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June 28, 1974

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MSFC SKYLAB APOLLO TELESCOPE MOUNT

Skylab Program Office

NASA

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

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16. ABSTRACT

This report presents a technical history and management critique of the Skylab Apollo Telescope Mount (ATM) from initial conception through the design, manufacturing, testing and prelaunch phases. A mission performance summary provides a general overview of the ATM's achievements in relationship to its design goals. The report also includes recommendations and conclusions applicable to hardware design, test program philosophy and performance, and program management techniques for the ATM with potential application to future programs.

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NON-STANDARD ABBREVIATIONS

ACE	Acceptance Checkout Equipment
AMA	ASAP Memory Assembly
ASA	Amplifier Switch Assembly
ASAP	Auxiliary Storage and Playback
CBR	Charger/Battery/Regulators
CCS	Computer Control System
CMGEA	Control Moment Gyro Electronics Assembly
CMGIA	Control Moment Gyro Inverter Assembly
COFW	Certification of Flight Worthiness
CRS	Cluster Requirements Specification
DRO	Destructive Readout
DSIU	Data Storage Interface Unit
EBW	Exploding Bridge Wire
EPC-RPM	Experiment Pointing Control-Roll Positioning Mechanism
FPSV	Flow Path Selector Valve
FRV	Flow Restrictive Valve
JOP	Joint Observing Program
MFCV	Modulating Flow Control Valve
MLU	Memory Loading Unit
NDRO	Non-Destructive Readout
PAM	Pulse Amplitude Modulated
PCM/DDAS	Pulse Code Modulation/Digital Data Acquisition System
PMC	Post-Manufacturing Checkout
PSK/FM	Phase Shift Keyed/Frequency Modulation
QCM/CM	Quartz Crystal Micro Balance/Contamination Monitor
RACS	Remote Automatic Checkout System
RCS	Reaction Control System
RNBM	Radio Noise Burst Monitor
RTG	Radioisotope Thermoelectric Generator
SI	Solar Inertial
SOCAR	Systems/Operations Compatibility Assessment Review
TCRSD	Test and Checkout Requirements and Specification Document
TSU	Thermal Systems Unit
WACS	Workshop Attitude Control System
Z/LV	Z Axis/Local Vertical

SECTION I. INTRODUCTION

PURPOSE

The purpose of the Skylab Apollo Telescope Mount (ATM) technical report is to present a technical history and management critique of the ATM from initial conception through the design, manufacturing, testing and prelaunch phases, and to summarize significant mission accomplishments and anomalies.

This report is one of a series of final technical reports on the Skylab modules and is subordinate to TM X-64808, "MSFC Skylab Final Program Report." Associated reports are the following:

1. TM X-64809, MSFC Skylab Corollary Experiments Final Technical Report.
2. TM X-64810, MSFC Skylab Airlock Module Final Technical Report.
3. TM X-64812, MSFC Skylab Multiple Docking Adapter Final Technical Report.
4. TM X-64813, MSFC Skylab Orbital Workshop Final Technical Report.

For more detailed descriptions and mission performance of the ATM systems, refer to TM X-74814, "MSFC Skylab Mission Report - Saturn Workshop," or the subordinate mission evaluation reports, TM X-64815 through TM X-64826.

SCOPE

This report describes and critiques the various phases, operations and program requirements associated with the development and testing of the ATM. A mission performance summary provides a general overview of the ATM's achievements in relationship to its design goals. The report also includes recommendations and conclusions applicable to hardware design, test program philosophy and performance, and program management techniques for the ATM with potential application to future programs.

Development is traced from the initial design phase in 1966 through program conceptual changes to the final design configuration. The major ATM project hardware including development units, simulators and trainers is described. ATM project programs are discussed, and a project chronology is presented. Hardware aspects include manufacturing; component development, qualification, acceptance and life testing; and systems qualification and acceptance testing.

SUMMARY

In August 1966, the National Aeronautics and Space Administration (NASA) initiated the development of the ATM spacecraft, an advanced, man-operated, orbiting solar observatory in space. The purpose of the ATM was to record highly detailed spectral data of active and quiescent regions on the solar sphere, and of the corona, with high spatial and temporal resolution. The project was conducted under joint sponsorship of the Space Science and Applications Office and the Manned Space Flight Office of NASA. The Marshall Space Flight Center, Huntsville, Alabama, was assigned responsibility for the payload design, development and integration.

The ATM concept was initially proposed in response to the recommendations made in the summer of 1965 as a result of a study by the National Academy of Sciences to determine directions for future space research. These recommendations suggested that a follow-on effort to the Orbiting Solar Observatory program was urgently needed, and that concepts which provide man's involvement to answer questions relating to the technology of manned space telescopes and data recovery should receive vigorous support. Success with the early Orbiting Solar Observatory flights also suggested that a major advancement in both spatial and spectral resolution should be immediately pursued. Consequently, an ATM design was prepared with sufficiently large dimensions to accommodate significantly scaled-up solar telescopes. It also incorporated all the required support functions, such as electrical power and active thermal control, within the module in order to maintain flexibility with respect to the eventual mission configuration.

Parallel to the ATM proposal, with knowledge gained from the preceding study effort, several advanced telescope concepts were proposed by some fo the foremost solar physicists and astronomers in the United States. Five Principal Investigators were selected to develop a complementary combination of six solar telescopes for flight on the ATM.

Upgrading of the scientific objectives was accomplished by major scale-up of available concepts and technology including utilization of focal lengths exceeding two meters and introduction of high precision optics and instrumentation. The improvements in instrumentation, in turn, placed stringent demands on the spacecraft design to assure compatibility in its performance characteristics. Advantage was taken of the presence of man in orbit to interface as necessary in order to gain the maximum possible scientific return. This included providing him with complete control over instrument operation, using him as a systems evaluator and observer, providing him pointing control capability, and taking advantage of his ability to bring back data in the form of very high resolution photographic film. The schedules for manned flight at the time of initial ATM design implied that a follow-on mission to the basic Apollo should be pursued expeditiously. Consequently, for this reason, as well as economy, the ATM design was developed as much as possible along lines of existing hardware.

The retrieval of high resolution spectrographic solar data from space placed a number of very stringent and unique performance requirements on the ATM. The most significant requirements related to an experiment pointing control system accuracy of 2.5 arc-seconds, thermal stabilization of the telescopes and related mounting structure, optics contamination control, and the physical retrieval and replacement of the photographic film. Also, the ATM Principal Investigators desired to achieve the highest possible spatial and spectral resolution within the program schedule and technological constraints. It was concluded early in the program that spatial resolutions of 2.5 to 5 arc-seconds and spectral resolutions of approximately .2 angstroms were within reach with essentially current state-of-the-art techniques. This dictated the general size of the telescopic instruments and the supporting structures.

Other major influences on the evolution of the spacecraft design included such factors as the various mission configurations and the mission lifetime. The initial Apollo Applications Program study envisioned the ATM as being an erectable payload stored in one quadrant of the Apollo Service Module, with a mission duration of 7 to 14 days. The second major configuration encompassed a larger telescope package enclosed in a universal rack, and attached to a Lunar Module (LM) ascent stage. This configuration would have been capable of docked CSM/LM/ATM operations or as a free-flying LM/ATM, with a mission duration of 14 to 28 days. The third major configuration utilized a still larger telescope package and rack affixed to the LM ascent stage, and was primarily intended to dock with the Saturn I S-IVB workshop after launch on separate vehicles. The mission requirements for this configuration were initially set at 18 months, reduced to 2 months, and increased to 6 months. The fourth and final configuration discarded the LM and mounted the ATM on a modified Saturn V, by means of a deployable truss assembly. The mission lifetime requirement with this configuration was eight months.

The overall ATM development program included fabrications and utilization of the following significant project hardware: structural, thermal and vibration test units; attitude and pointing control, electrical power, and control and display simulators; one-g, zero-g and neutral buoyancy trainers; a high fidelity mock-up; a fully operational prototype ATM; and the flight ATM. The design, development, manufacture, qualification, test and pre-launch phases proceeded within program milestones with no constraints to the overall program.

SECTION II. ATM PROJECT SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

PROJECT PLANNING SUMMARY

The Skylab Program Office, Office of Manned Space Flight (OMSF), was responsible for management of the ATM as part of the overall management of the Skylab Program. The OMSF Management Council, the Associate Administrator of Manned Space Flight, and the Director of the Skylab Office established the policy guidelines and broad plans which governed the ATM Project. The Office of Space Sciences and Application (OSSA) provided selection and support of the scientific experiments for ATM.

Subject to these policy guidelines, MSFC was responsible for the ATM project management, technical direction, and implementation. This included management and integration of the ATM experiments, the ATM systems and subsystems required, and the necessary GSE.

The continued flow of information, at all levels of management, between the Skylab Program Office, MSFC project managers, other centers, and industry was mandatory for the success of the ATM Project. The following basic concepts constituted the methods by which effective communication was carried out.

a. Bi-monthly meetings between the experiment principal investigators and the astronauts were held.

b. Project reviews were held bi-monthly wherein the complete technical, management, fiscal and schedule progress and problems were presented to center management.

c. Monthly inputs were made through center management for the OMSF Management Council meetings.

d. Intercenter coordination was accomplished through the Skylab panels structure.

e. The ATM project schedules were maintained to reflect approved plans and the status of effort against those plans through the Manned Space Flight Schedule and Reporting System (SARP).

The Skylab Management Center, in Building 4201 at MSFC, was used as a focal point for accummulating and displaying significant program data on the ATM project. Status and interrelationships with other Skylab projects and the overall mission were kept current. Frequent reviews and working sessions were held in the center, utilizing the data displays in the center on all elements of the ATM Project.

The ATM project manager established and required appropriate documentation and management practices to define, control, account, and verify configuration baselines of the ATM hardware and experiments. The implementation of management refinements that provided increased flexibility, simplification, document reduction and economy was practiced and supported. Data management controls and procedures were established which identified and controlled essential data items, eliminated redundancy, and established and controlled distribution of data items and changes thereto.

ATM project documentation provided management with a method for controlling and monitoring performance against in-project requirements and objectives. A baseline definition identified the program requirements and objectives against which performance could be monitored. The policies, requirements, and objectives were delineated in a series of plans which included the following:

a. Project Development Plan

b. ATM Project Requirements Document

c. ATM Project Schedule

d. Configuration Management Plan

e. Logistic Support Plan

f. Resources Plan

g. Quality and Reliability Assurance Plan

h. General Test Plan

i. Launch and Mission Operation Plan

TEST PROGRAM

Summary

All test activities were controlled by the General Test Plan and the Test and Checkout Requirements and Specification Document to provide the timely achievement of program objectives.

Major phases of the ATM test program consisted of development, qualification, acceptance, and integrated systems testing.

Development, qualification and acceptance testing was step-by-step with the manufacturing process to confirm that each operation had been performed in accordance with engineering documentation, that the tested items met all design criteria and intent, and that they interfaced physically and functionally with other flight and ground support equipment items.

Development tests included tests required to evaluate and optimize the ATM design and was performed to establish a configuration which complied with mission requirements. Development testing encompassed static structure, vibration, thermal-vacuum, temperature, shock, acceleration, and RFI testing.

Qualification testing was conducted on all unqualified components, systems and subsystems. Qualification by similarity was utilized where possible.

Acceptance testing was the final test activity following manufacturing and prior to delivery of the article for integration.

Integrated systems testing of the ATM was of the "building block" concept and was divided into five major areas: power distribution test, electromagnetic compatibility (EMC) test, subsystem test, systems test and simulated mission test.

Conclusions

The test team concept, as described in Section III, has proven its merit by reducing overall anticipated test and checkout costs, maintaining a schedule under extreme pressure, and exemplifying the expertise required for prelaunch checkout and launch operations. Since the test team had complete responsibility for preparing the test procedures, performing the tests, trouble shooting the problems, interfacing with design for solutions, and retesting the modifications, it matured into a capable, close-knit organization.

The philosophy of providing test articles to precede the flight article through test has proven its merit. Testing of the structural and vibration test units provided solutions to design problems involving the structure and vehicle dynamics.

The thermal systems unit provided much needed information for thermal predictions and analysis. Significant manufacturing and component anomalies were identified and resolved in the prototype vehicle throughout the test program. Resulting modifications were reflected back into the flight article during manufacture, saving much time and effort in testing of the flight article.

Such success can greatly be attributed to the test team concept and the testing philosophy followed; the fact that the prototype and the flight articles were tested in the same facilities, utilizing the same automatic checkout equipment, electrical support equipment/ground support equipment and were tested in accordance with the same basic test procedures and documentation.

The successful launch and activation of the ATM systems and experiments proved the validity of the ATM test program.

SYSTEMS

Conclusions and Recommendations

The ATM engineering design of systems and experiments was adequate, but for consideration in future programs the following conclusions and recommendations are offered.

Structural and Mechanical - Structural problems occurring during the test program were minor in nature and could be considered as being normal in design engineering.

The only major mechanical system problem was the sunshield aperture door operation. An aperture door operated satisfactorily for 5000 cycles at 1×10^{-5} torr during the life cycle development tests, yet during post manufacturing checkout of both the prototype unit and flight unit, recurring, operational problems existed causing numerous modifications and individual door tailoring. The probable mode of failure of the doors make several recommendations fairly obvious for improving door operation for future applications.

The door material should be changed to a more dimensionally and thermally stable material. A phenolic filled fiberglass is a more stable material and would resist warping more than the epoxy material used. The aperture doors on the Skylab ATM did not have any stiffeners. If a new door design of fiberglass is proposed it should be made with several internal stiffeners. Another alternate would be to use an aluminum top and bottom cover with a phenolic fiberglass center structure and stiffeners.

The ramp/cover latch design should be changed so that they are only used for their original purpose; that is support the door during launch loading.

The open/close mechanism should be redesigned to eliminate the open slider where contamination or foreign objects could cause jamming. Possible fixes could be a link or direct drive.

An experiment alignment anomaly, the lack of repeatability of the alignment readings during alignment verification operations, was prevalent for both the ATM prototype and flight units. The apparent experiment line of sight translations during ATM Flight Unit handling resulted in some out of tolerance final alignment conditions. These out of tolerance conditions did not adversely affect the function of the experiments.

A total review of the ATM structural/mechanical design and test program reveals improvements in the area of optical alignment that should be considered during the planning phase of similar or related programs. This Designed-in optical alignment mechanisms would increase installation, adjustment and verification efficiency and reliability. A standard instrument mount adjustment device could be specified to be utilized for all instruments within the project. This would also allow simultaneous operation of instruments requiring either sun-center or off-the-limb pointing. Further considerations should address instrument accessability for internal adjustment, component replacement, and routine inspection and maintenance during module assembly and testing. As alignment requirements for deep space surveilance telescopes will become more rigid, i.e., less that an arc-second, it is imperative that these projects include an active program to increase the state-of-the-art optical alignment capabilities.

The thermal control system test program proved to be quite adequate. However, some problems did occur which, had the TCS Breadboard test been initiated earlier in the program, the problems would have been apparent earlier thus saving valuable test time. In the ATM test program, scheduling and hardware delivery dates precluded earlier breadboard testing; however it is recommended for future built mechanical systems of this type that breadboard testing of the system be conducted prior to incorporating the design on the vehicle.

The need to operate the TCS during all systems and integrated systems tests in thermal vacuum testing at JSC and prelaunch testing at KSC has not been verified. The TCS was also operated at the VAB and the Pad at KSC. It is suggested that operation of the TCS during PMC and VAB or Pad testing would have been sufficient and should be considered to prevent excessive ground test time in future test programs.

The overall end-item structural and mechanical design proved adequate to attain the objectives of the ATM Skylab mission. There were no major ATM design failures that impacted the final launch date of Skylab.

Electrical Power System - The concept of progressive development and qualification testing on the component/end item level using both the Skylab Cluster Power Simulator and lab setups, through systems verification on the prototype and the flight unit, fully qualified the ATM EPS for flight. Most design and manufacturing problems were discovered and rectified prior to assembly of the flight unit.

The overall design of the ATM electrical power and networks system proved adequate to attain the objectives of the Skylab mission. Significant usage was made of components previously qualified for Gemini and Saturn programs, either in their original or modified form. The most significant design improvements would have been realized in 1) the use of replaceable batteries, and 2) earlier design attention to electromagnetic compatibility and interference studies.

1. The batteries were assembled inside the CBRM cases, requiring almost constant trickle charging and resulting in significant ground test usage. Since batteries are both life and cycle limited, ground testing significantly reduced potential mission reliability. Assuming that adequate accessibility could be maintained, it would be more feasible to use replaceable batteries for ground testing of simulated flight operations, and install flight batteries only for the flight readiness/mission simulation test and immediately prior to prelaunch closeout. Electrical power for normal ground test operations, not involving simulated flight operations, would be furnished by facility sources.

2. Electromagnetic incompatibility and interference created a great number of problems during both prototype and flight unit testing. In the earlier phase of component qualification, a

large number of EMI waivers were granted; this was partially due to the extensive redesign that would have been required and partially to the inability to foresee the extent of the problems during system testing. The extensive use of mechanical relays contributed to this problem. Greater emphasis must be placed on EM studies early in the design phase to eliminate noise sources and to incorporate proper shielding and filtering.

The ATM solar array system ground test performance gave confidence that the system would attain the objectives of the mission. This excellent performance was attributed to the design/engineering test experience gained during the development qualification phases of the test program and to the test procedures and methods utilized.

The solar wing deployment fixture provided an invaluable test apparatus for ground deployment of the solar wings. Prototype and flight unit wing deployment were generally smooth with establishment of test results repeatability. The remainder of the ATM solar wings handling fixtures and support ESE, designed and fabricated at MSFC, adequately supported all phases of handling and test operations both at MSFC and at KSC.

Based on lessons learned during ATM solar wings fabrication, PMC and final flight acceptance testing, the following recommendations are offered for consideration in the planning of any future program involving solar arrays.

1. Provide longer lead time for initial receiving inspection of solar cell modules to permit sufficient refurbishment time of rejected units.

2. Fully investigate prospective hardware fabrication facilities capabilities of maintaining total lot specification requirement prior to contract award.

3. Design ground test support equipment which would incorporate simplified calibration requirements.

Instrumentation and Communications - The concept of progressive development and qualification testing on the component/end item level and systems verification on the prototype and the flight unit, fully qualified the I&CS for flight. Most design problems were discovered and rectified prior to ATM flight unit assembly.

The overall design of the ATM Instrumentation and Communication system was determined to be adequate to attain the objectives of the Skylab mission. The significant usage of components previously qualified for the Saturn program proved satisfactory as a result of the various development/qualification/acceptance test programs.

The I&CS interfaces with the CSM, Saturn Instrument Unit, ATM Experiments, the STDN and other Skylab systems were proven flightworthy.

Attitude and Pointing Control - The overall design of the ATM Attitude and Pointing Control System was determined to be adequate to attain the objectives of the Skylab mission. For future missions involving attitude stabilization and experiment pointing the following recommendations are made. The recommendations are based on the need for additional system capability as determined from results of the test program and analysis.

Testing of high-speed type bearings, similar to the ATM CMGs, in a one "g" environemnt requires assurance that procedures used do not place undue stress on bearings due to improper orientation. Tests of his speed bearings should be conducted to further develop the state-of-the-art in bearing/lubricant technology.

Qualification and life testing of rate gyros, specifically for drift rate and scale factor, should be done in the proposed environment for use. In the case of the ATM rate gyros, testing was accomplished under ambient conditions rather than under thermal vacuum conditions.

In a system involving a startracker, where an accurate roll reference is required, i.e., pointing for experimentation, consideration should be given to incorporating redundancy, in the form of additional redundant circuitry or an additional startracker.

In the present design of the fine Sun sensor, the crew is required to rezero wedges at every orbital sunrise. For future manned missions it is desirable and for future unmanned missions it is mandatory that a method be found to automatically determine the angle of offset pointing any time the sensor is powered up.

Acquisition Sun sensor design improvements should be made in which the sensor would be insensitive to solar light intensity changes caused by contamination (ex. outgassing of materials, RCS thruster propellent reactive venting).

ATM Experiments - The ATM experiments met all of ground test requirements and was determined to be adequate to attain the objectives of the Skylab mission. Numerous anomalies were detected during the ATM testing and were classified as design deficiencies, manufacturing deficiencies and hardware failures. A summary of the cause of anomaly and the approximate number detected for each experiment is shown below.

	Number of Anomalies Detected					
Cause of Anomaly	Design Deficiencies		Manufacturing Deficiencies		Hardware Failures	
Unit / Instrument	Prototype	Flight	Prototype	Flight	Prototype	Flight
S052	8	10	4	2	18	8
S054	31	8	13	4	17	13
S055A	16	8	5	1	11	10
S056	5	6	2	2	20	6
S082A	5	6	3	6	8	8
S082B	15	7	4	7	12	16
$H\alpha1$	6	10	2	3	5	7
$H\alpha2$	3	2	1	1	4	0

Resultant modifications were incorporated which were adequate to attain the experiment objective. A listing of some of the problems encountered on the ATM experiments are documented in NASA TM X-64839, so that experiences therein and associated recommendations might help to prevent similar problems on future programs.

The following recommendations are offered in an effort to improve and simplify experiment operations and compatibility.

1. Incorporate modular design into future experiment design to facilitate troubleshooting and repair or replacement either during test or during the mission. Include test point panels on the experiment for troubleshooting.

2. Provide for automated command of the experiments utilizing the building block approach and programmed computer control.

3. Replacement items like film camera/magazine should be easily and readily accessible.

4. Use automatic checkout equipment to record experiment TCS measurements.

5. Incorporate into the tests procedures for the first major systems test the impacts of the expected operating modes and sequences for launch and in-flight operations.

<u>Control and Display Console</u> - The overall design of the Control and Display Console was determined to be adequate to attain the objectives of the ATM Mission. As mission objectives and console concepts changes occurred during the duration of the test program, design changes were integrated.

One major design anomaly was evident during the control and display console development and test. This anomaly was related to providing a functional Inverter/Lighting Control Assembly. The unit was redesigned to eliminate the anomalies. There were no major design failures that impacted the final launch date of Skylab.

Recommendations for design of controls and displays on future missions concerned the high density of switches and the difficulty in identifying switch position on the three position toggle switches. The recommendation was to remove switches that were seldom or never used and incorporate them in a ground command system, in the case of the ATM C&D, the DAS. Rotary switches were recommended over the toggle switches due to ease of verifying switch position during panel scan.

SECTION III. MISSION PERFORMANCE SUMMARY

The ATM on Skylab has provided data that indicates the performance of the ATM, its experiments, the supporting systems, and the crew, either met or exceeded the premission objectives. This conclusion is based on the Skylab mission performance and the evaluation of the systems and experiment data. The excellence of the ATM performance during the critical early mission period provided ground personnel with the time and capability to effect the changes required 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). The detailed evaluation of the ATM module performance, which includes photographic examples, data resolution, supporting engineering data, and conclusions is contained in the 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.

At approximately 63 seconds into the boost phase, an anomaly occurred which resulted in the loss of the meteoroid shield around the Orbital Workshop. The loss of the meteoroid shield resulted in early 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 did not deploy on command because the wing was restrainted 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 released by the Skylab 2 crew during an extravehicular activity.

Loss of the meteoroid shield, which was designed to serve also as a thermal insulator for the workshop, resulted in a heating problem within 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. Due to these abnormal attitudes, the ATM electrical power system capability was reduced, and the following ATM components exceeded their redline temperature limit: charger-battery-regulator module 15 exceeded the lower limit; the primary tape recorder momentarily exceeded its upper limit; and charger-battery-regulator module number 17 exceeded its upper limit.

Abnormal attitudes were maintained 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 capability and eliminating the temperature problems created by direct solar radiation on the ATM rack-mounted components.

The irregularities 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, a Saturn IVB stage and IU, with the Command and Service Module as its payload.

All ATM systems were operational throughout the Skylab 2 mission and at the conclusion was configured for Skylab 3 unmanned operations. The following system components were considered to have failed or became inoperative during the Skylab 2 mission: S054 Sun-end aperture door was latched open; power was on continuously to S054 experiment; control and display console history plotter on the X-RAY/RF ACTIVITY panel experienced permanent jam; charger-battery-regulator module number 3 regulator failed; wheel speed monitor for control moment gyro number 3 was inoperative; two of nine rate gyro processors (Y3 and Z1) were considered failed; and transmitter number 1 was restricted to operating on ATM forward antenna.

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 was configured for Skylab 4 unmanned operations. The following system components were considered to have failed or became inoperative during the Skylab 3 mission: rate gyro processor Y3 was declared failed but could possibly be used in an emergency; rate gyro processor Z1 failed; I/LCA pulse width modulator AC1 failed; television bus 2 shorted in the power transfer distributor; charger-battery-regulator module (CBRM) 5 failed; and television monitor 1 failed.

The Skylab 4 mission included the unmanned phase that began on DOY 268 with Skylab 3 CSM undocking, and ended on DOY 039 (1974) with Skylab 4 CSM undocking. All ATM systems were operational throughout the Skylab 4 mission. The only system components considered to have failed or became inoperative during the Skylab 4 mission were CMG number 1 and the star tracker.

Due to the management of the ATM systems, workarounds and redundancy designed into the ATM systems, anomalies encountered during the Skylab mission had no appreciable impact on the ability of the ATM to support the ATM mission objectives.

EXPERIMENT SYSTEMS

The ATM experiment instruments consisted of a White Light Coronagraph (S052), an X-Ray Spectrographic Telescope (S054), an Ultraviolet (UV) Scanning Polychromator Spectroheliometer (S055A), an X-Ray Telescope (S056), an Extreme Ultraviolet (XUV) Spectroheliograph (S082A), a Spectrograph and XUV Monitor (S082B), and two Hydrogen-Alpha Telescopes (H-Alpha 1 and H-Alpha 2).

The ATM instruments exhibited outstanding performance throughout the entire Skylab mission. No major hardware problems occurred which significantly impacted the operation of a single instrument. The outstanding performance of the instruments was substantiated by comments from the Principal Investigators (PI) regarding the excellent quality of the scientific data returned. Resolutions approximating one arc-second were attained on much of the solar imagery.

Operation of the instruments was initiated following activation of the control and display (C&D) console by the Skylab 2 crew on 26 May 1973 at 146:18:05 (GMT). The instruments obtained scientific data during scheduled operating periods covering a time span of approximately 8.5 months. Final ATM instrument operation terminated by ground command on 8 February 1974 at 039:08:07 (GMT). All of the instruments were still operational at the conclusion of the Skylab mission although their design life had been exceeded.

The instruments obtained photographs 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 collected high-quality data on the Mercurian atmosphere, Earth-Moon Lagrangian points, the Earth's atmosphere, and, during Skylab 4, on Comet Kohoutek. The number of photographs obtained exceeded premission goals by more than 23,000, because opportunity through the mission allowed extra cameras or magazines to be supplied for all instruments except S082B. More than 2,000 hours of photoelectric data were transmitted real-time or recorded onboard for subsequent transmission. Table 3-I is a tabulation of the quantity of scientific data obtained by the ATM instruments during the Skylab mission.

The video-taped and real-time televised images of the Sun in UV, H-alpha, and whitelight spectra were satisfactory. Improvements initiated for Skylab 3 and Skylab 4 based on the Skylab 2 results, included the use of a Polaroid camera. During Skylab 3 crew debriefing, the crew pointed out the usefulness of pictures taken with the Polaroid camera. An average of five pictures per day were taken and used in place of sketches for reference in solar observance. During the mission, a program of close coordination between the crew and PIs materialized. This resulted in an ability to conduct instrument operations in a manner to maximize data collection of greater scientific value throughout Skylab 3 and 4. The extensive duration of the Skylab 4 mission (83 days) allowed the crew to fully exploit the flexibility of the ATM instruments.

The ATM instruments were operated in accordance with Joint Observing Programs (JOPs) defined by the PIs for each mission. The JOPs were scheduled by the PIs on a daily basis during the mission, based on existing solar activity. The four basic objectives of the JOPs were:

1. Define a set of problems to be solved on ATM as an observatory, as opposed to eight individual instruments.

2. Write the JOP such that all operating instruments were working on the same scientific objective at the same time.

3. Define the JOPs so that maximum utilization of ground based observatories could be made.

4. In constructing the JOPs, provide maximum capability for the PI to make real-time changes in order to optimize his data return.

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

Experiment	Frames Available Per Load (1)	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		152 hrs	772 hrs	1,368 hrs	2,292 hrs

(1) Except for S082A and S082B, the frames available depended upon the amount of film in each load and varied slightly from load to 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) Date from approximately 1,500 additional frames were lost due to the sun-end aperture door having failed closed.

(5) The second film camera was 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 JOPs, related objectives, and planning guidelines were identified in the Mission Requirements Document (I-MRD-001).

A summary of planned and actual ATM observing time for each phase of the Skylab mission, manned and unmanned, is shown in Table 3-II. Only S052, S054 and S055A were schedule for unmanned and unattended operations.

Table 3-II. 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.

During Skylab 2, four JOPs were accomplished.

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, the large number of partial cycles (29), the lack of proper cycle sequences, and limited solar phenomena occurrences.

During Skylab 3, actual attended operation time exceeded the premission plan by almost 50 percent. The additional observing time was a result of improved mission proficiency and crew request for more ATM observing time. Scheduled crew observation time was initiated on Skylab 3. This was time specifically designated by the PIs for use by the crew to observe targets of opportunity. Suggestions for observations were made from the ground, but the final decision remained with the crew.

Of the 15 JOPs and related objectives planned for Skylab 3, 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 this data was not considered significant since more useful data were obtained from other JOPs.

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 Skylab 4, 30 hours were devoted to Comet Kohoutek observations. 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 JOPs as originally planned. Of the eight new JOPs added specifically for Skylab 4, 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

Data were acquired on all JOPs, new and old.

Instrument Performance

White Light Coronagraph (S052) - The White Light Coronagraph successfully accomplished mission objectives by obtaining 35,918 high quality photographs of the solar corona in the white light range. Examination of telemetered engineering data verified the successful operation of the pointing error sensor, the internal occulting disk and internal alignment sensor, the television camera and associated mirror, the polarizer wheel, and the thermal control system. The film transport motor in the Skylab 2 camera failed on DOY 161, after 55 percent of the available film had been exposed. No further film camera operation was possible until a new film camera was installed on DOY 170. Television recording of synoptic observations minimized the loss of film data. A misalignment between the instrument boresight and the instrument pointing error detection system was corrected by aligning the pointing error detection system 8 arc-seconds up and 16 arc-seconds right with respect to the instrument boresight. Thereafter, the S052 television system was used as the primary means of Sun-centering the ATM. Approximately 100 partial frame advances were observed toward the end of the developed film on the first camera used for Skylab 3, resulting in overlapping of approximately one percent of the film data. No partial frame advances were observed on the film from the second camera used on Skylab 3. However, inspection of the camera revealed that the takeup spool had accumulated a larger diameter of film than anticipated, causing interference.

The two S052 film cameras used during the Skylab 4 mission performed as designed. The second Skylab 4 film load was included for Skylab 4 to permit observations of Comet Kohoutek. On DOY 337 the crew observed a white spot on the S052 television monitor, and on DOY 340, the presence of a black bar extending across the screen through the white spot. The condition remained static until DOY 031, when a second white spot and corresponding black streak was observed on the S052 television monitor. The problem was in the S052 television camera vidicon tube and was considered to have resulted from intense scattered light. The video degradation did not prevent the use of the television during the remainder of the mission, and did not impact instrument objectives, as the data were also on film.

X-Ray Spectrographic Telescope (S054) - The X-ray Spectrographic Telescope successfully accomplished mission objectives by obtaining 31,785 high resolution X-ray photographs. This included several hundred exposures taken through the telescope transmission grating to obtain dispersed spectra. Telemetry data and crew observations verified the successful operation of the onboard displays, power supplies, thermal control system, the telescope and imaging system, and onboard and ground control of experiment operation, with the exception of the main-power-off capability, which failed on Skylab 2. During the extended extravehicular activity (EVA) on DOY 218, the film in both magazines was subjected to excessive temperatures. Analysis of the returned film indicated no significant fogging due to the high temperature.

During Skylab 4, the filter wheel, which had stuck between filter positions 5 and 6 on DOY 331, was manually moved to position 3 (no filter) by the crew on DOY 359. It remained at position 3 permanently. This position provided an overall spectral range of 3 to 60 angstroms and the data taken was limited to features of relatively high surface brightness, such as coronal bright spots, active regions, and flares. It was also necessary to lock the shutter blades open. Although operation with the shutter open produced some image blurring on short exposures, it allowed better temporal resolution and coronal data correlation with the S052 instrument.

UV Scanning Polychromator Spectroheliometer (S055A) - The UV Scanning Polychromator Spectroheliometer successfully accomplished mission objectives. The total operating time for the instrument was 2,292 hours. Approximately 18,750 raster scans and approximately 9,880 grating scans were performed. Examination of coalignment, primary mirror raster patterns, detector characteristics, and temperature and voltage excursions verified successful operation of the instrument.

High-voltage tripouts occurred throughout the mission, but had no significant impact on the instrument or data. During the unmanned period between Skylab 3 and Skylab 4, the instrument low-voltage power supply switched from the main (primary) converter to the redundant (secondary) converter, and would not respond to main power off or main power primary radio frequency (RF) commands. A power bus transient was suspected to have caused the switchover, but could not be verified. Instrument operation was normal and all voltage monitors were stable; therefore, no action was taken and the instrument was left in the same power configuration throughout the remainder of the mission. There was no impact on instrument operations.

X-Ray Telescope (S056) - The X-Ray Telescope successfully accomplished mission objectives by obtaining 27,775 high resolution X-ray filtergrams and 1,174 hours of X-ray spectra data. Telemetry data from the camera electronics and X-ray event analyzer, including events, current and temperature, and telescope temperatures verified proper operation of the instrument. Operational sequences terminated prematurely at random times in the sequence throughout the Skylab mission. The premature termination was caused by increased mechanical drag buildup resulting in insufficient motor drive capability. The impact on the mission was slight, as the crew could always restart the camera.

<u>XUV Spectroheliograph (S082A)</u> - The XUV Spectroheliograph successfully accomplished mission objectives by obtaining a total of 1,024 exposures of the solar chromosphere and corona in the XUV region to 1.5 solar radii when Sun-centered. Telemetry indications on all electronic voltages and position switch monitors verified correct operation for all S082A mechanisms. The temperature data indicated that all exposures were within the focus specification and should have no noticeable smear due to temperature gradients. A failure of the first camera to transport film on DOY 150 was rectified by installing a new camera on DOY 158. The new camera and all subsequent cameras operated properly for the remainder of the mission. Skylab 2 scientific data exceeded that anticipated, as the first camera obtained data on 19 frames prior to the failure and the second camera obtained data on the full load of film. Film streaks observed on the developed film from both Skylab 3 cameras were considered to be caused by the ribbed stainless steel film holders. The scientific data were acceptable; however, the S082B flat aluminum film holders used in the S082A cameras on Skylab 4 corrected this problem.

<u>Spectrograph and XUV Monitor (S082B)</u> - The Spectrograph and XUV Monitor successfully accomplished mission objectives by obtaining 6,411 high resolution photographs of line spectra of small selected areas on and off the solar disk and across the limb. All telemetry indications were normal and indicated proper operation of the instrument, except for the pointing reference system problem that occurred on Skylab 4. All electronic voltage monitors were within specified limits used during ground test, and event monitors indicated correct operation of all S082B mechanisms, except for an occassional loss of the film advance indication on Skylab 3. The temperature control was such that focus was maintained near optimum and no objectionable image smear occurred except as anticipated during Skylab 4, when off-set pointing for Comet Kohoutek caused excessive thermal distortion. The high temperatures in the front of the instrument were only temporary, and caused no film damage or hardware problems. Review of the Skylab 2 film data by the PI revealed that exposures taken in the long wavelength during automatic modes were overexposed. A new operational procedure was developed for Skylab 3 and an auxiliary timer was supplied on Skylab 4. The timer was

used for the majority of the S082B exposures taken during Skylab 4, and performed as designed throughout Skylab 4. Toward the end of Skylab 4, the operation of the pointing reference system (PRS) became marginal. The PRS would search but not always lock onto the limb of the Sun. A suitable workaround was established by using the ATM pointing system to position the limb of the Sun for the S082B instrument. This was accomplished by scheduling S082B observations so as not to conflict with pointing for the other instruments. The XUV Monitor television system performance was acceptable; however, the image was faint, causing some crew inconvenience. As the sensitivity was low, video information was available only by use of the video integration capability. This was discovered during Skylab 2, and for Skylab 3, an image persistence scope and a Polaroid camera were supplied. Performance of the scope was acceptable. It retained the one-30th second flash of the video integrate information long enough for the crew to view the Sun and its features. A replacement scope was supplied on Skylab 4 as a result of a malfunction of the first scope during Skylab 3. The Polaroid camera was used to record the images viewed on film. This allowed the crew to identify major changes in the solar surface. A resupply of Polaroid film was included for Skylab 4. The XUV Monitor was used following the closeout of the Skylab observing programs to coordinate the XUV Sun image with the Kitt Peak Observatory reviewing. The crew periodically sent XUV Monitor video pictures to the ground for comparison purposes.

Hydrogen-Alpha Telescopes (H-Alpha 1 and 2) - The H-Alpha Telescopes successfully accomplished mission objectives by obtaining more than 68,000 high resolution photographs which provided scientific data and a record of ATM pointing for other instruments. The telescopes also provided real-time solar images to the crew and ground personnel for supporting planned JOPs. An excellent example of target selection was the observation and data gathering of a large flare on DOY 166 and limb prominence downlinked to Earth and displayed on television. Downlinked and onboard images and engineering data from telemetry verified the successful performance of the heat rejection window, the Fabry-Perot filter, the blocking filter, the movable reticles, the television, film camera, and the thermal control system. The jiggle observed on both H-Alpha television images during Skylab 2 continued throughout the Skylab mission, and remained approximately one arc-second. The jiggle did not affect observations or pointing. During Skylab 3 and 4, vidicon persistence from H-Alpha 2 was observed on downlinked real-time television, and during review of video tapes. The vidicon persistence was not observed on the onboard television monitors, and did not degrade solar observations. H-Alpha 2 vidicon blossomed occasionally at about one second intervals when it was initially powered up on the full zoom-out position. The condition was eliminated by zooming in for a few seconds, and would not recur when zooming back to full zoom-out. During Skylab 4, film advance became intermittent, causing many overlapped and multiple exposures. Toward the end of the Skylab 4 mission, the H-Alpha 1 TV picture detail degraded after approximately 15 minutes of use. The larger solar detail would remain through the day. After the telescope was off for 8 to 10 hours, the imagery would return to normal.

STRUCTURES AND MECHANICAL SYSTEM

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 included 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, and 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.

On DOY 364, the S082B aperture door malfunctioned, 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.

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

ELECTRICAL POWER SYSTEM

The ATM electrical power system met all Skylab mission requirements, in spite of the extreme loading condition impact during the first 24 days after launch of Skylab 1.

Due to the problem of the inoperative Airlock Module electrical power system, power management procedures were initiated to assure that the output capability of the ATM electrical power system would not be exceeded. The power management procedures included delayed activation of large heater loads and control moment gyro spin-up, and additional real-time power management techniques. The goal of power management was to allow the ATM batteries to obtain energy balance each orbit.

During the 10-day period from insertion of Skylab 1 to start of activation on DOY 147, the total average cluster load varied from 4,400 watts in solar inertial mode to 2,400 watts in 50 degree pitch attitude. The original predicted load range was 3,500 to 6,500 watts. The ATM average load during the activation phase was approximately 1,500 watts, with the remaining available power (800 to 2,800 watts) being transferred by the

ATM power sharing network to the Airlock Module interface for distribution throughout the cluster. The ATM electrical power system continued to supply the total Saturn Workshop power for the first 14 days of the planned 28-day Skylab 2 manned mission. After deployment of the Orbital Workshop solar wing number 1 on DOY 158, the load on the ATM electrical power system was reduced to normal, approximately 3,000 watts with the command service module docked.

During the unmanned period of the Skylab 3 mission the ATM power system operating in parallel with the Airlock Module power system had a combined average system capability in excess of 5,000 watts with a positive power margin of over 2,000 watts. During the manned phase of the Skylab 3 mission, the power systems had a power capability of 6,250 to 7,440 watts with an open circuit voltage on the AM regulator buses of 29 volts. The average load was 5,800 watts, with a positive power margin of 450 to 1,640 watts. Power management techniques were implemented during Earth resources passes to restrict the depth of discharge of the batteries. Power management was not required while the Orbital Assembly was in the solar inertial attitude because of the positive power margin.

The average ATM load during the unmanned Skylab 4 mission was 2,000 watts and the average system capability varied from 3,800 watts to 4,900 watts. As the Saturn Workshop was activated the load increased incrementally until at the end of the activation period the load was 4,800 watts average when the crew was awake and 4,200 watts during the crew sleep period. Compared to the 7,900 watt ATM and AM system capability for this period, a minimum power margin of 3,100 watts existed.

During Skylab mission, there were approximately 16 anomalies; four were considered significant, as to have an impact on the mission. 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 this happened, on DOY 145, 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. 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 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 155, during the first Earth resources pass, four batteries discharged to approximately zero percent state of charge and were automatically turned off by the battery low voltage logic in the CBRM. These batteries were recharged on subsequent orbits and were reactivated to normal operation. On DOY 256, CBRM 5 ceased charging. Analysis indicated that the input bus was shorted to the battery relay, which was 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. These anomalies and other related electrical problems are covered in more detail in section 3 of the MSFC Skylab Systems Mission Evaluation Reports.

Although the loss of CBRMs 3 and 5 during the Skylab mission reduced the ATM electrical power capability by approximately 10 percent (470 watts), the better than predicted operating efficiency of the 16 remaining CBRMs made up for most of the deficit. The 16 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 by the cluster specification (RS003M00003) to supply 3,716 watts of power. The system was designed to supply 4,230 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.

THERMAL CONTROL SYSTEM

The ATM thermal control system performed flawlessly throughout the Skylab mission.

After Skylab 1 launch, the problem of rising temperatures within the Orbital Workshop prompted the placing of the Skylab 1 in various pitch-up attitudes in an attempt to control the internal workshop temperatures. While in these abnormal attitudes, during exposure to direct solar radiation, two rack-mounted components, the primary tape recorder and CBRM number 17 temperatures increased to 303.3 kelvins, exceeding their redline upper temperature limits of 303.2 kelvins, but suffered no apparent degradation. The ATM active thermal control system was not activated during this period due to electrical power limitations. Instead, the thermal control system of one experiment in each canister quadrant was turned on, maintaining a temperature above the lower limit for all the ATM experiments.

During the Skylab 2 mission, subsequent to deployment of the thermal parasol to shade the Orbital Workshop, the Orbital Assembly was maneuvered into the solar inertial attitude. Then, with power available for operation of the ATM experiments, the ATM active thermal control system was activated on DOY 147, and the ATM components returned to predicted temperatures within their respective limits.

After activation, the 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.

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, with the coefficient of absorptivity having increased from approximately 0.2 at launch, to approximately 0.37 at the end of the Skylab 3 mission.

During the Skylab 4 mission, system operation was still within its design limits. However, during a high Beta angle period, DOY 015 through 018, the H-Alpha 1 front extension tube exceeded its upper limit by 7.4 kelvins, the H-Alpha 2 heat rejection window exceeded its upper limit by 10.6 kelvins, 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 control temperature 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 0.43 and remain there. Actually, it had increased to approximately 0.525 at the end of the mission, and gave no indication that it was leveling off.

After DOY 018, with decreasing Beta angle, the canister temperatures returned to the normal values, and were within the specified limits at the end of the mission. All non-failed rack-mounted components remained within their specified temperature limits throughout the Skylab 4 mission.

The primary pump and primary controller of the active thermal control system were used throughout the mission. Before undocking of the Skylab 4 Command and Service Module, the ATM thermal control system was deactivated and reactivated, using the secondary pump and secondary controller. Performance of the system was within the design limits. The system was then switched back to the primary pump and primary controller, and again, performance was within the design limits.

INSTRUMENTATION AND COMMUNICATIONS SYSTEM

The ATM instrumentation and communications system satisfactorily performed all ATM command, data conditioning and transmission, and television functions required in support of the Skylab mission.

The ATM digital command subsystem was powered up for 6,506 hours. The total number of commands executed during the Skylab mission was approximately 59,650. Both primary and secondary subsystems were operating normally, with no indication of degradation, at the end of the mission.

The ATM data subsystem was powered up for 6,506 hours. The subsystem data acquisition included 308 sensors, 292 channels of signal conditioning, 686 high level analog channels, 289 low level analog channels, 228 digital channels and 391 auxiliary storage and playback (ASAP) channels. A coaxial switch malfunctioned during Skylab 2 restricting transmitter number 1 to the forward antenna. Although this initially caused data loss or degradation on some ASAP tape recorder dumps due to procedural inconsistencies, procedural changes and improved management of the dumps eliminated the problem. Due to the rate gyro processor six pack supplied on Skylab 3, a requirement developed for an additional temperature sensing method. Nine liquid crystal thermometers were supplied on Skylab and six were mounted on the end of the rate gyro six pack, between connectors, by the crew, and functioned as designed.

The ATM television subsystem met or exceeded the design requirements throughout the Skylab mission. Considerable downlink time was devoted to solar observatory television giving excellent views of the Sun. This gave the Principal Investigators a preview of the data being recorded on the film cameras and provided solar experiment pointing and adjustment.

From DOY 161 through DOY 170, the S052 experiment misalignment resulted in an inability to obtain Sun center. The ATM television network was the only means of continuing the synoptic observations of the corona on the S052 experiment.

During Skylab 3, on DOY 265, an electrical short on the control and display console television power bus number 2 which fed the television monitor number 1 resulted in the loss of this monitor. ATM operations continued normally using television monitor 2 until a replacement monitor was resupplied on Skylab 4.

The ATM caution and warning subsystem functioned as designed resulting in two categories of alarms during the Skylab mission. The first type was caused by ground management malfunction procedures being performed by the crew, and was anticipated. The second type resulted from either control moment gyro saturation or failure of vehicle rate gyro processor integral tests.

ATTITUDE AND POINTING CONTROL SYSTEM

Preliminary review of photographic data indicated that the pointing stability of the attitude and pointing control system was better than 1.0 arc-second compared to the design goal of 2.5 arc-seconds. The vehicle rate gyro processors, connected in a triple redundancy configuration, provided vehicle rate signals adequate for maintaining vehicle control although nine vehicle rate gyro processors exhibited various unexpected drift characteristics. The drift characteristics were successfully managed by entering compensations into the ATM digital computer.

During Skylab 1 and Skylab 2, the temperature measurements of vehicle rate gyro processors X2, Y2, Y3, Z1, and Z2 indicated off-scale high. The same rate gyro processors exhibited scale factor deviations. The deviations were compensated in the Y axis only. Compensations were not implemented for the X axis because there were two rate gyro processors exhibiting acceptable performance in the X axis. Compensations were not implemented for the Z axis because the scale factor and drift characteristics were too erratic. The Y3 and Z1 vehicle rate gyro processors at various times exhibited full scale oscillations; therefore, their use for control purposes was discontinued.

All vehicle rate gyro processors continued to exhibit various drift characteristics during the Skylab 3 unmanned period and during the first days of the manned period. Because of drift and oscillation problems with the vehicle rate gyro processors during Skylab 1 and Skylab 2, a rate gyro processor six pack was designed, fabricated, and launched 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 gryo processors, two per axis. It was designed to be connected to the workshop computer interface unit and be used in conjunction with the one most stable vehicle rate gyro processor in each axis. On DOY 236, the rate gyro processor six pack was installed in the Multiple Docking Adapter per extravehicular activity plan. No problems were experienced; the vehicle drift while in standby mode was less than 9.0 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. A short time later, 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 available-if-needed status. After installation of the rate gyro processor six pack, there were no significant rate gyro processor problems attributed to rate gyro processor malfunctions. The six pack performed well and no compensations for six pack misalignment were required in the ATM digital computer software. Only one rate gyro processor, Y5, required drift compensation.

The ATM digital computers, their software, and the workshop computer interface unit performed as designed. Software patches were successfully loaded into both ATM digital computers using the digital command system (ground command). The onboard digital address system operated as designed. The software momentum desaturation scheme was a new technique and performed as designed.

The automatic redundancy management scheme and adaptive control law concept were new techniques and both performed as designed. The memory loading unit was not exercised until postmission testing, at which time, operation was as designed. The thruster attitude control system and control moment gyro system satisfactorily maintained vehicle attitudes and provided the torques necessary for maneuvers. 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 was observed. Due to ATM spar bending modes, this vehicle motion caused the 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.

Control moment gyro number 1 failed on DOY 327 due to a bearing failure. This control moment gyro was turned off by ground command. The power-off condition was sensed by the ATM digital computer which initiated the two control moment gyro program option which was resident in the computer. The Skylab mission continued normally under two control moment gyro control.

Two of the four spar rate gyro processors, the primary left/right (yaw) and the secondary up/down (pitch), used for experiment pointing, operated as designed. The primary up/down (pitch) rate gyro processor exhibited off-scale high temperatures and eventually failed. Prior to the failure, oscillation of the rate gyro processor caused continuously alternating torque signals to be applied to the experiment pointing pitch actuator; as a result, high temperatures were experienced by the actuator. Normal operation was resumed using the secondary up/down rate gyro processor. The secondary left/right (yaw) spar rate gyro was not exercised until postmission tests; at that time operation was normal.

During Skylab 2, the star tracker experienced some difficulty due to tracking contaminant particles and the Earth's horizon. Also, some degradation of star tracker sensitivity occurred. The star tracker was unable to track stars with S-20 magnitude of +0.66 (Alpha Crux) but could track stars with S-20 magnitude of +0.52 (Achernar) and brighter. The loss of sensitivity was attributed to exposure of the star tracker to Earth shine and other brightly illuminated objects. This loss of sensitivity caused no significant impact on the mission. The star tracker position encoder failed on DOY 361 rendering the star tracker inoperative.

The experiment pointing electronics assembly, the acquisition Sun sensor and the fine Sun sensor performed as designed.

CREW SYSTEMS

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

Through use of the restraints, translation aids, film transfer booms, the film transfer clothesline, the external lighting, and the workstations, the crews were able to perform all planned extravehicular activities successfully. In addition, many other extravehicular tasks were performed on the ATM which made it possible to continue operating individual ATM experiments. In the case of the rate gyro processor six pack, successful installation of a cable at the workshop computer interface unit enabled 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.

CONTROL AND DISPLAY CONSOLE

The control and display console performed satisfactorily. The console provided the interface for crew operation of the ATM experiments and supporting systems by providing operating controls and various displays for monitoring performance and status.

During Skylab 2, the activity history plotter jammed and became inoperative when it was rewound past a torn section of the paper.

During Skylab 3, the AC1 pulse width modulator assembly in the I/LCA failed on DOY 214, resulting in losing the capability of varying the brightness of the displays, but presented no problem. Brightness had been in the fixed position since activation of Skylab 1 and was not changed during the Skylab 2 mission. Also during Skylab 3, the operation of television monitor number 1 became intermittent on DOY 259, with failure occurring on DOY 265. ATM operations were continued using only television monitor number 2. A replacement monitor was carried up and successfully installed by the Skylab 4 crew and normal ATM TV monitoring operations resumed.

During Skylab 4, on DOY 003, the console integral lighting was lost. Impact on the mission was slight, presenting only a crew inconvenience, since all of the control and display functions could be performed without integral lighting.

CONTAMINATION

The contamination measures employed for the Skylab missions were adequate. The contamination evaluation continued throughout all missions, utilizing the two ATM quartz crystal microbalances, S052 experiment, star tracker data, and internal canister pressure.

Flight data and preliminary evaluation by ATM Principal Investigators indicate that there were no contamination problems on Skylab. Although contamination was observed by the crew, and on some television and film, there was no evidence that any external contamination such as outgassing or discharged particles degraded ATM experiment data. Telemetry indicated that the ATM quartz crystal microbalances surfaces were clean throughout the Skylab mission.

It is suspected that the star tracker experienced some difficulty due to tracking contaminant particles, however the frequency of occurrence was greatly reduced due to a change in star tracker management.

Internal pressure of the ATM canister was monitored to provide an assessment of the degree of outgassing within the ATM canister. This assessment verified it took 10 days longer than expected for internal canister pressure to decay and stabilize at a pressure sufficiently low to prevent coronal discharge within experiment high voltage power supplies.

SECTION II. ATM EVOLUTION

EARLY HISTORY

In January 1966, the Office of Space Sciences and Applications (OSSA) requested proposals from JSC, MSFC, GSFC, and Langley Research Center for a telescope mounted on the Apollo Service Module. The request was the culmination of a year of feasibility studies to include optical technology experiments on extended Apollo flights.

Service Module ATM Concept

MSFC's initial response on the ATM program was in the form of a project proposal in February 1966, based upon MSFC management of a Command Service Module (CSM) mounted ATM.

In April 1966, Office of Space Sciences and Applications had the results of a seven and one-half month study of technical requirements for the CSM conceptual Apollo Telescope Mount. The primary guidelines under which the study was conducted were as follows:

1. Minimum interface with the Apollo spacecraft.
2. Near Earth orbit mission.
3. Maximum utilization of existing technology and hardware.
4. Maximum experiment versatility for future Apollo science mission.
5. Solar oriented system concept with adaptability to a variety of other celestial targets.
6. Location in Sector I of Apollo Block II Service Module.
7. Optimum utilization of the Apollo astronaut crew.

The CSM mounted ATM system concept was a three axis oriented solar research platform mounted in Section I of the Apollo Service Module. It would accommodate several solar experiments capable of resolving solar features of about five arc-seconds in size. The ATM system would point such experiments to any position on the solar disk and hold the selected alignment to within plus or minus five arc-seconds in pitch and yaw, and limit roll about the line-of-sight to one arc-sec/sec during data acquisition.

Lunar Module (LM) Concept

Trade-off studies were conducted by the Saturn/Apollo Applications Office of MSFC in April 1966 to compare the CSM concept with a LM/ATM concept. These studies indicated certain advantages for the LM concept. On the basis of these findings MSFC received a request from OSSA to study the LM configuration with a hard mounted ATM. Simultaneously, OSSA studied the LM mounted concepts for the ATM. MSFC subsequently initiated an intensified inhouse study effort. To compliment the inhouse MSFC study, arrangements were made through JSC to perform a study of the specific implications of the ATM mission on the LM configuration. The inhouse and contract studies were intended to provide the necessary information for establishing a series of recommendations leading to the selection of an optimum configuration and operational mode.

In late June 1966, MSFC presented the hard mounted LM/ATM concept to OSSA and to OMSF. On July 11, 1966, a decisions was made by NASA Headquarters to assign ATM, including experiment management responsibility, to MSFC. A preliminary ATM Project Development Plan was submitted by MSFC on July 25, 1966.

The preliminary Project Development Plan contained the LM/ATM system definition as based upon the then present status of design and mission analysis. The primary design was based upon location of an experiment package, containing up to four telescopes, in a universal rack which replaced the Lunar Module descent stage. The LM/ATM would rendezvous and dock with the CSM (launched one day earlier) and be carried to a 220 mile orbit by the CSM. Two astronauts would occupy the free flying LM/ATM for 7 days, redock and exchange one of the astronauts with the CSM astronaut, and undock for another 7 day mission. The total mission duration was to be a minimum of 14 days with a design goal to extend its life up to 28 days. Consideration was given to a quiescent orbital storage mode for 3 to 6 months after its initial operation and be capability for reactivation for another 14 to 28 day mission.

For the initial LM/ATM concept a universal rack was considered that was previously designed for use by Project Thermo and Payload Module Project. The rack provided structural support for the ATM experiments, for the auxiliary equipment such as batteries and the control moment gyros, and also for a LM ascent stage. The rack attached to the launch vehicle at the four SLA/LM support points and provided the lateral stiffness required by the SLA. The ascent stage, when supported by the rack, occupied the same position relative to the SLA as an ascent stage in a normal Apollo/LM mission. The overall dimensions of the octagonal plane form truss structure was 97 inches in the longitudinal direction with an inscribed circle diameter of 114 inches. A 5 foot diameter payload support ring was located at the center of the aft plane of the rack for attachment of the experiment package parallel to the thrust axis. The overall dimensions of the octagonal plane form structure was 60 inches in diameter by 120 inches in length. It was capable of accepting a single large telescope of approximately 50 inches in diameter, or with the installation of a cross-frame spar, several smaller telescopes could be mounted.

<u>Alternate Concepts</u> - Alternate concepts were presented in the Preliminary Project Development Plan as follows:

1. Modified LM Descent Stage Concept - A study resulted in a configuration mounting the experiment package in the LM descent stage engine compartment with the package extending into the LM ascent engine-well. An additional adapter structure, mounted to the existing hard points on the bottom of the descent stage, was required. The telescope package, CMG's, and supporting modules were attached to this adapter structure. Solar array's were considered to be attached to the descent stage landing leg attach points.

2. Command Service Module Docked to the Lunar Module - With the CSM continuously docked to the LM, the astronauts would not necessarily have to leave the CSM, which allowed an emergency re-entry to be activated in a short period of time. Some additional advantages obtained from this concept were a major reduction of LM equipment whose functions could be provided by the CSM. In addition, the CSM could provide more suitable astronaut living conditions.

CLUSTER CONCEPT

Wet Workshop

In conjunction with the Preliminary Project Plan, studies were underway to utilize a Saturn S-IVB/Spent Stage Experiment Support Module, mounted on the forward end of the S-IVB stage, to provide docking and an airlock passageway into the S-IVB hydrogen tank. This Orbital Workshop concept evolved into the clustered wet workshop configuration. A CSM would transport the LM/ATM module to the cluster, separate from the LM/ATM, and dock to the forward MDA port. The LM/ATM would dock to a side port of the MDA. In addition to the LM/ATM docked concept, Dr. George Mueller suggested a cluster concept with the ATM tethered to the orbiting cluster by umbilicals carrying cooling fluid, oxygen, electrical power, etc. Study of the LM/ATM tethered configuration continued through early 1967, but the concept was abandoned in favor of the CSM/LM/ATM docked configuration.

ATM design evolution to meet the uprated mission requirements resulted in the addition of solar arrays, an experiment gimbal system, attitude pointing control system, and in early 1967 an active fluid cooling system for the experiment canister.

Dry Workshop

In late 1968 a concept was being studied at MSFC to substitute a "dry" workshop for the "wet" workshop configuration. The "dry" workshop consisted of a multiple docking adapter, airlock module, and orbital workshop. In mid 1969 NASA Administrator, Dr. Thomas O. Paine approved the change to a dry workshop configuration. This concept would launch the ATM and workshop together using the first two stages of the Saturn V as the orbit insertion vehicles. Changes to the ATM resulting from the dry workshop configuration included the deletion of the Lunar Module, addition of an ATM Deployment Adapter, modifications of ATM structure to accommodate a Sun-end up launch configuration, and modifications to the Attitude and Pointing Control System for experiment pointing and for stabilization of the total cluster. Sections IV through XVIII of this report contain system descriptions of the final ATM configuration.

SECTION V. SKYLAB - ATM PROJECT

ATM DESCRIPTION

The major systems that made up the Apollo Telescope Mount (ATM) were electrical, structural and mechanical, thermal, instrumentation and communication, experiments, attitude and pointing control, and the control and display console. The ATM Electrical Power System (EPS) generated, conditioned, stored, controlled, and distributed 26.5 to 30.5 volts 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 Module (CBRM). The CBRMs provided continuous regulated direct current to the ATM main buses for distribution. The ATM Structures and Mechanical Systems were designed and configured to accommodate eight, high resolution solar astonomy instruments and supporting equipment. An internal cruciform structure divided the canister assembly into quadrants to house and support experiment instruments. It served as an optical bench to provide the necessary pointing and acquisition of high quality data. To maintain thermal stability, a loop within the skin of the canister assembly circulated liquid coolant. The Thermal Control System was self contained within the canister. The inner walls were composed of cold plates that absorbed the heat dissipated in the experiment package. The water/methanol cooling fluid transferred heat absorbed from the cold plates to radiators on the exterior side of the canister assembly, where it radiated into space. Each experiment had its own thermal control heaters, designed to maintain its temperature within ±1° throughout the length and width of the instruments. A passive system consisting of thermal insulation and thermal coating regulated the ATM supporting rack structure and the components mounted on it.

The ATM Instrumentation and Communication System consisted of the data, command, and television 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 experiments were designed to provide high resolution scientific data of the entire solar disk and corona or features of interest. The design provided for data to be stored on film for crew return to Earth, telemetered real-time, or stored on tape for delayed transmission to Space Tracking Data Network. The experiments included an X-Ray Spectroheliograph (AS&E), an X-Ray Telescope (MSFC), a

White Light Coronagraph (HAO), an Ultraviolet Spectrograph, an XUV Spectroheliograph (NRL A&B), an EUV Spectrometer Spectroheliometer (HCO-A), and two Hydrogen-Alpha telescopes which were carried to provide video images to the astronaut for instrument pointing.

The Attitude and Pointing Control System (APCS) consisted of two separate but interrelated control subsystems. The attitude control subsystem, provided attitude control and stabilization for the Skylab Orbital Assembly. The Experiment Pointing Control (EPC) subsystem, stabilized and fine pointed the ATM experiment package. The attitude control subsystem consisted mainly of computers, sensors, cold gas thrusters, and three Control Moment Gyros (CMGs). The EPC subsystem, using the fine sun sensor as reference, fine pointed the experiment canister. The Control and Display console provided the interface for the crew operation of the ATM experiments and supporting systems and various displays for monitoring performance and status.

ATM PROJECT PROGRAMS

Test Program - Major phases of the ATM test program consisting of development, qualification, acceptance, and systems integration and verification were closely interwoven to provide maximum utilization of test hardware. All tests were performed at the highest hardware generation level practicable with minimum piece part testing.

Acceptance testing was conducted at the origin of manufacture when practicable to reduce duplicate testing and resources at the integration and/or assembly site. Results of other programs were utilized where possible and only deltas between the programs were tested.

Qualification was accomplished by analysis where practical, and was supplemented with testing when the analysis was not considered adequate for qualification.

Material compatibility testing was conducted to verify that the material selected was compatible over the specification range with both fluids and other interfacing materials under the expected use condition (e.g., manufacturing testing, and extended flight in the space environment).

The "test team" concept was utilized during systems verification. This "test team", managed by the ATM Project Office, utilized test engineers from MSFC's Science and Engineering Laboratory and contractor personnel from Martin Marietta Corporation, Bendix Corporation, Sperry Rand, Federal Electric Corporation, and Ball Brothers Research Corporation. The test team provided expertize for testing at MSFC and traveled with the ATM prototype and flight articles to Johnson Space Center (JSC) and to Kennedy Space Center (KSC), as applicable, providing continuity from initial testing through ATM close-out at KSC.

Major milestones and test schedules are discussed later in this section.

Configuration Management - The ATM Project Manager required appropriate documentation and management practices which defined, controlled, and verified configuration baselines of ATM systems.

Associated with configuration management of the ATM project were reviews, inspections and certifications for the ATM. These checkpoints were oriented to the hardware design, development, fabrication and test as well as mission phases of the program. The basic management principal was to insure that, at appropriate and progressive points in the program life cycle, sufficient visibility was obtained of the status of design, manufacture, and testing to adequately determine the integrity of the system prior to mission accomplishment.

Reliability - Failure mode effect and criticality analyses were conducted, reliability predictions were made, and critical categories were established for all flight hardware. All ATM components were classified in one of the six criticality categories listed below:

Category 1 - Loss of life of crew member(s) (ground or flight). Most of the ATM equipment was outside the cluster environment and failure could not result in hazard to the crew.

Category 1B- Applies to safety and hazard monitoring systems when required to function because of failure in the related primary operational system(s); potential effect of failure is loss of crew member(s).

Category 2A- Immediate mission flight termination or unscheduled termination at the next planned Earth landing area.

Category 2B- Launch scrub.

Category 3 - Launch delay.

Category 4 - None of the above.

Development and qualification tests were organized to provide data in support of reliability analyses. Data from all appropriate sources were utilized in updating and substantiating reliability predictions.

Material Compatibility - Material compatibility control on the ATM program was regulated by the Material Utilization Control Board. The board's origin, authority and function was required and authorized by the "ATM Optical Environmental Contamination Control and Abatement Plan." This document was applicable to all NASA organizations and contractors engaged in, or concerned with, selection of material for use in the ATM program.

Material testing was accomplished through the cognizance of S&E-ASTN and S&E-ASTR Laboratories in accord with the responsibilities and test criteria contained in the "ATM Optical Environmental Contamination Control and Abatement Plan." These organizations were required to submit their test data to S&E-ASTN-MEV or S&E-ASTR-PR for concurrence and submittal to the board chairman.

Contamination - A contamination control plan was developed by Marshall Space Flight Center to ensure that the ATM cleanliness levels were not compromised by contaminants from the environments or ground support equipment (GSE) to which the ATM was exposed during fabrication, transportation, handling, and testing activities.

Logistics - System/equipment analysis, to provide maintainability recommendations, began with the start of components and/or module design to optimize the design installation trade-offs to ensure easy accessibility and economical maintenance. Maintenance analysis began prior to the critical design review to establish the initial maintenance concepts, requirements, and provide data for provisioning of long lead spares. Logistics and maintenance capability was established to support the test and checkout activities conducted at MSFC, thermal vacuum test at JSC, prelaunch and launch operations at KSC, and on-orbit operations. Maintenance on the flight article was minimized by performing only first level maintenance (remove and replace) at JSC and KSC. Second and third levels of maintenance normally accomplished on flight equipment was performed only at MSFC or the supplier's facility. Maintenance of GSE included first and second-level maintenance at MSFC, JSC and KSC due to the repeated usage of this equipment. The third-level maintenance was accomplished at MSFC or the supplier's facility.

Maintenance documentation was developed to identify special tools or equipment required to perform the necessary maintenance. All maintenance activities were recorded to provide a historical record of the scheduled and unscheduled maintenance accomplished on the ATM systems and equipment.

Spares provisioning for the flight article was to the black box level, with only long lead or critical piece parts being spared. Spares were subjected to the same acceptance test and change control as flight and GSE hardware.

All logistics support requirements for the ATM and its associated support equipment at JSC and KSC were provided by MSFC/MSFC contractors except for the support specifically requested from JSC/KSC via support requests established in accordance with applicable inter-center agreements.

All logistics related functions and activities for the ATM program were accomplished in accordance with the requirements set forth in 50M02541, "ATM Safety Plan," to ensure personnel and equipment safety. The consolidated logistics requirement were defined in 50M02539.

The ATM Experiment Principal Investigator (PIs)/experiment contractors were responsible for logistic support for their respective experiments. The logistics related ATM preflight operations procedures (ATM POPs) described the interfaces, activities and responsibilities of MSFC and KSC organizations.

Safety Program - It was the MSFC policy to enforce a comprehensive safety program for the benefit of employees, equipment, facilities, and related activities. The responsibilities of key project personnel for managing the system safety program were delineated as follows:

The ATM Project Manager had the overall responsibility for the safety of all operations concerned with the ATM design, manufacturing, test, and operations. The engineering manager was responsible to assure that all the design, manufacturing, test and operation were performed in a safe manner and in accordance with provisions set forth in the safety plan. He assured that (1) safety requirements were being fulfilled and that adequate safety surveillance practices were being implemented; (2) engineering changes were reviewed for safety impact; (3) accident/incident investigation were reported in accordance with applicable procedures. He maintained a follow-up of requirements/criteria which had been established for the project.

The MSFC Science and Engineering Systems/Products Office was responsible for providing safety review of all procedure and procedure changes. They participated in program milestone reviews and assured that the safety requirements specified in the safety plan were adhered to.

The test operations team was responsible for identifying appropriate design provisions and/or constraints to assure that safety was included in all test and operations aspects of the ATM project. The test team reviewed GSE test fixtures and facilities to ensure safe operations. All handling and test procedures were reviewed by the test operations team. Personnel certification and training was established by this team for all test operations.

MAJOR ATM PROJECT HARDWARE

This section describes each of the major ATM project hardware items and their respective functional application to the overall ATM program.

Structural Test Units

The Structural Test Units used in static test to verify the structural integrity for the designed loads of the ATM during transportation, handling and launch, were the canister, spar, and rack.

Canister - The canister structural test unit was built to flight configuration except for the LM end bulkhead. The cover in the center of the bulkhead was made of heavy welded-up plate designed to accommodate loading jacks. The test article had neither aperture doors nor Sun shield. To maintain pressure, the holes for the doors were covered with two sheets of plywood which were clamped together.

Spar - The spar structural test unit was build to flight configuration. The telescope mass simulators were designed to provide a load application point at the center of gravity of the actual telescopes with the loads being reacted by the spar through the simulator to spar attach points. The mass simulator to spar attach point locations were the same as the proposed flight unit telescope to spar attach point locations.

Canister Assembly - The canister assembly test unit, canister mated to spar, was supported during static tests by a test fixture. The test article had supports in the X direction at all four axes with radial supports on the +Y and +Z axes and tangential supports on the +Y and -Y axes. The canister assembly included cold plates, two of which were pressurized during the flight simulation tests.

Rack - The rack structural test unit was built to flight configuration. The structurally significant sub-assembly simulators mounted on the rack during the tests were:

1. Control Moment Gyros
2. Solar Array Assemblies
3. Thermal Shield
4. Cable Rack
5. Cable Beam and Cable Arch
6. Spar/Canister Assembly
7. Launch Locks and Roll Lock
8. Equipment Panels

Fixtures were designed to simulate these items. Installation of the actual spar/canister assembly or thermal shield would have cut down considerably on access to the rack for applying loads and locating instrumentation. The simulators were affixed to the rack to allow their respective loads to be introduced into the structure in a manner closely duplicating the way the rack will be loaded during transportation, handling, and launch.

Thermal Test Articles

Thermal test articles, identified in the following text, were necessary for experimental verification of the thermal control techniques that were used on the ATM flight article.

Quadrant IV Thermal Unit - A full-scale mockup of an experiment package quadrant (designated quadrant IV) was constructed to obtain preliminary design information on the canister and experiment thermal control concepts. This quadrant was chosen because its associated experiment designs were the most defined when fabrication was initiated. The test article canister wall temperature was maintained at 50°F for the Quadrant IV tests by controlling the heat flux on the external surface of the canister. All thermal simulators were fabricated inhouse of aluminum. The electrical and solar heat input were simulated with electrical heaters.

An analytical thermal model of the ATM Quadrant IV test article was developed to predict thermal response and temperature gradients during thermal-vacuum testing. The Quadrant IV thermal model utilized a mathematical, lumped-parameter representation of the physical system into a network of nodes. An electrical analogy network was used to represent the thermal conduction and radiation paths. Heaters utilized to simulate solar and electrical heat dissipation in the test article instruments were included in the thermal model. Each node temperature represented the average temperature of the mass contained within the node. Special computer programs were used to calculate geometric shape factors between the surface nodes of the instruments, spars, ends, and canister wall. These shape factors were then utilized in a thermal analyzer program to determine the net heat transfer and temperatures of the nodes.

Experiment Canister Thermal Unit - The Experiment Canister thermal unit was a full-scale test article designed for thermal simulation of prelaunch, launch and orbital conditions. It consisted of a cruciform spar, cylindrical framework, end plates, girth ring, Thermal Mechanical Units (TMU) experiments and components, active Thermal Control System (TCS), cabling, and special instrumentation.

It was a cylindrical structure approximately 134 inches long and 87 inches in diameter including insulation, the canister multiple docking adapter (MDA) end components, and the aperture covers.

The canister's cylindrical exterior was insulated with two inches of aluminized mylar multilayer insulation and was covered with one layer of Tedlar. The Sun-end of the canister was insulated with two inches of aluminized mylar and covered with a fiberglass plate. The MDA-end was covered with one inch of aluminized mylar and one layer of Tedlar. The girth ring was covered with one-half inch of aluminized mylar and one layer of Tedlar. The spar was insulated with one and one-half inches of aluminized mylar insulation and one layer of black Tedlar. In general, all surface finishes, coatings and insulation were identical to the flight ATM canister.

The equipment enclosed within the canister, eight solar telescopes, four rate gyros, and a fine Sun sensor, was simulated by TMUs for the experiment canister test. The experiment solar and electrical heat was simulated using electrical resistors that were controlled to operate in simulated orbital sequences.

The active TCS was a liquid closed-loop heat transporting system designed to remove heat from the simulated experiment package and transport it through a series of cold plates to the radiator for heat dissipation. There were 16 canister cold plates used in the test article. The Sun-end half and the MDA-end half of the canister wall each contained eight cold plates.

The cylindrical radiator covered approximately one-third of the canister lateral wall and was supported with fiberglass low conductance mounts attached to the cold plates. The radiator consisted of four identical quarter panels connected for series flow. The radiator had a total area of 80 square feet and was located on the Sun-end half of the canister. It was coated with S-13G white paint and had a solar absorptivity of 0.2 and an emissivity of 0.9.

The pump package consisted of two modified Apollo pumps (primary and secondary). The transport coolant was methanol/water and contained an anti-corrosive additive of 0.1 percent by weight of sodium benzoate.

The remaining components of the TCS were: a modified in-line Apollo heater was used in the radiator by-pass line, a modulating flow control valve to maintain the cold plate coolant inlet temperature at 50 ± 1°F, an electrical control assembly and temperature sensor, an accumulator, and flow restricting valves.

Thermal Systems Unit (TSU) - The ATM thermal systems unit was a full scale test article of the ATM that was designed for thermal unit simulation of nominal and extreme orbital conditions. The rack and canister components and experiments were simulated with TMUs. The TMUs were similar in size, mass, and surface characteristics to flight hardware and were equipped with resistance heaters to simulate electronic and experiment heat dissipation.

Fabricated at MSFC, the TSU consisted of the two main ATM assemblies: 1) the Experiment Canister; and 2) the Rack Assembly. The experiment canister was supported by the rack assembly, an octagonal truss structure which was virtually identical to the flight unit. The canister was supported by the rack assembly through the four launch locks located between the rack and canister. The ATM solar array panels were not mounted to the test article, but the thermal effects were included in the environmental simulation system.

The canister, structure, spar, and gimbal system were of flight configuration. Control Distributor No. 4, Remote Digital Multiplexers J and K, and liquid TCS Pump Inverter Assembly components mounted on the canister MDA-end were flight units. All other components on the TSU canister MDA-end and all internally mounted experiments and components were simulated by TMUs. In addition to electrical heat dissipation, the experiment TMUs simulated the experiment absorbed solar energy of the flight hardware. The liquid thermal control system was a modified flight system. The modification consisted of strap-on temperature sensor, reduced by-pass leg pressure drop, control "dither" box, special Electronic Control Assembly, and modified connecting tubing. The thermal control system pump assembly was located on the canister lateral wall, and a second pump assembly was attached between the fill and drain lines on the MDA-end of the canister. The motors and mechanical mechanisms used to actuate the Sun-end aperture covers were not included or simulated in the TSU canister.

The TSU components located on the rack were not flight hardware, but were simulated by TMUs. All rack flight components were simulated for testing except the Roll Control Panel in the Astronaut Workstation, two RF Multicouplers, and the EBW firing units located at various locations on the rack structure. Component mounting panels and thermal shields on the rack were similar to flight hardware.

Semi-passive thermal control of rack-mounted components was utilized and included superinsulation, surface coatings, and thermostatically controlled heaters. The insulation patterns were those planned for the flight vehicle. All external surfaces of the test article were coated with S-13G paint which was to be used on the flight ATM to minimize absorption of solar radiation on the ATM. Several coatings of S-13G paint were used on internal rack surfaces rather than the uniform black planned for flight.

The CBRM and rate gyro thermostatically controlled heaters were included in the test article. Several additional flight unit heaters were not mounted on the TSU. These heaters were support for the Star Tracker Optical Mechanical Assembly, the redundant ATM Digital Computer, Remote Analog Submultiplexer 2, and the Main Electronics Assembly.

Vibration Test Unit

The ATM Vibration Test Unit was an assembly of mass, shape, and stiffness simulated dummies along with a few selected pieces of flight-type hardware on an ATM flight-type rack to simulate dynamic loads associated with handling and transportation, launch and ascent. The major structural elements of the ATM vibration test unit were the rack assembly, the canister and spar assembly, the solar shield, and the truss mounting structure.

The rack assembly was an ATM flight-type rack with removable strut. This structure was as nearly identical to the ATM flight structure as practical. Where necessary, ballast was used to simulate mass loads and adjust the center of gravity. Attachment hardware for equipment was identical to flight hardware so that it was dynamically identical to flight hardware.

All ATM rack mounted components weighing five pounds or more were represented by mass simulated dummies with the proper center of gravity. Each component with significant influence on the dynamic behavior had the proper stiffness simulated along with the weight and center of gravity. Rack component cabling were routed to all simulated equipment and sensors, and attached to properly located plugs. Actual cable harnesses were used between each dummy and the first tie down point, and simulated cable harness were used in other locations. Cable simulators represented the approximate weight distribution of the actual cables.

The experiment canister was of a flight-type design with the TCS represented with flight-type cold plates, radiators and fluid enclosed under pressure. Other tubing, cabling, and valves were mass simulated, and positioned onto the canister in such a manner as to not distort the proper center of gravity of the canister. Flight-type canister insulation was utilized where practical.

The Sun-end canister doors (aperture and film) were operable. The H-Alpha-2 door was of the flight-type design and was vibrated in the open position to simulate the pressure dump system upon launch. The MDA-end film retrieval doors were operable.

A flight-type caging and gimbal assembly was utilized. The launch lock assembly was of the flight-type design. Torque motors, and electronic cabling relative to this assembly were mass simulated.

The cable roll adapter was mass and stiffness simulated. This was the hardware necessary to provide a means of transporting wires from the canister to the rack.

The spar was of the flight-type design with proper location drilled to accept mass, center of gravity and stiffness simulated experiment dummies. The spar had the purge lines and electrical cables simulated along with the flight-type insulation installed.

Solar array assemblies were represented by simulator dummies in three locations, and a flight-type solar array in a fourth location. The dummy solar arrays were designed to represent the total mass and center-of-gravity, and to have the same fundamental resonant frequencies in bending rotation and translation.

The canister and rack solar shields were of the flight-type design.

Prototype and Flight Units

The ATM prototype and flight units were basically identical units and consisted of the ATM rack, the experiment canister, and supporting systems.

The prototype unit, as its title indicates, was built as a flight identical unit to provide a test article to preceed the flight unit through the ATM test program. Following completion of the test program, the Prototype was refurbished, retested, and used as a flight backup unit through launch.

The ATM Flight Unit was built to perform as an integral part of the Skylab, performing those scientific objectives assigned to it and providing support to the cluster as required to accomplish the mission objectives. Electrical power, thermal control, instrumentation and communications, attitude and pointing control, and controls and displays were provided as support to the experiments and to other mission objectives. Details of these experiments and systems are described in sections IV through XVIII of this report.

Neutral Buoyancy Simulator

The Neutral Buoyancy Simulator was located in the Water Immersion Facility, building 4706, MSFC. The simulator baseline was developed from 1966 through May 1968 concurrently with initial Skylab Cluster hardware design and development. Final fabrication, assembly, and updating took place from July 1968 through August 1971.

The simulator consisted of full-scale metal and wire mesh mockups of all four modules of the Skylab Cluster. The simulator configuration reflected the flight article configuration relating to geometric form, fit, and function in all areas affecting flight crew interface and performance. The experiment canister could be rotated ±120 degrees from the zero position, and the canister skin allowed visual observation of the removal and replacement of cameras and film magazines. Installed equipment, with the exception of EVA aids, was volume-representative only and non-functional. All equipment items that required demounting, transfer, and remounting were neutrally buoyant with the center of mass coincident with the center of buoyancy. Moveable items with large frontal areas were perforated to facilitate movement through water.

Initial development tasks conducted with the simulator were oriented to design and integration of major components on a full-scale basis. As the basic design matured, emphasis was given to placement of astronaut extra/intra-vehicular aids such as handholds, restraints and tethers, and placement of equipment in the living and working areas. The simulator was first used as a formal training device for astronauts in February 1972, and each prime and backup flight crew received a minimum of 48 hours of zero-g training in the simulator.

ATM One-G Trainer

The ATM One-G Trainer was fabricated at MSFC between October 1968 and September 1971, and shipped to JSC in October 1971. Its primary function was utilization for development of flight crew procedures and flight crew training exercises for inflight operations performed at the C&D Console in the MDA and during EVA for recovery and replacement of ATM experiment cameras and film magazines.

The trainer was composed of two major sections: an ATM section and a C&D Console section. Both sections were full scale mockups and reflected the flight article configuration in all areas affecting flight crew interface and performance. A trainer-peculiar interface console provided facility interface connections with necessary controls for electrical power to the EVA lights and canister roll actuator, and umbilical connections including caution and warning signals for suited subjects.

ATM Section - The ATM section of the trainer consisted of a flight type ATM with stub mockups of deployed solar array wings. It was capable of operation in either a horizontal (ATM X-axis horizontal) position or a vertical position with the Sun-end down. Transfer between horizontal and vertical support fixtures was accomplished with a facility crane. The structural sections included the ATM rack, experiment canister, and solar and thermal shields. The canister roll mechanism was operable through ±120 degrees from the zero position. The center workstation camera/film magazine access doors, the Sun-end film retrieval doors, and S082A/B aperture doors were flight type hardware and fully operable. The EVA lights and all EVA mobility and stability aids and transfer devices were functionally operational. No other systems were operable, but components and wiring visible to the flight crew from any direction had the same appearance as flight hardware.

C&D Console Section - The displays on the C&D panel were not operable, but had the same appearance as the flight article except that electroluminescent lighting was not installed. Switches, circuit breakers, and other controls were electrically inert but mechanically operable with the same appearance, feel, and movement as the flight article.

ATM Zero-G Trainer

The ATM Zero-G Trainer was fabricated at MSFC and shipped to JSC in October 1971. Its primary function was utilization for development of flight crew procedures and flight crew training exercises for inflight EVA operations, performed in the KC-135 zero-g aircraft.

The trainer was composed of two major sections: the center workstation and the Sun-end workstation. Both sections were full scale mockups and reflected the flight article configuration in all areas affecting flight crew interface and performance.

Center Workstation Section - The Center Workstation section of the trainer consisted of that portion of the ATM which encompassed the center workstation including a portion of the ATM rack and a portion of the experiment canister. It was designed to be placed in the aircraft with the experiment canister X-axis perpendicular to the aircraft floor and the Sun-end down. The experiment canister was made up of four sections, capable of being mounted one at a time on the center workstation section. Each portion of the canister included a different experiment access door and mounting provisions for the appropriate film camera/magazine receptacle. Crew mobility and stability aids were fully functional. Displays were not operable but had the same appearance as the flight article. Switches and other controls were mechanically operable and had the same appearance, feel and movement as the flight article.

Sun-End Workstation Section - The Sun-End Workstation section consisted of that portion of the experiment canister Sun-end containing the S082A and S082B experiments aperture doors and film retrieval doors mounting provisions for the camera receptacles, plus a portion of the solar shield at the Sun-end workstation. The experiment canister section could not be rotated. The S082A and S082B experiment aperture doors were fixed in the open position, and the film retrieval doors were fully operable. Aperture doors for the other experiments were fixed in the closed position. Crew mobility and stability aids were fully functional.

Hi-Fi Mockup

The Hi-Fi Mockup was located in building 4619, MSFC. The mockup comprised earlier development units of all four Skylab modules, and also included the ATM deployment assembly and the fixed airlock shroud. Its primary purpose was to support the Crew Systems Mission Support Group for real time problem solutions. Accumulation and assembly of the modules commenced in November 1972, and the mockup was completed in March 1973.

The mockup was separated into two sections: the S-IVB workshop was separated from the cluster and was positioned vertically with the aft end down; and the remainder of the cluster was positioned with the AM and MDA horizontal and the deployed ATM Sun-end down. The ATM portion of the mockup was derived from the Vibration Test Unit. The mass simulators were removed and all equipment affecting flight crew interface and performance was replaced with flight configuration hardware, or with other equipment whose operational or visual characteristics were the same as the flight hardware. The ATM solar array was simulated with four stub mockups in various deployed positions, each consisting only of the structural mounts and inboard panel with dummy solar cell modules. The C&D console in the MDA had the same appearance as the flight article with mechanically operable controls, but was electrically inert.

Controls and Displays Simulator

The Controls and Displays (C&D) Simulator was located in building 4663, MSFC. It was originally intended only as a part task simulator and was operational as such in late 1967. Expansion to a complete multi-task simulator was accomplished in mid-1968. The initial purpose of the simulator was to verify basic design concepts and to assist in the development of experiment controls and displays and the associated logic. Subsequent expansion provided control of all ATM systems as well as the experiments, and the simulator was used for integrated ATM evaluation and training.

Solid state breadboards were fabricated to simulate the experiments, and provided known outputs to given stimuli from a control and display mockup. As development progressed, two EAI 680 analog computers and a CDC 6050 general purpose digital computer were added in individual and hybrid configurations to simulate the ATM systems and to provide integrated experiment simulation. A full C&D Console mockup was fabricated inhouse and modified as required to match the latest accepted flight configuration. The C&D console was located in a full-fidelity mockup of the MDA.

The results of all design and development tasks were evaluated by the responsible engineer, designer and crew representative, and provided to the MSFC Manned Systems Integration Branch for integration and dissemination to the responsible program organizations. The simulator provided familiarization and training to a number of program and qual test personnel. It was also utilized for early astronaut training by all three prime and backup flight crews, and assisted in the development and verification of inflight procedures.

APCS Hardware Simulation Laboratory

The APCS Hardware Simulation Laboratory was located in building 4487, MSFC. The laboratory provided a dynamic test and simulation facility for testing the APCS under near simulated orbital flight conditions. This simulation laboratory integrated flight or flight-type hardware into a complete control system for Skylab. Laboratory buildup and test activities commenced in June 1970 and were completed in March 1972. Simulation test activities, including both hardware and software verifications, commenced with a partial system in January 1971.

The laboratory consisted of a hybrid computer and various simulation laboratory equipment, using as much flight-type equipment as possible. The hybrid computer, an XDS Sigma V/Comcor 5000, simulated vehicle dynamics and internal and external disturbance torques. The major simulation laboratory equipment consisted of the following:

1. The CMG motion simulator was a three degree of freedom table gimballed about three axes by hydraulic actuators to simulate the motion of the vehicle cluster. The CMG-produced torques were sensed by torque measuring fixtures and transmitted to the hybrid computer in which vehicle dynamics were simulated. Error signals corresponding to simulated vehicle position and rate were then routed to the three gimbal torquers that drove the CMG motion simulator to the desired attitude. The acquisition Sun sensor, star tracker, and three rate gyros were mounted on this table.

2. The EPC motion simulator was a three degree of freedom table used to simulate the motion of the spar or telescope package. The EPC table was controlled in two axes by errors from the fine Sun sensor via the experiments pointing electronics assembly to the control torquers. The third axis was positioned by the hand controller. Rack or cluster motion was simulated by a rack motion servo mounted to drive the rack relative to the EPC table.

3. A simulated cockpit included a hand controller and a vidicon display. The hand controller provided the operator manual control and enabled EPC offset pointing. In conjunction with this, a camera mounted on a three axes gimbal pointed toward a picture of the Sun to generate the picture on the display. The camera was driven proportional to the motion of the EPC table.

4. Two Sun sources were used to activate the fine and acquisition Sun sensor, and a star source was used to activate the star tracker.

5. A SEL 810A general purpose digital computer was used to compare actual and commanded CMG motion simulator gimbal angles and output the error to the torque motors that drove the table.

6. A SEL 810A general purpose computer was used to process ATMDC telemetry data, to provide a Digital Address System capability with the ATMDC, and to provide an interface capability between the ATMDC and the Sigma 5.

7. A control relay package was used to control the thruster attitude control engine valve coils dummy loads.

8. A control console consisting of 15 racks of equipment provided all interface, control, and monitor functions.

The CMG control system was exercised in two vehicle configurations and operated in several control modes. The two vehicle configurations were designated cluster and cluster less CSM. Control modes included solar inertial day, solar inertial night, attitude hold (CMG), attitude hold (TACS), and Z-local vertical. The EPC control system was active during the experiment pointing control mode, in either the cluster or cluster less CSM configuration.

Dynamic system design verification was accomplished in six configurations for the CMG control system and three configurations for the EPC control system. The test configurations were established to utilize progressively more flight-type hardware. Softwave verification was accomplished in four phases, including prototype, phase I and phase II program validation, and flight program verification. Details of specific test configurations can be found in 50M02826 "ATM Control System Dynamics Verification Plan." IBM 70-G31-0001 "Preflight Program Validation Plan," and IBM 71W-00209 "Flight Program Verification Plan."

Skylab Cluster Power Simulator

The Skylab Cluster Power Simulator was located in building 4436, MSFC. The simulator was configured to represent the complete ATM and AM electrical power systems, and was utilized for design, development and operational verification of the flight systems. The simulator was operational with half-system capability in February 1972, and fully operational by July 1972.

The simulator consisted of 3 racks of ATM/AM control and display equipment, 18 ATM flight-type CBRMs, 8 AM flight-type power conditioning groups, a flight-type ATM power transfer distributor, and 21 racks of Electrical Support Equipment (ESE). The ESE included ATM and OWS solar array simulator power supplies, ESE power supplies, a digital data acquisition system, networks switching and control, cluster load banks, and a liquid cooling unit for the power conditioning groups. The data acquisition system utilized magnetic tape recorders and a SEL 810 computer for recording and processing test data. All interconnecting cables from the C&D racks to the CBRMs, power conditioning groups and power transfer distributor approximated flight length.

The objectives of the simulator were to:

1. Provide capability to demonstrate the parallel operation of the ATM and AM power systems over the range of the flight power profile.

2. Determine that adequate wiring circuit impedance had been provided in the flight design to enable proper load sharing between the power systems.

3. Provide a means to analyze the single point ground system concept of the cluster power system.

4. Perform limited electromagnetic/radio frequency interference testing and analysis.

5. Analyze effects of simulated orbital operations on the cluster power system and batteries.

6. Analyze power system failure and contingency modes.

7. Provide capability to analyze power system performance and problem solutions before and during flight.

The simulator was utilized by Astrionics personnel for numerous design and development tests. Many of these tests were performed in parallel with construction of the simulator. In addition, the simulator was used to provide training, system analysis and mission support efforts.

ATM PROJECT CHRONOLOGY

The Apollo Telescope Mount (ATM) study phase started late in 1964. The ATM Project Manager was appointed on July 3, 1966, and Project Management of the ATM was assigned to MSFC on July 13, 1966.

Major Program Reviews

Preliminary Requirements Review (PRR) - The ATM systems design preliminary requirements review was held in January 1968, which included Attitude and Pointing Control System (APCS), Structural and Mechanical, Instrumentation and Communication (I&C), Electrical, Controls and Displays (C&D), and Thermal Control System (TCS). The PRR resulted in baselined definition of the systems and assignment of action items for resolution of problem areas.

Preliminary Design Review (PDR) - The ATM PDR was held during September 1968, to review the ATM basic design approach, design concepts, drawings and specifications. The PDR resulted in action items being assigned for design critique and problem solving. None of the actions resulted in significant design changes.

Cluster Systems Design Review (CSDR) - The CSDR was held during December 1969, to review the ATM design approach, concept, drawings, and specification required to integrate the ATM with other Skylab modules. The CSDR was the first major review held after the selection of the dry workshop, and resulted in the assignment of action items to every Skylab system discipline. All action items were closed by November 1970.

Ordnance Systems and Critical Mechanisms Review - This review was held in 1971 to satisfy the need for a review of critical mechanical Skylab items and ordnance systems. A detailed design and hardware review was performed which included the ATM solar array system, launch locks, and aperture doors. This review verified performance of all ATM critical mechanisms. A need for manual capability to open the aperature doors was identified.

Critical Design Review (CDR) - The ATM CDR was completed with the CDR board meeting at MSFC in May 1970. This review gave final approval to the ATM design.

Systems/Operations Compatibility Assessment Review (SOCAR) - The SOCAR was held during May 1972, to review the documentation being used to design, integrate, test, checkout and launch, mission rules, and malfunction procedures of the Skylab cluster. Significant studies and action items were completed during SOCAR involving every major system. The review did not result in any significant hardware changes.

ATM Special Review - The ATM anomalies review was held in May 1972, to review problems identified with ATM experiments. Four significant experiment problems were resolved, resulting in wiring changes to the ATM networks design. These items were closed by August 1972.

ATM Design Certification Review (DCR) - The DCR was held in three phases during the time period of June through October 1972. The purpose of the Skylab Mission/Cluster Systems portion of the DCR, which included the ATM, was to assess and certify the adequacy of the performance design requirements and the verifications program of the major Skylab systems and their interfaces. There were 27 significant action items which were closed out by January 1973.

ATM Turnover Reviews - The ATM flight unit Turnover Review for delivery started January 31, 1972, and was completed February 9, 1972. These reviews covered configuration/fabrication, NR/MRB/

Waiver/Deviation, alignment data, fabrication, in-process test, weights and balance, procedure/specification, data file, fit check, preflight software, ACE software, ESE, component qualification, component time and cycle, component log book, and spares. There was a total of 19 action items; eighteen of these action items were for establishing ATM hardware configuration. One was to schedule a solar wing turnover meeting.

The ATM flight unit turnover review for thermal vacuum testing at JSC started June 20, 1972, and completed June 22, 1972. An audit of the material presented during the review disclosed no open items or problems which represented a constraint to the flight unit shipment to JSC or to the start of thermal vacuum testing.

The ATM flight unit pre-delivery turnover meeting was held on September 15, 1972, at JSC. There were no unresolved problems resulting from the ATM flight unit pre-board meeting. There were no open items identified which represented a constraint to shipment of the ATM flight article to KSC. There were no items identified which impacted the start of checkout activities in the MSOB. There were five certification of flight worthiness (COFW) endorsements which were: 1) delivery for acceptance testing, March 8, 1972; 2) transfer of open work, September 25, 1972; 3) turnover of hardware to receiving organization, January 8, 1973; 4) integrated test requirements compatibility, March 14, 1973; 5) Skylab ready for flight, April 14, 1973.

Skylab Activation Sequence/Critical Mechanisms Review - This review was held in February 1973. The review was performed to access critical functions and mechanisms associated with the Skylab activation sequence and to penetrate potentially delinquent areas. The only hardware change resulting was "beefing up" the ATM gimbal system. The aperature door problem was identified but was accepted due to the manual capability to open the doors.

Skylab Activation Sequence Hardware Integrity Review - This review, held in April 1973, was a reassessment of all activation sequence hardware. Prior to completion of the review, an "MSFC Blue Ribbon Audit Committee" was established to further investigate hardware integrity. No new ATM problems were surfaced.

ATM Flight Readiness Review (FRR) - The final NASA top management review and approval of the launch and mission readiness for the SL-1/SL-2 mission was completed in the FRR at KSC on April 18-20, 1973. No major anomalies were noted.

OMSF Management Council Decisions

While the ATM program reviews were providing the authority for problem resolution via hardware changes, major adjustments in program/mission philosophy were occurring which affected the ATM. The authority for these major program realignments was the OMSF Management Council. Decisions and their impacts on the program are shown in Table 5-I.

Major Hardware Milestones

The ATM project major hardware milestones are chronologically listed in Table 5-II. The ATM test articles, previously described in this section, the prototype and flight units, and the solar arrays are listed from fabrication and assembly through testing at KSC.

Table 5-I. OMSF Management Council Decisions

DATE	MANAGEMENT COUNCIL DECISION	SYSTEMS IMPACTED
May 21, 1969	Recommended for wet-to-dry workshop conversion.	APCS - deleted transfer system and control computer. Added WCIU, one digital computer, rate gyros, and additional wires at interfaces.
July 18, 1969	Dr. Thomas O. Paine approved wet-to-dry conversion.	Structural - outrigger attach points, launch locks, deployment assemblies. Electrical - power network changes. TCS - thermal shield.
Sept. 9, 1969	Assigned the ATM attitude control system responsibility for cluster attitude control.	APCS - single point failure modes and added redundancy. Electrical - additional networks.
Dec. 4, 1969	Paralleled the ATM electrical power with the rest of the cluster.	Electrical - Additional wires across the interfaces.
Jan. 23, 1970	Launch date for AAP-1 re-aligned to Nov. 15, 1972 with a target date of July 15, 1972.	No impact on hardware.
Aug. 31, 1970	Launch date re-aligned to Nov. 1, 1972, and the July 15, 1972, target date was dropped.	No impact on hardware.
Jan. 28, 1971	Dr. George Low announced that Skylab would be flown about four months after the last Apollo flight. This would set new launch date for approximately mid 1973.	No impact on hardware.

Table 5-II. ATM Project Major Hardware Milestones

DATE	MAJOR HARDWARE MILESTONE	COMMENTS
	APOLLO TELESCOPE MOUNT	
Sept. 1966	Responsibility for ATM telescopes transferred to MSFC and GSFC.	
April 1968	Structural Rack test article fabrication and assembly started.	
Jan. 1969	TSU fabrication and assembly started.	
Feb. 1969	Vibration unit fabrication and assembly started.	
Jan. 1970	Prototype unit fabrication and assembly started.	
Jan. 1970	Vibration unit spar, canister, and structural test started.	
March 1970	TSU canister complete and delivered to S&E-ASTN for T/V in Sunspot I Chamber.	To checkout TCS prior to T/V at JSC.
March 1970	Vibration unit spar, canister, structural test complete.	
April 1970	TSU canister T/V test complete in Sunspot I.	
May 1970	TSU fabrication and assembly complete.	
May 1970	ATM Flight unit fabrication and assembly started.	
July 1970	TSU thermal vacuum testing at JSC started.	

Table 5-II. ATM Project Major Hardware Milestone (Continued)

DATE	MAJOR HARDWARE MILESTONE	COMMENTS
	APOLLO TELESCOPE MOUNT (Continued)	
Aug. 1970	TSU thermal vacuum testing complete.	
Sept. 1970	Structural Unit Transportation Load Test started.	
Oct. 1970	Structural Unit Transportation Load Test complete.	
Dec. 1970	Vibration Unit fabrication and assembly complete.	
Jan. 1971	Vibration Unit testing started.	
April 1971	Prototype fabrication and assembly complete, post manufacturing checkout started.	
June 1971	Vibration unit testing complete.	
July 1971	Vibroacoustic testing started at JSC.	
Aug. 1971	Prototype post manufacturing checkout complete, shipped to JSC for T/V testing.	
Dec. 1971	Prototype thermal vacuum testing complete.	Anomalies were identified during thermal vacuum (Fuse, post shorted out in power transfer distributor).
Jan. 1972	Flight unit fabrication and assembly complete, PMC started.	
Feb. 1972	Prototype vibration testing started.	

Table 5-II. ATM Project Major Hardware Milestone (Continued)

DATE	MAJOR HARDWARE MILESTONE	COMMENTS
	APOLLO TELESCOPE MOUNT (Continued)	
April 1972	Prototype vibration testing complete.	
May 1972	Flight unit PMC complete and vibration testing started.	
June 1972	Flight unit vibration tests complete, post-vibration complete, unit shipped to JSC for T/V testing.	
Aug. 1972	Vibration unit vibroacoustic testing complete, unit shipped to KSC.	Used for fit and functional check.
Sept. 1972	Flight unit T/V testing complete, shipped to KSC for prelaunch checkout at O&C and VAB.	
April 1973	Last major milestone prior to launch, Skylab I left VAB, started roll out to Launch Complex 39A	
May 1973	Skylab I launch.	
	SOLAR ARRAY WINGS	
Nov. 1969	Development model delivered for test.	
Sept. 1970	Development model tests and fixture checkout started, prototype wing fabrication and assembly started.	

Table 5-II. ATM Project Major Hardware Milestone (Continued)

DATE	MAJOR HARDWARE MILESTONE	COMMENTS
	SOLAR ARRAY WINGS (Continued)	
Jan. 1971	Flight wing fabrication and assembly started.	
April 1971	Prototype wing fabrication and assembly complete.	
June 1971	Prototype wing PMC started.	
Nov. 1971	Prototype wing PMC complete.	
Jan. 1972	Prototype wing #4 Thermal Vacuum Test started and completed.	Anomalies were noted with the thrusters and decinching mechanism.
Feb. 1972	Prototype wings installed on the Prototype unit for Vibration testing, Flight wing PMC started.	
April 1972	Prototype wings removed from the Prototype unit for post-vibration verification.	
May 1972	Flight Wing fabrication and assembly complete, PMC complete, wings installed on Flight unit for vibration test.	
June 1972	Flight vibration test complete, post-vibration test started.	
Nov. 1972	Flight wing post-vibration checkout complete.	
Dec. 1972	Flight wings shipped to KSC and mated with the ATM.	

ATM WEIGHT GROWTH

Figure 5-1 graphically shows the ATM weight growth from the original estimated baseline weight through launch. The baseline weight was established from an ATM/LM preliminary weight study dated October 23, 1966. Since the LM ascent stage weight and the life support items were later deleted or moved to other modules, these items were deleted from the initial baseline. The total estimated ATM/LM weight was 15,302 pounds; this was reduced by the ascent stage weight of 5,000 pounds and the life support items of 1,380 pounds, to arrive at the total ATM baseline weight of 8,922 pounds. The ATM launch weight was 24,692 pounds, providing an overall growth factor of 2.768.

Weight growth on the ATM was classified according to the following categories:

1. Design modification

   a. Program changes impacting weight

   b. Revised design concept including new or changed experiments or functional system hardware.

   c. Revised loads, schedules, budget, or reliability requirements.

2. Revised weight estimates

   a. Inadequate weight analysis in the definition phase.

   b. Corrections to or additional information during the acquisition and development phase.

3. Estimated to calculated weight.

   a. Weight deviations between the layout and calculation of released production drawings.

4. Calculated to actual weight

   a. This category includes differences between calculation of released drawings and the actual weights of the components.

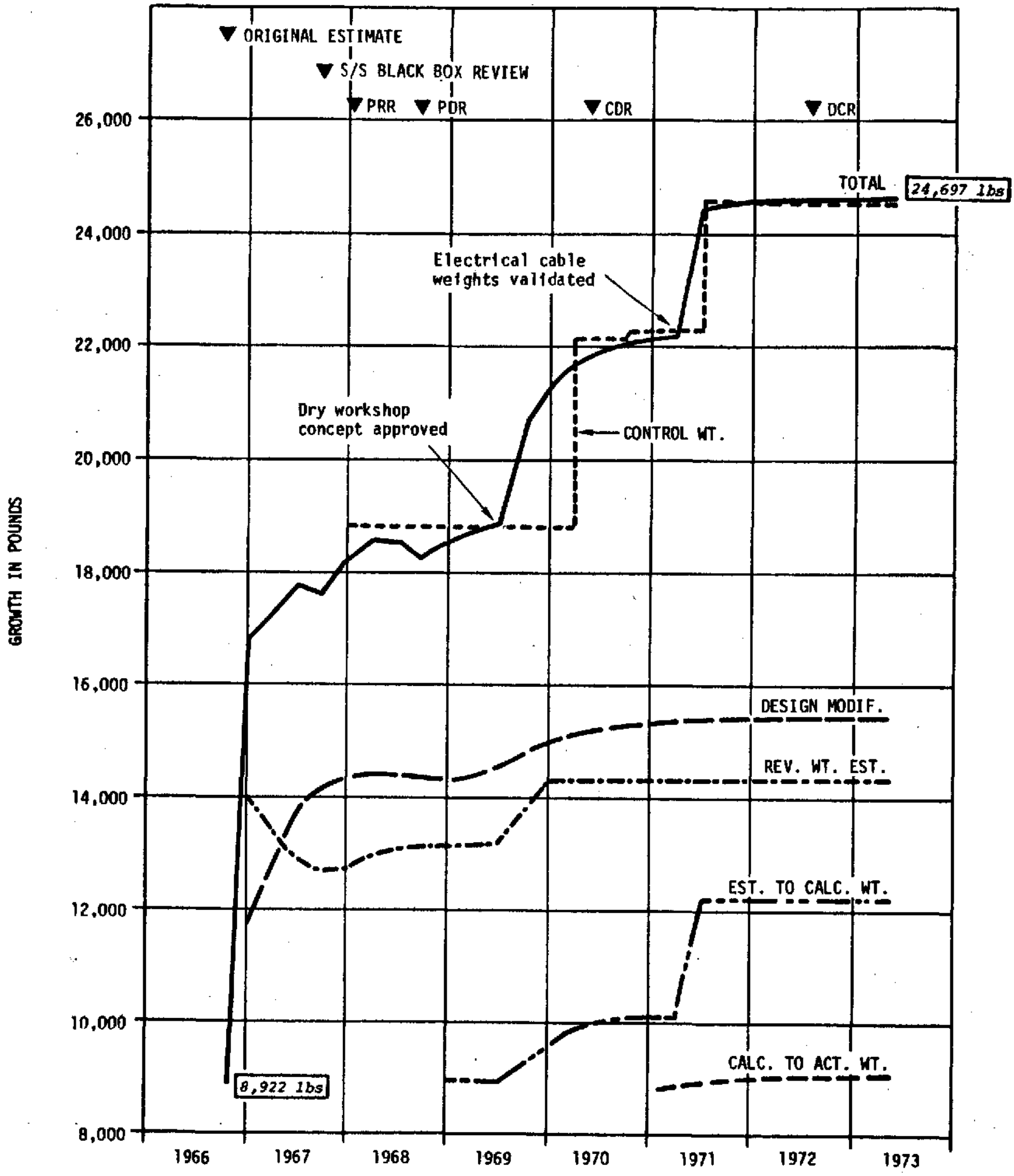


Figure 5-1. ATM Weight Growth Summary

Weight growth in each of the categories was determined for each end item or component of the ATM; the graph shows the evolution of the growth versus time and design reviews. The ATM control weight is superimposed on the graph to show its evolution during the ATM development.

Prior to imposition of the control weight in January 1968, the most significant growth was attributed to the experiment canister and spar, experiments, electrical system, and solar array. Specific figures for this period are not available. The most significant weight changes after January 1968 are listed below:

Date	Reason for Change	Weight (Pounds)	
March 1968	Convert from passive to active thermal control.		+ 149
January 1969	Redesign charger/battery/regulators (CBR).		+ 162
August 1969 through August 1970	Convert from wet to dry workshop:		+ 1906
	Add solar shield and cable beam support.	+ 383	
	Add meteoroid protection to MDA-end rack.	+ 100	
	Redesign thermal shield on MDA-end of rack from thin wall aluminum and insulation to wedge shape removable section of aluminum and honeycomb structure.	+ 274	
	Update cable drum assembly, strut retraction assembly, MDA-end door assemblies, canister insulation and rack thermal covers from sketches to released drawings.	+ 151	

Date	Reason for Change	Weight (Pounds)	
	Add heavier covers and insulation on solar shield and thermal shield; add mounts, brackets, latches, ramps and hardware to Sun-end doors; add cable struts, brackets, hardware and equipment mounts to rack	+ 326	
	Incorporate redesigned structural members in cable tray and retractable strut motor/gear assemblies.	+ 126	
	Revise electronic components	+ 1546	
November 1969	Change CBR material from titanium to aluminum due to increased vibration loads.		+ 270
July 1970	Add EVA handrail, workstation and mounts.		+ 176
November 1970	Delete removable diagonal strut assembly and center cinching mechanism on solar array wings. Vibration analysis indicated these components not required.		- 63
	Replace round wire with flat cable connectors.		- 40
April 1971	Revise weights of wiring based on calculations of wire lists and cable lengths. Previous to these calculations, all wire weights had been estimated.		+ 2071

The ATM increased from 18,600 pounds in January 1968 to 24,697 pounds on May 14, 1973, an overall increase of 6,097 pounds. The final control weight was 24,650 pounds. A breakdown of these weight changes are as follows:

Structure	+1,323
Electrical Components	+1,797
Wiring	+2,031
Miscellaneous detail weight changes	+ 645
Weight adjustments from calculated to actual weight	+ 301
Total	+6,097

ATM PROJECT SCHEDULING

Figure 5-2 shows the as-run schedule of the major milestones in the development, fabrication, assembly, test, and/or checkout of the Structural, Thermal, Vibration, Prototype-Backup and Flight units. The activities were performed at MSFC, JSC and KSC.

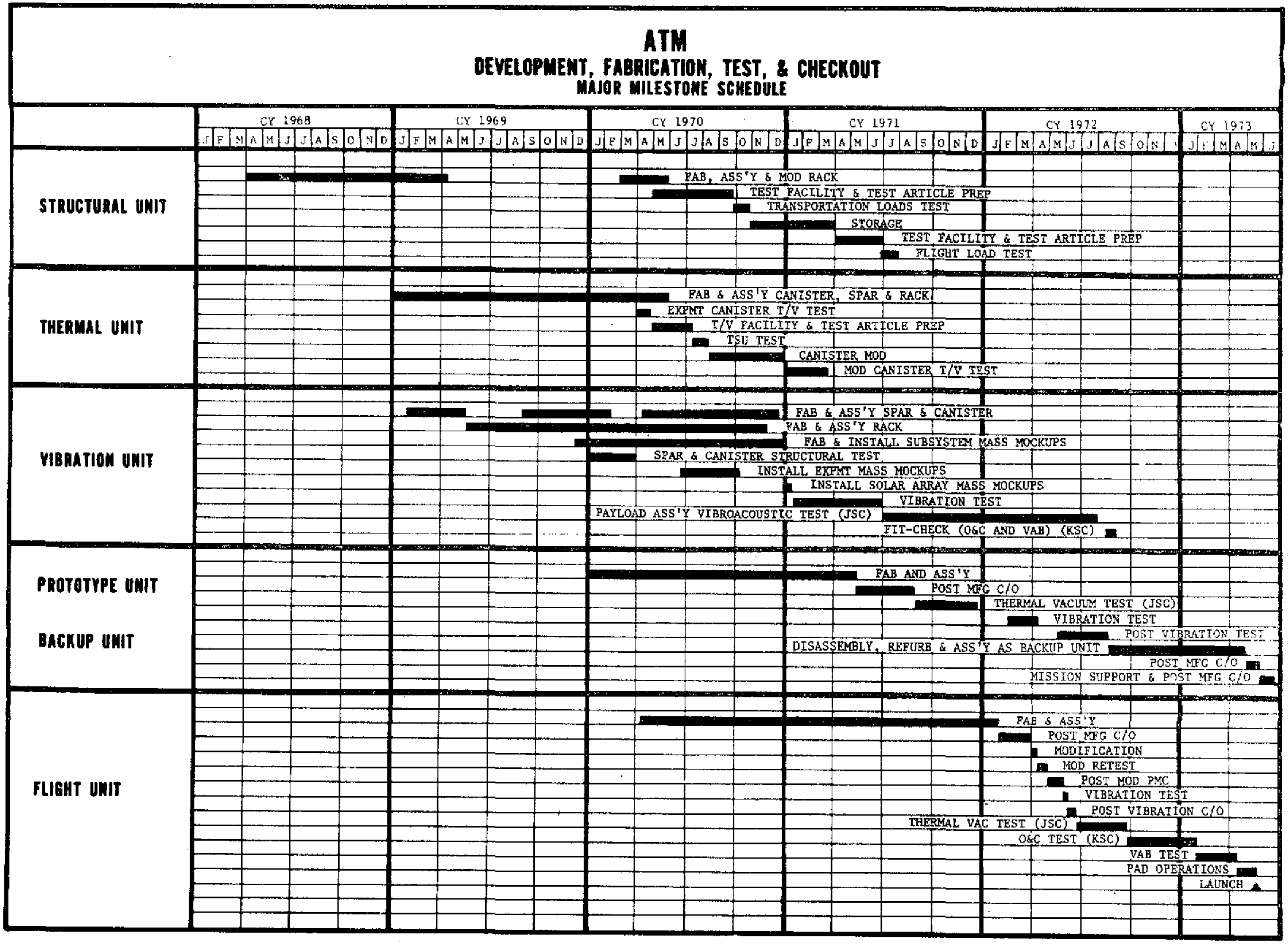


Figure 5-2. ATM Project Major Milestone Schedule

SECTION VI. STRUCTURES AND MECHANICAL SYSTEM

SYSTEM DESCRIPTION

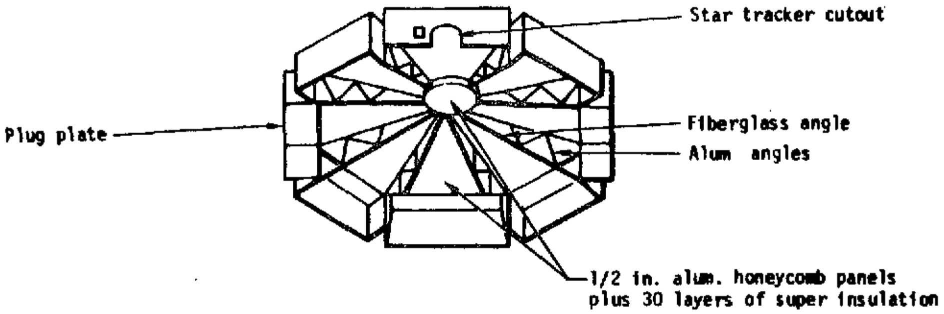
The ATM Structure and Mechanical system provided for the mounting of all ATM equipment and the ATM experiment canister. It provided the means of mounting the ATM to the rigidizing frame. The rigidizing frame was mounted to the ATM-DA which deployed the ATM in orbit. It also provided the mechanisms to unlock and fine point the canister, operate the canister Sun shield aperture doors, and unlock the film retrieval doors. Structural outriggers provided the attach points for ATM to Launch Vehicle mating. Finally, it provided mechanical aids for astronaut EVA.

Major Components

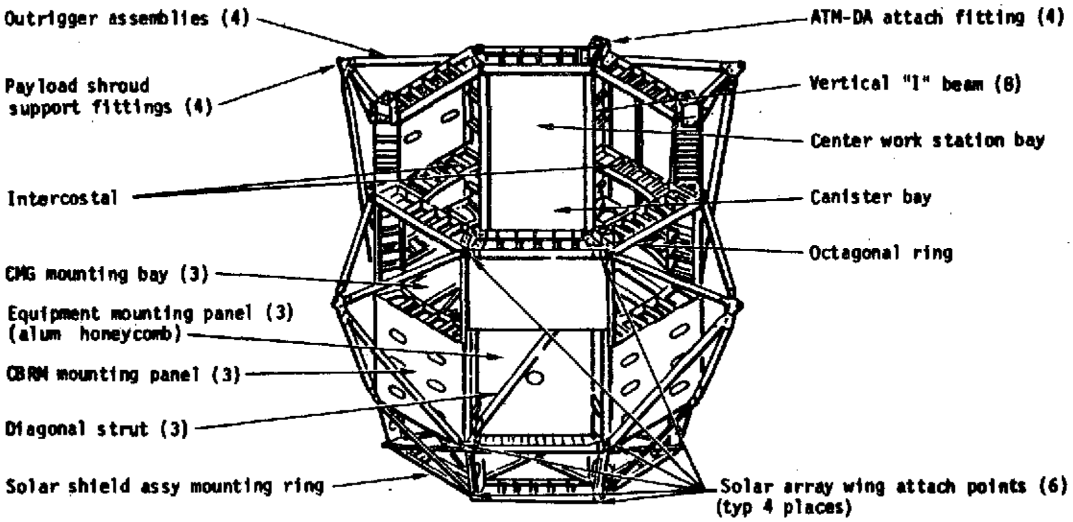
Rack - The ATM rack structure was an octagonally shaped frame to which were attached a thermal shield assembly, a solar shield assembly, four canister support roller assemblies, and four outrigger assemblies (figure 6-1). The frame was made up of two large octagonally-shaped aluminum rings open in the center and separated by eight aluminum vertical beams attached to the corners of the rings. Panels for equipment were mounted in seven of the bays between these beams. One bay was open for access to the canister film retrieval doors and designated the center workstation. Three bays were braced by a tubular diagonal strut. Four bays were braced by outriggers attached to the octagonal rings. A smaller third ring, also octagonal and open in the center, was attached to the Sun-end of the frame by open truss work. This ring provided support for the solar array the mounting for the solar shield assembly and support points for ground transportation. A small trapazoid-shaped structure extended down from one side of the small ring to provide a mount for the acquisition sun sensors.

Thermal Shield Assembly - The thermal shield assembly was an octagonal structure 20 inches deep and 11 feet 2 inches across the flats. It was made up of eight triangular truss structures attached to a ring in the center and connected by channels at the flats. This structure was covered by thermal panels on its sides and top. The thermal shield assembly was attached to the MDA end of the frame structure.

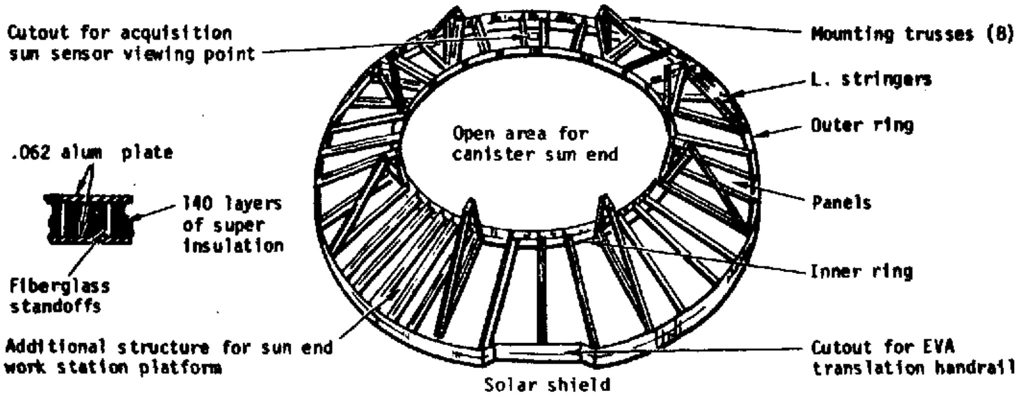
Solar Shield Assembly - The solar shield assembly was a cone shaped ring 14 feet 4 inches in outside diameter, 8 feet 2 inches in inside diameter, 15 inches deep, covered with thermal panels, and mounted on a 25-inch high open truss structure. It was



Thermal shield
MDA end



Rack
Sun end



Solar shield

Figure 6-1. ATM Rack Structure

attached to a small octagonal ring at the Sun-end of the rack to protect the ATM rack equipment from direct solar radiation.

Outrigger Assemblies - The four outriggers were open truss tubular assemblies that provided support for the ATM in the Payload Shroud during launch. Each outrigger was composed of four aluminum tube assemblies. Two each of the tube assemblies were attached at one end to the corners of each of the two large octagonal rings and at the other end to the Payload Shroud support fitting.

Canister Support Roller Assemblies - The support roller assemblies were the only rack structural interface between the rack and the experiment canister during orbital operation. The support roller assemblies were functionally a part of the Experiment Pointing Control-Roll Positioning Mechanism. Their function will be discussed in that section.

Experiment Canister - The experiment canister enclosed the ATM Experiments and provided the structure for mounting the TCS cold plates, radiators and associated fluid transfer hardware. The structure was composed of a spar, MDA end canister half and Sun-end canister half.

1. Spar - The spar was a cruciform structure made up of three one-inch thick aluminum plates (figure 6-2). Two-inch diameter lightening holes were drilled throughout the plates for an approximate 40 percent weight reduction. Stiffener rings were attached to the center of the spar. The girth ring was the attach point for the MDA and canister half, Sun-end canister half, and the inner gimbal ring actuators. The spar was wrapped with insulation and the experiments and rate gyros mounted on low-conductance mounts. The spar was isolated from the canister by low-conductance mounts.

2. MDA End Canister Half - The MDA end canister half consisted of an aluminum ring of L-shaped cross section and a machined aluminum bulkhead supported by stringers of T-shaped cross section (figure 6-2). Short spacers separated the stringers. Eight cold plates for the active Thermal Control System (TCS) were attached to this framework. The active TCS components were mounted on standoffs on some of the cold plates, and others had opening for experiment film retrieval doors. Some subsystem equipment was mounted on the outside of the machine aluminum bulkhead. The MDA end canister half was slipped over the spar and spar mounted experiments and attached to the girth ring. The outside was covered with insulation.

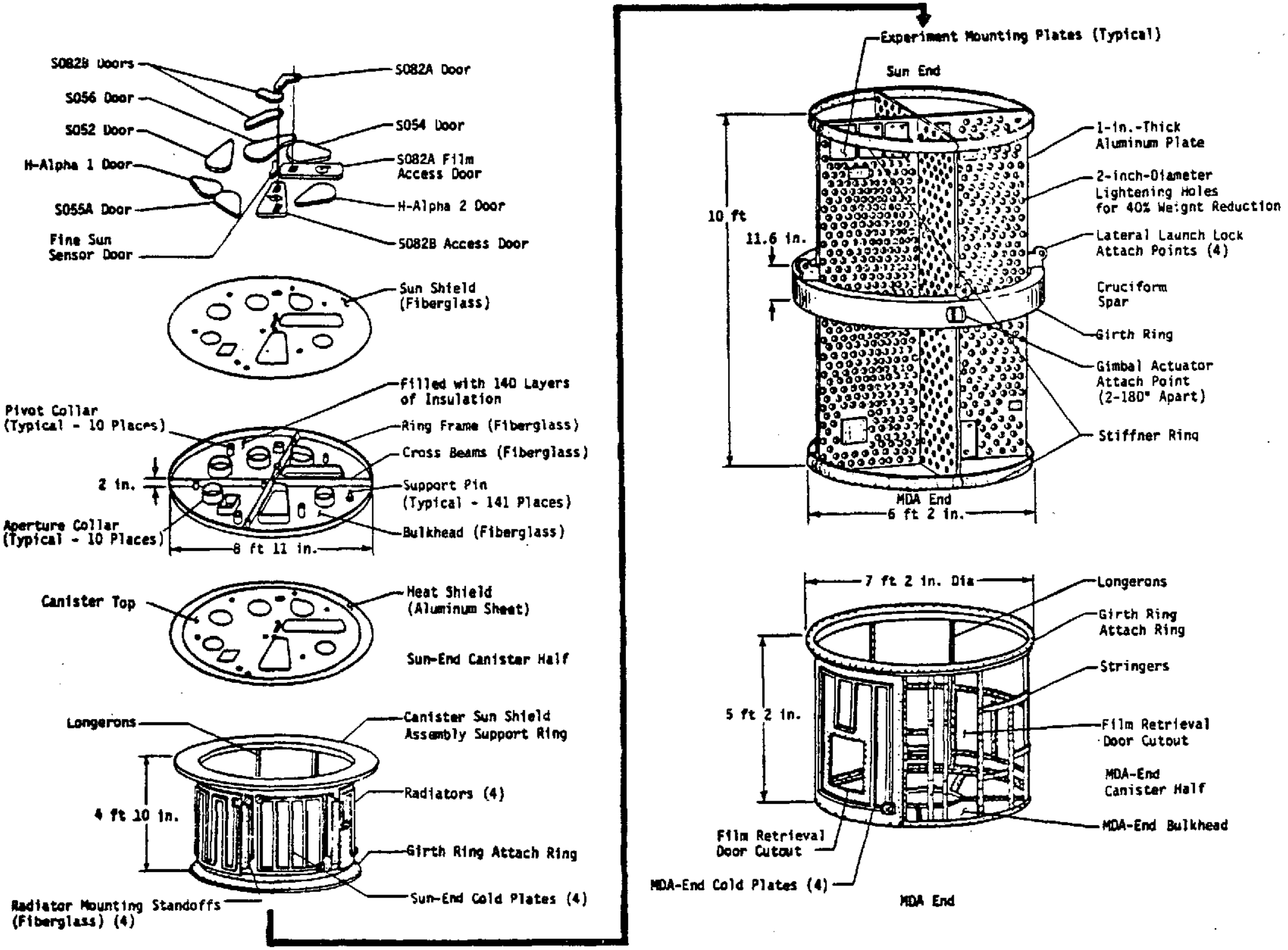


Figure 6-2. ATM Spar and Canister

3. Sun-End Canister Half - The Sun-end canister half was constructed in the same manner as the MDA end canister half. There were no openings in the cold plates of this half. The cold plates were covered with insulation. Four TCS radiators were mounted on "I" beams outside with cold plates. A machine aluminum bulkhead covered the Sun-end of this canister half with bulkhead openings for each experiment. There were two one-way vent valves mounted on the bulkhead. The purpose of these valves was to passively vent the canister whenever delta pressure build-up occurred inside. These valves were designed to keep the delta pressure below 0.5 psi in order to meet canister design requirements. A fiberglass sunshield was mounted on the outboard side of the bulkhead. It had mounting provisions for each experiment aperture door and associated door operating mechanisms. This half of the canister was also slipped over the spar and attached to the girth ring.

<u>Experiment Pointing Control - Roll Positioning Mechanism (EPC-RPM)</u> - The EPC-RPM provided a three degree of freedom mount for the ATM experiment canister within the ATM rack. The EPC-RPM consisted of two concentric welded aluminum rings; four actuator assemblies; a roll drive and brake assembly; a roll position indicator assembly; two orbital lock assemblies; a roll stop assembly; four lateral launch lock assemblies; a torsional launch lock assembly (figure 6-3); and four support roller assemblies (figure 6-4).

The four support roller assemblies were attached to the rack structure. They supported the outer or roll ring by means of a cluster of three rollers at four locations. The roll ring was attached to the inner or gimbal ring by means of two actuators for right/left motion. The gimbal ring was attached to the canister girth ring for up/down motion. A ring gear on the roll ring was driven by the roll drive and brake assembly for roll motion. The roll ring gear drove the roll position indicator. One orbital lock locked the roll ring to the canister girth ring. Four launch locks were provided to prevent all canister motion during launch (figure 6-5). These launch locks were released by pin pullers operated by explosive devices.

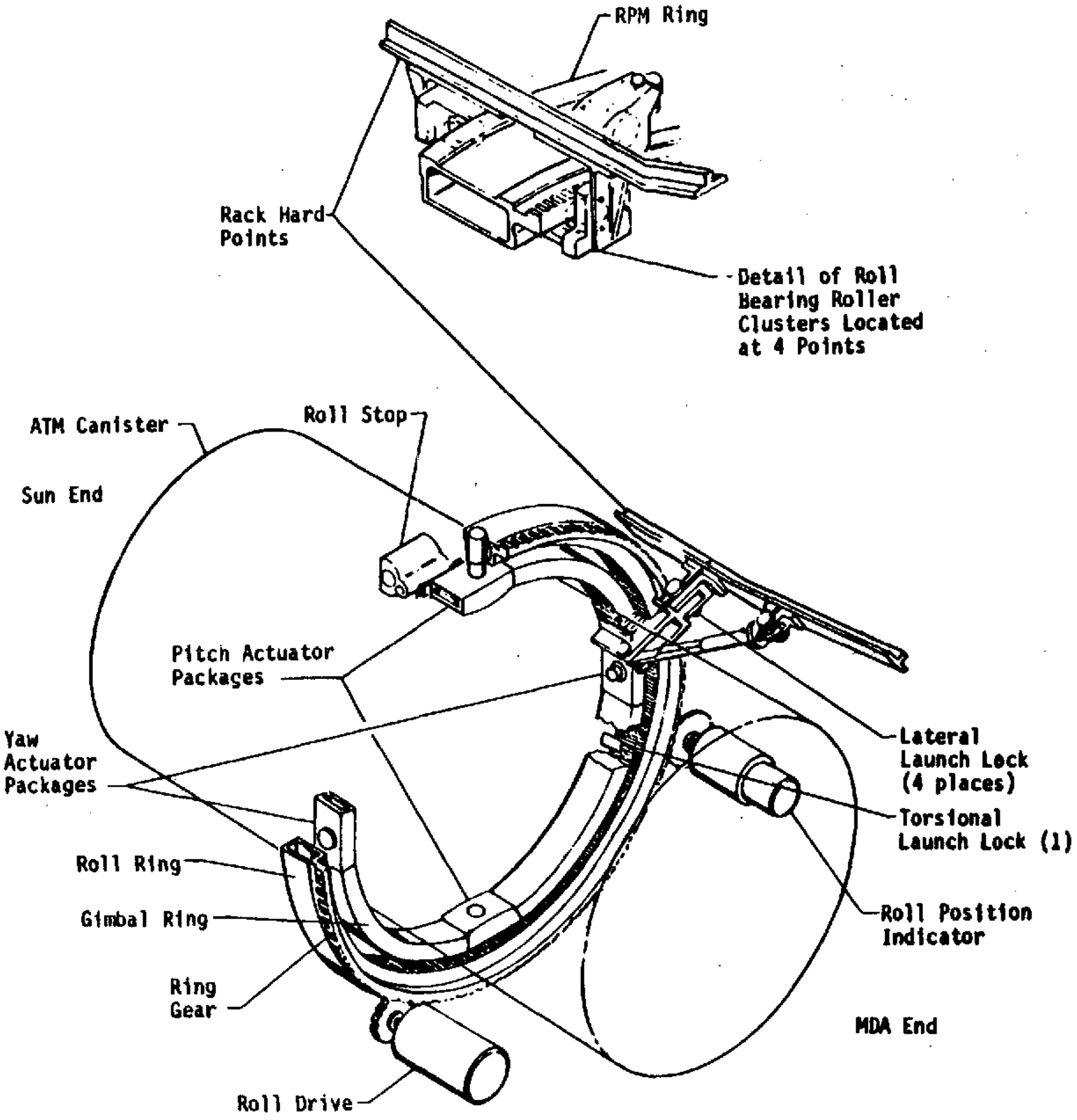
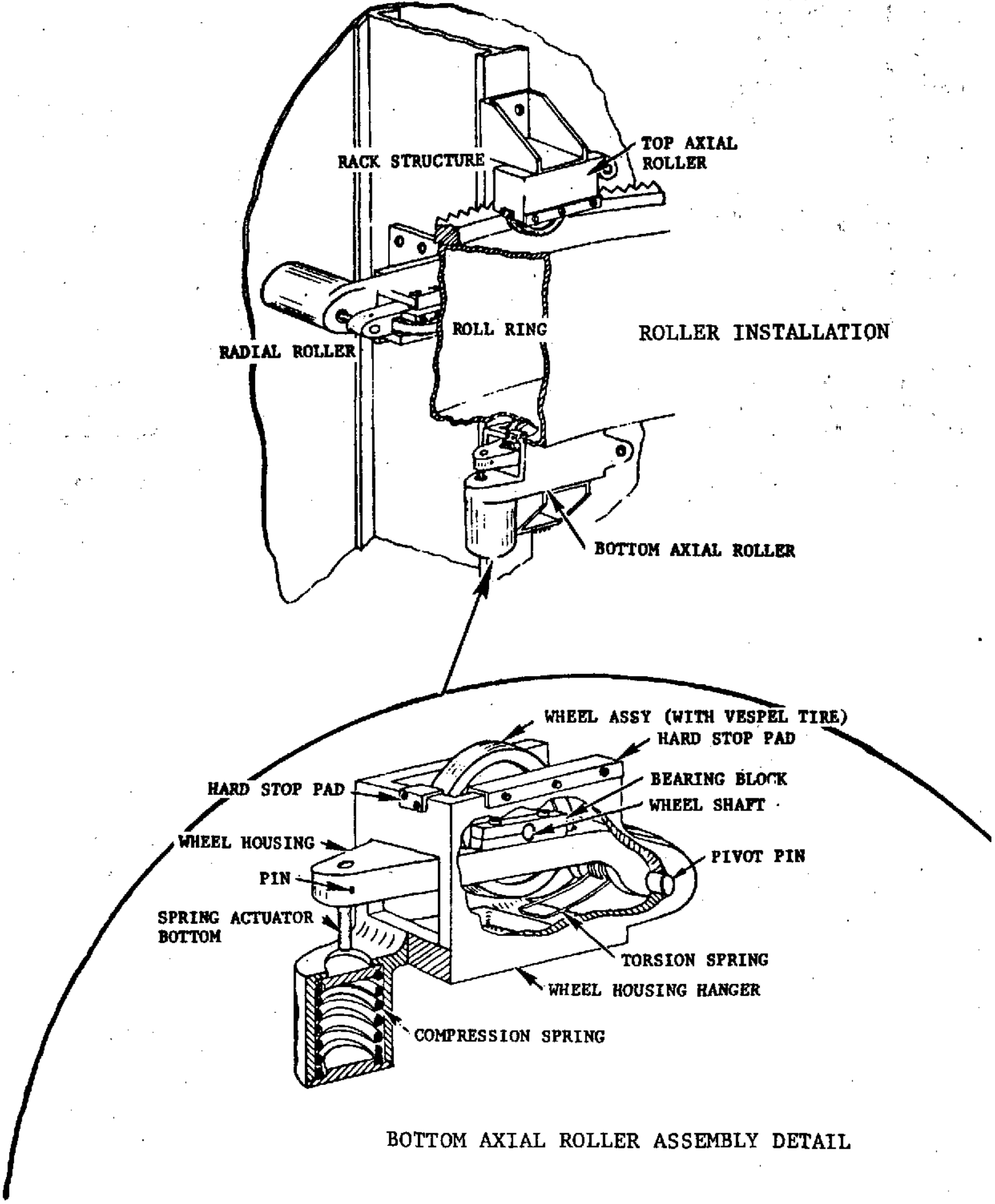


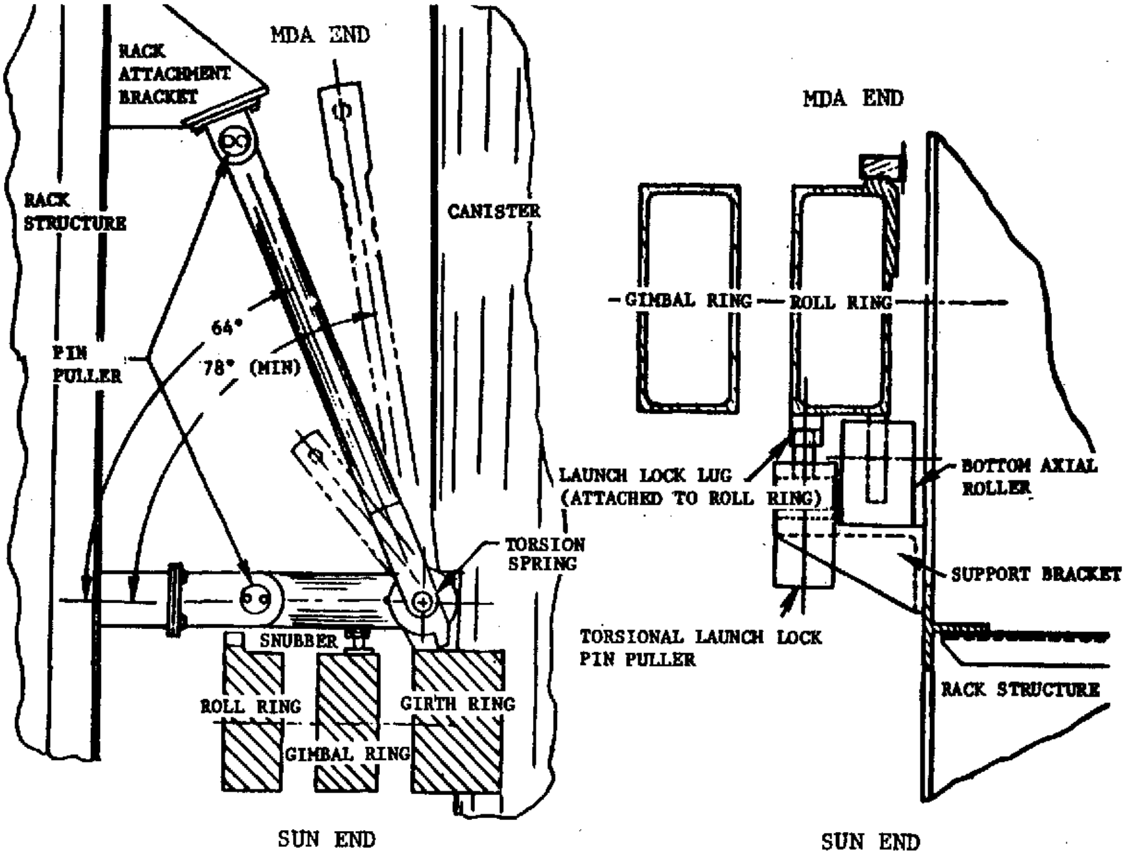
Figure 6-3. Experiment Pointing Control Roll Positioning Mechanism



ROLLER INSTALLATION

BOTTOM AXIAL ROLLER ASSEMBLY DETAIL

Figure 6-4. Roll Ring Support Assemblies



LATERAL LOCKS

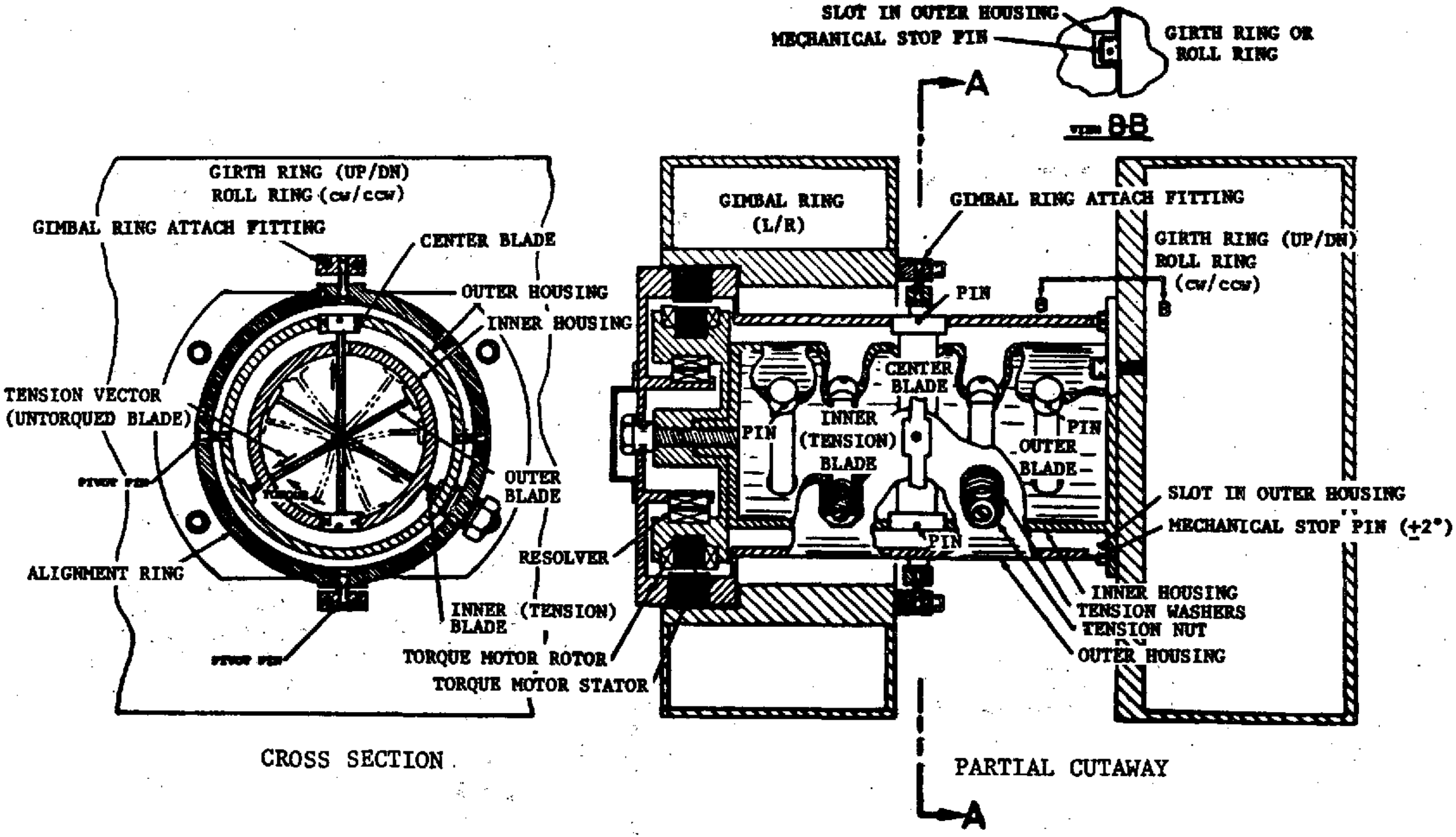
TORSIONAL LOCK

Figure 6-5. Canister Launch Locks

1. EPC Actuator Assembly - The EPC actuator assembly consisted of one mechanical flexure bearing assembly, one torque motor, and one multispeed electrical resolver (figure 6-6). The mechanical flexure bearing provided a support system with a limited mechanical rotation similar to ball bearings, but did not require lubrication since there were no rubbing parts. The torque motor drove the flexure bearing to provide the required ±2 degrees (maximum) motion.

2. Roll and Drive and Brake Assembly - The roll drive and brake assembly consisted of torque motors, two tachometers and a two-coil solenoid operated brake (figure 6-7). The motors, tachometers, and solenoid coils were arranged for electrical redundancy and the unit was rated for one unit to be operational at a time. The motors drove the ring gear on the roll ring to rotate the canister ±120°. The brake assembly provided the braking force for positioning accuracy and to maintain the desired position. The tachometer measured the rotational speed of the motor shaft.

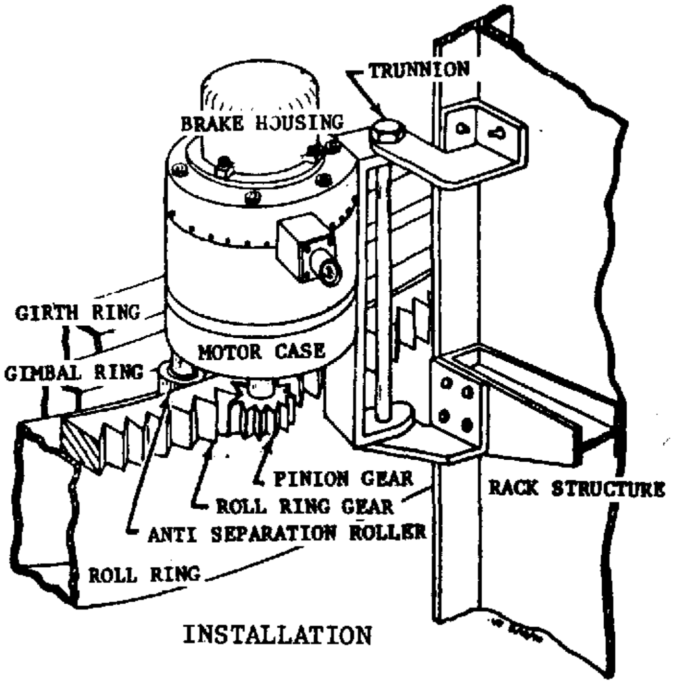
3. Roll Position Indicator Assembly - The Roll position indicator assembly was attached to the rack by a spring loaded bracket and



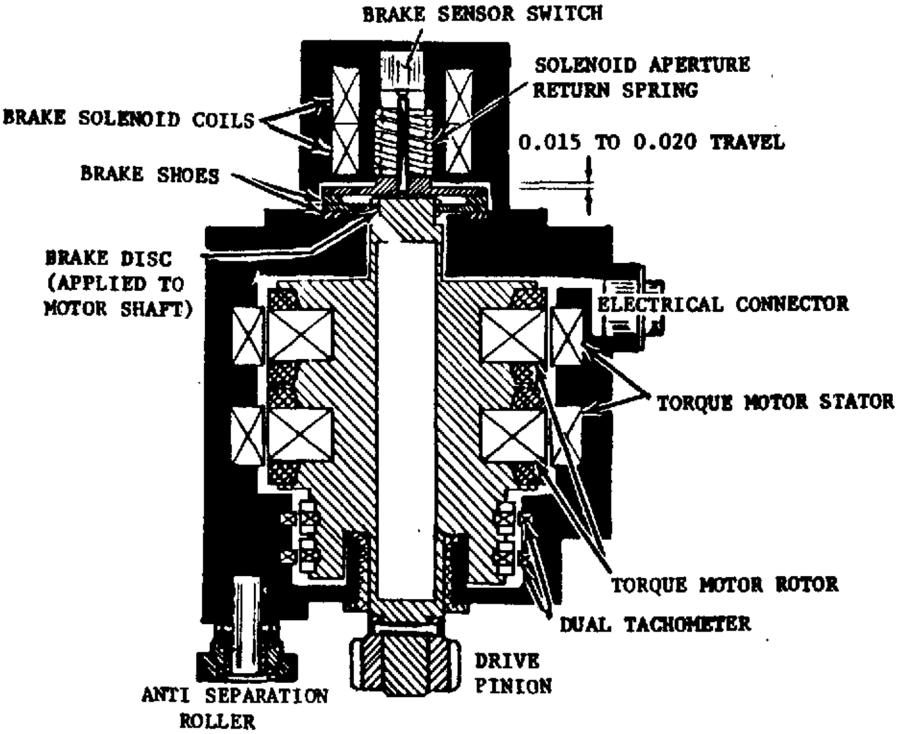
CROSS SECTION

PARTIAL CUTAWAY

Figure 6-6. EPC Actuator Assembly



INSTALLATION



SIMPLIFIED CROSS SECTION

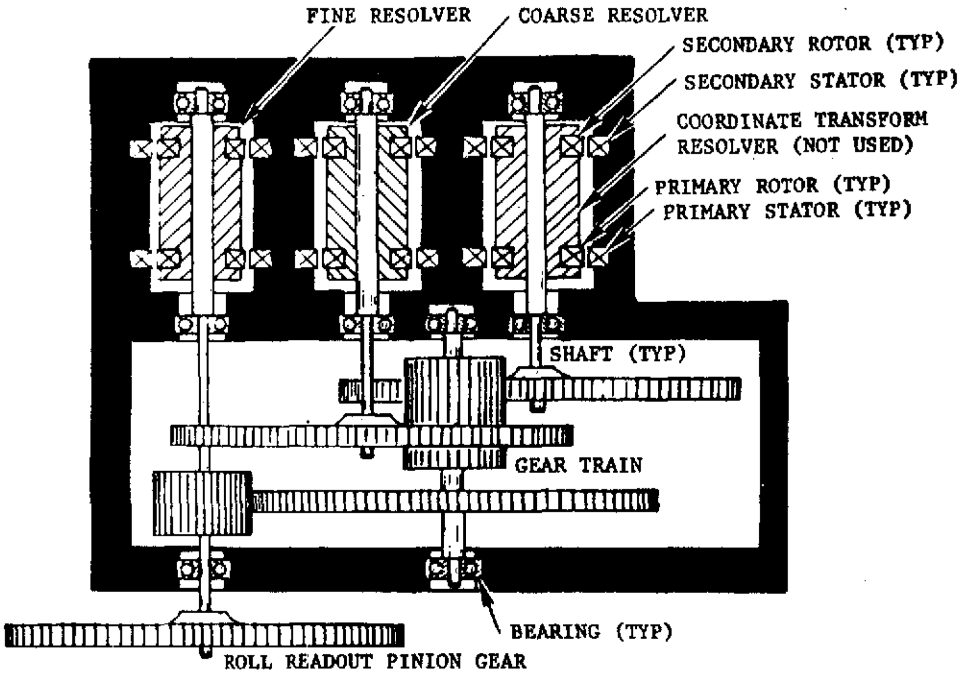
Figure 6-7. Roll Drive and Brake Assembly engaged the roll ring gear by means of a small pinion gear. The assembly provided an electrical indication of roll axis position. It consisted of a tandem installation of two fine and four coarse resolution resolvers (figure 6-8). The fine resolvers were driven directly by the input shaft and rotated at 16 times the roll axis speed. The coarse resolvers, comprised of two coarse resolution units and two coordinate transformation units, were driven by a reduction gear train and resolved at roll axis speed. The coordinate transform resolvers were not used. The pairs provided electrical redundancy.

4. Roll Stop Assembly - The roll stop assembly (figure 6-9) limited the canister rotation to $\pm 120^{\circ}$ and dampened the impact forces when the canister was stopped at its limits. The pawl on the Roll Stop Assembly was engaged by one of two stop blocks on the roll ring, compressing the spring, and preventing further canister rotation in that direction.

5. Orbital Lock Assembly - The orbital lock assembly caged the experiment canister to the gimbal ring and the gimbal ring to the roll ring. It consisted of a roller mechanism driven by one or the other of two redundant brush-type DC motors and a set of rails (figure 6-10). The roller mechanism and motors were attached to the gimbal ring. The rails were attached to the canister girth ring and roll ring. To cage the canister, the torque motor rotated the roller mechanism until the rollers contacted the stops on the rails. In the caged position the rollers were slightly over "top dead center" with respect to the rails, and were firmly compressed preloaded between the rails. The pitch and yaw orbital lock center lines made a 23 degree angle which resulted in an equal moment arm for both axes.

Film Retrieval Door Mechanisms

1. Canister Side Doors - There were five doors in the side of the canister. Four doors were for film retrieval by the crew during EVA from the center workstation. The fifth door was for ground access to the S055A experiment and for contamination monitoring equipment access prior to launch. The canister was rotated and had no remote position indication. The Experiment S052 door was a double door with a latching mechanism on one side and a fixed handle on the other. All doors incorporated a launch lock mechanism, latch mechanism, door position indicator (flag), magnetic latches, and rim seal (figure 6-11). The latch mechanism had spring loaded lock pins to hold the latch pins in the retracted position. To open the door the crewman first released the launch



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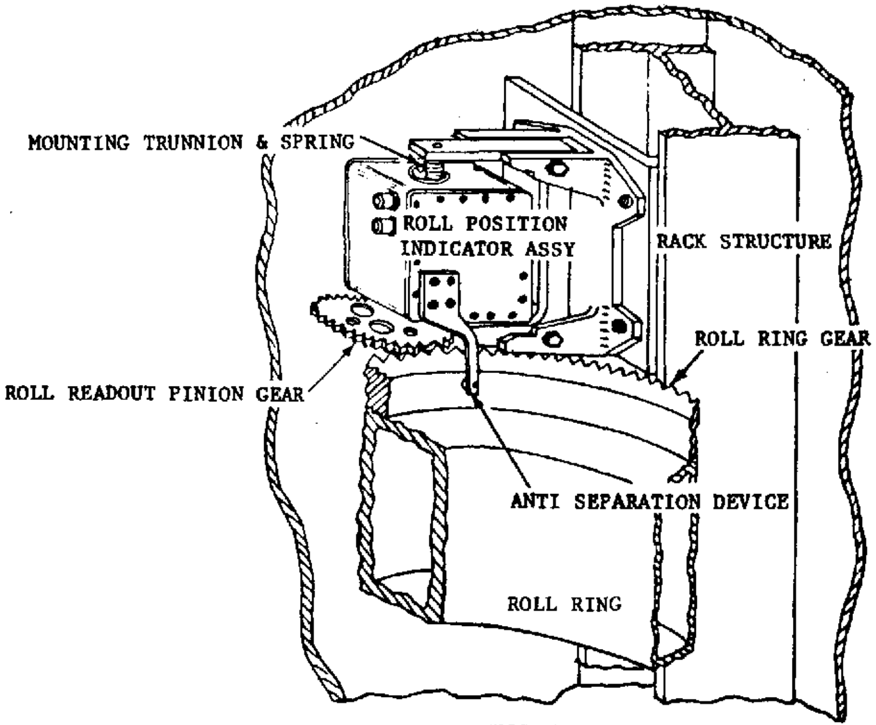
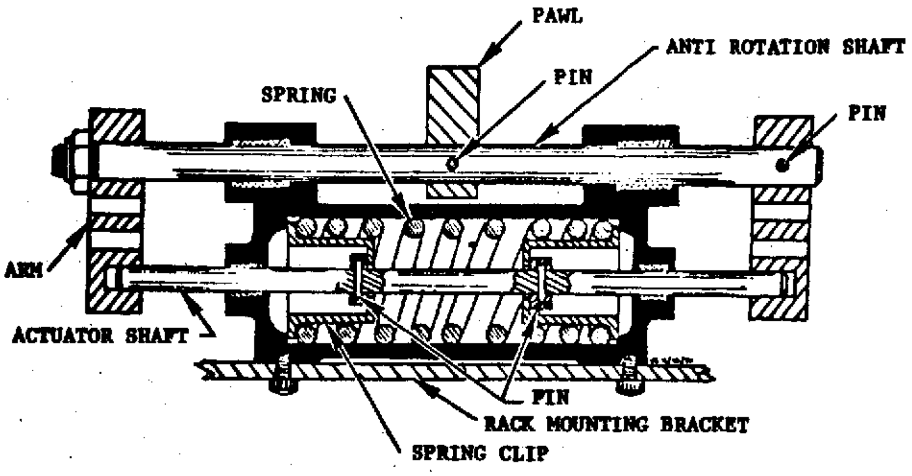


INSTALLATION

Figure 6-8. Roll Position Indicator Assembly



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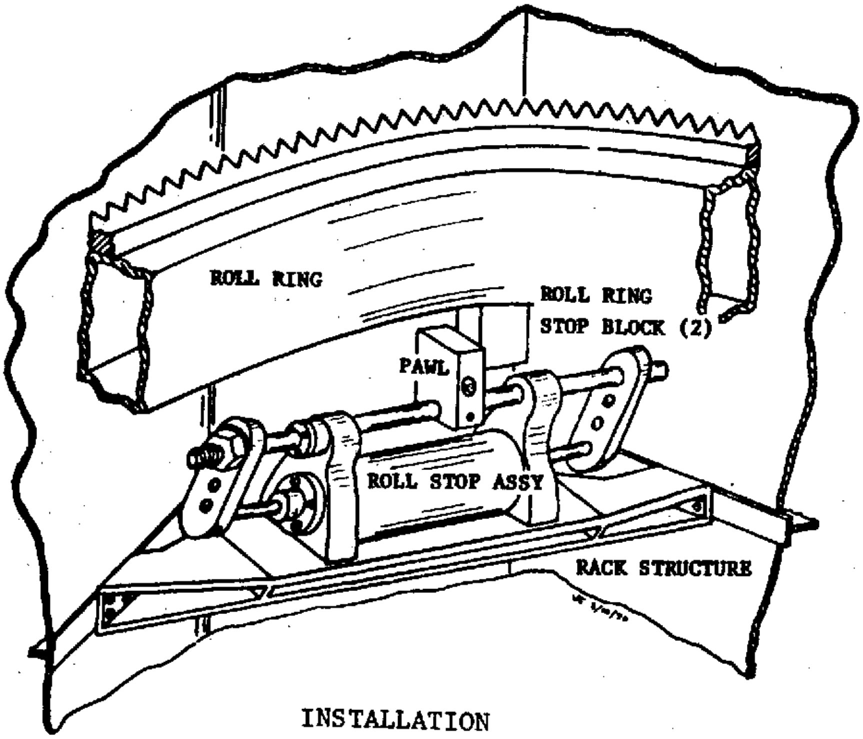
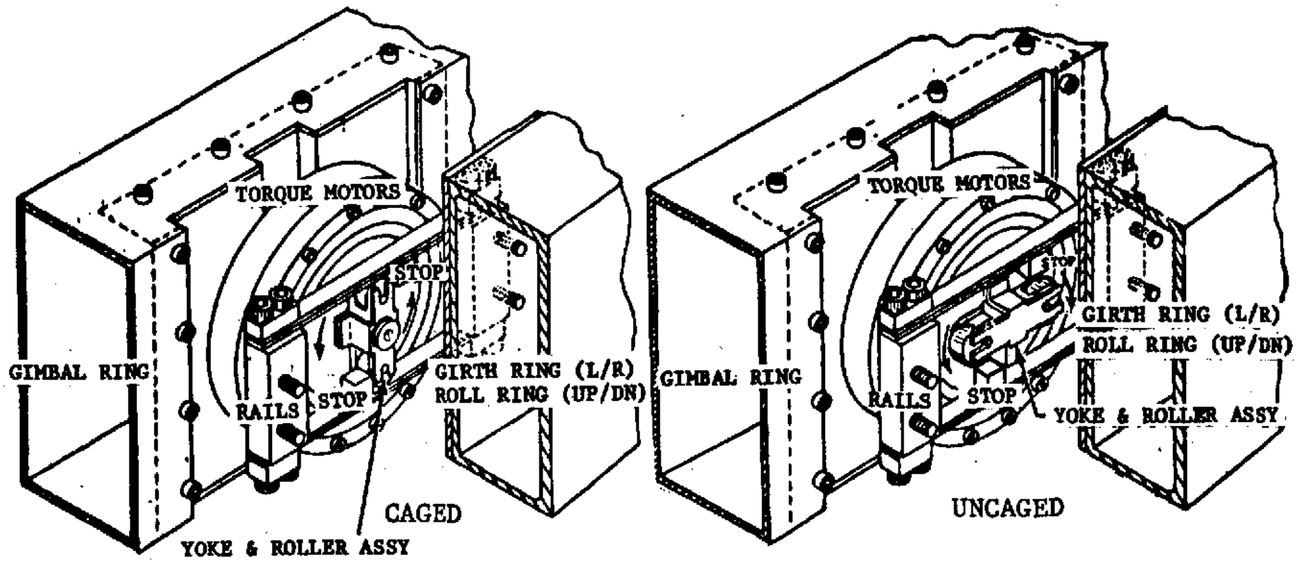


INSTALLATION

Figure 6-9. Roll Stop Assembly



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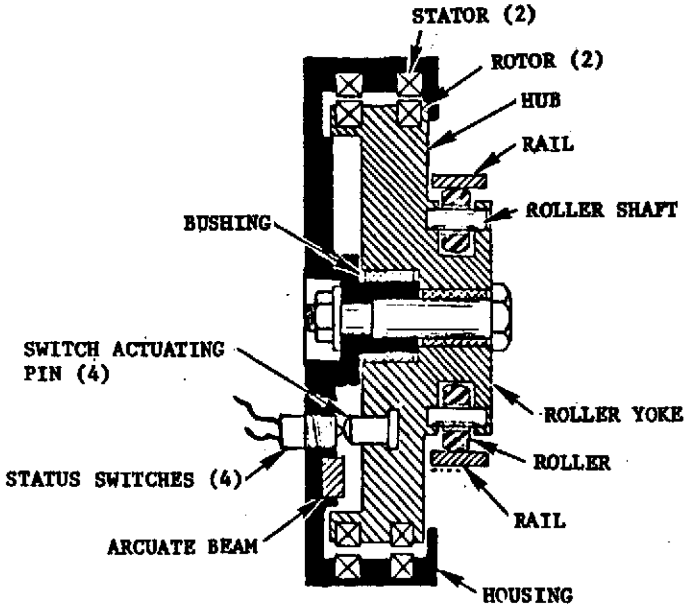


SIMPLIFIED CROSS SECTION

Figure 6-10. Orbital Lock Assembly

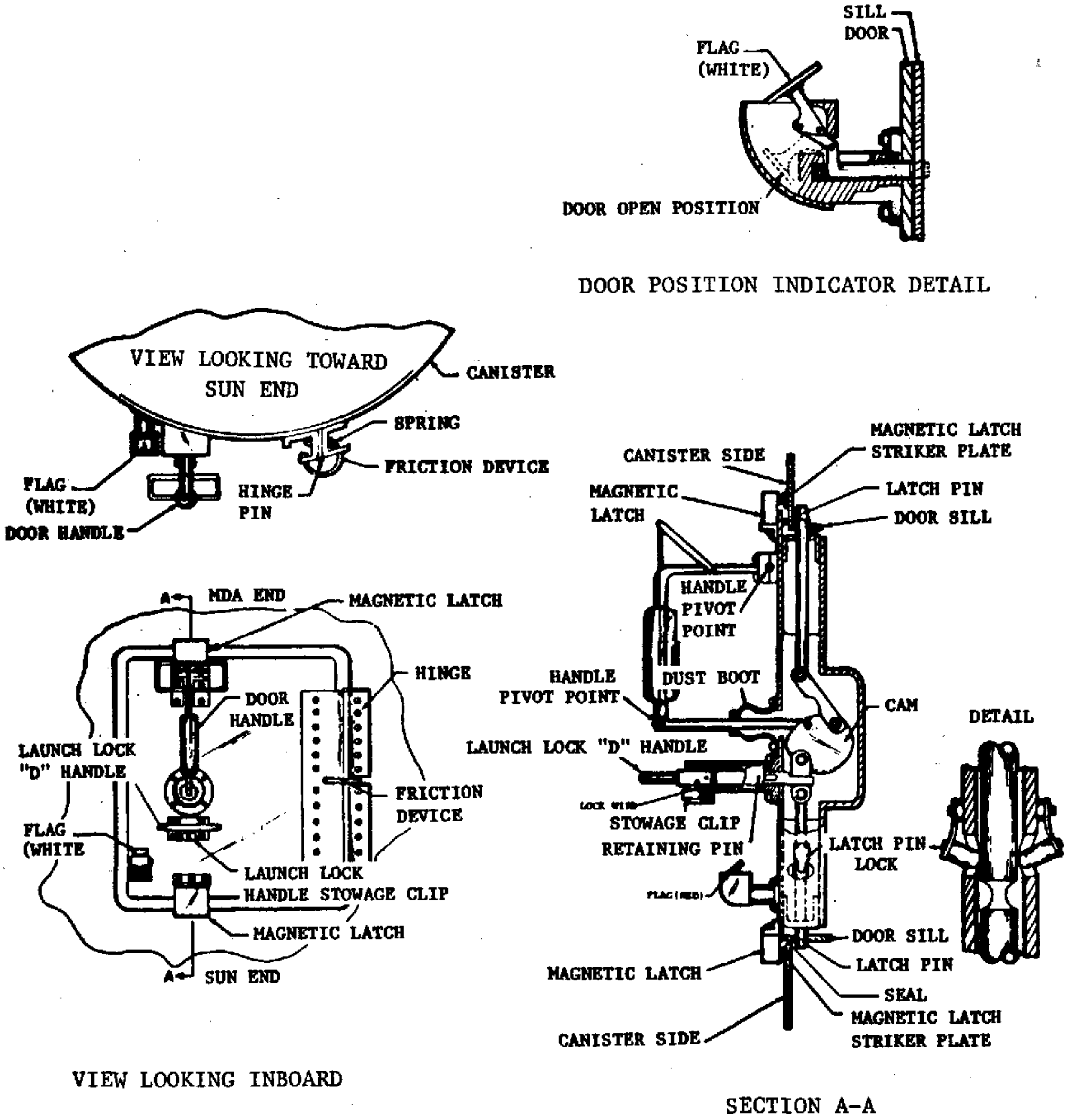


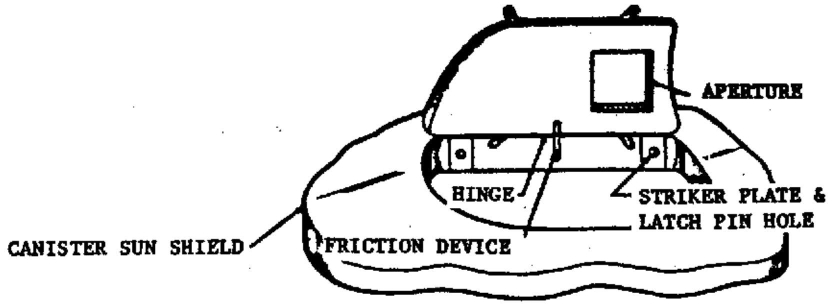
Figure 6-11. Canister Side Door (Typical)

lock by pulling out on the "D" handle far enough to break the lock wire and allow the split handle to be rotated and snapped into the stowage clip. The launch lock was not used again. The door opened by pushing the handle into the dust boot, which rotated the cam and retracted the latch pins. The latch pin locks dropped into the detent section of the latch pin shaft to keep them in a retracted position. The door was pulled open to overcome the magnetic latches at the top and bottom of the door. A friction device kept the door open using the friction of a spring against a curved rod. The door hinge pin was dry film lubricated to prevent cold welding in space.

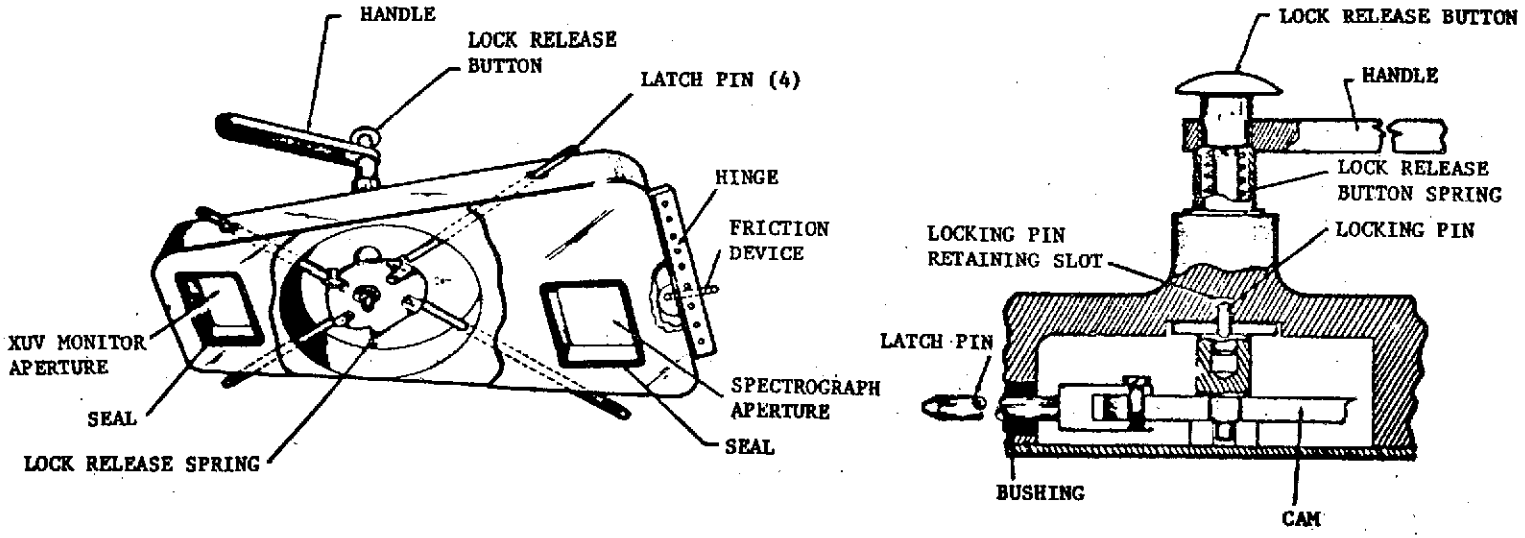
When the door was opened, a spring loaded pin in the door open indicator released allowing a red flag to drop into the housing. When the door was closed, it was held by the magnetic latches until the handle was pulled out. Pulling out the handle rotated the cam in the opposite direction forcing the latch pins outward into holes in the door sill. The door sill pushed the pin on the door open indicator in, raising the red flag up out of the housing and into view.

2. Sun Shield Doors - There were two film retrieval doors on the Sun shield for the S082A and B experiments. The three aperture doors that covered the film retrieval doors had to be opened from the center workstation before the film retrieval doors could be opened. The canister also had to be rotated into the proper position so the doors would be accessible from the Sun-end workstation. The two film retrieval doors were manually operated and had no position indicators.

The door assemblies were composed of a fiberglass shell filled with aluminized mylar insulation, latch mechanism, lock mechanism, friction device and seals (figure 6-12). The latch mechanism was unlocked by depressing the lock release button on the top of the handle. This pushed the spring loaded inner shaft down far enough to allow the locking pins to clear the retaining slot. The lock release leaf spring then rotated the cam and shaft far enough to prevent the lock release button spring from pushing the locking pins back into the retaining slot. The handle was then rotated, causing the cam to rotate and retract the latch pins from holes in the door sill. A friction device kept the door open using the friction of a spring against a curved rod. The door hinge pins were coated with a dry film lubricant to prevent cold welding in space. If the handle was rotated in the wrong direction when trying to unlatch the door, the lock pins would be forced back into the retaining slots again. The door could not be unlatched



S082A CAMERA RETRIEVAL DOOR



S082B CAMERA RETRIEVAL DOOR
(UNDER SIDE)

LATCH LOCK PIN DETAIL

Figure 6-12. Sun Shield Door (Typical)

until the lock release button on the top of the handle was depressed again. The door latched by rotating the handle in the opposite direction causing the cam to rotate and force the latch pins into the holes in the door sill. The latch release button spring then forced the locking pins into the retaining slots to lock the door latches.

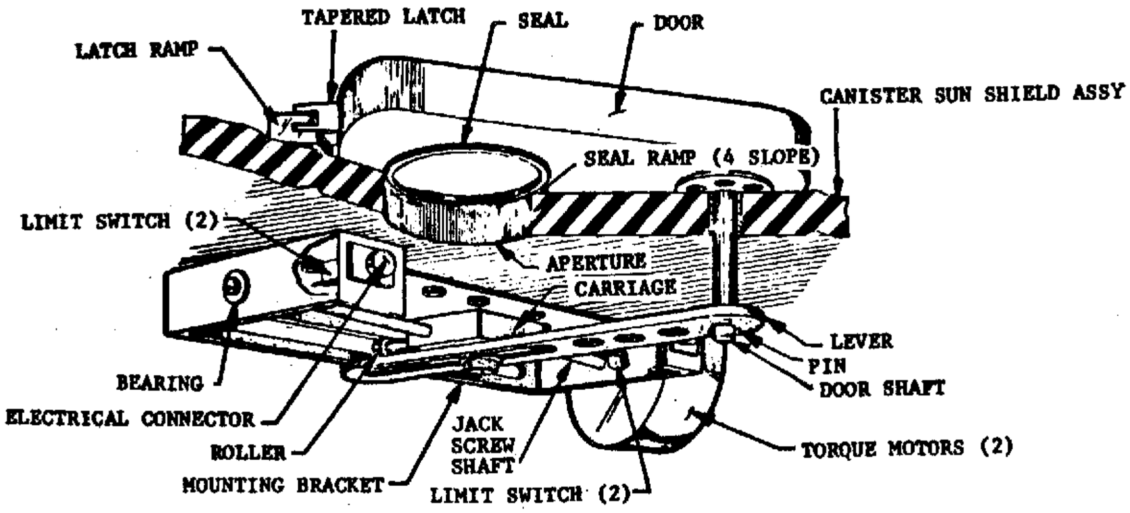
Sun Shield Aperture Door Mechanism - The ATM experiments and the fine Sun sensor viewed the Sun through openings in the Sun shield. These openings were covered by doors to protect the experiment and FSS optics from contamination when they were not in use. The S082A and B experiments also had internal aperture doors that will be described in the experiment section. The operating mechanism for all doors was identical and is shown in figure 6-13.

The aperture doors consisted of a fiberglass shell filled with aluminized mylar with a shaft attached to one corner and a tapered ramp opposite the shaft. The tapered ramp fit into a "U" shaped ramp latch attached to the Sun shield. Each door had a ramp latch which provided support during the launch boost. A four degree sloping ramp around the Sun shield opening aided in sealing the doors. The door operating mechanism consisted of redundant 28 Vdc torque motors driving a common jack screw shaft, a carriage, a lever, a mounting bracket and four limit switches. The mechanism was attached to the inside of the Sun shield. The lever was attached to the door shaft.

The door control circuits were basically the same. When commanded the selected torque motors rotated the jack screw moving the carriage and lever. The lever rotated the door shaft to open the door. When the carriage reached full travel it activated the door open talkback indicator circuit and the door open TM indicator circuit. The door closed circuit operated in a similar manner. The aperture doors had a manual operation capability to preclude loss of mission objectives if the electromechanical door operation system failed. The EVA astronaut could remove the tee-shaped EVA pin from the door opening assembly and manually translate and lock the door in the open position.

GSE N2 Purge Fitting Retract Mechanism - The ATM experiment canister was purged on the pad with gaseous nitrogen (GN_2). A retractable fitting (figure 6-14) carried the GN2 from the ATM rack to the canister. The GSE line was disconnected at the rack prior to launch, but the retractable fitting between the rack and canister was not. The rack to canister fitting was released when the crew rotated the canister in a clockwise direction the first time in orbit.

SUN END SEAL (CROSS SECTION)



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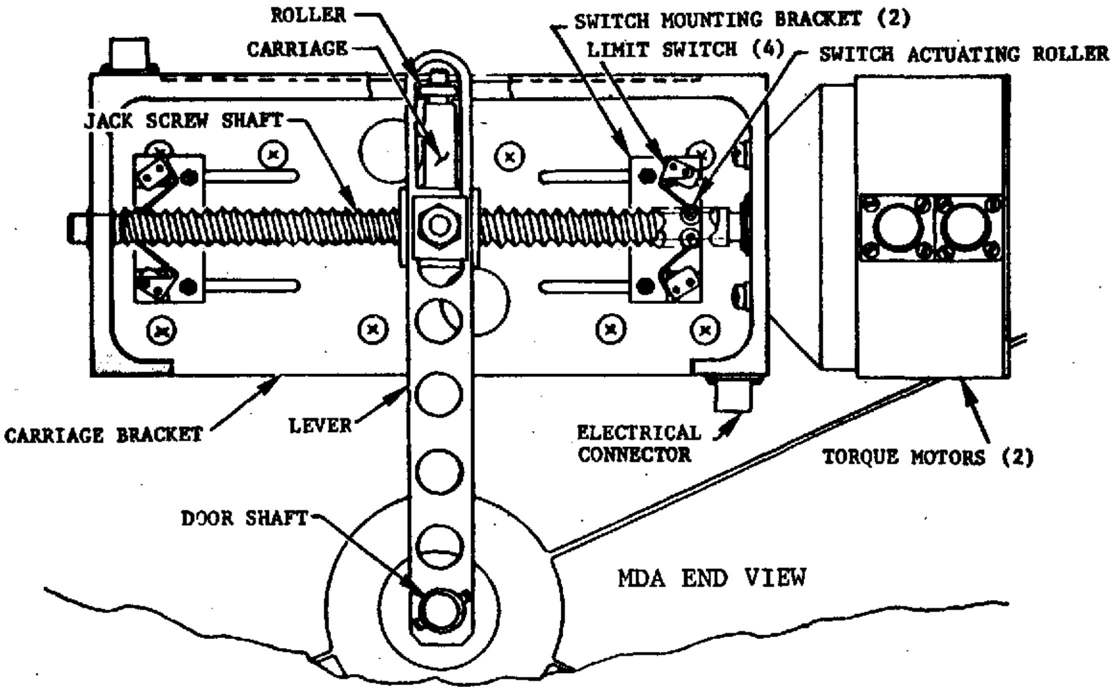


Figure 6-13. Sun Shield Aperture Door (Typical)

NOTE: MALE DISCONNECT IS REMOVED FROM FEMALE DISCONNECT HOUSING IN ORBIT WHEN CANISTER IS ROTATED CLOCKWISE FOR THE FIRST TIME. SPRING THEN RETRACTS SWING ARM WHEN ROLLER LEAVES GUIDE

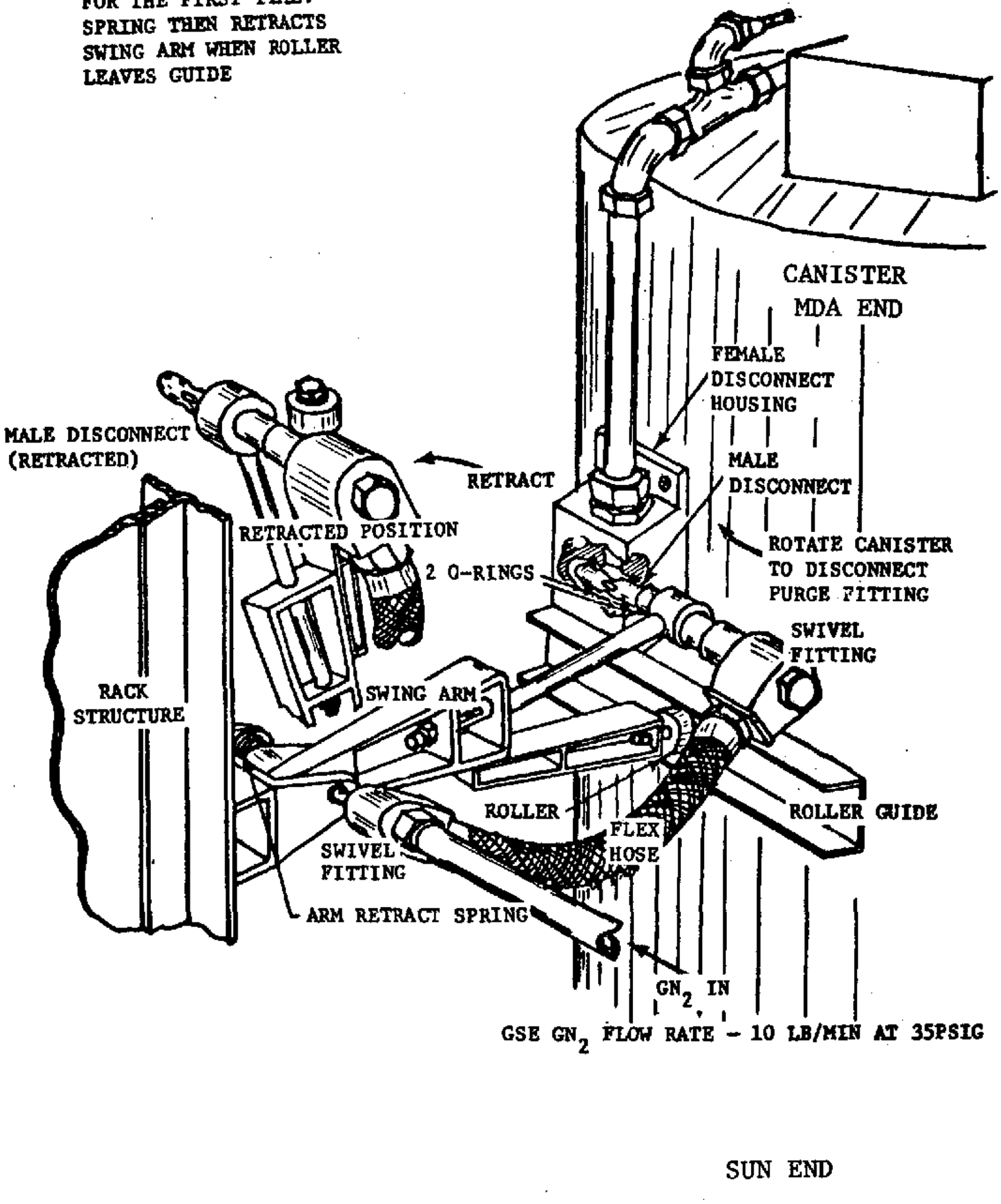


Figure 6-14. GN$_2$ Purge Fitting Retract Mechanism

Rack

The ATM rack structure was derived from an open truss type structure, called the payload module, capable of performing multiple missions. The initial mission concept incorporated a docking truss on top of the rack structure. The rack was mounted in the same location inside the SLA as the Lunar Module descent stage. After separation, the CSM docked with the rack in a similar manner as to the Lunar Module. The payload was then extracted from the spent S-IVB stage. This configuration was planned for solar missions lasting up to two months in duration.

Payload Module Concept - As ATM program studies evolved, MSFC presented a Lunar Module Ascent Stage configuration with a hard mounted ATM concept in June 1966. This concept utilized the Lunar Module ascent stage as the crew work area for an ATM mission. Figure 6-15 illustrates the basic experiment support structure and rack.

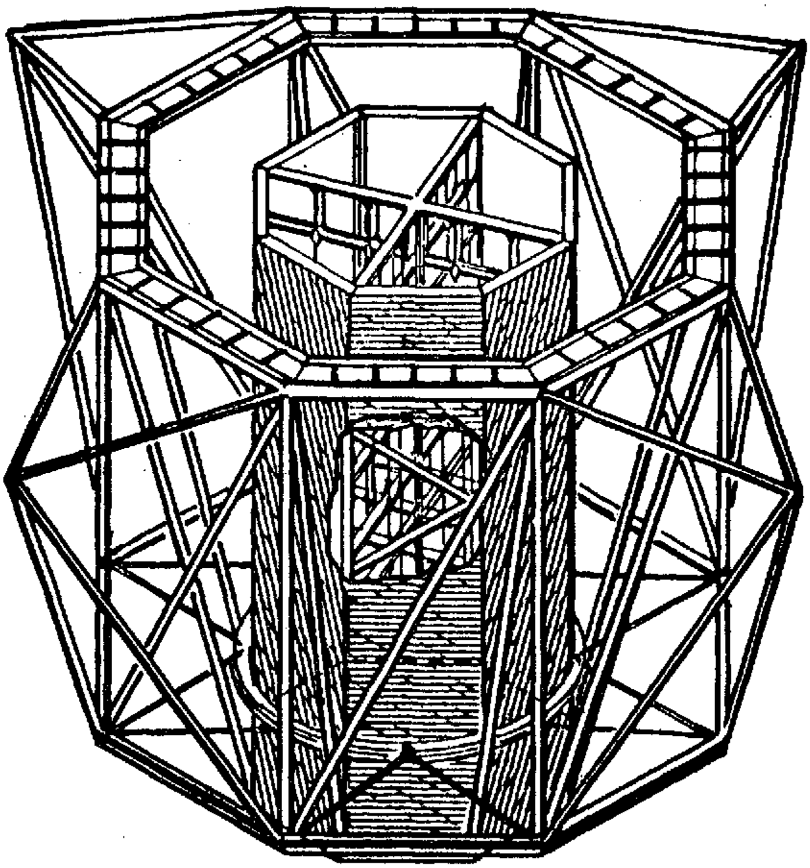


Figure 6-15. Basic Payload Module

The rack provided structural support for the ATM experiments, for the auxiliary equipment such as batteries and the CMG's, and for the Lunar Module ascent stage. The rack was a truss structure of octagonal plan form 97 inches deep in the longitudinal direction with a shear web beam around the forward periphery giving a clear area of 114 inches diameter inscribed circle in the center plane for installing experiments and equipment. The universal payload module rack concept provided for a wide range of experiment structure mounting schemes.

Wet Workshop Concept - During the last quarter of 1966, ATM experiment definition indicated that the 60 inches diameter experiment package was inadequate. It was determined that, with modifications to the rack, an experiment package of 80 inches diameter could be accommodated. In the same period, a requirement for fine pointing of the experiment package was established thus requiring a gimbal system. A requirement for solar arrays to be attached to the ATM rack dictated the need for a third structural ring to be added to the rack. This permitted the solar arrays to be packaged within the ATM withdrawal cone of the Saturn LM Adapter. Subsequently, an experiment package 82 inches in diameter, 120 inches in length and with gimbal capabilities evolved. The ATM rack to accommodate this package evolved from the universal payload module rack with the following considerations:

1. Use to the maximum extent possible of existing manufacturing tooling.

2. Use of existing materials to minimize long lead time procurement problems.

3. Provisions for maximum black box mounting area on the rack.

Dry Workshop Concept - As the ATM program progressed into the Dry Workshop orbital cluster concept requirements for the rack and experiment package expanded. The ATM was to be launched Sun-end up which required redesign of the outriggers and launch locks for launch load considerations. System redundancy requirements instigated addition of mounting panels to the rack and the double tiering of black box components. An ATM deployment adapter structure was added.

In May 1970 the ATM Critical Design Review was completed. This review gave final approval to the ATM design as described in the System Description portion of this report.

Spar

The ATM spar structure evolved from a rigid open truss structure in a cruciform configuration for the mounting of experiments.

Payload Module Concept - The initial ATM experiment package had an octagonal plan form in cross section with a 60 inch diameter and length of 120 inches. The integral spar was of 2219 alloy standard shapes, fastened together mechanically in a gridwork configuration as illustrated in figure 6-15. This cross frame spar could be removed to house a 30 to 50 inch diameter experiment telescope. The entire experiment package was covered with multilayered insulation to stablize the internal thermal environment.

The package was initially rigidly mounted to the rack structure. As pointing control studies indicated that pointing requirements could not be met as a result of crew induced disturbances, a girth ring and gimballing capability were added.

Wet Workshop Concept - In late 1966, ATM experiment definition resulted in an increase in the experiment package dimensions to an 82 inches width with the length remaining at 120 inches. Three major spar construction concepts were considered. They were a solid aluminum plate with two blades, a composite of aluminum honeycomb and aluminum plate, and an aluminum plate and blades configuration with two inch lightening holes drilled throughout for a forty percent weight reduction. The drilled aluminum plate and blades concept was chosen as illustrated in figure 6-16. A removable canister with an active thermal control system was added to the experiment package. Thermal control is discussed in detail in the Thermal Control section of this report.

Dry Workshop Concept - Subsequent program evolution from the Wet to Dry Workshop concept imposed no major changes in spar structure. A requirement to vent the experiment canister during launch was introduced. Initial venting procedure called for the opening of two aperture doors immediately after launch. This was deleted due to possible contamination of the experiment optics. The second design encompassed mechanically operated vent valves which were subsequently deleted in favor of a simple one-way flapper type valve.

The final design of the spar structure and associated hardware was as described in the Systems Description portion of this report.

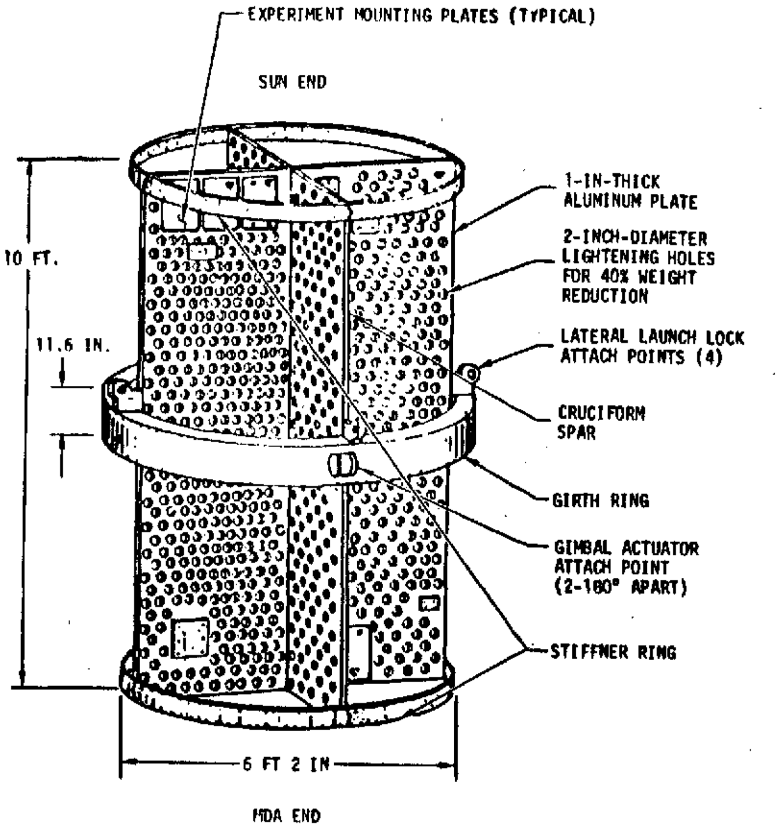


Figure 6-16. ATM Spar

MANUFACTURING

There were no new manufacturing procedures nor methods implemented during manufacture of the ATM structural and mechanical systems. Major problems encountered during manufacturing included stressing of spar, interference of Sun-end bulkhead mounted equipment with experiments and insulation, and experiment alignment.

Stressed Spar

The flight ATM spar was stressed due to a faulty crane during a moving operation. One spar attach lug was displaced 0.010 inches. This anomaly is discussed in the Special Tests portion of this report.

Interference

The Sun-end bulkhead mounted components of the canister interferred with the HAO optical bench, spar insulation, and boot on the HCO-A telescope. A 1.5 inches spacer was added to the Sun-end of the canister to resolve the problem.

Alignment

Optical alignment of the ATM telescopes brought forth unique requirements of aligning massive structures and optical trains to within plus or minus ten arc-seconds of a baseline reference and to maintain alignment within specification in the space environment.

Alignment Techniques - To assure standardization of alignment proceedings among the responsible telescope Principal Investigators and to coordinate alignment problems through the program, an ATM Alignment Team was organized during March 1967. The team met periodically to formulate guidelines, discuss alignment problems and assign action items to facilitate problem solution.

An alignment technique was developed and documented in the Manufacturing Optical Alignment Procedure for ATM Experiments and Fine Sun Sensor - 50M05069 dated July 30, 1971. This procedure assured alignment of each experiment to the baseline reference (Fine Sun Sensor).

The alignment and adjustment were completed under a simulated zero gravity configuration utilizing a load cell and spring support mechanism attached to the experiment and ATM Test Fixture. Each experiment was supported concurrently in this manner for zero gravity alignment operations. Figure 6-17 illustrates the zero gravity assembly. After resolving the problems which arose, the alignment techniques and procedures developed during the ATM program were very successful.

Alignment Problems - Seven major problems were encountered during the experiment alignment program. The problems and their solutions were as follows:

1. It was discovered early in the program that the experiment internal optics were not always aligned with the center line of the telescope adjustment travel. S&E-QUAL-AAA instigated a receiving inspection procedure through coordination with the Principal Investigators. An alignment adjustment travel fixture was

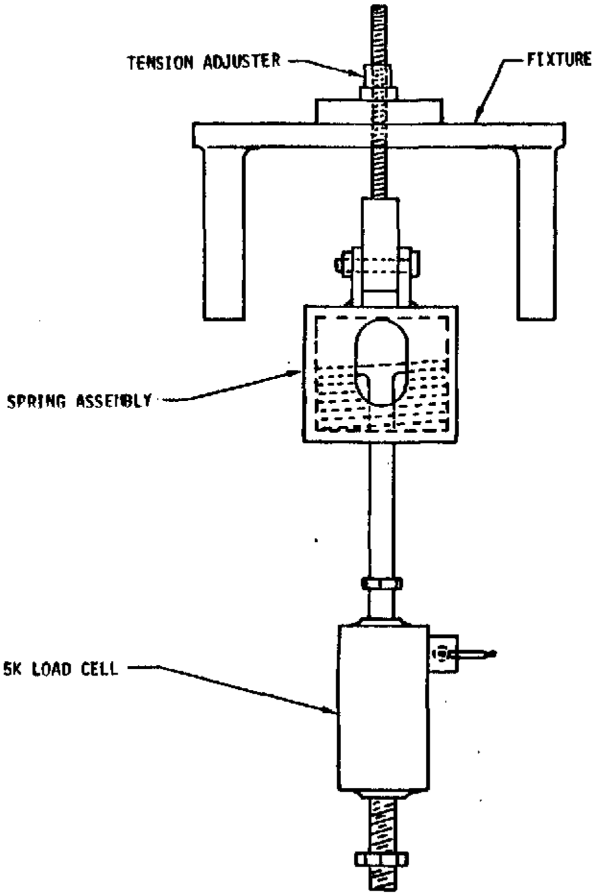


Figure 6-17. Experiment Zero Gravity Fixture

designed for each experiment for use at the manufacturing facility. This action substantially alleviated the problem.

2. Anomalies related to misalignment between quality and manufacturing alignment data long with dissatisfaction expressed by the Principal Investigators resulted in the formalizing of a

manufacturing alignment procedure. This procedure was reviewed by all units concerned, review comments integrated, and the procedure accepted.

3. With the Sun-end canister installed, the optical reference mirrors on experiments H-Alpha 1, H-Alpha 2, and GSFC (S056) were not accessible for a direct line of sight optical reading. Personnel of S&E-QUAL-AAA designed an offset periscope device which was inserted at the aperture door opening. This device permitted utilization of the existing optical alignment equipment. Figure 6-18 illustrates the offset method equipment set-up.

4. The optical reference mirror on AS&E (S054) experiment degraded in reflectivity during the ATM program. This problem was solved by utilizing the auto reflection method of optical alignment in preference to the autocollimation method.

5. During initial manufacturing of the experiments the reference alignment mirrors mounted on the outer case of experiments HCO-A (S055A) and NRL-B (S082B) were determined to be unstable. A method of backlighting the internal optics with fiber optics was developed. The light through the aperture slit was utilized as the alignment target.

6. When HCO-A (S055A) experiment was suspended in the vertical position, the internal optics bench translated 105 arc seconds toward the +Z reference and 3 arc seconds toward the -Y reference. This translation was corrected through overall instrument adjustment during installation and alignment. Approval of this deviation was documented in E.O. number 1 to 10M03786, Apollo Telescope Mount-A, Alignment Control Drawing.

7. Throughout the experiment alignment verification program of the ATM Prototype and Flight Units repeatability of alignment readings could not be accomplished. The readings varied to a maximum of one arc minute twenty arc seconds with an average variation of approximately fifteen arc seconds. The variations were most notable if the ATM had been moved between alignment reading operations. It was concluded that ATM structural creep and alignment equipement set-up variations were the major contributing factors.

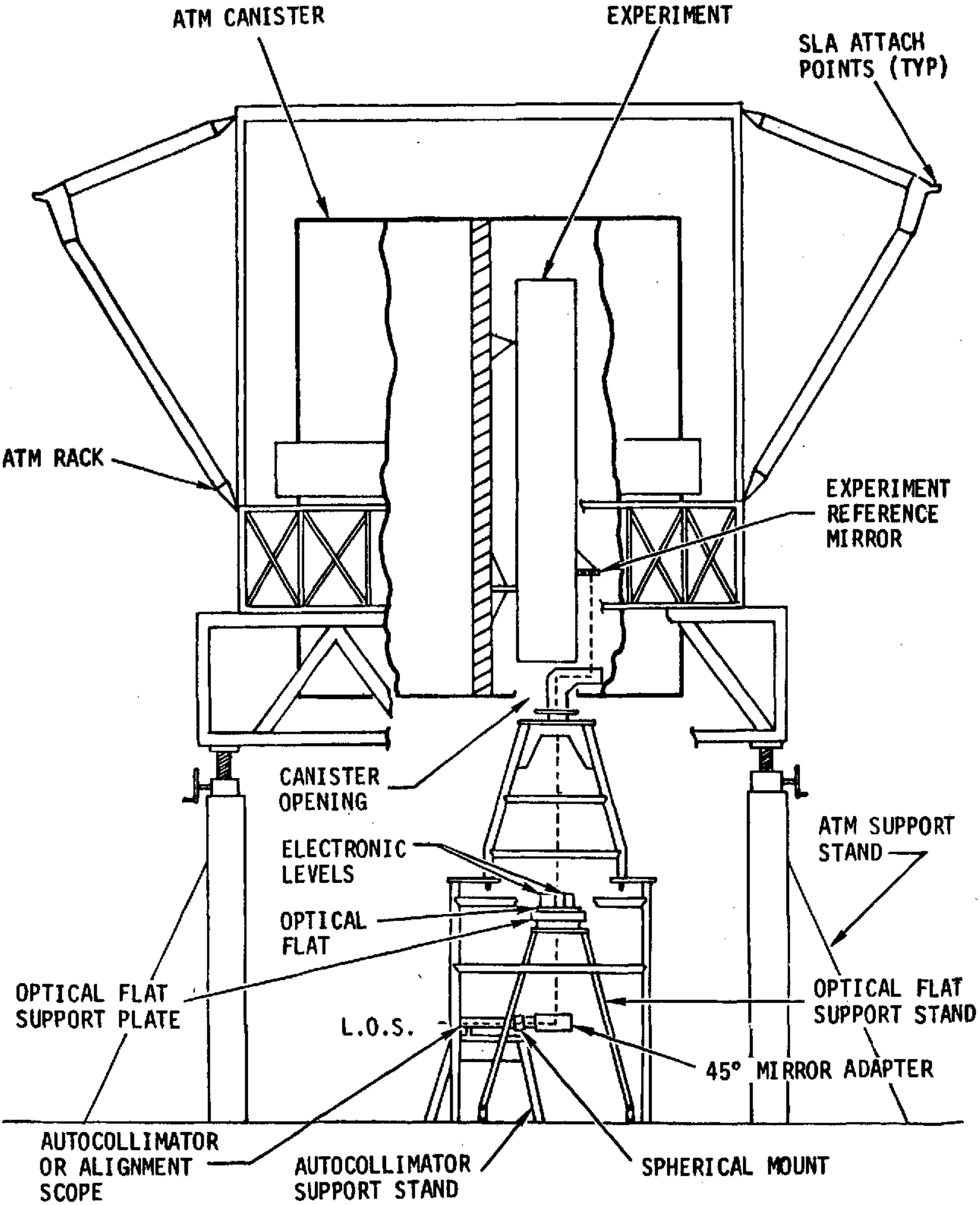


Figure 6-18. Experiment Alignment Equipment Set-Up

COMPONENT/END ITEM QUALIFICATION

Qualification testing/assessment was conducted as a formal demonstration of performance and design adequacy under anticipated operational environments. The verification method consisted of tests and assessment of similarity, analysis, inspection, and demonstration. Flight type test hardware was identical in fabrication, configuration and performance to the space vehicle flight hardware. Data from development tests were utilized in qualification assessment where feasible.

Qualification Test and Analysis

Qualification by test and/or analysis for the ATM Structural and Mechanical Systems consisted of qualification of the primary structural components and end items described in the Major Component portion of this report.

Test - Components which were qualified by test are noted in Table 6-I along with the test report and results. The roll stop assembly, canister cold plates, and radiators were qualified on a systems level with no anomalies noted.

Analysis - The remaining components and end items as follows were structurally qualified by stress analysis only:

1. Sun-end solar shield
2. Thermal Shield
3. Cable rack
4. Torsional Launch Lock
5. Film casette trees and receptacles
6. ATM Canister Cable Entrance and Spacer Redesign
7. Acquisition Sun sensor support
8. Star tracker support
9. Star tracker shield
10. Thermal control system components
11. Various bracketry
12. Black Box connections to primary structure

Life Cycle Test

Seven components were subjected to life cycle tests. The basis for selecting these components for life testing was their repetitive operation throughout the mission or as in the case of

Table 6-I. ATM Structures Qualification Program Summary Matrix

Component	Test Report	Test Results
ATM Rack	50M02485 Rack Test Data Evaluation	Satisfactory - No Anomalies.
ATM Spar/Canister with Spar	50M02490 ATM Spar and Canister Test Evaluation Report	Satisfactory - No Anomalies.
Film Retrieval Doors and Mechanisms (H-Alpha 1 and HAO)	S&E-ASTN-TMM (71-70) Qualification Test Report, Apollo Telescope Mount H-Alpha 1 and HAO Film Retrieval	Door Latch System Redesigned for Positive Locking and One Handed Operation - Retest Satisfactory.
AS&E Aperture Door/Torque Motor	S&E-ASTN-TMV (71-91) Results of AS&E Aperture Door/Torque Motor Assembly Vibration Test	Satisfactory - Recommendation to Secure Torque Motor Housing Screws to Prevent Door Creep Implemented.
Gimbal Ring/Ring Gear Assembly (Roll Ring) EPC Actuator (Pitch/Yaw)/Roll Actuator/RPM	PE-10095 ATM EPC-RPM Static Test Report PE-10425 Environmental Penalty Qualification Test Report for EPS/RPM Actuators for ATM	Slippage Between Gimbal Ring and Orbital Lock Mounting Block. Added Dowel Pins - Retest Satisfactory. Status Sensor Switch Failed - Redesign Approved.
Orbital Locks	PE-9526 Orbital Cage Mechanism Development Test	Stop Pin Diameter Increased from 1/8 inch to 1/4 inch.

Table 6-I. ATM Structures Qualification Program Summary Matrix (Continued)

Component	Test Report	Test Results
Roll Drive and Brake/ Roll Position Indicator	PE-10303 Environmental Qual Test Report for EPS/RPM and Roll Positioning Mechanism Actuators for ATM	Satisfactory - No Anomalies.
Launch Locks	PE-10323 Report on the Static and Retraction Tests on a Lateral Launch Lock of the Saturn V Dry Workshop Vehicles	Pin Failed to Fully Retract and Mounting Flange Cracked - Redesigned End Cap and Increased Flange Thickness from .25 to .50 Inch. Retest Satisfactory.
GN_2 Purge Mechanism	S&E-ASTN-TMM (72-44) GN_2 Retract Mechanism Test	Satisfactory - No Anomalies.
Vent Valve	S&E-ASTN-TMM (71-52) ATM Vent Valve Flow Test	Added Epoxy to Adjusting Screws and Jam Nut to Counterbalance Shaft.
Cable Roll Adapter	S&E-ASTN-TF (56-71) Functional Rotation Verification Test of the ATM Cable Roll Adapter	Satisfactory - No Anomalies.
Cable Arch/Beam	ASD-ASTN-13665 ATM Test Fixture Analysis and ATM Cable Arch and Beam Static Test Evaluation	Cable Tray End Fitting Failed. Redesign and Retest Satisfactory.

the GN_2 Retract Mechanism, found to be a Single Point Failure candidate. Table 6-II delineates the components along with Test Report identification and Test Results.

Component Acceptance Test

The ATM components were acceptance tested and documented per Acceptance Test Plane 50M03524 and 50M03666. Results of these tests are contained in Acceptance Test Reports S&E-ASTN-TMV (72-74) and 83TP-1.

SYSTEM VERIFICATION PROGRAM

ATM systems verification testing were accomplished on the ATM vibration unit, prototype unit, and flight unit. Included were special tests as required to determine structural integrity of ATM. In-process, post-manufacturing, vibration, and Post-vibration tests were conducted at MSFC. Thermal vacuum and post-thermal vacuum testing were accomplished at JSC. The final Pre-launch tests were conducted at KSC. These tests were completed per the ATM Test and Checkout Requirements and Specifications Document Flight Article "As Flown", 50M02425 Rev. E.

In addition to the above a vibration test was conducted at MSFC using the ATM vibration unit as a test specimen. The ATM Vibration Unit Vibration Test Specification, 50M03509 provided the specifications and control tolerances for the test.

The vibration unit was subjected to both sinusoidal and random vibration testing in all three axes. The test data when coupled with dynamic analyses were used to evaluate the ATM structural math model and to investigate the effects of complex localized vibration response induced through the ATM primary structure.

Results of this test indicated excessive response of the ATM canister to longitudinal vibration. The problem was attributed to high cross coupling of lateral and vertical excitations. A flight plan change was initiated and approved which implemented a staggered engine cut-off sequence on the SI-C Booster Vehicle. Figure 6-19 illustrates the 4-0 versus 2-2 70 millisecond staggered engine cut-off sequence acceleration pattern.

Systems Verification (Prototype)

During Post-Manufacturing Checkout (PMC), problems were encountered with the experiment aperture doors overrunning the mechanical stops and driving into the hardstops. Redesign of the doors

Table 6-II. ATM Structures Component Life Cycle Tests

Component	Test Report	Test Results
Film Retrieval Doors	S&E-ASTN-TMM (71-70) ATM H-Alpha 1 and HAO Film Retrieval Doors	Satisfactory - No Anomalies.
Cable Roll Adapter	S&E-ASTN-TF (56-71) ATM Cable Roll Adapter	Satisfactory - No Anomalies.
Aperture Door/ Torque Motor	S&E-ASTN-TMM (71-68) ATM Aperture Door Development Test Report	Paint Peeled and Cracked. Lubricant Flaked Off. Added a Motor Run-In Procedure prior to Installation to Prevent Lubricant Flaking.
GN_2 Retract Mechanism	DOP-TMM-72-20 The Vacuum and Life Cycle Test for the GN_2 Retract Mechanism	Satisfactory - No Anomalies.
Roll Actuator Drive/ EPC Actuator	S&E-ASTR-SI-9-70 Life Test Duty Cycle for Astrionics ATM Components	Roll Actuator Drive Pinion Gear Failed; Redesign and Retest Satisfactory. EPC Actuator Satisfactory.
Orbital Locks	S&E-ASTR-SI-9-70 Life Testing Duty Cycle for Astrionics ATM Components	Mechanical Stops Failed. Redesigned Stop Assembly, Status Switch Roller Surface and Changed Lubricant.

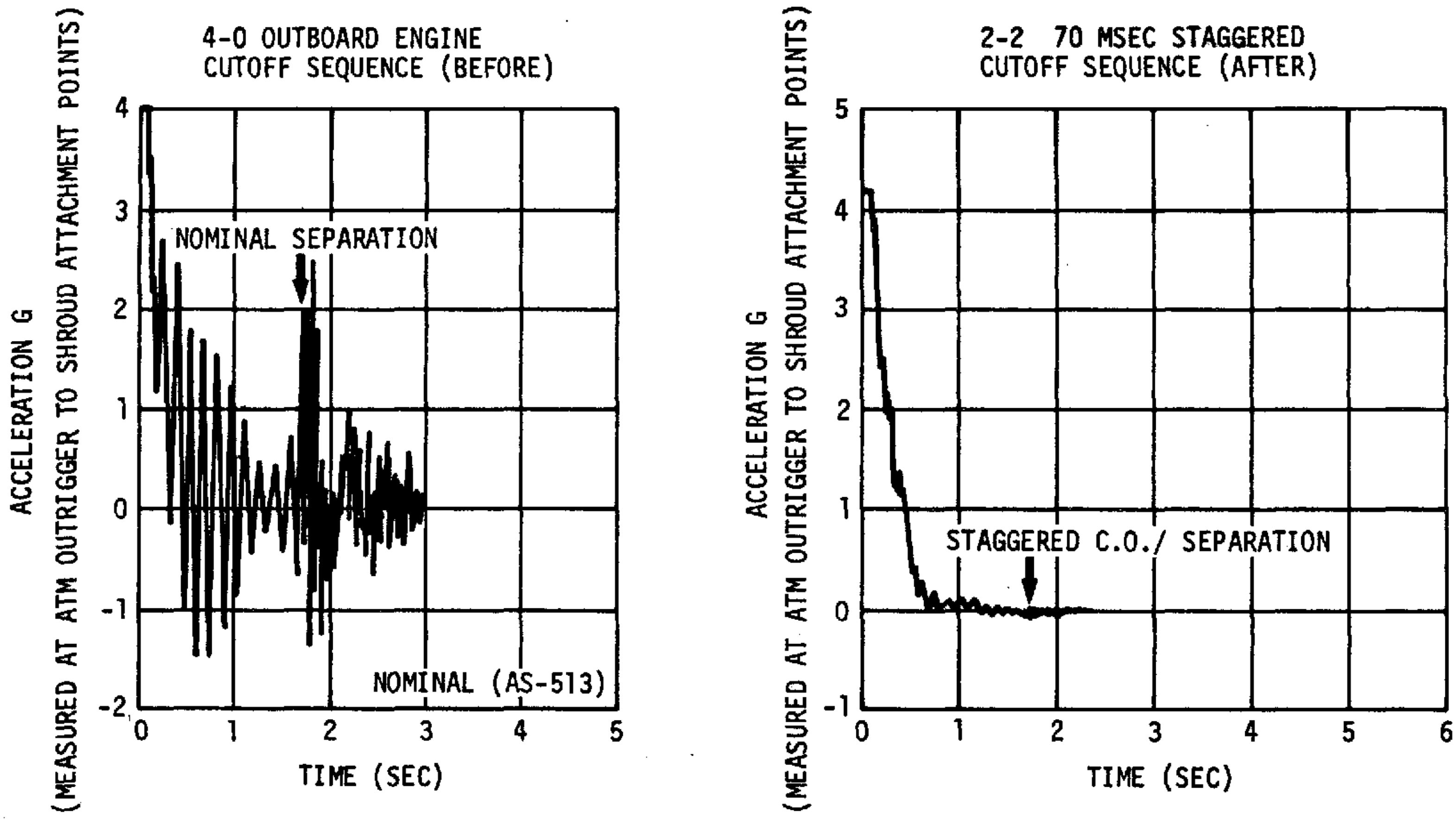


Figure 6-19. Saturn V. Engine Cut-Off Acceleration Pattern

included improved limit switches and stops. A door-operate timer was also added to the door electrical circuitry along with operation of one rather than both motors to close the doors.

Vibration - To satisfy structural requirements, the prototype underwent vibration testing at MSFC, February through May 1972. The module was subjected to expected flight vibration levels (3 db below qualification levels) in the flight, lateral, and tangential axes. It was subjected to both random vibration and vehicle (Quasi-Sinusoids resulting from total vehicle moments due to liftoff, engine shutdown, and staging) dynamic transients. There were no discrepancies reported.

Thermal Vacuum Testing - During the thermal vacuum and post-thermal vacuum testing problems were again encountered with the experiment aperture doors. Individual tailoring of the doors to adjust ramps, latches, etc. was required to obtain satisfactory operation.

System Verification (Flight)

The ATM flight unit underwent the same testing during the Systems Verification Program as the prototype, plus prelaunch testing at KSC.

Throughout the flight unit verification problems with the experiment aperture doors continued. The doors were modified as indicated in figure 6-20. Final configuration of the doors permitted manual operation and procedural techniques that could be utilized in a contingency mode.

The flight unit was subjected only to random vibration in the flight axis at MSFC in June 1972. The article was tested to vibration levels of 6 db below the expected flight levels (i.e., 25% of flight levels).

No other structural or mechanical problems occurred during any of the tests.

Special Tests

Special tests were conducted on the ATM components as discussed in the following paragraphs.

Rack/CMG Structure - A static load test of the ATM rack was required to determine effects of rack loading on the operation

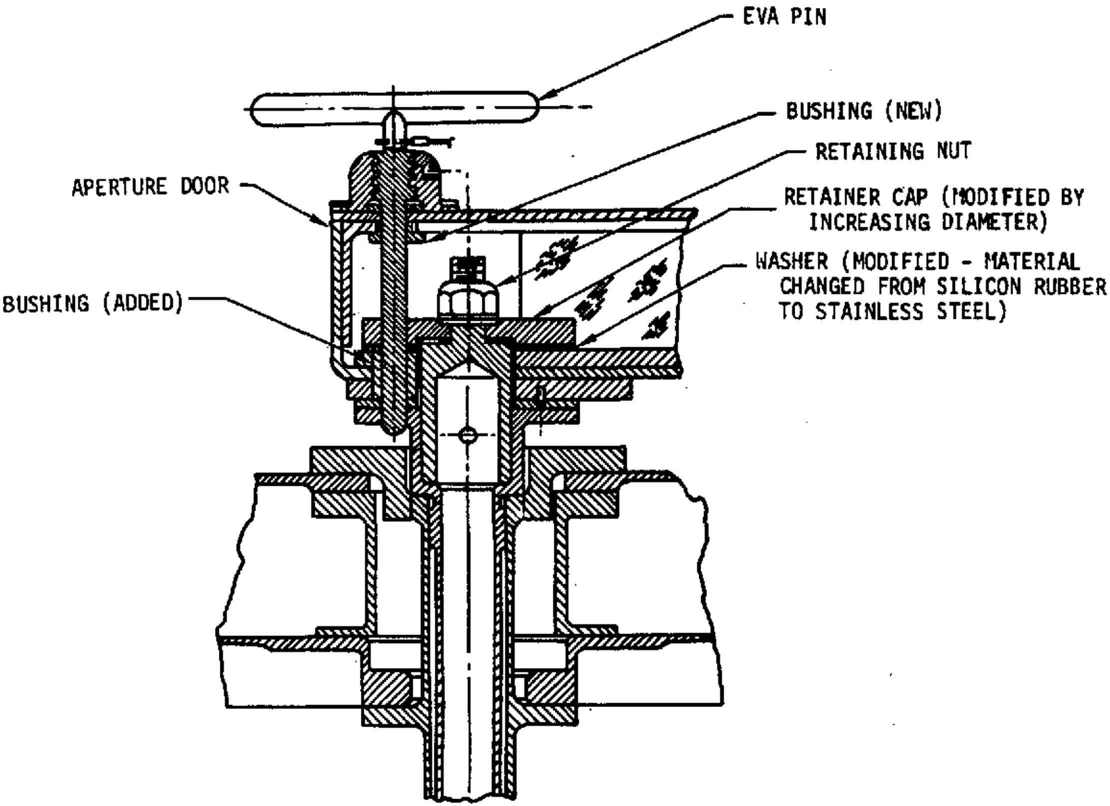


Figure 6-20. ATM Aperture Door Modifications

of the outer gimbal of the ATM CMG. Conclusions which were drawn from this test include the following:

1. The CMG was completely elastic for the loadings imposed, implying that the orbital operation of the CMG would not be impaired by any rack/CMG lifetime loadings.

2. Each CMG exhibited certain unique operating characteristic due to its design and assembly, which could be affected by loading imposed on the four support points.

3. Because the CMG structural model, on which this test was based, was apparently stiffer than the actual structure, and because the flight conditions considered in the study were envelope values, the loading imposed on the CMG was conservative.

4. Whatever anomalies might arise in the CMG operation from rack loadings should be limited to the outer gimbal, with no degradation indicated in the inner gimbal or gyro rotation axis.

Launch Lock Pin Puller (Shear Loads) - This test was required to determine the maximum load under which the ATM experiment package launch lock pin puller would perform its function under ambient conditions.

Eight tests were completed with applied loads ranging from 4,740/2,135 pounds to 15,420/2,134 pounds with resultant loadings of 4,360 to 16,000 pounds. In each test the pin puller functioned normally and withdrew the pin, releasing the launch lock arm.

Spar Alignment Test - Misalignment of the flight ATM spar in a 1-G environment was suspected due to a faulty crane during handling. Subsequent measurements on the spar indicated one lug head had moved .010 inches with respect to the other lugs. The spar structure was mounted to a fixture and vibrated to preclude any subsequent movement due to residual stress at Wyle Laboratories, Huntsville, Alabama. Numerous alignment checks were made with the experiments mounted on the spar both in 1-G environment and 0-G environment. All experiment alignment and co-alignment requirements were met.

Spar Plate - This test was run to determine the effective structural characteristics of the spar for axial and bending loads for use in an experiment alignment investigation. The test was successfully completed.

Launch Lock/Rack - This test was run to determine the structural characteristics of the launch locks under lateral loadings in orbit. The program was a part of an investigation to determine the loads on the launch lock pin pullers at time of retraction. The test was successfully completed.

Analytical Analysis

During the analytical analysis requirement to the Cluster Dynamic Model it was determined that the in-orbit docking loads were potentially damaging to the orbital locks. Resolution of this problem was the addition of backup rails to the existing orbital lock rails.

SECTION VII. THERMAL CONTROL SYSTEM

SYSTEM DESCRIPTION

The ATM Thermal Control System (TCS) was designed to maintain all temperature sensitive hardware within acceptable temperature range throughout the Skylab mission by assuring that an acceptable thermal balance was maintained between waste heat dissipation and the varying space environment. Two types of thermal control techniques were utilized. Passive thermal control management consisting of insulation, low-conductance mounts, reflective/non-reflective surface coatings, and thermostatically controlled heaters was utilized for rack mounted equipment which generally had broad allowable temperature bands. An active Thermal Control System consisting of coolant fluid and associated pumps, radiators, and controls was required for the experiment canister to eliminate experiment temperature fluctuations and gradients which would adversely affect the scientific data. In addition, individual experiment heaters, canister and spar insulation, and surface coatings contributed to the canister thermal control.

A gaseous nitrogen canister purge system provided assistance in thermal conditioning and maintained a positive canister pressure to prevent contamination of the experiments. The purge system operation was a ground checkout and prelaunch function.

Major Components

Rack Passive Thermal Control - For passive thermal control, rack components, which generally had large operating temperature ranges, were controlled using multilayer aluminized mylar insulation, structure isolation using titanium and fiberglass mounts, surface coatings, solar shields, radiation shields, and component power dissipation rates. This type of passive thermal control was supplemented with thermostatically controlled heaters. The passive system was cold biased to prevent hot conditions. Heaters were installed on forty components with a total rated power of 1281 watts. The CBRMs and rate gyros had proportional circuits which varied the heater power with the sensed temperature. The remaining component heaters utilized on-off mechanical type thermostats which were quad-redundant in design. The individual experiment thermal control systems are detailed within the experiment section of this report.

Canister Active Thermal Control - The major element of canister thermal control was the active fluid TCS. This closed loop system provided a stable environment for the experiments by removing the heat generated by the telescopes and translating it to a radiator which rejected the heat to the external environment. The active TCS consisted of 16 cold plates, 4 radiator panels, a pump package, an accumulator, an inline heater, mixing valve, hand valves, and tubing. Figure 7-1 is a schematic of the active TCS. The working fluid was a methanol/water mixture of 80/20 percent by weight. Sodium Benzoate in an amount of 0.1 percent by weight of mixture was added as an anti-corrosion agent.

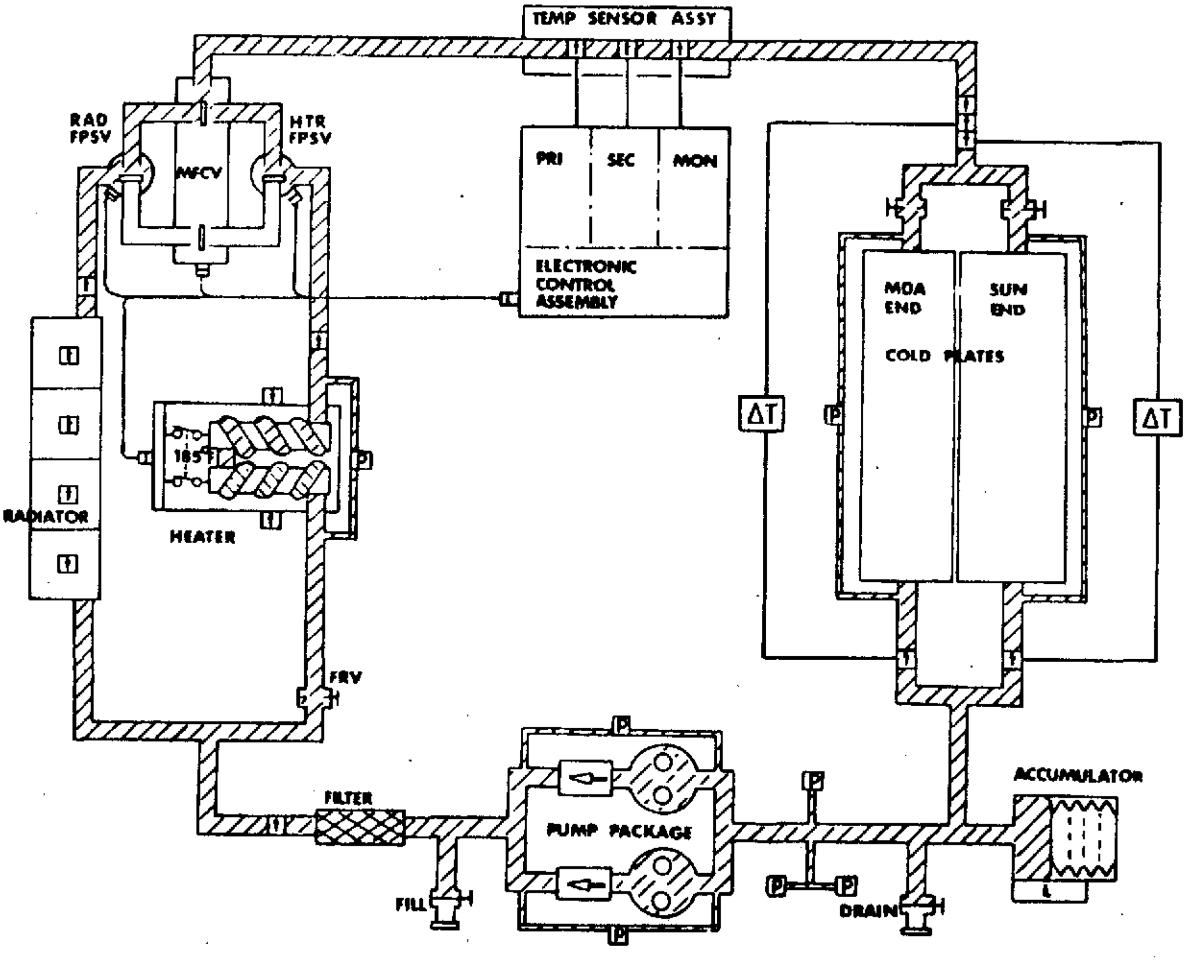


Figure 7-1. ATM Thermal Control System

As the fluid exited the pump at a nominal flow of 900 lb/hr, it was passed through a 400 micron absolute filter and routed into parallel radiator and heater paths. Flow proportioning through the paths was controlled by a mixing valve at the outlet connecting point. The mixing valve was positioned by signals from an electronic control assembly which monitored the canister inlet temperature to maintain a 10 ± 1.67°C inlet temperature at the cold plates. The fluid flow divided into equal paths where it flowed in parallel through the two canister halves consisting of eight cold plates each. Flow leaving the canister halves mixed and then passed by an accumulator before again entering the pump. The system was redundant except for fluid flow path.

SYSTEM EVOLUTION AND DESIGN RATIONALE

Responsibility for the conceptual design and development of a flight qualified ATM thermal control system was assigned to the Astronautics Laboratory (S&E-ASTN), Marshall Space Flight Center, Huntsville, Alabama. The basic charter was to provide the ATM with a thermal system that would maintain all temperature sensitive hardware within acceptable temperature ranges throughout the Skylab mission. This was to be accomplished by assuring that an acceptable thermal balance be maintained between waste heat dissipation and the varying space environment.

Early History

The initial design concept encompassed a passive/semi-passive thermal control system. The passive system considered the tailoring of high performance insulation, reflective/non-reflective surface coatings and low conductance mounts. The semi-passive thermal management included on/off and proportional heaters with sensed temperature controls. As the basic overall design of the ATM evolved with the spar and experiments enclosed within a canister, thermal analyses dictated a need for a positive high load thermal management system to maintain the stringent temperature gradient requirements for the experiments. From this requirement evolved the active fluid thermal control concept with related cold plates and radiators in addition to the passive/semi-passive thermal control system.

Design Evolution/Rationale

In the 2nd quarter of 1967, a firm decision was made to use the liquid thermal control system for canister thermal management in addition to the existing passive and semi-passive concepts. Studies were underway considering freon or methonal/water mixtures as the coolant fluid. A mixture of methonal/water at 80/20 percent was utilized in the final design of the system. This decision was based upon utilization of existing hardware for the system. The Command Service Module thermal control system used glycol as a coolant which is similar to methonal/water. Modified Command Service Module pumps were first considered but were found to be inadequate. An enlarged version of this pump and motor was designed and proved satisfactory.

As ATM design progressed, basic thermal management requirements were finalized. The following criteria summarize these basic guidelines:

1. Canister fluid inlet temperature must be controlled to 10 ± 1.67°C with 10 ± 0.56°C control as a design goal.

2. The maximum fluid temperature rise in the canister must not exceed 2.78°C as a design goal.

3. The maximum canister heat load was 500 watts.

4. The radiator fluid temperature could be expected to range between + 10°C and - 73.4°C.

5. No boiling or freezing of the fluid was allowed.

6. Maximum use of off-the-shelf hardware was necessary.

7. The spar must be thermally stable within a temperature range of 10 to 21°C.

8. Astronaut EVA touch temperatures must not exceed a maximum of 121°C.

9. Fluid lines cannot cross the gimbal plane.

During the development phase of the ATM TCS, the design concept proved satisfactory with only two major redesign efforts required. Flow instability problems early in the testing phase required relocation of the modulating flow control valve and associated equipment. Consideration was given to replacing the modulating flow control valve with a thermal mechanical valve to resolve the instability problem. Although the thermal mechanical valve assembly performed satisfactorily, the modulating flow control valve mixing concept remained as the desired system. This decision was based upon the modulating flow control valve having previously completed extensive qualification testing and consideration of scheduling impacts. The second design anomaly was seizure of the pump shaft due to bearing swell from long duration soak in the methanol/water mixture. Increased shaft to bearing clearances resolved this design problem.

MANUFACTURING

All components except radiators, cold plates, and tubing to component fittings were vendor supplied. Assembly operations were carried out by S&E-PE Laboratories at MSFC.

Radiators and Cold Plates

The radiators and cold plates were manufactured by machining flow channels in a thick plate, cold forming the machined plate to the canister contour and welding a matching face plate to the machined surface.

Figures 7-2 and 7-3 illustrate the radiator and cold plate config-

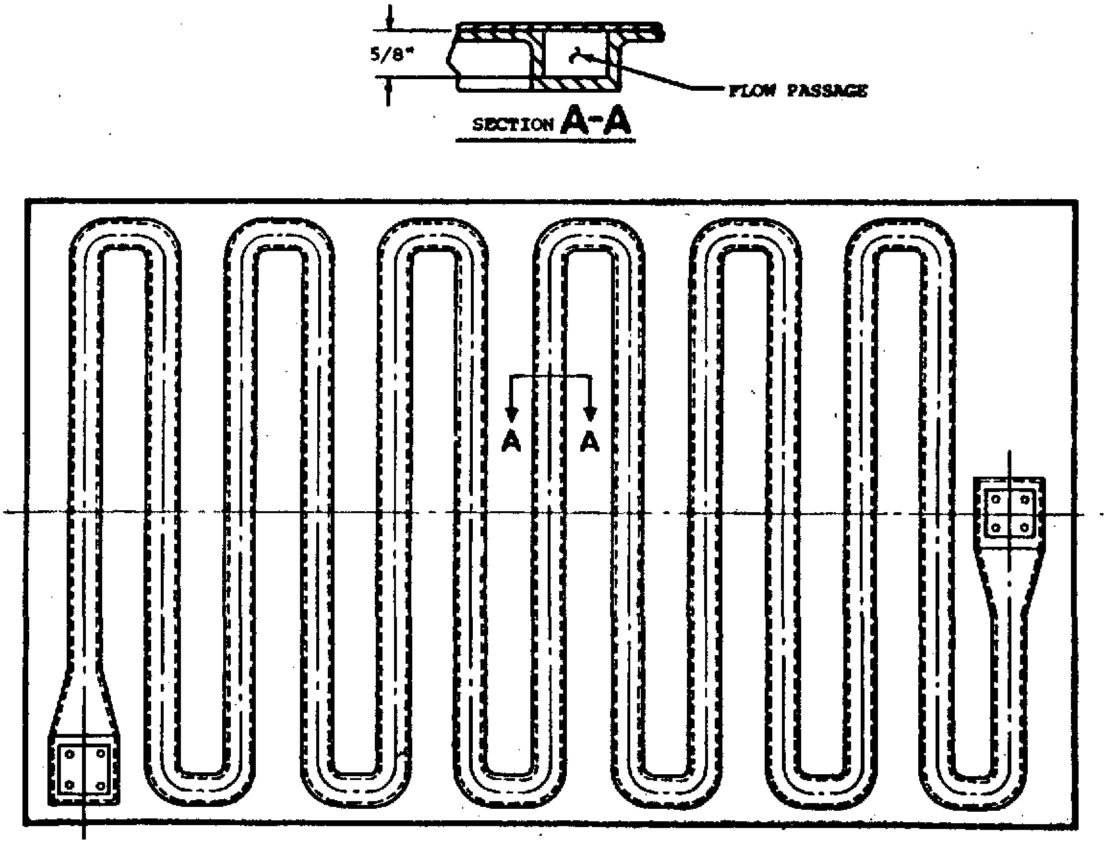
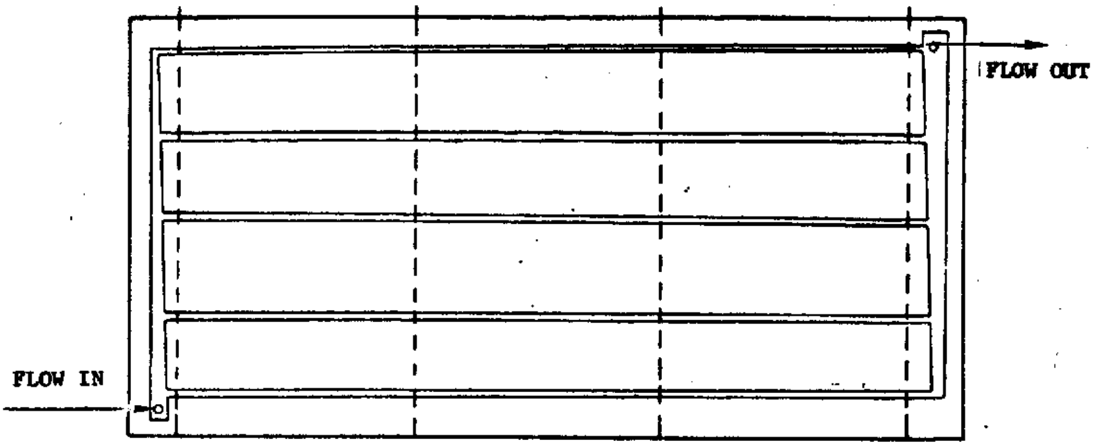
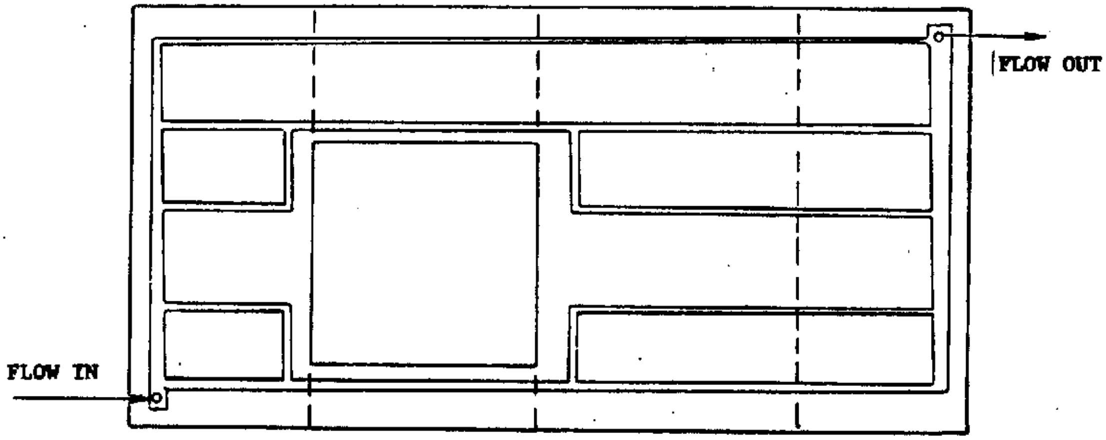


Figure 7-2. ATM Radiator Panel



Cold Plate without Film Retrieval Door



Cold Plate with Film Retrieval Door

Figure 7-3. ATM Cold Plate

uration. Three methods of securing the face plate to the machined plate were tested. The bonding and fusion welding concepts were deleted in favor of a resistance roll seam welding process. Special fixtures were developed to ensure stability of the machined plate and face plate as the welding operation was accomplished. Prior to the start of each production welding operation, a series of sample weld runs was accomplished. The sample welds were tested and the welding equipment adjusted accordingly to produce satisfactory production weld seams. No major problems were encountered with this method of manufacturing.

Tube Brazing

The TCS tubing was assembled utilizing Aeroquip Spacecraft fittings with associated Aeroquip brazing equipment. The brazing material was 82 percent gold and 18 percent nickel. The brazing function was at 1900°F. The Aeroquip method of joining the TCS tubing was chosen based on its high reliability and low weight to strength ratio. Initially, minor problems were encountered as the tube cleaning process deactivated the tube acceptance of the brazing process. This problem was resolved by plugging the tubes after chemical cleaning, sand blasting the braze area, and then cleaning the external surface by ultrasonic process.

Special fittings were developed to connect the tubing to the TCS components. The design was based on a four bolt flange with O-ring compression concept.

The TCS cold plates were mated with the ATM canister structural framework. The radiators were attached to the cold plate mounted standoff hardware. The fluid transfer hardware was then mounted and the connecting tubing routed to the respective components. Special tube routing jigs were utilized to ensure correct tube length prior to the brazing operation. After cutting and fitting of the fluid tubing, the tubing was braze assembled in place. The Aeroquip brazing method of tube assembly proved to be 100 percent satisfactory.

COMPONENT/END ITEM QUALIFICATION

Qualification of the TCS was a culmination of analytical studies and development, life, special and qualification testing operations. The analytical studies results compared favorable with the final configuration test data. A few problems were encountered during the physical testing phase requiring two major redesign efforts and the addition of thermal isolators to a number of the electronic black boxes. Successful redesign was demonstrated in the System verification tests. The analytical studies and test programs are discussed in the following paragraphs.

Analytical Studies

Although the ATM underwent several thermal vacuum tests, verification of an acceptable thermal design was based in part upon analysis, since the space environment imposed during tests cannot exactly duplicate flight conditions. In addition, flexibility and rapid response can only be obtained by math models. Therefore, analytical models were constructed to predict temperatures of the

ATM structure, electronics, components, experiments and TCS performance. Possible errors in the environmental model were reduced by utilizing two independent groups to calculate matching fluxes. The thermal analyses were checked by comparison with two full scale thermal vacuum tests wherein known environments were imposed on the model and the test vehicle.

Generally, the test versus analytical data indicated that the ATM was cold biased. The analyses further indicated that for the cold conditions, the maximum orbital average heater power required was 600 watts (approximately 50 percent of the total rated heater power). Both tests and analyses indicated that the rack components should be powered up within two hours after launch, and that the greater majority of rack components must be powered at all times to remain above minimum temperatures. Also, predictions for Z/LV maneuvers versus test data results indicated that no rack component would exceed upper temperature limits during planned maneuvers within existing constraints.

Thermal analyses of the canister were conducted for the various mission phases. Studies included hot and cold case plus Z/LV maneuvers. These studies established the maximum and minimum environments for the canister. The predicted spar temperature was within the 10 - 20°C allowable temperature range under all normal operating conditions. The experiment operational temperatures were primarily dependent upon the operational modes, active or standby, of the experiments. The electrical load of the telescopes was relatively constant with the exception of intermittent power increases due to camera operation. The normal heat load variation internal to the canister resulting from the experiments, electrical components and solar energy was found to be between 400 and 500 watts. Final thermal analysis versus physical test data results correlated within the predicted limits.

Development Tests

Development testing of the TCS was performed on the following ATM test articles:

1. Experiment Quadrant (Quad IV)
2. Rack Quadrant
3. Experiment Canister
4. Thermal Systems Unit (TSU)
5. ATM Canister TCS Breadboard
6. Redesigned Canister

Experiment Quadrant (Quad IV) - A full-scale mockup of an experiment package quadrant (designated Quadrant IV) as described in section III of this report was constructed to obtain preliminary design information on the canister and experiment thermal control concepts. The canister sidewalls were controlled to specified thermal boundary conditions that simulated requirements for the fluid TCS. Other tests were accomplished to assess the time required for the spar and experiment packages to attain an equilibrium temperature under varying thermal conditions; to measure temperature gradients across the spar and experiments; to determine the experiment temperature levels for given solar and electrical heat dissipation rates; to establish procedures for correlating analytical predictions with experimental results and to become familiar with ATM thermal system testing to minimize the test program expense, complexity, and time required to conduct future tests.

Thirteen tests were conducted at MSFC in the Sunspot I vacuum chamber facility. Data analysis indicated that the standoff heater design for the BBRC experiments was not adequate to provide the temperature control required for the experiments. The studies indicated heat losses from the instrument sides, which were not covered by standoff heaters, were greater than anticipated. Insulation and/or low emissivity coatings were incorporated in these areas to minimize heat leaks. Also, thermal isolation of the NRL-A camera from the experiment case was shown to be necessary to obtain acceptable operating temperature. The results of this test program were incorporated into the ATM thermal design prior to the PDR in September 1968.

Rack Quadrant - Initial development tests for the ATM rack thermal control were conducted in the Sunspot I vacuum chamber. Due to the chamber size, the ATM rack was divided into 4 parts, as described in Section III of this report. The thermal test data indicated that the passive thermal control scheme would provide thermal control of the rack and that the math models could predict operating temperatures with reasonable accuracy. The tests also indicated that some components were running too cold, either as a result of the wet workshop configuration or design deficiencies. Other than the verification of analytical techniques utilized to analyze the ATM thermal design, the results were negated by the switch from the wet workshop configuration to the current Skylab configuration.

Experiment Canister - Thermal vacuum tests were conducted to evaluate Experiment Canister thermal performance under conditions simulating ground operations, ascent and Earth orbit.

A series of 11 tests were conducted at MSFC in the Sunspot I vacuum chamber facility simulating various operating conditions. Included in the tests were steady-state and transient hot and cold orbital simulation, rapid ascent, orbital insertion and activation, and ground operations purge tests.

During the activation transient test a major TCS anomaly was noted. The strip chart that recorded the TCS methanol/water inlet temperature to the cold plates indicated extreme oscillations of the Modulating flow control valve. The valve oscillated continuously throughout the test program. During the cold case tests, the valve oscillations were minimal, allowing these tests to be conducted. However, during the hot case tests, the valve oscillated so severely (4.5°C to 10.2°C) that testing had to be discontinued. A strap-on temperature sensor was added and used as the electrical control assembly input signal instead of the normal inline sensor. Valve oscillations were noted with this modification but the oscillation amplitudes were small enough to allow the hot tests to be conducted. Even with the small oscillations the methanol/water was controlled within the design operating tolerance (10 ± 1.67°C). Testing and subsequent design changes required to solve the valve oscillation problem are discussed in the Redesigned Canister and ATM Canister TCS Breadboard paragraphs of this report.

In general, the ATM experiment canister thermal vacuum test series demonstrated the adequacy of the canister thermal design and provided sufficient test data to verify the canister thermal models. Specific conclusions were as follows:

1. The canister purge system demonstrated its ability to maintain the experiments within acceptable temperature limits during ground operations. Also, by utilizing 65°F preconditioning, the TCS and dry-gas purge could be deactivated and all canister equipment operated for 6 hours without exceeding any component temperature limits (for ground checkout purposes).

2. The preoperation and activation tests indicate that a minimum of 10 hours of ATM operation time was required to bring the canister experiments to acceptable thermal status following ATM activation after launch.

3. Oscillations hampered methanol/water TCS model verification. Further testing was required to resolve this problem. Therefore, no updates were made to this model. Even with the oscillation problem, the methanol/water TCS model agreed to within ± 15°F for radiator temperatures.

4. The canister experiment thermal model was capable of accurately predicting the ATM experiment package thermal response except for the optical and electronic assemblies associated with each experiment. Math model updates were necessary to enable satisfactory prediction.

5. Both H-Alpha experiments were cold compared to the analytical math model analysis. It was believed that this was due to contamination of the gold thermal control coating and was not anticipated on the flight instruments because of the stringent contamination control requirements.

Thermal Systems Unit (TSU) - To verify the ATM thermal design prior to manufacturing the flight unit, a thermal vacuum test was conducted utilizing a full-scale ATM as described in Section III. During the TSU assembly phase, a parallel effort had been in progress relating to an ATM Canister TCS breadboard test. Results of the breadboard tests indicated a redesign of the TCS was required relocating the modulating flow control valve to resolve the valve oscillation problem. Details of this test phase are noted in the ATM Canister TCS Breadboard paragraph of this report. Due to schedule constraints, the TSU could not be reconfigured to the latest design prior to its thermal vacuum test at JSC.

The ATM/TSU thermal vacuum test was conducted in the SESL Chamber A at NASA/JSC, Houston, Texas. The TSU was subjected to the extreme thermal environmental conditions of deep space, various mission phases, and variable internal power dissipation. These test conditions were sequentially oriented to minimize the required thermal vacuum test time; however, each test condition was carefully established to support achievement of the test objectives. The test objectives were:

1. Verification of thermal design and operation of the ATM when exposed to maximum and minimum thermal vacuum environmental conditions.

2. Collection of test data for verification of analytical techniques used to construct ATM thermal models.

3. Determination of any significant thermal problems that could adversely affect the success of the ATM program in subsequent testing and flight.

During ambient checkout of the TCS prior to chamber pumpdown (pumpdown number 1), the primary TCS pump would not operate after repeated attempts to start the pump. Pumpdown number 1 was completed using only the secondary pump. Prior to pumpdown number 2 a new pump assembly was attached across the TCS fill and drain valves. This added pump assembly was then utilized during the second pumpdown. The initial pump failure was attributed to the swelling of the pump bearing material against the impeller shaft. The pump bearing clearances were increased in all pumps to prevent this problem from recurring. This pump failure problem was also encountered during pump life testing and is discussed in the Component Qualification/Life Test paragraph of this report.

No other canister thermal design changes were required as a result of this test. For the rack components, the effectiveness of the passive system to maintain acceptable temperatures was generally confirmed. The CBRM and the rate gyro heaters were proven adequate. The need for other heaters designed for the flight unit but not installed on the TSU was proven. The test identified cold problems with the tape recorders, remote analog submultiplexer number 1, signal conditioning rack numbers 2 and 3, acquisition sun sensor, and the two Sun sensor electronic assemblies. Insulation patterns were altered to correct these problems on the flight unit. Verification of these modifications was accomplished during prototype and flight unit thermal vacuum tests. The test showed good correlation between model predictions and measured data which increased confidence in flight predictions. The successful completion of the ATM TSU thermal vacuum test, in general, demonstrated the adequacy of the ATM thermal design, and post-test data analyses verified the vehicle thermal models. Also, existing mission thermal constraints were verified to be adequate, and no new constraints resulted from the tests.

ATM Canister TCS Breadboard - Due to the TCS temperature oscillation problem encountered during the ATM canister thermal vacuum tests, a breadboard TCS model was constructed to help evaluate the problem and determine a design fix for the prototype and flight articles. The breadboard unit used flight type hardware with the exception of the radiator panels. Two TSU radiator panels were used to simulate the pressure drop of the flight system since the TSU radiator panels had smaller flow passages (0.447 inches square instead of 0.625 inches square). The hardware was arranged and mounted as the flight system with the radiator panels enclosed in a cold box through which cold GN_2 was purged to simulate the radiator fluid outlet temperature. The objectives of the ATM canister breadboard tests were:

1. Flow calibration of the canister TCS.

2. Verification of modulating flow control valve operation.

3. Verification of a thermal mechanical valve as an adequate replacement for the modulating flow control valve.

The valve did control the canister inlet temperature within the required range of $10 \pm 1.67^{\circ}C$ when operating in the proposed flight configuration. The thermal mechanical valve assembly also performed well and controlled the canister inlet temperature within the required range. However, since the modulating flow control valve had completed extensive qualification testing and due to scheduling problems, it remained the desired component for the flight article.

As a result of the program, after the TSU was returned to MSFC, three TCS design changes were made. The modulating flow control valve was relocated and utilized as a mixing valve at the junction of the heater and radiator outlets. The temperature control sensor was moved closer to the modulating flow control valve. The system control time constant was increased from 10 seconds to 100 seconds. The new design was verified by subsequent thermal vacuum testing.

Redesigned Canister - The thermal vacuum test of the redesigned ATM TCS was conducted in the Sunspot I Space Simulation Chamber at MSFC. The TCS was as nearly identical to the ultimate flight configuration as possible. Specific test objectives were to:

1. Verify satisfactory performance of the flight configured TCS.

2. Evaluate vent valve operation and canister venting characteristics during simulated ascent.

3. Evaluate canister leakage rate during chamber repressurization.

The test program demonstrated that the flight TCS design with the relocated modulating flow control valve and temperature control sensor remained stable in all modes of operation and the canister inlet temperature remained within the specified 10 ± 1.67°C at the radiator temperature extremes expected in flight. The flight pressure decay test proved adequacy and operation of the flapper vent valves. Negative canister pressure during chamber repressurization was not significant.

Special Tests

Special testing was performed during the development phase in the following disciplines:

1. Spar Stability

2. Pump Jitter

3. Canister and Radiator Pressure Drop

Spar Stability - Spar thermal deflection tests were performed from July through September 1967. Results of these tests were documented in Internal Note IN-P&VE-67-7. The test objectives were to evaluate spar stability for anticipated temperature gradient extremes and to obtain temperature/deflection data to be correlated with analyses. The full-scale spar was tested at ambient pressure. Maximum experiment mount conductance and maximum experiment/spar temperature gradients were simulated to create severe transient conditions. The shroud and gimbal conduction were not simulated. From the data accumulated, it was concluded that 1/2 arc second was the maximum deflection any experiment axis would encounter during any 15 minute period in the operational mode. These test results were incorporated into the overall ATM pointing and stability studies documented in 50M04967, Skylab Experiment Accuracy Analysis, ATM Experiments, Final Report.

Pump Jitter Test - Since the TCS hardware was mounted on the experiment package, the pump package might induce unacceptable vibration loads, thereby causing a "jittery" motion on the experiment pointing control. Therefore, a test was conducted to provide data on the effect of pump operation (induced vibration and forces) on the ATM experiments. At the time of the test, a flight pump was not available and an Instrument Unit pump was substituted since both were centrifugal pumps. For the tests the pump was rigidly mounted to a massive object and methanol/water (80/20) at 24°C was circulated through the pump at variable outlet pressures. The test results indicated that the pump output frequency could be easily isolated if required. However, subsequent tests conducted on the pump showed that isolation was not required. Vibration data was obtained from the ATM pump during thermal vacuum testing of the redesigned flight TCS. This test was conducted at MSFC in the Sunspot I test chamber during January and February of 1971. The results of the analysis showed that the pump induced vibration loads to the spar mounted equipment were negligible (reference memorandum S&E-ASTN-ADV-71-86).

Canister and Radiator Pressure Drop - A test program was conducted to determine the flow distribution in a cold plate section of the canister sidewall and the pressure losses in both the cold plate and the radiator modules. Another test objective was to evaluate two possible fabrication techniques for the modules. The canister module was welded and the radiator module was bonded. The test program and results are documented in memorandum R-P&VE-PT-68-156.

In summary, methanol/water (80/20) at 10°C was circulated in the test sections with variable fluid flow rates. The pressure losses in the cold plate flow passages indicated that the flow distribution was uniform in the test section. The maximum pressure losses in the cold plate and radiator sections were found to be acceptable since system pressure losses were within allowable limits. Also, the data verified that the analytical model used for pressure drop calculations was correct. Both fabrication techniques proved adequate as determined by the pressure loss data and additional testing was performed before selecting welded panels as the most desirable manufacturing technique.

Component Qualification/Life Tests

ATM Rack - The ATM rack heaters successfully completed the qualification tests. With the exception of the thermal performance test on the thermostat assemblies, both the heaters and thermostats were successfully subjected to tests shown in Table 7-I. Thermal performance testing of the flight thermostat assemblies was completed during thermal vacuum testing.

ATM Canister - All canister TCS components with the exception of the pump package successfully completed their qualification testing. The types of tests conducted on each component are shown in Table 7-I. Documentation reflecting qualifications test procedures and test criteria is shown in Table 7-II. TCS component life requirements are shown in Table 7-III.

TCS Pump - A pump failure occurred during pump life testing. The pump had been in operation 5500 hours of the required 7000 hours and had been soaked in methanol/water for 20 months of the required 24 months. After failure of the primary pump, attempts to operate the redundant pump also proved unsuccessful. Subsequent investigation revealed that extended exposure of the non-metallic bearing material, Fiberate (E2748-10275), to the methanol/water solution caused longitudinal swelling of the bearing resulting in pump seizure. The design modification was to enclose the non-metallic bearing in an aluminum case to prevent longitudinal swelling. This modification was successfully performance tested and installed on the flight unit. Delta qualification tests were performed to verify the acceptable long term effects of this modification.

The delta qualification test program for the TCS pump consisted of operating the pump for an additional 1500 hours to complete the total required 7000 hours lifetime testing and subjecting the pump to 200 start/stop cycles to confirm thrust bearing wear was not detrimental. The pump redesign affected only the pump bearing. Completing the remaining 1500 hours qualified the pump except for the bearing assembly. The qualification criteria for the bearing

Table 7-I. ATM Thermal Components Qualification Tests

COMPONENT	TEMP		LIFE	FLW VS ΔP	BURST	RFI	VIBR	ACO NOISE	HUMID	COMPAT
	SOAK	CYC								
FLOW PATH SELECTOR V	X	X	X	X	X	X	X			
MANUAL FLOW RESTRICT V	X	X	X	X	X		X		X	(Elastomer Seals)
M/W ACCUMULATOR	X	X	X		X	X	X	X	X	X
COLD PLATE	X				X		X	X		
RADIATOR	X				X		X	X		
PUMP	X	X	X	X	X	X	X	X	X	X
HEATER	X	X	X	X	X	X	X	X	X	X
TEMP SENS.	X	X	X			X	X	X	X	X
ELECT. CONTR. ASSY.	X	X	X			X	X	X	X	
MOD FLOW CONTR VALVE	X	X	X	X	X	X	X	X	X	X
FILTER	X	X		X	X		X	X	X	X
RACK HEATER & THERMOSTAT	X	X	X			X	X		X	

Table 7-II. Qualification Test Procedure and Documentation

COMPONENT	TEST PROCEDURE	TEST REPORT
Rack Heaters & Thermostats	Tylan Report R-2004-7 (Appendix A)	Tylan Report R-2004-7
Flow Path Selector Valve	STP-SSD-1024	NAS8-30075 (Final Report)
Manual Flow Restrictor Valve	5350-8219 HTL Industries	255920 HTL Industries
M/W Accumulator	Metal Bellows Corp CR-119	Metal Bellows Corp M-70432
Cold Plate	DOP-TMM-72-9	S&E-ASTN-TMM-72-78
Radiator	DOP-TMM-72-9	S&E-ASTN-TMM-72-78
Pump	AiResearch 695078	AiResearch 71-7254
Heater	DOP-TMM-69-20,21,24,28,29 DOP-TMM-70-5,7,12,13,23	In-ASTN-T-71-11
Temperature Sensor	Same as Heater	IN-ASTN-T-71-11
Modulating Flow Control Valve	Same as Heater	IN-ASTN-T-71-11
Electronic Control Assembly	Same as Heater	IN-ASTN-T-71-11
Filter	DOP-TMM-70-4, Rev. B QTP-P1D-10074	S&E-ASTN-TMM (71-32) QTP-F1D-10074
Pump Inverter	40M26576, Rev. E	40M26992

Table 7-III. TCS Component Life Requirements

COMPONENT	MAXIMUM LIFE REQUIREMENTS
Pump	7000 Hours Operation and 200 Starts
M/W Accumulator	200 Cycles
Electronic Control Assembly	7500 Cycles
Modulating Flow Control Valve	7500 Cycles
Temperature Sensor	7500 Cycles
Heater	7500 Cycles
Flow Path Selector Valve	1000 Cycles
Manual Flow Path Restricter Valve	1000 Cycles
Rack Thermostats and Heaters	15000 Cycles

assembly was that excessive wear must not occur on the thrust and journal surfaces and that swelling of the journal surface would not produce interference with the shaft. Wear of the thrust surfaces was verified by the 200 start/stop tests performed since wear of the thrust surfaces was most critical during stop/start cycles because there was no fluid film available to separate the moving part. Wear of the journal surface was shown to be nonexistant during the 5500 hours of operation. Review of the journal swelling indicated that the clearances available swelling would be within acceptable limits for the entire mission.

SYSTEMS VERIFICATION PROGRAM

The functional operation of the TCS was verified as an integral part of the ATM prototype and flight units module testing. This testing was conducted in accordance with 50M02425, ATM Test and Checkout Requirements and Specifications (TCRSD).

Configuration changes and thermal vacuum test anomalies precluded complete thermal systems checkout on the prototype unit. These items, as discussed below, were verified during flight unit systems verification.

System Verification (Prototype)

Post Manufacturing Checkout (PMC) - Post manufacturing checkout of the thermal system consisted primarily of checking out the active fluid loop and the pump package. The tests performed on the TCS were: 1) leakage, 2) system cleanliness, 3) flow balance, and 4) operation of all valves and controls. Test results indicated the TCS functioned properly.

Thermal Vacuum Test - The prototype thermal vacuum test sequence consisted of two pumpdowns of the Space Environment Simulation Laboratory Chamber A at Johnson Space Center (JSC). The purpose of the initial chamber pumpdown was to calibrate the S082A, S055A, and S082B experiments under vacuum conditions in a Sun-end down position. Following this calibration, the ATM was rotated to Sun-end up position and a system verification check was made in ambient conditions to verify system operation in preparation for the second pumpdown. The second pumpdown consisted of an infrared (IR) lamp flux calibration followed by thermal vacuum simulation of preoperation, activation, and six operational thermal simulation test sequences as well as a contingency mode run. The prime objectives of the test were to verify proper operation of the ATM systems in a simulated orbital thermal vacuum environment; determine if any significant thermal problems existed; and provide test data for verification of the analytical techniques used to construct the ATM thermal mathematical models.

From analysis of the test data, it was concluded that all major thermal test objectives were achieved. The canister TCS functioned properly and maintained all experiment interface thermal requirements; however, some experiments ran slightly outside prescribed temperature limits during various test phases. Some of the out-of-limit conditions on the experiments were attributed to test anomalies and the remaining conditions were due to excessively stringent temperature limits which were changed for the flight article. Canister test results indicated no thermal problems requiring a redesign of any canister component. The data correlated reasonably well with the analytical model. Ninety-three percent of prototype canister and experiment temperature measurements correlated within $\pm$ 3°C. This correlation provided confidence that the models could be utilized to make satisfactory flight predictions and to help resolve real time flight thermal problems and/or anomalies.

Test results also showed that the passive thermal design could maintain specified allowable temperatures on the rack for all planned missions. However, there were anomalies requiring minor correction on the flight unit. The star tracker optical-mechanical assembly operated below allowable limits for the cold runs. An additional 10 watt heater was added to the flight unit to correct the deficiency. The acquisition sun sensor electronic assemblies operated below their limits during the cold runs due to a thermal short in the insulation blankets. This was corrected on the flight unit by adding insulation to the inside surface of the thermal cover. The digital computer heaters failed to maintain the powered down computer above its minimum turn on temperature. This was corrected on the flight unit by decreasing the conductance to the mounting panel by inserting stainless steel washers and by increasing the thermostat turn-on temperature. The same type washers were also utilized for the RASM #2 heater to raise the component temperature since the RASM operated below the lower temperature limit during the test.

Four of the rack heaters could not be checked during prototype thermal vacuum testing. Sufficient temperature measurements were not available to check out the three CMG inverter heaters and an instrumentation failure prevented checkout of the EVA rotation control panel heater. All flight unit thermostatic heaters were checked for proper operation during flight unit thermal vacuum testing.

Analytical models were verified by the prototype unit thermal vacuum tests for transient and steady state conditions. The data showed that 66 percent of all analytical correlations were within $\pm$ 5°C and 96 percent were within $\pm$ 10°C. A normal distribution statistical analysis of the prototype cold case data gave a standard deviation of 5.1°C. It was concluded that the updated models could confidently be utilized for making satisfactory flight predictions and for resolving real time flight thermal problems and/or anomalies.

Vibration Test - Upon completion of the thermal vacuum test, the ATM prototype unit was subjected to a series of vibration tests. Results from the vibration testing did not influence the system thermal design.

System Verification (Flight)

The flight article verification program consisted of PMC, vibration and thermal vacuum tests. The primary purpose of the test program was to serve as an acceptance test for the flight article.

Post Manufacturing Checkout - Tests conducted during PMC on the flight article were the same tests as conducted on the prototype. No thermal related anomalies occurred during PMC testing.

Vibration Test - The vibration test was conducted on the flight article following PMC. No anomalies relating to the thermal system occurred during this test.

However, concurrent with PMC, the qualification pump being subjected to life testing failed resulting in a bearing redesign. The redesign on the pump was not completed until after the completion of the vibration test at which time the flight article pump package was replaced.

Thermal Vacuum Test - The flight article thermal vacuum test objective was to verify proper operation of the ATM systems in a simulated orbital thermal vacuum environment. The objectives of the test were satisfied through a series of test runs simulating as closely as possible the predicted extreme thermal vacuum environments expected during the ATM mission. This subsection is limited to a discussion of the canister liquid TCS and the rack auxiliary heaters. The other thermal control system components such as surface coatings, insulation, experiment TCS heaters, etc., are integral parts of other subsystems, and are discussed in the appropriate system subsection.

The canister liquid TCS flow was stable throughout testing. The temperatures were within their allowable operational limits, except during periods when the MFCV was unable to control the canister inlet temperature. This condition existed because the radiator outlet temperature exceeded 10°C. This situation initially occurred during the last 34 minutes of Z/LV (R) Phase II of the test. The radiator outlet and canister inlet temperatures reached maximum of 14.2°C and 12.7°C respectively. The system flow was diverted through the radiator during this period. The same situation occurred during Phase II of the prototype Z/LV (R) test, but only for a period of 18 minutes. The out of specification condition was analytically predicted and determined to have negligible influence on experiment temperatures. Therefore, it was not considered as a system amlfunction or anomaly. Overall TCS performance was satisfactory during the thermal vacuum tests.

Several ATM rack components were equipped with auxiliary heaters. The rate gyros and CBRMs had proportional heaters. The other component heaters were of the on/off type. During the thermal vacuum test there were no major anomalies related to the rack auxiliary heaters. Details of each component heater performance were delineated in the ATM Flight Thermal Vacuum Test Final Report, ED-2002-1531-2 dated December 29, 1972.

Prelaunch Checkout - The only significant event occurring at KSC related to the TCS was the impact of removing the Sun-end canister. A drain and dry operation was performed on the TCS prior to removing the canister. After the canister was reinstalled the TCS was refilled and a flow balance performed. A TCS monitor test was performed to verify the operation of the TCS high and low temperature warnings and heater surface high temperature warning which were displayed on the caution and warning panel. The flow and functional tests consisted of a verification of methanol/water flow rates; checkout of TCS heaters; modulation of the methanol/water flow from bypass to radiator and radiator to bypass of both the primary and secondary systems. Control circuits of control and display panel and monitor circuits of the caution and warning system were verified.

The TCS was operated during the all systems test in order to verify its integrity relationship to the operation of the ATM systems. All tests of the ATM TCS performed at KSC were accomplished with no anomalies noted and test results met all applicable requirements specified in the Test and Checkout Requirements and Specifications Document, 50M02425 Rev. E.

SECTION VIII. ELECTRICAL POWER AND NETWORKS SYSTEM

SYSTEM DESCRIPTION

The ATM electrical power system was a combination of the ATM solar array system, charger/battery/regulator modules, transfer buses, switch selectors and power, control, measuring and logic distributors. The transfer buses were designed to transfer power from the ATM to the rest of the cluster, as required to meet the overall requirements of the cluster. The ATM power system could be operated independently or in parallel with the AM/OWS power system, having a sharing capability of 2500 watts in either direction.

ATM Electrical Power and Networks System

The ATM electrical power system (EPS) generated, conditioned, stored, controlled and distributed 26.5 to 30.5 Vdc power to the ATM system and experiment loads and to the transfer buses during normal orbital operations. The ATM solar array deployed from the ATM rack provided unregulated dc power during the sunlight portion of each orbit to the charger/regulator/battery modules (CBRMs) on the ATM rack. The ATM EPS was controlled and monitored by the crew using the switches on the C&D panel or the digital address system. Ground control capability was provided through RF uplink commands. Table 8-I lists the components of the ATM APS. Figure 8-1 shows the sections of the C&D panel that were associated with control and monitoring of the ATM EPS.

Power Generating System

The ATM electrical power system consisted of a four-wing solar-cell array and 18 CBRMs for power conditioning, storage and control. The output of each solar cell panel was connected to a single CBRM to form an individual power generation unit. (The ATM solar array is covered in Section VII of this report.) The output of each CBRM was connected in parallel through isolation diodes to the two ATM main buses via the two collector buses in the power transfer distributor of the distribution system. Each main bus was capable of supplying the ATM electrical requirements independently. Figure 8-2 is a block diagram of the ATM electrical power system.

Table 8-I. ATM Electrical Power System Components List

COMPONENT	PART NO.
CHARGER/BATTERY/REGULATOR MODULES (18)	40M26200
MASTER MEASURING SUPPLIES (2)	40M26271
NRL/HAO POWER SUPPLIES (3)	40M26580
POWER TRANSFER DISTRIBUTOR	40M37380
MAIN POWER DISTRIBUTOR	40M37381
AUXILIARY POWER DISTRIBUTOR	40M37382
CONTROL DISTRIBUTOR NO. 1	40M37383
CONTROL DISTRIBUTOR NO. 2	40M37384
CONTROL DISTRIBUTOR NO. 3	40M37387
CONTROL DISTRIBUTOR NO. 4	40M37388
CONTROL DISTRIBUTOR NO. 5	40M37393
CONTROL DISTRIBUTOR NO. 6	40M37394
C&D LOGIC DISTRIBUTOR	40M37390
MEASURING DISTRIBUTOR NO. 1	40M37385
MEASURING DISTRIBUTOR NO. 2	40M37386
MEASURING DISTRIBUTOR NO. 3	40M37389
"J" BOX	40M33680
"J" BOXES (11)	40M33681
"J" BOX	40M33691
SWITCH SELECTORS MOD II (3)	50M67864-7
SWITCH SELECTOR MOD III	50M67864-7
WATT HOUR ASSEMBLY	40M37998
EBW FIRING UNITS (4)	40M39515-131/135
EVA LIGHTS (12)	40M51269
TRANSIENT FILTER	40M38547-1
MOTOR TRANSIENT SUPPRESSORS (4)	40M38697-1
CABLE SYSTEM (625)	(*)

(*) REFER TO ATM CABLE INTERCONNECTION DIAGRAM 40M33651, AND ATM ELECTRICAL SCHEMATICS 40M33652

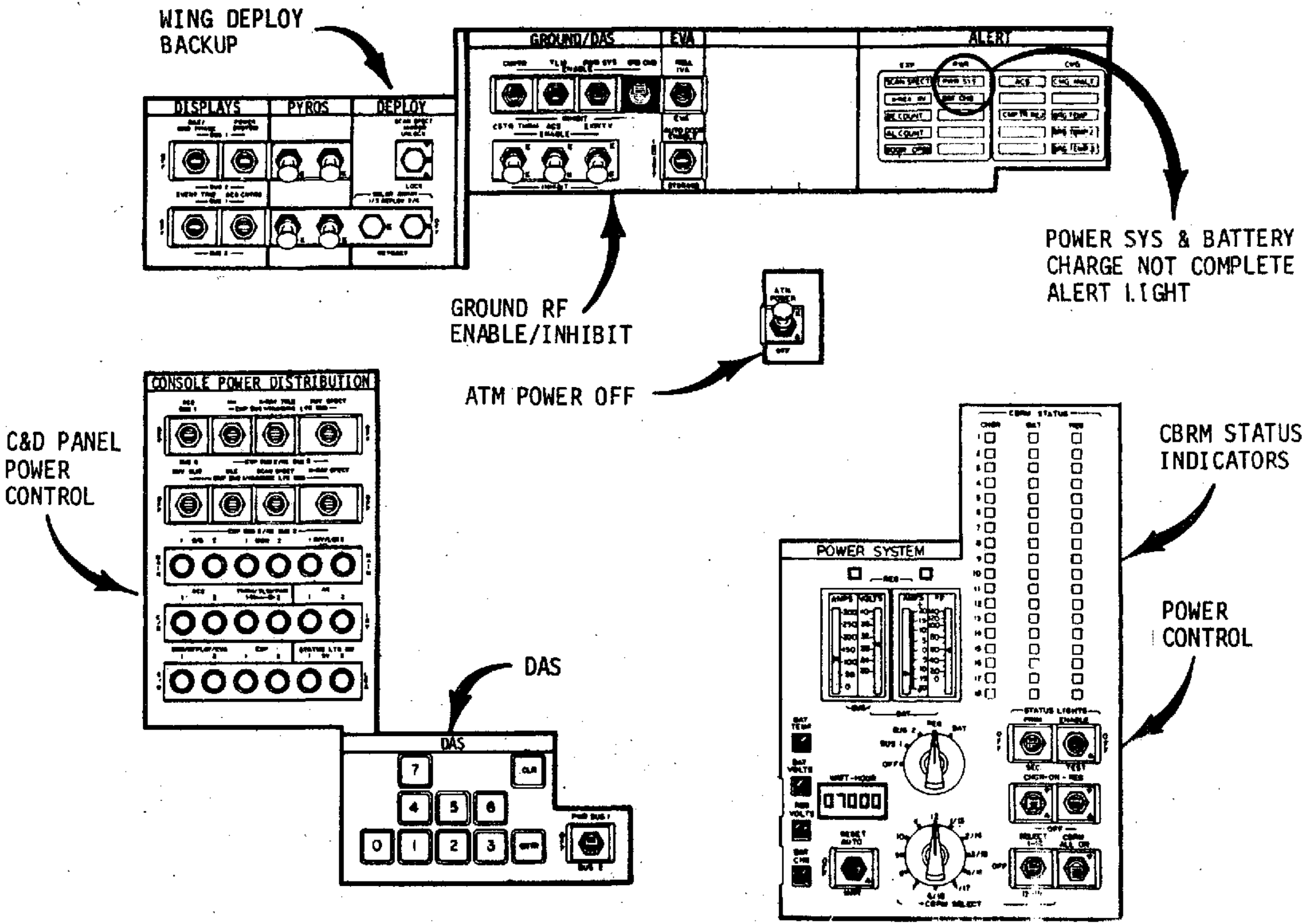


Figure 8-1. C&D Panel Sections Associated with the ATM EPS

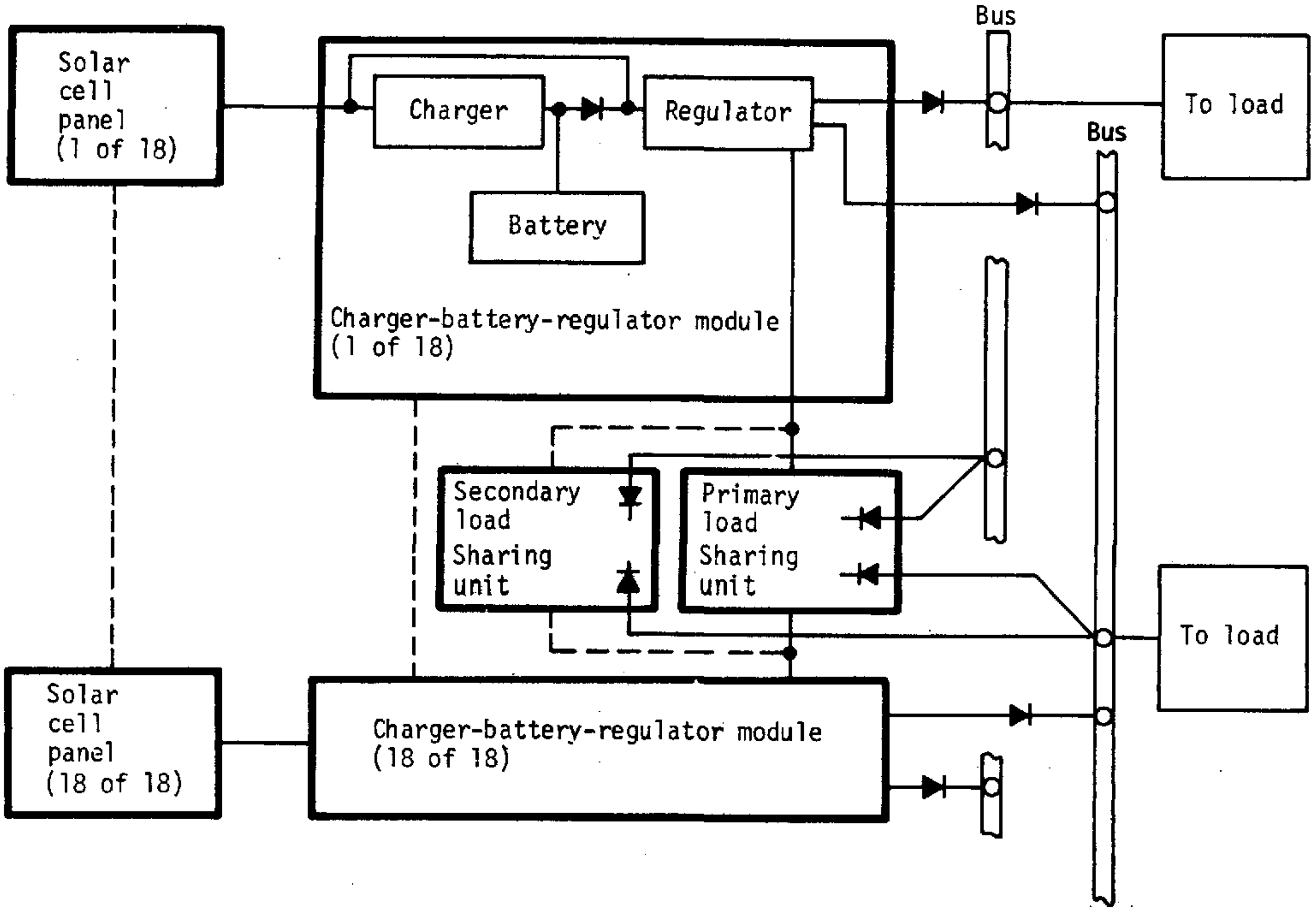


Figure 8-2. ATM Electrical Power System, Functional Diagram

Networks Distribution System

The ATM networks system provided an electrical interface between all ATM components, assemblies and subsystems, and between the ATM module and other Skylab modules. Distribution of the power, commands and indications throughout the ATM was accomplished by a network consisting of 13 distributors, 4 switch selectors and 625 cables. The distribution system provided the capability to operate the ATM EPS in parallel with the AM/OWS EPS; to manage and evaluate the power by crew and/or ground station; to provide power and control logic circuitry to the various ATM subsystem loads; and to perform integrated prelaunch test and checkout, module testing and launch operations.

Redundant subsystem buses were established to facilitate power management, power evaluation and an integrated system operation. Several methods of control were used to ensure that the buses could be turned "ON" or "OFF" during manned and unmanned modes of operation. At launch, the main buses were "ON" and the subsystem buses were "OFF". Subsystem buses were energized during the initial orbital phase.

When the subsystem buses were activated in the power transfer distributor, power was immediately distributed to the other 12 distributors. Each redundant subsystem bus was capable of providing the total power required by its subsystem. The power return was isolated from structure except in those items which had been waivered. Each distributor maintained power redundancy and bus isolation. The distributors were used to aid in routing of all signals, to contain the logic and switching required by the ATM subsystems, and to contain any special electronics to ensure proper operation.

Connections to ground power sources used in test and launch operations were provided by the networks system. Regulated +28 Vdc applied to the two main buses through the use of ESE carry-on cables provided the capability to check out the ATM Module without the use of ATM EPS. Solar array simulated power (15-80 Vdc) was supplied to the CBRMs to allow the checkout and testing of the ATM Module using the CBRMs. When the CBRMs were onboard, the batteries received trickle charge power through the ESE umbilical.

Charger/Battery/Regulator Module (CBRM)

The CBRM was a complete package containing charger, battery, voltage regulator, and associated auxiliary circuits and control devices. The CBRM operating conditions are listed in table 8-II.

Table 8-II. CBRM Operating Conditions

Operating Condition	Total 94 Minute Cycle	
	58 minutes solar power input	36 minutes no solar power input
Output Voltage	27.1 to 30.4 Vdc	27.1 to 30.4 Vdc
Maximum output voltage ripple	0.10 V-peak-to-peak	0.18 V-peak-to-peak
Maximum input voltage	80 Vdc	35 Vdc
Regulator minimum input voltage	40 Vdc	25.5 Vdc
Maximum power output	415 W	415 W
Continuous power output	235 W, average	235 W, average

Charger Section - The CBRM battery charger was a stepdown single-ended switching regulator circuit designed to convert the wide range of input voltages from the solar array source to the level required for charging the battery. The solar array source fed the charger and regulator in parallel; the regulator demands were met first, and excess power was used to charge the battery. The charger sensed the voltage and current input of the solar array and the voltage, temperature, charger current and third electrode voltage of the battery to accomplish charging. The charger was turned on automatically when the solar panel input voltage exceeded 42 volts and a charger ON command had been initiated. The charger discontinued charging when the CBRM input voltage became less than 38 Vdc and turned off at 36 Vdc. The output of the charger was protected from short circuit by current limiting; current limit was 15 amperes.

Battery Section - The ATM electrical power was supplied by the 18 nickel-cadmium storage batteries during the dark portion of the orbit. The batteries were rechargeable and the energy depleted during dark orbit discharge was replenished during the daylight portion of the orbit. Each CBRM battery was composed of 24 type AB-12-G, nickel-cadmium, 4-electrode, hermetically sealed cells connected in series. In addition to normal positive and negative electrodes, the cells had a third electrode which was used in charge control, and a passive fourth electrode which was an oxygen and hydrogen recombination electrode. Each battery had a rating of 20 ampere hours when discharged at a 10 ampere rate and a battery temperature of 25°C (77°F). The voltage output was 26.4 to 32.5 Vdc when discharged in the load range of 10 amperes or less. Each battery weighed 48 pounds and had a life requirement of 4000 cycles at an average maximum depth of discharge of 30 percent. The battery was protected from temperatures below 5°C (41°F) by an automatic electrical heater. Heat was removed from the battery by passive cooling.

Regulator Section - The CBRM regulator was a single-ended switching regulator circuit designed to convert the input voltage (25.5 to 80 Vdc) into a closely regulated output voltage. The output voltage was maintained between 27.1 Vdc at full load and 30.4 Vdc at no load, with the output current limited to 20.0 amperes maximum under output short circuit conditions. The regulator had a peak output power capability of approximately 415 watts. Power sharing between regulators was maintained by a power sharing signal derived from redundant circuitry located in the power transfer distributor. The circuit provided protection to the bus from over-voltage if it exceeded 31.8 Vdc. Any failure in the regulator power circuit would result in no output voltage, thus protecting the buses from high battery and solar panel voltages.

Auxiliary Power Supply Section - This section developed the required 15 Vdc biasing voltage for operation of the CBRM circuitry. The input power was supplied by either the solar panel or the CBRM battery. Input voltage sensing was provided which would automatically turn off the power supply if input voltage decreased below 26 Vdc. Normal operation was automatically restored if input voltage increased above the minimum level. If the 15 Vdc bias power supply reference voltage exceeded 15.2 Vdc or dropped below 14.8 Vdc, the CBRM was automatically deactivated.

Control, Metering, Telemetry and Alert Section - This section of the CBRM provided control, protection, and monitoring of the charger, battery, and regulator for porper CBRM operation. The section responded to commands originating from the C&D panel or ground command, and to the CBRM malfunction detection circuitry to activate and deactivate relays that controlled the operation of the CBRM.

Power Supplies

Master Measuring Voltage Supply - There were two redundant, independent measuring voltage power supplies which were controlled by the ATM command system. The power supply converted 28 Vdc main power to highly regulated 5 Vdc output. The 5-volt output was supplied to measuring distributors which distributed the 5 Vdc throughout the ATM measuring system.

NRL/HAO Power Supply - The NRL/HAO power supply was a solid state dc-to-dc converter capable of supplying 28 ± 2 Vdc at 0 to 1 ampere continuously with an input of 25 to 30.5 Vdc. The isolated 28 volts was distributed through control distributors to the Naval Research Laboratory (NRL) and the High Altitude Observatory (HAO) experiments.

Distributors and Switch Selectors

Power Transfer Distributor - The power transfer distributor served as the point of origin for all of the main ATM power buses. The power transfer distributor also provided control and logic circuitry for selected ATM components and systems. Control of the circuitry in the power transfer distributor was accomplished through switch selector commands, interface commands, or panel commands issued at the C&D panel by the crew.

Main Power Distributor - The main power distributor received power from the power transfer distributor primarily to drive some of the major power loads and control and logic circuitry in the Attitude and Pointing Control System (APCS). Circuit control within the main power distributor could be accomplished by either switch selector commands or crew-issued commands from the C&D panel.

Auxiliary Power Distributor - The auxiliary power distributor routed the power primarily to the APCS and to the video system. The logic of the auxiliary power distributor could be controlled either by switch selector commands or interface commands issued by the crew at the C&D panel.

Control Distributor - The six control distributors provided flexibility in the assignment of proper routing of power measurements and commands to all of the experiments and to the ATM command system. The control distributors also routed logic circuitry for commands, measurements and indications necessary for the proper operation of the ATM. All of the control distributors could be controlled by switch selector commands or commands issued at the C&D panel in the MDA.

Control and Display Logic Distributor - The C&D logic distributor provided an interface on the ATM rack for the C&D panel located in the MDA. Most of the relay logic for the console was located in the C&D logic distributor. The C&D logic distributor also contained special circuits (isolation amplifiers, pulsers, etc.) required to operate the experiments.

Measuring Distributor - The three measuring distributors were associated primarily with assemblies of the telemetry system. The measuring distributors routed indications and measurements to the proper telemetry assembly for ultimate transmittal to ground receiving stations. All of the telemetry-associated assemblies were powered by the measuring distributors.

Switch Selector - The four switch selectors used in the ATM were controlled by the digital address system or by RF uplink. Each switch selector could activate, one at a time, 112 different output channels; this provided the ATM command system with the capability of 448 commands.

Miscellaneous Components

Watt Hour Assembly - This assembly monitored the current being used on the ATM two main buses and converted it to watt-hours for display on the C&D panel and telemetry equipment. The crew was able to determine the watt-hours used, especially when the EPS operated on the batteries during a night orbit, to facilitate power management and evaluation.

EBW Firing Units - The exploding bridgewire (EBW) firing unit was a solid state electronic device that provided a high current pulse to fire an EBW detonator. This unit was used to decinch the ATM solar array and canister.

EVA Lights - The 12 EVA lights were 18.75 watt redundant filament incandescent lamps which were used to light the walkway and crew workstation when the crew performed an EVA to collect the experiment package film.

Transient Filter - The transient filter was designed to filter the +28 Vdc power before it was sent to the experiment packages.

Motor Transient Suppressor - The motor transient suppressors were designed to suppress the transients induced by the collapsing field of the aperture door motors. This assembly also had the capability to remove power from a stalled motor after one minute to prevent burn-out of the motor.

Cables - The 625 ATM cables provided a means of interconnecting all the ATM components and of routing power, commands and indications throughout the ATM system.

System Interfaces

Vehicle Interfaces - The ATM EPS interfaced with the AM/OWS EPS, the ATM experiment loads, and the C&D console in the MDA. Details of the ATM electrical interfaces can be found in:

1. 40M35601, MDA/ATM C&D Electrical Interface
2. 40M33662, ATM Electrical Schematics
3. 50M02417, Performance and Design Requirements
4. 50M35659, ATM/AM Electrical Interface
5. 50M72900, ATM Equipment List

Caution and Warning Interfaces - The ATM EPS interfaced with the OA caution and warning system in the AM. The EPS was connected to two warning signals: ATM BUS 1 LOW and ATM BUS 2 LOW. The signals were activated when the respective bus voltage fell to 25.0 ± 0.5 Vdc, indicating a high load on the bus and possible loss of the CBRMs supplying it. Each ATM main bus fed a dc-dc converter and redundant detectors. The detectors compared the ATM bus voltage with that of the dc-dc converter and, if the voltage was low, activated the warning signal relay circuitry. There were no indications for high voltage as the regulators were automatically disconnected if they reached 31.8 ± 0.2 Vdc.

SYSTEM EVOLUTION AND DESIGN RATIONALE

Early History

A primary battery system was recommended as the most feasible and economical approach for the proposed 14 to 28 day mission. The average total electrical power requirement for the ATM and LM was estimated to be 1247 W during sunlight and 1325 W during darkness, with a total capacity of 800 kWh needed for the 28-day operational period. It was anticipated that loads could be reduced by power management procedures, but not more than 20 percent.

Several battery configurations were considered, with the final proposal being a total of 62 silver/zinc batteries in four packs mounted to four sides of the rack in a symmetrical pattern. The total battery weight was expected to exceed 8,000 pounds, or more than half the total ATM weight allocation of 14,000 pounds. Two batteries in the LM ascent stage were to be utilized only for free flight maneuvering, rendezvous and docking.

Two of the ATM battery packs were allocated to the LM through a rack-mounted distributor and four main buses to the relay junction box in the LM, with distribution through the existing LM system. The other two ATM battery packs were centralized into two buses for distribution to the ATM systems and experiments. Power system controls and monitoring were to be located on the ATM control panel in the LM ascent stage. Consideration was given to recharging the ATM batteries from the CSM fuel cells in the docked mode, but this was not definitized.

The networks system to be used was based on the same concept as was eventually used in the final ATM configuration (with the exception of the power paralleling requirement, which evolved later). That is, a combination of hardwire commands and binary commands via the ATM control panel, switch selectors, power logic distributor and measuring distributors. Since the major components to be utilized were already available from the Saturn program and their individual capability was known, only the quantity of components required was not definitized because the overall ATM systems had not been defined in detail.

Design Evolution/Rationale

The design concept change to the wet workshop, which encompassed a larger rack and experiment canister and was designed for extended missions, utilized a four-wing solar array and secondary batteries in lieu of primary batteries due to weight and storage capacity decay considerations. To meet the electrical load requirement of 3600 W average, three types of power sources were originally considered: fuel cell, radioisotope thermoelectric generator (RTG), and solar cell array/secondary battery system. Fuel cell operation was limited by reactant storage limitations and heat removal problems. The RTG system had two prominent limitations: fuel was not available for a large system, and radiation danger to personnel could exist.

A solar cell array sized electrically to two and one-half times the spacecraft load was required to allow for charging secondary batteries to supply power during Earth occultation periods. Solar cells with proven performance and reliability were readily available. Solar cells were particularly attractive on Sun-oriented missions because of the availability of 90 degree incident solar radiation without ancillary array pointing systems.

The choice for the secondary batteries was nickel-cadmium, which was desirable because of low weight and volume, and proven lifetime. Also, existing secondary battery designs already included 28 volt, 20 ampere-hour nickel-cadmium batteries.

The major spacecraft constraint was the requirement for passive cooling of the power system components. High power conversion and energy efficiencies were necessary to reduce the amount of heat generated. Other constraints imposed on the power system included minimum weight and volume, and no single failure point that could result in a system failure. These constraints, the passive cooling requirements, and the desirability of having the electronic power conditioning be an integral unit with the battery to simplify interconnect problems, suggested what ultimately became the CBRM.

The maximum load for each CBRM was based primarily on the battery ampere-hour rating and the allowable depth of discharge for the batteries to assure sufficient cycle life to meet the mission lifetime requirement. The electrical load requirements and reliability considerations indicated the number of CBRMs required. The number was originally determined to be 24 when the mission requirements were 18 months of operation at 20 percent allowable depth of discharge. Later, when the mission requirements were changed to two months of operation at 25 percent allowable depth of discharge, the number of CBRMs was reduced to 20, then to 18. A subsequent analysis showed that 18 CBRMs were still sufficient for the final wet workshop mission requirement of six months of operation at 30 percent depth of discharge (nominal maximum).

All of the CBRM requirements analyses were based on continuous Sun orientation of the solar array, and supplying of power to the ATM and LM only. The subsequent mission requirement to include A-LV orientation, as well as cluster reliability considerations, predicated a requirement to provide power paralleling capabilities between the LM/ATM and AM power systems of 2,500 watts in either direction.

The networks system to be used was conceptually the same as the final ATM configuration, and the number of components closely paralleled the final configuration.

Conversion from the wet workshop concept to the dry workshop concept, which disposed of the LM and hard mounted the ATM to the AM/MDA/OWS via a deployable truss assembly, resulted in little theoretical change to the basic power system or networks system. Inversion of the ATM, discarding of the LM and relocation of the C&D console to the MDA did require an extensive physical redesign effort. Analysis determined that 18 CBRMs were still sufficient for the mission requirement of eight months of operation at 30 percent allowable depth of discharge.

Final Design Specifications and Requirements

The final ATM EPS design was specified in the Cluster Requirements Specification (CRS), the ATM System Performance and Design Requirements (SPDR), and the Test and Checkout Requirements and Specifications Document (TCRSD). These and other documents listed in the reference documentation tree given in table 8-III, were used to provide control for the integration of ATM electrical assemblies and module-to-module interfaces.

Table 8-III. ATM EPS System Design Specifications and Requirements Documentation Tree

ATM ELECTRICAL POWER & NETWORKS SUBSYSTEM

DESIGN REQUIREMENTS	INTERFACE REQUIREMENTS	ATM EXPERIMENTS INTERFACE REQUIREMENTS	CONTROL DOCUMENTS
CLUSTER REQUIREMENTS SPECIFICATION RS003M00003	ICD, ATM/ESE CARRY-ON 40M35590-1, 2	ICD, GSFC EXPERIMENT (S-056) 40M35583	ATM INSTRUMENTATION PROGRAM & COMPONENTS LIST 50M12711
ATM SYSTEM PERFORMANCE AND DESIGN REQUIREMENTS 50M02417	ICD, MDA/ATM C&D CONSOLE 40M35601-1, 2	ICD, AS&E EXPERIMENT (S-054) 40M35584-1, 2, 3	ATM CIRCUIT TRANSIENT SPECIFICATION 50M02477
ATM TEST & CHECKOUT REQUIREMENTS & SPECIFICATIONS 50M02425	ICD, ATM/AM INTERFACE 40M35659-1, 2, 3	ICD, HAO EXPERIMENT (S-052) 40M35580	ATM POWER ALLOCATION DOCUMENT 40M33699
	ATM/AM/MDA C&D ELECTRICAL 40M35679	ICD, NRL-A&B EXPERIMENTS (S-082) 40M35586	ATM ELECTROMAGNETIC COMPATIBILITY CONTROL PLAN 50M12725
		ICD, Hα-1, -2 EXPERIMENTS 40M35588	ATM RF COMMAND LIST 50M16140
		ICD, HCO EXPERIMENTS (S-055) 40M35589	ATM MATERIALS CONTROL FOR CONTAMINATION DUE TO OUTGASSING 50M02442

Basic Design Specifications and Requirements - The following extractions from the CRS and SPDR comprised the ATM EPS basic design specifications and requirements:

1. The ATM shall be powered by solar array/nickel-cadmium battery power sources. (SPDR paragraph 3.3.3.2)

2. The electrical power system shall be capable of operating in parallel with the Airlock Module power system. (SPDR paragraph 3.3.3.2.5)

3. The electrical power system shall be capable of power management and evaluation by the crew and/or ground station. (CRS appendix C paragraph 2.2)

4. The electrical power system shall be capable of operating for 4000 cycles (94 minutes day/night cycle) which includes the preflight testing and the 8 months mission time. (SPDR paragraph 3.1.3.3.1)

5. The electrical power system shall be capable of continually supplying 3716 watts at a nominal +28 Vdc to the cluster loads while in the solar inertial (SI) mode, 3000 watts in the Z-LV (EREP) mode, and 1300 watts in the Z-LV rendezvous mode. (CRS appendix C paragraph 2.5.2)

6. The electrical power system shall have a peak load capability of 5574 watts (3716 watts orbital average). (SPDR paragraph 3.3.3.2)

7. There shall be no single failure points which would result in crew loss and/or mission termination. (SPDR paragraph 3.3.3.2.4)

8. The networks shall be capable of functioning with its respective electrical power sources to provide the following:

    a. An isolated two bus system (CRS appendix C paragraph 2.3.9)

b. Power management shall be facilitated by grouping of loads on sub-buses. (CRS appendix C paragraph 2.2)

c. A two wire power distribution system (no return current allowed through vehicle structure). (CRS appendix C paragraph 2.3.1) (Note: The ATM transmitters and command receivers were waivered to use structure and single point ground as a current return path - reference RS003M00003 SCN 186D.)

d. All positive polarity lines of d.c. distribution wiring shall be protected with circuit breakers or fuses. (CRS appendix C paragraph 2.3.4)

e. Electrical bonding and grounding of all electrical equipment. (CRS appendix C paragraph 2.3.3)

System Interface Specifications and Requirements - The ATM EPS interfaced with the ATM equipment loads, the C&D console in the MDA, the AM/OWS EPS via the transfer buses, and electrical support equipment during ground operations. The following extractions from the CRS, SPDR and applicable Interface Control Document (ICD) comprised the ATM EPS system interface specifications and requirements:

1. Voltages at the interfaces shall be as specified in table 8-IV. (CRS appendix C paragraph 2.3.8)

2. Power feeders shall be provided between the ATM and AM/OWS power distribution system capable of carrying 2500 watts in either direction. (CRS appendix C paragraph 2.3.7)

3. The ATM electrical power system shall be designed for a single point ground. (SPDR paragraph 3.3.3.2.4)

4. In an emergency the crew shall have the capability to turn off all ATM subsystem buses, turn off the ATM power modules, and interrupt the ATM/AM power feeders. (CRS appendix C paragraph 2.2)

5. Bus 1 and bus 2 "low" indications shall be provided to the Skylab Caution and Warning System. (CRS appendix H table H-1)

6. The capability shall be provided for control and monitoring of the ATM electrical system by both the crew and ground stations. (CRS appendix C paragraph 2.2)

Table 8-IV. ATM EPS Interface Voltage Requirements

INTERFACE		FUNCTION	DC VOLTAGE* AT INTERFACE**
FROM	TO		
ATM	EXP	POWER SUPPLIED FROM EPS TO ATM EXPERIMENT (DIODE INSIDE OF EXPERIMENT)	26.0 TO 30.5
ATM	EXP	POWER SUPPLIED FROM EPS TO ATM EXPERIMENT (DIODE OUTSIDE OF EXPERIMENT)	25.0 TO 30.5
ATM	AM	ATM C&D POWER (VIA MDA)	27.8 TO 30.5
AM	MDA	ATM C&D POWER	27.3 TO 30.5
MDA	C&D	ATM C&D POWER	27.0 TO 30.5
ATM	AM	POWER TRANSFER BETWEEN ATM AND AM	28.3 TO 30.5

* MAXIMUM AC COMPONENT OF BUS NOISE = 1.0 VAC PEAK TO PEAK FOR ALL FREQUENCIES FROM 20 HERTZ TO 20 KILOHERTZ.

** OVER-VOLTAGE AND UNDER-VOLTAGE WITH A DURATION GREATER THAN 10 MICROSECONDS AND LESS THAN 100 MILLISECONDS SHALL NOT GO BELOW OR EXCEED THE LIMITS SHOWN BY MORE THAN 1.5 VOLT FOR ALL INTERFACES EXCEPT EXPERIMENTS. EXPERIMENT VOLTAGES MUST NOT EXCEED LOWER LIMITS SHOWN. MAXIMUM TRANSIENT VOLTAGE ± 50 VOLT PULSE WIDTH NOT GREATER THAN 10 MICROSECONDS.

7. The capability shall be provided for performing prelaunch test and checkout, integrated module testing and launch operations. (ICD 40M35659)

8. The capability shall be provided for the following ground power sources used in test and launch operation. (ICD 40M35659)

  a. Regulated +28 Vdc power.

  b. Solar array simulated power.

  c. Battery charging power.

New Technology

The CBRM power sharing scheme was a new and unique technology application. Analysis made early in the ATM program indicated the electrical power system effectiveness could be increased by up to 25 percent if a reliable power sharing scheme could be developed to assure that all batteries shared power equally. The resulting circuit, which has a redundant master control that automatically demands equal current from all on-line regulators, was a departure from previous designs and fulfilled the system requirements. The master/slave principle normally used for this purpose in ground applications was not applicable to flight since its reliability depends on the reliability of the master (a CBRM), and thus would be a single failure point in the system.

MANUFACTURING

Fabrication and Assembly

Fabrication and assembly of the EPS components was accomplished in accordance with standard manufacturing procedures. The Astrionics Laboratory (S&E-ASTR), MSFC, had the program responsibility for supplying all EPNS components. The Process Engineering Laboratory (S&E-PE), MSFC, did all of the in-house (MSFC) manufacturing. The control distributors, measuring distributors, switch selectors, J-boxes and EBW firing units from the Saturn program, and the EVA lights from the Gemini program, were accepted without modification. The power transfer, main power, auxiliary power and C&D logic distributors from the Saturn program were modified to conform to ATM-peculiar requirements. The remaining EPS components were new items.

The CBRM electronics was built by Brown Engineering Company, the battery cells by General Electric, and the CBRM case manufacture and final assembly by the MSFC PE Lab. The control distributors, measuring distributors and switch selectors were built by IBM. The master measuring supplies were built by Gulton Industries. The EVA lights were built by McDonnell Douglas. The EBW firing units were built by General Laboratory Associates. All remaining EPNS components were built by the MSFC PE Lab.

Component Development Testing

The CBRMs underwent extensive development testing. The Skylab Cluster Power Simulator, located in building 4436, MSFC, was utilized during some of the development testing. The CBRM regulator performance was verified at various power levels up to 450 watts from -50°C to +85°C. The CBRM charger performance was also verified. Additional development tests of the CBRM included vibration, RFI, solar array compatibility and CBRM system simulation. Additional filtering was added to the CBRM as a result of RFI testing. Minor oscillations were detected during the solar array tests and were corrected with a circuit design change. The CBRM system simulation test verified proper load sharing by paralleling the output of two CBRMs. The CBRM design was baselined as a result of these tests prior to the beginning of manufacture.

No development testing was required for the remaining EPS components. However, a problem was encountered with outer insulation flaking off wire (40M39513A/7) used in cable manufacture. A new type of wire having a single outer layer of polytetrafluorethylene (40M39513/5) corrected the flaking problem.

Component Acceptance Testing

All EPS components were subjected to end item acceptance testing by the Quality and Reliability Assurance Laboratory (S&E-QUAL). Table 8-V lists the test procedure or test specification number for each type of end item. Test results were processed and distributed via an internal data processing printout, and were not formally released as test reports.

There was only one significant anomaly encountered during EPS end item acceptance testing. Several of the CBRM tubular tantalum wet slug input capacitors were found to be leaking. These Mallory capacitors were replaced with a similar type manufactured by Sprague.

Table 8-V. EPS End Item Acceptance Test Procedures

End Item	Test Procedure/ Specification	End Item	Test Procedure/ Specification
CBRM	40M26710	SWITCH SELECTOR	50M11548
MASTER MEASURING SUPPLY	40M26270A	MOTOR TRANSIENT SUPPRESSOR	40M38703
NRL/HAO POWER SUPPLY	40M26213	WATT HOUR ASSEMBLY	40M39627
POWER TRANSFER DISTRIBUTOR	40M39617	CABLES	40M39513/5, 40M39526A/5
MAIN POWER DISTRIBUTOR	40M39617	TRANSIENT FILTER	40M38571
AUXILIARY POWER DISTRIBUTOR	40M39617	EBW FIRING UNIT	MSFC PROC 396B
CONTROL DISTRIBUTOR	40M39617	EVA LIGHTS	FUNCTIONAL TEST CONSTITUTED ACCEPTANCE
C&D LOGIC DISTRIBUTOR	40M39617	J-BOXES	SUCCESSFUL CONTINUITY AND INSULATION RESISTANCE CHECKS
MEASURING DISTRIBUTOR	40M39617		RESISTANCE CHECKS CONSTITUTED ACCEPTANCE

COMPONENT/END ITEM QUALIFICATION

Component Qualification

Qualification testing of EPS components covered high and low temperature, thermal shock, vibration, acoustical noise, acceleration, humidity, altitude, thermal-vacuum, outgassing and electromagnetic compatibility. Assemblies were also tested for functional operation. In some cases an assembly was qualified by similarity to another assembly. As an example, the measuring distributors were all basically the same item; therefore, the complete series of tests was conducted on only one distributor and the remainder were qualified by similarity. The baseline for component qualification was established in 50M02408, Environmental Design and Qualification Test Criteria for Apollo Telescope Mount Components. Table 8-VI lists the EPNS components, their respective qualification test specification/procedure, and the respective qualification test report. A detailed qualification summation of all components which were involved in the Skylab mission activation sequences, which includes most of the EPNS components, is presented in the ATM Hardware Integrity Review Summary Report, dated April 30, 1973.

Three CBRMs failed during the preliminary low temperature test. Failures resulted from poor solder joints or component failure. A low temperature test was conducted at -20°C during electronics acceptance test to screen out failures; no further failures of this type occurred.

A power transistor in the NRL/HAO power supply failed due to over temperature. The transistor mounting bracket was redesigned to reduce operating temperature.

As a result of CBRM design changes implemented after problems in the component acceptance test and ATM Prototype Unit qualification testing, a CBRM delta qualification test was performed. The qualification test CBRM was retrofitted with all the latest design changes, and subjected to vibration testing at higher levels than specified in 50M02408. The higher levels were used as a result of evidence from the ATM qualification testing that the actual flight vibration would be greater than predicted. The CBRM passed the delta qualification at the new high vibration levels.

During investigation of the CBRM tantalum wet slug input capacitor problem which occurred on both the Prototype Unit and Flight Unit CBRMs, a CBRM was modified with tantalum wet foil capacitors and

Table 8-VI. ATM EPS Component Qualification Test Summary

<table>
<tr><th>Component</th><th>Qual Test Specification/Procedure</th><th>Qual Test Report</th></tr>
<tr><td>CBRM 40M26200</td><td>40M26709A</td><td>40M26993B</td></tr>
<tr><td>MASTER MEASURING SUPPLY 40M26271</td><td>40M26269A</td><td>40M26263</td></tr>
<tr><td>NRL/HAO POWER SUPPLY 40M2658C</td><td>40M26662B</td><td>40M26619</td></tr>
<tr><td>POWER TRANSFER DISTRIBUTOR 40M37380</td><td>50M02408D, 40M39601</td><td>40M39608</td></tr>
<tr><td>MAIN POWER DISTRIBUTOR 40M37381</td><td>50M02408C, 40M39599</td><td>40M39606, 40M39629</td></tr>
<tr><td>AUXILIARY POWER DISTRIBUTOR 40M37382</td><td>50M02408D, 40M39600</td><td>40M39607, 40M39629</td></tr>
<tr><td>CONTROL DISTRIBUTORS 40M37383, 40M37384, 40M37387, 40M37388, 40M37393, 40M37394</td><td>50M02408C, 40M39597</td><td>40M39604, 40M39629</td></tr>
<tr><td>CONTROL & DISPLAY LOGIC DISTRIBUTOR 40M37390</td><td>40M39610</td><td>40M39610</td></tr>
<tr><td>MEASURING DISTRIBUTORS 40M37385, 40M37386, 40M37389</td><td>50M02408C, 40M39598</td><td>40M39605, 40M39629</td></tr>
<tr><td>J-BOX ASSEMBLIES 40M33680, 40M33681, 40M33691</td><td>50M02408C, 40M39613</td><td>40M39615</td></tr>
<tr><td>SWITCH SELECTOR MOD-II 50M67864-7</td><td>50M02408C, IBM-373-66644-06</td><td>40M51488, IBM-66-373-001</td></tr>
<tr><td>WATT HOUR ASSEMBLY 40M37998</td><td>50M02408D, 40M39620</td><td>40M39621, 40M39628</td></tr>
<tr><td>EBW FIRING UNIT 40M39515</td><td>50M02408C, 40M39566</td><td>40M51487, 40M39056</td></tr>
<tr><td>EVA LIGHTS</td><td>DELTA QUAL TEST REPORT 9-71</td><td>61A-82-0008</td></tr>
<tr><td>TRANSIENT FILTER ASSEMBLY 40M38547-1</td><td>50M02408D, 40M38570</td><td>40M39631</td></tr>
<tr><td>MOTOR TRANSIENT SUPPRESSOR 40M38697</td><td>50M02408D, 40M38704</td><td>40M39149</td></tr>
<tr><td>CABLES</td><td colspan="2">CABLES WERE ASSEMBLED FROM A QUALIFIED PARTS LIST. THE END ITEM RECEIVED CONTINUITY TEST, INSULATION RESISTANCE TEST AND QUALITY INSPECTION.</td></tr>
</table>

a delta qualification test performed. The test consisted of a vibration test, thermal vacuum test, and EMI tests. No failures or operational problems related to the modification occurred during testing, and all flight-rated CBRMs were likewise modified.

The leads of two capacitors on the voltage conditioner board in the C&D logic distributor failed during qualification vibration testing. A change was approved for staking these capacitors to the PC board with 2850GT on the Prototype Unit and spare boards, but not on the Flight Unit. The failed board was repaired and retested successfully at somewhat lower vibration levels. The new vibration levels resulted from a review of system vibration test data by S&E-ASTN-ADV.

The auxiliary power distributor failed the pressurization test due to defective fabricated parts. The unit was not retested, but was qualified by its similarity to the main power distributor which successfully passed pressure tests.

Component Life Testing

Due to the mission-essential nature of the CBRMs, a life test was run in accordance with 40M26998 to determine probable performance characteristics over the life time of the mission. Six CBRMs were submitted to an eight-month simulated mission in a thermal vacuum environment. All input and output parameters were controlled as predicted for the mission. During the storage mode, after the simulated Skylab 1/2 mission, two battery failures occurred; the failures were traced to shorted cells that evidently resulted from non-uniform pressure on the cell plates in the third electrode area. The test was completed with no further significant problems. A detailed life test report is contained in 40M26994.

The GE 42B020AB12 cells were redesigned to relocate the third electrode, and new cell cleanliness controls were implemented. The new cells were redesignated with a "-G" suffix. In addition, fuses were added in series with the negative leads to protect the CBRM electronics in event of a battery short circuit. A life test on two of the new types of batteries commenced in mid-October 1972. As of June 28, 1974, these batteries had been cycled through more than two complete simulated missions successfully. The life test is continuing to obtain endurance information for application to future programs.

SYSTEMS VERIFICATION PROGRAM

The hardware acceptance test program included systems verification of the ATM prototype and flight units. The prototype test series included post-manufacturing checkout and vibration testing at MSFC, and thermal vacuum testing at JSC. The test series on the flight unit consisted of basically the same series of tests as performed on the prototype, plus prelaunch checkout at KSC. Vibration testing was accomplished subsequent to thermal vacuum testing on the prototype, and prior to thermal vacuum testing on the flight unit. Design changes that developed from problems and their solutions during testing of the prototype were incorporated into the flight unit prior to testing.

The basic module test specification for both the prototype and the flight units was 50M02425, ATM Test and Checkout Requirements and Specifications Document. Also included in this testing were specific procedures to determine compliance of the EPS with many of the design and interface requirements.

Systems Verification (Prototype)

Post-Manufacturing Checkout - Post-manufacturing checkout on the prototype unit was conducted in building 4708, MSFC, between May 14 and September 3, 1971. The objective of post-manufacturing checkout was to verify the manufacturing and design integrity of the prototype by assuring that each system and the assembled vehicle performed in accordance with program requirements and specifications. EPS testing included single point ground and bus isolation checks, limited power application and verification test, CBRM control and regulation tests, networks distribution and system verification, and an integrated all systems test for electromagnetic compatibility. The EPS also supported other subsystems testing.

During the single point ground test, a 1.5 ohm resistance was measured between 7DCOM and vehicle skin with no external connection to the ATM. The specification was one megohm. Further checks revealed that, although 7DCOM bus was not directly connected to vehicle skin, the paralleling of resistances resulted in a poor reading. All ATM bus isolation resistances were acceptable both with and without external connections to the ATM.

Several problems occurred during functional testing of the CBRMs. When four CBRMs could not be activated, investigation by S&E-ASTR determined the ±15 Vdc internal power supplies had failed. Other CBRMs were removed for modifications. Bench tests were performed and five additional CBRM ±15 Vdc internal power supplies were found to be inoperative. The problem was corrected by replacing failed transistors with higher-rated components. An additional transistor and a diode were replaced with higher-rated components as a safety measure.

Noise on the CBRM cables, such as from applying a trickle charge, caused the CBRMs to actuate in an intermittent and random manner, requiring additional filtering.

During verification of power to the EBWs, a relay in the 702A1 distributor operated abnormally. Failure investigation revealed that the normally open contacts could close before the normally closed contacts opened, causing a bus short. The relay circuit was modified to use a common wiper.

There were numerous cases in the ATM where a relay was controlled by a switch selector output channel, a switch from the C&D panel, and the ESE. When a relay was energized from the C&D panel or the ESE, 28 Vdc was also applied to the output channel of a switch selector. This caused the switch selector to intermittently and randomly output another channel, as well as causing the switch selector analog output to TM to indicate that more than one channel had been outputted. Blocking diodes were placed in the switch selector output channel lines to correct this condition.

Numerous problems were encountered during post-manufacturing checkout with the pulsers associated with commands from the C&D panel. The following types of problems are listed rather than each individual case of a malfunction:

1. When a pulser was energizing relays that were unsuppressed, the pulser outputted pulses continuously when a constant 28 Vdc was applied to its input. Diodes were placed on the pulser output lines to serve as suppression.

2. With 28 Vdc applied to the input of a pulser, a voltage fluctuation caused the pulser to output another pulse. A design fix made the pulsers less sensitive to input voltage fluctuations. (The downstream test program revealed that C&D panel switch noise was also contributing to this problem.)

3. The output of the pulsers were ac coupled to the input such that a pulse applied on the output of a pulser was reflected through the pulser to its input. Blocking diodes were installed in the input of the pulsers to correct this condition.

During the EMC all systems test, a high number of excessive transients and safety margin violations were found. Details are contained in the ATM Prototype Unit PMC Test Summary Report, dated November 22, 1971. The following general problems were encountered:

1. System incompatibilities were found in the pulser circuits. S054 logic and control problems, noise, and dc shifts occurred as systems were turned "ON" and "OFF". During operation of the door aperture motors, electrical transients were generated by the absence of suppression devices. Temporary fixes were installed on the prototype unit to eliminate the worst sources, and motor transient suppressors were later incorporated in the flight unit.

2. Almost all of the test points monitored for the 6 db safety margin to critical circuits were not within requirements.

3. The power buses did not meet the transient specification or the ± 1 V peak-to-peak noise limit.

Thermal Vacuum Test - Prototype thermal vacuum testing was conducted at JSC's Space Environment Simulation Labolaraoty Chamber A, building 32, between September 8 and December 15, 1971. The EPS was tested in both ambient and thermal vacuum conditions. Testing at thermal vacuum conditions included support of experiment calibration at vacuum and a series of ten test runs. The CBRMs were active for all ten runs, although failure of four CBRMs required a ground power supplement for the last run.

After initial chamber pumpdown, at battery temperatures of +5.0°C and lower, a large number of battery cells exceeded the upper limit of 1.54 Vdc during the 58 minute recharge cycle, with several reading 1.60 Vdc. In addition, seventeen of the CBRMs failed to give a battery recharge cutoff signal, activating alert lights on the C&D panel during each night cycle. Investigation revealed that the third electrode signals were not reaching the required level of 200 mV at low temperatures. A design change was made to activate heater turn-on at a higher temperature (+10°C verses 0°C). This change was retrofitted on the prototype CBRMs during prototype refurbishment.

During the ten run test series at vacuum, numerous problems were encountered in the EPS. Of four CBRM failures, only one was determined to be generic in nature. The generic failure was caused by a defective tantalum wet slug capacitor in the input filter. Of the other three failures, one was caused by a shorted battery cell, one by a defective capacitor in the 15 Vdc power supply, and one by a defective diode in an ESE SAS input line not used in flight.

The short in the tantalum wet slug capacitor was attributed to four separate internal reverse biasing paths. These failures occurred during ground test and storage modes but not during simulated flight operations. The reverse current caused silver from the case of the capacitor to migrate to the anode, eventually resulting in a short. A relay module and several resistors were added to the CBRMs to eliminate the reverse currents in the capacitors. This modification was retrofitted into CBRMs S/N 1 through 28, which included the prototype CRBMs, and installed during assembly in S/N 29 through 56, which included the flight unit CBRMs.

The battery failure was attributed to contamination. This was an earlier design battery (GE 42B020AB12); all batteries were subsequently replaced with a modified design (GE 42B020AB12-G). In addition to the redesigned battery and imposition of additional cleanliness requirements, fuses were added in series with the negative leads to protect the CBRM electronics in event of a battery failure.

During one of the ten-run series, main bus current became erratic for approximately 90 seconds with a peak current of 260 amperes. During this time all bus voltages decreased from 28 to 0 Vdc for four seconds. However, the bus voltages and current returned to normal and the EPS continued to function for the remainder of thermal vacuum testing. Post-test analysis of the 702A1 main power distributor by S&E-ASTR indicated the main power leads had made contact with a screw holding a fuse module. A redesign of the fuse module was made and a requirement to radiographically inspect all new fuse modules was added.

Post-Vibration Verification - The prototype unit was subjected to vehicle dynamics and random vibration testing between February 14 and April 12, 1972, in the S&E-ASTN vibration test facility in building 4619, MSFC. Subsequent to vibration testing, the prototype unit was moved to building 4708 for post-vibration verification from April 19 to June 16, 1972. The objective of post-vibration verification was to verify the operational integrity of the ATM by comparing performance before and after vibration.

During the initial post-vibration verification phase, five CBRMs failed and were removed from the ATM. The electronics was shipped to the vendor for repair and failure analysis. Testing of one of the CBRMs failed to reveal any anomaly and it was reinstalled on the ATM; however, it failed again during later testing. Analysis indicated shorted tantalum wet slug input filter capacitors, some of which cleared themselves temporarily. All failed capacitors were replaced with the same type. Zener diode clamps were added to the solar simulators to prevent damaging high voltage transients and a requirement was imposed to monitor and record the solar simulator output voltages used to support the ATM flight unit.

Systems Verification (Flight)

Post-Manufacturing Checkout - Post-manufacturing checkout on the flight unit was conducted in building 4708, MSFC, between January 28 and May 25, 1972. PMC objectives were essentially the same as those stated for the ATM prototype unit.

During the single point ground test, a 0.5 ohm resistance was measured from 7DCOM to vehicle skin. Discrepancies were traced to a short in one cable and metal shavings in another. With plugs out and vehicle cables connected, the resistance was 270K ohms. The specification at that time was 100K ohms minimum. After correcting the problem, bus isolation with and without external connections to the ATM was satisfactory. Pulsers commanded from the C&D panel did not operate correctly. This problem required a modification to the pulser boards in the C&D logic distributor.

Throughout PMC testing, four CBRMs failed. Three of the failures occurred during the ± 15 Vdc power supply test with an 80 Vdc input to the CBRMs, and the other during the all systems test.

In all cases, the tantalum wet slug input capacitor failed. Similar problems had occurred on prototype CBRMs during post-manufacturing checkout and post-vibration verification, and had been attributed to internal reverse biasing and an ESE transient problem which were corrected. The tantalum wet slug capacitors were replaced on a qualification unit CBRM with wet-foil type capacitors, and the CBRM was subjected to requalification. Following successful requalification, all flight unit CBRMs were likewise modified, but not until the flight unit had already completed thermal-vacuum testing at JSC and most of the O&C prelaunch checkout at KSC.

During the EMC all systems test, a high number of excessive transients and safety margin violations were found.

1. The CMG ON/OFF function was found to be triggering logic amplifiers located in the C&D logic distributor. Investigation revealed that the amplifiers were too sensitive to transients, and would inadvertently output to the experiments. The amplifiers were modified to desensitize their susceptability to transients.

2. Thirty-six automatic transient detection system detectors monitored power inputs to critical components to verify compliance with various levels of the ATM Transient Specification, 50M02477; nine of these detected out-of-tolerance conditions. During verification of 6 db safety margins on signal inputs to critical components, 51 of a total of 90 test points did not have the required 6 db margin. The non-compliances consisted of 9 relay inputs and 42 solid state inputs from a total of 35 relay inputs and 55 solid state inputs. The normal signals were out of tolerance on 35 of the solid state inputs. Details of these incompatibilities are contained in the EMC test report section of the ATM Flight Unit PMC Quick-Look Report, S&E-QUAL-P-106-72.

Post Vibration Verification - The ATM flight unit was subjected to random vibration testing in the flight axis only between May 31 and June 2, 1972. Post-vibration verification was combined with the pre-thermal vacuum testing at JSC.

Thermal Vacuum Testing - ATM flight unit thermal-vacuum testing was conducted at JSC between June 26 and September 12, 1972. Testing was essentially the same as stated for the prototype unit, with the exception of the addition of post-vibration verification to the pre-thermal vacuum subsystems and ambient all systems tests. The test series under thermal-vacuum conditions was reduced to six runs for the flight unit compared to ten runs on the prototype.

There were no significant EPS anomalies during thermal vacuum testing.

Prelaunch Checkout - ATM prelaunch checkout was conducted at KSC between September 22, 1972, and January 30, 1973. The objective of the testing was to verify that the ATM systems performed in accordance with program requirements and specifications prior to mating with the other Skylab modules. There were three significant EPS discrepancies encountered during testing.

During the single point ground test, an 800 ohm return was measured to vehicle structure; should have been not less than 150K ohms. The cause was found to be a cable short to a clamp due to damaged insulation. The cable was repaired and retested satisfactorily.

A CBRM failed due to an internal short in a tantalum wet slug capacitor in the input filter. Similar failures had occurred during prototype thermal vacuum testing and post-vibration verification, and had been attributed to internal reverse biasing and an ESE transient problem which were corrected. Similar failures had also occurred on the CBRMs during post-manufacturing checkout after the suspected failure mechanisms had been corrected. After extensive analysis, the failure was determined to have resulted from reverse biasing during ESE trickle charging. The reverse bias caused silver to migrate from the case to the tantalum slug, providing a low resistance path. All CBRMs, including those on the prototype unit and spares, were retrofitted with GE tantalum wet-foil capacitors which were insenstitive to reverse bias. The procedure for application and removal of trickle charger power was also modified to eliminate back biasing.

The watt hour assembly "hold" circuitry was sensitive to noise; electrical noise on ATM grounds caused false readings to be displayed to telemetry. A noise filter was added to the hold circuitry, and retest was satisfactory.

The ATM was transferred to the VAB on January 30, 1973, and mechanically mated to the Skylab cluster atop the two-stage Saturn V booster. Subsystem checks were made prior to electrical connection, then flight systems and subsystems interface and functional compatibility testing was conducted between the ATM and the other Skylab modules. VAB testing was concluded on April 6, 1973.

There was only one significant EPS discrepancy encountered during VAB testing. The 702A21 CBRM trickle charger circuit became intermittent due to a diode failure, which was attributed to an isolated manufacturing discrepancy. The CBRM was replaced with a flight-rated spare.

The SL-1 vehicle was transferred to LC-39 Pad A on April 16, 1973. Planned operations included three launch pad power verifications. During the first launch pad power verification, two days after move to the pad, one CBRM failed due to faulty circuitry for switching the input relay from ESE to the solar array input. The CBRM was replaced with a flight-rated spare and retested satisfactorily. On May 9, 1973, lightning struck the mobile service structure, necessitating performance of a contingency lightning retest procedure. The lightning retest procedure displaced one of the launch pad power verifications. It was determined that no damage was sustained by the vehicle or systems by the lightning strike.

An in-depth review of the 587 ATM Networks magnetic latching relays was conducted to ensure that the relays were or would be positioned to the required liftoff configuration (reference MMC document H-73-103, dated May 1, 1973). This review resulted in several deviations written against launch pad test checkout procedures, and a number of changes to the ATM Networks Launch Configuration document, 40M33728. However, all of these changes were considered non-critical in relation to mission success.

SECTION IX. ELECTRICAL POWER SYSTEM - SOLAR ARRAY

SYSTEM DESCRIPTION

The ATM Solar Array (Figure 9-1) consisted of 18 independent photovoltoic power generating systems (solar panels) divided amont 4 wing assemblies. Each wing contained four full panels and one half panel. Each panel contained 20 solar cell modules and was capable of supplying its respective charger/battery/regulator module (CBRM) 580 watts. Each solar cell module contained either 684 type A cells (2x2 cm), or 228 type B cells (2x6 cm). The ATM solar wings, when deployed, were locked within five degrees of a plane perpendicular to the ATM main axis.

The solar array was comprised of two major sections, the electrical (power generating) section and the mechanical (structural and deployemnt) section. Table 9-I presents the ATM solar array electrical section physical and electrical characteristics. Table 9-II presents the ATM Solar Array structural and mechanical characteristics.

The solar wing cinching system (Figure 9-2) and wing deployment system (Figure 9-3) were essentially one-time operational systems with the primary purpose of deploying the wings from launch (folded-cinched) configuration to orbital (decinched-deployed) configuration.

The solar wing mounting structures provided the basic support for the entire wing assembly and was the interface to the ATM rack. Figure 9-4 is an illustrated breakdown showing the mounting structure components. The inboard half panel interfaced with the mounting structure through five hinge points at the ATM Sun-end, and the inboard scissors arms interfaced with the mounting structure through two sliders and tracks. The wing assembly five solar panels were tightly cinched against the mounting structure forming an integral package that could be handled and transported independently of other ATM hardware.

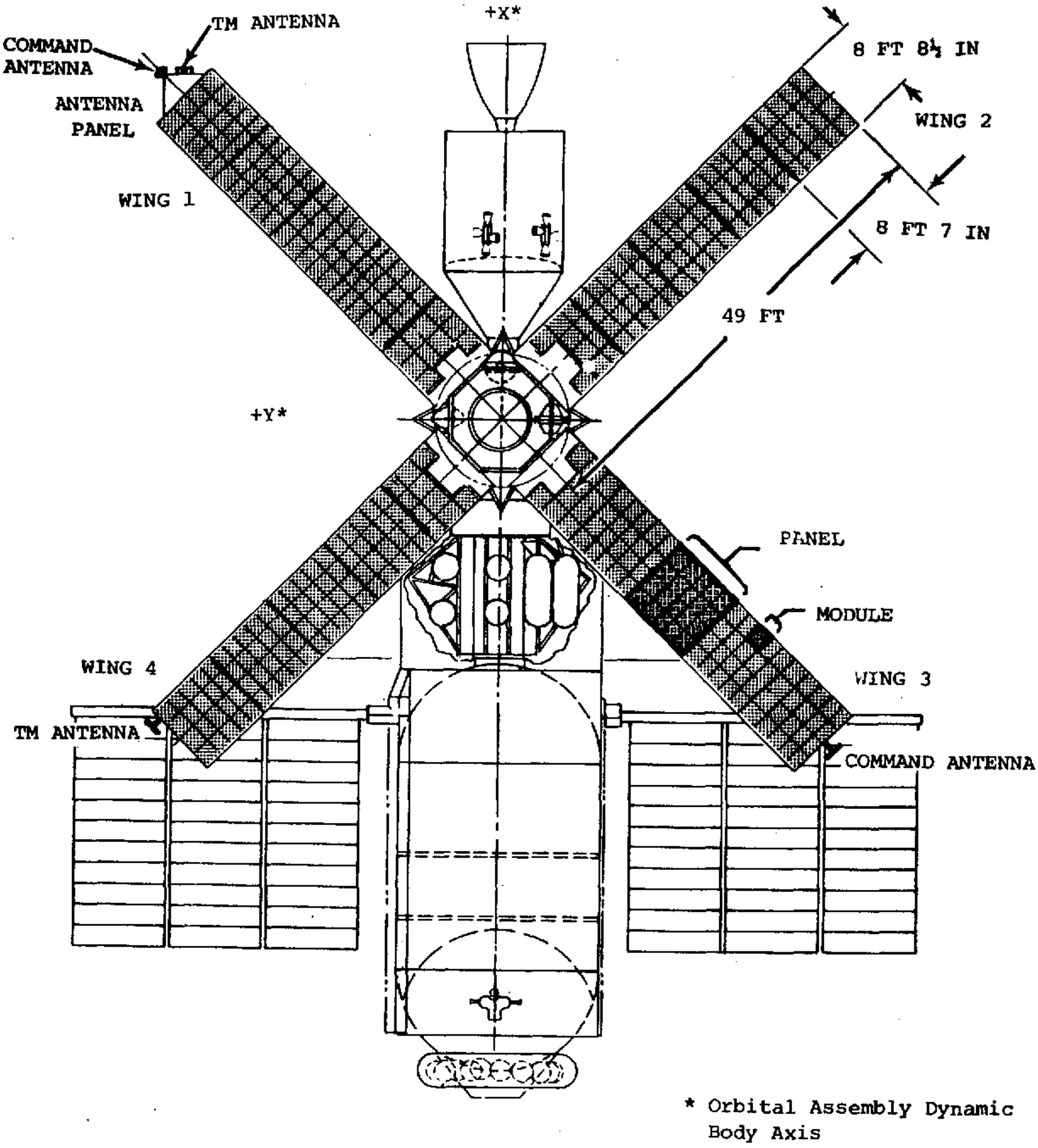


Figure 9-1. Solar Array Configuration

Table 9-I. ATM Solar Array Physical and Electrical Characteristics

ARRAY	
Configuration	4 wings in a cruciform pattern oriented 45 degrees to SWS X-axis
Size	Each wing - length 521 inches, width 104.5 inches
Weight	Total including deployment structure, 4,300 pounds
Total panels	20 individual - actual 18 "electrical" panels, 4 full and 1 half panels per wing
Total power output	11,224 watts (at 55°C, 140 mw/cm^2 AMO) nominal BOM; 10,298 watts (at 55°C, 140 mw/cm^2 AMO) predicted EOM
Total modules	360 modules - 90 modules per wing
SOLAR PANEL	
Size	Length 104.3 inches, width 104.5 inches
Weight	Including frame - 146 pounds
Modules	20 each full panel, 10 each half panel
SOLAR CELL MODULES	
Size - both types	Length 20.0 inches, width 24.6 inches, thickness 0.5 inches
Weight - both types	4.7 pounds
Types -	
A	2x2 cm cells
B	2x6 cm cells

Table 9-I (Cont'd). ATM Solar Array Physical and Electrical Characteristics

SOLAR CELL MODULES (Cont'd)	
Connections	
Series	Both types - 114
Parallel	Type A-6, Type B-2
Total Solar Cells	
Type A	684
Type B	228
Interconnectors	
Type A	Expanded silver mesh
Type B	Solder-plated copper
Substrate	0.5 inch aluminum face sheet/ aluminum honeycomb
Cover Slide	0.012 inch fused silica Dow Corning 7940
UV reflective coating	0.400 microns cut-on wavelength region
Anti-reflective coating	0.700 micron wavelength region
Insulation	0.005 inch mica ply (fiberglass)
Adhesives	
Cover slide to cell	0.003 inch Dow Corning Sylgard 182
Cell to insulation	0.005 inch Dow Corning Sylastic 140
Insulation to substrate	0.005 inch EP 101 or RTV 118
Power (max) output	29.5 watts (at 55°C, 140 mw/cm^2 AMO)
SOLAR CELLS	
Type	N/P silicon
Thickness	0.014 inch nominal - both types

Table 9-I (Cont'd). ATM Solar Array Physical and Electrical Characteristics

SOLAR CELLS (Cont'd)	
Contacts	Sintered solder dipped
Base resistivity	7 to 14 ohms-cm
Conversion efficiency	10 percent nominal at AMO

Table 9-II ATM Solar Wings Structural and Mechanical Physical Characteristics

SUPPORT STRUCTURE - MAIN	
Construction	Stiff frame, box beam (2 vertical track, 1 upper and 1 lower box beams with stiffeners and braces)
Material	Aluminum (6061-T6)
ATM/wing interface	6 main attachment points symmetrical about wing longitudinal centerline
Dark end attachment points	2 each turnbuckle fittings (with spherical bearings)
Sun end (main) attachment points	2 each attachment fittings (with spherical bearings)
SUPPORT STRUCTURE - PANELS	
Construction	Rectangular frame - 5 parallel tubes, inter-connected at ends by hinge fittings and short tube sections

Table 9-II(Cont'd). ATM Solar Wings Structural and Mechanical Physical Characteristics

Material	1 x 2 in. tubing, 0.06 in. wall thickness Inboard panel, heat treated steel (4140); all other panels, extruded aluminum (2219-T87)
PANEL/PANEL INTERFACE	
Hinge fittings	5 sets of male/female clevises (teflon lines spherical bearings on male halves)
Shear plates	5 sets of tapered male and female plates - mounted adjacent to hinges
DEPLOYMENT MECHANISM - WINGS	
Construction	5 sets of scissors arms, end attachment hinges incorporate torsion springs. Centers incorporate pivot (flanged journal bearings) points which attach to panel outboard centers
Material	1 in. by 2 in. tubing 0.06 in. wall thickness (except inboard pair - 0.125 in.) Inboard, second and third pairs, steel. Fourth and fifth pairs, aluminum. All hinge fittings, aluminum castings. Scissors arms cross beam, aluminum (6061-T6). Beam interconnect between inboard scissors ends and track beam sliders.
Electro/mechanical rotary actuator	Dual tandem mounted, metal bellows hermetically sealed 28 vdc torque motors with nutating gears driving a dual slip clutch output ball drive cable sheave.

Table 9-II (Cont'd). ATM Solar Wings Structural and Mechanical Physical Characteristics

DEPLOYMENT MECHANISM - WINGS (Cont'd)	
Ball/drive cable slider	Dual closed loop 291 in. long cable/slider. Nominal 0.125 in. diameter aircraft cable with 0.312 in. diameter swaged steel balls spaced 2.35 in. apart and secured via turnbuckles at both ends to track beam sliders.
CINCHING MECHANISM	
Cinching ties	11 each (7 Sun end, 4 dark end) ties mounted on a fifth panel (outboard) and retained to main structure by ball end rod seated in torque tube rotary ball seat. Consists of arm, clevis, turnbuckle ball end rod, pivot bolts and torsion springs.
Pyrotechnic thrusters/ torque tubes	2 each dual piston and cylinder assembly utilizing two CDF 2000 pyrotechnic cartridges. Pistons are secured to a crank which, in turn, is secured to the torque tubes.
DEPLOYMENT MECHANISMS - WING ANTENNAS	
Wing No. 1	Triangular panel assembly hinge mounted to outboard end of fifth panel. Deployed by dead position torsion springs, retained by a pretensioned cable activated spring plunger and sear pin.

Table 9-II(Cont'd). ATM Solar Wings Structural and Mechanical Physical Characteristics

DEPLOYMENT MECHANISM - WING ANTENNAS (Cont'd)	
Wings No. 3 and 4	Dipole antenna assembly. Nestled in a teflon lined cradle which is bolted to the outboard end of the fifth panel. Deployed by torsion springs, retained by cinching strap and pre-tensioned cable activated spring loaded plunger and sear pin.

SYSTEM EVOLUTION AND DESIGN RATIONALE

The Astrionics Laboratory (S&E-ASTR) at Marshall Space Flight Center was assigned the prime responsibility of conceptual design and development of the ATM solar array. The array mechanical section was the responsibility of the Electromechanical Engineering Division (S&E-ASTR-M). The array electrical section, including the solar cells, substrates, and electrical interconnection was the responsibility of the Electrical Division, Power Branch (S&E-ASTR-E).

Early History

The initial overall ATM solar array system design requirements were based on the general requirements outline in Apollo Telescope Mount Project Development Plan, dated 13 April 1967. The size of the array was largely determined by the ATM rack size and the capability to mount the array in the launch configuration within the lunar module (LM) AAP adapter cone and the ATM in-orbit withdrawal from the adapter.

The choice of using solar cells for power generators on the ATM evolved early in the program from initial project power conditioning tradeoff studies. Initial ATM electrical power system requirements provided for the ATM to power both the LM ascent stage and ATM systems via 24 solar panels/power modules (6 panel/wing).

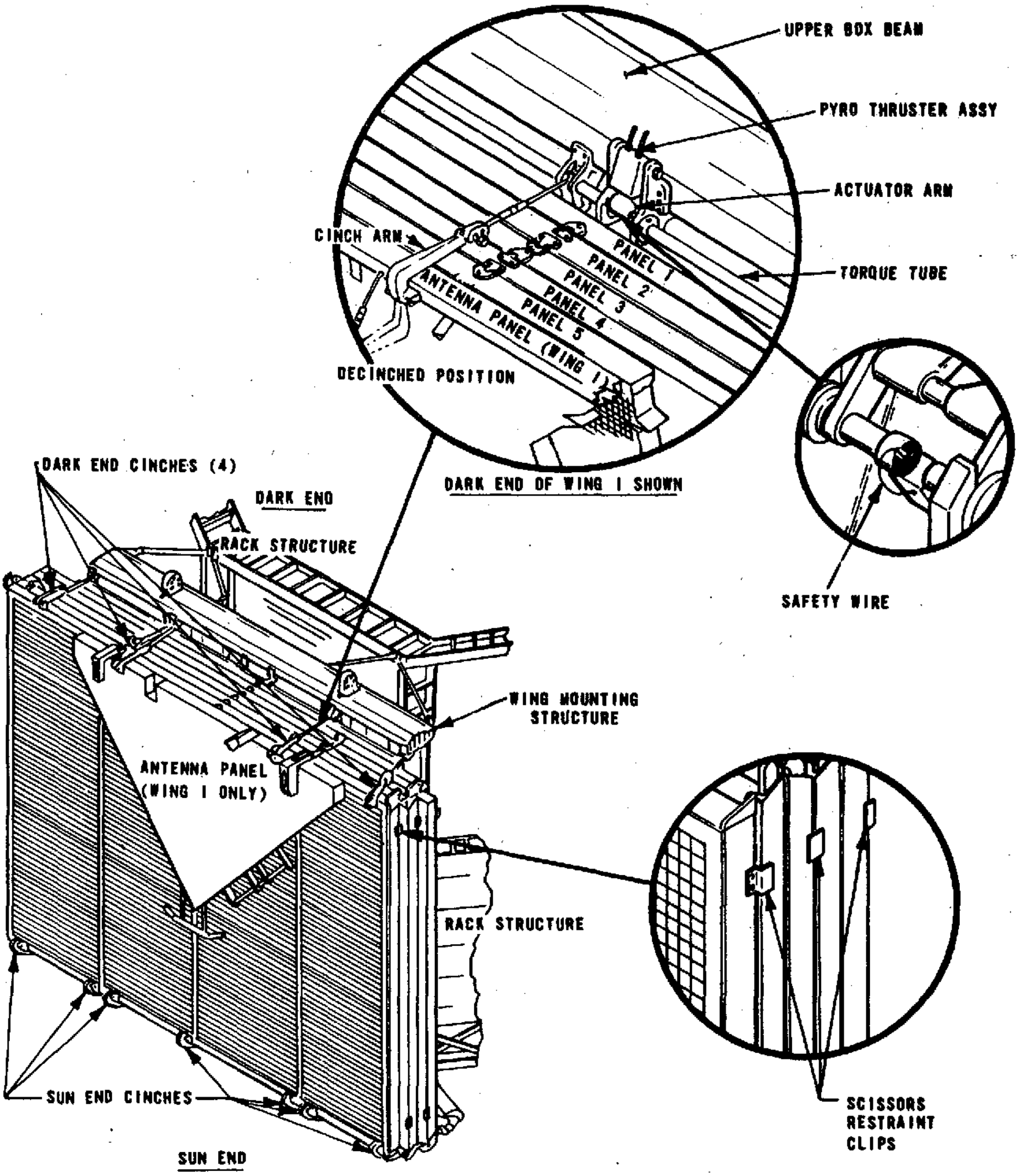


Figure 9-2. ATM Solar Wing Cinching System

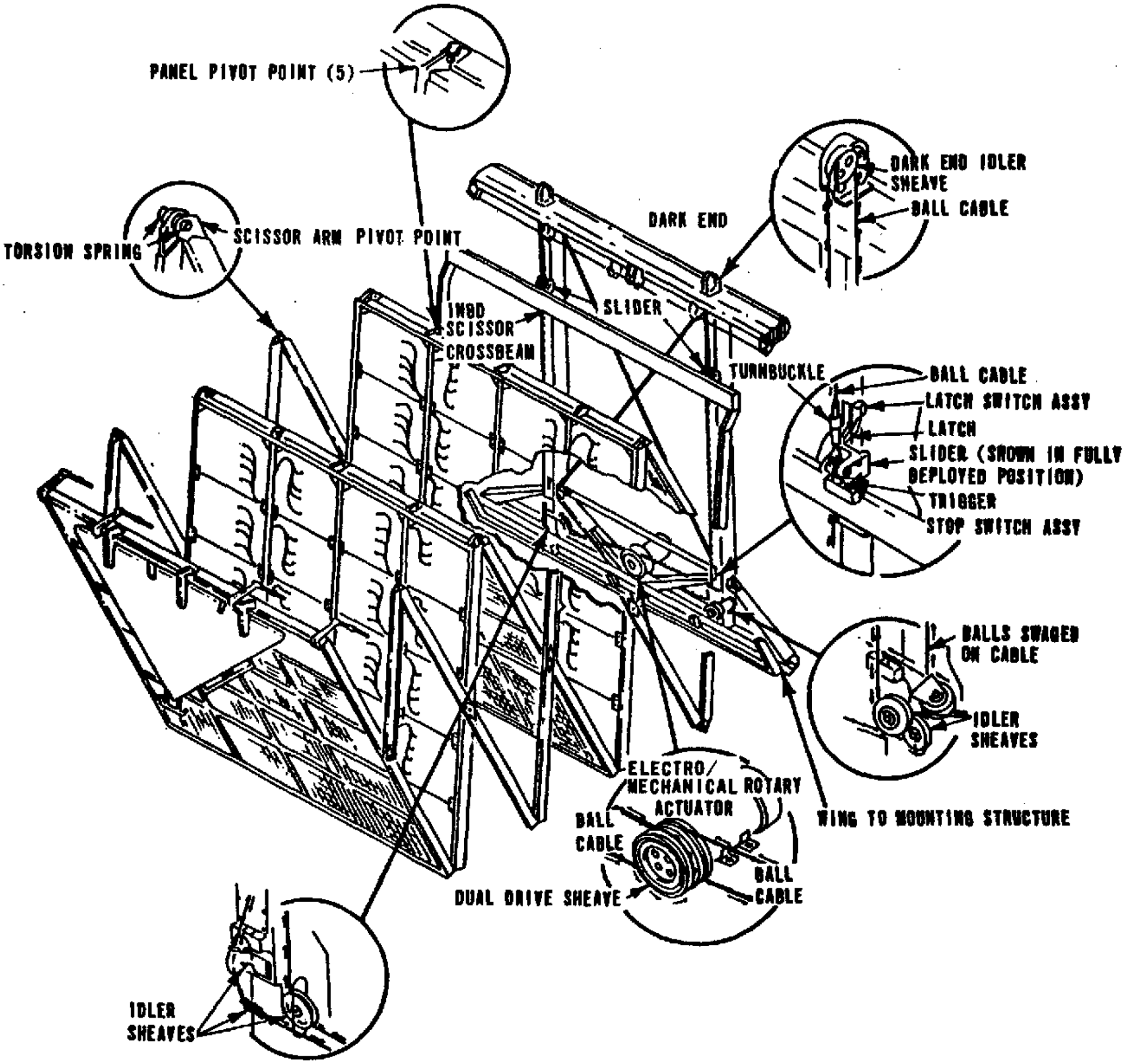


Figure 9-3. Wing Deployment System

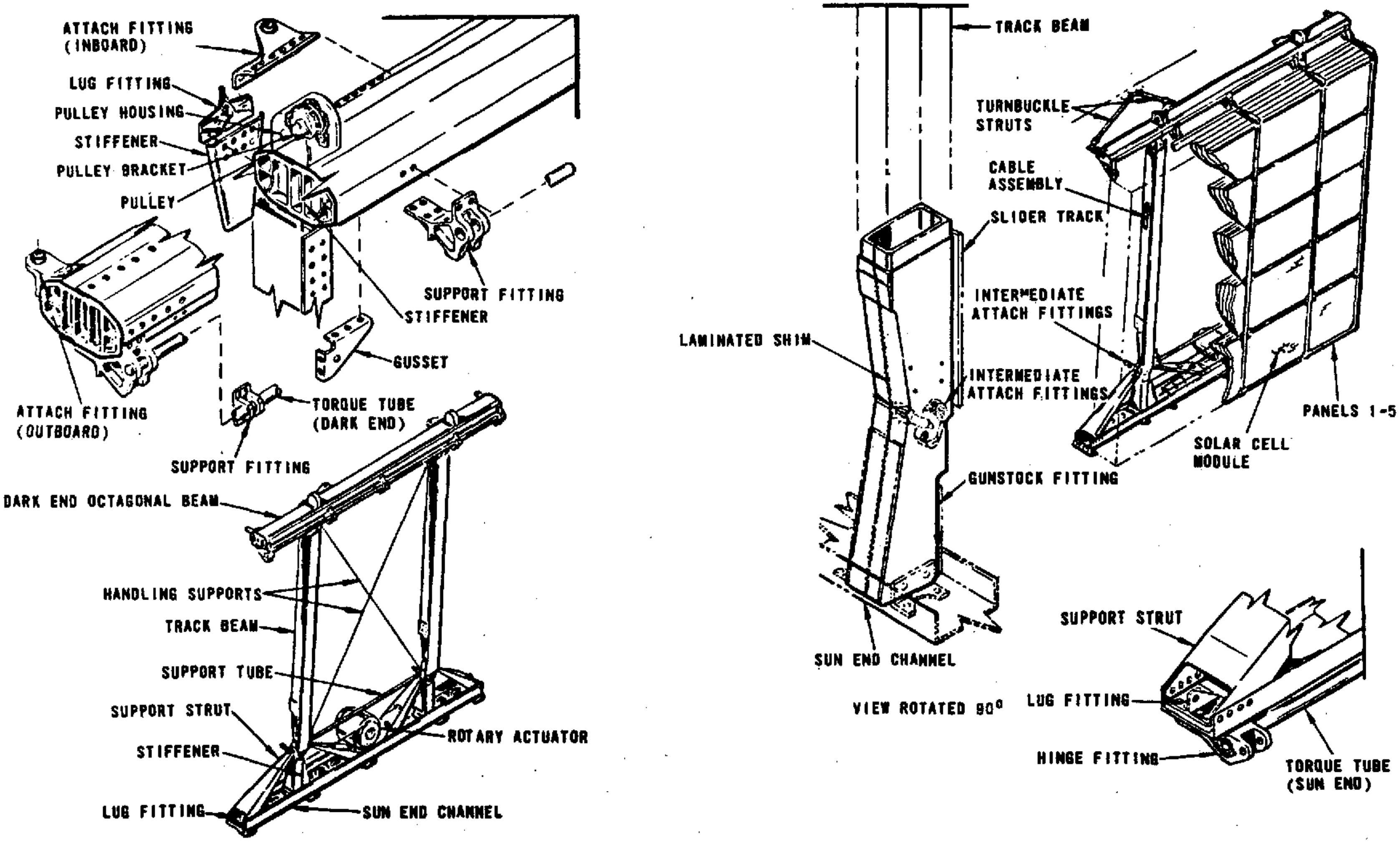


Figure 9-4. Mounting Structure

Subsequent power requirement evaluations against the predicted power output of solar module panels incorporating the more efficient solar cells reduced the wing assembly panel configuration; first to five full panels, total array configuration of 20 panels/CBRMs, and finally to four full panels and the inboard half panel per wing. The final total array configuration was 18 panels/CBRMs. The size, number of panels, solar cell type and series/parallel connectors were specified in 40M26423, Specification for Solar Cell Module for Apollo Application Program, dated November 22, 1968.

Early solar cell module environmental tests established the maximum limitation of 114 solar cells connected in series per module. The tests revealed that at extreme low temperatures, predicted for the ATM solar array operations, high module/panel output voltages were experienced. These voltages were of such magnitudes that damage to components (capacitors) within other ATM systems could occur. The solar cell module cell series connection string limits were set for a maximum panel output of 115-120 volts at the expected orbital low temperature. The size and number of module parallel connections were set to maintain sufficient current for proper equipment operation. The final 18 solar panel/CBRM configuration power output capability was still in excess of the expected ATM systems requirements. Subsequently this excess power capability was allocated for SWS power network sharing.

To obtain the required surface area for mounting the solar cell modules, an array of four deployable wing assemblies was selected. The cruciform pattern was chosen to minimize reaction forces during deployment and the wings orientated 45° to the SWS X-axis for minimum shading to other SWS areas and to fit the launch configuration packaging envelope.

Initial requirements specified that the solar wing have a retract capability. During docking operations the wings were to be retracted to minimize docking loads; however, this requirement was deleted for astronaut safety considerations. Once the wings were deployed, the deploy/retract control circuit was deactivated and the wing sliders mechanically locked to prevent an inadvertent wing retraction during a crew EVA.

The mechanical, electromechanical and structural design requirements were initially defined in 50M60422, Apollo Telescope Mount Solar Array System (Mechanical) Development Design Criteria, dated 15 April 1969. The requirements were subsequently finalized in 50M60451, Apollo Telescope Mount Solar Array System (Mechanical) Design Specification, dated 9 May 1969.

Design Requirements

The wing assembly structural components were designed to accept all ground handling and ground deployment testing loads as well as launch and orbital docking loads. All four wing assemblies were identical with respect to their structural components and mounting interfaces.

The Engineering Analysis Office of the Electromechanical Engineering Division, Astrionics Laboratory (S&E-ASTR-MA) provided load requirements, structural member analysis and generated test plans to support the ATM solar array program through all phases of design, development and qualification testing.

Operational Requirements - All ATM solar array components were required to function in the temperature extremes and hard vacuum environment of outer space. Optical surfaces of the ATM experiments and solar cell surfaces restricted wing structure and component material selection as set forth in 50M02442, ATM Material Control for Contamination due to outgassing. Special material selected, which was not on the approved materials list, was subjected to environmental testing prior to approval for design incorporation.

Solar panel hardware and components that impinged upon the ATM star tracker's field of view were required to possess nonreflective surfaces. These nonreflective surfaces were coated with Specification 10M01831 Thermal Control Flat Black Paint. All remaining solar array hardware and panel backs were coated with high reflection white paint (CAT-A-LAC epoxy or S-136) for thermal control purposes.

To reduce panel to panel, and panel to mounting structure alignment problems and decrease deployment functional forces, spherical bearings were incorporated in all wing assembly attachment and hinge points. In addition, springs were incorporated in the scissor arm joints to assist in overcoming the folded scissors arms dead zone during the initial 20% of the wing deployment phase.

To improve impingement protection and to minimize the folded wing assembly package, all solar cell modules were recess-mounted respective to their panel structural members. Each solar wing assembly was a self-contained independent system permitting individual handling, testing and shipment separate to other ATM hardware.

Safety Requirements - Anticipated astronaut extravehicular activities (EVA) were considered in wing assembly design requirements. All wing assembly surfaces near specified EVA areas were required to have smooth edges. Astronaut safety also dictated that the wings be mechanically locked in the deployment position and provisions be incorporated to electrically indicate this condition.

Electromagnetic Interference - To produce a good electrical ground for the wing assembly mounted antennas, the entire solar array had to be maintained at the ATM rack electrical potential. Because the metallic substrate material was unreliable as an electrical path due to the insulating effect of the adhesive edge, clips on each solar cell module were incorporated to provide the necessary RF path between the two surfaces of the substrate. The RF path between modules and panels was provided by four aluminum wire mesh washers 1.38 inch in diameter, sandwiched between the module back sheet, the panel mounting brackets and module attachment screws. Two electrical connecting straps between each panel were required for the RF path because the panel-to-panel hinges were nonconductive mono-ball bearings riding on teflon-glass fabric.

MANUFACTURING

All of the ATM Solar Array components, with the exception of the deployment rotary actuators and solar cells and modules, were fabricated at MSFC by the Process Engineering Laboratory. The deployment rotary actuators were manufactured by the Kearfott Division of the Singer Company. Due to the inability of any one manufacturer to fabricate all of the solar cells and modules required within the original program time constraint, several manufacturers were selected: the 2 x 2 cm cells were built by Texas Instruments and Centralab, with module assembly by S&J Industries; the 2x6 cm cells were built by the Heliotech Division of Textron, with module assembly by the Spectrolab Division of Textron. There was no intermixing of different types of modules within a given panel.

Fabrication and Assembly

A development model wing, utilizing dummy solar modules, was built from pre-production drawings between July 1968 and September 1969. Development testing was conducted on this wing from March 1969 through February 1971, providing a baseline for production of the prototype unit and flight unit wings. These development tests are discussed in the Solar Array Qualification section.

Fabrication and assembly of the structural and mechanical sections of the prototype unit wings took place between February and June 1971, and for the flight unit wings between July 1971 and January 1972. Installation of the solar cell modules, wiring connections, and bonding were completed after structural assembly, painting and bakeout. A high rejection rate of the solar cell modules discussed later in this section, resulted in shortages and resultant delays in completion of the flight unit wings.

Solar Wing Deployment Fixture

The solar wing deployment fixture (Figure 9-5) was fabricated by the MSFC Process Engineering Laboratory as a special tooling fixture. Its primary purpose was to provide support for each solar wing during development testing and during post-manufacturing deployment verification testing. It was also used to permit simulation of docking loads with the wing assembly fully deployed, and to accommodate static launch load testing of the wing assembly package.

The deployment fixture consisted essentially of five subassemblies; the back support structure, which provided a firm base for the simulated ATM rack solar wing interface, two side support structures, which were rigid mylar coated 50 foot air pad tracks for longitudinal movement of the crossbeam assembly and wing panels, and the main and intermediate crossbeam assembly, which contained the air pads that rode along the side support tracks and supported the intermediate crossbeams. The intermediate crossbeams provided semicylindrical double air bearing interfaces with the main cross support of each of the three outboard wing panel hinge joints and the outboard panel frame. The intermediate crossbeam air bearing permitted lateral movement of the wing panel along the main crossbeam during deployment.

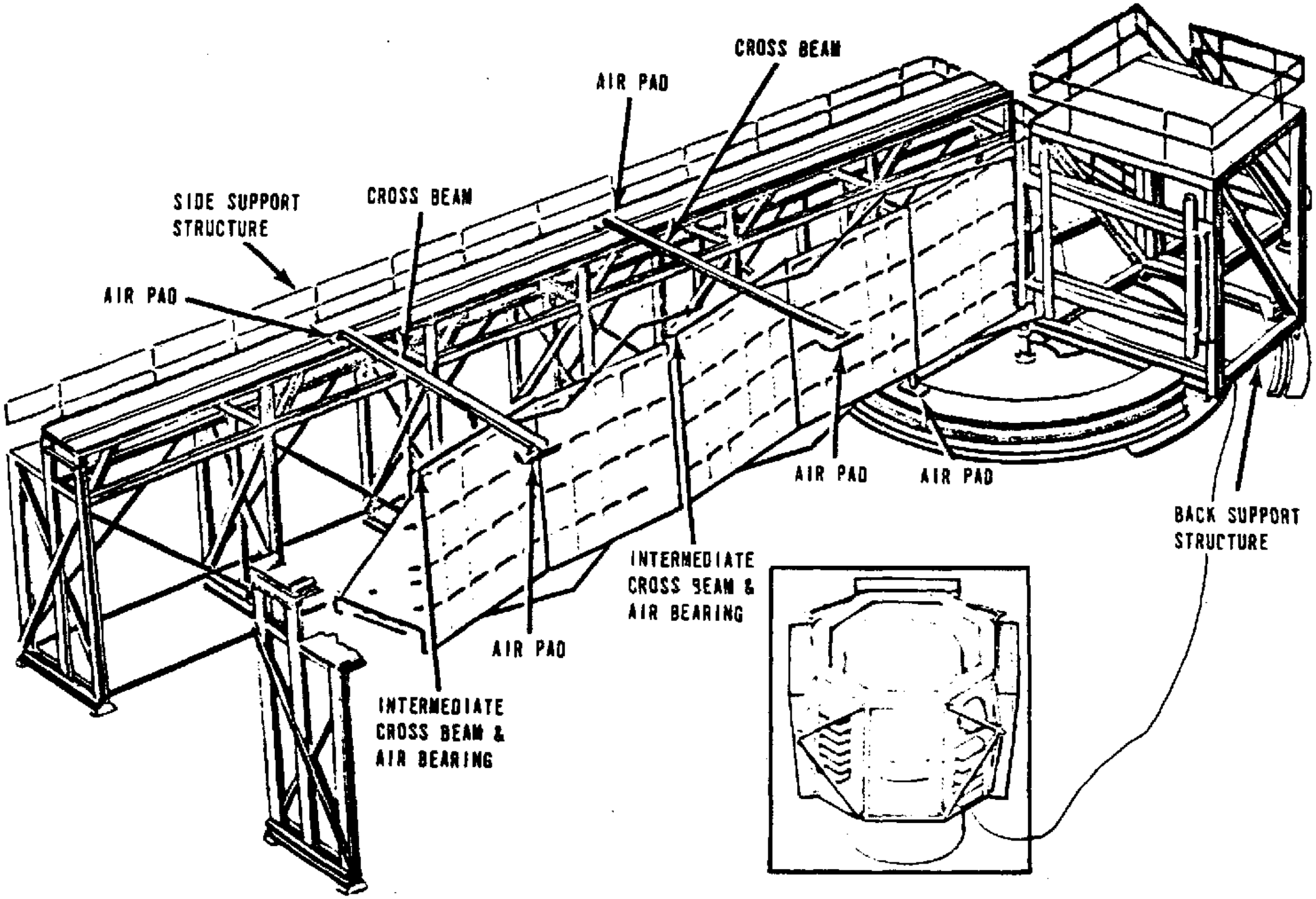


Figure 9-5. Solar Wing Deployment Fixture

Manufacturing Problems

Significant problem areas were encountered during manufacturing concerning the solar cell modules and frame tubing.

Solar Cell Modules - Cracked quartz cover slides on the solar cells were responsible for significantly impacting wing checkout and delivery schedules. Many were discovered during receiving inspection, but a significant number occurred during subsequent handling due to their extremely fragile nature. A cracked cover slide on one cell rendered that particular module unusable and required return to the respective vendor for repair. There were several occasions when wing assembly operations were stopped due to the large number of modules being repaired. Delivery of the flight unit wings to KSC was approximately three months behind schedule; however, this did not impact the overall Skylab program schedule.

Contamination of the solar cell modules was another significant problem which impacted both manufacturing and checkout schedules. considerable time was lost attempting to clean the modules to acceptable levels. Special cleaning procedures were implemented, but, even with the utmost care and caution, damage to the cells occurred frequently during the cleaning process.

Broken cell interconnects and shorted cell problems were also encountered. Most of these were detected during final pre-shipment checkout. A small percentage were detected during panel assembly continuity and megger tests.

Most of the solar cell module manufacturing problems were unavoidable due to the inherently fragile nature of the cells and the ever-present airborne contamination. Module handling techniques were considered the chief cause of cover cell cracking.

Wing Panel Frame Tubing - Difficulty in obtaining 1x2 inch type 4130 steel frame tubing that was within the specified straightness tolerance also impacted assembly of the solar wings. It was extremely difficult to obtain precision parts from a mill where the folling tolerance was less than specified for the end product. The initial solution to the problem was to request a large run and then hand select only those pieces which met specified straightness requirements. As a final solution, the Process Engineering Laboratory fabricated a special tube straightening jig and worked the frame tubing into tolerance.

COMPONENT/END ITEM QUALIFICATION

Component qualification testing was conducted on all solar array mechanical operating components and solar cell modules. The majority of the component qualification testing was performed concurrently with system development testing.

This section discusses electrical, mechanical, and structural components qualification testing and wing assembly development testing.

Mechanical Components/End Item Testing

Pyrotechnica Decinching Thruster - The pyrotechnic decinching thruster was subjected to an extensive development and qualification testing program in which the design parameters were constantly varied to obtain optimum efficiency without component damage. A total of 98 thruster were test fired during this development/qualification program.

The first 45 test firings were conducted to define the thruster piston size, energy absorbing interface stop and size of the required pyrotechnic cartridge. The next 15 test firings were conducted to define the optimum efficiency of the thruster unit. As a result of this series of tests the energy absorbing section was incrementally reduced. The next 21 tests were conducted using redesigned pistons with an extended, knurled interference section. The last two development test firings were conducted to determine the effects of increasing the diametrical interference.

The next 15 thrusters were selected for qualification testing. These units incorporated the latest design changes and were identical in all respects to the final flight thruster configuration. After initial inspection, live pyrotechnic cartridges were installed in their chambers and the units subjected to vibration and acoustical noise test environment. All of these thrusters were subsequently fired successfully under various temperature and pressure conditions.

Ball Drive Cable - Component qualification testing was performed on the cable test fixture which was constructed to simulate the deployment mechanism, the ball drive cable, pullup, track/slider assembly and cable sheaves.

The static deployment cable tension test revealed that the cable failure would occur adjacent to the balls at approximately 1200 lbs. This was far in excess of the anticipated tension which would be applied during flight deployment.

During the early part of the operational load test phase a problem was encountered. Minute particles picked up by the slider teflon liners began to score and gall the bare aluminum track. The problem was resolved by replacing the unprotected aluminum track with a hard anodized aluminum track.

Testing conducted at +36°C, -87°C and ambient temperatures verified the reliability of the total system components under all environmental conditions.

Deployment Rotary Actuator - Six deployment rotary actuators were subjected to extensive qualification testing to verify performance reliability. One actuator was repeatedly tested during development wing deployment operations. Excessive deflection of one of the drive bearing supports cause the output gears of this unit to fail during test, resulting in a redesign of the bearing support.

One actuator was extensively tested to obtain power dissipation versus input current, current versus output torque, and speed versus torque data.

Another actuator was designated as the endurance test model. Loss of lubrication on the output gear teeth caused this unit to fail repeatedly, requiring the manufacturer to change the lubricant specified for the output gear. After the output gear was lubricated with dry lubricant MLR-2, the unit ran continuously under load in a vacuum and was within specification when the test was concluded after 500 hours. After completion of this test, the output gears for all actuators were coated with MLR-2 dry lubricant.

Tests conducted at the manufacturer's test facility on two actuators demonstrated that the nonmetallic slip clutch facing material could not perform satisfactorily at low temperatures. A new ball-detent slip clutch, dry lubricated with MLR-2, was designed and all actuators were modified to incorporate the new type clutch.

One of the factory test actuators was fully updated and was subjected to a more thorough test program than had thus far been performed on any of the other actuators. The actuator was operated at ambient conditions, vibrated, and then tested in thermal vacuum conditions at varying torque levels and temperatures. Problems were encountered and the actuator was disassembled and inspected. A laminated shim had been peeled and shredded by the nutating gears and bearings. This shim was replaced with a solid shim and a complete series of tests repeated successfully. All flight actuators were modified to include the solid shim.

Deployment System Ball Bearing Lubricant - Delayed cinching system release during development wing cold (-40°C) deployment testing was found to be a result of frozen lubricants binding the deployment system bearings. Additional testing confirmed findings that the Kendall KG-80 oil specified for the bearings, the only oil on the ATM approved materials list, was unsuitable at low temperatues. The KG-80 oil was replaced by MEL-1 dry film lubricant, and retesting indicated the bearings now possessed insignificant rotational resistance at -40°C.

Cinching Mechanism - The cinching mechanisms were subjected to extensive experimental and developmental testing at extremely low temperatures to assure performance reliability.

The initial testing was performed to determine the torques required to rotate the rotary ballseat fittings relative to the ball end rod with various mating conditions and to evaluate loads between the ball and the seat. Mating conditions evaluated were unlubricated balls, gold-plated balls, and MLR-2 dry film lubricated balls. The test results revealed that the required rotation torques for the MLR-2 dry film lubricated balls was about 33 to 50 percent less than the gold plated balls and about 75 to 80 percent less than the unlubricated balls.

A simulated torque tube assembly with multiple release fittings and cinching arms was tested to determine the reliability, repeatability and release characteristics under various preload conditions. During the initial test phases, the release rotation was accomplished by using a pneumatic piston to operate the torque tube crank. After a series of tests had been conducted with the pneumatic piston, the fixture was modified to incorporate design changes. The test series was repeated before pyrotechnic release was initiated. After the pyrotechnic thruster had undergone several development firing tests, the thruster replaced the pneumatic piston on the bench test model.

The cinching mechanism was then tested as an assembly on the development model wing. Pneumatic pistons were used to rotate the torque tube crank during the major part of the test program. Pyrotechnics were used for six releases at the end of this test program. Test results were repeatable with a few problems. In one case, the springs on the cinching arms snagged on the torsion springs of the scissors arms. A design modification eliminated this problem. In another case, the lubricant in the Sun end torque tube ball bearings became viscous during low temperature tests. This problem was corrected by changing the ball bearing lubricant.

Antenna Deployment Mechanisms - The antenna deployment mechanisms test program was conducted in three phases: coaxial cable flexure tests; antenna panel deployment tests; and dipole antenna deployment tests.

The coaxial cable flexure tests were conducted to determine the initial cable torque resistance and cable variance respective to temperature conditions and antenna rotation angle. An antenna cable torque test fixture was erected in an insulated thermal test chamber and an inflight configuration RG-115A/U coaxial cable installed. The torque tests were conducted at ambient, hot (+100°C) and cold (-10°C) temperatures, with the hot and cold tests in a dry, missile grade air environment. The test results revealed that the cold test required the greatest torque for full rotation and the hot test required the least torque. The cold test, after flexing, provided the largest amount of negative torque; the hot test provided the least. The torque difference between cold and hot conditions was a ratio of 5:1 in torque requirements. This variation of torque could not be tolerated with a spring deployment system; therefore, a short jumper of RG-142B/U coaxial cable was installed at the twist location. Additional testing with the RG-142B/U coaxial jumper cable installed indicated no effective deployment resistance. As a result, the RG-142B/U coaxial jumper was incorporated for the flight configuration.

Antenna panel deployment tests were conducted to define the antenna panel deployment and dead position torsion spring requirements. An antenna panel deployment test fixture was constructed which held the panel deployment hinge vertically. The effects of the deployment springs and dead position torsion springs were observed and measured in ambient conditions. The size and number of both types of springs were tried experimentally until an acceptable deployment occurred.

It was found that the large deployment springs, as originally designed, lost much of their energy in friction between the coils. This effect was remedied by designing a torsion spring with an increased coil pitch to eliminate this friction. A development model antenna panel incorporating the redesigned torsion springs was installed on the development model wing assembly and underwent systems and environmental testing as part of the development wing assembly.

Dipole antenna deployment tests were conducted separately from the wing deployment tests series, due to the difficulty in simulating zero-g forces during wing deployment. Deployment was achieved at ambient temperatures, at low (-40°C), and high (+71°C) temperatures. No problems were encountered. Following the temperature tests, the dipole was subjected to vibration testing in three axes and accoustical noise tests, after which deployment tests were rerun with satisfactory results. Deployment of the dipole antenna on the development model wing as part of system testing was waived because zero-g simulation could not be duplicated.

Wing Deployment Test Program

The development model wing was a preproduction flight-similar wing. Dummy solar modules were used. Three sets of scissors arm torsion springs were manufactured to measure the effects of varying spring constants during deployment.

Before installation of the cinching and deployment mechanisms, the wing was deployed manually on the deployment fixture by pulling the panels and walking them to full deployment. Manual deployment was initiated from the position which the wing assumed when released from its cinched position. Deployment during this test was smooth. The actuator and drive cables were then installed in the system and the cables adjusted to the desired pre-tension, 50 lb.

For the test program, operations were conducted and data gathered on two distinct functions, decinch and deployment. To decinch, the torque tubes were rotated pneumatically, allowing the wing to spring outward. To deploy, actuator operation moved the decinched wing from the point reached in decinch to full extended condition. Tension in the deployment cables was monitored by strain gages at each end of the cables. It was noted throughout the test program that adjustment of the pretension was very sensitive. The slightest movement of the slider beam caused a large variation in the preload. After initial wing detach, the preload values tended to differ greatly when the wing reached a point of rest.

Torsion Spring Testing - The first eight development wing deployment tests were conducted with the manual engineering model deployment actuator installed with the slip clutch at manufacturer's setting, approximately 300 in.-lb.; intermediate scissors arm torsion springs installed, 505 in.-lb.; and deployable antenna panle installed. Despite a considerable imbalance in the forces applied to the slider beam by the upper and lower drive cables during deployment, movement of the wing was very smooth throughout the deploument, and there was no detectable tendency of the slider beam to walk or chatter. Total deployment time was 71 seconds. Also noted during the initial deployments was spring-out of the released wing was not permitted by slippage of the slip clutch. This situation precluded one of the primary functions of the slip clutch, but with no detrimental effect on the wind operation.

After run 08, the low stiffness scissors arms torsion springs were installed and used in the next three tests. With low scissor arm torsion springs, the distance traveled under the force of the scissors arm torsion springs was shorter and provided a smaller mechanical advantage for the actuator; consequently, slippage of the clutch was noticeably greater. The maximum total force applied to the slider was slightly less than with the intermediate springs, but it occurred over a longer time period due to slower acceleration of the wing. Toal deployment time was approximately 75 seconds.

The next series of tests, runs 12 through 18, were conducted with the heavy scissors arm torsion springs (1050 in.-lb). This was the most significant change made in the wing system. The mechanical advantage provided to the rotary actuator at initiation of deployment was considerably increased by the position of the wing after decinch. Acceleration was noticeably greater at the start of deployment. The total net force applied to the slider beam did not differ appreciably from that experienced with the intermediate springs. Operation of the wing during this series of tests was smooth, and no problems were noted; however, stress calculations indicated the heavy springs to be over stressed in the cinched position.

It was concluded from this series of deployments that the intermediate springs were the proper size and they were reinstalled in the scissors arms for a series of baseline tests.

Slip Clutch Torque Testing - Following the decision to use the intermediate scissors arm torsion springs, the effect of varying the clutch torque of the deployment actuator was tested. The slip clutch setting was adjusted to 460 in.-lb. and two runs were conducted. To determine the minimum slip clutch setting required to fully deploy the wing, the setting was then reduced in steps during the next three runs allowing the wing to barely deploy and lock. The minimum torque was found to be approximately 140 in.-lb. Slippage of the clutch occurred throughout the deployment, and total deployment time was 2.5 minutes.

Influence Coefficient Tests - An influence coefficient test was performed to obtain extended wing deflection data respective to small loads applied at the hinge joints. This data was used as a baseline for comparison to a similar test to be performed after the vibration and acoustical noise tests.

Baseline Deployment Tests - Data acquired during the deployment tests were utilized for establishing the baseline test operational conditions. Prior to performance of the baseline tests the ball drive cable pretensioning technique was changed. The wing was extended and locked and the cable pre-tensioning process was interspersed with a manual side-to-side manipulation of the wing tip. The baseline tests consisted of five decinches/deployments and were concluded without any noted problems. The wing cinching ties were then torqued and the tie turn-buckles safety wired for the vibration and acoustical noise test series.

Vibration and Acoustical Noise Test - Prior to the vibration and acoustic tests, 295 strain gages were installed on the deployment wing. The strain gage cable bundles hampered the normal spring-out of the wing at decinch and added the task of manually moving the cables along with the deploying wing. The latter operation had to be accomplished in a manner which would minimize the strain gage cable effects to the deployment forces, permitting data comparison to previous test results.

Post-Vibration and Acoustical Noise Deployment Tests - The post-vibration test deployment series consisted of six runs (29 through 34). Four runs were decinch/deployments; two runs were deployments only. In the initial decinch the No. 9 cinching tie rod caught on an adjacent shear plate. This prevented the wing from springing out when the torque tubes were rotated. Deployment of the wing could not be accomplished until the tie rod was manually released. During vibration, a sharp edge on one of the shear plates had worn a small groove in the cinching arm and the arm was trapped by the shear plate. This problem was corrected by beveling all shear plate edges. The wing operated smoothly during the remaining tests with no problems noted. Slider forces during deployment were consistent with those established in baseline tests.

Post-Vibration and Acoustical Noise Influence Coefficient Tests - Following the post-vibration deployment series, an influence coefficient test was performed on the deployed wing for comparison to the similar test conducted prior to wing vibration and acoustical noise tests. The deflections were approximately 30 percent less than those of the first test.

Launch Load Tests - Launch load tests were perfomred on the cinched wing assembly to verify its structural integrity. The loads were applied statically to the cinched wing assembly using whippletrees. Outrigging beams were added to the back support structure of the deployment fixture to support the wing during the test and ro provide a support base for the hydraulic cylinders used to apply loads to the whippletrees.

Two launch load tests were performed. The first was with a normal preload of 300 lbs applied to the cinch rods. The second test was performed with no preload on the cinch rods. Analysis of both launch load tests verified wing assembly structural integrity. Following each test, a deployment series was conducted. During these tests, no indication of detrimental effects from the launch load tests were noted and operation of the wing was smooth in every case.

Docking Load Tests - Three docking tests were conducted with the wing fully extended and locked on the deployment fixture to simulate the effects of the CSM docking with Skylab. The tests consisted of out-of-plane loads in two directions, torsional loads, and in-plane loads.

The overall docking load test results indicated that the maximum straings and stresses were well below critical levels in all cases. Deployment operations conducted after the cocking load tests were smooth with no noticeable effects related to the docking load tests. A complete docking test evaluation is contained in SP-209-0519, ATM Solar Array Docking Loads Test.

Cold Deployment Tests - To verify the satisfactory performance of the wing assembly in a cold environment, a cold test for wing operation at a temperature of approximately -40°C was conducted. Problems were encountered during both the decinch and deployment operations. During decinch, the Sun end torque tube rotated under normal penumatic pressure but the dark end torque tube had to be manually rotated. During deployment, the actuator failed to operate for 250 seconds at which time the wing had warmed to approximately 0°C and deployment commenced.

The rotary actuator was removed following the test, and in a subsequent bench test the lubricant in one of the roller bearings was found to solidify at -40°C. This problem was also encountered by the manufacturer during qualification testing of the rotary actuator. The manufacturere reported a silicone lubricant greatly improved the low termperature operation of the actuator when substituted for the original roller bearing lubricant. This particular lubricant problem was confined to a sealed unit and could not outgas. The silicone lubricant was adopted as a substitute and the actuator lubricant changed.

The cold temperature testing was repeated. In this test, the pneumatic cinching cylinders was heated, since it was suspected that cylinder contraction caused the original torque tube rotation failure. The Sun end cinching release did not function and the deployment system did not operate for approximately 3 to 4 minutes until the bearing components warmed to 0°C to +5°C.

As a result of these tests, the lubrication problem in the idler sheave bearings and torque bearings was identified. After the lubricant was changed to a dry film lubricant, the decinching and deployment operations were successful at low temperatures. Two successful low temperatures decinches and deployments were performed.

Deployment Endurance Tests - An endurance test series consisting of 20 deployments was conducted on the wing to increase the engineering confidence level in the system. The deployments were made without any changes or adjustments, and the wing performed well throughout the series.

Pyrotechnic Thruster Decinch/Deployment Tests - Pyrotechnic thruster decinch tests were conducted to verify the operation of the pytotechnic release system as an integral part of the wing assembly. The wing was cinched by adjusting the single cinching tie rods to 300 lbs. Cylinders previously used to rotate the torque tubes were replaced by the pyrotechnic thruster assemblies. Pyrotechnic release tests were limited to two due to a shortage of cartridges. For the first test, one PC-85-2000 cartridge was installed in each thruster assembly. The simultaneous firing of these primary cartridges released the wing; the decinch operation was smooth and the subsequent deployment was normal in all respects.

In the next run, a secondary redundant PC-85-2000 cartridge was placed in each thruster assembly in addition to a primary cartridge. The thruster firing resulted in rotation of the torque tubes by the primary cartridges only. This certified that possible sympathetic firing of the secondary redundant cartridges was not a problem. After release of the wing, the secondary redundant cartridges were fired and did not cause any detrimental effects to the wing assembly. The subsequent deployment was smooth throughout.

Thermal Vacuum Decinch and Deployment Force Tests - A thermal vacuum test series was conducted on prototype unit wing number 4 to verify the reliability of pyrotechnic cinching release and deployment force output in a vacuum with both low and high temperature environments. This test series was conducted in the MSFC Sunspot I Thermal Vacuum Chamber. Temperatures of all critical mechanical components and selected solar modules were monitored. Angular speed of the torque tubes rotated by the pytotechnic thrusters and the loads in the deployment cables were monitored. The wing was restrained by special clamps which prevented deployment when the cinching mechanisms were decinched.

The time required to decinch the cinching mechanism was almost twice that of the typical tests performed on the bench test fixture. Investigation revealed galling between the piston shaft and cylinder bore of the thruster. Chemical analysis verified no trace of dry film lubrication on the piston. The piston was disassembled, lubricated and reinstalled.

The deployment actuator produced the specified amount of torque and a successful deployment was conducted after the wing was returned to the deployment fixture.

Electrical Components/End Items

Solar Cell Modules - The ATM solar cell modules were subjected to an extensive technology establishment and verification test progarm. This test program was concerned with reliability of solar cell interconnects, reliability of insulation, solar cell matching criteria, reverse bias operating limits and optimum operating power.

Initial solar cell module testing was primarily concentrated around module power output testing and thermal vacuum testing. The module power output testing was conducted at MSFC by S&E-ASTR-E, utilizing first the X-75 Solar Simulator and later the X-200 Solar Simulator. The thermal vacuum testing was performed at Denver, Colorado, by the Martin Marietta Corporation with simulated space illumination produced by a X-25 Solar Simulator.

Qualification modules were randomly selected from production modules. The power output testing consisted of rating the tested modules respective to their current output at a specified voltage, average maximum power point, and comparing this to the average maximum power point of a standard solar cell module.

The qualification modules were subjected to 200 cycles of thermal vacuum testing at a vacuum of 1×10^{-4} torr and temperature of -60°C to +80°C to verify no degradation in module thermal characteristics, electrical performance or physical integrity, and to provide solar cell temperature coefficient baseline data. Thermal vacuum testing identified two major problems. The first was the failure of the individual solar cell series interconnects. After repeated thermal cycling the contacts would open. A redesign of the cell interconnects, longer loops, and revision of solder application techniques relieved the problem. The second problem involved the module turnaround copper buses only on the modules made up of 2x6 cm cells. At extreme low temperatures the buses buckled and after repeated thermal cycling bus continuity was lost. This problem was corrected by application of RTV adhesive to the buses.

The qualification solar cell modules were also subjected to the following tests to verify no material or electrical performance degradation: vibration, acoustical noise, acceleration, altitude, thermal shock, insulation resistance, and deflection. No significant problems were encountered during these tests.

The selection and manufacture of the ATM solar modules was prior to finalization of the ATM approved materials specification; subsequently, the solar modules materials did not meet the outgassing requirements. To overcome this problem all solar cell modules procured for the prototype and flight unit solar wings were subjected to a vacuum bakeout prior to final acceptance.

The qualification solar cell modules were also utilized in establishing the forward diode characteristics, dark I-V testing parameters for acceptance testing of a complete solar wing panel. The dark I-V technique was not new but it had only been utilized in laboratory testing of individual solar cells and modules. As a result of the study, the Solar Array Checkout Equipment 40M51478 was assembled and utilized for the power output acceptance testing of all the prototype and flight unit solar wings.

Prior to completion of the solar cell module qualification testing program, ASTR performed thermal cycling tests on several qualification modules with periodic electrical performance tests until failure occurred. The data acquired during this additional testing period further aided in predicting solar cell module operating life expectancies.

SYSTEMS VERIFICATION PROGRAM

Each of the prototype and flight unit solar wings was subjected to verification testing. The solar wings did not go through thermal vacuum testing at JSC, consequently this section discusses the test program at MSFC and KSC only.

System Verification (Prototype)

Post-Manufacturing Checkout (PMC) - Post-manufacturing checkout was conducted by S&E-QUAL-AAA. The testing was conducted to evaluate the acceptance criteria specified in 50M02425, ATM Test Checkout Requirements and Specifications Document. The deployment fixture used for the development wing was disassembled and re-erected in the 100K cleanroom in building 4708 for PMC. The development model wing was first deployed in the fixture to assure proper re-erection of the fixture.

All four prototype wings were tested during PMC. The primary acceptance criteria were decinch visual observations, deployment forces, antenna release sequence, actuator current, locking switch operation, deployment times, wing panel wiring continuity checks, wing panel wiring megger tests, wing panel module power (light) output tests, and wing panel forward diode (dark I-V) characteristics tests.

Electrical tests were conducted to verify the integrity of individual solar modules, panels and the overall wing to establish baseline solar panel power output tests. The power output tests, light output and forward diode (dark I-V) characteristics tests were conducted utilizing the solar array checkout equipment.

Minor problems were encountered during the electrical portions of PMC, which resulted in rework of the panle/module wiring and/or replacement of a panel module.

Deployment tests were conducted with actuator motor windings energized independently and then simultaneously. Minor mechanical problems were encountered which prompted design changes on the flight wings. They were as follows:

1. Modification of the antenna release mechanism for earlier release.

2. Relief of the gunstock fittings in the mounting structure to eliminate deployment cable abrasion.

3. Modification to drive and idler sheaves to eliminate deployment cable ball interference.

4. Rerouting of electrical cabling.

5. Better slider alignment with deployment cable pretensioning specifications.

Systems Verification (Flight)

Post-Manufacturing Checkout - One problem encountered during flight wing PMC was one deployment ball drive cable on wing number 2 consistently walked out of the actuator sheave seats during deployment actuator operation. Inspection of the cables verified that the balls were not swaged to the cable within drawing dimensional tolerances; however, further investigation verified that the cables could be matched in pairs and operate effectively although manufactured outside the overall drawing tolerance limits. As a result, all the cables on the flight wings were matched in pairs to ensure smooth and proper deployment.

The same electrical tests were conducted on the flight wings as previously described on the prototype. Minor random problems of the same nature as on the prototype were encountered requiring rework or replacement of a panel or module.

Prelaunch Testing (KSC) - Initial ATM solar array acceptance test activities were performed at the Operations and Checkout (O&C) Building and were conducted in three phases. The first phase included initial receiving inspection and a forward (dark IV-I) diode characteristic test. The second phase was the pre-solar wing/ATM installation checks consisting of wing panel megger tests, deployment actuator motor torque checks and ball drive cable pre-tension checks. The third phase included the mechanical and electrical solar wing/ATM mate with subsequent forward (dark IV-II) diode characteristics tests through the ATM circuitry.

One major problem was encountered during pre-installation checks. During megger testing of wing number 2, an out-of-specification condition was detected in the inboard half panel, panel number 1. Investigation indicated a short in one of the panel's solar cell modules. Due to the accessibility of the short, a decision was made to replace the module. Megger retest of flight wing number 2 inboard half panel was satisfactory.

Installation of the wing on the ATM was completed with no significant problems or anomalies encountered. Subsequent forward diode characteristics test through the ATM electrical power system circuitry was completed with no significant problems.

Solar array acceptance test activities were completed in the Vertical Assembly Building (VAB) and were conducted to verify solar wing/ATM systems electrical integrity, and assure flight readiness of the solar array. Test activities included activation of the deployment mechanisms through the ATM circuitry, through the Workshop Computer Interface Unit and Digital Address System. In addition, a final forward (dark IV-II) diode characteristic test was performed to verify the solar array panels power generating capabilities to support the mission.

There were no major solar array associated anomalies encountered during the VAB checkout activities. There were, however, several instances when wing deployment actuator motors were operated in excess of the maximum specified cinched wing actuator motor operating times. Evaluation of the test data and subsequent actuator motor runs indicated these overruns had no detrimental effects on the actuator motors. The final forward (dark IV-II) diode characteristics test indicated no evidence of degradation when compared to the data from the dark IV test performed during O&C testing.

SECTION X. INSTRUMENTATION AND COMMUNICATIONS SYSTEM

SYSTEM DESCRIPTION

The ATM Instrumentation and Communications System (I&CS) was designed to perform ATM data processing and transmission, provide command control of ATM subsystems and experiments, and aid in experiment operations and pointing for solar data acquisition. The ATM I&CS consisted of 1) ATM data subsystem; 2) ATM digital command subsystem; and 3) ATM television subsystem.

Each of the subsystems is described in the following paragraphs. The I&CS interfaces are shown in figure 10-1. Table 10-I lists the components of the I&CS.

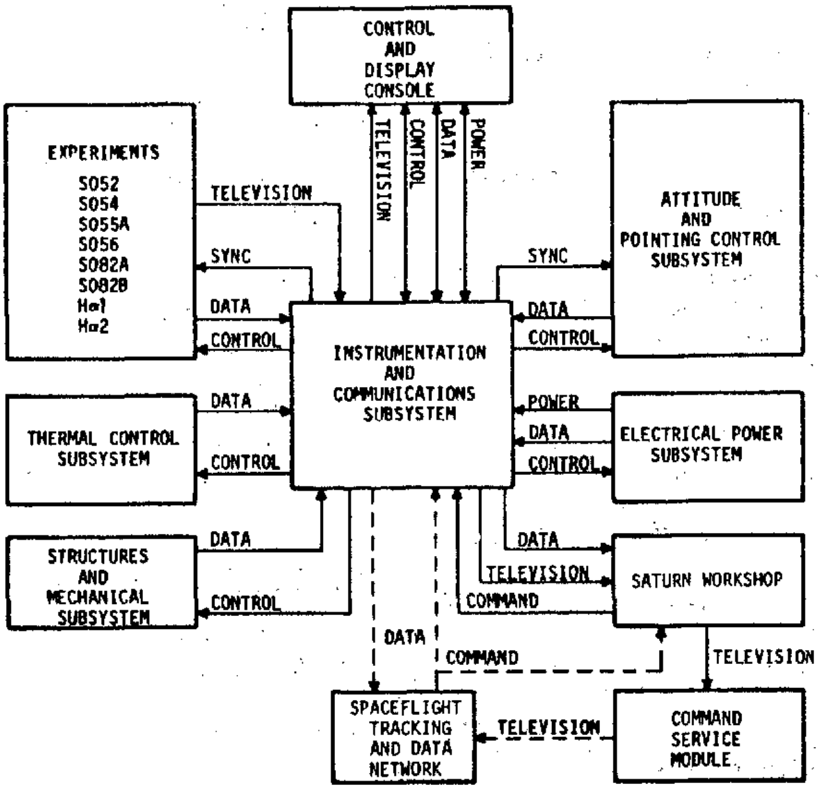


Figure 10-1. ATM I&CS Electrical Interfaces

Table 10-1. ATM I&CS Components List

Component	Part No.
ATM Data Subsystem	
Pulse Code Modulation/Digital Data Acquisition Subsystem Model 301 (2)	50M12991
Time Division Multiplexer Model 270 (4)	50M12989
Remote Analog Submultiplexer Model 103 (6)	50M12970
Remote Digital Multiplexer Model 410 (6)	50M12990
Telemetry Transmitter (2)	50M12993
Voltage Standing Wave Ratio Measuring Assembly Model 230	50M12779
RF Multicoupler Model 232 (2)	50M17210
Coaxial Switch (2)	50M12742
Auxiliary Storage and Playback Tape Recorder (2)	50M17010
Auxiliary Storage and Playback Data Storage Interface Unit	50M16223
Auxiliary Storage and Playback Memory Assembly	50M12958
ATM Data Subsystem (Continued)	
Auxiliary Storage and Playback Redundant DC-DC Converter	50M16225
Amplifier and Switch Assembly	50M12785
Signal Conditioning Rack (9)	50M12724
Signal Conditioning Rack Filter Assembly (9)	50M17211
Antenna Panel Assembly Model 316	50M12735
Telemetry Antenna Model 231	50M12733
Remote Analog Submultiplexer Thermal Isolator Standoff	50M04963
Tape Recorder Thermal Isolator Standoff	50M04964
ATM Digital Command Subsystem	
Command Receiver MCR 503-D (2)	50M73323
Command Decoder (2)	50M12746
Directional Coupler Model 318 (2)	50M12781
Command Antenna Model 356	50M16490

Table 10-I. ATM I&CS Components List (Continued)

Component	Part No.	Component	Part No.
ATM Digital Command Subsystem (Continued)		ATM Television Subsystem (Cont'd)	
		Sync Generator	50M12727
Command Antenna Panel Assembly Model 316	50M12735	Switcher/Processor (2)	50M17848
		Pointing Reference System Isolation Amplifier	50M17598
ATM Television Subsystem			
Vidicon TV Camera (2)	50M12731		
		Miscellaneous	
Low Level Light TV Camera (2)	50M12729	Radio Noise Burst Monitor	50M17527
Image Dissector Camera (integral part of S082B XUV Slit pointing reference system)	(ref S082B experiment)	Quartz Crystal Microbalance/ Contamination Monitor	50M18270
Camera Control Unit (4)	50M12730		

ATM Data Subsystem

The ATM data subsystem is shown in figure 10-2. The data subsystem was designed to process and transmit analog, digital and discrete data to the Spaceflight Tracking and Data Network (STDN) in real time. The Auxiliary Storage and Playback (ASAP) assembly provided the capability to record ninety minutes of real-time data and to play it back in five minutes for downlink transmission. Synchronization signals to other ATM subsystems were also provided by the data subsystem.

The functions of the data subsystem, however, were normally controlled by ground command. The functions which could be controlled and monitored from the control and display console included main telemetry power on/off, record-playback-stop for tape recorders, transmitter modulation modes and real versus delayed time data transmission.

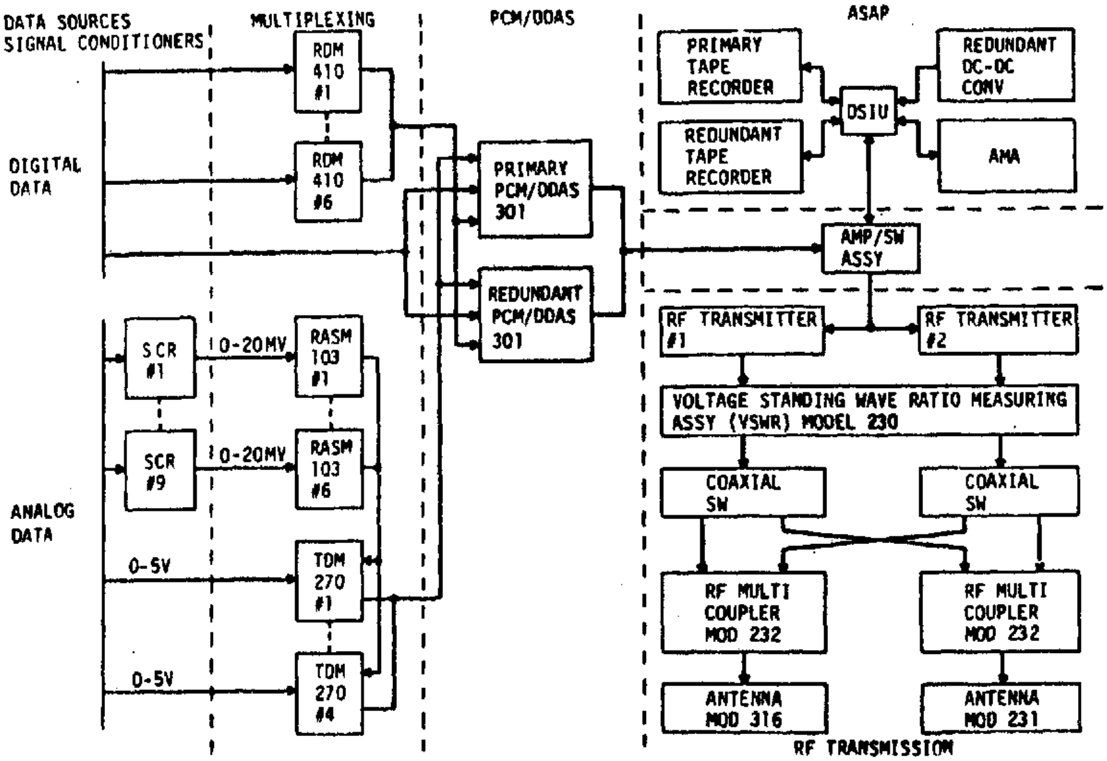


Figure 10-2. ATM I&CS Data Subsystem Block Diagram

Processing - Processing of the data utilized signal conditioners, analog and digital multiplexers, redundant digital data acquisition assemblies, and an amplifier and switching assembly. Nine signal conditioning racks conditioned incoming analog measurement data to a voltage range compatible with the input requirements of the remote analog submultiplexers model 103. The submultiplexers converted the analog data into pulse amplitude modulated (PAM) wavetrains which were input to the model 270 time division multiplexers. Analog measurement data not requiring signal conditioning were input directly to the model 270 multiplexers. These multiplexers transferred the multiplexed analog data to the Pulse Code Modulation/Digital Data Acquisition System (PCM/DDAS) assembly model 301. The PCM/DDAS converted each multiplexed analog signal into a 10-bit digital word and placed the word into a predetermined location in the 72 kbs data format.

Digital measurement data were primarily sampled by the model 410 remote digital multiplexers. The digital multiplexer outputs were transferred to the PCM/DDAS, which also inserted this data into a predetermined location in the 72 kbs data format.

In addition to the data conversion and formatting functions, the PCM/DDAS generated various signals used to synchronize the ATM subsystems and experiments data with the data subsystem. The PCM/DDAS provided the data format (parallel and serial forms) and various synchronization signals as outputs to the Amplifier and Switch Assembly (ASA).

The ASA served principally as a data and synchronization signal switching interface. This signal switching was controlled by ground commands issued through the ATM switch selectors.

The ASA simultaneously selected all outputs from either the primary or redundant PCM/DDAS. The PCM data format was distributed by the ASA to the telemetry transmitters in serial form for real time data transmissions and to the ASAP in parallel form for delayed-time data selection and storage.

Data Storage and Handling - The ASAP extracted preselected portions of the PCM data routed through the ASA, stored the PCM data, and upon command played back the stored data. The data was recorded on either of two magnetic tape recorders at 4 kbs. Recorder playback speed was 18 times the record speed, producing a playback data rate equivalent to 72 kbs to the selected telemetry transmitter for transmission to STDN. The ASAP contained two major subassemblies in addition to the two tape recorders, an ASAP memory assembly and a data storage interface unit.

The Data Storage Interface Unit (DSIU) was the central controlling unit of the ASAP assembly, performing interface functions between the PCM/DDAS and two asynchronous subsystems, the ASAP Memory Assembly (AMA) and the tape recorder. The DSIU synchronized timing, accepted data inputs from the AMA, provided appropriate outputs, and performed various other control functions including the AMA, tape recorder or data synchronization.

The AMA provided memory capability for the ASAP. The AMA had two distinct memory sections, non-destructive readout (NDRO) and destructive readout (DRO). The NDRO section contained 400 addresses which were routed to the DSIU. These 400 addresses were written into the AMA in a final program prior to installation in the vehicle. If the NDRO program should have been inadvertently altered due to some transient or other destructive event, it could be restored by a memory reprogram command. The DRO section provided an interface between the asynchronous systems, permitting the acceptance of ASAP words at a quasi-random rate and the readout of these words at a fixed rate of 400 words per minute.

The entire ASAP format consisted of 60 frames, each 250 milliseconds in length and containing 100 ten-bit words, totaling 6,000 words per master frame. The master frame was 15 seconds in duration during the record mode and 15/18 second during playback.

Transmission - The transmission portion of the subsystem consisted of two very high frequency transmitters, a voltage standing wave ratio measuring assembly, two coaxial switches, two RF multicouplers and two telemetry antennas. Transmitter modulation input switching was provided such that either transmitter could transmit the PCM real time or the ASAP delayed time data. Both transmitters could transmit the same data simultaneously. The voltage standing wave ratio measuring assembly measured the incident and the reflected RF power at the output of each of the transmitters. The coaxial switches and the RF multicouplers allowed either transmitter to be connected to either antenna independently or simultaneously.

A model 316 VHF antenna was mounted on the forward edge of the 316 antenna panel on ATM Solar Wing 1. The antenna panel was mounted with offset stops to compensate for the slight angular offset between adjacent panels on the solar array wing. The antenna's position on the panel enabled its longitudinal axis to be parallel to the orbital assembly axis. A VHF model 231 antenna was located at the outer end of ATM Solar Wing 4. It was mounted with offset stops and was oriented with the dipole element perpendicular to the wing plane. The normal mode of operation was for PCM real time data to modulate both transmitters. The output of both transmitters was routed to the antenna that had the best pattern for the ground station receiving the signal. When delayed time data were required, the modulation to one of the transmitters was switched to ASAP delayed time data.

For antenna coverage patterns, see ED2002-1120 (Martin Marietta Corporation) "Skylab Antenna Coverage Handbook."

ATM Digital Command Subsystem

The ATM I&CS Digital Command Subsystem (DCS) consisted of a command receiver, decoder, directional coupler and antenna assemblies. The DCS provided the STDN with real-time command capability during the mission,after ATM solar array deployment. The subsystem was redundant for backup capability. Command data transmission was in the form of a phase shift keyed/frequency modulated signal (PSK/FM). The command data, either on ATM switch selector command or ATM digital computer (ATMDC) command, were coded such that only a unique function was performed in the ATM. Command data were placed in computer storage at the STDN stations. When command data were transmitted to the ATM they were recovered from computer storage, encoded, and transmitted by a 450 MHz UHF link. During normal operation, the redundant digital command systems were also addressed. With proper code selection, either system was addressed individually. Figure 10-3 is a block diagram of the DCS showing the functional interfaces.

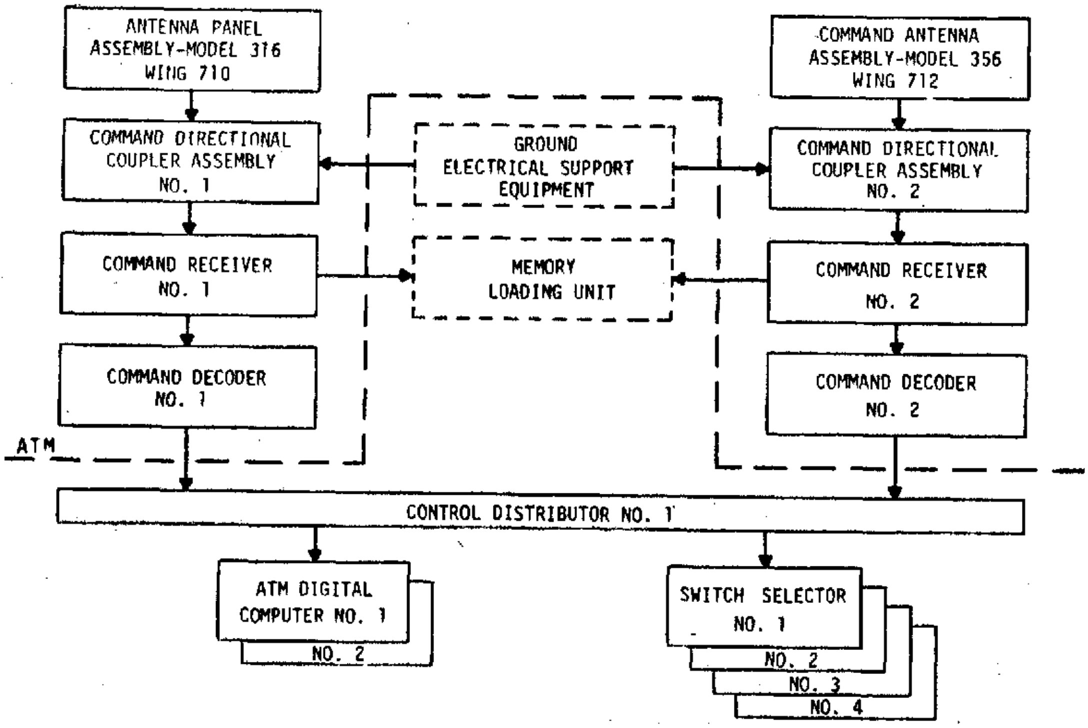


Figure 10-3. ATM I&CS Digital Command Subsystem Block Diagram

Command Receiver - The command receivers were super heterodyne receivers model MCR 503D, operating continuously and simultaneously with an input signal of 450 MHz. The IF bandwidth was 340 KHz, and after demodulating provided a dual phase shift keyed (PSK) audio output to the command decoders. Receiver inputs to the Memory Loading Unit (MLU) enabled ground stations to load the ATMDC memory modules in flight.

Command Decoder - The command decoder received a PSK baseband signal from the receiver, separated the 1 and 2 KHz signals, compared the phases and recovered the sub-bit data. The decoder also verified the proper vehicle address sub-bit patterns. If the patterns were correct the data were passed on to the designated subsystem, but if an error was detected, the data were rejected and the decoder started the verification cycle over again.

The decoder output consisted of five enable pulses, one each for the four switch selectors and the ATMDC, and twelve data lines to the ATMDC of which eight were connected in parallel to the corresponding inputs of the four switch selectors. In addition, execute and reset pulses were connected to each switch selector and to the computer. An address verification pulse was routed to the TM system when a correctly addressed command was received. The STDN could address both decoders or either one individually. The uplink command list is contained in 50M16140 "ATM DCS Radio Frequency Command List."

DCS Antennas - The ATM utilized two antennas. Each antenna was connected to one of the two command receivers. DCS antenna model 316 was mounted at the apex of the antenna panel located at the outer end of ATM Solar Array Wing 1. The antenna panel was mounted with offset stops to compensate for the slight angular offset between adjacent panels on the solar array wing. DCS antenna model 356 was located near the center of the outer end of ATM Solar Wing 3. It was also mounted with offset stops and was oriented with the dipole element perpendicular to the wing plane. For DCS antenna patterns see ED2002-1120 (Martin Marietta Corporation) "Skylab Antenna Coverage Handbook."

Television Subsystem

Figures 10-4 and 10-5 illustrate the TV subsystem functional block diagram and interfaces. The ATM TV subsystem utilized five cameras and associated electronics to support ATM experiments. Two video output signals were selected via a remotely controlled switch for routing and display on two TV monitors at the ATM Control and Display (C&D) Console in the MDA. In addition, each video switcher/processor combined sync signals with a selected camera video signal for transmission to the STDN. The TV subsystem consisted of three vidicon TV cameras, two low light level TV cameras, four camera control units, two video switcher/processors, a video isolation amplifier and a sync generator.

The three vidicon TV cameras had a resolution of 600 horizontal lines and 330 vertical lines, with full resolution discernible at 0.01 foot candle. These cameras were used in the S082B XUV Slit, H-Alpha 1 and H-Alpha 2 experiments. The two low light level T" cameras had a resolution of 550 horizontal lines and 330

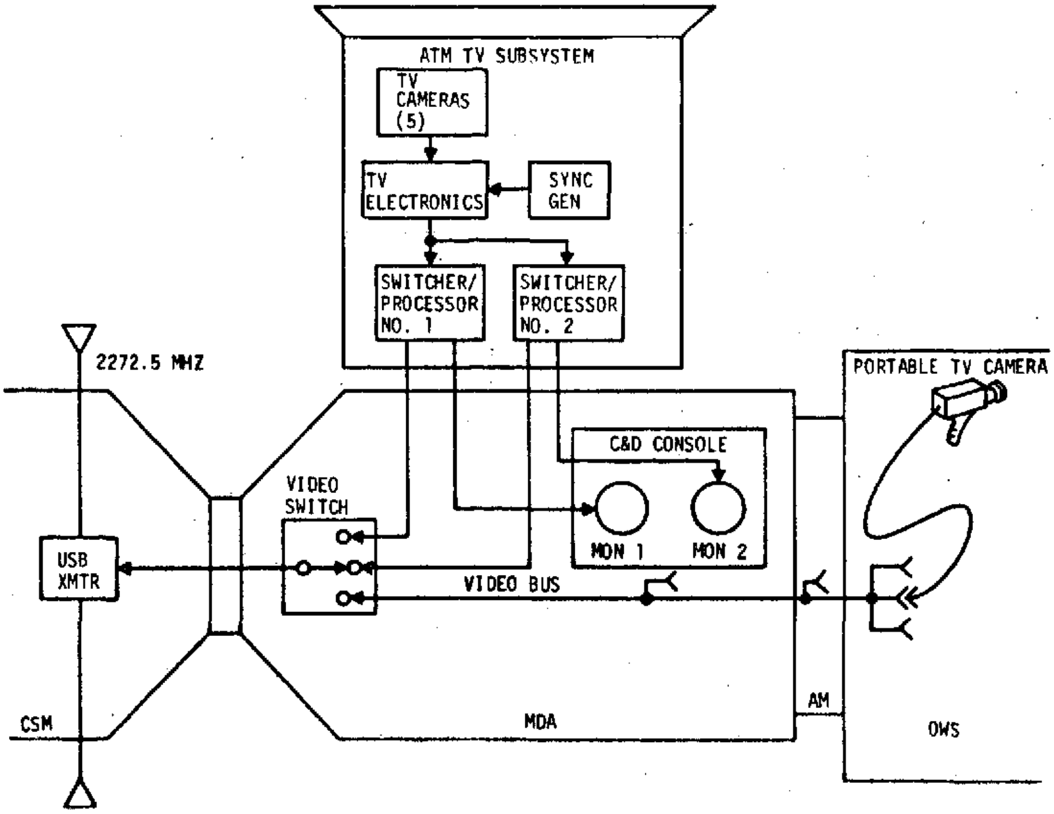


Figure 10-4. Television Subsystem Block Diagram and Interfaces

vertical lines, with full resolution discernible at 3 x 10^{-3} foot candle and 200 horizontal line resolution discernible at 5 x 10^{-5} foot candle. These cameras were used in the S052 and S082B XUV Monitor experiments. The S082B XUV Slit image dissector vidicon TV camera was an integral part of the S082B Pointing Reference System. All of the TV cameras were physically attached to their respective experiment and received their images through an optical system in the experiment. The camera control units provided all operational voltages and currents required by the camera systems and processed the video received from the TV cameras. The TV cameras and control units are further discussed in their respective experiment sections of this report.

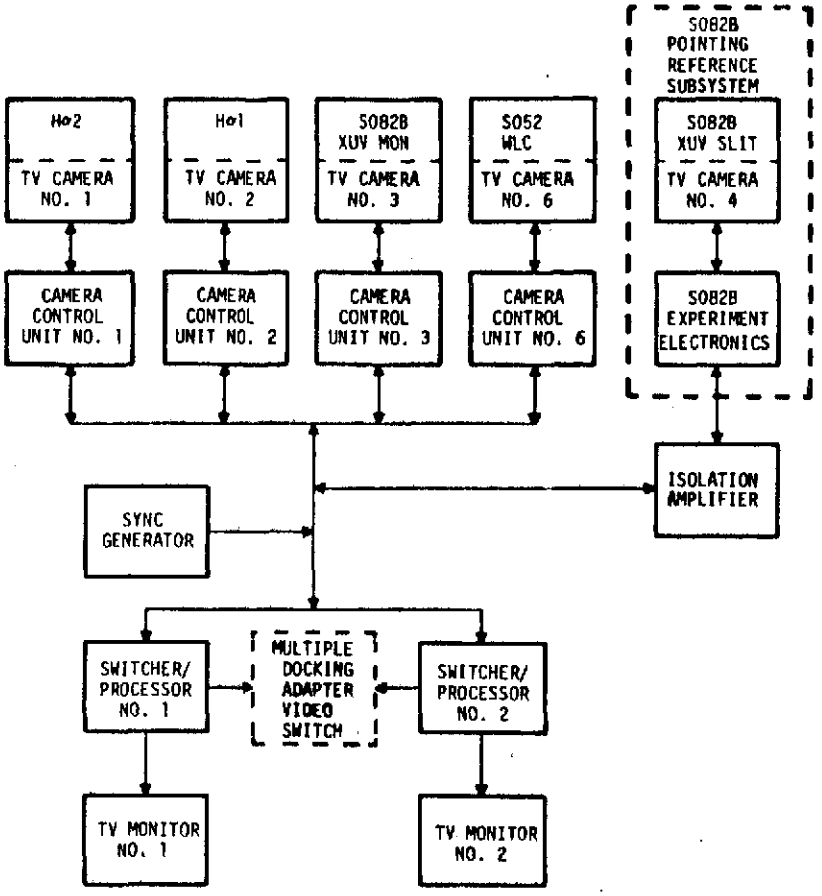


Figure 10-5. ATM I&CS Television Subsystem Block Diagram

The function of the video switcher/processor was to provide camera selection for the television monitor, add sync to video signals for downlink transmission, isolate TV signal grounds from ATM structure ground, and provide switching to interchange signals to the two TV monitors.

A video isolation amplifier was mounted on top of each video switch and sync adder to isolate the video and pulse signals from the canister ground. These two combined units formed the switcher/processor.

The video isolation amplifier used on the pointing reference system isolated the pulse signals in the S082B image dissector camera from the canister ground. These isolation amplifiers provided ground isolation for video and drive signals going to the monitor and video downlink, and switching capabilities for interchanging video and drive lines to the monitors.

Miscellaneous I&CS Components

Solar Radio Noise Burst Monitor (RNBM) - The RNBM detected electromagnetic emissions which would alert the crew of solar flare activity. Solar flares are preceded by solar radio emissions (noise). The receiver operated at a center frequency of 4995 MHz with an RF bandwidth of ±15 MHz. A 2-foot diameter parabolic disc antenna was mounted on the Airlock Module. Should the emissions exceed the preset threshold level, an audio alarm in the SWS would activate and the noise level was displayed on the SRNBM meter in the MDA and recorded on the activity history plotter on the C&D Console.

Quartz Crystal Microbalance/Contamination Monitor (QCM/CM) - The QCM/CMs were pressure sensing devices used to measure contamination onboard the spacecraft. The two sensors were capable of measuring masses of 10^{-9} gram, and measuring characteristics were valid through mass accumulation of 10^{-4} gram. The sensors were relatively independent of temperature changes within the range of operation. The outputs from the QCM/CMs were utilized in flight to obtain telemetered data on the mass of the deposited contamination.

SYSTEM EVOLUTION AND DESIGN RATIONALE

Early History

ATM Universal Rack Concept - In June 1966, the ATM integration study began. ATM systems were designed to be functionally independent with minimum interface with the LM. The I&CS consisted of a command and display system, an instrumentation system for data retrieval, and an RF transmission system. Reliability considerations resulted in redundancy in critical ATM elements and separation of ATM and LM functions. Based on the use of the universal rack as the carrier for the ATM, it was determined the I&CS would be self-contained and located on the rack. It would utilize as much Saturn generation hardware as possible, while maintaining Saturn data formats and frequencies for compatibility with existing ground systems. The physical packaging concept was greatly influenced by thermal considerations. While most of the Saturn-generation hardware was designed for cold plate mounting, ATM requirements predicted passive cooling only.

The I&CS would include telemetry transmission of real-time and/or recorded data, a measuring system to sense and condition data stimuli, television providing the crew the means to aim the optical axis of the ATM, voice communications between the LM crew and the Earth, and digital command update capability to facilitate ground and orbital checkout.

The telemetry system for ATM employed Saturn hardware with the exception of the data storage device. The Auxiliary Storage and Playback Unit (ASAP) would extract data from the PCM wavetrain, combine it with appropriate code words, and record it on tape for subsequent playback.

The RF system for ATM/LM consisted of Saturn developed hardware, composed of a Computer Control System (CCS), a command decoder, and an omnidirectional telemetry antenna system. The CCS consisted of an S-band transponder, a power amplifier, and an omnidirectional receive/transmit antenna system and would provide command data uplink for prelaunch checkout, orbital checkout prior to reactivation of the ATM from quiescent storage, and any other required command functions. The CCS also would provide telemetry downlink for real time transmission of all experiment and housekeeping data.

The measuring system for ATM/LM used Saturn hardware consisting of transducers, five measurement racks, signal conditioning cards, channel selectors, and one measurement rack selector. The rack and channel selectors were on-board units required for automatic checkout. To provide remote checkout of the measurement system during prelaunch activities and orbital reactivation, a remote automatic checkout system (RACS) was to be used. Binary coded signals were to be sent from ground equipment by manual keyboard or computer program via hardline before launch, and via CCS command link during flight. The RACS was active only for ground checkout, however, and a redesign was required for ATM to add inflight capability.

The television system consisted of two cameras to be used interchangeably. The cameras would be aligned with the optical axis of the experiment telescopes and use individual optics. The TV cameras were based on technology developed for the Saturn program. A 4 by 6 inch display monitor would be provided on the ATM console. A camera control unit for switching cameras and field-of-view was included, plus appropriate switches on the ATM console.

All voice communications would be provided by the LM operational systems during launch.

Design Evolution/Rationale

The design concept change from LM/ATM universal rack configuration to wet workshop had minimal impact on the basic instrumentation and communications system design rationale. Flight-proven Saturn hardware remained the basic criteria for continued I&CS development. The major change to the I&CS was the elimination of the 51 LM measurements from the I&CS measurement program. These LM measurements were to have been across the ATM/LM interface to ATM telemetry.

Conversion from wet workshop to dry workshop concept resulted in additional changes to the ATM I&CS configuration. The ATM digital computer was interfaced with the I&CS to accommodate a greater portion of the measurement program. The original scheme to employ a digital 40-bit word sampled 12 times per second was modified to use a 50-bit word sampled 24 times per second.

The final ATM I&CS design was specified in the Cluster Requirements Specification, RS003M0003, ATM System Performance and Design Requirements, 50M02417, and Test and Checkout Requirements and Specifications Document, 50M02425. These and other documents listed in the reference documentation tree, Table 10-II, were used to provide control for the integration of ATM systems and module-to-module interfaces.

Table 10-II. ATM I&CS Design Specifications and Requirements Documentation Tree

ATM INSTRUMENTATION & COMMUNICATIONS SYSTEM

DESIGN REQUIREMENTS	INTERFACE REQUIREMENTS	ATM EXPERIMENTS INTERFACE REQUIREMENTS	CONTROL DOCUMENTS
CLUSTER REQUIREMENTS SPECIFICATION RS003M00003	ICD, ATM/AM I&C 50M16131	ICD, GSFC EXPERIMENT (S-056) 40M35583	SKYLAB FREQUENCY PLAN 50M13120
ATM SYSTEM PERFORMANCE AND DESIGN REQUIREMENTS 50M02417	ICD, AM/MDA I&C 50M13122	ICD, AS&E EXPERIMENT (S-054) 40M35584	SKYLAB TV REQUIREMENTS 50M16132
ATM TEST & CHECKOUT REQUIREMENTS & SPECIFICATIONS 50M02425	ICD, MDA/CSM I&C 50M13125	ICD, HAO EXPERIMENT (S-052) 40M35580	ATM RF COMMAND LIST 50M16140
	ICD, ATM/AM/MDA RNBM 50M16155	ICD, NRL-A&B EXPERIMENTS (S-082) 40M35586	ATM MEASUREMENT LIST 50M16136
		ICD, H-ALPHA-1, -2 EXPERIMENTS 40M35588	ATM INSTRUMENTATION PROGRAM & COMPONENTS LIST 50M12711
		ICD, HCO EXPERIMENTS (S055A) 40M35589	ATM ELECTROMAGNETIC COMPATIBILITY CONTROL PLAN 50M12725

Compatibility with cluster attitude and orbit changes was required relative to antenna coverage and radiation patterns. Reliability was achieved through redundancy for all system elements except signal conditioning, transducers and multiplexers. I&CS requirements included overall constraints relative to crew safety and mission success. Component design useful life was required to be 150 percent of required operational service life. During ground checkout, capability to utilize RF and/or hardline operations was provided.

The following describes I&CS interfaces with other ATM systems and with other modules which placed specific requirements on the I&CS.

The ATM data subsystem was required to accept and transmit ATM-originated measurements. Signal returns for ATM analog measurements was provided by the AM/ATM electrical power return. The ATM data subsystem return bus was statically grounded through the AM/CSM single point ground.

The AM provided certain RF commands to the ATM primarily affecting the ATM data subsystem, but also the ATM DCS. Hardline AM/ATM connection permitted control of ATM functions through the AM DCS by means of momentary contact closures in the AM. The AM provided excitation power to the contacts sending commands for ATM solar array deployment and APCS activation, while the ATM provided the power for ATM data subsystem operation commands.

ATM data subsystem-generated strobe pulses (4pps) were sent to the ATM star tracker assembly. Parallel binary gimbal position data were returned to the ATM data subsystem for transmission to the STDN. Other signals furnished for transmission were "star presence" and "shutter closed" indications.

Video signals from the ATM crossed the ATM/AM interface by means of coaxial cables. Signal returns by coaxial shields were isolated from the structure by a minimum of 5 megohms.

The Skylab television subsystem transmitted real-time television data from the Orbital Assembly to the STDN when the CSM was docked to the SWS. All television transmission was through the CSM USB link, from signals routed through two switcher/processors on the ATM and from a portable television camera used by the crewmen.

Video output from the ATM experiment television cameras were channelled from the ATM to the MDA, through the three-input MDA video switch, and onto the CSM transmitter.

The RNBM microwave receiver in the MDA was connected to the antenna/cable assembly in the AM to provide RF flare alerts to the crew.

New Technology

The video isolation amplifiers were an improvement on relatively new state-of-the art devices primarily used in low frequency digital isolation applications. The ATM application increased the frequency bandwidth so that relatively wide band (0 to 8 MHz) TV signals could be used.

Isolation was achieved by using optically-coupled isolators. The desired signal was used to modulate a light beam, which was in turn detected by a photo diode. Isolation then became a function of the resistivity of the printed circuit board base material, in excess of 1×10^8 ohms.

MANUFACTURING

Fabrication and Assembly

Fabrication and assembly of the I&CS components was accomplished in accordance with standard manufacturing procedures. The Astrionics Laboratory, MSFC, had the program responsibility for supplying all I&CS components. The telemetry transmitter, directional coupler, coaxial switch, PCM/DDAS, TDM, RDM and RASM from the Saturn program were utilized with little or no modification. The command receiver, VSWR measuring assembly, and SCR were modified versions of Saturn hardware. The remaining I&CS components were developed specifically for the ATM program.

The following list identifies the vendors of procured I&CS components:

- Borg/Warner Controls, Inc.
  - ASAP Tape Recorder
- CONIC Corporation
  - Telemetry Transmitter
- Teledyne Telemetry-Lewisburg, Inc.
  - PCM/DDAS Model 301
  - TDM Model 270
  - RASM Model 103
  - ASA
  - ASAP DC-DC Converter
- Motorola Communications & Electronics, Inc.
  - Command Receiver
- Atlantic Research Corporation
  - QCM/CM
- SCI Electronics, Inc.
  - RDM Model 410
  - Command Decoder
  - ASAP DSIU
  - RNBM

The thermal isolator standoffs for the ASAP tape recorder and the RASM were built by the MSFC Process Engineering Laboratory. The remainder of the I&CS components were built by the Astrionics Laboratory.

Problems and Solutions - The only significant manufacturing problems encountered involved parts alerts after all affected end items had already been assembled. A parts alert was released against all solid tantalum capacitors in critical components; consequently, the capacitors were X-rayed and defective ones replaced. Also, a parts alert was released against tubular wet tantalum capacitors in critical components and these were replaced. Both alerts resulted in considerable rework time and effort.

Component Development Testing

Development testing was minimal due to the significant utilization of already developed Saturn program hardware.

A telemetry simulator was built, using flight cable lengths to provide the capability of testing the equipment. The simulation revealed that the RASMs were cabled up for six amplifiers per RASM (Saturn configuration) rather than for one amplifier per RASM (ATM configuration). The extra cable loaded the output of the amplifier and the unit would not operate properly. Cable modifications were accomplished correcting the problem prior to ATM Prototype Unit checkout. Testing the PCM/DDAS and the ASA in the flight configuration revealed that the serial 72 kbs data amplifier in the ASA was not needed. Therefore, the amplifier was removed and its commands deleted.

Antenna characteristics for the telemetry transmitting antenna and the command receiving antennas were measured on the antenna pattern range. Gain of the transmitting antenna subsystem was found to be -6 db or better, referenced to a linearly polarized isotropic antenna over 97 percent of sphere. The receiving antenna subsystem gain was also -6 db or better, referenced to a linearly polarized isotropic antenna over 82 percent of sphere for one antenna. With both antennas operating the gain was -6 db or better with respect to 95 percent of sphere which exceeded design requirements in both receiving and transmitting.

Thermal Analysis - The following design modifications were required due to thermal analyses conducted on I&CS components:

Component	Design Changes Made
ASAP DC to DC Converter	Area of radiation surface sized at 1.33 feet minimum
PCM/DDAS Model 301	Bonded copper heat sinks to VCO regulator, VCO multivibrator, and 6 volt power supply printed circuit cards Installed beryllium copper heat sink clips to VCO regulator and 6 volt power supply printed circuit cards

Component	Design Changes Made
	Inserted mica sheet under transistors when utilizing component side mounted heat sinks
	Applied Eccoshield SV-R gasket material for top housing and intra housing gaskets
Telemetry Transmitter	Mounted transmitter on equivalent radiation panel of 210 square inches and 0.4 inches thick
Time Division Multiplexer Model 270	Added copper heat sink to the DC to DC converter printed circuit card
	Installed tinned copper wire braids on DC to DC converter printed circuit card
	Applied Eccoshield SV-R gasket material at interfaces
Remote Digital Multiplexer Model 410	Added copper heat sink to DC to DC converter printed circuit card
	Used Dupont Viton A for gasket material at interfaces
	Installed tinned copper wire braids on DC to DC converter printed circuit card
Remote Analog Submultiplexer Model 103	Added copper heat sinks to DC to DC converter and low level amplifier printed circuit cards
	Used Cho-Seal 1215 for gasket material at interfaces

<u>STDN Compatibility Special Tests</u> - A requirement was identified to verify the compatibility of the ATM I&CS and the STDN hardware and software. The tests were performed at GSFC during June and July 1972, and were supported by S&E-ASTR-I, MSFC. Tests proved all I&CS hardware to be compatible with the STDN.

Memory Loading Unit (MLU) Special Tests - Tests were conducted in March 1972, by the MSFC Astrionics Laboratory and IBM on the memory loading unit. The purpose of the tests was to determine the feasibility of providing an input to the MLU in order to reload the program into the ATM digital computer. The tests were divided into two phases, as follows: 1) load the MLU from a program stored on an auxiliary storage and playback recorder, and 2) load the MLU from the ATM command receiver by ground command. Both methods proved feasible.

Corona Special Tests - All ATM I&CS components having operating voltages of 150 volts peak were assessed for corona susceptibility. No problems were detected.

Component Acceptance Testing

All I&CS components were subjected to end item acceptance testing by the Quality and Reliability Assurance Laboratory (S&E-QUAL). Table 10-III lists the test procedure or test specification number for each type of end item.

There was only one significant anomaly encountered during I&CS end item acceptance testing. The PRS isolation amplifier response at 8 MHz exceeded the specification tolerance of -3db by as much as 1.5db. A waiver for this problem was requested and approved.

Table 10-III. ATM I&CS End Item Acceptance Test Procedures

End Item	Test Procedure/ Specification
Pulse Code Modulation/ Digital Data Acquisition Subsystem Model 301	50M13181B
Time Division Multiplexer Model 270	50M13180B
Remote Analog Submultiplexer Model 103	50M60438
Remote Digital Multiplexer Model 410	SCI-SIP-1750-1
Telemetry Transmitter	50M16996
Voltage Standing Wave Ratio Measuring Assembly Model 230	54TP3-1-50M60419
RF Multicoupler Model 232	54TP3-1-50M17208
Coaxial Switch	50M60418
Auxiliary Storage and Playback Tape Recorder	50M12971
Auxiliary Storage and Playback Data Storage Interface Unit	ATP-2579066
Auxiliary Storage and Playback Memory Assembly	50M16172
Auxiliary Storage and Playback Redundant DC-DC Converter	50M17176
Amplifier and Switch Assembly	50M17527
Signal Conditioning Rack	54TP3-1-50M16040
Signal Conditioning Rack Filter Assembly	54TP3-1-50M17469
Antenna Panel Assembly Model 316	54TP3-1-50M04664B
Telemetry Antenna Model 231	54TP3-1-50M04663
Command Receiver MCR 503-D	50M12808
Command Decoder	50M12804
Directional Coupler Model 318	54TP3-1-50M60432
Command Antenna Model 356	54TP3-1-50M16758
Sync Generator	50M12741
Switch/Processor	50M16762, 50M17795
Pointing Reference System Isolation Amplifier	50M17795
Radio Noise Burst Monitor	SCI-12537065
Quartz Crystal Microbalance/Contamination Monitor	61B880062

COMPONENT/END ITEM QUALIFICATION

Component Qualification

Qualification testing of I&CS components covered high and low temperature, thermal shock, vibration, acceleration loads, acoustic, humidity, altitude, thermal vacuum, outgassing and electromagnetic compatibility as well as functional operations. The baseline document for component qualification was 50M02408, Environmental Design and Qualification Test Criteria for ATM

Components. Table 10-IV lists the I&CS components, their respective qualification test specification/procedure, and the respective qualification test report. A detailed qualification summation of all components which were involved in the Skylab mission activation sequences, which included most of the I&CS components, is presented in the ATM Hardware Integrity Review Summary Report, dated April 30, 1973.

The video isolation amplifier failed during vibration testing due to a poor bond of a wire to the integrated circuit. This failure was believed to have been caused by thermal cycling. Flight units were subjected to extensive thermal cycling and vibration testing. In addition, mission rules were changed to reduce the on-off cycling to three power on-off cycles for the entire mission to reduce thermal stressing.

The ASAP tape recorder failed during vibration testing due to a broken wire in the wiring harness. The harness was redesigned to provide additional support. During a second vibration test, a negator spring retainer ring came off. This failure was traced to improper installation, and the assembly procedure was changed.

The ASAP data storage interface unit failed after 48 hours at $-40^{\circ}C$. Failure analysis revealed that glass encased diodes and resistors were broken, and that glass seals in dual-in-line integrated circuits had hairline cracks. All glass encased components were replaced with non-glass where possible, and the remaining glass components were sleeved with teflon. The conformal coating on the circuit side of the PC card was crosshatched for stress relief, and the conformal coating was omitted from the integrated circuits. Retest of the modified qualification unit was satisfactory.

Component Life Testing

The ASAP tape recorder was subjected to both accelerated and normal cycling endurance testing. Two failures were encountered during the accelerated testing which consisted of 150 percent of mission requirements at ambient pressure and temperature. Two negator springs failed and were redesigned. A reel bearing failure resulted in adding lubricant to the previously dry bearing. During normal cycling in a simulated mission thermal vacuum environment, the tape broke after 67 days of testing due to tape instability at turn-around. This problem was caused by increased capstan-to-tape friction due to the end-of-tape sensor window and high humidity and temperature. The end-of-tape sensor window was shortened to five inches which prevented turn-around from occurring on the window, the internal humidity was reduced to ten percent (at room temperature), and the upper operating temperature limit was decreased from +40°C to +30°C.

Table 10-IV. ATM I&CS Component Qualification Test Summary

Component	Qual Test Specification/ Procedure	Qual Test Report
Pulse Code Modulation/ Digital Data Acquisition Subsystem Model 301	54TP1-1-50M13181	54TR1-1-50M13181
Time Division Multiplexer Model 270	PTP-NASA-061, 50M13180B	54TR1-1-50M13180
Remote Analog Submultiplexer Model 103	PTP-NASA-438, 50M60438	54TR1-1-50M60438
Remote Digital Multiplexer Model 410	SCI-QPT-1750-1, 50M13182	54TR1-1-50M60274
Telemetry Transmitter	17011130, 50M12996	54TR1-1-50M12996
Voltage Standing Wave Ratio Measuring Assembly Model 230	54TP1-1-50M60419	54TR1-1-50M60419
RF Multicoupler Model 232	54TP1-1-50M17208	54TR1-1-50M17208
Coaxial Switch	54TP1-1-50M60418	54TR1-1-50M60418
Auxiliary Storage and Playback Tape Recorder	50M12971B	54TR1-1-50M12971
Auxiliary Storage and Playback Data Storage Interface Unit	50M17249	50M17766
Auxiliary Storage and Playback Memory Assembly	T0912974, 50M16172	54TR1-2-50M16172
Auxiliary Storage and Playback Redundant DC-DC Converter	50M17176A-E01	54TR1-1-50M17176

Table 10-IV. ATM I&CS Component Qualification Test Summary (Continued)

Component	Qual Test Specification/ Procedure	Qual Test Report
Amplifier and Switch Assembly	NASA-413-Q, 50M16995	54TR1-1-50M16995
Signal Conditioning Rack	54TP1-1-50M12982	54TR1-1-50M12982
Signal Conditioning Rack Filter Assembly	54TP1-1-50M17469	54TR1-1-50M17469
Antenna Panel Assembly Model 316	54TP1-1-50M04664	54TR1-1-50M04664
Telemetry Antenna Model 231	54TP1-1-50M04663	54TR1-1-50M04663
Command Receiver MCR 503-D	Qualified by similarity to Saturn version 50M10697	
Command Decoder	50M12790, 50M12807	54TR1-1-50M12790
Directional Coupler Model 318	54TP1-1-50M60432	54TR1-1-50M60432
Command Antenna Model 356	54TP1-1-50M16758	54TR1-1-50M16758
Sync Generator	54TP1-1-50M12741A	54TR1-1-50M12741A
Switcher/Processor	54TP1-1-50M16762, 54TP1-1-50M17795	54TR1-1-50M16762, 54TR1-1-50M17795
Pointing Reference System Isolation Amplifier	54TP1-1-50M17795	54TR1-1-50M17795
Radio Noise Burst Monitor	SCI-2537065	SCI Report dated 1/1/72
Quartz Crystal Microbalance/ Contamination Monitor	Qualified by similarity to MDAC-E unit	

The following items were life tested with no problem encountered:

1. Complete ASAP assembly, including following telemetry components:
    - Model 103 RASM
    - Model 410 Multiplexer
    - Model 270 Multiplexer
    - Model 301 PCM/DDAS
    - ASA
2. Telemetry Transmitter
3. Directional Coupler
4. Coaxial Switch

SYSTEMS VERIFICATION PROGRAM

The hardware acceptance test program included systems verification of the ATM prototype and the ATM flight unit. The prototype test series included post manufacturing checkout, vibration testing, and thermal vacuum testing. Verification of the flight unit consisted of basically the same series of tests as performed on the prototype, plus prelaunch checkout at KSC. Vibration testing was accomplished after thermal vacuum testing on the prototype and prior to thermal vacuum testing on the flight unit. Design changes resulting from testing on the prototype unit were incorporated in the flight unit.

The basic test specification for both systems qualification and acceptance testing was 50M02425, ATM Test and Checkout Requirements and Specifications Document.

Systems Verification (Prototype)

Post Manufacturing Checkout - Post manufacturing checkout verified the manufacturing and design integrity by assuring that each system performed according to program requirements and specifications. The measurements were tested for channelization and functional performance and verification of proper operation of analog and discrete telemetry measurements by performing an automatic measurement profile test. Telemetry testing verified operation of signal conditioning, multiplexing, PCM/DDAS assemblies, and ASAP equipment. Test objectives were met through individual components and subsystems verification and operating with other systems of the ATM to verify compatibility. No major problems were detected.

RF and television testing verified integrity of the command receiver and decoders, transmitters, cables, multicouplers, coaxial switches, antennas, sync generators, camera control units, video switch/sync adders and video monitors. EMC testing verified operation free from electromagnetic interference. The plugs-out test verified that the RF systems would operate satisfactorily in a near-flight configuration. No major problems were revealed.

Thermal Vacuum Testing - Thermal vacuum testing was accomplished at JSC from September 8 to December 15, 1971. The I&CS was tested in both ambient and thermal vacuum conditions. Ambient testing included procedures for full ATM operation with two all systems tests (pre- and post-thermal vacuum), and support of integrated ATM/ESE-GSE/ACE verification and an astronaut C&D panel environmental verification. Testing at thermal vacuum conditions included support of experiment calibration and a series of ten test runs. Document 50M05116A, dated March 15, 1972, describes the testing. All subsystems functioned within specifications. Significant problems and actions are described below.

1. Several data subsystem SCR measurements were noisy during T/V. The problem was solved by increasing the value of capacitors on range card outputs. All SCRs were reworked.

2. High attenuation was measured through the coaxial switch during PMC and there was no output from one switch during one phase of thermal vacuum. Failure analyses revealed a black sticky substance on the contacts and flaking of the gold plating on the copper contacts. New teflon fiberglass printed circuit boards were substituted, along with changes in sealant and fill gas. Residual gases were baked out prior to sealing the switches. Switch sensitivity was reset and armature travel reduced.

3. The primary PCM/DDAS model 301 produced no output in 600 KHz or 4K bit modes. Omission of a heat-conducting washer under a power supply transistor caused overheating and failure. All ATM prototype, flight and spare units were retrofitted.

4. Tape recorder number 2 had excessive sync dropout. The failure mechanism could not be determined. The unit was designated as a non-flight item, and was replaced.

Post-Vibration Testing - Vibration testing was accomplished from February 14 until April 12, 1972, in the S&E-ASTN vibration test facility at MSFC. The post-vibration verification was completed June 16, 1972. There were no I&CS anomalies.

Systems Verification (Flight)

Post-Manufacturing Checkout - Post manufacturing checkout on the flight unit was completed May 25, 1972. Objectives were to verify operation of individual subsystems independently and then operation with other ATM systems for compatibility. Testing progressed satisfactorily, and no major I&CS problems were encountered.

Post-Vibration Testing - Post-vibration verification was accomplished at JSC as part of the pre-thermal vacuum testing. It was accomplished using two levels of testing, individual components and subsystems operation individually, and then operation with other ATM systems to verify compatibility. No major problems were encountered.

Thermal Vacuum Testing - Thermal vacuum testing was accomplished at JSC between June 26 and September 12, 1972. Acceptance of the flight unit was determined through six thermal vacuum runs and similarity of prototype thermal vacuum testing. The I&CS encountered no major anomalies.

Prelaunch Checkout - Prelaunch checkout was conducted at KSC beginning September 22, 1972, and ending January 30, 1973. The objective of the testing was to verify that the ATM systems performed in accordance with program requirements and specifications prior to mating with the other Skylab modules. There were no major anomalies encountered relative to the I&CS operation during the checkout.

The ATM was mated and integrated into the Skylab cluster at the VAB between January 30, 1973, and April 6, 1973. Subsystem checks were made prior to cluster activation, then flight systems and subsystems interface and functional compatibility testing was conducted between the ATM and the other Skylab modules. There were no significant I&CS anomalies encountered during the integration and checkout.

The Skylab-1 vehicle was transferred to LC-39 Pad A on April 16, 1973. All I&CS subsystems continued to perform satisfactorily on the pad. It was determined that the lightning strike of May 9, 1973, caused no damage to the I&CS.

SECTION XI. ATTITUDE AND POINTING CONTROL SYSTEM

SYSTEM DESCRIPTION

The attitude and pointing control system (APCS) was designed to provide three-axis attitude stabilization in the required operational attitudes, to provide for controlled operational maneuvers of the Skylab and to provide pointing control in support of the ATM experiments. Figure 11-1 is a functional block diagram of the attitude and pointing control system.

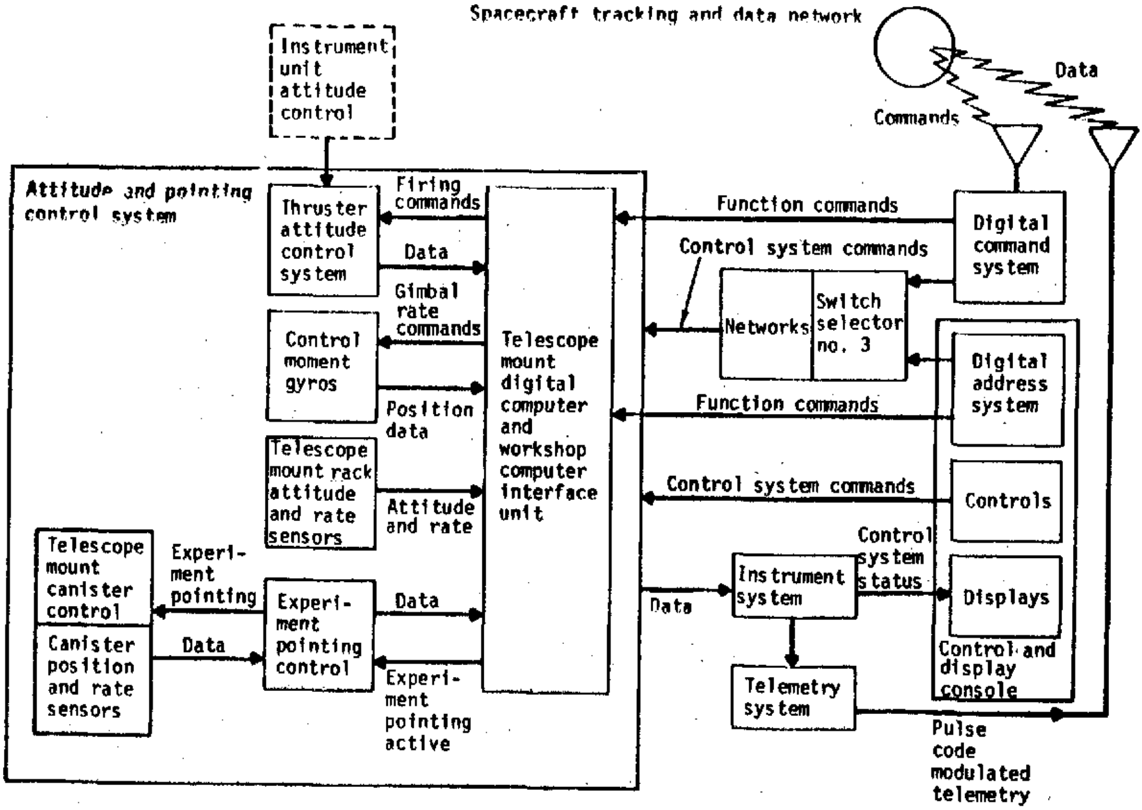


Figure 11-1. Functional Block Diagram of the APCS

A control moment gyro (CMG) system and a thruster attitude control system (TACS) provided the torques necessary for attitude control and maneuvering of the Skylab. The TACS was used to assist the CMG's when the Skylab attitude control, maneuvering and docking requirements exceeded the CMG momentum storage capacity and for the purpose of desaturating the CMG when needed.

The APCS was designed for two basic attitude modes of operation: solar inertial (SI) and Z local vertical (Z-LV). All other attitude modes were attained by maneuvering or offsetting from the two basic attitudes.

Table 11-I shows the pointing accuracy and stability requirements for the assembly and the ATM Experiment canister.

Table 11-I Pointing Accuracy and Stability Requirements of the Attitude and Pointing Control System

MODE	ABOUT AXIS	ANGULAR DISPLACEMENT	STABILITY ANGULAR DISPLACEMENT PER 15 MINUTES TIME
ORBITAL ASSEMBLY			
Solar Inertial	X & Y	± 6 arc minutes	± 9 arc minutes
	Z	± 10 arc minutes	± 7.5 arc minutes
Z Local Vertical	X & Z	± 2.5 degrees	none
	Y	± 2.5 degrees	none
EXPERIMENT CANISTER			
Experiment Pointing	X & Y	± 2.5 arc seconds	± 2.5 arc seconds
	Z	± 10 arc minutes*	± 7.5 arc minutes*

*Accuracy and stability about the roll axis of the experiment canister was dependent upon the Orbital Assembly parameters. Roll positioning of the experiment canister was accomplished with manual controls.

Logic required to drive the CMGs and TACs for attitude control of the Orbital Assembly was implemented in the ATM digital computer (ATMDC). Experiment pointing control was implemented in an analog computer.

Flight program specifications were documented in the ATM Digital Computer Program Definition Document, IBM 70-207-002, Revision 22, 10 May 1973.

The Skylab APCS Functional Schematics, 50M04969, Revision F, March 31, 1973, describe in three schematic levels, the functional interrelationships of the APCS constituent and related components. Following are brief descriptions of each component of the APCS.

Major Components

Control Moment Gyro Assembly - The ATM CMG Assembly consisted of an induction-motor-drive constant-moment rotor supported with gimbals which provided two degrees of freedom. Associated with each CMG was an electronics assembly (CMGEA) for the purpose of positioning the gimbals and controlling the gimbal rates, and an inverter assembly (CMGIA) for providing power to the CMG and other APCS hardware. Figure 11-2 is a line pictorial of a control moment gyro.

The actuator pivots each contained a direct-current torque motor, output shaft, and rate-feedback tachometer. The sensor pivot assemblies each contained a ball-bearing-mounted pivot shaft, a resolver assembly, and a flex-lead assembly. The resolver assembly provided gimbal position information to the ATM digital computer for gimbal caging, control law computations, and momentum management.

Each CMG had an angular momentum storage capacity of 2,300 foot-pound-seconds. The rotor was driven by two identical double-squirrel-cage, three-phase, induction motors. The two motors provided redundancy as well as a symmetrical design for balance and heat dissipation. A single motor was capable of maintaining rotor operating speed. The motors required a 130-volt (line-to-line), 455 Hz, three phase power supply. Each motor operated with a slip of approximately 1.0 percent when the rotor was at operating speed. The spin motor bearing temperature could be monitored via telemetry and on the control and display console. Bearing heaters were provided to warm the bearings when required. The CMGs were sized to maintain adequate attitude control with any two CMGs with minimal use of TACS.

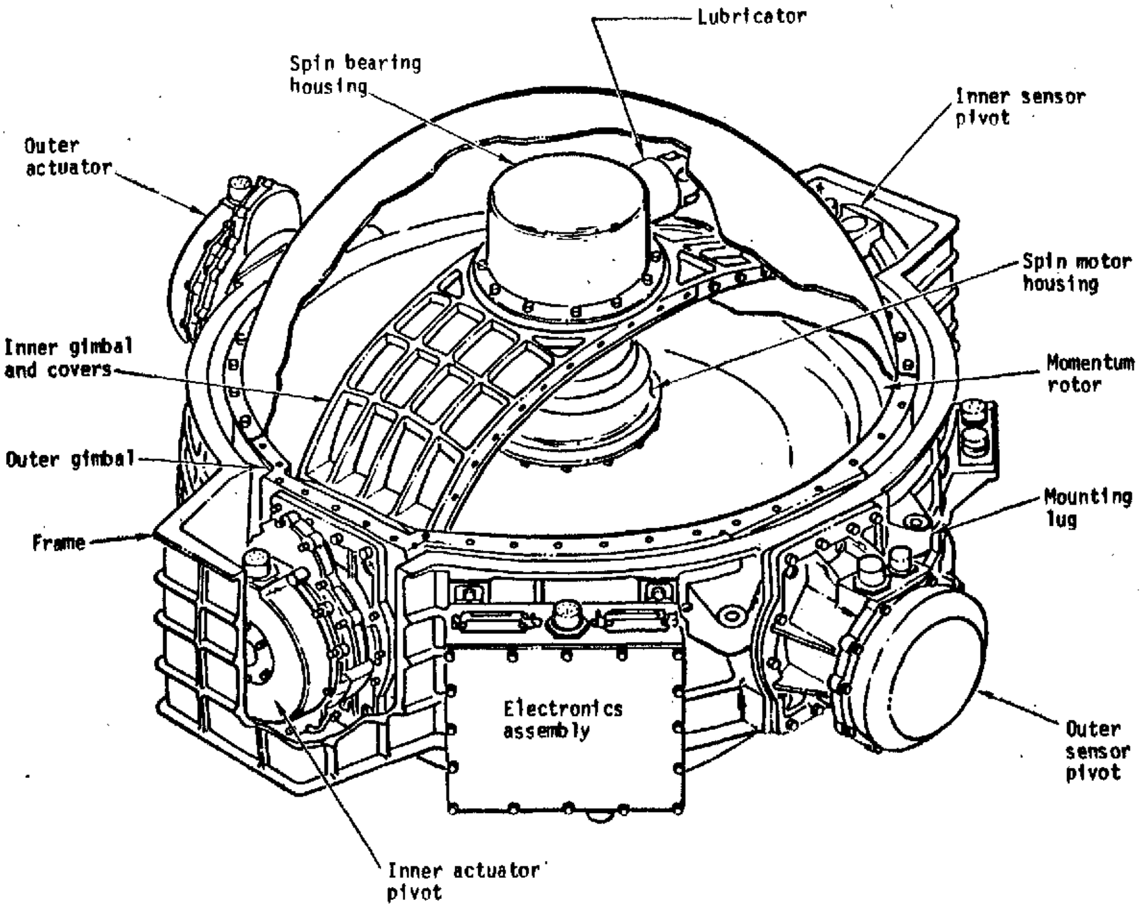


Figure 11-2. Line Pictorial of a Control Moment Gyro

Star Tracker and Electronics - The ATM star tracker function was to provide star sightings for use in calculating roll reference angle and orbital plane error. The roll reference angle provided an experiment canister pointing reference relative to the solar disk for telemetry, experiment film recording, and display on the control and display console.

Subsystems of the star tracker were the optical-mechanical assembly and the star tracker electronics assembly.

Fine Sun Sensor - The fine Sun sensor provided highly accurate attitude information for the X and Y axes of the experiment pointing and control system. The fine Sun sensor was comprised of four separate components: 1) an optical-mechanical assembly, 2) preamplifier electronics assembly, 3) control electronics assembly, and 4) signal conditioner.

The two primary and two secondary Sun sensor channels were housed in the optical-mechanical assembly. Similarly, redundant electronics were housed in the other three assemblies. There was no provision for simultaneous operation of primary and secondary fine Sun sensor channels.

The Sun's rays were refracted by a critical angle prism on to a silicon detector which produced an attitude error signal in each active channel. The preamplifier electronics assembly conditioned the attitude error signals for use in driving the canister actuators to null the error signals.

The offset pointing capability was provided by rotating an optical wedge in the path of the incoming sunlight to refract the light in a controlled manner. An optical encoder provided the offset information in the form of sine-cosine signals which were processed by the preamplifier electronics, converted to binary in the signal conditioner, and sent to the ATM digital computer via the workshop computer interface unit.

Acquisition Sun Sensor - The acquisition Sun sensor consisted of two optical systems and an electronics assembly. It provided attitude information relative to the X and Y axes of the orbital assembly. This attitude information was used to update the strapdown computation in the ATMDC during orbital day. Both of the optical systems were active in the vehicle control loop during normal operation. However a specific optical unit could be selected via the ATM digital command system (DCS) or digital address system(DAS), or automatically by the redundancy management scheme implemented in the ATMDC. The system (sensors plus electronics) provided electrical analog signals proportional to the pointing error (Sun reference) of the orbital assembly and a Sun presence signal which indicated when the sun was in the field-of-view of the error sensors.

Rate Gyro Processors - The rate gyro processors, each consisting of a gyro and its associated electronics, performed the vehicle rate sensing function for the ATM attitude and pointing control system. Nine processors, three per vehicle axis, were used in a compare and spare redundancy management scheme. Additionally, four identical processors were used for rate feedback to the experiment pointing system's pitch and yaw axis control loops. The experiment pointing control's processors were manually managed relative to redundancy; management being by either the onboard control and display panel or ground command.

Experiment Canister Caging and Gimbal Assembly - The experiment canister caging and gimbal assembly is discussed in Section VI, Structures, Experiment Canister.

Manual Pointing Controller - The manual pointing controller was used to either offset point the ATM instrument canister or manually point the star tracker. In either case the manual pointing controller signals were conditioned in the experiment pointing electronics assembly and routed to the fine Sun sensor or the star tracker electronics assembly.

Experiment Pointing Electronics Assembly (EPEA) - The EPEA was a multipurpose analog assembly used for signal processing in the Experiment Pointing Control (EPC) system. The electronics in the EPEA were divided into 12 channels. The six primary channels according to their functions were:

Canister UP/DN control

Canister L/R control

Fine Sun Sensor UP/DN wedge or Star
Tracker outer gimbal positioning

Fine Sun Sensor L/R wedge or startracker
inner gimbal positioning

Canister Roll drive

Orbital Locks operation

Six identical secondary channels were available for redundancy. Switching from primary to secondary and return could be done by ground command or by the crew. The EPEA included the interface circuitry between the manual pointing controller and the fine Sun sensor and star tracker.

ATM Digital Computer/Workshop Computer Interface Unit (ATMDC/WCIU) - The ATM/WCIU provided high-speed general-purpose computing capabilities and multipurpose, flexible input/output capability. It accepted analog and discrete signals from sensors and control sources which were used to perform calculations under direction of the stored program. The ATMDC/WCIU also provided analog and discrete outputs for control and monitoring purposes.

The subsystem consisted of two identical ATMDC units and a single WCIU. The WCIU was divided into two identical sections and a common section. One ATMDC and the corresponding section of the WCIU were used at one time. The other ATMDC and its corresponding WCIU section were powered down and maintained in standby mode for redundancy. The ATMDC had a 16K memory capacity.

Memory Load Unit - The memory load unit provided a means of loading either ATMDC memory from an onboard tape recorder or from the ground via radio frequency command uplink.

Control Functions

Attitude Control - Vehicle attitude information was derived from a strapdown reference computation in the ATM digital computer (ATMDC). Nine vehicle rate gyro processors mounted on the ATM rack, three per axis, provided vehicle rate information to the ATMDC. During orbital day in solar inertial mode, two acquisition Sun sensors provided X- and Y-axis attitude information and the star tracker provided Z-axis information to the ATMDC for periodic update of the strapdown reference. The ATMDC processed the sensor signals with the CMG control law to generate CMG gimbal rate commands.

The CMG control law utilized three normalized torque commands and the CMG momentum status to generate proper CMG gimbal rate commands. The control law consisted of three parts: The steering law, the rotation law and a gimbal stop avoidance law. Additional routines were included for specialized situations.

The steering law provided torques on the vehicle for attitude maneuvers or to oppose torques from gravity gradient, vehicle vents, or crew disturbances. Gimbal rate commands were generated in such a way that the torques resulting on the vehicle were identical to the desired torques in direction and magnitude.

The rotation law attempted to minimize the probability of contact with the gimbal stops by reducing the largest gimbal angles. This was accomplished by rotation about the vector sums only. The total angular momentum was unaffected and no torque was exerted on the vehicle.

The last portion of the CMG control law utilized a mathematically defined pseudo gimbal boundary in a manner that precluded the spin vector from ricocheting against hard gimbal stops.

A reset routine was incorporated into the CMG control law to allow the CMG system to recover from undesirable gimbal angle positions and/or momentum configuration.

In addition to the attitude control provided by computations, the crew could enter attitude commands into the ATMDC by using the DAS located on the control and display console. Attitude maneuver commands could be entered to 1.0 degree resolution; maneuver bias commands could be entered to 0.1 degree resolution.

There were six control modes which were addressable by control and display console switches for APCS operations. To meet the overall APCS requirement the following control modes were implemented:

Solar Inertial Mode - During orbital day, this mode was used for maintaining the vehicle's minimum moment of inertia axis (X principle axis) near the orbital plane and the Z axis parallel to the Earth-Sun line. During orbital night, this mode was used to perform gravity gradient momentum dump maneuvers for desaturating the CMGs.

Experiment Pointing Mode - This mode was identical to the solar inertial mode except that the experiment pointing control system was automatically activated each orbital sunrise and deactivated each orbital sunset.

Z-Local Vertical Mode - This mode was used during rendezvous phase and during Earth resources experiment operation. The rendezvous mode, Z-LV(R) was the -Z axis pointed toward the Earth, the X axis in the orbital plane, and -X axis in the direction of the velocity vector. The Earth resources mode, Z-LV(E) was the -Z geometric axis pointed toward the earth, the X axis in the orbital plane, and the +X axis in the direction of the velocity vector.

Attitude Hold (CMG) Mode - This mode was used to maneuver the Orbital Assembly to any inertial-oriented attitude and hold.

Attitude Hold (TACS) Mode - This mode was used to maneuver the Orbital Assembly to any inertial-oriented attitude and held using TACS only. The experiment pointing control subsystem was deactivated and the experiment canister caged.

Standby Mode - This mode was to be used when control was not required of the APCS.

Three double gimballed CMGs orthogonally mounted to the ATM were the subsystem actuators. Figure 11-3 is a functional diagram of the CMG configuration. During normal operation the CMGs provided the torques necessary for orbital assembly control. Momentum management computations were performed by the ATMDC. Unloading the momentum stored in the CMGs was accomplished by gravity gradient maneuvers performed during orbital night. The ATMDC monitored the momentum stored in each axis during the orbital day; then, during orbital night, the ATMDC sent rate commands to the CMGs such that the stored momentum was dissipated by the gravity gradient. Although the CMGs were orthogonally mounted, when they were in the zero stored momentum position the spin axes of the CMGs were all in the same plane and displaced 120° from each other.

Flight Program - Digital implementation of attitude control was accomplished using an ATMDC and WCIU. The flight program was responsible for:

1. Operating modes
2. Skylab attitude reference
3. Navigation and timing
4. CMG control law
5. TACS control law
6. Maneuvering
7. Automatic redundancy management
8. Function command, data display, telemetry, and experiment support

The ATMDC Flight Program was modular in design, and consisted of two basic software subsystems: the executive or control program and the application subsystem. The control program controlled the sequence of the program execution and provided a software priority on executable functions in order to achieve a multitask keying capability. The application subsystem consisted of all the application program modules which when executed by the control subsystems performed all required flight program functions. From a timing standpoint the flight program consisted of two loops. A slow loop completed approximately once per second and an intermediate loop completed five times per second. The attitude control functions were performed at the rate of five times per second.

CMG Momentum Management - Any noncyclic disturbance-torque acting on the vehicle would result in a net momentum buildup of the CMG cluster. Because of finite storage capacity of the CMG cluster this momentum accumulation would eventually cause CMG saturation.

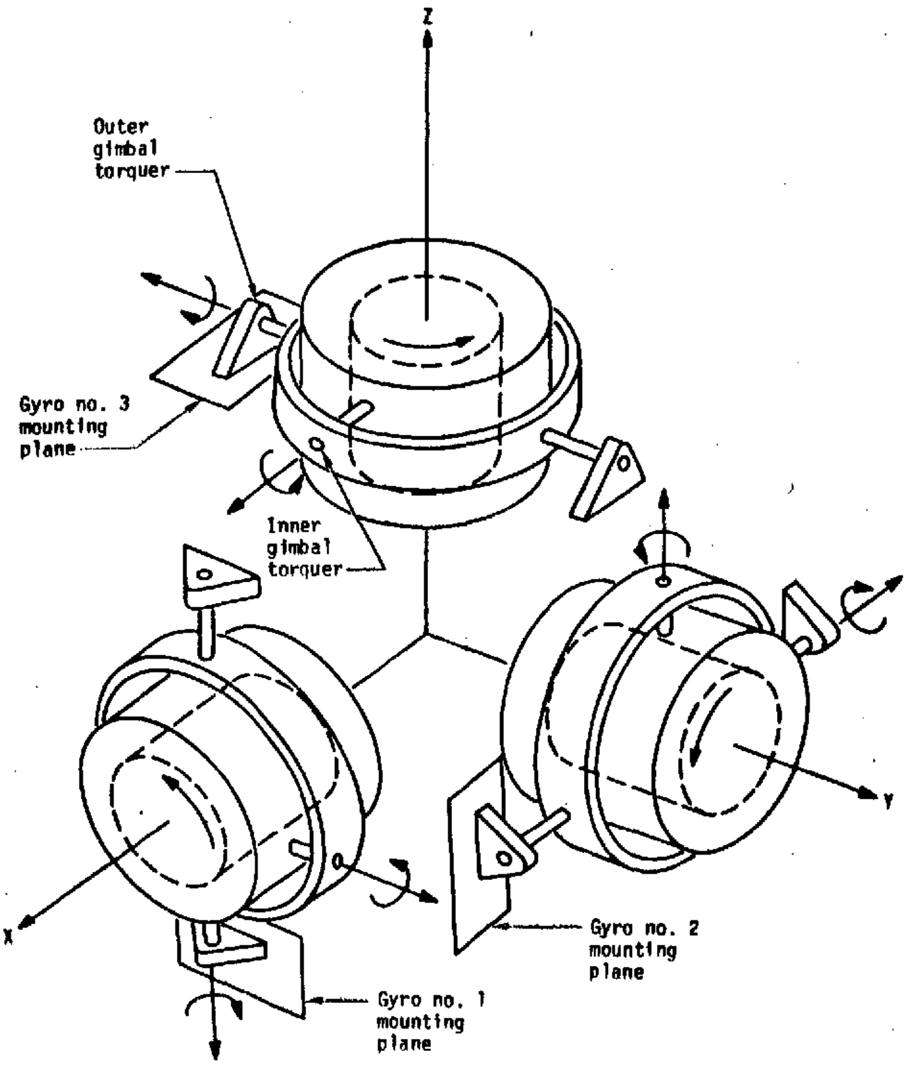


Figure 11-3. Functional Diagram of the CMG Configuration

This means that after complete saturation the CMG cluster could not compensate for disturbance torques about the axis of saturation.

To preclude this possibility and minimize the effects of non-cyclic gravity gradient torques the vehilce X-axis was maintained close to the orbital plane and CMG momentum desaturation maneuvers were performed periodically during the night portion of the orbit.

The magnitude of the desaturation maneuvers was based on factors obtained by sampling normalized components of the total momentum four times during the day portion of the orbit.

Experiment Pointing - The experiment canister was mounted on the ATM rack with a gimbal and caging assembly. A functional drawing of the mount is shown in figure 11-4. The actuators provided approximately ± 2 degrees of movement about the X and Y axes. The roll positioning mechanism provided ± 120 degrees rotation about the Z axis. The solar north pole was used as the canister roll position zero reference.

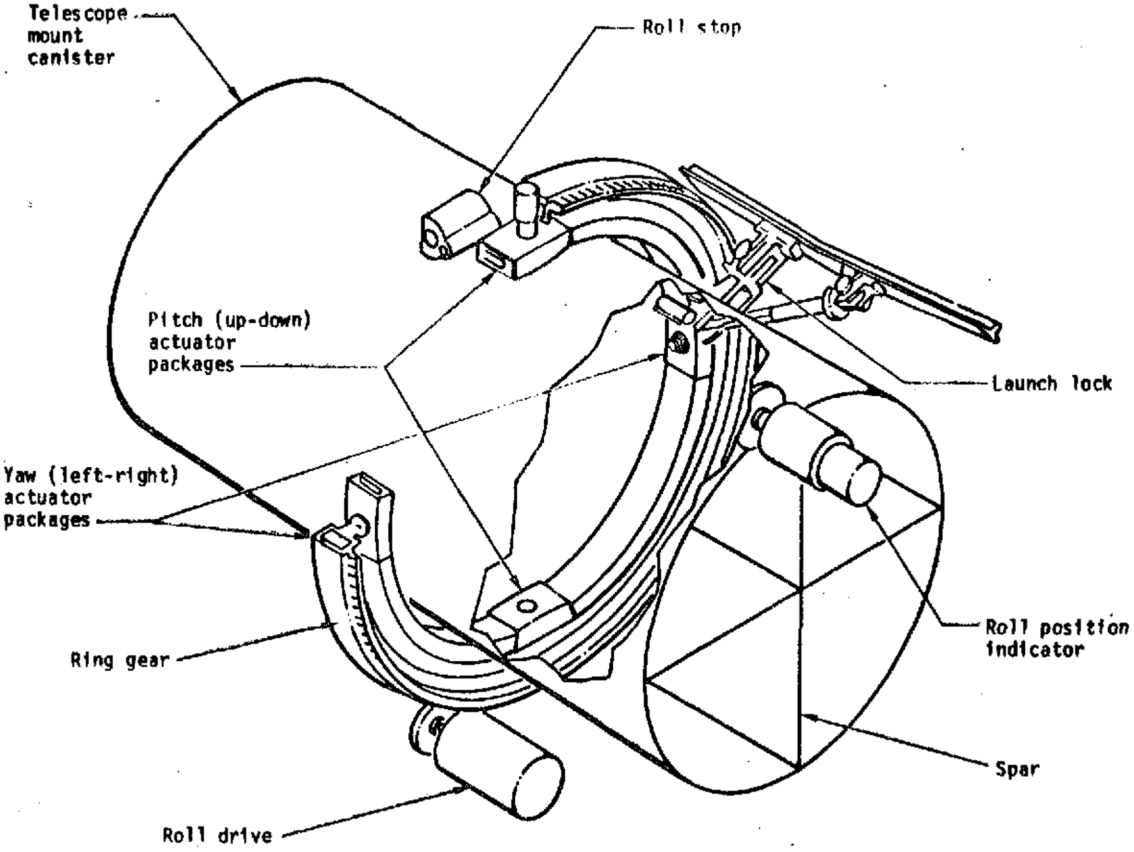


Figure 11-4. ATM Experiment Canister Pointing Mechanism

The experiment pointing control (EPC) system was used to fine point the experiment canister and isolate the canister from pertubations in the attitude of the Orbital Assembly. The EPC system provided automatic pointing control of the experiment canister about the X and Y axes. The fine Sun sensor was used for sensing canister pointing errors. Canister rate gyro processors provided rate information to the closed loop servo system used for pointing. The EPEA conditioned the pointing error and rate signals from the fine Sun sensor and spar rate gyro processors and provided command signals to the canister up/down (pitch) and left/right (yaw) actuators.

The experiment canister could be offset pointed ± 24 arc minutes about the X and Y axes. The center of the solar disk was used as a reference zero. Offset pointing was accomplished by positioning an optical wedge in each optical channel of the fine Sun sensor. The wedges were positioned by the Skylab crew via the manual pointing controller and its associated wedge drive mechanism. Driving the wedges away from zero reference position caused the image of the solar disk to be offset from zero reference on the fine Sun sensor light detector. This offset of the image appeared to the detector as an error. The error signal generated by the fine Sun sensor was processed by the EPEA which then commanded the canister actuators to drive in the direction necessary to null the error signal generated by the fine Sun sensor. The desired offset pointing of the experiment canister was thus accomplished. Fine Sun sensor wedge positions were displayed on the control and display console. The console also contained TV displays of the Sun as viewed through the experiment telescopes, and experiment readout displays to assist the crew in pointing the experiment canister.

The roll position mechanism (RPM), used to rotate the canister about the Z axis within the range of ± 120 degrees, was commanded by the crew by way of actuating the manual pointing controller rate switches. These switches were located on the control and display console. During extravehicular activities (EVA), canister roll was controlled by the crew using the EVA rotation control panel.

Redundancy Management

Reliability considerations for long mission times required component redundancy. All mission-critical single point failures were made redundant by switchover capability and duplex components. System redundancy was provided to the point that any component failure that could cause the mission to be aborted or preclude mission objectives was provided with a backup unit or with an alternate subsystem configuration that could be selected without performance degradation.

The redundancy management philosophy was that primary APCS mission-critical systems, those related to system performance or crew safety, would be monitored and managed automatically, utilizing the flight program and backed by a manual switching capability. Capability existed to inhibit all or portions of the automatic redundancy program. The less critical systems were monitored manually by the astronauts using the C&D panel and by ground support using the telemetry link. Manual redundancy management switching capability existed via a switch selector and were commanded using the DAS/DCS.

To ensure the integrity of the flight program, an ATMDC self-check capability was included. To increase the reliability of the computer system, capability to reload the ATMDC from the memory load unit or via the DAS/DCS was included.

SYSTEM EVOLUTION AND DESIGN RATIONALE

Early History

The evolution of APCS was based on evolving ground rules and directives for the ATM PCS dating from June 1966. Prior to that time, various proposals and control moment gyro systems were studied. The set of ground rules was drawn up in response to directives from the Office of Manned Space Flight and were included in a Preliminary Design Review in July 1966.

Free Flying ATM - The PCS ground rules provided for a design using the Langley CMG LM/Rack in free flight, a 28-day maximum life and no redundancy. The extended ATM orbital mission required that the ATM vehicle roll axis to be colinear with the solar vector. Requirements for extremely precise attitude control during long duration missions eliminated consideration of conventional reaction jet control systems for attitude control. The practical limitation on minimum impulse vehicle rates obtainable with reaction jet control systems was inconsistent with precision control in the arc-sec range. Also, fuel consumption with the associated weight penalty precluded the use of reaction jet control systems for long-term mission.

The CMG, a momentum exchange device, was therefore chosen as the controlling device for the ATM vehicle, since it offered the advantage of precision attitude control by momentum exchange. Use of CMGs also avoided optics contamination that would result if a reaction control thruster system was used.

Based on these ground rules, the PCS design (1966) consisted of a fine and coarse Sun sensor, a single analog control computer with switching and logic, three CMGs, CMG electronics and inverters, three rate gyros, a hand controller and analog meters. This system depended on a reaction control system for manual dumping of CMG bias momentum and visual pointing of the experiments.

Cluster Configuration

The first major design impact occurred when the primary ATM vehicle was clustered. This assembly was referred to as the cluster configuration.

WACS Development - The necessity for a major new operational capability, unmanned rendezvous and docking and provision for attitude stabilization during the manned and storage periods prior to the ATM docking required the development of the Workshop Attitude Control System (WACS).

The WACS was to be activated following S-IVB stage passivation and commanded to assume control of the cluster configuration. Astronaut commands or ground commands selected the WACS control modes and the necessary control phases. After PCS activation the WACS would be placed in a minimum power consumption condition and could be re-energized as required. The CSM RCS would be turned on to maneuver the cluster configuration to the ATM acquisition attitude. Control of the cluster configuration would then be assumed by the PCS.

PCS Concept Changes - Clustering the ATM also imposed additional requirements on the PCS. Increased CMG momentum was required due to increased vehicle moments-of-inertia. To significantly reduce constant gravity gradient bias torques the vehicle's principal axis of minimum moment-of-inertia had to be constrained to lie as closely as possible to the orbital plane while the ATM experiment canister was pointed toward the Sun. Since this constrained the vehicle attitude about the line-of-site to Sun, a roll positioning capability was added to the experiment canister.

To preclude CMG saturation, the LM and CSM reaction control systems would be used to dump excess momentum. About the same time, experiment demands and crew motion combined to require a decoupled experiment canister mounting with separate controls. It was realized that man-motion disturbances would possibly exceed the minimum error capability of the PCS. These impacts along with increased readout needs and the addition of a star tracker reference, added to the complexity of the analog control computer such that a separate electronic box, called the Information correlator assembly was proposed.

By August, 1967, the following PCS changes were incorporated to satisfy the corresponding need. During the daylight portion of the orbit the cluster pitch and yaw attitude errors were sensed by the acquisition Sun sensor. During the night when the experiment canister was caged, the EPC rate gyro outputs were integrated to obtain attitude error information. Due to ± 95° EPC roll capability, resolvers were provided to transform the gyro rates to the CMG control system coordinate system. Roll attitude errors for the cluster were obtained by integrating the rack-mounted roll rate gyro signals.

Attitude error signals for the EPC were derived from the Fine Sun Sensors (FSS) and rate damping was provided by the spar mounted rate gyros. The experiment canister offset capability for each axis was developed by controlling the FSS optical wedges.

Isolation between the rack and canister was provided by a gimbal system using frictionless compensated flex-pivots. This allowed canister pointing in the X and Y axes. A ± 95° roll position mechanism provided roll attitude positioning of the experiment canister. A star tracker was used to provide an attitude reference. An analog computer was used to implement the CMG H-vector control law, the CMG steering law and the EPC and CMG error processing.

Wet Workshop - By June 1969, the WACS had evolved to a system consisting of the following basic hardware:

1. Rate Gyros
2. Discrete Horizon Sensors, Conical Scan Horizon Sensors and Processing Electronics
3. Sun Sensors
4. Control Computer
5. Control Switching Assemblies
6. Thrusters
7. Control and Display Panel

Redundant components and circuitry were provided to meet crew safety and mission success criteria. With the aforementioned equipment, the WACS provided the following operational modes which would maintain the reference attitudes in addition to maneuvering through the transitional phases:

1. Gravity Gradient
2. Storage
3. X-POP (Perpendicaular to Orbital Plane) Acquisition
4. X-POP
5. X-POP/A-LV
6. Inertial Hold and Maneuver
7. Standby

During the manned missions, the Orbital Assembly (originally the cluster configuration) would have most often been maintained in the X-POP reference attitude.

The WACS used rate sensors in its inertial reference systems. To compensate for gyro and integrator drifts and orbital regression effects, the X-POP attitude was to be updated regularly. Updates were determined using the horizon sensor system and the Sun sensor. During the storage mode the OA would be placed in the gravity gradient attitude and all WACS components would be turned off except the discrete horizon sensors and the thermal control system for the electronics. With no active control, OA oscillations due to aerodynamic and gravity gradient torques could build up attitude errors. When a 20 degree attitude error was reached, the discrete horizon sensors would issue a telemetry signal and a power-up command. At power-up a gravity gradient orientation was commanded and then the system reverted to a power-down state.

Additional rate gyros were added to the ATM rack for redundancy. The flex pivots were designed to allow ± 2 degrees of rotation about the EPC X and Y axes. Rotation about the X-axis was extended first to +95, -120 degrees, then to ± 120 degrees by moving the roll ring gear stops. A digital computer and an input/output assembly were added to interface with the PCS. In August 1969, to minimize the CSM and fuel requirements, a CMG momentum desaturation scheme utilizing vehicle maneuvers during night portion of the orbit was instituted.

<u>Wet-to-Dry Workshop Transition</u> - The capability to reduce program cost and complexity and the opportunity to significantly expand mission potential were the rationale for conversion from a wet to a dry workshop. New APCS concepts became desirable to satisfy new requirements. Changes attributed to the wet-to-dry decision are noted below.

The PCS and WACS, previously designed to operate separately during separate mission phases, were combined. This new system was renamed the Attitude and Pointing Control System (APCS). Due to more ample weight margins the WACS was replaced by the simpler blowdown cold-gas TACS.

The role of the digital computer was increased and the ATM control computer was displaced. The CMG control law, error processing, and the bending mode filtering were performed in a digital fashion. The EPC analog portion of the control computer was retained and assembled in a new unit called the Experiment Pointing Electronic Assembly (EPEA).

Additional Concept Changes - The inclusion of the Earth Resources Experiment Program (EREP) into the mission, although not an ATM responsibility in itself, imposed a major new operational requirement on the APCS. EREP required an Earth pointing capability with the minus Z vehicle axis colinear with the local vertical and the principal axis in the orbital plane. Initially, all these attitude maneuvers were to be handled exclusively by the TACS and the remainder of the mission was to be controlled by the CMGs.

As the impact of this requirement and others were determined, the inadequacies of both the TACS and the CMGs became apparent. The TACS did not have sufficient propellant to perform the total number of maneuvers being planned. Also, longer mission time, increased inertias of the new Skylab, and a more thorough accounting of external disturbances made the design of the CMG system marginal. A solution was sought by combining the operation of the two systems. Thus, the CMGs would provide assistance in making maneuvers and the TACS would be available if the CMGs momentarily were unable to control the Skylab. As studies progressed on the nested system, several problems arose which necessitated change in both the CMG and TACS control laws.

Vehicle inertia increased to the point where performance in the two CMG case became marginal. The CMG wheel speed was increased approximately fourteen percent to increase performance and momentum storage capability, accomplished by modifying the CMG inverters.

The ability to offset command the EPC system via the ATMDC was added. The ability to control the star tracker automatically with the ATMDC was considered, but due to mode restrictions in the star tracker and because of the magnitude of the change the redesign was not made.

To increase the probability of the ATMDC's successfully completing the Skylab mission the Memory Load Unit (MLU) was developed to provide the means of reloading the computer during flight. A skeleton program capable of filling one of the two 8K ATMDC memory modules was provided to maintain limited use of the ATMDC during flight should a failure occur which precluded the use of the 16K program.

When the EPC was in the offset position and a roll command was initiated, the solar image, as viewed from the crew's display screen, underwent an apparent roll about the Sun center. For some experiments this would have required repositioning of the line-of-sight after a roll adjustment. To correct this and decrease the response time for experiment set, a line-of-sight roll capability was added.

Design Requirements

Specific design requirements for the attitude and pointing control system are defined below.

Control Moment Gyro/Thruster Attitude Control System (CMG/TACS) - The CMG/TACS was to be capable of controlling the attitude of the Orbital Assembly from the instrument unit/TACS control transfer to the Skylab mission end.

The CMG/TACS was to have control authority for using either the CMG supported by TACS or TACS only during the following maneuvers and attitudes:

1. Solar inertial attitude, with the following vehicle configurations:

    a. SWS without a docked CSM.

    b. SWS with docked CSM at MDA port 5 (axial).

    c. SWS with CSMs docked at both MDA ports 5 and 3 (radial). The TACS-only mode applied for this case and the allowable attitude control errors were ± 5 degrees maximum.

    While under CMG/TACS control, these requirements included the three-axis CMG momentum desaturation maneuvers during orbital night. CMG momentum desaturation maneuvers were to be performed automatically but with a capability to be inhibited by the crew or ground commands.

2. Rendezvous attitude, Z-LV(R): The CMG/TACS was to be capable of initiating acquisition of the Z-LV(R) attitude as early as orbital midnight and return to the solar inertial attitude at approximately orbital midnight after a maximum of two orbits. The design was to be such that attitude errors at the end of the second orbit of Z-LV(R) would not exceed ± 12 degrees about the Y axis and ±6 degrees about the X and Y axes. The Z-LV(R) attitude capabilities applied to the following vehicle configurations:

a. SWS without a docked CSM.

b. SWS with CSM docked at MDA port 5 (axial).

3. Earth resources attitude, Z-LV(E): The CMG/TACS were to be capable of performing the Z-LV(E) attitude within an accuracy of ± 2.5 degrees in all axes during each pass. The vehicle configuration for this attitude was with a CSM docked at MDA port 5 (axial).

4. Maneuvers: The CMG/TACS was capable of acquiring the solar inertial attitude from any other attitude and:

a. Maneuvering from solar inertial attitude to Z local vertical and return to solar inertial attitude.

b. Maneuvering from the solar inertial attitude to any other attitude and return to solar inertial attitude.

c. Rolling 45 degrees from solar inertial attitude, clockwise about the X axis (viewed in the +X direction) and maintaining this attitude for approximately 30 minutes to support CSM docking operations at the MDA port 3 (radial).

d. A random reacquisition maneuver to return to solar inertial attitude from any other attitude during the unmanned phase as a contingency mode only. This maneuver to be commanded at a maximum rate of 0.8 degree per second.

e. Maintaining the solar inertial attitude within ± 10 degrees during orbit-adjust maneuvers.

5. Docking and undocking transients: The CMG/TACS were to be capable of damping vehicle transient motions resulting from CSM undocking operations and maintaining solar inertial attitude.

Experiment Pointing Control (EPC) - The experiment pointing control was to provide for fine pointing of the experiment canister when the APCS was in the solar inertial mode. The requirements for accuracy and stability of the EPC were defined in table 11-I. The EPC was to be designed such that the jitter at the experiment mounting interface would not exceed ± 1 arc second per one second of time about the cluster X or Y axes and not exceed ± 3 arc minutes per one second of time about the cluster Z axis.

Command and Monitoring - The APCS was required to interface with the launch vehicle Instrument Unit, ATM, and Airlock Module communications and data systems to provide ground controllers with system status and permit selection of functions. Interfaces with the ATM and control and display console were to provide the Skylab crew with controls and monitors. A caution and warning system interface was to provide the crew with knowledge of out-of-tolerance conditions.

System Failures - The APCS was to be capable of maintaining attitude control in all modes with a single CMG failure. Single failures within either the CMG or the TACS was not to result in loss of attitude control. The capability existed to isolate individual APCS components, switch to backup components, and deactivate failed components either automatically, by ground command, or by onboard crew command. The APCS was to provide adequate isolation to preclude total failure of the APCS due to any instrumentation, display, data management, or other system malfunction. The capability for inflight total ATMDC memory reloading from an onboard source and from the ground was required.

The experiment pointing control (EPC) subsystem did not incorporate redundancy management; however, the components within the EPC could be switched by the crew and by ground command.

MANUFACTURING

Table 11-II is a list of the major APCS components and component manufacturers. The significant problems encountered during development and manufacturing of APCS components are described in the following paragraphs.

Table 11-II. Table of Components and Component Manufacturers

COMPONENT	MANUFACTURER
Control Moment Gyros	Bendix
CMG Inverter Assemblies	Bendix
Star Tracker Optical - Mechanical Assembly	Bendix
Star Tracker Electronics Assembly	Bendix
Fine Sun Sensor Signal Conditioner	Motorola
Fine Sun Sensor Preamplifier Assembly	Honeywell
Fine Sun Sensor Optical - Mechanical	Honeywell
Fine Sun Sensor Control Electronics Assembly	Honeywell
Acquisition Sun Sensor Assemblies	BALL/MSFC
Acquisition Sun Sensor Electronics	BALL
Vehicle Rate Gyro Processors	Martin Marietta
Spar Rate Gyro Processors	Martin Marietta
Canister Actuators (pitch, yaw, roll)	Perkin - Elmer
Experiment Pointing Electronics Assembly	Bendix
Digital Computers	IBM
Workshop Computer Interface Unit	IBM
Memory Loading Unit	IBM

Manufacturing Problems

CMG Actuator Pivot - The actuator pivot assembly was the major component of the CMG. It was this component that determined the useful life of the CMG.

The limited life components of the CMG were designed to have a minimum life of 1.5 mission time without degradation. At the beginning of the program this period was 84 days because at that time the ATM mission was defined as 56 days. This goal of CMG lifetime was achieved by mid 1969.

Some major problems encountered and solved during development of the first version of the actuator pivot were: a) potting in the servo motor; b) backlash in the gear trains; c) dry lubricant debris falling into the gimbal bearings; and tachometer brushes bonding to the brush holders. All of these problems were resolved and the actuator met all design goals.

When the wet workshop concept was changed to the dry workshop concept in July 1969, the mission time was redefined as 240 days, resulting in a major impact on the actuator design.

Evaluation of the CMG actuator design, considering the increased mission time requirement, resulted in a design change. The new design incorporated grease lubricated gears and gimbal bearings and upgraded gears of higher precision with more metal in the teeth. The useful life of the actuator (still 1.5 times mission life) was increased to 360 days.

During redesign of the pivots, several lubricants were investigated. The final choice of lubricant was one which contained a powdered teflon filler and had a vapor pressure of 10^{-9} torr. Subsequent life testing of the CMGs indicated the lubricant was excellent. Because of possible contamination from the new grease, baffles were designed and installed between the motor-tachometer commutators and the gears and between the output shaft and the gears. A labyrinth seal vent was installed to relieve atmospheric pressure inside the pivots during ascent (of the Skylab) and to prevent molecular migration of the lubricant outside the pivot.

Star Tracker - Significant changes that were incorporated during development of the star tracker were a) addition of heater, b) modification of initialization logic, c) change to compensate for change of operating voltage and d) change in search logic.

A thermostatically controlled 10-watt heater was mounted close to the photomultiplier tube assembly. The thermostat turned the heater on when the temperature decreased to +5°C. This change was incorporated as a result of a failure during a thermal vacuum test; the photomultiplier tube cracked at a temperature of approximately -30°C. The original design specification was -50°C. Also, the tube supports were modified slightly to relieve stress points encountered at low temperatures.

The initialization logic in the gimbal drive circuitry was modified to assure that the tracker, when powered up, would drive the gimbals to zero (zenith angle position). The original design was such that the gimbals drove to the limit stops when power was applied.

The star tracker electronics unit was modified to operate with an input of 130 volts at 455 Hz instead of the original 115 volts at 400 Hz. This modification was required due to the change in CMG inverter power. The star tracker was powered from the CMG inverters.

The search pattern logic was redesigned after the discovery of noise in a one-shot circuit. The noise was encountered at certain positions in the search pattern and would cause the tracker to stop while executing the search routine.

Arcing occurred in the phototube high voltage area as a result of air pockets in the encapsulating material around the phototube. This problem was corrected by revising the encapsulating procedure.

The phototube dark current (noise) level was excessively high causing out of specification detection threshold and operation of the video circuits in the star tracker. Internal design changes which included relocation of the high voltage and focus plate connections reduced the noise in the video output circuits.

COMPONENT/END ITEM QUALIFICATION

Qualification testing/assessment was conducted as a formal demonstration of performance and design adequacy under anticipated operational environments. The verification methods consisted of tests and assessment of similarity, analysis, inspection and demonstration. Flight type test hardware was identical in fabrication, configuration, and performance to the space vehicle flight hardware. Data from development tests were utilized in qualification assessment where feasible. Two significant problems were encountered during component qualification testing.

A digital computer failure was caused by foreign material inside an integrated circuit. Further assessment revealed that the contaminant was the gold eutectic used for sealing the devices. Approximately 10 percent of the integrated circuits supplied by a single vendor contained gold particles of 0.001 to 0.005 inch in size that caused shorts within the devices.

A significant number of Hartman relays used on the EPEA failed. These failures were due to contact fractures. The blades were redesigned which corrected this problem. Another problem was that the relay blades came to rest at mid position. Larger magnets were installed which corrected this problem. All relays of this type were changed out in the flight unit, prototype unit and spare EPEA.

Table 11-III is a summary of the component qualification tests.

SYSTEMS VERIFICATION PROGRAM

The following are descriptions of problems and solutions relative to system verification.

System Verification (Prototype)

Post Manufacturing Checkout (PMC) - During prototype PMC, neither the EPC pitch nor yaw actuators would drive the canister. Investigations revealed that the actuators were binding against the ring. This problem was cleared by making some cuts on the ring and changing the actuator installation procedure to ensure that the actuators were not preloaded.

The digital computers, when mounted on the payload, responded to system transients. This response resulted in altering stored memory data when the EPEA was powered up. The problem was isolated to transient signals, which occurred as a result of powering up the EPEA, being coupled onto the field operating unit memory cycle resulted in the storage buffer being reset after good information had been read from memory and placed in the storage buffer register. This transient-induced reset signal caused the storage buffer to be cleared to all zeros. The

Table 11-III. ATM APCS Component Qualification Documents

Component	Qualification Test Procedure/Specification	Test Report
CMG Subsystem (Includes EA & Invert)	50M22162B	50M22163
Rate Gyro	50M37742A, 50M37743A	50M37740
Star Tracker	2124424, 2124424 D GQTP	QTR 8960
Fine Sun Sensor (OM, CEA)	EEP2206C	MH21001918
Fine Sun Sensor Signal Conditioner	12-P01030A	12-P01031A
ACQ Sun Sensor	BB31031, BB30471	TR69-54
Roll Drive Actuator	PE-8911	PE-10425
Orbital Lock	50M22164	50M22165
Roll Readout	PE-8911	PE-10303
Yaw Pitch Actuator	PE-8911	PE-10425
Manual Pointing Controller	ED-2002-946	QTR8057
EPEA	MT-15661C, MT-15662C	MT-15732
Digital Computer	SL-K39-70-001, 7919149B	70-K39-0001
WCIU	SL-K39-70-002, 7921235	72W-00007
MLU	MLU-197-72-001, 7927085	7-15-72
Tape Recorder	50M12971B	54 TRI-1-50M 12971

Note - No significant deviations or waivers occurred during qualification test.

zeros were subsequently transferred to computer memory. This problem was corrected by reducing the EPEA power transient and incorporating a set of load-enabled gates in each computer. The gates disabled the critical field operating unit memory load and control lines when the lines were not required for actual loading of the ATMDC memory.

Thermal Vacuum Test - During thermal vacuum testing, the star tracker displayed false star presence signals. This problem was caused by an increase in the star tracker threshold sensitivity which was caused by change in the value of resistors in the photomultiplier voltage divider circuit. All resistors of the type causing the problem were replaced with another type.

Prototype thermal vacuum testing revealed that the CMGs required excessive caging commands. Investigation of this condition revealed that the tachometer brush feedback into the loop was erratic. The erratic feedback was caused by irregular conduction of the brushes. A silver graphite brush was tested and found to be superior to the polymer material. The flight and prototype CMGs were retrofitted with silver graphite brushes.

Immediately following thermal vacuum testing, it was noted that the outer gimbal friction forces on one CMG were much higher than the 10-pound specification value. The subject CMG was removed from the payload with difficulty. The CMG mounting hardware appeared to be unduly loaded; the mounting studs had to be driven out. The CMG gimbal force during subsequent stand-alone tests was normal. Examination of the mounting interface revealed that the alignment and dimensions were correct; however, the studs and associated inserts did not have adequate tolerance, and the surfaces were metal to metal without a lubricant. The studs were undercut and a lubricant was applied to the surfaces. After remounting, the outer gimbal friction forces were within specification.

Systems Verification (Flight Unit)

Post-Manufacturing Checkout - There were no anomalies during PMC on the flight unit.

Thermal Vacuum Test - Rate Gyro Processor serial number 124, failed during the simulated flight portion of thermal vacuum testing. At the time of failure, an external torqueing voltage had been applied for approximately 40 seconds. No commands were being issued from the Acceptance Checkout Equipment (ACE) and commands being issued from C&D panel were normal. Fault isolation revealed that there was no measurable output from the power supply printed circuit card. Component investigation showed three transistors had failed. Failure analysis revealed a shorted collector-to-emitter lead, a shorted chip and open emitter lead, and an open emitter lead in the three transistors.

Rate Gyro Processor, serial number 129, also failed during the simulated flight portion of thermal vacuum testing. At the time of failure, no commands were being issued from ACE, or the C&D panel. Fault isolation revealed that the problem was caused by the SM-107G-1 operational amplifier located on the 4800 Hz generator P/C card. The failure was at the -12 volt input of the operational amplifier.

During post-T/V testing, a wheel bearing of the Z-axis CMG (S/N 11) failed. The spin axis of the Z-axis CMG was normally vertical when the ATM was mounted in the test fixture. The lower bearing failed. A detailed analysis of the failure was performed. It was concluded that the failure occurred because the oil flow rate in the bearing was insufficient to maintain an adequate lubrication film in one "g", spin axis vertical operation with the normal range of gimbal rates. This unit was subsequently changed-out at KSC.

<u>Prelaunch Testing (KSC)</u> - During prelaunch tests, star tracker gimbal oscillations were recorded when the star tracker was commanded to hold. The star tracker electronics unit was replaced with the flight spare. The problem on the original flight unit was traced to a faulty connection in a potted logic module.

SECTION XII. CONTROLS AND DISPLAYS SYSTEM

SYSTEM DESCRIPTION

The ATM Control and Display (C&D) Console provided a man-machine interface for the operation and monitoring of the ATM systems. The console functional configuration is illustrated in figure 12-1. Refer to Table 12-I for a list of functional panel sections and their assigned numbers and to figure 12-2 for their locations. Commands by the crew to the ATM systems were provided by toggle and rotary switches, the manual pointing controller, and the Digital Address System (DAS). All critical switch functions were redundantly wired or were redundantly available through the DAS. Monitoring of system parameters was accomplished by the use of status lights, meter confidence lights, alert lights, dual scale vertical meters, time-shared digital displays and TV displays. Controls were available for power distribution, overload protection, lamp testing, parametric selection, ground command enable/inhibit, and console lighting.

Coolant control for the C&D console was provided by the AM liquid water coolant loop. The system was designed to reduce and maintain average console temperatures at approximately 85°F and operate at a maximum loop pressure drop of 3.0 psi at 220 lbs/hour flow. Cold rails were structurally integrated to the console structure using a dip brazing technique for improved thermal conduction. The console frame served as an intermediate heat sink, transferring component heat loads to the coolant loop for removal from the console.

Equipment ancillary to the C&D console consisted of an Inverter Lighting Control Assembly (I/LCA), a Backup Inverter Lighting Control Assembly, an EVA Canister Rotation Control Panel (RCP), and a Digital Address System (DAS) Backup Panel.

Ancillary Equipment

Inverter/Lighting Control Assembly - The I/LCA provided regulated and unregulated electrical power, both alternating and direct current, exclusively to the ATM C&D console. The power/voltage requirements for the console are specified in Table 12-II. The I/LCA utilized electrical power provided by the ATM buses. Figure 12-3 is a functional block diagram of the I/LCA.

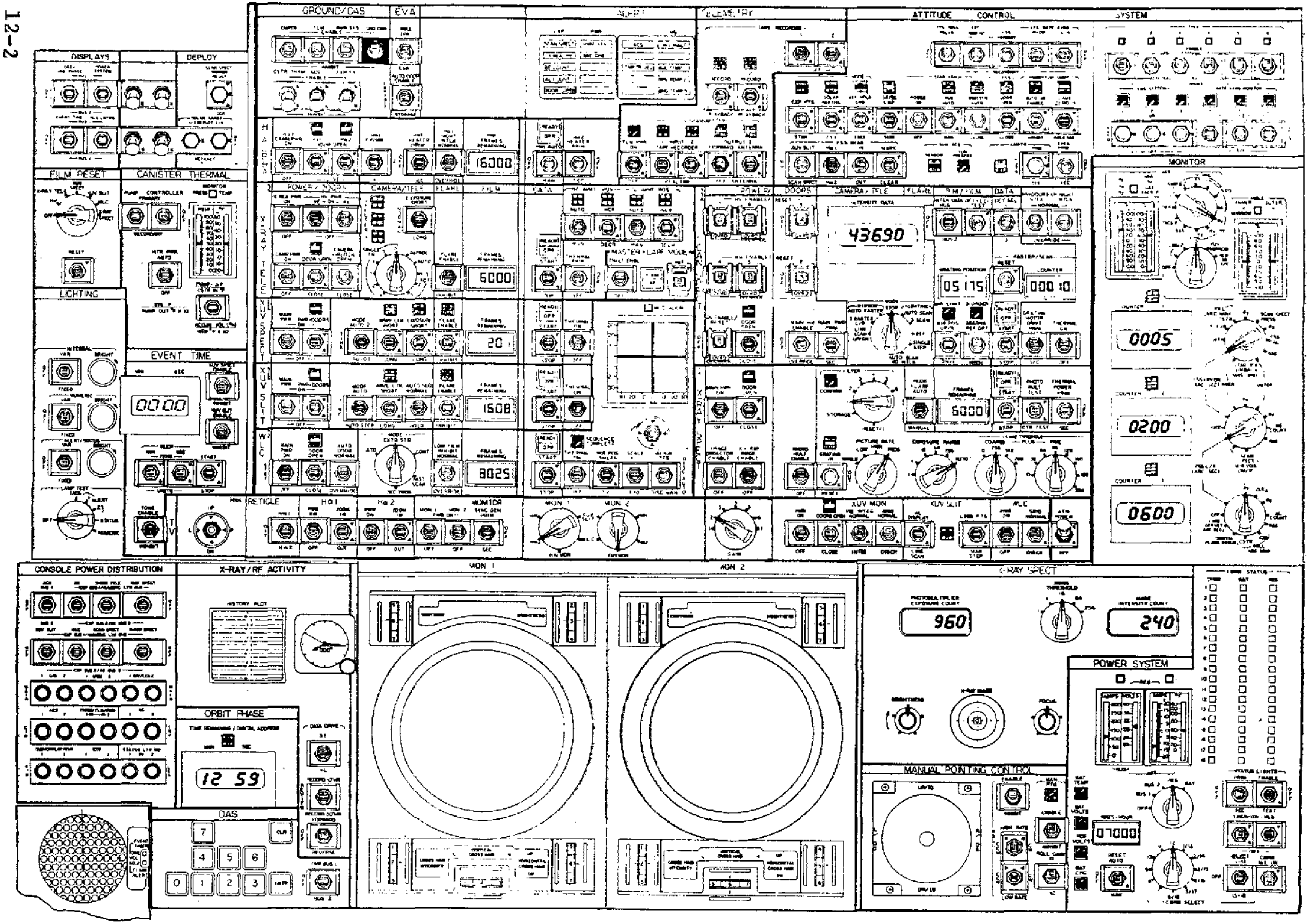


Figure 12-1. ATM Control and Display Console Panel Configuration

Table 12-I. ATM Control and Display Console Functional Panel Sections

Reference Panel No.	Panel Name	Reference Panel No.	Panel Name
1	DISPLAYS	14	WLC (S052)
2	SPARES	15	SCAN SPECT (S055A)
3	DEPLOY	16	X-RAY SPECT (S054)
4	FILM RESET	17	VIDEO
5	CANISTER THERMAL	18	ALERT
6	LIGHTING	19	TELEMETRY
7	EVENT TIME	20	ATTITUDE CONTROL SYSTEM
8	CONSOLE POWER DISTRIBUTION	21	MONITOR
9	GROUND/DAS/EVA	22	POWER SYSTEM
10	H-ALPHA 1 AND 2	23	MANUAL POINTING CONTROL
11	X-RAY TELE (S056)	24	X-RAY/RF ACTIVITY
12	XUV SPECT (S082A)	25	ORBIT PHASE/DAS
13	XUV SLIT (S082B)	26	MASTER FLARE MODE

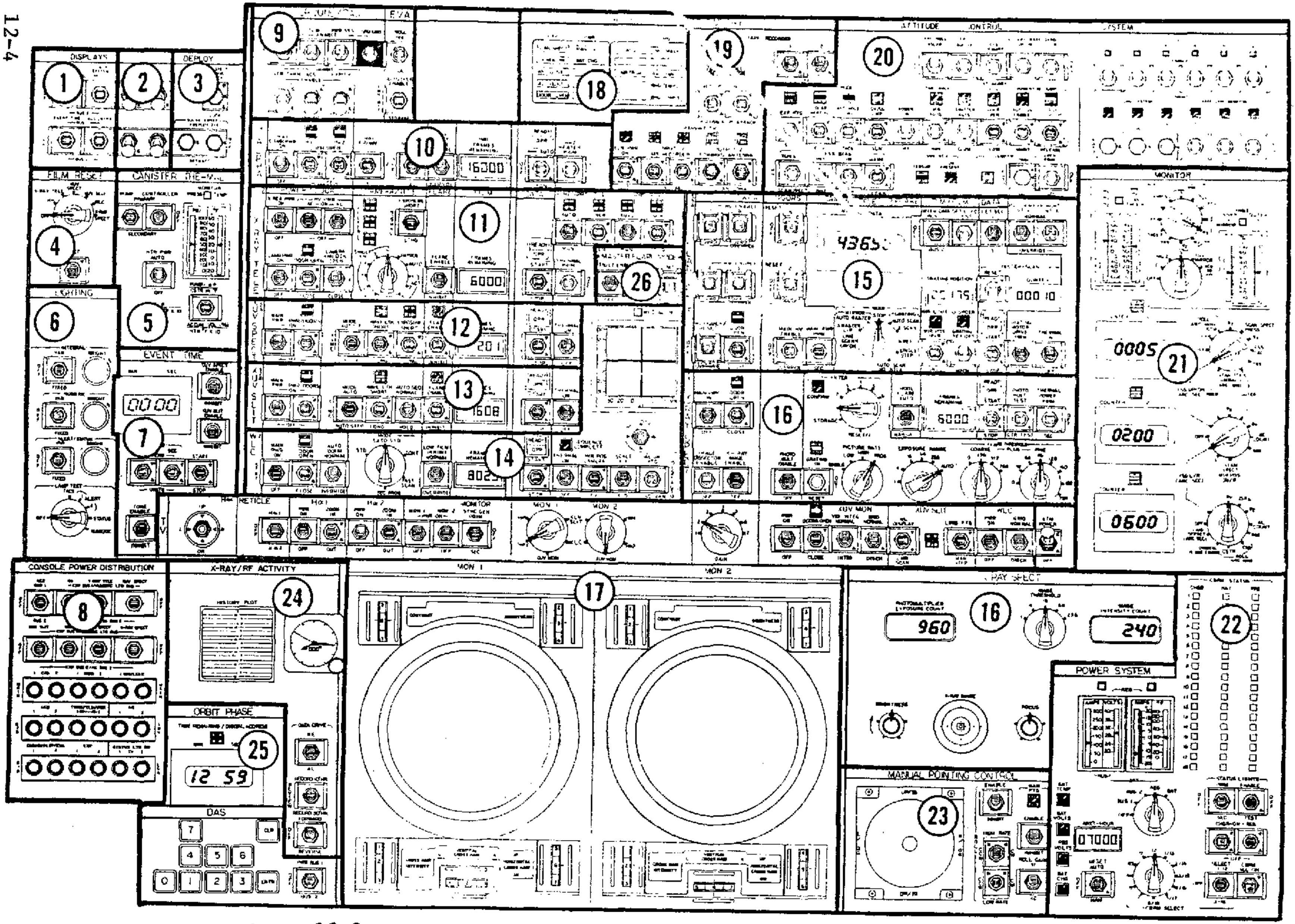


Figure 12-2. ATM Control and Display Console Functional Panel Locations

Table 12-II. ATM C&D Power/Voltage Requirements

	Type	Source	Function
(1)	FIXED DC POWER, +28 VDC	ATM	OPERATIONAL POWER FOR CONSOLE DISPLAYS, TV MONITORS, ELECTRONICS, ETC., AND I/LCA BU DAS AND RCP. REDUNDANT INPUTS ARE PROVIDED FOR EACH C/D MAIN, AND I/LCA MAIN.
(2)	FIXED AC POWER, 115 VAC, 400 HZ, SINGLE PHASE, 31 WATTS MAX	I/LCA	OPERATIONAL POWER TO CONSOLE X-RAY SPECT CRT ELECTRONICS, MONITOR COUNTERS 1, 2, AND 3, SCAN SPECT INTENSITY DATA INDICATOR, DAS INDICATOR, AND EVENT TIME INDICATOR.
(3)	FIXED AC POWER, 115 VAC, 400 HZ, SINGLE PHASE, 98 WATTS MAX	I/LCA	BACKUP OPERATIONAL POWER FOR COMPONENTS ITEMIZED IN 2, 4, AND 5.
(4)	VARIABLE AC POWER, 40-130 VAC, 400 HZ, SINGLE PHASE, 75 WATTS MAX	I/LCA	POWER FOR CONSOLE VARIABLE INTEGRAL ELECTRO-LUMINESCENT LIGHTING (PANEL NOMENCLATURE, VERTICAL METERS, STATUS FLAGS, CROSS POINTER AND HISTORY PLOTTER INDICATORS, AND DAS DEYBOARD).
(5)	VARIABLE AC POWER, 40-130 VAC, 400 HZ SINGLE PHASE, 10 WATTS MAX	I/LCA	POWER FOR CONSOLE VARIABLE NUMERIC ELECTRO-LUMINESCENT LIGHTING (MONITOR COUNTERS 1,2, AND 3, PULSE COUNTERS, DAS INDICATOR, X-RAY SPECT INDICATORS, EVENT TIME INDICATOR AND CROSS POINTER INDICATOR).

Table 12-II. ATM C&D Power/Voltage Requirements (Continued)

	Type	Source	Function
(6)	FIXED REGULATED, +5 VDC POWER, 23 WATTS MAX	I/LCA	POWER FOR TACS AND CBRM STATUS LIGHTS
(7)	FIXED UNREGULATED, +5 VDC POWER, 51 WATTS MAX	I/LCA	BACKUP POWER FOR COMPONENTS LISTED IN 6, 8, AND 9.
(8)	VARIABLE DC POWER, 3.5 - 5.0 VDC, 23 WATTS MAX	I/LCA	VARIABLE INPUT POWER FOR THE LIGHTING OF THE ALERT LAMPS.
(9)	VARIABLE DC POWER 2.0 - 5.0 VDC 7 WATTS MAX	I/LCA	VARIABLE INPUT POWER FOR THE CONSOLE STATUS LAMPS: READY/OPR, X-RAY/RF AND METER POWER FAILURE LAMPS.
(10)	28 VRMS 800 HZ	ATM	FIXED AC VOLTAGE INPUT TO MPC FOR MANUAL CONTROL OF EPC AND STAR TRACKER GIMBAL POINTING.

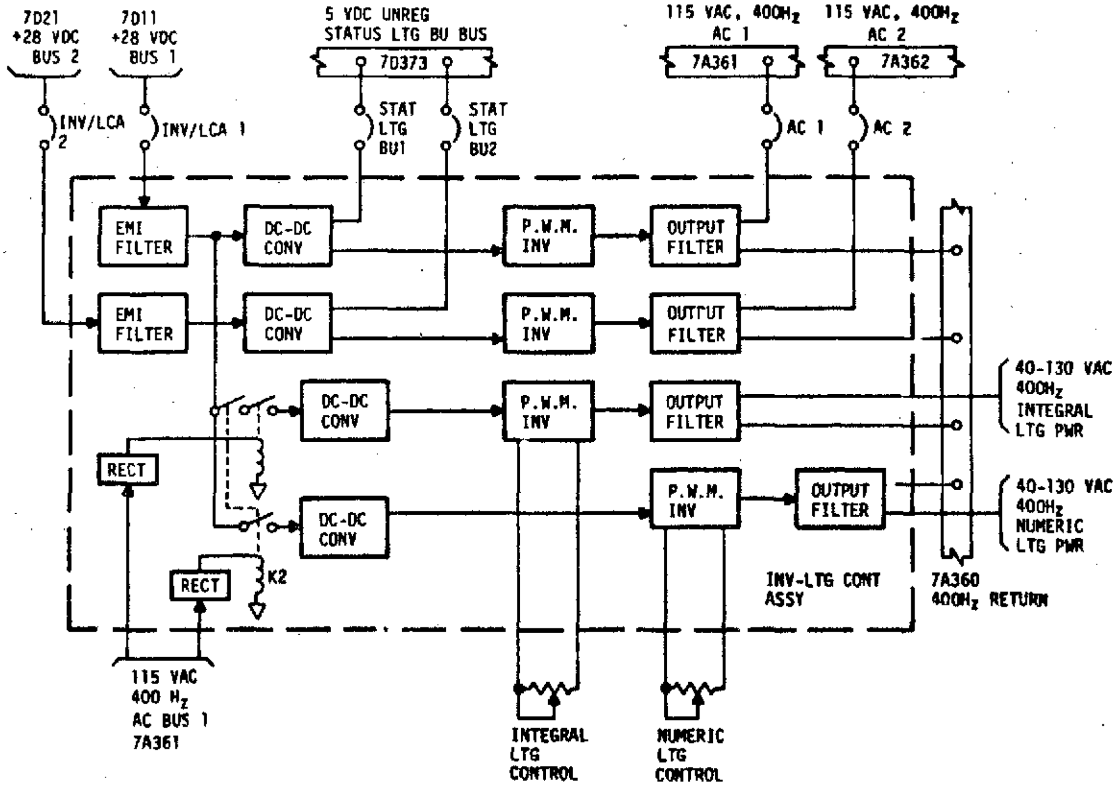


Figure 12-3. Inverter/Lighting Control Assy Block Diagram and ATM C&D Console Interface

The I/LCA was located externally on the forward conical section of the MDA and mounted on the L-Band antenna truss. Input and output electrical power circuit breakers were located on the ATM C&D console. Two 90-watt heaters located internal to the I/LCA were provided input power from the AM power buses.

A backup I/LCA was provided. The "black boxes" components of this system consisted of two inverters, two converters, internal and numeric lighting brightness control panels, a connector panel, and a patch plug stowage panel. These components were located internal to the MDA. Utilization of the backup I/LCA plugs removed power from the primary I/LCA and completely isolated its circuits.

Rotation Control Panel - The EVA canister rotation control panel, figure 12-4, was located at the ATM Center workstation. It served as a control panel to position the ATM experiment canister such that each of the four film retrieval/replacement doors (S052, S054, S056, and H-Alpha) of the ATM could be aligned with the Center Workstation. Also, the S082A and B thermal shield aperture doors could be aligned with the Sun end workstation and controlled to the open/close position to facilitate manual opening of the related film access doors.

Digital Address System Backup Panel - The DAS backup panel, figure 12-5, was added to the C&D subsystem to provide DAS command redundancy. It was located in the MDA adjacent to the right side of the console and in normal operations was electrically disconnected from the system allowing the console DAS to provide commands. To connect the DAS Backup Panel required removal of power from the console DAS and pulling of the CMD/DEPLOY/EVA circuit breakers. The console DAS command cable could then be disconnected from the shorting connector and connected to the Backup Panel. Redundant power was then applied to the panel upon activation of the CMD/DEPLOY/EVA circuit breakers. Five manual rotary switches and three momentary toggle switches completed the unit. Unlike the console DAS, feedback from the ATM was not available to verify command transmission. The position of the rotary switches were the only indications to the crew of the command transmitted. An enter switch provided an execute command to the ATM. A clear switch allowed the clearing of erroneously transferred commands from the ATM systems.

SYSTEMS EVOLUTION AND DESIGN RATIONALE

Control and Display Console

Early History - Early C&D console design was based upon the general requirements as outlined in the ATM Project Development Plan, dated 13 April 1967, and the ATM Control and Display Console Contract End Item Specification, CP1941000 Rev. A, dated 14 February 1964. General design philosophy is summarized as follows:

1. Utilize LM panel concept where practical.

2. Make maximum use of LM and CM flight-qualified hardware.

3. Maintain flexibility for design changes.

4. Provide for operation by either one or two crew members in a "shirt-sleeve" environment.

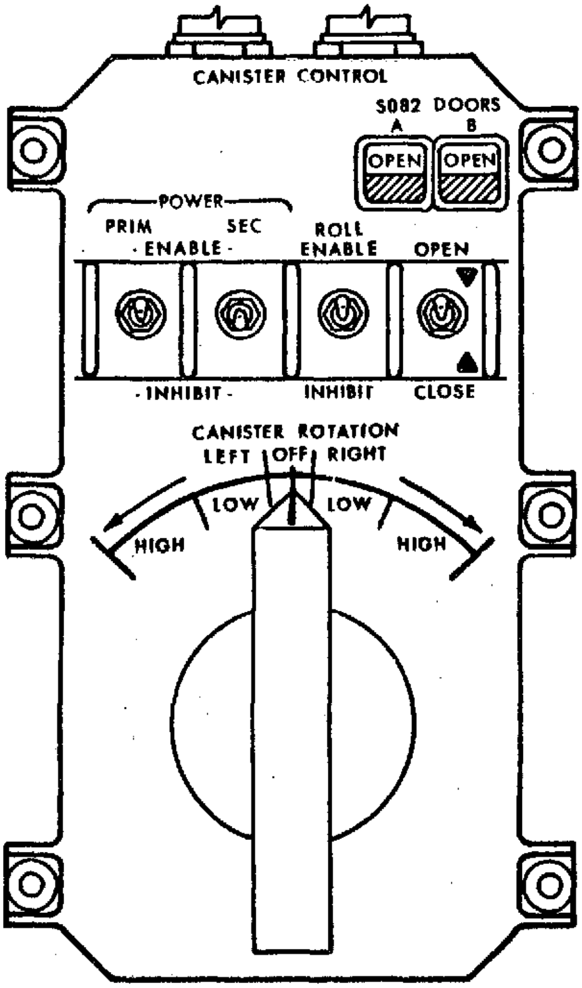


Figure 12-4. ATM Rotation Control Panel

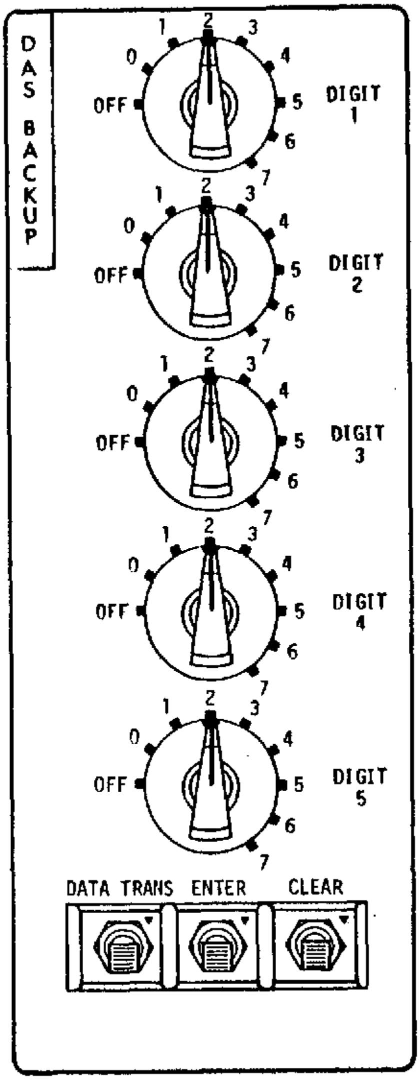


Figure 12-5. ATM DAS Backup Panel

5. Maintain capability to operate continuously while the cabin is pressurized, and under limited performance while cabin is unpressurized.

6. Assure that design, location, and use of all controls and displays are in accordance with MSFC-STD-267 and supplements, where practical.

7. Assure that redundant circuitry and circuit protection is incorporated to eliminate the possibility of loss of parts of more than one experiment, or loss of an entire experiment or subsystem due to a single point failure.

The C&D console functions are delineated in figure 12-6.

The initial ATM C&D concept was based on a requirement for controlling the ATM from a small console located in a Command Module with the ATM mounted on a Command Service Module. As the ATM design evolved from the CSM to Lunar Module Ascent Stage mounted concept, space limitations in the Command Module required the individual experiment control panels be mounted in the Lunar Module. The panels were to be attached to the LM interior structure just aft of the astronaut couches.

<u>Design Evolution/Rationale</u> - During the Preliminary Design Requirements Review in January 1968, the individual experiment panel layout was considered not functional. A concept of horizontal sequential grouping with system matrix incorporation, where possible, was introduced along with a request to include ready/operate light capabilities. This concept was to be located in the tunnel area of the Lunar Module ascent stage. Anthropometric concepts included operation of the console by two men in depressurized suits and by one man in a shirt sleeve environment.

As the console design evolved during 1968, major inputs were as follows:

1. Panel type electrical connectors were chosen over the small circular connectors for durability and ease of maintenance.

2. Switch guards similar to CM hardware were to be utilized.

3. Lockswitch application was based on mission critical and crew safety criteria.

4. Relocated the distributor box to the console lower rail to delete bending of electrical cables during distributor box access activities.

FUNCTIONS	
CONTROL AND MONITOR SOLAR EXPERIMENTS	CONTROL AND MONITOR ASSOCIATED SUBSYSTEMS
S052 WHITE LIGHT CORONAGRAPH S082A EXTREME ULTRAVIOLET (XUV) CORONAL SPECTROHELIOGRAPH S082B EXTREME ULTRAVIOLET (XUV) SLIT SPECTOGRAPH S055A UV SCANNING POLYCHROMATOR SPECTROHELIOMETER S054 X-RAY SPECTROGRAPHIC TELESCOPE S056 X-RAY TELESCOPE HYDROGEN-ALPHA TELESCOPES MASTER FLARE MODE	POINTING CONTROL: ATTITUDE CONTROL SYSTEM CMG (CONTROL MOMENT GYRO) MONITOR MANUAL POINTING CONTROL TACS POWER AND HOUSEKEEPING: ATM POWER SYSTEM LIGHTING CONSOLE POWER DISTRIBUTION DEPLOY COMMUNICATIONS: GROUND/DAS TELEMETRY TV SYSTEM MISCELLANEOUS: ALERT FILM RESET EVENT TIME TONE GENERATOR

Figure 12-6. ATM Control and Display Console Functions

5. Provided console with a protective cover incorporating resettable latches.

6. The console overlay was made of electroluminescent panels.

7. Indicator flags were changed from nomenclature configuration to standard color codes.

A soft mockup provided two major changes. The DAS electronics assembly was modified to clear electrical cables and a disassembly problem with panel A6 resulted in a satisfactory structure design change.

During the initial half of 1969, a Phase II Technical Design Review resulted in a circuit components being located in the distributor assembly whenever possible and all panel matrix lines were to be electroluminescent illuminated. Requirements for an orbital clock installation capability and console interchangability capability were introduced during this period. Highlighted activities included changes to the H-Alpha movable reticles which resulted in redesign of the event timer panel area, panel A1, and TV control panel A2. The caution and warning lights on panel A2 were deleted and on panel A3 were converted to alert indicators. Consideration of utilizing the existing Apollo sextant controller hardware with modification for the ATM manual pointing control was abandoned as the modification costs were too high. A new design for the MPC was initiated. In July 1969, the LM/ATM module was reoriented to the Saturn Workshop (SWS) Dry Configuration concept. As a result, major changes were initiated. The console envelope remained basically the same but was to be mounted in the MDA. Notable activities for the remainder of the period included:

1. Addition of console sidewall structure and shock mounts to satisfy launch stress requirements.

2. Deletion of the console panel covers and resettable latch requirement.

3. Revision of the attitude control system controls and displays.

4. Requirement for a canister Rotation Control Panel (RCP) for EVA operations.

5. Redesign of the C&D distributor to include smaller diode modules and a new heat sink for the power diodes.

6. Initiation of a study on inflight replacement of the activity history recorder.

Design modifications continued during 1970 through 1972. The electroluminescent overlay of Lexon material failed the required flammability tests. The overlay material was changed to copper-clad plexiglass. Controls for the EVA lights were removed from the ATM control and display console.

Development Problems - A Single Failure Point (SFP) was noted at the common connection to the redundant 28 volt bus and reworked. The initial design utilized diodes. The redesign to eliminate the SFP incorporated magnetic latch relays with dual coils for redundancy. To complete the flammability resistance of the console, No-Burn Compound, Beta-Bags, and shielding were incorporated. An electrical interaction coincident to the Activity history plotter, digital address system, and event timer was solved by removing the forward/reverse power switching capability. An anomaly of uncommanded extra zeros in the DAS output code was eliminated through the removal of jumpers and a resistor value change on DAS circuit board number four. To enhance visibility contrast ratio, a new white plexiglass overlay was installed on the console. Final configuration changes included minor nomenclature changes and the incorporation of override lockout devices on the S055A SCAN SPECT POWER/DOORS panel.

The high heat loads associated with a compact electrical control console made necessary a coolant control system for the ATM control and display console. Initially, two configurations were considered, one being a cold plate system and the other a cold rail (fluid line) system. The cold rail method of thermal maps and system layout studies were initiated. The system was designed for a 220 lbs/hour flow at a 2 psi system pressure drop. This requirement dictated a minimum tube diameter of 3/8 inches.

Subsequent to acceptance of the Saturn Workshop dry configuration concept, consideration was given to utilizing Multiple Docking Adapter air as the primary coolant medium for the control and display Console. Another aspect considered water in place of the methonal/water medium. The final configuration was baselined utilizing an interface with the existing AM liquid cooling system for coolant medium supply.

A cooling problem with the C&D activity history plotter was resolved by adding a length of extended surface rail to the console structure. In March 1970, the preliminary development tests indicated a satisfactory system. The design changes required for the Saturn Workshop dry configuration were essentially completed.

During thermal interface compatibility checks of the C&D console with the MDA/AM thermal control system, it was discovered that the MDA thermal control system was unable to provide coolant to the C&D within specifications. The C&D console touch temperature could not be maintained below 105°F. It was suggested that the touch temperature limit be raised to 110°F which was the limits set for the Command Service Module control and display console. A floodlight dimming rheostat with an operating temperature 10°F higher than any of the other equipment operating temperatures was removed from the console. As a result, the Console total operating temperature fell within the 105°F touch temperature maximum requirements. However, the overall average operating temperature was found to be 98°F which exceeded the specified 85°F maximum average temperature requirement. An analysis of this anomaly resulted in acceptance of the overtemperature, as it was not considered a significant degradation to crew comfort.

Ancillary Equipment

Inverter/Lighting Control Assembly (I/LCA) - The initial LM/ATM C&D console was to be supplied with power from the Lunar Module Lighting Control Assembly (LM/LCA). Several approaches were considered as dependency upon the one LM/LCA was a matter of concern. A proposed use of a control moment gyro square wave inverter was discarded upon the basis of high peak power starting characteristics plus the need for shaping and filtering circuit additions. A modified LM/LCA to be used as backup for the LM/LCA was also considered.

The advent of the Saturn Workshop dry configuration concept required a new design of inverter and lighting control assembly be developed for the ATM C&D console to be located in the MDA module. The preliminary design concept encompassed a 15 KH$_z$ transformerless output pulse-width modulator in a 17 x 30 x 15 inch envelope. Thermal output studies resulted in a recommendation that the assembly be mounted external to the MDA due to the high heat loads predicted.

As design and development testing progressed, problems were encountered with the 400 H_z oscillator/controller. Excessive second harmonics (800H_z) resulted in changes to signal amplitude across the field effects transistor gain control. An increase in the rectifier time constant to reduce ripple in the feedback control loop and an addition of a low pass filter after the variable gain amplifier were incorporated. Through refinement of circuit design the I/LCA envelope had been reduced to 10 x 24 x 8 inches. Results of the phase II design review were acceptable except for concern that the single resistor heater power and sources were inadequate. A review of the thermal design was initiated covering the following points:

1. Prelaunch to C&D turn on thermal profile.
2. Heater power provided through the C&D console.
3. Relocation of the I/LCA.
4. Package design change including new thermal coating.
5. Expand operating temperature range to zero degrees F.

An engineering development unit was manufactured to be utilized as a test unit for the development phase of I/LCA. Many changes were required throughout the design development phase. These design changes will be discussed in Component/End Item Qualification and System Verification paragraphs of this report. Figure 12-3 depicts the I/LCA functional block diagram and ATM C&D console interface.

Due to the many problems encountered during the development and qualification phase of the I/LCA, the requirement for a Backup I/LCA was recognized. This system was designed utilizing off-the-shelf aircraft inverters and converters. These components and associated equipment were located within the MDA.

Rotation Control Panel - The EVA Crew Station RCP was required to permit the EVA astronaut access to the canister enclosed experiments for film camera retrieval and installation. The initial design of the RCP included several power and door control switches and two large push button type canister roll switches. A crew compatibility review of the operational characteristics resulted in a request for further design configurations.

Only two major changes were required during the RCP development phase. Thermal considerations required a redesign of the panel heater system. The final concept utilized two heater resistors resulting in a total output of 24.2 watts. The specifications stated a requirement of a minimum of 20 watts. The rotation control handle operational mode was revised from a detent in the high range to a soft stop at the end of the low range.

Initial EVA crew station tests revealed that the orientation of the operator with respect to the ATM canister resulted in the opposite rotation of the canister to the RCP command relative to the operator. The electrical interface requirements were redefined and the RCP outputs reversed to satisfy the requirements. In subsequent operations the RCP was operated successfully during the ATM module tests. No further problems were encountered. Figure 12-7 illustrates the RCP and ATM C&D interface.

Digital Address System Backup Panel - To preclude loss of major mission objectives through failure of the primary DAS panel, a backup panel design effort was initiated. The unit was of simple design utilizing five manual rotatry switches for coding and three momentary toggle switches for data transfer, enter and clear functions. To maintain simplicity, command transmission feedback circuitry was not included. Command transmitted verification was accomplished by observing the position of the rotary switches. Enabling of the backup panel required removal of power from the console DAS and transfer of the console DAS command cable to the backup panel.

MANUFACTURING

A total of four control and display consoles, engineering development, prototype, qualification, and flight units, were manufactured. The engineering development unit was the initial manufacturing effort. This unit was utilized as the test bed for design and manufacturing. The quality assurance functions observed the build cycle of this unit to determine required inspection points and to formalize their documentation requirements.

The prototype unit was manufactured to be utilized during the development testing phase of the control and display console. This unit was subjected to the various vibration, thermal, operational and functional tests during development. Upon completion of the development testing phase, the unit was refurbished, updated to the latest configuration similar to the flight unit,

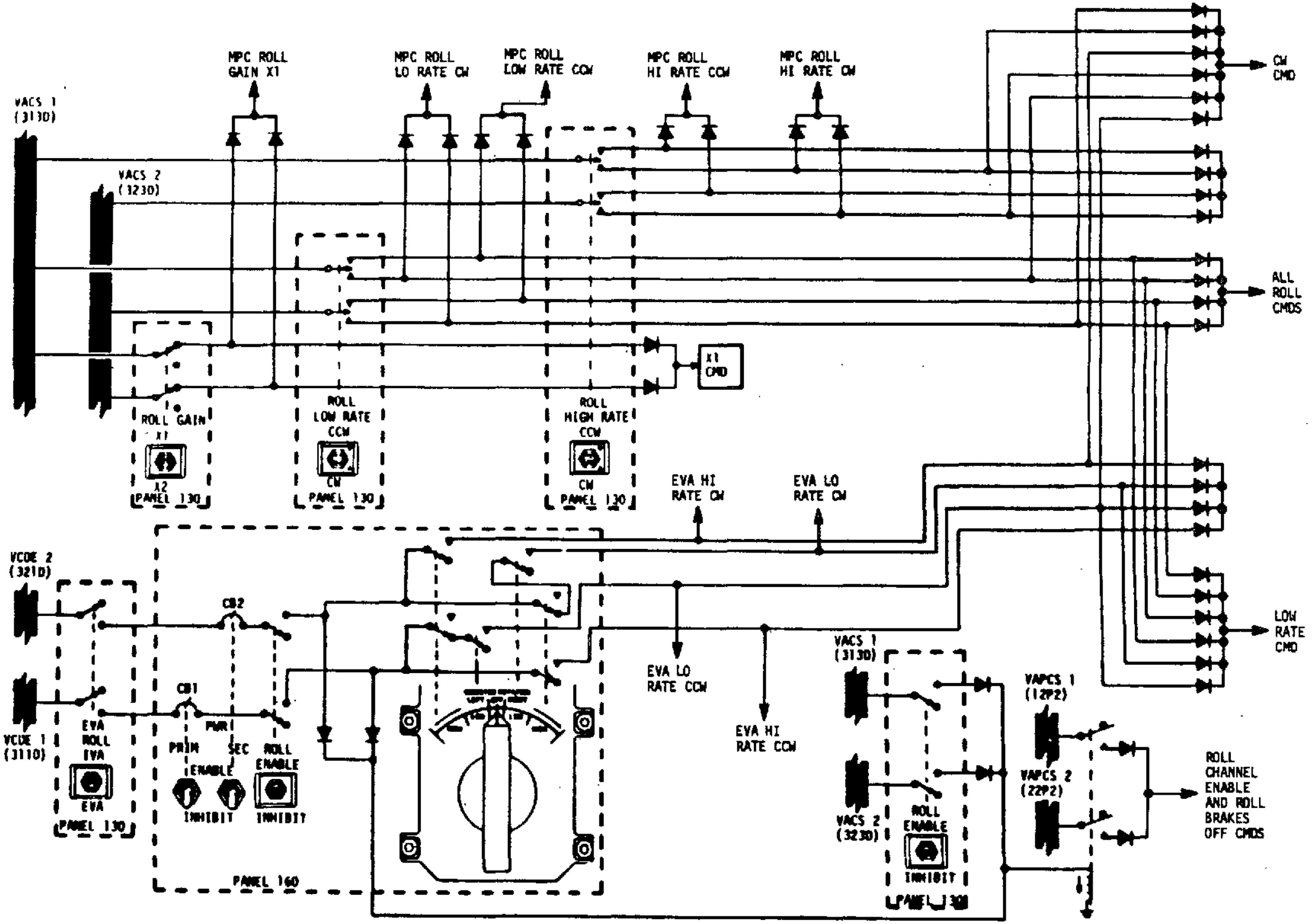


Figure 12-7. Rotation Control Panel and ATM C&D Interface

acceptance tested and utilized as a flight backup spare unit.

The qualification unit was manufactured and utilized for the initial qualification testing program.

The flight unit manufacturing cycle was completed without any major physical problems. Design changes and modifications were integrated satisfactorily.

To assist human engineering design and panel layout design, full scale mockups of the preliminary C&D console concept and the Lunar Module ascent stage left tunnel area was fabricated and mated. A vibration test mockup unit mass simulator was fabricated for use in the initial vibration analysis program.

Control and Display Console

Fabrication operations of the C&D console were carried out by the Bendix Corporation, Navigation and Control Division at their Teterboro, New Jersey manufacturing facility. The fabrication and assembly was accomplished in a controlled area which was maintained at $75^{\circ} \pm 10^{\circ}$F with a relative humidity of 50 percent or less. A slight positive air pressure was introduced into the enclosed area to prevent the infiltration of dust-laden air.

The initial efforts of the manufacturing operations in late 1967 and through 1968 were expended upon the fabrication of several C&D console mockups, a LM ascent stage left tunnel area mockup, and the buildup of various assembly and component test fixtures. Through May 1969, fabrication of a vibration test mockup unit with component weight simulators installed had been completed and fabrication initiated on an Engineering Development Unit (EDU). The prototype, qualification, and flight unit fabrication operations followed with the units being completed in March, July, and August 1971, respectively. Refurbishment and modification activities were prevelant throughout the total project prior to launch operations initiation. There were no new manufacturing methods or techniques developed during the C&D console manufacturing program.

One problem encountered during the manufacture of the C&D console occurred during the initial dip brazing process used to attach the thermal system fluid lines to the console frame. Unsatisfactory bonding was noted. This anomaly was removed by implementing more rigid cleaning processes and pre-dip brazing preparation procedures.

Ancillary Equipment

The I/LCA was fabricated through standard manufacturing procedure. A minor design change was necessary to facilitate assembly of the I/LCA unit enclosure. A problem was encountered during potting of the I/LCA transformers due to vacuum cycling spatter of the designated stycast potting. This problem was resolved by replacing the stycast with potting cups and using soldered connections.

There was no manufacturing problems noted with the backup I/LCA, the RCP or the DAS backup panel.

COMPONENT/END ITEM QUALIFICATION

Qualification of the C&D console and ancillary components was the culmination of analytical studies and development, life, special, and qualification testing operations. The analytical study results compared favorably with the final configuration test date. Problems were encountered during the physical testing phase requiring redesign activities, especially with the I/LCA. Successful redesign was demonstrated in special and scheduled downstream testing.

Analytical Studies

Control and Display Console - Thermal analysis was performed utilizing a thermal math model for the console. Local and average temperatures were predicted as a function of ambient temperature, coolant flow rate, and inlet temperature. Analytic results, subsequently correlated with development test results, indicated console thermal performance to be within design specicication. Refer to Thermal Analysis Report ED-2002-679-9 dated 29 December 1970, for thermal analysis detailed data.

Initial vibration studies indicated isolation of the console was required as a launch vibration levels were present above that for which some components were qualified. Subsequently, a console vibration isolation system analysis was performed to determine the resonant frequency, deflection, and cross axis coupling of the console when supported by four matched isolators. The effect on performance of center-of-gravity shift was also evaluated. These data were utilized to support the design and development of the isolators. Results of development and qualification testing verified performance to be satisfactory and within specifications. Refer to Free Vibration Analysis Report ED-2002-725 for detailed analysis data.

Two areas of concern were noted as a result of the Failure Modes, Effects and Criticality Analysis. The first being alert indicators, which are intended to cue the panel operator to low-level non-time critical malfunctions. These indicators were energized from a nonredundant 3.5 to 5 Vdc bus. Final configuration of the circuitry provided a switching capability to energize the indicators from a secondary 5 Vdc bus for redundancy. The second area of concern related to the monitor panel vertical meters which were energized from the non-redundant ACS bus, 7D399. Power removal from the meters required that a normally closed relay be energized. As presently implemented the same bus provided both meter power and relay power, thus a meter short to ground could not be removed by an "off" command. A loss of the ACS bus, 7D399, would occur. A similar circuit existed involving the power system dual vertical meters and power system displays bus 7D390. The existing condition was acceptable based upon the capability of monitoring the subject systems through the telemetry subsystem.

Inverter/Lighting Control Assembly - A complete system and component thermal analysis was performed. Analytic results indicated that the I/LCA baseplate temperature would vary from 20°F minimum (cold orbit case) to 110°F (hot orbit case). All electronic subassemblies, piece parts and materials would operate within their capability with an adequate safety margin. Details of the study are contained in the technical report Inverter-Lighting Control Assembly Thermal Analysis Report ED-2002-1595, Inverter-Lighting Control Assembly Thermal Analysis Report ED-2002-1595, dated May 28, 1971.

The piece parts reliability analysis revealed no single failure points which would result in a loss of conditioned power being sent to the I/LCA loads. The redundancy was such that if a failure did occur in a functional block, the redundant output could be manually switched on to deliver the power. The details of the study are available in technical report Inverter/Lighting Control Assembly (I/LCA) Failure Modes, Effects and Criticality Analysis D-2002-1215 Rev B, dated February 4, 1972.

A meteoroid penetration analysis was performed revealing that the probability of penetration of an I/LCA in free space exceeded the requirement of 0,955. The probability factor was enhanced due to the shading effect (protection) afforded by the MDA, CSM, L-Band truss, and L-Band antenna adding additional margin to exceed the requirement.

In accordance with the Martin Marietta Corporation electronic circuit design practices, a worst case circuit design analysis was performed. The analysis evaluated electrical stress of all electronic piece parts and devices. A satisfactory performance determination was made with the circuits under the worst case summation of all forseeable input, output, environmental and piece part parametric changes.

Rotation Control Panel - An analysis was conducted to determine the failure modes of the subassemblies of the rotation control panel, their effect on the performance of the rotation control panel, and the resultant effect on the ATM. A criticality analysis was included. The analysis indicated that the rotation control panel was highly redundant in electrical functions. Therefore, it had sufficient protection against Single Failure Points (SFPs) in the electrical circuitry. However, four mechanical SFPs were identified. The probability of occurrence of the failures was considered to be of magnitude to constitute an acceptable risk. Details of this analysis may be found in ED-2002-1143 Rev A, ATM-EVA Rotation Control Panel Failure Mode Effects and Criticality Analysis, dated November 25, 1970.

Development Tests

Control and Display Console - The engineering development testing provided the basic confidence that the flight configuration Control and display console would meet its qualification test requirements. Details of the console development test program, data, parameters, range of operation, limits, etc. are given in the ATM C&D Console Engineering Development Test Report E-2002-1319 dated 4 June 1971 with appendix MT-17693. Development testing of the console was performed as described in the following paragraphs.

The vibration isolation system of the console, utilizing a structural mockup with a set of flight isolators, was evaluated under all vibration environmental requirements. No mechanical degradation of the isolators was observed. The console structural responses indicated the isolator system provided satisfactory vibration enviornment for its structure mounted components and assemblies.

Representative panels of the Engineering Development Unit (EDU) control and display console were subjected to vibration sine evaluation tests and modified vehicle dynamics vibration tests. The anticipated console response was based upon the vibration isolation system being utilized to mount the console. No detrimental mechanical or electrical effects resulted from the exposures. However, the digital address system panel A9 from the EDU, indicated excessive first resonance response in the 20-2000H_z vibration input level. Deflection was excessive, therefore additional holddown screws and a center support was incorporated into the flight configuration.

Tests were performed early in the program with the cooling fluid, a water-glycol mixture. Extended surface tubing sections were evaluated for pressure drop characteristics. Test results indicated that the specified 2 psi system pressure drop was not feasible, therefore the specification was expanded to a 3.5 psi maximum system pressure drop.

An overall console cooling test was performed on the console EDU. This test was accomplished by circulating water through the coolant tubing of the console at specific inlet temperatures. The heat generating elements in the console panels were energized. Test data confirmed satisfactory thermal system performance in relation to system requirements.

The EDU console was subjected to EMI testing in accordance with MIL-I-6181D specifications. The test results showed that the electronics components were basically within tolerance with the exception of the 4 digit BCD displays, history plotter, and AS&E electronics assemblies. The AS&E components produced a sizable out of tolerance condition over the widest range of frequencies. Manual switching via toggle switches produced an out of tolerance condition as expected. This condition existed only during a switching operation and was not expected to be an overall system problem. A waiver was requested subsequent to the qualification test and approved per Deviation Approval Request BEP909.

Tests were performed on a representative electroluminescent panel from the EDU console to evaluate brightness and brightness variations. The test results indicated the EL lamp and overlay assembly met the system requirements. Life testing and the effects of temperature. The test sample was within the system brightness requirement after more than twice the specification life of 2000 hours.

A lighting evaluation of the EDU console was performed to determine the uniformity of the brightness of the various components both photometrically and subjectively at different voltage levels. The results indicated the overall brightness uniformity as acceptable.

The console was observed for proper operation of each device when it was operated and when other related and non-related components were being operated. All operations were satisfactory except for the event timer which was susceptable to switching transients created from the lighting switches on Panel A1. As a result of these tests, the planned wiring for the flight configured console was modified by separating the sensitive circuit wiring to minimize this susceptability.

Thermal cycling tests of representative distributor modules were conducted over a range far more severe than that anticipated in flight. No mechanical or electrical degradation was detected as a result of this testing.

Inverter Lighting Control Assembly (I/LCA) - The development test phase of the I/LCA project provided the vehicle for satisfactory resolution of the many design problems encountered. The only anomaly that required further investigation was the out of specification EMI problem. This resolved during the qualification test phase. Development testing performed and test results are described in the following paragraphs.

Functional operational operation of the I/LCA revealed several malfunctions in the output power switching transistors. The inverters were found to be susceptible to noise. This noise coupling interference created severe cross-over problems in the output power switches. The initial resolution of separating high level conductors from sensitive circuitry partially solved the problem. Further testing revealed that common mode $15KH_z$ noise generated in the power switch was being coupled through the control loop into the power transistors. This imposed a potentially catastrophic cross-over condition on the transistors. This anomaly was partially resolved by the addition of an isolation transformer coupled with the control loop to the AC output. Additional investigations revealed that the output power transistors were being procured to a DC breakdown voltage specification recommended by the vendor for this application. However, the breakdown voltage under AC conditions were found to be significantly less, thereby causing the transistors to fail. The breakdown specification was revised to define the required AC breakdown levels with sufficient margins. These devices operated successfully in the Engineering Development Unit. Another problem was the AC output voltage overshoot at turn-on. This overshoot was due to loop response time relative to the rate of application of 400 H_z modulation. By balancing the 400 H_z output lines and adding a common mode filter to the output of each inverter the rate of modulation rise was reduced such that the control loop was able to perform its function and prevent overshoot.

The initial high temperature tests were completed satisfactorily with non-production parts. Repeat of this test with production transistors revealed inadequate thermal bonding of the chips to the headers. The screening process requirements were revised to assure adequate control and monitoring of the transistors. The low temperature tests were conducted successfully with no resulting design changes.

EMC conducted interference tests performed during the development phase of the I/LCA resulted in out of specification data in the 1 MH_z and 10 MH_z frequency range. Additional EMC testing was conducted during the I/LCA Qualification Test Program. Results of that testing is discussed in the Component Qualification section of the report.

The high level random vibration development tests revealed that the packaging approach for chasis and printed circuit boards would satisfy the design requirements.

As a result of corona tests, materials and processes were defined which would adequately protect against certain types of corona generation. Ground/shield planes and structural bleed resistance devices were incorporated.

Console interface compatibility tests were performed with the prototype ATM C&D console and resulted in no-load shutdowns in the DC circuit. An over voltage generated in the AC circuits was also noted. The DC no load operation automatic shutdown was caused by a frequency shift in the down regulator and a resultant partial loss of the minus 5 volts used in DC regulation. In addition, a 5 ampere load switched to an open circuit would cause an automatic shutdown. The over voltage sensing circuit would sense the voltage increase at the console end of the interconnecting cable and cause a shutdown. These problems were eliminated by the addition of small load resistors to the output of the DC regulators. An extensive investigation for sources of

AC over voltage anomalies resulted in design changes for:

a. Sequencing of turn on/off condition.

b. Damping of the control loop.

c. Utilization of a master oscillator for variable AC outputs.

d. Over voltage shutdown for overload, excessive load changes and power down conditions.

Tests were completed successfully on the above design and package changes. Console interface compatibility tests were rerun with the qualification console verifying the compatibility of the above design changes. These tests resulted in high spike noise in the 5 volt output circuits at turn-on. The noise was being coupled from the regulator switching. Investigation revealed turn-on transients in excess of 300 volts for the first cycle. This problem was eliminated by incorporating two inductor-diode networks to the down regulator and adding AC coupling capacitors due to the non-linearity of the AC loads.

Interface compatibility tests with the flight ATM and flight ATM C&D console were performed satisfactorily during a component test as well as during the all systems test.

Rotation Control Panel - The engineering development test program provided the confidence that the RCP flight configuration hardware would meet the qualification test requirements. There were no problems encountered requiring design, specification change, or waiver of requirements. Development testing on the RCP was performed in the following disciplines:

1. Electrical outputs/Handle Application
2. Vibration
3. Thermal Vacuum
4. Electromagnetic Interference

There were no anomalies noted during the above noted test operations.

Digital Address System Backup Panel - Due to the conservative design of the DAS backup Panel, development testing was not performed.

Life Tests

Life testing was accomplished on the I/LCA, the rotation control panel rotation mechanism, and the C&D Console Electroluminescent lamps, pushbutton switches, and manual pointing controller. Life test history is presented in Table 12-III.

Special Tests

Special Tests conducted included a C&D Console 5 PSIA test, an I/LCA - S - 194 electromagnetic compatibility test, and a Console audio tone generator signal level evaluation test.

C&D Console 5 PSIA - In October 1971, a special test was performed on the flight C&D console at a pressure of 5 PSIA. A water system provided coolant to maintain proper C&D console operating temperatures. Experiments and support subsystems were operated by crew members to evaluate the man/machine interface. Console lighting was evaluated at various combinations of ambient lighting levels and console EL lighting levels. It was determined that an ambient level of 2 foot candles provided the best condition for C&D panel nomenclature discrimination. This determination was based upon operation with the C&D panel EL illuminated and non illuminated and TV monitor operation. No anomalies resulted from this test.

I/LCA - S-194 Compatibility - An electromagnetic compatibility test between the I/LCA and the S-194 band antenna was conducted in July 1972. The results of this test indicated no EMC problems.

Console Audio Tone Generator - A special test was performed at JSC during May 1972 to evaluate the audio tone generator levels in a simulated MDA background noise enviornment. During the test, both of the tone generators exhibited partial failures. Failure analyses were performed and resulted in modifications of assembly techniques. Subsequent performance of all tone generators was satisfactory.

Component Qualification Tests

Control and Display Console - Qualification tests, as noted in Table 12-IV, were performed on C&D console serial number 002 which was built to production drawings. One of two TV monitors was not installed and several customer furnished components were substituted. Since none of the configuration variations affected

Table 12-III. Component Life Test History

Component	Test Goal	Test Summary
C&D CONSOLE		
ELECTROLUMINESCENT LAMPS (EL) (LIMITED LIFE)	RATE OF DEGRADATION AT NOMINAL AND HIGH TEMPERATURES	TWO EL TEST PANELS WERE SUBJECTED TO A 3000 HOUR LIFE TEST. ONE PANEL WAS TESTED AT ROOM TEMP, ONE PANEL WAS TESTED AT 105°F. THE TEST RESULTS INDICATE THAT AFTER 4200 HOURS OF TESTING AT EITHER TEMPERATURE, NOMENCLATURE WOULD BE READABLE WITH 2 FT CANDLES AMBIENT ILLUMINATION.
PUSHBUTTON SWITCHES (LIMITED LIFE)	LIFE TEST	TWO SWITCHES WERE ACTUATED 30,000 CYCLES AT RATED LOAD WITH NO FAILURES.
MANUAL PTG. CONTROLLER (BINDING & WEAR)	LIFE TEST	ONE MPC WAS CYCLED IN 4 DIRECTIONS OF TRAVEL 30,000 CYCLES AT RATED LOAD WITH NO FAILURES
ROTATION CONTROL PANEL		
ROTATION MECHANISM (BINDING & WEAR)	LIFE TEST	ONE HANDLE ROTATION MECHANISM WAS CYCLED 30,000 TIMES WITH NO APPRECIABLE INCREASE IN TORQUE NOR ANY SHAFT DISPLACEMENT.
INVERTER LIGHTING CONTROL ASSEMBLY		
I/LCA	75 HOUR OPERATIONAL TEST	UNIT WAS TESTED AT FULL LOAD AND INPUT VOLTAGE CYCLED BETWEEN 25 VDC & 30.5 VDC FOR 100 HRS AT HIGH TEMPERATURE (110°F) WITH NO FAILURE.

Table 12-IV. Component Qualification Matrix

Environment	C&D Console	I-ILCA	DAS Backup	RCP
HIGH TEMPERATURE	X	X	X	X
LOW TEMPERATURE	X	X	X	X
VIBRATION	X	X	X	X
ACOUSTICS	X	ANALYSIS	X	NOT REQ'D
ACCELERATION	X	ANALYSIS	X	NOT REQ'D
HUMIDITY	X	NOT REQ'D	X	X
THERMAL SHOCK	X	ANALYSIS	X	X
ALTITUDE-THERM/ VACUUM	X	X	X	X
OUTGASSING	*	ANALYSIS	*	ANALYSIS
FLAMMABILITY	**	**	**	**
ELECTROMAGNETIC INTERFERENCE	X	X	X	X
TEST REPORT	ED-2002-1470 QTR-8971	ED-2002-1583	40M39630	ED-200-1471 QTR-8978

* RESIDUAL GAS ANALYSIS REQUIRED BY MSFC.

** LISTS OF MATERIALS, PARTS AND PROCESSES SUBMITTED TO MSFC FOR APPROVAL. NON-METALLIC MATERIALS EVALUATED/TESTED BY MSFC MATERIALS LAB AND USAGE AGREEMENTS APPROVED.

or were affected by the environmental exposures, the qualification tests were not invalidated by use of the varient parts. The high/low temperature, vibration, humidity, and electromagnetic interference tests were performed in the Navigation and Control Division Laboratories of the Bendix Corporation; the acoustic noise tests at the Ogden Laboratories; and the thermal shock, acceleration, altitude and thermal vacuum tests at the Cayton C. Brown Laboratories. The test procedure details, test results, data conclusions, etc., are provided in the Qualification Test Report ED-2002-1470 with Bendix Corporation appendix QTR8971 dated April 21, 1972.

The console met the qualification test requirements with the following significant functional problems encountered during the test program.

1. The DAS failed and was damaged during the transient susceptability testing. A design modification was necessary to protect the unit from negative transients. The DAS was retested successfully after the modification.

2. One vibration isolator (lower right) was observed to have a surface crack during the environmental sequence. The testing was completed (including acceleration) successfully with the isolator in place. At this point, the isolator was returned to the manufacturer for failure analysis. Results of the failure analysis determined the crack to be an infrequent surface flow which would not affect the isolator performance.

3. One experiment Ready/Operate indicator failed with the indication of a shorted internal diode in its lamp test circuit. The unit was removed and returned to the vendor for failure analysis. Based on seven additional Ready/Operate indicators, mounted and used in the identical application, and performing satisfactorily after environmental exposure the one failure was viewed as a random failure.

4. Electromagnetic Interference (EMI) test results generally exceeded the specification limits for the mechanical switching functions. Based on the usage factor of the devices causing the EMI, a DAR, BEP-909, was submitted and approved, requesting waiver of the EMI limits.

The remaining tests were completed satisfactorily with no anomalies noted. After evaluation of the above items, a COQ was prepared and approved.

Inverter/Lighting Control Assembly - Qualification tests as noted in table 10-IV, were performed on a flight configuration I/LCA. The test procedure details, test results, data, etc., are provided in the Qualification Test Report, Inverter/Lighting Control Assembly ED-2002-1583, dated January 9, 1973.

The unit failed to meet the EMI requirements of 50M12725, Electromagnetic Compatibility Control Plan. A Deviation Approval Request, DAR I/LCA-6 was submitted and approved. The remaining tests were completed satisfactorily with no anomalies noted.

Upon completion of the qualification tests, the I/LCA was subjected to a visual examination with the cover removed. No defects of potential problem areas were observed. After evaluation of the above items, a COQ was prepared and approved.

Rotation Control Panel - Qualification tests, as noted in table 10-IV, were performed on a flight configured RCP. The test procedure details, test results, data conclusions, etc., are provided in the Qualification Test Report ED-2002-1471 with Bendix Corporation appendix QTR8978 dated April 21, 1972.

The vibration tests were repeated due to a random failure of a switch during the first test. The switch was replaced and the vibration tests successfully performed in their entirety. All other tests were satisfactorily completed with no anomalies noted.

Upon completion of the qualification tests, the RCP was partially disassembled and visually inspected. There was no evidence of damage or deterioration as a result of the tests. After evaluation of the above items, a COQ was prepared and approved.

Digital Address System Backup Panel - The DAS backup panel was subjected to the Qualification Tests as noted in table 10-IV. The test procedures, test results, data, etc., are provided in the ATM Digital Address System Backup Device Qualification Test Report 40M39630 dated February 25, 1972.

The DAS backup unit did not meet the requirements of the radiated and conducted RF portion of the EMI tests. This anomaly was waivered per AP-5236. All other tests were satisfactorily completed with no anomalies noted. After evaluation of the qualification test results, a COQ was prepared and approved.

ATM Component Acceptance Test

ATM module tests performed on the ATM flight unit and the ATM prototype unit utilized the C&D system hardware, both flight and prototype units. These tests were the vehicle for final acceptance tests of the C&D system hardware. The backup device was acceptance tested as a part of the MDA systems tests and will not be discussed in this report.

SYSTEMS VERIFICATION PROGRAM

The functional operation of the C&D console was verified as an integral part of the ATM prototype and flight unit module testing. This was accomplished during post-manufacturing checkout at MSFC, thermal vacuum testing at JSC, and prelaunch testing at KSC. The configuration of the prototype and flight C&D console were functionally identical; therefore, the consoles were interchanged during some testing.

ATM C&D System Verification (Prototype Unit)

The prototype ATM C&D console was utilized for ATM prototype post-manufacturing checkout (PMC) at MSFC and returned to Bendix, N&C Division, for update modifications to the ATM C&D flight unit configuration. Following the update modification, it was utilized for ATM prototype post-vibration checkout at MSFC, completion of ATM flight thermal vacuum tests at JSC, and ATM flight acceptance test at KSC. During the Skylab flights, the prototype console supported the ATM prototype unit at MSFC. Significant anomalies were encountered during these tests as noted.

The DAS switch selector operated without commands and when inserting DAS codes via the keyboard, a verify code appeared sometimes after only four digits were entered. Investigation revealed a requirement for modification of the pushbutton switch bounce elimination network to remove circuit pulsation as the keyboard was activated.

The Activity History Recorder stylus burned through the recording paper. Investigation revealed a requirement for flight test rack modification. Integrated circuits were changed to a low level input with diodes for isolation. In addition, several transistors were found to have been overstressed during initial acceptance testing. They were replaced and procedures implemented to preclude further damage during testing.

ATM C&D System Verification (Flight Unit)

The flight ATM C&D console was utilized for ATM prototype all systems test at MSFC, ATM prototype thermal vacuum testing at JSC, ATM flight unit checkout at MSFC, and initial ATM flight unit thermal vacuum testing at JSC. The flight C&D console was shipped to McDonnell Douglas, St. Louis, installed in the MDA flight unit and utilized for MDA acceptance test and all systems tests at KSC. The problems noted were evidenced during the testing prior to prelaunch activities.

The DAS and activity history recorder had the same problems as noted in Systems Verification (Prototype).

The S052 frames remaining counter would not retain its count when switched to off. Investigation revealed an RF radiation output related to the power input wiring. The problem was resolved by twisting the power input wires together to reduce the RF radiation.

The S054 frames remaining counter decremented without an input signal. Investigation revealed that a recessed connector generated noise inputs to the counter. The connector was redesigned to an external configuration and resolved this problem.

Prelaunch Checkout

Control and Display Console - One C&D console anomaly remained unresolved at the time of Flight Readiness Review. During the initial Power-up of the ATM at KSC, five CBRM status lights on the C&D console failed to come on. Trouble shooting, including 160 subsequent repetitions of the sequence in which the anomaly occurred, did not reproduce the anomaly. EMI/EMC in the ground test configuration was accepted at the most probable cause of this anomaly.

Three modifications were accomplished on the flight console at KSC. New overlays were installed on the seven C&D panels. Switchguards were installed on the S055A high voltage enable/reset switches, and teflon tape was placed over the five vertical scale meters.

Inverter Lighting Control Assembly (I/LCA) - The functional operation of the I/LCA was verified through electrical compatibility and EMI compatibility tests with the C&D console. The final acceptance testing of the flight I/LCA was accomplished as a part of the MDA Acceptance testing and will not be covered by this report. However, final acceptance testing of the backup I/LCA verified that the problems encountered during development and qualification of the I/LCA were satisfactorily resolved.

Digital Address System Backup Panel - The DAS Backup Panel final acceptance testing was performed as a part of the MDA systems test and will not be explored in this report.

The backup I/LCA final acceptance testing at KSC revealed an anomaly requiring modification of the unit. Fuses in both the AC and DC overvoltage protection devices for the output of the Backup I/LCA failed during testing at KSC. Failure analysis and testing identified the problem as transients generated in the C&D circuits. The AC fuse would fail when the backup I/LCA was on and the circuit breaker AC-1 was switched on. The DC fuse would fail when AC loads, integral lighting bus and numeric display bus were switched on and off. The problem was resolved by the modification of the DC overvoltage protection device to reduce sensitivity to transients and the revision of the crew checklist to include specific instructions on activation of the AC portion of the backup I/LCA.

SECTION XIII. WHITE LIGHT CORONAGRAPH (S052)

EXPERIMENT DESCRIPTION

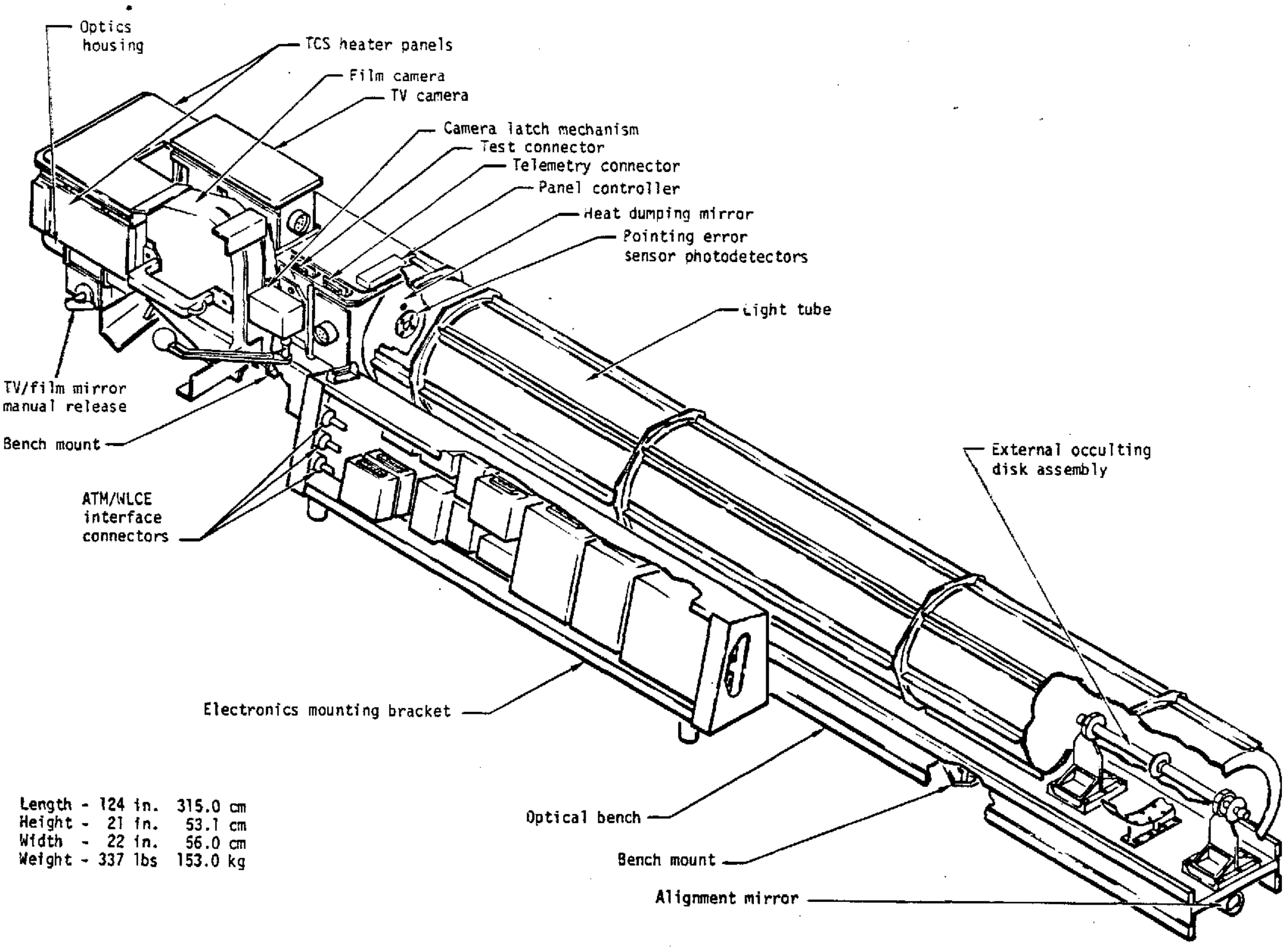
The White Light Coronograph, shown in figure 13-1, was an externally occulted coronagraph, designed to photograph the solar corona in the visible region of the electromagnetic spectrum. Scientific characteristics of the instrument are shown in Table 13-I.

Table 13-I. Scientific Characteristics

PARAMETER	VALUE
Spectral Range:	3500 to 7000 Å
Resolution:	
Spatial:	
Optics	15 arc-sec
Film	8 arc-sec
TV	30 arc-sec
Temporal:	≥40.5 sec
Field of View:	
Film	1.5 to 6.0 solar dia. ($D_\odot$)
TV	1.5 to 4.5 $D_\odot$

Optics

The instrument was an f/13.7 system with an effective focal length of 43.7 centimeters. An external occulting disk assembly was located on the forward end and an optics housing on the aft end of a dimensionally stable optical bench. The S052 optical schematic is illustrated in figure 13-2. Three external occulting disks blocked direct sunlight from the 3.2-centimeter diameter primary objective lens and reduced diffracted light to an acceptable level. Lenses and folding mirrors imaged the solar corona at either the film camera or the TV camera depending on the position of the TV folding mirror (M6). The Lyot spot on the secondary objective lens occulted internally reflected images from the primary objective lens. The internal occulting disk, which was servo-controlled to maintain internal optical alignment, blocked residual diffracted light from the external occulting disks. Final traces of stray light were intercepted by light baffles.



Length - 124 in. 315.0 cm
Height - 21 in. 53.1 cm
Width - 22 in. 56.0 cm
Weight - 337 lbs 153.0 kg

Figure 13-1. S052 White Light Coronagraph

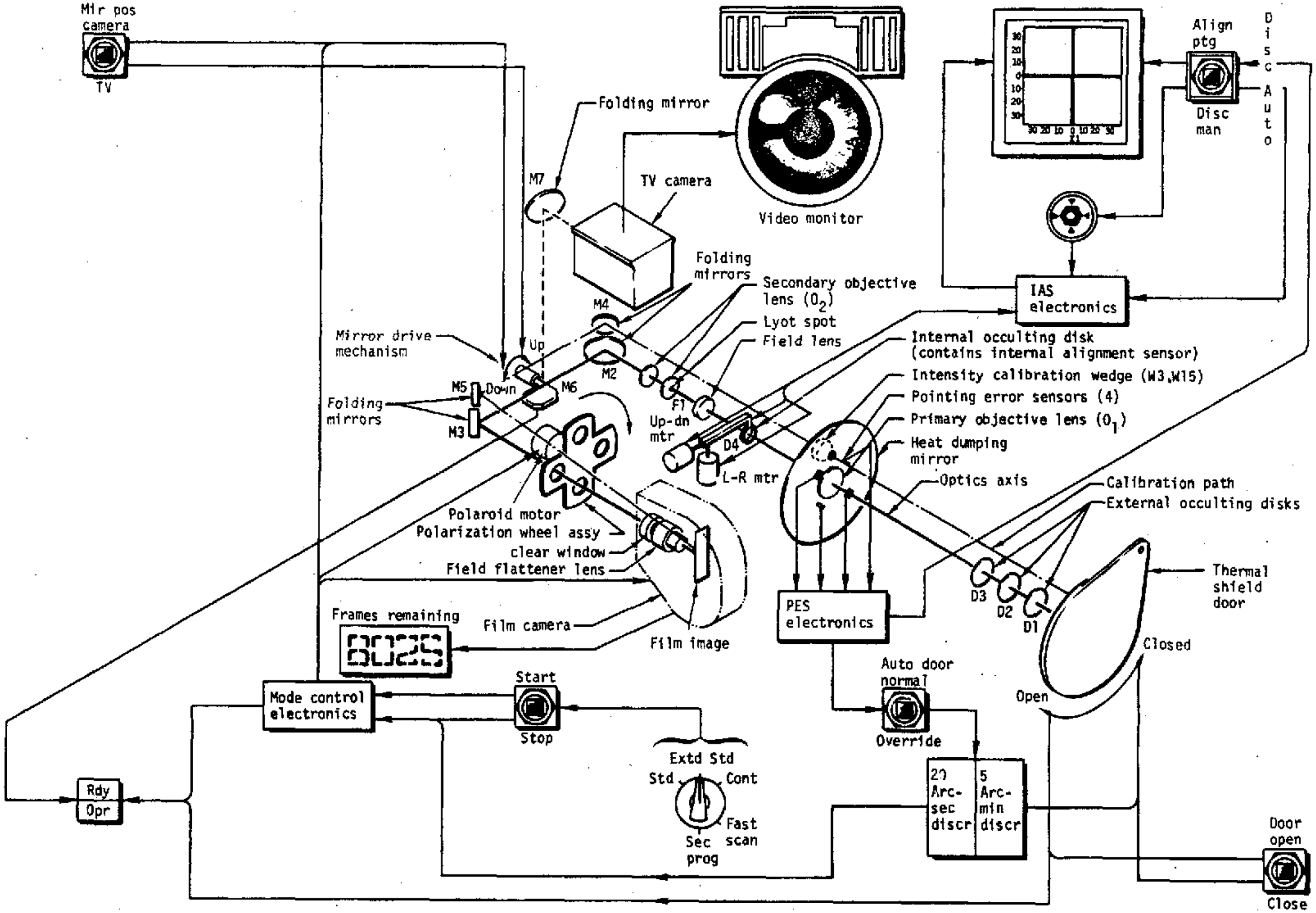


Figure 13-2. S052 Optics Layout and Controls and Displays Operation Schematic

The instrument optical elements performed the function of variable vignetting, which provided a damping of brightness variation with radius. For a given exposure, this enhanced faint outer corona detail and suppressed blooming in the bright inner corona. Three polaroid filters, oriented 60 degrees from each other, and one clear window were positioned sequentially into the optical path by the polaroid wheel mechanism. A mirror on the forward end of the optics housing rejected excess heat to space. A light baffle tube was integrated between the optics housing and the ATM canister.

A separate calibration path imaged direct sunlight through an 18 step wedge filter upon the central (occulted) portion of each film frame, providing a precise calibration of brightness from 3×10^{-8} to 1×10^{-10} radiance of the mean solar disk.

An ATM thermal shield door and a flexible boot between the S052 entrance aperture and the canister Sun-end was provided to protect the instrument from contamination, micrometeoroid impact, and direct sunlight when not in use. The instrument provided automatic thermal shield door closure when the ATM was not pointing to with 5 arc-minutes of Sun-center.

Film Camera

Five film loads (film cameras) were provided for the S052 instrument. Film load 1 was installed on the instrument prior to Skylab 1 launch, and three were stowed in the MDA film vaults. Each film load consisted of a film camera, containing 228 meters (8,025 frames) of 35mm Kodak Special 026-02 thin base film Each camera contained its own film transport system, shutter mechanism, frame count pulse generator, fiducial marking system, and diode matrix, which imprinted pertinent data on each film frame. Since the S052 optics formed an image at the camera film plane, the only optical element in each camera was a field flattener lens, which also served as the entrance window. Each camera was pressurized to 5 psia with 45-percent relative-humidity gaseous nitrogen. The film camera was mounted on the side of the optics housing and was held in place with the camera latch mechanism. Changing of film loads on the instrument was accomplished by EVA.

Pointing Reference System

The pointing reference system (PRS) consisted of a pointing error system (PES) and an internal alignment system (IAS). The PES consisted of four photovoltaic detectors mounted around the primary objective lens in the penumbra of the occulting disk assembly shadow; together with associated electronics, these provided pointing error measurements. The IAS consisted of one photovoltaic chip, divided into four quadrants, mounted on the internal occulting disk. Infared sunlight from an aperture in the external occulting disk assembly energized the four quadrants to provide signals proportional to the misalignment of the internal and external occulting disks. These signals activated the servomechanism which aligned the internal occulting disk.

The PES incorporated two discriminator circuits: 1) offset pointing of the ATM in excess of approximately 20 arc-seconds automatically terminated instrument operation to prevent waste of film; 2) offset pointing in excess of approximately 5 arc-minutes automatically closed the thermal shield door to prevent damage to the vidicon, film camera shutter and polaroid filters. A manual override of these discriminators was provided. Pointing control requirements are shown in Table 13-II.

Table 13-II. Pointing Control Requirements

PARAMETER	VALUE
Target:	Sun center
Accuracy:	
Pitch & Yaw	±20 arc-sec from Sun Center
Roll	±300 arc-min
Stability:	
Pitch & Yaw	±5 arc-sec for 16 min
Roll	±30 arc-sec for 1 min
Roll Orientation:	The yaw axis shall be parallel to the solar pole within ±5 degrees

Television Camera

A low-light-level TV camera was mounted on top of the optics housing. The TV image was available for viewing by the crew on either of two TV monitors on the C&D console, or was transmitted to ground when Skylab was in communication with a ground station. The camera control unit was mounted separately in the ATM. The only electrical interface between the TV camera and the rest of the instrument was grounding.

Electronics

The instrument electronics were contained in a separate bracket assembly which mounted directly to the ATM spar. The elctronics provided automatic programming of operation in the various modes, film camera diode matrix drive logic, and PRS logic electronics. Logic was also provided for a redundant programmer mode. Drive signals were provided for the polaroid wheel and internal occulting disk mechanisms, and automatic thermal shield door close. The electronics provided TV folding mirror drive signals and status indication signals. Instrument power was provided by a dc-to-dc converter having five output voltages. A secondary power supply offered complete redundancy. The electronics bracket assembly also contained a TCS power supply, various junction boxes, filter boxes and connectors.

Thermal Control

The instrument TCS provided semi-passive thermal control, consisting of insulation, thermal coatings and active heater panels. It maintained instrument temperature level and minimized thermal gradients.

Operation

The film camera was operated automatically in five modes to vary the exposure duration and filter wheel position. Activation of any of four primary operating modes resulted in the primary programmer automatically sequencing the instrument through a series of exposure with various combinations of exposure time and polaroid wheel position. Should the primary programmer fail, a one-mode, secondary programmer was available to the operator as a backup. These modes are summarized in Table 13-III.

The S052 experiment operated in either manned, unattended or unmanned modes. During manned operation, the instrument was entirely controlled by the crew from the C&D Console, as shown schematically in figure 13-2.

During unmanned and unattended operations, the instrument was operated by ground command with limited modes of operation. The functions performed by ground commands are shown in Table 13-IV.

Table 13-III. S052 Operating Modes

Mode	Sequence Duration	Polarization Wheel	Frames/ Sequence	Exposure (sec.)
Standard Patrol	5.5 min Auto Stop	All positions sequenced	12	9,27,3
Extended Standard Patrol	16.2 min Auto Stop	All positions sequenced	36	9,27,3
Continuous Patrol	Continuous Manual Stop	Clear position only	3/ 82.5 sec.	9,27,3
Fast Scan	16.2 min Auto Stop	Clear position only	72	27,3,9
Secondary Program	Continuous Manual Stop	Clear position Only	3/ 64 sec	6,18,2 6,18,2

Table 13-IV. S052 Ground Commands

Command	Function
Main Power	On, Off, Standby
Mode Select	Standard, Patrol, Fast Scan
Align Disk	Up, Down, Left, Right, Manual, Stop
Aperture Door	Open, Close
Converter	Primary, Secondary
Thermal Power	On, Off

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM Experiment program was initiated in January, 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application requested proposals for experiments to be considered for the ATM systems. The High Altitude Observatory (HAO) submitted a formal porposal in response to Dr. Newell's letter, entitled "White Light Coronagraph for Apollo". On September 1, 1966, HAO was informed of the selection of the HAO white light coronagraph for design and development for flight on the ATM. Subsequently, on September 6, 1966,responsibility for development of the experiment was transferred from the Goddard Space Flight Center (GSFC) to the Marshall Space Flight Center (MSFC). The instrument was designed, fabricated, and tested by Ball Brothers Research Corporation (BBRC) under the scientific direction of HAO, Boulder, Colorado. Dr. G. Newkirk, Jr. was the principal investigator until October 1970, when he was succeeded by Dr. R. MacQueen.

Experiment S052 was an outgrowth of the White light coronagraph preposed for the Advanced Orbiting Solar Observatory (AOSO). Previous to the transfer of responsibility, the experiment was within the AOSO scope of work at GSFC. In November 1966, the white light coronagraph became established within the ATM scope of work. The AOSO project established some of the basic design concepts for the experiments used on the ATM. Three features of the ATM experiment distinguish it from the AOSO counterpart: (1) the use of photograph recording with pronounced improvement in spatial and temporal resolution; (2) the crew control of instrument operations such as pointing and mode selection; and (3) the much longer orbital lifetime. Much of the experiment definition performed by the Principal Investigators (PI) on AOSO was directly applicable to the ATM Experiment. In some cases the PI used previously fabricated AOSO components as models and breadboards in the ATM S052 experiment development.

Design Evolution/Rationale

The concept employed in the design of the white light coronagraph was to create an artifical eclipse of the Sun with an occulting disk. Three external occulting disks with diameter slightly larger than the diameter of the apparent Sun were used to occult the Sun. In previous designs, the coronagraph revealed only the structure of the innermost corona. Many exciting unsolved problems were to be found in intermediate and outer corona $(1.5R_0 \leq R_0 \leq 6R_0)$. Therefore a modified Lyot coronagraph was designed to allow the faint corona to be viewed and recorded. Because the corona was very faint, light scattering by optical elements and by structural surfaces were suppressed by the use of appropriate baffles, apertures and anti-reflecting coatings. The light radiating from the corona is polarized; therefore polarizing filters were used to record coronal polarization. Because of the rapid motion of material in the corona, a camera with a high temporal resolution was designed. A low-light TV camera was provided to the crew to make visual observation of the corona.

Several design changes and/or modifications were made as a result of improvements in the state of the art, and design or manufacturing problems. The numerous modifications that were made to the experiment from initial concepts through all phases of development and testing were documented in engineering change proposals/modifications.

MANUFACTURING

Manufacturing of the S052 experiment consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into completed instruments. Three units were assembled - the Thermal Mechanical Unit (TMU), the Prototype Instrument and the Flight Instrument. The fabrication dates were as follows:

Unit	Date
TMU	July 1967 through November 1967
Prototype	November 1967 through May 1969
Flight	November 1967 through November 1968

Unique fabrication techniques employed in the fabrication of S052 were:

1. Fabrication and assembly of the internal occulting disk alignment sensor. A procedure for soldering and welding was devised for the attachment of signal wires to the sensor to prevent heat transfer into the cell.

2. Aligning and centering of film camera field flattener assembly to adjust the orientation of the lens optical axis with respect to the lathe axis of rotation both on angle and translation.

3. Imprinting fiducial marks on each exposed film frame by the use of four miniature incadesient bulbs mounted in the 0.060-inch-thick available space.

Following fabrication, all units were subjected to both functional and environmental tests. The TMU was tested to verify instrument envelope dimensions, spar attachment interfaces, thermal structural mount adjustments, and thermal control operation. The prototype instrument was subjected to qualification tests and the flight instrument subjected to pre-delivery acceptance tests. Numerous studies, tests, breadboarding and special tests such as the scattered light tests, environmental film tests, flight design verification unit tests and contamination tests, were accomplished to develop the design of the instrument. The results were documented in BBRC reports F67-04, F68-08, TR 69-02, TN 69-97, TN 70-35, High Altitude Observatory number NCAR-TN/IA-66, NASA TMX-53666 and NASA CR-61364.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements at levels approximately 1.5 times those expected during the Skylab Mission as specified in 50M02403, Environmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, acceleration and acoustics. In addition, camera pressure leak, electromagnetic compatibility and outgassing tests were performed on the instrument. The qualification test program is described in End Item Test Plan BBRC number TR 67-76. The results of the qualification test are documented in BBRC test reports TR 70-12, TR 70-03, TR 70-03 Supplement A and TR 71-09. Dates of qualification testing were as follows:

Test Article	Test Date
Prototype Instrument	January 1970 to April 1970
Prototype Redundant Electronic System	July 1970
Internal Occulting Disk Mechanism	November 1970
Film Camera CM14A-2	May 1970 to November 1970
Low Level TV Camera	March 1972

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on April 28, 1972 with no open items.

Some of the problems encountered during component qualification and the corrective actions taken are listed below.

Problem	Corrective Action
1. Radiated noise level too high.	Design changed to ground TCS power supply case and cover, and to provide filter chokes.

Problem (Continued)	Corrective Action
2. 20 arc-sec and 5 arc-min discriminators fired at incorrect set points.	Increased discrimator firing limit.
3. External occulting disk alignment shifted during vibration.	None. Approved to use as was. Alignment shift did not appear detrimental to operation.
4. Partial frame advance between exposures.	Reworked clutch mechanism.

ACCEPTANCE TEST

The flight instrument was subjected to pre-delivery acceptance tests to levels anticipated during the mission to verify that the instrument met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in End Item Test Plan BBRC number TR67-76.

All testing was accomplished at the contractor's facility. Testing on the complete flight instrument was conducted between September 1970 and January 1971. Testing on the six flight film cameras was conducted between August 1971 and September 1972. The results of these tests are documented in BBRC test reports TN 72-24, TN 73-04, TR 73-07, TN 73-13, TN 73-15, TN 73-16, TN 73-17, TR 71-22, TR 71-22 and TR 72-05.

Some of the problems encountered during acceptance testing and the corrective actions taken are listed below.

Problem	Corrective Action
1. Insufficient light passing through calibrative optics.	Reversed position of apertures in calibration libht tube.
2. External occulting disk assembly shifted during vibra-	Reworked pylon brackets to provide more secure attachment.
3. Film camera latch mechanism locked in detent position.	Replaced ball with roller and moved detents out from shaft to distribute load on larger surface.
4. Camera would not interface with experiment mechanically.	Reworked guide plate, added inserts and relocated holes.

All acceptance tests/reviews were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System verification testing was performed on the S052 prototype and flight instruments in accordance with 50M02425, ATM Test and Checkout Requirements and Specifications (TCRSD) to determine conformance to design specifications. The ATM test programs for the prototype and flight units were essentially the same except for the lower vibration levels in the vibration test and the prelaunch tests for the flight unit.

System Verification (Prototype)

In-Process Testing - After delivery of the S052 experiment hardware from the manufacturer, the instrument was mounted to the ATM spar and connected to spar cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the experiment subsystems (electrical and optical). Several anomalous conditions involving test equipment occurred. Film camera resolution was out of tolerance but was attributed to the lack of an optically stable test environment. No experiment hardware failures occurred.

Post Manufacturing Checkout - The S052 prototype was tested during PMC to verify satisfactory performance of the instrument, film camera, and system interfaces. Emphasis was given to EMI and EMC testing with all ATM systems operating.

The following anomalies were encountered during testing:

The S052 instrument did not provide a door open signal to telemetry. This was a design error which could not be corrected without hardware disassembly. It was decided to forego modification of the instrument until refurbishment. (The design change was incorporated on the S052 flight unit.)

Extended standard mode continued to operate after the thermal shield door closed. This was determined to be a normal instrument function and 50M02425 (TCRSD) was revised to reflect this condition.

The film camera allowed a partial frame advance. The camera was reworked and retest was successful.

ATM wiring and distributor problems caused erroneous conditions on S052 as listed below.

a. The S052 ready light illuminated at all times when the main power was on.

b. The thermal shield door open indicator to the S052 instrument was incorrect.

c. Sequence complete flag on the C&D console was incorrect.

d. Switch selector and RF commands did not turn standby power on or turn main and standby power off. These problems were corrected by ATM wiring and distributor modifications.

Upon completion of PMC, all S052 problems were cleared except for RF command verifications and telemetry indication of thermal shield door open. The RF command verification was subsequently completed during pre-thermal/vacuum testing. The telemetry indication of thermal shield door open was corrected during refurbishment.

Thermal Vacuum Testing - Thermal vacuum testing at JSC was composed of three distinct test phases; pre-thermal vacuum tests, thermal vacuum tests, and post-thermal vacuum tests. Pre thermal vacuum testing was performed to verify systems readiness. No S052 anomalies were reported during this test.

Thermal vacuum testing was performed to subject the ATM prototype to thermal vacuum conditions that simulated the first eight hours following orbital activation, failed canister TCS, and six operational insertion sequences. The six operational sequences included both hot and cold steady state and hot and cold transient thermal environments; Z-local vertical attitudes, and orbital storage. The S052 system was tested to verify that the thermal control system heater panels could maintain the optical bench at $21.1 \pm 3.3^{\circ}C$ and could minimize temperature gradients across the optics housing while being subjected to the environmental conditions noted above.

Three deviations from the normal S052 experiment operation were made for the prototype thermal vacuum test.

1. A cover was positioned over the primary objective lens;

2. The thermal shield aperture door was closed during hot steady state; and

3. The DC/DC converter was turned off during standby modes.

The second and third deviations were not considered thermally significant. However, the first deviation had the effect of eliminating all solar heating on the experiment. Because the total solar load was 12.0 watts, the experiment optics temperatures would have been significantly higher during solar exposure had the solar flux not been eliminated. The first deviation was necessary because the solar simulators did not geometrically simulate the Sun.

Operational thermal performance of the S052 experiments was satisfactory with the exception of a low optical bench temperature during simulation of orbital storage. The optical bench stabilized at a temperature of 17.5°C compared with a minimum operational limit of 17.8°C.

Thermal stabilization was achieved during activation with the exception of the Sun-end mount temperatures which reached thermal equilibrium approximately 6 hours into the cold transient simulation. The time required for stabilization ranged between 5 hours for the optics housing and 36 hours for the Sun-end mount.

Z-local Vertical Attitude (Z-LV) simulation had no adverse thermal effect on the experiment. The brief increase in cold plate temperature that occurred was not sufficient to change the telescope temperatures. The temperature trend during X-LV was a general decrease in experiment temperatures resulting from a decrease in environmental and component heating from those levels imposed during hot steady state conditions.

The vidicon temperature measurement was noisy throughout the test, often oscillating by as much as 6°C.

When the secondary voltage supply was utilized, the temperature data were 2°C higher than that associated with primary voltage supply operation. Post-test investigation showed that the data associated with primary voltage supply was correct.

Post-thermal vacuum testing was performed to verify that no adverse effects occurred as a result of the space simulated environment. No such problems were evident.

Post-Vibration Testing - Following vibration testing the S052 instrument was tested to verify that the experiment was operational after being subjected to launch-level vibration. Two S052 problems were identified as follows:

One thermal control system controller monitor output went to 0 Vdc (should have been 5 Vdc). This could not be resolved at the time because of inaccessability and was deferred until prototype refurbishment. The failure was not a result of thermal vacuum environment, but an isolated component failure. No design change was necessary.

The laser (alignment equipment) could not be centered on the internal alignment sensor detector located on the internal occulting disk. The cause could not be determined. Maintenance of optical alignment could not be verified.

An all systems test was performed to determine if any interaction existed between subsystems during highly active functional conditions, to verify bus redundancy, and to verify all other functions not checked during the subsystem test phase. The S052 experiment performed as required with no problems reported.

Systems Verification (Flight)

In-Process Testing - In-process testing on the flight instrument consisted of the same functional verification as was conducted on the prototype. No significant problems were noted during this test.

Post-Manufacturing Checkout - Post-Manufacturing Checkout was conducted on the flight instrument to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. The following problems were noted:

The frames remaining counter on the C&D console decremented erroneously. A filter was added to the circuit which cleared the problem.

When the mode switch was rotated from secondary programmer to standard mode, no stop command was issued. The C&D mode switch was revised to add a stop command.

The S052-10Vdc telemetry measurement was intermittently open. This condition was waived since it did not affect experiment operations.

The film camera temperature was noted to be about 5°C colder than other experiment temperatures. Investigation showed all camera temperature calibration data to be incorrect. The cameras were returned to the manufacturer for recalibration.

Thermal Vacuum Testing - Pre-thermal vacuum testing was performed to verify system readiness. No S052 anomalies were reported.

Thermal vacuum testing was performed to verify proper operation during simulated orbits in a thermal vacuum environment. During one test sequence,S052 stopped operating when power was applied to the S082B instrument. Repeated attempts to duplicate this occurance were made with no success. The item was closed as a one-time anomaly. No other anomalies were reported.

Post-thermal vacuum testing was conducted to verify that exposure to the space-simulated environment had not caused any instrument degradation. No problems were encountered during this test. One special test was run to verify that no deterioration of the polaroid filters occurred due to aging or thermal vacuum exposure. Test results indicated the polaroid filters were in excellent condition and no degradation was evident.

During thermal vacuum calibration of the XUV experiments S052 was powered up only to thermally simulate space conditions and for protection from the thermal vacuum environment. No anomalies were reported during this test.

Prelaunch Testing (KSC) - Upon arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab module. Significant S052 tests were the interface verification test, optics and polaroid examination, all systems test and crew compartment fit and function.

During interface verification, it was found that all S052 analog measurements were noisy when the secondary power supply was operating. Investigation revealed a wiring error in the secondary power supply. The noisy measurements did not affect instrument operations, and due to the degree of difficulty and the time constraints to change out the converter, it was decided to launch the instrument in this condition. The optical inspection was peformed to verify that no degradation had occurred to the lenses or polaroid filters. Results indicated these elements were in excellent condition. No S052 anomalies were reported during the flight all systems test.

Crew compartment, fit and function checks verified that the S052 film cameras could be fitted onto the telescope and also in the storage area. No anomalous conditions were evident.

Vertical Assembly Building (VAB) testing occurred in two phases; ATM alone, and ATM with other modules. VAB testing consisted of C&D panel interface test, end-to-end systems test, swing arm overall test, mission simulation flight readiness test, sub-system bus redundancy and camera installation and close out.

During the C&D panel interface test, the S052 camera failed to operate properly. The camera was replaced and proper operation was verified. No other anomalies were experienced on S052 throughout the remaining tests. Testing ceased with the instrument in the proper closed-out configuration.

SECTION XIV. X-RAY SPECTROGRAPHIC TELESCOPE (S054)

EXPERIMENT DESCRIPTION

The X-ray Spectrographic Telescope, shown in figure 14-1, was designed to study solar emissions in the soft X-ray spectrum. The instrument was designed to photograph solar flares within this spectrum during active periods and obtain broadband X-ray photographs of the Sun in selected regions of the X-ray spectrum during non-flare periods. Scientific characteristics of the instrument are shown in Table 14-I.

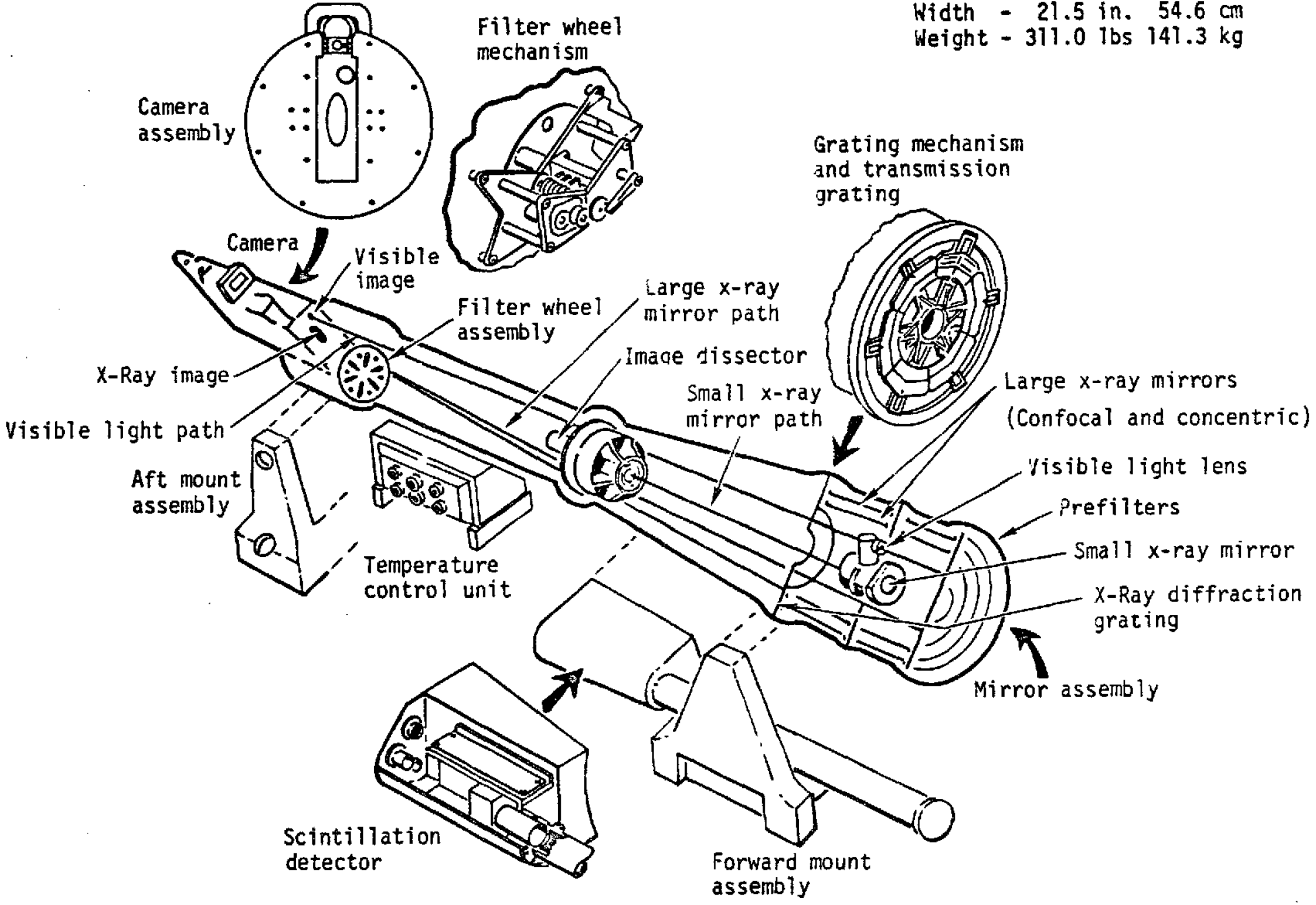
Table 14-I. Scientific Characteristics

PARAMETER	VALUE
Spectral Range:	3 to 60 Å
Resolution:	
Spectral:	50 at 7 Å
Spatial:	1.5 arc-sec
Temporal:	≥2.5 sec
Field of View:	48 arc-min ($1.5R_\odot$)

The S054 system contained a telescope assembly and seven electronic assemblies. Location of components is shown in figure 14-2. The telescope assembly contained X-ray and visible light optics, a film camera, X-ray transmission gratings, a thermal prefilter assembly, broadband filters, and photoelectric detectors. The main electronics assembly (MEA) contained the majority of the electronics required to support operation of the telescope subsystems, C&D console displays, and telemetry.

Optical Systems

The telescope contained 3 distinct optical systems which are shown in figure 14-3. The primary imaging system consisted of prefilters, grazing-incidence X-ray telescope mirrors transmission grating filters, and a film camera. The coaxially-mounted, grazing incidence x-ray mirrors provided a total collecting area of approximately 42 square centimeters at 8.3 angstroms. The mirror inside diameters were 22.8 centimeters and 30.5



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 14-1. S054 X-Ray Spectrographic Telescope Configuration

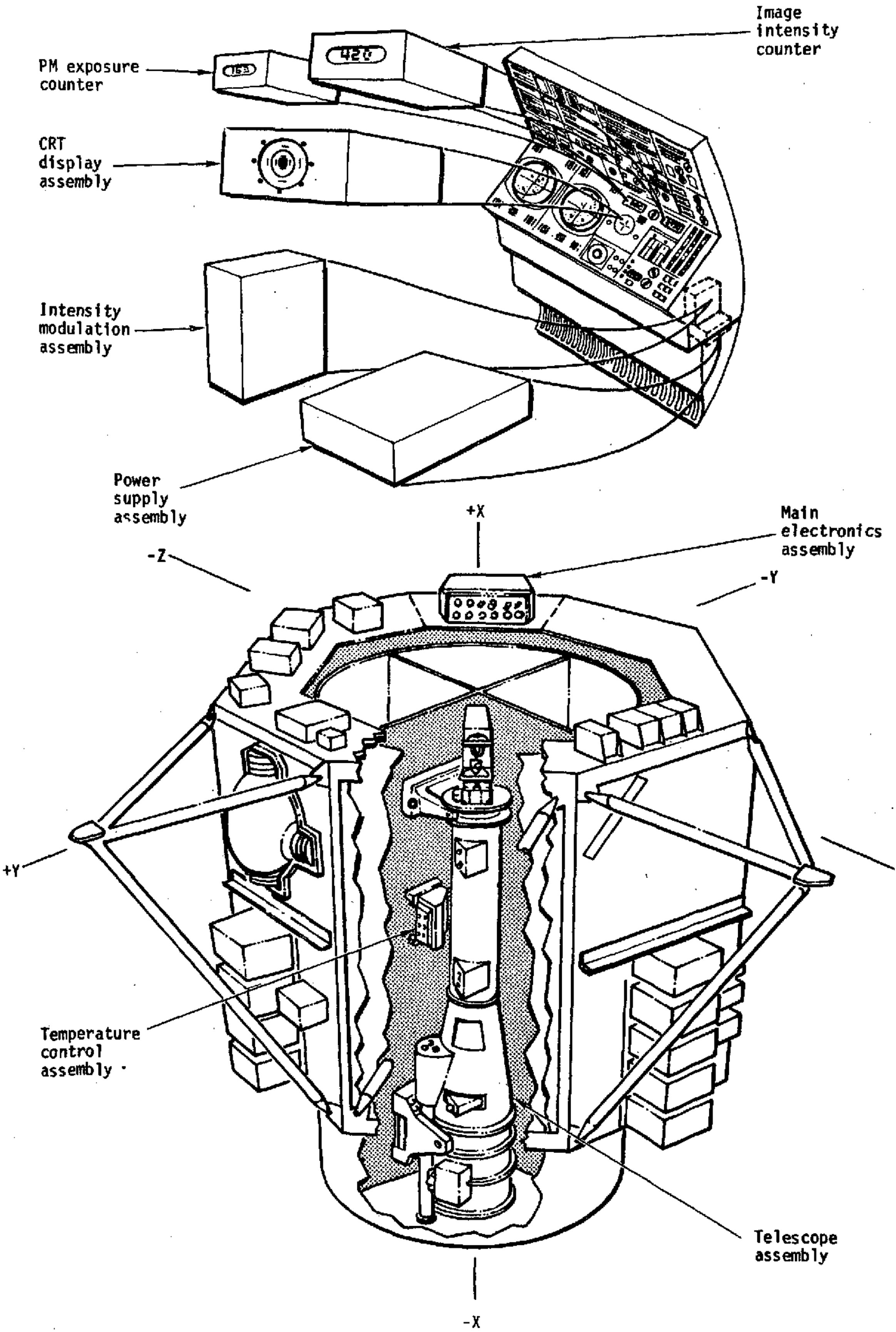


Figure 14-2. S054 Assembly Location

centimeters and the focal length was 213 centimeters. The transmission grating was positioned into or out of the X-ray radiation path by C&D console command. The grating intercepted a portion of the incident energy and produced a dispersed image over a range of 3 to 60 angstroms. Five broadband X-ray filters were mounted on a rotating filter wheel located in front of the camera. The wheel also contained an open aperture position. Any one of the six filter wheel positions could be selected from the C&D console. Any one of three positions could be commanded from the ground. In addition to the five wheel-mounted filters, a prefilter and a camera magazine window were mounted in the radiation path. The prefilter was located in front of the telescope mirrors, and reduced the heat transmitted to the X-ray filters and film. The camera magazine window prevented exposure to visible and ultraviolet light.

The second optical system consisted of a visible light lens which recorded a solar image on each film frame. The lens was an achromatic doublet with 2 neutral density filters and was 4.45 centimeters in diameter.

The third optical system contained a 7.6 centimeter X-ray mirror which provided a solar image to the C&D console for X-ray pointing.

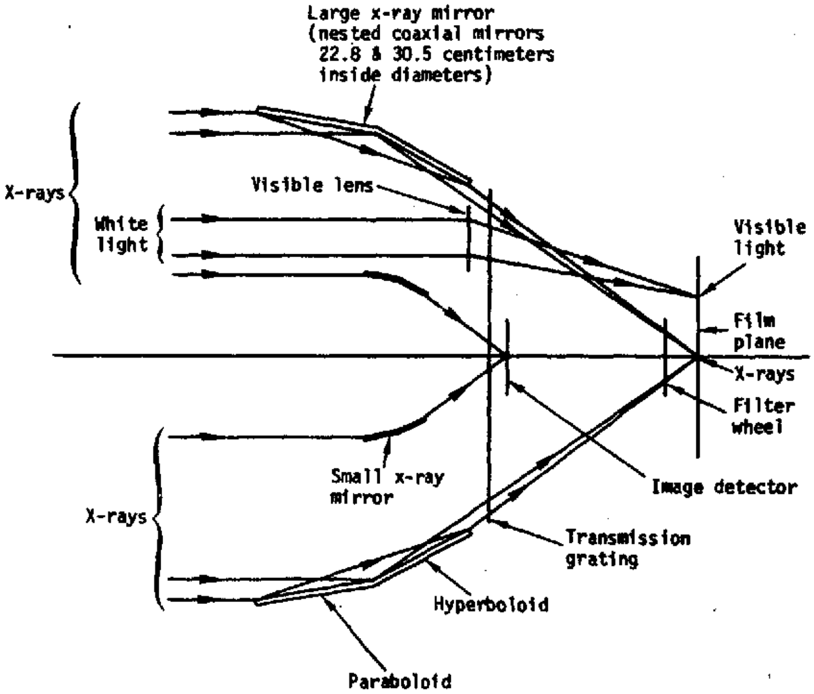


Figure 14-3. S054 Optical Schematic

Film Camera

The film camera consisted of a shutter assembly, a removable magazine assembly, a support structure, and electronics. The shutter assembly contained a visible light shutter and X-ray shutters. The visible light exposure time was fixed at 1/100 second. The X-ray shutter consisted of two blades which moved across the X-ray aperture. X-ray exposure duration was controlled by moving the first blade clear of the aperture and then moving the second blade to cover the aperture. X-ray exposure time ranged from 1/64 to 256 seconds. Each frame recorded X-ray and visible light images, spacecraft time, exposure duration, grating position and filter position. The magazine consisted of the film transport mechanism and the takeup and supply casette. A film load consisted of 6,970 frames of 70-millimeter SO-212 film.

Pointing System

The pointing system provided position information and an image intensity count of active solar regions. X-ray energy was collected by the 7.6-centimeter mirror and was imaged on the image dissector. The output of the image dissector was displayed on the X-ray image monitor on the C&D console. During flares the location of the emitting region was detected by the brightening of a portion of the X-ray image monitor and the crew could point the ATM canister to center the flare on the display. The adjacent digital image intensity counter indicated the overall relative solar X-ray intensity. Pointing control requirements are shown in Table 14-II.

Table 14-II. Pointing Control Requirements

PARAMETER	VALUE
Target:	Selected active regions on the solar disk and Sun-centered
Accuracy:	
Pitch & Yaw	±2 arc-min
Roll	N/A
Stability:	
Pitch & Yaw	±2.5 arc-sec per 5 min
Roll	±7.5 arc-min per 100 sec
Offset:	±17 arc-min in pitch and yaw

Photomultiplier

The photomultiplier monitored X-ray activity within a 6-degree field-of-view. The output of the photomultiplier was used for automatic flare detection, automatic control of camera and exposure times, and telemetry data on solar activity for scientific analysis. Photomultiplier activity counts were also displayed on the C&D console. Flare alarm intensity threshold levels were set by the crew at the C&D console according to mission philosophy. When the photomultiplier exposure counter readout exceeded the flare threshold setting, outputs were provided to the flare alert system which triggered a visual and audible alarm.

Thermal Control System

The TCS consisted of primary and secondary control loops which provided a fully redundant thermal control capability. Four primary temperature sensors were located within the telescope assembly and regulated proportional controllers which supplied power to the primary elements of heater blankets located within the telescope assembly. The primary thermal control loop maintained an average temperature of $21.1 \pm 1.1^{\circ}C$ when the telescope was in the $10^{\circ}C$ environment of the ATM canister. The secondary temperature control loop was controlled by four mercury thermostat temperature controllers located on the telescope assembly.

Operation

The camera operated in four modes, manually and automatically to vary the exposure range sequence and rate (Table 14-III). Shorter exposure ranges were selected during periods of high activity. A faster picture rate was used during flare rise observations, and the X-ray diffraction grating was placed in the optical path during some post-flare observations. Filters were selected as required to vary the spectral transmission characteristics of the instrument.

The S054 experiment operated in either manned or unattended or unmanned modes. During the manned operation the instrument was entirely controlled by the crew from the C&D console as shown schematically in figure 14-4. During the unattended and unmanned operation, the instrument was operated by ground with limited modes of operation. The functions performed by ground commands are shown in Table 14-IV.

TABLE 14-III. S054 Modes of Operation

EXP RANGE	PICT RATE	MODE		TIME	FRAMES PER SECOND
		MAN	FLARE		
1	SINGLE	X		2.7 SEC	4
1	SINGLE		X	2.7 SEC	4
1	LOW	X		13.25 MIN	76
1	LOW		X	N/A	4/50 SEC UNTIL FLARE LOSS OF MAN. STOP
1	HIGH	X		13.25 MIN	1472
1	HIGH		X	N/A	4/2.7 SEC UNTIL FLARE LOSS OF MAN. STOP
1	PROG	X		13.25 MIN	420
1	PROG		X	N/A	4/2.7 SEC FOR 4.25 MIN THEN 4/50 SEC UNTIL FLARE LOSS OR MAN. STOP
4	SINGLE	X		7 SEC	5
4	SINGLE		X	7 SEC	5
4	LOW	X		13.25 MIN	60
4	LOW		X	N/A	5/66 SEC UNTIL FLARE LOSS OR MAN. STOP
4	HIGH	X		13.25 MIN	710
4	HIGH		X	N/A	5/4 SEC UNTIL FLARE LOSS OR MAN. STOP
4	PROG	X		13.25 MIN	590
4	PROG		X		5/7 SEC FOR 4.25 MIN THEN 5/66 SEC UNTIL FLARE LOSS OR MAN. STOP
16	SINGLE	X		22.3 SEC	6
16	SINGLE		X	22.3 SEC	6
16	LOW	X		13.25 MIN	65
16	LOW		X	N/A	6/94 SEC UNTIL FLARE LOSS OR MAN. STOP
16	HIGH	X		13.25 MIN	270
16	HIGH		X	N/A	6/22.3 SEC UNTIL FLARE LOSS OR MAN. STOP
16	PROG	X		13.25 MIN	96
16	PROG		X	N/A	6/22.3 SEC FOR 4.25 MIN THEN 6/94 SEC UNTIL FLARE LOSS OR MAN. STOP

TABLE 14-III. S054 Modes of Operation (Cont'd)

EXP RANGE	PICT RATE	MODE		TIME	FRAMES PER SECOND
		MAN	FLARE		
64	SINGLE	X		86.6 SEC	7
64	SINGLE		X	86.6 SEC	7
64	LOW	X		13.25 MIN	41
64	LOW		X	N/A	7/170 SEC UNTIL FLARE LOSS OR MAN STOP
64	HIGH	X		13.25 MIN	93
64	HIGH		X	N/A	7/86.6 UNTIL FLARE LOSS OR MAN. STOP
64	PROG	X		13.25 MIN	42
64	PROG		X	N/A	7/86.6 FOR 4.25 MIN THEN 7/170 SEC UNTIL FLARE LOSS OR MAN. STOP
256	SINGLE	X		342.9 SEC	8
256	SINGLE		X	342.9 SEC	8
256	LOW	X		13.25 MIN	16
256	LOW		X	N/A	8/438 SEC UNTIL FLARE LOSS OR MAN. STOP
256	HIGH	X		13.25 MIN	23
256	HIGH		X	N/A	8/342.9 SEC UNTIL FLARE LOSS OR MAN. STOP
256	PROG	X		13.25 MIN	16
256	PROG		X	N/A	8/4.25 MIN THEN 8/438 SEC UNTIL FLARE LOSS OR MAN. STOP

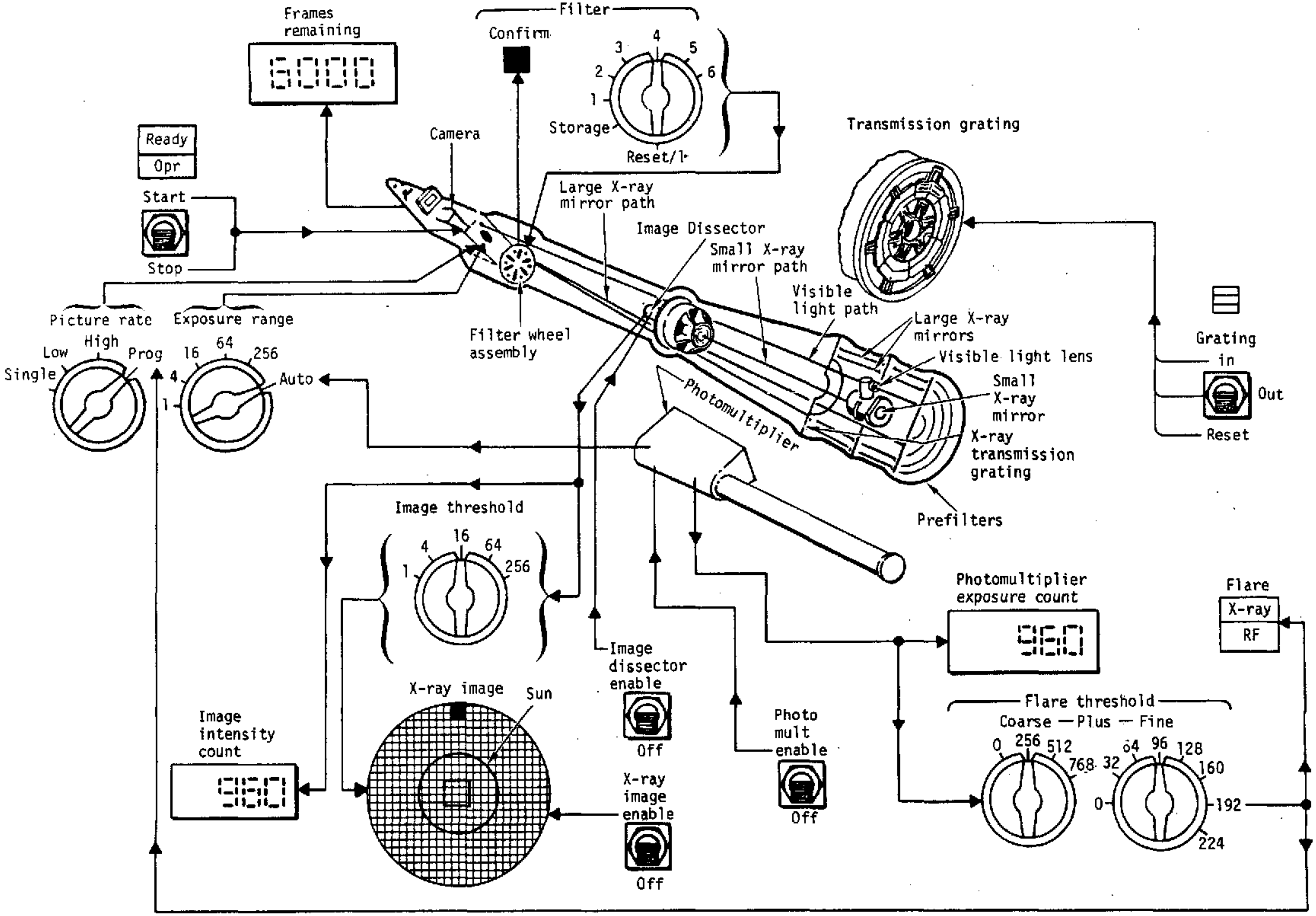


Figure 14-4. S054 Controls Displays Operation Schematic

Table 14-IV. Ground Commands

COMMAND	FUNCTION
Main Power	On, Off
Start/Stop	Start, Stop
Filter Select	1, 2, 3, Reset
Thermal Power	Primary, Secondary, Off
Aperture Door	Open, Close

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM Experiment program was initiated in January 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application requested proposals for experiments to be considered for the ATM system. American Science and Engineering (AS&E) submitted a formal proposal in response to Dr. Newell's letter, entitled "Spectrographic X-ray Telescope Flare Experiment for ATM". On September 1, 1966, AS&E was informed of the selection of theSpectrographic X-ray Telescope experiment for ATM for design and development for flight on the ATM. Subsequently, on September 6, 1966, responsibility for development of the experiment was transferred from the Goddard Space Flight Center (GSFC) to the Marshall Space Flight Center (MSFC). The instrument was designed, fabricated and tested by American Science and Engineering (AS&E) of Cambridge, Massachusetts. Dr. R. G. Giacconi was the principal investigator until February 1973, when he was succeeded by Dr. G. S. Vaiana.

Experiment S054 was an outgrowth of the Spectrographic X-ray Telescope proposed for the Advanced Orbiting Solar Observatory (AOSO). Previous to the transfer of responsibility, the experiment was within the AOSO scope of work at GSFC. In November 1966, theX-ray Spectrographic Telescope became established within the ATM scope of work. The AOSO project established some of the basic design concepts for the experiment used on the ATM. Three features of the ATM S054 experiment distinguish it from the AOSO counterpart: (1) The use of photographic recording, with pronounced improvement in spatial and temporal resolution; (2) Crew Control of instrument operations such as pointing and mode selection and; (3) The much longer orbital lifetime. Much of the experiment definition performed by the Principal Investigators (PI) on AOSO was directly applicable to the ATM experiment.

In some cases the PI used previously fabricated AOSO components as models and breadboards in the ATM S054 experiment development.

Design Evolution/Rationale

The concept employed in the design of the S054 optics makes use of the fact that at soft X-ray wavelengths, the real part of the index of refraction of the mirror material is less than one. As a consequence, total external reflection occurs at grazing angles of incidence. The S054 X-ray Telescope consisted of two nested grazing incidence X-ray mirrors which were both coaxial and confocal. The X-ray mirrors developed for ATM employed double reflection from paraboloidal and hyperboloidal surfaces. With this system the collecting area is the annular portion of the cross section. A smaller X-ray mirror finder was mounted on the same optical axis as the major mirror and was used as an aid to the crew in pointing the telescope. The inclusion of a visible lens was necessary to provide white light images of the Sun for pointing information. An objective grating was incorporated in the X-ray path. The grating consisted of an array of parallel absorbing strips supported by a parylene substrate thin enough to be transparent to the soft X-ray range of interest. A six-position filter with various materials, thickness and wavelength responses was used to provide broadband spectral resolution.

Hard X-rays are associated with flares. To detect hard X-rays, a scintillation crystal coupled to a photomultiplier was used. The output of the photomultiplier was digitized and transmitted to a readout on the control panel to provide the crews with an indication of the level of solar activity. To provide the crews with a TV-like display of the X-ray activity, a thin scintillator at the focus of the finder telescope was coupled to an image dissector. The output of the image dissector was transmitted and displayed on a cathode ray tube located on the C&D console. In order to correlate with ground based measurements and to make quantitative intensity measurements, it was necessary to know the time and duration of each exposure. Information such as the exposure duration and time of exposure was recorded on the film by a series of binary coded lights.

Several design changes and/or modifications were made as a result of improvements in the state of the art, and design or manufacturing problems. The numerous modifications that were made to the experiment from initial concepts through all phases of development and testing were documented in engineering change proposal/modifications.

MANUFACTURING

Manufacturing of the S054 experiment consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into units. Three units were assembled: the Thermal Mechanical Unit (TMU), the prototype instrument and the flight instrument. The fabrication dates were as follows:

Unit	Date
TMU	June 1967 through November 1967
Prototype	November 1967 through November 1969
Flight	November 1967 through January 1970

Unique fabrication techniques employed in the fabrication of S054 were:

1. Kanigen-coated confocal mirrors - a thin layer of Kanigen, a nickel alloy was deposited on a machined beryllium support structure. The surfaces were then ground, figured, and polished.

2. The transmission gratings consisted of an array of parallel absorbing strips supported by 1.2 micron parylene C substrate thin enough to be transparent to the soft X-ray range of interest. The absorbing material was gold having an average depth of 1000Å per line. There were 1440 lines per millimeter. The parylene substrate was first formed on a thick replica of a conventional ruled grating by precipitation from the vapor phase. The thin plastic layer was then stripped off and retains an impression of the grooves of the thick grating. The absorbing strips, which were the dispersing element of the grating, were formed on the plastic layer by evaporation at an angle to the surface.

3. Before the beryllium filters were assembled their thicknesses were determined by weighing measured areas of the material. The uncertainty in the calculated average mass thickness was 0.4%. It was not possible to follow exactly the same procedure for the organic filters as they have to be attached to the frames under a slight tension to prevent wrinkling. The stretching process changes the thickness of the material and it was necessary to calculate the mass thickness of the stretched material. The uncertainties in the area and, since they are lighter, in the mass were somewhat higher for the organic filters than the beryllium up to 1%. After determination of average mass thickness, the filters were mounted in aluminum frames which form a sandwich around the filter material. The frames were bonded together with RTV adhesive.

4. Largely as a safety measure to protect the astronauts, AS&E developed special techniques for assembling the Cathode Ray Tube in the pointing system. These consisted essentially of attaching the glass to a very dense metal, hypernom, and developing special welding techniques.

5. A very compact means of packaging the three Image Dissector high-voltage supplies was developed for this experiment. They were vacuum potted in glass beads in three individual cylinders, which were in turn placed in a larger cylinder that also contains the low voltage units.

6. The window of the S-054 camera magazine was a micron-thick polypropylene membrane with a 1700Å thick deposition of aluminum. The fabrication sequence for these windows was: polypropylene film of 0.001-inch thickness is stretched to 1 micron thickness; an aluminum coating of 1700Å thickness is deposited on the stretched polypropylene by vacuum deposition; the filters are checked by visual examination and light shadowgraphs; the X-ray transmission of the completed window is measured at least 4 wavelengths; the transmission data are used to determine the exact thickness of the polypropylene and the aluminum coating.

7. The prefilters were situated in front of the telescope mirrors. They reduced the heat load transmission to the broadband organic filters and the magazine window. They also aided in preventing visible light exposure of the film in X-ray image areas. The filters consisted of approximately 1300Å of aluminum foil on a nickel mesh. The total area of any pinhole was required to be less than ½ percent of the total prefilter area. This integrity was established by visible light shadow graphs.

All units were subjected to both functional and environmental tests. The TMU was tested to verify instrument space envelope dimensions, spar interface, and thermal control operation. The prototype instrument was subjected to qualification tests and the flight instrument subjected to pre-delivery acceptance tests. Numerous studies, tests, breadboarding, and special tests such as the calibration testing, point spread function, spectral resolution of transmission gratings, effective area of telescope as a function of wavelength, X-ray filters calibration and environmental film tests were all accomplished to develop the design of the instrument. The results were documented in American Science and Engineering reports ASE-1985, ASE-2405, ASE-2406, NASA TMX 53666 and NASA CR-61364.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements at levels approximately 1.5 times those expected during the Skylab mission as specified in 50M02408, Environmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, acceleration and acoustics testing. In addition, mechanical and electromagnetic compatibility tests and outgassing tests were performed on the instrument. The qualification test program is described in End Item Test Plans, ASE Documents 2181, 2535, 2631, 2632, 2574, 2814, 2607, 2720, 2767, 2954, 3001, 3046 and 3094. The results of these tests are documented in ASE test reports 2712, 2629, 2720, 2767, Volumes I, II, III, and 2954. Dates of the qualification testing were as follows:

Test Article	Test Date
Telescope Assembly	Feb. 1970 to May 1970
Temperature Control Assembly	Feb. 1970 to May 1970
Main Electronics Assembly	Feb. 1970 to May 1970
Control & Display Component	Feb. 1970 to Aug. 1970
Grating Assembly	March 1971
Prototype Instrument	Nov. 1970 to Nov. 1971
Power Supply # 2	Feb. 1971
Prefilter Assembly	Feb. 1971
Shutter Override Assembly	Oct. 1971

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on March 20, 1973, with no open items.

Some of the problems encountered and the corrective action taken are listed below.

Problem	Corrective Action
1. Loss of -15 volts, an increase in voltage to +43V and +22V.	Design was changed to eliminate differential thermal expansion stresses to critical components of the power supplies.
2. After vibration, gratings did not drive to "out" position. Grating drive began to function properly after 20-30 commands.	Changed design of ball slide to specify hardened and ground chrome steel balls with a ½ inch H yellow brass retainer.
3. Film advance pulse signal was not generated by camera after shutter command issued.	Clarified loading procedure and added knurled handles to film spools to permit winding minimum of 2-3 film layers to take up cassette.
4. Camera failed to operate properly due to one X-ray shutter blade intermittently hanging up across the aperture.	Design was changed to provide more blade tip clearance.
5. Arcing observed at the CRT high voltage brightness and focus potentiometers.	Packaging design was changed to incorporate Eccosil 4640, Solith arc 113 and high voltage lead redress.

ACCEPTANCE TEST

The flight instrument was subjected to predelivery acceptance tests to levels anticipated during the mission in order to verify that the unit met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in End Item Test Plan ASE-2535B. All testing was accomplished at the contractor's facility and at Acton Environmental Testing Corporation, Acton, Massachusetts. Testing on the complete fabricated flight instrument was achieved between October 1970 and March 1971. Test results were documented in ASE test reports 2720, 2730 and 2954.

Some of the problems encountered and the corrective action taken during acceptance tests are listed below.

Problem	Corrective Action
1. Aluminum chip found in the alignment hole on the top of the magazine	Incorporated steel bushings in the alignment holes
2. Wrinkles were apparent in Parylene window of film magazine	Changed window material from Parylene to Polypropylene

All acceptance tests/reviews were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System verification testing was performed on the S054 prototype and flight instruments in accordance with 50M02425, ATM Test and Checkout requirements and Specifications (TCRSD) to determine conformance with design specifications. The ATM test programs for the prototype and flight instruments were essentially the same except for the lower vibration levels in the vibration test and prelaunch tests for the flight instrument.

System Verification (Prototype)

In-Process Testing - After delivery of the S054 experiment hardware from the manufacturer, the instrument was mounted to the ATM spar and connected to spar cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the instrument. The test consisted of a complete functional verification of all experiment subsystems.

All test functions were normal; however, after film development, it was discovered that high fogging levels on the exposed film rendered the film unacceptable. It was concluded that the fogging occurred during magazine loading prior to hardware delivery. New film was installed and re-test was performed. The developed film verified that camera operation was normal. No other experiment anomalies were reported.

Post-Manufacturing Checkout - The S054 prototype instrument was tested during PMC to verify satisfactory performance of the telescope assembly, temperature control assembly, main electronics assembly, C&D components, camera, and system interfaces. Emphasis was given to EMI and EMC testing with all ATM systems operating.

The following anomalies were encountered during testing:

The experiment film camera was found to be inoperative during the first attempt of operation. The problem was found to be a deformed camera shutter blade. The camera was removed and repaired, and successfully retested.

Three faulty electronic components were detected and repaired or replaced. Two of the faulty components, the S054 exposure counter and the S054 intensity counter on the C&D console, were loading the input signals excessively because of failures resulting in abnormally low input impedances. The supplier for the counters reported that a small negative voltage (-1 volt) applied to these input circuits could have caused the failures. The third faulty component as a PC card in the main electronics assembly. This card was reported to have an intermittent open circuit.

Two S054 console components were found to have been wired incorrectly. The CRT assembly (prototype C&D panel) had two pairs of lines reversed. The result was a CRT raster sweeping from right to left and from bottom to top. The assembly was returned to the vendor for correction and reinstalled. The intensity modulation assembly (IMA) in the flight C&D panel had 2 lines reversed. The result was a chassis ground connection to an ATM common bus. The IMA was replaced with a spare unit.

The S054 filter wheel did not respond correctly to RF commands. This condition could not be repeated and was closed as a one-time anomaly. The camera occasionally skipped a 4 second exposure during a sequence. This was not considered significant. The S054 prefilters on the telescope were damaged. The prefilters were replaced and a protective cover was developed to preclude further occurrences.

Thermal Vacuum Testing - Thermal vacuum testing of the S054 instrument was the same as that for the S052 instrument as described in Section XIII. No S054 anomalies were reported during pre-thermal vacuum tests.

During thermal vacuum testing, telescope temperatures remained within operational limits with the exception of a low rear housing (forward section) temperature during the orbital storage simulation. The housing temperature stabilized at 19.6°C compared with a minimum allowable temperature of 20°C.

The temperature range experienced by the rear housing throughout thermal vacuum testing, except during orbital storage simulation, indicated the temperature control was satisfactory. The temperature ranged between 20.8°C and 21.1°C, representing an excursion of 0.3°C, which was comparable to the ranges experienced by the remaining three housing sections. During orbital storage simulation, however, the rear housing temperature stabilized at 19.6°C, a decrease of 1.2°C over the previous low, while the remaining housing temperatures dropped by 0.5°C or less.

The following S054 operational problems were noted during testing.

System noise caused decrementing of the frames remaining counter and high counts on binary intensity counter and pulse height analyzer counter.

Filter wheel failed to operate properly during initial turn-on. An erroneous filter reset command had been sent.

No S054 anomalies were encountered during post-thermal vacuum test activities.

During thermal vacuum calibration of the XUV experiments, the S054 was powered up only to thermally simulate space conditions and for protection from the thermal vacuum environment. No anomalies were reported during this test.

<u>Post-Vibration Testing</u> - Following launch-land type vibration the S054 instrument was first tested to verify that the experiment was operational.

One problem was reported during this test. The film magazine was jamming or not taking up film properly. The unit was replaced.

The skipped 4-second exposure problem which was first encountered during PMC was solved during this test phase. A driver circuit was added in MEA by ECP to correct the problem which was caused by the capacitance of the long interconnecting cables.

An all systems test was performed to determine if any interaction existed between subsystems during highly active functional conditions, to verify bus redundancy, and to verify all other functions not checked during the subsystem test phase.

The only problem reported was decrementing of the frames remaining counter, which was not an S054 hardware problem.

Systems Verification (Flight)

In-Process Testing - In-process testing on the flight instrument consisted of the same functional verification as was run on the prototype. No S054 problems were noted during this test.

Post Manufacturing Checkout - Post manufacturing checkout was conducted on the flight unit to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. The following problems were noted:

The film magazine transported 14 frames of film and then stopped. The problem was caused by an improper setting of an adjustment screw. Silicon rubber was added to the screw to aid in holding adjustment.

The target on the C&D panel was incorrectly oriented by 90°. The MEA was modified to correct this problem.

Long manual exposures could not be terminated before the end of a sequence. Camera electronics was modified to allow stop commands in manual modes.

Thermal Vacuum Testing - Thermal vacuum testing was performed on the flight unit similar to that described for prototype testing. However, pre-thermal vacuum testing also served as post-vibration testing. No S054 hardware problems were encountered.

Thermal vacuum test results indicate that all S054 components, except the MEA, remained within operational limits.

The rack-mounted MEA operated below its lower limit of $0.0^{\circ}C$ during the cold orbital transient simulation. It reached a minimum temperature of -0.8° even though its heater actuated properly at $0.0^{\circ}C$. This out-of- tolerance condition was not considered significant enough to warrant corrective action.

Functional tests during this test phase revealed the following problems.

The camera sequenced exposures each second during a mode and would not complete the range. Filtering was added to the reset-pulse-line input to the intensity modulation assembly and the problem cleared.

The intensity display counter had low light output. The unit was replaced.

Post-thermal vacuum activities were performed and no new problems were evident.

During thermal vacuum calibration of the XUV experiments the S054 instrument was powered up only to thermally simulate space conditions and for protection from the thermal vacuum environment. No anomalies were reported during this test.

- Prelaunch Testing (KSC) - Upon arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab module. Individual system testing and all systems testing were performed. No anomalies were reported during the individual systems test. One problem was reported during the all systems test. A defective subcommutator card was replaced in the MEA. Retest was satisfactory.

Crew compartment, fit and function checks verified that the S054 film magazines could be fitted onto the telescope and also in the storage area. No anomalous conditions were evident.

Vertical Assembly Building (VAB) testing occurred in two phases: ATM alone, and ATM with other modules. VAB testing consisted of C&D console interface test, end-to-end systems test, swing arm overall test, mission simulation flight readiness test, subsystem redundancy, and closeout. No S054 problems were noted.

SECTION XV. ULTRAVIOLET SCANNING POLYCHROMATOR SPECTROHELIOMETER (S055A)

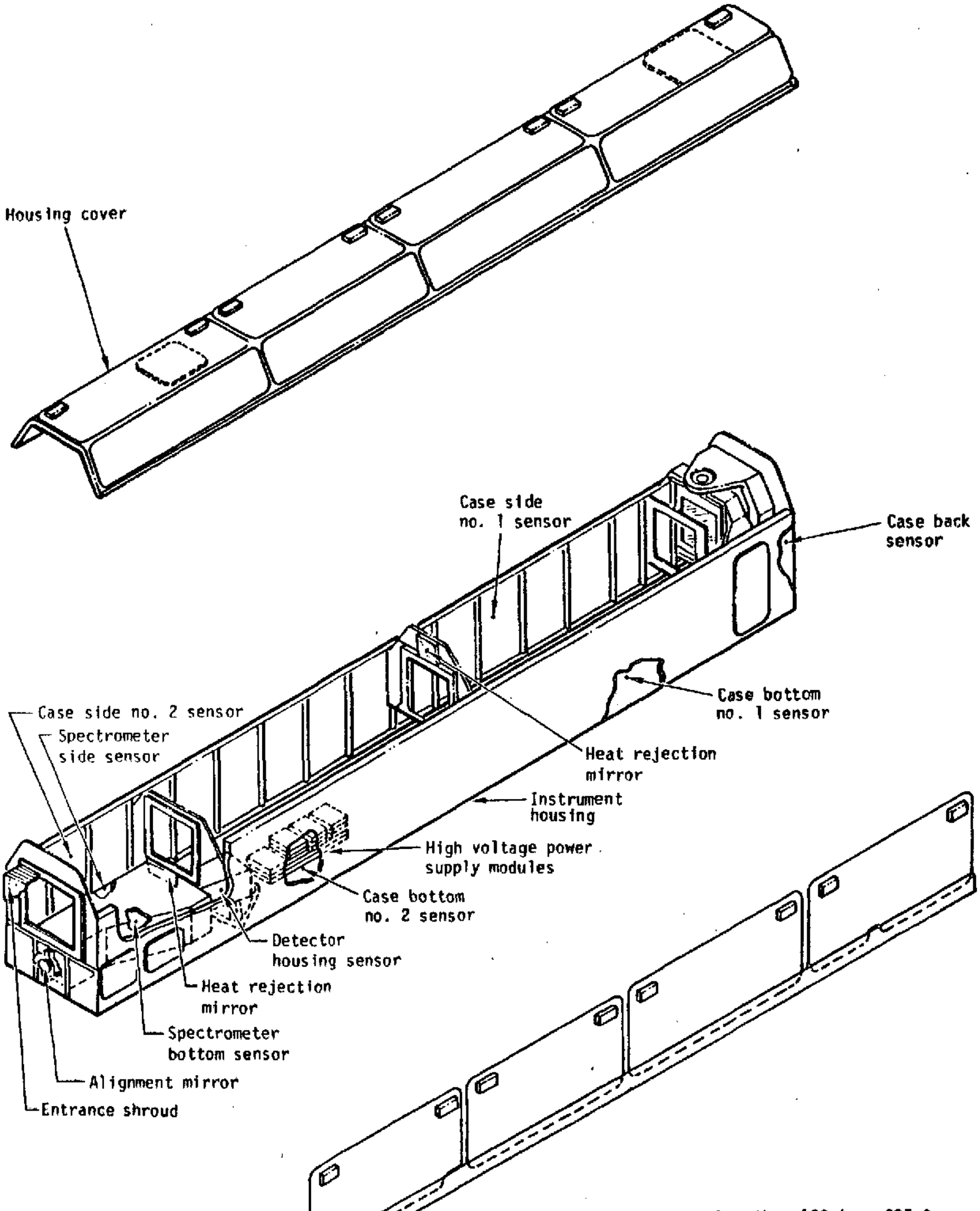
EXPERIMENT DESCRIPTION

The Ultraviolet (UV) Scanning Polychromator Spectroheliometer, shown in figure 15-1, was designed to measure the intensity of solar radiation from selected regions of the Sun in the far ultraviolet wavelength region. Simultaneous raster patterns of seven atomic lines were used to construct spectroheliograms. These were used to examine temperature changes between regions of super granulation, measure the apparent size of the Sun at various wavelengths, and determine the temperature and density structure of the low corona. Active regions of the solar atmosphere were examined by wavelength scan, selected single-line scans, and raster patterns. Scientific characteristics of the instrument are shown in Table 15-I.

Table 15-I. Scientific Characteristics

PARAMETER	VALUE
Spectral Range:	296 to 1350 Å
Resolution:	
Spectral:	1.4 Å
Spatial:	5 arc-sec
Temporal:	
Full Raster	5 min (for 5 x 5.5 arc-min)
Line Scan	5 sec (for 5 arc-min x 5 arc-sec)
Single Point	40 ms (for 5 x 5 arc-sec)
Field of View:	
Full Raster	5 x 5.5 arc-min nominal
Line Scan	5 arc-min x 5 arc-sec
Single Point	5 x 5 arc-sec

Unlike other ATM instruments, this instrument carried no film. Data in various wavelengths were obtained by seven photomultiplier detector units (PDUs). The conditioned PDU outputs were telemetered to ground throughout the mission.



Length -	120 in.	305.0 cm
Height -	24 in.	61.5 cm
Width -	21 in.	54.5 cm
Weight -	351 lbs	160.0 kg

Figure 15-1. S055A UV Scanning Polychromator Spectroheliometer Configuration

The S055A instrument consisted of the telescope, spectrometer, electronics and TCS. Control of the instrument was maintained through ground command or the C&D console.

Telescope

The primary purpose of the telescope was to provide the instrument optical bench and primary mechanical structure. The telescope optics provided an image of the solar disk to the spectrometer. As shown in figure 15-2, this was accomplished by allowing light from the Sun to enter the instrument through the entrance aperture to the primary mirror. The mirror was an off-axis paraboloid, controllable in two axes, which then reflected the light back to the spectrometer entrance slit where an image of the solar disk was formed.

The operational elements of the telescope were the instrument housing, external alignment supports, primary mirror assembly, and optical heat-rejection mirror assemblies. The instrument housing formed the basic structure to which all other assemblies were mounted. The external alignment supports provided the attachment points of the instrument to the ATM spar. The supports also provided instrumental thermal isolation and an adjustable alignment capability between the instrument and ATM optical axis. A flexible boot was provided between the instrument front-end and the ATM canister for contamination isolation. Structural support for the heat rejection mirror assemblies was provided by the telescope structure. The primary mirror assembly provided a raster scan image of the solar image at the spectrometer slit. The raster pattern was formed from 60 lines, 5 arc-seconds apart and 5.5 arc-minutes long. The lines were scanned in alternate directions across the pattern. Pointing control requirements are shown in Table 15-II.

Spectrometer

The primary purpose of the spectrometer was to diffract the solar energy which was admitted through the entrance slit, to measure intensity of the resultant spectral array at seven preselected lines, and to scan the UV spectrum across PDU 1.

Major operational elements of the spectrometer were the grating assembly, zero order detector, pressure gauge, and detector assembly. The grating was mechanically drive to scan the selected portion of the spectrum. The grating upon command

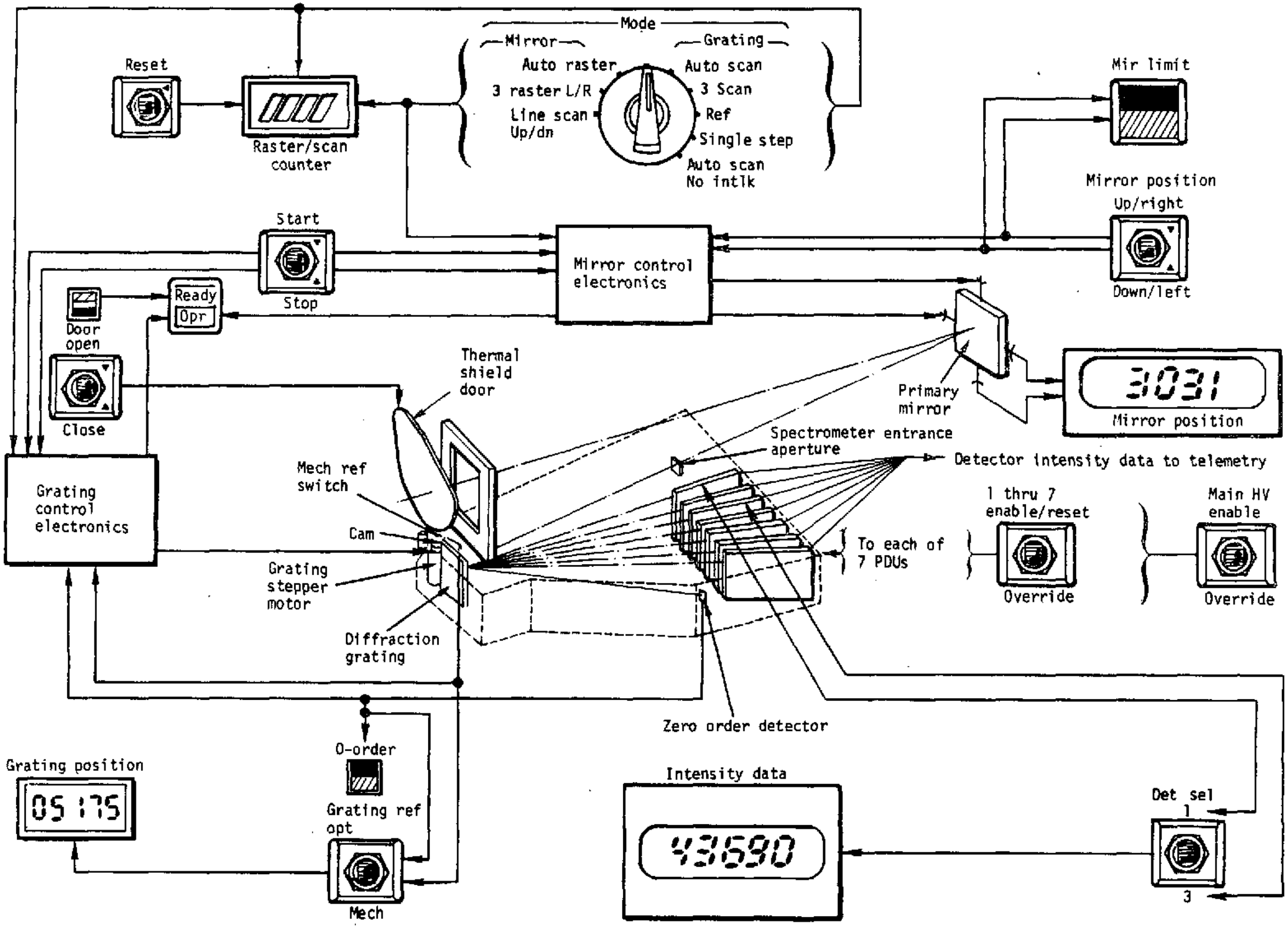


Figure 15-2. S055A Optical Controls and Displays Operation Schematic

Table 15-II. Pointing Control Requirements

PARAMETER	VALUE
Target:	Selected regions of the photosphere, chromosphere and the corona
Accuracy:	
Pitch & Yaw	±10 arc-sec
Roll	±120 min
Stability:	
Pitch & Yaw	±2.5 arc-sec per 16.5 min
Roll	±9 arc-min per 16.5 min
Offset:	
Pitch & Yaw	22 ±0.5 arc-min radius
Roll	±120 degrees

stopped at a preselected reference position. The zero order detector assembly provided an optical reference signal when the zero meter image, reflected by the grating, crossed a white-light detector. The selectable mechanical and optical references provided an accurate method of locating the grating position as the high end of the spectral range. A cold cathode gauge provided a measurement of the pressure within the spectrometer case to detect safe operating pressure for the PDU high voltage power supply. The detector assembly consisted of seven PDUs, located with their slits on the Rowland circle. Their individual high voltage supplies were mounted external to the spectrometer.

As shown in figure 15-2, solar energy passed through a 5 arc-second by 5 arc-second entrance slit to the spectrometer grating. The light was diffracted by the movable grating so that the slit images fell on the entrance apertures of seven PDUs which measured the light intensity. The outputs of the PDUs sampled 24 times per second provided the intensity measurements in terms of counts per unit time.

Electronics

The instrument electronics subsystem provided the power, and control and monitoring capabilities necessary for operation.

The electronic elements included data handling electronics, temperature monitoring electronics, low voltage power supplies, the electrical distribution system, and the test pulse generator.

The instrument data handling electronics accepted the simultaneous pulse outputs of the seven PDUs, counted the pulses, and conditioned the pulse counts, as necessary, for presentation to the ATM telemetry system. The output (selectable from PDU 1 or 3) was also displayed on the C&D console.

The temperature monitoring electronics provided the temperature monitoring of critical elements of the instrument via telemetry.

The instrument electronics included two completely redundant low-voltage power supplies. Either power supply was capable of supplying the power necessary to operate the instrument.

The S055A electrical distribution system distributed power and control signals throughout the instrument. It also provided an electrical interface with the ATM, and operational information and control capabilities to the crew.

A crew activated pulse generator provided an input pulse to the detector electronics for verification of the performance of the amplifiers and data handling system.

Thermal Control System

The TCS system consisted of sensors, thermal panels, heat rejection mirrors, a control system and insulation. The TCS was designed to automatically maintain instrument temperatures of 18.3° to 25°C. Over-temperature sensing was included to prevent overheating in the event of failure of the control circuitry.

Operation

The basic design of the instrument included the capability of moving both the primary mirror and the grating, such that four basic modes of operation could be obtained; raster scan, line scan, wavelength scan, and wavelength select.

The raster scan mode was the primary operating modes of the instrument. In this mode the grating was stationary at a point in the wavelength scan range so that preselected spectral lines were focused at the entrance slits of the PDUs. Many grating positions were used to provide a variety of lines at the PDU slits. The instrument was pointed at the desired location on the Sun and the seven PDUs were activated. The primary mirror then executed a raster pattern to scan a nominal 5 by 5.5 arc-minute region of the 32-arc-minute diameter Sun across the spectrometer entrance slit.

The line scan mode was similar to the raster scan mode relative to instrument setup and operation. In this mode, one of the 60 lines that formed the raster pattern was selected by the crew. The instrument then continuously scanned this line across the spectrometer entrance slit. This mode was used for events when the instrument was operating in conjunction with S082B and the line selected was that line which best brought the two instruments into coalignment. This mode was used for events requiring high temporal resolution such as flares.

In the wavelength scan mode the primary mirror remained in a fixed position selected by the crew, and the grating was rotated through 6 degrees to scan the wavelength range from 1350 to 296 angstroms across PDU 1. The remaining PDUs were not energized. (PDU 3 was available as a backup to PDU 1.)

In the wavelength select mode, the crew used the grating drive and the intensity display to position a desired spectral line at the entrance slit of the selected PDU (1 or 3). A numerical display on the C&D console indicated grating position relative to the optical or mechanical reference. When operating in the wavelength select mode, the crew was able to stop the grating drive in the vicinity of the desired wavelength. The grating position was then advanced in single steps, while observing the detector intensity numerical display on the C&D console, to position the grating for maximum response. Once the grating was positioned, the instrument was operated in either the raster scan or the line scan mode.

The S055A operated in either manned, unattended or unmanned modes. During the manned operation the instrument was entirely controlled by the crew from the C&D Console as shown in figure 15-2. The C&D console enabled the crew to select the mode of operation, the spectral line(s) to be observed, and PDU(s) to be activated. The C&D console also provided the capability to monitor instrument status, grating and mirror position, internal instrument pressure, and digital output from PDU 1 or 3. During the unattended and unmanned operation the instrument was operated by ground with limited modes of operation. The functions performed by ground commands are shown in Table 15-III.

Table 15-III. S055A Ground Commands

COMMAND	FUNCTION
Main Power	Primary, Secondary, Off
Thermal Control	On, Off
Start/Stop	Start, Stop
Mode Select	Mirror Auto Raster, Grating Reference, Grating single Step
Pressure Gauge	On, Off
High Voltage 1, 2, 3, 4, 5, 6, 7	Enable/Reset, Off
Aperture Door	Open, Close

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM Experiment program was initiated in January 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application requested proposals for experiments to be considered for the ATM systems. The Harvard College Observatory (HCO) submitted a formal proposal in response to Dr. Newell's letter, entitled "Far Ultraviolet Solar Spectrometers on the ATM". On September 1, 1966, HCO was informed of the selection of the Far Ultraviolet Solar Spectrometers for design and development for flight on the ATM. Subsequently, on September 6, 1966, responsibility for development of the experiment was transferred from the Goddard Space Flight Center (GSFC) to the Marshall Space Flight Center (MSFC). The instrument was designed, fabricated, and tested by Ball Brothers Research Corporation (BBRC) of Boulder, Colorado, under the scientific direction of Harvard College Observatory of Cambridge, Massachusetts. Dr. L. Goldberg was the principal investigator until July 1973, when he was succeeded by Dr. E. Reeves.

Experiment S055A was an outgrowth of the Far Ultraviolet Solar Spectrometers proposed for the Advanced Orbiting Solar Observatory

(AOSO). Previous to the transfer of responsibility, the experiment was within the AOSO scope of work at GSFC. In November 1966, the far ultraviolet solar spectrometer became established within the ATM scope of work. The AOSO project established some of the basic design concepts for the experiments used on the ATM. Three features of the ATM S055A experiment distinguish it from the AOSO counterpart: (1) the use of seven EUV photomultipliers, with pronounced improvement in spatial and temporal and spectral resolution and data gathering capability; (2) crew control of instrument operations such as alignment, pointing and mode selection, and; (3) the much longer orbital lifetime. Much of the experiment definition performed by the Principal Investigators (PIs) on AOSO was directly applicable to the ATM Experiment. In some cases the PI used previously fabricated AOSO components as models and breadboards in the ATM S055A experiment development.

Design Evolution/Rationale

The concept used in designing the S055A was based on the principle of spectographs. However, the mirror and the diffraction grating were both mounted on two axes to permit scanning of the solar surface. The instrument used the focusing property of sections of revolutions. However, as the object moved off axis, the resolution got rapidly worse due to the optical aberration known as coma. To circumvent this difficulty, an off-axis parabolic mirror was used. Because of the absorption of ultraviolet light by ordinary diffraction devices, a reflection grating was used. Flat reflection gratings required a lens to focus the diffracted light into a spectrum. A lens could introduce optical defects; therefore, a spherical concave grating eliminated the requirement of a focusing lens. Because of the requirement of high quantum efficiency, much wider dynamic range and linearity of response, photoelectric techniques such as photomultipliers were used for detecting the dispersed UV light.

Several design changes resulted from improvements in state-of-the art, and design or manufacturing problems. Numerous modifications that were made to the experiment from initial concepts through all phases of development and testing were documented in engineering change proposal/modifications.

MANUFACTURING

Manufacturing of the S055A experiment consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into completed instruments. Three units were assembled--the thermal mechanical unit (TMU), the prototype instrument and the flight instrument. The fabrication dates were as follows:

Unit	Date
TMU	July 1968 through March 1969
Prototype	May 1968 through December 1969
Flight	May 1968 through January 1970

Unique fabrication techniques employed in the fabrication of S055A were:

1. Pancake type flexible pivot in support of the primary mirror to minimize friction and hysteresis.

2. Special motor brushes to achieve superior operating and wear characteristics in nitrogen and vacuum environment.

All units were subjected to both functional and environmental tests. The TMU was tested to verify instrument envelope dimensions, spar interface, and thermal control operation. The prototype instrument was subjected to qualification tests and flight instrument was subjected to pre-delivery acceptance tests. Numerious studies, tests, breadboarding and special tests such as PDU corona, high pressure life, gain versus pressure versus temperature tests, dynamic analysis of the primary mirror and spectrometer assemblies, flight design verification unit flight test and contamination tests were accomplished to develop the design of the instrument. The results were documented in Ball Brothers Research Corporation reports TN 70-52, TN 70-54, TN 70-55, TN 70-56, TN 70-57, TN 70-62, TN 70-65, TN 70-75, TN 70-77, TN 71-2, TN 71-3, TN 71-26, TN 71-29, TN 36, TN 41, F70-6 and F 71-10.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements approximately 1.5 times those expected during the Skylab Mission as specified in 50M02408, Environmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, acceleration and acoustics testing. In addition, electrical, redundant functional tests, optical alignment, mirror reflectance test, UV baseline, leak tests, electromagnetic compatibility tests and outgassing tests were performed on the instrument. The qualification test program is described in End Item Test Plan BBRC number 29540. The results of these tests are documented in BBRC test report numbers TN 70-53, TN 70-74, TN 71-1, TN 74-4 and TN 71-29. Dates of the qualification testing were as follows:

Test Article	Test Date
Instrument	May 1970
Spectrometer	February 1971

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on May 19, 1972 with no open items. Some of the problems encountered during qualification testing and the corrective action taken are listed below.

Problem	Corrective Action
1. The raster scan stopped operation during thermal vacuum testing. Two resistors were burned out.	A design change was made to preclude thermal runaway of the transducer excitation driver.
2. Pre-vibration check, mirror launch lock did not function.	Transistors were replaced with relays.
3. Raster scan was truncated. Raster pattern was truncated.	Rubbing of the outer gimbal wire bundle on the case and temperature sensitive flex-pivots were at fault. Both items changed. The wire bundle was rerouted and the flex-pivots were checked more carefully before assembly. Was accepted on prototype.
4. Primary mirror unlocked.	After exposure to one and one-half axes of vibration the inner gimbal launch locks became partially disengaged. The launch locks were changed and were qualified in a separate test performed on the engineering model mirror assembly.

Problem (Cont'd	Corrective Action
5. Transducer shaft was cracked.	The ramp axis transducer shaft found to be cracked at the root of the necked down portion. This was a classic fatigue failure, probably accelerated by the type of material, i.e., free-machining 303 stainless steel. A fatigue resistant material was employed.
6. Power supplies were causing the failure light to turn on in the wrong mode.	The experiment electronics were changed so that the power supplies delivered a proper fail signal to the flight console.

ACCEPTANCE TEST

The flight instrument was subjected to pre-delivery acceptance tests to levels anticipated during the mission in order to verify that the unit met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in End Item Test Plans BBRC 29540. All testing was accomplished at the contractor's facility. Testing on the complete fabricated flight instrument was achieved between February 1971 and June 1971. Test results are documented in BBRC test report F71-1.

Some of the problems encountered and the corrective action taken during acceptance testing are listed below.

Problem	Corrective Action
1. Grating optical reference shifted.	Modified zero order signal conditioning electronics.
2. Mirror optical alignment shifted out of specification	Replaced snubber with new designed unit.

All acceptance tests/reviews were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System verification testing was performed on the S055A prototype and the flight instrument in accordance with 50M02425, ATM Test and Checkout Requirements and Specifications (TCRSD) to determine conformance with design specifications. The ATM test programs for the prototype and flight units were essentially the same except for the lower vibration levels in the vibration test and prelaunch tests for the flight unit.

System Verification (Prototype)

In-Process Testing - After delivery of the S055A experiment hardware from the manufacturer, the instrument was mounted on the ATM spar and connected to spar cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the instrument. The test consisted of a complete functional verification of all experiment subsystems. The following problems were noted:

The high voltage supply of the primary low voltage power supply output was 34 volts; should have been 28 volts. The secondary converter was used to complete the S055A testing after failure of the primary unit. The faulty power supply was returned to the supplier where retests failed to repeat the failure. Retests after reinstallation were acceptable.

The decay time of both primary and secondary supplies should have been almost instantaneous, but was several seconds in length. The power supply J-box was removed and returned to the supplier where investigation revealed that bleeder resistor for the power supplies had not been connected during manufacturing.

The outputs of data handling electronics were erratic at the high count rate for detectors 3, 5, 6, and 7. This was dispositioned to use-as-is. This was a known problem with the prototype instrument and was resolved for the flight instrument.

The mirror optical raster pattern duration was measured as 6 min, 18 sec of arc vertical and 6 min and 20 sec of arc horizontals should be 5.0 vertical and 5.5 horizontal. The raster problem had been observed previously and the specification was changed for the prototype.

The backup (overtemperature) circuit of TCS controller number 5 did not turn off when heated. This was dispositioned to use as is for the prototype. This condition was not present in the flight instrument.

Post Manufacturing Checkout - The S055A prototype instrument was tested during PMC to verify satisfactory performance of the instrument and system interfaces. Emphasis was given to EMI and EMC testing with all ATM systems operating.

The following anomalies were encountered during testing:

Instrument did not stop when mode switch was rotated. Modification was made to match impedance and the problem cleared.

The primary mirror moved down when given an up command. ATM networks wiring was changed to correct the problem.

The C&D panel intensity counter did not respond to inputs. A modification was made to the instrument to solve the problem.

Thermal Vacuum Testing - Thermal vacuum testing for S055A was the same as for the S052 instrument (reference Section XI). No anomalies were reported during pre-thermal vacuum testing.

During thermal vacuum testing, the S055A thermal performance was satisfactory with the exception of high telescope temperatures during one period. Although the telescope temperatures remained within operational limits during the operational test sequences, several temperatures were at or close to the upper limit and increasing at the termination of the hot steady state condition. The average spectrometer case temperature measurements reached the upper limit of 25.0°C at the end of the sequence was increasing. Similarly, the telescope case temperature was 23.8°C and 23.6°C, respectively (compared with a 23.9°C upper limit) and were increasing. The temperatures were affected by an erratic solar simulator output which precluded their stabilization during this sequence. It was, therefore, not possible to determine at what temperature levels thermal equilibrium would have been attained. However, it is probable that the spectrometer case would have exceeded its upper limit with proper solar simulator output.

During thermal vacuum testing several problems were encountered. TCS power supply number 2 was not supplying ±10 Vdc. It was concluded that the operational amplifiers in the output regulators saturated as the result of an abnormal line transient that occurred during the bus redundancy test. The TCS was turned off, then on, and the TCS was verified to be functioning normally.

The mirror raster truncated during both cold and hot operational sequences. This was corrected in the flight instrument by an engineering modification to increase raster drive capability. It was an accepted condition in the prototype.

Post-thermal vacuum testing was performed to verify that no adverse effects occurred as a result of the space simulated environment. No such problems were evident.

Post-Vibration Testing - Following vibration the S055A instrument was first tested to verify that the experiment was operational after being subjected to launch vibration levels. No anomalous conditions were detected.

An all systems test was performed to determine if any interaction existed between subsystems during highly active functional conditions, to verify bus redundancy, and to verify all other functions not checkded during instrument testing. The S055A performed as required with no problems reported.

Systems Verification (Flight)

In-Process Testing - In process testing on the flight instrument consisted of the same functional verification as was run on the prototype. The only problem noted was the absence of -10 Vdc power. The power supply was replaced and retest was successful.

Post Manufacturing Checkout - Post manufacturing checkout was conducted on the flight instrument to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. No S055A hardware problems were reported.

Thermal Vacuum Testing - Pre-thermal vacuum tests were performed to verify system readiness and to serve as a post-vibration test. One S055A problem was discovered during this test series. The test pulse count on telemetry was 10,410 and should have been 10,922. The data handling unit was replaced and the problem cleared.

Thermal vacuum testing was performed to verify proper operation during simulated orbits in a thermal vacuum environment. S055A thermal performance was satisfactory throughout the test. All measurements recorded temperatures comparable to those experienced during the prototype test. The major difference in results was that during this test the case temperatures remained within their operational temperature limits because the upper limit had been increased to 35°C. Test results showed that S055A performed satisfactorily when its ATM thermal shield door was open continuously.

Two problems were reported during the test. The pressure gage firing time was excessive, requiring almost two and one-half hours on some occasions. No corrective action was taken.

The high voltage power supplies tripped out during the turn-on sequence. Investigation showed that the EMR power supplies had to be turned on prior to the Bendix power supplies. A procedure was developed for a flight use to regulate the turn-on sequence.

Thermal vacuum XUV calibration testing provided data on S055A detector performance, optical performance and stability of UV calibrations. No problems were reported.

Post-thermal vacuum testing was conducted to verify that exposure to the space-simulated environment had not caused any instrument degradation. No S055A probems were noted.

Prelaunch Testing (KSC) - Upon arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab module. Significant S055A tests were the interface verification test and all systems test. No S055A problems occurred during these tests.

VAB testing occurred in two phases; ATM alone, and ATM with other modules. VAB testing consisted of C&D console interface test, end-to-end systems test, swing arm overall test, mission simulation flight readiness test, subsystem bus redundancy, and close out. Test results were satisfactory with no S055A problems reported.

SECTION XVI. X-RAY TELESCOPE (S056)

EXPERIMENT DESCRIPTION

The X-ray Telescope, shown in figure 16-1, incorporated two separate and independently operated instruments: the X-ray telescope and the X-ray event analyzer (XREA). The telescope design provided for X-ray filtergrams (solar images of narrow wavelength intervals) in five wavelength bands and one in visible light. The X-REA design provided for spectral data (intensity versus wavelength) in 10 wavelength bands. Scientific characteristics of the instrument are shown in Table 16-I.

Table 16-I. Scientific Characteristics

PARAMETER	VALUE
Spectral Range:	5 to 33Å, (For X-RT) 6328 ± 40Å (Visible light) 2.5 to 20 Å (For X-REA)
Resolution:	
Spectral:	2.5 Å
Spatial:	2.5 arc-sec
Temporal:	3.5 sec
Field of View:	40 arc-min (1.25 $R_\odot$)

Optics

The X-ray telescope consisted of two major assemblies, the telescope and camera assembly, and the camera/thermal control electronics assembly. The telescope was the prime structural unit of the instrument. It formed the X-ray images of the Sun and provided the physical support for the camera. The glancing-incidence mirrors, supporting tubes, centermount, and thermal control components were parts of the telescope. The glancing incidence optics provided an image of the Sun to one of the six different filters of the film camera. Soft X-ray solar images were formed using the two-element, double-reflection

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

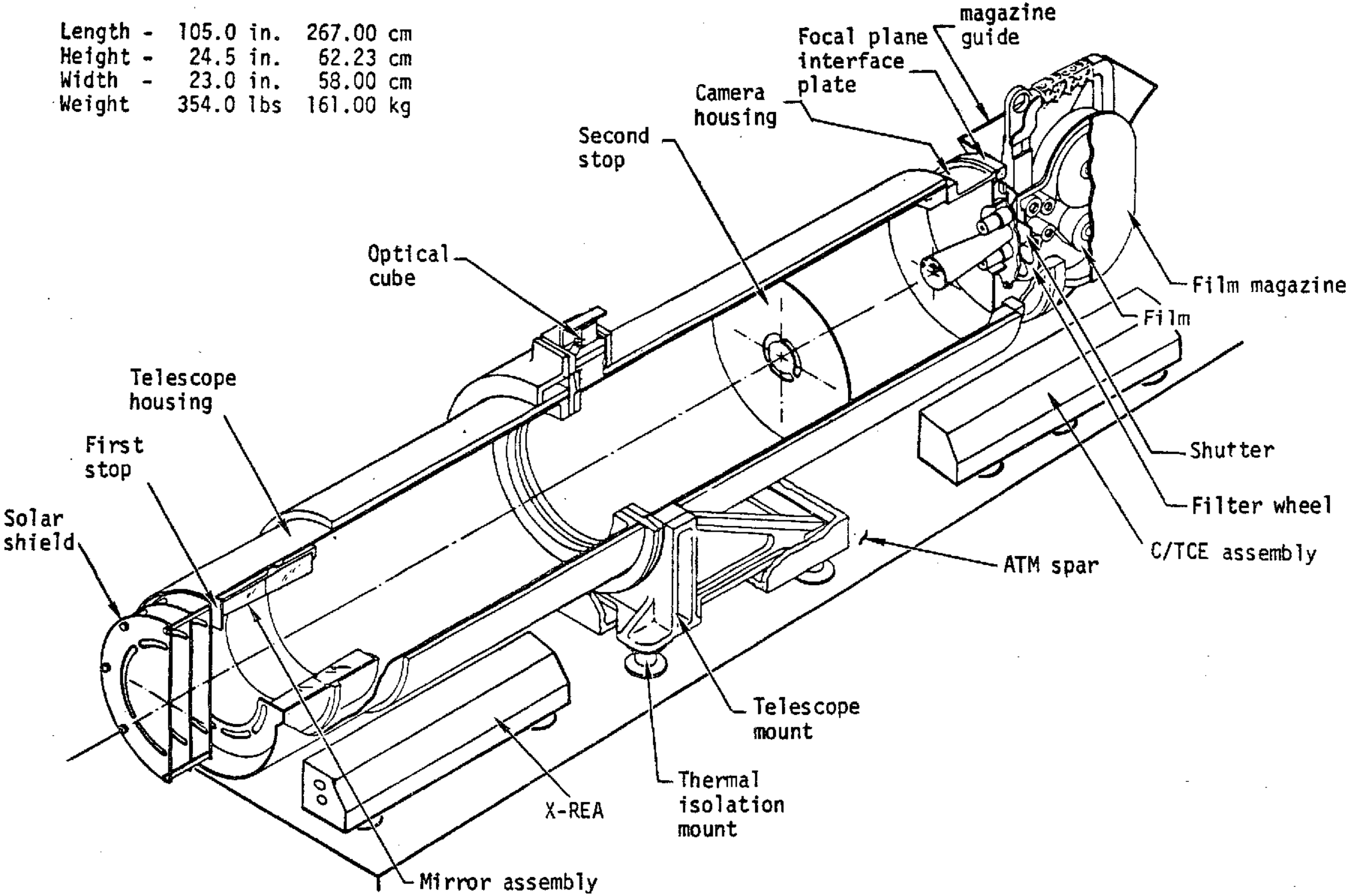


Figure 16-1. S056 X-Ray Telescope Configuration

aplanatic telescope. Figure 16-2 illustrates the instrument optical arrangement. The optics consisted or paraboloidal and hyperboloidal elements placed confocal to each other. The optical elements surfaces were almost parallel to their axes of revolution forming surface of high incidence angles to the incoming solar photons. Incoming paraxial rays first strike the paraboloidal surface and undergo total external reflection. The rays then strike the confocally placed hyperboloidal surface, where they again undergo total external reflections, and are imaged at the hyperboloid's focal point. Image quality of this type focusing device is excellent on the optical axis, but is degraded with angular deviations from the optical axis.

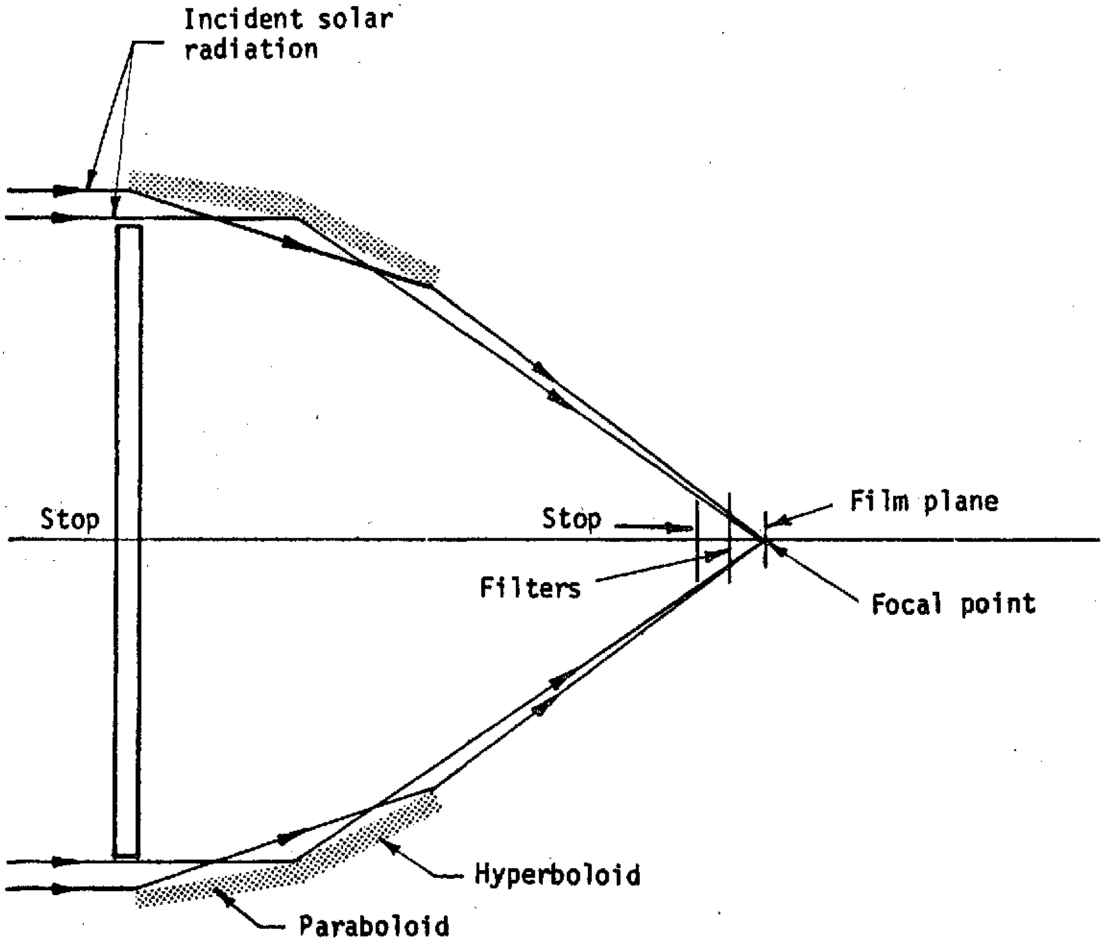


Figure 16-2. S056 Optical Schematic

Mounting on the ATM spar was such that during zero-gravity conditions, the optical alignment reference of the telescope was aligned in pitch and yaw to the fine sun sensor within ± 1 arc-minute. Pointing requirements are summarized in Table 16-II.

Table 16-II - S056 Pointing Requirements

PARAMETER	VALUE
Target:	Selected active regions of the solar disk
Accuracy:	
Pitch and yaw	± 2 arc-min
Roll	N/A
Stability:	
Pitch and yaw	± 2.5 arc-sec per 100 sec
Roll	± 7.5 arc-min per 100 sec
Offset:	± 16 arc-min

Film Camera

The film camera was designed to place the film plane coincident with the focal point and to alternately position six different filters ahead of the film plane. The resulting data consisted of five solar filtergrams in the 5 to 33 angstrom region and one in visible light. The camera, consisting of the film magazine guide, the interface plate, the shutter and filter wheel, and associated drive mechanisms, recorded the X-ray image on film along with the ancillary data describing the experiment conditions that existed at the time of exposure. One loaded film magazine was placed in the camera prior to Skylab I launch and three were stored in the MDA film vault for replacement by the crew during EVA. A film load consisted of 6,000 frames of 35-mm, SO-212 black and white roll film.

Electronics

The camera/thermal control electronics assembly controlled the operation of the electromechanical components within the camera and the operation of the telescope TCS. It consisted of exposure sequencers, timers, mode logic circuitry, motor-drive power generators, and thermal control units.

X-ray Event Analyzer

The X-REA was mounted adjacent to the telescope on the ATM spar. It consisted of two, gas-filled proportional counters with thin metallic windows (one of beryllium and one of aluminum), aperture size control, pulse-height analyzers (PHA), digital-channel counters, rate meter and activity history recorder drive circuits, signal conditioners, and power supplies. The proportional counters produced linear outputs proportional to the intensity of the energy detected. The PHA electrically sorted the output of the proportional counters, relative to the voltage amplitude of the pulses, into six energy levels (beryllium) and four energy levels (aluminum), to give the spectral distribution of the solar X-ray intensity. These data were transmitted via telemetry to ground. The level of the X-ray energy passing through either the aluminum or beryllium filter could be numerically displayed on counters and recorded on the activity history plotter on the C&D console. These displays were designed to aid the crew in selection of the camera modes of operation.

The X-REA obtained X-ray spectral data when the aluminum and beryllium high voltages were on. With the aluminum and beryllium high voltages off, the proportional counters were disabled, permitting a calibration signal to be processed by the electronics. Both the X-ray spectral data and the calibration data were displayed on the C&D console and telemetered to ground.

Thermal Control System

The instrument TCS used both active and passive elements to maintain temperature control. The passive elements of the system consisted of 20 layers of super insulation wrapped around the two telescope tubes, four thermal isolation mounts supporting the telescope on the ATM spar, two thermal radiators at the extremities of the telescope tubes, and the solar shield mounted at the front of the telescope.

The active elements for the system consisted of two redundant and identical thermal control units, primary and secondary, each having two electrical thermofoil heaters wrapped around the extremities of the telescope tubes, and a chain of six power resistors placed at the center mount casting. Each of these three heaters was capable of delivering 10 watts to the telescope. Control for the heaters was derived from a series of thermistors placed about the telescope to sense minute variations in temperature. To prevent a thermal runaway condition, current for the three heaters was supplied through thermostats preset at a temperature slightly above the maximum permissable operating telescope temperature. Either primary or secondary TCS was selected at the C&D console by the crew. The telescope temperatures were monitored by ground personnel to assure that the instrument remained within the thermal limits required to maintain an infocus condition at the film plane.

Operation

The camera operated in manual and automatic modes at various exposures. The camera electronics automatically sequenced the camera through each mode of operation. Each mode action included shutter open/close, filter movement, and film advance. The crew could lengthen or shorten the normal exposure time, by a factor of 3.2, by selecting long or short exposure. Operating time at the normal exposure setting is shown in Table 16-III.

Table 16-III - S056 Normal Exposure Operating Time

CAMERA MODES	NORMAL OPERATING TIME	FRAMES
Patrol	5 min 5 sec	6
Active 1	5 min 10 sec	36
Active 2	24 min	60
Active 3	49 min 35 sec	18
Auto	89 min 35 sec	114
Single Frame 1	1 min 32 sec	1
Single Frame 2	33.5 sec	1
Single Frame 3	53.5 sec	1
Single Frame 4	1 min 11 sec	1
Single Frame 5	58 sec	1
Single Frame 6	4 sec	1

The S056 operated only in the manned mode. During the manned operation the instrument was entirely controlled by the crew from the C&D console as shown in figure 16-3.

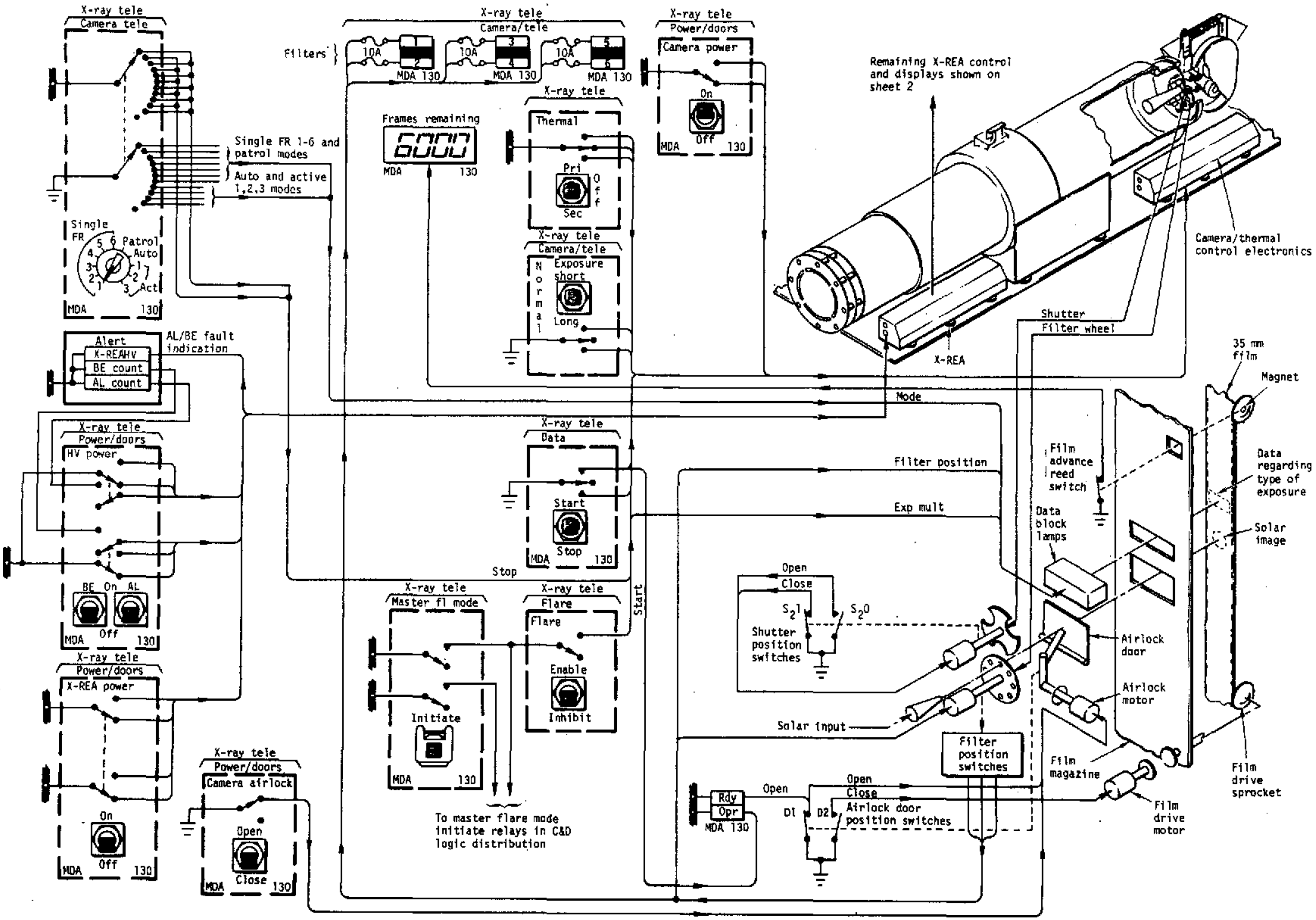


Figure 16-3. S056 Controls and Displays Operation Schematic (Sheet 1)

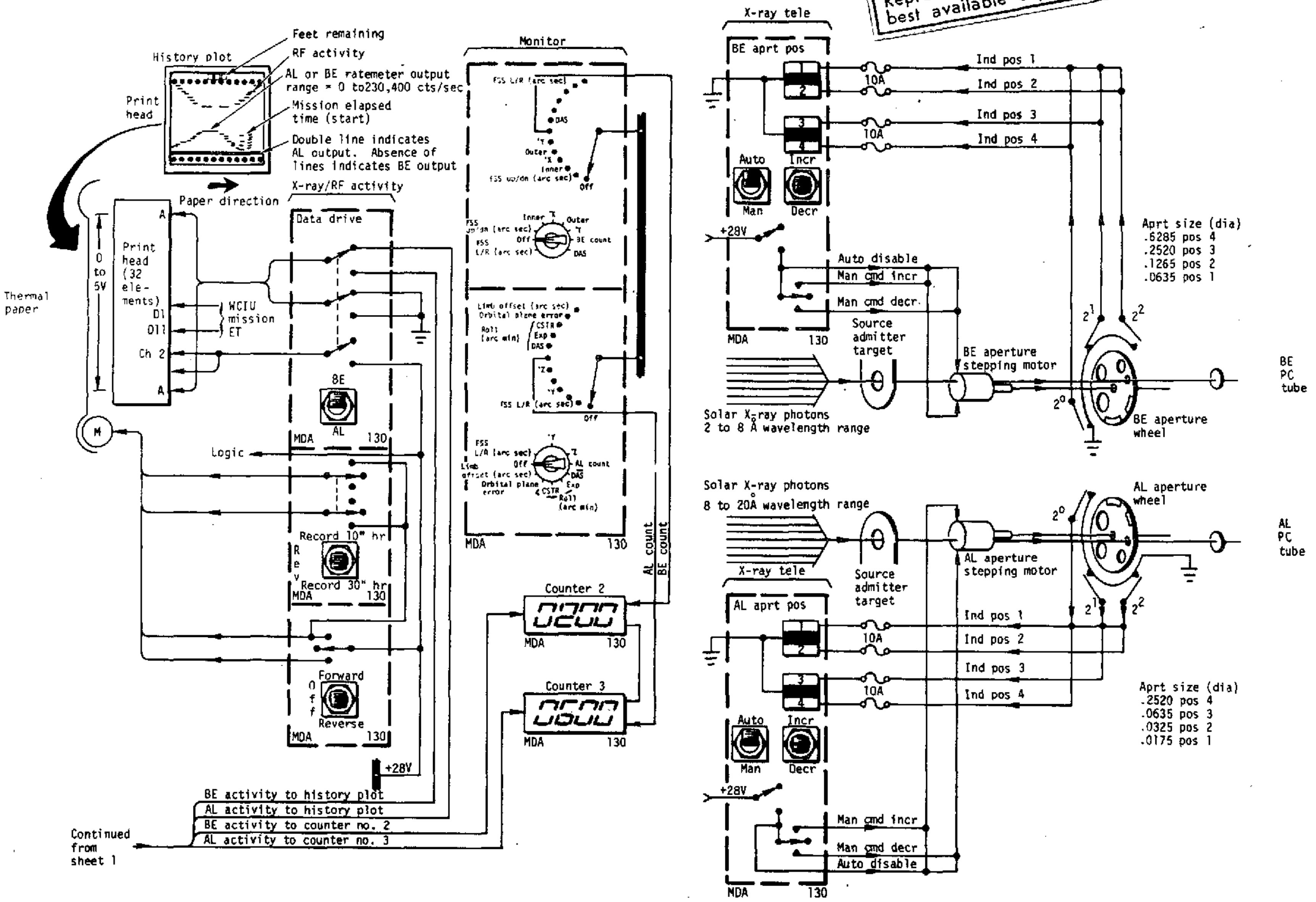


Figure 16-3. S056 Controls and Displays Operation Schematic (Sheet 2)

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM Experiment program was initiated in January, 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application requested proposals for experiments to be considered for the ATM systems. The Marshall Space Flight Center (MSFC) submitted a formal proposal in response to Dr. Newell's letter entitled "X-ray Telescope". On September 1, 1966, MSFC was informed of the selection of the X-Ray Telescope for design and development for flight on the ATM. Subsequently, on September 6, 1966, responsibility for development of the experiment was transferred from the Goddard Space Flight Center (GSFC) to MSFC. The instrument was designed, fabricated, and tested by MSFC, Huntsville, Alabama with Mr. J. Milligan as the principal investigator.

Experiment S056 was an outgrowth of the X-ray Telescope (GSFC) proposed for the AOSO. Previous to the transfer of responsibility, the experiment was within the AOSO scope of work at GSFC. In November 1966, the X-ray telescope became established within the ATM scope of work. The AOSO project established some of the basic design concepts for the experiment used on the ATM. Three features of the ATM experiment distinguish it from the AOSO counterpart: (1) the use of photographic recording with pronounced improvements in spatial, spectral and temporal resolution; (2) crew control of instrument operations, and (3) the much longer orbital lifetime. Much of the experiment definition performed by the PIs on AOSO was directly applicable to the ATM Experiment. In some cases the PI used previously fabricated AOSO components as models and breadboards in the ATM S056 experiment development.

Design Evolution/Rationale

The concept employed in the design of the S056 optics makes use of the fact that at soft X-ray wavelengths, the real part of the index of refraction is less than one. As a consequence, total external reflection occurs at grazing angles of the incidence. The S056 X-ray Telescope used parabolic/hyperbolic grazing incidence uncoated quartz(fused silica) mirrors. The X-ray mirrors employed double reflection from paraboloidal and hyperboloidal surfaces. Such a double-reflecting system gives a reasonable image over a usable field of view. The collecting area of the S056 was less than the S054, since the latter used nested confocal mirrors. Fused silicon was chosen as the optical mirror surface material because this material scatters less on the X-ray region than most other usable materials, when properly polished.

At very short wavelengths of the X-ray spectrum, a grating would no longer provide sufficient dispersion to yield good resolution of the spectrum. At such wavelengths a variation of the Geiger-Mueller tube known as the proportional counter was used which was not as sensitive to background radiation in orbit and, consequently, provided flux resolution at low levels. One of the limitations of proportional counters was their sensitivity to counting. In normal range, the pulse amplitude was proportional to photon energy. However, if the number of photons entering the tube became too great (10^9 counts), the proportionality no longer existed. To eliminate this factor, the count rate circuits of the pulse height analyzer controlled a motor driven disc having four different size apertures. The aperture disc was located in front of the proportional counter tube window to limit the radiation entering the tube. Six filters were selected to concentrate on the harder X-ray emissions.

In order to correlate with ground based measurements and to make quantitative intensity measurements, it was necessary to know the time and duration of each exposure. Information such as the exposure duration and time of exposure was recorded on the film by a series of binary coded lights.

Several design changes were made to advancements in the state-of-the-art, and problems encountered in design or manufacturing. Numerous modifications were made to the experiment from initial concepts through all phases of development and testing were documented in engineering change proposal modifications.

MANUFACTURING

Manufacturing of the S056 experiment consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into completed instruments. Three units were assembled - the TMU, the prototype instrument and the flight instrument. The fabrication dates were as follows:

Unit	Date
TMU	April 1967 through July 1967
Prototype	February 1968 through January 1970
Flight	April 1968 through January 1970

Unique fabrication techniques employed in the fabrication of S056 were:

1. High quality aspheric optical surfaces on the inside of cylindrical components was achieved.

2. Mounting of the mirror necessitated that the beryllium cell be precisely constructed such that the inner surface made contact with the mirror's center surface at 32.2°C.

All units were subjected to both functional and environmental tests. The TMU was tested to verify instrument envelope dimensions, spar interface and thermal control operation. The prototype instrument was subjected to qualification tests and the flight instrument was subjected to pre-delivery acceptance tests. Numerous studies, tests, breadboarding, and special tests such as the optical and X-ray performance verification and film performance verification were accomplished to develop the design of the instrument. The results are documented in Federal Electric Corporation reports AS-S-3-68, AS-S-19-68, AS-S-23-68, AS-S-33-68, RA-A-7-69, SI-E-1-70, SI-E-2-70, Perkin-Elmer Corporation report 9527, Sperry Rand reports SP-505-0279, SP-580-0501, Martin-Marietta reports ED-2002-907-1, ED-2002-907-2, Southern Research Institute report 15173, Wyle Laboratories report 54128, NASA reports CR-61364, TMX-53666, and MSFC 50M17334.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements at levels approximately 1.5 times those expected during the Skylab Mission as specified in 50M02408, Enrivonmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, acceleration and acoustics testing. In addition, baseline tests, leak tests, electromagnetic compatibility tests and out-gassing tests were performed on the instrument. The qualification test program is described in end item test plan MSFC 50M16613. The results of these tests are documented in MSFC reports numbers 50M17269, 50M17270, 50M16589. Dates of the qualification testing were as follows:

Test Article	Test Date
X-REA/Camera	September 1970
Camera/Thermal Control Electronics	September 1970
X-Ray Telescope	January 1970

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on March 6, 1973 with no open items.

One of the problems encountered during qualification testing and the corrective action taken is listed below.

Problem	Corrective Action
Static discharge observed on film after use in vacuum	A technique was developed to maintain the magazine internal pressure above the static threshold.

ACCEPTANCE TEST

The flight instrument was subjected to pre-delivery acceptance tests to levels anticipated during the mission in order to verify that the unit met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in end item test plan MSFC 50M16613. Testing on the complete fabricated flight instrument was achieved between September 1970 and January 1971. The results are documented in MSFC test report 50M17271.

One of the problems encountered during acceptance testing and the corrective action taken is listed below.

Problem	Corrective Action
During thermal vacuum testing, the camera failed to operate due to a frictional increase between a cam and follower in the torque equalizer system.	The torque equalizer system was removed from all S056 cameras.

All acceptance tests/reviews were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System verification testing was performed on the S056 prototype and flight instruments to determine conformance with design specifications in accordance with 50M02425, ATM Test and Checkout Requirements and Specifications (TCRSD). The programs for the prototype and flight units were essentially the same except for the lower vibration levels in the vibration test and prelaunch tests for the flight unit.

System Verification (Prototype)

In-Process Testing - After assembly of the S056 experiment hardware, the instrument was mounted to the ATM spar and connected to spar cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the experiment. The test consisted of a complete functional verification of all experiment subsystems. Two problems were encountered with the X-ray Event Analyzer (XREA). The beryllium (Be) and aluminum (Al) count rates did not respond to the test source. The XREA was removed from the spar and the Be and Al counters were verified to be defective. The counters were replaced and proper operation was verified. Secondly, the count rate bits 2^0 through 2^3 were inoperable. An output register card in the XREA was replaced and the unit tested satisfactorily.

Evaluation of the developed film indicated that 10 data lights were weak (dim). Power to the lights was increased and their brightness was verified.

Post-Manufacturing Checkout - The S056 prototype instrument was tested during PMC to verify satisfactory performance of the telescope assembly, XREA, and system interfaces. Emphasis was given to EMI and EMC with all ATM system operating.

The only significant anomaly reported concerned the camera. The camera stopped prior to completing a mode. This problem occurred frequently throughout the prototype test program. Analysis showed that the camera electronics failed to receive the film advance pulse due to a mechanical failure in the film magazine. The camera logic reacted by stopping the mode. This condition was not repaired during the prototype test program but was corrected during refurbishment. During refurbishment, it was found that the magnet on the shaft in the magazine film drive mechanism had worked loose. All film magazines were reworked, the magnets epoxied in, and nylon inserts were used to lock down holding screws.

Thermal Vacuum Testing - Thermal vacuum testing for the S056 instrument was the same as for the S052 instrument (reference Section XI).

During pre-thermal testing, two problems were encountered which involved the XREA. The XREA apertures moved two positions for each switch actuation when the switch was actuated slowly instead of only one position. The extra movement was caused by switch bounce. During prototype refurbishment, switches were replaced and a larger capacitor installed. The problem did not recur. When the XREA high voltage was turned on the XREA proportioned counter alert lights on the C&D console flashed. The problem was solved by a networks change.

During thermal vacuum testing, the S056 system was tested to verify that the thermal control system could maintain design temperatures while being subjected to the environmental conditions. Two problems were encountered during thermal vacuum testing. The camera stopped operating during a mode. This was a known condition (first occurred during PMC) and was accepted for the prototype instrument. The Al and Be counts fell to zero. Evaluation showed that the counter failures were caused by an electronic fault in the high voltage supply which in turn damaged the counters. The unit was replaced and verified.

No further S056 anomalous conditions were reported during the thermal vacuum or post-thermal vacuum test activities.

Post-Vibration Testing - Following vibration to launch levels, the S056 instrument was first tested to verify that the experiment was operational. An all system test was performed to determine if any interaction existed between subsystems during highly active functional conditions, to verify bus redundancy, and to verify all other functions not checked during instrument testing. The S056 instrument performed as expected with no new problems reported during either of these test phases. The camera continued to stop operating prior to the completion of a mode.

Development of the film following system verification of the prototype unit revealed a light leak in the camera. A light baffle was designed, fabricated, tested, and installed on the flight camera.

Systems Verification (Flight)

In-Process Testing - In-process testing on the flight instrument consisted of the same functional verification as was run on the prototype. No S056 problems were noted.

Post-Manufacturing Checkout - PMC was conducted on the flight instrument to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. The following problems were noted:

The film camera stopped during one picture taking sequence. Analysis showed the timer for this sequence was too short. The film camera electronics was removed, modified and reinstalled. After rework, the camera was tested and operated successfully in all modes.

When the A1 aperture position switch was placed to increase, the aperture position increased by 2 rather than 1. The XREA was reworked to increase the time constant of the input to the aperture position circuitry. The XREA was reinstalled and retested successfully.

The XREA A1 proportional counter output showed excessive counts. This condition corrected itself. Apparent cause was contamination. The problem did not recur.

Thermal Vacuum Testing - Thermal vacuum testing was performed in three distinct phases similar to prototype testing. However, since the flight unit ATM was subjected to vibration testing prior to shipment to JSC, pre-thermal vacuum testing served as post-vibration verifications. No S056 anomalies were encountered during any of the test phases. No out-of-limit temperature conditions were reported.

Following thermal vacuum testing of the flight unit, examination of the optics revealed that contamination, dry lubricant from the thermal shield door drive mechanisms, had been deposited on the optics. The optics were cleaned and a contamination shield was designed, developed, tested, and installed on the flight telescope.

Pre-Launch Testing - Upon Arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab Module. Significant S056 tests were the interface verification test, all system test, and crew compartment fit and function. No S056 anomalies were encountered.

Crew compartment, fit and function checks verified that the S056 film magazines could be fitted onto the telescope and also in the storage area. No anomalous conditions were evident.

VAB testing occurred in two phases; ATM alone, and ATM with other modules. VAB testing consisted of C&D console interface test, end-to-end systems test, swing arm overall test, mission simulation flight readiness test, subsystem bus redundancy and close out. All S056 hardware performed satisfactorily and no failures occurred.

SECTION XVII. EXTREME ULTRAVIOLET SPECTROHELIOGRAPH (S082A)

EXPERIMENT DESCRIPTION

The Extreme Ultraviolet (XUV) Spectroheliograph, shown in figure 17-1, was designed to photographically record images of the solar chromosphere and corona to 1.5 solar radii (when Sun-centered) in the XUV wavelengths between 150 and 625 angstroms. Scientific characteristics of the instrument are shown in Table 17-I.

Table 17-I. Scientific Characteristics

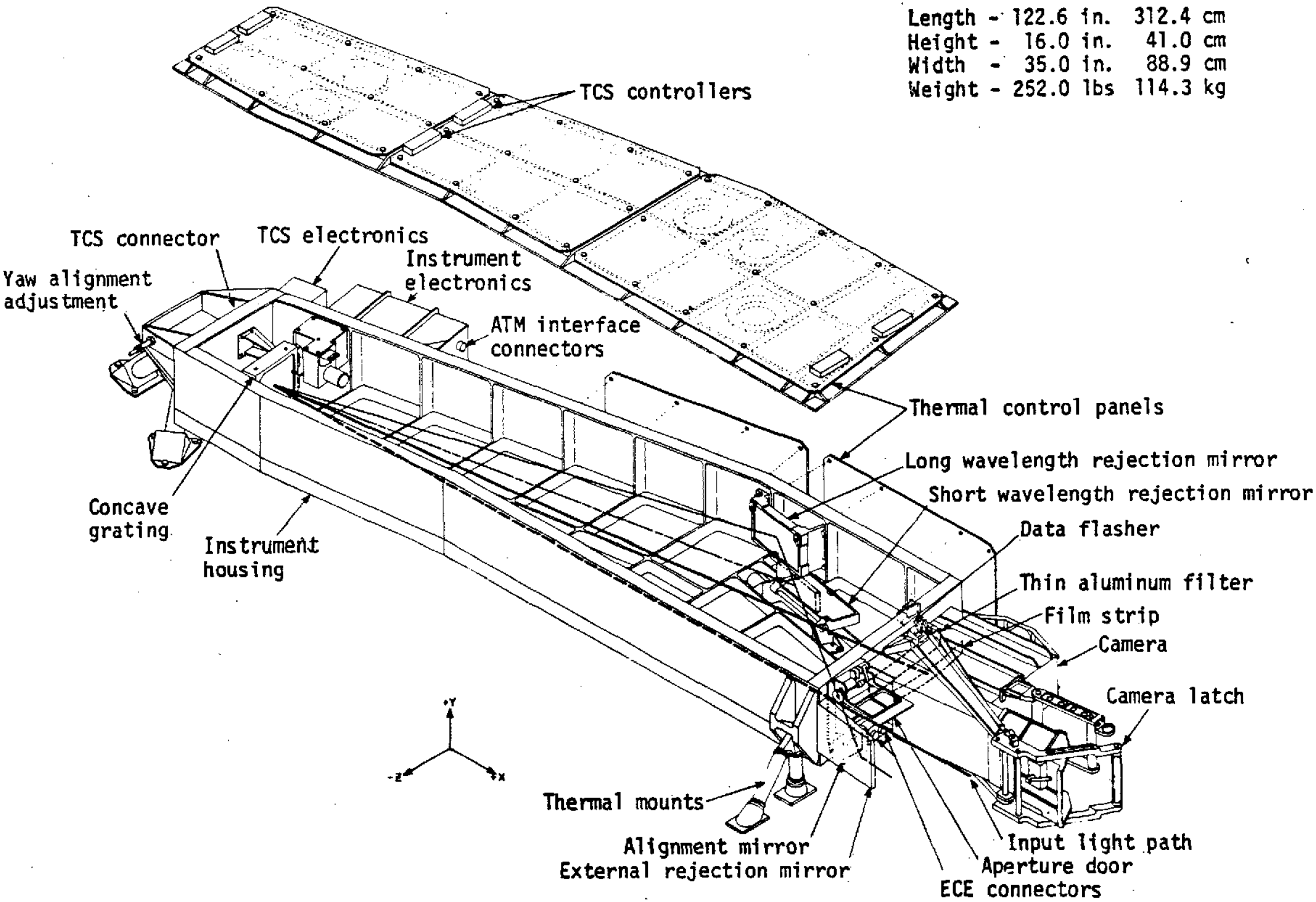
PARAMETER	VALUE
Spectral Range:	150 Å to 335 Å (short wavelength) 321 Å to 625 Å (long wavelength)
Resolution:	
Spectral:	0.13 Å (For feature 10 arc-sec in size)
Spatial:	5 arc-sec
Temporal:	$\geq$2.5 sec
Field of View:	55 x 55 arc-min

The S082A housing was a light-tight, aluminum housing, consisting of a rigid case and removable cover enclosing the optical system. The instrument was designed for operation from the ATM C&D console, or in an automatic mode by ground command.

Optics

The optical system, shown in figure 17-2, consisted of a main grating, three heat rejection mirrors and an aluminum filter. The filter was physically located in the camera.

The main grating was a finely-ruled (3600 lines per millimeter) concave, precision optical element mounted in a movable frame that allowed light, in either of two wavelength bands (150 to 335 or 321 to 650 angstroms), to be directed to the film camera.



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 17-1. S082A XUV Spectroheliograph Configuration

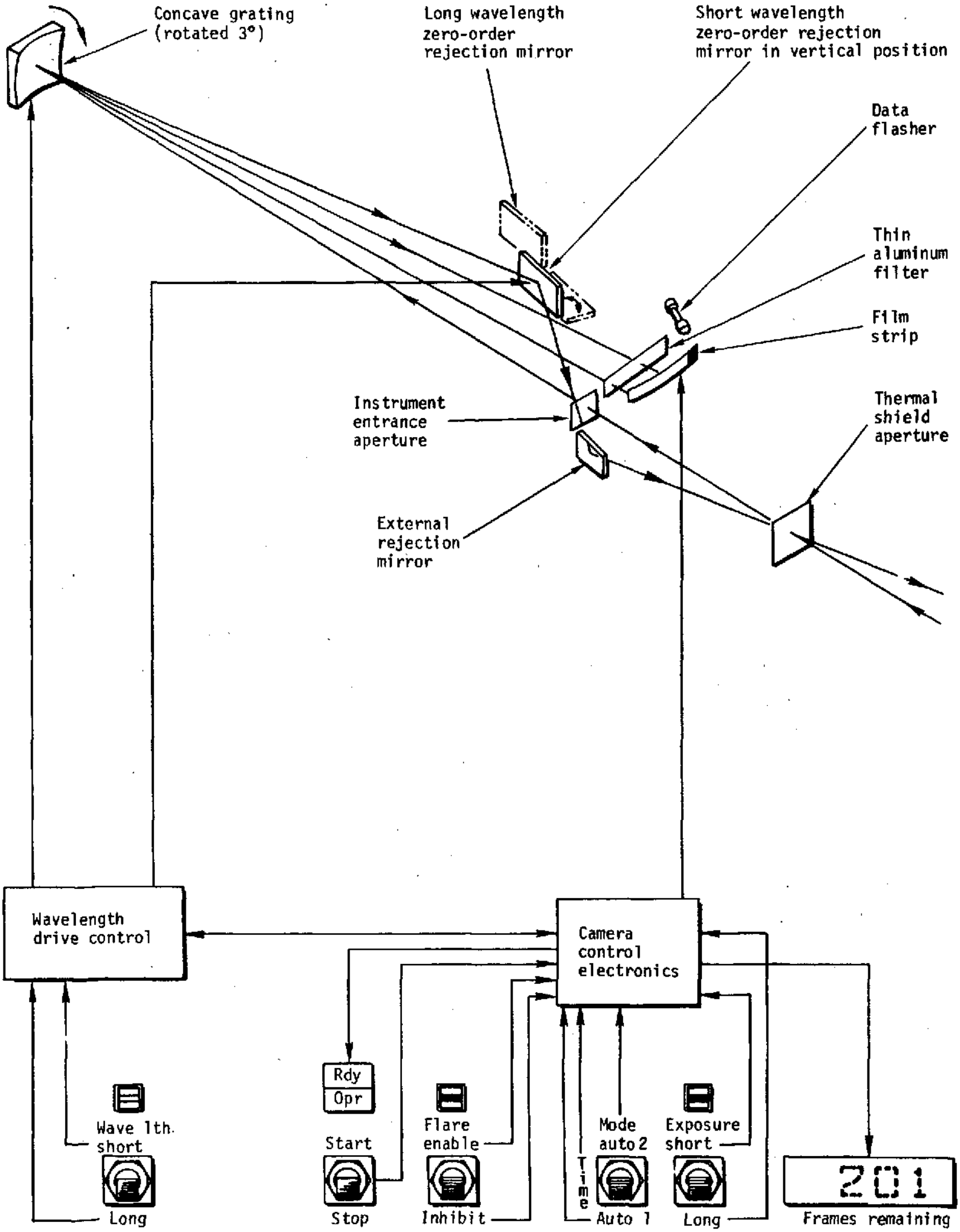


Figure 17-2. S082A Optical and Controls and Displays Operation Schematic

Two of the three heat rejection mirrors were mounted inside the instrument housing. The short-wavelength rejection mirror moved up into or down out of the zero-order light path. The up or down position was controlled automatically in conjunction with the main grating position. In the raised position, it reflected the zero-order whitelight to the third (external\ heat rejection mirror.

When the long wavelength band was directed to the camera, the long-wavelength rejection mirror reflected the zero-order whitelight to the external rejection mirror.

The external heat-rejection mirror was mounted on the instrument housing, next to the aperture. It received and dumped overboard the zero-order whitelight from either of the internal rejection mirrors.

The instrument had an internal aperture door in addition to the ATM thermal shield door. Both doors operated from a single C&D console or ground command.

Although the usual operation was in the Sun-centered mode, the design provided for offset pointing up to 24 arc-minutes from Sun-center. Pointing requirements are shown in Table 17-II.

Table 17-II. Pointing Requirements

PARAMETER	VALUE
Target:	Selected regions of the solar disk and corona
Accuracy:	
Pitch & Yaw	±1.5 arc-min
Roll	±5 degrees
Stability:	
Pitch & Yaw	±2.5 arc-sec per 15 min
Roll	±7.5 arc-min per 15 min
Offset:	±21 are-min from center of the solar disk

Camera

The camera was the only data-recording device of the instrument. The camera contained 201 strips of 35 x 25 8 mm XUV-sensitive film and was designed for one exposure per strip. At Skylab 1 launch, one camera (film loaded) was installed on the instrument. Two cameras were stored in the MDA film vaults.

When all the film in a camera was exposed, the camera was removed and replaced by the crew. The camera was attached to the Sun-end of the instrument by means of the camera latch and guide rail mechanism. The camera latch handle provided for easy installation of the camera on the instrument.

Electronics

The major elements of the instrument electronics were the power supply, reset and preset logic, mirror/grating drive controllers, camera and diode array electronics, operational mode logic, and a temperature monitoring subsystem.

Thermal Control System

The TCS consisted of an active heating system and a passive insulation system for controlling and stabilizing instrument temperature. The active heating system provided eight independent honeycomb panels with strip heaters. Each heater panel was equipped with its own independent temperature-sensing thermistors and controller circuitry. Six of the heater panels were mounted on the top surface of the instrument, and two were mounted on the right-hand (viewed from Sun-end) side wall. The passive insulation system consisted of eight insulation panels which were mounted at locations not covered by the heater panels. The insulation panels consisted of multiple layers of aluminized Mylar enclosed in thin plastic cover sheets.

The average case temperature requirements were 21.1 $\pm 4.4^{\circ}$C while operating. An additional requirement was necessary to control image smear. Allowable dynamic temperature gradients across the instrument case were specified at 0.12°C in a five-minute period of time. Temperature changes greater than this value would degrade image resolution by smearing.

Operation

The camera operated in three automatic and one manual mode to vary the exposure time, grating position and picture sequence (Table 17-III).

Table 17-III. S082A Modes of Operation

Mode	Frames	Exposure (Sec)			Wavelength	
		Short	Normal	Long	Short	Long
Time	1	As Desired			1 or 1	
Auto 1	3					
	SW	1.0	3.6	14.1	3	
	LW	1.8	7.1	28.1		3
Auto 2	6	2.8	10.7	42.2	3 and 3	
Flare	24	19.2	19.2	19.2	15 and 9	

The instrument required the use of the XUV monitor (reference Section XVIII) and/or one of the H-Alpha telescopes (reference Section XIX) to identify solar features of interest, the manual pointing control system for positioning the instrument, and the event timer for use during manual operations of the camera.

The S082A operated only in the manned and unattended mode. During the manned and unattended operation the S082A instrument was entirely controlled by the crew from the C&D console, as shown in figure 17-2.

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM experiment program was initiated in January 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application, requested proposals for experiments to be considered for the ATM systems. Naval Research Laboratory (NRL) submitted a formal proposal in response to Dr. Newell's letter, entitled "Proposal to investigate the extreme ultra violet spectrum of the Sun's corona and chromosphere on an Apollo Mission";

the proposal was modified in August 1966 to read, "Proposal for the Astronomical Telescope Mounting (ATM) for Apollo, Experiment A - ATM Coronal XUV Spectroheliograph, and Experiment B-ATM Chromosphere XUV Spectrograph". On September 1, 1966, NRL was informed of the selection of the Coronal XUV Spectroheliograph for design and development for flight on the ATM. Subsequently, on September 6, 1966, responsibility for development of the experiment was transferred from the Goddard Space Flight Center (GSFC) to the Marshall Space Flight Center (MSFC). The instrument was designed, fabricated, and tested by Ball Brothers Research Corporation (BBRC) of Boulder, Colorado, under the scientific direction of Naval Research Laboratory of Washington, D.C. Mr. J. D. Purcell was the principal investigator until August 1970, when he was succeeded by Dr. R. Tousey.

Experiment S082A was an outgrowth of the Extreme Ultraviolet Spectroheliographs proposed for the Advanced Orbiting Solar Observatory (AOSO). Previous to the transfer of responsibility, the experiment was within the AOSO scope of work at GSFC. In November 1966, the XUV Spectroheliograph became established within the ATM scope of work. The AOSO project established some of the basic design concepts for the experiments used on the ATM. Three features of the ATM experiment distinguish it from the AOSO counterpart: (1) improvements in spatial and temporal resolutions; (2) crew control of instrument operations, and (3) the much longer orbital lifetime. Much of the experiment definition performed by the PI on AOSO was directly applicable to the ATM experiment. In some cases the PI used previously fabricated AOSO components as models and breadboards in the ATM S082A experiment development.

Design Evolution/Rationale

The concept employed in the design of S082A was based on the principle of slitless objective grating sepctrograph. Because of the absorption of ultraviolet by ordinary diffraction devices, a reflection grating was used. However, flat reflection gratings required a lens to focus the diffracted light into a spectrum. A lens would introduce optical defects. Therefore, a spherical concave grating was used to eliminate the requirements of a focusing lens. Because it was necessary to select either a short wavelength range of 150 to 335Å or a longer wavelength range of 321 to 630 Å, the grating was made to rotate 3 degrees. To record many spatial features simultaneously, photographic film was used. Because light in wavelengths longer than 835Å was undesirable, a thin aluminum filter in front of the film was used.

Several design changes resulted from improvements in the state-of-the-art and design or manufacturing problems. Numerous modifications made to the experiment from initial concepts through all phases of development and testing are documented in engineering change proposal/modifications.

MANUFACTURING

Manufacturing of the S082A experiment consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into completed instruments. Three units were assembled - the TMU, the prototype instrument and the flight instrument. The fabrication dates were as follows:

Unit	Date
TMU	April 1967 through December 1968
Prototype	February 1968 through August 1969
Flight	February 1968 through January 1971

Unique fabrication techniques employed in the fabrication of S082A are listed below.

1. Wire cutting electrical discharge machining was used for miscellaneous complex parts. This technique allowed precision cutting of prehardened parts and greatly reduced warpage from heat.

2. Special tooling was employed for the film camera carrier. This tooling consisted of one meter and two meter curvature generation tooling and two meter assembly tooling.

3. All moving surfaces were lubricated with non-outgassing materials such as Nituff (Anodized aluminum/Teflon), Polyimide bonded dry film, or mechanically bonded dry film.

4. Ruling of a 120 x 120 mm, 4 meter concave grating surface with 3600 lines/mm was accomplished.

5. Cer-vit substrate was used for grating instead of grating quartz for thermal control because of very low thermal coefficient of expansion.

6. 1000 Å thick aluminum film filter mounted on wire mesh to assure surviving launch environment.

7. Photographic film with no protective emulsion over grain was fabricated.

8. Optical/mechanical and laser shadowgraph tooling was developed to measure conformance of film to focal curve without touching it.

9. A special fixture was developed for handling, cutting and loading film into holders.

All units were subjected to both functional and environmental tests. The TMU was tested to verify instrument envelope dimensions, spar interface and thermal control operation. The prototype instrument was subjected to qualification tests and the flight instrument was subjected to pre-delivery acceptance tests. Numerous studies, tests, breadboarding and special tests such as the XUV calibration, contamination, camera zero - g, camera and canister combined vibration/acceleration tests, film, and calibration rocket tests were all accomplished to develop the design of the instrument. The results are documented in Ball Brothers Research Corporation reports 620-40, 620-61, 620-13, 620-78, 620-139 and NASA reports CR-61364, TM X-53666.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements at levels approximately 1.5 times those expected during the Skylab Mission as specified in 50M02408; Environmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, acceleration and acoustics testing. In addition, leak tests, electromagnetic compatibility tests and outgassing tests were performed on the instrument. The qualification test program is described in End Item Test Plans BBRC 620-143. The results of these tests are documented in BBRC test reports 620-69, 620-75, 620-74. Dates of the qualification testing were as follows:

Test Article	Test Date
Instrument (S/N001)	March 1970
Camera (S/N 002)	September 1971 to Jan 1972)
Camera (S/N001)	January 1972
Camera Canister (S/N 001)	February 1972

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on February 18, 1972, (NRL-A-XUV Spectroheliograph), April 22, 1972 (NRL-A Film Camera) and May 15, 1973 (Isolation amplifiers) with no open items. Some of the problems encountered during qualification testing and the corrective actions taken are listed below.

Problem	Corrective Action
1. Excessive torque required for adjustment of pitch mechanism on tripod assembly during post vibration optical checks.	Design changed to require polimide lubricated piston.
2. Canister lid O-ring permitted leak rate to exceed 2×10^{-5} SCC/SEC	Extensive evaluation resulted in a change of O-ring material, addition of apezion L to meet leak rate.

ACCEPTANCE TEST

The flight instrument was subjected to pre-delivery acceptance tests to levels anticipated during the mission in order to verify that the unit met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in End Item Test Plans BBRC 620-143. All testing was accomplished at the contractor's facility. Testing on the complete flight instrument was achieved between June 1970 and December 1970. Testing of the six flight cameras was achieved between January 1972 and May 1972. Testing of the five camera canisters was achieved in March 1972. Test results are documented in BBRC test reports 620-80, 620-146, 620-148, 620-149, 629-150 and 620-151.

One of the problems encountered during acceptance testing and the corrective action taken is listed below.

Problem	Corrective Action
Lubrication breakdown occurred on the retractor cam and follower in the film camera	Lubrication technique changed. Miscellaneous changes were made to various parts.

All acceptance tests/reviews were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System verification testing was performed on the S082A prototype and flight instruments in accordance with 50M02425, ATM Test and Checkout Requirements and Specifications (TCRSD) to determine conformance with design specifications. The ATM test programs for the prototype and flight units were essentially the same except for the lower vibration levels in the vibration test and pre-launch tests for the flight instrument.

System Verification (Prototype)

In-Process Testing - After delivery of the S082A instrument hardware from the manufacturer, the instrument was mounted to the ATM spar and connected to spar cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the experiment. The test consisted of a complete functional verification of all experiment subsystems. Testing was completed with no malfunctions reported.

Post-Manufacturing Checkout - The S082A prototype instrument was tested during PMC to verify satisfactory performance of the instrument, film camera, and system interfaces. Emphasis was given to EMI and EMC testing with all ATM systems operating.

Although numerous problems with instrument interfaces were encountered during test activities, no S082A hardware problems were identified.

Thermal Vacuum Testing - Thermal vacuum testing for the S082A instrument was the same as for the S052 instrument (reference Section XI). No S082A anomalies were noted during pre-thermal vacuum testing.

During thermal vacuum testing, the S082A system was tested to verify that the thermal control system heater panels could maintain design temperatures, and minimize temperature gradients across the instrument case, while being subjected to the environmental conditions.

S082A thermal performance during the operational sequences were satisfactory. All experiment temperatures remained within operational limits during the test. An anomaly did occur, however, with respect to the instrument electronics temperature. The electronics temperature exceeded the thermistor limit (26.7°C) during hot steady state and hot transient simulations. A transducer with a larger range would correct this problem. UV calibration was performed under thermal-vacuum conditions. Results indicated that S082A met all test requirements.

Post-thermal vacuum testing was performed to verify that no adverse effects occurred as a result of the space simulated environment. No problems were evident.

Post-Vibration Testing - Following vibration to launch levels, the S082A instrument was first tested to verify the experiment was operational. S082A test performance was satisfactory.

An all system test was performed to determine if any interaction existed between subsystems during highly active functional conditions, to verify bus redundancy, and to verify all other functions not checked during instrument testing. No S082A problems were noted.

Systems Verification (Flight)

In-Process Testing - In-process testing on the flight instrument consisted of the same functional verification as was run on the prototype. One problem was detected during this test phase. The main grating failed to change from one wavelength position to the other. It was decided to accept the condition without repair because the grating change failure had occurred only 2 times out of 600 operations.

Post-Manufacturing Checkout -PMC was conducted on the flight instrument to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. Three film camera transport anomalies occurred during PMC. One was attributed to a film loading error, one was caused by contamination, and the third was caused by lack of clearance between the backplate and shutter assembly. Each camera was corrected and retest was successful.

Thermal Vacuum Testing - Pre-thermal vacuum testing was performed to verify system readiness, and to serve as a post-vibration functional test. Thermal vacuum testing was performed to verify proper operation during simulated orbits in a thermal vacuum environment. The thermal performance of S082A was satisfactory. The average temperatures of the six instrument case measurements differed less than 0.5°C between the hot and cold transient conditions. As occurred on the S082A prototype unit, the instrument electronics recorded erroneous data during most of the test because of the narrow range of the transducer. A decision was made not to change the transducer as it had no effect on instrument performance.

Vacuum UV calibration tests were conducted to verify instrument focus, resolution and photometric calibration. Comparison of this data with original laboratory calibration test data provided a baseline reference for flight use and means of detecting any deterioration. Data analysis indicated that no significant system deterioration had occurred.

No significant S082A anomalies were reported during the thermal vacuum test activities.

Prelaunch Testing - Upon arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab module.

Crew compartment, fit and function checks verified that the S082A film cameras could be fitted onto the telescope and also in the storage area. No anomalous conditions were evident.

Vertical Assembly Building (VAB) testing occurred in two phases: ATM alone, and ATM with other modules. VAB testing consisted of C&D console interface test, end-to-end systems test, swing arm overall test, mission simulation flight readiness test, subsystem bus redundancy, camera installation, and close out. S082A test performance was satisfactory and no problems were reported.

SECTION XVIII. SPECTROGRAPH AND EXTREME ULTRAVIOLET MONITOR (S082B)

EXPERIMENT DESCRIPTION

The XUV Spectrograph, shown in figure 18-1, consisted of the Spectrograph and Extreme Ultraviolet (XUV) Monitor, two different but rigidly attached telescopes. The Spectrograph was larger of these telescopes and contained both a TV imaging system and a spectrograph. The smaller telescope was the XUV Monitor. Both telescopes were designed for operation from the ATM C&D console.

The spectrograph 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 XUV Monitor was used for observing a video image of the full solar disk in the wavelength band from 170 to 550 angstroms and to identify solar features of interest. Scientific characteristics of the instrument are shown in Table 18-I.

Table 18-I. Scientific Characteristics

PARAMETER	VALUE
Spectral Range:	
Spectrograph	970 to 1970Å (2nd order of main grating) 1940 to 3940Å (1st order of main grating)
XUV Monitor:	170 to 550Å (integrated picture)
Resolution:	
Spectral:	0.06Å (2nd order of main grating) 0.12Å (1st order of main grating)
Spatial:	
Spectrograph:	3 arc sec
XUV Monitor:	10 to 20 arc sec
Temporal:	≥ 0.15 sec
Field of View:	
Spectrograph:	2 x 60 arc sec
XUV Monitor:	60 arc min (display field of view)

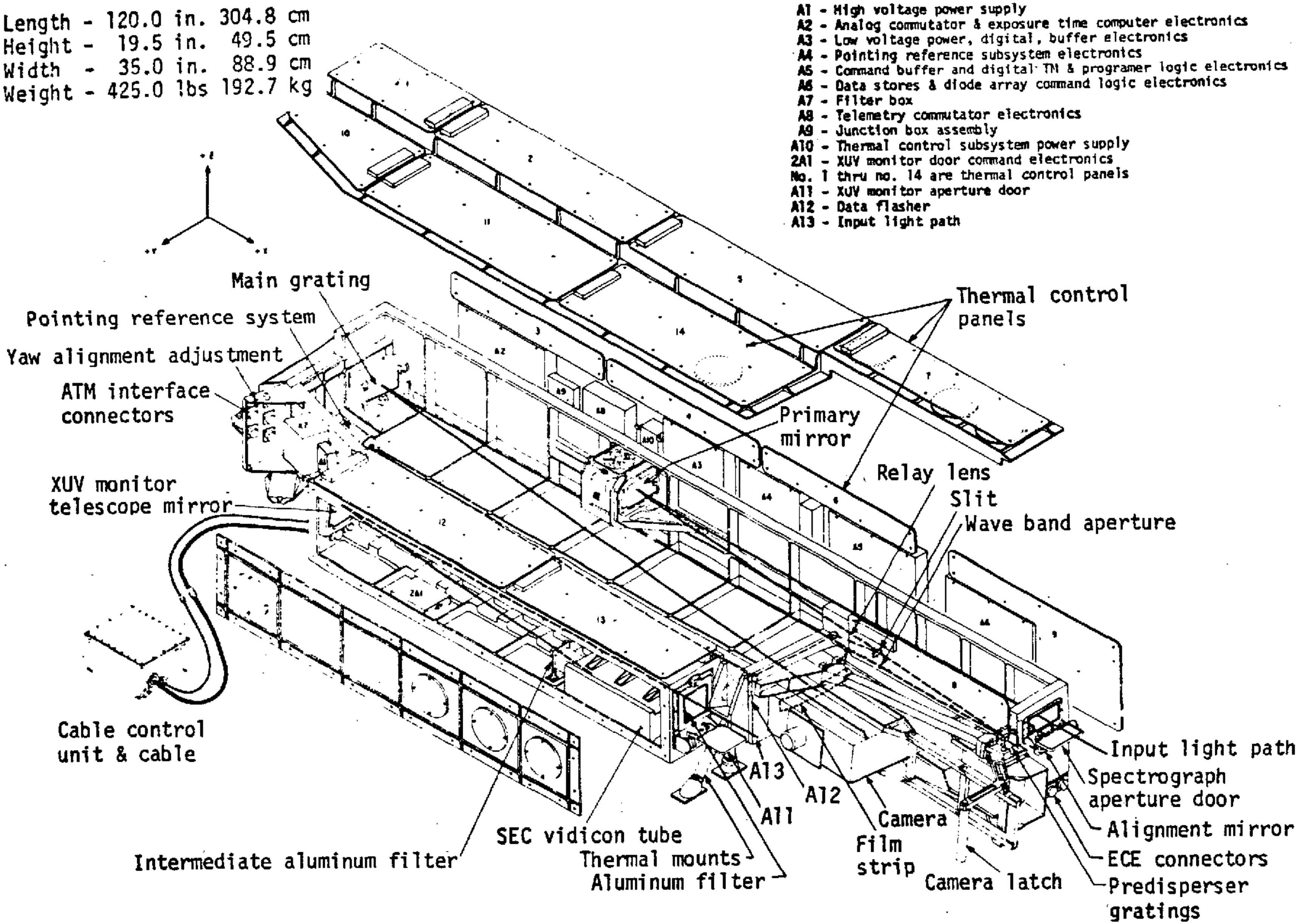


Figure 18-1. S082B XUV Spectrograph Configuration

The main housing consisted of two attached aluminum cases and two removable covers. The spectrograph optical system and the pointing reference system were both enclosed by the main case and cover. A removable film-strip camera was attached by a hand-operated latch. The XUV Monitor was enclosed by the secondary case and cover.

Spectrograph

The spectrograph had an internal aperture door in addition to the ATM thermal shield door. When both doors were opened, a concave mirror focused the solar image on a slit plate. The slit allowed a portion of the solar image, approximately 2 by 60 arc-seconds, to be photographed by the film strip camera. A predisperser grating, a waveband aperture, and the main grating functioned together to disperse the light passing through the slit into spectral lines which were focused onto the film strip by the main grating. The predisperser grating was changed by command from the C&D console, or automatically during an exposure sequence, to select either of two wavelength bands (970 to 1970 angstroms or 1940 to 3940 angstroms) to be photographed. Figure 18-2 is an optical schematic of the spectrograph.

Film Camera

Prior to Skylab 1 launch the film strip cameras were loaded with film (1,608 exposures per camera). One camera was mounted on the instrument, and two cameras were stored in the MDA film vault. Cameras were retrieved and replaced on the instrument during EVA.

Pointing Reference System

The PRS basically consisted of an optical system (separate from the spectrograph optics), an image dissector tube video camera, and electronics to control experiment pointing to within 1 arc-second. Pointing requirements are shown in Table 18-II.

The optical system shown in figure 18-2 consisted of a neutral-density filter, a relay lens, and two folding mirrors. The function of the optical system was to re-image the slit plate, including slit, fiducial lines, and solar image, onto the face plate of the image dissector tube with a 15 to 1 magnification. The slit plate had a polished optical surface broken by the spectrograph slit and the darkened fiducial lines. The neutral-density filter reduced the light intensity from the solar image to an acceptable level for the image idssector tube.

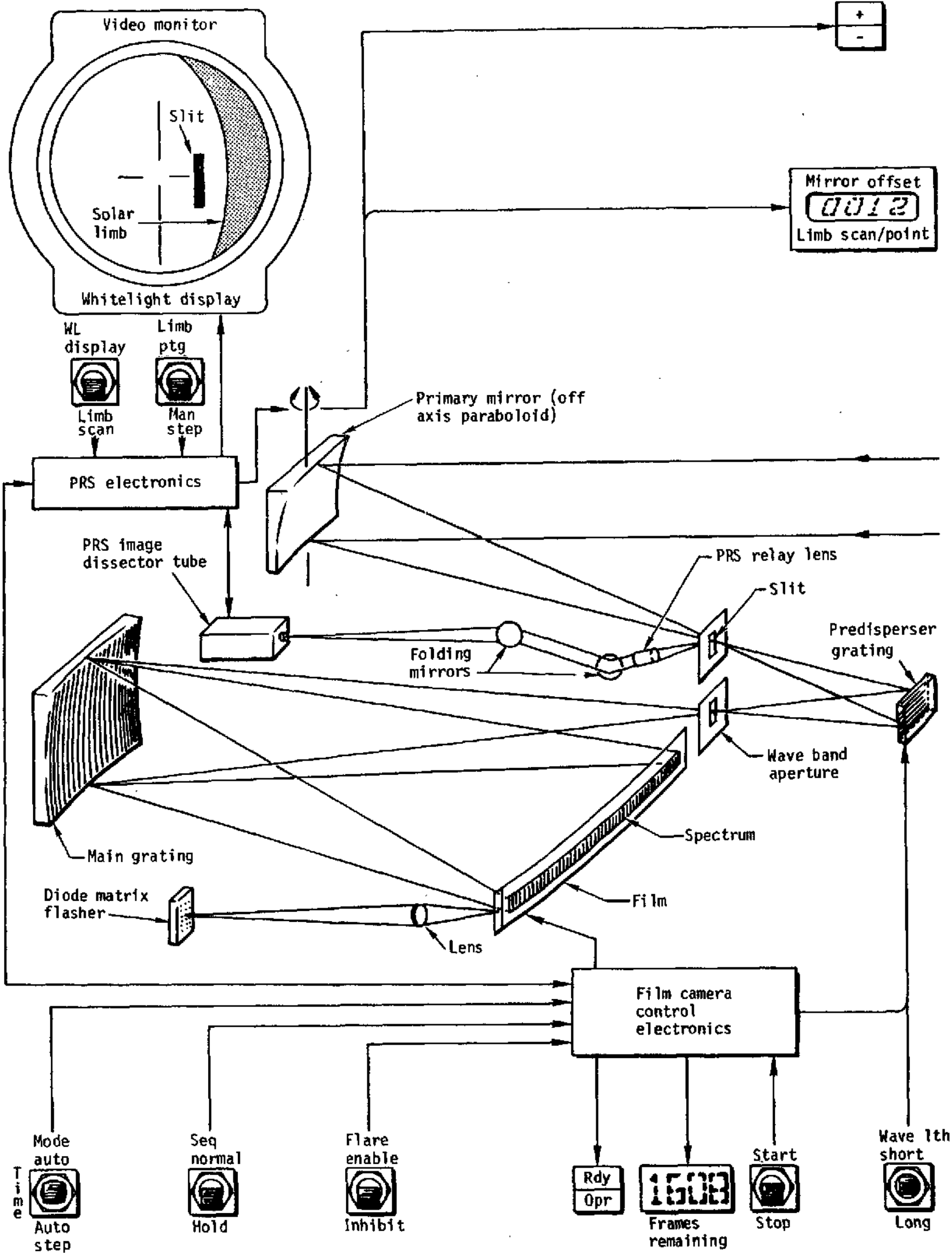


Figure 18-2. S082B Optical and Control and Displays Operation Schematic

Table 18-II. Pointing Control Requirements

PARAMETER	VALUE
Target:	Selected regions on the solar disk, on the limb and above the limb.
Accuracy:	
Pitch & Yaw	± 2.5 arc-sec
Roll	± 10 arc-min
Stability:	
Pitch & Yaw	± 2.5 arc-sec
Roll	± 7.5 arc-min for 15 min
Offset:	± 21 arc-min from center of the solar disk

The image dissector tube and electronics generated either a standard TV image of the area of the Sun presented to the slit plate, or an electrical signal representing the distance between the solar limb and the slit. The TV image was displayed on a monitor, and the limb offset in arc-seconds, on a digital indicator on the ATM C&D console.

XUV Monitor

The XUV Monitor operated independently of the spectrograph to provide a real-time image of the solar disk in the XUV waveband between 170 and 550 angstroms. The XUV Monitor optical schematic is shown in figure 18-3. The XUV Monitor consisted of a mirror, three thin aluminum filters, and a low-light-level TV camera. The XUV Monitor had a separate, independently operated aperture door in addition to an ATM thermal shield door that admitted light to its compartment.

The mirror had a concave reflecting surface, and was ridigly mounted to the rear wall of the XUV Monitor case.

The filters were aluminum films approximately 1500 angstroms thick. One filter was located inside the XUV Monitor instrument aperture door, one was in front of the TV camera, and one was deposited on the face plate of the TV camera.

The TV camera contained a secondary-electron-conduction vidicon with an aluminum filter and a thin layer of conversion material bonded to the face plate of the tube. The conversion material

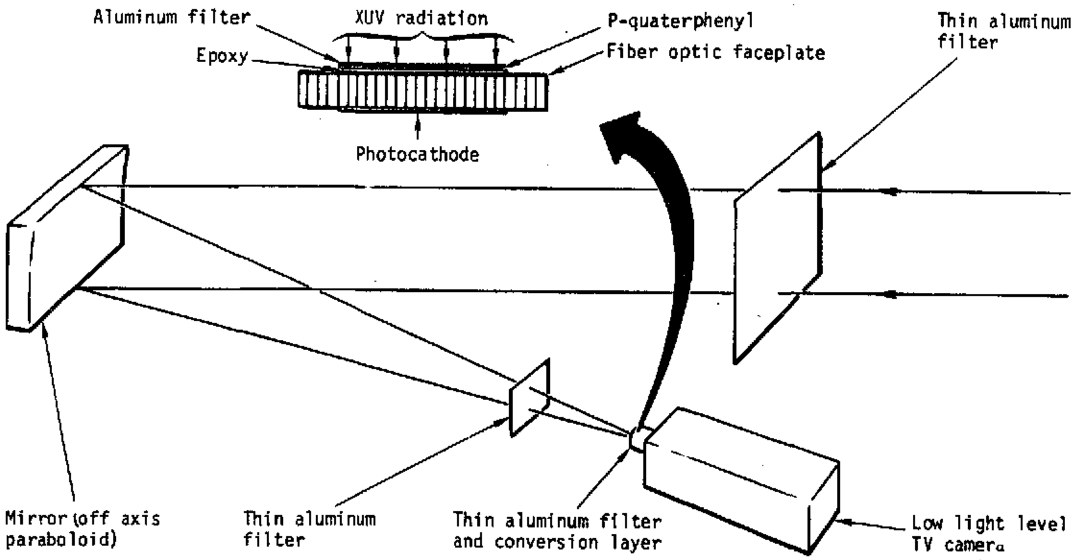


Figure 18-3. XUV Monitor Optical Schematic

converted the filtered XUV wavelengths to visible light in the 4000 to 4500 angstrom range which the camera transmitted to the ATM C&D console and to the CSM transmitter for transmission to ground stations. The TV camera was mounted at the Sun-end of the XUV Monitor case.

Thermal Control System

An active TCS was required because of the critical alignment and focus requirements of the S082B instrument. The TCS consisted of low-thermal-capacity standoff heater panels and passive insulation panels. The system was designed to operate in the controlled environment of the ATM canister at 8.3°to 14.4°C and maintain the instrument average case temperatures at 21.0 ± 0.67°C. The most critical thermal control requirements were rates of change of instrument side-to-side differential temperatures since these affected image smear. The rate of change of side-to-side differential temperatures was specified to be no more than $\pm0.18^{\circ}$C per 15 minutes time. The heating system had 14 independent honeycomb panels with strip heaters. Each heater panel was equipped with its own temperature-sensing thermistors and controller circuitry. An analog telemetry monitoring subchannel for heater panel and instrument reference temperatures was provided for each heater panel. Nine of the heater panels were mounted on the top surface of the instrument. The remaining five were installed on the side walls.

Operation

The SO82B operated only in the manned mode. During operation the SO82B instrument was controlled by the crew from the ATM C&D console. The instrument required the use of the H-alpha telescope for pointing to solar features of interest, the manual pointing control system for pointing the canister, and the event timer for use during manual operation of the spectrograph camera.

The pointing reference system had 3 operating states; whitelight display, limb scan, and limb pointing. In whitelight display, a 3-arc-minute portion of the solar image was displayed on the TV monitor showing the relative position of ths slit to the limb. In limb scan, a numerical display in arc-seconds was provided to aid positioning of the slit with reference to the solar limb. In limb pointing, the primary mirror position was maintained automatically within 1 arc-second of the selected limb offset. In limb scan or limb pointing, no video display was provided.

The SO82B instrument functioned in four operating modes to provide spectrograms; one manual mode and three automatic modes (auto, flare, and auto step). An additional hold mode was provided to stop and retain automatic mode logic for continuation of a mode on the next orbit. The crew, in addition to selecting the mode of operation, selected either of two wavelength bands (long or short).

The auto mode was preprogrammed to photograph the two wavelength bands alternately by positioning one and then the other of the two pre-disperser gratings into the optical path. The two wavelength bands were photographed with different exposure times for a total of eight exposures. Exposure times were automatically prescaled in the programmer electronics by a zone signal from the PRS when operating in limb point or limb scan mode. The three zones were: 1) on the disk, or within 1 arc-second off the limb, 2) +2 to +9 arc-seconds off the limb and 3) +10 arc-seconds or greater off the limb.

In the auto step mode with the PRS in limb pointing, the instrument automatically pointed to ten different positions in the vicinity of the limb, and took eight exposures at each position. Exposure times were prescaled by the PRS as in the auto mode.

The flare mode was preprogrammed to take a series of 48 exposures to record the rise and early stages of a flare.

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM Experiment program was initiated in January, 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application requested proposals for experiments to be considered for the ATM systems. Naval Research Laboratory (NRL) submitted a formal proposal in response to Dr. Newell's letter, entitled "Proposal to investigate the extreme ultraviolet spectrum of the Sun's corona and chromosphere on an Apollo Mission". The proposal was modified in August 1966 to read "Proposal for the Astronomical Telescope Mounting (ATM) for Apollo, Experiment A-ATM Coronal XUV Spectroheliograph and Experiment B-ATM Chromospheric XUV Spectrograph". On September 1, 1966, NRL was informed of the selection of the Chromosphere XUV Spectrograph for design and development for flight on the ATM. Subsequently, on September 6, 1966, responsibility for development of the experiment was transferred from the Goddard Space Flight Center (GSFC) to the Marshall Space Flight Center (MSFC). The instrument was designed, fabricated, and tested by Ball Brothers Research Corporation (BBRC) of Boulder, Colorado, under the scientific direction of Naval Research Laboratory of Washington, D.C. Mr. J. Purcell was the principal investigator until August 1970 when he was succeeded by Dr. R. Tousey.

Experiment SO82B was an outgrowth of the Extreme Ultraviolet Spectroheliographs proposed for the AOSO. The AOSO project established some of the basic concepts for the experiment used on the ATM. Three features of the ATM experiment distinguish it from the AOSO counterpart: (1) The use of photographic recording, with pronounced improvements in spatial and temporal resolution; (2) Crew control of instrument operations; (3) the much longer orbital lifetime.

Much of the experiment definition performed by the PI on AOSO was directly applicable to the ATM Experiment. In some cases the PI used previously fabricated AOSO components as models and breadboards in the ATM S082B experiment development.

Design Evolution/Rationale

The concept employed in designing S082B was based on the principle of spectrographs. The instrument used the focusing property of sections of revolutions; however, as the object moved off-axis, the resolution got rapidly worse owing to the optical aberration known as coma. To circumvent this difficulty, an off-axis parabolic mirror was used. Because of the absorption of ultraviolet light by ordinary diffraction devices, a reflection grating was used. Flat reflection gratings required a lens to focus the diffracted light into a spectrum. A lens would introduce optical defects. The use of a spherical concave grating would eliminate the requirement of a focusing lens. But, if a diffraction grating was used alone, the entire solar spectrum would be focused at the film plane, with the result that details of the spectra would not be detected or resolved. However, by using a predisperser grating and waveband selecting slit, details of the spectra could be detected. Two different predisperser gratings were used which had a different blaze and number of lines.

A photographic film camera was used to record the spectra. Because it was necessary to photograph the limb of the Sun, an off-solar disk accurate pointing technique was necessary. A pointing reference system was used to provide pointing, selection and verification by the crew. The pointing system employed the slit of the spectrograph which was located in the focal plane mirror. The slit plate carried an image of the Sun. By making the surface of the slit plate reflective, the solar image was reflected and viewed by an image dissector which provided a white light display of the Sun's limb, a digital indication of the angular distance between the limb and spectrograph slit, and controlled the distance between the limb and the slit.

Several design changes resulted from improvements in state of the art and design or manufacturing problems. Numerous modifications made to the experiment from initial concepts through all phases of development and testing are documented in engineering change proposals modifications.

MANUFACTURING

Manufacturing of the SO82B experiment consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into completed instruments. Three units were assembled - the TMU, the prototype instrument and the flight instrument. The fabrication dates were as follows:

Unit	Date
TMU	April 1967 through Jan. 1969
Prototype	Feb. 1968 through Dec. 1969
Flight	Feb. 1968 through Jan 1970

Unique fabrication techniques employed in the fabrication of SO82B were the same as SO82A.

All units were subjected to both functional and environmental tests. The TMU was tested to verify instrument envelope dimensions, spar interface and thermal control operation. The prototype instrument was subjected to pre-delivery acceptance test. Numerous studies, tests, breadboarding and special tests such as the flight design verification unit, XUV calibration, contamination, camera zero-g camera and canister vibration, acceleration test film and calibration rocket tests were all accomplished to develop the design of the instrument. The results are documented in BBRC reports 620-42, 620-61, 620-33, 620-72, 620-78, 620-128, 620-158 and NASA reports CR-61364, TM X-53666.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements at levels approximately 1.5 times those expected during the Skylab Mission as specified in 50M02408; Environmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, acceleration and acoustics testing. In addition, leak tests, electromagnetic compatibility tests and outgassing tests were performed on the instrument. The qualification test program is described in end item test plan, BBRC 28341. The results of these tests are documented in BBRC test reports 620-87, 620-137, 620-73, 620-79, 620-165, 620-74. Dates of the qualification testing were as follows:

Test Article	Test Date
Instrument (S/N 001)	July 1970
Instrument Power Line Filters	July 1970
Instrument Predisperser Assembly	September 1970
XUV Monitor Filter Wires	December 1970
Camera (S/N B001)	May 1972
Canister (S/N A001)	February 1972

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on March 30, 1972 (XUV Spectrograph), and on October 25, 1972 (Film Camera) with no open items.

Some of the problems encountered during qualification testing and the corrective action taken are listed below.

Problem	Corrective Action
1. Limb offset read +4 arc sec; should be 0 ± 1 arc sec.	Conformal coating on the 2 MHZ oscillator was affecting tuning. Conformal coating was removed.
2. When film camera was operated, XUV monitor door would also drive.	Caused by noise susceptibility of XUV monitor door drive Circuitry. Noise immunity of the door drive box was increased.
3. When auto mode was in progress and start/stop switch was placed to start, auto mode recycled to 1st exposure; should have no effect.	Start command was not locked out when in auto mode. Electronics was reworked to correct problem.
4. Camera shutter opened while predisperser was driving	Escapement pawl drive was too long. It was reduced to 25 ms.
5. TCS unable to bring instrument to operating temperature at low shroud temperature.	TCS modified

Problem (Cont'd)	Corrective Action
6. Predisperser failed to drive to commanded position.	Redesign of predisperser mechanism.

ACCEPTANCE TEST

The flight instrument was subjected to pre-delivery acceptance tests to levels anticipated during the mission in order to verify that the unit met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in end item test plan , BBRC 28341. All testing was accomplished at the vendors facility. Testing on the flight instrument was achieved in August 1971 and on the film camera in June 1972.

Testing on the five canisters was achieved between March 1972 and April 1972. Test results are documented in BBRC test reports 620-133, 620-152, 620-153, 620-155, 620-156 and 620-127.

Some of the problems encountered during acceptance testing and the corrective actions taken are listed below:

Problem	Corrective Action
1. Predisperser grating failed to repeat alignment within 30 arc seconds when cycled.	Gear clearance was opened up to stop interference. The flight drum was replaced because of the damaged gears.
2. Results of XUV calibration indicated a reduced efficiency of the optical system. This was due to reaction between the gold and aluminum layers on the gratings.	NRL had new gratings manufactured that did not use gold. These gratings were installed and aligned in the instrument before delivery.
3. Camera stepped through teeth causing missed exposures.	Corrected during refurbishment

All acceptance tests/reviews were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System Verification testing was performed on the S082B prototype and flight instruments to determine conformance with design specifications. The ATM test programs for the protype and flight units were essentially the same except for the lower vibration levels in the vibration test and pre-launch tests of the flight units.

System Verification (Prototype)

In Process Testing - After delivery of the S082B experiment hardware from the manufacturer, the instrument was mounted to the ATM spar and connected to spar cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the experiment. The test consisted of a complete functional verification of all experiment subsystems. The only problem identified during this test was that the predisperser grating failed to move from short to long wavelength. This was a builtin characteristic of the drive mechanism and the condition was accepted.

Post-Manufacturing Checkout - The S082B prototype experiment was tested during PMC to verify satisfactory performance of the instrument, film camera, and system interfaces. Emphasis was given to EMI and EMC testing with all ATM systems operating.

The following anomalies were encountered during testing. The XUV Monitor aluminum filter had several large holes. The filter was replaced.

The XUV Monitor aperture door displayed incorrect open/close indications. Door limit switches were adjusted and retest was satisfactory.

The instrument randomly issued double pulses for film transport. This was a design problem and was corrected during refurbishment.

Film evaluation indicated that the diode data was incorrect. The instrument was corrected during refurbishment.

The XUV monitor door occasionally opened when XUV slit power was enabled. The condition was accepted with procedural workarounds.

Thermal Vacuum Testing - Thermal vacuum testing for the S082B instrument was the same as for the S052 instrument (reference Section XI). No instrument problems were noted during pre-thermal vacuum testing.

During thermal vacuum testing the S082B system was tested to verify that the thermal control system heater panels could maintain design temperatures and minimize temperature gradients across the case,while being subjected to the environmental conditions.

The XUV monitor vidicon camera became overloaded during cold transient conditions due to excess light. This was caused by the absence of the secondary aluminum filter in the light path. The filter had been mistakenly rotated out of the light path prior to thermal vacuum testing and left there. As the filter could only be repositioned manually, the XUV monitor instrument door was closed for the thermal portions of the balance of the test. The thermal objectives were, therefore, not met with respect to evaluating the XUV monitor during cold transient hot steady state, hot transient and failed canister TCS conditions. These conditions would normally have subjected the XUV to a solar heat load.

The XUV vidicon temperature measurement was noisy throughout the prototype test. This was not considered significant on the prototype. The camera shutter failed to operate in automatic modes. This was attributed to a random electronic component failure which was corrected at refurbishment. Voltages in the pointing reference system were fluctuating. This was determined to be caused by lack of sufficient grounding. This was accepted on the prototype and corrective measures were taken on the flight instrument.

In addition to thermal vacuum testing, a vacuum UV calibration was performed to check optical operation of the XUV instruments. The exposures made with S082B were compromised due to optical misalignment between the test source and the S082B instrument Operation of the XUV Monitor was successful.

An earlier PMC problem repeated during post thermal vacuum testing. The XUV Monitor aperture door limit switches went out of adjustment. A different design was developed for use on the flight unit.

No additional problems were reported during post-thermal vacuum test activities.

Post-Vibration Testing - Following vibration to launch levels the S082B instrument was first tested to verify that the experiment was operational. No significant S082B problems were identified.

An all system test was performed to determine if any interaction existed between subsystems during highly active functional conditions to verify bus redundancy, and to verify all other functions not checked during instrument testing. No new problems were reported.

Systems Verification (Flight)

In-Process Testing - In-process testing on the flight instrument consisted of the same functional verification as was run on the prototype. Two problems were noted during this test. The predisperser failed to move from short to long wavelength. This was a known condition and due to its infrequent nature was accepted. An S082B commutator operational amplifier failed. The unit was removed, repaired, and replaced.

Post Manufacturing Checkout - PMC was conducted on the flight instrument to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. The following problems were noted:

Erratic camera operations occurred during the high-low voltage test. Lower impedance 28 Vdc-line filters were added and the problem cleared.

During the plugs-out test, the XUV Monitor aperture door opened when power was applied to the instrument. This was a known condition and due to its infrequent nature was accepted

Thermal Vacuum Testing - Pre-thermal vacuum testing was performed to verify subsystem readiness and to verify integrity after vibration testing. No anomalies were reported.

Thermal vacuum testing was performed as described for the prototype instrument. All S082B temperatures remained within limits and no functional problems were reported.

Vacuum UV Calibration was performed to verify original laboratory calibration with respect to focus resolution and photometric calibration. Test performance involved illuminating the S082B apertures (slit and monitor) with collimated UV light of known intensity. The film camera was operated with the same type film as in the laboratory calibration. The XUV monitor was operated with the data recorder on a video tape recorder. Comparison of the facuum data (and ambient data) with the original calibration provided a baseline reference of the operational conditions of the instrument. No anomalies were reported during the test.

Post-thermal vacuum testing was performed and no problems were evident.

Prelaunch Testing (KSC) - Upon arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab. S082B tests consisted of an interface verification test, an all systems test, and crew compartment fit and function. No S082B problems were identified.

VAB testing occurred in two phases; ATM alone and ATM with other modules. VAB testing consisted of C&D console interface test, end-to-end systems test, swing arm redundancy, camera installation and closeout. S082B testing was successful. Testing ceased with the instrument in the proper closed-out configuration.

SECTION XIX. ATM EXPERIMENTS HYDROGEN ALPHA TELESCOPES (H-ALPHA 1 AND H-ALPHA 2)

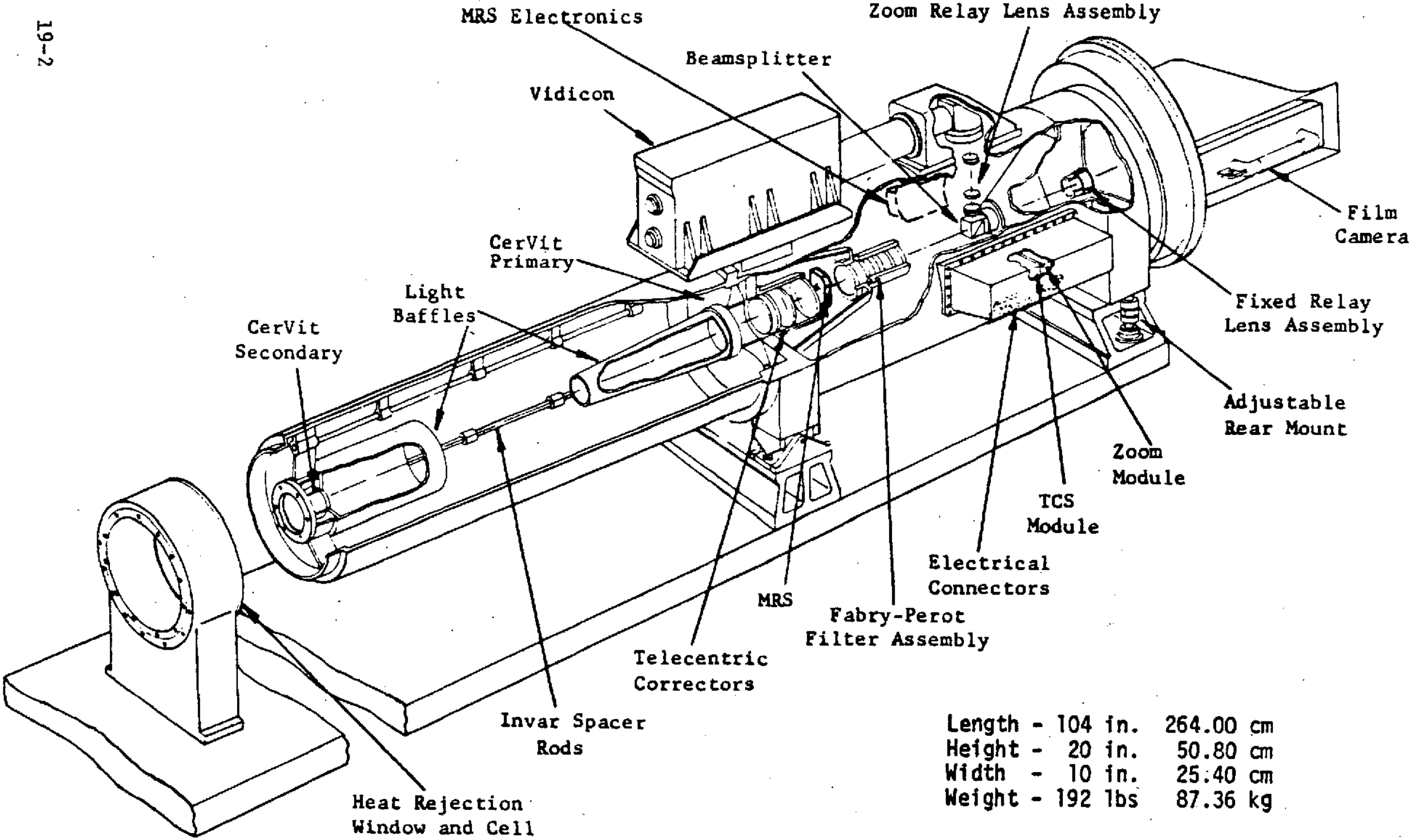
EXPERIMENT DESCRIPTION

The Hydrogen-Alpha Telescopes, shown in figures 19-1 and 19-2 provided a diffraction-limited image of the Sun in H-Alpha line of the Balmer series (6562.8 angstroms). Scientific characteristics of both instruments are shown in Table 19-I.

Table 19-I. Scientific Characteristics

PARAMETER	VALUE	
	H-Alpha 1	H-Alpha 2
Spectral Range	6562.8Å (red lt)	6562.8Å (red lt)
Resolution:		
Spectral:	0.7Å at 6563Å	0.7 Å at 6563Å
Spatial:		
Film:	1.0 arc-sec	
TV: Zoom In	1.5 arc-sec	1.5 arc-sec
Zoom Out	5.0 arc-sec	7.0 arc-sec
Field of View:		
Film:	35 arc-min ($1.1R_O$)	
TV: Zoom In	4.4 arc-min ($0.14R_\odot$)	7 arc-min ($0.22R_\odot$)
Zoom Out	16 arc-min ($0.5R_\odot$)	35 arc-min ($1.1R_\odot$)

Both telescopes were equipped with a vidicon which displayed real-time solar detail on the C&D console for crew observation. Video images were periodically transmitted real-time to ground or recorded onboard for subsequent transmission. A film camera, mounted at a second image plane on the H-Alpha 1 telescope, provided high-resolution photographs of the solar disk, and permanent records of ATM pointing. The H-Alpha telescopes provided a view of the entire solar disk or, by using the zoom feature, a view of specific solar detail for further study by other ATM instruments. The S055A and S082B instruments were coaligned with the H-Alpha telescopes. Pointing control requirements are shown in Table 19-II.



Length	-	104 in.	264.00 cm
Height	-	20 in.	50.80 cm
Width	-	10 in.	25.40 cm
Weight	-	192 lbs	87.36 kg

Figure 19-1. Hydrogen Alpha One Telescope Configuration

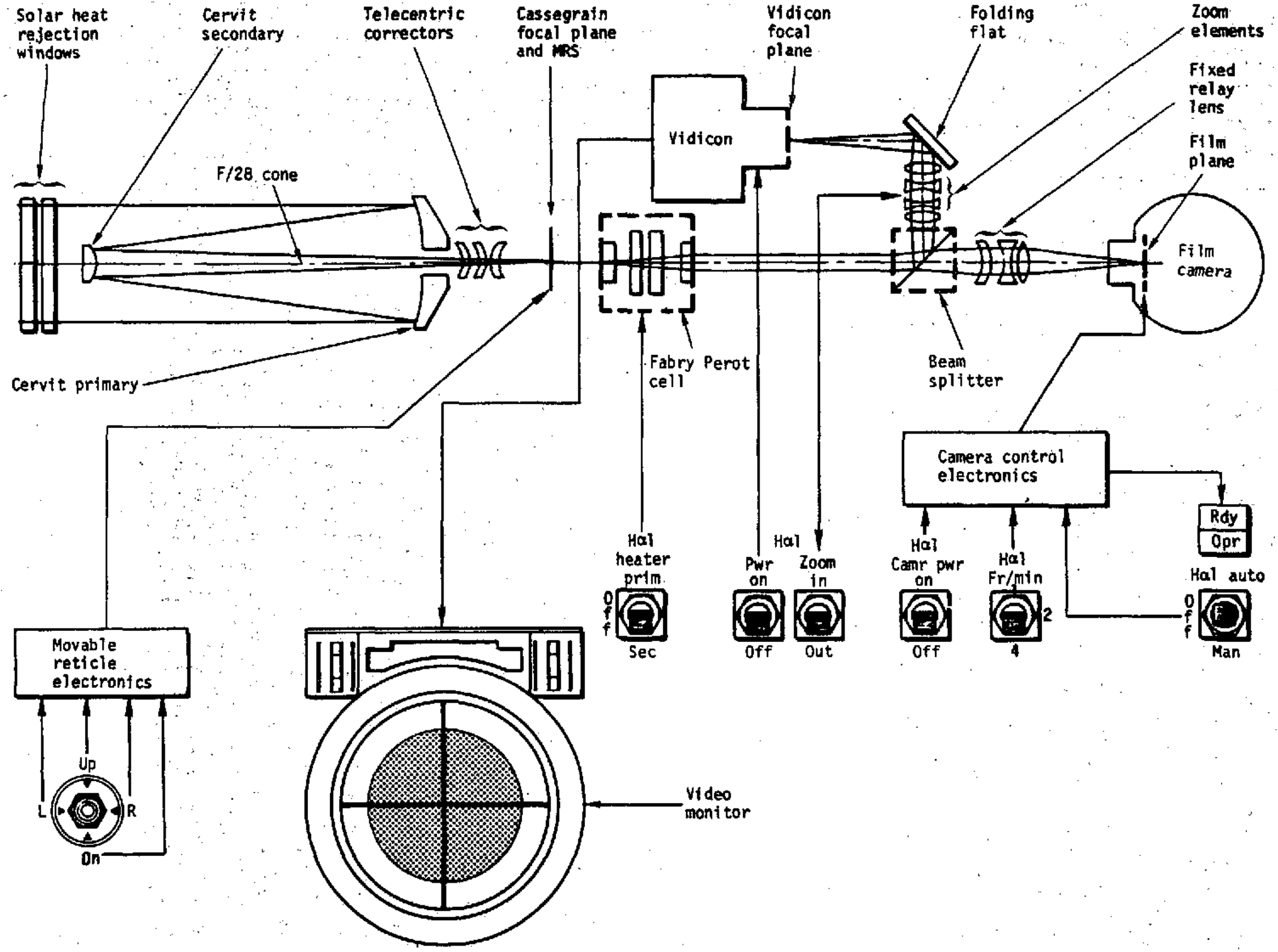


Figure 19-2. H-Alpha 1 Telescope Optical and Controls and Displays Operation Schematic

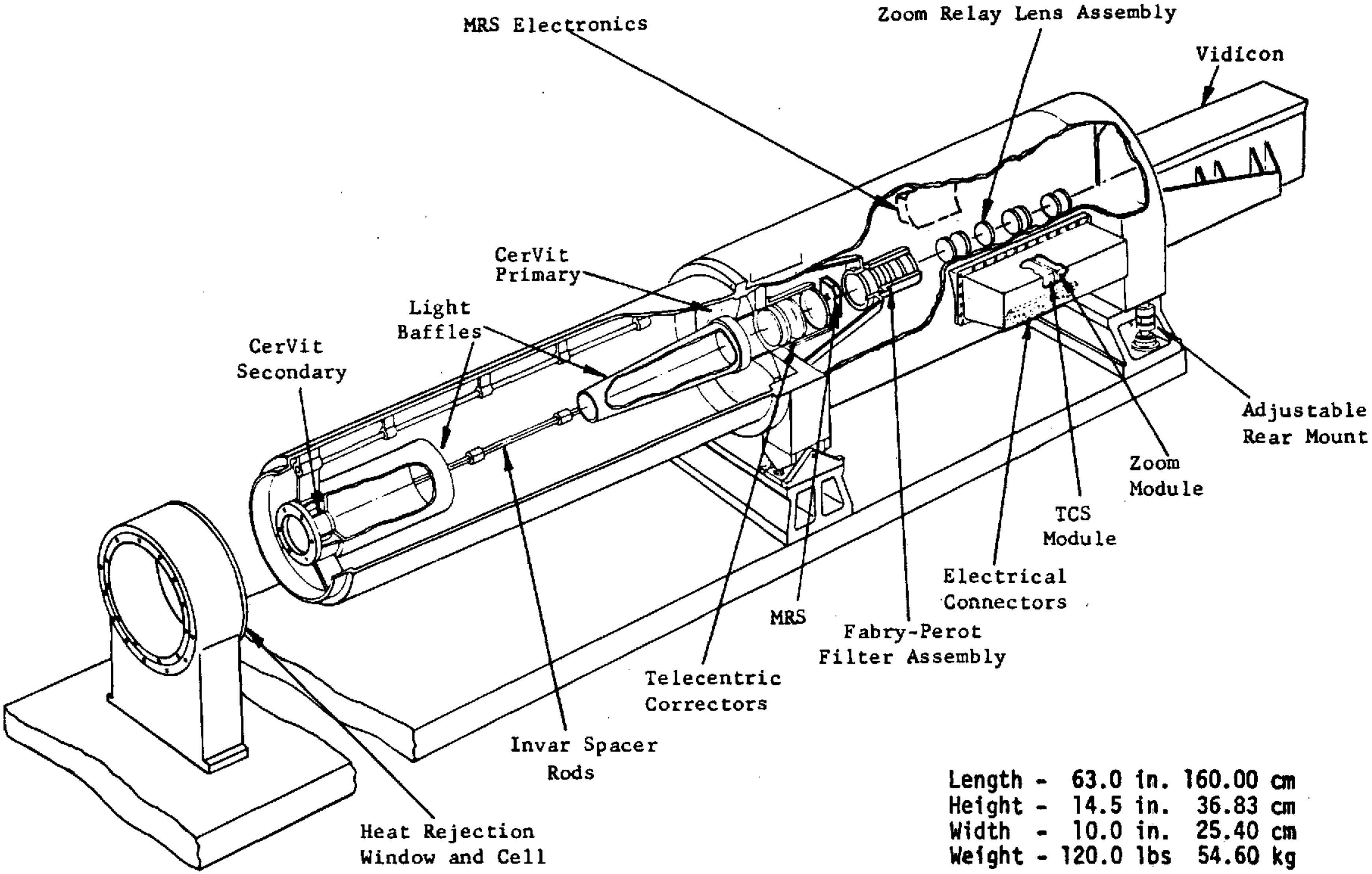
Table 19-II. Pointing Control Requirements

PARAMETER	VALUE	
	H-Alpha 1	H-Alpha 2
Accuracy:		
Pitch and Yaw	± 5 arc sec	± 5 arc sec
Roll	N/A	N/A
Stability:		
Pitch and Yaw	± 2.5 arc sec	± 2.5 arc sec per 5 min
Roll	± 3.0 arc min per sec	± 7.5 arc min for 5 min
Offset:	± 24 arc min	± 24 arc min

Each telescope consisted of two major structural assemblies: the front extension tube assembly, which contained the heat-rejection windows, and the main telescope assembly, which housed the remaining optical components. The only element in the H-Alpha telescopes that required an active TCS was the temperature-critical Fabry-Perot filter assembly. Otherwise, the two telescopes were passively temperature-controlled. Insulating spacers were used between the telescope and spar. Temperature-sensing thermistors, located at various points on the telescope, provided telescope thermal performance data.

Optics

An optical schematic of the H-Alpha 1 instrument is shown in figure 19-3. The H-Alpha 2 telescope was designed to present the crew with a redundant H-Alpha viewing system. The H-Alpha 2 optical design was similar to that of H-Alpha 1 with the exception of a beam splitter, film camera, and TCS ground commands. An otpical schematic of the H-Alpha 2 instrument is shown in Figure 19-4. Light from the Sun first contacts the two-element heat-rejection window, which covers the aperture of the telescope. The first element was primarily a UV-rejection filter, and the second was an induced-transmission filter, designed to reject visible and infrared energy, while providing high transmission in hydrogern-alpha. The light was then transmitted to the paraboloid primary mirror, reflected to the hyperboloid secondary mirror, and then transmitted through the f/28 telecentric correctors to the focal plane, which contained the mechanical,



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 19-3. Hydrogen Alpha Two Telescope Configuration

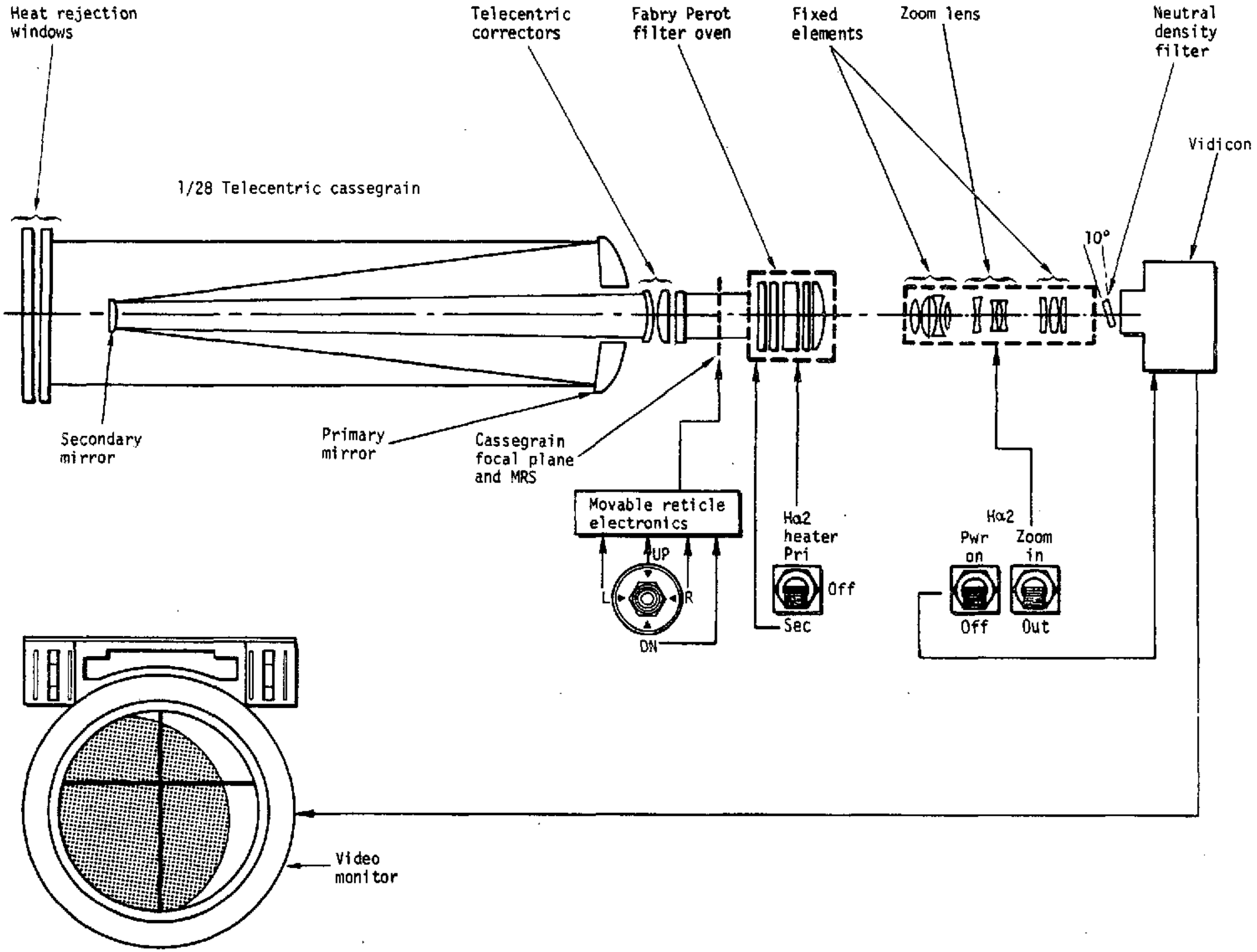


Figure 19-4. H-Alpha 2 Telescope Optical and Controls and Displays Operation Schematic

movable reticles. The light was then transmitted through the Fabry-Perot filter and onto the beam splitter, which directed 90 percent of the light through relay optics to the photographic film camera, and 10 percent of the light through the zoom lens to the vidicon TV camera.

The zoom system was designed to provide a continuously-variable field-of-view from 4.4 to 16 arc-minutes, with a resolution of 1.5 arc-seconds to 5 arc-seconds, respectively. The zoom lens position was controlled by a three-position, center-off switch, which energized the zoom motor.

A movable reticle system (MRS) consisted of vertical and horizontal stretched-wire reticles, which were independently moved ± 3 1/2 arc-minutes about the center position, by two, 28-Vdc motors. The MRS, in combination with a set of fixed fiducial marks, oriented at 45-degree intervals around the edge of the field, was primarily used for alignment and pointing of other ATM instruments.

Fabry-Perot Filter Assembly

The Fabry-Perot assembly determined the bandpass characteristics of the H-Alpha telescopes. The two primary components of the filter assembly were a solid-spaced Fabry-Perot etalon and a blocking filter. These two elements were housed in a temperature controlled cell with the other optical elements necessary to achieve the desired optical system performance.

The filter assembly spectral bandwidth of 0.7 angstrom at H-alpha (6562.8 angstroms) was obtained by placing two, interference optical filters in series. The heart of the system was a solid-spaced Fabry-Perot etalon filter which transmitted 65 percent of the energy at the H-alpha line, with a half-bandwidth of 0.7 angstrom. This filter had transmission peaks separated by 11 angstroms. These adjacent etalon peaks were suppressed by a blocking filter which had a half-bandwidth of 7 angstroms. The combined transmission was 40 percent of the H-alpha energy.

Television System

The TV system used vidicon cameras in a standard operational mode. The TV camera voltages were controlled by the camera control unit, mounted on the rear of the ATM canister. Sync signals were provided from the system syn generator. All TV signals were transmitted to two video switches which were controlled from the ATM C&D console. The signals could be displayed on the C&D console and also recorded and/or transmitted to ground stations. The transmitted signal to ground was limited to a 2 MHz bandwidth and consequently the onboard resolution was much greater than that available at the ground station.

Film Camera

The H-Alpha 1 camera was a 35-millimeter, roll film sequential type camera. The film camera including the shutter assembly was permanently mounted on the telescope. Film-load replacement was accomplished by inserting film magazines containing 100 feet of SO-101 film into the camera during EVA.

Thermal Control System

Because both filters in the Fabry-Perot Assembly were temperature-sensitive, they had to be maintained at a constant, preset temperature, when in operation. This was accomplished by the TCS, which consisted of a heater surrounding the Fabry-Perot cell, and the necessary electronics to maintain the cell at the desired level within 0.5°C. Primary and secondary heater power could be controlled by C&D console or ground command. This was the only active TCS in the H-alpha telescopes. All other parts of the telescope were temperature controlled by passive measures.

Operation

The film camera had two modes of operation, automatic and manual. In the automatic mode, photographs were taken at 1, 2, or 4 frames per minute, as selected by the crew. In the manual mode, only one frame was exposed per command.

The H-Alpha instruments operated only in the manned mode. During the manned operation, the H-Alpha instruments were entirely controlled by the crew from the C&D console.

SYSTEM EVOLUTION AND DESIGN RATIONALE

History

The ATM experiment program was initiated in January 1966, when Dr. Homer E. Newell, Associate Administrator for Space Science and Application requested proposals for experiments to be considered for the ATM systems. In response to Newell's letter, Harvard College Observatory requested that an H-Alpha telescope camera should be flown aboard the ATM, to provide pointing data for the experiments. Subsequently the ATM pointing telescope system and the Hydrogen-Alpha Telescope Camera System were approved as part of the experiment complement and pointing system. In May 1967, a request for proposal, drawn by Marshall Space Flight Center, was distributed to industry. In January 1968, Perkin-Elmer was chosen as the prime contractor.

The instruments were designed, fabricated, and tested by Perkin-Elmer of Norwalk, Connecticut. H-Alpha 1 was actually a part of the S055 experiment and was under the scientific direction of Harvard College Observatory (HCO) of Cambridge, Massachusetts. Initially, Dr. L. Goldberg was the principal investigator. He was later succeeded by Dr. E. Reeves.

Experiment H-Alpha 1 was an outgrowth of the H-Alpha telescope/camera system, which was one portion of the HCO S055 solar experiment. Experiment S055, commonly referred to as HCO experiment "A" was a short UV wavelength spectrometer. In support of this vacuum ultraviolet spectrometer, was a telescope camera with a hydrogen-alpha filter to provide photographic records (filtergrams) of the solar disk. A vidicon TV camera with zoom capability was later added to provide the crew with vidicon display of all or part of the solar disk. Complement to H-Alpha 1 was the H-Alpha 2, referred to as the ATM pointing telescope, also with zoom capability, to provide a backup vidicon display of the solar disk.

Design Evolution/Rationale

The concept employed in designing the H-Alpha telescope was based on the principle of reflecting telescopes. The ATM required a narrow field of view. The optical path of these telescopes was relatively long which conflicted with the physical limitation of the ATM. A folding system was therefore used to overcome this incompatibility. In this configuration, the physical length was shortened while the optical length of the telescope was retained by multiple reflections. Therefore, a Cassegrain telescope was used. Since H-Alpha radiation is the desired component of the spectrum, the telescope was fitted with a filter that transmitted only H-Alpha red light. But only a very narrow band about that wavelength was to be transmitted. Therefore, a filter using the concept of constructive and destructive interference, known as an interferometer, was used.

Because most of the filters exhibited erratic behavior as they aged and also the spectra pass band shifted, a Fabry-Perot interferometer was used. To make the interferometer wavelength selective in the H-Alpha red only, a bandpass red filter was placed in front of the interferometer so that only red light in the spectral region of H-Alpha was admitted to the interferometer. To achieve uniform spectral response from the Fabry-Perot assembly over the entire field required the use of two refractive telecentric corrector elements to correct the field off axis and render all exit chief rays parallel. Because it was necessary to provide a permanent record of the ATM pointing throughout the mission and also provide high quality photographs of the Sun in H-Alpha light, a film camera mounted at the second focal plane of H-Alpha 1 Telescope was used.

A vidicon TV camera mounted at the other image plane provided the crew with a TV display for detecting and pointing the ATM at significant features on the Sun to be studied by the other ATM experiments. A beam splitter was employed instead of a plane mirror since it was necessary to view and record simultaneously where the ATM was pointed. Since both H-Alpha telescopes required a variable field of view, zoom lens in the vidicon optical path was used. A set of fixed fiducial marks and a pair of movable cross-hairs located at the Cassegrain focal plane were provided for aiming reference.

Although these telescopes were of a new design, the development of the state of the art, design or manufacturing problems involving other systems necessitated several design changes and/or modifications. The numerous modifications that were made to the experiments from initial concepts through all phases of development and testing were documented in engineering change proposals modifications.

MANUFACTURING

Manufacturing of the H-Alpha experiments consisted of fabrication of components, assembly of the components into black boxes and assembly of the black boxes into completed instruments. Three units were assembled - the TMU, the prototype instrument and the flight instrument. The fabrication dates were as follows:

Unit	Date
TMU	May 1968 through November 1968
Prototype	June 1968 through March 1969
	May 1969 through November 1969
Flight	June 1968 through March 1969
	May 1969 through January 1970

A unique fabrication technique was the uniform coating of the heat rejection windows over an 8 inch clear aperture.

All units were subjected to both functional and environmental tests. The TMU was tested to verify instrument envelope dimensions, spar interface, and thermal control operation. The prototype instrument eas subjected to qualification tests and the flight instrument was subjected to pre-delivery acceptance tests. Numerous studies, tests, breadboarding, and special tests, such as the stability tests on the heat rejection windows and blocker filters, the flight design verification unit, contamination, zoom assembly simulated zero gravity test, film testing, and UV radiation testing were all accomplished to develop the design of the instrument. The results are documented in Perkin-Elmer Corporation reports 9656, 10994, 11481, NASA TMX-53666 and NASA CR-61364.

COMPONENT/END ITEM QUALIFICATION

The prototype instrument was subjected to qualification level tests for environmental requirements approximately 1.5 times those expected during the Skylab Mission as specified in 50M02408; Environmental Design and Qualification Test Criteria. Qualification tests consisted of vibration, thermal vacuum, shock, and acoustics testing. In addition, leak tests, electromagnetic compatibility tests, and outgassing tests were performed on the instrument. The qualification test program is described in end item test plans PE 9322. The results of these tests are documented in Perkin-Elmer reports 10092, 10782, 10745, 10977, 10980 and MSFC test reports 50M17578, 50M17468, and 54-TR-3-1-50M12740. Dates of the qualification testing were as follows:

Test Article	Test Date
Telescope	February 1970 through
Vidicon TV Camera	May 1967 through January 1973
Film Camera (S/N 306)	May 1967 through January 1973
Camera Electronics	May 1967 through January 1973

The prototype instrument successfully completed the qualification test program and an ATM Certificate of Qualification was approved on July 27, 1972 (telescope), on March 6, 1973 (film camera) and on April 17, 1972 (vidicon TV camera) with no open items. Some of the problems encountered during qualification testing and the corrective actions taken are listed below.

Problem	Corrective Action
Blocking filter used in conjunction with the Fabry-Perot filter underwent a transmission shift of as much as 1.5Å toward shorter wavelength after fabrication.	Blocking filters in flight telescopes were biased 0.5Å toward red to compensate for some of the shift. Longer baking cycles were used during fabrication in an attempt to achieve better stability.
Field test revealed the heat rejection window transmission band shifted about 100Å toward longer wavelengths causing a decrease in transmission of H-Alpha light. Evaluation of the windows showed the shift occurred after exposure to high humidity conditions.	Coating sequence was modified to produce a filter coating that was not affected by humidity.
Electronic control of the Fabry-Perot heater temperature was lost because of the failure of an operational amplifier. The failure was associated with a shift in the input offset voltage of the operational amplifier caused by excessive input voltage.	Circuit changes were made to include input circuit protection, isolation of a voltage-sensitive detuning connection to protect against accidental grounding, and an offset bias applied to a voltage regulator operational amplifier to guarantee proper start-up of the circuit.
The zoom lens contained movable elements that should allow the zoom lens to have a magnification range of 1X to 5X. The H-Alpha zoom lens showed a tendency to stick near the 1X position, expecially when the movable elements operated against gravity.	A 1.4X stop mechanism was added to the H-Alpha zoom assembly. This modification has been fully qualified. It reduced the maximum field of view of H-Alpha 1 from 22 arc-min to 16 arc-min.

Problem (Cont'd)	Corrective Action
Thermistors used in the Fabry-Perot filter TCS failed causing loss of temperature control or monitoring capability. The glass probe thermistors developed cracks in the glass coating which extended through to the bead and caused the resistance to change.	Potting method was modified to include the use of a soft encapsultant around bead which would transmit more uniform (hydro static) pressure to thermistor bead. Thermal cycling at higher than qualification levels did not result in failures of the thermistors soft-potted in a test cell.

ACCEPTANCE TEST

The flight instrument subjected to pre-delivery acceptance tests to levels anticipated during the mission in order to verify that the unit met the specified functional requirements and to verify the quality of fabrication. The acceptance test program is described in Perkin-Elmer end item test plan 9322. All testing was accomplished at the vendors facility and at Lockheed Solar Observatory, Rye Canyon, California. Testing on the complete H-Alpha 1 flight instrument was achieved between February 1971 and July 1971. Testing on the complete H-Alpha 2 flight instrument was achieved between January 1971 and March 1971. Test results are documented in Perkin-Elmer test reports 10667, 10880, 10616 and in MSFC test reports 50M17578, 50M17283, 50M17284, 50M17285, 50M17498.

Some of the problems encountered during acceptance testing and the corrective action taken are listed below.

Problem	Corrective Action
1. Image quality was degraded at outer field positions at film camera focal plans.	The degraded image quality was found to be caused by an out of tolerance element in the fixed relay lens. The element was reworked and subsequent acceptance testing verified that the problem had been corrected.

Problem (Cont'd)	Corrective Action
2. The TCS failed to control in the secondary mode.	TCS was modified.
3. The TCS sensing thermistors exhibited erratic performance.	An investigation into the TCS malfunction (items 2 and 3) was undertaken, and the design described in Perkin-Elmer Engineering Report No. 10731.
4. Two small pupil images appeared in the film camera plane and 1X vidicon plans.	Localized hot spots in the Fabry-Perot filter coating account for the images at the focal planes.
5. A pupil images in the 5X vidicon plane.	The pupil images represent state-of-the-art coating limitations that existed at the time of filter fabrication. A neutral density filter was installed in front of the vidicon to remove the pupil image in the 5X vidicon plane.
6. A crescent-shaped bright area in the 5X vidicon plane.	The crescent shaped bright area was removed by modifying a zoom lens retainer to include knife-edge baffling.
7. Stray light enter the vidicon at the vidicon/telescope interface.	Stray light at the vidicon/telescope interface was eliminated by additional baffling.
8. Image at video display did not hold focus at all zoom positions.	The defocusing condition was corrected by realigning the zoom lens assembly and modifying the zoom lens mirror mount.
9. Nonuniform illumination at the film camera focal plane.	Nonuniformities in the film camera plane were attributed to the beamsplitter coating which was angle sensitive. This condition was corrected by substituting a metallic coating for the beam-splitter dielectric

Problem	Corrective Action (Cont'd)
	coating. Following disposition of these problems, the telescope was evaluated by the PIs at Lockheed solar observatory and performance was considered acceptable.

All acceptance test/review were completed and applicable problems resolved.

SYSTEM VERIFICATION PROGRAM

System verification testing was performed on the H-Alpha prototype and flight instruments in accordance with 50M02425, ATM Test and Checkout Requirements and Specificaions (TCRSD) to determine conformance with design specifications. The ATM test programs for the prototype and flight instruments were essentially the same except for lower vibration levels in the vibration test and pre-launch tests for the flight unit.

System Verification (Prototype)

In-Process Testing - After delivery of the H-Alpha telescopes from the manufacturer, the instruments were mounted to the ATM spar and connected to spare cabling. In-process tests were then performed to verify integrity of signals to and from the experiment test console through the spar cabling to the experiments. The test consisted of a complete functional verification of all experiment subsystems. The following problems were identified.

Both the movable reticle assembly and the zoom assembly on H-Alpha 1 and H-Alpha 2 had wiring reversals within the telescope systems. The problems were corrected by wiring changes in the ATM networks.

Post Manufacturing Checkout - The H-Alpha prototype instruments were tested during PMC to verify satisfactory performance of the instruments, film camera, and system interfaces. Emphasis was given to EMI and EMC testing with all ATM systems operating.

The only H-Alpha problem noted was contamination on the vidicon face. This was corrected at refurbishment.

Thermal Vacuum Testing - Thermal vacuum testing for the H-Alpha telescopes was the same as for the S052 instrument (reference Section XI).

During thermal vacuum testing, data from the H-Alpha 1 telescope showed that the average rear tube temperature was below the lower operational limit of 17.8°C. During cold steady state conditions the rear tube temperature stabilized at 17.4°C compared with a 17.8°C lower operational limit. At the termination of the cold transient condition the tube temperature was 17.1°C, but it had not fully stabilized. During the hot case simulations the rear tube temperature remained above the 17.8°C lower limit.

The Fabry-Perot filter TCS maintained the filter between 38.9°C and 39.0°C. Assuming a 9.6°C tolerance applied to the set point temperature of 36.9°C, indicated that the actual TCS set point temperature was approximately 2.0°C above the design value.

Thermal performance of the H-Alpha 2 telescope was satisfactory with the exception of a slightly high Fabry-Perot filter temperature throughout the test. The Fabry-Perot filter temperature ranged between 40.6 and 40.7°C compared with a design set point temperature of 39.5°C and an upper limit of 40.0°C. This was attributed to a maladjusted set point.

Post-thermal vacuum testing was performed to verify that no adverse effects occurred as a result of the space simulated environment. Problems identified duirng post-thermal vacuum testing were as follows:

H-Alpha 1 television was inoperative and H-Alpha 1 temperature measurement was noisy. These items were repaired during refurbishment.

No H-Alpha 2 problems occurred.

Post Vibration Testing - Following vibration to launch levels, the H-Alpha telescopes were first tested to verify the instrument was operational. No anomalous conditions were detected.

An all system test was performed to determine if any interaction existed between subsystems during highly active functional conditions, and to verify bus redundancy, and to verify all other functions not detected during instrument testing. No anomalies were reported on either H-Alpha 1 or 2.

System Verification (Flight)

In-Process Testing - In-process testing on the flight instruments consisted of the same functional verification as was run on the prototype. Contamination was noted on the H-alpha 1 vidicon. The unit was cleaned and retested successfully.

Post-Manufacturing Checkout - PMC was conducted on the flight instruments to verify integration integrity of all ATM systems in all operational modes. Tests were the same tests conducted on the prototype. The only anomalous conditions reported was the operate light on H-Alpha 1 went off for approximately 1 second. No cause was found.

Thermal Vacuum Testing - Pre-thermal vacuum testing was performed to verify system readiness.

Thermal vacuum testing was performed to verify proper operation during simulated orbits in a thermal vacuum environment. Except for the Fabry-Perot filter assembly, the telescope temperature was within operational limits. The Fabry-Perot operated above its upper temperature limit throughout the test. The average temperature of the three Fabry-Perot measurements was 37.0°C during activation and 37.3°C during hot orbital transient. The allowable upper limit is 36.8°C.

The rear tube which operated out of limit during the cold conditions of the prototype test performed satisfactorily during this test.

H-Alpha 2 performance was satisfactory except for the Fabry-Perot filter assembly which operated above its upper temperature limit of 36.2°C at times during the test. The average of the three measurements exceed the upper limit by 0.2°C during hot orbital transient and 0.3°C during Z-local vertical simulations.

Post-thermal vacuum testing was conducted to verify that exposure to the space-simulated environment had not caused any instrument degradation. The only problems encountered were Alpha 1 frames remaining counter miscounts and further occurrence of the operate light blinking. These problems were apparently caused from noise generated within the ATM.

Pre Launch Testing (KSC) - Upon arrival at KSC, testing was performed in the Operations and Checkout Building to verify correct ATM operation prior to assembly to the Skylab. Significant H-Alpha tests were the interface verification test, Fabry-Perot laser test, all systems test, and crew compartment fit and function. The following problems were encountered. With the H-Alpha 1 frames/minute switch at 4 frames/minute, the camera operated at 7 frames/minute. A PC card was replaced in the camera electronics and retested satisfactorily. The ready/ operate light was erratic. The problem was traced to a faulty film magazine. The magazine was replaced and retested successfully.

VAB testing occurred in two phases; ATM alone, and ATM with other modules. VAB testing consisting of C&D console interface test, end-to-end systems test, swing arm overall test, mission simulation flight readiness test, subsystem bus redundancy, and electrical close out. The only anomalous condition reported was extra decrements on the H-Alpha 1 frames remaining counter. This condition was accepted for flight.

SECTION XX. ATM CREW EVA EQUIPMENT

SYSTEM DESCRIPTION AND DESIGN RATIONALE

The Extravehicular Activity (EVA) equipment required for the completion of the ATM EVA objectives is divided into three categories: the crew translation hardware system; the film handling and transfer equipment; and the workstations.

Crew Translation

The crew translation hardware system (figure 20-1) consisted of handrails, foot restraints, and life support umbilical clamps. The purpose of the handrails was to provide a translation route for the crew from the airlock latch to the ATM workstations. Handrails were provided in the fixed airlock shroud area, and on the deployment support truss to a point adjacent to the ATM outrigger with the ATM in the deployed position. The ATM handrails consisted of a single handrail on the outrigger, a single handrail from the outrigger to the center workstation, a dual handrail from the outrigger to the transfer workstation at the solar shield, and a single handrail from the transfer workstation to the Sun-end workstation. Foot restraints were provided at the workstations, where the crewmen were required to be secured in order to perform hand tasks. Life support umbilical clamps were provided at the workstations to aid in managing the umbilicals.

The design criteria for the handrails were that they be designed for an ultimate load of 600 pounds applied at any location, that the rails, supports, and fasteners have no burrs or sharp edges, and that the routing of the rails be constrained to provide adequate clearance for the payload shroud in the launch configuration.

In the design, protruding fasteners were avoided wherever possible. Where it was not possible, the protrusions were covered with silicone rubber (RTV-140) to eliminate sharp edges and burrs. The cross section of the handrails was the standard Apollo size, as specified in the CRS, and was selected as being the optimum for grasping with the pressure-suit gloved hand.

The design criteria for the foot restraints were that they be designed for a 100-pound concentrated load at the heel clips, a torsional load of 1800 inch-pounds, and they fit the boot sizes of all crewmen. The critical fit of the boot to the foot restraint was the heel clip. The heel was the same size for all boots, and a heel clip was designed with the critical dimensions being controlled by an Interface Control Document. In addition

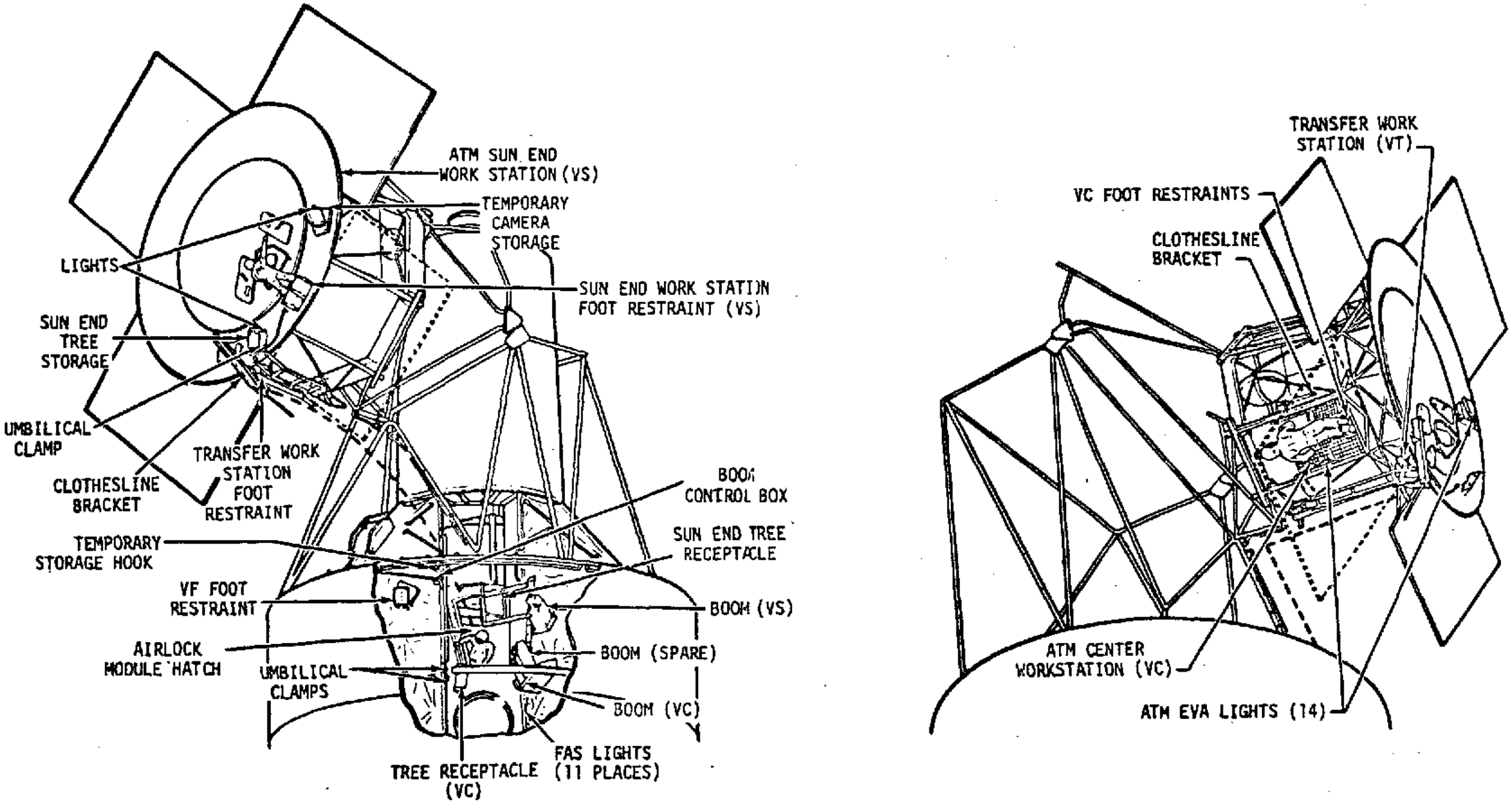


Figure 20-1. Crew System Aids

to the heel clip, a loose fitting toe clip was provided which allowed clearance for the largest boot size. The heel and toe clips were fastened to a 0.25-inch plate to provide a smooth surface for movement of the heel and sole in entering the restraint. The foot restraints were secured to the ATM structure at the center, transfer and Sun-end workstations.

The life support umbilical clamps were designed with a fixed jaw and an over-center, spring-loaded, movable jaw which could be opened for insertion of the umbilical. If fully opened, the clamp would remain open until it was closed. The surfaces of the jaws which contacted the umbilical were covered with rubber to provide a friction surface and to protect the umbilical.

Film Handling

The film handling and transfer equipment included the film trees and receptacles, the film transfer booms and clothesline film transfer systems, and a temporary stowage container.

The film trees were pallet-type devices used in handling the film cameras or magazines. The design rationale for the film trees was to provide a frame to which film cameras or magazines could be attached to expedite their handling during retrieval/replacement operations. The loads criteria for the trees were that they take a load of 100 pounds applied at any place on the tree when the tree was mounted on a receptacle.

The tree for servicing the center workstation was loaded inside the vehicle during EVA preparation, as was the tree for servicing the Sun-end workstation. During EVA, the center workstation tree was secured on a receptacle at the fixed airlock shroud workstation, and the loaded S052 film camera, or the S054, S056, or H-Alpha 1 film magazine, was removed from the tree, attached to the film transfer unit, and transferred individually, to the center workstation. In a like manner, the exposed units were returned and secured on the tree.

The tree for servicing the Sun-end workstation, containing the loaded S082A and S082B film cameras, was attached to the film transfer unit and transferred to the Sun-end workstation. There, the tree was installed on a receptacle.

The film tree receptacle was a metal plate with a hole which could accept a spring-loaded latch at the base of the tree, and provided an effective means of securing the tree at a desired location.

Three film-transfer booms were provided as part of the equipment of the fixed airlock shroud workstation. The clothesline film-transfer system was ATM equipment, and served the same purpose as the film-transfer booms.

There were two clothesline units, each unit being an endless-type clothesline, with pulleys, tether hooks and hardware for attachment to special brackets. The units were manually deployed. One end of each unit was attached at the fixed airlock shroud workstation. The other end was attached to a clothesline pole at the ATM workstation. The pole tips were a considerable distance out from the workstations, which required a long clothesline pole, and dictated that the poles be in a stowed position for launch, and be deployed for use. The poles were designed for a maximum load of 300 pounds applied to the tip after deployment.

One unit was designed to transfer a loaded film camera or film magazine to the center workstation and return the camera or magazine containing exposed film. The second unit was designed to transfer the film tree holding the loaded S082A and S082B film cameras to the Sun-end workstation and return the tree holding exposed film cameras.

A temporary stowage container was located at the Sun-end workstation, and was designed to be used for temporary stowage of the S082A or S082B film camera during film replacement operations.

Workstations

The ATM workstations were the center workstation, the transfer workstation, and the Sun-end workstation.

The ATM center workstation was designed for the retrieval or replacement of film in the S052, S054, S056, and H-Alpha 1 experiments. The rationale used was to provide foot restraints for the crewman, placed such that he could reach the film retrieval doors in the canister sidewall, operate the roll control panel for access to the film retrieval doors, accept and replace cameras or magazines from either the film transfer boom or clothesline unit, and to provide adequate lighting for performing these tasks. Power to the lights was provided by redundant buses, to preclude loss of lighting caused by a single bus failure.

The transfer and Sun-end workstations were designed for retrieval or replacement of the S082A and S082B film cameras. The rationale used was to provide foot restraints at the transfer workstations, where the crewman received the tree from the film transfer boom or clothesline unit. The foot restraints were located such that the crewman could receive the tree and secure it on a receptacle located on the solar shield. The crewman could then translate to the Sun-end workstation by means of the handrails provided, and proceed with the task of retrieval or replacement of the S082A or S082B film cameras. In the case of retrieval only, the camera was removed from the instrument through the film retrieval door, and attached to the tree. In the case of replacement, a temporary stowage container was provided for the crewman, so that he was required to handle only one film camera at a time.

Again, adequate lighting was provided for the crewman to perform the tasks, and the lights were powered by redundant buses.

CREW INTERFACE/TEST PROGRAM

Crew Translation

In the test program, the handrails were installed on the ATM vibroacoustic test article and no problems were found. The strength of the handrails was verified by analysis, and their functional adequacy was verified by neutral bouyancy simulation testing.

Vibration testing of the foot restraints was waived, based on previous experience and the component structural analysis. The structural integrity of the foot restraints and their installation were verified by analysis. A qualification test foot restraint was checked at ambient, low and high temperatures with a JSC-supplied boot gage which represented maximum and minimum toleranced boot heel clips, and no problems were found. The functional adequacy of the foot restraints were verified by neutral bouyancy simulation testing.

In the testing of the life support umbilical clamps, a qualification test unit (flight design) was functionally cycled 150 times, which was approximately 5 times the expected flight usage. In addition to the ambient temperature testing, the unit was also cycled at high and low temperature extremes. During these tests, the clamp was closed on a section of simulated flight umbilical, and no problems were encountered.

Based on experience in the qualification testing of EVA components, a waiver was granted on vibration testing of the umbilical clamps considering that the structural integrity was adequate by design. Their functional adequacy was verified by neutral bouyancy simulation testing. Also during the neutral bouyancy simulations, it was determined that film retrieval/replacement at the Sun-end workstation could be accomplished without using the clamp. However, the clamp was left on the ATM for use if it should be required in an unanticipated situation.

Film Handling

The film trees were stowed in the MDA for launch. Both trees were subjected to vibration tests in their stowed configuration and no problems were found. The structural integrity of the trees was verified by analysis.

In addition to the vibration tests, functional tests were made on the qualification test units. The trees were latched and locked to their receptacles under ambient, low and high temperature extremes. The cameras and magazines were installed and removed. In all of the functional tests, the operations were repeated five times the scheduled use. No problems were encountered.

The clothesline film transfer units were functionally tested as a system, and the components were individually tested. The center workstation clothesline pole was vibration tested on the vibroacoustic test article and then functionally tested by deploying it five times the maximum anticipated flight usage at ambient, low and high temperature extremes. The Sun-end clothesline pole was vibration tested on a test fixture and then functionally tested in the same manner as the center workstation pole.

A section of the clothesline cord containing a splice was tested for strength after fabrication and then subjected to the equivalent of 2000 hours of solar exposure (in a vacuum), and then retested. The average load at failure for 3 samples initially was 427 pounds. After solar exposure, 3 samples failed at an average load of 352 pounds. Based on these tests, the clothesline material was considered to be satisfactory.

The structural integrity of the clothesline hooks was verified by analysis, and their functional adequacy was verified by cyclic testing at ambient, low and high temperature extremes.

Workstations

In the case of the workstations, crew compartment fit and functional (C^2F^2) tests were conducted. These tests verified the component operation, and the component/subsystem and crewman/equipment interfaces.

The center workstation was subjected to 18 1-g tests and 28 neutral bouyancy tests. The transfer workstation had no 1-g tests, but 15 tests were conducted in the neutral bouyancy facility. The Sun-end workstation was subjected to 16 1-g tests and 19 tests in neutral bouyancy.

SECTION XXI. CONTAMINATION CONTROL PROGRAM

A Contamination Control Plan was incorporated by Marshall Space Flight Center to ensure that the Apollo Telescope Mount certified cleanliness level was not compromised. This plan was two-fold; first, to keep optic degradation, due to material outgassing and redepositing on the optics, to a minimum, and second, to prevent particulate contamination of the experiment field of view.

The above plan was initiated early in the program. The plan provided for the control and testing of material to be used on the ATM and for the control of hydrocarbon and particulate matter during assembly, testing, handling, transportation and prelaunch operation.

MATERIAL CONTROL

All candidate material to be utilized on the ATM were presented to S&E-ASTN-MEV and S&E-ASTR-PR Laboratories in accord with the responsibilities and test criteria contained in the ATM Optical Environment Contamination Control and Abatement Plan. All organizations or contractors performing testing and desiring that a material be accepted were required to submit their test data to S&E-ASTN-MEV or S&E-ASTR-PR for concurrence and submittal to the board chairman. The criteria used to determine acceptable or unacceptable material was contained in the ATM Optical Environment Contamination Control and Abatement Plan, which covered thermal degradation, weight loss, and identification of outgas products. After reviewing the test data, a determination was made that material was acceptable, acceptable with certain restraints, or unacceptable for use. The data for each sample, accepted or rejected, was compiled and published in the "ATM Material Control for Contamination Due to Outgassing" document (50M02442). This was to: 1) provide a reference document for approval or disapproval, and 2) to provide engineering designers a usable material selection index.

CLEANLINESS REQUIREMENTS

In order to comply with the ATM cleanliness requirements as imposed by 50M02412, the ATM assembly, test and checkout was performed in environmentally controlled facilities (class 10K and 100K cleanrooms) as follows:

1. Rack and solar arrays assembly - 100K.

2. Experiment package assembly - 10K.

3. Final assembly and test - 10K (except vibration test - 100K).

The hydrocarbon and particulate contamination was controlled by:

1. All components being cleaned for LOX application.

2. All components were subjected to thermal vacuum bake.

3. All personnel were required to wear gloves when handling flight hardware.

The status of the facility environment was monitored daily for particulate content during routine operation. Hydrocarbon level was checked weekly after initial cleanroom certification. The facility temperature and humidity was measured and recorded continuously with automatic devices. Appropriate records were maintained at all times. Facility cleanliness levels were verified during operation by monitoring the air velocity and filter pressure drop, controlling the entry of personnel and materials, and utilizing manual methods for periodic counts per SAE-ARP-743A. If, at any time from assembly to launch, the cleanliness or environmental levels dropped below the specified requirements, the following procedure was followed:

1. All operations were stopped.

2. Appropriate action was initiated per contingency mode procedures to maintain the required cleanliness, temperature, and relative humidity. The ATM was bagged in nylon for the required length of time. The canister was purged. All purge gas was cleaned and dried in accordance with procedure specified in 50M02538.

3. Failure was corrected in environmental equipment.

4. Operations resumed after failure was corrected.

Other precautions utilized in manufacturing, testing and prelaunch activities included:

1. Double bagging, with antistatic nylon of all components after cleaning and after vacuum bake to maintain cleanliness.

2. Purging of the experiment package with dry N_2 at all times when not in 10K cleanroom (except vacuum testing).

3. Internally purging selected experiments at all times (except thermal vacuum testing).

4. Double bagging, with antistatic nylon, of the experiment package and the rack assembly during handling and transportation.

5. Transporting ATM in shipping container certified to maintain the 100K cleanroom requirement.

6. Utilizing membrane to isolate the ATM from the payload shroud purge area (up to 48 hour prior to liftoff).

7. Constructed cleanroom to enclose ATM during VAB operations.

8. During vibration testing ATM was double bagged and installed in a 100K tent with temperature and particulate control and N_2 purge on the canister and experiments.

9. Maintaining access control to all cleanrooms.

APPROVAL

MSFC SKYLAB

APOLLO TELESCOPE MOUNT

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

Rein Ise JUL [illegible] 1974
Manager, Skylab Program Office

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