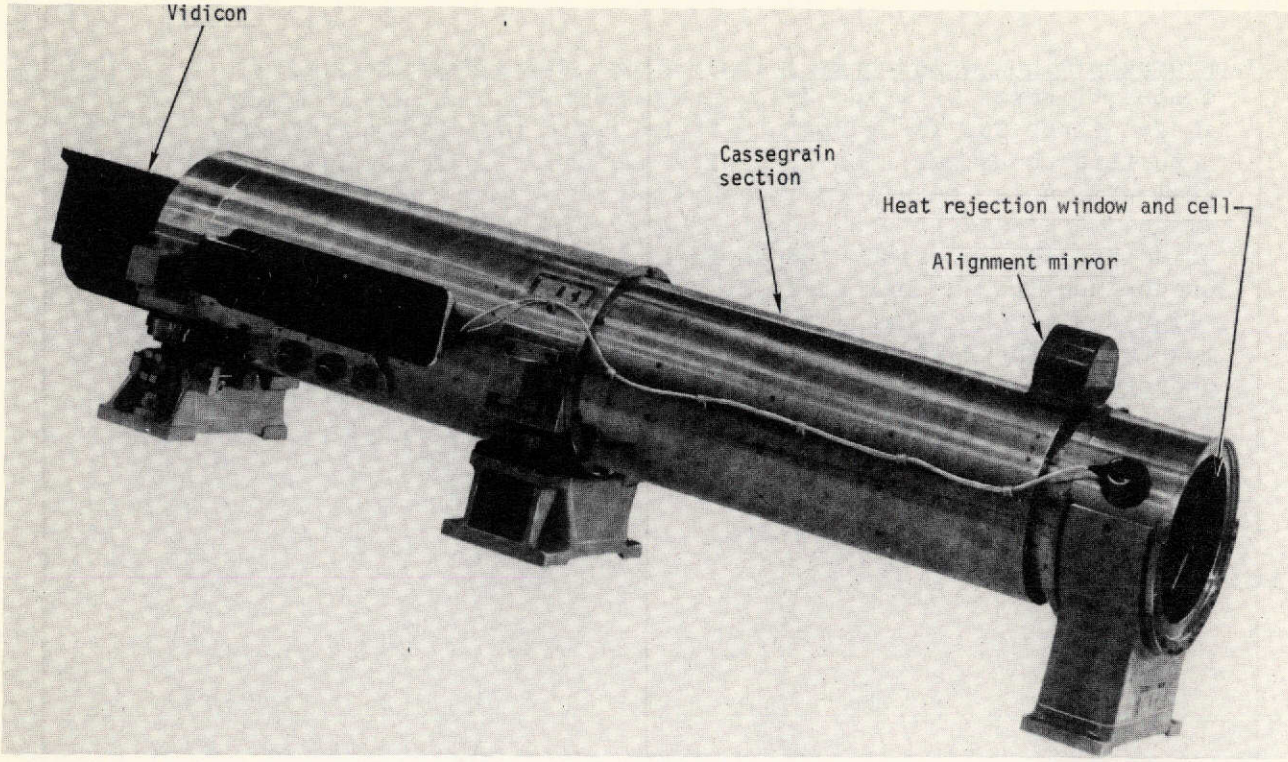


Figure 2-11. H-Alpha 1 Telescope



Length -	63.0 in.	160.00 cm
Height -	14.5 in.	36.83 cm
Width -	10.0 in.	25.40 cm
Weight -	120.0 lbs	54.60 kg

Figure 2-12. H-Alpha 2 Telescope

Structures and Mechanical Systems

The ATM structures and mechanical systems, figure 2-13, were designed and configured to accommodate eight, high resolution solar astronomy instruments and supporting equipment. The ATM structures provided the means of attaching the ATM to the payload shroud and to the ATM deployment assembly. Mechanisms were provided to deploy the ATM solar array, to unlock the canister for experiment pointing, for operation of the canister Sun-end aperture doors and film retrieval doors, and for rotating the canister on its roll axis for film retrieval doors access.

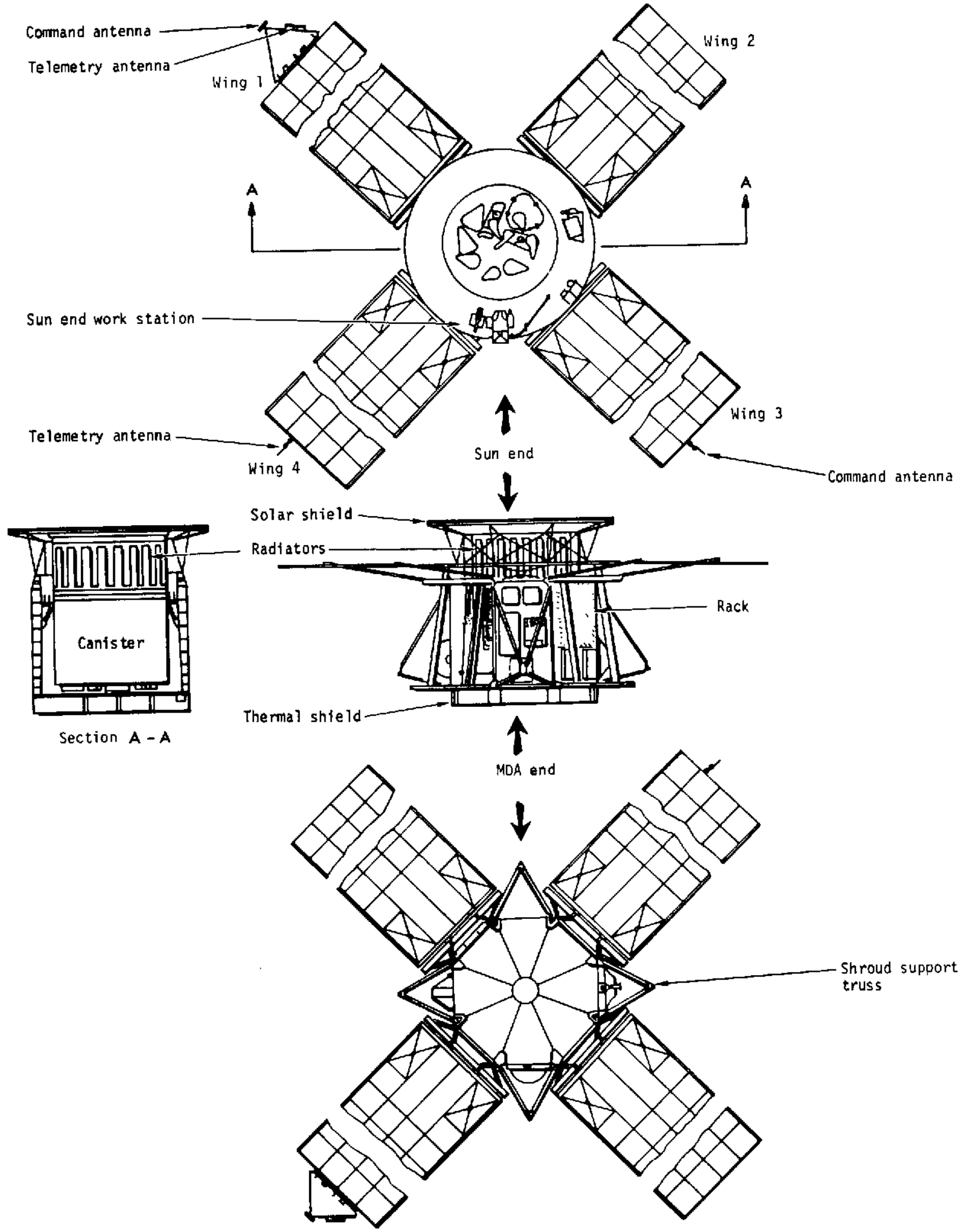


Figure 2-13. Structures and Mechanical System

Electrical Power System

The ATM electrical power system generated, conditioned, stored, controlled, and distributed 26.5 to 30.5 volt direct current to the ATM main power buses and to the Orbital Workshop transfer buses. The ATM solar array provided unregulated direct current during the sunlight portion of each orbit to the ATM Charger-Battery-Regulator Modules (CBRMs) storage devices. The ATM CBRMs provided continuous regulated direct current to the ATM main buses for distribution to ATM systems and experiments, the ATM control and display console in the Multiple Docking Adapter, and the Command and Service Module buses through the Orbital Workshop/Airlock Module electrical power transfer buses. The ATM electrical power system was paralleled with the Airlock Module electrical power system, having a power sharing capability of 2500 watts in either direction. Figure 2-14 is a diagram of the ATM electrical power system and its internal power sharing network. The internal power sharing network regulated the individual CBRMs output voltages to the ATM main power buses.

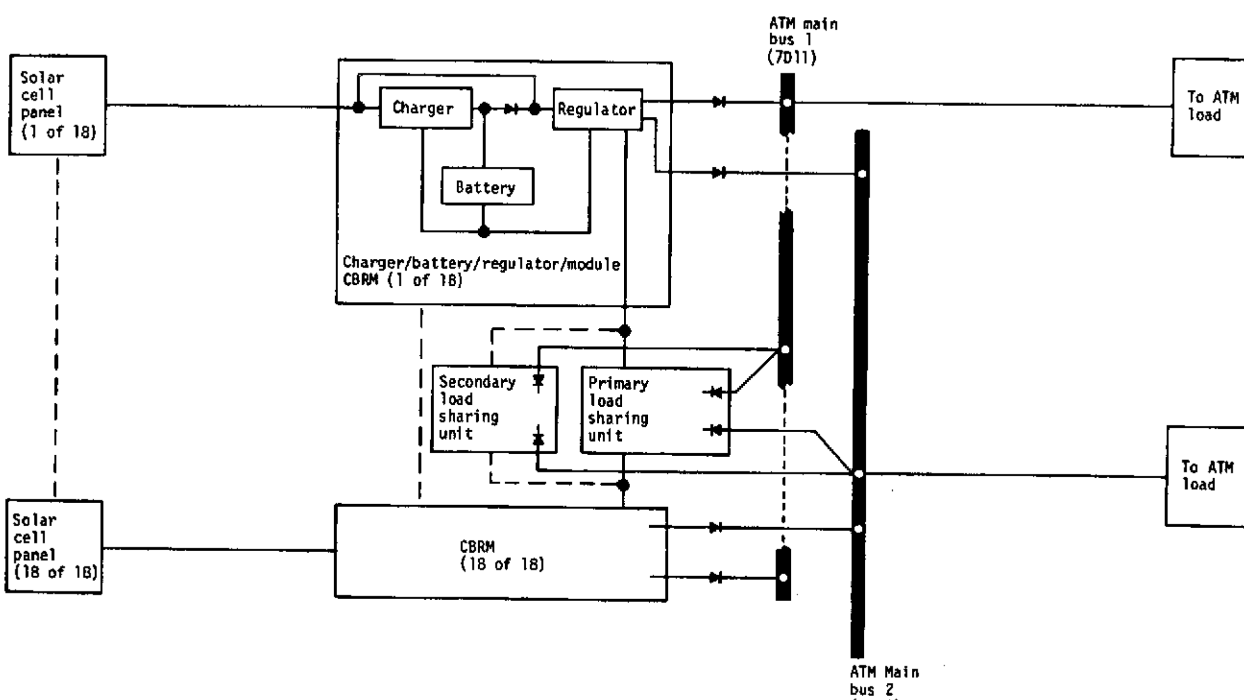


Figure 2-14. ATM Electrical Power

Thermal Control System

The ATM thermal control system was designed to provide an acceptable thermal environment for the ATM solar experiments and supporting system components. Thermal control was achieved by a combination of an active thermal control system and a semi-passive system of surface coatings, radiation shielding, insulation, thermal isolation techniques, and auxiliary thermostatically controlled heaters.

The active thermal control system was an integral part of the ATM canister. The experiments were mounted on a thermally isolated cruciform structure called the spar. The canister lateral wall consisted of the active thermal control system cold plates which provided a nearly constant temperature sink for heat radiated by the experiments. Fluid circulating through the cold plates absorbed the heat, was then transported to radiators where the heat was rejected to space. The radiators were externally mounted on the sidewall of the Sun-end canister. The design requirement specified that the fluid entering the cold plates be at a temperature of 281.49 to 284.83 kelvins, and that the cold plate fluid temperature rise be no greater than 2.78 kelvins. The individual experiment thermal control systems employed passive techniques and, except for the H-alpha experiments, individual thermostatically controlled heaters.

Thermal control for the rack-mounted ATM supporting system components was accomplished by both passive means, and by auxiliary thermostatically controlled heaters. Emphasis was placed upon minimizing the requirement for heaters.

Instrumentation and Communication System

The ATM instrumentation and communication system consisted of the data acquisition, digital command, television, and caution and warning subsystems. These subsystems were designed to perform ATM data processing and transmission, provide command control of ATM subsystems and experiments, and aid in experiment operation and pointing for solar data acquisition.

The ATM data acquisition subsystem was designed to provide the capability of accepting analog, digital, and discrete data. The 896 processed data measurements were transmitted at 72 kilobits per second to the Space Tracking Data Network in real time. Critical data measurements were converted to 4 kilobits per-second format and recorded on the auxiliary storage and playback recorder for delayed time transmission.

The ATM digital command subsystem was designed to provide the capability for commanding the ATM subsystems and experiments during manned and unmanned periods of the mission through either the ATM switch selector or the ATM digital computer.

The ATM television subsystem was designed to provide data from the experiments either to the television monitors located on the control and display console, or to the television subsystem in the Multiple Docking Adapter. Television transmission to the Space Tracking Data Network was via the telecommunications subsystem in the Command and Service Module.

The ATM caution and warning subsystem identified out-of-tolerance critical temperature and pressure measurements on the ATM by an alarm in the AM, and alert lights on the control and display console. The subsystem interfaced with the Airlock Module caution and warning subsystem by means of discrete contact closure in the control and display logic distributor.

Attitude and Pointing Control System

The attitude and pointing control system, figure 2-15, provided three-axis attitude stabilization and maneuvering capability for the entire Saturn Workshop or Orbital Assembly, and fine pointing capability for the ATM experiment canister.

The system consisted of three control subsystems: The control moment gyro subsystem and thruster attitude control subsystem, which were both managed by the ATM digital computer; and the experiment pointing control subsystem, which was controlled by the experiment pointing electronics assembly.

The control moment gyro subsystem used three orthogonally mounted, double gimbal gyros as momentum exchange devices for Saturn Workshop or Orbital Assembly attitude maneuvering and stabilization. Acquisition sun sensors provided X- and Y-axis attitude information during orbital day in solar inertial attitude, and the star tracker provided the Z-axis information. Three-axis rate information was provided by rate gyro processors.

The thruster attitude control subsystem, located on the Orbital Workshop, provided torque for Saturn Workshop or Orbital Assembly stabilization and maneuvering beyond the capability of the control moment gyros. Control of the thrusters was by the ATM digital computer.

The experiment pointing control, using the fine sun sensor as reference, fine pointed the experiment canister with accuracy and stability of 2.5 arc-seconds. The pointing was accomplished by means of actuators at the canister gimbal pivots. Canister roll positioning was accomplished by the roll position mechanism, operated at the control and display console.

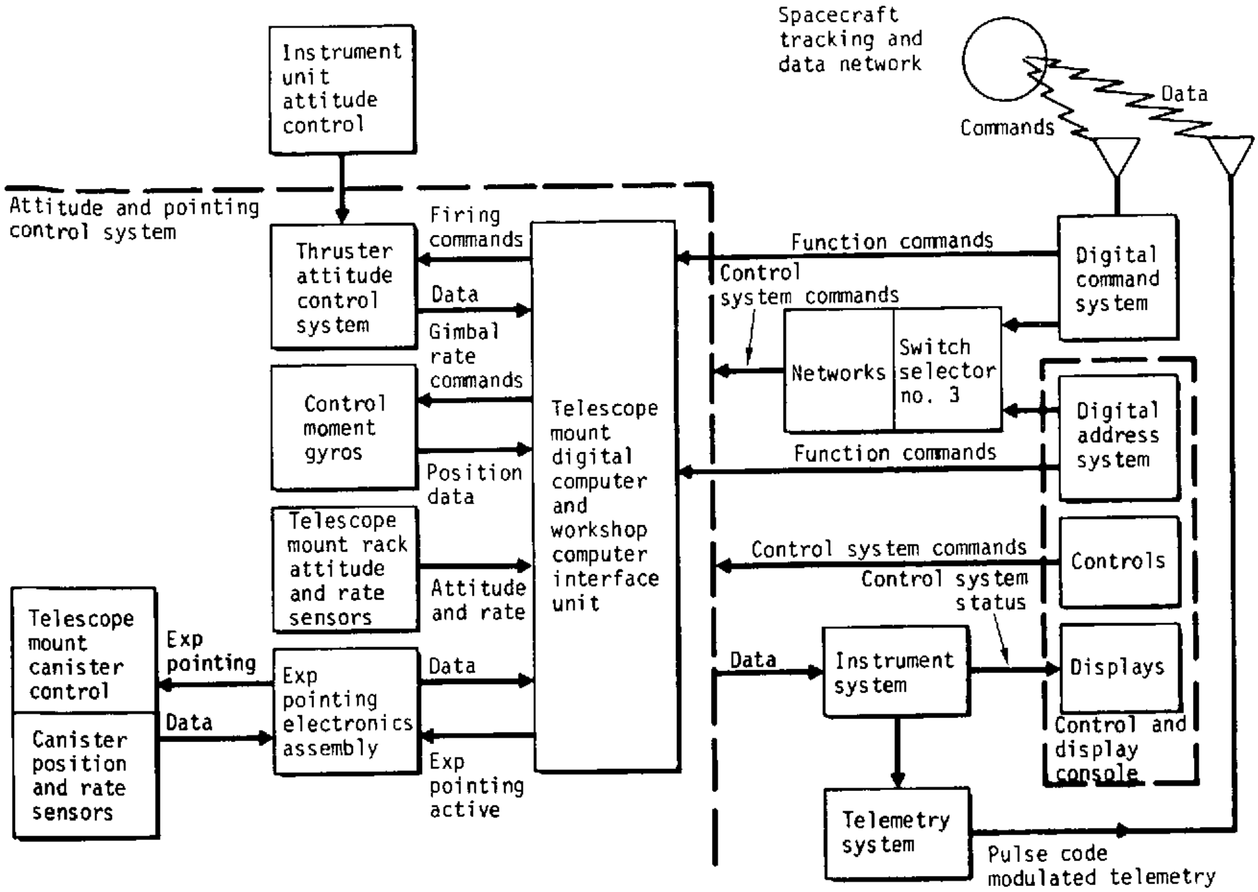


Figure 2-15. APCS Block Diagram

Crew Systems

The crew systems facilitated crew operations during the performance of the ATM extravehicular activity. Specific support equipment and structures, figure 2-16, were required for extravehicular activity when the crew serviced ATM cameras, film magazines, and experiments. Extravehicular activity was accomplished through utilization of restraints, translation aids, the film transportation boom, external lighting, and the workstations. A canister roll control panel was located at the center workstation. This control allowed the crew to position the canister for film retrieval.

The ATM control and display console was the major interface between the crew and the ATM. The ATM control and display console, figure 2-17, was located in the Multiple Docking Adapter and provided the means for the crew to operate and monitor the ATM experiments and supporting systems.

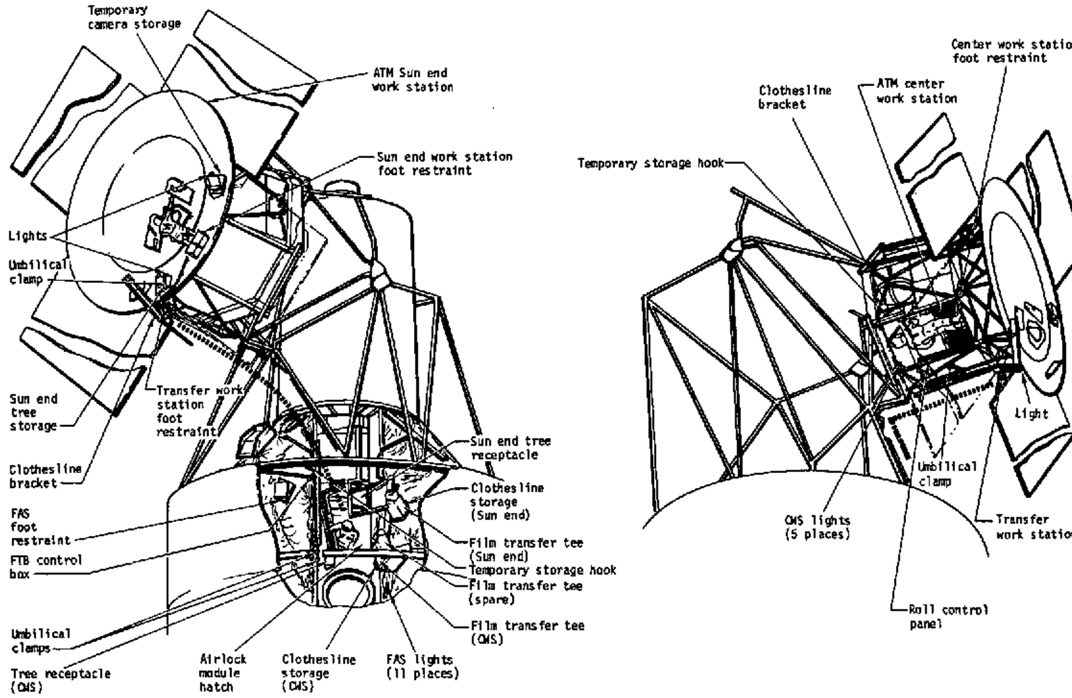


Figure 2-16. Crew System Aids

Commands to the ATM experiments and supporting systems were provided by toggle and rotary switches, the manual pointing controller, and the digital address system. All critical switch functions were either redundantly wired, or were available through the digital address system. Parameters were monitored by the use of status lights, meter confidence lights, alert lights, meters, digital displays, and television displays. Controls were also available for power distribution, overload protection, lamp testing, and console lighting.

Contamination

Two quartz crystal microbalances were provided to monitor ATM contamination. The ATM quartz crystal microbalances monitored the mass of contamination particles entering the ATM Sun-end aperture doors of the S082B and the S055A experiments. The two ATM quartz crystal microbalances were mounted on the ATM solar shield, looking along the Z axis, slightly recessed, with a 4.14-steridian (70 degrees half-cone angle) field-of-view.

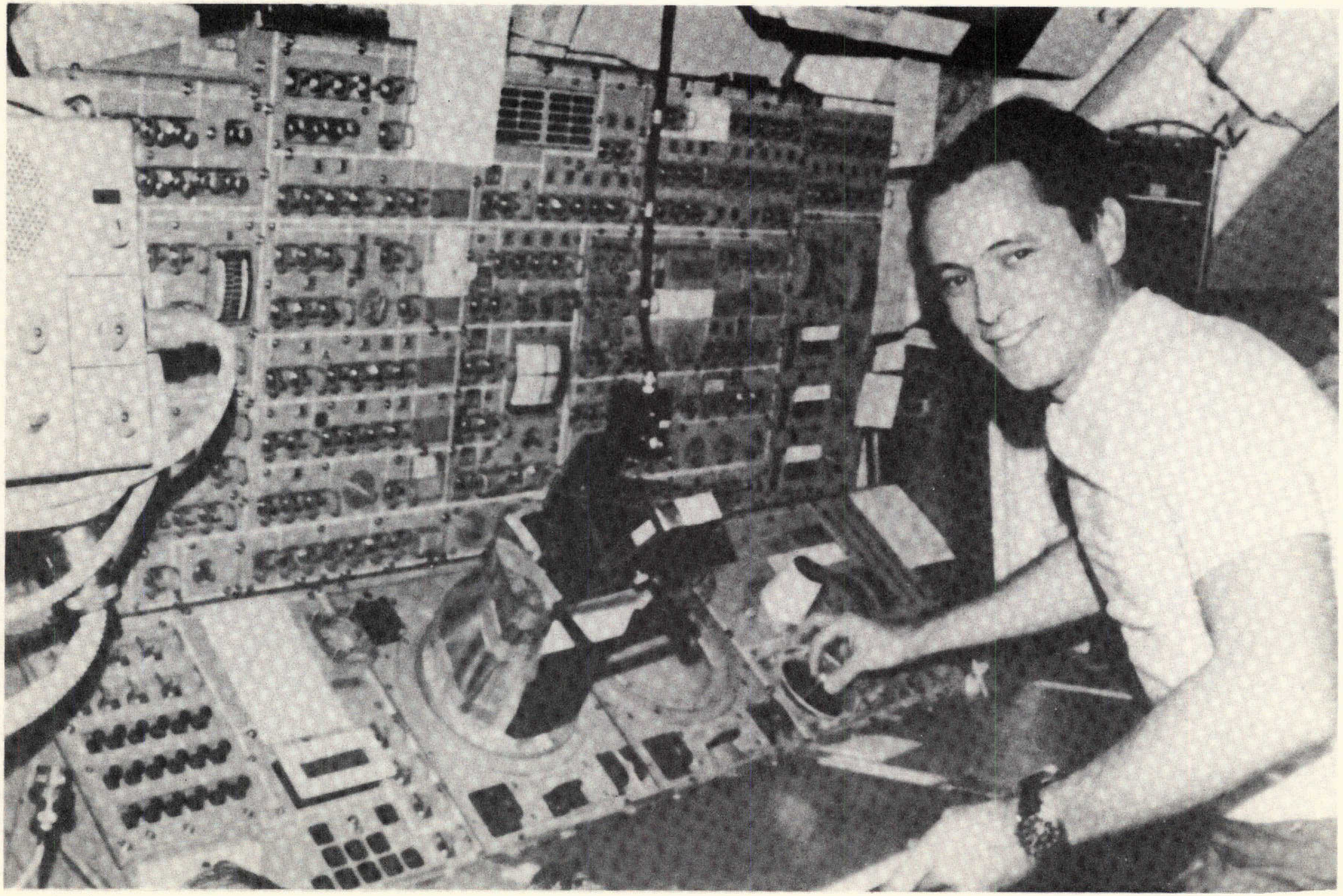


Figure 2-17. Control and Display Console

SECTION III. PERFORMANCE

ATM MISSION PERFORMANCE

The Skylab ATM has provided data that indicated the performance of the ATM, its experiments, and supporting systems either met or exceeded the premission objectives. This conclusion is based on the Skylab mission performance and the evaluation of systems and experiment data. The ATM's excellent performance during the critical early mission period provided ground personnel the opportunity to effect the changes necessary to continue the Skylab mission.

The Skylab mission began on 14 May 1973 (DOY 134) with the launch of Skylab 1 and ended on 8 February 1974 (DOY 039) with the undocking of the Skylab 4 Command and Service Module (CSM). Detailed evaluation of the ATM systems performance, including photographic examples, data resolution, supporting engineering data, and conclusions is contained in the respective MSFC Skylab Apollo Telescope Mount System Mission Evaluation Reports.

The unmanned Skylab 1 Saturn V vehicle was launched on DOY 134 from Launch Complex 39A at the NASA Kennedy Space Center, Florida. The launch vehicle consisted of the Saturn-IC first stage, Saturn-II second stage and the payload. The payload elements were the ATM, Multiple Docking Adapter, Airlock Module, Instrument Unit, Orbital Workshop, and Payload Shroud. The unmanned payload was placed in a nominal 435 kilometer near-circular orbit, inclined 50 degrees to the equator.

An anomaly occurred at approximately 63 seconds into the boost phase which resulted in the loss of the meteoroid shield around the Orbital Workshop. The meteoroid shield loss resulted in the partial deployment of the Orbital Workshop solar array wings. Wing number 2 subsequently separated from the Orbital Workshop apparently when the exhaust plume of the Saturn II stage retrorockets impacted the partially deployed wing. Orbital Workshop solar array wing number 1 failed to deploy on command because the wing was restrained by debris from the meteoroid shield and jammed at approximately 10 percent deployed position.

The ATM and the ATM solar wings deployed normally. With the Orbital Workshop electrical power supply system inoperative, the ATM electrical power system provided power to the Orbital Workshop until DOY 158, at which time the jammed Orbital Workshop wing was fully deployed by the Skylab 2 crew during an extravehicular activity.

Loss of the meteoroid shield, which was designed to also serve as a thermal insulator for the workshop, resulted in high internal temperatures in the Orbital Workshop due to direct solar radiation on the workshop wall. To control the rising temperature within the Orbital Workshop the vehicle was maneuvered into various abnormal attitudes, causing a reduction in the ATM electrical power system output, due to the unfavorable incidence to the ATM solar array.

Abnormal maneuvers were performed until DOY 147, when the thermal parasol was deployed by the Skylab 2 crew. The vehicle was then maneuvered into the solar inertial attitude, permitting full ATM solar array capabilities and eliminating the temperature problems created by direct solar radiation on the ATM rack-mounted components.

The incidents that occurred during the boost phase necessitated a delay in the launch of Skylab 2 from DOY 135 to DOY 145. The Skylab 2 launch vehicle consisted of a Saturn IB stage and a Saturn IVB stage, with the Command and Service Module as its payload.

The Skylab 3 mission included the unmanned phase that began on DOY 173 with Skylab 2 CSM undocking, and ended on DOY 209 with Skylab 3 liftoff, and the manned phase which began with Skylab 3 liftoff and ended on DOY 268 with Skylab 3 CSM undocking. All ATM systems were operational throughout the Skylab 3 mission and at the conclusion were configured for Skylab 4 unmanned operations.

The Skylab 4 mission included the unmanned phase that began on DOY 268 with Skylab 3 CSM undocking and ended on DOY 320 with Skylab 4 liftoff, and the manned phase which began with Skylab 4 liftoff and ended on DOY 039 (1974) with Skylab 4 CSM undocking. All ATM systems were operational throughout the Skylab 4 mission.

The significant ATM related events that occurred from liftoff of Skylab 1 through splashdown of Skylab 4 are identified in table 3-1.

Table 3-1. Significant ATM Related Events

EVENT TITLE	TIME (GMT) DOY	HOUR	MINUTE
Skylab 1 Liftoff	134	17	30
ATM Deployment and Activation	134	17	46
S052, S055A, S082A, S082B, TCS Activated	135	18	34

Table 3-1. Significant ATM Related Events (Continued)

EVENT TITLE	TIME (GMT) DOY	HOUR	MINUTE
Switched Transmitter Number 1 to Forward Antenna for Remainder of Mission	136	17	03
Charger-Battery-Regulator Module Number 15, Contactor Failed Open	145	03	20
Skylab 2 Liftoff	145	13	00
ATM Control and Display Console Activated	146	18	05
Parasol Deployed	147	01	39
Thermal Control System Activated	147	06	26
Experiment Pointing Control System Activated	148	00	21
Control Moment Gyro Number 3 Wheel Speed Monitor Failed	148	09	23
S082A Camera Failed	150	18	22
Charger-Battery-Regulator Module Number 3 Failed	150	22	00
S054 Sun-End Aperture Door Failed in Closed Position - Indicated Open	153	21	44
Unable to Command S054 Main Power Off	158	13	03
Extravehicular Activity (Unscheduled) o Workshop Solar Wing Number 1 Deployed o S054 Sun-End Aperture Door Latched Open o Retrieved and Replaced S082A Camera	158	15	20
S052 Camera Failed	161	18	40
Activity History Plotter Paper Jammed	168	10	30

Table 3-1. Significant ATM Related Events (Continued)

EVENT TITLE	TIME (GMT) DOY	HOUR	MINUTE
Extravehicular Activity (Scheduled)	170	10	53
o Charger-Battery-Regulator Module Number 15 Returned to Normal Operation by Striking Component o Removed and Installed Instrument Cameras/Magazines o S052 Occulting Disk Contamination Removed			
Terminated Skylab 2 Manned ATM Operations	170	13	00
Rate Gyro Processor Y3 Failed	188	00	00
Rate Gyro Processor Z1 Failed	192	20	14
Primary Up/Down Rate Gyro Processor Failed	197	01	22
Skylab 3 Liftoff	209	11	10
ATM AC1 Pulse Width Modulator Assembly (Master) in I/LCA Failed	214	22	25
Short on TV Bus-2 (Power Transfer Distributor)	216	03	20
Extravehicular Activity (Hatch Open)	218	17	32
o S055A Latch Ramp Removed o ATM Power Transfer Distributor Check o S056, S082A, S082B and H-Alpha 1 Film Installed			
Extravehicular Activity (Hatch Open)	236	16	24
o S082A and S056 Door Ramp Latch Removal o Removed and Installed Instrument Cameras/Magazines o Rate Gyro Processor Six Pack Installed			
Charger Battery Regulator Module 5 Failed	256	02	30

Table 3-1. Significant ATM Related Events (Continued)

EVENT TITLE	TIME (GMT) DOY	HOUR	MINUTE
Extravehicular Activity (Hatch Open) o Removed and Installed Instrument Cameras/Magazines o S052 Occulting Disk Contamination Removed	265	11	18
Television Monitor Number 1 Failed	265	14	40
Terminated Skylab 3 Manned ATM Operations	268	11	00
Skylab 4 Liftoff	320	14	01
Extravehicular Activity (Hatch Open) o Removed and Installed Instrument Cameras/Magazines o H-Alpha 2 Sun-End Aperture Door Latched Open	326	17	44
CMG 1 Failed	327	08	42
ATM TV Monitor and S082B Timer Installed	329	15	25
S054 Filter Wheel Stuck	331	01	48
Manual Control of CMG Heaters Initiated	356	00	54
Extravehicular Activity (Hatch Open) o Removed and Installed Instrument Cameras/Magazines o S082A Sun-End Aperture Door Latched Open o S054 Filter Wheel Moved to Position 3	359	16	55
Star Tracker Failed	361	19	40
Extravehicular Activity (Hatch Open) o Kohoutek and Solar Photos o SL-2 Sail Sample Retrieval	363	17	30

Table 3-1. Significant ATM Related Events (Continued)

EVENT TITLE	TIME (GMT) DOY	HOUR	MINUTE
Extravehicular Activity (Hatch Open) o Film Retrieval S052, S054, S056, S082A, S082B, and H-Alpha 1 o Documentary Photos	034	15	19
Terminated ATM Unattended Operations	039	08	08
Skylab 4 CSM Undocked	039	10	31
Skylab 4 Splashdown	039	15	17
ATM Powered Down	040	19	57

ATM SYSTEMS PERFORMANCE

The ATM systems performance was excellent during all phases of the Skylab mission. This was evidenced by such mission accomplishments as: the ATM electrical power system providing emergency support to the total Skylab cluster when the Airlock Module electrical system was inoperative due to improper deployment of its solar wings; the use of the attitude and pointing control system to maintain various attitudes to control the workshop internal temperatures; the use of the ATM experiment thermal control system in lieu of the canister thermal control system to maintain ATM canister temperature stability, to conserve power early in the mission.

Considering the complexity of the ATM systems, relatively few functional problems were experienced. Due to the mission management and workarounds of the ATM systems, and redundancy designed into the ATM systems, the anomalies and failures encountered had no appreciable impact on the ability of the ATM to support the Skylab mission. An abstract of the performance and synoptic evaluation of each of the ATM systems is presented in the following paragraphs.

ATM Experiment System

The ATM experiments performance was outstanding throughout the entire Skylab mission. No major hardware problems occurred which significantly impacted the operation of a single instrument. This evaluation of instrument performance is substantiated by comments from the Principal Investigators regarding the excellent quality of the scientific data returned. Resolutions approximating 1.0 arc second were attained on much of the solar imagery.

Operation of the instruments was initiated following activation of the control and display console by the Skylab 2 crew on 146:18:05 (GMT). The instruments obtained scientific data during scheduled operating periods covering a time span of approximately 8.5 months. Instrument operation was terminated by ground command on 039:08:07 (GMT). All of the instruments were still functional at the conclusion of the Skylab mission.

Photographs were obtained of the solar disk, corona, and solar features of interest in various wavelengths on more than 93 percent of the total film available for the Skylab mission. In addition to solar observations, the instruments were able to collect high quality data on the mercurian atmosphere, Earth-Moon Lagrangian points, the Earth's atmosphere and, during the final Skylab flight, on Comet Kohoutek. The total number of 171,098 photographs obtained exceeded premission goals by 24,231 as extra cameras or magazines were supplied for all instruments except S082B. More than 2,000 hours of photoelectric data were transmitted real-time and recorded onboard for subsequent transmission.

A summary of planned and actual ATM observing time for each Skylab mission, manned and unmanned, is shown in Table 3-2. Table 3-3 is a tabulation of the quantity of scientific data obtained. The observing time is defined as the time the Sun vector was above 400 kilometers as shown in figure 3-1. S052, S054 and S055A were successfully operated during the unmanned and unattended mission phases as planned. The remaining ATM instruments operated in the manned phases only.

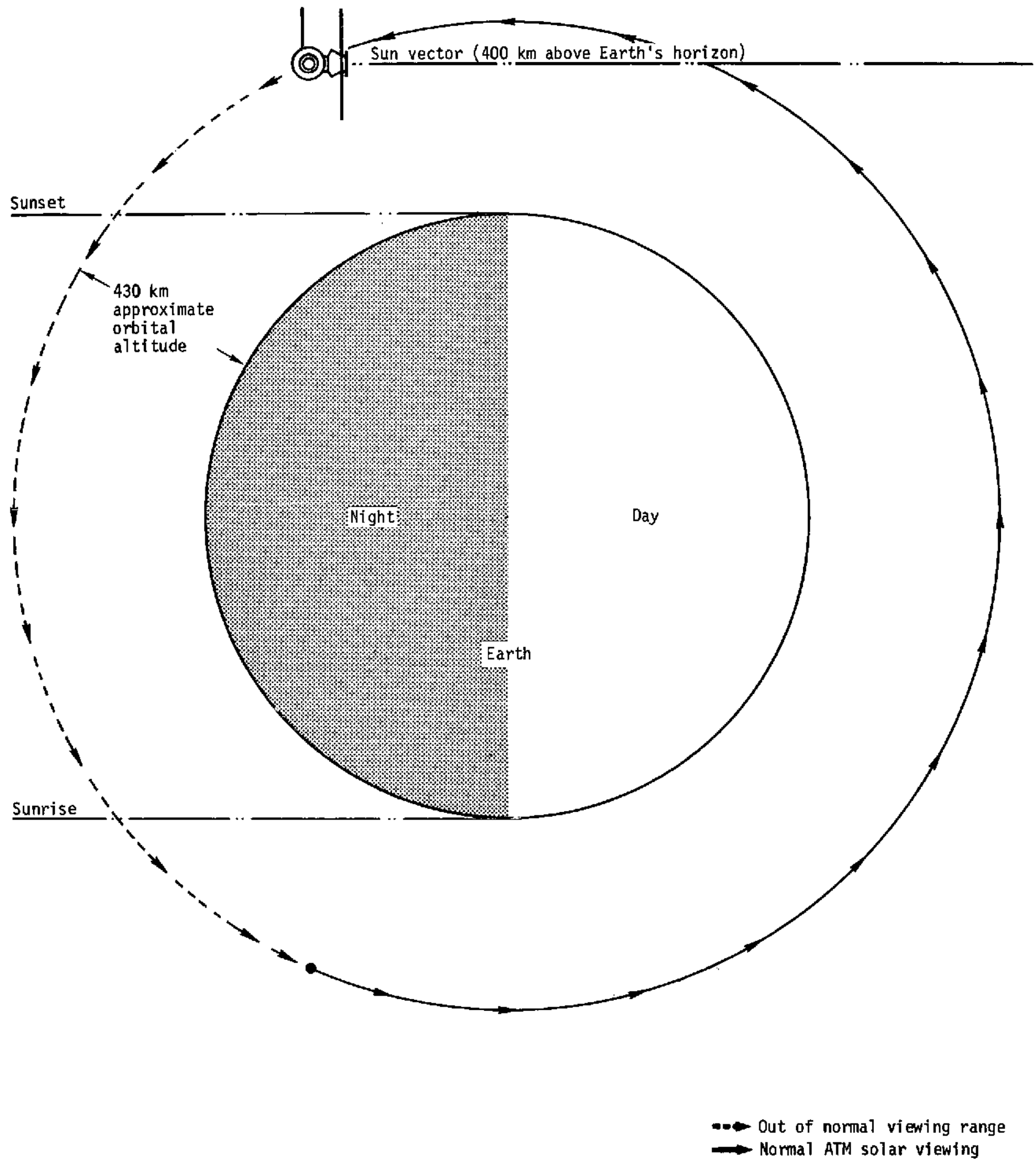


Figure 3-1. ATM Solar Viewing Altitudes

Table 3-2. ATM Experiments Observing Time

MISSION PHASE	HOURS OF OPERATION	
	PLANNED	ACTUAL
Skylab 2		
Attended	101.5	81.7
Unattended	As Available	154.0
Skylab 3		
Unmanned	As Available	191.0
Attended	205.0	305.1
Unattended	As Available	276.0
Skylab 4		
Unmanned	As Available	556.3
Attended	350.0	338.0 (1)
Unattended	As Available	473.0 (2)
Total	656.5	2,375.1

(1) Includes 30 hours devoted to Comet Kohoutek observations.

(2) Includes 8 hours devoted to Comet Kohoutek observations.

The ATM experiments were operated in accordance with joint observing programs defined by the Principal Investigators prior to each mission. The joint observing programs were scheduled on a daily basis during the mission by the Principal Investigators based on existing solar activity. The four basic objectives of the joint observing programs were:

1. Define a set of problems to be solved on ATM as an observatory, not as eight individual instruments.

2. Write the joint observing program such that all instruments are working on the same problem at the same time.

3. Define the joint observing programs so that maximum utilization of ground based observatories can be made.

4. In constructing the joint observing programs, provide maximum capability for the Principal Investigator to make real-time changes in order to optimize his data return.

Table 3-3. Quantity of Skylab Mission ATM Scientific Data

Experiment	Frames Available (1) Per Load	Frames Exposed			
		Skylab 2	Skylab 3 (2)	Skylab 4 (2)	Total
S052	8,025	4,381 (3)	15,735	15,802	35,918
S054	6,970	5,155 (4)	13,325	13,305	31,785
S056	6,000	4,184	11,493	12,098	27,775
S082A	201	220 (5)	402	402	1,024
S082B	1,608	1,608	3,195	1,608	6,411
H-Alpha 1	15,400	12,998	30,787	24,400 (6)	68,185
Total	38,204	28,546	74,937	67,615	171,098
S055A HOURS OF PHOTOELECTRIC DATA		153 hrs	772 hrs	1,368 hrs	2,292 hrs

(1) Except for S082A and S082B, the frames available varied slightly with the amount of film in each load.
(2) For Skylab 3, two film loads were used in each instrument. For Skylab 4, two film loads were used in each instrument except S082B, which used only one film load.
(3) The film transport mechanism in the Skylab 2 film camera jammed. See text.
(4) Data from approximately 1,500 additional frames were lost due to the thermal shield door having failed closed. See text.
(5) Second film camera used after first malfunctioned. See text.
(6) The second Skylab 4 film load transport mechanism became intermittent. See text.

This approach was achieved and proven through highly efficient and successful orbital operations. The joint observing programs, related objectives, and planning guidelines are identified in the Mission Requirements Document (I-MRD-001).

During the Skylab 2 mission four joint observing programs (JOPs) were completed.

1. JOP 6 - Synoptic Observations - degraded due to S052 (White Light Coronagraph) camera failure and several instances where morning and/or evening observations could not be accomplished.

2. JOP 9 - Solar Wind - degraded due to a requirement for two back-to-back cycles which were not executed.

3. JOP 10 - Lunar Libration Clouds

4. JOP 11 - Chromospheric Oscillations

The remaining eight JOPs, except JOP 13, were accomplished to some extent but could not be completed due to insufficient total time, a large number of partial cycles (29), lack of proper cycle sequences, and limited solar phenomena occurrences.

Fifteen joint observing programs and related objectives were planned for the Skylab 3 mission; all but two were completed.

1. JOP 5 - Limb Profile Studies - This JOP was not completed because the necessity to manually operate S082B created an inconvenience that impacted concurrent operation of other instruments. JOP 5 was not scheduled again; however, the absence of these data is not considered significant since more useful data were obtained from other joint observing programs.

2. JOP 13 - Night Sky Objects - This JOP was not completed because of spacecraft maneuvering restrictions. Prior to aborting JOP 13, SCO X-1, an X-ray star was observed (DOY 262). No ultraviolet star observations were made.

During the Skylab 4 mission a total of 223 full and 141 partial cycles were scheduled for manned solar observations. The high percentage of partial cycles and the lack of available orbital sequences precluded scheduling as many joint observing programs as originally planned. Of the eight new joint observing programs added specifically for Skylab 4 and identified in the Skylab 4 Mission Requirements Document (I-MRD-001), the following were completed:

1. JOP 18 - Comet Kohoutek

2. JOP 19 - Alfven Waves

3. JOP 21 - Time Variations in Coronal Structure

4. JOP 25 - Maxi and Super Rasters

The following paragraphs summarize the performance of each of the instruments. Scientific data, photographic and photoelectric, are presented only to illustrate the design integrity of the instrument. These data are not intended to convey scientific findings, accomplishments, or achievements. Individual reports, published by each Principal Investigator, address the scientific accomplishments of the ATM.

S052 - White Light Coronagraph - The White Light Coronagraph performed successfully during the Skylab mission. The primary objectives to provide high resolution photographs and television images of the solar corona in the visible region of the electromagnetic spectrum were accomplished. The S052 instrument was used by the crew for Sun centering the ATM and for recording real-time downlink of televised images of the solar corona. The design specification orbital life of 56 days was exceeded by a factor of approximately five and the instrument was still operational at the conclusion of the Skylab mission.

Five S052 film cameras were used during the entire Skylab mission. Table 3-4 illustrates the film usage from each film load.

Table 3-4. S052 Film Load Usage

FILM LOAD	SKYLAB MISSION	FRAMES AVAILABLE (1)	FRAMES EXPOSED UNMANNED	FRAMES EXPOSED MANNED	INSTALLED (DOY)	REMOVED (DOY)
1	2	8025	---	4381	Prior to Skylab 1 Launch	170
2	3	8025	1230	6747	170	236
3	3	8025	---	7758	236	265
4	4	8025	1630	6227	265	359
5	4	8025	---	7945	359	034

(1) The frames available depends upon the amount of film in each load and varies slightly from load to load.

Evaluation of the Skylab 2, 3, and 4 flight film indicated that high quality photographic coronal data were obtained. Considerable coronal detail was visible on the film as illustrated by the photograph taken during Skylab 2 shown in figure 3-2. The spatial resolution of 8 arc seconds was better than the instrument specification of 15 arc seconds and equal to the limiting resolution of the film except for a few brief periods when vehicle motion degraded the resolution. The synoptic observations provided a view of the dynamic features of the corona indicating good optical performance by the instrument. No optical degradation occurred; this is substantiated by the consistently good photographic quality of the film from Skylab 2, 3, and 4.

The film cameras exhibited some anomalous behavior. On DOY 161, an unusual rate of temperature rise occurred in the film camera (film load 1). The crew reported that the operate light did not illuminate and the frames remaining counter did not decrement. These were symptoms of a stalled film transport motor which prohibited further operation with that film camera. On DOY 170, the Skylab 2 crew replaced the film camera. After installation, the new camera (film load 2) was checked out and operated properly. Investigation of the failed camera (film load 1) revealed numerous partial frame advances, and torn, and jammed film. Before the camera failure, 4381 frames of approximately 8025 frames for the Skylab 2 mission were exposed. The quantity of film not exposed was less than 10 percent of the film in the five film loads for the total Skylab mission. Evaluation of the film from load 2 revealed approximately 100 partial frame advances. These partial frame advances resulted in a less than one percent overlap of Skylab 3 film data. There were no further partial frame advances. The impact on scientific data was minimal. On DOY 264, one day before changing camera loads on Skylab 3, the film transport (film load 3) stalled. The camera had exposed 7758 frames prior to this time. The number of frames exposed denoted successful film camera performance.

During the unmanned Skylab 3 mission, the first Skylab 3 film camera (film load 2) was operated by ground control via radio frequency command until DOY 219. During this time a synoptic observation program was followed and exposures of the solar corona as well as of the solar eclipse on DOY 181 were obtained. During the manned phase of the Skylab 3 and 4 missions, the S052 instrument was operated both in the attended and unattended modes. During the manned portion of Skylab 4, 1600 frames were exposed during Comet Kohoutek observations. Figure 3-3 shows comet Kohoutek (1973f) when it was 14.6 million miles (0.157 Astronomical Unit) from the Sun and 106.0 million miles (1.140 AU) from Earth.

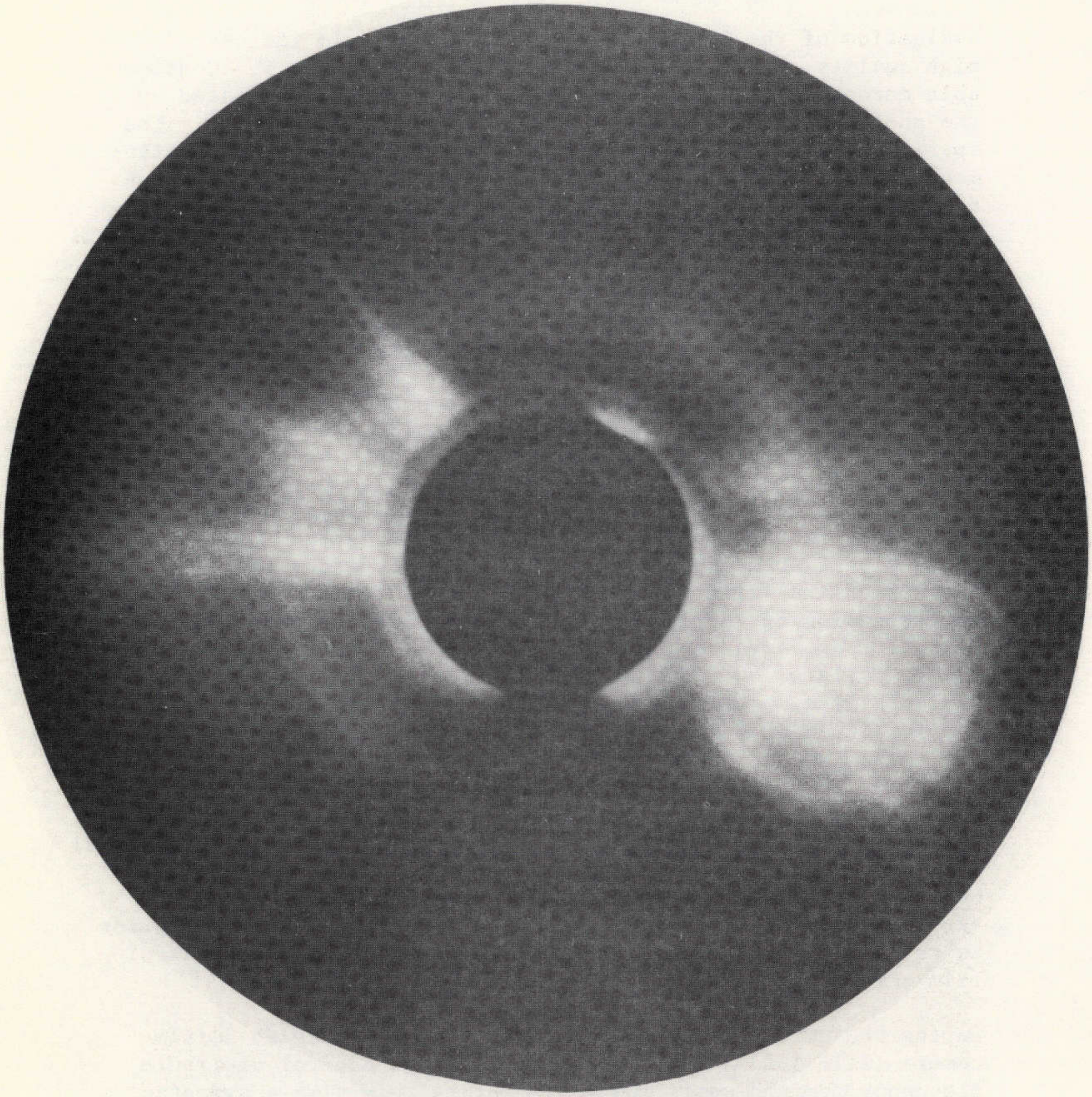


Figure 3-2. S052 Filmed Corona Detail

Figure 3-3. S052 Film Camera Photograph of Comet Kohoutek

The S052 television system performance was satisfactory throughout the Skylab mission. A typical television monitor display recorded from television downlink is shown in figure 3-4. The television system was used as the primary means for calibrating the pointing error system cross pointers when centered on the Sun and was the only means of continuing the synoptic observations of the corona from DOY 161 until exchange of cameras on DOY 170. Television recording of synoptic observations, while film was not being exposed, minimized loss of scientific data. Three to five minutes of television observation via downlink were scheduled twice daily until the Skylab film camera failure. Then television downlink and video tape recordings were increased to three or four times daily for 3 to 5 minutes on each observation. Resolution of the television system was within the design specification of 30 arc seconds.

Observation of the coronal image on the television monitor indicated that the instrument pointing error detection system had become misaligned with the instrument boresight 8 arc seconds up and 16 arc seconds right. Therefore, the crew used this amount of bias in Sun-centering the instrument, and the centering was verified with the television monitor on the control and display console. The only anomalous behavior of the S052 television system occurred during the Skylab 4 mission. On DOY 337, the crew observed a bright spot on the television monitor. On DOY 340, the crew reported the existence of a black bar across the screen through the white spot. On DOY 031, a second bright spot and corresponding black bar appeared. It was concluded that damage to the vidicon had resulted when scattered light impinged on the vidicon face.

The five outputs of the S052 power supply remained stable and within operating limits throughout the Skylab mission. The thermal control system for the instrument operated as designed throughout the Skylab mission. The instrument thermal performance characteristics during the mission corresponded very closely to the calculated performance predicted by computer analysis prior to the Skylab 1 liftoff. The instrument primary programmer, pointing error detectors, polaroid wheel mechanism, television folding mirror mechanism, internal occulting disk mechanism, film camera latching mechanism, and the electronics operated properly.

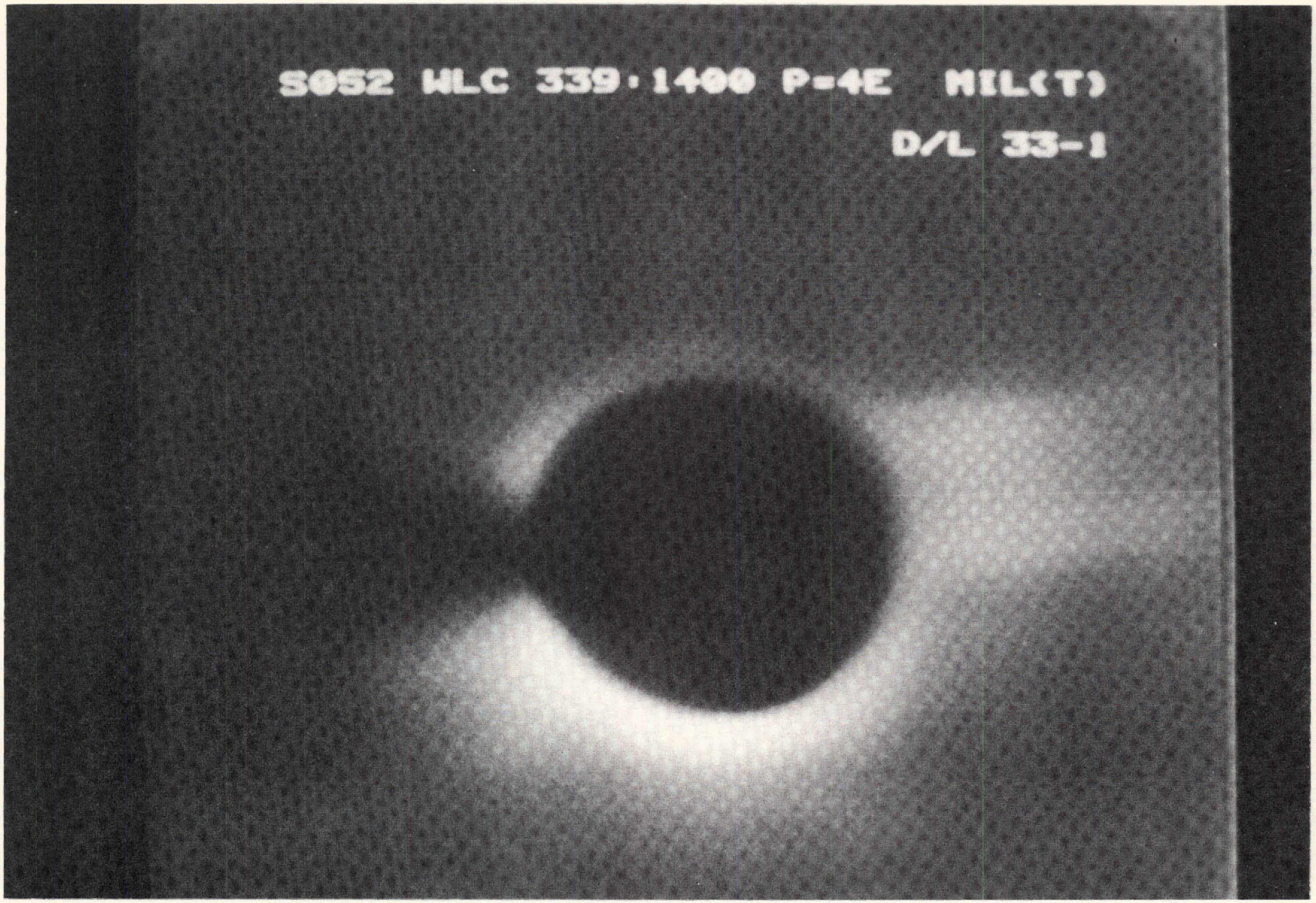


Figure 3-4. S052 Television Monitor Display Recorded From TV Downlink

The value of Man in space was demonstrated on S052. Installation of a replacement camera after failure of the first camera, contamination removal from the occulting disk, avoiding degraded data, and repeated use of the television monitor to manually center the instrument to correct for system misalignment assured a successful experiment.

All ATM interfaces adequately supported the instrument. The S052 film camera for Skylab 2 was launched on the ATM spar and the film cameras to be used on Skylab 3 and 4 were stored in film vaults in the Multiple Docking Adapter. The film vault temperatures indicated that even during the period of high thermal stress from DOY 135 until the thermal parasol was deployed on DOY 147, the upper temperature limit of the film was not exceeded. Several minor problems occurred but had no significant impact on mission objectives.

During Skylab 2 on DOY 164, contamination on the foremost occulting disk was detected, appearing as a bright spot which remained stationary with the disk as the ATM canister was rolled. On DOY 170, this contamination was removed by the crew and it did not affect the data obtained from the instrument. During Skylab 3 on DOY 238, contamination was again noted on the S052 occulting disk, both by the crew and on the television downlink. The area was brushed on DOY 265, and the contamination was removed but reappeared a short time later. Again the area was brushed and no further evidence of contamination appeared.

S054 - X-Ray Spectrographic Telescope - The X-Ray Spectrographic Telescope performance was satisfactory throughout the Skylab mission. The primary objective, to obtain X-ray data of the solar disk, was successfully accomplished.

Five film loads were used during the Skylab mission. Table 3-5 illustrates film usage for each mission. Only four film magazines were launched aboard Skylab 1. The fifth film load was a film cassette launched on Skylab 4 and loaded by the crew into a spent magazine.

Table 3-5. S054 Film Load Usage

FILM LOAD	SKYLAB MISSION	FRAMES AVAILABLE (1)	FRAMES EXPOSED UNMANNED	FRAMES EXPOSED MANNED	INSTALLED (DOY)	REMOVED (DOY)
1	2	6970	---	5155 (2)	Prior to Skylab 1 Launch	170
2	3	6970	2000	4595	170	236
3	3	6970	---	6730	236	265
4	4	6970	2201	4359	265	359
5	4	6970	---	6745	359	034

(1) Frames available depends upon the amount of film in each load and varies slightly from load to load.

(2) Data from approximately 1500 additional frames were lost due to the Sun-end aperture door being failed closed.

Optical quality of the developed film was excellent, indicating alignment of the telescope optical elements was maintained. Figure 3-5 is an X-ray photograph of the solar disk taken by S054 on DOY 148 showing details of the quiet corona and bright points. Evaluation of film data revealed that spatial resolution was better than 2 arc seconds which compares favorably with the design requirement of 3 arc seconds. Spectral resolution was 50 at 7 angstroms, as compared to the design requirement of 30 at 7 angstroms. No noticeable jitter or drift was evident on any of the photographs except, as anticipated, in the case when the experiment pointing control system was disabled.

The photomultiplier performed as designed. No noticeable degradation was observed on either the onboard monitor or the photoelectric data received on downlinked telemetry and recorded on magnetic tape. Figure 3-6 is a plot of photomultiplier response during a solar flare on DOY 166. No change in resolution, sensitivity or efficiency was noted throughout the mission. The photomultiplier detected X-ray radiation within a 3-degree field-of-view and provided a proportional pulse count to the S054 flare detection system. The crew, in conjunction with ground recommendations, selected a flare threshold which, when exceeded by high flux, actuated a flare alert signal.

The system functioned as designed; however, false flare alarms were generated by the high energy radiation in the South Atlantic Anomaly.

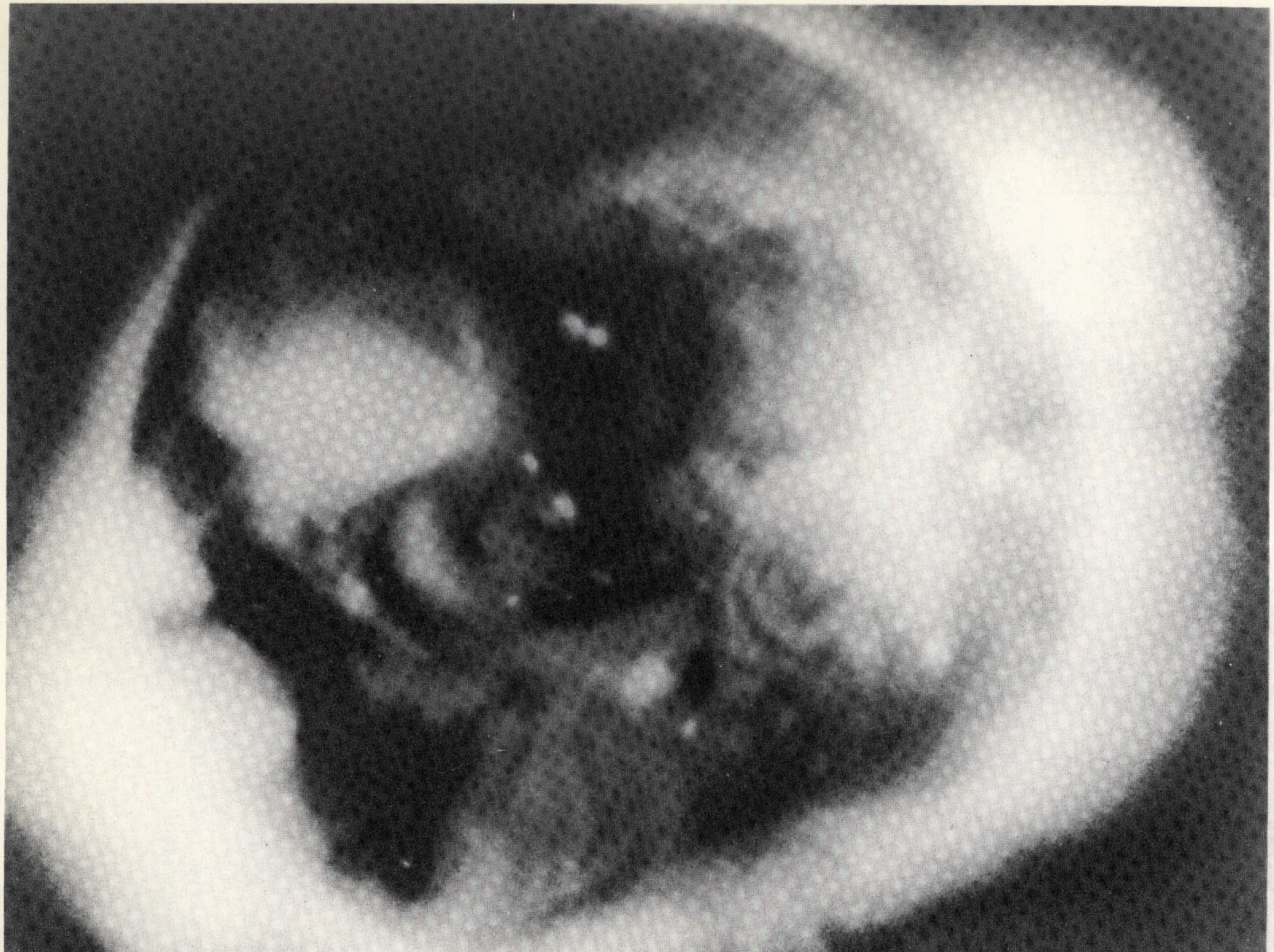


Figure 3-5. S054 X-Ray Photograph of the Solar Disk

The instrument pointing system (image dissector, X-ray image monitor, and image intensity counter) performed as required. The X-ray image monitor provided positional information on solar X-ray activity by displaying X-ray images of the solar disk over a region of 1.5 solar diameters. X-ray intensity data was also displayed in digital form by the image intensity counter and telemetered to ground. Figure 3-7 is a plot showing X-ray intensity monitor radiation response during a solar flare on DOY 166. When X-ray activity was indicated, the pointing system provided a means to verify instrument boresight centering on the target of interest. No failures were noted in the pointing system. However, some degradation was evident on the X-ray image monitor during the latter portion of Skylab 4, but no loss of experiment objectives resulted.

All experiment power supplies operated as designed. Telemetered data indicated all instrument voltages remained stable and within the prescribed limits.

The thermal control system performed satisfactorily throughout the Skylab mission. All instrument temperatures were maintained within the allowable limits and corresponded closely to the values experienced during the thermal vacuum flight unit test.

During the Skylab 4 mission, the experiment filter wheel stopped between position 5 and 6. Since positions 5 and 6 were the most dense filters contained in the experiment, data taken during this period were limited to features with relatively high surface brightness. During extravehicular activity on DOY 359 the crew manually rotated the filter wheel to position 3 (clear). During the repair procedure the shutter blade became disabled and had to be bent out of the light path. The bent shutter blade later moved into the light path and caused some image degradation as shown in figure 3-8. Exposure durations were subsequently controlled by selection of film transport intervals. Although operation with the shutter constantly open produced some image blurring on the shortest exposures, it allowed two modes of operation that provided better temporal resolution and data correlation with the S052 experiment.

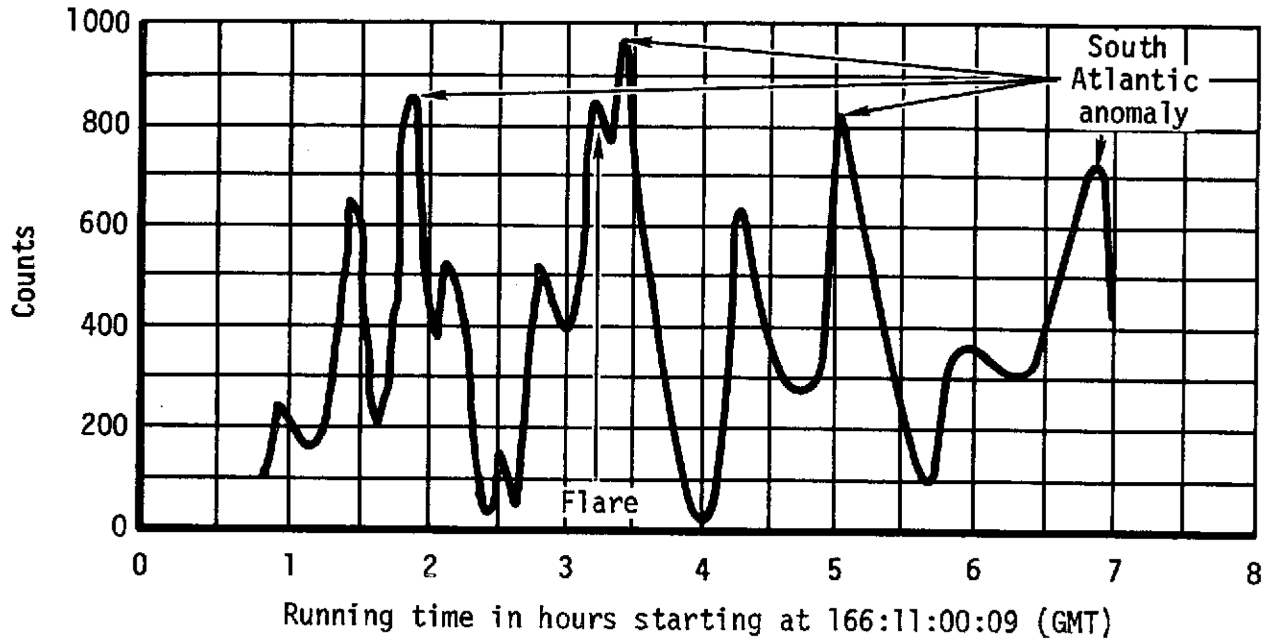


Figure 3-6. S054 Photomultiplier X-Ray Response

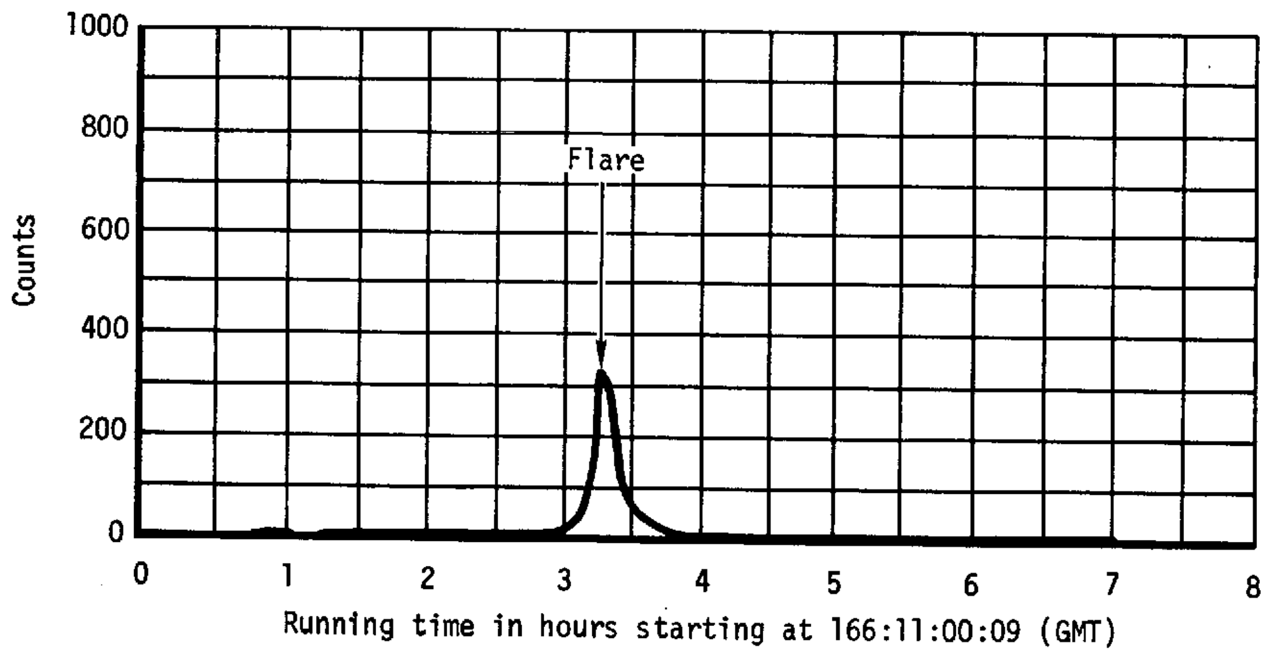


Figure 3-7. S054 X-Ray Intensity Monitor Radiation Response

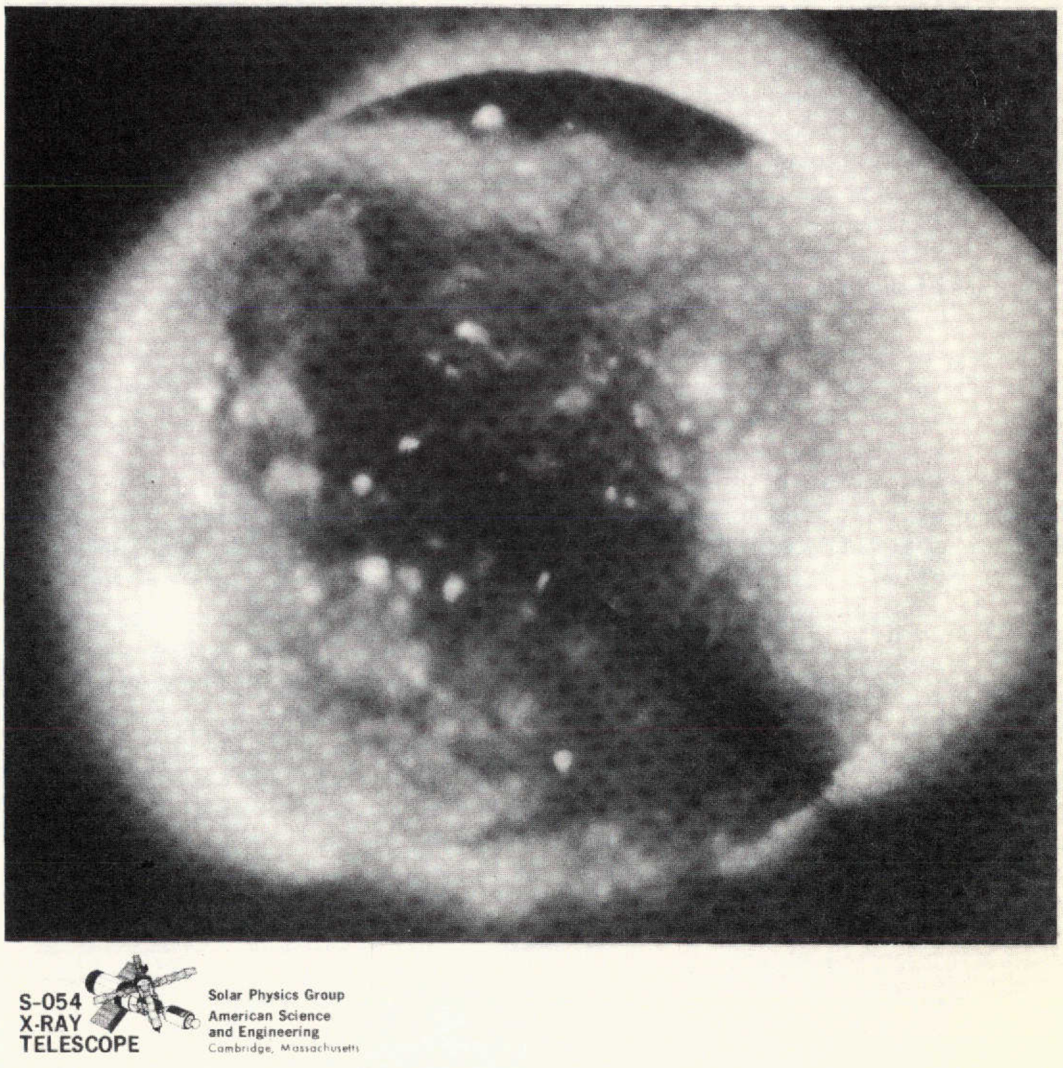


Figure 3-8. Degraded solar Image Caused by Bent Shutter Blade

The other S054 subsystems, the grating change mechanism, displays, controls, visible image system, telemetry, and diode array performed as designed.

ATM interfaces adequately supported the S054 instrument with the exception of two occurrences that marred the otherwise optimum support. During the Skylab 2 mission the Sun-end aperture door failed to cycle. The crew performed the malfunction procedure and obtained a door open indication which was later discovered to be erroneous. Exposures taken during the failed door period resulted in lost data. The crew pinned the door open but this caused a loss of the ready/operate light function. A timer was supplied for the Skylab 3 and 4 missions to aid the crew in camera mode statusing. On DOY 147, it was discovered that main power off commands from the control and display console and from the ground did not turn off instrument power. Thus, power remained on throughout the mission. No adverse effects to the crew during extravehicular activity or to the hardware were experienced. MDA film vaults maintained the stored film magazines within the prescribed environmental limits and no film degradation resulted.

During the extended extravehicular activities on DOY 128, involving film magazine exchange, both the exposed film in the magazine being removed and the unexposed film in the magazine being installed were subjected to excessive temperatures. After the replacement of the S054 film magazine, the telemetered temperature of the film transport assembly was 312.3 kelvins. This is well above the maximum allowable temperature of 295.4 kelvins for the film. Film temperatures of both the unexposed magazine and the exposed magazine were calculated to be 299.3 kelvins and 314.5 kelvins, respectively. The unexposed magazine had remained in the fixed airlock shroud for 1.5 hours and the exposed magazine for 2.5 hours. The data showed that the S054 film magazine should not be left in the fixed airlock shroud longer than 1 hour, 12 minutes if the film temperature is not to exceed 295.4 kelvins. Subsequent analyses of background and fog levels on the returned film indicated no significant fogging due to the high temperatures.

<u>S055A - Ultraviolet Scanning Polychromator Spectroheliometer</u> - The Ultraviolet Scanning Polychromator Spectroheliometer performed successfully through the Skylab mission. The primary objective to obtain data in the far ultraviolet region from 1350 to 296 angstroms to construct spectroheliograms was successfully

accomplished. The quality of the data obtained was excellent and indicated extremely good optical and electrical performance of the instrument. Figure 3-9 shows a spectroheliogram constructed of S055A data illustrating a solar prominence on the southeast quadrant of the Sun detected by photomultiplier number 4 on DOY 161.

The total operating time of 2292 hours utilized approximately 75 percent for mirror modes and 25 percent for grating modes. Table 3-6 illustrates operating time per mission.

Table 3-6. S055A Operating Time

SKYLAB MISSION	OPERATING TIME		
	UNMANNED	MANNED	TOTAL PER MISSION
2	-	153 hrs	153 hrs
3	191 hrs	581 hrs	772 hrs
4	556 hrs	811 hrs	1367 hrs
			2292 hrs Total

The S055A instrument primary mirror was stepped 110 arc seconds up and 5 arc seconds to the right to achieve coalignment with S082B during the initial inflight coalignment operations. The alignment was checked several times in orbit and no significant change was detected. Scientific data indicated a finer resolution of experiment pointing than the ATM instrumentation could verify. The fine Sun sensor error and the experiment pointing control rate gyro processor telemetry signals indicated approximately $\pm$1.5 arc seconds and 15 arc seconds per second, respectively.

Performance of the primary mirror system was evaluated by examining parameters of the raster pattern, such as overall size, duration, line separation, and scan rate. These parameters were within the allowable tolerances and long term performance of the raster system was very stable throughout the total instrument operating period.

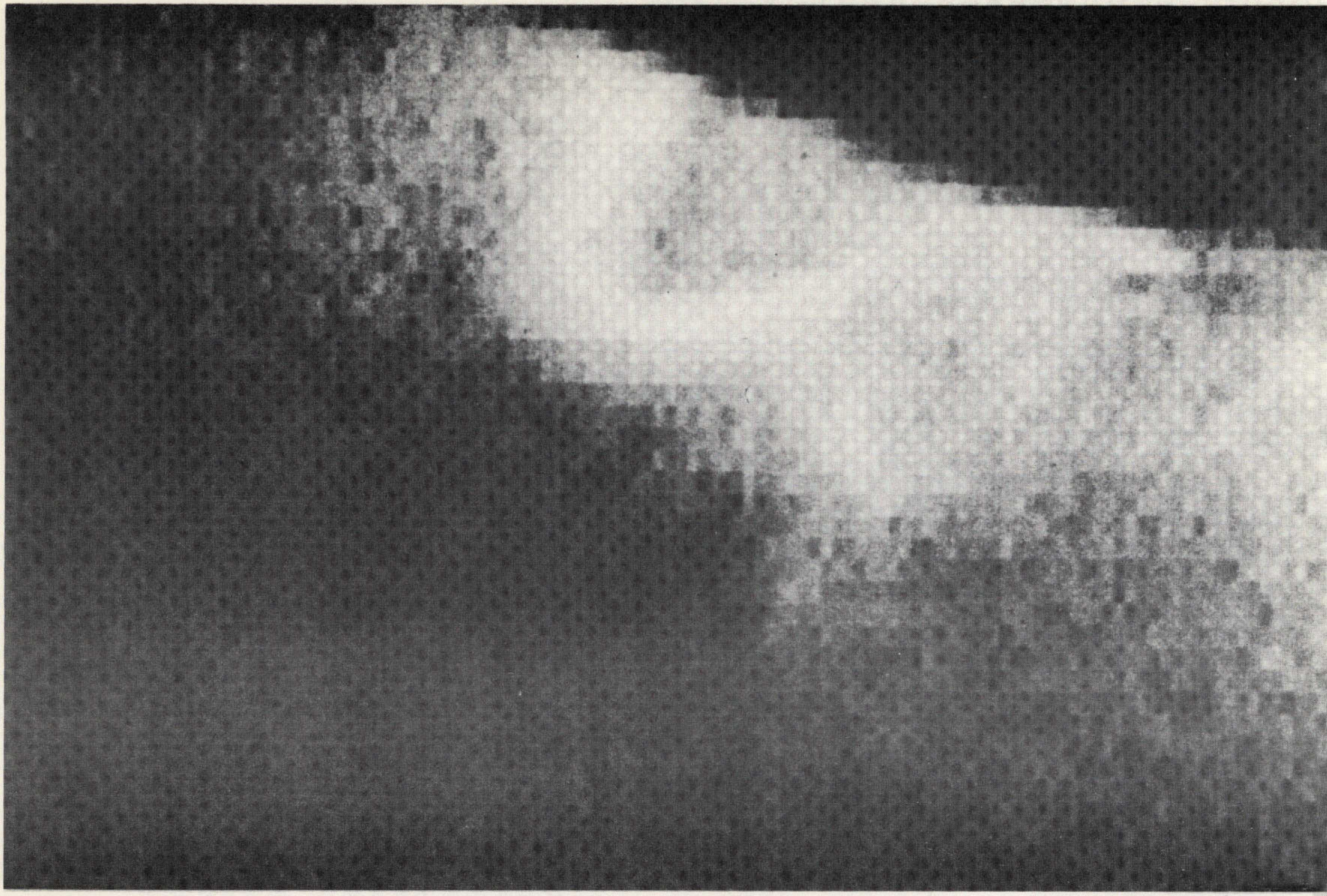


Figure 3-9. S055A Solar Prominence

The spectrometer subsystem performed as designed during the Skylab mission. Tripout of the detector number 5 high voltage occurred frequently. Analysis of the known tripouts led to the suspicion that they were related to ATM proximity to the South Atlantic Anomaly and/or the North or South Horns. It was concluded that detector 5 was most susceptible to tripout. To verify these conclusions, two high voltage tests were performed by the crew on DOY 251 and 255 in an attempt to determine why detector 5 tripped out during normal operating modes, and whether the instrument could be operated successfully with the main high voltage in the OVERRIDE position. This configuration disabled the circuitry which causes all detectors to turn off if any one turns off. The tests verified that the instrument could operate successfully in this configuration. Therefore, detector 5 was left with the overload sensing protective circuitry enabled and the main high voltage in the OVERRIDE position. This minimized data return from detector 5 since it continued to trip out; however, the data return from the other six detectors was maximized and total data loss was minimal.

The grating system performed within specification. Analyses of telemetry data indicated a nominal 102 steps between mechanical reference and optical reference. Optical reference was the primary reference point and was utilized when pointing anywhere on the solar disk. Mechanical reference was used as the reference point when pointing anywhere off the disk. A complete grating rotation was shown to consist of a nominal 5497 steps, circular from either the mechanical or the optical reference. The width of the optical reference indication was a nominal 38 steps, whereas the mechanical reference indication was a nominal 600 steps in width.

The cold cathode ion gauge functioned properly throughout the Skylab missions. The longest known time to fire in orbit was approximately 20 seconds. This was in contrast to the considerable difficulty encountered in firing the gauge during thermal vacuum ground tests. Gauge activations indicated pressures in the 5×10^{-7} torr range. This was well below the maximum operating pressure for the high voltage supplies.

The instrument responded properly to all control functions throughout the Skylab 2 and 3 missions. Analog and digital telemetry monitors functioned properly and permitted engineering evaluation of the instrument performance. Although the system continued to perform satisfactorily during Skylab 4, the monitoring activities revealed that on DOY 277 the low voltage (28 volts) power supply in the instrument apparently changed from the main (primary) converter to the redundant (secondary) converter. At the same time it was also noted that the instrument would not respond to the main power off or main power primary radio frequency commands. A check of the instrument showed its operations were unaffected; therefore, it was decided to continue with normal planned operations.

The instrument thermal control system continued to operate properly and the instrument remained within the temperature design limits. Slightly higher than normal temperatures were detected on DOY 353. This increase was attributed to the fact that Kohoutek operations were being conducted during that time frame. The operations required pointing away from the Sun at an angle such that efficiency of the heat rejection system was impaired. This resulted in instrument temperature levels above those experienced during nominal Sun-centered instrument operations but had no impact on the scientific data obtained.

All ATM interfaces adequately supported the instrument. The loss of main power commands, Sun-end aperture door malfunctions, and ATM pointing problems had only slight impact and did not affect achievement of experiment objectives.

S056 - X-Ray Telescope - The X-ray telescope performed satisfactorily throughout the Skylab mission. The primary objectives, to obtain X-ray filtergrams from 5 to 33 angstroms and X-ray spectral data from 2.5 to 20 angstroms, were successfully accomplished. The filtergrams were recorded by the film camera and the spectral data were displayed on the control and display console and telemetered to the ground.

Five film loads were used throughout the Skylab mission. Table 3-7 illustrates film usage per mission. SO-242 color film was used to obtain photographs of greater spectral resolution. The low number of exposures taken on film load 1 was attributed to the low level of solar X-ray activity during its period of use.

Table 3-7. S056 Film Load Usage

FILM LOAD	SKYLAB MISSION	FRAMES (1) AVAILABLE	FRAMES EXPOSED	INSTALLED (DOY)	REMOVED (DOY)
1	2	6000	4184	Prior to Sky- lab 1 Launch	170
2	3	6000	5671	218	236
3	3	6000	5822	236	265
4	4	6000	5191	326	359
5	4	6000	6907	359	034

(1) Approximately 1200 additional frames per load were available for contingency use.

The overall X-ray image quality of the film was good and indicated stable optical performance of the telescope. Spatial resolution on the order of 2 arc seconds was attained as compared to the design goal of 2.5 arc seconds. Spectral resolution was equal to or better than the design requirement of 2.5 angstroms. Figure 3-10 is a representative photograph taken by the S056 camera with SO-212 black and white film. Figure 3-11 is a photograph taken with the SO-242 color film.

Evaluation of the film data from Skylab 3 revealed a light leak in filter 3 that allowed visible light to penetrate and partially expose the film. X-ray data was still recorded on film using filter 3 but was degraded. The condition of filter 3 became progressively worse during the remainder of the mission. It was determined that filter 3 suffered damage due to thermal stresses during long exposures.

The S056 film camera terminated picture sequences at random times prior to completing the prescribed number of exposures. As a workaround the crew had only to restart the camera to continue the sequence. Analysis showed that the camera sequences terminated prematurely due to excessive mechanical drag in the film magazine. A film magazine with lubricated clutch surfaces was launched aboard Skylab 4. The premature terminations occurrence was less with this magazine (film load 4) but was not entirely eliminated.

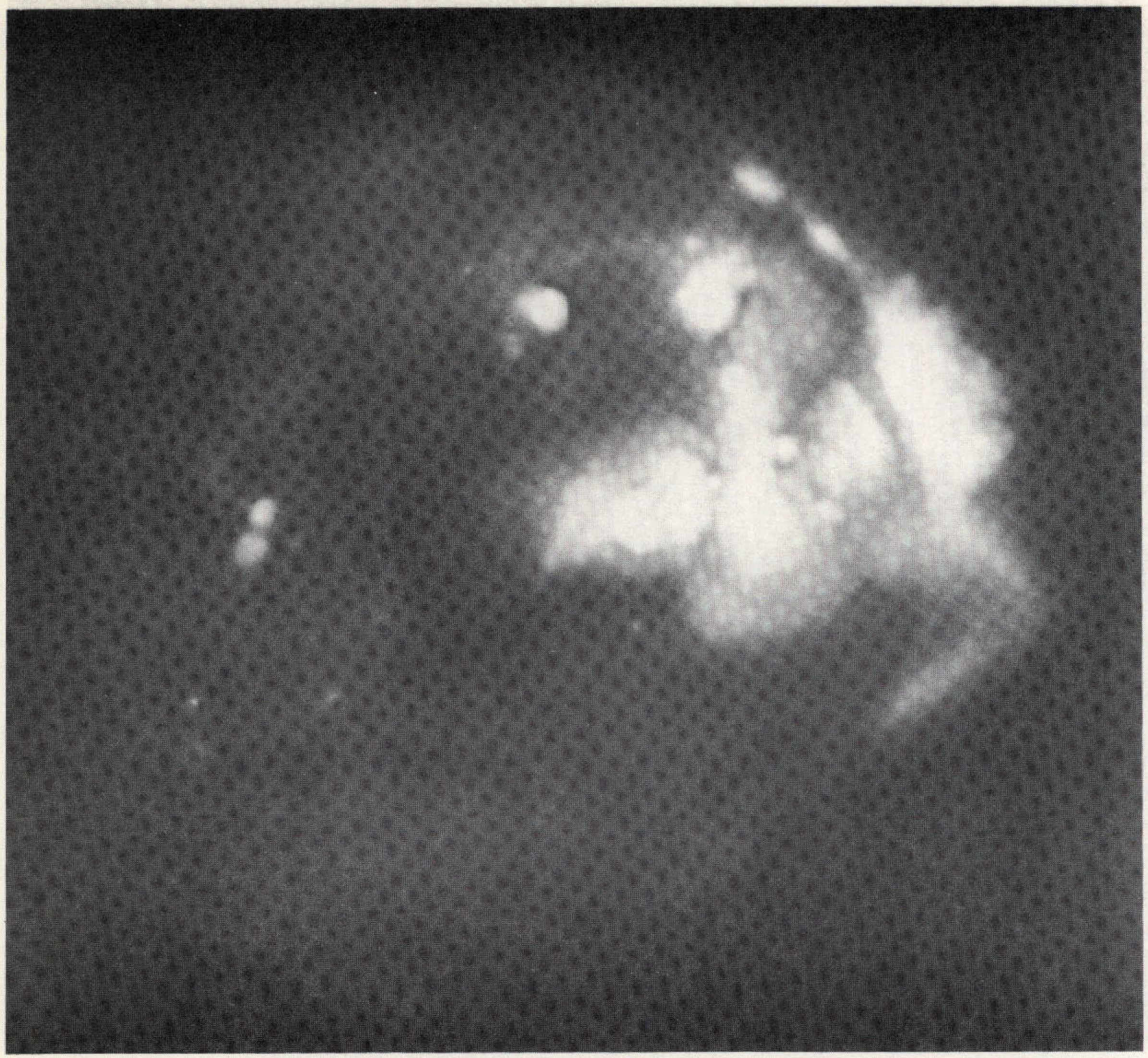


Figure 3-10. S056 X-Ray Solar Activity

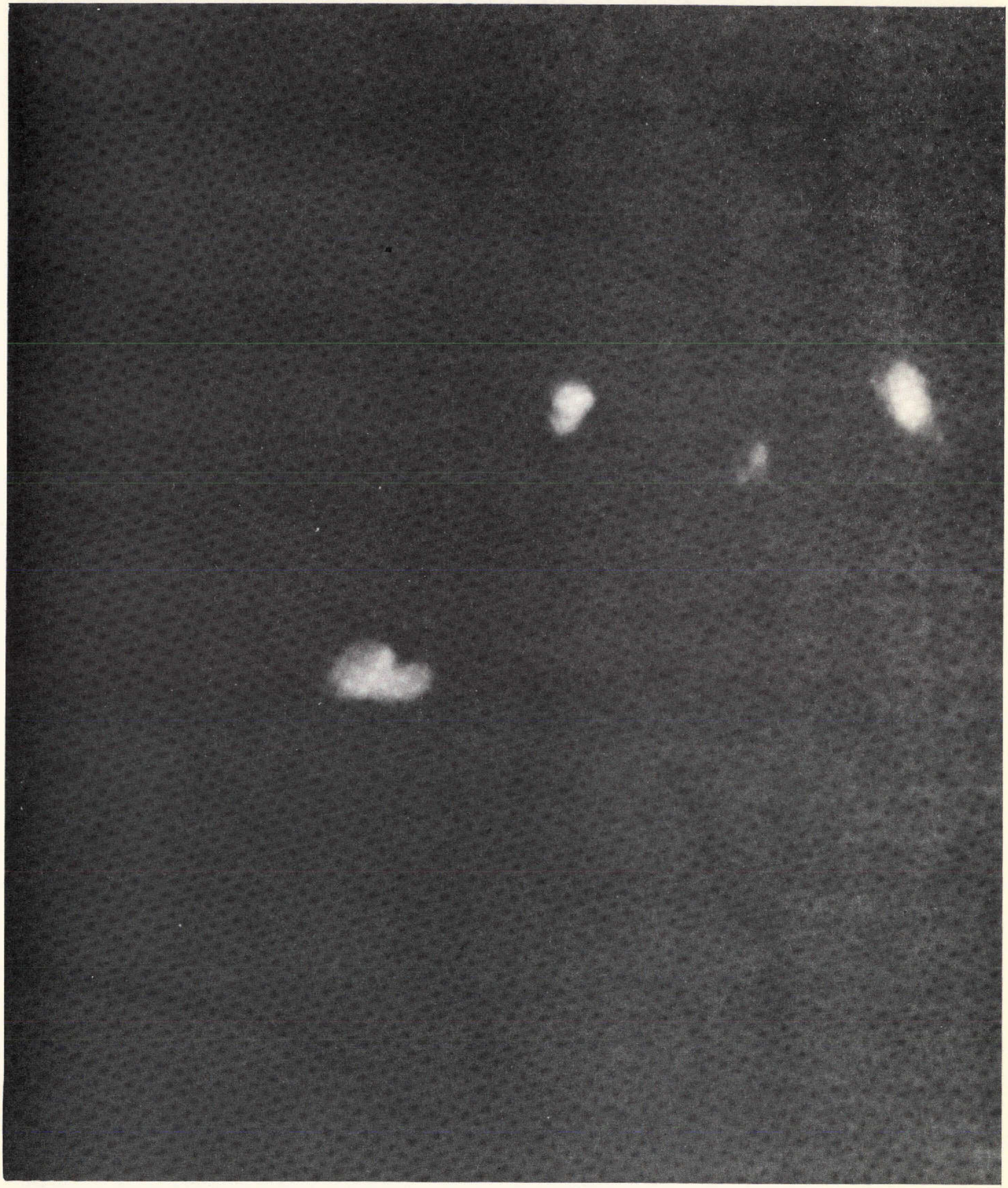


Figure 3-11. S056 Filmed Solar Image Taken with Color Film

The X-ray event analyzer performance was satisfactory. The aluminum and beryllium proportional counters were operated continuously during the manned portions of the mission after DOY 155 and were used by the crew to detect solar flare activity. Figure 3-12 is a plot of telemetered data taken during a solar flare on DOY 166.

The power supplies, camera electronics, telemetry and controls operated properly throughout the mission.

The thermal control system performed as required. Telemetered temperature data indicated that the telescope and X-ray event analyzer were being held within the prescribed limits. Some rise in telescope forward end temperature was experienced during Skylab 3 and 4 but this was attributed to degradation of the canister thermal coating and high Beta angles. The instrument did not exceed the maximum specified allowable operational temperature.

All ATM interfaces adequately supported the instrument. The activity history plotter became inoperable during Skylab 2 and the beryllium counter display failed during Skylab 4, but achievement of experiment objectives was not impaired. The MDA film vaults maintained the stored magazines within the prescribed environmental limits and no film degradation was evident.

S082A - Extreme Ultraviolet Spectroheliograph - The Extreme Ultraviolet Spectroheliograph performed satisfactorily throughout the Skylab mission. The primary objective to photographically record images of the solar chromosphere and corona to 1.5 solar radii in wavelengths between 150 and 625 angstroms was successfully accomplished.

The spectroheliograms obtained from the flight cameras indicated correct functioning of the instrument optics, and all scientific objectives were accomplished. Spatial resolution of 2 to 5 arc seconds was attained. This compared favorably with the design requirement of 5 arc seconds. Figure 3-13 is a representative photograph taken during the Skylab 2 mission by the S082A camera. An eruption on the limb (at the top, in the image at the left) is in progress, shooting out 6,000 Kilometer-long jets of helium, emitting its characteristic extreme UV radiation at 304 angstroms. The jets seem to be following the loops characteristic of the magnetic fields above active regions. In the corona (image at the right) the eruption is entirely different. There is a great diffuse mass of million-degree glowing iron ions; but still they show effects of the magnetic field. Six film cameras were used during the total Skylab mission. Table 3-8 illustrates film load usage for each mission.

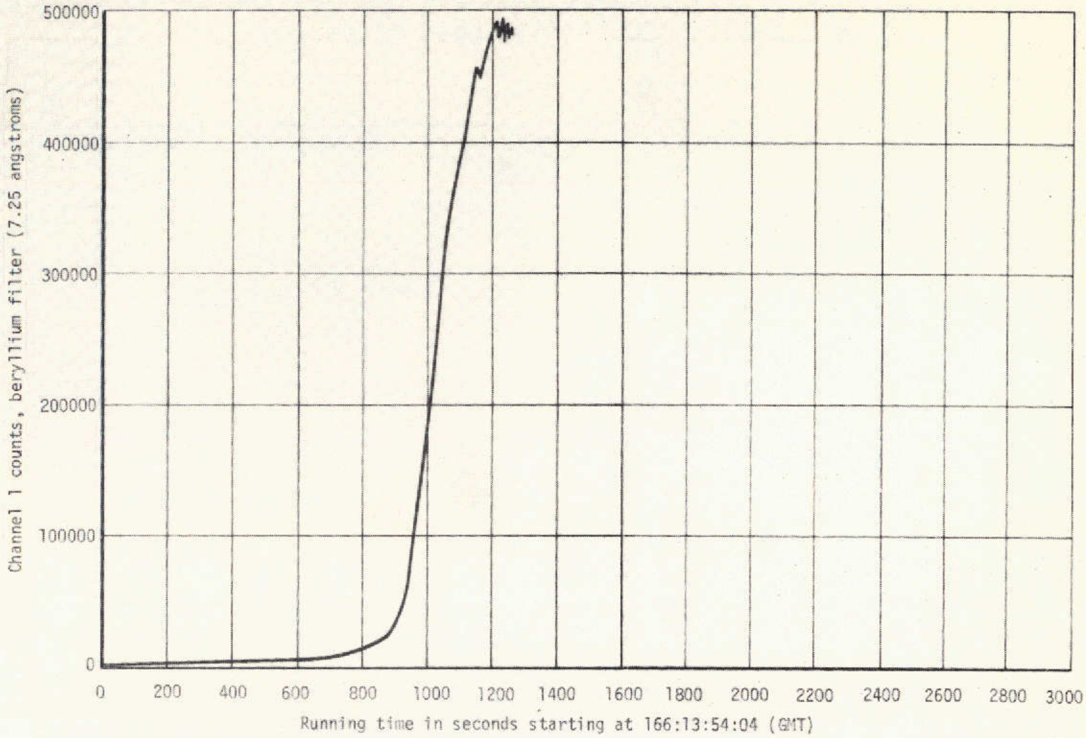


Figure 3-12. X-Ray Event Analyzer Flare Response

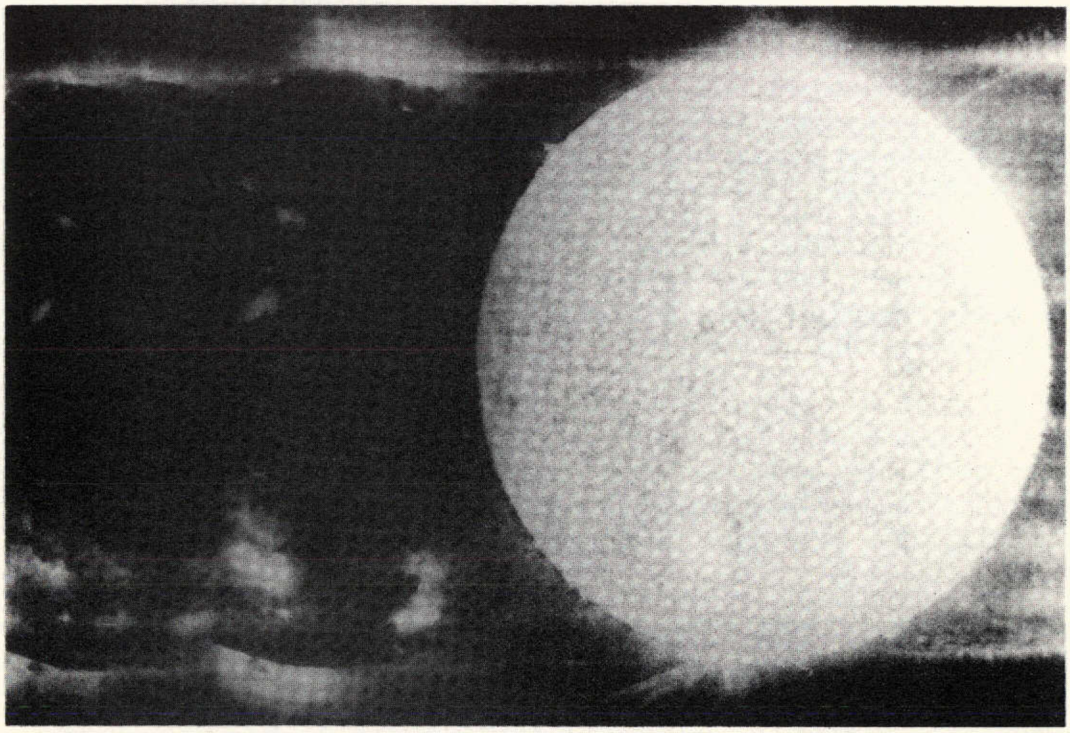


Figure 3-13. S082A Film Camera Photograph

Table 3-8. S082A Film Load Usage

FILM LOAD	SKYLAB MISSION	FRAMES AVAILABLE	FRAMES EXPOSED	INSTALLED (DOY) (1)	REMOVED (DOY) (1)
1	2	201	19 (2)	Prior to Skylab 1 Launch	158
2	2	201	201	158	170
3	3	201	201	218	236
4	3	201	201	236	265
5	4	201	201	326	359
6	4	201	201	359	034

(1) Unmanned mission phases did not require S082A instrument operations.

(2) The first film camera failed on DOY 150.

The first film camera was scheduled for removal on DOY 170. However, because of a failure, the camera was replaced on DOY 158. The second camera and all subsequent cameras operated properly.

Analyses of developed film indicated that the photographic fidelity of the instrument was good. There was no noticeable smear due to temperature gradients. Spectral resolution was well within the design goal of 0.13 angstroms for features 10 arc seconds in diameter and was consistent with ground test observations. Photographs from both Skylab 2 and 3 did, however, show streaks across the film. The streak locations corresponded to the contour of the film holder corrugations. The film cameras used on Skylab 4 utilized different film holders and streaks were not evident on that film.

During Skylab 3 a program of close coordination between the crew and Principal Investigators was established. This resulted in an ability to conduct experiment operations in a manner to maximize data collection of greater scientific value throughout Skylab 3 and 4.

The thermal control system performance was acceptable throughout the Skylab mission. Instrument thermal expansions never exceeded allowable image defocus limits. Rates of change of differential temperatures across the instrument case remained within the allowable levels precluding image smear due to thermal bending. All temperature measuring circuits functioned as designed and indicated proper functioning of the eight thermal control panels.

The S082A power supplies operated within design limits. All other subsystems, including the grating change mechanism, heat rejection mirror and telemetry subsystems performed satisfactorily. All ATM interfaces adequately supported the experiment. MDA film vaults maintained the film cameras within the required environmental limits and no film degradation resulted. Sun-end aperture door malfunctions occurred on Skylab 3 and 4 but did not impact achievement of experiment objectives.

<u>S082B - Spectrograph and Extreme Ultraviolet Monitor</u> - The Spectrograph and Extreme Ultraviolet Monitor performed successfully throughout the Skylab mission. The primary objective of the spectrograph, to photograph line spectra of small selected areas on and off the solar disk and across the limb in two wavelength bands; 970 to 1970 and 1940 to 3940 angstroms was successfully accomplished. The extreme ultraviolet monitor was used to observe the video image of the full solar disk in the wavelength band from 170 to 550 angstroms, and to point the spectrograph to solar features of interest. All experiment objectives were accomplished. Slit images were approximately 15 microns wide. This was within the maximum allowable limit of 25 microns; defocus or image smear would have caused a wider slit image. Figure 3-14 illustrates a comparison of emission spectra obtained by the S082B camera during the Skylab 2 mission. The spectra shown represents 12 arc seconds from the limb on the solar disk exposed for 1.25 seconds and 4 arc seconds off the disk (corona) exposed for 2.5 seconds in the 2300 to 2440 angstrom wavelength band.

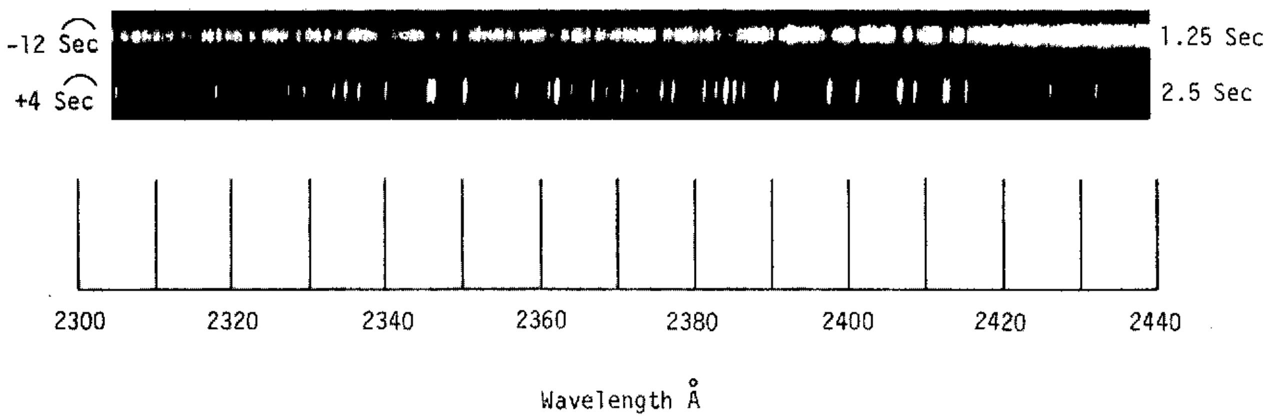


Figure 3-14. Comparison of Photospheric Fraunhofer and Chromospheric Emission Spectra

Four film cameras were used on the total Skylab mission. Table 3-9 illustrates film usage on each mission.

Table 3-9. S082B Film Load Usage

FILM LOAD	SKYLAB MISSION	FRAMES AVAILABLE	FRAMES EXPOSED	INSTALLED (DOY) (1)	REMOVED (DOY) (1)
1	2	1608	1608	Prior to Skylab 1 Launch	170
2	3	1608	1602	218	236
3	3	1608	1593	236	265
4	4	1608	1608	326	034

(1) Unmanned mission phases did not require S082B operation.

The quality of the data from the exposed film was excellent. The absence of truncated images on the film indicated that optical alignment of the slit in the slot baffle and on the film aperture remained correct. The focus and efficiency of the experiment were constant throughout the mission. The crew obtained excellent targets of opportunity data. Comet Kohoutek was much weaker than predicted and 5 exposures out of 100 had marginal data. The remaining 95 comet exposures were blank. The spectral dispersion varied throughout each bandwidth and was about 8.3 angstroms per millimeter in the short wavelength band and about 4.2 angstroms in the long wavelength band. These values remained constant throughout the Skylab mission and provided spectral resolutions of 0.06 angstroms (short wavelength) and 0.12 angstroms (long wavelength) which was the design requirement. The spatial resolution was 3 to 4 arc seconds from the top to the bottom of the image and approximately 60 arc seconds across the image, as predicted.

A review of the Skylab 2 film data by the Principal Investigator revealed that exposures taken with the grating in the long wavelength position were overexposed when the longer exposure times were used. Daily flight plans were altered during Skylab 3 to take fewer long wavelength exposures and to take only long wavelength exposures of very short duration. This procedure obtained more desirable data with less expenditure of film, but created an inconvenience to the crew because exposures had to be manually timed. An auxiliary timer was supplied for the Skylab 4 mission.

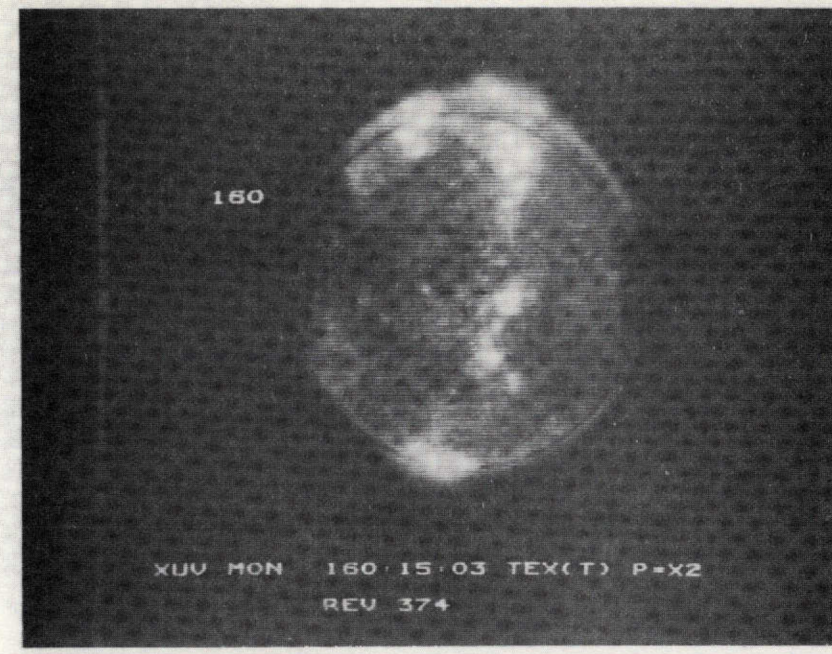
Only 1602 frames were exposed on film load 2. The onboard frames remaining counter indicated that all frames had been exposed. Investigation showed that a noisy microswitch in the film camera had caused multiple decrementing on the frames remaining counter. Film load 3 had only 1593 frames exposed. Investigation of this film camera revealed that the camera had reached lockout early, leaving 15 frames unexposed.

The extreme ultraviolet monitor television system performance was acceptable, but presented some inconvenience for the crew. The intensity of the extreme ultraviolet monitor television display on the ATM control and display console was very faint. Upon using the integrate function of the extreme ultraviolet monitor, the brightened display was flashed on the control and display console television monitor. The crew could not effectively utilize the integrated display for ATM pointing, but the integrated extreme ultraviolet monitor television downlink was acceptable for scientific use. A persistance image scope and a polaroid SX70 land camera were launched on Skylab 3. Performance of the scope was acceptable. The SX70 camera was of considerable value because major changes in the solar surface could be identified and sketching, which was done on Skylab 2, was eliminated.

The extreme ultraviolet monitor downlink was excellent. Since video integrate was required to obtain meaningful data, a series of increasing time period integrations were performed for each downlink. Representative photographs of an extreme ultraviolet monitor downlink transmission are shown in figure 3-15. These photographs were obtained by the extreme ultraviolet monitor camera on DOY 160 and 014. The significant features that can be seen from these photographs include high prominences on each limb and light areas in the center where there is extreme ultraviolet activity.

The crew indicated the white light display presentation on the monitor was of less than optimum quality but sufficient for accurate pointing capability. The pointing reference system remained stable throughout Skylab 2 and 3. However, during Skylab 4 some degradation was evident. Sensitivity of the system had decreased so that the pointing reference system could not be used for limb pointing or limb scanning. The ATM experiment pointing control was used thereafter for S082B limb pointing. A representative downlink photograph of the white light display is shown in figure 3-16.

Skylab 2



Skylab 4

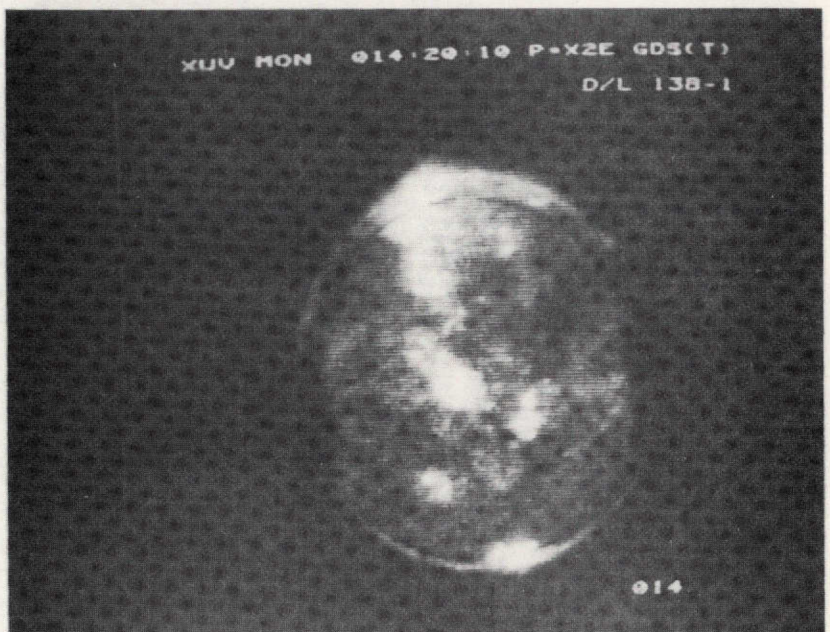


Figure 3-15. S082B XUV Monitor Downlink Photographs

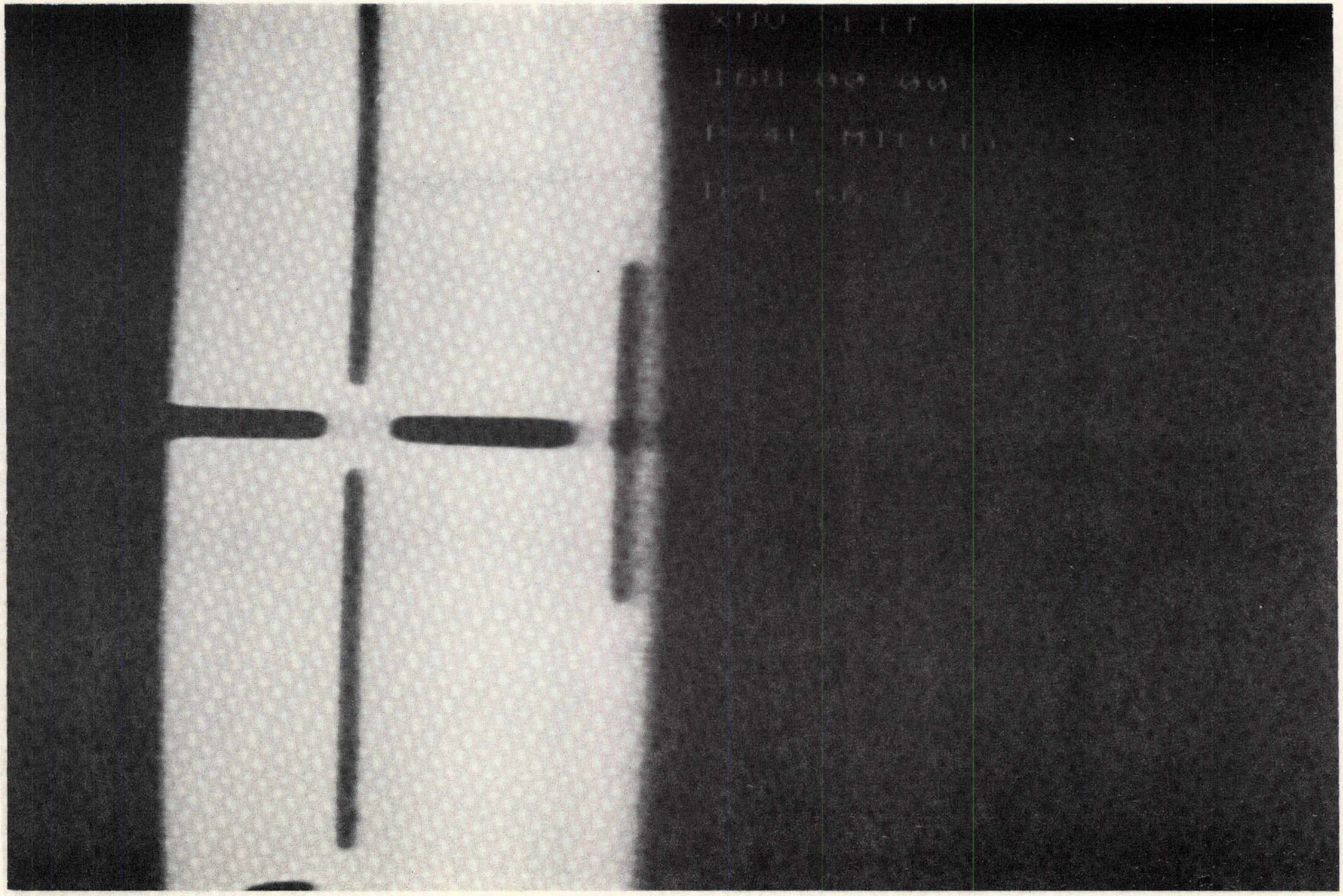


Figure 3-16. S082B White Light Display Downlink Photographs

Thermal distortion analysis of the S082B instrument was completed for numerous orbits during the Skylab mission. The results of the analysis show that the thermal control system performed successfully. No failures occurred in the thermal control system, the associated temperature probes, or the experiment temperature measurements. During some of the off-the-Sun pointing for Comet Kohoutek observations, thermal distortions were excessive because of high temperatures on the front end of the instrument. These temporary excursions caused horizontal image smear rates of the slit images to be 200 percent of the maximum allowable value. However, the maximum allowable value is based upon a 15 minute duration exposure. Therefore, shorter exposures experienced less smear and were within the allowable value.

All electronic voltage monitors were within the specified requirements. The S082B telemetry and predisperser changing mechanism subsystems performed satisfactorily.

All ATM interfaces adequately supported the experiment. MDA film vaults maintained the stored film cameras within the prescribed environmental limits and no film degradation resulted. Sun-end aperture door malfunctions occurred on Skylab 4 but achievement of experiment objectives was not impaired.

Hydrogen-Alpha Telescopes - The H-Alpha 1 and H-Alpha 2 telescopes successfully performed their three primary functions of solar observations, pointing, and photography throughout the Skylab mission. They were used by the crew to observe the Sun and search for regions of scientific interest. The telescopes were also used as a boresight for pointing other ATM instruments at specific features on the Sun. The H-alpha 1 film camera was used extensively during the mission to provide a record of ATM pointing and to obtain high resolution photographs of the Sun.

Five film magazines were used on H-alpha 1 during the entire Skylab mission. Table 3-10 illustrates film usage for each film load. Figure 3-17 is an example of the developed film from Skylab 2 showing the solar flare that occurred on DOY 166.

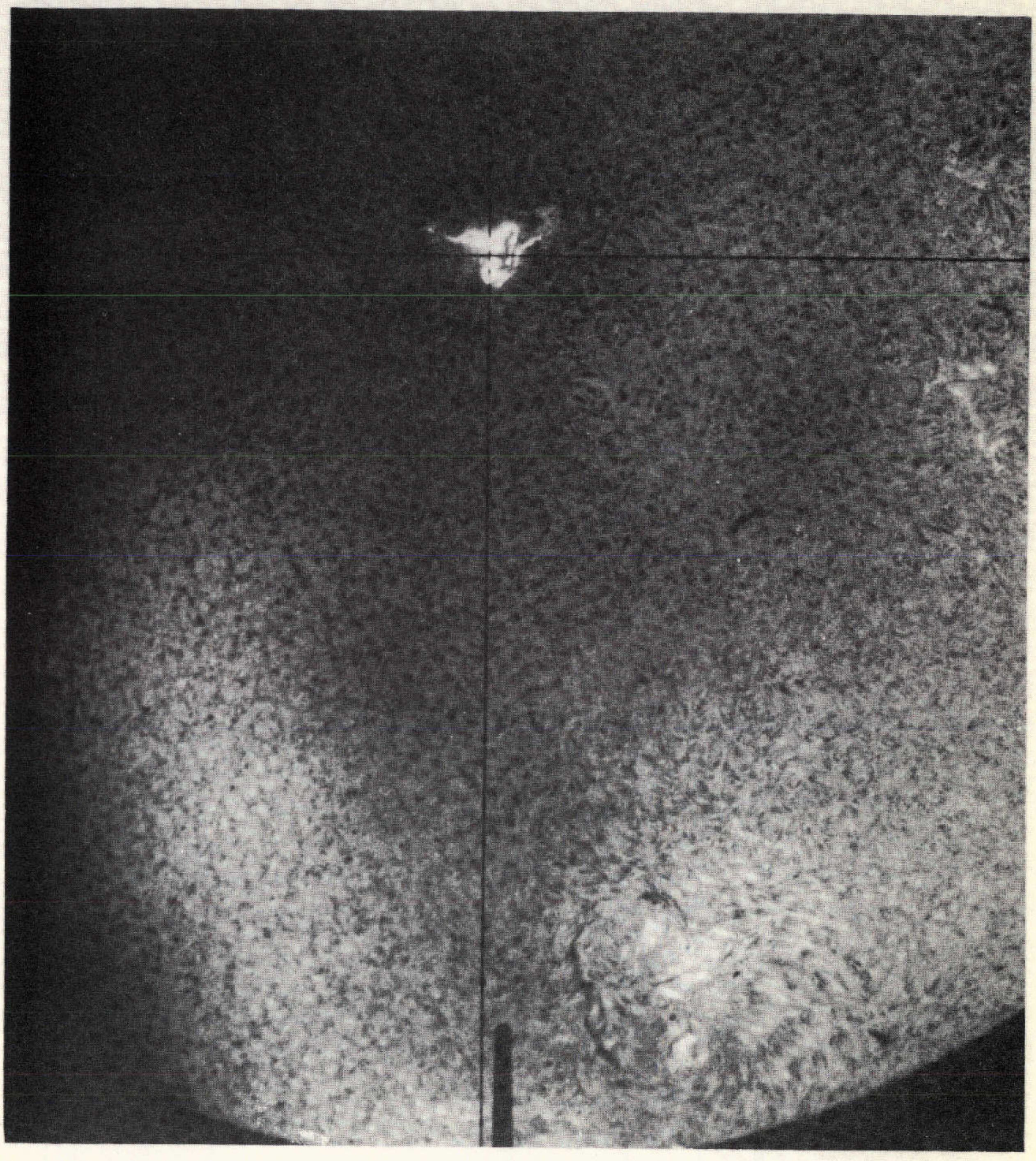


Figure 3-17. H-Alpha Solar Flare

Table 3-10. H-Alpha 1 Film Load Usage

FILM LOAD	SKYLAB MISSION	FRAMES AVAILABLE (1)	FRAMES EXPOSED	INSTALLED (DOY) (2)	REMOVED (DOY) (2)
1	2	15,400	12,998	Prior to Skylab 1 Launch	170
2	3	15,400	15,405	218	236
3	3	15,400	15,382	236	265
4	4	15,400	15,400	326	359
5	4	15,400	9,000(3)	359	034

(1) The frames available depends upon the amount of film in each load and varies slightly from load to load.
(2) Unmanned mission phases do not require H-Alpha telescope operation.
(3) This is an approximation. The low number of frames is attributed to an anomaly that occurred on Skylab 4.

Evaluation of the Skylab 2, 3, and 4 flight film indicated that high quality photographs of 0.7 angstrom spectral resolution and 1.0 arc second spatial resolution were obtained. These were the design specifications. Figure 3-18 is an example of the developed film from Skylab 2 showing the solar disk in fine detail taken on DOY 166. All five film magazines operated satisfactorily; however, evaluation of the film from Skylab 4 revealed that approximately 20 percent of film load 4 and 35 percent of film load 5 contained overlapped pictures brought about by intermittent film advances.

The H-Alpha 1 and 2 television systems performed as designed. Both vidicon cameras operated normally and displayed real-time solar detail to the crew on the control and display console video monitors and provided downlink television images to the Principal Investigator for use in solar observation planning. Table 3-11 illustrates television usage for each manned mission.

Table 3-11. H-Alpha Television Time

SKYLAB MISSION	H-ALPHA 1 TELEVISION (HOURS)	H-ALPHA 2 TELEVISION (HOURS)
2	107	107
3	305	305
4	338	338

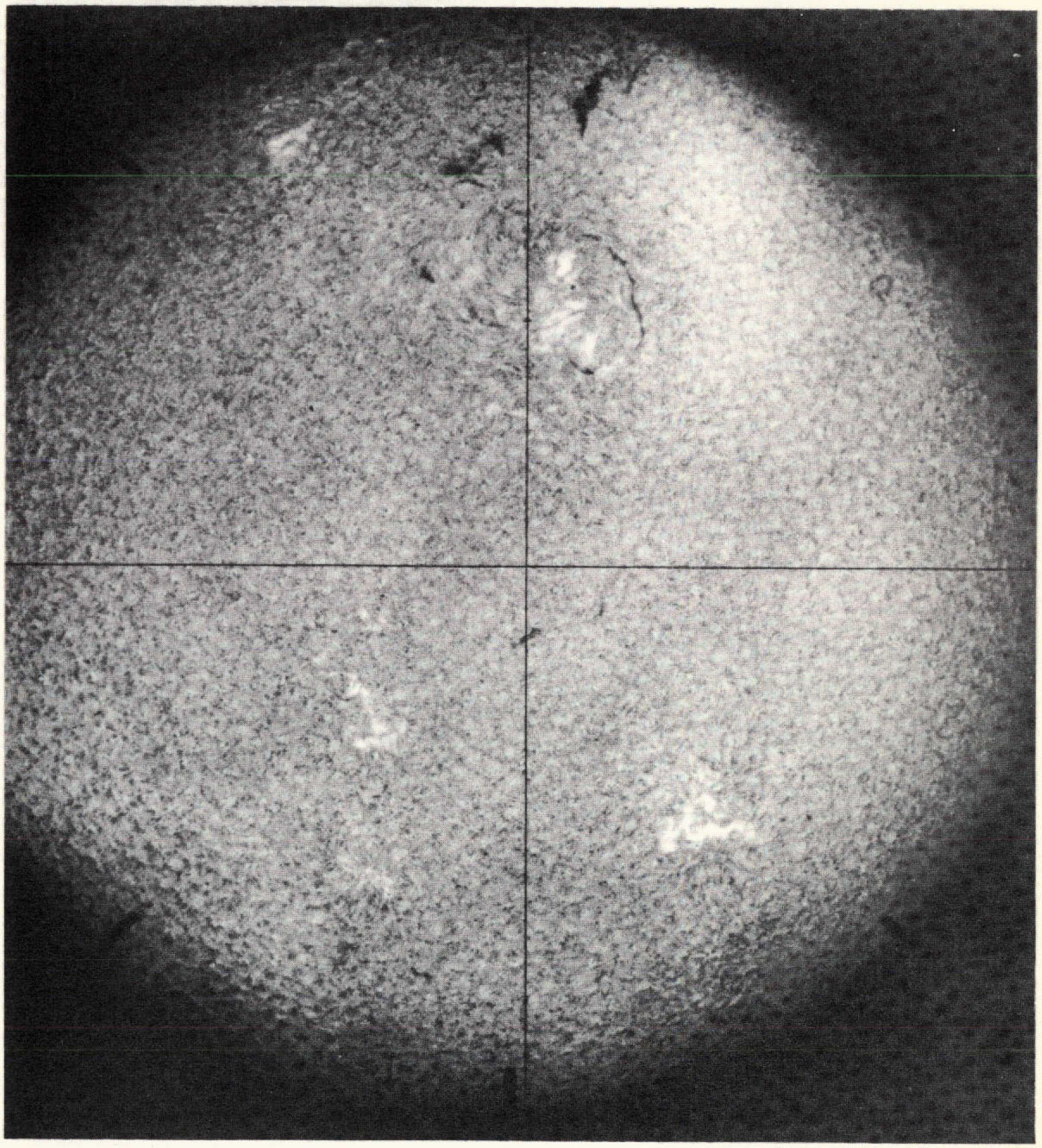


Figure 3-18. H-Alpha Full Solar Disk

Television imagery remained stable throughout the mission except for some degradation evident on H-alpha 1 during the last month of the mission. It was found that the H-alpha 1 image significantly improved when the vidicon was left off for a period of 8 hours. Thus, the crew was instructed to leave the H-alpha 1 television camera powered down when not in use. Figures 3-19 and 3-20 are photographs of downlink television images taken on DOY 166. Table 3-12 lists the H-alpha television resolution parameters. In all cases the resolutions obtained were equal to or better than the design specification.

Table 3-12. H-Alpha Television Resolution

DISPLAY AND ZOOM POSITION	FIELD OF VIEW (ARC MINUTES)	SPATIAL RESOLUTION (ARC SECONDS)	SPECTRAL RESOLUTION (ANGSTROMS)
H-Alpha 1 Vidicon at 1X	16.0	5.0	0.7
H-Alpha 1 Vidicon at 3.6X	4.4	1.5	0.7
H-Alpha 2 Vidicon at 1X	35.0	2.0	0.7
H-Alpha 2 Vidicon at 5X	5.0	1.0	0.7

The H-alpha 2 television system exhibited some anomalous behavior such as image persistance and blossoming. However, these did not impact any solar observations.

The H-alpha thermal control systems performed flawlessly throughout the Skylab mission. Each filter oven was operated approximately 4000 hours and maintained the Fabry-Perot filters at the prescribed temperatures. The heat rejection windows temperatures were as expected and varied porportionately with the amount of time in the sunlight. This was particularly evident on H-alpha 2 after a failure of the Sun-end aperture door necessitated pinning the door open.

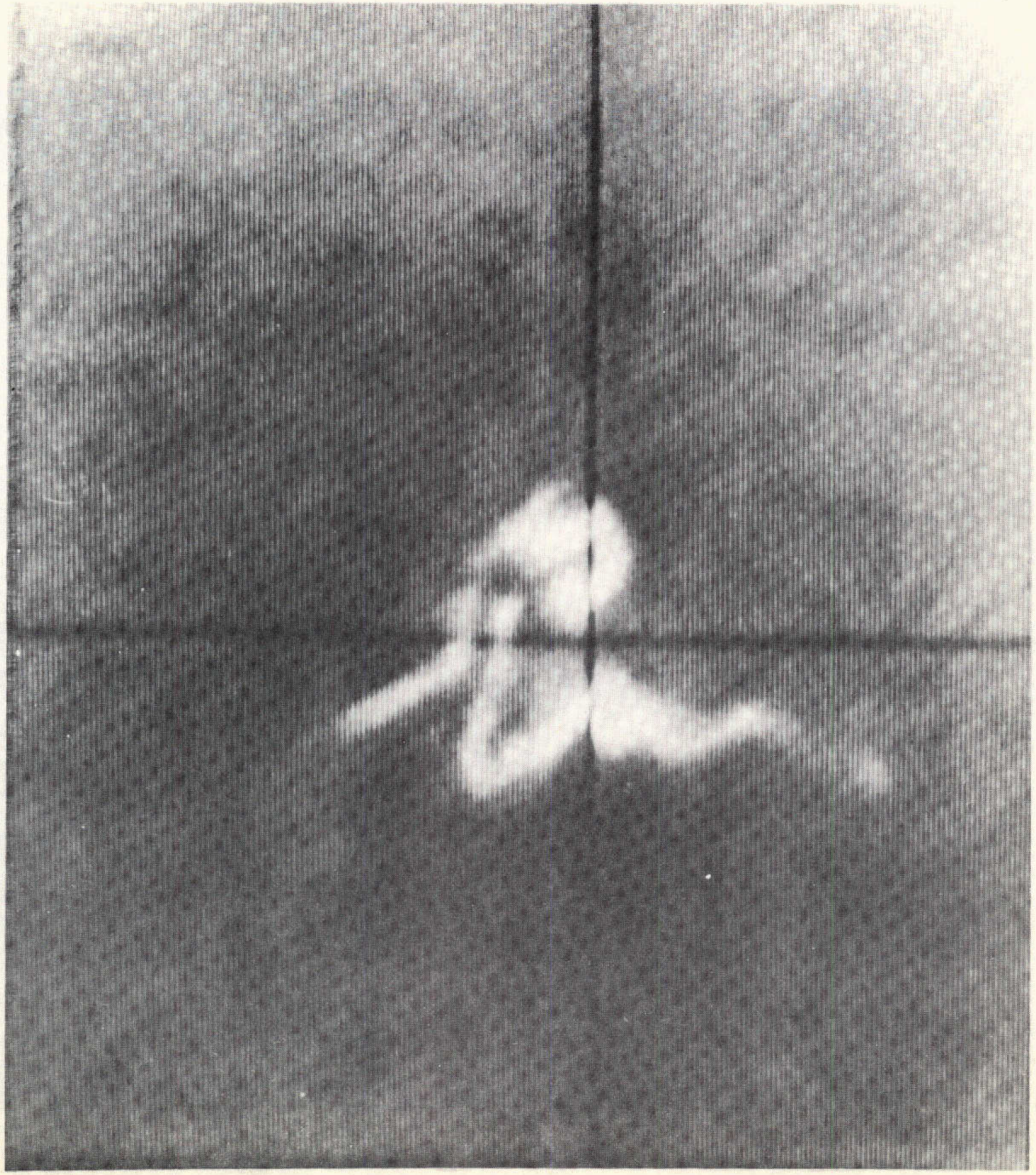


Figure 3-19. H-Alpha 1 Television

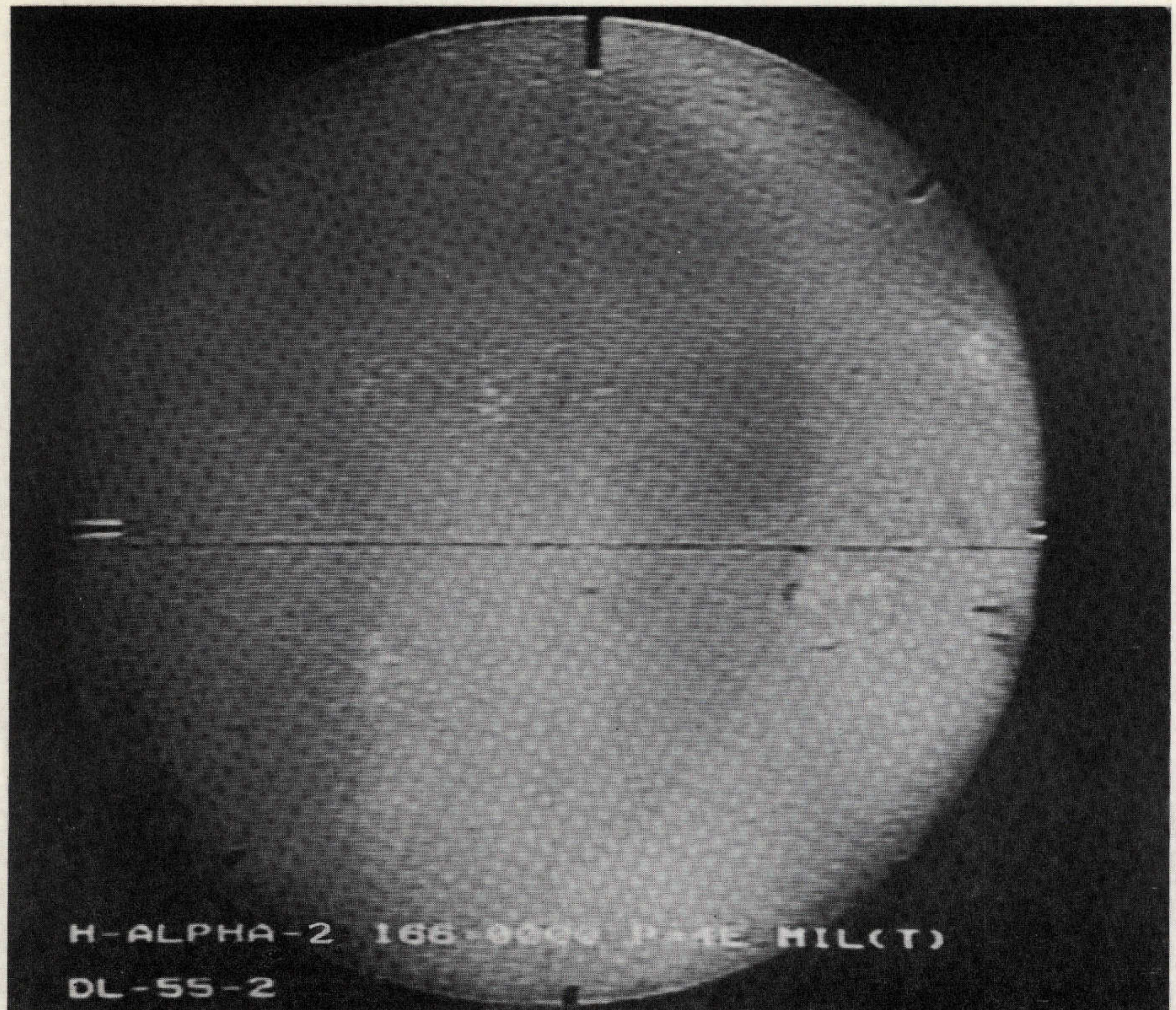


Figure 3-20. H-Alpha 2 Television

The movable reticle systems were exercised repeatedly throughout the mission and performed as designed.

The zoom assemblies of both H-alpha telescopes performed as designed. The zoom assemblies provided magnification of television images to aid in selecting targets of opportunity and pointing. Some slight image jiggle was noted in the full zoom-in positions but no detrimental effects on pointing, resolution or operation occurred.

All ATM interfaces adequately support the instruments. The H-alpha 2 Sun-end aperture door had to be pinned open because of intermittent operation but had no impact on instrument operations. Co-alignment with S055A and S082B was within the required 2 arc seconds with no detected change. Film vault temperatures remained within specification and no film degradation was evident.

Structures and Mechanical Systems

The ATM maintained its structural integrity during the boost phase and orbital insertion, and the canister vent valves operated properly relieving internal pressure. After the ATM was deployed, the canister launch locks were released, and the ATM solar array wings were decinched and deployed, as programmed.

During the Skylab 2 mission, the canister roll and gimbal actuators operated satisfactorily, and the nitrogen purge disconnect mechanism released and retracted, as planned, during the first roll motion of the canister. The roll control panel at the center workstation and the film retrieval doors were operated without difficulty during extravehicular activities, and the crew expressed satisfaction with the extravehicular activity support hardware, which includes the ATM lighting, single and double handrails, foot restraints, and the film transfer booms.

A failure occurred with the S054 Sun-end aperture door on DOY 153. It was unpinned and latched open during extravehicular activity on DOY 158. This did have an impact on the mission, in that the S054 instrument was operated during the period from DOY 153 through 158 in the belief that the aperture door had failed in the open position. Whereas, in reality, the door had failed in the closed position, with an erroneous indication of open.

During the Skylab 3 mission, the ATM structures and mechanical systems performed normally, and the crew again expressed satisfaction with the extravehicular support hardware.

Three of the Sun-end aperture doors showed evidence of increased friction in their operation, and, to preclude failures, their ramp latches were removed during extravehicular activities. Ramp latch removal was effected on the S055A door on DOY 218, and on the S056 and S082A doors on DOY 236.

During the Skylab 4 mission, the ATM structures and mechanical systems continued to perform satisfactorily. During the last extravehicular activity, the film transfer clothesline was successfully deployed and used instead of the film transfer booms.

The S082A aperture door operations indicated that friction was increasing, even after the ramp latch was removed on DOY 236. Rather than risk curtailing operation of the S082A instrument, the door was unpinned and latched open during extravehicular activities on DOY 359.

The S082B aperture door malfunctioned on DOY 364, but responded to the malfunction procedure. However, since the indication was that friction in the mechanism had increased, the door was commanded open, and power to the mechanism was then inhibited. The door was left open through the end of the mission, thus precluding an impact on operations that would have been a result of failure of the door operating mechanism.

The ATM structures and mechanical systems and extravehicular activity support hardware performed satisfactorily in support of mission objectives with the exception of the S054 Sun-end aperture door, which failed.

Electrical Power System

The ATM power system, designed primarily for a Sun oriented mission, was initially required to operate with the solar panels oriented at various Sun angles for 10 days to minimize thermal problems within the vehicle. Although the power capability was reduced, the power system performance was maintained. Because of the problems encountered during launch and the unknown condition of the Airlock Module power system, the ATM transfer and Airlock Module transfer relays were not commanded closed at 134:22:10 (GMT) as originally scheduled. The transfer relays were closed at 134:19:27 (GMT) after analysis ascertained that the ATM should provide the Orbital Workshop power, thereby preventing the AM batteries from completely discharging, and to allow the ATM electrical power system to supply all the Orbital Workshop power requirements. Power management procedures were initiated immediately to ensure that demands on the ATM electrical power system did not exceed its output capability. The procedures included delaying use of the Orbital Workshop radiant heaters and the docking adapter wall heater high temperature settings.

The launch-to-activation phase was 10 days longer than the pre-mission plan because launch of the Skylab 2 vehicle was delayed until DOY 145. Thermal problems, which developed as a result of the loss of the meteoroid shield, dictated that the vehicle be maneuvered out of the normal solar inertial attitude. Each departure from the solar inertial attitude resulted in a reduction in the ATM power system capability during that departure; therefore, the requirement to manage power for the necessary electrical loads became critical. During the non-solar-inertial modes, the mission rule that imposed a 30-percent maximum depth-of-discharge of the ATM batteries was waived. The goal of power management was to allow the ATM batteries to obtain an energy balance during each orbit; that is, all power removed from the batteries during the orbital night was to be replaced before entering the next orbital night. This goal was not completely feasible, and management of individual CBRMs was required to allow recharging of individual batteries. Frequently, several orbits would elapse before a particular battery would be recharged. Figure 3-21 shows the combined ATM and AM electrical power system capability and load profile for the total Skylab mission. Both electrical power systems were operated in the parallel mode from the time the transfer relays were closed, as noted above, until splashdown of Skylab 4, except for the unmanned period between splashdown of Skylab 3 and launch of Skylab 4, and on DOY 39 to DOY 40 when end of mission battery capacity tests were conducted prior to power system shutdown.

<u>Skylab 2</u> - During the unmanned period of Skylab 2, the total spacecraft load varied from 4,400 watts average per orbit in the solar inertial mode to 2,400 watts at 1.05 radian pitch attitude. The average load for the ATM during this period was approximately 1,600 watts. Since the ATM power system was providing all the Skylab power, the remaining 800 to 2,800 watts were transferred across the interface to the transfer buses for distribution to the Orbital Workshop loads. The majority of the Orbital Workshop load fluctuations for this period were on Airlock Module bus 1 and bus 2; the ATM buses remained relatively stable at 28.69 to 28.97 volts. The specification requirement was 26.0 to 30.5 volts. The voltage levels for this time period were substantially above the imposed minimum bus voltage of 24-volts direct-current needed by the com-

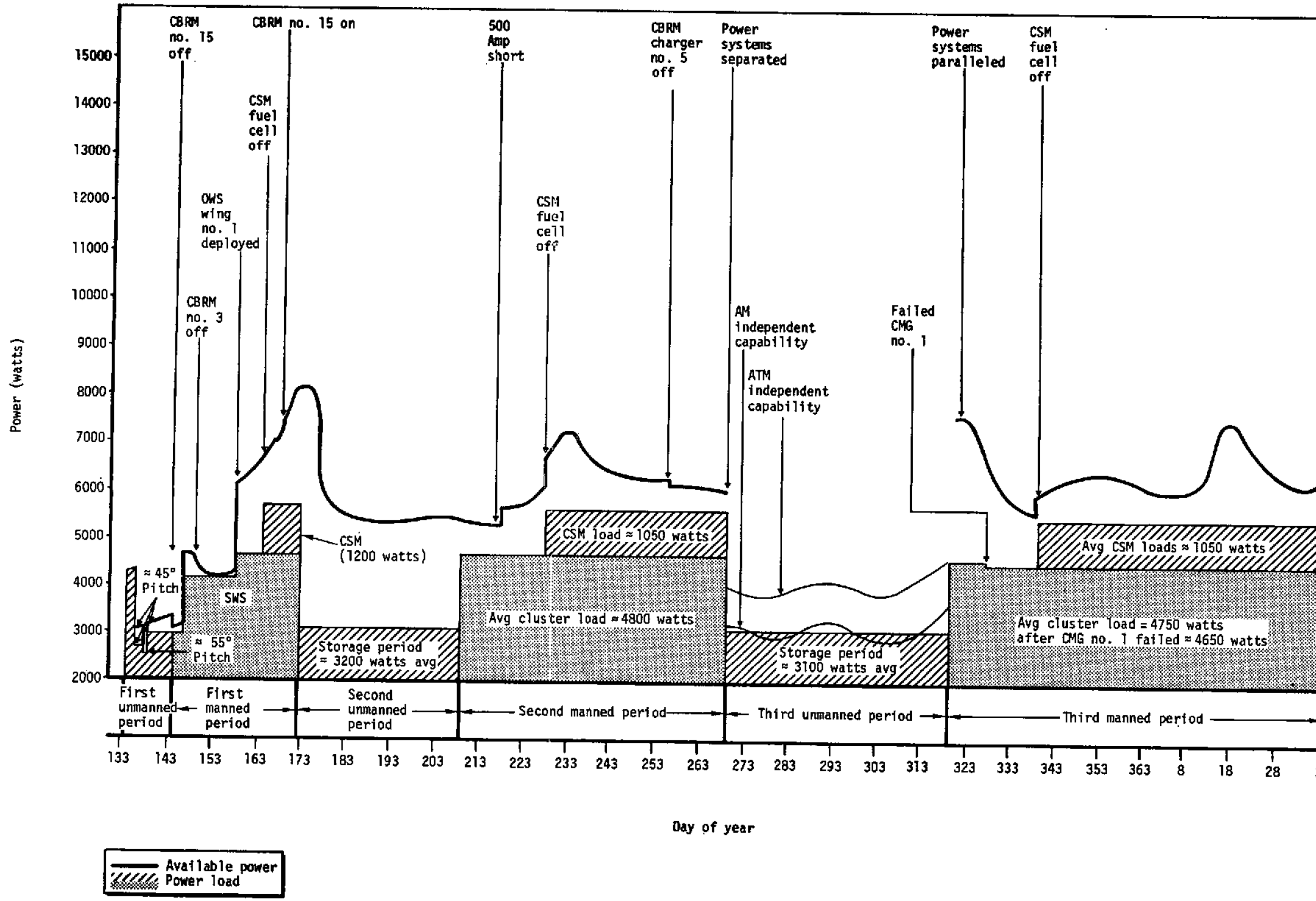


Figure 3-21. Skylab EPS Capability/Load History

ponents. Figure 3-21 shows the average system capability for the Skylab 2 unmanned phase. During this time, the loads were adjusted to ensure the load requirements did not exceed the capability of the electrical system.

The Orbital Assembly was maneuvered to the solar inertial attitude after deployment of the thermal parasol. It remained in this attitude through the Skylab 2 mission, except for occasional excursions to the Z-axis local vertical attitude for operation of the Earth resources experiments. Maneuvering to the solar inertial attitude increased ATM power capability.

The ATM continued to supply the total Skylab electrical power requirement for the first 14 days of the 28-day manned mission. The command module power was being supplied by its fuel cells; therefore, it did not require power from the ATM power system. The total load capability for the first 14 days of the Skylab 2 mission is shown in figure 3-21. Extensive load management was continued to ensure that the electrical loads did not exceed the power capability of the system.

On DOY 145, 8 CBRMs tripped off, then an unexpected automatic regulator trip occurred upon re-entry into sunlight, which caused the input power contactor to disconnect the solar array from CBRM 15. The contactor then failed in the open position. On DOY 150, a further reduction in the ATM power capability occurred when CBRM 3 regulator output failed, leaving 16 modules in operation. Additional degradation occurred on DOY 157, when CBRM 17 exhibited a reduced power output during orbital day. The estimated loss of capability of module 17 was approximately 20 percent, a reduction of approximately 50 watts in ATM average power.

On DOY 158, the crew performed extravehicular repair operations that resulted in Orbital Workshop solar wing 1 deployment. An approximately 2000-watt increase in Skylab power system capability resulted, and ended the necessity for critical power management techniques for proper load sharing of the two power systems. During extravehicular activity, on DOY 170, the crewman tapped the case of CBRM 15, resulting in jarring the stuck contactor loose. This allowed CBRM 15 to come back on line, and it operated normally from then on. For the remaining 14 days of the Skylab 2 mission, all solar inertial mode orbits had a minimum positive power margin of 800 watts. This capability is shown in figure 3-21 for the regulator bus open-circuit voltage setting of 29.0 volts after the Orbital Workshop solar array wing 1 was deployed.

Skylab 3 - The ATM power system operated normally during the unmanned period of Skylab 3. The total Skylab electrical loads averaged 3,100 watts during each orbit. Since the average power system capability exceeded 5,000 watts for this period, a positive power margin of over 2,000 watts existed.

The average loads during the activation period of Skylab 3 did not increase beyond 3,900 watts, and since the electrical power system capability was 5,500 watts, a positive power margin of over 1,600 watts was maintained. As the astronauts began the activation process, the loads were increased incrementally until at the completion of activation, the total Skylab average load was 4,800 watts. Figure 3-21 shows the Skylab 3 power capability and depicts the average cluster load for this period. The 5,000-watt electrical power system capability during the activation period reflected an AM regulator bus open-circuit voltage setting of 29.4 volts. This high open-circuit voltage setting resulted in a minimum power transfer between the AM and ATM. Initially, the AM transferred power to the ATM, but as the loads were increased in the AM during the activation period, this was reversed.

The ATM and AM power systems operated in parallel to provide the total cluster power requirements. Since both systems had a battery depth-of-discharge constraint, it was necessary to adjust the regulator bus open-circuit voltage periodically to ensure that these constraints were not violated. During the mission, the total power capability varied as the open-circuit voltage adjustments were made. Several open circuit voltage adjustments were made during the Skylab 3 mission, and the load sharing between the ATM and AM power systems was affected by each of the adjustments. Since the objective in determining the open-circuit voltage adjustment was to share the total load such that the depth-of-discharge constraints of both the ATM and AM power systems were not violated, the depth-of-discharge increased with decreasing Beta angle, and decreased with increasing Beta angle.

Two significant anomalies occurred during the Skylab 3 mission. These were CBRM 5 failure on DOY 256 causing a power capability reduction of approximately 5 percent (235 watts), and ATM battery capacities lower than prelaunch predictions.

The ATM electrical power system operated normally with the exception of CBRM 17. Due to the off-nominal operation of this CBRM, its contribution to the total ATM output was 150 watts less than any of the remaining 15 CBRMs. On DOY 284, CBRM 17 was removed from the load bus for a period of 20 hours; after it was returned to the load bus it began to function properly and for the remainder of the mission its contribution to the total ATM power capability was equal to that of the other 15 CBRMs.

Skylab 4 - The ATM and AM power systems were operating independently from DOY 269 to DOY 320, as shown in figure 3-21, during the unmanned period of the Skylab 4 mission. The average ATM load requirement during the unmanned period of Skylab 4 was 2000 watts and the average Skylab capability varied from a minimum 3800 watts to a maximum 4900 watts at the launch of Skylab 4. The resulting battery depth-of-discharge for the 2000-watt load over the range of Beta angles encountered during the unmanned period varied from 12 to 14 percent. Since a large positive power margin was indicated on both systems for the entire unmanned period, daily load predictions were not computed.

The ATM and AM electrical systems were paralleled on the first day of Skylab 4 activation and the AM open-circuit voltage was adjusted to 29.1 volts and then was increased to 29.3 volts for the remainder of the activation period. The power system capability of the two systems operating in parallel at the 29.1-volt open-circuit voltage was 8000 watts. The adjustment to 29.3 volts decreased the cluster capability to 7900 watts. As the cluster was activated the load increased incrementally until at the end of the activation period the load was 4800 watts average when the crew was awake and 4200 watts during the crew sleep period. Compared to the 7900-watt capability for this period a minimum power margin of 3100 watts existed. The power system capability for this period is shown in figure 3-21.

The ATM and AM power systems continued to operate in parallel for the remainder of the Skylab 4 mission to supply the total cluster power requirements. Since both systems had a constraint of the maximum depth-of-discharge it was necessary to periodically adjust the AM open-circuit voltage to ensure that the constraints were not violated. As the open-circuit voltage was adjusted the total cluster power system capability varied the capability at that specific setting.

Even though a positive power margin was indicated for each mission day the summary flight plans for each day were analyzed to insure that the integrity of the power system was protected orbit by orbit. Power management techniques were utilized for the off-nominal pointing modes. The power system performance for the Skylab 4 mission provided adequate power to support the planned activities without undue restrictions on the astronaut schedule or unmanned experiment operation.

ATM Solar Array - Solar array performance during the Skylab mission agreed with preflight predictions, with the exception of one panel, supplying required bus loads and adequate power for normal recharging of the ATM batteries. Panel 710A4, which supplied CBRM 17, indicated a possible short external to the CBRM. On DOY 157 CBRM 17 was delivering full power output after approximately 10 minutes into each night cycle, zero power during the day portion. This problem has been simulated in the laboratory, and flight data supported the theory of a short in one of the solar array modules. This short disappeared on DOY 270, reappeared on DOY 284, then disappeared later on the same day. CBRM 17 continued to operate normally for the remainder of the mission, indicating panel 710A4 was again delivering full power.

Solar Array Degradation - The solar panels were predicted to experience a power reduction of 8.8 percent due to micrometeoroids, space radiation, and temperature cycling effects during the Skylab mission. At the end of the Skylab mission analysis of data showed a power capability reduction of 8.6 percent. This was within 0.2 percent of the predicted value. Throughout the entire Skylab mission the solar array system fulfilled all requirements in supplying electrical power to the CBRMs with power to spare.

Solar Panel Capability at End of Mission - The ATM solar array was not required to produce full power output for the full sunlight duration, even under periods of high ATM power requirements. Figure 3-22 shows a typical plot of power output versus time for panel 710A5. At 30 minutes after sunrise, battery charging was complete and the panel output was reduced. Also shown in the figure is the estimated power output at 13.5 amperes over the complete illuminated portion of the orbit. From this data it can be found that the actual watt-hours output was only 74 percent of the watt-hour capability. Therefore, in this case, the panel could have supplied 26 percent more electrical energy if required.

Charger-Battery-Regulator Modules - The redundancy afforded by the 18 modules was capable of compensating for all electrical problems; however, multiple battery degradation caused some concern. Three times during the mission, the capability of the power system was exceeded, causing the depletion of battery power. This resulted in automatic battery disconnect. The first time

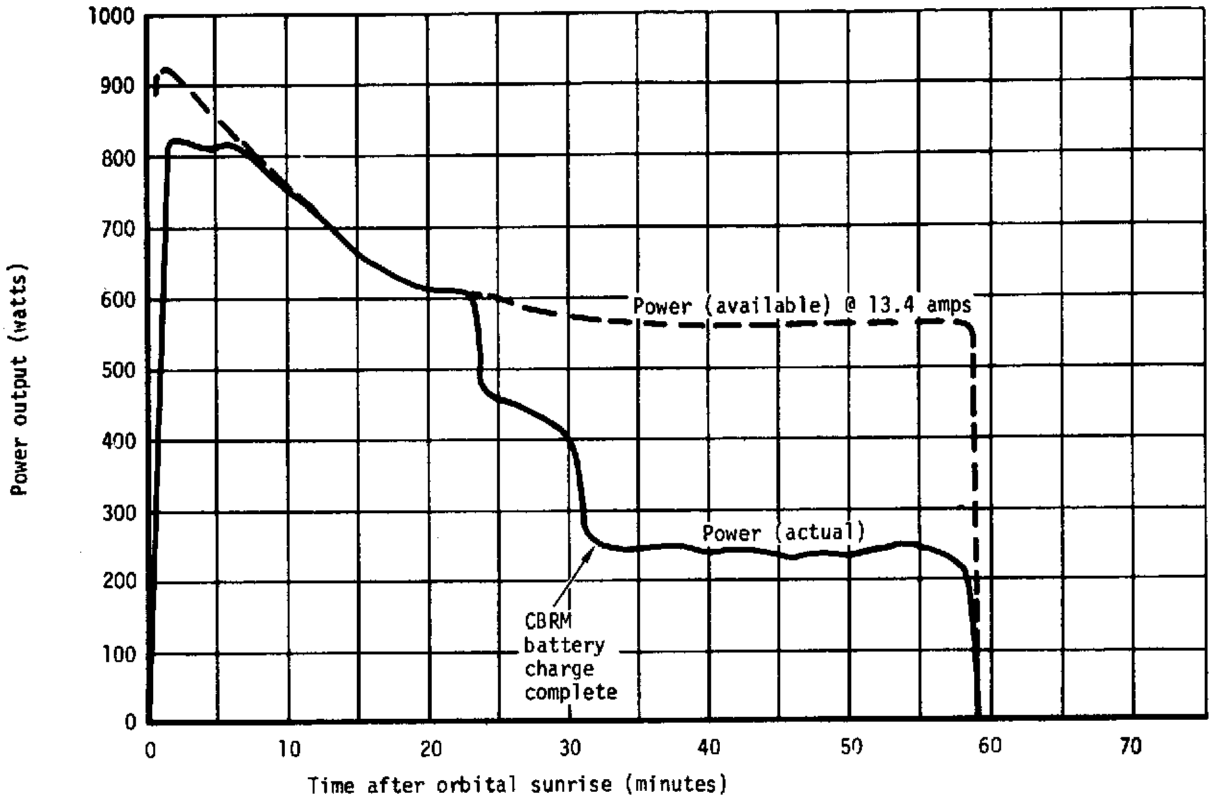


Figure 3-22. ATM Solar Panel Capability vs CBRM Requirement

this happened, on DOY 145, 8 CBRMs tripped off. Then an unexpected automatic regulator tripout occurred upon re-entry into sunlight, which caused the input power contactor to disconnect the solar array from CBRM 15. The contactor then failed in the open position. The crew, during extravehicular activity on DOY 170, struck the case of the module to generate internal forces to free the stuck contactor and restored the module to full operating capacity. On DOY 146 two other CBRMs tripped off because of depleted battery capacity. On DOY 150, during the first Earth resources pass, four batteries discharged to approximately zero percent state of charge and were automatically turned off. In all cases the batteries were recharged on subsequent orbits and were reactivated to normal operations.

On DOY 150, CBRM 3 ceased to deliver power. It was determined that the failure probably resulted from a solder joint or component failure in the regulator control circuit; therefore, the module was turned off for the remainder of the mission.

On DOY 256, CBRM 5 ceased charging. Analysis indicated that the input bus was shorted to the battery relay. This condition was probably caused by a short in one of the charger transistors, but also could have been the failure of a battery isolation diode. CBRM 5 could not be repaired, so the charger and regulator were commanded off, except when it was used during Earth resources experiment passes. CBRM 5 could have been used in an emergency since the charger failure mode basically allowed the charge voltage to exceed the maximum programmed voltage by 1.0 volt. Automatic safety circuits would terminate the charge at this point. Laboratory simulation tests demonstrated that a CBRM could function under these conditions and maintain the battery operating parameters within their safe limits.

The loss of CBRMs 3 and 5 during the Skylab mission reduced the ATM electrical power capability by approximately 10 percent (470 watts); however, better than predicted operating efficiency of the 16 remaining CBRMs made up for most of the deficit. The 16 CBRMs operated at 75-percent efficiency, as opposed to a predicted worst case of 68 percent. CBRM efficiency is defined as that percentage of energy originating at the solar array that reaches the bus in the form of usable electrical power. The ATM was required to supply 3,716 watts of power. The system was designed to supply 4,250 watts with 18 CBRMs, providing a pad of 514 watts. When the Skylab mission ended 16 CBRMs were delivering 4,033 watts of power. This was 317 watts greater than the cluster specification required.

Networks - Between Skylab 1 and 2, the electrical networks portion of the ATM system, power generation, conditioning, distribution, and control circuitry, were acceptable. A few exceptions were associated with CBRMs, experiment thermal shield aperture doors, and S054 main power anomalies. Except for the S054 main power anomaly, all commands and control by panel or ground were received and functioned as designed. No power transfer problems were encountered by ATM networks. All components involved in the ATM and Airlock Module power transfer function performed normally.

All commands and controls continued to function normally throughout the Skylab 3 period, except for the operation of the experiment Sun-end aperture doors, which continued to be a problem, and a hard short, which appeared on ATM television bus 2 (7D26). After analysis and testing, it was concluded that a hard short circuit, from the ATM television bus 7D26 to ground, occurred in the power transfer distributor, resulting in the loss of the bus. The location and total damage could not be assessed. ATM bus 7D26 was de-energized, and power for the television systems was provided by bus 7D16 only. A bus connector module was flown on Skylab 4 to be used in the event that power from bus 7D16 was not available.

Performance of the power control and distribution circuitry during Skylab 4 was normal. Commands and telemetry performed as designed during this period until DOY 318 when the ATM experiment pointing control primary pitch orbital lock/unlock mechanism failed to unlock the experiment canister upon entering an experiment pointing mode of operation. Switching to the secondary experiment pointing control system succeeded in clearing the problem for the rest of the mission.

On DOY 277, the S055A main power could not be turned off. Several attempts to deactivate it by ground command were unsuccessful. Due to limited permissible troubleshooting, the failure mode could not be ascertained. Possible failures include a relay or open circuit in the command line. This condition had no impact on the mission.

On DOY 03, all alternating current lighting on the ATM control and display console (integral-lighting and numeric buses 7A363 and 7A364) was lost. The direct-current lighting, meter, ready and alert lights were unaffected. The crew performed a malfunction procedure to restore the alternating current lighting; only the numeric bus loads were returned to operation. Circuit analysis revealed that a short on any of several loads which were hard wired to integral-lighting bus 7A363, could result in the shutdown of the inverter supplying power to 7A362 bus 2. Since all loads on the integral-lighting bus were hard wired, isolation of the short was not possible, except by turning off the bus itself. The integral-lighting bus loads were lost for the remainder of the mission.

The few anomalies encountered during the Skylab mission did not restrict normal operations as workarounds were always achieved. The total number of verified electrical network and circuit control anomalies were comparatively few in number.

Thermal Control System

The ATM thermal control system was activated on DOY 147, after the thermal parasol had been deployed and the vehicle had been maneuvered into the solar inertial attitude.

During the period between launch of Skylab 1 and activation of the thermal system, some components exceeded their redline temperature limits, but suffered no apparent degradation. These components were the ATM solar array, the primary tape recorder, and CBRM 17. The solar array temperature decreased to 201.2 kelvins, exceeding its lower limit of 208.2 kelvins for a period of approximately 10 minutes. The primary tape recorder and CBRM 17 temperatures momentarily exceeded their upper limits of 303.2 kelvins, and reached temperatures of 303.3 kelvins. Once the ATM thermal control system was activated, all ATM components returned to predicted temperatures within their respective, specified limits.

After activation, the canister active thermal control system operated within its specified design limits, using the primary pump and primary controller. The thermal coatings, insulation, and low-conductance mounts used for rack-mounted components were adequate, and the components operated within their specified temperature limits.

A matter of concern during the first part of the mission was the slow decay of the canister internal pressure. The pressure decreased slower than anticipated, and there were several pressure spikes during the decay period. After extensive analysis of the data, it was concluded that the pressure gauge was reading correctly, and the pressure spikes were caused by outgassing, internal to the canister. It is believed that the outgassing was due to water vapor trapped in the insulation. Acceptable canister operating pressures were maintained from DOY 151 through the end of the Skylab 2 mission.

During the Skylab 3 mission, the system continued to operate within its design limits, and all non-failed rack-mounted components operated within their specified temperature limits. The S-13G white thermal coating on the canister Sun-end degraded as predicted; the coefficient of absorptivity increased from approximately 0.2 at launch, to approximately 0.36 at the end of the Skylab 3 mission.

During the Skylab 4 mission, the active thermal control system operation was still within its design limits. However, during the high Beta angle period from DOY 015 to DOY 018, with full Sun, some canister components exceeded their upper temperature limits. The S056 mirror assembly exceeded its upper limit by 0.1 kelvin, the spar exceeded its upper limit by 0.1 kelvin, and the temperature of the coolant fluid at the canister inlet reached its upper design temperature limit of 284.8 kelvins. This had not been anticipated in preflight analysis, and the condition appears to have been caused by higher-than-expected external heat loads, and by greater-than-expected degradation of the S-13G thermal coating on the Sun-end of the canister. Based on ground testing, it had been predicted that the coefficient of absorptivity would increase to approximately 0.36 and remain there. However, figure 3-23 shows that the coefficient of absorptivity had increased to approximately 0.52 at the end of the mission, and that it gave no indication of leveling off.

Figure 3-24 compares the premission and the actual calculated heat fluxes on the radiator of the thermal control system. The maximum and minimum predictions were based on a ± 3 sigma variation from nominal environments, and a degradation in the coefficient of solar absorptivity to 0.5 for the S-13G thermal coating. At the time when the canister inlet reached 284.8 kelvins, the radiator outlet temperature was at its maximum of 284.4 kelvins. The higher-than-expected temperatures can be attributed to two factors: external heat fluxes higher than anticipated, and elevated internal heat loads due to unexpectedly high solar shield temperatures and latched-open aperture doors. However, due to the margin inherent in the system, no temperature limits were violated, nor were functional problems experienced. After DOY 018, with decreasing Beta angle, the radiator outlet and canister inlet temperatures decreased to normal values.

The ATM active thermal control system utilized the primary pump and primary controller throughout the Skylab mission. On DOY 038, performance of the system using the secondary pump and controller was monitored, in a test to determine the effect of long storage under orbital conditions. After this test, the system was again operated using the primary pump and primary controller. This data is presented in Table 3-13. The table shows that performance of the secondary system was not degraded by orbital storage for approximately nine months, and that the primary system parameters were unchanged after restart.

The active thermal control system was deactivated at 039:08:33 (GMT), after having performed flawlessly throughout the mission.

Instrumentation and Communication System

The ATM instrumentation and communication system, during the ten day critical period of Skylab 1, was a prime factor contributing to the continuation of the Skylab mission. The communication system provided the means by which corrective ground commands could be transmitted to the ATM to optimize the thermal and electrical balance. The instrumentation system provided the ground with the critical data required to evaluate the existing conditions so that necessary corrective action could be determined.

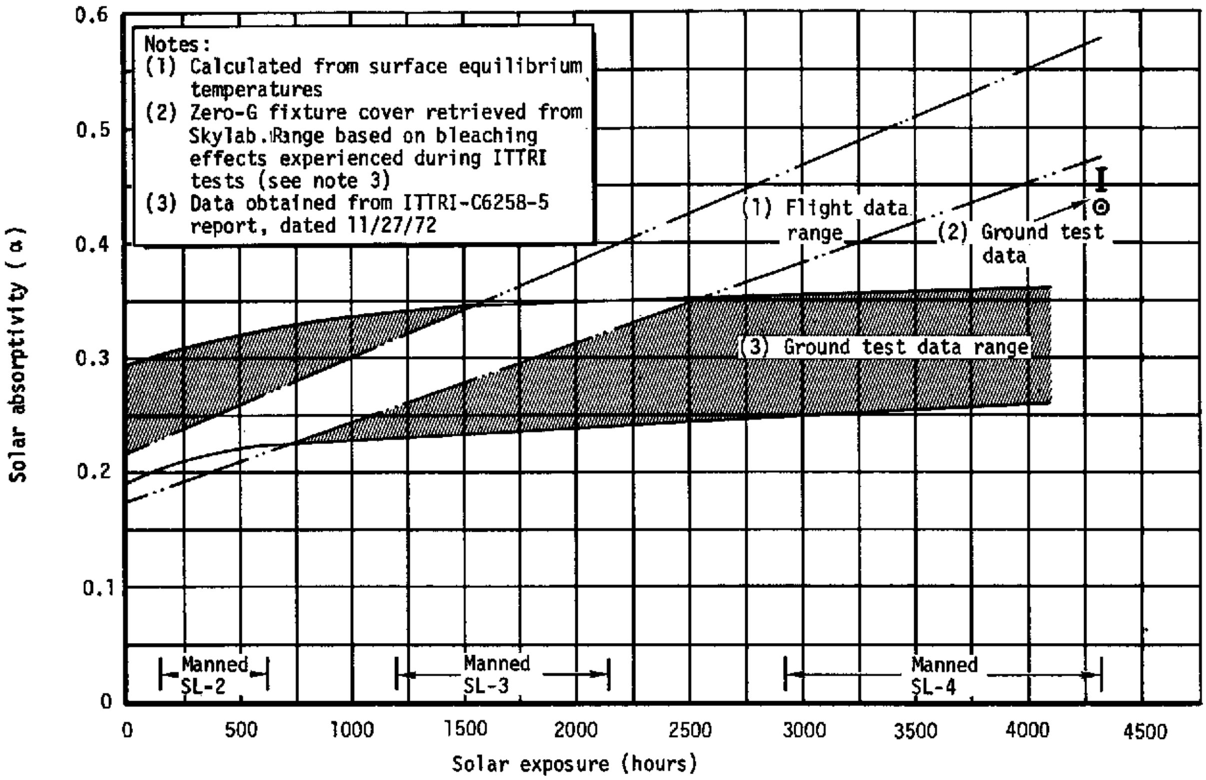


Figure 3-23. Degradation of Solar Absorptivity on ATM Canister Solar Shield (S-13G Paint)

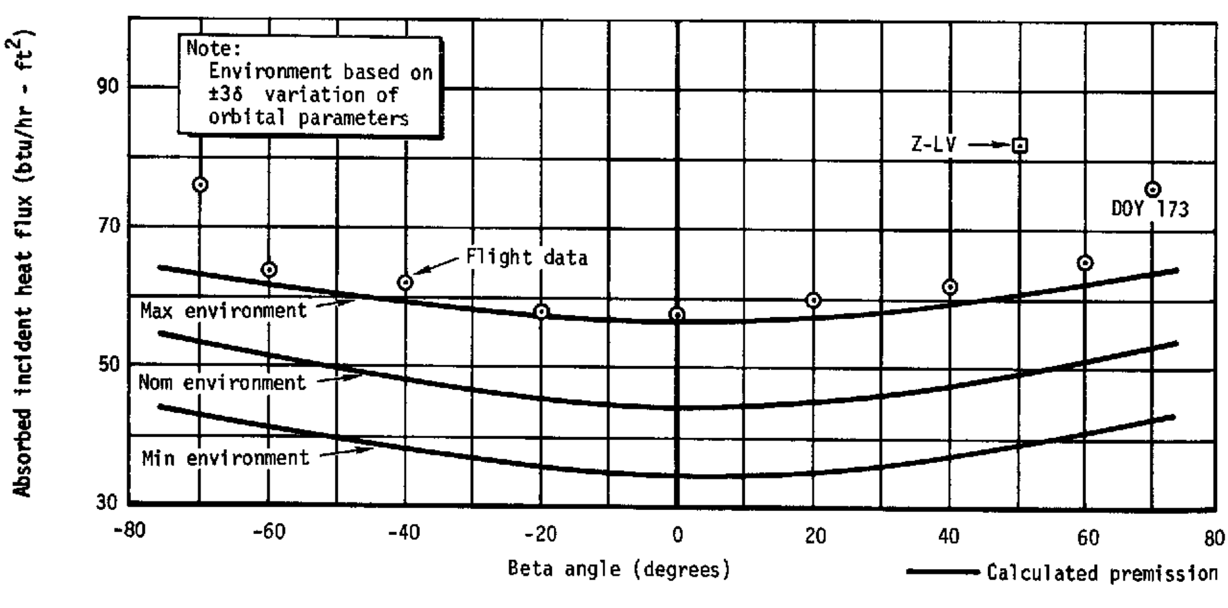


Figure 3-24. Radiator Total Average Absorbed Incident Heat Flux vs Beta Angle

Table 3-13. ATM Canister Thermal Control System Orbital Performance

System Parameter	Design Requirements		Primary System				Secondary System	
			DOY 153		DOY 038			
	Min	Max	Min	Max	Min	Max	Min	Max
Canister Inlet Temperature (K)	281.5*	284.8*	282.4	282.9	282.8	293.0	282.9	283.0
Canister Inlet to Outlet ΔT (K)	---	2.8*	0.4	1.3	0.5	1.5	0.7	1.4
System Flowrate (kg/sec)	.107	---	0.122	0.125	0.121	0.125	0.122	0.124
System Pressure (N/m^2)	48263	131000	86184	88942	86184	89632	87563	88942
Accumulator Level (%)	---	---	74	75	74	75	73	73
System Heat Load (watts)	---	500	366	452	400	514	452	482
System Operational Time (hours)	---	5664	---	---	---	6154	---	2

*Specification Limits

NOTES:
1. Primary system activated at 147:06:27 (GMT)(1973)
2. System turned off from 158:12:38 (GMT) until 159:02:41 (GMT)
3. System switched to secondary at 038:05:26 (GMT)(1974)
4. System switched back to primary at 038:07:46 (GMT)
5. System deactivated at 039:08:33 (GMT)

The ATM instrumentation and communication system met or exceeded the design requirements in support of the ATM system and experiments during the entire Skylab mission.

The performance of the ATM data acquisition subsystem met all planned mission requirements. Onboard signal conditioning, processing, displaying, storing, and transmitting of performance data were successfully accomplished on the primary system for 6506 hours.

The ATM solar array wings, on which the telemetry antennas were mounted, deployed as planned 27 minutes after the Skylab 1 lift-off. Nine minutes later the ATM data system was activated and all systems indicated proper operation. The ATM data subsystem processed 896 separate measurements. Seven of these measurements, Table 3-14 exhibited indications considered abnormal. Evaluation of the observed conditions indicated that six of these measurements were true readings and related to the anomalies experienced by the rate gyros.

Table 3-14. ATM Measurement Indications

NO.	TITLE	DESCRIPTION & MISSION IMPACT
T003	CMG #3 Wheel Speed	CMG #3 wheel speed transducer failure. This measurement was backed up by the Phase A, B, and C wheel currents; therefore, no mission impact.
C281	Temp Z1 Rate Gyro	These measurements were off-scale high. There was sufficient information available to indicate that this was a true indication. Possibly caused by rate gyro heater failure. No mission impact.
C441	Temp X2 Rate Gyro	
C442	Temp Y2 Rate Gyro	
C443	Temp Z2 Rate Gyro	
C464	Temp Y3 Rate Gyro	
C282	Temp U/D Primary Spar Rate Gyro	

A problem was encountered with the coaxial switch on the ATM communication system during the Skylab 2 mission. When transmitter number 1 was switched from forward to aft ATM antenna, extremely high reflected power was detected. Subsequent tests verified that the problem existed only with transmitter number 1 on the aft antenna.

ATM transmitter number 1 was constrained to the forward antenna and used, as required, to support real time data retrieval. Transmitter number 2 was used for auxiliary storage and playbacks. Evaluation of the problem resulted in the modification of ground operations and procedural changes in ground management which prevented data loss. Tests determined that transmitters number 1 and number 2 maintained power output levels of approximately 13.6 watts and 14.4 watts, respectively, and the modulation characteristics and carrier deviations of both transmitters were within design specifications.

The spacecraft was flown in non-solar-inertial attitudes to control workshop temperatures during the early portion of the mission. This created extreme temperatures on the auxiliary storage and playback tape recorders, constraining operation to cyclical operations to allow one to cool while the other operated. Tape recorder number 1 reached 302.1 kelvins and recorder number 2 reached 305.2 kelvins. The upper redline limit was 303.2 kelvins. After the spacecraft returned to the solar inertial attitude, normal operations were resumed with no degradation to the recorders. The ATM tape recorder status for the mission is shown in figure 3-25.

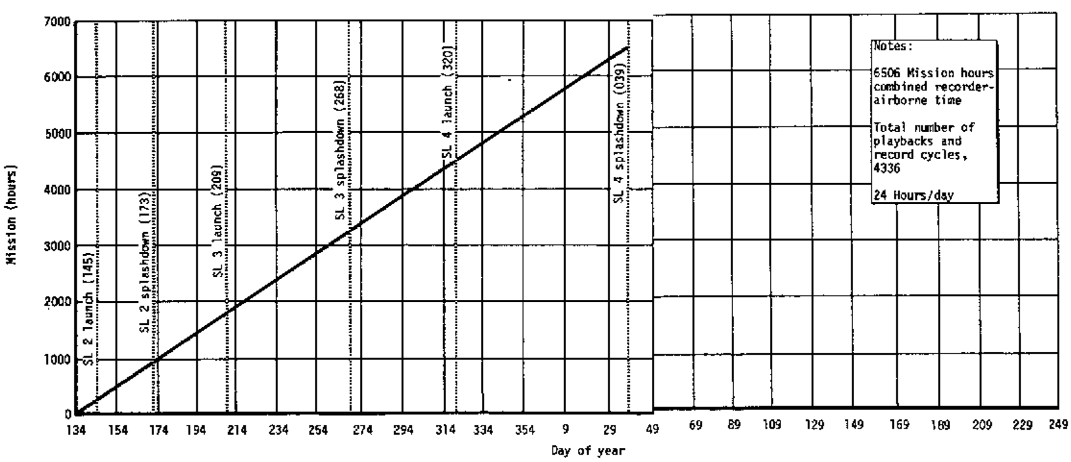


Figure 3-25. ATM ASAP Tape Recorder Status

A requirement developed for an additional temperature sensing method when the rate gyro processor six pack was installed on Skylab 3. Nine liquid crystal thermometers were supplied on Skylab 4 and were mounted by the crew on the end of the rate gyro six pack between connectors. The thermometers functioned as designed.

The ATM digital command subsystem was powered up for 6506 hours during the Skylab mission. The subsystem met the design requirement and exceeded the scheduled usage. Because of the initial mission problems of the Orbital Workshop solar array wing, the digital command subsystem was used more than anticipated.

Approximately 59,650 commands were executed during the mission with both primary and secondary subsystems operating normally.

The ATM television subsystem performed as designed. Review of the system performance, based on real time and recorded transmissions during the mission, indicated excellent performance. The picture quality, as viewed in monochrome at the Marshall Space Flight Center Astrionics Laboratory, was good to excellent, considering the radio frequency bandwidth available from the Command and Service Module transmitter. The onboard television system had a minimum 4-megahertz bandwidth. The 2-megahertz bandwidth of the transmitter reduced the fine detail of the picture as displayed on the onboard monitor, as predicted. The range-of-gray scale was excellent, indicating that the crew used the proper lens aperture setting and that the camera circuitry was effective. Considerable downlink time was devoted to ATM television. The H-alpha 1, H-alpha 2, S052 and S082B monitor sequences gave excellent views of the Sun and showed the Principal Investigators a preview of the data to be expected from the ATM film cameras.

When the White Light Coronagraph, S052, experiment became misaligned, the experiment television system was used as the primary means for centering the experiment on the Sun. The television system was the only means of continuing the synoptic observations of the corona during Skylab 2 from DOY 161 until exchange of cameras during extravehicular activity on DOY 170. The use of the television system allowed the S052 to obtain an additional 1.5 hours of scientific data. During Skylab 4, the crew used the H-alpha experiment television to approximate the Sun-center pointing and then used the cross pointers on the S052 experiment for detailed Sun-centering.

Television monitor number 1 displayed an image that oscillated slightly and contained black streaks during Skylab 3 on DOY 259. The crew switched to monitor number 2, and reported normal operations. Television monitor number 1 had no image on DOY 265, however, television downlink of monitor number 2 remained good. Telemetry data indicated that monitor number 1 was drawing no current from television power bus number 2. A short was detected on the control and display console television power bus number 2, which supplied television monitor number 1. Continued operation on power bus number 1 gave satisfactory service of all ATM television equipment. ATM operations were continued using monitor number 2 only. The failed monitor was subsequently replaced on Skylab 4 to provide nominal television capability.

ATM Caution and Warning - The ATM caution and warning subsystem performed as designed. The subsystem monitored the attitude and pointing control system, the thermal control system, and the ATM buses. The subsystem monitored the entire cluster through an interface with the Airlock Module caution and warning subsystem.

Two types of alarms occurred during the Skylab mission. The first type was caused by malfunction procedures being performed by the crew, and was anticipated. This type resulted in an alarm in the ATM through an interface between the ATM and AM caution and warning systems. The second type resulted from either control moment gyro saturation, or failure of vehicle rate gyro processor integral tests. Both the control moment gyro saturation, and the rate gyro processor integral test alarms were displayed on the alert light portion of the control and display console in the MDA.

Attitude and Pointing Control System

The attitude and pointing control system provided three-axis attitude stablization and maneuvering for the entire Orbital Assembly, and fine pointing for the ATM canister during the Skylab mission. A number of revolutionary concepts evolved into the design of the Skylab attitude and pointing control system. Skylab was the first manned spacecraft to use: 1) large control moment gyros for momentum storage and attitude control, 2) maneuver momentum desaturation, 3) an all-digital control system with in-orbit reprogramming capability and extensive automatic redundancy management, and 4) an attitude reference system based on a four parameter strapdown.

Because it contained sufficient built-in redundant equipment, the attitude and pointing control system was able to satisfy all pointing and maneuvering requirements in spite of anomalies which occurred during the mission. This system played a central role in the survival of Skylab after the loss of the OWS meteoroid shield and OWS solar wing. The attitude and pointing control system, because of its inherent flexibility, was able to execute the off-nominal vehicle attitude maneuvers which were required for vehicle thermal control until a Sun shield could be manually deployed. The attitude and pointing control system satisfactorily supported the Skylab mission to its successful conclusion.

The man-machine interface with the attitude and pointing control system was satisfactory, providing knowledge from experience throughout the Skylab mission. Following is a description of one of the experiences that increased knowledge of the man-machine interface. Note that all subsystems performed as designed during this experience. A major attitude irregularity occurred on DOY 224. At this time the vehicle parameters indicated: auto thruster attitude control only, gravity gradient dump terminated, control moment gyros caged to nominal momentum, control moment gyro saturation alert, vehicle overrate, and stuck thruster alert. This sequence of events occurred as a result of an extremely bad momentum state, especially in the X axis, due to the following series of events: Earth resources experiment pass, Earth resources experiment calibration, and two momentum dump inhibits. The momentum dump scheme was designed so the momentum, under saturated conditions, was prorated in the various axes in accordance with the system control gains with the X axis set at approximately 1/6th the gain of the Y and Z axes. In the case of the irregularity, the Y and Z axes required so much momentum that very little remained for the X axis. This borrowing of momentum resulted in a rate buildup in the X axis and a consequent buildup in attitude

C-8

error. Eventually, the error exceeded 20 degrees, and switch to auto thruster attitude control was commanded by the computer. This command automatically terminated the momentum dump, caged the control moment gyros to nominal momentum, and initiated a return to solar inertial attitude. Thus, normal inertial attitude was reestablished. The alert signals generated were a result of the high vehicle rates produced by the thruster attitude control system. The impact was that 2574 pound-seconds of thruster propellant was expended during this series of events.

<u>Experiment Pointing Electronics Assembly</u> - The experiment pointing electronics assembly operated as designed. Review of photographic data indicated that the experiment pointing control system performed with a stability better than 1.0 arc-second compared to the design goal of 2.5 arc-seconds.

The orbital locks were launched in the uncaged position. The experiment pointing electronics assembly was to have been turned on 2 hours after the launch of Skylab 1, for the purpose of setting the orbital locks to cage position. Because of the initial problem with Skylab, the experiment pointing electronics assembly was not turned on until after 5 hours in orbit, at which time the caging logic functioned properly and the locks were set to the caged position. Power to the experiment pointing electronics assembly remained on throughout the 10-day unmanned period. During this period while Skylab was in abnormal attitudes, the experiment pointing electronics assembly temperature remained within the storage temperature specification limits. During crew activation of the ATM, the first canister roll was performed, successfully disconnecting the ground support equipment nitrogen purge fitting. The star tracker logic was activated on DOY 147, and manual pointing was performed satisfactorily. Experiment pointing mode was commanded by the ground on DOY 148, and the ATM digital computer was used to command fine sun sensor wedge position. During experiment pointing mode operation, the orbital lock cage and uncage logic performed as designed as the workshop cycled through orbital day and night.

The crew operated the ATM for the first time on DOY 149. The secondary fine sun sensor was switched on and remained in use until DOY 155, when the primary fine sun sensor was again switched on. Satisfactory operation of the roll control panel at the center workstation was confirmed on DOY 158 and DOY 170, during extravehicular activities.

During the unmanned period of Skylab 3, ground operation of the ATM experiments continued until DOY 197, at which time the primary up/down (pitch) rate gyro processor failed. The secondary up/down (pitch) rate gyro processor was activated and switched to the input of the experiment pointing electronic assembly. Operation appeared normal; however, unmanned ATM experiment operations were curtailed until start of the manned ATM operations on DOY 210.

Fine Sun Sensor - The fine sun sensor operated as designed. It provided the experiment pointing control subsystem with pitch and yaw signals accurate to tenths of an arc-second. The response to both manual pointing controller and ATM digital computer commands was flawless.

The fine sun sensor operated in primary mode for the first 4600 hours of the mission. Due to a suspected drift in alignment of the primary yaw channel, the fine sun sensor was switched to secondary mode on DOY 346. It operated for the last 1600 hours of the mission in secondary mode.

The thermal environment and the power source supplying the fine sun sensor were maintained at an ideal level resulting in maximum accuracy of the fine sun sensor. However, due to noise on the critical angle prism telemetry channel, the error signals could never be fully appreciated or demonstrated by telemetry. Best analysis was obtained by evaluation of the experiment pictures and data.

Rate Gyro Processors - The rate gyro processors were operated and managed successfully during Skylab 1 and Skylab 2. During the first hours of operation, the vehicle rate gyro processors exhibited abnormal drift characteristics as high as 18 degrees per hour. This drift rate is two orders of magnitude above specification limits. These drifts were managed, for approximately 15 days, by uplinking compensation factors to the ATM digital computer. The drift uncertainties began a decreasing trend after about 15 days of operation, and after about 40 days, were relatively stable and predictable. Laboratory tests have shown that the excessive drift rates were caused by gas bubbles in the gyro flotation fluid of the rate gyro processors. The formation of bubbles was caused by the sudden decrease of external pressure during ascent and a design deficiency which exposed the float chamber bellows to the hard vacuum of space. The magnitude of drift decreased with passage of time as a result of either reabsorption of the gas in the float fluid or relocation of the bubbles in the float cavity due to float fluid agitation.

Another major rate gyro processor problem was excessive temperature. Five of the nine vehicle rate gyro processors and one of the four spar rate gyro processors indicated off-scale high temperatures. The excessive temperatures were estimated to be approximately 381 kelvins. The normal operating temperature was 340 kelvins.

The hot rate gyro processors exhibited periods of oscillations which made them unsuitable for vehicle control or experiment pointing control rate damping. The Y3 and Z1 vehicle rate gyro processors at various times exhibited full scale oscillations; therefore, their use for control purpose was discontinued. Extensive investigations including laboratory and flight vehicle tests isolated the cause of excessive temperatures to a design deficiency which allowed loosening of the power switching transistor mounting system. Loosening of the transistor from the mounting plate, which served as the transistor heat sink, allowed the transistor to thermally saturate. Under a condition of thermal saturation, the transistor leaked excessive current to the heater blanket causing the rate gyro processor to overheat.

The rate gyro processor problems encountered on Skylab 2 stimulated a program to develop and produce a vehicle rate gyro processor six pack. The six pack was stowed in the Command and Service Module for launch with Skylab 3. The six pack was designed to measure rates about the vehicle X, Y, and Z axes. It consisted of an orthogonal triad of six ATM rate gyro processors, two per axis. It was designed to be connected to the workshop computer interface unit and be used with the one most stable vehicle rate gyro processor in each axis.

The rate gyro processors used in the six pack contained non-vented bellows covers replacing the vented covers previously used. The non-vented covers were used to effect a pressure seal to avert the gas bubble problem. At the time the six pack was being developed, the cause of the off-scale-high temperature problem had not been determined. Therefore, no corrective action was taken prior to Skylab 3 launch.

During Skylab 3, all vehicle rate gyro processors continued to exhibit various drift characteristics. Rate gyro processor Y3 was declared failed, use in emergency only, on DOY 188, and Z1 failed on DOY 192. The primary up/down (pitch) rate gyro processor failed on DOY 197, and the secondary up/down (pitch) rate gyro processor was activated. All other rate gyro processors, except the secondary left/right (yaw) unit which was not exercised, were manageable and able to perform their functions successfully.

On DOY 236, the rate gyro processor six pack was successfully connected per extravehicular activity plan. The vehicle drift while in standby mode was less than 9 degrees. After the rate gyro processor six pack was installed, it was placed in primary control of the vehicle with vehicle rate gyro processors X1, Y1, and Z3 available, if needed. The other vehicle rate gyro processors were powered down. Because a single failure point existed in the six pack power line, and workshop computer interface unit multiplexer redundancy was desirable, the control configuration of rate gyro processors was established as: six pack rate gyro processors X6, Y6, and Z6 on multiplexer A; and vehicle rate gyro processors X1, Y1, and Z3 on multiplexer B. Six pack rate gyro processors X5, Y5, and Z5 were placed on an available-if-needed status. After installation of the rate gyro processor six pack, there was no significant rate gyro processor problem attributed to rate gyro processor malfunctions. The six pack performed well, and no compensations were required in the ATM digital computer software for six pack misalignment.

Only one rate gyro processor, Y5, required drift compensation. Integral test failures occurred when the six pack was inadvertantly bumped by the crew, or when the vehicle was in a dynamic state. These test failures were caused by using, for control purposes, one six pack and one vehicle rate gyro processor in each axis; consequently, the different resonance modes of the locations contributed to the integral test failures. There was no impact on the mission due to these test failures.

<u>Acquisition Sun Sensor</u> - The acquisition sun sensor performed as designed. Some cases of the Sun presence signal appearing before the calculated orbital sunrise were noted. This was attributed to an accumulation of timing error in the ATM software navigation scheme. This error was corrected by updating the ATM digital computer software periodically with no impact on the mission.

The typical day/night temperature differential experienced by the optical assembly ranged typically between 273 and 293 kelvins. These temperatures are well within the specification limits of 288 ± 55 kelvins. There was no active heating element on the optical assembly; all heating was due to the Sun, and cooling due to conduction and radiation in the absence of sunlight.

The acquisition sun sensor operated satisfactorily with all interfaces. There were differences of 0.1 kelvins between telemetered analog data directly from the acquisition sun sensor and telemetered digital information from the ATM digital computer. This level of noise in analog telemetry is considered acceptable. There were instances at null when the readings between the primary and secondary optical assemblies differed by 0.02 kelvins. This small difference is attributed to differences in sampling times and in analog-to-digital conversion.

Control Moment Gyro System - Evaluation of the control moment gyro system indicated that the system performed within the design limits.

Telemetry data verified the successful acquisition of solar inertial attitude when the control moment gyro system was enabled and during the period of null control operation following the attitude acquisition transient. The minimum control torque variations were ± 10 newton-meters with no visible frequency characteristics. Attitude error was maintained within 0.007 degrees as predicted from simulations. Gimbal rate excursions were less than 0.1 degree per second, as predicted.

Control moment gyro number 1 failed on DOY 327 due to bearing ball retainer instability and insufficient bearing lubrication.

During postmission tests, control moment gyro number 1 was reenergized to obtain engineering test data and to determine if the wheel would run. The bearing heaters were turned on approximately 24 hours before the run-up test was started. When the power was applied to the wheel motor, the phase A current was 2.26 amperes and all phases were balanced. For the first 1.5 hours, there was a slight decrease in the phase current of 110 milliamperes. This current decrease followed the normal run-up curve for current versus time. At this point the current leveled off at 2.15 amperes, diverging from the norm. The current remained constant at 2.15 amperes until power was removed. The slight decrease in current is attributed to an increase in the motor winding impedance due to a rise in temperature and a decrease in the rotor gap.

Power was applied to the wheel for 8.5 hours. The wheel speed should have been 6700 revolutions per minute and the current should have been 1.85 amperes at the time power was removed. There was no wheel speed indication during the run-up test. The bearing temperature was 286 kelvins when the wheel was energized and the temperature increased normally up to 298 kelvins where the heaters were automatically turned off. There was an initial drop-off in the bearing temperature and then a slow increase due to the heating effect from the motor. It is concluded that the motor torque did not overcome the bearing friction and the wheel failed to turn.

During Skylab 4, control moment gyro number 2 exhibited bearing anomalies comparable to those observed on number 1 before it failed. Data were obtained for 24-hour coverage of control moment gyro numbers 2 and 3 to determine if any deleterious trends were developing. This coverage gave almost continuous data for the phase A currents. The bearing temperatures were acquired daily, through the end of the mission, by real time telemetry downlink. Due to the increasing frequency of control moment gyro number 2 bearing anomalies, manual control of that gyro's bearing heaters was initiated to maintain the bearing temperature between 294 and 300 kelvins. The bearing heater circuit was designed to automatically cycle between 289 and 300 kelvins. To improve bearing lubrication, control moment gyro number 2 bearing heaters were manually controlled by ground commands starting on DOY 356.

During bearing anomalies, there was a slight decrease in the wheel speed and a corresponding increase in wheel current. The change in wheel speed was due to insufficient lubrication at the proper locations in the bearings, i.e., in the ball track and the ball retainer interfaces. The bearing lubrication was enhanced by operating the bearings at a higher temperature. This lowered the oil viscosity and increased the oil flow from the lubrication nut. It also allowed better distribution of oil in the bearing.

Control moment gyro number 2 exhibited signs of distress starting before DOY 185. These signs had been infrequent and of short duration until DOY 22. At that point, there was a definite trend toward increase in wheel phase currents with a decrease in wheel speed. Bearing number 2 temperature exceeded bearing number 1 temperature by 1.4 kelvins. This continued for six days. Then, the operating conditions changed frequently back and forth from normal operation to the anomalous condition. The control moment gyro continued to operate to completion of the mission.

A wheel run-down test was performed at the end of mission on control moment gyros number 2 and number 3 to determine the condition of the bearings by measuring the bearing torque. Gyro number 2 time and wheel speed were recorded when power was removed from the wheel. The wheel was allowed to coast for one hour and twenty-five minutes and the wheel speed decreased 496 revolutions per minute. This was very close to the expected run-down rate. Calculations from the run-down test indicates that the bearing torque was 0.03 newton-meter. This is within the range of torque for normal bearings and would indicate that there had been little or no permanent damage incurred. Since control moment gyro number 2, bearing 2 had obviously been in distress frequently, these results support the theory of retainer ring instability due to insufficient lubricant in the bearing ball track and consequently on the retainer ring.

The run-down torque test for control moment gyro number 3 was calculated to be 0.02 newton-meter and this is considered to be nominal. Since the wheel speed sensor on this unit had failed early in the mission, the decrease in speed was determined from wheel speed versus wheel current curves. Control moment gyro number 3 bearings functioned normally through the mission. Other than the failed wheel speed sensor, this unit performed nominally throughout the mission.

Star Tracker - The star tracker was activated at the beginning of Skylab 2 and operated as designed. Operation was plagued with a problem of tracking contaminant particles. A particle reflecting light having an intensity above the photomultiplier tube threshold sensitivity was tracked as a target star. This type disturbance was noted 35 times during Skylab 2. Typically, particles were generated by sloughing paint, dust, outgassing, and venting from the vehicle. To circumvent this problem, revised operating procedures were implemented starting with Skylab 3.

During Skylab 2, the tracker was operated in auto track mode throughout orbital day and was automatically switched to shutter close and hold mode during orbital night and gravity gradient momentum dump maneuvers. Since the tracker was operating continuously during orbital day, any bright particle that passed through the field of view could be tracked. During Skylab 3, the tracker was operated in shutter close and hold mode at all times except when it was used for attitude updates. Since most updates were accomplished in less than three minutes, the occurrence of stray particles in the field of view was decreased considerably. As a result of this change in procedure, only four cases of contaminant particle tracking were experienced during Skylab 3.

During Skylab 3, there were five occasions when the shutter stuck in the open position. On each occasion the problem cleared itself, and usually within several hours. Reactivation of the star tracker resulted in normal operation. After the first failures of the shutter, procedures were established to prevent damage to the photomultiplier tube due to sunlight or reflections from the surface of the Earth or the vehicle impinging on the photomultiplier tube. The procedure consisted of immediately powering down, and later, during orbital night, reapplying power and positioning the star tracker at parking angles, looking at the black surface on a blocking plate. The shutter failures were analyzed by evaluating data, performing a sneak circuit analysis, and reviewing mechanical and electrical designs. The possible failures were: 1) the mechanical shutter mechanism, 2) an intermittent relay that activates the shutter motor, or 3) an intermittent failure in the logic circuits that command the shutter. It was concluded that the probable cause was mechanical binding of the shutter drive mechanism.

One consequence of the first shutter problems was that it is presumed to have allowed bright light from the Earth's albedo to impinge the photomultiplier tube. This apparently degraded the tube response and lowered the sensitivity so that the target star, Alpha Crux, could not be acquired. A light as bright as the Earth's albedo would degrade the tracker 50 percent if it were exposed for 20 minutes. It was estimated that the tube was degraded 30 to 50 percent during Skylab 3 before protective procedures were established. During the time when Canopus and Achernar were both occulted by the vehicle, the star Rigel Kent was tracked successfully, in lieu of Alpha Crux.

The star tracker was designed to provide both fine, outer gimbal ± 2 degrees arc and inner gimbal ± 1.5 degrees arc; and coarse, outer gimbal ± 15 degrees arc and inner gimbal +5.25, -4.5 degrees arc, search patterns. The coarse search was not exercised. All interfaces with the ATM digital computer, experiment pointing electronics, and telemetry performed as designed. The internal heaters maintained the temperature above the critical 255 kelvins lower temperature limit.

<u>ATM Digital Computer, Workshop Computer Interface Unit, and Memory Loading Unit</u> - The ATM digital computers performed as designed. A manual switchover from primary to secondary computer was accomplished on DOY 160. The switchover was executed to test and verify the secondary computer. The primary computer had been operating since DOY 134, an operating time of 622.5 hours. The secondary computer was operated until DOY 40 (a continuous operating time of 5902 hours) at which time the primary computer was commanded on from the ground in support of the memory loading unit load tests.

No computer failures occurred during the Skylab mission; therefore, the memory load unit was not used until it was tested after the mission. The tests proved that the memory loading unit operated as designed loading computer memory from both magnetic tape and 72-kilobit-per-second data interface via radio frequency uplink. This was the first time an inflight computer had been loaded via radio frequency uplink.

The workshop computer interface unit operated as designed during the entire mission, an inflight operating time of 6527 hours. The concept of full digitized control systems for large spacecraft was satisfactorily demonstrated.

Crew Systems

The primary requirements of the crew systems, to facilitate crew operations during the performance of ATM activities, were satisfactorily met.

All of the planned tasks of film retrieval and replacement were successfully performed through use of the translation aids, film handling and transfer equipment, and the workstations.

In addition to the planned tasks, several tasks were successfully performed which had not been anticipated in pre-mission planning. Among these were the unpinning and latching open of three aperture doors, removal of the ramp latch of three aperture doors, returning CBRM 15 to service by tapping it with a hammer, removal of lint from the occulting disk of the S052 instrument on two occasions, installation of the rate gyro processor six pack, and manually moving the S054 filter wheel to position 3.

The most notable of these accomplishments was the installation of the rate gyro processor six pack. In performing the task, the successful installation of a cable at the workshop computer interface unit enabled a continuation of the Skylab mission. Had the connection not been properly made, or had there been pin breakage, the mission would most likely have been terminated, since all rate gyro processor signals were fed into the ATM digital computer through that connector.

The ATM control and display console, which provided the means for the crew to operate and monitor the ATM experiments and supporting systems, performed well, with no major problems.

Three failures occurred during the mission. These problems presented an inconvenience to the crew, but caused no impact on the mission.

On DOY 168, the activity history plotter jammed and became inoperative when it was rewound past a known torn section in the paper.

On DOY 214, failure of the pulse width modulated inverter assembly in the inverter/lighting control assembly resulted in losing the capability of varying the brightness of the displays, but presented no problem. The brightness control had been in the fixed position since activation, and the variable control had not been used.

On DOY 003 (1974), all of the integral lighting and numeric displays were lost. The numeric displays were restored when the crew performed a malfunction procedure. Indications were that a short existed on the integral lighting bus. However, all of the control and display functions could be performed without the integral lighting.

Contamination

The flight data evaluation indicated there was no major contamination problem on Skylab. The ATM systems and experiments contamination evaluated include; induced atmosphere, ATM experiments, solar array, and star tracker. The contamination control measures applied during the missions were adequate to reduce the contamination environment, external to the Cluster, below the threshold sensitivity levels for experiments and affected subsystems. Orbital contamination control features included the development of operational constraints and mission rules to minimize contamination.

ATM Experiments - A review of flight data indicates that the ATM experiments were not impacted by external contamination. It was concluded that throughout the mission internal pressure and deposition rates from external contamination were within nominal values causing no degradation of ATM experiment hardware or data. Although four thermal shield aperture doors were pinned open during the mission, no experiment contamination was reported by the ATM principal investigators.

Quartz Crystal Microbalance - Two quartz crystal microbalances were mounted on the ATM solar shield with field of view along the Z-axis to monitor the return flux of contamination molecules that could enter the ATM Sun-end aperture doors.

A zero mass deposition reference level was chosen to represent a clean crystal on DOY 134 at liftoff of Skylab 1, and all mass changes were referenced to those values.

The quartz crystal microbalances were first activated at 32 minutes after launch. Therefore, the initial outgassing could not be detected. At the time of activation, both quartz crystal microbalances indicated 0.24 micrograms per square centimeter above the initial reference value. This increase above reference could be due to thermal shifts, loss of initial contamination on the reference crystals, or some contamination may have occurred during launch.

A gradual loss of mass was observed because these units were exposed to the Sun. The trend continued throughout all missions and at the termination of Skylab 4 the ATM quartz crystal microbalances were indicating a mass deposition of -4.46 micrograms per square centimeter. It is possible the units were indicating the effect of near continuous exposure to solar radiation.

It was not expected that the ATM QCMs would record any deposition since their field-of-view did not contain any contaminant source and their temperatures were such that most contaminants would not deposit.

<u>Particle Sightings - S052</u> - The S052 experiment observed particles on numerous occasions. However, most of these occasions showed 1 to 10 particles and had no effect on the data. There were a few occasions when particle storms were created by venting during ATM operations which resulted in momentary S052 data degradation.

Many particle sightings (other than particle storms) from the S052 have not been correlated with specific events. This indicates that a random source of particulate contamination also exists. It is thought that the majority of the particulates were created by sloughing of paint and insulation from the solar side of the Cluster.

<u>ATM Canister Pressure, Internal</u> - Internal pressure of the ATM Canister was monitored during the mission to provide an assessment of the degree of outgassing within the ATM canister. Although it took 10 days longer than expected for ATM internal pressure to stabilize in the 10^{-5} torr range, this time span was available because of the meteoroid shield problem, and the resulting delay of the manned mission.

From DOY 134 through DOY 139, there were random pressure increases from the low 10^{-5} to 10^{-6} torr steady state level. Periodically, pressure transients up to 8 times 10^{-5} and occasionally up to 1 times 10^{-4} torr were observed. These pressure fluctuations apparently were caused by sources internal to the ATM canister, such as pockets of trapped outgassing from within the many layers of insulation. No correlation with external events such as thruster attitude control system firings, reaction control system thruster activity, or workshop venting was established to indicate any of these external sources contributed to internal ATM canister pressure readings.

After the canister pressure reached steady state in the 10^{-5} to 10^{-6} torr range, ATM experiments high voltages were turned on. No problems due to the pressure were noted.

The internal pressure of the ATM canister indicated that on DOY 216 the pressure increased from the 10^{-7} torr range to the 10^{-5} torr range in approximately 1 hour. This pressure rise was attributed to an electrical short between television bus number 2 and ATM bus number 1 in the power transfer distributor assembly. The pressure dropped back to the 10^{-6} torr range in 2 days and never exceeded the 10^{-5} torr range.

During the Skylab 2 and Skylab 3 missions, an extravehicular activity crewman removed particles from the S052 occulting disk. The particles produced an area of scattered light, prior to being removed, that created some problems during scientific data analysis.

Star Tracker - Analysis of the star tracker data indicated that of the 39 anomalies recorded on the star tracker, 11 were identified as contaminant particles, because of high gimbal tracking rate and correlation with the aerodynamics drag. Correlations of these anomalies with events on Skylab indicate that the false stars possibly originated from the deterioration of, and structural damage to, paints and insulation on the solar side of the Orbital Workshop and transported by molecular flow fields from various vents and the drag of the ambient environment. Fewer contamination related star tracker anomalies were observed on Skylab 3 than on Skylab 2 due to the tracking of a brighter target star and a change in star tracker procedures. There were no false star anomalies during Skylab 4, although on DOY 361 the star tracker failed.

ATM Solar Array System - The evaluation of the ATM solar array data indicated that no noticable degradation occurred as a result of contamination. The high temperatures of the solar panels cause contaminants to boil off and not collect. There was an 8.6 percent power reduction throughout the mission, slightly less than predicted, due to micrometeoroids, space radiation, and thermal cycling.

SECTION IV. ATM ANOMALIES

ATM MISSION ANOMALIES

All ATM Systems were operational throughout the Skylab mission. This section contains a brief discussion of the major anomalies occurring during the ATM Skylab mission.

The anomaly and the cause is identified by system. The discussion includes workarounds initiated to facilitate continued performance of the system or the results of the loss of a function within a system.

Detailed anomalies discussion, analysis, conclusions, and recommendations are contained in the following reports:

TM X-64817	MSFC Skylab Attitude & Pointing Control System Mission Evaluation Report
TM X-64818	MSFC Skylab Electrical Power System Mission Evaluation Report
TM X-64819	MSFC Skylab Instrumentation & Communication System Mission Evaluation Report
TM X-64821	MSFC Skylab Apollo Telescope Mount Experiment Systems Mission Evaluation Report
TM X-64823	MSFC Skylab Apollo Telescope Mount Thermal Control System Mission Evaluation Report
TM X-64824	MSFC Skylab Structures & Mechanical Systems Mission Evaluation Report
TM X-64825	MSFC Skylab Crew Systems Mission Evaluation Report
TM X-64826	MSFC Skylab Contamination Control Systems Mission Evaluation Report

ATM Experiment System

S052 Pointing Error System Bias - A discrepancy was observed between Sun-center pointing as observed on the control and display console television monitor versus the pointing error system readouts when the Skylab 2 crew began operations with the S052 instrument. With the S052 instrument boresighted on Sun-center using the television monitor, the pointing error system read 14 arc seconds up and 62 arc seconds right. This bias was relatively constant throughout the Skylab mission. In order to reduce diffracted light, it was necessary to point the S052 instrument as accurately as possible to Sun-center; but an offset of 14 arc seconds up and 62 arc seconds right would trigger the 20 arc second discriminator in the pointing error sensor which automatically prevented operation of the instrument in any mode. It was possible to override the 20 arc-second discriminator to permit instrument operation, but this would also override the 5 arc-minute discriminator, thus eliminating protection against instrument damage from excessive mispointing with the S052 Sun-end aperture door open. Therefore, a compromise was effected by pointing the instrument 8 arc-seconds up and 16 arc-seconds right as indicated on the control and display console pointing error system crosspointer display. This provided instrument pointing as close as possible to Sun-center without triggering the 20 arc-second discriminator. Since diffracted light was not minimized due to the Sun-center pointing error of 6 arc-seconds down and 46 arc-seconds left, the quality of the scientific data was slightly degraded. Possible causes of this anomaly were analyzed; however, data available were insufficient to determine the specific cause.

S052 Camera Jam and Torn Film - On DOY 161 an unusual rate of temperature rise was observed inside the film camera. The rate of rise was comparable to that derived by computer simulation for a stalled film transport motor. This comparison is shown in figure 4-1.

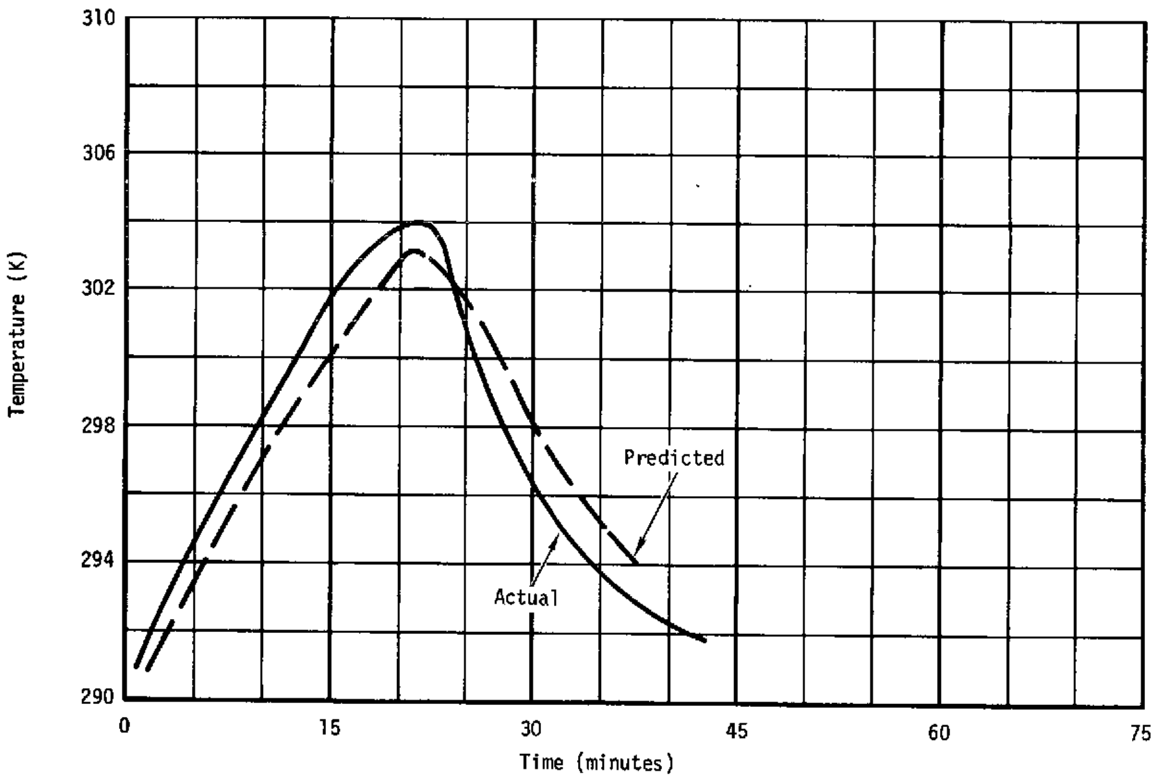


Figure 4-1. S052 Camera Temperature During Stall on SL-2

At the next scheduled operation of the instrument, the crew reported that the operate light did not illuminate and the frames remaining counter did not decrement. The anomalous temperature condition was observed to be repeated. The crew had performed the applicable malfunction procedure which indicated a possible film camera or primary programmer failure. These indications confirmed that the film transport motor was stalled, and further film camera operation was not possible until the camera was replaced. Coronal observations were performed using television downlink. After installation, the second film camera was checked out and operated properly.

After return of the Skylab 2 film camera to Earth, the exposed and unexposed film reels were carefully removed without disturbing the jammed portion of the film. The film appeared to have caught on a film sprocket hole near the trailing edge of the second pressure plate in the aperture area. The film, as shown in figure 4-2, was torn completely in two and the takeup side of the film had threaded completely out of the transport mechanism and was wound onto the takeup reel, torn and all. The supply side drive sprocket had continued to feed film but with no film takeup. After the film was torn, it piled up around the supply side drive sprocket until it jammed and stalled the transport motor.

Failure analysis showed that a particle of silicon and calcium composition shown in figure 4-3 became lodged in the aperture plate area. Emulsion built up on the particle and was hardened due to friction. The particle cut a deep furrow along the performation area of the film. When the emulsion buildup had sufficiently enlarged the particle, it caught and notched the film. Further film drive force tore the film apart.

<u>S052 Occulting Disk Contamination</u> - On DOY 164 and DOY 238, contamination was noted on the S052 occulting disk. This was observed by the crew and verified by downlink television. During extra vehicular activity on DOY 170 and DOY 265, the crew brushed the occulting disk area and removed the contamination. However, on DOY 265, additional floating particles were observed. The S052 Sun-end aperture door was left open in hopes that the contamination would drift out. While DOY 265 extravehicular activity was in progress the crew reported streaking of the S052 television display, the S052 Sun-end aperture door automatically closed twice, and contamination was observed on the occulting disk again. The occulting disk area was brushed again and no further evidence of contamination was observed.

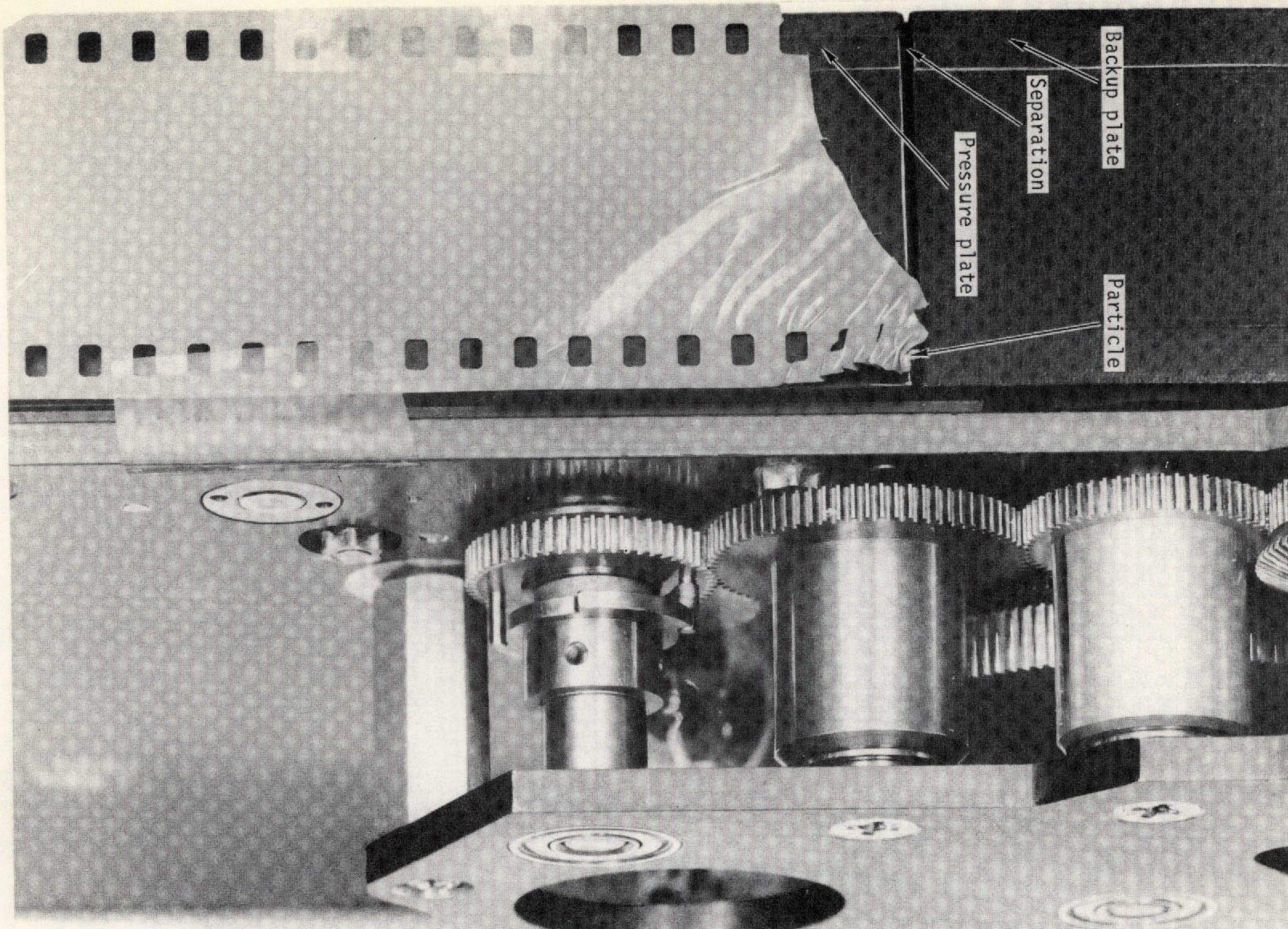


Figure 4-2. S052 Torn Film

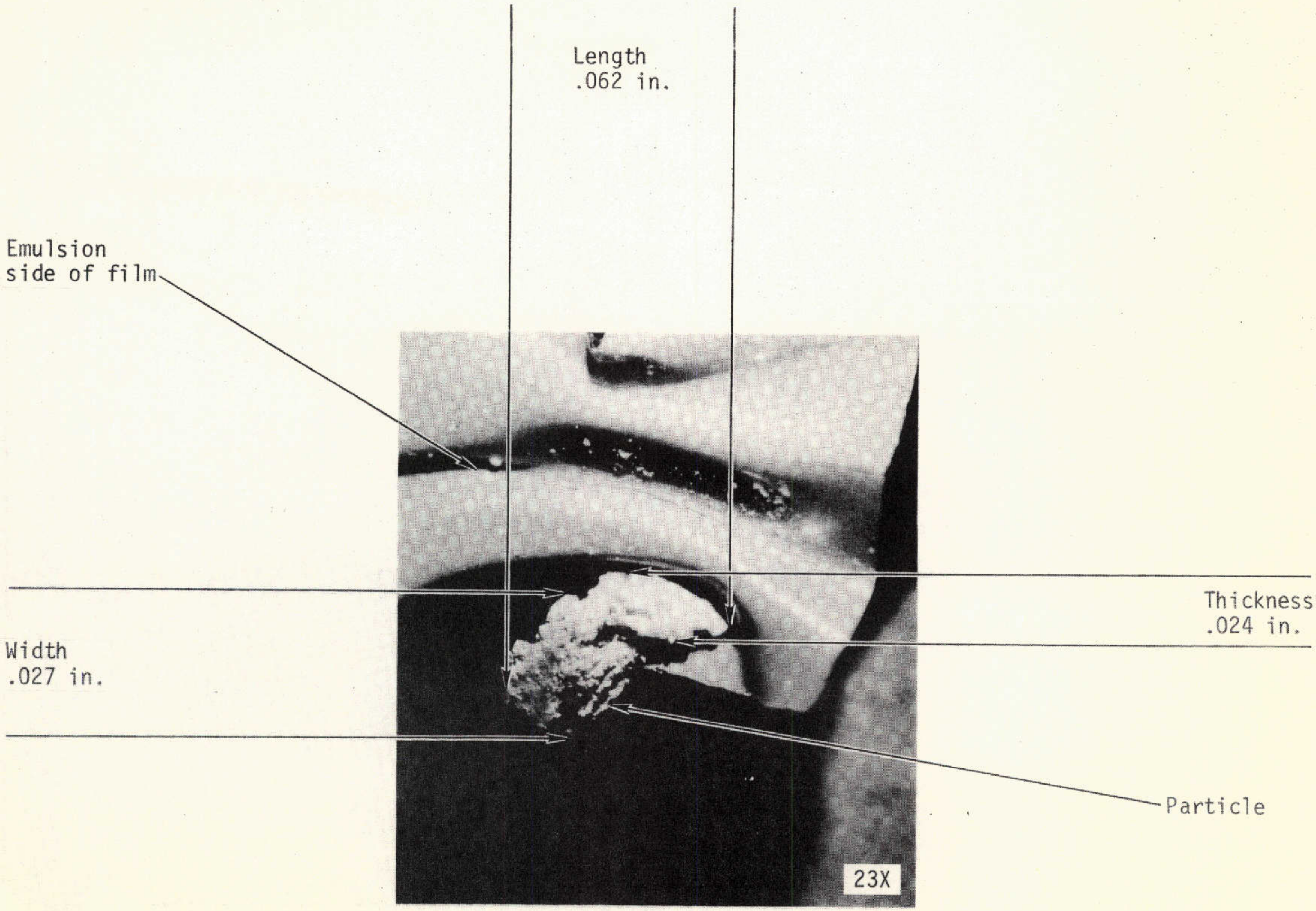


Figure 4-3. S052 Camera, Silicon and Calcium Particle

S052 Television Degradation - On DOY 337 the crew observed a bright spot on the S052 television monitor. A test was performed onboard which indicated the problem was in the S052 television camera. The exact cause could not be determined but was probably the result of scattered light impinging on the vidicon face during S052 Sun-end aperture door closing with the mirror inadvertantly left in the television position. On DOY 340 the crew reported the existance of a black bar across the screen through the white spot. The bar remained even when the mirror was in the film camera position. This indicated that the problem was in the S052 television camera vidicon tube. The damage was considered permanent and normal S052 operations continued with the degraded television system. The condition of television vidicon remained static until DOY 031 when a second bright spot and corresponding black bar appeared on the television monitor. This was also considered to have resulted from intense scattered light. The condition of the television remained unchanged until the end of S052 operations on DOY 034. The S052 television degradation did not impact the experiment mission objectives significantly, nor were experiment operations or scientific data quality compromised as the data is available on film.

S054 Filter Wheel Malfunction - During Skylab 4, on DOY 331, the filter wheel stuck between positions 5 and 6. On DOY 359 a crewman, using a screwdriver, moved the wheel to position 3, no filter. It was necessary to bend the shutter out of the way, and during installation of the camera magazine, the mechanical shutter override moved the bent shutter partially into the optical path. This produced several shadows on the X-ray image, resulting in approximately 25 percent data loss of the last film load; however, it also allowed two modes of operation that provide better temporal resolution and data correlation with the S052 instrument.

S055A Photomultiplier Detector Tripouts - On DOY 150, during the Skylab 2 mission, the first detector tripout occurred. The photomultiplier detector units were designed with a built-in current sensing overload protection device. When this circuitry sensed a higher than allowable current, the photomultiplier detector unit turned off (tripout). In normal operation a multiple tripout property exists, i.e., tripout of one photomultiplier detector unit will automatically cause tripout of all others.

During Skylab 2, the frequency of detector tripouts was insufficient to determine the exact cause. During Skylab 3 the tripouts occurred with increasing regularity, detector 5 being the most susceptible to tripout. Because of the increasing inconvenience in having to reset the detectors each time detector 5 tripped out, two high voltage tests were performed by the crew. The tests were designed to determine why detector 5 tripped out during normal operating modes and whether the instrument could be operated successfully with the ganged-tripout circuitry disabled.

Analysis of the test data implied that the cause of the tripouts was high voltage breakdown or corona. It was decided to operate with detector 5 overload sensor protection circuitry enabled and the main high voltage in override. This prevented all other detectors from tripping off when detector 5 tripped out. Data from detector 5 was minimal due to the frequent tripouts and because it was off for long periods. However, by placing lines of interest on other detectors and using second and third order emissions, the data loss resulting from detector 5 tripping out was less than 5 percent.

<u>S055A Electrical Malfunction</u> - On DOY 277 the low voltage 28-volt power supply on the instrument apparently changed from the main (primary) converter to the redundant (secondary) converter. A radio frequency command to turn the S055A main power off was sent, received and verified; however, the instrument failed to respond. The main power off command was sent three times with no success. The instrument also failed to respond to the main power primary command. At the time of the switchover, instrument operation was nominal and telemetry indicated all voltages were stable. Therefore, no action was taken during the unmanned period. Inflight tests, which would determine the exact cause of the problem, involved the risk of loss of some scientific data should the instrument fail to respond. As the instrument operation was normal with the secondary converter in use, no further action was taken and the instrument was left in the same power configuration throughout the remainder of the mission with no impact on instrument operation. While the exact cause of the switchover from the primary to the secondary low voltage power supply system was not determined, the most probable cause was an electrical transient on one of the main ATM experiment power buses or a transient generated within the S055A instrument. The failure of the instrument to respond to the radio frequency main power off and main power primary commands was probably caused by failure of the radio frequency command momentary relay or the latching relay for switching power.

<u>S056 Premature Terminations</u> - On DOY 160, during the Skylab 2 mission, the S056 experiment had three premature cutoffs of the active 1 mode. The camera sequence terminated prior to completing the full sequence of exposures. In all cases, several exposures (6 or 9) were taken normally prior to the termination. Prior to the

first occurrence, the camera operated without error for 1764 frames. The premature camera sequence termination continued in the active modes until the experiment was powered down for the unmanned Skylab 3.

On DOY 234 and 235, the first Skylab 3 film magazine experienced premature terminations. The S056 camera terminated early in two patrol short modes and three active 1 long modes. These terminations occurred after approximately 5177 frames had been successfully taken. Additional premature terminations occurred on DOY 244 and 245 (Skylab 3, second film magazine) in the active 1 long modes after approximately 3000 frames had been taken. The premature terminations occurred more frequently throughout the remainder of the Skylab 3 mission.

On DOY 358, with the first Skylab 4 film magazine in use, the S056 camera terminated early in an active 1 normal mode. This premature termination occurred after approximately 5000 frames had been successfully taken and was the only premature termination to occur on the first Skylab 4 film load.

This magazine had been loaded with SO-242 color film without the antistatic (rem-jet) backing, and the clutch surfaces had been coated with a dry lubricant to reduce drag. Apparently, this procedure reduced the number and frequency of hangups experienced on the other magazines.

On DOY 019, the second Skylab 4 film magazine experienced premature terminations in the patrol and active modes after approximately 5000 frames had been exposed. This continued to occur throughout the remainder of the Skylab 4 mission although the frequency of occurrence appeared to be less than on Skylab 2 and Skylab 3.

The premature terminations were caused by the loss of the film active pulse. The film advance pulse originates within the film magazine by use of a magnet-reed switch arrangement directly coupled with the transport of film from the supply side of the film roll. The magnet-reed switch assembly is an integral part of the idler sprocket; therefore, an increase in tension or torque, or difficulty in rotating the idler sprocket, can interrupt the film advance pulse. Excessive mechanical drag in the magazine would prevent the film from being driven a complete frame, thereby causing the film advance decoding system to indicate a short frame. Sufficient short frames in sequence would cause the film advance decoding system to indicate no film advance, shutting off camera operations until the start/stop switch on the control and display panel is reactivated.

The conclusion, based on the data examined and tests performed, was that mechanical drag build-up within the film magazine was sufficient to stall the film drive motor. This build-up was caused by the conductive backing from the film being deposited in the platen, the take-up clutch, and the supply brake.

S082A Film Camera Jam - On DOY 150, the crew indicated that the frames remaining counter failed to decrement. Telemetry verified the failure by absence of the film transport signal. The cause of the failure was determined to be a camera jam.

The camera was exchanged on DOY 158. The replacement camera was cycled and the frames remaining counter and all ground telemetry indicated proper operation. The failed camera was evaluated and found to have jammed on the nineteenth exposure. Although the failure mode was identified, the cause could not be positively identified. The problem did not recur with any of the other four cameras used during Skylab 3 and Skylab 4.

S082A Film Streaks - On DOY 278, following development and evaluation of the Skylab 3 film, parallel horizontal pairs of streaks were observed on the film. The streaks were also present on the Skylab 2 film but to a lesser extent. The streaks corresponded to the stiffening ribs in the film holder as shown in figure 4-4. Not all of the wavelength images were affected and only a small part of the images that were affected were degraded. The degraded images contained acceptable scientific data; however, S082B aluminum film holders were used in the S082A film camera on Skylab 4 to correct this problem. Evaluation of the Skylab 4 film data confirmed that use of the flat aluminum S082B film holders eliminated the streaks.

S082B Extreme Ultraviolet Monitor Low Sensitivity - Following initial ATM experiment operation, the Skylab 2 crew reported the extreme ultraviolet monitor video display on the control and display console was very faint. The crew was unable to adequately determine solar activity without the use of the video integrate capability. With integration the display time was too short to allow visual study of details. The insufficient video signal level was due to low sensitivity of the monitor. To correct the problem a persistence image scope, a night vision pocket scope with long persistance phosphor, and a polaroid SX70 camera were included for the Skylab 3 and Skylab 4 missions. The image persistance scope retained the one-thirtieth second flash of the video integrate information long enough for the crew to view the Sun and its features. The polaroid camera was used to record the video images on film which provided the crew with a permanent

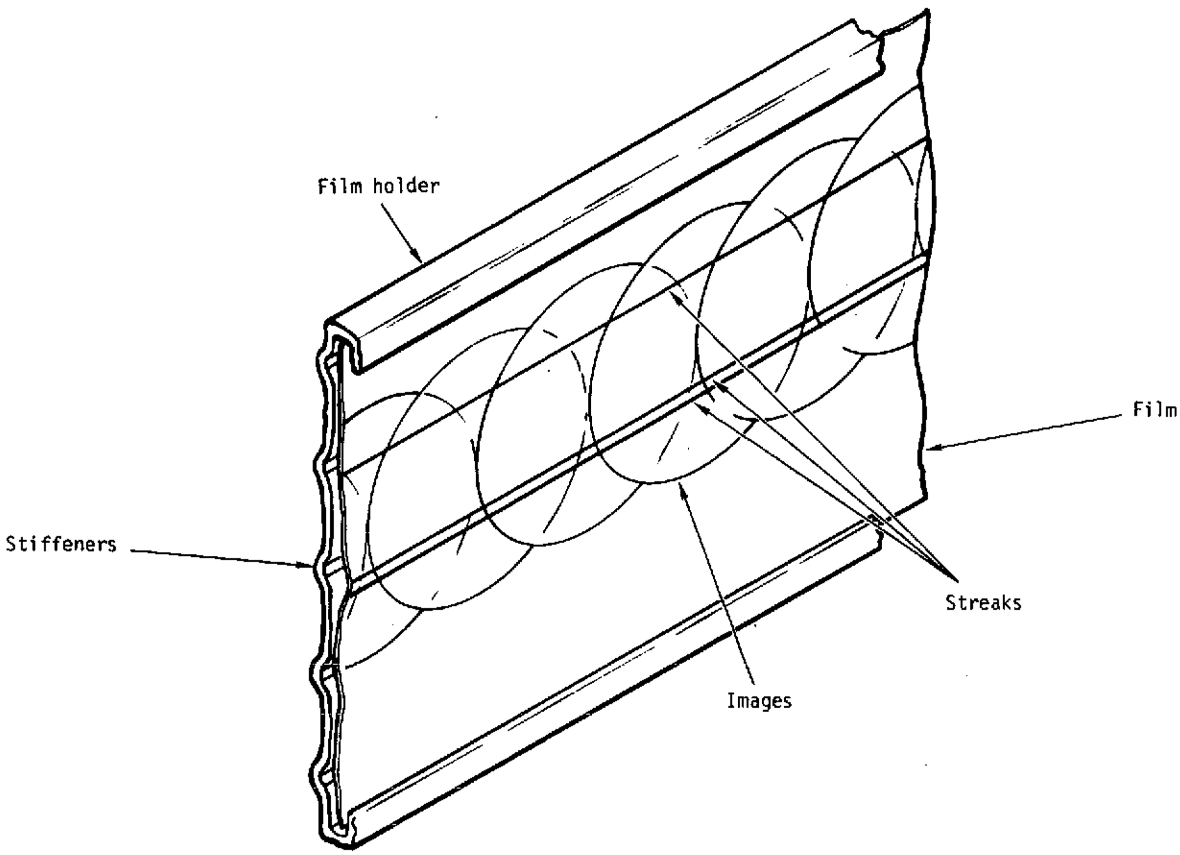


Figure 4-4. S082A Film streaks

record of the integrated display. This allowed the crew to identify major changes in the solar surface. To correct a malfunction of the persistance image scope, a replacement scope was included for Skylab 4. Additional polaroid film was also supplied for use during the Skylab 4 mission.

S082B Overexposures - On approximately DOY 215, review of the Skylab 2 film data by the Principal Investigator revealed that exposures taken with the grating in the long wavelength position were overexposed when longer exposure times were used. The modes affected were the auto and auto step modes in which a series of eight exposures were taken alternating between long and short wavelengths. Five of the eight exposures were overexposed.

During Skylab 3 the daily flight plans were altered to take fewer long wavelength exposures and to take long wavelength exposures only of very short duration. This resulted in a scheduled containing very few auto or auto step modes. A new procedure called a mini limb scan was developed which contained very short time duration long wavelength exposures. This procedure involved the use of the time mode in which the crew manually selected the time for the exposures on the control and display console. The procedure obtained more desirable data with less expenditure of film, however was very time consuming for the crew. The Skylab 3 crew requested that an auxiliary timer be developed and installed on the ATM control and display console to allow automatic exposure sequencing. The auxiliary timer, associated cabling and switch selector was developed, launched aboard Skylab 4, and installed by the crew. Crew procedures were revised to incorporate the change. The timer was used for the majority of the Skylab 4 exposures. No problem was encountered with the use of the auxiliary timer. The newly developed timer automatically controlled three exposures of 10 seconds, 40 seconds, and 160 seconds in the short wavelength. Six additional exposure times were obtainable since switch selections provided multiply and divide by four capability. Due to using five times more sensitive film on Skylab 4 for Kohoutek, the Kohoutek exposures were made with the switch in the normal position. Skylab 4 solar observations required the divide by four (1/4) switch setting.

<u>S082B Pointing Reference System Malfunction</u> - On DOY 347, the crew noticed limb offset indication fluctuations on the television monitor when pointing the S082B slit on the solar limb. When performing limb pointing, the required accuracy was ± 1 arc-second. Similar type fluctuations occurred on DOY 360, 362, and 003. All of these malfunctions had limb off-set fluctuations of from +2 to +6 arc-seconds while scanning the solar limb. When the limb point mode was selected, the limb off-set fluctuations increased to a maximum of from +50 to -50 arc-seconds. On DOY 003, the crew reported seeing oscillations of the primary mirror on the television display. This agreed with the analysis of the data by ground personnel, and indicated the malfunctions were probably caused by the video signal level from the S082B electronics being below the level required for detection of the reference points. A test performed by the crew on DOY 009 verified that the malfunction was caused by the low video signal level. Since the planned solar observations were within the pointing reference system failure region, use of the pointing reference system for limb pointing was discontinued for the remainder of the Skylab 4 mission. The ATM experiment pointing control was used for S082B limb pointing allowing successful operation of the S082B instrument to the conclusion of the mission.

H-Alpha 1 Television Image Degradation - On DOY 015 the crew reported that the onboard H-Alpha 1 television images were degrading. The degradation was reported by the crew again on DOY 021. The television image appeared to be out of focus. On DOY 060, during the Skylab 4 crew debriefing, the crew reported that the H-Alpha 1 image was very good until approximately one month before the end of the mission. The video started to degrade gradually at that time, approximately DOY 365, but the crew did not become aware of it until DOY 015. From that time on, the video was good only for the first 15 to 30 minutes after powering up each day, and then degraded. The imagery would not improve until the television was turned off for at least 8 hours. The crew was requested by ground personnel to turn the H-Alpha 1 television camera off when not in use. The quality of the downlinked H-Alpha 1 television recordings was inconsistant due to transmission problems, but when the quality was good, the downlinked video confirmed the image degradation. The cause of the problem was not determined and as the problem occurred late in the mission, there was little total mission impact.

H-Alpha 1 Film Advance Failure - On DOY 016 the crew reported that the H-Alpha 1 film camera was not operating. Reinitializing the system cleared the problem. On DOY 017 the crew reported that the frames remaining counter on the control and display console failed to decrement. The camera appeared to be working based on the shutter telemetry indications and the crew's statement that the camera operate light on the control and display console was operating properly. A daily comparison of the onboard frames remaining counter indication and the ground estimate of frames remaining indicated that the frames remaining counter or the signal from the camera electronics to the frames remaining counter was intermittant. Normal operation continued until the scheduled removal of the film magazine on DOY 034. Ground personnel estimated the number of frames exposed daily. When the film magazine was removed on DOY 034, ground personnel estimated 15,191 exposures had been taken. However, review of the film showed that only 50 percent of the film had advanced, and 20 percent of these images were overlapped. The cause of the problem was a malfunction of the film drive electronics.

The evaluation of the Skylab 4 scientific data by the Principal Investigators may be hampered somewhat by the lack of a complete ATM pointing record normally provided by the H-Alpha 1 film images. The H-Alpha 1 images that were obtained, in conjunction with limited pointing data available from the H-Alpha 1 and H-Alpha 2 video downlink recordings and from the ATM digital computer telemetry data, may be sufficient to provide an adequate ATM pointing record for the latter part of the Skylab 4 mission.

Structures and Mechanical System

S054 Sun-End Aperture Door Problem - The problem occurred on DOY 153, at orbital sunrise. The auto door open command was issued, and the door talkback indicated that the door did not fully open. The malfunction procedure was performed and the talkback indicated that the door had fully opened. The telemetry indication on the ground was also that the door was fully open. The malfunction procedure had been performed several times, and when the talkback and telemetry indicated that the door was fully open, power to the door operating mechanism was inhibited, rather than risk a failure of the mechanism with the door closed, which would preclude operation of the S054 instrument.

On DOY 158, during extravehicular activities, it was discovered that the door had failed in the closed position, with an erroneous indication of open. The impact on the mission was the loss of the S054 film exposed during the period from DOY 153 to DOY 158. The corrective action taken was to unpin the door, thus removing the mechanical link between the door and its operating mechanism, and permanently latch it open.

The actual cause of the failure was not determined. However, during the extensive analysis performed while investigating the problem, it was revealed that when a door is in the fully closed position and is commanded open, if the operating motor stalls before the door reaches the fully open position, the limit switches within the operating mechanism are not contacted. When this occurs, no indication of either open or closed is given, and the 60-second timer ultimately removes motor power. Then, if the door motors are inhibited and then re-enabled, the talkback will indicate the last command to the door; in this case, open. Similarly, if the door is open and the close command is given and the door motor is inhibited and then re-enabled, the indication will be that the door is closed.

The analysis also showed that if the malfunction procedure was not followed, it was possible to drive the primary and secondary motors in opposing directions. As an example, a door is open and a close command is sent to the primary motor but the motor stalls before the door is fully closed. Then, before the 60-second timer removes power from the primary motor, the secondary motor is enabled and an open command is sent. The result is that both motors are energized, and opposing each other. This would not happen if the malfunction procedure were followed.

It was concluded that the malfunction procedures generated as a result of this analysis should be followed stringently. Deviation from the procedure could result in erroneous indications, or failure of the mechanism.

Some problems were encountered in the operation of the other aperture doors. However, in every stance, the doors responded to the new malfunction procedure. During the Skylab 3 mission, three doors showed evidence of increased friction in their operation, and their ramp latches were removed. During the Skylab 4 mission, two doors that exhibited increased friction were unpinned and latched permanently open.

Electrical Power System

Charger-Battery-Regulator Module Number 15 Off-Line - CBRM number 15 solar array contactor apparently failed open on DOY 143. A troubleshooting procedure indicated that neither the regulator nor the charger was receiving power from the solar array.

During extravehicular activity on DOY 170 the crewman tapped CBRM 15 in an attempt to unstick the solar panel input contactor. The procedure was successfull performed. The battery was then recharged and the regulator was successfully turned on. CBRM 15 functioned normally for the remainder of the mission.

Low Capacity Performance of CBRM Batteries - On DOY 145, 8 CBRMs tripped off due to depleted batteries and associated low voltage trip off. CBRM 7 and 8 tripped off again the following day (DOY 146). Then, on DOY 150, CBRM batteries 6, 7, 8, and 16 auto disconnected during the first Earth resources experiment pass. The depth-of-discharge for the batteries was approximately 50 percent. However, the trip-off occurred at approximately 8 ampere-hours, as opposed to the premission predicted capacity for this time in the mission of greater than 15 ampere-hours. Power management techniques were implemented to assure that battery depth-of-discharge was assessed each orbit to prevent this from recurring.

Subsequent capacity checks on DOY 255 (11 ampere-hours) and on DOY 362 (10 ampere-hours) indicated that the available capacity increased slightly after DOY 150 and remained relatively constant during the remainder of the mission. Although the capacity loss did not seriously affect the mission, it was an anomaly that was unexpected and unexplained. Battery aging, as a result of prelaunch testing and cycling, had caused degradation greater than anticipated. Figure 4-5 shows ATM actual and predicted battery capacities were lower than anticipated. There was no impact on the Skylab mission, since a power margin of not less than 800 watts existed after DOY 158, when the Orbital Workshop wing was deployed.

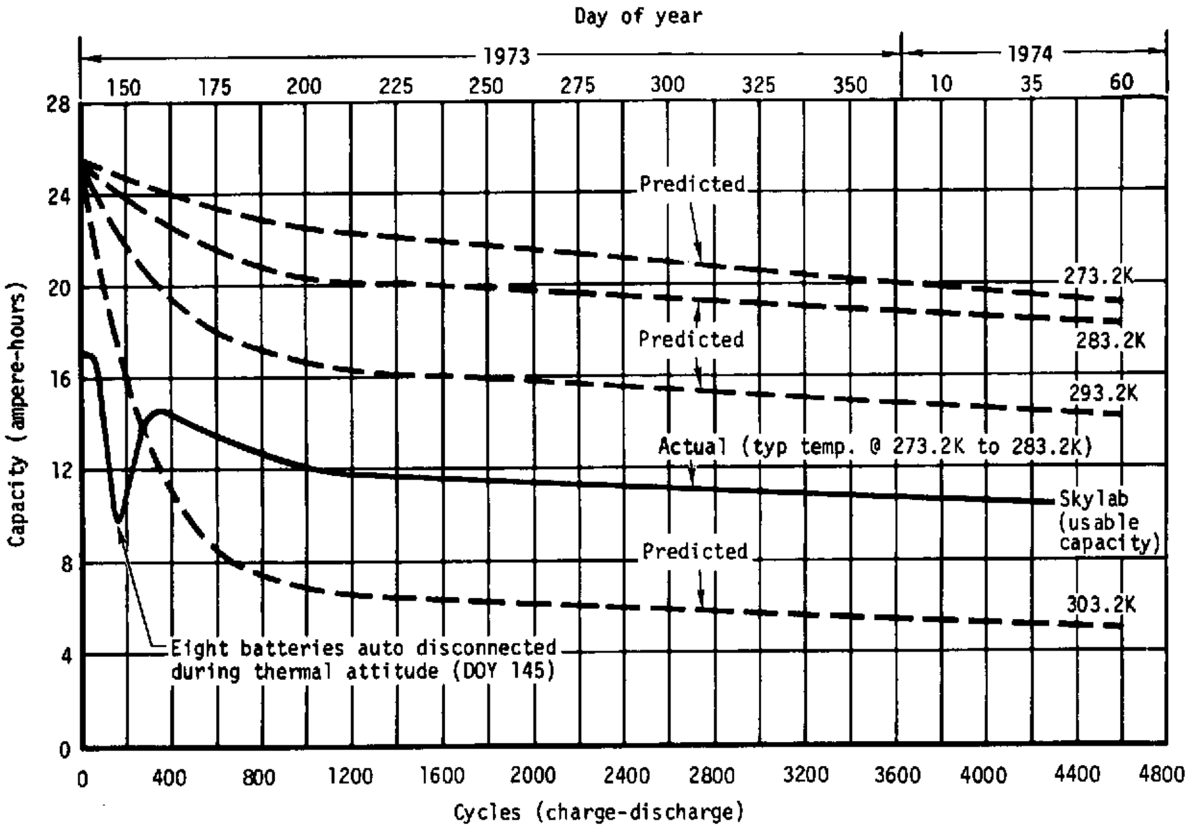


Figure 4-5. ATM Battery Capacity for Skylab Mission

<u>S054 Power Could Not Be Turned Off</u> - On DOY 147 a command to turn off the S054 main power was transmitted. The command was confirmed, but main power did not turn off. On DOY 158, the control and display console S054 main power switch was set to off. The main power remained on. The power-off command was again sent with no effect. A failure of K102 coil or associated wiring was suspected. The only way to power down the S054 experiment was to power down ATM experiment buses 7D31 and 7D41. These buses also powered three of the four switch selectors one of which provided ground command capability for all ATM experiments. Therefore, it was decided not to power down S054 for the scheduled extravehicular activity. Analysis of all aspects of this condition proved no hazard to the crew existed. Therefore, S054 remained in a power-on condition for the remainder of the mission with no additional power problems.

<u>Charger-Battery-Regulator Module Number 3 Off-Line</u> - CBRM number 3 regulator ceased to deliver power on DOY 150. Status lights on the control and display console indicated that the regulator on command had been received by the module, but the regulator would not deliver power to the bus.

Attempts to bring CBRM 3 on-line failed. Based on the following information it was concluded that the cause was a failure in the regulator control circuitry: 1) all other functions of the charger-battery-regulator were normal, 2) talkback from the regulator command was received, and 3) there was no other indication of a short circuit or high current that might result from a power component failure.

It was determined that the failure of CBRM 3 probably resulted from a solder joint or component failure in the regulator control circuit. The probability of recovering this module was considered nil; therefore, the module was turned off for the remainder of the mission.

Low Regulator Output on Charger-Battery-Regulator Module Number 17 - CBRM number 17 was not delivering full power to the bus. The anomaly was observed on DOY 157. This module delivered approximately 80 percent power output after approximately 10 minutes into orbital night, but none during orbital day. When the panel cooled during the night portion of each orbit the solar cells in series with the short became capable of blocking the voltage that was driving the fault current.

The short disappeared on DOY 270, reappeared on DOY 284, then disappeared on DOY 284. CBRM 17 functioned normally for the remainder of the mission. This anomaly did not impact the Skylab mission, since a reduction of 50 watts in the power capability was insignificant during that period; a minimum power margin of 800 watts existed.

Hard Short on ATM TV Bus 2 - On DOY 216 there was a Command and Service Module master caution and warning alarm. This was followed by a 3-second, 500-ampere, current spike on ATM Bus 2 (7D21). The fine sun sensor wedge-position count went to zero, and the ATM television bus 2 (7D26) voltage went to zero. It was believed that a short in the power transfer distributor television bus 2 was the cause of the electrical problem.

Investigation included determination of the possibility of the wiring of other components being damaged by the short, and the correlation of other vehicle systems and experiment systems with this anomaly. Analysis of all power feeder lines from the power transfer distributor was performed. Tests were conducted on 10-ampere and 15-ampere fuses, and current handling capacity of size 16 and 20 wire. Test of the television bus 2 circuitry was performed in the prototype power transfer distributor. The test wires burned open in 1.8 to 2 seconds at 355 amperes, scattering copper debris inside the distributor. Adjacent wires were not burned open, and the bus arrangement withstood the current surges.

It was concluded that a hard short from ATM television bus 2 to ground had occurred in the power transfer distributor, resulting in the loss of the voltage telemetry signal for that bus, and loss of the bus. Location of the short, and the extent of damage could not be assessed.

Television bus 2 was de-energized and television bus 1 (7D16) was activated. A connector module was fabricated and carried by the Skylab 4 crew as a backup, in case of a failure on television bus 1. The module provided the capability to jumper 28-volt direct current power with a 15-ampere, fused wire from the ATM main bus (7D21) to the television bus 2. This module was to be installed only in the event that the primary television bus 1 failed. Installation of this module was not necessary, since television bus 1 functioned as designed.

<u>Charger-Battery-Regulator-Module 5 Charger Malfunction</u> - On DOY 256, during the recharge of CBRM 5 after its battery capacity test, charging of the battery stopped at about the time voltage cutback was expected. Battery-voltage telemetry was not available during this time but the crew reported charger and battery status lights were on, indicating that the battery and charger had tripped off.

Examination of the data and crew troubleshooting confirmed that the CBRM input bus was shorted to the battery relay. This was possibly caused by a short in one of the charger transistors, but also could have been the failure of a battery isolation diode.

With the solar array tied directly to the battery, the battery would be charged until the high voltage cutoff auto-disconnected the battery. Three additional attempts to turn on the charger resulted in battery voltage high cutoff. Since the CBRM 5 charger could not be repaired, the charger and regulator were turned off. CBRM 5 could have been used in an emergency since the charger failure mode basically allowed the charge voltage to exceed the maximum programmed voltage by one volt. Automatic safety circuits would terminate the charge at this point. Laboratory simulation tests demonstrated that a CBRM could function under these conditions and maintain the battery operating parameters within their safe limits.

Although the loss of CBRM 5 reduced the power output by 250 watts, a power margin of 1,200 watts minimum, for this period in the mission, was more than enough to offset this loss.

Instrumentation and Communication System

Radio Frequency High Reflected Power - The radio frequency link, consisting of transmitter number 1, coaxial switch number 1, radio frequency multicoupler number 1, and the aft antenna, exhibited high reflected power at approximately 62 minutes after ATM activation. Transmitter 1 reflected power was 3.6 watts, nominal was 0.5 watt, and the specification limit was 2.0 watts. Transmitter number 1 was commanded off. Transmitter number 1 was commanded back on and cycled from aft to forward antennas three times but continued to exhibit high reflected power in the aft antenna position. Transmitter number 1 was left on the forward antenna and operation was normal. Transmitter number 2 incident and reflected power remained nominal on both forward and aft antenna positions.

The problem was evaluated using the ATM instrumentation and communication simulator. The possible locations of the fault were limited to points from the input of the coaxial switch to the input of the radio frequency multicoupler. The simulated switch failure more closely resembled the actual flight condition, it was concluded that the switch was the failure point. A mission constraint was imposed to leave transmitter number 1 on the forward antenna for the remainder of the Skylab mission.

Loss of ATM Television Monitor Number 1 - During Skylab 3, on DOY 259, the crew reported that ATM television monitor number 1 on the control and display console displayed an image that oscillated slightly and contained black streaks. The display was switched to television monitor number 2 and appeared normal. On DOY 265 the crew reported that television monitor number 1 had no image, however, the video downlink of monitor number 1 remained good.

Telemetry data indicated that the monitor was not drawing current from television power bus number 2. Previously on DOY 216 there had been a short detected on power bus number 2 of the control and display console which had drawn approximately 500 amperes for approximately 3 seconds until the circuit breaker had tripped out. However, continued operation on power bus number 1 gave satisfactory service of all ATM television equipment. The television monitor contained steering diodes between power bus number 1 and number 2 and the surge current of the short may have damaged the diodes so that continued usage led to an early failure of the diode in series with bus number 1. The other possibility was that the power wiring from the bus to the monitor failed. ATM operations were continued using monitor number 2 only.

A test was performed on DOY 265 in an attempt to regain an image on monitor number 1. This test concluded that television monitor number 1 could have failed due to the short on the television power bus number 2. A replacement television monitor was supplied and installed on Skylab 4 and television monitor performance was normal for the remainder of the mission.

Attitude and Pointing Control System

Vehicle Rate Gyro Processors Drift and Noise - Five of the nine vehicles rate gyro processors, Z1, Z2, Y2, Y3, and X2 temperature indicators read off-scale high. Laboratory tests indicated the gyro processors could perform with a continuous heater on condition and a base heat sink of 285 kelvins. The effect of overheating was long term deterioration and scale factor shifting. Oscillations occurred on three of the five rate gyro processors, Y3, Y2, and Z1, with high temperatures.

A full scale oscillation occurred on vehicle rate gyro processors Y3 at approximately 156:15:50 GMT. The frequency of the oscillation was approximately 2 to 3 hertz. The wheel was powered down and spun up on the next data pass at 156:05:57 GMT, indicating the rate gyro processor was functioning. The oscillation recurred at approximately 164:03:20 GMT. The gyro was powered down and troubleshooting tests were scheduled.

On DOY 154 and DOY 157, failure declarations of rate gyro processor Z1 occurred. These failure declarations occurred when coarse gain was selected due to canister roll/terminate commands. The failures were related to a relay switching malfunction.

Vehicle rate gyro processor Z1 was powered up on DOY 173 to be powered down during anticipated high rate maneuvers, greater than ± 0.088 degrees per second, at which scale switching occurs. At 192:16:51 GMT, vehicle rate gyro processor Z1 again started oscillating, saturated full scale, and remained saturated. No scale switching occurred and fine gain was operating. On DOY 192, Z1 oscillation was comparable to the Y3 type oscillations and not the previous Z1 type oscillations observed during scale switching. It was believed that the Z1 problem was temperature related and that Z1 could be operated for short periods of 5 to 10 days.

Small amplitude oscillations, approximately 0.004 degrees per second peak-to-peak, were observed on rate gyro processor Y2 continuously, starting at 194:13:00 GMT.

Tests were performed on DOY 185 and 186 to determine the condition of rate gyro processor Y3. The tests showed that: 1) the Y3 power supply was functioning, 2) the wheel appeared to spin up, 3) the heater had failed on, and 4) a possible servo electronics failure, coupled with a torquer drive relay failure, had occurred. Gyro processor Y2 was noisy, but usable.

The findings of the test on rate gyro processors Y3 and Z1 on DOY 220 were:

1. Y3 responded to vehicle rates after being initially hard over for the first hour after turn on. The noise output was acceptable. The drift changed too fast to compensate and exceeded 60 degrees per hour within a few hours. It could have been used for control for a few hours at a time if it had been the last gyro in the Y-axis. Rate gyro processor drift compensation limits were 22 degrees per hour.

2. Z1 did not respond to vehicle rates in fine gain mode and oscillated full scale about one hour after turn on. It was unusable for control in fine scale and the condition was not determined in coarse mode.

3. Y2 was temporarily removed from control on DOY 221 because the drift changed too rapidly to track with bias updates. Y2 was returned to control at 219:22:00 GMT. Drift and noise (oscillation) were measured at 0.02 to 0.03 degrees per second peak-to-peak; this was an acceptable value since most of the oscillation was filtered in the computer.

The findings of the tests on rate gyro processors Y3 and Z1 on DOY 226 were:

1. Y3 and Z1 were powered up and operated in coarse gain mode only. Y3 operated with large drift excursions of approximately 150 degrees per hour peak-to-peak. The noise level of Y3 was not as great in the coarse gain mode as the noise level of some of the other rate gyro processors which had off-scale-high temperature indications, and it tracked with Y1 and Y2.

2. Rate gyro processor Z1 did not have any noticeable output or track with the other Z-axis rate gyro processors for the first four hours after turn on. It then exhibited a normal output and tracked with the other Z-axis rate gyro processors; however, it demonstrated a varying positive drift tendency up to about 15 degrees per hour. The noise level on rate gyro processor Z1 was not as great as some of the other rate gyro processors which had off-scale-high temperature indications.

Laboratory investigation of the excessive drift problem revealed that the drift was caused by gas bubbles in the gyro flotation fluid of the rate gyro processors. The formation of gas bubbles was caused by the sudden decrease of external pressure during ascent.

To work around this problem, a rate gyro processor six pack was designed, fabricated, and launched on Skylab 3. The rate gyro processors used in the six pack contained non-vented bellows covers replacing the vented covers previously used. The non-vented covers were used to effect a pressure seal to avert the gas bubble problem. The rate gyro processor six pack unit was successfully installed during extravehicular activity on DOY 236. Based on data from the Saturn Workshop maneuvers performed on DOY 239, the misalignment angles were as follows:

Theta x = 0.1 $\pm$ 0.1 degrees

Theta y = 0.24 $\pm$ 0.1 degrees

Theta z = 0.30 $\pm$ 0.2 degrees

These misalignment angles were determined by two independent methods, one using the acquisition sun sensor measurements and one using the integrals of the six-pack rate gyro processor and vehicle rate gyro processor outputs. Both methods produced similar results. It was recommended that no factors be changed in the ATM digital computer flight program to compensate for the rate gyro processor six-pack misalignment.

Laboratory investigation of the off-scale-high temperatures revealed that the problem was caused by thermal runaway of the heater power control transistor in the rate gyro processor. The thermal runaway was due to the loosening of the transistor mounting nut which caused poor thermal conductivity between the transistor and its heat sink. At the time six pack was being developed, the cause of the off-scale high temperature problem had not been determined. Therefore, no corrective action was taken prior to Skylab 3 launch.

Control Moment Gyro Number 1 Failure

At approximately 327:08:15 (GMT), control moment gyro number 1 drive motor current rose rapidly indicating that the control moment gyro had failed. At 327:08:41 (GMT), the wheel speed indicated 40 revolutions per minute; normal speed was approximately 9,027 revolutions per minute. This rapid deceleration is improbable; the low indication was probably due to wheel speed pickup failure. The temperature of bearing number 1 was 356 kelvins and the temperature of bearing number 2 was 296 kelvins. Normal temperatures for these bearings were 288 to 298 kelvins. The phase currents, which were normally 1.0 ampere, were 2.05, 2.02, and 2.04 amperes for phase A, B, and C, respectively.

The control moment gyro wheel power was turned off by ground command at 327:05:50. The turn-off was sensed by the ATM digital computer which initiated the two control moment gyro control law scheme. The Skylab mission continued normally. There was some impact on the mission in the form of increased usage of thruster attitude control system cold gas usage; however, enough cold gas was available to successfully complete the Skylab mission.

The control moment gyro failure had two primary causes and these causes were mutually reinforcing. The causes were bearing ball retainer instability and insufficient bearing lubrication, primarily at the ball track and ball retainer interface.

Prior to the failure, several indications of bearing anomalies had occurred. The anomalies were characterized by a change in the differential temperature between the two bearings, a slight decrease in the wheel speed, and a corresponding increase in the wheel current. The failure occurred during loss of signal. Consequently, the only data available for analysis was the phase A motor current which was recorded by the auxiliary storage and playback unit. Prior to loss of signal, the bearing temperature was approximately 295 kelvins. The bearing heaters had stopped cycling due to the high Beta angle on DOY 327, but the temperature was below the normal cut-off temperature of 300 kelvins. The cycle cessation on control moment gyro number 1 had occurred before at high Beta angles during manned phases of the mission. The manned configuration docked the CSM near control moment gyro number 1 and Sun reflection caused this gyro to run slightly warmer than it ran without the docked CSM.

Control Moment Gyro Number 2 Anomaly - On DOY 323, control moment gyro number 2 developed an anomaly which continued throughout the Skylab mission. The anomaly was characterized by the following: 1) a change in differential temperature between the bearings, 2) a slight decrease in wheel speed, and 3) a slight increase in spin motor current. The anomaly was intermittent, the frequency of occurrance and severity increased as the mission progressed. However, this unit was used successfully through conclusion of the Skylab mission. To eleviate this problem, bearing temperatures were controlled from the ground because slightly elevated temperatures increased oil viscosity improving lubrication. Post mission tests indicated that the anomaly was caused by bearing ball retainer ring instability and insufficient lubrication.

ATM Jitter - During periods of high crew activity, a vehicle motion as great as 0.1 degree per second with a frequency of approximately 1.0 hertz observed. Due to ATM spar bending modes, this vehicle motion caused the experiment pointing control torquer to saturate, resulting in experiment pointing control excursions up to 30 arc-seconds. These attitude excursions, which lasted as much as 6 seconds, resulted in degraded experiment data. The crew was advised to avoid excessive activity during experiment pointing. This change in procedure eliminated the problem.

Spar Rate Gyro Processor Failure - On DOY 197 the primary up/down spar rate gyro processor failed. The failure resulted in unusually high temperatures in the experiment pointing control up/down actuators. The secondary up/down spar rate gyro processor was commanded on DOY 199 and switched to the experiment pointing control. The cause of the rate gyro processor failure was overtemperature operation resulting in an undetermined secondary failure which caused loss of power to the unit.

Tests performed indicated that the overall experiment pointing control was operating nominally using the secondary up/down spar rate gyro processor. In view of the possibility that more failures of spar rate gyro processors might occur, a device called the experiment pointing control derived rate control system was launched on Skylab 3. This device was designed to be inserted in series with the output of the fine sun sensor for the purpose of producing a pseudo rate signal to stablize the experiment pointing system in lieu of rate gyro processor signals. The secondary rate gyro processor continued to function normally so this device was never used.

Star Tracker Failed - On DOY 361 the star tracker failed. The failure was noted when the outer gimbal position indication went to zero and the outer gimbal rate signal recorded a constant output. An analysis of telemetry data was made and laboratory tests were performed to simulate the failure mode. The failure was exactly duplicated by interrupting the outer gimbal encoder output or the encoder lamp excitation. It was therefore concluded that the outer gimbal encoder had failed and in all probability would not recover. This failure mode rendered the star tracker useless and its operation was terminated. Backup techniques were implemented to calculate the vehicle roll reference. This was used in lieu of the star tracker for the remainder of SL-4 mission.

APPENDIX A

SKYLAB ATM CALIBRATION ROCKET PROJECT

Introduction

This appendix provides a summary of the Skylab ATM Calibration Rocket (CALROC) performances. The performance period included six CALROC flights during the Skylab mission.

Project Purpose - The purpose of the calibration rockets was to obtain solar scientific data to calibrate solar data taken by the S055A, S082A and S082B instruments during the Skylab mission. The Skylab ATM instruments were calibrated approximately two and one-half years prior to the Skylab launch. In addition, sensitivity checks were made periodically during development and test of the instruments. The last check prior to launch was conducted in September 1972. Due to unpredictable changes, such as reflectance characteristics of optical equipment, limit operational life of photomultipliers, and ultraviolet film characteristics, calibration during Skylab operations was a necessity.

To assure the solar data accumulated by the S055A, S082A and S082B instruments was accurate, it was necessary to measure the solar phenomenon present, by a separate system coincident with the Skylab ATM operations. The system selected was a Black Brant VC sounding rocket motor and payload consisting of scaled-down versions of the Skylab experiments and the necessary supporting subsystems. The solar scientific data will be used in post-Skylab Mission data analysis to adjust the ATM data for degradation effects.

The sounding rocket instruments were calibrated immediately before and immediately after the flight and the calibration transferred to the CALROC and Skylab flight data. The CALROC instruments and ATM experiments simultaneously (or within four Skylab orbits) measured the average intensity of the extreme ultraviolet radiation emitted by a quiet area of the solar disc for several arc-minutes. It was required that this area of the disc be relatively free of centers of activity, filamentary structure, and coronal holes.

Launch Facilities - White Sands Missile Range (WSMR), White Sands, New Mexico, was chosen as the site for all CALROC launches because it provided land recovery, and was available throughout the CALROC project.

CALROC used tower launches rather than rail launches for better accuracy and impact predictions. Figure A-1 shows a typical CALROC launching at White Sands Missile Range. Rapid payload and film recovery was required so that CALROC pointing coordinates could be relayed to the Skylab crew for updating ATM pointing.

CALROC launch dates and times were based on the Skylab flight plan. The exact Sun area for calibration data gathering was selected jointly by the CALROC and ATM Principal Investigators within 24 hours prior to a CALROC launch. During the CALROC launch day, Skylab mission operations was contacted periodically by the CALROC representative at WSMR and apprised of the CALROC countdown progress. During the last 15 minutes of countdown the telephone line to Skylab Mission Operations was kept open so that the flight controllers could hear the actual countdown and launch. Continuous contact was maintained with Skylab Mission Operations throughout the CALROC powered flight, calibration data taking period, and verification that the payload was on the main parachute during recovery. If the actual flight CALROC pointing coordinates were different from the targeted coordinates previously relayed to the Skylab crew, new coordinates were relayed by telephone to Skylab Mission Operations for transmittal to the crew.

Data Analysis - Scientific data analysis will be done by the organization responsible for design, manufacture and test of the scientific instruments. Actual calibration curves from the CALROC flight data are not available for this report, however, the data are being processed and the curves and/or data will be available in late 1974 or early 1975.

Skylab ATM CALROC Flight Summary

The Skylab ATM CALROC project had a minimum success criteria of one successful flight for calibrating S055A data and one successful flight for calibrating S082A and S082B data during the overall Skylab mission.

Six calibration rockets were flown during the overall Skylab mission; two each during Skylab 2, 3, and 4. Five of the six flights were successful, as shown in Table A-1, in obtaining good calibration data for use in calibrating the S055A, S082A and S082B scientific data. All payloads were recovered in refurbishable condition, and some hardware was refurbished and reflown. Initial calibration data analysis indicates that calibration of the Skylab ATM solar data will be successfully achieved.

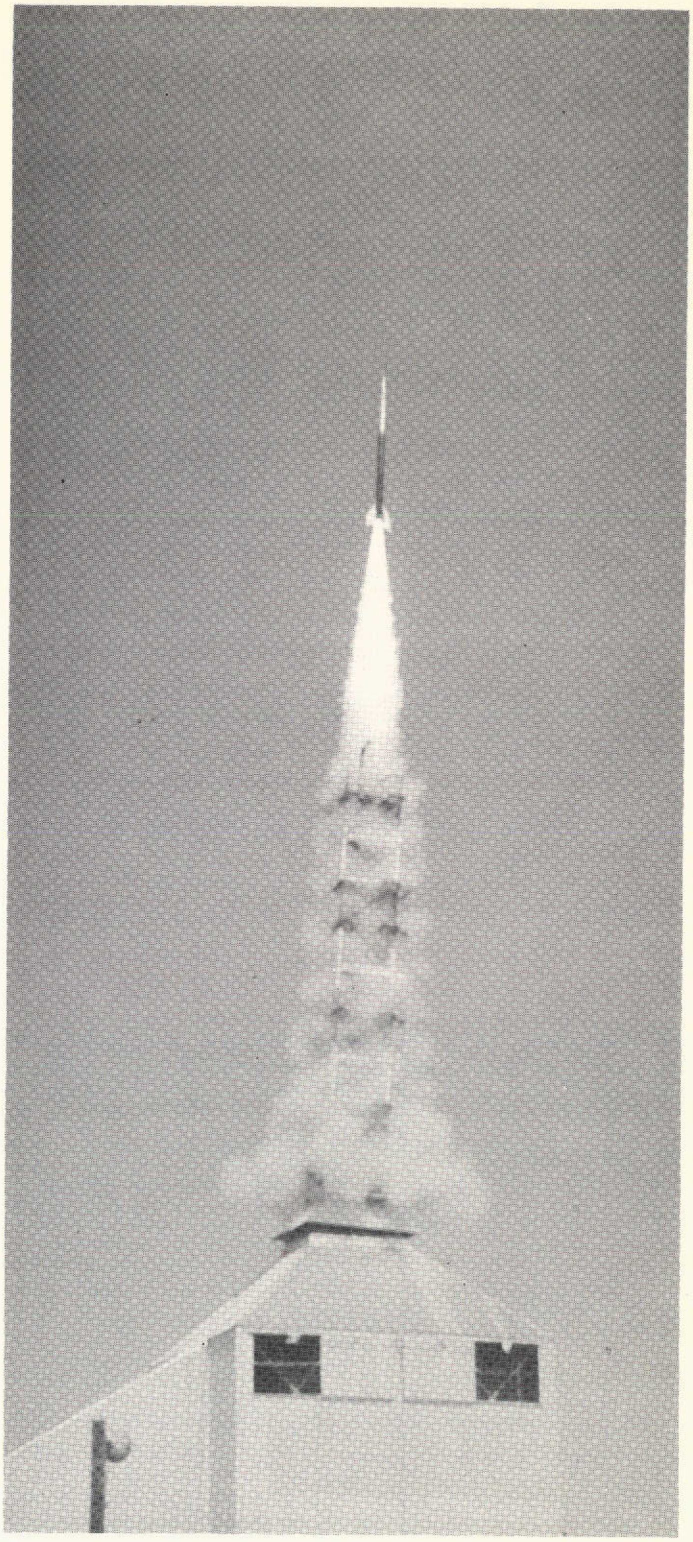


Figure A-1. Typical CALROC Launching

Table A-1. CALROC Flight Summary

FLIGHT NUMBER	LAUNCH DATE	ALL SYSTEMS SUCCESSFUL	REMARKS
HCO 21.021	6-4-73	No	Flight was terminated early by WSMR safety officer because it appeared to be going off range. The payload Telemetry, Nosecone Separation and payload Recovery Systems worked properly. The Igniter Housing, Payload Separation, Scientific Instrument and SPARCS could not perform properly due to excessive tumbling, contamination and electrical malfunctions as a result of termination. No calibration data were obtained.
NRL 21.012	6-13-73	Yes	All subsystems, except the SPARCS and Scientific Instrument, performed as expected. SPARCS had some large excursions causing some loss of calibration data. Calibration data was somewhat degraded by film fogging, overexposure and stray light within the Scientific Instrument. Adequate data was obtained to calibrate the Skylab 2 Mission S082 data.
HCO 21.022	8-9-73	Yes	All subsystems performed as expected. SPARCS provided excellent pointing and the payload was recovered in very good condition. Excellent calibration data were obtained even with the Scientific Instrument power supply #2 inoperative. This caused a loss of first order data in the wavelength range below 800 Å. Second order data was obtained down to 419 Å. Calibration data via telemetry was excellent.
NRL 21.013	9-4-73	Yes	All subsystems performed adequately to obtain sufficient data for a good calibration. Except for a few minor "jumps" of 5-10 arc-seconds, SPARCS provided excellent pointing. These "jumps" had a minimal effect on calibration data. One-half of the "A" camera subsystem filter shutter failed in flight causing a minor effect on calibration data. Except for some minor dents during impact, the payload was recovered in excellent condition.
HCO 21.023	12-10-73	Yes	The flight was a complete success. Excellent calibration data were obtained with all subsystems performing in excellent fashion. The payload was recovered in very good condition.
NRL 21.014	1-15-74	Yes	Except for a small SPARCS roll drift during early flight all systems performed as designed. The roll drift caused a slight smearing of the first exposure on the "A" camera subsystem. All remaining "A", "B", "C", "H" and H-alpha camera exposures were very good, thus providing very good calibration data during the Skylab 4 Mission.

S055A Calibration Payload (21.021) - The only failure occurred with the first CALROC launch on June 4, 1973, which was terminated early (2.2 seconds prior to motor burnout). Thrust termination was commanded because radar data indicated that the payload would land outside WSMR. Postflight analyses indicate a normal rocket motor performance and that the WSMR boundary overshoot was due to an incorrect launch tower setting. Early thrust termination resulted in no calibration data, however, many of the subsystems performed as designed. The payload was recovered, refurbished and reflown on December 10, 1973.

S082A and S082B Calibration Payload (21.012) - The first S082A and S082B calibration payload was launched on June 13, 1973. The Solar Pointing Aerobee Rocket Control System (SPARCS) design goal was to provide pointing accuracies within 20 arc-seconds in pitch and yaw and 1.2 degrees in roll. Except for a 100-second period where unexplained motions of approximately 60 arc-seconds occurred, SPARCS maintained pointing errors of less than 0.25 arc-seconds in pitch, 0.5 arc-seconds in yaw, and 1.2 degrees in roll. The total solar observing or calibration data time was approximately 318 seconds (108 to 426 seconds flight time), providing approximately 218 seconds of good calibration data. The scientific instrument operated successfully obtaining adequate calibration data even with some minor problems such as background film fogging, overexposure and stray light.

S055A Calibration Payload (21.022) - The second S055A calibration payload launch occurred during Skylab 3. This launch was successful except for a high-voltage power supply tripout which caused a loss of first order calibration data through the 296 to 770 angstrom range and second order calibration data through the 296 to 419 angstrom range. First order calibration data was obtained through the 770 to 1340 angstrom range and second order spectral lines of 499 angstroms, 537 angstroms, 584 angstroms, 625 angstroms and 629 angstroms. The SPARCS maintained pointing errors within 0.3 arc-seconds in pitch and yaw and within 0.1 degree in roll throughout the calibration data taking period (109 seconds to 472 seconds).

S082A and S082B Calibration Payload (21.013) - The second S082A and S082B calibration payload which was launched during the Skylab mission was launched September 4, 1973. All payload subsystems performed satisfactorily. Good calibration data were obtained with each camera subsystem; however, the data were somewhat different from the data obttained on the first S082A and S082B calibration flight. This difference was resolved with the third S082A and S082B CALROC flight January 15, 1974.

S055A Calibration Payload (21.023) - The third S055A calibration payload launch occurred December 10, 1973. All payload subsystems performed as designed resulting in a completely successful flight. Excellent calibration data were obtained from all three detectors with the CALROC and the ATM S055A instruments observing the same region of the solar disc.

S082A and S082B Calibration Payload (21.014) - The third S082A and S082B calibration payload was launched January 15, 1974. All payload subsystems performed as designed. Calibration data were excellent, except for a slight smearing of the first film exposure, caused by an unexplained roll drift. The SPRACS roll drift caused some calibration data to be taken of an unplanned Sun filament. However, through close coordination with the Skylab flight controllers and crew, the ATM S082 and CALROC instruments were pointed at the same filament. This flight resolved the differences between first and second payload calibration data, indicating that the second payload data was correct.

Adequate to excellent calibration data were obtained on three S082A and S082B calibration CALROC flights and two S055A calibration CALROC flights. Details on the CALROC payloads, test flights and Skylab flights may be obtained from the "SKYLAB ATM CALIBRATION ROCKET PROJECT FINAL REPORT", TMX-64846, dated April 30, 1974.

APPROVAL TM X-64815

MSFC SKYLAB

APOLLO TELESCOPE MOUNT

SUMMARY MISSION REPORT

BY

APOLLO TELESCOPE MOUNT PROJECT OFFICE

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

A.R. Morse
Skylab ATM Technical Manager

E.H. Cagle
Skylab ATM Engineering Manager

Rein Ise JUN 14 1974
Manager, Skylab Program Office