NASA TECHNICAL MEMORANDUM

April 1974

NASA TM X-64812

MSFC SKYLAB MULTIPLE DOCKING ADAPTER
Vol. I

Skylab Program Office

NASA

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

(NASA-TM-X-64812) MSFC SKYLAB MULTIPLE DOCKING ADAPTER, VOLUME 1 Final Report (NASA) 461 p HC $26.25 CSCL 22B

N74-26328

Unclas
G3/31 40531

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TMX 64812	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE MSFC Skylab Multiple Docking Adapter Vol. I		5. REPORT DATE April 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, AL 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum Final
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Airlock/Multiple Docking Adapter Project Office

16. ABSTRACT

This report presents the history of the development of the Skylab Multiple Docking Adapter (MDA), NASA Contract No. NAS8-24000, from initial concept through its final design, related test programs, mission performance, and lessons learned.

The MDA performed with no significant problems throughout the three manned Skylab missions.

NOTE: Vol. I presents section 1 and 2
Vol. II presents sections 3 through 13

17. KEY WORDS	18. DISTRIBUTION STATEMENT Unclassified - Unlimited L. A. McCool L. McCool Project Manager, Airlock/MDA

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	461	NTIS

TABLE OF CONTENTS

Volume I

VOLUME II

LIST OF ILLUSTRATIONS

Volume I

VOLUME II

LIST OF TABLES

LIST OF ACRONYMS

AAP: Apollo Applications Program
ADP: Acceptance Data Package
AETL: Approved Engineering Test Laboratories
AID: Air Interchange Duct
ALC: Audio Load Compensator
AM: Airlock Module
APCS: Attitude Pointing and Control System
AR: Action Request; Anomaly Report
AS&E: American Science and Engineering
ATM: Apollo Telescope Mount
AWS: Automated Wiring System
BCA: Boresighted Camera Array
BI/LCA: Backup Inverter Lighting Control Assembly
B/U: Backup

CACC: Corrective Action Control Center
CAPS: Corrective Action Problem Summary
CBRM: Charger Battery Regulator Module
CCB: Configuration Control Board
CCBD: Configuration Control Board Directive
CCCHA: Crewman Communication Control Head Assembly
C^2F^2: Crew Compartment Fit and Function
CCOH: Corrosive Contaminants, Oxygen and Humidity
CCSR: Crew Compartment Stowage Review
CCU: Crewman Communication Umbilical
CD: Countdown
CDDT: Countdown Demonstration Test
CDR: Commander; Critical Design Review

List of Acronyms (Continued)

CEI: Contract End Item
CFE: Contractor Furnished Equipment
CIL: Critical Item List
CLLCD: Critical and Limited Life Component Drawing
CN: Change Notice
COFW: Certificate of Flight Worthiness
CORT: Certificate of Readiness to Test
CRS: Cluster Requirements Specification
CS&A: Configuration Status & Accounting
CSCU: Coolant System Checkout Unit
CSM: Command and Service Module
CSR: Crew Station Review
CTU: Command Transfer Unit
CWA: Conference Work Area
CWG: Constant Wear Garment
C&D: Control and Display
C&DM: Configuration and Data Management
C&W: Caution and Warning

DA: Deployment Assembly
DAC: Data Acquisition Camera
DAR: Deviation Approval Request
DAS: Digital Address System
DAT: Design Assurance Testing
DCN: Design Change Notice
DC&R: Discrepancy Check & Report
DCS: Digital Command System
DEA: Digital Electronics Assembly
DMU: Development Mockup
DQLS: Data Quick Look Station

List of Acronyms (Continued)

DR: Discrepancy Report
DRL: Data Requirements List
DSR: Denver Support Room
DRSS: Discrepancy Reporting System Squawks
DTA: Dynamic Test Article

ECF: Electrical Conductive Film
ECP: Engineering Change Proposal
ECR: Engineering Change Request
ECS: Environmental Control System
EDCS: Engineering Design Change Schedule
EDDU: EREP Diagnostic Downlink Unit
EDP: Engineering Data Package
EIS: End Item Specification
EL: Electroluminescent Lighting
EMC: Electro Magnetic Compatibility
EMI: Electro Magnetic Interference
EMU: Engineering Mockup
EREP: Earth Resources Experiment Package
ESE: Experiment Support Equipment
ESS: Experiment Support System
ETH: Engineering Test Hardware
ETO: Engineering Test Order
ETS: Electrical Test Set
EU: Electronics Unit
EVA: Extra Vehicular Activity
EWO: Engineering Work Order

FA: Failure Analysis
FAIR: Failure Analysis Investigation Report

List of Acronyms (Continued)

FAS:	Fixed Airlock Shroud
FCE:	Flight Crew Equipment
FIV:	Functional Interface Verification
FMC:	Forward Motion Compensation
FMEA:	Failure Mode Effects Analysis
FOMR:	Flight Operations Management Room
FPM:	Feet Per Minute
FRR:	Flight Readiness Review
FSA:	Fire Sensor Assembly
FSCP:	Fire Sensor Control Panel
FTTH:	Flight Type Training Hardware
GFE:	Government Furnished Equipment
GFP:	Government Furnished Property
GSE:	Ground Support Equipment
GSFC:	Goddard Space Flight Center
$H\alpha$:	Hydrogen Alpha
HAO:	High Altitude Observatory
HCO:	Harvard College Observatory
HOSC:	Huntsville Operations Support Center
ICD:	Interface Control Drawing
ICWG:	Interface Control Working Group
IDR:	Interim Discrepancy Report
IFM:	In Flight Maintenance
IFOV:	Instantaneous Field of View
IFTU:	Interface Functional Test Unit
I/LCA:	Inverter Lighting Control Assembly
INC:	Installation Notice Card

List of Acronyms (Continued)

IR: Infra Red

IRN: Interface Revision Notice

ISR: Incremental Summary Review

ISS: Input Signal Simulator

IVA: Intra Vehicular Activity

I&C: Instrumentation and Communication

JSC: Johnson Space Center

KSC: Kennedy Space Center

LC: Launch Complex

L/C: Liaison Call

LCCU: Lightweight Crew Communications Umbilical

LM: Lunar Module

LM&SS: Lunar Mapping and Survey System

LOE: Log of Exceptions

LOF: Lack of Fusion

LOLI: Limited Operating Life Item

LTF: Leak Test Facility

LWHS: Light Weight Head Set

MAR: Mission Action Request

MARS: Martin Automatic Reporting System

MCC: Mission Control Center

MDA: Multiple Docking Adapter

MDAC-(E)(W): McDonnel Douglas Astronautics Corporation (East)(West)

MEF: Multipurpose Electric Furnace

MER: Mission Evaluation Room

MEWG: Mission Evaluation Working Group

MI: Modification Instructions

List of Acronyms (Continued)

MMC: Martin Marietta Corporation
MOPS: Mission Operation Planning System
MPC: Manual Pointing Controller
MPF: Material Processing Facility
MPP: Manufacturing Process Plans
MPS: Mission Preparation Sheets
MRB: Material Review Board
MRD: Maintenance Requirements Document
MRR: Material Review Reports
MSA: Mount Support Assembly
MSFC: Marshall Space Flight Center
MSG: Mission Support Group
MSGL: Mission Support Group Leader
MSPF: Multispectral Photographic Facility
MUTH: Mockup Training Hardware
MUX: Multiplexer

NA: Not Applicable
NASA: National Aeronautics and Space Administration
N/B: Neutral Buoyancy
NBF: Neutral Buoyancy Facility
NBG: Non Burning Gunk
NR: Nonconformance Report
NRL: Naval Research Laboratory

OA: Orbital Assembly
OCP: Operational Checkout Procedure
OD: Operating Director
OM&H: Operation, Maintenance and Handling Procedure
OSM: Operations Support Manager

List of Acronyms (Continued)

OV:	Orbiting Vehicle
OWS:	Orbital Workshop
O&C:	Operations and Checkout
PAM:	Pulse Amplitude Modulation
PCM:	Pulse Code Modulation
PCN:	Procedure Change Notice
PCR:	Procedure Change Request
PDA:	Power Distribution Assembly
PIE:	Product Integrity Engineer
PIRN:	Preliminary Interface Revision Notice
PIRR:	Parts Installation/Removal Record
PIT:	Pre Installation Test
PLT:	Pilot
PRT:	Partial Retest
PS:	Payload Shroud
PTFE:	Polytetrafluoroethylene
PTR:	Problem Tracking Request
PWM:	Pulse Width Modulator
P&S:	Pack & Ship
QC:	Quality Control
QE:	Quality Engineering
QTSS:	Qualification Test Summary Sheet
RCP:	Rotation Control Panel
RECP:	Record Engineering Change Proposal
RID:	Review Item Discrepancy
RM:	Resupply Module
RMO:	Resident Management Office

List of Acronyms (Continued)

RNBM: Radio Noise Burst Monitor
RTV: Room Temperature Vulcanizing

SAL: Scientific Airlock
SAS: Solar Array System
SAT: Systems Assurance Test
SCN: Specification Change Notice
SEDR: Service Engineering Department Report
SE&I: Systems Engineering and Integration
SFIV: System Functional Interface Verification
SFP: Single Failure Point
SFU: Solar Flux Unit
SIA: Speaker Intercom Assembly
SL: Skylab
SLCN: Stowage List Change Notice
SOW: Statement of Work
SPS: Service Propulsion System
SPT: Science Pilot
SSB: Space Support Building
SSFIV: Super System Functional Interface Verification
STACR: System Test and Checkout Requirements
STDN: Spacecraft Tracking and Data Network
STS: Structural Transition Section
STU: Skylab Test Unit
SWS: Saturn Workshop
S&E: Science and Engineering

TACS: Thruster Attitude Control System
TCN: Test Change Notice
TCOP: Test and Checkout Plan

List of Acronyms (Continued)

TCP:	Test and Checkout Procedure
TCRSD:	Test and Checkout Requirements and Specification Document
TCS:	Thermal Control System
TDR:	Time Domain Reflectometer
TIP:	Trainer Interface Panel
TIR:	Temporary Installation Record
TLM:	Telemetry
TPS:	Test Preparation Sheet
T/R:	Tape Recorder
TU:	Transport Unit
TVIS:	Television Input Station
UCR:	Unsatisfactory Condition Report
USB:	Unified "S" Band
UV:	Ultra Violet
VAB:	Vertical Assembly Building
VCO:	Voltage Controlled Oscillator
VITS:	Vertical Internal Test Signal
VLDU:	Volumetric Leak Detection Unit
VPP:	Volts Peak to Peak
VSWR:	Voltage Standing Wave Ratio
VTF:	Vertical Test Facility
VTR:	Video Tape Recorder
VTS:	Viewfinder Tracking System
WITS:	West Integrated Test Stand
WLC:	White Light Coronograph
X-REA:	X-Ray Event Analyzer
XUV:	Extreme Ultra Violet

1. INTRODUCTION

1.1 PURPOSE

This report was compiled to provide a historical record of the development, manufacturing, test, and use of the Skylab Program's Multiple Docking Adapter (MDA).

1.2 SCOPE

This report discusses the MDA from the identification of the need for a multiple docking capability on the Skylab program to its final mission configuration. Significant events discussed include the evolution from a wet to dry workshop configuration, the growth in complexity (primarily through the addition of experiments and experiment support capabilities), the build and test cycle and the performance during the mission on orbit.

1.3 SUMMARY

1.3.1 Design Goals

The MDA was originally conceived to extend the capability of the Skylab program's orbiting workshop to allow selected spacecraft to rendezvous and dock with the laboratory. Since that initial concept the functional capability of the MDA was expanded as discussed in paragraph 2.1.1 herein. At the time of Skylab -1 (SL-1) launch, which placed the workshop in orbit, this growth had led to the development of a spacecraft with the following functional capabilities:

A. Docking Facility - An axial docking port was provided for normal Command & Service Module (CSM) docking and a radial docking port was provided for emergency rescue or backup docking use.

B. Environmentally Controlled Work and Stowage Area - The environmentally controlled work and stowage area capabilities and features were:

- A pressurized passageway between the docked CSM and the Airlock Module/Orbital Workshop (AM/OWS).
- Work stations to support crew operations.
- Mounting and operation facility for experiments.

- Mounting and operation facility for the Apollo Telescope Mount (ATM) Control and Display Console.
- Control and monitoring for the Radio Noise Burst Monitor (RNBM) and Proton Spectrometer.
- Crew intercommunication and caution & warning facility.
- Cluster TV control.
- Mounting and operation of the 16 mm Data Acquisition Camera (DAC).
- Passive Thermal Control (external insulation).
- Active Environmental Control (atmospheric ventilation, orbital venting, and external radiators).
- Optical windows.
- Meteoroid protection.
- MDA lighting.
- Structural mounting (external) for the L-Band Antenna.
- Signal conditioning and instrumentation sensors.
- Stowage for cluster hardware and commodities.

C. Interface Between the Saturn Workshop (SWS) and the CSM - The MDA provided a physical interface between the SWS and the CSM to accomplish the following:

- Access between the CSM and the AM/OWS.
- Distribute electrical power to the CSM.
- Transfer of conditioned air from the MDA to the CSM.
- Transfer of control, instrumentation, TV, and communication signals between the MDA/AM/OWS and the CSM.

1.3.2 Mission Results

This discussion briefly summarizes the performance of the MDA module during the Skylab mission. The criteria employed are the three functional capabilities identified in the preceding paragraph.

A. Docking Facility - The MDA axial docking port facility was utilized by each CSM crew in accessing the orbiting laboratory. There were no anomalies reported in the operations of this port facility. The first crew did experience some difficulty in obtaining a hard dock with the MDA but this was resolved in real time and corrected through CSM probe and docking procedure modifications.

The MDA radial docking port was provided for contingency CSM docking during the mission. Its use was not required and therefore the configuration of this port remained unchanged from that tested during pre-launch operations at Kennedy Space Center (KSC).

B. Environmentally Controlled Work and Stowage Area - The performance of the MDA in providing accessible work stations, crew protection and comfort, and adequate stowage for designated hardware was within the limits identified in the Contract End Item (CEI) Specification and all applicable Interface Control Drawings (ICD's).

The environment was, with the exception of a brief period early in the mission, within the comfort zone of the crew. The exception occurred during the employment of contingency thermal managment techniques that were imposed to alleviate the excessive temperatures in the OWS. The high temperatures experienced were the direct result of OWS Meteoroid Shield and Solar Array failures that occurred during launch. These failures left the OWS vulnerable to solar heat radiation and effectively reduced the SWS power by one half. SWS reorientation to reduce the OWS temperature rise imposed further limitations on available power. This effect restricted the use of the MDA heaters with a resultant drop in MDA internal temperatures. Once the OWS problems had been significantly reduced through parasol deployment and particularly after deployment of the remaining Solar Array System (SAS) Wing, when power was no longer critical, the MDA heaters were activated and internal temperatures were restored to normal.

The remainder of the MDA, as a work and stowage area, had been verified prior to launch. This effort proved to be satisfactory since no significant comments were received from the three crews that would suggest poor access, limited work envelopes, limited stowage, inadequate electrical interfaces, or potentially dangerous conditions existed in the MDA.

C. Interface between the SWS and the CSM - The MDA interfaces with the SWS and the axially docked CSM were nominal throughout the Skylab mission. Crew access was provided from/to the CSM and the AM/OWS without incident. AM/OWS and MDA interfaces included electrical, caution & warning, instrumentation, communications, atmospheric and physical/structural functions. No problems were observed or reported with these interfaces.

2. DISCUSSION

The MDA was first conceived during the development of the "Wet Workshop" (SIVB used as a normal propulsive stage during boost, passivated and converted to a habitable laboratory on-orbit) concept to provide the capability for docking more than one spacecraft to the orbiting workshop. As discussed in the following paragraphs, this concept evolved during subsequent months to provide additional laboratory capabilities and ultimately grew into a prime experiment laboratory for use during the Skylab Mission. This section traces that evolution through the identification of major program milestones and concludes with a detailed description and discussion of each of the "as-flown" MDA systems including those lessons learned on the program.

2.1 MODULE DESCRIPTION

2.1.1 History/Design Evolution

The requirement for a multiple docking capability for the orbital laboratory was first identified on the Apollo Applications Program (AAP) in the summer of 1966. The development of this concept into the MDA hardware is illustrated in Figure 2.1.1-1 and is chronologically discussed below. Except for the events of 1966, which reflected a rapid evolution of the concept, this discussion is limited to the identification of major events that occurred year by year. Those related to hardware should not be construed as contractual events but rather as the general development of concepts that were either expanded later or deleted.

A. Year 1966 -

(1) Initial concept developed with 2 radial ports and 1 axial port to accommodate:

- LEM/Apollo Telescope Mount (LM/ATM).
- Relief/Replacement crew in CSM.
- Prime CSM (Axial port).

(2) Initial concept was approximately 38 inches in length (main tunnel).

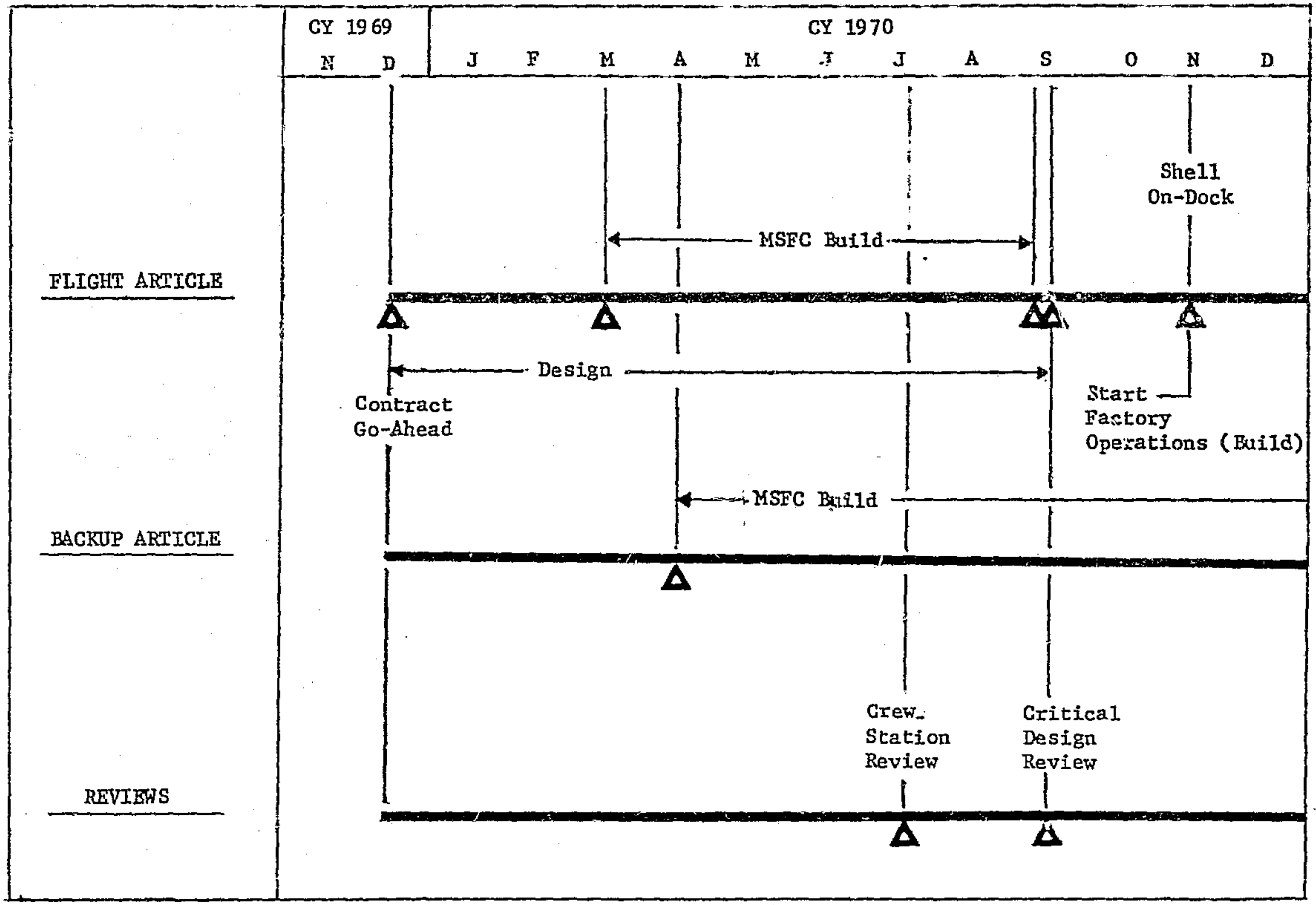


Figure 2.1.1-1 MDA Program Historical Events

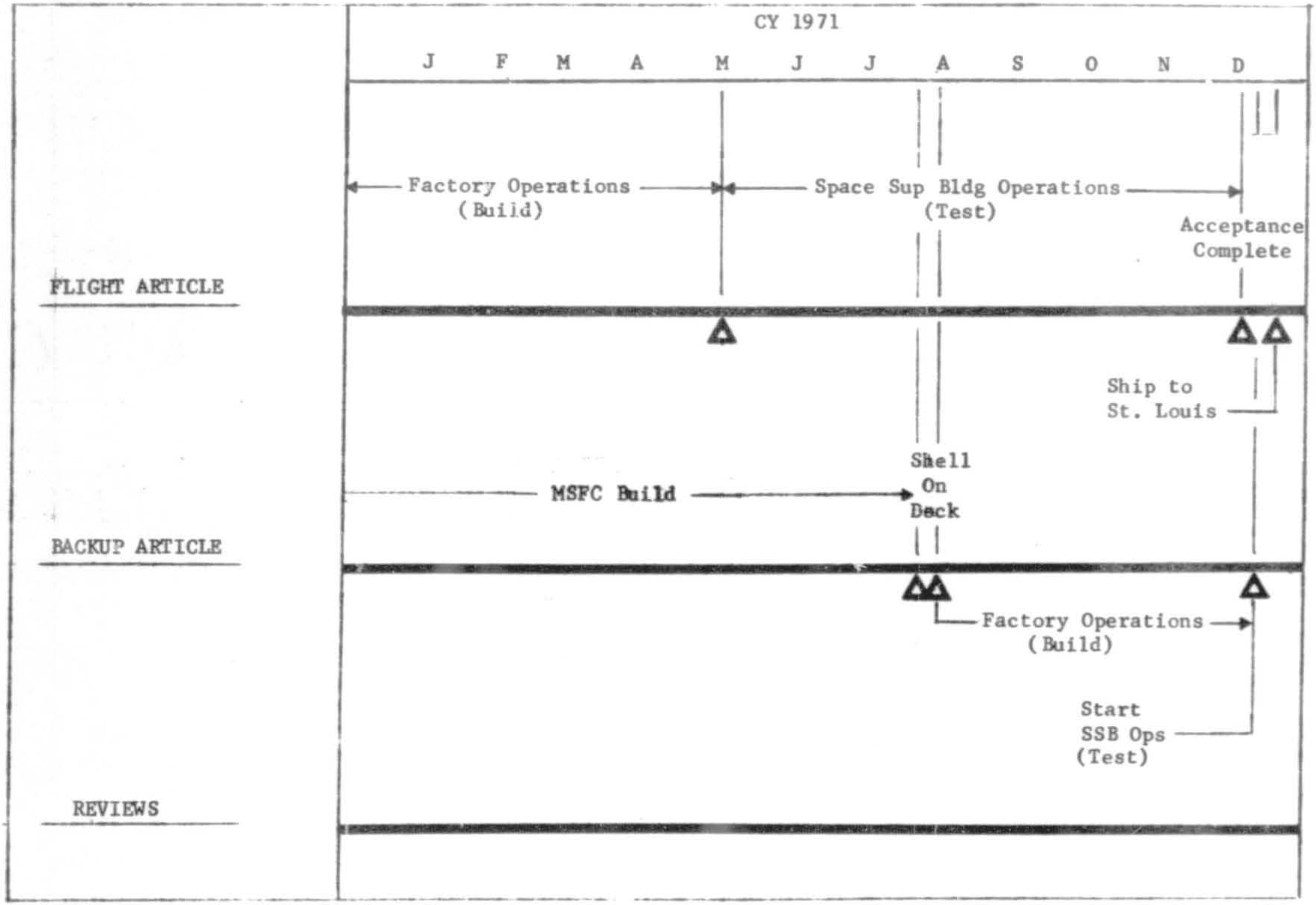


Figure 2.1.1-1 (Continued)

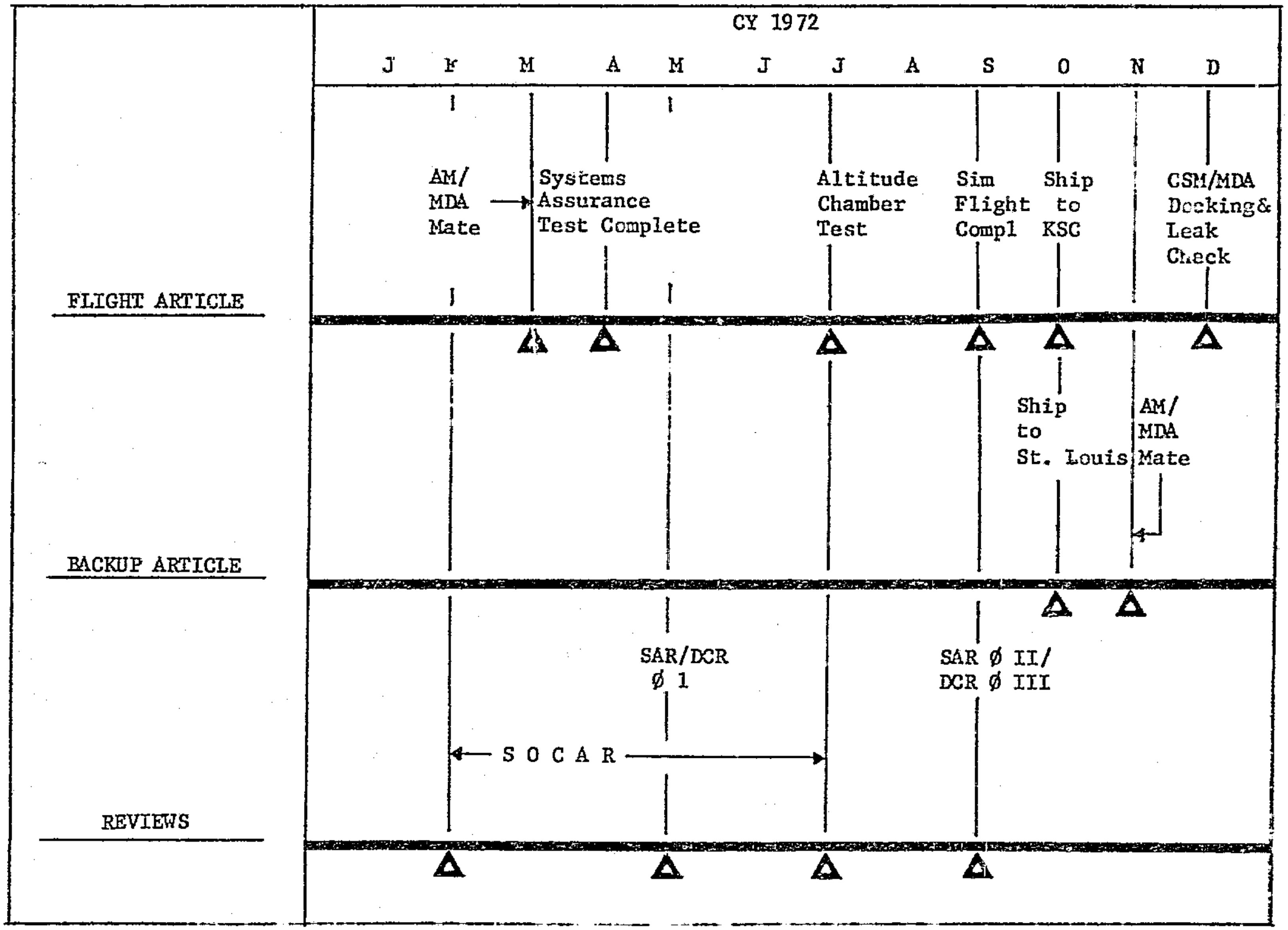


Figure 2.1.1-1 (Continued)

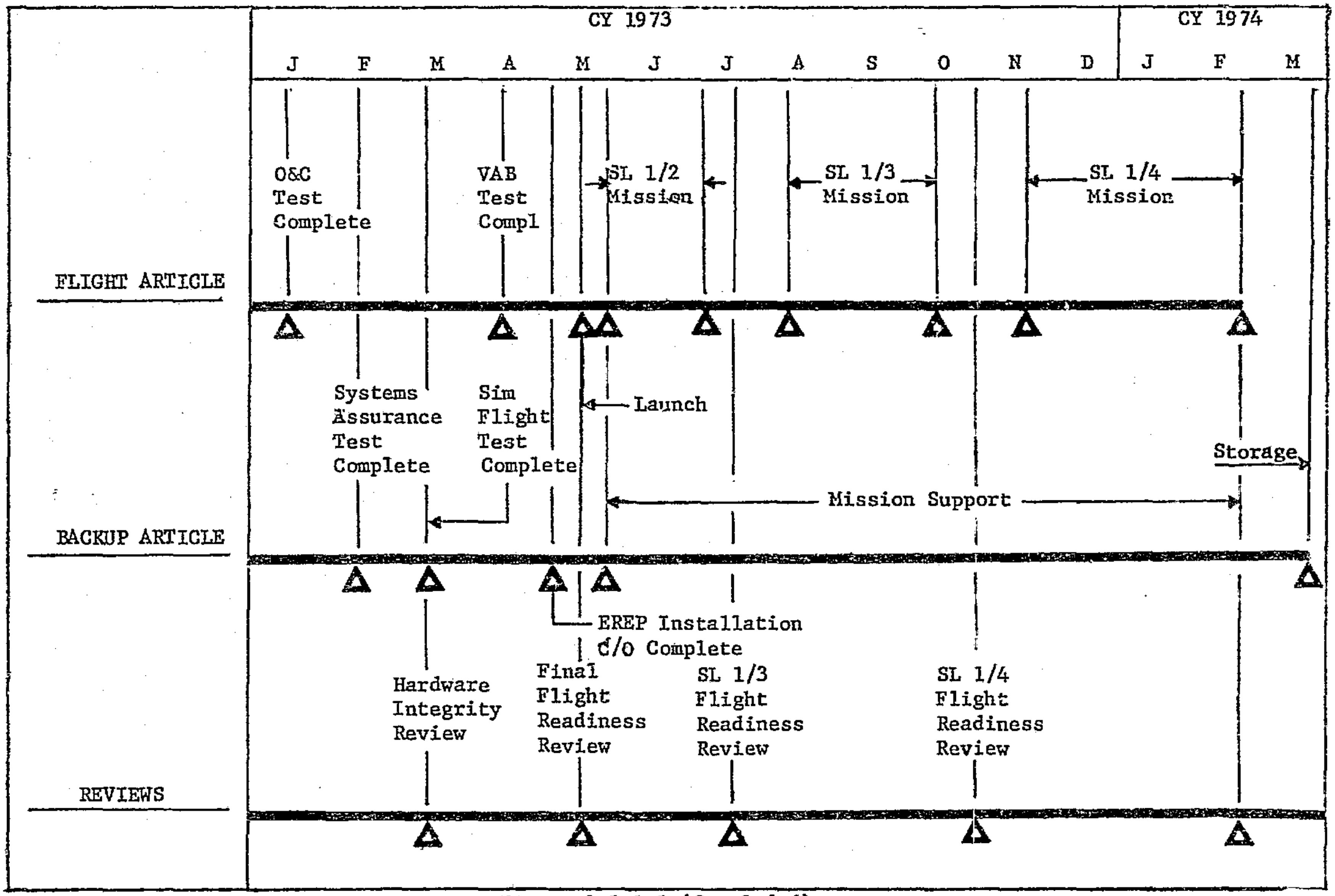


Figure 2.1.1-1 (Concluded)

(3) Second concept in November added 2 radial ports to accommodate:

- Lunar Mapping & Survey System (LM&SS).
- Resupply Module (RM).

Note: Figure 2.1.1-2 illustrates this concept with LM/ATM, RM and CSM docked.

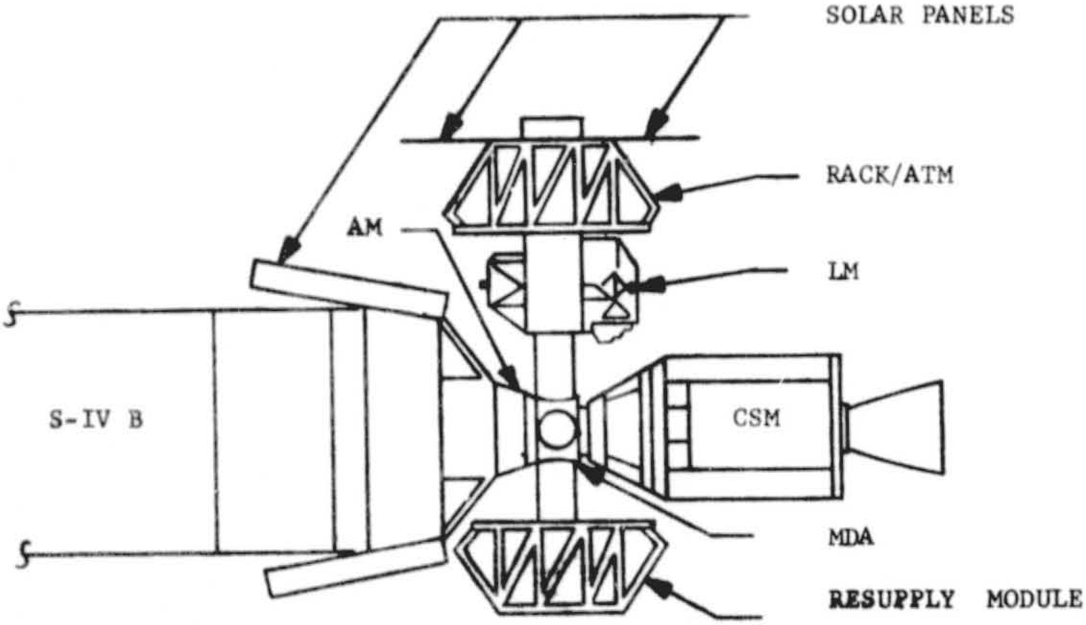


Figure 2.1.1-2 Early MDA Concept

(4) November version described as follows:

- Main Tunnel: 65 inches dia x 38 inches length.
- Radial Tunnels: 56 inches length.

- Each Port: 34 inches diameter.

- Gross Weight: 900 lbs.

- Thermal Control: Passive.

- Environmental Control System (ECS): O_2 makeup from AM.

- Electrical: Wiring from AM to ports.

(5) Third concept in 1966 enlarged the MDA as follows:

- Main Tunnel: 115 inches diameter x 84 inches length.

- Radial Tunnels: 20 inches length.

- Gross Weight: 2000 lbs.

- Electrical: Added lighting to second concept.

- Instrumentation & Communications (I&C): Display/monitor pressurization and consumables transfer.

- Experiments: Stow S017 panel, stow/operate S063.

B. Year 1967 -

(1) 1966 concepts resolved into preliminary design as announced by the National Aeronautics & Space Administration (NASA) in March. This version described as follows:

- Main Tunnel: 120 inches dia. x 180 inches length.

- Four radial ports.

(2) Subsequent to announcement of the March version the following events occurred:

- Running and internal lights specified.

- Two radial ports deleted (LM&SS and RM).

- Added experiment stowage/operational requirements.

- MDA identified as candidate for contingency workshop study.

C. Year 1968 -

- S009 Nuclear Emulsion added.

- Expanded ECS to include fans/ducts, heaters (16 wall, 3 port, 2 window crank), and 2 vent valves.

- Electrical expanded to include 4 auxiliary power outlets and power distribution capability.

- I&C expanded to include voice communications, instrumentation sensors (temperature), signal conditioning, and multiplexing (2 low level and 1 high level).

- Several medical experiments identified for stowage/performance in the MDA including an Experiment Support System (ESS). These items were eventually deleted from the MDA.

D. Year 1969 -

- Dry Workshop concept adds ATM Control & Display (C&D) Console, deletes OWS experiment storage.

- MDA design, development, integration, fabrication, test, delivery contract to Martin Marietta Corporation (MMC).

- MDA shell provided by Marshall Space Flight Center (MSFC).

- Reduced radial port requirement to one for a backup CSM.

- S190 Multispectral Photographic facility added.

- M512 Materials Processing Facility added.

- Film Vaults added.

E. Year 1970 -

- S191, S192, S193 and S194 added (Earth Resources Experiment Package, EREP, completed).
- RNBM added.
- Inverter/Lighting Control Assembly (I/LCA) added.
- U/V fire sensors added.
- Orbital Assembly (OA) TV system components added.
- Flight shell received in Denver.
- MDA Critical Design Review (CDR) held in Denver.
- AM/MDA Crew Station Review (CSR) held at St. Louis.

F. Year 1971 -

- MDA GSE identified for component install/remove capability for Denver, St. Louis, KSC.
- EREP pre-installation tests in Denver.
- Crew Compartment Fit and Function (C^2F^2) held in Denver.
- Flight article acceptance review held in Denver.
- Flight article shipped to St. Louis.
- M512 facility experiments expanded.
- Backup shell received in Denver.

G. Year 1972 -

- Video Tape Recorder (VTR) added.
- AM/MDA mated at St. Louis.
- EREP bench tested at St. Louis.
- Experiment M518 added.

- AM/MDA C^2F^2 completed at St. Louis.
- Altitude tests completed.
- EREP installation completed.
- Electromagnetic compatibility (EMC) tests on AM/MDA.
- Shipped AM/MDA to KSC in October.
- Initial pre-launch including inverted docking tests completed at KSC.
- Backup MDA shipped to St. Louis.

H. Year 1973 -

- Completed pre-launch tests at KSC.
- SL-1 launched in May.
- Two Skylab missions completed and final initiated.

I. Year 1974 -

- Skylab mission completed.

2.1.2 Test Evaluation

The MDA test program was structured to make use of program developed mockups, simulators and test hardware to supplement flight and backup hardware testing. The test and design verification hardware developed and used on the program included the following:

- Zero G Mockups (5 configurations).
- Neutral Buoyancy (N/B) Mockup.
- Engineering Mockups (EMU).
- One G Trainer (developed from EMU).
- Static Test Article.
- Dynamic Test Article (DTA)(developed from static article).

- Development Mockup (DMU).

In addition the above programs, the MDA flight and backup articles were subjected to a comprehensive series of tests from fabrication through launch. The following paragraphs provide a brief description of each test program associated with the MDA.

2.1.2.1 Zero Gravity Test Hardware

The zero gravity test program was conducted from October 1969 through July 1970. It included the design, fabrication and flight testing in a KC-135 aircraft of 5 separate packages as follows:

- ATM C&D Console/Structural Transition Section (STS) Panel Crew Station.
- Film Vaults.
- Initial Entry Package.
- Experiment Package.
- Miscellaneous Hardware.

The corresponding purpose of the above test hardware was as follows:

- Verify restraints and work envelopes.
- Evaluate removal of canisters and film magazines.
- Evaluate initial entry to MDA including removal of drogue and probe, hatch stowage, installation of vent plugs, CM/MDA umbilical installation, deployment of the flex duct, and drogue and probe stowage.
- Evaluate the crew station for experiments M512 and S009.
- Evaluate miscellaneous hardware such as utility outlets, portable light, experiments S082A and S082B canisters and stowage provisions, CO_2 absorber container with absorbers.

2.1.2.2 Neutral Buoyancy Mockups

Several test programs were developed and implemented to evaluate the MDA/Crew interfaces in a simulated space environment. These programs were conducted in 1970 at MSFC with mockups immersed in a neutral buoyancy tank and were instrumental in the design verification of MDA equipment locations, clearances, work envelopes, and gross operation after integration into the SWS configuration.

2.1.2.3 Engineering Mockup (EMU) 1-G Trainer

The shell for the EMU was supplied by NASA-MSFC, refurbished and outfitted by MMC and used during the MDA CDR.

The development of this hardware was instrumental in evaluating the MDA design from a human engineering/crew interface point of view. The fidelity of this mockup was later increased to meet the requirements of a 1-G trainer for delivery to Johnson Space Center (JSC). Prior to delivery the mockup was used to support crew interface reviews in Denver and St. Louis (CDR and CSR) and MDA illumination level tests and acoustic noise level tests.

2.1.2.4 Static and Dynamic Test Article

The structural test article test program was developed in two phases, the first for static testing and the second for dynamic testing. MSFC designed, fabricated and tested the static test article. This unit was then shipped to Denver to allow MMC to update the configuration with mass simulators for planned dynamic testing. The DTA was then shipped to JSC where MSFC personnel supported the dynamic test program. Results of these test programs were instrumental in the final design and build of a quality flight MDA vehicle.

2.1.2.5 Development Mockup

The DMU was used to develop the MDA wiring harness. The structure used for this purpose was partially fabricated at MSFC and completed at Denver. This program was instrumental in the development of the MDA cable trays, a major program modification. Following completion of this program, the hardware was converted to a display model and was exhibited at the 1973 Paris Air Show.

2.1.2.6 Flight Article

The MDA flight shell was designed, fabricated, x-rayed, leak tested and pressure tested by MSFC prior to shipment to Denver.

Following receipt of the structural shell in Denver in November 1970 the MDA was first updated primarily through incorporation of penetrations necessary to install required flight hardware. The structure was then moved to the Leak Test Facility (LTF) for proof pressure and leak testing. It was then painted, cleaned and moved (May 1971) to a class 100,000 clean room. Available flight hardware, including the M512 Materials Processing facility, the ATM C&D Console structure, film vaults, etc. was installed in the clean room.

The EREP experiments and support equipment were received during this time and subjected to Pre-Installation Test (PIT). This system was then installed and tested in the flight module. Problems encountered during this activity led to the removal of several experiments for return to their vendors for rework.

MDA systems installed and tested in Denver included the following:

- M512 facility (Electron Beam Gun not tested).
- RNBM.
- Proton Spectrometer.
- S009.
- Electrical System Components.
- I&C components including TV.
- ECS components.
- Radiator (leak tested).
- Insulation Purge System.
- Thermal Control System (TCS) components.
- Structural Devices and Mechanism.

At the conclusion of these activities the MDA was given a final leak decay test, subjected to Acceptance and C^2F^2 Reviews and then shipped to McDonnell Douglas Astronautics Corporation (MDAC) at St. Louis for planned mating with the AM and further AM/MDA testing.

The sequence of events at St. Louis began with the preparation and validation of the MDA prior to mating with the AM. This period was used primarily for structural activities such as installing ship loose and late arriving items and included an MDA leak check validation. Prior to the complete installation of EREP experiments a program decision was made to remove those installed and conduct an off-module bench test on this system in parallel with the scheduled AM/MDA interface compatibility testing. The MDA was hard mated to the AM in March 1972 and this event precipitated a series of tests including systems assurance testing, simulated flight testing, crew compartment fit and function validation, and altitude chamber testing. The EREP bench testing included limited experiment Functional Interface Verification (FIV) testing, System Functional Interface Testing (SFIV) and Simulated Data Passes. At the conclusion of these separate test programs the EREP equipment was installed in the MDA and all EREP interfaces were reverified employing a Super Systems Functional Interface Test (SSFIV). At this time the total AM/MDA system, including EREP, was tested in a Delta Simulated Flight which included EMC testing. The combined AM/MDA was then prepared for shipment via "super guppy" to KSC.

The AM/MDA arrived at KSC in October 1972. It was immediately transferred to the Operations and Checkout (O&C) Building and installed in a launch upright orientation in the West Integrated Test Stand (WITS). AM and MDA compatibility was first verified by test procedure KM0003, AM/MDA Integrated System Test and Experiment Test. Following completion of this test procedure the AM/MDA was removed from the WITS, inverted and, after the CSM was installed in the WITS, was hard docked to the CM. This operation was primarily controlled by procedures K0071, CM-SWS AM/MDA Mechanical Docking and Leak Check, and KM0001, CSM-AM/MDA Electrical Interface Test and Docked Simulated Mission. The tests performed in this configuration included cluster leak testing with emphasis on the docking interfaces, CM to AM/MDA electrical interface testing, and a mission simulation involving the crew.

The final major step in the O&C Building test activity was initiated after the CSM had been removed from the WITS and the AM/MDA reinstalled in a launch upright orientation. The controlling procedure was KM0002, Deployment Assembly Functional and Experiment Test. This procedure, as it applied to the MDA, was primarily used to verify experiment performance.

The AM/MDA with Deployment Assembly (DA), Fixed Airlock Shroud (FAS), and the Payload Shroud (PS) installed was transferred to the Vertical Assembly Building (VAB) for final payload integration tests after mating with the launch vehicle and the remaining SWS modules (OWS and ATM). Generally, the MDA was subjected to the following SWS tests at the VAB:

- Vent Valve Operation.
- Insulation and Window Purge.
- Electrical Interfaces.
- Experiment Testing.
- Countdown/Countup Simulation.
- On-Orbit Activation Tests.
- Ventilation Tests.

These tests were controlled by many different procedures; two of the more significant that affected the MDA were KS0045 (AM/MDA/OWS End to End System Test and Experiment Test) and KS0009 (SV OAT). The ATM C&D Console to ATM interfaces were verified through the performance of approximately eleven procedures.

The assembled SWS installed on the launch vehicle was transferred to Launch Complex (LC) 39A after successful completion of VAB testing. The MDA participation at LC 39A was controlled primarily by procedure KS0007, Countdown Demonstration Test (CDDT) Wet and Final Countdown. The MDA functions verified by KS0007 included Vent Valve operation, pressurization, and insulation and window purge. SL-1 launch was successfully performed in May 1973.

2.1.2.7 <u>Backup Article</u>

The Backup (B/U) MDA shell was provided by MSFC in much the same manner as that described for the Flight Article (2.1.2.6). It followed generally the same flow in Denver as the flight article but, due to hardware shortages, was subjected to rather limited testing prior to shipment to St. Louis. These tests were primarily in the following areas:

- Proof Pressure and Leakage.
- Lighting/Illumination.
- Heaters.
- Radiator Leakage.
- Insulation and Window Purge.
- ECS components.
- Structural Devices and Mechanisms.
- Instrumentation components.
- TV Components
- Caution and Warning (C&W) System Components.
- Experiment S009.

At the completion of these tests the MDA was subjected to an acceptance review and shipped to St. Louis via "super guppy."

At St. Louis the B/U MDA was installed in a launch upright orientation for installation of ship loose items and late mod kits. It was then mated to the B/U AM, leak tested and moved to another building for AM/MDA compatibility testing. This series of tests included:

- AM/MDA to CM power transfer capability.
- Lighting/Electrical components.
- Heaters.
- Insulation and Window Purge.
- ECS Components.
- I&C Components.

- VTR Installation and Checkout.
- TV System Components.
- C&W System Components.
- Experiments S009, M512, Proton Spectrometer and RNBM Verification.

In addition, the EREP experiments were installed and verified through the performance of an SSFIV and two simulated data passes. At this time the EREP hardware was removed and returned to Denver to be connected as a laboratory system for mission support. Qualification ATM C&D panels were installed in the MDA at St. Louis and the I/LCA and Backup I/LCA (BI/LCA) were then verified.

Overall the AM/MDA was subjected to a Systems Assurance Test (SAT) program and three simulated flight programs. At this point the AM/MDA was designated for mission support and was thereafter used to verify various mods and procedures identified for the SL-1 orbiting workshop, e.g., verification of gyro 6-pack installation in the MDA.

2.1.3 MDA Systems Description/Functions

The MDA was comprised of the Structures, Thermal Control, Environmental Control, Electrical, Instrumentation and Communications, Experiments and Crew Systems. Significant systems components and their locations in the MDA are shown in Figure 2.2.1-4

The primary functions of the MDA were to provide a docking interface for the CSM, a pressurized passageway between the docked CSM and AM, and a work area for the crew to operate experiments. Non-crew MDA functions included distribution of electrical power to the CSM, transfer of conditioned air to the CSM, and sensing and control of instrumentation, communication and TV signals.

Sections 2.1.3.1 through 2.1.3.7 provide brief descriptions of the MDA systems.

2.1.3.1 Structures

The MDA was a 10-foot diameter, 17.3-foot long pressure vessel that weighed approximately 14,000 pounds fully equipped. The

MDA had two docking ports, one primary and one backup, designed for docking the CSM. External and internal mountings were provided for earth viewing experiment sensors. Film stowage vaults, equipment stowage containers, tape recorders, and television equipment were installed internally. Controls and displays for EREP and ATM experiments were installed in the MDA. Work stations and mountings for scientific experiments performed inside the MDA were also provided.

The MDA exterior structure consisted of radiator panels, meteoroid shields, insulation blankets, an electrical wiring tunnel, an L-Band truss, structural supports for EREP experiments S191 and S192, orientation lights, and docking targets.

The L-Band truss structure supported the I/LCA, Proton Spectrometer, S194 L-Band Antenna and the S194 Electronics.

The MDA basic structure contained four windows which provided viewing for certain Earth Resources Experiments (S-190, S-191 and S-192). The windows were designed to meet optical requirements of the experiments and to provide MDA pressure integrity.

The S190 window external cover protected the window from meteoroid impact and radiation when the window was not in use. The crew controlled the cover from inside the MDA by operating a latching mechanism and an actuator.

A safety shield provided a structural backup in the event of an S190 window failure. This shield also provided impact protection to the window when the S190 experiment was not in its operating position over the window.

Two foot restraint platforms were provided for astronaut support when operating experiments. The platforms were fabricated of standard astrogrid which interfaced with the astronauts' shoes.

Four film vaults were provided to house ATM cameras, ATM film, contingency components, and electrical umbilicals.

The MDA included the following containers: CO_2 absorber, miscellaneous stowage, STS miscellaneous, control head, S054 return, S190 equipment, in-flight maintenance tools and flight data file. The containers protected the equipment against launch loads and provided easy access for on-orbit removal and reinstallation.

2.1.3.2 Thermal Control

Thermal control of the MDA was provided by a combination of passive and active subsystems. The passive subsystem limited the heat loss from the MDA interior to a value that would allow the active subsystem to control the internal temperature. The passive subsystem consisted of insulation blankets, fiberglass standoffs, paints, coatings, and low emissivity aluminized Mylar tape. The active thermal control subsystem consisted of wall heaters and thermostats, docking port heaters and thermostats, and a self-contained subsystem that controlled S190 window and frame temperatures.

Temperatures within the MDA were also controlled by the air circulation subsystem and coolant loops, as described in the following section.

2.1.3.3 Environmental Control

The mechanical environmental control system included five major subsystems: ventilation, MDA/CSM hatch pressure equalization, MDA vent, M512 experiment vent, and ATM C&D panel/EREP cooling.

The ventilation subsystem consisted of fans and ducts. Three Structural Transition Section (STS)/MDA ducts provided cooled atmosphere from the STS into the MDA. A mol sieve duct introduced purified (CO_2 removed) atmosphere from the AM into the MDA. Fans for these ducts were located in the AM. Atmosphere circulation within the MDA was provided by two fan/shroud/diffuser assemblies that controlled the air velocity at the crew stations. One additional fan/shroud/diffuser assembly was coupled to a flexible duct to circulate ambient MDA atmosphere into the CSM.

The MDA/CSM hatch pressure equalization subsystem provided a means of equalizing the atmospheric pressure between the CSM and the MDA after CSM docking and prior to SWS entry. Each docking port hatch was equipped with a visual differential pressure gage and a manually-operated valve. Equalization of pressure across the hatch was achieved by opening the valve.

During launch, the MDA internal atmosphere was vented through the MDA vent subsystem. The venting was accomplished by two motor operated vent valves connected in series for closure redundancy. The internal valve opening was capped by the astronauts after entry into the MDA using a special sealing device.

The M512 experiment vent subsystem provided a means of venting the experiment chamber to space vacuum. Venting was accomplished through two manually operated valves connected in series for redundancy. M512 battery venting to space vacuum was provided by an additional valve on the venting control panel.

The ATM C&D Panel/EREP coolant subsystem provided a flow of inhibited water coolant to electronic cold plates in the ATM C&D/EREP system. A manually operated four-port selector valve provided the means of directing the coolant to only the ATM C&D Panel or to both this panel and the EREP system. The coolant carried the heat generated by the electronic equipment to the AM where the heat was transferred through the AM heat exchanger to the AM coolant system.

2.1.3.4 Electrical

The MDA Electrical System operated within the overall cluster power systems and distributed electrical power for the functional operation of MDA systems and docked CSM systems. The MDA received all its electrical energy across the AM interface from the OWS/AM and ATM power systems.

Specific features of the electrical system included electrical inter-connections and circuit breaker control between MDA electrical components and between the MDA and other module interfaces. Power was provided for interior lights, external running lights, heaters, utility outlets, fans and MDA experiments.

2.1.3.5 Instrumentation and Communication

The I&C system of the MDA operated as part of the overall AM, ATM and CSM systems to perform telemetry, television, audio and caution and warning functions within the MDA. More specifically, these functions consisted of astronaut-to-astronaut voice communications, biomed monitoring, fire detection sensing and warning, MDA statusing and environmental monitoring, portable TV camera coverage, and ATM TV camera operation.

These functions were accomplished by four subsystems within the I&C system. The communications subsystem consisted of three speaker intercom assemblies which provided an audio interface and an information transfer link to the AM data acquisition subsystem, communicated temperature (both internal and external), pressure and video selector switch position data through the MDA to the AM for transmission.

The television subsystem consisted of a TV input station, a video selector switch and a video tape recorder. This system provided an input interface for the portable TV camera, conditioned video signals from the TV camera or ATM camera, and provided for real time TV transmission or recording of video and audio data for subsequent replay.

The caution and warning subsystem performed fire sensing detection and provided visual and audible signals which warned of potentially hazardous conditions in the orbital assembly. These signals were provided through the speaker intercom assemblies.

2.1.3.6 Experiments

The MDA provided support and operating facilities for the EREP experiments, corollary experiments, manufacturing-in-space experiments, and the ATM Control and Display Console. The EREP consisted of the S190A Multispectral Photographic Facility, S191 IR Spectrometer, S192 Multispectral Scanner, S193 Microwave Radiometer/Scatterometer/Altimeter, S194 L-Band Radiometer, an EREP Control and Display Panel, and two Tape Recorders. Corollary experiments included the S009 Nuclear Emulsion experiment, the RNBM and the Proton Spectrometer.

Manufacturing-in-space experiments (Reference paragraph 2.2.10.2 herein) were performed in the M512 Materials Processing Facility (MPF) that provided stowage, operating environments (vacuum, heat source, and heat dissipation), controls and displays for their on-orbit performance.

The ATM C&D Console was operated in the MDA to remotely control and monitor the experiments that were located in the ATM Module.

2.1.3.7 Crew Systems

The MDA Crew Systems provided for the protection, comfort, and assistance of the crewman and consisted of crew operational equipment and stowage containers. The crew operational equipment included flight data file , tools, a fire extinguisher, an oxygen pack and mask, speaker intercoms and communication headsets, portable equipment, utility cables, cameras and accessories, maneuverability equipment, and miscellaneous aids. The stowage containers and stowage provisions provided launch and orbital storage of crew and experiment equipment.

The MDA flight data file included on-board data, launched on SL-1, necessary to support inflight crew operations throughout SL-2, SL-3, and SL-4 missions. This file consisted of checklists, logs, note tablets, maps, star charts, update pads,, schematics and malfunction procedures.

Tools for operational and contingency use were located at strategic points, such as the contingency hatch opening tools which were mounted on the hatch. Other tool kits and loose miscellaneous hand tools were available in the MDA contingency tool containers.

The fire extinguisher was secured to the MDA wall by a quick release clamp. It had a modified nozzle to facilitate use on open fires and behind-the-panel fires.

The portable oxygen pack and mask were stowed in the MDA to provide oxygen to the crewmen in the event of a hostile environment on orbit. The secondary oxygen pack provided a backup oxygen supply to the pressure control unit on the crewman pressure garment assembly in case of insufficient supply from the umbilical, or flow demand beyond the capacity of the umbilical supply. An oxygen mask was provided to enable use of the secondary oxygen pack while crewmen were in a shirtsleeve condition.

Maneuverability equipment consisted of restraints, handrails, handholds, and astrogrid foot platforms.

2.2 MDA SYSTEMS

2.2.1 Structures

2.2.1.1 Structures System

A. Design Requirements - The MDA structures system was designed to meet the requirements specified in the MDA CEI. A general loads philosophy which was developed early in the program was applied to the design of all components, brackets and installations, and in analytical verification of the shell structure.

(1) Basic Requirements - The MDA structures system was configured to serve the following purposes:

(a) Provide structural support for internal and external packages during pre-launch, launch, and orbital loading conditions.

(b) Provide a primary and contingency docking capability with the CSM.

(c) Provide a pressurized environment.

(d) Provide a shirtsleeve thermal environment.

(e) Provide a design which is compatible with crew requirements.

- Maintain a 40 inch diameter clearance through the center of MDA.
- Maintain a comfortable touch temperature on knobs, handles, and surfaces that can be touched.
- Provide knobs of adequate size for ease of astronaut operation.
- Internal acoustic level not to exceed an overall level of 72.5 db as defined in MDA CEI.

(2) Loads Philosophy - Design of the MDA shell and component support structure was based on critical vehicle loading conditions which were used to determine the loads induced in the components.

The conditions considered were ground handling and transportation, launch, boost, separation and docking. Although all loading conditions were considered, usually the loads resulting from a single condition were critical for each component.

The analysis of the shell for component loads was handled as follows. The highest stresses in the structure were at or near heaviest loaded components. Components in adjacent bays were assumed to act simultaneously for random vibration loads. These random loads were combined using a root-sum-square technique. The resulting member loads were then added to the member loads caused by vehicle dynamics and steady state acceleration. Positive margins of safety were demonstrated analytically for the MDA shell subjected to this combination of loads.

(a) Transportation and Handling - Load factors for transportation and handling were found by enveloping the criteria determined from an industry literature search. As an example, the Guppy air criteria was taken from Apollo Program criteria and was based on tests conducted on the Guppy Aircraft by Specialized Testing Services for Aero Spacelines, Inc. Besides air transportation, dolly and truck transportation and hoisting were included in the criteria. Detailed transportation and handling criteria are contained in ED-2002-2010. Transportation and handling loads were never more critical than flight loads, except at the four lifting points.

(b) Launch and Ascent - The highest loads for most of the components installed in the MDA occurred during the Saturn V launch and ascent. The loads were caused by steady state acceleration, vehicle dynamics and random vibration. The worst time-consistent combination of these loads occurred shortly after lift-off and was governed primarily by random vibration.

- Steady State Acceleration - The Saturn V accelerated from approximately 1.2 g's at lift-off to 4.7 g's shortly before staging (Ref. IN-ASTN-AD-70-2).

- Vehicle Dynamics - Vehicle dynamics were low frequency excitations due to flight transients. The maximum transient was encountered at SIC-SII separation. These criteria are defined in ED-2002-2010.

- Random - The maximum random vibration environment occurred at lift-off and at maximum dynamic pressure. It was caused by acoustic excitation of the structure and was defined in IN-ASTN-AD-70-1. This document divided the MDA into zones, which were regions between ring frames, and subzones, which accounted for mass attenuation effects or type of structural mounting (skin, longeron, etc.).

  The static equivalent load to the random environment was determined from simple, conservative analyses. The following major assumptions were used: 1) largest loads occur in first few modes, 2) light damping (Q=10), 3) first few modes are uncoupled, 4) response was peaked to the 2.24 sigma level. Details of the analyses are contained in ED-2002-2010 and ED-2002-2033.

(c) Orbit - Orbital loading conditions consisted of pressure loads, CSM docking/latching event, astronaut push-off loads, and thermal gradients. These environments are defined in the MDA CEI and IN-ASTN-AD-70-1. The limit pressure differentials were 6.2 psi positive, and 0.5 psi negative (collapsing) pressure.

(3) Factors of Safety - The following factors were applied to the design loads. These factors are defined in the MDA CEI Specification.

- Equipment Support Structure: (not tested) F.S. = 2.00 on yield; 3.00 on ultimate

- Basic Structure (Unmanned): F.S. = 1.10 on yield; 1.25 on ultimate

- Basic Structure (Manned): F.S. = 1.10 on yield; 1.40 on ultimate

- Pressurized Structure: Proof Pressure=1.50 X Limit
  Yield Pressure=1.10 X Proof
  Burst Pressure=2.00 X Limit

B. Description - The structures system comprised the MDA shell, and the structural members and components mounted on it. Externally, these components included the L-band truss, radiators, meteoroid shield, insulation and their supporting structures. Internally, structural components included pressure hatches, windows, experiment supports, film vaults and stowage containers. These components are discussed in the following sections. Figure 2.2.1-1 shows the MDA structure and external components.

C. Test - The following tests were performed on the Dynamic Test Article (DTA) to verify the MDA structures system:

(1) Structural Description - The DTA consisted of the Static Test Article shell with mass and center-of-gravity simulators for most equipment weighing more than 5 lbs. In some cases flight type brackets were used. Pressure was not simulated. At a large saving in cost and schedule, many mass simulators were eliminated where dynamic response would be little affected by their omission.

(2) Test Objectives

- Dynamic verification of the structural assembly.

- Verification of dynamic criteria.

- Verification of modal response data from math model.

- Structural impedance data.

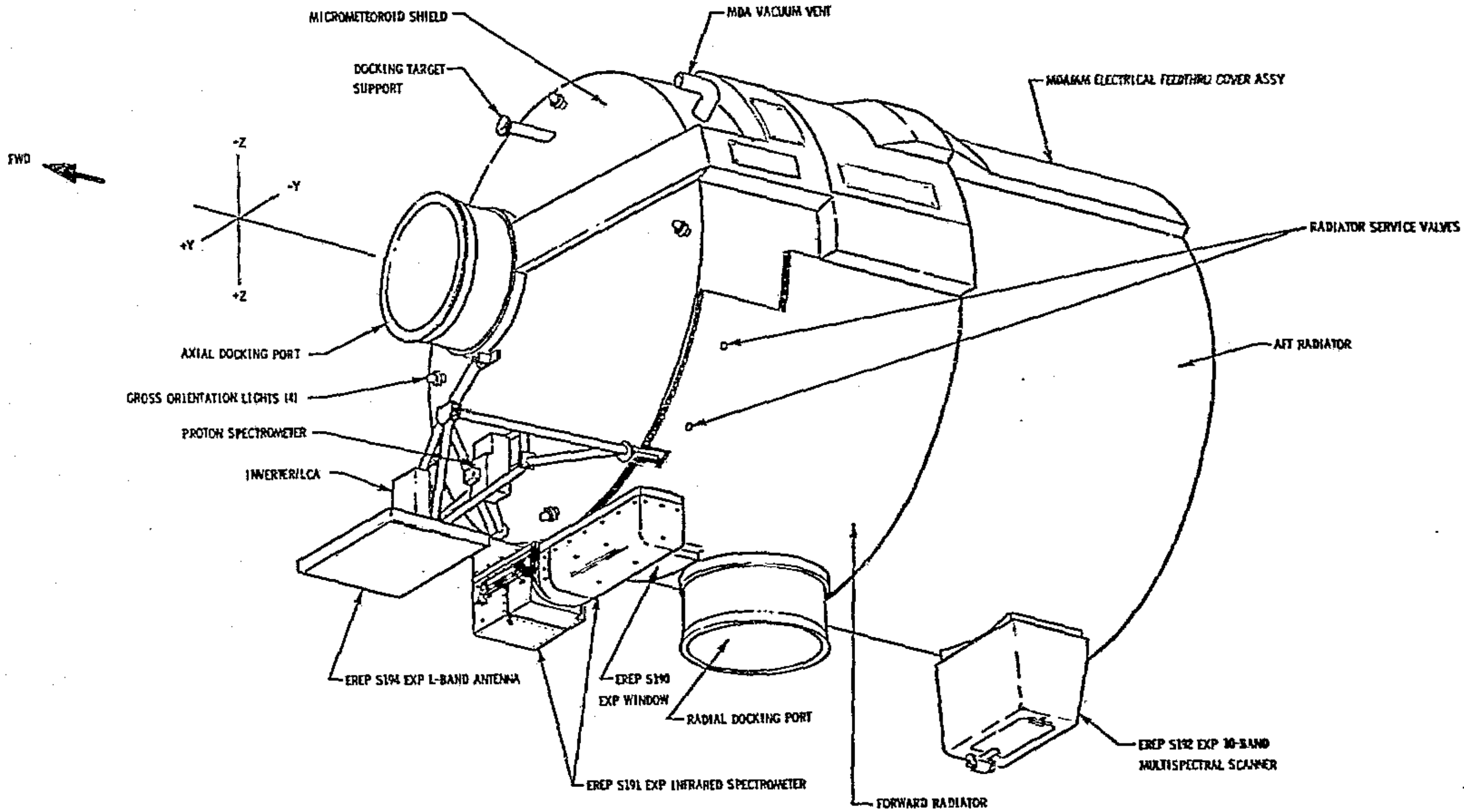


Figure 2.2.1-1 MDA Exterior View

- Dynamic structural qualification of flight hardware components.

(3) Dynamic Test - Three phases of dynamic testing were performed:

- Lift-off and boundary layer acoustic spectra.

- Low frequency vehicle dynamics.

- Modal surveys.

(4) Test Results - No primary or secondary structural failures occurred during the Payload Assembly vibroacoustic tests. This fact, considered in conjunction with the low stress levels indicated by the strain gages, resulted in the conclusion that the MDA was capable of sustaining the lift-off boundary layer and transient flight environments. The tests showed that the design criteria of IN-ASTN-AD-70-1 were conservative. Details of the vibroacoustic tests are contained in S&E-ASTN-ADD-72-29.

(5) Conclusions - Design vibration, shock and acoustic levels for the L-Band truss, delta pressure gage, vent valve sealing device, fan mufflers and shroud, M518, M512 foot restraint and ATM C&D foot restraint were derived from vibroacoustic test data. Deviations were requested for these items, making it feasible to design to the reduced, more accurate criteria. It was possible to show an analytical factor of safety of 3.0 for all these items using the reduced criteria, thus eliminating the requirement for testing. The reduced shock and vibration environments for the delta pressure gage are discussed in Section 2.2.2.5.

D. Mission Results - The MDA Structures System performed as planned throughout the launch and orbital phases of the Skylab mission. Loads on the MDA during launch and boost were nominal. Transient loads caused by loss of the OWS meteoroid shield and SAS wing were not significant at the MDA. Hard docking was accomplished three times on the axial port.

E. Conclusions and Recommendations - The highest loads were derived from the random vibration criteria contained in IN-ASTN-AD-70-1. These loads were used to design most structural subsystem brackets. This document was generated to reflect environments in the dry workshop. However, some of the earlier wet workshop ideas were carried over and influenced the criteria.

In particular, the wet workshop MDA contained standardized inter-longeron structural members called rails. The longeron vibration levels were amplified for components mounted on rails. IN-ASTN-AD-70-1 contained subzones called "rail criteria". However, no effort was expended to maintain a standard rail section in the final MDA design. Thus, the criteria turned out to be very conservative.

The following conclusions and recommendations were reached as a result of the analyses and tests conducted on the MDA structures system:

(1) The MDA structures system was verified to be capable of withstanding all the environments imposed upon it.

(2) The concept of using a higher factor of safety on loads was a good one for eliminating expensive component qualification testing where payload weight saving was not a prime objective.

(3) The vibration design criteria was too conservative when compared with the DTA vibroacoustic test data. It is concluded that a more accurate prediction technique should be investigated for future design.

(4) The high frequency, basic structure shock criteria in IN-ASTN-AD-70-1 was a good approximation of MDA shock levels. However, the secondary structure shock levels, which were intended to show attenuation through the structural joints, were too low for qualification testing. It is recommended that only fragile components on secondary structure be shock tested.

2.2.1.2 MDA Shell

A. Design Requirements - The shell was designed to meet the following requirements:

(1) Withstand imposed loads from

- Handling and transportation
- Launch
- Ascent
- Orbital Operations
- Docking

These requirements are defined in the MDA CEI and ICD 13M20979, CSM to MDA Physical Interface.

(2) Limit interface loads at the STS interface per ICD 13M02521, AM to MDA Mechanical Requirements.

(3) Provide physical and structural facilities for experiments as defined by the following ICD's:

- 13M07397 MDA/EREP Support Equipment Mechanical Interface
- 13M07399 S191 IR Spectrometer/MDA/EREP Physical Interface
- 13M07400 S192 Multispectral Scanner/MDA Mechanical Requirements
- 13M12191 S009/MDA Mechanical Interface
- 13M12201 S190 Multispectral Photographic Facility/MDA Mechanical Requirements
- 40M37870 MDA/ATM C&D Console Physical Requirements

(4) Provide Ground Support Equipment (GSE) interfaces (Ref. Section 2.2.11).

B. Description - The MDA shell was a 10 foot diameter, 17.3 foot long, semi-monocoque pressure vessel that weighed approximately 3382 pounds. It consisted of a cylinder 13.6 feet long, a 120° included angle cone 2.1 feet long, an axial docking port on the forward end of the cone and a radial port attached to the cylinder on the +Z axis. The two docking ports were approximately 20 inches long by 33 inches in diameter. The shell structure in its handling fixture is shown in Figure 2.2.1-2.

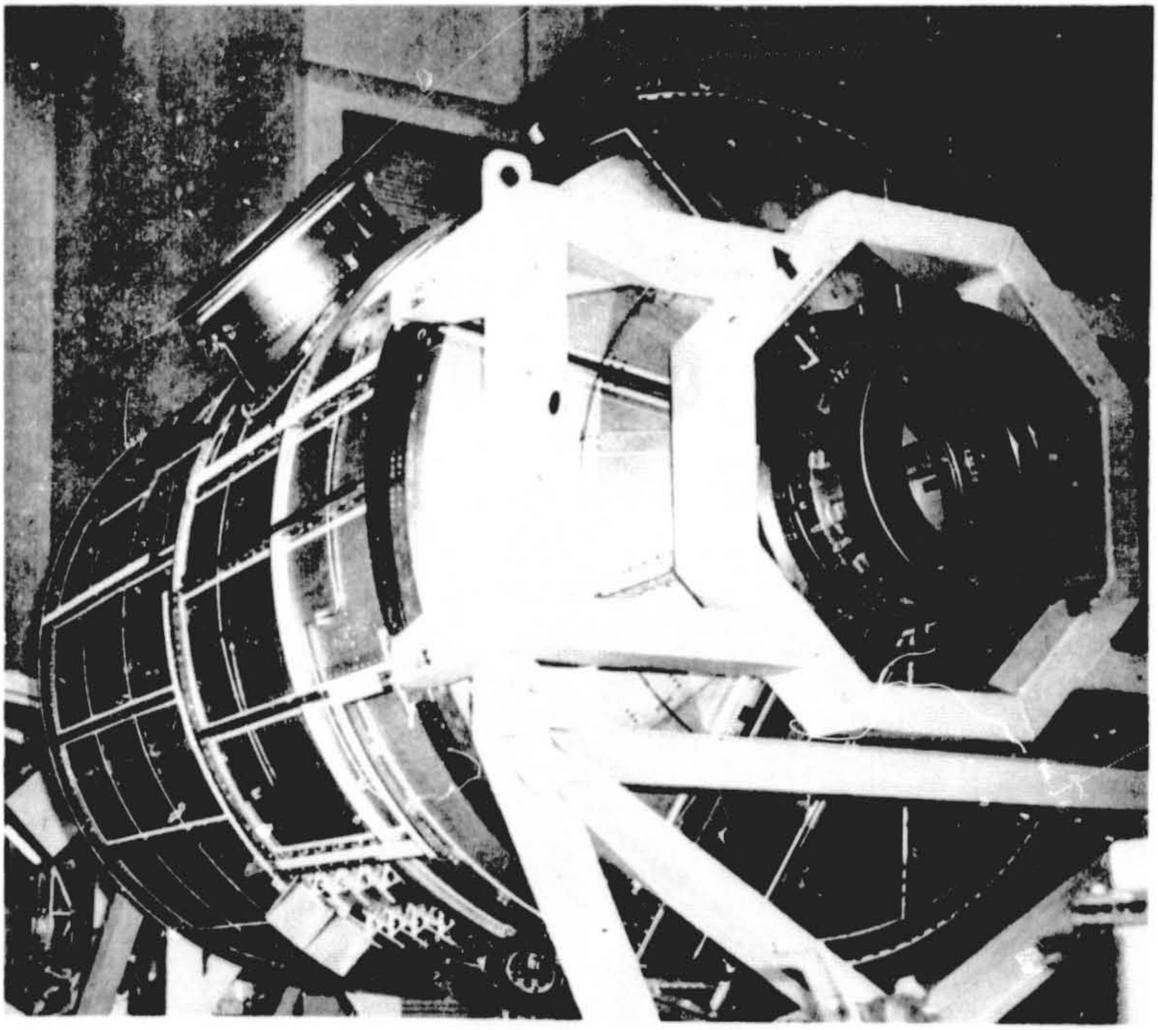


Figure 2.2.1-2 MDA Shell

The shell was made of welded 2219-T87 aluminum. Nominal skin thickness was .25 inch, with a minimum of .076 inch. In the docking port area, the skin ranged from .45 to .65 inch thick. Eight longerons and five ring frames were used in the cylindrical section to stabilize the skin and to provide mounting surfaces for internal components. Two ring frames were welded to the skin to form part of the pressure shell. The other frames and longerons were attached to the skin with mechanical fasteners. To minimize leakage, sealing washers were installed under the heads of all skin penetrating fasteners, and sealant was applied to the surface of the longerons and frames that came in contact with the shell.

The longerons were designed to provide two parallel facing surfaces on adjacent longerons to facilitate the attaching of intercostals. Each of the two faces had two rows of blind nuts installed on three-inch centers, providing capability to install support hardware at any location in the MDA.

The cone consisted of four machined panels welded together. The panels were .250 inches thick in the weld lands and around a vent cutout, and .125 inch thick in the remaining areas. A ring bolted to the forward end of the cone was used to attach the docking port and hatch ring. The cone was attached to the cylinder by welding a common frame to the aft end of the cone and the forward end of the cylinder.

The two docking ports were built-up cylinders consisting of machined aluminum rings at each end with a center filament wound fiberglass cylinder to provide thermal isolation. All mechanical joints were sealed to minimize leakage. Both docking ports had provisions to install a drogue and provide the proper interface for CSM docking. The axial port had provisions for transferring power, communications and instrumentation between the MDA and the docked CSM. The radial port did not have these provisions since it was intended for rescue only.

C. Test - Several tests were performed to verify structural and leakage integrity. Structural testing was done on a static test article. Pressure tests were also conducted on the Flight and Backup Articles.

(1) Flight Article - The Flight Articles (including Backup Article) was subjected to leak and proof pressure tests. Pressure tests were run at MSFC on the basic shell and again at MMC after all

major penetrations were made. Both modules passed proof pressure testing without any problems. Leakage tests were passed after minor repairs as noted in Section 7.5.4.

(2) Static Test Article

(a) Structural Description - The MDA Static Test Article consisted of an MDA shell with docking ports, windows, and Infrared (IR) Spectrometer fitting. Testing was conducted at MSFC in January and February 1971.

(b) Test Objectives

- Verify structural integrity of the MDA structure for docking loads and loads imposed on local structure by equipment, experiments and experiments support hardware.

- Determine deflections and stresses of the critical loads conditions.

- Verify analytical methods.

(c) Static Test - Nine separate conditions were tested. Six conditions simulated worst case pressure and docking/latching loads. Three conditions were tested to verify structural integrity for local loading conditions. The local loads were derived from the worst case, static equivalent combination of steady state acceleration, random vibration and vehicle dynamics. A factor of safety of 1.4 was applied to design limit shear, moment, and axial loads, and 2.0 to pressure loads. Details are contained in ED-2002-1264.

(d) Conclusions - The MDA Static Test Article verified the structural integrity of the MDA shell while subjected to the critical loading conditions.

D. Mission Results - The shell functioned as planned. All internal and external equipment was intact after orbital insertion, CSM docking was achieved, and pressure was maintained without significant leakage.

E. Conclusions and Recommendations - The basic shell configuration was conceived for the wet workshop. The intent was to make the shell a pure monocoque (unstiffened skin carrying all loads) with the longerons used only for attaching equipment and distributing loads into the skin. When the mission was changed to the dry workshop concept, the MDA was required to support additional equipment for which the shell was not originally designed. The existing longerons were modified to take flight loads and three ring frames were added to the shell to meet these new requirements. All changes were made before completion of structural testing, so that structural integrity of the "as flown" configuration was verified.

The shell performed its function during the complete Skylab mission without any problems. However, during the outfitting process, many problems were encountered using the blind nuts in the longerons. Galling occurred while installing bolts, some nuts came loose, the nuts were not located in the proper place for all installations, and repair techniques caused chips to fall into the longeron cavity.

Future pressure vessel designs for manned spacecraft should utilize a more efficient structural configuration, minimize the use of blind nuts, and eliminate skin penetrations to the greatest extent possible. One suggested method is to use integrally machined skin and stringer construction. This design is efficient in carrying loads and minimizes skin penetrations. The flanges of the stringers would permit equipment mounting with standard nuts and bolts.

2.2.1.3 External Components

The major components that were mounted external to the shell were the L-Band truss, radiators, meteoroid shield, and insulation. Other items included docking targets, acquisition lights, S191 and S192 experiment structure and MDA vents (MDA vacuum vent, M512 vacuum vent, M512 battery vent). The major components are considered in further detail below. Other items are described in the respective sections of this report; i.e., lights under Electrical Power System, vents under Environmental Control System, and experiments under Experiments.

A. L-Band truss

(1) Design Requirements - L-Band truss design requirements were:

- o Withstand prelaunch, launch, ascent, and orbital environments without permanent deformation.

- o Position experiments so that the location and viewing requirements were met per:

  ICD 13M13525 (S194 Interface Requirements)
  ICD 13M13513 (Proton Spectrometer Interface Requirements)

- o Attach to MDA so that cone stiffness would not be affected.

- o Do not interfere with CSM docking and ATM deployment or operation.

(2) Description - The L-Band truss consisted of aluminum tubular members welded and bolted together. (Figure 2.2.1-3). Additional frames,

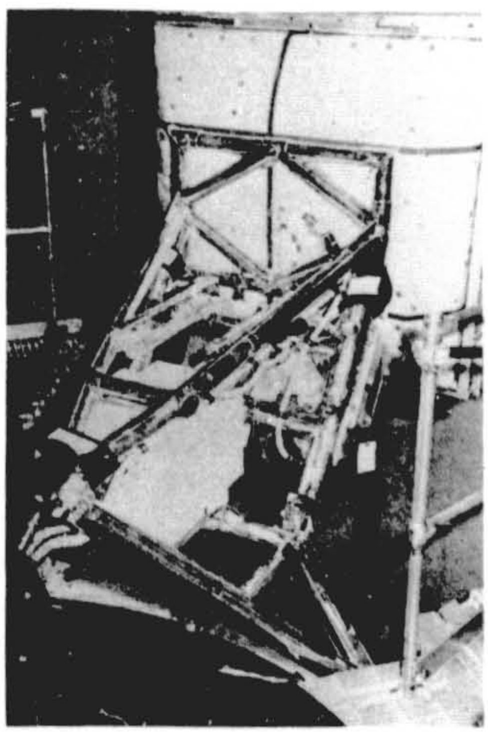


Figure 2.2.1-3 L-Band Truss Structure

brackets, etc. were attached to the truss to provide interfaces for the antennas, L-Band Electronics, Proton Spectrometer, and the I/LCA.

All truss members were wrapped with aluminized mylar tape to help maintain thermal balance within the MDA.

The truss was configured to interface with the MDA at three points. One point was an existing lifting fitting at the cone/cylinder juncture located to one side of the Z axis. A second point was equidistant from the Z axis to structural provisions added to the cone/barrel juncture. The third attach point was to an adjustable link that attached to the axial docking port/cone joint.

(3) Test - The following tests were conducted on the truss.

(a) Assembly Testing - A prototype L-Band truss with experiment mass simulators was installed on the DTA and tested as part of the vibroacoustic test. An analysis performed using load factors obtained from the vibroacoustic test showed a safety factor of 3.0; therefore, structural testing was not required. The load factors obtained were lower than shown in IN-ASTN-AD-70-1. A deviation was granted which reduced the composite high level random vibration level from 8.9 to 2.225 grms.

(b) Element Tests - Element tests were conducted on welded 5456-H111 Aluminum alloy (truss material) to determine the allowables in the "as welded" condition. These values were used to size members and in the final truss analysis.

(4) Mission Results - There were no anomalies reported involving the L-Band truss. Photos taken during fly around inspections showed the truss and associated hardware intact.

(5) Conclusions and Recommendations - The original design concept of the L-Band truss was a configuration that was attached to the MDA at four fittings at the cone/cylinder juncture. This was to comply with the ground rule not to stiffen the cone. The material for this truss was 6061 aluminum, which was to be heat treated after welding. It was obvious, from the geometry of the truss, that heat treating would cause distortions and that the truss would not meet requirements. A study was conducted to come up with a new material and a more efficient design. 5456-H111 aluminum was selected because of its high "as welded" allowables. A three point attachment truss design was developed which caused no increase in cone stiffness. The results of the study produced the as-flown L-Band truss design.

The basic truss members were welded together with a minimum of problems; however, when the experiment support provisions were welded to the tubes, distortion occurred. Additional machining operations and shimming were required to fix this problem. It is recommended in future designs, that any critical interface support bracketry be attached with hardware rather than welding.

B. Radiators and Meteoroid Shield -

(1) Design Requirements - Meteoroid shielding design requirements were:

- Withstand prelaunch, launch, and ascent environment.
- Meet .995 probability of no pressure shell penetration.
- Meet .995 probability of no electrical wiring penetration.

(2) Description - Approximately 75% of the barrel portion of the MDA was covered with radiators. They were constructed of .030 inch magnesium with coolant tubes attached, and were finished with a special reflective white paint. The radiators were bolted to three-inch high fiberglass standoffs attached to the MDA shell. The radiators were supplied to the MDA by McDonnell Douglas.

The entire surface of the MDA shell was covered with a meteoroid shield. The cone had a .050 inch aluminum cover and the barrel was protected by a .020 inch aluminum cover over area not protected by the radiator. The shield sections were bolted to three-inch high fiberglass standoffs attached to the MDA shell. Exposed electrical wiring was protected by wrapping with tape (see Section 2.2.1.5).

(3) Test - Panel acoustic vibration tests were conducted on .020 inch skin. High velocity pellet meteoroid penetration tests were run on all structural configurations and exposed wire harness configurations used on the MDA. All tests were successful in meeting the requirements.

(4) Mission Results - The radiators and meteoroid shield functioned as designed throughout the mission.

(5) Conclusions and Recommendations - Part of the shielding consisted of a formed .020 inch aluminum housing over external components. The .020 inch material (2024-T3) showed a tendency to crack during the forming operation and was difficult to handle and install because the thin material was unstiffened and unsupported before installation. In future applications it is recommended that handling be a design consideration for thin sheet structures in order to avoid repair problems that may be associated with such parts.

C. Insulation -

(1) Design Requirements - The insulation in its installed configuration was designed to:

- Provide a passive method to help maintain thermal balance.

- Withstand imposed environments without deforming and causing a heat short.

(2) Description - The high performance insulation was made into individual blankets that fit between the fiberglass standoffs mentioned above. The blankets consisted of 91 layers of aluminized mylar separated by 90 layers of dacron netting. A fiberglass frame which had "boot hooks" installed on four-inch centers was attached to the outboard surface of each blanket. Velcro was stapled to the edge of the inboard surface of each blanket and the total blanket was held together with Swiftachments (Nylon "I" shaped parts normally used to attach price tags to wearing apparel in clothing stores). The MDA was provisioned to accept the blankets by bonding mating velcro to the shell and drilling holes through the fiberglass standoffs to match the "boot hooks" on the frames. The blankets were installed by pressing the mating velcro together and by wire tying boot hooks on adjacent blankets together by passing the wire though holes provided in the standoffs.

In areas where the blanket could not be attached to the shell (e.g., the housing over the electrical components), a special design was created that attached the blanket to the inside of the meteoroid shield.

(3) Test - The following tests were performed with successful results:

(a) Thermal vacuum tests to determine insulation performance.

(b) Vibration tests using full-width panel specimens attached to a test fixture in the same manner as flight blankets were attached to the flight article. The test specimens (blankets) had weights attached to simulate acceleration loads that the blankets would be subjected to during the ascent phase of the flight. This configuration demonstrated that the blankets could withstand vibration and acceleration loads applied simultaneously without sagging. On previous designs, this demonstration was made by a centrifuge test or a sled test at White Sands Proving Grounds.

(c) Boot hook pull test.

(d) Wire tie strength test.

(4) Mission Results - The super insulation performed as planned throughout the mission.

(5) Conclusions and Recommendations - The original design concept of assembling an insulation blanket was to use fiberglass grids as the inner and outer surface and tying these and the insulation layers together with hand string ties at the grid intersection points (approximately two inches on centers). Through-type grommets were used around the periphery of the blanket for attachment to the vehicle. A value engineering study determined that substantial savings in cost and schedule would be realized if the design actually used was substituted for the original concept. Fabrication and installation of the super insulation blankets were accomplished with minimum problems.

2.2.1.4 Internal Components

A. Internal Arrangement -

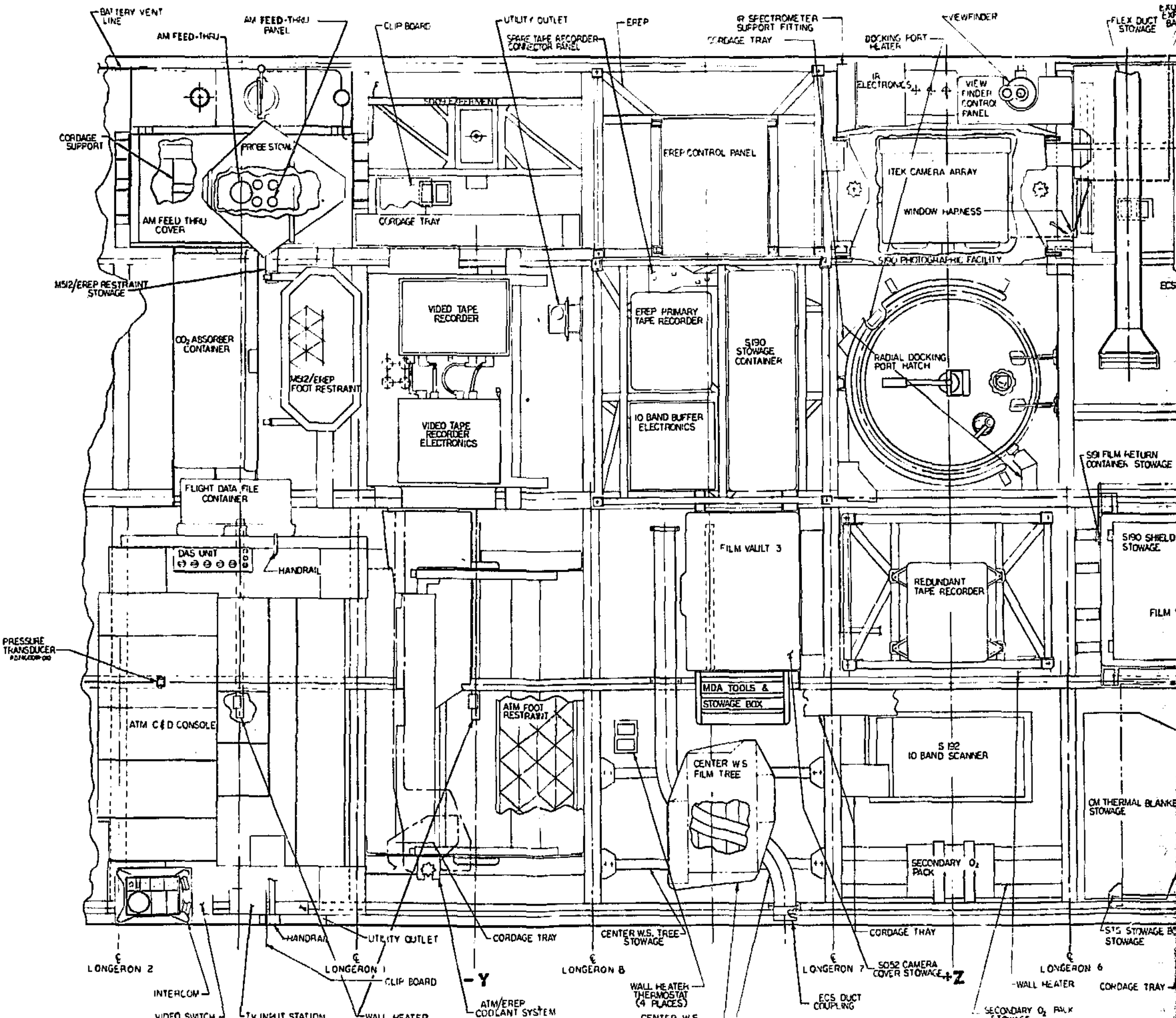
(1) Design Requirements - The primary objectives for integration of the equipment in the vehicle were as follows:

- Equipment with related functions be located for operational convenience.
- Provide mobility and stability aids for ease of movement and activity in the module.
- Provide opening clearance for the hatches and container doors.
- Minimize protrusions, sharp corners and cavities in the crew activity area that could cause injury.

(2) Description - The interior of the MDA provided the mounting structure for the equipment installed in the MDA. The major equipment items were:

- Docking port hatches.
- Windows and covers.
- Experiment support structure.
- ATM film camera support and radiation protection vaults.
- Electrical system protection and support.
- Environmental Control System.
- Crew equipment and stowage.
- ATM Control and Display Console.

Approximately 70 components are included in these installations. See Figure 2.2.1-4 for nomenclature and location.



BATTERY VENT LINE
AM FEED-THRU PANEL
AM FEED-THRU
CLIP BOARD
UTILITY OUTLET
SPARE TAPE RECORDER CONNECTOR PANEL
EREP
IR SPECTROMETER SUPPORT FITTING
CORDAGE TRAY
VIEWFINDER
DOCKING PORT HEATER
FLEX DUCT STOWAGE
CORDAGE SUPPORT
PROBE STOW
AM FEED THRU COVER
CORDAGE TRAY
EREP CONTROL PANEL
IR ELECTRONICS
VIEW FINDER CONTROL PANEL
ITEK CAMERA ARRAY
WINDOW HARNESS
S190 PHOTOGRAPHIC FACILITY
M512/EREP RESTRAINT STOWAGE
CO_2 ABSORBER CONTAINER
M512/EREP FOOT RESTRAINT
VIDEO TAPE RECORDER
VIDEO TAPE RECORDER ELECTRONICS
EREP PRIMARY TAPE RECORDER
S190 STOWAGE CONTAINER
10 BAND BUFFER ELECTRONICS
RADIAL DOCKING PORT HATCH
S191 FILM RETURN CONTAINER STOWAGE
FLIGHT DATA FILE CONTAINER
DAS UNIT
HANDRAIL
FILM VAULT 3
REDUNDANT TAPE RECORDER
S190 SHIELD STOWAGE
PRESSURE TRANSDUCER
MDA TOOLS & STOWAGE BOX
ATM C&D CONSOLE
ATM FOOT RESTRAINT
CENTER W.S. FILM TREE
S 192 10 BAND SCANNER
CM THERMAL BLANKET STOWAGE
SECONDARY O_2 PACK
HANDRAIL
UTILITY OUTLET
CORDAGE TRAY
CENTER W.S. TREE STOWAGE
CORDAGE TRAY
S15 STOWAGE BOX STOWAGE
LONGERON 2
LONGERON 1
LONGERON 8
LONGERON 7
S052 CAMERA COVER STOWAGE
+Z
LONGERON 6
-Y
WALL HEATER
CORDAGE TRAY
INTERCOM
CLIP BOARD
WALL HEATER THERMOSTAT (4 PLACES)
ECS DUCT COUPLING
VIDEO SWITCH
TV INPUT STATION
WALL HEATER
ATM/EREP COOLANT SYSTEM
CENTER W.S. FILM TREE BAG
MOL SIEVE DUCT
SECONDARY O_2 PACK STOWAGE

FOLDOUT FRAME

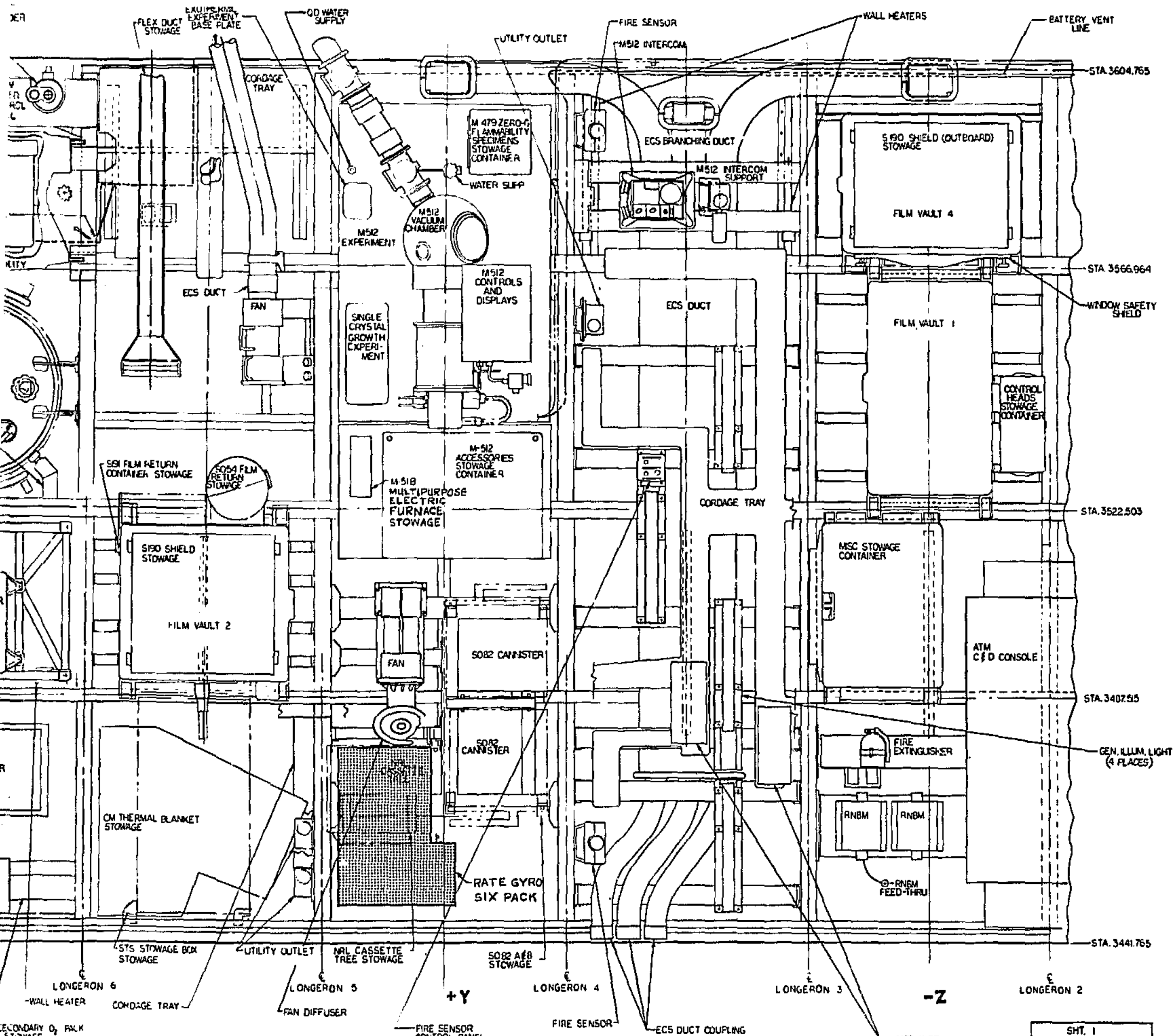


Figure 2.2.1-4 MDA Interior Arrangement

(3) Test - Several articles were fabricated to establish and verify acceptability of the internal arrangement. These include the Neutral Buoyancy Article, Engineering Mockup, and One-G Trainer. These units are described in Section 2.2.1.6 of this report.

(4) Mission Results - The internal arrangement met all crew requirements during the training program. Following the SL-2 mission, the crew stated the desire to have better orientation techniques, such as color coding and graphics to aid them in locating equipment. The SL-3 crew expressed difficulty in becoming oriented on entering the MDA, and suggested that a more orderly arrangement would have made it easier to locate specific stowed items.

(5) Conclusions and Recommendations - The final MDA internal configuration evolved as the program requirements were defined. Early in the program, the equipment identified as MDA installations was limited to major items such as the ATM C&D Panel, M512 experiment, foot restraints, film vaults, EREP, stowage items and life support equipment. As program objectives continued to be defined, additional major components were added to the MDA such as the Video Tape Recorder, BI/LCA, additional stowage containers and many miscellaneous stowage items. All equipment was mounted to the wall circumferentially for crew access and visibility. By the end of the design portion of the program, new items were being added in all locations capable of taking launch loads and meeting functional requirements during orbital operations. As a result of the enormous growth in amount of equipment in the MDA, the final design arrangement was not optimum for the functional and housekeeping activities of the crew.

The crew performed all functions in the MDA satisfactorily, indicating that the internal arrangement was workable if not optimum. Early identification of all equipment to be installed would be of great value in improving internal arrangement in future programs. Orientation and equipment location identification can be improved, in any case, by using color coding and graphics.

B. Docking Port Hatches -

(1) Design Requirements - Requirements of the hatch were to provide a pressure tight closure which could be operated easily by the crew and would withstand all handling and operational environments without functional degradation. Minimum and maximum operating forces were defined in the CEI Specification, as were temperature limits for the handles. The hatches were also required to be removable and interchangeable.

(2) Description - The MDA had two circular, inward-opening hatches, one at each docking port (see Figure 2.2.1-5). The hatches were 32 inches in

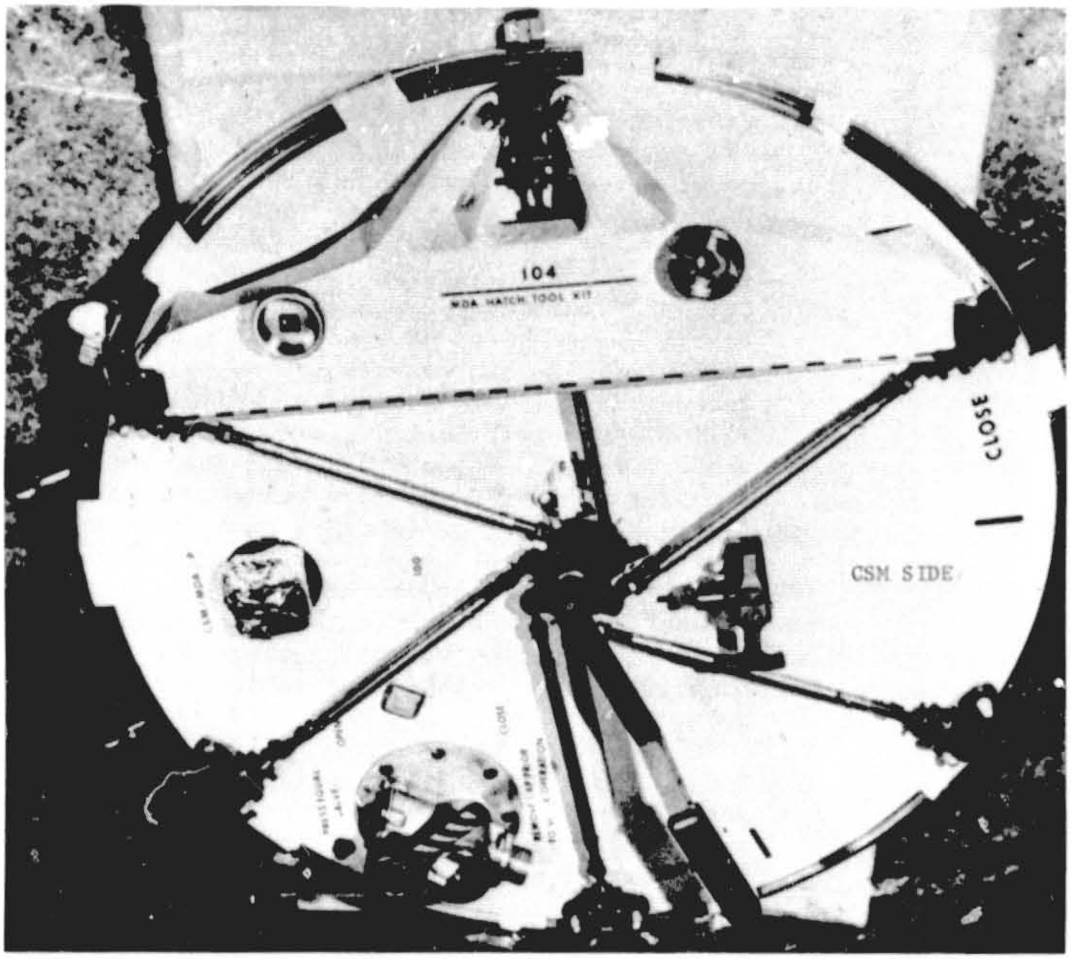


Figure 2.2.1-5 Axial Hatch

diameter and 1.2 inches thick. Each hatch was held in the closed position with six overcenter latches. The latches were controlled by linkages attached to a central shaft. Handles were attached to the shaft on both sides of the hatch, thereby allowing opening and closing from either side. The handles were restrained in the closed position during launch and orbital storage periods by a launch lock which was locked from the outside only but could be unlocked from either side.

Each hatch was operated by moving the operating handle through an angle of approximately 60°. Typical operating force on the handle was six pounds, although any force up to 25 pounds was considered acceptable. A ball plunger detent device held the handle in either the open or closed position. After the latches were released, the hatch was free to swing open on hinges to the full open (stowed) position, where it was restrained by ball plungers in the hinges. A force of approximately seven pounds was required to free the hatch from the stowed position.

Each hatch contained a delta pressure gage and a pressure equalization valve which are described in Section 2.2.2.5.

The edge of the hatch was a lip which depressed a silicone rubber seal in the MDA shell docking port ring to achieve a pressure tight closure. The amount of seal indentation was limited by six mechanical stops to prevent overstressing of the seal.

The axial hatch included a tool box mounted on the CSM side with tools for contingency opening of the hatch in event of a mechanism malfunction or a hatch to seal sticking problem.

The seals were held in their retaining rings by a pressure sensitive adhesive (see Section 2.2.1.5) which enabled the crew to replace a seal during the mission if required.

(3) Test - Component qualification tests of the hatch were used to demonstrate the adequacy of the design for launch and orbital conditions. The flight hatches were tested for leakage before installation and for handle operating forces after installation. The hatch seal was tested separately to assure its integrity under long life thermal vacuum conditions.

Qualification tests verified the final hatch design for pressure, vibration, pyrotechnic shock and ultimate handle forces. Details of the qualification tests are given in two test reports (0436/40-SL-112-2 and 0436/40-SL-126-2).

Tests were conducted on sections of hatch seals to determine the ability of the seal to withstand long periods of time while compressed under operational conditions and to determine whether sticking of the seal to the hatch could become a problem. Test specimens were four inch long pieces cut from a production seal. The specimens were compressed in a fixture resembling a seal retaining ring, and placed in a vacuum chamber with controlled temperature. Periodically, specimens were removed from the chamber, pulled to measure sticking force, and examined for damage. The test program was successfully concluded after eight months exposure of the final seal configuration with no damage and acceptably small sticking forces. Another test of a full-size seal was conducted to measure leakage degradation over eight months of compression. This test, which was at room ambient conditions, showed negligible leakage of the seal after the full mission time. The hatch seal tests are described in detail in ED-2002-2048.

(4) Mission Results - The axial hatch operated normally during activation and deactivation by the three Skylab crews. The contingency tools were not required. The radial hatch was not operated.

(5) Conclusions and Recommendations - The MDA hatch design was furnished by the Government. When responsibility for the design was assigned to MMC some new loading requirements were imposed. These made necessary some detail design changes and some parts were changed from aluminum to steel, but the basic design remained the same. Hinges were added to the hatch at this time. Mechanical stops were added to the hatch to limit indentation of the seal when a potential failure mode was shown by a test. Sticking of the seal to the hatch indenter was recognized as another potential failure mode, and contingency opening tools were designed to deal with this problem. A tool box was added to the axial hatch to hold these tools.

The original seal was made of an extremely soft and flexible silicone rubber. Several seals were successfully made of this material and two were installed in the MDA flight article. Later, an attempt was made to procure additional spare seals but the vendor was unable to supply satisfactory parts. The base polymer proved to be an experimental material on which work had been discontinued because of production problems. At about the same time, sticking began to appear in the thermal vacuum tests. The decision was made to use an alternate material, a conventional silicone rubber formulation of medium hardness. No production problems were encountered and a sufficient number of seals was fabricated for the flight and backup articles, test and spares.

The tendency toward sticking between the seal and metal lip was effectively counteracted by treatment of both surfaces. The silicone rubber had talc burnished into the sealing surface, and the hatch lip was coated by an aerosol spray of teflon particles in an acrylic binder.

The honeycomb sandwich design of the hatch was not basically adaptable to design changes, but no serious problems were encountered in designing stop fittings and a tool box to add to the completed hatch. Similarly, the seal was replaced although the original design did not anticipate this.

Several problems with the hatch resulted from not designing for ground handling conditions. The steel ball plungers that were used to hold the hatch in the open position wore grooves in the aluminum hinge fittings because of numerous open/close cycles during final assembly and checkout of the MDA. The solution was to remove the ball plungers until just before launch. A few retaining rings were lost from the hatches during transportation and handling. The precise cause of the problem could not be ascertained, but the rings were in a vulnerable location and apparently were inadvertently knocked off. The solution was to change to a heavy-duty ring design.

The MDA docking port hatches performed satisfactorily throughout the Skylab mission. The axial hatch was opened and closed three times. The radial hatch was not operated.

Experience with the MDA hatch leads one to the conclusion that early consideration of ground handling and prelaunch operations would have had a beneficial effect on the hatch. Several rework operations could have been eliminated and a last-minute installation avoided without compromising the weight, cost or flight worthiness of the hardware.

C. Windows - The MDA contained four single-pane windows which were installed in the structural shell of the vehicle. The S190 window was the largest of these and it served as a viewing port for the S190 camera. Whenever the camera was rotated back to its stowage position, a removable transparent cover (safety shield) was installed over the window's inside surface to protect the glass from accidental damage and to act as a redundant pressure seal in case the S190 window had failed.

The S191 window was used with the Viewfinder Tracker to locate EREP target sites and point the S191 Infrared Spectrometer at them. The other two MDA windows were used to pass visible and infrared light rays through the MDA wall from the external sensor of the S192 Multiband Scanner to the internal detector.

(1) S190 Window -

(a) Design Requirements - Two distinct sets of requirements were imposed upon the S190 window, one covering structural performance and the other dealing with optical parameters.

As an item of primary structure, the S190 window complied with all applicable requirements identified in the CEI Specification and in the Cluster Requirements Specification (CRS). Structurally, therefore, the window was designed to maintain structural and pressure leakage integrity by withstanding:

- Vibroacoustic loads
- Shock loads
- Pressure
- Internal operating environment
- Temperature extremes
- Van Allen Belt radiation
- Micrometeoroids
- Accidental impacts from the crew

The window's performance was demonstrated by analysis and extensive testing as described below.

As a viewing port for the S190 Multispectral Camera, the window was designed to comply with the requirements identified in the CEI Specification and in ICD 13M12201. The requirements included specifications for:

- Wavefront distortion
- Transmissibility
- Reflectance
- Glare
- Contamination control
- Moisture condensation prevention
- Crew protection from ultraviolet light

Optical performance was demonstrated by test.

(b) Description - The S190 window (Figure 2.2.1-6) was a single pane of borosilicate

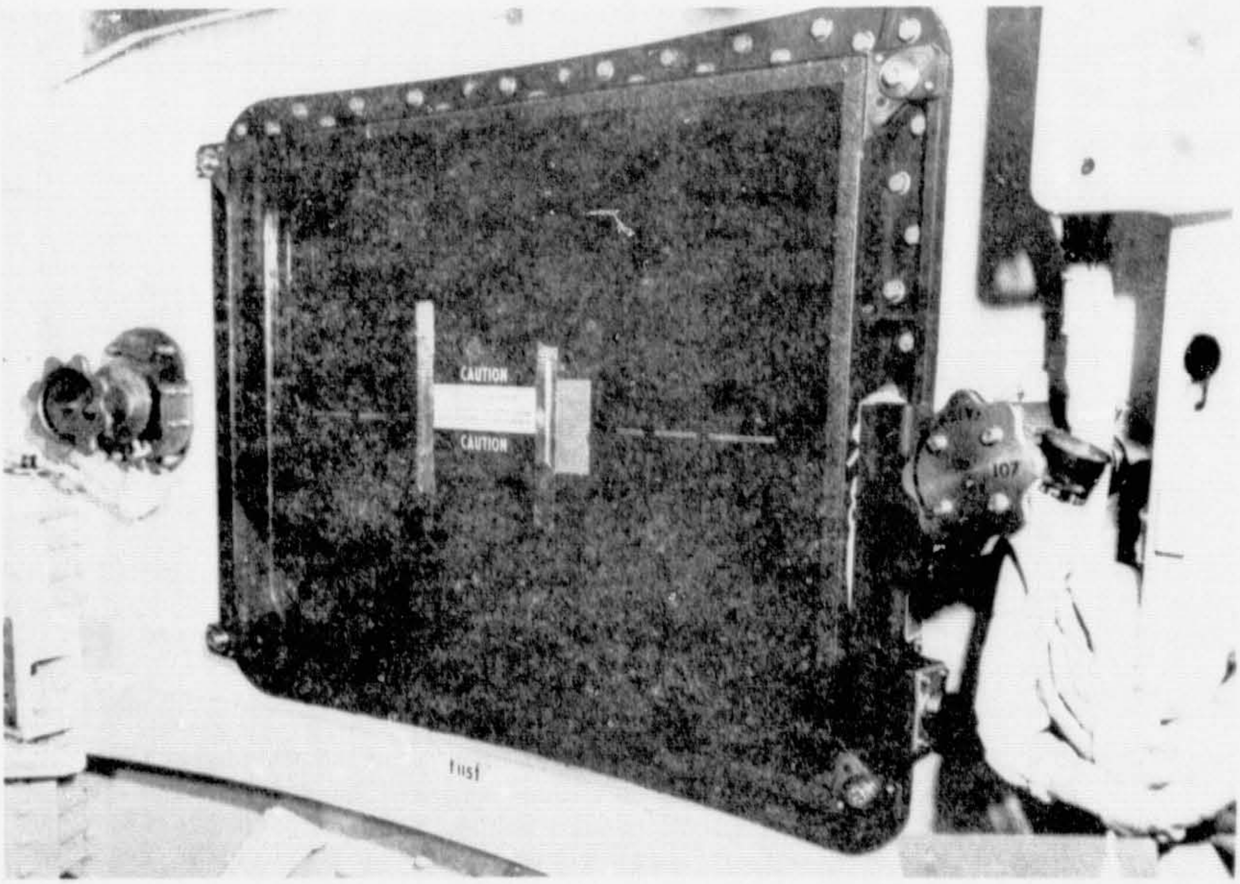


Figure 2.2.1-6 S190 Window and Mechanisms

crown glass (BK-7), 1.6 inches thick x 18" x 23", mounted and sealed in an aluminum frame and installed directly above the radial docking port in the MDA. The function of the S190 window was to maintain structural and pressure-leakage integrity of the MDA and to admit visible and infrared light to the S190 camera with a minimum of optical degradation. The window incorporated a heating system, which is described in Section 2.2.3.2.

(c) Test - Many tests were performed on the S190 window and window glass material. These include development, qualification, acceptance and specimen testing:

- Development, qualification and acceptance testing of prototype and flight windows included flaw-screening, vibration, shock, proof pressure, seal leakage, impact and thermal stress. Optical testing included wavefront distortion, transmissibility, reflectance and glare.

- Full-size specimens - A full-size window pane was successfully pressure tested to 124 psid (safety factor of 20). A second specimen successfully withstood 18 psid after being scored with a glass cutter to make an 18 inch long scratch; after a 0.35 inch deep flaw one inch long was made in the center of the other (unscratched) surface, the specimen broke at a pressure differential of 24 psid. (Both tests were conducted with the flawed surfaces in tension).

- Sample specimens - 100 six inch diameter test specimens of BK-7 glass were tested to determine the degradation caused by coatings, bus bars, humidity, temperature extremes, Van Allen Belt radiation and eight month vacuum exposure. The specimens were arranged in groups of 10 for statistical evaluation of individual environments. No degradation in glass strength was caused by any of the environments.

- Bar specimens - 25 bars of BK-7 glass were tested to obtain data about critical stress vs crack size and crack growth rate for long term loading effects.

- Block specimens - 12 pieces of BK-7 glass 1.6 inches thick did not static discharge or crack after being subjected to varying amounts of electron radiation.

(d) Mission Results - The S190 window operated normally throughout the mission. No problem was reported by any of the three crews. The window's optical performance met or exceeded all requirements and caused so little change in the wavefront passing through it that the window's presence in front of the S190 camera could not be detected in any of the photographs.

(e) Conclusions and Recommendations - One of the early designs of the MDA called for two windows, each using a single pane of Corning 7940 (fused silica) and sealed in its frame by completely embedding the edges of the pane in RTV sealant. The windows were to be compatible with the optical requirements of Experiments S101 and S063, but these had been only partially defined. When the EREP experiments were added to the MDA and Experiment S190 replaced S101, the optical requirements established for the window (because of the S190 experiment) affected almost all its key design criteria, including kind of glass and window size. Design concepts using double panes were studied but the optical requirement for wavefront distortion could be met only by using a single pane of BK-7 optical glass. Safety considerations stemming from the non-redundant single pane of glass led to the extensive test program described above, by which the strength of the glass material and structural integrity of the window assembly was demonstrated.

Each window pane was flaw-screened (checked for invisible defects) by pressure testing to 30 psid. RTV 566 was used to hold the temperature sensors against the glass. An epoxy was originally considered because of its high strength, but was rejected because epoxy bonding agents had caused glass spalling on the Lunar Module windows. The RTV did not cause any spalling and tests demonstrated that the RTV did not lower the breaking strength of the glass.

RTV also was used to fill and seal the small gap that occurs when the window frame is bolted against the MDA wall. In this application it was found to be superior to Dow-Corning's 93-500 silicone sealant. This was because the 93-500 would not cure in sections less than 0.010 inch thick and the actual gap between the two mating surfaces was less than this in many areas.

Early in the program it was determined that some varieties of optical glass develop structural damage after exposure to electron radiation such as that found in the Van Allen Belt. The damage is in the form of localized cracking (known as Lichtenberg figures) and occurs when the electrons trapped in the glass are discharged. The two prime glasses considered for the S190 window were BK-7 and BK-7G. BK-7G is very similar to BK-7 but is sometimes preferred because, unlike BK-7, it does not turn brown when irradiated. After BK-7 was selected as the window material, testing demonstrated that BK-7 glass was not degraded structurally by Van Allen Belt radiation. However, these tests results were not applicable to BK-7G. There was, in fact, some evidence that BK-7G glass had cracked after irradiation but only additional testing could provide conclusive evidence in this regard.

Plexiglas covers were successfully used to protect both surfaces of the window glass from scratches, smudges and other damage. The covers were used during manufacturing, shipping, during window installation in the MDA and after installation. They were removed about two weeks before launch. A special container was used to protect the window during shipping and storage.

Although the S190 window met all of its requirements throughout the Skylab mission, it is recommended that the requirements for optical windows for future spacecraft be defined in terms which relate to overall system performance and which include criteria that can be demonstrated by testing the entire optical system: window, camera, film, etc. It is also recommended that the S190 window design be used wherever possible because it is a proven design and also because, for many parameters, its optical performance cannot be improved unless significant advances are made in the present state of the art of spacecraft window manufacture.

(2) S191 and S192 Windows -

(a) Design Requirements - The S191 and S192 windows had both structural and optical design requirements. As structural items, the windows complied with all applicable requirements identified in the CEI Specification and in the CRS. The windows were designed to maintain structural and pressure-leakage integrity by withstanding:

- vibroacoustic loads
- shock loads
- pressure
- temperature extremes
- Van Allen Belt radiation

Performance was demonstrated by extensive testing as described below. As sensing ports for their respective experiments, the S191 and S192 Windows were designed to comply with the requirements identified in ICD 13M07399 and ICD 13M07400. These requirements included:

- transmittance
- reflectance
- wavefront distortion
- parallelism
- surface quality
- window material purity

The optical performance of these windows was demonstrated by test.

(b) Description - The S191 Window was a single pane of borosilicate crown glass (BK-7), four inches in diameter and 0.48 inches thick. It was installed with an elastomeric seal in the mounting fitting for the S191 Experiment. Its function was to maintain structural and pressure leakage integrity of the MDA and to act as a viewing port for the crewmen when pointing the experiment at the selected target.

There were two S192 Windows, one of germanium and one of fused silica. Each window was three inches in diameter and 0.25 inches thick. They were installed with elastomeric seals in separate openings in the S192 Experiment mounting fitting. The germanium window permitted certain infrared rays to pass into the S192 Internal Scanner/Processor while the fused-silica (Infrasil) window performed the same function for visible light rays.

(c) Test - An extensive test program was conducted on the S191 and S192 windows and window material. These tests include development, qualification, acceptance and specimen testing:

- Development, qualification and acceptance testing of prototype and flight windows included flaw screening, vibration, shock, proof pressure and seal leakage. Optical testing included transmittance, reflectance, wavefront distortion and surface quality.

- Full-size specimens - 25 germanium test specimens and 25 of Infrasil were tested to determine whether degradation was caused by coatings, humidity, temperature extremes, Van Allen Belt radiation, and eight month vacuum exposure. None of the environments caused a degradation in strength. (No separate tests were performed on a full size S191 Window because it was made of the same material ,BK-7 glass, as the S190 Window and the test results described above for the six inch diameter specimens were valid for both windows).

- Bar Specimens - Two bars of germanium and two of Infrasil were tested to obtain data about fracture toughness and crack growth rates under sustained loads. Similar data was obtained for BK-7 glass in connection with S190 Window testing.

(d) Mission Results - The S191 and S192 windows operated normally throughout the mission. No problem was reported by any of the three crews or by any of the experiment investigators.

(e) Conclusions and Recommendations - The S191 and S192 windows were first identified when those EREP experiments were added to the MDA. As the windows' optical requirements were firmed up, it became apparent that they could be met only by using single panes of window material. Because of this, the S192 windows were classified as critical items, failures of which would constitute a hazard to the crew. The testing described above was performed to demonstrate the windows' integrity. The S191 window was not defined as a critical item, because the S191 Experiment proved structural and pressure seal redundancy for the window, but this was not established until late in the program. Testing, therefore, was similar to that of the S192 windows.

Both S192 windows were flaw-screen tested by pressurizing to 30 psid; the S191 window was flaw-screened using 45 psid because its design was based on the possibility of a higher operating pressure, v[illegible] 15 psid vs 6.2 psid for the S192 windo[illegible]

It is recommended that the requirements for optical windows for future spacecraft be defined in terms of overall system performance and demonstrated by testing the entire optical system including any windows.

It is also recommended that [illegible]ble design stresses for window materials be established using fracture toughness data. This has been determined to be the only acceptable method for avoiding extreme conservatism in the design of structural windows. Strength of all window designs should be verified by burst tests. All windows should be flaw-screened or acceptance proof tested. Test conditions for these tests should be established by fracture mechanics calculations. For any new window design, a test program is necessary to determine effects of coatings and environmental exposure, and to establish fracture mechanics data for the window pane material.

(3) S190 Safety Shield

(a) Design Requirements - The S190 Safety Shield complied with all applicable requirements identified in the CEI Specification and in the

CRS. The safety shield was designed to provide sealing redundancy for the S190 Window and to withstand pressure, impact and vibroacoustic loads. Performance was demonstrated by testing as described below.

(b) Description - The safety shield was a removable internal cover for the S190 Window. It was positioned against the inside of the window frame and hand-fastened there by a crewman whenever the S190 Experiment was rotated into its stowage position back away from the window. The safety shield consisted of a high-strength glass panel (Corning Chemcor 0315), 0.290 inches thick, mounted and sealed in an aluminum frame. The frame included an O-ring on its mounting surface to provide sealing redundancy for the S190 Window. The function of the safety shield was to protect the S190 Window from possible damage resulting from the impact of loose objects within the MDA and to act as a redundant pressure seal in case the S190 Window had failed. The safety shield was launched in its stowage position on the aft end of Film Vault 4.

(c) Test - Acceptance tests of the glass panels included both structural and optical tests. Structural integrity was demonstrated by pressure testing and thermal-shock testing to 540°F to screen the panels for hidden flaws. Optical clarity was assured by testing for high transmittance and absence of distortion.

Acceptance and qualification testing of the safety shield included impact resistance, vibration, proof pressure and leakage of both the glass seal and O-ring redundant seal.

(d) Mission Results - The S190 Safety Shield performed normally throughout the mission. No problem or difficulty was reported by any of the three crews.

(e) Conclusions and Recommendations - Early concepts of the MDA included an internal window cover whose primary functions were to protect against internal impacts and to shield the crew from overexposure to ultraviolet (UV) rays. The ultraviolet shielding became less important when the S190 Window material was changed from fused silica to BK-7 glass because the BK-7 absorbs most of the UV light. Although the glass material used in the safety shields absorbs the residual UV light that passes through the BK-7 glass, it was not selected for that reason but because of its high impact resistance and because of its proven performance in the Lunar Module windows. Polycarbonates and acrylics were also considered as candidate materials for the safety shield panel but were rejected primarily because of flammability problems.

It is concluded that the S190 Safety Shield met all of its requirements during the Skylab mission.

It is recommended that the safety shield design be used wherever possible in future spacecraft to protect single pane windows from damage and to provide them with pressure leakage redundancy.

D. S190 Window External Cover

(1) Design requirements - The cover was designed to meet the following criteria:

- Provide meteoroid protection for the S190 window equivalent to the adjacent structure.
- Minimize heat loss through the area over the window.
- Provide contamination protection for the window.
- Provide venting for the cavity between the cover and window to accommodate pressure changes during transportation, purging and the ascent portion of the flight.

- Withstand all imposed loads.

- Meet outgassing criteria.

Another protection the cover provided for the window was against space radiation environment. This feature surfaced late in the program when the characteristics of the Van Allen Belt were obtained.

(2) Description - The external cover was a curved fiberglass honeycomb panel one inch thick by approximately 20 x 30 inches. It contained metal fittings, integrally bonded to the panel, for hinge attachment and latch engagement. Multi-layer insulation was installed in a fiberglass pan which was attached to the internal surface of the cover. The cover (including the pan) was painted black for thermal control and to minimize reflected light on the window. A resilient foam seal around the cover edge closed the gap between the cover and the meteoroid shield to prevent dust and other contaminants from reaching the window. The honeycomb panel had several vent holes to relieve internal pressure during boost.

(3) Test - No tests were conducted of the window cover alone. A development cover was included in the mechanism tests of vibration, acoustics and operating cycles. Although the sole purpose of the cover in these tests was as a mass simulator, the cover successfully withstood all test environments.

(4) Mission Results - The window cover successfully performed all required functions during the Skylab mission.

(5) Conclusions and Recommendations - The window cover was a conventional fiberglass honeycomb construction designed to minimize the effects of tolerance buildups in the components. The panel was first assembled and bonded in an autoclave. The edges and inserts were then bonded by using a room temperature curing adhesive. The panel was baked to release all

volatile products so the cover would meet outgassing criteria. The integrity of this approach was validated during the mission when the cover met all requirements with no problems.

E. S190 Window Cover Actuator and Latch -

(1) Design Requirements - The actuator and latch mechanisms were designed for ease of operation and to provide comfortable touch temperatures for the crew. They were also required to withstand all launch and operational environments without functional degradation. A mechanical design was specified to assure reliability. Maximum design loads and cycles were as specified in the CEI and CRS. Leakage requirements were defined that were compatible with MDA allowable leak rates.

(2) Description - Two mechanical devices, an actuator and a latch, were installed on opposite sides of the S190 window to hold the external cover in place during boost and storage periods, and to enable the crew to open the cover when the window was to be used. The latch was operated by turning the latch handle counterclockwise approximately seven turns. This operation moved an external latching arm outboard, freeing the edge of the cover so it could be opened. The cover was then opened by turning the actuator handle clockwise. The actuator handle was connected to the cover hinge through a gear set which moved the cover through one-half the angle of the handle. Rotating the handle 270° moved the cover to an angle of 135° from the window, which removed the cover from the field of view of the S190 camera. The actuator handle had a cam which operated a warning-light microswitch to indicate to the crew that the external cover was closed.

(3) Test - Tests were conducted to verify the capability of the mechanisms to withstand the design environments and operating conditions for the duration of the mission. The tests included measurements of operating torque and leak rate before and after exposure to vibration and acoustic excitation. A 30 day vacuum test

demonstrated that the mechanisms would function properly without excessive leakage under orbital conditions. These tests are described in two reports (0436/40-SL-113-2 and 0436/40-SL-128-2).

(4) Mission Results - The latch and actuator mechanisms functioned as planned throughout the Skylab mission. The SL-3 crew commented on the ease of operation of the external cover. The only anomaly was the failure of the cover-open indicating light which failed to operate correctly and consequently was not used by the crew. The procedure used was to visually make sure the cover was open.

(5) Conclusions and Recommendations - Conventional lubricants could not be used on the mechanisms because of their tendency to sublime in vacuum, which would reduce their lubrication value and cause contamination of the window. Various methods were employed to reduce friction and assure ease of operation. The heavily loaded bearings in the actuator hinge and the pinion gear were made of beryllium copper and the mating steel parts were coated with a baked dry film lubricant. Shaft bearings in both mechanisms were made of Rulon A, a reinforced polytetrafluoroethylene (PTFE) compound. During development of the mechanisms, problems were encountered with galling of bearing surfaces, which were apparently due to high local bearing stresses. These problems were solved by careful attention to cleanliness standards during assembly, by changing materials and by increasing clearances in some cases. Although the galling problems were solved for the window cover mechanisms, galling was not understood sufficiently to assure that the problem might not be repeated in future designs. Additional study of galling and identification of compatible material combinations is recommended for future space mechanism designs.

Each mechanism had a shaft that penetrated the pressure shell. Sealing of each shaft was accomplished by two seals between the shaft and housing. The self-activated seals were designed such that pressure increased the sealing force. The material of the seals was low-friction PTFE to minimize operating forces.

Mechanical devices of the type used for the actuator and latch provided a simple and reliable means for controlling the S190 window external cover.

F. Experiment Support - The MDA provided the structural supports for the following major experiments and equipment.

- S191 IR Spectrometer
- S190 Multispectral Camera
- M512 Material Processing Facility
- ATM C&D Panel
- S192 Multispectral Scanner
- S009 Nuclear Emulsion Experiment
- EREP Support Trusses

(1) Design Requirements - The experiment support structure was designed to meet physical design and functional requirements defined in their respective ICD's.

In all cases the structure was passive and the major design objectives were as follows:

- Withstand all imposed loads without degradation of shell or experiments.
- Design the structure using a factor of safety of 3.0.
- Maintain adequate rattle space.
- Provide crew operating space.
- Minimize hazards to crew.
- Maintain shell leakage integrity.

(2) Description - The supporting structure for the experiments were, in most cases, machined fittings that fastened to the MDA longerons and frames. The support structure was attached directly to the skin for experiments that penetrated the skin, i.e., S191, S190, and S192. The faying surfaces between the support structures and the skin were sealed with RTV; stat-o-seal washers were used on the attaching hardware to minimize leakage.

(3) Test - The structure supporting all of the experiments was designed and analyzed using a factor of safety of 3.0 based on ultimate strength. This precluded the requirement for any component testing. However, the support structure strength was verified in the vibroacoustic test (see Section 2.2.1.1) since the structure supporting the mass simulators was flight type. Leakage integrity was verified in the Flight Article leak tests (see Section 2.2.1.2).

(4) Mission Results - All experiments were securely mounted and there was no significant leakage in the MDA after ascent and during orbital operations. This indicates that the experiment support structure performed as planned.

(5) Conclusions and Recommendations - The addition of EREP to the baseline MDA resulted in many structural changes to provide the required support. The experiments had to be mounted on the "Z" axis of the Skylab for earth viewing. Also, the experiments had to be aligned within a specified tolerance so that integrated data could be obtained. The experiment support structure successfully met all requirements.

G. Film Vaults -

(1) Design requirements - The film vaults were designed to meet the following:

- Withstand imposed loads.
- Meet interface requirements as specified in their respective ICD's (Table 2.2.1-1).

FILM VAULT	SIZE (INCHES)	VAULT WEIGHT (POUNDS)	WALL THICKNESS (INCHES)	CONTENTS		LOCATION IN MDA	ICD
				ATM EQUIPMENT	MISCELLANEOUS EQUIPMENT		
No. 1	23x24x40	260	0.50	(2)S082A Cameras/ Canisters (2)S082B Cameras/ Canisters		Between ring frames at Sta 3422 & Sta 3566, & between longerons 2 and 3.	13M07405
No. 2	32x23x29	452	1.00	(2)S052 Cameras (2)S054 Magazines (2)S056 Magazines/ Shoe		Between ring frames at Sta 3487 and Sta 3522 & between longerons 5 and 6	13M07402 13M07403 13M07404
No. 3	21x24x30	495	1.50	(1)S052 Camera (1)S054 Magazine (1)S056 Magazine/ Shoe	(1) Hatch Seal (1) S183 Earth Terrain Camera	Between ring frames at Sta 3487 & Sta 3522 and between longerons 7 and 8	13M07402 13M07403 13M07404
No. 4	34x28x26	302	0.09 Min	(3)H Alpha 1 Magazines	(1)Spare TV Input Station (1)Spare Video Switch (1)Contingency Power Cable (1)Spare Video Switch Power Cable (3)Crewman Communication Umbilicals	Between ring frames at Sta 3566 and Sta 3604 and between longerons 2 and 3	13M07401

Table 2.2.1-1 MDA Film Vaults

- Provide quick release type supports for contents.

- Provide radiation protection for film.

- Allow one-hand operation for all functions associated with the film vaults and content removal.

- Provide crew with mobility aids on the external surfaces of the vaults.

- Eliminate sharp edges, corners and surface protrusions.

- Provide an adjustable device to hold the doors in any desired position.

- Arrange contents such that any individual component could be removed without interference with (or removal of) adjacent items.

(2) Description - Four film vaults were installed in the MDA to provide stowage for the ATM cameras and film and miscellaneous items for the Skylab mission. The film vaults were of various sizes and wall thickness to meet physical and radiation requirements defined in their respective interface control documents.

The film vaults were located and supported in the MDA at locations best suited for crew operation and to sustain launch loads. The vaults were fabricated from 6061-T6 aluminum. Doors were attached to the basic box with a continuous piano hinge and locked in place for launch loads with expando pins. During activation by the SL-2 crew, the expando pins were replaced with pip pins. The doors were equipped with a friction device to control inertia forces on the door during crew operations in zero-G. For additional information such as location, size, ICD's and additional usage of film vaults for other stowed items, see Table 2.2.1-1 and Figures 2.2.1-7, 2.2.1-8, 2.2.1-9 and 2.2.1-10.

(3) Test - The film vaults were designed using a factor of safety of 3.0 which eliminated the

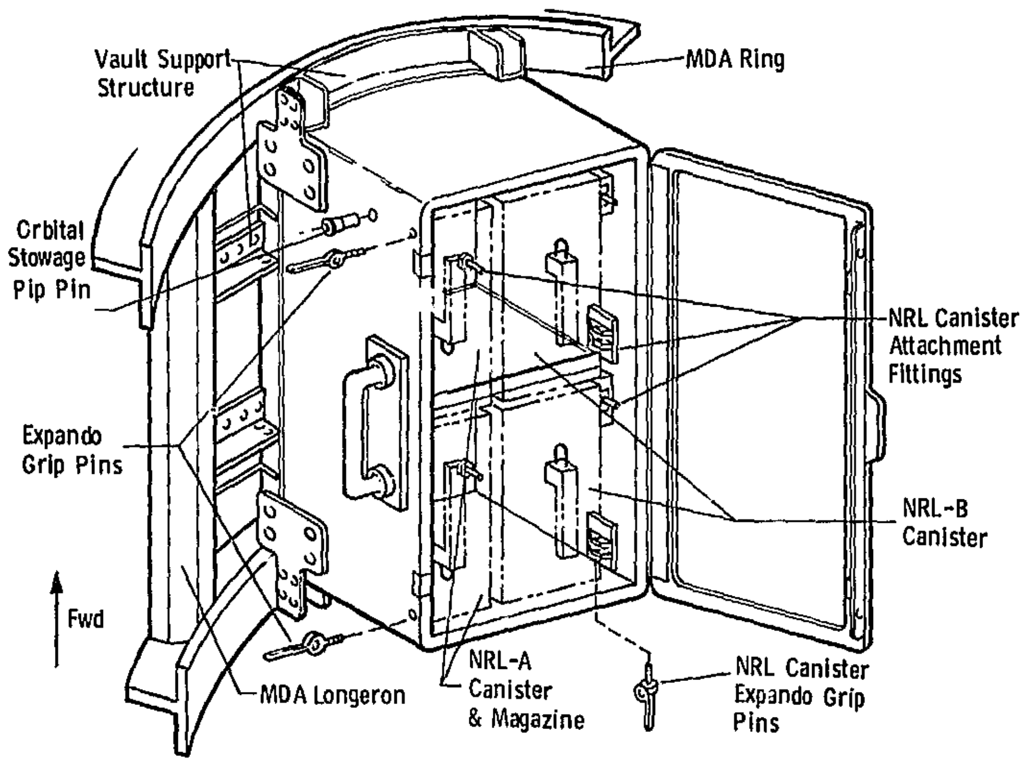


Figure 2.2.1-7 Film Vault No. 1

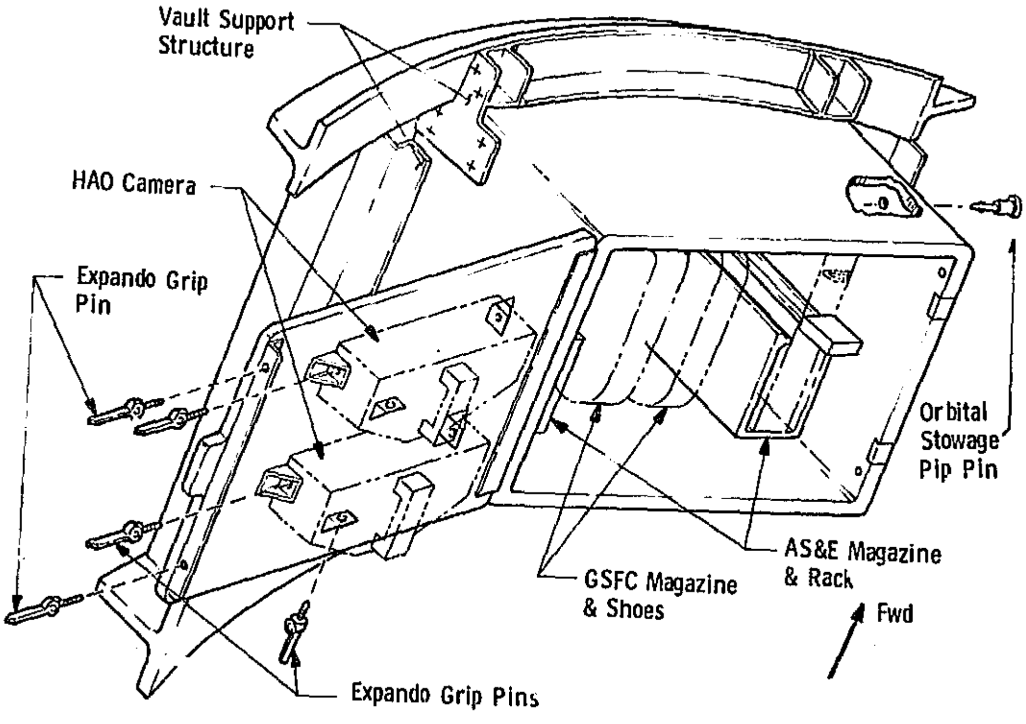


Figure 2.2.1-8 Film Vault No. 2

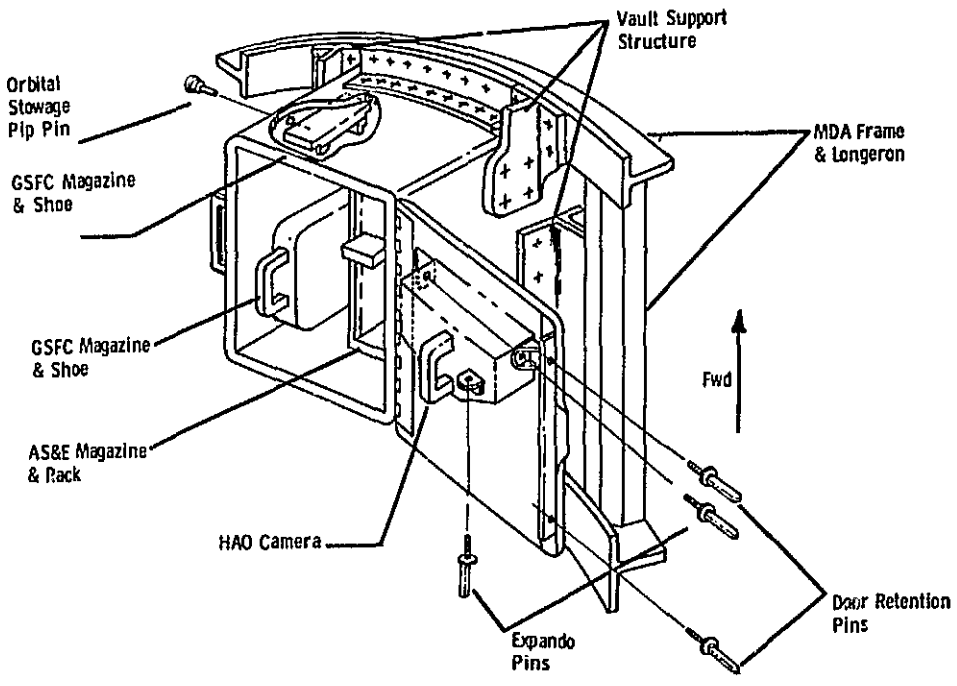


Figure 2.2.1-9 Film Vault No. 3

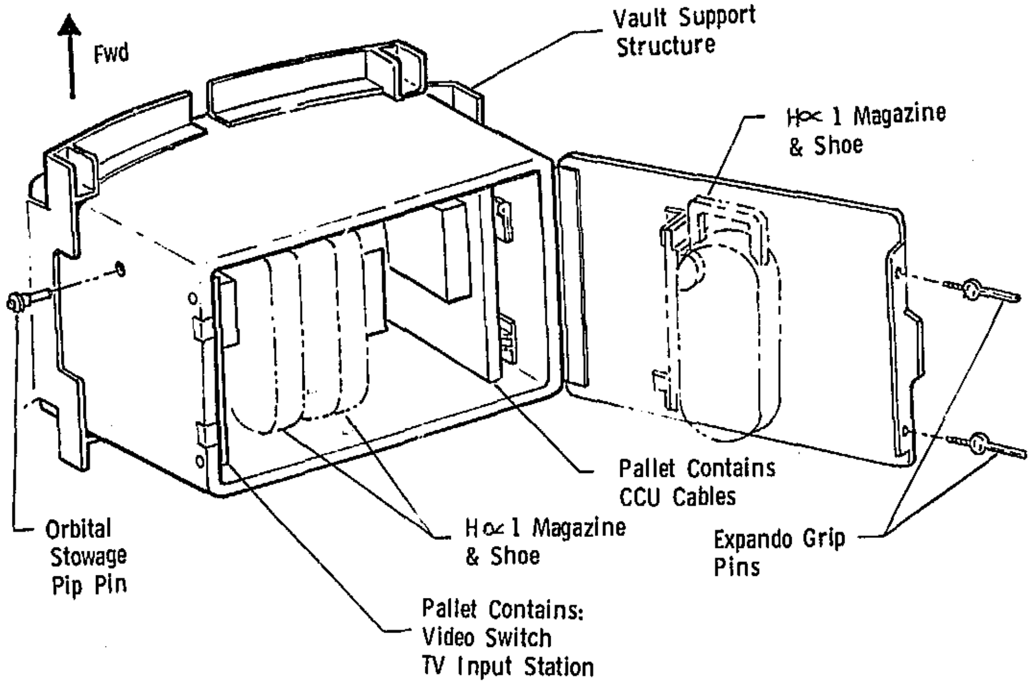


Figure 2.2.1-10 Film Vault No. 4

requirement for design verification testing. Form, fit and functional testing was performed on all the film vaults to verify interface control document and crew interface requirements.

A typical film vault test was conducted on a zero-G flight (see Section 2.2.1.6) to verify operability of the door friction device and the content quick release supports.

Film vaults 3 and 4 (the heaviest and lightest) prototypes were installed in the dynamic test article (see Section 2.2.1.1) with prototype contents. After the vibroacoustic tests, the vaults and contents showed no degradation.

(4) Mission Results - The film vaults performed as planned with no anomalies reported. The SL-3 crew stated that a door (or doors) did not appear to have any restraining friction. The crew apparently did not find it necessary to use the adjustable friction devices that were provided for each door.

(5) Conclusions and Recommendations - Film vaults 1, 2 and 3 were of welded construction with wall thickness from 0.50 to 1.50 inches thick. When welding the thick plates, warpage caused by excessive heat made it difficult to control flat surfaces in critical areas of interface and door fitting. The problem was overcome by machining after welding and shimming the fittings when required.

The doors were locked in the closed position for launch loads using expando pins in close tolerance holes. The matching holes in the door and vault tended to shift in alignment as the MDA position was changed under one-G conditions. This created problems with final manufacturing and checkout operations. However, alignment of the holes was not a problem on orbit.

During SL-3 and SL-4 missions the film faults functioned without any problems identified by the crew. A comment was made by the SL-2 crew that the camera removal/installation and door operation performed better than during training on the ground. However, future vault designs should consider improvements in the following areas:

- Study simplified fabrication methods. Alternate designs could use mechanical fasteners as a substitute for welding or employ thin-walled boxes with add-on mass for radiation shielding.
- Consider one-G operation as a design constraint with respect to door opening and closing.
- Replace expando pins with a one-hand operation mechanical latch.

H. Containers -

(1) Design Requirements - The design and functional requirements for the stowage containers were:

- Meet physical and environmental requirements defined in their respective ICD's.
- Containers and support structure must withstand launch loads.
- One-hand operation of container doors and removal of stowed items was desired.
- Design to a structural factor of safety of 3.0.
- Stowed items must be restrained in containers to prevent floating out in zero-G.
- Restraint must be provided on doors to hold in any position.
- Good accessibility to containers and stowed items was desired.

(2) Description - There were seven stowage containers located in the MDA. These containers were used to store a variety of items such as CO_2 absorber canisters, flight manuals, crew communication equipment, experiment support equipment, contingency tools, and in-flight maintenance tools and equipment. Several of the containers employed Mosites fluoroelastomeric closed cell foam as a cushioning material for stowed equipment.

The stowage containers were numbered in series according to their location, which aided the crew in finding a particular item. Each container lid had a decal listing the items and the quantities stowed inside. Locations of the containers are shown in Figure 2.2.1-4. The containers are described in Table 2.2.1-2.

(3) Test - All of the containers were functionally tested by crew operations engineers to insure operation of doors and fit of stowed items under simulated on-orbit operations. Removal and installation forces, restraint capabilities and door operation were evaluated during several crew compartment fit and function reviews and altitude-chamber exercises. During altitude chamber tests it was discovered that Mosite experienced growth when MDA internal pressure was reduced. This altered the dimension of stowage cavities in the containers. The problem was corrected by increasing the cavity size in the Mosite and revising the restraint system. No structural verification testing was required because of the large factor of safety used for the design.

(4) Mission Results - The stowage container configurations, locations in the MDA, door arrangement and methods of supporting and stowing the items in the containers were satisfactory for all applicable mission operations. The hardware performed during the mission without any significant problems.

CONTAINER	SIZE (INCHES)	CONTENTS	LOCATION IN MDA	TYPE OF INTERNAL RESTRAINT	TYPE OF LATCH	LAUNCH LOCK	ICD
CO_2 Absorbers Container (M) 125	7.00 X 16.50 X 40.00	10 Sealed CO_2 Canisters	Between Longerons 1 and 2 at Approx. Sta. 3544	Friction Between Mosites, Pads and Springs and CO_2 Canister.	Squeeze Tabs in Lid.	Hair Pin Clip with Pull Ring.	13M13427
Control Head Stowage Container (M) 142	5.50 X 8.50 X 18.00	4 Control Heads	Between Longerons 2 and 3 at Approx. Sta. 3533	Profile Cavities in Mosites with Interference between Control Head and Mosites.	2 Dialatches	Dialatches Torqued to 25 In.-Lb.	13M13424
S054 Return Container Stowage Rack (M) 151	12.50 Dia. X 23.25	4 S054 Return Containers	Forward Side of Film Vault No. 2, Between Longerons 5 and 6 at Approx. Sta. 3522	Close Fit Between Mosites Pads and S054 Return Containers. Beta Strap for Each Container.	2 Flush-Type Tension Latches.	Preload in Latches.	13M07408
Flight Data File (M) 126	10.75 X 11.50 X 21.50	Flight Manuals	Between Longerons 1 and 2 at Approx. Sta. 3522.	Adjustable Elastic Fabric Separator Partitions.	Squeeze Tabs in Lid.	Hair Pin Clip with Pull Ring.	None
Miscellaneous Stowage Container (M) 157	11.00 X 22.75 X 30.00	Misc. Comm. Equip., SOMA, Return Containers, Spare Umbilicals, Accutron Timer, etc.	Between Longerons 2 and 3 Between Stations 3487 and 3522.	Compartments Lined with Mosites and Removable Mosites Tray. Beta Straps for Zero-G Restraint.	Squeeze Tabs in Lid.	Hair Pin Clip with Pull Ring.	None
Hatch Tool Box (M) 104	3.60 X 7.50 X 25.60	Hatch Contingency Opening Tools	CSM Side of the Axial Hatch	Profile Cavities in Mosites Beta Straps for Zero G Restraint.	2 Calfax Fasteners	Fasteners Torqued to 30 In.-Lb.	None
MDA Tool Box (M) 144	10.00 X 15.25 X 17.50	In-Flight Maintenance Tools and Repair Materials.	Aft Side of Film Vault No. 3 Between Longerons 7 and 8 at Approx. Sta. 3487	Profile Cavities in Mosites with Velcro at Bottom of Cavity or Beta Straps.	1 Pip Pin Per Drawer.	2 Pip Pins per Drawer	None

Table 2.2.1-2 Stowage Containers

(5) Conclusions and Recommendations - Mosites foam was used as the cushioning material to provide environmental protection for stowed equipment. This material was selected because it met the flammability and toxicity requirements. The Mosites foam performed its function as designed during the mission, but several problems were encountered with it during fabrication and testing. The problems and concerns are listed below.

(a) Mosites foam must have its edges treated with a liquid fluorel which requires a long curing time to prevent flaking and wear. This condition presented a major development problem when repair in the vehicle was required.

(b) Mosites foam expands and contracts when subject to pressure cycles (See Section 2.2.1.5)

(c) Mosites foam is not very durable when subject to wear resulting from installing and removing stowed items by the crew.

(d) Mosites foam is a somewhat difficult material to work with in the shop during fabrication.

(e) The large tolerance on thickness of Mosites foam sheet stock makes it difficult to control dimensions of finished parts.

(f) Mosites foam takes a permanent set under sustained loads, causing dimensions of parts to change during use.

To provide a one-hand operation of container doors for the crew during orbital operations, the selection of door latches was of special concern. The basic types of latches used were Calfax and Dialatch fasteners. Data volunteered by the crew indicated that Dialatches were unsatisfactory because of their tendency to catch after loosening, making one-hand operation impossible. The crew indicated that the Calfax fasteners were satisfactory, although loose retaining washers on these fasteners were a nuisance. The main complaint of the crew was that the location and organization of the stowage containers sometimes made it difficult to find stowed items. Although the MDA stowage containers performed as planned, it is recommended that in future designs of manned space vehicles the following items be considered:

- When stowing items that are used to perform a similar function, they should be stowed in the same containers; i.e., all typical tools in the same container and drawer, if possible.

- Container doors, latches, and restraint hardware should be standardized and use off-the-shelf hardware adapted to meet spacecraft maintenance requirements, if necessary.

- Use standard Allen-head type drive tools, where possible, to release latching fasteners.

2.2.1.5 Materials

Selected materials used to fabricate the Multiple Docking Adapter are discussed in this section, including metallic as well as non-metallic materials; the design requirements; testing and conclusions and recommendations based on MDA experience for future manned space programs. A complete listing of all materials used on the MDA can be found in Report ED 2002-2021-11 Rev. A.

A. Metals - Metals used in the fabrication of the MDA included the following alloys:

- Aluminum - 2014, 2219, 2024, 6061 and 7075
- Steels - A286, 300 Series Stainless, 17-4PH, 17-7PH, PH15-7 Mo and MP-35N.

The basic structural shell of the MDA was designed and fabricated by NASA-MSFC from 2219-T87 aluminum alloy. (See Section 2.2.1.2 for details).

(1) Requirements - The requirements for the selection of metals by MMC for the MDA installations was based on the optimum inter-relationship of performance, cost, availability and reliability. One of the prime concerns was stress corrosion cracking. The initial controlling document was MMC drawing 82000000205, "Design Criteria - Material, Processes and Finishes". Later in the program MSFC document 10M33107, "Guidelines for Controlling Stress Corrosion Cracking", was imposed.

(2) Test - No element tests were conducted on the MDA program. Strength allowables were taken from MIL-HDBK-5A. Test bars were processed with parts for in-plant heat treatment as required by Standard Processes.

(3) Discussion - Parts were designed in accordance with MMC drawing 82000000205 to preclude the possibility of stress corrosion cracking. This drawing defined the maximum allowable stress as a percentage of tensile yield strength for each alloy and temper and for the longitudinal, long transverse and short transverse that cannot be exceeded. Table 2.2.1-3 shows the allowable stress

ALLOY	TEMPER	FORM (Bare or Iridited)	ALLOWABLE STRESS: % Fty LONGITUDINAL	LONG TRANSVERSE	SHORT TRANSVERSE
2014 AL	-T6, T62, -T651	Plate Rolled/Drawn Bar	70	50	15
	-T6, -T62, -T6510 -T6511	Extruded Bar	70	35	15
	-T6, -T62, -T652	Forged Bar	50	35	15
2024 AL	-T3, T351, -T4, T42	Sheet, Plate	70	50	15
	-T351, -T3511, -T42	Rolled/Drawn Bar, Extrusion	70	50	15
2219 AL	-T62,-T81 -T87	Plate	75	75	75
	-T62,-T81 -T87	Rolled/Drawn Bar, Extrusion	75	75	75
6061 AL	-T6, -T62 -T651	Plate	100	100	100
	-T6, -T62, -T651	Rolled/Drawn Bar	100	100	100
	-T6, -T62, -T6510 -T6511	Extrusion	100	100	100
7075 AL	-T6, -T62, -T651	Plate	75	70	12
	-T6, -T62 -T651	Rolled/Drawn Bar	75	70	20
	-T6, -T62 -T6510, -T6511	Extrusion	75	50	12
300 Series Steel		Plate & Bar	100	100	100
400 Series Steel		Plate & Bar	30	30	30
17-4PH Steel		Plate & Bar	75	75	75
PH15-7MO Steel		Plate & Bar	50	50	50
A-286		Plate & Bar	100	100	100
MP-35N		Bar	100	100	100

Table 2.2.1-3 Resistance of Metals to Stress Corrosion Cracking

reduction factors used in the MDA design. These values were conservative and were based on test data from various sources.

Additional steps that were also taken to minimize stress corrosion cracking were:

- Use of stress relieved tempers where possible.
- Use of chemical films, organic coatings and sealants.
- Avoiding interference fits on installation.
- Shim where required to minimize bending.
- Avoiding galvanic couples.
- Improving the surface by reducing surface roughness or increasing surface compressive stresses.

MSFC drawing 10M33107, "Guidelines for Controlling Stress Corroison Cracking" was imposed later in the program. A survey of all MDA structure was made and a total of 42 critical structural items made from 2014 or 2024 alloy were identified as susceptible to stress corrosion cracking. In accordance with the requirements of 10M33107, a Stress Corrosion Evaluation Form was prepared for each item. These evaluations took into account the alloy, temper, size and form, residual stress, assembly stress, finishes, function and rationale. They were submitted for approval to MSFC.

Steel alloys were used prim[illegible]ly in mechanical fasteners and mechanisms wh[illegible] high strength was required. Steels used were A286, Tensilized A286, 300 Series Stainless, 17-4PH, 17-7PH, and PH15-7 Mo. To minimize stress corrosion cracking, the precipation hardened steels were used in the following heat treat conditions:

Alloy	H.T. Condition
17-4 PH	H1025
17-7 PH	CH900
PH15-7 Mo	TH1050

All steel parts were passivated after final fabrication to further reduce any tendency for corrosion.

Multiphase MP-35N was used on the MDA where extremely high strength was required. This nickel-cobalt base alloy was hardened to strength levels of 260-300 Ksi by work strengthening and aging. This alloy had excellent resistance to corrosion and stress corrosion cracking.

(4) Conclusions - Avoid, where possible, all alloys known to be susceptible to stress corrosion cracking. Where this is not possible, use allowable stress reduction factors, coatings, sealants, shimming and stress-relieved tempers.

B. Nonmetallic Materials -

(1) Flammability, Odor, Offgassing and Vacuum Outgassing

(a) Requirements - The flammability, odor, offgassing, and vacuum outgassing requirements for nonmetallic materials used on the MDA were defined in the following documents:

- 50M02442 - This document, issued by NASA/MSFC, defined the vacuum outgassing requirements of high vapor pressure materials on the exterior surface of the MDA in line-of-sight with critical optical surfaces. This requirement was intended to control the deposition of contamination on these surfaces resulting from outgassing of materials from other surfaces.

- MSFC-SPEC-101A - This document defined the flammability, odor and offgassing requirements for materials within the MDA. The requirement for offgassing in this case was concerned with the carbon monoxide and total organics given off by nonmetallic materials when heated to 155°F in a 5 psia oxygen atmosphere.

(b) Tests - All materials used within the MDA were tested for flammability, odor, and offgassing of carbon monoxide and total organics unless rationale for not testing could be provided on the basis of similarity to materials or configurations already tested.

All materials used external to the MDA in significant quantities and in line of sight with critical optical surfaces were tested for vacuum outgassing to the requirements of MSFC Specification 50M02442 unless rationale for not testing could be provided on the basis of similarity to materials already tested. Results of these tests are summarized in 50M02442.

(c) Discussion - Final acceptability of nonmetallic materials to the requirements of MSFC-SPEC-101A and 50M02442 was based on the manner in which the materials were used relative to one another, ignition sources, heat sinks, flame barriers, flame enclosures, etc. Therefore, use of all nonmetallic materials was documented in numerous usage agreements which were submitted to NASA/MSFC for approval. The usage agreements described each application in which nonmetallic materials were used, and listed the quantity (weight and exposed surface area) in the particular application. They also included the test data which supported the acceptability of the materials as well as the rationale justifying their acceptability. The usage agreement, when approved by the Materials Branch of MSFC, was then submitted to the Materials Applications Evaluation Board for final approval.

The complete list of nonmetallic materials used by MMC in the MDA, together with a description of the applications, the quantity used, and the applicable usage agreement number is given in "Multiple Docking Adapter Materials Flammability, Odor, and Toxicity Report," ED2002-2021-11, Rev. A., dated March 1973.

A matrix was maintained for Government Furnished Equipment documenting the usage agreement or Government letter certifying that the nonmetallic materials used met the necessary flammability, odor, toxicity and vacuum outgassing requirements.

(d) Conclusions - Based on the rationale and supporting test data documented in usage agreements concerning the manner in which nonmetallic materials were used on the MDA, it is concluded that these materials met the intent and purpose of MSFC-SPEC-101A and 50M02442.

(2) Fungus -

(a) Requirements - CEI Specification CP114A1000026 specified that, unless design considerations dictated otherwise, materials used in the MDA must meet the fungus requirements of MIL-STD-810. These requirements could be met by materials testing or by analysis.

(b) Tests - MIL-STD-454C, dated October 1970, and MIL-T-152B, dated March 1961, listed a number of nonmetallic materials which were considered to be non-nutrients for the growth of fungi. A comparison of this list with the list of nonmetallic materials used in the MDA (MMC Report ED-2002-2021-11 Rev. A, dated March 1973) shows that practically all of the materials used in the MDA were non-nutrients for fungus. It could be shown by analysis that most of the other MDA materials were also non-nutrients for the growth of fungi, and that the remaining materials used, would not impact serviceability of the MDA if fungus growth occurred. No testing of materials for fungus was therefore performed on this program.

(c) Discussion - Many of the MDA materials specifically listed in MIL-STD-454C and MIL-T-152B are considered as being non-nutrients for the growth of fungi. The principal MDA materials not listed in these documents are:

- Fluorocarbon Rubber (e.g. Viton, Fluorel, REFSET)
- Silicone Rubber
- Polyurethanes
- Epoxies

All of the listed materials were investigated, either by the producer or MMC, and found to be fungus resistant, or used in a manner such that surface growth of fungus, should it occur, would not impair serviceability of the MDA or any equipment in it.

(d) Conclusion - It is concluded that practically all nonmetallic materials used were inert to fungus. Those that were not proven to be entirely fungus resistant were considered extremely poor sources of nutrients for fungus. Their use in the MDA was such that, if fungus growth occurred, serviceability of the hardware would not be impaired. The materials were therefore in conformance with the intent of the fungus resistance requirement of the CEI Specification.

(3) Hatch Seal Materials -

(a) Requirements - The design requirements for the hatch seal materials were:

- The seal material must be resilient over the temperature range of 35^{o} to $105^{o}F$. The specific requirements after postcure were:

- Durometer 27 to 40 Shore A.
- Tensile ultimate strength, 600 psi minimum.
- Elongation, 400 percent minimum.
- Tear, 20 lb/in. minimum.
- Compression set, 30 percent maximum, compressed to 75 percent of original height for 70 hours at 300 $\pm 5^{\circ}$ F, per ASTM D395, Method B.

- Allowable sticking force after the hatch had been closed for eight months in vacuum at 120° F was 0.45 pounds per inch with force applied at the center of the hatch and 1.38 pounds per inch with force applied at the edge of the hatch.

- The seal must be capable of inflight replacement by the astronauts. Therefore, the seal adhesive must conform to the following requirements:

  - It must be a pressure sensitive system that could be applied to the seals prior to flight, thereby relieving the astronauts of this task.

  - It must have sufficient adhesion to prevent any unwanted separation of the seal from the seal groove during hatch usage.

  - Its adhesion must be low enough that seal tearing does not occur during removal, thereby leaving residue in the groove and interfering with seal replacement.

- All materials must meet the flammability, odor, and offgassing requirements of MSFC-SPEC-101A.

- All materials must demonstrate stability in vacuum after eight months exposure.

(b) Tests - In the development of seal materials, the following types of tests were performed (detailed test results are given in ED-2002-2048, "Evaluation of Elastomers for the MDA Hatch Seals-Final Report, July 1973"):

- Physical testing of seal elastomers in test configuration:
  - Hardness
  - Tensile strength
  - Elongation
  - Tear strength
  - Compression set
- Physical testing of seal elastomers in hatch seal configuration:
  - Hardness
  - Tensile set
  - Elongation
  - Compression set versus temperature
  - Compression set after thermal vacuum exposure (up to eight months at 120° F)
  - Critical temperature (compression set)
  - Accelerated life test (compression set)
- Evaluation of Anti-stick Treatments:
  - Sticking force between seal and cover indentor (up to eight months at 120° F in vacuum)
- Evaluation of Adhesive:
  - Bond strength of various adhesives
  - Variation of catalyst ratio and cure schedule for optimum tackiness of DC282

- Effect of vacuum exposure on peel strength of DC282

- Flammability, Odor, Offgassing per MSFC-SPEC-101A

  - Material tests

  - Configuration test (flammability)

- Vacuum Outgassing per 50M02442

(c) Discussion - Kirkhill Rubber Co. compound 910-C-1093, was selected initially because of its reported hardness range of 12 to 18 Shore A. However, the hardness of preproduction seals was in excess of 18 and the formulation was modified to produce the desired 12-18 hardness range. It was redesignated 910-C-1093A.

The first production seals contained contaminations and undetected reversion spots in the seal. Use of one of these seals in a design verification test of the hatch resulted in a longitudinal split in the seal surface where the hatch indentor strikes the seal.

Continuing difficulties in producing seals of acceptable quality resulted in changing to an alternate material, Kirkhill silicone compound 935-C-2462. This material avoided all of the mixing and processing problems of the first material, but was significantly harder (35 Shore A as compared with 12-18). The amount of indentation was reduced so that the hatch closing forces were within acceptable limits.

The original adhesive selected for installation of the seal was Dow Corning A4000 silicone adhesive. It provided a permanent bond so that the seal tore during removal and left a residue of adhesive and seal material in the groove. When the requirement for a replaceable seal was imposed, a new adhesive material was required. Several double adhesive tapes and transfer tapes were evaluated but these did not adhere well to the seals. A satisfactory system was developed based on Dow Corning DC282 silicone adhesive. The adhesive was applied to the bottom surface of the seal and then heat cured. Until the seal was installed, the adhesive was protected by a film of polyethylene.

High sticking forces between the seal and hatch were encountered after exposure to thermal vacuum for three months. An anti-stick treatment was applied to the seal and to the hatch surface to minimize these forces.

Silicone material is basically flammable in the MDA atmosphere. However, when tested for flammability in a configuration simulating the actual seal installation, the seal would not support combustion. The spare seal was stowed in a double layer non-flammable Teflon coated glass cloth bag.

Odor and offgassing tests for the hatch seal and all related materials showed that they were acceptable per MSFC-SPEC-101A.

All materials functioned satisfactorily after an eight month exposure in vacuum at 120°F.

(d) Conclusions - When selecting seal materials, is is recommended that the designer choose those that have a significant history of manufacturing experience, are easily produced, and then design mechanisms based on the materials' mechanical properties including hardness.

(4) Mosites 1062C Fluoroelastomeric Closed Cell Foam For Use As Liners In Storage Containers -

(a) Requirements - a need existed in the MDA for a cushioning material, principally for use in stowage containers, meeting the following general requirements:

- It must have a low density.
- It must be resilient.
- It must not pose flammability or toxicity hazard in the MDA.
- It must be relatively easy to fabricate into various shapes, and to rework once installed in a container.

(b) Tests - The following tests were performed:

- Recovery/Permeation Tests - The variation of thickness of 1/2 inch thick Mosites 1062C Fluorel foam with variations in ambient pressure, and the ability of the material to recover after long periods of exposure to low pressure were determined. Application of 26 psia pressure from an initial ambient pressure of 12.0 psia reduced the thickness by 20 percent, but the material recovered immediately when the initial ambient pressure was restored. After 8 days exposure to 5 psia and 111 days exposure to 0.5 psia, repressurization to 5 psia reduced the thickness to approximately 4.4 percent less than original, due to permeation of gas out of the foam during the long term exposure to 0.5 psia. These results are shown in Figure 2.2.1-11.

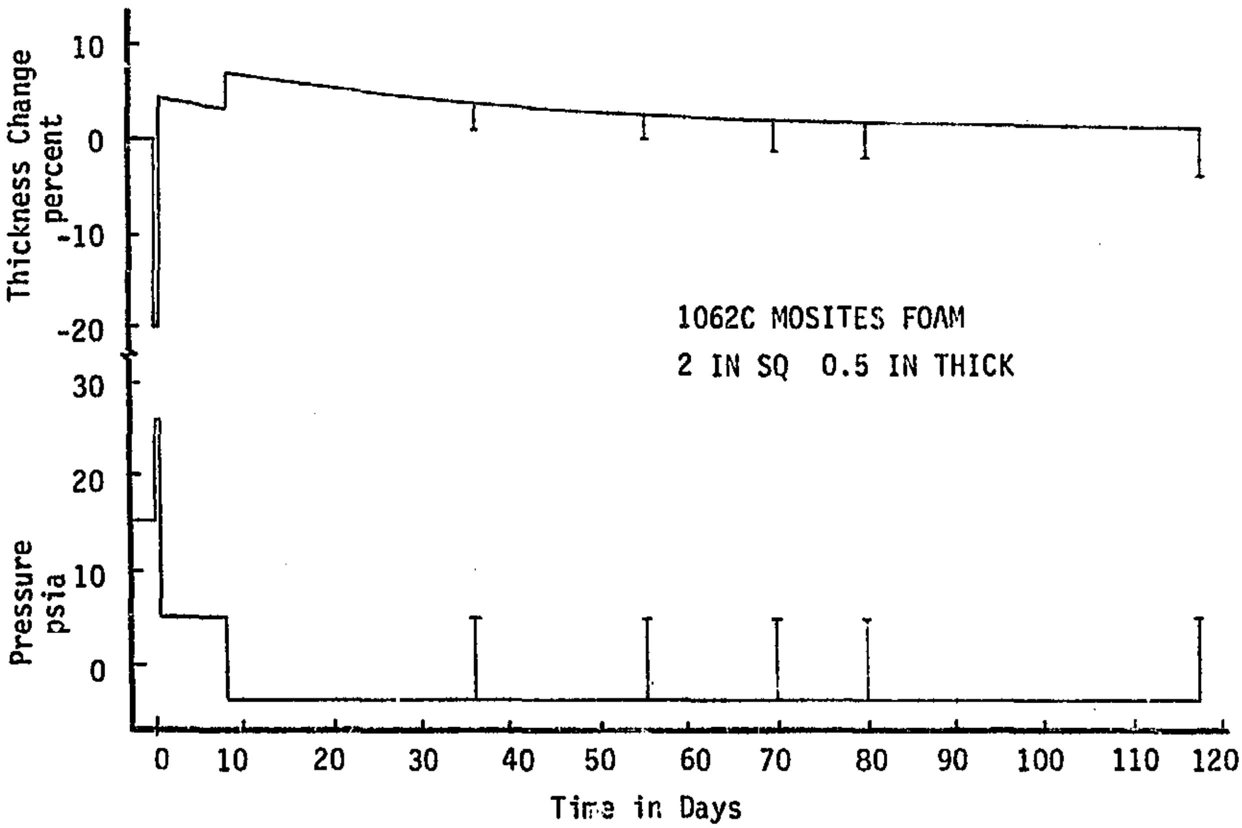


Figure 2.2.1-11 Pressure Effects on Mosites Foam

- Stowage Container Tests in Vacuum - The MDA stowage containers were included in the manned altitude chamber tests of the AM/MDA flight vehicle at St. Louis. Difficulty was encountered in removing stowed items from some containers because of expansion of the foam. Design changes were later made to compensate for expansion. Tests were run with these stowage containers at MMC/Denver in a vacuum chamber equipped with remote manipulators to verify the adequacy of the design changes.

- Flammability Tests - Flammability tests were run on MMC-designed stowage configurations similar to those used in the MDA. These tests showed that the material was nonflammable in the configurations tested, and was an effective flame barrier when used as a compartment lip seal and tested with an external igniter (Reference: White Sands Test Report 71-3199).

(c) Discussion - The original concept for restraining items within stowage containers involved tight fits of stowed items in cavities in the Mosites foam. Due to expansion of the foam at low pressure, items held in by moderate forces at sea level were held in too tightly at 5 psia. Therefore, the designs were changed to provide loose fits at sea level, and the items were restrained by the use of Astrovelcro hook and pile tapes.

(d) Conclusions - Experience with Mosites foam has led to the following conclusions.

- Certain design changes were made in the Mosites packing of some of the containers on the basis of the Altitude Chamber Tests and preliminary tests in the Vacuum Chamber at MMC. These changes involved removing some of the foam; replacing some of the foam with Mosites 1079K elastomer, which is solid rather than a foam; increasing the sizes of cut-outs in the foam; and adding Astrovelcro and straps for restraining purposes. Based on analysis as well as further tests in the vacuum chamber, it was concluded that the existing designs were satisfactory for operation at 5 psia.

- Mosites 1062C meets the required odor, carbon monoxide, and total organics off gassing, and flammability requirements of MSFC-SPEC-101A in the categories in which it is used.

- Future designs of stowage containers requiring the use of Mosites foam should allow for the expansion of the foam at reduced ambient pressure; therefore straps or other means of restraint must be considered as the preferred alternative to restraint by interference with the foam.

- Where expansion of the foam cannot be tolerated, consideration should be given to the use of open cell foam, shielded from ignition by a protective layer of Mosites sheet or foam. However configurations of this type must be tested to verify that they are satisfactory from a flammability standpoint.

(5) Astrovelcro Hook and Pile Fastening Tapes - Astrovelcro hook tape (H549) consists of polyester hooks held in a Beta glass tape, and the pile tape (P537) consists of etched Teflon filaments woven into a Beta glass tape to form many small loops. In both cases, a fluorel coating is applied to the back side of the tape to hold the hooks and loops in place, as well as to assist in preventing ignition of the flammable hooks from the back side and propagation of flame through the latched hook and pile.

(a) Requirements - Because of the convenience afforded by hook and pile fastening tapes, particularly in zero gravity, a need was defined for such fastening tapes meeting the following general requirements:

- They must be capable of repeated latching and unlatching operations.

- They must not shed particles excessively.

- They must not contribute a flammability or toxicity hazard in the Skylab atmosphere.

- Shear strengths of latched hook and pile.

  - 5 psi minimum, as received from the supplier

  - 3 psi minimum, installed

- Latching tension
  - 1 psi minimum, installed.

(b) Tests - Tests were performed to determine the following properties:

- Shear strength of latched hook and pile with a three-inch overlap.
- Latching tension of unused hook and pile with 7/8 inch diameter discs.
- Shear strength of latched hook and pile after 50 and 100 cycles of mating and unmating.
- Shear strength of Astrovelcro hook and pile tape sewn to Beta cloth.
- Acceptance evaluation of Astrovelcro installed in the MDA and required for latching applications at time of launch. All Astrovelcro tested met the shear and tension criteria.

(c) Discussion - The H549 hook and P537 pile used by MMC on the MDA were selected because of their demonstrated resistance to flame propagation. They also met the necessary odor and outgassing requirements. However, they had relatively low peel strength and were easily damaged by abuse, such as machine sewing; second, the did not have long durability, even under ideal conditions.

Tests with Astrovelcro sewn to Beta cloth showed that the use of pieces smaller than 1" x 1" was undesirable and that the practice of cross-stitching was also undesirable because the stitching interfered with the effectiveness of the hooks and loops in latching together. It also contributed to hook damage caused by the sewing machine foot.

Although no problems with Astrovelcro were experienced in the MDA, in December 1972 it was discovered that the Astrovelcro used in the Flight Biomedical Stowage Container in the OWS had poor latching capability. Close examination of the hook tape revealed that many of the hooks appeared to have "straightened out", a high percentage of loops were uncut, and loss of hooks was also observed. This material had been attached to straps in the stowage containers by machine sewing, using cross-stitiching, and had been exercised many times.

The hooks in the H549 hook tape are made by cutting loops of filament that are woven into the tape and held in place by the fluorel backing. The lot of tape used in the Biomedical Stowage Container was generally less stiff than any of the other lots of material examined due to smaller thickness of fluorel backing. It is possible that this contributed to the large number of uncut loops. Examination of unused material from the lot used in the Biomedical Container showed that there were 17 percent uncut loops. As a result of these observations and discussions with the manufacturer of the material, a maximum value of 15 percent of uncut loops was established as the acceptable criterion.

(d) Conclusions - Experience with Astrovelcro in the MDA has led to the following conclusions.

- Astrovelcro hook and pile tape installed in the MDA for restraint applications during launch and for astronaut aids were satisfactory.

- Future design applications should be made consistent with the following general recommendations.

  - Minimum size of pieces of Astrovelcro hook and pile should be 1" x 1".

- Astrovelcro hook and pile tape should not be cut lengthwise.

- Cross-stitching should never be used for attaching Astrovelcro hook and pile.

- Where conditions permit, adhesive bonding should be used for attaching Astrovelcro hook and pile.

- Astrovelcro hook and pile tape should not be used in high-use critical latching applications.

(6) Paint Systems Used on MDA - The interior and exterior paints were primarily polyurethanes.

(a) Requirements - The selection of paint systems for the MDA was based on the following requirements.

- Good abrasion and wear resistance.

- Ability to meet the total organics, carbon monoxide and odor requirements of MSFC-SPEC 101A for interior use.

- Ability to meet the vacuum outgassing requirements of 50M02442.

- Ability to meet the thermal control requirements and temperature extremes externally.

(b) Test - The following tests were conducted on paint systems.

- Interior Usage - Total organic, carbon monoxide and odor tests were conducted per MSFC SPEC 101A. It was determined from these tests that an elevated temperature bake cycle was required to meet the requirements. As a result, two bake cycles were used on the MDA depending on the configuration.

- Exterior Usage - Tests were conducted for vacuum outgassing products per 50M02552. It was determined that a one hour bake at 325°F enabled the paint system to meet the criteria.

  MMC also conducted a series of thermal shock tests to determine what effects, if any, would occur to the external paint system when exposed to the MDA orbital environment. After 20 cycles, the panels were removed from the chamber and visually examined. No flaking cracking or degradation was evident.

(c) Discussion - The interior polyurethane paint system with the prescribed bake cycle held up extremely well. It provided a hard, durable finish for the inside of the MDA.

The paint systems used on the MDA exterior and tested on this program were:

- Laminar X500 Polyurethane, Black, Dexter-Midland 4-B-33: MMC SPEC. STM-K738.
- "Nextel" Polyester Coating, Black, 3M 401-C10; MMC SPEC. STM-K760.
- Silicone Thermal Control Coating, White, Dow Corning 92-007; MMC SPEC. STM-K728.

The black polyurethane laminar X500 paint system was used on most of the exterior of the MDA and represents approximately 95 percent of the paint. The "Nextel" polyester black coating was used around the S-190 window where minimum reflectance was required and represents approximately two percent of the paint. The silicone white coating was used as a visual docking aid around the cone/barrel junction and represents about three percent of the exterior paint.

The three paint systems used on the exterior of the MDA showed no flaking, cracking or degradation when exposed to 10^{-6} torr vacuum and cycled between +275 and -180° F for 20 cycles at 90 minutes per cycle.

A problem with paint adhesion occurred on stainless steel parts, especially the liner in the radial docking port. A phosphoric acid etch of the stainless steel gave satisfactory adhesion results.

(d) Conclusions - Experience with paint systems on the MDA has led to the following conclusions.

- Polyurethane paint system performed well on the MDA during the mission.
- Almost all organic type coatings require an elevated temperature bake cycle to meet total organic, carbon monoxide, odor and outgassing requirements.
- Polyurethane paint systems showed no degradation due to thermal cycling from -180 to +275°F.

(7) Electrical Wire and Cable Flammability Protection System

(a) Requirements - The basic requirement for the electrical wire and cable flammability protection system was that the installed system shall meet the flammability, odor and offgassing requirements of MSFC-SPEC-101A. The installed wire and cable system shall not propagate a fire when exposed to an external ignition source, nor when the wire is tested for electrical overlaod to the point of melting the wire. It was also considered highly desirable that the flammability protection system be such that changes could be conveniently made in the wire bundles and routing of harnesses after installation. This obviated the use of any type of rigid conduit made of metal or other nonflammable material.

(b) Test - The basic MDA wire harness configuration, including the flammability protection system, was tested for overload and external ignition to the requirements of MSFC-SPEC-101A in 100% oxygen at 6.2 psia pressure. The configuration met the requirements (Ref. NASA letter - S&E-ASTN-MX-MDA-70-12, 2 October 1970, and PM-SL-AL/MDA (494-71), 30 March 1971). All materials have also been tested to the odor and toxicity requirements of MSFC-SPEC-101A, and those used in significant quantities have met the requirements.

(c) Discussion - The basic wire and cable configuration consisted of single and multipe conductor silver plated copper wire, insulated with PTFE and a polyimide coating. Multiple conductor shielded constructions had a fluorinated ethylene-propylene (FEP) copolymer jacket over the shield. Flammability protection was provided by a continuous fire barrier from connector to connector, and consisted of a combination of lengths of Bentley-Harris Type 66LWA fluorelastomer-coated fiberglass tubing.

Continuity of the tubing was accomplished by means of butt-joints covered with additional lengths of the next larger size tubing to provide a two-inch overlap on each side of the splice. The tubing was tied in place with Bentley-Harris Pyrolace STVR, a fluoroelastomer coated fiberglass lacing tape. Terminations into connectors were covered as follows:

- Zero-G type connectors were covered by Raychem NBG fluoroelastomer convoluted tubing and boots. This material was qualified to MSFC-SPEC-101A by MDAC-West.
- Other connectors were covered by Beta bags (See Section 2.2.4). A Beta bag was essentially a sleeve made from a double layer of PTFE-coated Beta-glass cloth. A length of Bentley-Harris Pyrolace STVR lacing tape was sewn into each open end of the sleeve to provide the capability of pulling and holding the ends of the

sleeve snugly in place, one end around the connector, and the other end around the sleeving that covers the wire or cable. Thus if the nonmetallic insert in the rear of the connector ignited due to a short-circuit or overload, the flame would be held within the bag, and would be extinguished due to lack of oxygen.

(d) Conclusions - Experience with the flammability protection system has led to the following conclusions.

- The MDA electrical wire and cable system, in conjunction with the flammability protection system, met the flammability, odor, and offgassing requirements of MSFC-SPEC-101A.

- The use of Bentley-Harris Type 66LWA fluoroelastomer-coated fiberglass sleeving in conjunction with Beta bags to cover connectors proved to be a convenient, flexible technique for providing flammability protection to electrical wire and cable systems.

C. ATM C&D/EREP Coolant Loop Contamination -

(1) Requirements - The design requirements for the ATM C&D/EREP Coolant Loop are discussed in Section 2.2.2.2. This section of the report is concerned with the Materials Engineering requirements relating to corrosion of the metallic components, the formation of precipitates in the coolant and the possible problems of coolant loop leakage and filter clogging.

The coolant loop consisted of a combination of stainless steel and various aluminum alloys. This heterogeneous combination resulted from the need to use already-developed hardware. The ATM C&D Console was originally intended to be used in the LM in conjunction with the wet workshop concept, using ethylene glycol as the coolant. Aluminum was selected for this application. The pump had originally been developed for the suit cooling loop, for which a stainless steel system was used. When the decision was made to use the dry workshop and move the ATM C&D Console into the MDA, the result was a coolant loop containing a combination of stainless steel and aluminum. MDAC developed an inhibited coolant to preclude corrosion within the system.

The basic requirement for the system was that it continue to operate throughout the Skylab mission, without leakage or excessive filter clogging.

(2) Test - The following tests were performed to determine if galvanic corrosion of metal components in the system could be a significant problem:

- Corrosion rate of aluminum alloy (6061-T6) when coupled directly with stainless steel (304) in the coolant.

- Assessment of corrosion for simulated tubing arrangements representing coolant loop configuration and consisting of aluminum tubing, aluminum Voi Shan washers, nickel Voi Shan washers, stainless unions, etc.

- Corrosion rate of aluminum-stainless steel couples as a function of coolant pH. Testing was conducted over a pH range of 8 to 11.

Tests were conducted to evaluate the effect of current flow through various configurations of stainless steel-aluminum alloy joints immersed in the coolant. Tests were also conducted to determine the effect of elevated temperature on corrosion rate, the effect of dissolved oxygen on corrosion rate, and the effect of applied potential on current density at the 6061 aluminum electrode in the coolant.

Results of the testing program indicated that excessive corrosion did not occur under the conditions of test, but corrosion rates did increase at higher pH values and at elevated temperature, as well as with oxygen in the lines. These results showed that corrosion should not be a problem, since the coolant normally operates at relatively low temperatures (49° - 78°F), is deaerated before being put into the system and is buffered to keep the pH at 9.1 to 9.5. It was also learned from the tests that the flow of current across a stainless steel-aluminum joint in contact with the coolant could cause the aluminum to react if the electrical resistance were high. Again, tests showed that the electrical resistance between stainless steel and aluminum in the MDA coolant loop was negligible, so that there would be no reaction resulting from this cause.

Analysis of the basic coolant solution indicated that its chemical formulation was acceptable and that performance should be satisfactory for the life of the mission.

(3) Discussion - The coolant loop pumps in the Airlock Module were protected by a 25 micron absolute filter located just downstream of the MDA-AM interface. While servicing the system in January 1973, a blue millipore separator paper was improperly used in a millipore filter assembly located in the GSE servicing system, in place of the millipore filter paper itself. The separator paper tore during loading before the error was identified. The separator paper was removed and replaced with a millipore filter paper servicing continued. After the system had been circulated, it was decided to remove the system filter and examine it for blue fibers from the separator paper. Filter #1 was thus removed from the flight unit coolant loop following testing corresponding to approximately one year of service and filter #2 was installed. Examination of filter #1 showed a few blue fibers but the filter was relatively clean.

Filter #2 was installed on February 1, 1973. During operation of the coolant loop, the accumulator bladder in the AM ruptured (approximately 15 February) causing the pumps to cavitate. Soon after replacing the bladder, MDAC observed increasing pressure across the filter and suspected that fragments of the bladder material may have been responsible. Upon removing the filter, it was observed that 80 percent of the filter surface area was covered with white to gray residue. Analysis of the residue indicated that it contained approximately 14 percent by weight of aluminum. This raised the question as to whether or not rapid corrosion of aluminum tubing in the ATM or EREP cooling system had occurred.

Results of examinations of filters used in the coolant loop from January 13, 1972 through the SL-1/2 mission disclosed the following information:

Filter Installed	Filter Removed	Filter Contamination
January 13, 1972	January 20, 1973	Insignificant
February 1, 1973	March 6, 1973	Contaminated
March 12, 1973	March 26, 1973	Insignificant
March 26, 1973	April 12, 1973	Insignificant
April 12, 1972	May 28, 1973 (SL-1/2 Mission)	Moderate
May 28, 1973 (SL-1/2 Mission)	June 14, 1973 (SL-1/2 Mission)	Insignificant
June 14, 1973 (SL-1/2 Mission)	Sept. 23, 1973	Insignificant

Filters returned from SL-3 and SL-4 likewise showed insignificant contamination. This investigation indicated that the contamination formation was peculiar to operation of the coolant system between February 1, 1973, and March 6, 1973.

(4) Conclusions - Experience with the ATM C&D/EREP coolant loop led to the following conclusions with respect to contamination.

(a) The primary concern that coolant loop system leakage could occur through corrosion effects is not a problem. No leakage occurred in orbit on the inhibited water side (ATM C&D/EREP side) of the system.

(b) The secondary concern that clogging of the system filter could occur is not a problem since analysis of the two filters removed during the first mission and one removed during the second mission indicated only a moderate buildup of particles on the first filter and an insignificant buildup on the other two filters.

2.2.1.6 Mockups and Trainers

A. MDA Zero-G Article

(1) Design Requirements - The design of the Zero-G Article was constrained by the size of the KC135 aircraft and a regulation crash load factor of 6 g's. The equipment was to be designed free of sharp edges and sized, shaped and located to correspond to tentative flight article design. The equipment was to be evaluated under Zero-G conditions in an effort to satisfy component design, crew work envelopes, restraint and translation requirements.

(2) Description - The MDA Zero-G test article consisted of a one-eighth segment of the MDA inner shell mounted to a support base structure (Figure 2.2.1-12). Attached to the shell were five separate packages of flight test hardware:

(a) ATM C&D Console Crew Station
(b) Film Vaults
(c) Initial Entry Package
(d) Experiment Package
(e) Service

The test packages, mounted inside the KC135 aircraft, were subject to a number of parabolic Zero-G maneuvers. Two test personnel checked and operated the equipment, and their actions were to be evaluated by an astronaut for 30 seconds of each maneuver. All the equipment was mechanically functional to the extent that it satisfied the design requirements.

(3) Test - A test procedure was written for each of the five test packages. The test subjects and evaluator averaged 2.5 hours of flight time and 40 parabolic Zero-G maneuvers of testing and evaluation on each package. Component design work envelopes, restraints, mechanical equipment operations and translation devices were evaluated on all described hardware in accordance with design requirements.

(4) Test Results - All equipment performed according to plan. Work envelopes were established for the ATM C&D console, film vaults, initial entry or activation tasks, and for the operations of the M512 and S009 experiments.

Restraint platforms at the ATM C&D and the M512 work station were verified for flight use with requirements for improvements identified in positioning and markings. Handholds and handrails were fixed for the MDA at all work stations. Improvements were recommended in the area of pressure hatch stowage retention, fan removal and replacement, and retention pins for film vault doors and cameras. Lastly, relocation of ECS flex duct stowage was suggested for flight design.

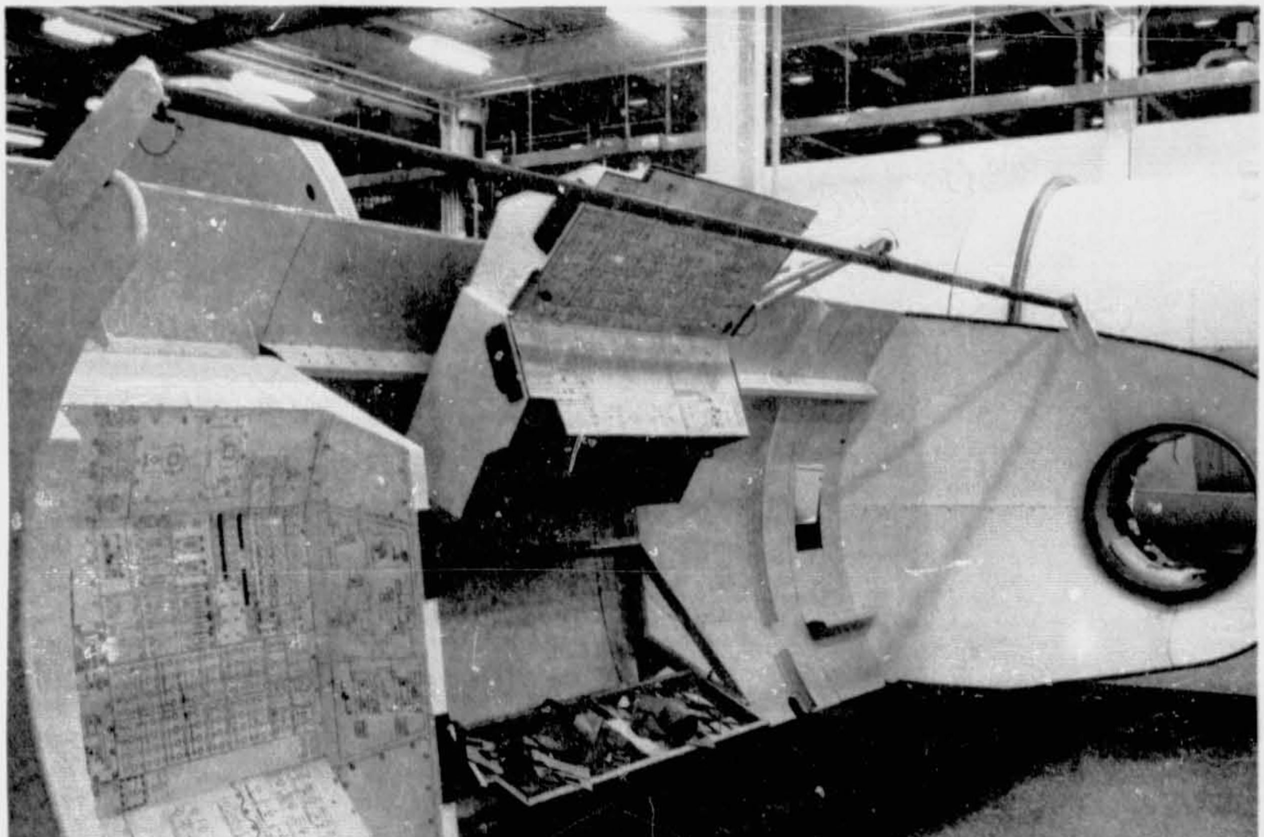


Figure 2.2.1-12 Zero-G Trainer

(5) Conclusions - Generally, this was a successful program. The Zero-G Trainer did not faithfully represent final design configuration in some instances, because it was delivered while the MDA was in an early design phase. However, the tests were valuable in establishing ground rules for design and resulted in a vehicle that functioned successfully in orbit.

From the MDA Zero-G test program results, a similar program is recommended to develop and verify the design of future manned spacecraft.

B. MDA Neutral Buoyancy (N/B) Article

(1) Design Requirements - The N/B Article was designed for long-duration water immersion in a 40-foot-deep N/B Simulator facility located at MSFC. The article was to be used by astronauts and engineers to study and test MDA equipment and for performing crew activities in a neutrally buoyant environment free of sharp edges and corners. Equipment was to be attached in a manner to permit installation and removal under water by qualified personnel.

(2) Description - The N/B Article consisted of a full-scale "wire mesh" structure of the MDA configuration including a radial and axial docking port (Figure 2.2.1-13). The interior and exterior were outfitted with envelope-type mockups for stationary equipment and neutrally buoyant mockups of equipment that was required to be moved during the underwater tests. Certain loose equipment was foam filled to achieve neutral buoyancy. The equipment had special paint finishes and metals to meet water contamination and materials corrosion requirements.

The N/B article was designed to be used for the initial verification of equipment location, crew training (or task verification), and for mission support. The initial article was delivered early in the program, and many modifications were added after the article was installed in the water.

(3) Test - Intravehicular (IVA) tests included activation exercises of probe and drogue removal and stowage, pressure hatch opening and stowage, electrical and communications umbilical hookup, flex duct hookup and vent sealing. IVA tests further included work station envelope checks using restraints lo-

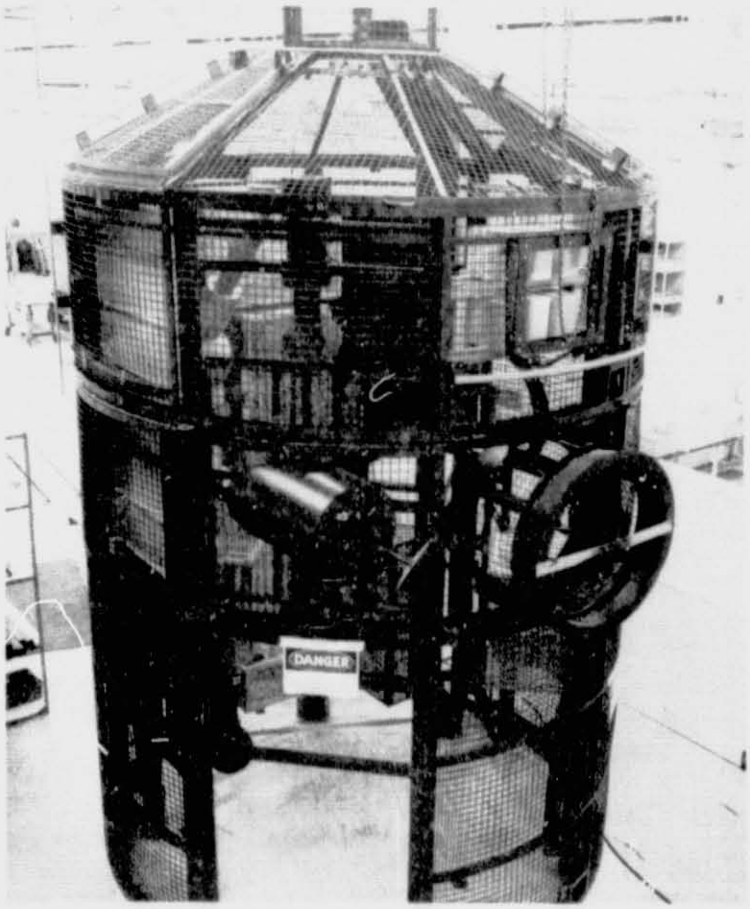


Figure 2.2.1-13 Neutral Buoyancy Article

cated at the ATM C&D, film vaults, EREP C&D and M512 work stations. Envelope structures of other MDA equipment permitted effective IVA evaluation of total work space and translation of equipment to and from stowage containers. Film vault doors and containers permitted checking constrained door swing envelopes, and vault contents could be removed to test installation of equipment on the cassette trees and translation through the MDA and the AM.

EVA test procedures for the most part included translating cameras and canisters from the MDA through the Airlock to the ATM Sun Shade. Later program developments included a test to determine procedures for releasing a jammed S191 door and checkout of an S190 window cover contingency operation.

(4) Test Results - All of the equipment performed to the satisfaction of the crew and their test requirements. MDA work station envelopes were verified for flight design. A location for launch and stowage of the camera trees were established for flight article design.

(5) Conclusions - The fidelity of the installations was periodically updated as equipment configurations were firmed up. Some of the neutral buoyancy training was thus conducted using out-of-date designs. However, the test article was generally successful in meeting the design requirements. A similar program is strongly recommended for future manned spacecraft.

C. MDA Engineering Mockup (EMU)

(1) Design Requirements - The EMU shell was furnished GFP, to be structurally refurbished by MMC to the latest configuration of the MDA. It was to be outfitted and updated with with mockups of equipment for incremental "Crew Reviews" and a final "Critical Design Review".

(2) Description - The EMU was a structure similar in appearance to the MDA Flight Article. It was simpler in construction than the Flight Article, consisting of a mechanically fastened shell structure complete with docking ports, window, longerons, frames and component supports. It was provisioned primarily with mockups of internal components, mostly wood, and was used to tentatively verify component design, physical interfaces and component placement.

The EMU was functional to the extent that it satisfied coordination between engineering design and crew operations personnel in locating equipment. Each new piece of equipment was mocked up, located in the vehicle and reviewed by a crew member. This resulted in constant change and therefore most of the equipment was of low fidelity envelope construction. As the EMU program came closer to its end, the mockup was updated to reflect late design changes, and the fidelity of some mockup components was improved. Thus, for the final CDR the accuracy of EMU hardware was significantly better than Zero-G Article components.

(3) Test - Tests on the EMU are better described as crew reviews. No procedures were written for these reviews. Five incremental crew reviews were conducted on the engineering mockup over a six-month period culminating in a final CDR.

A crew review consisted of an astronaut's evaluation of the latest EMU configur ation of the MDA. It enabled the designer to proceed with flight article layouts and equipment drawings and permitted definition of physical interfaces.

The CDR was the final review of the EMU, which brought customer and contractor engineering and crew personnel together for a final decision on the basic MDA configuration. The CDR allowed the designers to proceed with the design and release of flight article equipment drawings for fabrication and tests.

(4) Test Results - The EMU performed to the satisfaction of engineering and crew personnel. Crew reviews of the equipment were carried out according to plan. The CDR went according to plan and a minimum number of Review Item Discrepancies (RIDs) were dispositioned. Flight Article design was allowed to proceed according to schedule.

(5) Conclusion - The CDR was the first opportunity for physical interface fit checks of GFP equipment in the MDA. This included the interfaces between cameras and film vaults and cassette trees with MDA support structure.

The EMU tests resulted in the conclusion that it was a most successful program. The mockup served its intended purpose as an engineer/crew interface tool for the integration of the MDA equipment. A logical recommendation would be that an EMU is necessary for the development of manned spacecraft.

D. MDA One-G Trainer

(1) Design Requirements - The One-G Trainer was required to accurately represent the MDA for purposes of crew training. As the trainer was to be developed from the engineering mockup, no basic structural requirements were specified other than handling and transportation loads for movement of the trainer from Denver to JSC. Dimensional tolerances, processes and materials selection requirements were not stringent, as long as appearance and functional training values were not adversely affected.

(2) Description - The One-G Trainer was converted from the EMU. Structural revisions made to the shell permitted handling for horizontal and vertical training positions. The fidelity of its equipment was improved so the trainer was mechanically accurate and also included some electrical systems. This included a complete set of "flight-type" electrical cable trays and equipment support structures. A mod kit program kept the One-G Trainer updated with current flight hardware changes after delivery to JSC for crew training.

(3) Test - The One-G Trainer was provided for the purpose of familiarizing the astronaut with the MDA and its related equipment. It was further used for the development of crew (on-orbit) operations and procedures. Two types of hardware were used during astronaut training; i.e., Flight-Type Training Hardware (FTTH), and Mockup-Type Training Hardware (MUTH). MUTH was used for MDA module training and FTTH was used for MDA equipment bench training.

Training was separated into tasks using procedures such as inflight maintenance, activation and deactivation. This necessitated the use of both FTTH and MUTH. After familiarization with module and bench hardware and procedures was apparent, training was extended to the total Skylab cluster in what was called a "Mini-Sim". "Mini-Sim" was an integrated Skylab One-G training program for a specified number of days. Three astronaut crewmen simulated on-orbit tasks and procedures for the total Skylab mission.

(4) Test Results - The MDA One-G Trainer was a most successful piece of hardware. It permitted the integration of man with machine, from which procedures were developed that were used for MDA Flight Article crew/hardware operations.

(5) Conclusions - The timeliness, quality and cost effectiveness of the MDA One-G Trainer was most apparent to the Skylab astronauts. Alan Bean, SL-3 Commander, has specifically cited the excellence of One-G training hardware as a key to the success of Skylab missions. Especially evident was trainer hardware use and effectiveness in solving Skylab contingencies encountered during the mission.

A One-G Trainer is necessary for the familiarization with hardware on "on-orbit" crew procedures of future manned spacecraft systems.

2.2.1.7 Mass Properties

A. MDA Mass Properties Program - During the three-year period from May 1970 until launch on May 14, 1973, MMC conducted an active mass properties program and issued monthly status reports. These activities included weighing of the MDA structural shell upon receipt from MSFC, calculation and weighing of components during design and build, weighing of the MDA when it was moved to the MMC High Bay Clean Room and upon delivery to MDAC at St. Louis, followed by continual tracking of weight of new equipment installations up to launch.

Launch weight of the MDA was 13,650 pounds. One of the first recorded MDA weight estimates was 8,819 pounds in October 1969. The first MMC MDA status report of May 1970 shows the MDA had grown to 10,934 pounds, including EREP. These three weight numbers will be key to the discussion of weight growth presented below.

The following paragraphs will discuss MDA weight growth history and control with emphasis on those items which caused unexpected weight growth. Where possible, data will be presented showing the reasons for growth along with analysis of the final weights and related design factors to provide basis for future weight estimates. In this discussion the following mass properties definitions will apply.

B. Definitions

(1) Control Weight - A maximum allowable weight which is allocated by the customer and derived from booster payload capability.

(2) Current weight - Represents the current design information available at any point during design or development.

(3) Margin - The difference between control weight and current weight.

(4) Baseline Weight Estimate - The weight estimate based upon the design concept at some defined point in the designing process.

(5) Weight Growth - The increase in vehicle weight from baseline weight estimate. Growth is of two types; i.e., Mission Requirement Changes, and Design Process Changes.

(6) Mission Requirements Changes - These are additions to the requirements of the baseline definition made deliberately to increase vehicle utility and take full advantage of booster capability.

(7) Design Process Changes - As design and fabrication of a vehicle progresses, current weight will reflect refinements of the design within the concept of the initial definition.

(8) Contingency - Weight allowance added to a weight estimate (usually a percentage based upon past experience) to project a final vehicle weight.

C. Growth Rate History - A detailed study was conducted to evaluate the Skylab weight growth. In this study, the concept of Mission Requirements Changes and Design Process Changes was explored in depth. Results of this study, as it applies to the MDA, are shown in Figure 2.2.1-14.

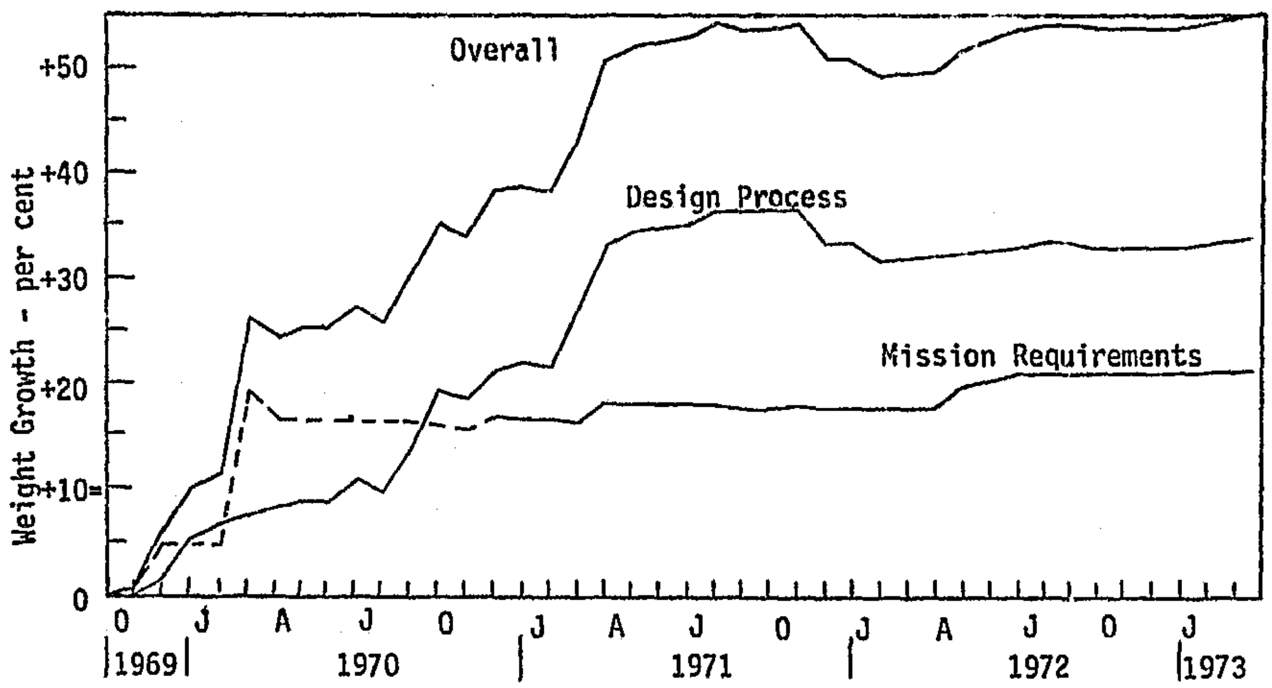


Figure 2.2.1-14 MDA Weight Growth Relative to Initial Requirements

MDA weight growth is shown graphically in Figure 2.2.1-15, of which four periods of rapid growth are of special interest; i.e., November and December 1969, February 1970, September and October 1970, and February and March 1971. The changes during November and December 1969 were mostly mission requirements changes and included such things as docking port changes, ATM C&D console and wiring. In addition, there were compensating lower estimates on external wiring, film vaults, and other minor equipment. During February 1970, EREP was added as a mission requirement change with an estimated weight of approximately 1200 pounds. September and October 1970 was the period when EREP estimates were incorporated, along with new estimates on film vaults and a major addition to stowed equipment. During February and March 1971, the S-194 L-Band Radiometer was added which, along with other EREP changes, contributed 256 lb of increase. New estimates on wiring installation added approximately 300 pounds, and stowed equipment and several approved changes incorporated at this time added another 400 pounds, including 100 pounds for flammability protection changes. In between these major jumps there were many compensating changes within any one month; however, examination of these periods of increase point up particular weight estimating problems in EREP, film vaults, stowed equipment, docking ports, ATM C&D Console, and electrical wiring installation.

Total growth of the MDA from the initial weight estimate of October 1969 to launch was 55 percent, with 21 percent attributable to mission requirements changes, and 34 percent to design process changes.

Certain conclusions may be drawn from this record of MDA weight growth relative to the ability to predict final weight. One is to use more realistic weight projections for experiments (based on MDA-EREP experience); and second is to allow a contingency of at least 10 percent for unforeseen additions. Weight factors, based on actual MDA experience, were developed for film vaults, electrical

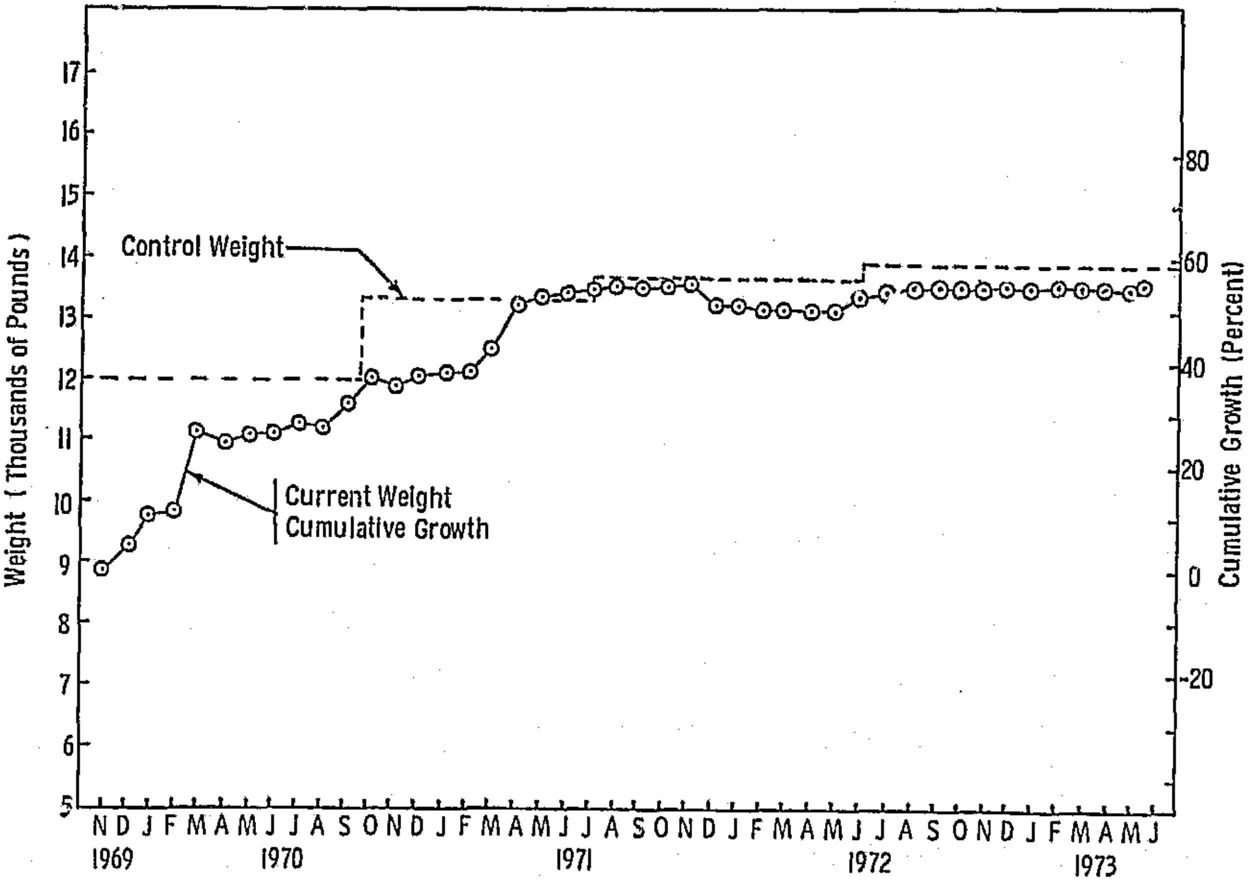


Figure 2.2.1-15 Weight Growth History

cable supports, cable trays, thermal insulation and meteoroid shields. These factors, when used with criteria similar to the MDA, can be of valuable assistance in estimating the weight of comparable equipment on future programs.

(1) Film vaults: $Wt = \frac{1.34 \text{ Vol}}{(\text{Allow. Rads/Day})^{1.35}}$

where "Vol" is internal volume of the vault in ft^3, and (Allow. Rads/Day) is obtained by dividing the film total allowable dosage by the exposure time in days.

The empirical equation gives a good weight approximation when Surface Area/Volume Ratio is between 2.5 and 3.5 (ft^{-1}).

(2) Support for electrical wire harnesses

- Internal Wiring: Ratio of cable tray weight to wire harness weight was 1.00. (Cable trays are defined as the total enclosure provided for the wire bundles including supports and removable access covers).

- External Wiring: Ratio of support structure weight to wire harness weight was .35.

(3) Thermal Insulation: .315 pounds/sq ft (This factor is for the 91-layer insulation system defined in Section 2.2.3).

(4) Meteoroid Shielding Including Standoffs (supports): .271 pounds/sq ft.

(5) EREP - The final weight data for the EREP experiments is presented in Table 2.2.1-4. Column 2 shows the total weight for each experiment including the basic experiment, its ancillary equipment (electronics, spares, tools, etc) and its supporting structure. Column 3 shows the weight ratio of ancillary equipment to basic experiment. Column 4 shows the weight ratio of supporting structure to the sum of the weights of the experiment and its ancillary equipment. Values in Column 4 are higher than normal because all untested structure on the MDA was designed with a safety factor of 3.0.

(1) EREP Experiment	(2) Total Weight	(3) Ratio-Ancillary Equipment to Basic Experiment	(4) Ratio-Support Structure to Basic Experiment Plus Ancillary Equipment
S-190	528.4	.530	.535
S-191	536.7	.310	.331
S-192	497.6	.108	.422
S-194	194.6	0	3.900
ESE	573.2	.695	.154
TOTALS..	2230.5	.454	.410

Table 2.2.1-4 EREP Weights

D. Weight Control - Weight control on the MDA was mostly indirect in nature. The initial thinking was that there was plenty of growth capability; therefore, to eliminate testing, a factor of safety of 3.0 was used on many of the structural items. The indirect type of weight control may be seen in Figure 2.2.1-15, which shows the relationship between control weight and current weight, where each time the current weight approached the control weight it levelled off. This indicates that proposed changes were examined most carefully at these points.

Formal weight control studies were conducted in August 1970 when the current weight was approaching the 12,000-pound control weight then in effect. The studies included weight-saving proposals such as deleting the external handrails, reducing the number of insulation layers, changing the material and design of the film vaults, changing the material of the L-Band truss, and reducing the design safety factor for untested structure. The handrail deletion was the only weight saving suggestion implemented. All others were considered to have an unacceptable impact on the program. The final result was to increase the control weight to encompass the actual MDA weight.

This Page Intentionally Left Blank

2.2.2 Environmental Control System

2.2.2.1 MDA Ventilation System

A. Design Requirements - The ventilation system design requirements per AM/MDA ICD 13M02521 consisted of the following:

- System operating pressure - 4.8 to 6.0 psia.
- Flow rate per cabin atmosphere hard duct (3 ducts) - 55.7 cfm.
- Allowable pressure drop for cabin atmosphere ducts - 0.0172 inch water at 55.7 cfm.
- Flow rate for molecular sieve duct (two compressors) - 62 ± cfm.
- Allowable pressure drop for molecular sieve duct - 0.035 inch of water at 62 cfm.
- Dew point temperature range for the cabin atmosphere duct flow - 46°F to 60°F.
- Dew point temperature range for molecular sieve duct flow - 46°F to 60°F.
- MDA/STS bulk atmosphere temperature - 60°F to 90°F.

Operating design requirements per CEI CP114A1000026E specified that the atmosphere velocity be between 15 and 100 feet per minute at crew stations.

Operating design requirements per CSM/MDA ICD 13M04632 were as follows:

- Flow rate through the Atmosphere Interchange Duct (AID) - 100 to 170 ACFM @ 70°F.
- Atmosphere temperature - 60°F to 90°F.
- Interface pressure - line pressure loss in CM portion of AID not to exceed 0.07 inch of water @ 150 ACFM, 70°F and 5 psia.
- Acoustic noise - no greater than 72.5 db (sound pressure level) from all sources.

B. System Description - The MDA Ventilation System consisted of three fan/muffler assemblies, two adjustable diffusers to control air distribution in the MDA, and various ductwork to conduct air from the AM to the MDA and from the MDA to the CSM.

The MDA ECS ducts carried atmosphere from the STS area into the MDA. The AM introduced cooled atmosphere into the MDA when the AM ECS fans were on. The interface of these ducts were at the AM/MDA interface.

The MDA to CSM Fan/Duct System introduced MDA ambient atmosphere into the CM and recirculated the atmosphere to the MDA through the docking port tunnel.

The Mol Sieve Duct introduced fresh (CO_2 and odors were scrubbed) atmosphere to the MDA. One (1) or two (2) compressors could be used to deliver the conditioned air. The atmosphere could be diverted to the MDA or OWS depending on the damper position located in the STS duct. The interface of this duct was at the AM/MDA splice.

The atmosphere velocity at crew stations was controlled by operating one or both of the MDA Cabin Fans at high, low or off settings and by adjustment of their attached diffusers. The diffusers established the direction and shape of the existing atmospheric stream.

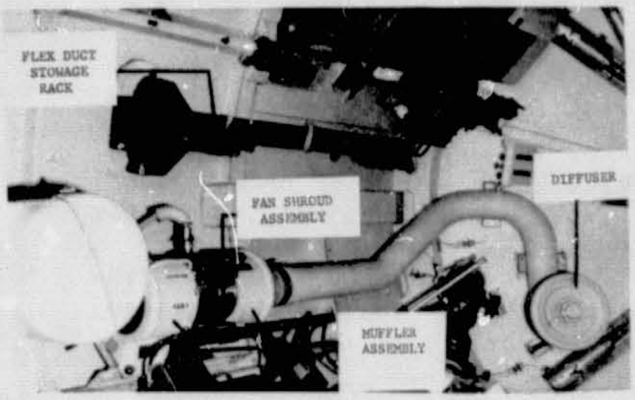
The MDA ventilation system is shown in Figure 2.2.2-1.

C. Test

(1) Flexible Duct Assembly, P/N PD6000195-009

(a) Development Test - The development test for the flexible duct consisted of a flow and pressure drop test. The flow criteria being a pressure drop of less than 0.03 inches of water at a flow rate of 150 ACFM. The data indicated a ΔP of approxiamtely 0.018 inches of water at 150 ACFM which was well under the 0.03 maximum ΔP requirement.

No problems occurred during development tests of the Flexible Duct Assembly.



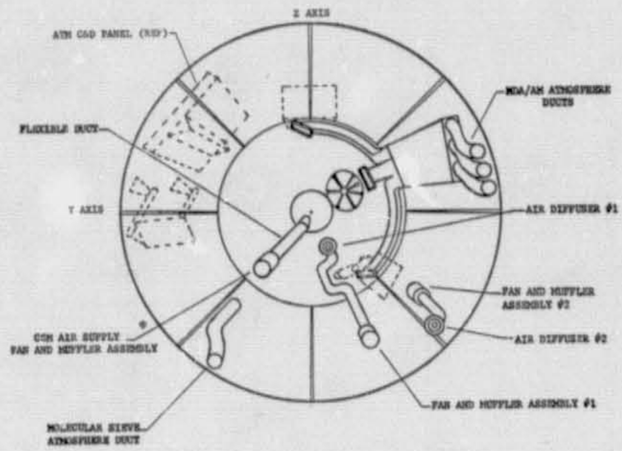


Figure 2.2.2-1 MDA Ventilation System

(b) Qualification Test - Lyon Environmental Lab, Report No. 71-341 - Qualification tests were run on two flexible ducts, P/N PD 6000195-009, serial numbers 0000010 and 0000011. The following tests were conducted: visual and dimensional inspection, temperature, altitude, storage and transportation, resilience, and vibration.

The two flexible ducts met all requirements of the qualification tests. There was no evidence of cracking, delamination, permanent deformation, deterioration or physical damage as a result of the required tests.

(c) Acceptance Test - Each flexible duct assembly received an acceptance test to demonstrate suitable quality, correct assembly and required performance. These flexible ducts were visually and dimensionally inspected for size, configuration, weight, welding, workmanship and proper cleaning.

All flexible duct assemblies met the acceptance test requirements with no exceptions.

(2) Muffler Assemblies, MMC P/N 82000008520 and 82000008620

(a) Development Test - Development testing of the muffler assemblies was conducted on a "slide tube" configuration which provided for a lever release of the fan. Development tests were conducted by MSFC in accordance with S&E-ASTN-TMM operating procedure. The tests consisted of functional (acoustic noise), contamination, flow, vibration and shock.

(b) Qualification Test, MMC Report No. 3181 - The muffler assembly configuration qualified by MMC was modified from the Development configuration to a "hard" mounting which bolted the fan to the muffler bases. This design change was made to simplify the structure and to preclude tolerance and dynamic susceptability that was evident in the "slide tube" configuration.

The qualification tests consisted of sinusoidal evaluation, vehicle dynamics and high and low level random vibration. A performance test was conducted prior to and after the vibration tests. The performance test consisted of an acoustic noise test.

During the initial noise test, the muffler attenuation of fan noise did not meet the required level. Martin Automatic Reporting System (MARS) B-73823 and B73810 were written. The acoustic criteria was reevaluated and new criteria was incorporated in the test specification. Testing was resumed. The test units successfully passed the tests.

(c) Acceptance Test - The assemblies are verified to be built in accordance with the engineering drawings. Their installation in the MDA is verified by a fit check with a Government Furnished Equipment (GFE) fan assembly.

(3) Diffuser, MMC P/N 82000001720

(a) Development Test - Development tests were conducted to verify the capability of the diffuser to provide the required distribution of air flow in the MDA. This requirement specified that the air velocity range at the MDA crew work stations be between 15 to 100 FPM.

Initial testing of the diffuser was conducted by MSFC. Flow tests were run at 5 psia and at 14.7 psia. Based on the test results, it was recommended that an Anemostat Corporation, type C-2, five inch neck diameter or an equivalent diffuser be used for the MDA. The Anemostat diffuser was used, as recommended, though modified to conform to structural and human engineering design requirements.

A system air distribution test was conducted by MMC. A mockup of the CSM, STS and the AM were mated with the engineering mockup of the MDA. The MDA and the STS were outfitted with the best available fidelity of internal hardware and experiment packages. The diffusers were installed and positioned as for the flight configuration. A mapping of the air velocity profile within the MDA/STS was made. The distribution characteristics were determined by observation of smoke cloud dispersion and by taking velocity measurements. The test results verified the system capability to maintain the air velocity requirements at the crew stations.

A development test was conducted to demonstrate the capability of the diffuser control bridge to withstand design yield and ultimate stress loads. Torque loads, providing equivalent design stress loads, were applied to the diffuser control knob. The diffuser successfully passed the tests. The diffuser was mechanically functional even after being subjected to ultimate stress loading.

(b) Qualification Test - MMC, Report No. 3184 - The qualification testing of the diffuser was conducted by MMC. The qualification tests consisted of a performance test, a sinusoidal evaluation test, a vehicle dynamics low frequency sinusoidal test, a high level random vibration test, and a low level random vibration test. The performance test was conducted prior to and after the diffuser was tested in each axis of vibration. The performance test procedure was a manual adjustment of the control knob from one extreme position to the other.

A mechanical failure of the diffuser occurred during the high level random vibration tests. A failure analysis disclosed that the structural support hangers for the movable cone of the diffuser slipped out of their installed position. The analysis is presented in Failure Analysis Report no. B67415. A modification was made to the diffuser in which the hangers of the movable cone were welded to the interfacing detail part to form an integral assembly. A complete retest of the diffuser was conducted without any subsequent failures. Refer to MMC Report No. 3184 for the qualification test data.

(c) Acceptance Test - Acceptance test requirements for the diffuser were specified in the 82000001720 MMC engineering drawing. The test consisted of a verification of the number of turns of the diffuser control knob required to move the movable cone from one extreme position to the other. This adjustment of the movable cone verified that sufficient movement of the cone was available to change the air flow pattern.

(4) Fan Shroud Assembly MSFC P/N 20M42270

(a) Development Test - Development testing of the fan shroud assembly was conducted by MSFC.

(b) Qualification Test - MMC Report No. 3310 - The qualification testing of the fan shroud assembly was conducted by MSFC. A portion of the testing was done by MMC. The latter included vibration and shock testing of the fan assembly, 20M42270-3, with the MDA hard mounted mufflers. The fan assembly successfully passed these tests. The results of the 20M42270-3 fan shroud assembly tests are presented in MMC Qualification Test Report No. 3310. The dash three (3) 20M42270 assembly was used in the MDA.

D. Mission Results - The crews' evaluation on the performance of the ventilation system was that the air circulation was more than adequate, the screens on the inlet mufflers were an ideal size for collecting dust and debris and that the operation of the fan-muffler assemblies produced a low level acoustic noise output. It was very quiet. No problems existed with any of the system components.

During SL-2 the fans were operated at temperatures below the design requirements. This off-design operation did not adversely affect later fan performance. During the post SL-3 storage period cabin fan 2 remained on as a cooling fan for the rate gyro six-pack. This unscheduled operation added 1250 hours to the operating time accumulated by fan #2. As a result of the extended SL-4 mission to 84 days, the total operating time for each fan at the end of the SL-4 manned mission was as follows: CSM fan - 4100 hours, cabin fan #1-3550 hours, cabin fan #2-4800 hours. Design operating life of the fans was 3360 hours but all fans were performing perfectly at the end of SL-4.

E. Conclusions and Recommendations - The MDA ventilation system provided good air circulation to the CSM and within the MDA. No hot or cold locations were found within the MDA. The fans continued to provide circulation long after their design operating life. The crews' debriefing comments indicated that the muffler screens, mesh size .14 in. x .14 in., was a good size to collect debris. It is recommended similar sized screens be used for future systems. Also it is recommended that future fan systems be capable of ground command or that a portable utility outlet be tied to ground command so that a fan or other electrical component could be plugged into the outlet for command during unmanned periods.

2.2.2.2 ATM C&D Panel/EREP Coolant System

A. Design Requirements - The ATM C&D Panel/EREP Coolant System design requirements were specified in several documents because the system crossed several interfaces. The requirements were as specified below but when the same requirement appears in more than one document, it is not repeated. The requirements per AM/MDA ICD 13M02521 were as follows:

- Operating pressure - 37.2 psia maximum.
- Inlet fluid temperature - 49°F to 78°F.
- Fluid - high purity water plus additives.
- Flow rate - 220 pounds per hour, minimum.
- Allowable pressure drop - 6.75 psi @ 220 lb/hr.
- Leakage - 35 cu-in. (from time of fill to end of 240 day mission).

Requirements per EREP/MDA ICD 13M07397A* were pressure drop (EREP system) - 2.0 psi @ 220 lb/hr and leakage - 17 cu-in. from time of fill to end of 240 day mission.

Requirements as specified in ATM/MDA drawing 40M37870* were a pressure drop of 3.0 psi @ 220 lb/hr and a leak requirement of no bubbles at 300 psi GN_2.

B. System Description - ATM C&D/EREP Coolant System consisted of the hard tubing, flexible lines, valves, and cold plates associated with conducting a flow of coolant to and from the ATM C&D panel, the EREP tape recorders, the EREP C&D panel, and the S192 electronics. MDA ECS components included in the system were 4 port manual selector valve, ATM C&D panel flexible lines, EREP tape recorder selector valve, and EREP flexible lines. The MDA system interfaced with the AM system which contained the pumps, heat exchangers, and accumulator. Configuration of the coolant system and components is shown in Figures 2.2.2-2 and 2.2.2-3.

*These requirements were inclusive in the AM/MDA pressure drop and leakage allocations.

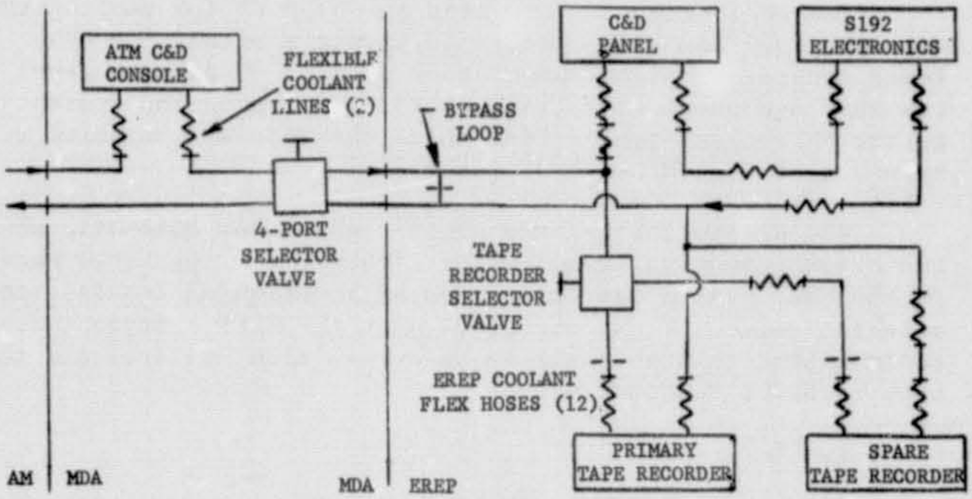


Figure 2.2.2-2 MDA ATM-EREP Coolant Systems

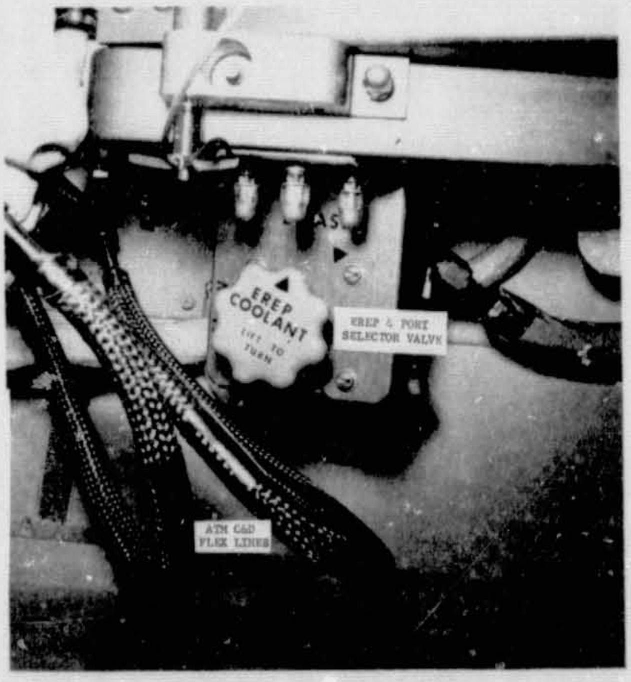


Figure 2.2.2-3 ATM C&D Console Coolant Installation

The coolant system provided the support for cooling the ATM C&D panel and EREP electronic packages within the MDA. Heat loads generated by instrumentation within the ATM C&D panel and the EREP equipment were transported by means of the coolant loop to the AM coolant system from which the heat was rejected to space by means of the AM/MDA radiator system.

Fluid flow through the ATM C&D panel was automatic whenever the coolant pumping system was activated. On the other hand, flow to the EREP system was controlled by positioning the four port manual selector valve. Flow control through the EREP subsystem was accomplished through usage of balancing flow orifices and the EREP tape recorder selector valve.

C. Test

(1) Coolant Valve, Manual, 4 Port, Selector-MMC P/N PD4700191.

(a) Development Tests - The 4 Port Selector Valve was an adaptation of the Apollo glycol bypass valve as manufactured by AiResearch. The MMC design modification consisted of removing the electrical actuator and replacing it with a manually operated actuator. The fluid control portion of the two valves, including the pressure relief mechanism were identical.

Development tests were performed primarily on the manual actuating mechanism. Cycle life tests were conducted to demonstrate capability to withstand the required number of operating cycles plus margin (475 wet cycles and 25 dry cycles). The actuating mechanism, including the position locks, performed all cycles without malfunction and only a slight marking was witnessed as indication of wear. Vibration testing was also conducted to verify that both the actuating mechanism and fluid control portion of the valve would not degrade under vibration conditions. There was no structural degradation as a result of this test and the valve performed well during functional tests following vibration. There was no measurable internal leakage at operating pressures using volumetric displacement and nitrogen gas over a 15 minute period.

Allowable leakage was 1.54 cc/day of water or an equivalent of 2 scc (GN_2) in 15 minutes. Also, there was no degradation of the pressure relief machanism as a result of the vibration testing. Relief pressures remained the same, within the accuracy of the pressure gauge, as pressures recorded prior to starting of the test.

(b) Qualification Test - AiResearch, Report No. 71-7933 - Qualification testing on the 4 Port Selector Valve was completed on 21 October 1971. The qualification tests consisted of Physical Inspection, Proof Pressure, Over Torque, Ultimate Torque, Vibration, Cycle Life, and Burst Pressure. A performance test was conducted prior to and after each environmental test. There were no problems encountered during qualification testing.

At the completion of qualification testing, one of the two test units had no detectable internal leakage and the second unit had a leakage rate of 0.8 scc (GN_2) in 15 minutes. External leakages for the first and second units were 9.2×10^{-9} scc/sec (He) and 2.3×10^{-6} scc/sec (He), respectively. The maximum allowable external leak rate was 1×10^{-4} scc/sec (He).

(c) Acceptance Test - Each valve received an acceptance test to demonstrate quality assurance with respect to fabrication and performance. To satisfy the quality assurance requirements the valves received a visual and dimensional inspection, a proof pressure test, and internal leakage check, an operating torque check, a pressure drop test, a pressure relief test and an external leak check.

All valves met these requirements without difficulty. Typically, internal leakage rates were non-detectable in 15 minutes using volumetric displacement and GN_2. The maximum allowable rate was 2 scc/sec. Operating torque was in the range of 6 to 8 inch-pounds with an allowable of 23 inch-pounds. Pressure drop was in the range of 2.4 to 3.0 inches of water in the normal flow direction and 1.25 to 1.4 inches of water in the bypass direction. Maximum allowable pressure drop was 5.54 inches of water for each direction, respectively. Relief valve cracking pressures were in the range of 12.2 to 19.2 psi with an allowable range of 10 to 30 psi.

(2) Line, Coolant, Flexible - MMC P/N PD3200048

(a) Development Test - Not applicable.

(b) Qualification Test - AETL, Report No. 5350-00-9023 - Qualification testing on the flexible coolant line was completed on 16 October 1971. The qualification tests conducted on two test units were as follows: Pressure Drop, 1st Pressure Fatigue, Vibration, Flexing, 2nd Pressure Fatigue, and Burst Pressure. Performance tests consisting of proof pressure and a leakage test were conducted prior to and after each major test. There were no problems encountered during qualification testing.

At the completion of the qualification testing, the two test units were leak tested. A net leakage of 3.6×10^{-10} scc/sec (He) was measured on one unit and 1.0×10^{-9} scc/sec (He) was measured on the second. The maximum allowable leakage was 2.0×10^{-4} scc/sec (He).

(c) Acceptance Test - Each flex line received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To fulfill this demonstration, the following quality assurance inspections and tests were accomplished: visual and dimensional inspection of the unit, x-ray and penetrant inspection of welds and braze joints, proof pressure and a leakage test.

All flex lines met these requirements without difficulty. Typical measured leak rates on production hardware were in the range of 1.7×10^{-8} to 5.6×10^{-8} scc/sec (He) with the line interior pressurized to 50 psig with helium and the exterior evacuated in a bell jar. Maximum allowable leakage was 2.0×10^{-4} scc/sec (He).

(3) Coolant System Flexible Hose - MMC P/N ST32D11

(a) Development Test - Not applicable to these parts.

(b) Qualification Test - Qualification of the EREP Coolant System Flexible Hoses was by similarity to several hoses qualified by MDAC-E for use in the Airlock Module. The sizes and configurations of the MDAC-E hoses were sufficient to bracket the configurations selected by MMC and the structural, environmental and functional requirements either met or exceed the MMC requirements for the EREP hoses.

The hose size and configurations to which the EREP hoses were qualified by similarity were documented in the following reports:

Approved Engineering Test Laboratories
Report No. 5310-00-9627

Durkee Testing Laboratories
Report No. QT 9060

Durkee Testing Laboratories
Report No. QT 8619

(c) Design Verification Test - Two design verification tests were conducted on the EREP coolant System Flexible Hoses to verify suitability and effects of hose installation in specific uses in the EREP system.

Flexure tests were conducted to verify that the ST32D11-4 and -5 (now -12 and -13 resulting from fitting finish revisions) flex hoses could be subjected to a simulated life cycle flex test without experiencing a catastrophic failure. The two hoses were installed in MDA simulated configurations but the flex section of the hoses were not preformed to eliminate localized bending. As a result of the non-preformed installation, the bend radius was severe at the bellows-hard tube interface. The hoses were subjected to 500 cycles of ± 0.35 inches of movement in each of 3 axes. Both hoses failed after being subjected to the cycling. Both failures occurred where the convolutions were welded to the tubing (at the first convolution adjacent to the welded end). Review of the failure, test specimen installation and test criteria indicated that; the hose installation in the test setup was incorrect, i.e., the flexible portion of the hose should have been preformed to the proper installation configuration to avoid severe bending at the bellows-hard tube interface convolution; and that the maximum ± 0.35 inch of movement was incorrect in that 0.35 inch was the maximum physical travel of the equipment (to which any of the flex hoses were attached) shock mounts and not the maximum physical movement possible resulting from loads imposed on the various EREP equipment. The maximum physical movement under load should be ± 0.10 inches for the ST32D11-4 typical hoses. Tests were re-conducted using properly preformed hoses and applicable test displacement. The 500 cycle requirements were completed without further difficulty and the hoses were considered suitable for use on the EREP coolant system.

A pressure loading test was conducted on the flex hoses to determine loads imposed on the attached equipment when the hoses tended to straighten from internal pressure. Hose spring rates were also measured for inclusion in the resulting loads. The test was conducted on six different configurations of hoses and at zero, 5 psig, and 50 psig. It was determined from the tests that the spring rate of the hoses accounted for most of the induced end fitting loads and there was little variation in load resulting from pressure. Also, it was determined that none of the loads were of a magnitude sufficient to cause concerns for the equipment attachment points.

(d) Acceptance Test - Each flex hose assembly received an acceptance test to demonstrate suitable quality, correct assembly and required performance. The tests were conducted by the vendor in accordance with the requirements of MMC Standard Drawing ST32D11 and included proof and collapse pressure, flow and pressure drop, leakage, visible and dimensional inspection, and x-ray and dye penetrant inspection of all welds. All hoses met the acceptance test requirements. There was no detectable leakage when the hoses were leak checked with helium at 50 psig. Maximum allowable leakage was 1×10^{-5} scc/sec (He).

(4) EREP Tape Recorder Coolant Selector Valve - MMC P/N ST47D52

(a) Development Test - Development tests were not conducted on this valve because the design had been proven in previous development and qualification testing required by other NASA programs on similar valves.

(b) Qualification Test - Report No. QTR557, Vibration Test Report (Qualification) for James, Pond and Clark Division Three Way Selector Valve, P/N P32-419, MMC P/N ST47D52 - This vibration test was conducted to demonstrate compliance for qualification of the selector valve for use in the EREP coolant system. Testing was completed on 30 March 1971. There was no evidence of physical damage, water leakage or change in handle position as a result of the testing. The test unit was subjected to a high level random criteria of 10.4 Grms for 5 minutes in each of three axes.

(c) Design Verification Test - A cycle life test was conducted on the selector valve to demonstrate the capability to withstand 500 operating cycles. The test was conducted under flow conditions of 220 pounds per hour of water.

The test was completed with no problems encountered. Operating torque measurements were made every 25 cycles throughout the test and were always in the required torque range. A bubble type leakage test at the completion of the cycling resulted in no indicated leakage with nitrogen at 50 psig. The maximum allowable internal leakage was 0.5 sccm of water at 50 psig. A burst pressure test was conducted at 200 psig for 15 minutes. There was no evidence of physical degradation as a result of this test.

(d) Acceptance Test - Each valve received an acceptance test in accordance with requirements of the standard drawing to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration each valve received a proof pressure test, a leakage test, and a physical inspection. All valves met these requirements.

(5) EREP Coolant Loop System Design and Development History

(a) Design Considerations - In order to maintain minimum pressure drop, the initial sizing of interconnecting tubing was selected as ½ inch (O.D.) and cold plate tubing was selected as 3/8 inch (O.D.). This initial concept was designed for series flow through the entire EREP coolant system, and was based upon a single tape recorder in the loop at one time. Flexible hoses constructed of reinforced silicone rubber were selected and qualified by similarity to M509 (oxygen) hoses.

Thermal studies revealed that all of the coolant to the EREP interface at minimum fluid temperatures could not be utilized without danger of causing condensation on the heads of the tape recorder. In addition, it was deemed necessary to permanently install a spare tape recorder. These factors resulted in a redesign incorporating an approximate 1/3 coolant flow by-pass to the ATM C&D Panel loop and to the primary or spare tape recorder loop. A selector valve was incorporated to direct coolant only to the operational tape recorder.

Coolant loading and prelaunch readiness studies indicated that the upper portions of the cold plates and interconnecting tubing would be subjected to vacuum prior to orbital insertion.

Since the flex hose silicone rubber was known to be significantly permeable to gasses, this could result in cabin gas being ingested into the coolant, both as free gas and in coolant solution. A review conducted by JSC, MSFC, MDAC-E and MMC concluded that the gas ingestion should be precluded by changing to non-permeable hoses, rather than the pump-accumulator system maintaining positive pressures. The system design was then changed to utilize convoluted stainless steel flexible hoses similar to those utilized by MDAC-E (i.e. the same supplier).

Flexible hoses were required to accommodate installation tolerances between equipment mounting racks, and to withstand the launch environment vibrations and displacements through the equipment mounting points.

Test points were "designed out" of the system since these would have added a significant number of mechanical joints, and the overall leakage verification was considered to be a difficult manufacturing, build and test task even with the minimum required joints.

Flared fitting inserts (Voi Shans) were incorporated as a corrective measure for leaking or remade joints only, whereas the MSFC influenced systems (AM and ATM coolant tubing) specified general application of inserts. JSC cited some unsatisfactory applications of flared fitting inserts in previous applications. All flared fittings were made with the MS "precision" series of 32 rms finish on sealing surfaces, vs the "standard" MS fittings of 100 rms finish. Lockwires were not utilized on the fittings since the joints leakage would be considered failed by the time lockwire could become effective. The flared joint dynamic susceptability at the specified installation torque was demonstrated by inclusion of the connecting flexible hoses to the EREP Tape Recorder in the qualification-random vibration test. The shock mounts of the tape recorders allowed for the greatest relative motions between any segments of the coolant system.

Tubing and cold plates were insulated to minimize cold radiant surface conditions and touch temperatures and to preclude surface condensation.

(b) Test - In order to verify flow distribution by "design" rather than by "calibration" of the flight installation, a breadboard tubing and cold plate simulation was constructed. Breadboard tests provided the data and verification of flow control orifices (diameters), flow balance vs flow range, leakage test methods and comparisons, flex line geometry effects, cold plates flow vs pressure drop characteristics and blocked leg pressure drop values.

The pressure drop and values to be tested were of small enough magnitude to be affected by conventional flow instrumentation. Therefore, each simulated cold plate was bench calibrated for flow vs pressure drop so that these system segments could serve as flowmeters with only pressure taps added to the representative flight configuration.

The Tape Recorder Selector Valve flow characteristics vs position were determined to assure that no major flow disturbances would occur in the operating transition. In addition, operating torque, leakage and cycle life testing were performed as design verification tests. Qualification of this valve was accomplished by similarity to Apollo and Gemini applications and a vibration test to demonstrate leakage and position integrity.

Corrosion tests were conducted subsequent to system and component design verification tests to satisfy customer and associate contractor concerns regarding coolant inhibitors and dissimilar metals. These tests showed slight corrosion to occur, but well within acceptable rates for the duration of all Skylab missions.

EREP equipment modules which were replaced during MDA flight article preparations required drying and verification to low dew points (-65°F to -30°F). Initial test techniques were invalid due to the dew pointers requiring a continuous gas supply, and the test method allowing cold plate purging from a dry N_2 supply. The acceptable test technique for use with any type dew pointer required a pressure lockup (50 psig for 2 hours or more) then a slow bleedoff through the dew pointer to the maximum steady state value.

(c) Conclusions - Flow balancing and sensitivity to geometric tolerances were determined to be satisfactory for the thermal cooling criteria. JSC representatives concurred by breadboard tests that test points or calibration controls would not be required for this system.

Leakage techniques and comparisons resulted in the following conclusion:

- Bubble testing is useful in off module, sub-assembly testing to eliminate gross leaks.
- Helium - mass spectrometer probe tests allows some bad joints to pass when complete peripheral access is not available.
- Water volumetric testing is useful for a basis of establishing test comparisons, but requires too long a test period to be practical for on module production testing.

- Gas volumetrics tests provide the highest confidence of guaranteeing overall water leakage within practical test time limits.
- The mass spectrometer evacuation test method, with external helium flooding provides the best leak isolation technique for the levels of liquid leakage required to be detected.

Changes in design concept, such as the change from series flow to parallel flow, should be accompanied by the appropriate size reduction accordingly. A reduction in size to 3/8 or 5/16 inch tubing would have simplified the installation and increased mechanical flexibility with no probable time cost overall.

Metals used for construction of new coolant systems should belong to the same family group of dissimilar metals. The present system contains aluminum/stainless steel junctions.

Even though the MDA/EREP coolant system has performed satisfactorily, every system anomaly has resulted in re-reviews and tests for corrosion.

(6) System on Module - Flow and pressure drop and leakage tests were the only complete coolant loop system tests performed "on module". No specific thermal coolant flow tests were performed, since off module tests of experiment assemblies showed that thermal performance was satisfactory when the coolant flow and inlet temperature was within specified limits. Flow balance and distribution was demonstrated by powered operation of EREP modules with tubing surface temperature measurements during systems tests at St. Louis.

Leakage tests "on module" were performed to a "Volumetrics" measurement limit of 1.0×10^{-3} scc/sec of N_2. The volumetrics test method verified all joints in the coolant system, from the AM interface, which included 144 joints. The "Volumetrics" instrument showed a high sensitivity to temperature, such that the entire system had to be wrapped with a super insulation blanket, all lights turned off inside the MDA, and all personnel restricted from the test area during conduct of system leakage measurement.

In order to achieve an acceptable "Volumetrics" measurement, a helium mass spectrometer probe (sniffer) test to a maximum reading of 2.5×10^{-8} scc/sec was imposed as the system build was in process. During the System Test and Checkout Requirements (STACR) checkout, this probe test was relaxed to 5×10^{-7} scc/sec helium which still allowed sufficient volumetrics test margin.

D. Mission Results - During SL-2 no anomalies were observed. At the end of the SL-3 mission anomalies occurred on pump "A" as witnessed by noise and flow drop. The following is the ATM C&D/EREP coolant loop history on SL-4 through splashdown:

The ATM C&D coolant loop was activated for SL-4 on DOY 321 at 21:10:00. Shortly after activation erratic flow fluctuations, from pump "B", were observed with the flow dropping from 30 to 50 pounds per hour. The dropouts in flow were a random occurrence happening once an orbit then not occurring for several orbits. The flow dropouts became larger, up to 100 pounds per hour as mission operation time continued. On DOY 336 pump "B" was turned off and pump "C" was turned on, almost immediately erratic flow conditions were observed on pump "C", with dropouts up to 100 pounds per hour.

As a result of the above mentioned erratic flow conditions the following investigations were conducted.

All hardware in the system was reviewed for failure modes similar to what was exhibited on orbit. The 4-port selector valve was the first suspect. Tests were conducted in St. Louis on the Back Up Article and on orbit by the crew. The tests consisted of rotating the valve handle at 10° increments from a by-pass position to a flow-through position and back again. Test results showed that flow varied as the valve handle was moved from one position to the other, but the erratic flow fluctuations could not be duplicated. The 4-port selector valve was ruled out as the possible cause.

System contamination was suspected as a possible cause. The pump flows on orbit had never been as high as on the ground. Flow rates were from 285 to 300 pounds per hour on the ground dropping to 240 to 250 pounds per hour on-orbit. The 240 to 250 pounds per hour flows were very close to the relief valve setting around the pump, it was felt that perhaps some of this flow was relieving back to the inlet side of the pump. If contamination were the cause, the filter should show some evidence of it. Inspection of the filter by the crew on DOY 352 revealed some contamination on the filter as well as bubbles and foam at the quick disconnects. The following is a description of the filter inspection by the crew. "Some debris looks like little pieces of human skin. Took one of the large pieces and put on end of my finger and let dry, rubbed with thumb and it immediately disappeared in a sort of a dry powder and sort of smeared over my finger. What it really looks like is little bits of lubricant that have gathered together and became sort of a little plate. There are 5 pieces <1 mm, 6 pieces = 1 mm and 4 pieces = 2 mm. Considering the surface area of the filter and number of pieces found we feel this is a negligible amount of contamination." Analysis of filters returned from SL-2 and SL-3 did not reveal contamination that could cause flow fluctuations.

A review of all available system flight data from SL-2 and SL-3 was conducted. It was found that 8 dropouts had occurred on SL-2, 23 dropouts on SL-3 and to date 21 dropouts on SL-4 and dropouts were becoming more frequent. (See Table 2.2.2-1 and Figure 2.2.2-4 for flow dropouts data and sample plot of a dropout.)

Another possible cause of flow dropouts could be that the coolant system could have gas in it. Gas could have been ingested into the system, either during ground testing or on-orbit operations. The filter had been replaced 4 times on-orbit and the accumulator has a viton bladder. Leakage through the bladder and Quick Disconnects would be the most likely suspects for getting gas into the system. On DOY 352 the liquid/gas separator procedure was given to the crew. The Space Suit Umbilical System (SUS) loop separator was installed into the ATM C&D Coolant loop replacing the filter. After several hours of operation switching from pump "B" to "C", the flow increased to 295 pounds per hour on pump "B" and 280 pounds per hour on pump "C". Previously both pumps had been flowing 240 to 250 pounds per hour. When the gas removal procedure was completed, a new filter was installed into the system and pump "C" was activated. Flow was normal at 280 pounds per hour. Pump "B" was then activated and the flow was 297 pounds

MISSION	DOY	TIME GMT	FLOW RATE CHANGE (LB M/HR)	DURATION OF DROPOUT (MINUTES)
SL-2	153	5:27	239.5 to 91.2	1/2 to 1
	157	2:10	240.6 to 198.6	1 to 2
	157	3:22	240.6 to 183.5	1 to 2
	159	18:27	240.6 to 192.8	4-1/2 to 5-1/2
	161	2:16	240.6 to 157.8	1/2 to 1
	164	0:44	233.6 to 36.3	1/2 to 1
	164	7:40	241.8 to 42.2	1/2 to 1
	171	20:36	245.3 to 216.1	2 to 3
SL-3	214	6:09	235.9 to 88.9	3 to 5
	218	13:47	231.3 to 161.3	5
	221	12:26	230.2 to 10.6	1/2 to 1
	223	1:10	231.3 to 81.9	1-1/2 to 2
	226	5:18	227.8 to 5.9	1-1/2 to 2
	227	21:03	227.8 to 153.1	1/2 to 1
	229	1:45	230.2 to 42.2	1/2 to 1
	230	1:01	229.0 to 11.8	1/2 to 1
	232	15:50	230.2 to 81.9	1/2 to 1
	236	18:14	228.9 to 154.2	1 to 1-1/2
	237	15:25	231.3 to 4.8	1 to 1-1/2
	242	16:54	234.8 to 85.4	1/2 to 1
	247	19:51 - 19:55	234.8 to 32.8	3 to 4
	248	15:49	235.9 to 37.5	4 to 5
	248	19:19	237.2 to 28.2	-
	252	4:20:30	234.8 to 5.99	1/2 to 1
	252	3:01:30	234.8 to 11.83	8-1/2
	253	18:40:30	234.8 to 21.2	1/2 to 1
	253	13:08:00	233.6 to 24.7	Data Time Dropout
	256	4:28:00	240.7 to 91.2	1/2 to 1
	259	0:49:30	238.3 to 11.83	1/2 to 1
	259	15:13:00	238.2 to 161.27	1/2 to 1
	262	1:37:00	238.3 to 25.8	1/2 to 1
SL-4	321	23:14	252 to 212	1/2 to 1
	321	23:19	240 to 191	1/2 to 1
	323	23:06	249 to 99	1 to 1-1/2
	323	23:10	250 to 25	1 to 1-1/2
	334	15:09	250 to 110	1/2 to 1
	334	15:10	220 to 110	1/2 to 1
	335	01:00	240 to 190	1

Table 2.2.2-1 Coolant Loop Dropout History

MISSION	DOY	TIME GMT	FLOW RATE CHANGE (LB M/HR)	DURATION OF DROPOUT (MINUTES)
SL-4	335	01:02:30	220 to 145	3-1/2
(Cont)	336	10:07	235 to 0	1/2
	338	12:25	230 to 160	1/2
	339	05:33	Fluctuations 220 to 150	5
	340	10:57	240 to 120	1-1/4
	340	09:00	240 to 140	1
	340	07:38	240 to 120	2
	343	12:37	240 to 10	1-1/4
	344	7:04	240 to 0	3 (minimum)
	345	00:38	240 to 157	2 maximum
	345	03:42	240 to 12	2 maximum
	345	10:36	240 to 100	2 maximum
	346	03:14	From 243 to 232 And Cycles 227 to 259	1/2 approximately
	346	10:17	244 to 217	1/2

Table 2.2.2-1 (Concluded)

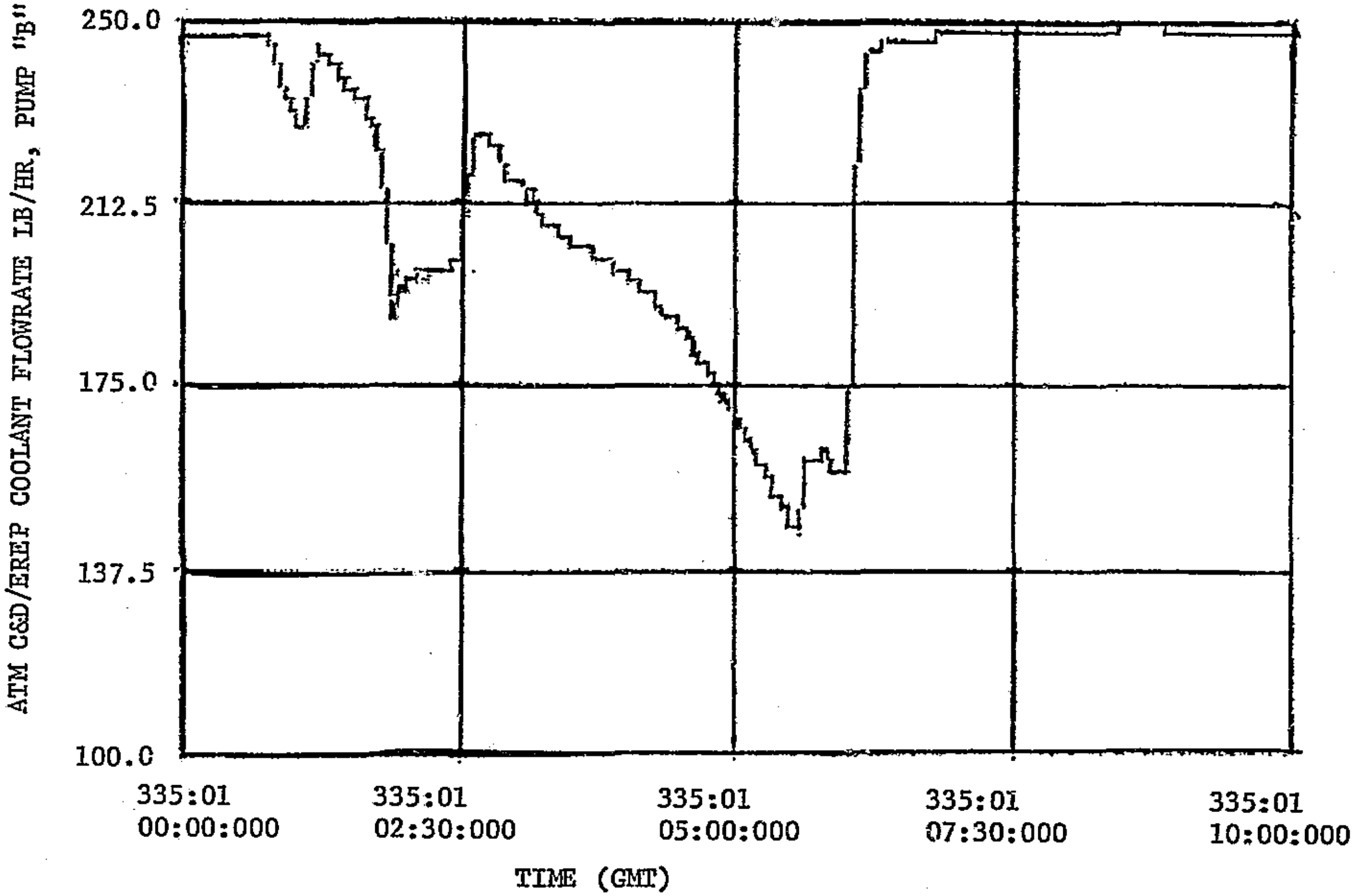


Figure 2.2.2-4 ATM C&D/EREP Coolant Flow Dropout

per hour, similar to ground operation.

Subsequent to removal of the gas from the coolant loop on DOY 352, the crew reported that pump "C" was noisy and bothering them during sleep periods. After operating pump "B" for a short period of time, the crew reported that it had the same noise level as "C" and that the noise level was comparable to the SUS pumps. The loop was left on during DOY 352-353, sleep period, but was turned off for DOY 353-354 sleep period. Pump "C" was then used when the loop was reactivated on DOY 354. On DOY 359 the coolant loop again exhibited 50 pound per hour fluctuation occurring approximately once every minute. The 4-port selector valve was switched from by-pass to EREP flow position. The decrease in flow which had been seen in the by-pass position, were damped out over a period of time and the flow stabilized at approximately 260 pounds per hour, (approximately 25 pounds per hour below the normal flow for pump "C"). This flow rate was maintained after the valve was changed back to the by-pass position. The decision was then made that the pump would remain on during the upcoming sleep period.

On DOY 004 the liquid/gas separator was again used to remove gas from the coolant loop. Both pumps "B" and "C" were operated and produced normal flow rates, (299 pounds per hour and 285 pounds per hour respectively), after the gas was removed. Flow remained constant for a period of time and then flow dropouts were observed again on DOY 030. At various times toward the end of the mission pumps "A", "B", and "C" were operated with similar flow dropouts occurring on each pump. Even with these dropouts, sufficient cooling was always available to the experiments.

E. Conclusions and Recommendations - The MDA/EREP part of the coolant system operated satisfactorily and remained leak proof throughout all Skylab missions. Even though coolant flow fluctuations were observed, the ATM C&D panel and EREP electronic modules received sufficient cooling during all experiment operations. Corrosion of the dissimilar metals in the coolant system appeared to be minimal.

It is recommended that future coolant systems incorporate metal bellows type bladders in accumulators rather than non-metallic bladders which are more susceptible to leakage and gas permeation. However, if the possibility of air ingestion exists, then it is recommended that a liquid/gas separator be designed into the system, much as that in the SUS cooling system. Also dissimilar metals should not be used in the same system.

2.2.2.3 MDA Vent System

A. Design Requirements - The MDA Vent System design requirements were specified in CEI CP114A1000026E as follows: The MDA shall be equipped with series redundant, remotely-operated vent valves. The valves shall be sized to assure that the MDA maximum shell pressure will not exceed 6.2 PSID during the launch phase of mission. The vent valves shall be provided with a plug which shall be installed by the crew. Venting studies were performed to determine the internal MDA pressure during launch. The maximum pressure predicted by analysis was 5.3 psid. The actual results during launch ascent phase were 5.25 psid.

B. System Description - the MDA Vent System consisted of two 4-inch motor operated vent valves mounted in series, one sealing device, and one stowage fitting.

The vent valves provided a means of venting the MDA during pre-launch, launch and ascent. The valves were opened prior to launch and were closed during ascent, via I.U. Command, to maintain a positive pressure within the AM/MDA.

The vent sealing device provided a positive sealing capability of the vent valves during orbital operation. The sealing device was installed upon initial entry of the astronauts into the MDA.

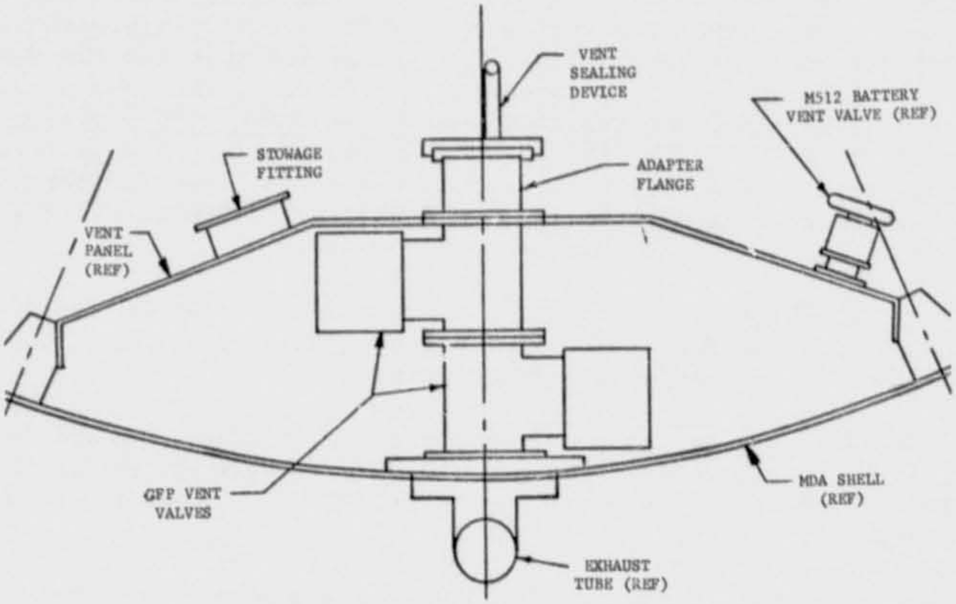
The MDA Vent System is illustrated in Figure 2.2.2-5.

C. Test

(1) Four-Inch Vent Valve, Electric Motor Operated, MSFC P/N 20M32043

(a) Development Test - The design and development testing of the four-inch vent valve was accomplished by MSFC prior to Martin Marietta's MDA contract. Examples of tests conducted were: internal and external leakage, electrical checks, high and low temperature operation, life cycle, vibration, and Electro Magnetic Interference (EMI) tests. The unit successfully completed the test with results that either met or exceeded the specification requirements.

(b) Qualification Test - The four-inch vent valve was a GFP item through qualification. The qualification testing was completed on May 10,



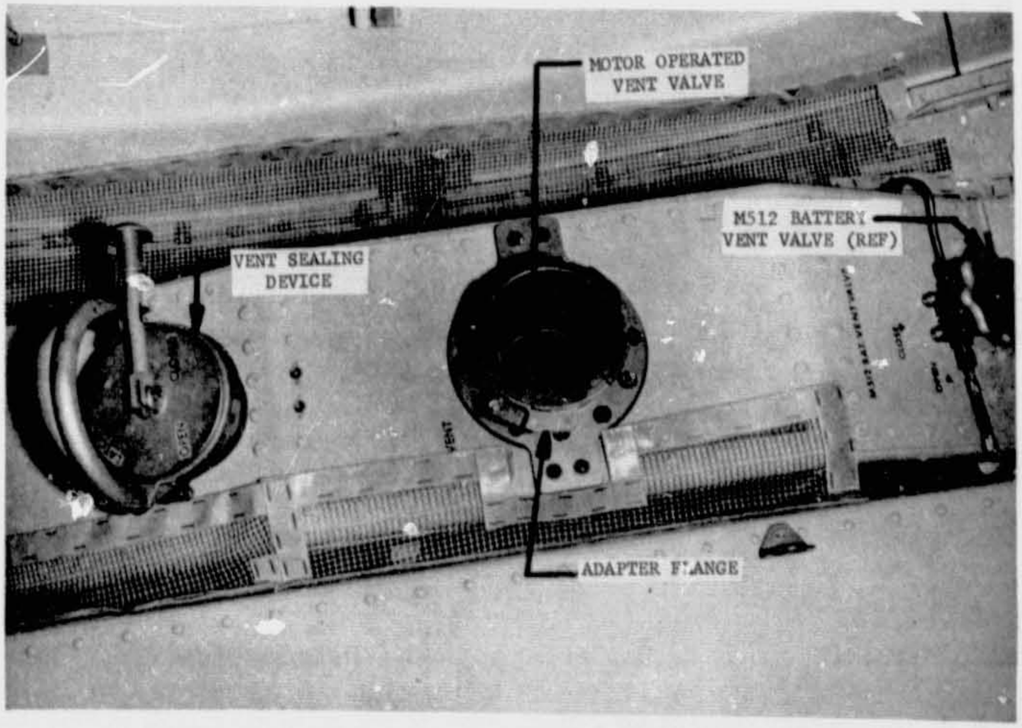


Figure 2.2.2-5 MDA Vent Valve Panel

1971. The results of the tests were presented in Ametek/Calmec Report No. CM-605.

The testing consisted of the following environmental tests: Corrosive, Contaminants, Oxygen and Humidity (GCOH), EMI Compatibility, Vibration, Shock, Vacuum Storage, Explosive Atmosphere, Burst Pressure, and Life Cycle. A performance test was conducted after each environmental test. The problems encountered during qualification testing are summarized below.

During functional test, prior to qualification test, with external pressure of 10^{-4} torr, the valve failed to operate when 22 VDC power was applied. The failure was attributed to the deflection of the end plate resulting from the 14.7 psi differential pressure, thereby causing the brake to hang up. The corrective action taken was to reduce the internal pressure of the hermetically sealed actuator to 7.0 ± 1.0 psia, thus reducing the deflection of the end plate.

During high level random vibration testing in the "Y" axis, one of the test units exceeded the response time requirements (14.4 seconds instead of required 8 seconds maximum). During the same test, a second test unit had both open and close indicator lights on simultaneously. Post vibration fixture evaluation revealed an amplification of input level at the secondary mounting bracket of the vibration fixture of approximately 9 to 1 over the input level. According to the qualification test report, the specimen failure was due to overtest. The fixture was redesigned and "Y" and "Z" axis vibration tests re-run. Both units passed the post-vibration functional test requirements.

Delta qualification tests were conducted on the two test units. These delta tests consisted of vibration fixture evaluation, functional test, and vibration tests in X, Y, Z axes. During fixture evaluation it was found that the location of control accelerometers for the previous qualification tests produced an undertest condition. The accelerometers were relocated in order to simulate a realistic test during the following vibration tests. During post-fixture evaluation functional tests, one of the two units failed to operate. Valve failure was attributed to overtesting resulting from the excessive number of tests conducted during qualification and fixture evaluation test programs. This valve was used as a dummy mass for the following vibration tests. During Z axis high level random vibration, the test unit failed to cycle properly. The unit had cycled properly subsequent to the vibration environment. The requirement to cycle the valve during vibration was re-evaluated. It was determined that the vibration levels were negligible when the valve had to cycle closed after launch, therefore the requirement was changed to cycle subsequent to vibration. Vibration testing in each of the three axis was then completed successfully.

(c) Acceptance Test - Each valve received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration the valves were visually and dimensionally inspected, subjected to proof pressure, checked for internal and external leakage, and were checked electrically for operating voltage, valve response, current draw, open and closed position switch actuation and deactuation. No problems which required hardware redesign were encountered during acceptance testing of the production units.

(2) Habitation Area Vent Outlet Sealing Device, MDAC-W P/N 1B74832.

(a) Development Test - Not applicable. Used existing MDAC design (See OWS Final Program Report).

(b) Qualification Test - MDAC-W, Report No. TM-DSV7-F&M-R6823 - Qualification testing was performed on the sealing device P/N 1B74832, stowage fitting P/N 1B78876, and adapter flange P/N 1B78003 which was similar to Martin Marietta procured adapter flange P/N 1B82837. All critical sealing surfaces and flange sealing device interfaces were the same for both adapter flange parts. The function 1B78003 was the same as 1B82837. Testing was completed in December 1970.

The qualification tests consisted of the following environmental and functional tests: handle locking force, proof pressure, leakage, pre-vibration life cycle, vibration - sine evaluation and random, post vibration life cycle, thermal vacuum. All of the above tests were conducted with the sealing device mated to the adapter flange except for vibration and post vibration life cycle during which the sealing device was mated to the stowage fitting.

The problems encountered during qualification testing are summarized below.

During the life cycle test, the handle locking pin fell out of the handle when the retaining ring, which retains the locking pin in place, broke during the latching portion of a cycle. Subsequent examination of the failed part revealed a design deficiency wherein the retaining ring could catch in the latching slot of the handle. Redesign of the unit changed the locking pin assembly to a press fit plus a locking nut design instead of a retaining snap ring. Retest of the redesigned unit was completed successfully.

Following the completion of pre-vibration life cycle testing, aluminum particles were discovered on the sealing device O-ring. The particles caused no failure of the tested units but an investigation revealed that the particles were generated by contact between the aluminum sealing device and a detent spring tab used on the adapter flange. This contact occurs during normal installation and removal of the sealing device onto the flange.

The adapter flange was revised to change the spring tab from steel to aluminum. Subsequent post vibration life cycle testing resulted in only normal wear of the two parts and no generation of particles. All other testing was completed with no other problems encountered.

(c) Acceptance Test - The acceptance tests conducted on each sealing device were as specified on drawing 1B74832 Rev E. These tests were an internal leak check and a proof pressure test. All units met these requirements without difficulty. Acceptance testing of the non-functional adapter flange and stowage fitting was limited to a visual and dimensional inspection.

D. Mission Results - The two motor operated vent valves were opened at T-5 hours, 15 minutes, per the normal countdown procedure for SL-1, and were commanded closed at T + 280 seconds. The valves closed in 6.2 seconds. The maximum MDA shell pressure achieved during ascent was 5.25 psid, well below the MDA CEI limit of 6.2 psid. The vent sealing device was installed during the SL-2 activation.

The vent system was not used or operated after SL-2 activation, however, the valves and sealing device maintained structural and leakage integrity throughout the entire Skylab missions.

E. Conclusions and Recommendations - The design of the MDA vent system and its components were adequate. No design changes were proposed for its usage.

2.2.2.4 M512/M479 Experiment Vent Systems

A. Design Requirements

(1) M512/M479 Chamber Vent System - The M512/M479 Experiment Chamber Vent System design requirements were specified in CEI CP11411000026E as follows:

- The system shall include manual redundant valves.
- One valve shall be located on or near the MDA bulkhead, the second valve shall be located at the experiment vacuum chamber.
- The valve system shall be capable of providing a variable orifice system.

Dimensional requirements were specified in ICD 13M12161.

System Analysis - An analytical study was performed to verify adequate sizing of the chamber vent line system to maintain a vacuum condition at 1×10^{-4} torr during welding experiment operations.

(2) M512 Battery Vent System

The M512 Battery Vent System design requirements were as follows:

- The battery vent system shall include a ¼ inch shutoff valve and the interconnecting system tubing.
- Battery vent allowable leakage of 1×10^{-4} scc/sec N_2 @ 5 psi external pressure.

  @ 15 psid internal pressure and 1×10^{-3} scc/sec N_2.

- Chamber vent system allowable leakage of 1.85×10^{-4} scc/sec helium @ 1×10^{-5} torr and 5×10^{-4} scc/sec N_2 @ 20 psid.

B. System Description - The M512/M479 Experiment Chamber Vent System provided a conduction path from the experiment chamber overboard to space. It consisted of two (2), series mounted (4") manually operated valves separated by a metal bellows assembly and a short section of hard duct penetrating the MDA shell. The vent system had the capability of providing isolation of the experiment chamber from space vacuum, maintaining a vacuum environment within the experiment chamber or providing a conduction part for venting experiment contaminants overboard as required.

The M512/M479 Battery Vent System incorporated a redundant manually operated valve for vent or shutoff capability of the battery case. The ¼" valve was mounted on the MDA vent panel. The M512/M479 Experiment Vent System is shown in Figures 2.2.2-6 and 2.2.2-7.

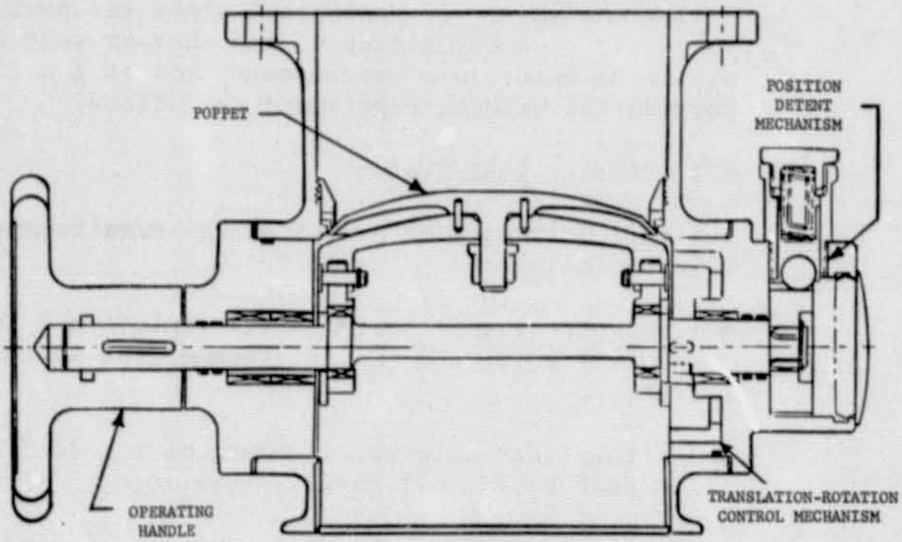


Figure 2.2.2-6 4 Inch Chamber Vent Valve

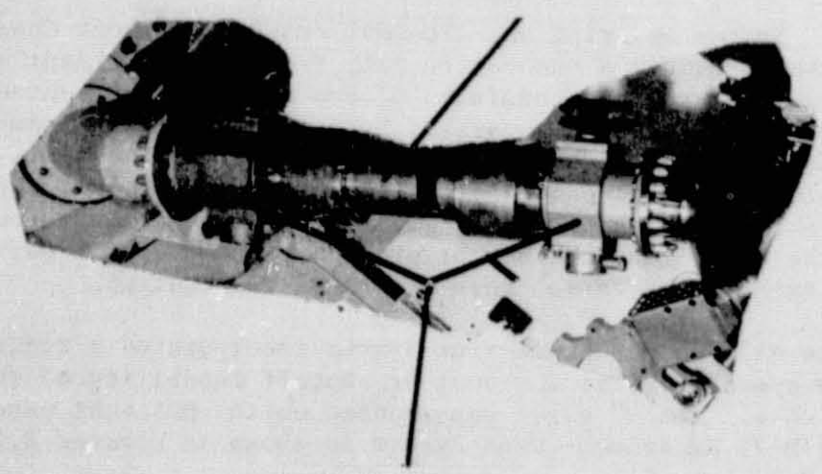


Figure 2.2.2-7 M512/M479 Vent System

C. Test

(1) M512/M479 Vent Valve, Manually Operated (4 inch) - MMC P/N 82000009820

(a) Development Test - Development tests on the M512/M479 Vent Valve were limited to lubrication evaluation and valve shaft bearing load tests under vacuum conditions. Other tests were not conducted because of previous test experience on similar valve configurations developed for the Titan propellant systems.

Three bearings were utilized in the tests. Two were lubricated with Vac-Kote (Ball Brothers Corporation) grease and one was lubricated with Microseal 200-1. The bearings were mounted in test fixtures designed to load the bearings radially from 0 to 500 pounds when cycled, simulating vent valve operation.

Tare torque values were obtained prior to starting the test. The test items were then placed in a vacuum chamber and maintained at a pressure of 1×10^{-6} torr or less for 100 hours. After the 100 hour soak and while maintaining the vacuum chamber pressure at 1×10^{-6} torr or less, the bearings were load cycled 1000 times with torque measurement made every 20th cycle.

Test results indicated that both lubricants performed satisfactorily but Vac-Kote provided the least increase in torque and the smoothest operation during load cycling. Vac-Kote was selected for use in the production valves.

(b) Qualification Test - MMC, Report No. 3300 - Qualification testing on the MDA Vacuum Vent Valve, P/N 82000009820-010, was completed on 22 September 1971. The qualification tests consisted of the following environmental tests: Vibration (consisting of Sinusoidal Evaluation), Vehicle Dynamics, High and Low Level Random; Shock; Thermal Vacuum; Temperature, Altitude, Storage and Transporation; Burst Pressure; Vacuum Storage; Cycle Life; and CCOH. A performance test was conducted prior to and after each environmental test. Two problem areas were encountered during qualification testing. These problems are summarized below.

During vibration testing (the first environmental test following initial performance testing) the operating handle became loose and began rattling. The test was stopped and the handle setscrew examined. It was found to be peened and subsequent examination revealed the setscrew material to be too soft for the intended usage. The setscrew design was modified to alleviate the peening problem and also to provide positive handle positioning even if the setscrew became loose. The valve dash number was changed from -009 to -010. The valve was then placed back into vibration test with the entire test being re-run.

During performance of the external leak portion of the functional test, following the CCOH test, the leakage exceeded the allowable level. The valve was rejected on MARS No. B73828 and a failure analysis conducted. Examination of the valve during failure analysis revealed no evidence which would indicate leakage was caused by exposure to the CCOH test. Failure was attributed to contamination of a static O-ring seal located between the operating handle adapter and valve body. The contamination of the seal occurred during the original build cycle of the valve. The contaminated seals were replaced and the valve placed back into qualification test at the point testing was terminated (functional test following CCOH) since the CCOH test was not considered a contributing factor in the failure. The entire functional test was completed without further difficulty.

During performance of the qualification test program, each of the two units tested were manually cycled 1000 times. Three hundred of the cycles were conducted at pressures less than 1 x 10^{-8} torr. At the completion of all testing, the units still operated within the allowable operating torque and leakage was 5.4×10^{-7} scc/sec helium with 2.67×10^{-4} scc/sec allowable and maximum external leakage of the units was 1.02×10^{-8} scc/sec helium with 1×10^{-7} scc/sec allowable.

(c) Acceptance Test - Each valve received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration the valves were visually and dimensionally inspected, checked for proper operating torque, demonstrated an over torque capability, demonstrated functional capability under normal operating pressure, withstood proof pressure, and met the internal and external leakage criteria.

All valves met these acceptance test requirements without difficulty. Typically, internal and external leakage values were in the 10^{-7} and 10^{-8} to 10^{-9} scc/sec helium range, respectively. Allowable leak rates were 2.67×10^{-4} scc/sec and 1×10^{-7} scc/sec for internal and external leakage, respectively.

(2) M512/M479 Bellows Vent Line - MMC P/N PD4400011

(a) Development Test - Not applicable.

(b) Qualification Test, Ametek/Straza, Report No. 8-480119 - Qualification tests on the two bellows, P/N PD4400011-009, Serial No's 0000005 and 0000006, were completed on 26 February 1971. The qualification tests, as called out in Table I of the MMC PD4400011, consisted of the following environmental tests: Proof Pressure, Spring Rate, Leakage, Vibration, Cycle Life, and Burst Pressure. The Proof Pressure Test, Leakage Test, and Inspection of the welds followed and preceded the Vibration Test and the Cycle Life Test.

The qualification tests were all successfully accomplished without difficulty on both bellows tested. The two bellows passed the internal leakage rate of 1×10^{-8} scc/sec (max.), the

1000 cycles test, the proof pressure test of 32 psig for 3 minutes, and the internal burst pressure of 52 psig for 1 minute. One bellows (S/N 0000005) was subjected to an external pressure test - the tube collapsed at 60 psig. The other bellows (S/N 000006) was subjected to an internal rupture test - at 300 psig, the bellows did not rupture, only the convolutes of the bellows "squirmed" to a permanent set.

(c) Acceptance Test - The individual bellows were acceptance tested to demonstrate suitable quality, correct assembly and required performance. The following tests were conducted for acceptance: visual and dimensional inspection of the hardware, inspection of welds, proof pressure, internal leakage, and subjected to cleaning tests. All the bellows passed the acceptance tests.

(3) M512 Battery Vent Valve (½ inch) - MSFC P/N 20M32042

(a) Development Test - One unit was subjected to the following development tests: weight, proof pressure, external leakage, operating torque, internal leakage, life cycling, pressure drop, vibration, shear torque and burst pressure. The unit completed the development tests with results that met or exceeded the specification requirements. It was concluded that the design objectives of NASA MSFC Specification No. 20M32042 had been accomplished.

Subsequent to development testing, the vibration levels were revised and it was determined that the Vespel seal material was incompatible with potassium hydroxide (KOH) vapors given off by the M512/M479 battery. Consequently, the design specification was revised to reflect the new vibration levels and the valve seat material was changed from Vespel to Kel-F.

(b) Qualification Test - Ametek/Calmec. Report No. CM-512 - Qualification testing on the Valve Assembly, Manual Astronaut Operated, ½" diameter, P/N 20M32042 was completed on 17 December 1969.

The qualification consisted of the following tests: Salt Spray, Pressure Drop, Temperature, Life Cycle, Vibration (closed), Vibration (open), Thermal Vacuum, Flow vs Handle Position, Shear Torque and Burst Pressure. Subsequent to each vibration test, a functional test consisting of proof pressure, internal leakage and external leakage was performed.

The only anomaly occurring in qualification testing was excessive leakage attributed to frost build-up on the valve seat during a post vibration functional test. The test personnel were cautioned to follow specific evacuation and purge times prior to performing a test.

Three units successfully completed qualification testing per Ametek/Calmec Report No. CM-512 dated 18 December 1969 with results that met or exceeded the design specification criteria.

(c) Acceptance Test - Each valve received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration the valves were visually and dimensionally inspected, checked for proper operating torque, demonstrated an over torque capability, withstood proof pressure and met the internal and external leakage criteria.

(4) M512/M479 System Test Summary - During the performance of the MDA-OCP-3002 SEQ 05, 15, and 16; failure reports were issued on the M512/M479 work chamber vent valves and against the battery vent valve.

The purpose of the test was to verify that the internal leakage of each of the two work chamber vent valves had remained within the allowable range and that the external leakage of the total chamber vent system was within the allowable range, and to verify that the battery vent line and valve leakage rates were within the allowable range.

These tests were conducted at St. Louis because the M512/M479 work chamber was not available for test at Denver.

During performance of the system leak checks, Valve #1 (at the work chamber) had no detectable leakage using the volumetrics leak detector and Valve #2 (at vent elbow) had a leak rate too large to measure. The allowable rate is less than 1×10^{-4} scc/sec (GN_2).

Valve #2 was removed on MARS B88131 and returned to Denver for failure analysis. Since there was obvious contamination on the rejected valve seat, the bellows assembly was also rejected for suspected contamination and returned to Denver on MARS B87982. Both rejected items were replaced in the vent system. Retest of Valve #2 (replacement item) resulted in no indicated leakage.

External leakage of the work chamber and vent line is measured by evacuating the chamber and vent line through a CEC helium leak detector and externally bagging the chamber and vent line and filling the bag with helium. The measured leak rate for the total chamber vent system was 1.4×10^{-8} scc/sec (He) and the allowable rate is less than 3.7×10^{-6} scc/sec (He).

Leakage verification of the M512/M479 battery vent valve resulted in rejection of the vent valve for excessive internal leakage. The measured leak rate was 1.06 scc/sec (GN_2) and the allowable leak rate was 0.4 scc/sec (GN_2). The valve was rejected on MARS B88054 and returned to MMC for failure analysis. The results of the analysis revealed that the excessive leakage was caused by contamination imbedded in the valve seat. The rejected valve was replaced in the system with another valve and the leak test re-run. The retest was successful with a measured leak rate of 0.47 $\times 10^{-7}$ scc/sec (GN_2).

D. Mission Results - The M512 vent system operated properly during all Skylab missions. No atmosphere leakage or hardware problems were encountered. During initial experiment operation, the valves were left in the "vent" position overnight due to excessive outgassing of the chamber and experiment specimens. Normal operation was to position the valves in the "open" position for a shorter period of time. This normal method of operation was used during all succeeding experiments following the initial outgassing period. During the electron beam welding experiment, at which time the most gaseous effluents are produced, pressure within the chamber was maintained at less than 10^{-4} torr as required.

E. Conclusions and Recommendations - The vent system operated as expected, and met all design requirements. Success of the electron beam welding experiment indicated that the vent system was sized correctly and that no leaks were present. No design improvements are recommended. However, for ground operations, it is recommended that all thin walled components, such as the bellows, should be provided with protective covers.

2.2.2.5 MDA Pressure Equalization System

A. Design Requirements - The pressure equalization system requirements per CEI CP114A1000026E consisted of the following:

- Visually indicate pressure differential across the hatch from either side.
- Capable of measuring 0.1 psid.
- Manually operated valve(s) for pressure equalization.

B. System Description - Prior to entry into the MDA, the pressure between the CM and the MDA required equalization. This function was accomplished by means of a manually operated pressure equalization valve and a differential pressure gage which were located in the MDA axial hatch. The equalization valve provided an atmosphere flow path through the hatch for pressure equalization and for atmosphere sampling through the valve on SL-2. The differential pressure gage indicated the CM/MDA differential.

A pressure cap provided a redundant seal to the equalization valve and was installed on the outer (CM) side of the hatch. The cap was removed prior to valve operation. The system was operable from either side of the hatch after the pressure cap was removed.

A similar system as described above was located in the radial docking hatch to provide the same equalization with a radial dock.

The pressure equalization system gage and valve are shown in Figure 2.2.2-8.

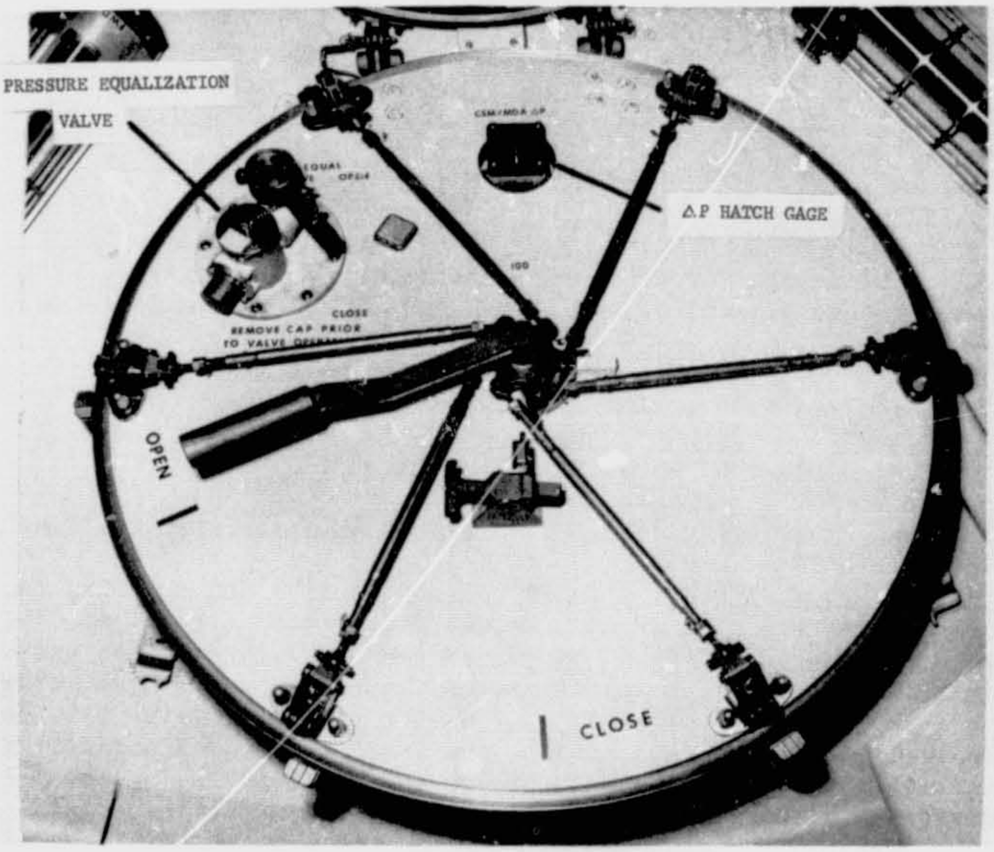


Figure 2.2.2-8 Axial Hatch Equalization System

The differential pressure gage was a bourdon tube type gage with a dial range of -1.0 psid to +1.0 psid. The gage assembly consisted of two gage units mounted back-to-back in a bracket which was then installed through a hole in the hatch. The inside of the coiled bourdon tube of each gage unit was exposed, via a sensing tube, to the atmosphere on the opposite side of the hatch, while the outside of the bourdon tube is exposed to atmosphere pressure on the near side. A difference in pressure across the bourdon tube will caused the tube to coil or uncoil, thereby, by mechanical linkage, causing the dial pointer to move.

C. Test

(1) Pneumatic Gage Assembly

(a) Development Test - Development tests were not conducted on the gage assembly because the same basic gage design was qualified for and used on the Apollo CSM. A review of the Apollo gage design at the start of the Skylab program revealed that the -1.0 to +4.0 psid dial range would not meet the ± 0.05 PSID initial accuracy requirement. The design was subsequently changed to provide a dial range of from -1.0 to +1.0 psid. This design change consisted simply of increasing the number of coils in the bourdon tube thereby providing a full range movement of from -1.0 to +1.0 psid and consequently greater sensitivity and accuracy.

(b) Qualification Test - Kratos, Report No. KER 681 - Qualification testing of the Pneumatic Gage Assembly, P/N PD8300139-009, was completed on 16 May 1972. The qualification tests consisted of the following environmental tests: CCOH; Temperature; Life Cycle; Vibration - Sinusoidal Evaluation, Vehicle Dynamics, High and Low Random; Shock: Vacuum; Burst and Collapse Pressure. A performance test, consisting of proof pressure, accuracy and leak check, was performed after each environmental test. The problems encountered during qualification testing are summarized below.

During temperature testing, the glass lens of the gages cracked. Epoxy was discovered between the lens and bezel, creating stresses due to thermal coefficient differences. The epoxy was removed from the unit and the assembly successfully passed the temperature retest.

During shock testing to a 1500g spectrum, the pressure sensing bourdon tube shifted from its original position. Corrective action consisted of two spearate efforts: (1) the gages were redesigned to incorporate small rubber shock isolators around the gages' mounting screws, and (2) hatch evaluation tests at MMC resulted in lowering the shock criteria to a 500g specturm. Shock and vibration retesting was then completed successfully. However, the addition of metal stops to the hatch design resulted in shock paths which increased the shock criteria back to the 1500g spectrum. Retest of the gage assembly resulted in the same failure as had occurred previously. Analysis of data from docking tests performed at MSFC with actual flight-type hardware indicated that the docking shock data could be enveloped by a spectrum which was lower in the 600-4000 Hz frequency range than the original 1500g spectrum. Subsequent retest of the gage assembly to this revised shock spectrum was completed successfully.

Additional vibration testing was conducted on the hatch with the gage assembly installed. Data showed that the amplification through the hatch to the gage location resulted in a vibration level higher than had previously been experienced in earlier qualification testing. Following this testing, it was determined that the gage accuracy was approximately $\pm$0.07 psid instead of within the $\pm$0.05 psid requirement. It was decided that the accuracy requirement could be increased to $\pm$0.10 psid without adversely affecting mission performance. With this change the qualification test program was completed.

(c) Acceptance Test - Each gage assembly received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration, the gages were visually and dimensionally inspected, checked for pressure indicating accuracy, submitted to a proof pressure integrity check, subjected to a leak test, and then cleaned and packaged. In addition the flight units were tested after installation in the vehicle. This testing consisted of leakage and accuracy checks and was conducted at ground checkout of the MDA in Denver and St. Louis and KSC. All testing proceeded normally throughout system checkout except for one anomaly during KSC testing. During the inverted docking test of the AM/MDA to the CSM, the gage pointer on the CSM side of the hatch stuck during pressure equalization. The pointer moved to the proper pressure reading when tapped slightly by the crew members. A thorough analysis was conducted on the installed flight gage units and one available spare unit. When each unit was cycled in the correct orientation, i.e. gage dial horizontal and facing upward, there was no indication of a sticking operation. However, when cycled in the dial face down orientation, each unit exhibited some sticking operation. Conclusions reached during disassembly inspection were that the unit was subject to gravity effects in the upside down orientation which increase friction forces that could not be overcome by the extremely low return spring forces exerted by the two psi bourdon tube. This anomaly was closed out and the gages designated acceptable since the problem would not exist in space operation.

The acceptance testing of the qualification units revealed an assembly problem involving the linkage subassembly resulting in binding during full range cycling. A small redesign and assembly procedure change alleviated this problem on all qualification and production units. Test requirements were: accuracy at 0.0 psid was ± 0.05 psid; at any other pressure, accuracy was ± 0.10 psid; proof pressure + and -9.2 psid; maximum leak rate was 2.0×10^{-2} scc/sec He.

(2) Pressure Equalization Valve, P/N82000040320

(a) Development Test - The equalization valve was

√

developed for McDonnell Douglas, Eastern Division for use in the Airlock Module. Martin Marietta procured the same part for use on the MDA hatches. Development tests conducted were vibration, shock and flow tests with performance evaluation before and after each test. The vibration test consisted of a high level random test of 10 Grms; the shock test consisted of synthesized shock pulses of 1500g maximum per IN-ASTN-AD-70-1. The test unit sustained no physical damage and passed all performance tests after the environmental exposures.

(b) Qualification Test - Accessory Products Company, Report No. 500200-1 QTR - The equalization valve was qualified to requirements set forth in McDonnell Douglas procurement specification 61B830014. These requirements were as stringent as those of the MDA, therefore upon qualification to these criteria, the valve was qualified for use in the MDA. Qualification testing of the valve was completed on 2 April 1971. The tests consisted of the following environmental tests: High and Low Temperature, Oxygen Atmosphere, Vacuum Exposure, Vibration - High Level Random, Shock, Cycle Test, Limit Load Test, Proof Pressure, Ultimate Load Test, Burst Pressure, Salt, Fog and Humidity. A performance test was conducted after each environmental test. No problems were encountered during the qualification tests and the test units successfully passed all environmental and functional tests.

(c) Acceptance Test - Each valve received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration the valves were visually and dimensionally inspected, checked for flow rate capacity, subjected to proof pressure, tested for internal and external leakage, and the detent spool was examined for centering adjustment. All valves thus tested met the acceptable requirements without difficulty. These valves were installed in the MDA docking port hatches at a position approximately 4 inches from the hatch seal lip. The length of the chain attaching the cap to the valve body could, if the cap was unscrewed from the valve, allow the chain and/or cap to become lodged between the seal and the hatch lip upon closing the hatch. Martin Marietta procured the valve, P/N 61B830014-5, from Accessory Products Company and changed the length and location of the chain prior to installing the valve in the hatch.

D. Mission Results - The axial hatch pressure equalization valve was operated by each of the three crews and the ΔP gage monitored during hatch opening activities. The equalization valve and cap was used for an unprogrammed toxic gas sampling during SL-2 activation. A spare cap was modified to accept a gas sampling apparatus. This cap and the gas sampler were stowed in the SL-2 command module. Prior to SWS/CSM pressure equalization the crew removed the flight cap from the valve and attached the modified cap and sampler. The valve was then opened and a sample of the atmosphere in the MDA was taken. When the gas was found satisfactory, SWS/CSM pressure equalization was performed, and the hatch was opened in a normal manner. The system performed properly during all operations.

E. Conclusions and Recommendations - Since the equalization system operated satisfactorily during all missions, it is concluded that the system was designed adequately. However, from the experience gained during this program, it is recommended that a differential pressure gage need not be required when one of the volumes to be equalized is small (greater than 5:1 ratio) or if both volumes are small. The equalizing process could be accomplished procedurely by simply waiting a short length of time after opening the equalization valve before opening the hatch. However, if a visual gage is to be required, the accuracy requirement should be at least 0.1 psi. This would allow a gage to be designed with a greater pressure range and therefore a stiffer bourdon tube which would be less susceptible to gravity effects and shock testing practices.

In addition it is recommended that future equalization valve designs incorporate a detachable cap similar to this Skylab valve in order that instruments such as gas samplers can readily be attached to them for unscheduled operations or usage.

This Page Intentionally Left Blank

2.2.3 Thermal Control System (TCS)

2.2.3.1 Passive System

A. Design Requirements and Analyses - Design requirements for the passive MDA are contained in the MDA CEI Specification, the AM and CSM ICDs and several equipment

Some design requirements were applicable only to the Passive TCS. Others were applicable to the Active TCS. Many requirements, however, were applicable to both the Active and Passive TCS. Table 2.2.3-1 indicates CEI requirements for the MDA. An identifying letter, either (P),(A), or (B) preceding each requirement, indicates whether the requirement was pertinent to the Passive TCS, Active TCS or both systems respectively.

Tables 2.2.3-2 and 2.2.3-3 indicate vehicle ICDs and equipment requirements. The (P),(A), or(B) identification convention, indicated above, is applicable to these tables.

The primary requirements as imposed by the above mentioned CEI and ICDs were that average wall temperature be controlled between 60°F and 90°F during the manned mission period and between 40°F and 90°F during the orbital storage mode of operation.

No requirement was imposed on the MDA to meet comfort criteria during the manned mission phase. However, it was an objective to provide environments that fell within the comfort box presented in Figure 2.2.3-1.

Numerous analyses were performed in support of the effort directed toward the meeting of design requirements. Table 2.2.3-4 summarizes these analyses. A discussion of these analyses follows:

(1) Systems Studies - Passive TCS - Several systems studies were performed on the Passive TCS. A description of these studies is indicated below:

(a) Error and Sensitivity Analysis - The purpose of this analysis was to predict the tolerances that could exist on calculated MDA temperature and heat balance due to errors and uncertainties in basic environmental and material property assumptions. Calculated MDA external temperature values were subjected to preliminary error(continued on page

(A) Distribute atmosphere from the AM ECS (Para 3.1.1.2.4.1.1a)

(A) Cabin fans and diffusers will provide capability to maintain atmosphere at crew stations between 15-100 feet/min (Para 3.1.1.2.4.1b)

(A) Atmosphere shall be delivered from the MDA to the CSM by a fan/duct system (Para 3.1.1.2.4.1.1c)

(A) Wall heaters to be thermostatically controlled to approximately 45°F during storage and 70°F during manned operation. Penetration heaters to be thermostatically controlled (Para 3.1.1.2.4.1.1e)

(A) Heater elements shall be protected by overtemperature thermostats to deactivate individual heater circuits (Para 3.1.1.2.4 .1.1e)

(A) An equipment coolant system shall be incorporated to distribute coolant fluid from the AM thru the MDA to the ATM C&D console and EREP System (Para 3.1.1.2.4.1.1f)

(P) MDA passive thermal control shall consist of high performance insulation, thermal paint and material selection to meet the thermal requirements herein (Para 3.1.1.2.4.1.2)

(P) The high performance insulation shall be attached to the primary structure with Velcro and shall be laced together with dacron lacing and boot hooks. The multilayers shall be assembled by means of nylon swiftachment devices (Para 3.1.1.2.4.1.2)

(P) MDA shall be designed to be purged internally (Para 3.1.1.2.4.1.2a)

(P) MDA shall incorporate provisions for purging the insulation blanket with GN_2 (Para 3.1.1.2.4.1.2b)

(P) Insulation shall be installed on the external window cover to minimize heat loss (Para 3.1.1.2.10.2.2)

(A) The S190 window shall incorporate heaters to prevent moisture condensation on the glass during all periods when the window is in use (Para 3.1.1.2.10.2.4)

Table 2.2.3-1 MDA CEI Requirements Summary - TCS

(B) Docking port-hatch handle temperatures shall be maintained between +105°F and +35°F during docking and all manned operations (Para 3.1.1.2.10.3.1)

(B) The MDA shall be designed to withstand effects of space environments as in TMX-53798 and earth environments as per TMX-53872. Thermal properties of the sun and earth (albedo) shall be as defined in TMX-53957 (Para 3.1.2.4)

(B) The MDA shall be designed to withstand thermal stresses and shock resulting from atmospheric conditions defined in TMX-53872 and NASA TMX-53798 (Para 3.1.2.4.2)

(B) Net total steady state heat load to the MDA atmosphere shall be defined in ICD 13M02521 (Para 3.1.2.8.7)

(B) MDA to provide equipment environments as follows:

Vehicle Condition	External Environment T max (°F)	Tmin (°F)	Internal Environment Tmax (°F)	Tmin (°F)
Ground Hold & Ascent	90	40	90	40
Orbital Coast/ Storage	277	-180	90	40
Active ECS Mode	277	-180	90	50

(Para 3.1.2.8.7.1)

(B) Local wall temperature not to exceed 105°F (Para 3.1.2.8.7.2)

(B) MDA wall average area temperature shall be a minimum of 60°F at launch and during the active ECS mode, and a minimum of 40°F during the orbital storage modes (Para 3.1.2.8.7.2)

(B) Maximum wall average area temperature shall be 90°F during the active ECS mode (Para 3.1.2.8.7.2)

(B) The external temperature requirement for the axial docking port interior walls shall be -40°F min to +200°F max (Para 3.1.2.8.7.2)

Table 2.2.3-1 (Continued)

(B) The interior wall of the axial docking port between the drogue assembly and the pressure hatch will stabilize to an average temperature between 40°F and 90°F within 8 hours after successful CSM docking (Para 3.1.2.8.7.2)

(P) The external paint shall be of a type which will aid the thermal characteristics of the passive environmental control system (Para 3.3.10.1)

CODE

(P) - Requirement applicable to the passive TCS
(A) - Requirement applicable to the active TCS
(B) - Requirement applicable to both the passive and active TCS

Table 2.2.3-1 (Concluded)

AM/MDA ICD

(P) • MDA Insulation Purge - Flow rate 5 lb/min when supplied with 150 psig gas at 70°F.

(B) • Bulk Atmosphere Temperature within the MDA of 60°F to 90°F.

(B) • Internal Mean Radiant Environment -

	Manned Orbit	Ascent & Orbit Storage
Minimum	60°F	40°F
Maximum	90°F	90°F

(A) • AM/MDA Water Loop Requirements

• Pressure Drop 6.75 psid @ 220 lb/hr

• MDA Maximum Heat Additions 1335 BTU/hr at 78°F. Influence of water supply and compartment temperature shall be as determined from "AM/MDA Environmental Data".

MDA/CSM ICD

(B) • Temperature Requirements just before docking.

	Maximum °F	Minimum °F
MDA Docking Ring	200	50
MDA Drogue	200	-100

(B) • Temperature Requirements after docking.

CODE
(P) - Requirement applicable to the passive TCS
(A) - Requirement applicable to the active TCS
(B) - Requirement applicable to both the passive and active TCS.

Table 2.2.3-2 MDA Requirements Summary, AM/MDA and MDA/CSM ICDs

MDA/CSM ICD

ITEM	Prior to Tunnel Pressurization Tmin °F	Prior to Tunnel Pressurization Tmax °F	After 8 Hours T, °F	Quasi Steady State Tmin °F	Quasi Steady State Tmax °F
MDA Docking Ring	20	200	65 ± 25	50	90
MDA Drogue	-100	200	N/A	50	90

(B) • MDA Atmosphere Supply to CM

Flow	Temperature (1)	AM Controlled Dewpoint (2)
100-200 (ACFM)	67°F to 80°F	46°F to 55°F

(1) Attainable by exercising operational constraints.

(2) During specified brief mission periods dewpoint may exceed the above limits.

CODE

(P) - Requirement applicable to the passive TCS
(A) - Requirement applicable to the active TCS
(B) - Requirement applicable to both the passive and active TCS

Table 2.2.3-2 (Concluded)

C-3

DOCUMENT	PERIOD	AVERAGE INTERNAL TEMP °F	ATMOS TEMP °F	LOCAL WALL °F	DEW POINT °F	RELATIVE HUMIDITY %	EXTERNAL TEMP °F
FILM VAULT ICD	PRELAUNCH	NR	40 to 80	40 to 80	NR	0-45	NR
	ORB. COAST	NR	40 to 80	40 to 80	NR	0-45	NR
	OPERATIONAL	NR	60 to 80	60 to 80	NR	30-80	NR
S190 ICD	PRELAUNCH	-40 to 160	-40 to 160	-40 to 160	NR	0-100	-40 to 160
	ORB. COAST	40 to 90	40 to 90	40 to 90	NR	0-45	-180 to 277
	OPERATIONAL	60 to 90	60 to 90	50 to 105	40 to 60	30-95	-180 to 277
S191 ICD	PRELAUNCH	-40 to 160	-40 to 160	-40 to 160	NR	0-100	-40 to 160
	ORB. COAST	40 to 90	40 to 90	40 to 90	NR	0-45	-180 to 277
	OPERATIONAL	60 to 90	60 to 90	50 to 105	40 to 60	30-95	-180 to 277
S192 ICD	PRELAUNCH	40 to 120	40 to 120	40 to 120	NR	0-65	-40 to 160
	ORB. COAST	40 to 90	40 to 90	40 to 90	NR	0-65	-180 to 277
	OPERATIONAL	60 to 90	50 to 105	50 to 105	40 to 60	30-95	-180 to 277
M512 ICD	PRELAUNCH	-40 to 160	-40 to 160	-40 to 160	NR	0-100	NR
	ORB. COAST	40 to 90	40 to 90	40 to 90	NR	0-45	NR
	OPERATIONAL	60 to 90	60 to 90	50 to 105	40 to 60	30-95	NR
S009 ICD	PRELAUNCH	-40 to 160	-40 to 160	-40 to 160	NR	0-100	NR
	ORB. COAST	40 to 90	40 to 90	40 to 90	NR	0-45	NR
	OPERATIONAL	60 to 90	60 to 90	50 to 105	40 to 60	30-95	NR
RNEM ICD	PRELAUNCH	-40 to 160	-40 to 160	-40 to 160	NR	0-100	NR
	ORB COAST	40 to 90	40 to 90	40 to 90	NR	0-45	NR
	OPERATIONAL	60 to 90	60 to 90	50 to 105	40 to 60	30-95	NR
ESE ICD	PRELAUNCH	-40 to 160	-40 to 160	-40 to 160	NR	0-100	NR
	ORB. COAST	40 to 90	40 to 90	40 to 90	NR	0-45	NR
	OPERATIONAL	60 to 90	60 to 90	50 to 105	40 to 60	30-95	NR
L-BAND ICD	PRELAUNCH	NR	NR	NR	NR	NR	20 to 100
	ORB. COAST	NR	NR	NR	NR	NR	-180 to 277
	OPERATIONAL	NR	NR	NR	NR	NR	-180 to 20
PROTON SPECT ICD	PRELAUNCH	NR	NR	NR	NR	NR	NR
	ORB. COAST	NR	NR	NR	NR	NR	-180 to 277
	OPERATIONAL	NR	NR	NR	NR	NR	

(1) AM CONTROLLED PARAMETER

Table 2.2.3-3 MDA Requirement Summary - Experiments

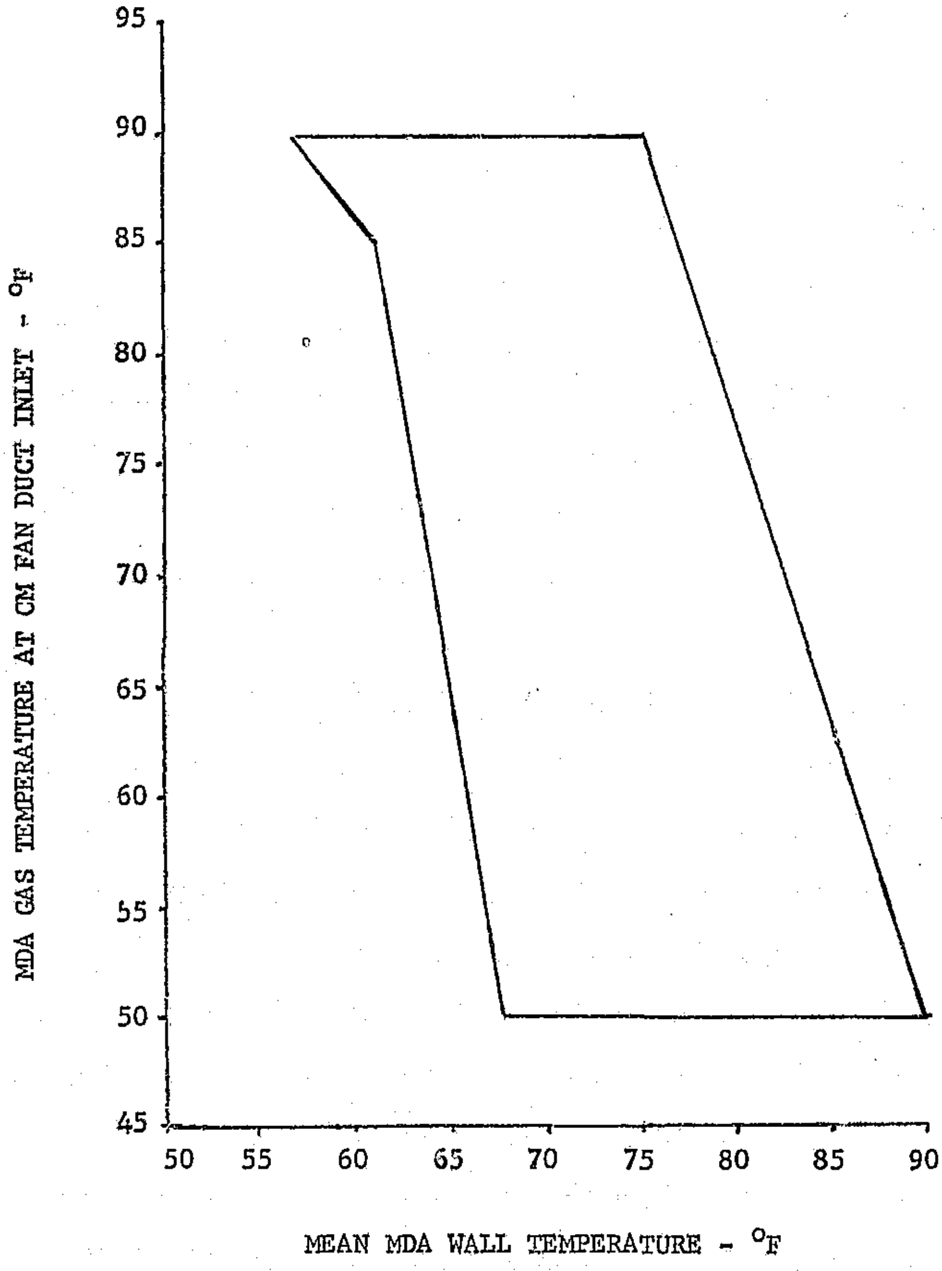


Figure 2.2.3-1 MDA Comfort Box

A. Systems Studies - Passive TCS

1. Error and Sensitivity Analysis
2. Wall Penetration Heat Leak Analysis
3. MDA Installed Equipment - Passive Thermal Features
4. MDA Heat Balance and Temperature Distribution
5. Development Test Data Correlation Analysis

B. Insulation Blanket

1. Design Support Analysis
2. Performance Evaluation
3. Manufacturing Analysis
4. Ascent Venting Study

C. Fiberglass Standoffs

1. Conductivity Assessment
2. Heat Leak Analysis

D. Low Emissivity Tapes

1. Fiberglass Standoff Coatings
2. L-band Antenna Truss Work
3. S-191, 192 Closure Angles

E. Surface Coatings

1. Parametric Studies
2. Docking Port Component Studies
3. Striping Effects Analysis

F. Insulation Purge System

Table 2.2.3-4 Passive MDA TCS Analyses

analysis early in the program to predict the effects of possible variations in boundary parameters such as surface emissive properties, solar constant, earth albedo, earth IR and MDA/STS radiator temperature. This preliminary analysis was followed up in the second half of 1970, with an uncertainty analysis which had the purpose of evaluating and updating the impact of the above mentioned parameters with the addition of configuration variables which became apparent as the detailed design evolved. The result of this analysis work was finally incorporated into later studies which evaluated MDA module heat leak, temperature distribution, heat-up and cool-down rates.

(b) Wall Penetration Heak Leak Analysis - The purpose of this analysis was to evaluate miscellaneous heat leaks through the MDA wall due to electrical and mechanical penetrations of the insulation blankets. Approximately 17 heat leak sources were identified and analyzed. The most significant of these heat leak sources included fiberglass rings and rails, insulation blanket, S191/S192 experiments, radial docking port, ATM feed thru cables, electrical penetration plate and the L-band truss. Individual detailed computer models were built for many of these heat leak sources.

(c) MDA Installed Equipment - Passive Thermal Features - These analyses were carried out to predict the effect of the MDA imposed environments on MDA equipment surface temperatures. The prime objective was to select passive features that would assist in keeping equipment surface temperatures low. This was desirable in order to prevent temperatures from exceeding ICD limits and from exceeding crew touch limits. Performance of the analyses involved construction of computer models including equipment details and selected MDA boundary conditions. Emphasis was placed on passive features such as equipment surface properties to increase radiation heat transfer, and mounting details to increase the conductance heat path through the particular piece of equipment. The EREP Support Equipment, M512 experiment, Back Up I/LCA, and Video Tape Recorder are typical of equipment receiving this detailed analysis. As final designs evolved, computer models were updated to reflect updated heat generation profiles and analyses were updated.

(d) MDA Heat Balance and Temperature Distribution Studies - These studies were carried out to determine the characteristics of the MDA Passive Thermal Control System in maintaining acceptable temperature levels, both internal and external. Subsequent analysis created the thermal network model for the internal MDA establishing a basis for the internal heat balance. The output of this effort was used to select external coatings, establish interface requirements with CSM and STS and also provide information on to what extent the basic Passive TCS may need to be supplemented with Active means such as wall heaters and atmospheric systems. This information was also used as input into the AM/MDA environmental control data book.

(e) Correlation Analysis of Development Test Data - The great majority of Passive TCS testing was accomplished on the MDA Thermal Component Test conducted at MSFC starting in September 1968 with a final series of tests completed in August 1970. This testing was supported by analysis to define the facility requirements, test conditions, and to provide thermal math models for test data correlations. These models were used initially to determine overall MDA wall performance in both steady state and a temperature decay mode. New, more detailed, models were developed to analyze individual heat paths to assign the contribution of the insulation blankets, the fiberglass standoffs and insulation gaps. A new set of test runs and test correlation analysis were made necessary when it was found, upon test article disassembly inspection, that the original fasteners had failed, significantly changing the heat paths in the structure. The final series of test runs in August 1970 used a test article which included the docking port and certain fabrication variations discovered in the disassembly inspection. The analytical models were revised to reflect these features.

(2) Insulation Blanket

(a) Design Support Analyses - These analyses were aimed at establishing the design of the insulation blanket. Included were heat flow calculations aimed at establishing design features such as the number of layers of aluminized mylar, emissivity of outer layer, effect of nylon swiftachments, emissivity requirements for fiberglass blanket border, effect of mounting blankets off of the meteoroid shield in certain MDA areas, etc. These studies were done prior to the final blanket design to evaluate potential design features and were terminated when the design was finalized. Most of these special evaluations involved separate computer studies of each item being investigated.

(b) Performance Evaluation of Installed Flight Blanket - The purpose of this task was to arrive at an accurate estimate of the heat flow expected to occur through the blanket during flight. Computer case studies were conducted to predict effects of lateral conduction through the blankets parallel to the aluminized mylar layers caused by butt joint thermal shorting at tab areas, and effects of blanket mounting on the vehicle. Test results from the thermal development test were compared with results of these studies in order to arrive at predicted blanket performance for the MDA flight vehicle.

(c) Manufacturing Analysis, Insulation Blanket - Numerous calculations were made to establish effects of special problems associated with installing the blankets of the MDA pressure shell. These analyses resulted in recommending fixes to local problems as they occurred during the manufacturing phase.

(d) Ascent Venting Study, Insulation Blanket - Available test information from other programs were reviewed and analytical calculations were performed to assure that the insulation blanket would vent properly during ascent.

(3) Fiberglass Standoffs

(a) Fiberglass structural standoffs were analyzed for the purpose of determining material thermal conductivity and also conductance of the attach points. A detailed math model was constructed of a 12 inch section o. fiberglass laminate with heat flow values calculated using temperature difference and heat inputs from tests.

(b) Additional analysis was carried out on fiberglass rings and rails to assess heat losses and provide means for retarding same (See Paragraph (1) (b) Wall Penetration Heat Leak Analysis).

(4) Low Emissivity Tapes - Analysis was carried out to identify areas of potential overboard heat leak and to assess the possible benefit of application of low emissivity tapes. It was revealed that an aluminum coated mylar tape ($\epsilon = 0.1$) applied to selected surfaces to reduce radiative heat paths could significantly reduce heat leak. Detailed analysis was performed on the fiberglass standoffs, L-Band antenna truss, and S191 and S192 closure angles to determine the most advantageous use of tape.

(5) Surface Coatings Analyses - Surface coatings were the subject of three basic analysis efforts. The first, and most extensive, was undertaken as part of thermal parametric studies with the purpose of selecting an optimum coating for use on external meteoroid shield surfaces under various operating modes. This study evaluated maximum and minimum heating rates, external and internal temperatures at various orientations and beta angles with α/ϵ as the independent variable. Computer runs were made for both manned and storage modes and a selection of black paint with $\alpha = .95$ and $\epsilon = .86$ was made. A second study was made which evaluated the effect of docking port component surface properties upon heat loss and component temperature levels. The heat loss was found to be a weak function of internal emissivity and temperatures did not exceed allowable levels. The third study was in the nature of an update of earlier studies to assess the effects of a white stripe painted about the circumference of the MDA cone.

(6) Insulation Purge System Analyses - Analysis was carried out on the insulation purge system in several areas; preliminary studies conducted at MSFC established the

initial requirement early in 1969. Purge system studies to establish system pressures, line and orifice sizes and flows were completed in the first half of 1970, and were later revised to include provisions for S190 window purge. Subsequent analyses were carried out to determine the effects of purge gas on MDA temperatures for various operational and ambient conditions on the launch pad.

B. Functional Description - The Passive Thermal Control system controlled the overboard heat loss from the MDA interior to a value that allowed the Active TCS to control internal temperature.

The MDA Passive TCS consisted of the following principal parts and features: insulation blanket assemblies, use of fiberglass as structural standoffs and spacers, use of aluminized tape and thermal control paints and coatings. While not used in flight, the insulation purge system was generally discussed in conjunction with the Passive TCS. A schematic of the Passive Thermal Control System is shown in Figure 2.2.3-2.

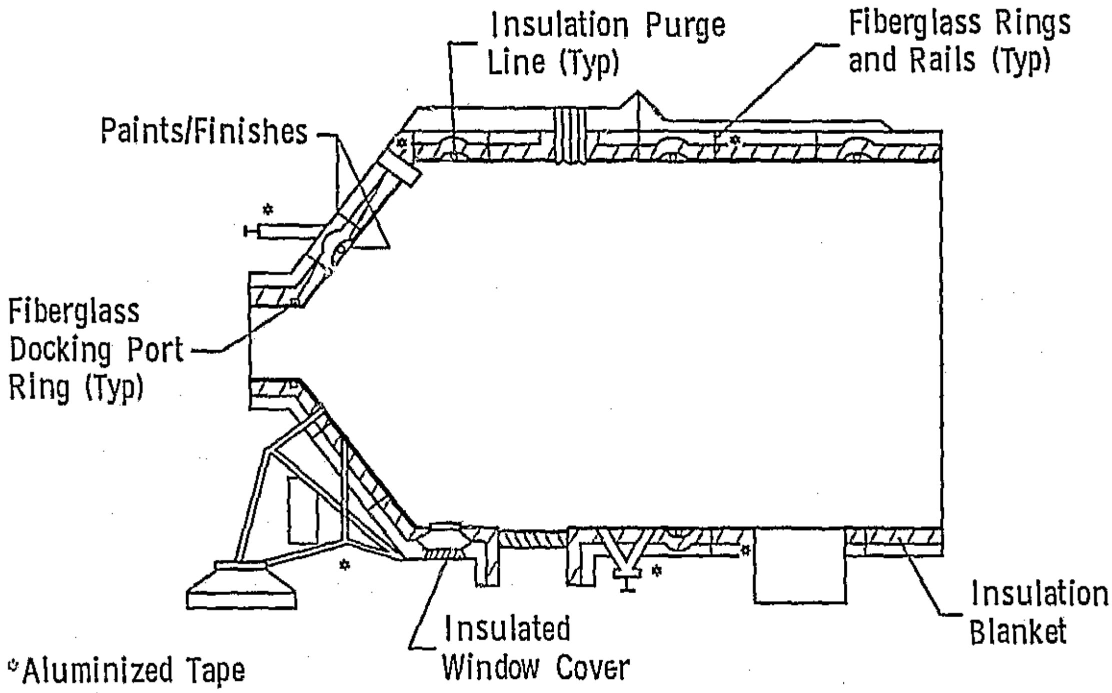


Figure 2.2.3-2 Passive Thermal Control System Schematic

(1) Insulation Blanket - The insulation blanket consisted of 91 layers of perforated double aluminized mylar separated by dacron netting. The blankets were held in position on the MDA exterior by using lacing and "boot hooks". The multi-layers were held together by the use of nylon swiftachments. The insulation blanket was placed between the MDA pressure shell and the radiator/meteoroid shield. The design of the insulation blanket allowed the multi-layer aluminized mylar to act as radiation shields. This retarded the flow of heat from the MDA.

A typical insulation blanket installation is shown in Figure 2.2.3-3. Further discussion on the insulation blanket is included in this report under the structures subsystem, Paragraph 2.2.1.

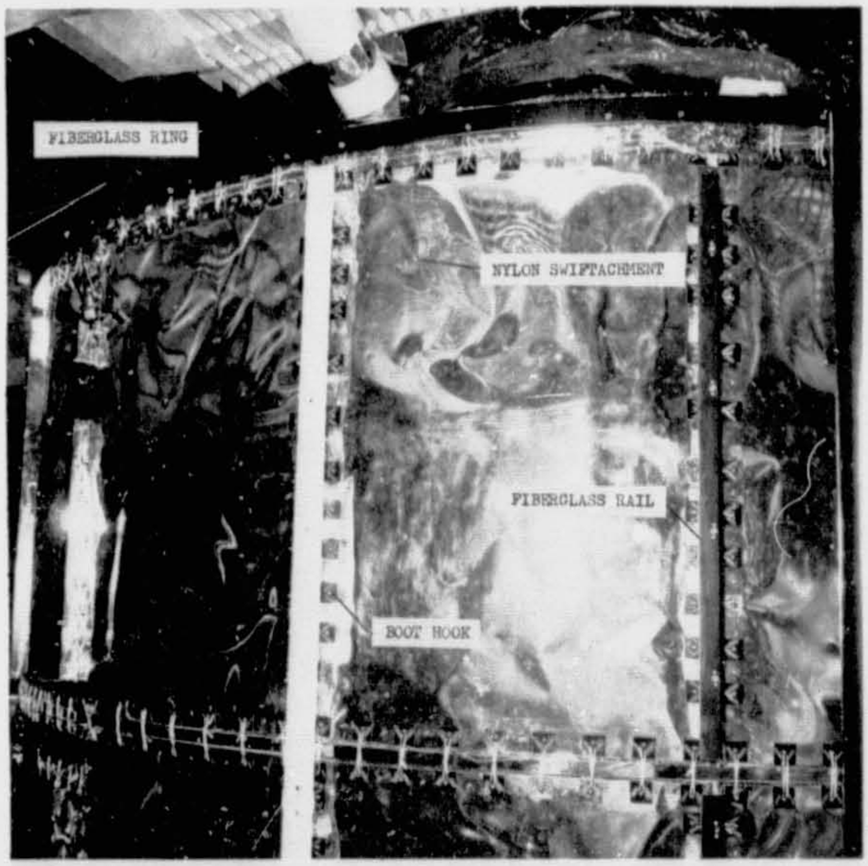


Figure 2.2.3-3 Insulation Blanket with Fiberglass Rings and Rails

(2) Fiberglass Standoffs - The use of fiberglass as structural standoffs and spacers retarded heat transfer from the MDA interior overboard due to the low thermal conductivity of the fiberglass. These standoffs took the form of circumferential rings and longitudinal rails to thermally isolate the MDA pressure wall from the external meteoroid shield. Fiberglass standoffs are shown in Figure 2.2.3-3.

(3) Low Emissivity Tapes/Paints & Coatings - The use of low emissivity aluminized tape and paints and coatings having special thermal properties also retarded heat transfer overboard. Low emissivity tapes were used principally on the L-band truss and the fiberglass standoffs to reduce heat leak in potentially high loss areas. Tape was also used in several other local areas such as the S192 and S191 penetrations. Use of tape is illustrated in Figure 2.2.3-4. Use of thermal paints is illustrated in Figure 2.2.3-5.

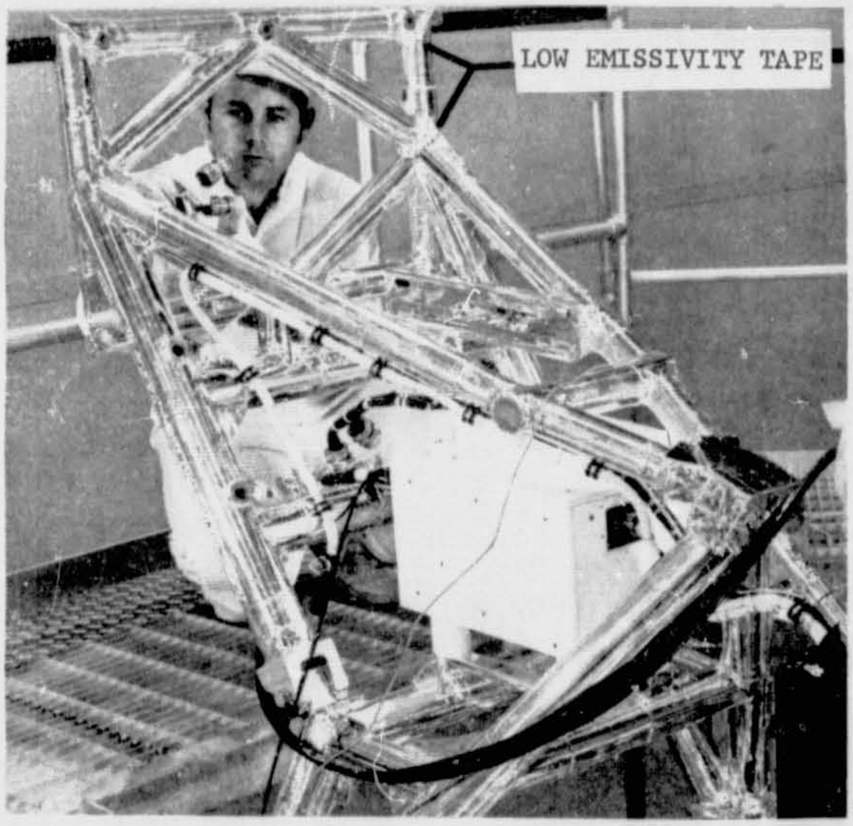


Figure 2.2.3-4 Low Emissivity Tape on L-band Truss

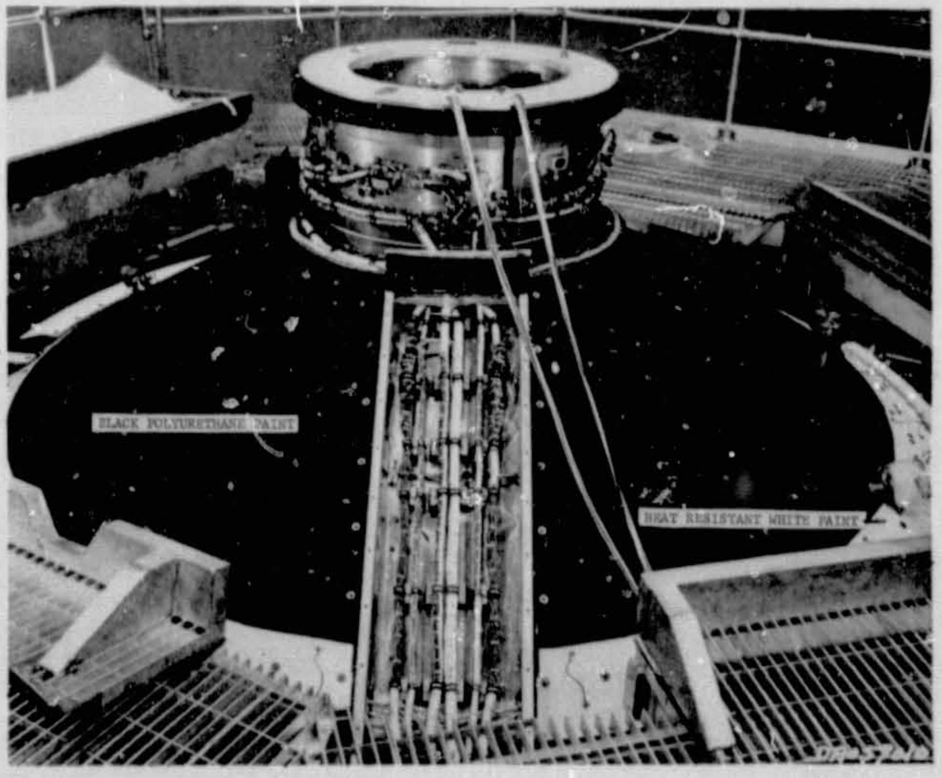


Figure 2.2.3-5 Thermal Paints on MDA Cone

(4) Insulation Purge System - The insulation purge system was used only prior to flight. The system provided dry GN_2 distribution for conditioning the insulation blanket and S190 window at various times during MDA ground operations, storage, and transportation.

The exterior of the MDA pressure shell was encircled with a network of perforated tubing. This tubing network, located beneath MDA insulation blankets, was the gas distribution system. It was used for purging the MDA insulation blankets and the exterior surface of the S190 window with dry gaseous nitrogen prior to launch and at other times when the MDA was not in a conditioned environment.

A photograph showing a section of the system is shown in Figure 2.2.3-6. After launch, the insulation purge system served no purpose.

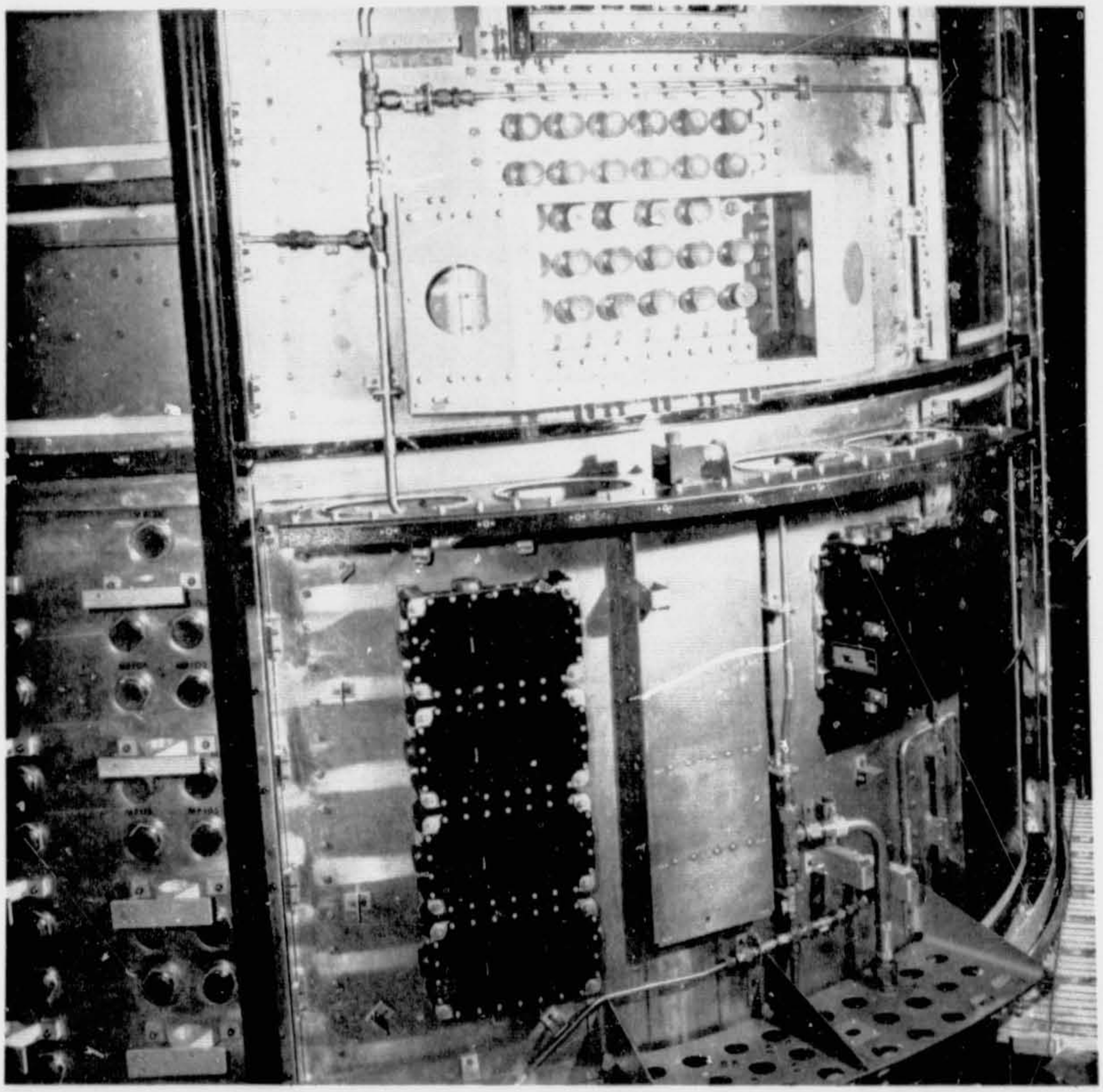


Figure 2.2.3-6 Insulation Purge System, Typical Installation

C. Test - The Passive Thermal Control System including insulation blankets, fiberglass stand-offs and external thermal coatings was evaluated thermally as part of an MSFC-ASTN MDA Thermal Component Wall Test Program. The test article incorporated two 88° arc MDA barrel sections, seven feet long, forming an elliptical cylinder. The test article wall sections consisted of the aluminum pressure wall with insulation blanket, fiberglass structural standoffs and meteoroid shield installed. The test article also had the capability of having two flight-simulated radial docking ports installed so that wall/port thermal effects could be tested. Significant tests were conducted during November and December 1969 in a vacuum chamber at MSFC. The purpose of this testing was to determine the overall thermal performance of the MDA simulated wall structure as a Passive Thermal Control system under specified test conditions. The inner wall was maintained at a constant temperature through regulation of an internal radiant heater. The test article was allowed to come to steady state conditions and temperature measurements were recorded on the pressure wall, the insulation surface and the meteoroid shield. The heater input was recorded and heat distribution through the walls analyzed.

Thermal conductivity value of the insulation blanket was derived and recommended for use in the MDA flight thermal model to predict the insulation's part on the overall thermal performance of the MDA.

The thermal conductivity was determined to be

$K = 0.000357 + .0000114T$ where K = BTU/hr-Ft-°F and T = temperature in °F.

The analytical techniques used for the MDA in simulating the various heat transfer paths (fiberglass rails, insulation blanket, lateral shorting via structural tees) were found adequate for predicting the distribution of heat transfer of the wall structure and port structure.

The test results thus provided useful data to predict thermal performance of proposed wall features and verified analytical techniques to be used in computer models of the MDA.

(1) Insulation Blanket Tests

(a) Development Tests

- Super-Insulation Blanket Pressure Drop Test - Flow rates of GN_2 proportional to values specified in the CEI (5 lb/min +2, -1) were run through a 6 inch diameter simulated MDA insulation blanket sample in order to determine the pressure drop across the blanket sample. Test results indicated a pressure drop of 0.004 psi for a flow corresponding to 5 lb/min. The test was completed 16 February 1970.

- Flammability Test - The objective of the flammability testing was to determine the conditions under which the insulation was flammable and how much damage was incurred. A total of five tests were conducted. Three of these tests used a standard bunsen burner applying the flame for 12 seconds with differences in orientation (vertical vs horizontal) to the flame and mounting provision (blanket unmounted vs blanket mounted on 1/4" plate). Departures from the above procedures were in the type of ignition used, in one case, a paraffin candle, and a match in the other. Results were evaluated on the basis of time to ignition, self extinguishing time, burning rate and depth of burning. Results indicated damage was greater where both sides of the blanket were exposed (unmounted), flame was self-extinguishing when propagating downward and when the blanket was in a horizontal position with one side exposed with the metal plate under it. Packaging of the MDA insulation blanket reduces flammability by minimizing convection currents, reducing air supply for combustion and creation of a heat sink by the aluminum pressure wall.

(b) Qualification Test - No qualification tests were performed on the insulation blanket as such.

(c) Acceptance Test - The assembled insulation blankets were subjected to an acceptance test before they were installed on the MDA. Emissometer readings showed that the outboard sheet (5 mil aluminized mylar) had an average emissivity of not more than 0.07. This data was compared with design values to assure adequacy of actual insulation hardware installed in the flight article.

(2) Fiberglass Standoff Tests

(a) Development Tests - Fiberglass Rings and Rails -

A series of tests to determine the thermal conductivity of a phenolic bonded fiberglass, CTL-91LD, were conducted at MMC between June 18 and July 6, 1970. Test samples were fabricated from 10 layers of fiberglass material, bonded with CTL-91LD phenolic resin. The fiberglass cloth was oriented so that the heat flow in the test specimens would be parallel to the fibers, as it is in the fabricated members that are installed in the MDA. Typical members are the MDA meteoroid shield support rails and rings. The thermal conductivity was determined to be $K = 0.315 + 0.0068T$ where K is thermal conductivity in BTU/hr-ft-°F and T is average temperature in °F ($T = -150°F$ to $0°F$).

(b) Qual Test - N/A

(c) Acceptance Test - N/A

(3) Low Emissivity Tape

(a) Development Test - Aluminized tape J462 was designated to be applied at various MDA regions where the passive thermal control property of low emissivity was required. Specimens of J462 aluminized tape were emissivity-measured as received, after fingerprinting, and after fingerprinting and cleaning. Methyl-ethyl ketone was used as the cleaning solvent. Several T2024-T3 aluminum alloy test specimens were coated in accordance with a standard MMC immersion process for corrosion protection and one specimen was irridited (brush-on process). The specimens processed by immersion for emissivity evaluation were much darker than usual and the results were considered representative of a "worse case" condition. The meteoroid shields were fabricated from T2024-T3 aluminum sheets. Following were the emissivity test results on the specimens measured on the Lion Model 25A emissometer:

Specimen	Emissivity
• J462 aluminized tape (handled with gloves)	0.03
• J462 aluminized tape fingerprinted	0.04
• J462 aluminized tape fingerprinted and wiped with clean cloth	0.035*
• J462 aluminized tape, fingerprinted and wiped with solvent and cloth	0.045*
• T2024-T3, regular irridite, 3 min immersion	0.14
• T2024-T3, brush-on irridite	.06

* Third place figures were obtained by interpolating between successive meter readings

(b) Qualification Tests (N/A)

(c) Acceptance Tests (N/A)

(4) Exterior Coatings

(a) Development Tests - Two exterior coating materials were chosen for application to the exterior of the MDA for thermal control purposes. 3M Nextel black velvet (401-C10) coating as measured in MMC's Materials Engineering Laboratory, using the Lion emissometer and reflectometer, had a normal emittance of 0.96 and an absorptance (solar) of 0.98. This coating is used on exterior surfaces of the MDA that are within line-of-sight to the S190 window.

The black coating applied on the meteoroid shield is Laminar X500 flat black polyurethane. Measured values were 0.92 for normal emittance and 0.95 for solar absorptance.

(b) Qualification Tests (N/A)

(c) Acceptance Tests (N/A)

D. Mission Results - An indepth discussion and presentation of mission results is contained in Volumes I, II, and III of the "MDA Module Report" for SL 1/2, SL3 and SL4, respectively (ED-2002-1702). Included are detailed plots of all MDA data and selected AM data for the entire mission period. However, a summary of mission results follows:

(1) Requirements vs Actual Results - Because of the close interaction between the Passive and Active TCS, this summary of mission results includes reference to both systems.

At various times during the SL 1/2, SL3 and SL4 missions, the MDA was operated differently than planned prior to the mission. Off-nominal operation included taking on a pitch attitude with increased solar exposure of the MDA, operation in a "Heater Management Mode" to conserve electrical power, and extended operation in the ZLV attitude to accommodate lengthy EREP passes. During these "off-nominal" periods, some of the MDA requirements were exceeded. The unplanned pitch attitude and extended ZLV attitudes resulted in external meteoroid shield temperatures exceeding upper limits. Operation of the wall heaters intermittently, in a heater management mode, resulted in the MDA exceeding low side limits during SL 1/2 and being lower than nominal for SL3 and SL4. Lower temperatures resulted in relative humidities that exceeded high side limits and operation outside of the comfort box on the low side. While the MDA periodically exceeded some limits throughout the mission, no detrimental effects on either the MDA, MDA equipment experiments, or the crew were noted because of it.

When the MDA was operated as planned, all parameters returned to normal limits with one minor exception. During temperature decay for the post SL 1/2 orbital storage period, the local temperature near the S190 window and S191 experiment attained 38 degrees fahrenheit. (Minimum limit is $40^{o}F$). No detrimental effects were noted, and the temperature returned to $41^{o}F$ after the heating system reached quasi-steady state conditions.

(2) On-orbit Passive TCS Performance - The MDA insulation blanket, fiberglass structural supports, low emissivity tape, paint pattern and details of construction, all contributed toward insulating the vehicle internal structure from the external environment. Assessment as to the individual insulative effect of all these items for the on-orbit period was not possible. However, the overall effect of these items has been calculated.

The MDA overboard heat loss thru the vehicle structure was calculated at 1401 Btu/hr when the MDA interior was at an average temperature of 59.6°F. A preflight estimate for the same internal temperature was predicted at 1285 Btu/hr. This was a maximum estimate and made under the assumptions of maximum wall conductance, coldest estimated orbital heating, and minimum radiator heat load. Thus the actual MDA heat loss was approximately 9 percent greater than the maximum predicted loss. The effects of this on vehicle operation were slight. Warmup from orbital storage temperature was slightly slower than anticipated in preflight estimates, and slightly more heater operation was required to keep the MDA at desired temperatures. The overall heat loss was well within the control capability of the MDA wall heating system.

One area of concern prior to flight was the overboard heat loss of penetration heat leaks. The S191 and S192 experiments fall into this category. Maximum heat leak for each of these experiments was to be 40 Btu/hr. Preflight testing indicated that S191 would lose about 85 Btu/hr. Preflight analysis, when matched with flight temperature measurements, indicated that S192 losses were about 100 Btu/hr on orbit. While S191 and S192 heat losses exceeded mission preflight allotments, there appeared to be no detrimental effects. Local wall temperatures near S192 and S191 simply were a few degrees cooler than expected.

(3) Insulation Purge System - The insulation purge system was turned on approximately 15 hours prior to launch and functioned satisfactorily until lift-off, when the purge was terminated.

E. Conclusions/Recommendations -

(1) Performance of Passive TCS - In conclusion, mission results have indicated that the MDA passive system adequately functioned in spite of off-design demands on the system. Overall vehicle insulating features were adequate to allow the active system to control the vehicle internal temperatures when normal electrical power was available.

(2) Instrumentation - Thermocouple placement on the MDA allowed for thorough monitoring of the MDA thermal performance. However, two recommendations are made concerning the instrumentation:

The S190 window was closely monitored during the mission due to the possibility of moisture condensation on its internal surface. Many analyses were performed to extrapolate measurement values from nearby instrumentation in order to predict window temperatures. A temperature transducer, located on the internal surface of the window, would have eliminated much analysis and given accurate real time information. It is therefore recommended that future spacecraft windows, that are sensitive to temperature, be equipped with temperature transducers wherever possible.

The axial docking port had two separate temperature transducers to monitor temperature. Shortly after launch, when the cluster was put in the pitch-up attitude, the temperature transducers in the axial tunnel pegged out on the high side at 113°F. Analyses had to be performed to estimate the true maximum temperature. It is, therefore, recommended that wherever there is redundant or dual instrumentation on future spacecraft, consideration be given toward making the calibration ranges different in order to allow for contingencies.

(3) Analysis vs Test - The MDA thermal effort involved many analyses because of the desire to reduce expensive testing, In some cases, testing would have been less expensive, and would have provided more assurance of a successful product. One case involved an extensive analysis performed to predict the ascent venting characteristics of the multilayer insulation blanket. This type of engineering problem does not lend itself well to an analysis. A test could have been set up and conducted for a fraction of the cost to do the analysis.

It is recommended that future programs give careful consideration toward running brief tests as a potential cost savings to certain analysis tasks.

F. Passive Thermal Control History - The MDA TCS design, conceived in 1968 preliminary design studies, incorporated a purely passive system which relied on a combination of wall insulation, radiative selective external coatings and internal atmospheric gas convection to maintain desired temperature levels. This system incorporated an inner pressure wall covered by a 27 layer high performance insulation blanket which in turn was covered by an aluminum meteoroid shield, thermally coated and supported by fiberglass structural standoffs. A design objective was to limit overboard heat leak to approximately 250 BTU/Hr. Subsequent design studies supported by tests revealed that a degree of active temperature control in the form of wall heaters would be required to maintain a minimum temperature level during orbital storage periods. Further wall insulation studies during 1968 and 1969 revealed that MDA heat leak was in the order four times that originally estimated due to heat shorts in insulation blanket penetrations and fiberglass standoffs. The following discussion summarizes the principal design decisions and events in the development of principal components of the MDA passive TCS.

(1) Insulation Blanket - The original 27 layer aluminized mylar with foam spacers, while judged an adequate insulation thermally, was replaced with a 91 layer aluminized mylar blanket with nylon spacers. This change was initiated by MSFC in August 1969 in order to minimize a potential contamination problem with foam spacers. The 91 layer configuration was selected to maintain a consistent MDA wall structural configuration even though it provides a wide margin with respect to insulative qualities. The nylon net spacers were subsequently replaced with dacron June 1970, due to nylon's undesirable outgassing characteristics and dacron's superior insulative properties. Concurrent studies supported by testing on the MDA Component Test Article indicated that approximately 65% of wall heat losses could be attributed to heat shorts through insulation joints. The potential problem of heat shorts through gaps at structural joints was met by close inspection of flight and backup articles during blanket installation with all questionable joints reworked prior to final inspection.

(2) Fiberglass Structural Standoffs - The fiberglass standoffs were assessed early in the program to be a potential source of overboard heat loss. The principal issue in the use of fiberglass standoffs was the thermal conductivity of the structural rings and rails. Tests run at MMC in 1969 revealed that actual thermal conductivity exceeded

original estimates by a factor of three, resulting in an increase in heat leak assessments. Inspection of the MDA component test article (See Para. C-1) after tests revealed shear failure of aluminum rivets due to high temperature extremes with the result that aluminum rivets were replaced by steel hi-lok fasteners. Analysis of standoff rings in November 1970 resulted in configuration modifications which reduced heat losses through the rings by 50%. The application of low emissivity tapes to fiberglass standoffs to further reduce heat shorts is discussed in Para. (3).

(3) Low Emissivity Tapes - Analysis of MDA heat losses through fiberglass structural standoffs, S191 and S192 closure angles and the L-band truss carried out during 1970 and 1971 revealed that significant improvement in heat loss could be obtained by judicious application of low emissivity tape. The application to fiberglass rings and rails was made to impede radiant heat exchange between the MDA pressure wall, fiberglass standoffs, and meteoroid shield/radiator surfaces. The L-band antenna truss heat loss was reduced by 50% by winding all truss members with tape.

(4) External Coatings - Parametric studies were carried out during 1968 in order to form a basis for selection of an exterior coating for the MDA meteoroid shield. These studies resulted in the selection of a black paint with properties of solar absorptivity to IR emissivity ratio (α / ϵ) of .95/.86. The selection was made on the basis of minimizing heat loss, limiting external temperatures (-180° to $+277^{\circ}F$) and the stability of property values under long term space environments. This selection was carried forward to the flight article with the exception of a circular white stripe added to the cone area in late 1970 to provide better visibility for docking. The overall effect of this stripe was judged minimal to the MDA heat balance.

(5) Insulation Purge System - A dry nitrogen purge requirement was established in early 1968 in order to assure that the MDA external insulation was free of moisture prior to launch. A preliminary study was made at MSFC which defined the system performance requirements. Final performance requirements were established and a design definition made.

2.2.3.2 Active System

A. Design Requirements and Analyses - Design Requirements for the active system are indicated in Tables 2.2.3-1, 2.2.3-2, and 2.2.3-3. As indicated before, an "A" or "B" indicated for each requirement designates whether the requirement is applicable to the Active TCS or both the Active and Passive TCS.

Table 2.2.3-5 lists the categories of analysis and studies performed for the active TCS. These are discussed in further detail in the following paragraphs:

(1) MDA Vehicle Computer Models - The MDA computer models consisted of three separate model systems; 1) an MDA heat flux model to obtain external environmental heating, (2) an MDA external thermal model to compute external temperatures, and 3) an MDA internal thermal model to compute internal temperatures.

The case studies with the MDA math model systems were used for numerous purposes in evaluation of active system performance. Included were the following:

(a) Effect of Equipment on the Active System - Included was the effect of M512, EREP, BILCA and other internal heat generators on the Active TCS. The Active TCS was investigated for ability to handle the imposed heat loads.

(b) Effect of heat generating equipment on nearby equipment. (Such as effect of M512 on the ATM film vaults).

(c) Thermal performance and internal MDA temperatures due to operation of the Active TCS and MDA internal equipment. This included orbital storage cool-down and warmup transients as well as manned mission period operation.

(2) MDA Wall Heating System

(a) Preliminary Studies - A trade study considering four thermostat systems was performed to establish the thermostat configuration to be used for the operation of the MDA wall heaters.

(1) MDA Vehicle Computer Models

(a) Effect of Equipment on Active System
(b) Effect of Heat Generating Equipment on Other Equipment
(c) Thermal Performance and Internal MDA Temperatures

(2) MDA Wall Heating System, Analysis & Studies

(a) Preliminary Studies
(b) Design Studies
(c) Final Design Studies to Establish Performance
(d) Failure Analysis
(e) Test Support Studies

(3) MDA Docking Port Internal Heating System Analysis & Studies

(4) MDA Axial Docking Tunnel Heating System Analysis and Studies

(a) Docking Port Temperature Prior to Adding Heaters
(b) Design Studies
(c) Final Design Analysis to Establish Performance
(d) Failure Analysis

(5) S190 Window Heating System

(a) Conceptual Studies
(b) Design Analysis
(c) Performance Evaluation
(d) Test Support Analysis
(e) Failure Analysis

Table 2.2.3-5 Active MDA TCS Analyses

(b) Design Studies - Calculations were made to evaluate the wall heater mounting location and establish the design features for their installation, for most efficient heat transfer into the wall. Analysis was also performed to establish the thermostat location. These analysis gave consideration to thermal conductive filler application between the mounting interfaces. These studies involved computer calculations for each item being studied.

(c) Final Design Studies to Establish Performance - These studies were made to establish the MDA interior temperature deltas, heat leaks and heater performance regarding warm-up times for selected cases. Computer models for this included an overall MDA Interior Model (supported by external models) and wall section models. Calculations were made to predict the maximum number of Thermostat cycles during operating periods to insure operation within specified limits.

(d) Failure Analyses - In support of manufacturing operations, a study was performed to determine effect of revision to thermostat specification regarding set points. Relaxing the criteria permitted reducing the rejection of units at acceptance test.

Thermal analysis of the wall heater wiring, in conjunction with stress analysis and an evaluation of test data, were employed in lieu of a qualitative life cycle test to eliminate concern of a thermal fatigue failure mode.

(e) Test Support Studies - System verification test data was analyzed to verify proper installation of the wall heaters and proper operation of the wall heater control. Previous data from computer math models was employed for comparison.

(3) MDA Docking Port Internal Heating System - The MDA Internal Thermal Model included representation of the Radial and Axial Docking port ring heaters. Studies using this model have included performance of these heaters.

(4) MDA Axial Docking Tunnel Heating System

(a) Preliminary Studies - These analyses were performed to establish docking port temperatures prior to and after docking. It was determined that heaters would be required to warm up the surfaces. Computer case studies were utilized.

(b) Design Studies - Analyses involving a range of heater sizes were performed to select the heater capacity to provide reasonable warm-up after docking. Computer math models of 'undocked' and docked CSM/MDA configurations were utilized to predict temperatures.

(c) Final Design Analyses to Establish Performance - Further analyses was performed after selection of heater size to determine cycle rates in conjunction with thermostat settings in order to insure the control relay would operate within its specified limits. Thermostat set point evaluation and thermostat cycle rate analysis were performed to determine proper operation of the thermostat.

(d) Failure Analysis - A thermal analysis was conducted in order to predict maximum temperatures in the docking port area in the event of runaway tunnel heater conditions.

(5) S190 Window Heating System - Several types of thermal analysis were required to design, analyze, and test the S190 window heating system. The analyses fall into the following general categories:

- Conceptual Studies
- Design Analysis
- Performance Evaluation
- Test Support Analysis
- Failure Analysis

(a) Conceptual Studies - The objective of these studies was to establish an optimum thermal control design that would satisfy all window requirements. Trade studies investigated nineteen thermal control designs involving both passive and active controls. The following thermal control techniques were considered in some combination with one, two, and three pane window configurations:

- fans with atmosphere heaters
- glass surface conductive heaters
- glass surface electrical conductive film heaters
- radiant heaters
- fans with no atmosphere heaters
- no active heating provisions

Most of these designs required thermal math models and computer analysis to calculate thermal performance.

(b) Design Analysis - The design analysis objective was to calculate window pane temperatures and temperature gradients as affected by the heater control system design. The window pane temperatures and gradients were calculated for the external radiant heater design and the Electrical Conductive Film (ECF) heater design. Selection of the ECF heater design resulted in analyzing the ambient reference sensor for optimum locations and temperature bias. The control system was analyzed for its affect upon MDA wall and atmosphere temperatures. Maximum control box temperatures and maximum wire temperatures were calculated to assess impact on touch temperature limits. All the preceding analysis required detailed thermal math model development and computer analysis.

(c) Performance Evaluation - The window thermal performance was predicted so that various EREP passes could be evaluated for optical performance. The baseline EREP passes were analyzed for the worst case pass. For this pass window pane temperature maps and temperature gradients were generated. The temperature maps were input to optical group for window optical performance evaluation. Extended duration EREP passes, night EREP passes and terminator EREP passes were evaluated. Baseline passes were evaluated with the window heater controller turned off. All of these performance evaluations required computer runs using detailed thermal math models.

(d) Test Support Analysis - Two test set ups were analyzed, full scale external radiant heaters and electrical conductive film (ECF) heater development test. The external radiant heater test analysis was used to predict the test article thermal performance during the simulated flight environment test.

The ECF test article analysis was used to evaluate the window test thermal performance and compare it with the predicted flight thermal performance. All analyses required thermal math models and computer studies.

(e) Failure Analysis - Computer math models of the window were used to predict area temperatures and window glass temperature gradients in the event of window frame heater and/or window glass heater failure for various operating conditions.

B. Functional Description - Primary items in the MDA active system included electrical and ECS hardware. Electrical hardware consisted of heating systems for the MDA wall, internal docking port areas, and the axial docking port tunnel.

During periods of low internal heat generation, the thermostatically controlled MDA heater systems provided heat to allow the MDA to meet specified temperature limits. During manned mission periods, the MDA plans were to set the heaters for the 70°F control mode. During orbital storage, plans were to use a 45°F control mode for the MDA interior.

During manned mission modes and periods of high internal heat generation, the MDA heating systems were inactive due to thermostat cut out. Cooling was provided by introducing cooled air from the AM via the ECS ducts. The cabin fans were used to provide satisfactory atmosphere circulation and velocities at crew stations.

(1) MDA Wall Heater System - The wall heating system was part of the Active TCS, Figure 2.2.3-7 depicts the Active TCS.

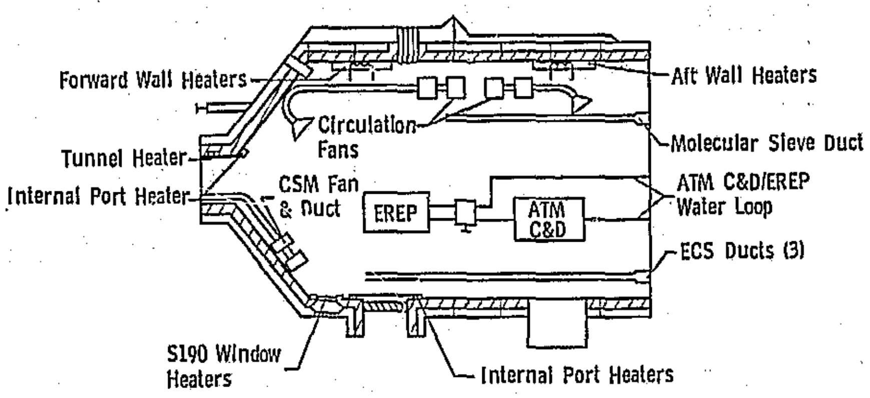


Figure 2.2.3-7 Active Thermal Control System Schematic

Eight 20-watt and eight 40-watt wall heaters were located in the interior barrel section of the MDA pressure shell to heat the MDA. Each heater had a primary and secondary (redundant) heater element. An overtemperature thermostat was electrically in series with each heater element. Four (4) wall heater, 70°F thermostats and four (4) wall heater, 45°F thermostats were provided to control the internal temperature during manned and unmanned flights respectively. Each thermostat had a primary and secondary (redundant) set of points.

A general arrangement of the wall heater system is shown in Figure 2.2.3-8. A typical installation of two wall heaters and one thermostat is shown in Figure 2.2.3-9. Further information concerning the wall heaters and thermostats is contained in the Electrical Subsystem, Paragraph 2.2.4 of this report.

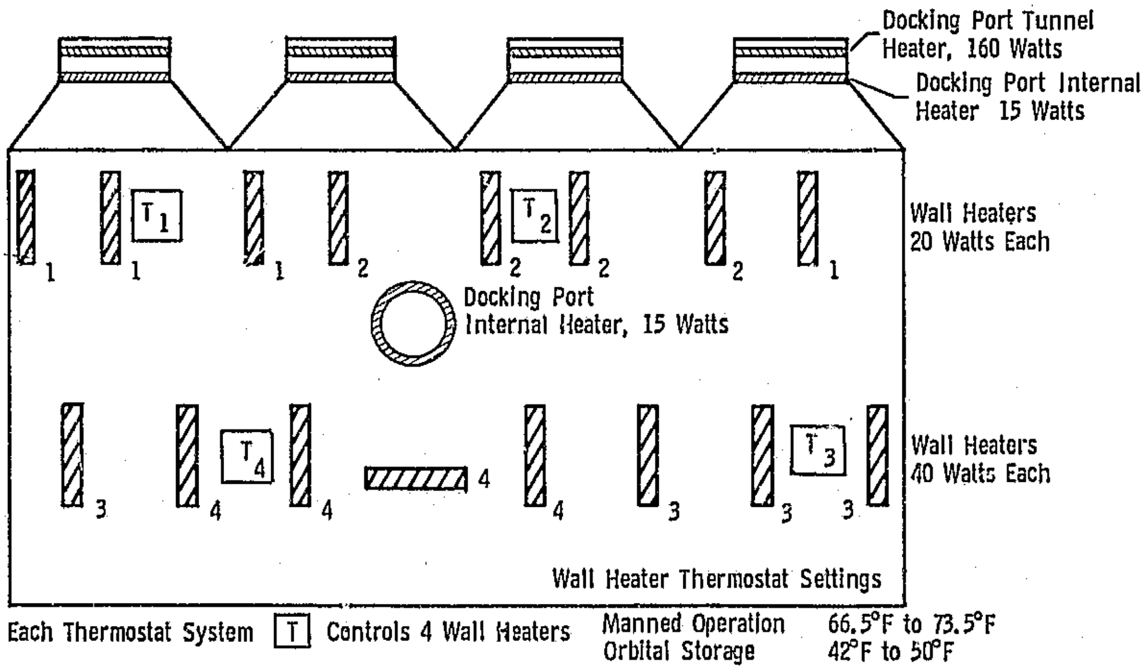


Figure 2.2.3-8 Wall Heating System, General Arrangement

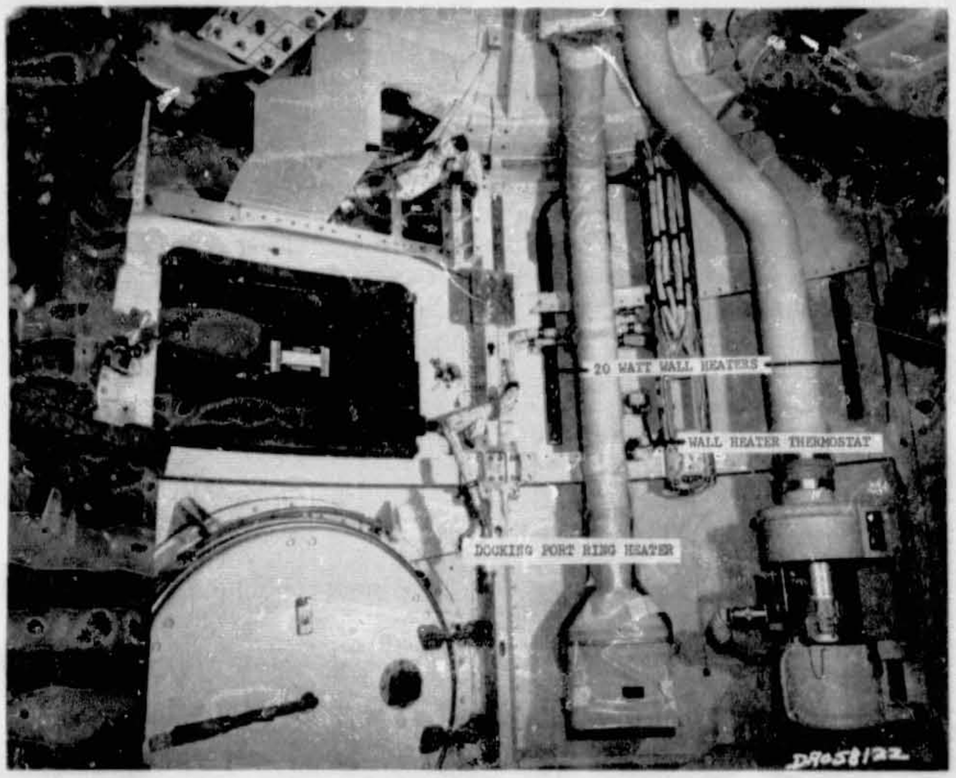


Figure 2.2.3-9 Wall Heater and Thermostat, Typical Installation

(2) MDA Docking Port Internal Heating System - Each docking port had a 15-watt heater to make up the heat lost through the docking port. Each heater had a primary and secondary (redundant) heater element. An over-temperature thermostat was electrically in series with each heater element. Each heater circuit had an inline thermostat to control the docking port temperature to between 60°F. and 70°F. Each thermostat had primary and secondary (redundant) contact points.

A typical docking port heater installation is shown in Figure 2.2.3-9. Further information concerning the heater system components is found in the Electrical Subsystem, Paragraph 2.2.4 of this report.

(3) MDA Axial Docking Tunnel Heating System - Two (2) semi-circular 80-watt strip heaters were installed around the external surface of the axial port docking tunnel. Each heater had a primary and secondary (redundant) heater element. The system was used to provide a shirt sleeve environment for crew entry into the docking tunnel. In addition, it assisted in overall vehicle thermal control during orbital storage and manned mission modes. An overtemperature thermostat was electrically in series with each heater element. Two (2) thermostats were provided to control the temperature of the axial port tunnel to between 60°F and 74°F. Each thermostat had primary and secondary (redundant) contact points.

A photograph of the axial docking tunnel heating system is shown in Figure 2.2.3-10. Further information on the system may be found in the Electrical Subsystem, Paragraph 2.2.4 of this report.

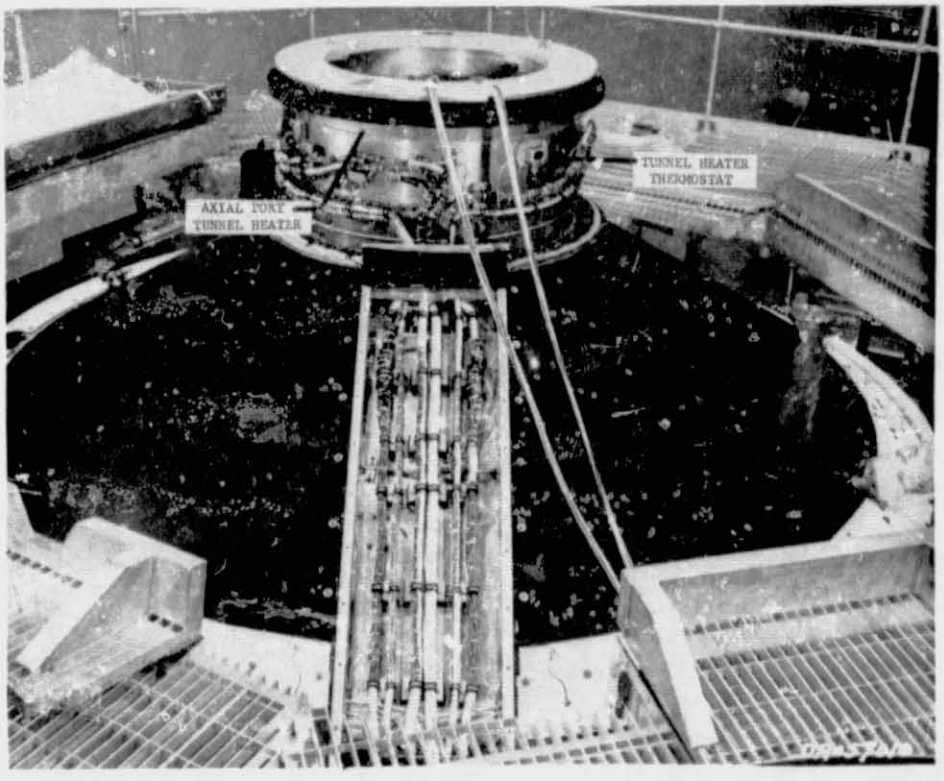


Figure 2.2.3-10 Docking Tunnel Heating System

(4) MDA EREP S-190 Window Heating System - The S-190 Window Heating System contained a window, electrical cable and heater controller subassemblies as depicted in Figure 2.2.3-11. The function of the window heating system was to control the window temperatures such that the glass temperature gradients were minimized and moisture condensation was prevented.

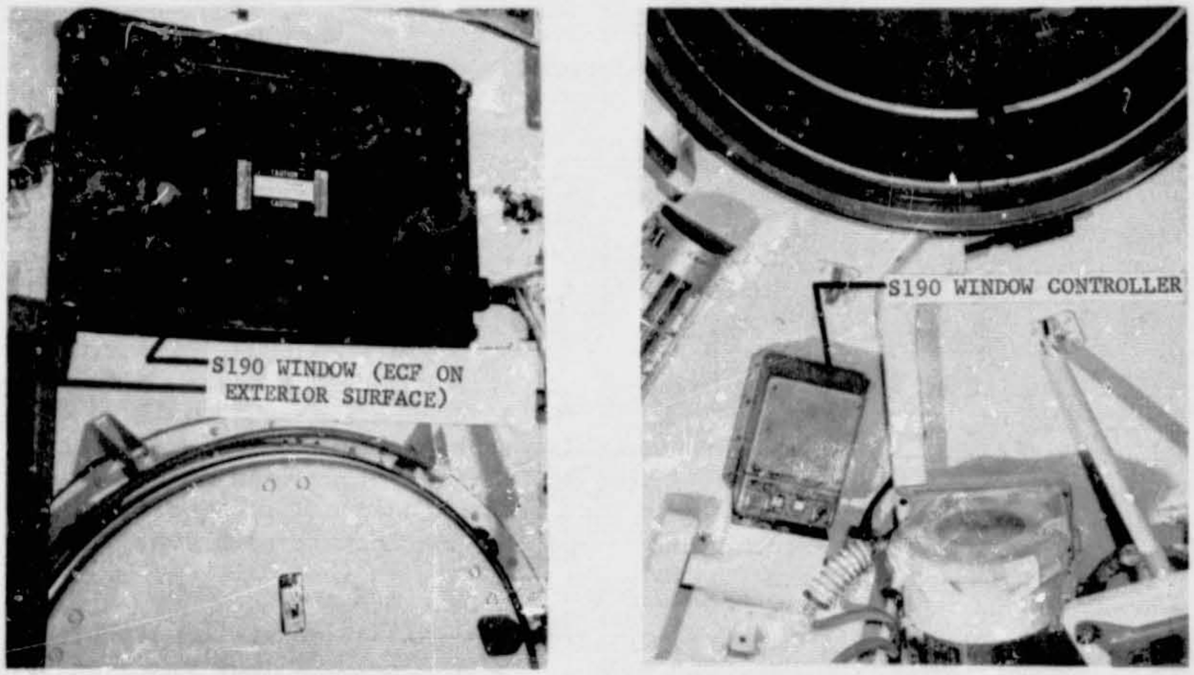


Figure 2.2.3-11 S190 Window Heating System

The window subassembly contained a 40-watt electrical conductive film heater on the glass outer surface. Two 100-watt frame heaters were mounted in the glass support frame. These three heaters contained a total of four temperature sensors for heating control and three sensors for overtemperature.

C. Test - Active Thermal Control System component development, qualification and acceptance tests are reported in this section of the report. Those tests performed as a function of MDA module level system testing are reported in Paragraph 7.8. Failures that occurred during all testing, including system level testing, will be reported in this section.

(1) MDA Wall Heater System Testing

(a) Wall Heaters - MSFC P/N 20M42245-17 and 20M42245-19. These were GFP components. Component testing of these items is not included in this report.

(b) Wall Heater Thermostat - MMC P/N PD7400083

- Development Tests - Not required. Simplicity of device precluded development tests.

- Qualification Test - AETL, Report No. 5350-00-9171 - Qualification testing on the thermostat assemblies was completed on 16 November 1971. Two thermostat assemblies were subjected to the following qualification tests: Vibration, consisting of sine evaluation, vehicle dynamics, high and low level random, shock, thermal vacuum, temperature, altitude, storage and transportation, and CCOH. A performance test was conducted prior to and after each environmental test. The performance tests consisted of a thermal switching test, an insulation resistance test, an electric strength test, and an electrical power test. All tests conformed to specification requirements and the thermostats were considered qualified.

  Heater thermostat assemblies did not comply with MIL-STD-461 EMI requirements. Waiver was granted since the switching events are infrequent and system performance was not degraded.

- Acceptance Test - Thermal Systems, Inc. - Each thermostat assembly received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration, the thermostats were visually and dimensionally inspected, electrical continuity checked, operating temperature checked, contact resistance checked, dielectric strength checked, current capability checked, insulation resistance checked and vibration tested followed by an operating temperature, dielectric strength and insulation resistance check.

Original Procurement Specification requirements for thermostat temperature settings (range) were found to cause a high rejection rate of thermostats during acceptance testing. The original requirements were as follows:

Manned Unit	Opening	72.0°F
	Closing	68.0°F
	Differential (Min)	2.0°F
Storage Unit	Opening	50.0°F
	Closing	42.0°F
	Differential (Min)	2.0°F

A re-analysis of the requirements using an updated thermal model resulted in relaxing the requirements without degradation of the system operating requirements. The following criteria were established as design requirements as a result of the re-analysis:

Manned Unit	Opening	73.5°F Max
	Closing	66.5°F Min
	Differential (Min)	1.5°F Min
Storage Unit	Opening	50.0°F Max
	Closing	42.0°F Min
	Differential (Min)	1.5°F Min

These were the criteria used for hardware acceptance and also the criteria used for qualification of the units.

(2) Docking Port Internal Heater System - System/Subsystem Testing - During Electrical Systems testing in Denver (August 1972) on the Backup MDA, the spare docking port primary thermostat failed to function. The unit was sent to MSFC for failure analysis. Failure analysis concluded the primary element of the thermostat assembly (S/N-002) failed as a result of a cold soldered connection. A second thermostat S/N-007 failed on the flight MDA during testing at KSC. A failure analysis at MSFC found fractured and loose terminals caused by insufficient solder and cold solder connection. As a result of the two failures, all docking port thermostats were removed, reworked and replaced in the Flight and Backup MDA.

- Docking Port Internal Heaters - MSFC P/N 20M42245-15 - These were GFP components. Component testing of these items is not included in this report.

- Docking Port Internal Heater Thermostats - MSFC P/N 20M42245-13. These were GFP components. Component testing of these items is not included in this report.

(3) Axial Docking Tunnel Heater System - MMC P/N PD6000202

(a) Development Tests - Not required. Simplicity of the heater components precluded the development tests.

(b) Qualification Test - AETL, Report No. 5350-00-9237 - Qualification testing on the MDA Docking Tunnel Heater System was completed on 12 November 1971. Two heater assemblies and two thermostat assemblies were subjected to the following environmental qualification tests: vibration, consisting of sine evaluation, vehicle dynamics, low level random, and high level random; shock; thermal vacuum; and life cycle. A performance test was conducted prior to and after each environmental test. The performance tests consisted of dielectric strength, insulation resistance, electrical power and heater dissipation. Other functional type tests conducted were the thermal switching tests on the heater assembly over-temperature switches and on the thermostat assembly thermal switches. One anomaly occurred during testing and is described below.

The procurement specification establishes a requirement for the thermostat assemblies of $4^{o}F$ minimum temperature difference between thermostat point open and thermostat point closed (ΔT). Because of lower differentials occurring during qualification, a thermal evaluation, was made to determine if a narrower temperature differential band was acceptable. It was concluded that the average ΔT of $3.7^{o}F$ obtained during qualification test was acceptable and the specification requirement was reduced to $3.7^{o}F$ minimum from $4.0^{o}F$ minimum. On this basis, the performance of the thermostat assemblies was considered acceptable and qualified.

Heater and thermostat did not comply with MIL-STD-461 EMI requirements. Waiver was granted since the switching events were infrequent and system performance was not degraded.

(c) Acceptance Test - Thermal Systems, Inc. - Each heater and thermostat assembly received an acceptance test to demonstrate suitable quality, correct assembly and required performance. To satisfy this demonstration, the assemblies were subjected to the following acceptance tests: physical inspection, continuity checks, operating temperature checks, heater dissipation, dielectric strength, altitude check, current capability check, insulation resistance and vibration followed by an operating temperature check, dielectric strength check and insulation resistance. All heater-thermostat assemblies met these requirements successfully.

(4) MDA EREP S190 Window Heater Control System Testing

(a) Development Tests - Hycon Engineering Co. - Development tests of a thermal nature were conducted on the window assembly, control cable assembly and heater controller assembly. The following thermal development tests were conducted:

- Temperature Control - The window assembly was instrumented with six thermocouples and placed in an environmental test chamber. The control cable reference sensor was instrumented with one thermocouple. The assembly was allowed to thermally stabilize. Temperature of the reference sensor was increased 5°F and the window sensor temperatures recorded. Results indicated that heater controller-applied power had increased the window assembly temperature 4.0°F, an acceptable test value.

- Heater Frame Step Function Temperature Test - Three thermocouples were attached to the window frames 1 and 2 and glass. The window assembly was allowed to thermally stabilize for thirty minutes.

  A resistance was calculated which would increase the frame temperatures by + 5°F. This resistance was set into the control box. As the temperatures of Frames 1 and 2 increased, readings were taken until the frame temperatures stabilized. Resulting curves indicated a change in frame temperature of 3.5°F and Frame 2 of 3.0°F which were satisfactory and within specification.

- Moisture Condensation Test - The window assembly was instrumented and mounted in the vacuum test chamber. The chamber interior was evacuated and a cold wall of liquid nitrogen applied. The window heater controller was turned on. The control cable reference sensor was held at 70°F. Results of the test indicated the window heaters maintained the glass at 70°F and; thus would prevent moisture condensation in flight worst case environment.

- Thermal Stress Test - The window assembly was instrumented and mounted in the vacuum test chamber. The chamber was evacuated and liquid nitrogen cold wall applied. Frame 1 heater was powered at full power while Frame 2 and the electrical conductive film (ECF) were not powered.

  Results of the test indicated no window structural flaws or damage resulting from a worst case heater failure.

- Coating Test (Uniformity of ECF) - A full-size window sample, coated with an electrical conductive film (ECF) was tested for eveness of heating. An AGA thermovision unit was used to take a "thermal" picture of the ECF. Results of this test indicated the window glass had an apparent thermal gradient of one degree centigrade and was within an acceptable value.

- Wavefront Condition 3 Optical Testing - The window assembly was instrumented and mounted in the vacuum test chamber. The chamber was evacuated with a "hot" interior wall for one test and a "cold" interior wall for the other test. These chamber wall temperatures represented "hot" and "cold" orbital flight conditions for the window assembly. An interferometer was used to measure the window glass optical distortion under these simulated worst case flight environments. Test results indicated the glass optical distortion was within acceptable limits.

Results of these thermal development tests indicated the window assembly, control cable assembly, and heater controller assembly designs were adequate and no changes were initiated because of these thermal tests.

(b) Qualification Tests - The thermal qualification tests were run on the window assembly, control cable assembly, heater controller assembly, and all three systems connected together.

The window assembly qualification tests are contained in Actron Report No. HWS-190-DI-9-1 and consist of the following tests:

- Pre-Qualification Acceptance Tests (System Level) which were: Temperature Control Test, Overtemperature Test, and Delta Temperature Test.

- Qualification Tests which were: Low-Temperature Storage Test, High-Temperature Storage Test, Random Vibration Test, Complex Wave Shock Test, CCOH Test, and Wavefront Deformation Condition 3 Test (System Level).

- Post-Qualification Tests which were: ECF Coating Resistance Test, Temperature Control (System Level) Test, Overtemperature (System Level) Test, and Delta Temperature (System Level) Test.

In the window overtemperature test, the ECF overtemperature sensor shut off the ECF power between 100.5°F and 105°F. This met the requirement that the 105°F value was not to be exceeded since it was the maximum allowable local temperature in the MDA.

The control cable assembly and heater controller assembly thermal qualification tests are contained in Actron Report No. HWS-190-DI-9-2 and consist of the following tests.

- Pre-Qualification Acceptance Test which were: Sensor Temperature Test, Temperature Control Test (System Level), Over-temperature Test (System Level) and Delta Temperature Test (System Level).

- Qualification Tests which were: Low-Temperature Storage Test, High-Temperature Storage Test, Random Vibration Test, Complex Wave Shock Test, and Corrosive Contaminants, Oxygen, and Humidity (CCOH).

- Post-Qualification Tests which were: Temperature Control Test (System Level), Over-temperature Test (System Level) and Delta Temperature Test (System Level).

The thermal qualification tests on the control cable and heater controller encountered no significant thermal problems. S190 Window Heater Controller was 2 DB out of specification for EMC Qualification testing. A waiver was granted since slight deviation presented no problem, technically, for the MDA system.

A delta qualification test was performed on the heater controller in March 1973. Results of the test are contained in Actron Report No. ETL (R) - 73-002. The tests performed were to establish thermal deltas and maximum temperatures reached on components and areas of the Heater Controller Case when operated under various load and electrical characteristics when the unit was subjected to the following test conditions:

- 0.1 PSIA atmosphere environment at a mean thermal ambient temperature of 70°F.

- 0.1 PSIA atmosphere environment at a mean temperature of 80°F.

In addition, the tests evaluated the thermal efficiency of heat sinks added to areas of the heater controller containing components with high thermal outputs during normal operation.

(c) Acceptance Tests - The window, control cable and heater-controller assemblies acceptance tests did not contain any thermal type tests. All tests were of an electrical, structural, and optical nature. The System Level acceptance tests did contain the following thermal tests:

- Temperature Control Test
- Over-temperature Test
- Temperature Test

These thermal acceptance tests were conducted on the flight and backup window articles and no problem areas were found. A thermovision test was run on the backup and qualification windows and the report indicated no thermal discrepancies during these tests.

(d) MDA EREP S190 Window Heater Control System Testing Failures - During testing of the flight MDA at St. Louis and KSC a single point ground violation occurred in the S190 Window Heater Controller. Failure analysis revealed that defective internal feed-through capacitors were the cause of the failure. All controller units were reworked.

Another failure occurred at St. Louis during MDA testing of the Window Heater Controller system. The controller cable shorted out one of the controller sensors. A redesign of the cable corrected this anomaly.

D. Mission Results - An in-depth discussion and presentation of mission results is contained in Volumes I, II, and III of the "MDA Module Report" for SL-1/2, SL3, and SL4, respectively (ED 2002-1702). Included are detailed plots of all MDA data and selected AM data for the entire mission period. However, a summary of mission results for the Active Thermal System follows:

(1) Requirements vs Actual Results - Because of the interaction between the MDA Active and Passive TCS, requirements and results are discussed under the Passive TCS.

(2) Hardware Performance -

(a) Wall Heater Operation and Thermostat Control - During SL-1/2, due to high OWS temperatures and the shortage of electrical power, the wall heaters were operated in an off-design mode. Heater operation in a power-managed mode by DCS command controlled the MDA to desired temperatures ranging from 50°F to 70°F.

Subsequent heater control in the 45°F and 70°F control modes for orbital storage periods, and for SL-3 and SL-4 manned periods, proceeded as planned for the majority of each period. Only during brief periods of time, during SL-3 and SL-4, were the heaters shut off for purposes of power management. While under heater control in the 45°F and 70°F mode, temperatures between 46°F and 47°F and 68°F and 70°F were attained, respectively.

(b) Axial Docking Tunnel Heater Performance - Due to the pitch-up vehicle attitude attained prior to the first manned period, the axial docking port attained internal temperatures in excess of 113°F. As a result, the docking tunnel heaters did not activate. After docking, temperatures in the docking port dropped to below 70°F and the tunnel heating system assumed control. As was the case for the wall heaters, the docking tunnel heating system was operated in a power-management mode during the manned period of SL-1/2.

The tunnel heating system was active throughout the subsequent storage periods and controlled the axial docking port tunnel between 61°F and 70°F. During the manned periods of SL-3 and SL-4, the heating system remained on for the majority of the time periods. During active manned periods, the system controlled the axial tunnel as expected, between 61°F and 71°F.

(c) Docking Port Internal Heaters - Both docking port 15 watt internal heaters were operated periodically during SL-1/2, as were the MDA wall and tunnel heaters.

After SL-1/2, the docking port internal heaters were armed continuously. The heaters operated as expected during the subsequent orbital storage periods. They were continuously on during storage periods because of the prevailing low MDA temperatures. During the manned periods, the heaters, as expected, were mostly off. This is because MDA temperatures were above the set points of the port heater thermostats.

(d) S190 Window Heater - Planned operations for the S190 heater system were to have the system activated during the manned mission periods and deactivated for the unmanned periods. However, in order to save power during SL-1/2, the system was powered for only brief periods of time near EREP operations.

During SL-3 and SL-4, the system was activated continuously for the intended duration.

The S190 heating system appeared to function normally whenever it was turned on. This was evidenced by the fact that the S190 window did not overheat and did not develop excessive temperature gradients. Both overheating and excessive gradients are monitored by TM signals or crew display, and at no time during the mission was an adverse condition noted.

E. Conclusions/Recommendations

(1) MDA Heating Systems - The MDA wall, axial docking port, port internal, and S190 heating systems all operated as designed when normal electrical power was available. When the wall heaters were continuously powered, the thermostats kept the MDA within the crew comfort box. There was no evidence that any of the heating systems malfunctioned during the mission and therefore it is concluded that they performed without failure.

(2) Thermal Characteristics of Electrical Components - Prior to flight, a defect in the S190 window controller was identified. The problem was due to thermal design on the circuit board level. Some electrical components

were predicted to exceed allowable temperatures in a Zero-G environment. This was due to the lack of natural convection in space. The controller was modified prior to flight and tested in a near vacuum to prove the ability of the design to be compatible with no natural convection.

A similar problem with overheating electrical components, on the circuit board level, was found on the backup inverter lighting control assembly (BI/LCA). A thermal fix was incorporated on a transistor to assist heat dissipation. Once again a test at near vacuum conditions verified ability of the design to dissipate heat.

It is recommended that future design reviews of spacecraft electronic assemblies specifically address the possibility of overheating at the component level.

F. History

(1) MDA Wall Heater System

(a) Year 1967 - The initial MDA concept incorporated passive thermal control. Wall heaters were not considered at this time.

(b) Year 1968 - The environmental control system was expanded to include active thermal control heating. Sixteen wall heaters were added. The concept envisioned wall heaters manually controlled from within the MDA or remotely controlled from the ground.

(c) Year 1970 - Bi-level thermostat controls were added for wall heater control to eliminate the need for extensive attention from ground controllers.

A thermal analysis of the MDA longeron mounted wall heaters indicated that a large temperature difference would exist between the heaters and the wall. The installation design was revised to mount the heaters on Z-bar brackets that exhibited better heat dissipation characteristics into the MDA wall.

(d) Year 1971 - The wall heating system was installed in the MDA at MMC. Thermal performance system tests were performed.

(2) MDA Docking Port Internal Heating System

(a) Year 1967 - The initial MDA concept incorporated passive thermal control. Heaters to minimize docking port heat leak were not included.

(b) Year 1968 - The environmental control system was expanded to include active thermal control heating. Heaters were added to the axial and to the radial docking port hatch ring.

(c) Year 1971 - The docking port thernal heating system was installed in the MDA at MMC. Thermal performance system tests were performed.

(3) Axial Docking Tunnel Heater System

(a) Year 1967 - The initial MDA thermal, control concept incorporated passive thermal control. Tunnel heaters were not included in the MDA design at this time.

(b) Year 1970 - In order to permit crew shirt-sleeve entry to the MDA from the CSM, two heaters were added to the axial docking port tunnel.

(c) Year 1971 - The axial docking port tunnel heating system was installed on the MDA at MMC.

(4) MDA EREP S190 Window Heating System

(a) Year 1967 - The initial window concept consisted of two double pane windows (11.5 in. X 11.5 in.) located on the +Z and the -Z axes. There were no plans for active thermal control of the window.

(b) Year 1968 - Window design changed to a single pane (12 in. X 17 in.) of Corning 7940 glass. A window trade study indicated the glass should be heated by electrical conductive heaters. Moisture condensation on cold surface was the prime concern.

(c) Year 1969 - Light transmission through the window glass became an important factor for photography. Two window design concepts were selected for further study:

- Electrical Conductive Films (ECF)
- External Radiant Heaters

Controls were to be a simple "Off-Low-High; manual switch."

A successful thermal test was completed on the external radiant heater concept which demonstrated its feasibility.

As a result of the study, the external radiant heater concept was selected to provide window heat because it permitted more light to be transmitted to the photographic experiment than did the ECF concept.

(d) Year 1970 - A full scale development test was completed on the external radiant heater concept using fused silica glass (19 in. X 16.5 in. X 1.6 in.).

Photographic experiment interface requirements redefined at this time, placed emphasis on optical distortion of the window glass, and relaxed transmission requirements. MMC selected the Hycon Company of Monrovia, California (later renamed Actron) to build a window that would satisfy the requirements specified. Hycon selected the ECF concept to meet the window light transmission and uniform glass temperature constraints of EREP S190 experiment.

An ECF heater test indicated the maximum temperature difference across the ECF surface to be less than one degree centigrade.

The ECF and the two window frame heaters were selected to be controlled automatically.

The window external radiant heaters and the -Z axis window were deleted from the MDA configuration.

(e) Year 1971 - Development, qualification and acceptance tests were conducted on the MDA window by Hycon.

The window was installed in the MDA at MMC.

(f) Year 1972 - Thermovision tests were conducted on the window qualification test item and the backup item at MMC.

(g) Year 1973 - A delta qualification test was conducted on the S190 Window Heater Controller by Actron Industries, Inc. to demonstrate the capability of the controller to operate at near space environments.

This Page Intentionally Left Blank

2.2.4 Electrical System

The following is a discussion of the MDA Electrical Systems design requirements, control documentation and subsystem/components.

A. System Design Requirements - The design requirements for the MDA Electrical System are defined in:

- MDA Contract End Item Specification, CP 114A1000026, Rev. E.
- MDA Electrical System Design Criteria, 82000001505.

Design was influenced and controlled by the following general requirements:

- Eight-month orbital mission
- Crew safety from electrical hazards
- No single point failures
- Material control for contamination due to outgassing
- Separation of cables into functional categories where practical
- Use of Zero-g and Microdot/Airlock connectors where circuits will be mated/demated by astronaut
- Voltage drop through MDA not to exceed one volt for power circuits
- Meet system EMC requirements of MIL-E-6051
- Meet components MMC requirements of ED-2002-1032
- Single point ground system to be incorporated
- Circuit breaker protection for all MDA electrical equipment

Specific design and performance requirements are referenced in the appropriate section as applicable to the hardware/subsystem discussed.

Electrical ICDs that impacted the MDA Electrical Design and Test Program are as follows:

AM/MDA	40M35662 (Volume II)
MDA/CSM	40M35661
ATM to AM to ATM C&D Console	40M35601-2
MDA to EREP Support System	40M35673
MDA to Proton Spectrometer	40M35664
MDA to I/LCA	40M37858
Cluster to Operational Support Equipment	40M35681

Cluster to Auxiliary Support Equipment	40M35690
MDA to Experiments	
M512 Material Processing in Space	40M35625
S190 Multispectral Photographic Facility	40M35646
S009 Nuclear Emulsion	40M35652
S191 Infrared Spectrometer and Viewfinder	40M35671
S192 10-Band Multispectral Scanner	40M35675
S193 Microwave Radiometer/Scatterometer/Altimeter	40M35662 (Volume II)
S194 L-Band Radiometer	40M35674

2.2.4.1 Utility Outlets

A. Design Requirements -

(1) Utility Outlet Assemblies - The MDA Electrical system provided four utility outlet assemblies which supplied voltage to low-power portable equipment. Each utility outlet had the following characteristics.

- One-ampere capability.
- Portable equipment case ground to structure.
- Local switch capable of de-energizing the outlet.

(2) High Power Accessory Outlet Assemblies - The MDA Electrical system provided two high power accessory outlet assemblies which supplied voltage to high-power portable equipment. Each high-power accessory outlet had the following characteristics:

- Twelve-ampere capability.
- Portable equipment case ground to structure.
- Local switch capable of de-energizing the outlet.

(3) Human Engineering - The units were designed so that the switches and outlets were readily accessible, suitably arranged, properly identified and of such size and construction as to permit convenience and ease of operation. The units complied with their design criteria and MSFC-STD-267.

(4) Electrical Connectors - The connectors on the units met the requirements of 40M39580 (Zero-g connectors).

(5) Switches - Switches met the requirements of MIL-S-8834 and MIL-S-25307-232.

(6) Short Circuit Protection - Short-circuit protection was provided by circuit breakers located in the Structural Transition Section (STS) of the AM.

(7) Circuit Continuity - The circuit continuity of the units was in accordance with applicable sheets of the Electrical Schematic Diagram (82000000401). Continuity was defined as 0.5 ohms maximum.

(8) Operating Life - The units were capable of 10,000 cycles of operation.

(9) Flammability, Toxicity and Odor - All materials used in the units met the requirements of MSFC-SPEC-101A.

(10) Grounding - Power input leads within the units were isolated from equipment case or structure by a minimum of ten megohms dc resistance.

B. Functional Description -

(1) Utility Outlets - Four one-amp utility outlets provided 28 vdc power to portable equipment. Case grounding of portable equipment was provided through the utility outlet to structure. Each utility outlet contained an ON/OFF switch and a zero-g connector which interfaced with the portable equipment cable connectors.

(2) High Power Accessory Outlets - Two 12-amp high power accessory outlets (See Figure 2.2.4-1) provided 28 vdc power to portable equipment, photographic equipment, experiments and the TV Video Tape Recorder. The outlets were located at each end of the MDA.

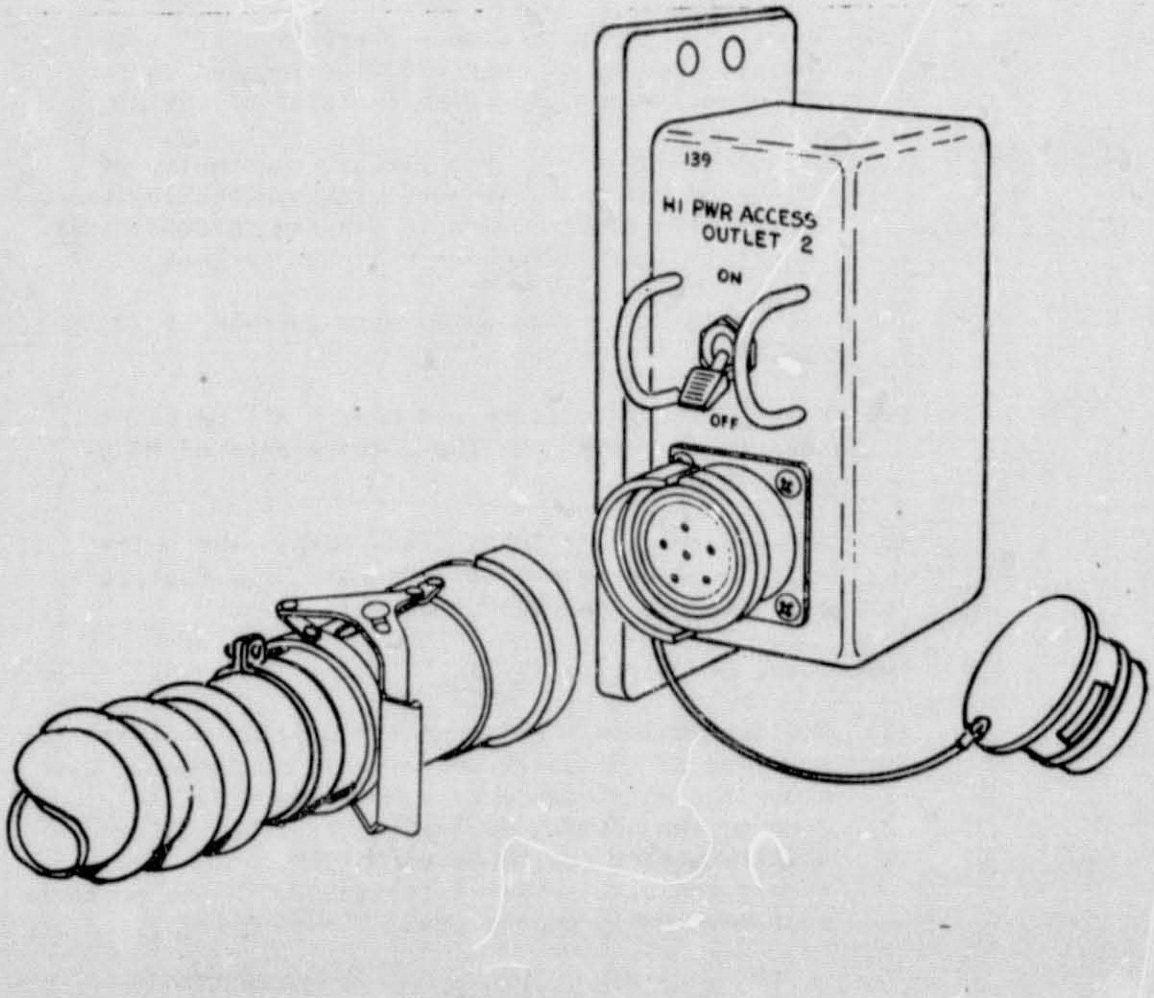


Figure 2.2.4-1 High Power Accessory Outlets

C. Test - Qualification testing of the MDA Outlet Boxes, P/N 82000008200-009, was completed on 9 April 1971. The qualification tests, as outlined in MMC Qualification Test Procedure No. 3183, consisted of the following environmental tests:

- Vibration, consisting of Sine Evaluation, Vehicle Dynamics, and High and Low Level Random
- Shock
- Thermal Vacuum
- Temperature, Altitude, Storage and Transportation (TAST)
- Corrosive Contaminants Oxygen Humidity (CCOH)

A performance test was conducted prior to and after each environmental test.

All qualification, acceptance and system level tests performed on the outlet boxes were accomplished successfully and without failure.

D. Mission Results - The utility outlets and high power accessory outlets performed satisfactorily during all missions. High Power Accessory Outlet No. 2 (Panel 139) was used as the power source for the Rate Gyro Six-Pack which was installed during the SL-3 mission.

E. Conclusions and Recommendations - Excessive usage of the high power accessory outlets during the Skylab missions for contingency operations and mission growth reassignments resulted in the conclusion that additional outlets were required.

2.2.4.2 Power Distributor Assembly (PDA)

A. Design Requirements - The design requirements for the Power Distribution Assemblies defined in 82000000916 "Equipment Specification, Power Distributor Assembly", and in 82000000401.

MDA design reviews were held in December 1969, August 1970 and May 1972. These reviews results in no RIDs or changes against the PDAs.

The PDAs were included in the MDA voltage drop analysis. The power levels were specified in the Power Allocation Document 40M35632 and the PDA circuits met the requirement of less than 1 volt drop. The PDAs are time life cycle critical components as defined in 82051000010, "Critical and Limited Life Components".

B. Functional Description - The PDAs consisted of 4 GFP aluminum boxes, NB connectors, hermetically sealed relays and associated blocking diode PC boards (See Figure 2.2.4-2). The PDAs were located outside the MDA, under the thermal blanket, and adjacent to the AM umbilical plate and MDA/AM interface connector plate.

There were four PDAs installed on each MDA. Two PDAs (82000000900) were used to control the tunnel heaters, docking port heaters and the MDA lights. The remaining two PDAs (82000009100) were used to control the MDA wall heaters. Each of the identical units received power/control inputs from the AM from separate power buses to provide redundancy/reliability.

The original design called for two units (82000000900) per system but this was expanded to four units when the MDA wall heaters were required to be thermostatically controlled.

A total of 14 units were built for the following usages:

- 4 units - flight article
- 4 units - spares
- 4 units - backup article
- 2 units - qualification test

C. Test

(1) Development Tests - Tests were performed on power distributor assembly relays to determine the degradation of contacts caused by the light assembly in-rush current. Relays were proven to be acceptable for this application.

(2) Qualification Tests

(a) Two units were subjected to qualification tests per the requirements of the MDA General Test Plan ED-2002-1032 as outlined in MMC Qualification Test Procedure No. 3180. Testing consisted of the following environmental tests:

- Vibration, Sine and Random
- Pyro Shock
- EMI
- Thermal Vacuum
- Temperature, Altitude, Storage, Transportation

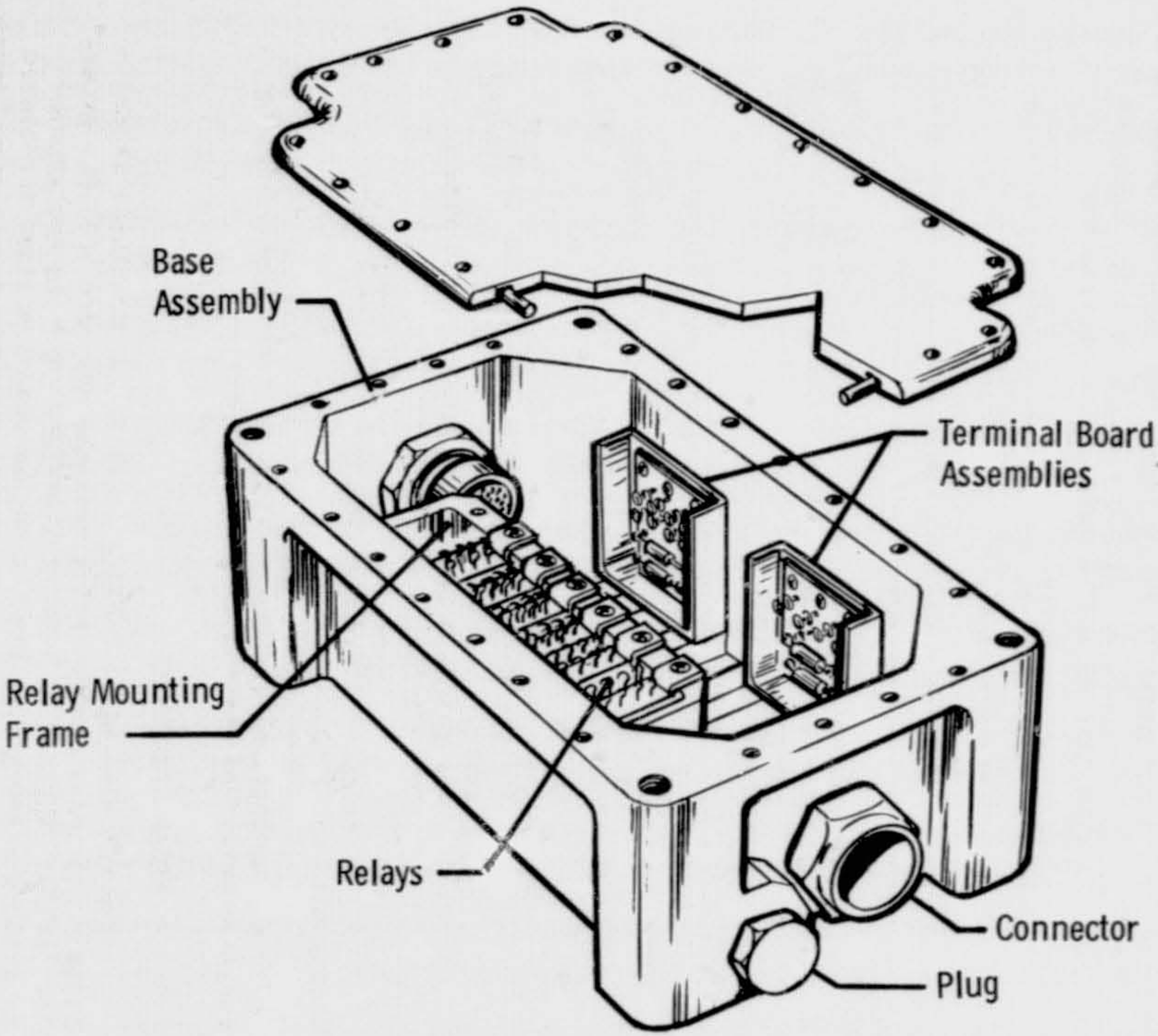


Figure 2.2.4-2 Power Distributor Assembly

A performance test was conducted prior to and after each environmental test. Units tested were P/N 82000000900-009. The -010 and 82000009100-010 were qualified by similarity.

(b) The PDAs did not comply with the EMI requirements of MIL-STD-461A. DAR-MDA-5 was submitted and approved. The conformance was of short duration and infrequent and resulted in no system performance degradation.

(3) Acceptance Tests - Each PDA was subjected to an Acceptance Test per 82000000900 OP 125.

The Acceptance Tests were conducted pre and post vibration using the AT506640 PDA test tool.

(4) System Tests - During the system testing, the PDAs were used to distribute power to the MDA heaters and lights and satisfied all requirements of the flight and backup STACR.

One PDA filed the MDA single point ground isolation test on the flight article at St. Louis. Failure analysis was performed and a bead of solder was found short-circuiting a relay case to the power return.

A discrepancy check and report was fun on all units, the acceptance test procedure was changed and the hardware was repaired. There were no further PDA failures.

D. Mission Results - The PDAs performed satisfactorily during all Skylab missions.

E. Conclusions and Recommendations - The PDAs performed satisfactorily and met all design requirements.

2.2.4.3 Cable Assemblies

The MDA electrical cabling construction consisted of two types: (1) those cables used inside the MDA; and, (2) the exterior cables. The interior cabling was designed and constructed to include flammability protection, and was installed in covered cable trays to provide protection against cable damage, see Figure 2.2.4-3. The exterior cabling configuration was the same as the

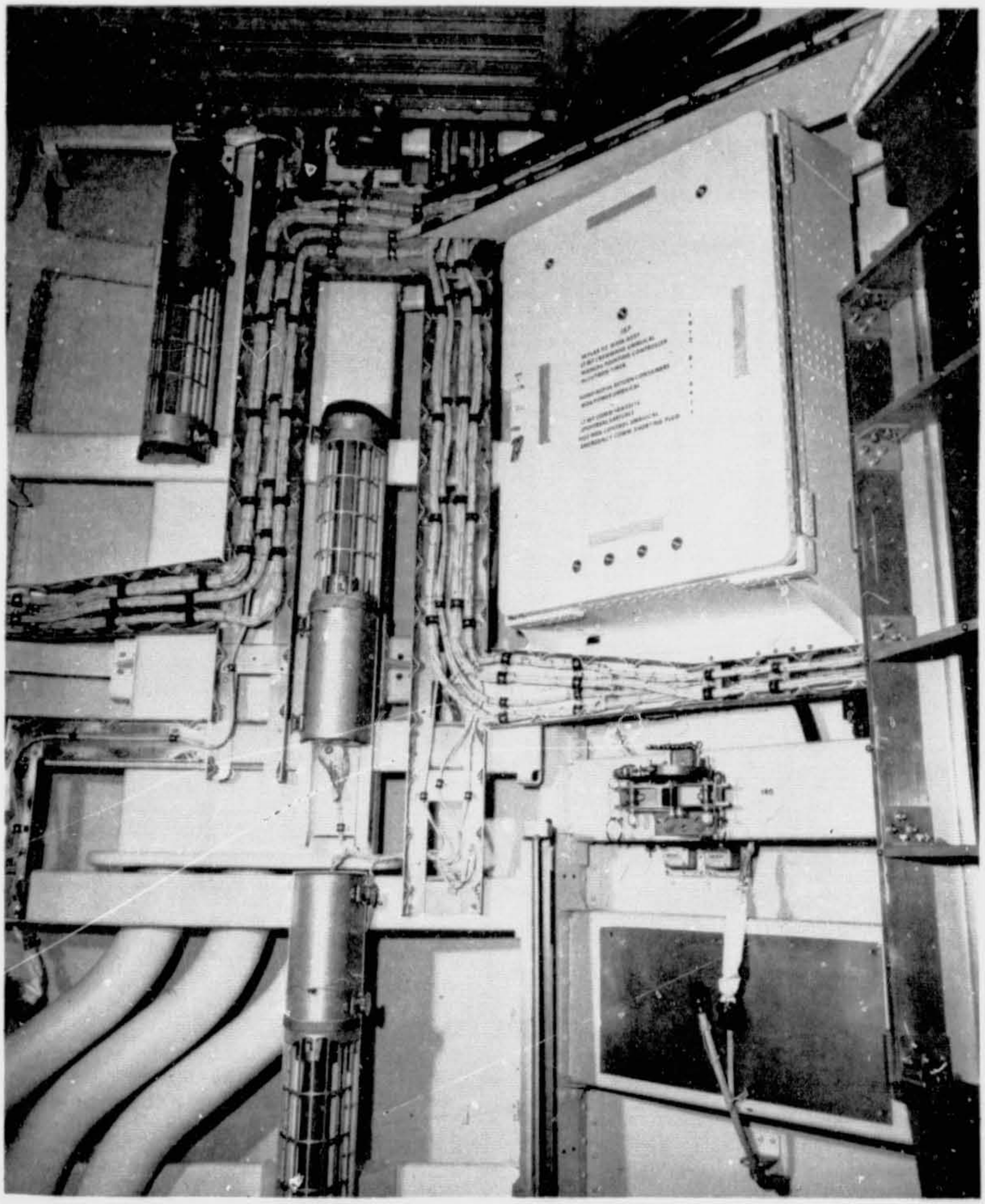


Figure 2.2.4-3 MDA Interior Cabling

interior design, with the exception of flammability protection and cable tray installation. The exterior cables were installed on the MDA structure and mounted under the meteoroid shield, see Figure 2.2.4-4. The L-Band truss cables, being exterior of the Meteoroid shield were wrapped in NBG material for meteoroid protection.

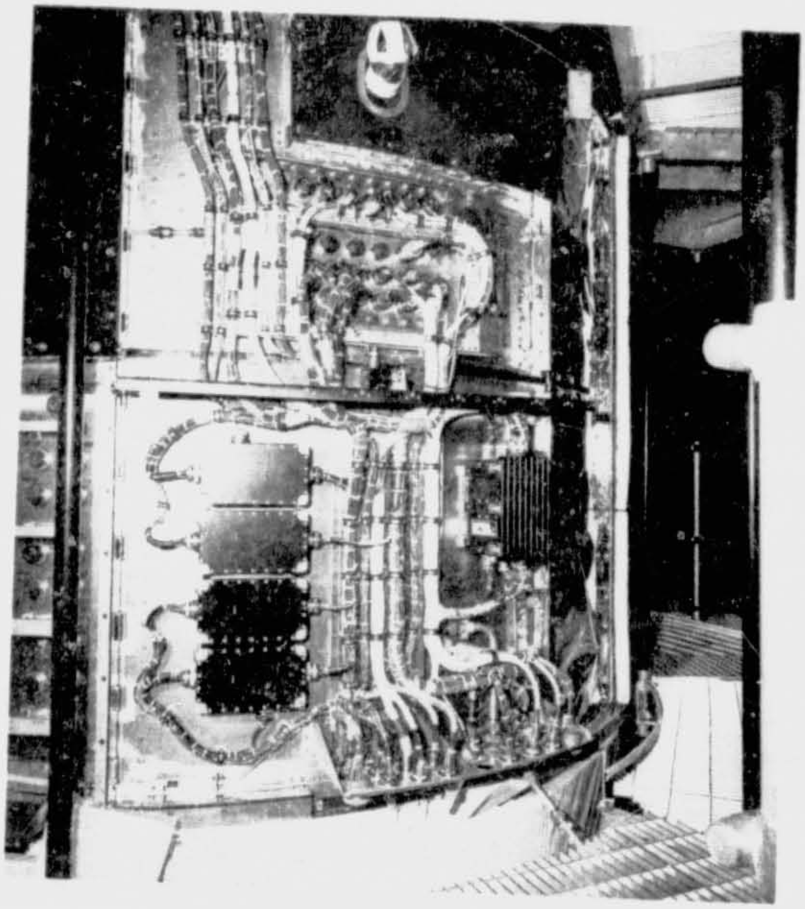


Figure 2.2.4-4 MDA Exterior Cabling

Mismating protection of similar connectors was accomplished by the use of identification tags, connector clocking, cable routing and clamping.

A. Design Requirements - MMC drawings that were applicable to MDA cabling design, fabrication and testing were:

- 82000000304 Automated Wiring Diagram
- 82000000401 Electrical Schematics
- 82000000503 Cable/Component Installation-Interior
- 82000000603 Cable/Component Installation-Exterior
- 82000000713 MDA Cabling Interconnect Diagrams

The MDA electrical cabling consisted of stranded and coax wire. The standard wire types were identified by MMC material specifications STME 843, 921 and 922. The wire was constructed of a polyimide coated teflon insulation over a silver plated copper conductor. The shield jacket was extruded teflon. The wire conformed to MIL-W-22759. The coax wire types were as follows: MMC material code E1300153 (RG179/U) - Teflon dielectric with a 30 awg silver plated center conductor - silvered copper braid with an extruded teflon outer jacket. This cable conformed to MIL-C-17 and was a 75 ohm coaxial cable. MMC material code #1700001 triaxial cable had the same materials and the same performance characteristics as the 75 ohm coax cable above.

The connectors used throughout the MDA were in general accordance with MIL-C-39012, MSFC 40M39569, MSFC40M39580, V56-421102-11, V56-531103-21 and MMC drawings ST81D78, ST81D88, ST81D89, ST81D107, ST81D108, ST81D110, ST82D28, ST82D29 and ST82D32. See Figure 2.2.4-5 for examples of coax connectors ST82D28, ST82D29 and ST82D32; Zero-g connector 40M39580; AM interface connector ST81D108; and feedthrough connector ST81D107.

Feedthrough connectors were used to provide hermetically sealed skin penetrations capable of transferring electrical signals and power through the MDA skin. These connectors consisted of various types: Deutsch Series 46000, pin to pin (mirror image) used with NAS 1599 (40M39569) plugs; Deutsch Series 22638-24-100-PP for coaxial penetrations used with Deutsch 38134-24-100SN Plugs; and Microdot/Airlock hermetic receptacle (GFP) for crew handling functions used with Microdot/Airlock Plugs (GFP). All of these connectors are single hole mount and were installed prior to any leak checks performed on the MDA. Protective covers were installed at all times prior to harness installations.

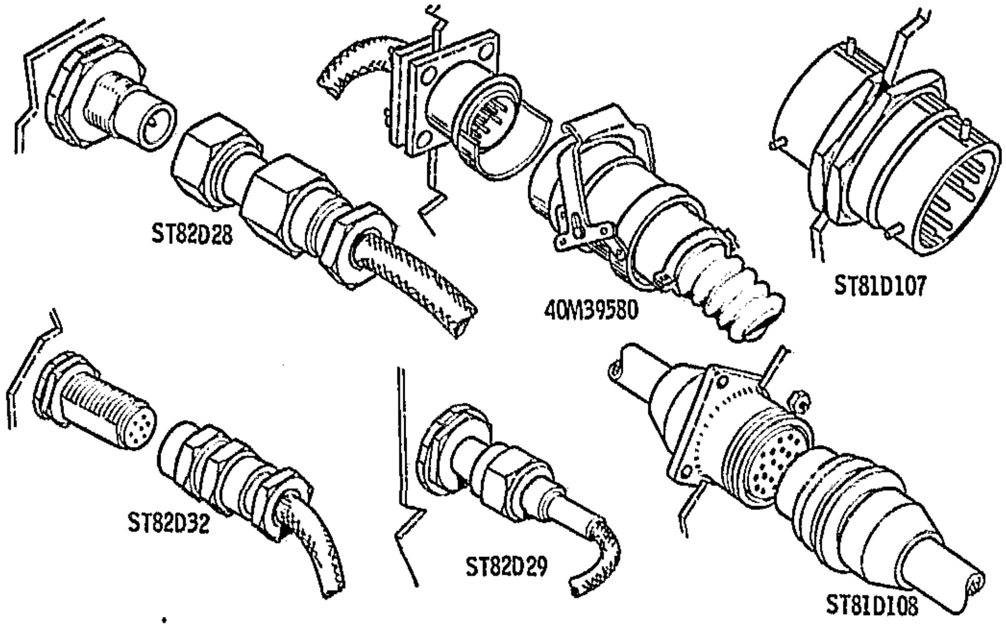


Figure 2.2.4-5 MDA Electrical Connectors

The development mockup, which started out as a 180° shell and was modified into a full 360° mockup, was used as a high fidelity structure to design and develop the flight electrical harness configuration for both the internal and external cables. It provided information in regard to bundle size, optimum bundle routing redundancy and EMC category separation, determination of clamping provisions, location and orientation of connector bracketry, design and development of cable trays, as well as cable tray covers. It was also used to: develop cable flexing methods for cables routed to shock mounted or moveable components; verify the cable forces on those particular components where necessary; locate shield terminations and ground studs for structural grounding; and finalize cable flammability protection, processes, and quantities. It was later used as a three dimensional tool for fabrication of the internal flight and backup harness.

The L-Band cables were also developed on a three-dimensional tool which served its purpose in the same capacity as the development mockup. Connector identification tags were positioned such that they could be read without twisting the cables or disconnecting the connector.

Cables terminating in a Zero-G connector were potted for strain relief and fitted with a flame proof piece of convoluted tubing extending from the rear of the connector through the first cable clamp. This was done to give the crew the same handling characteristics of these connectors in the MDA as they would experience throughout the cluster. See Figure 2.2.4-6.

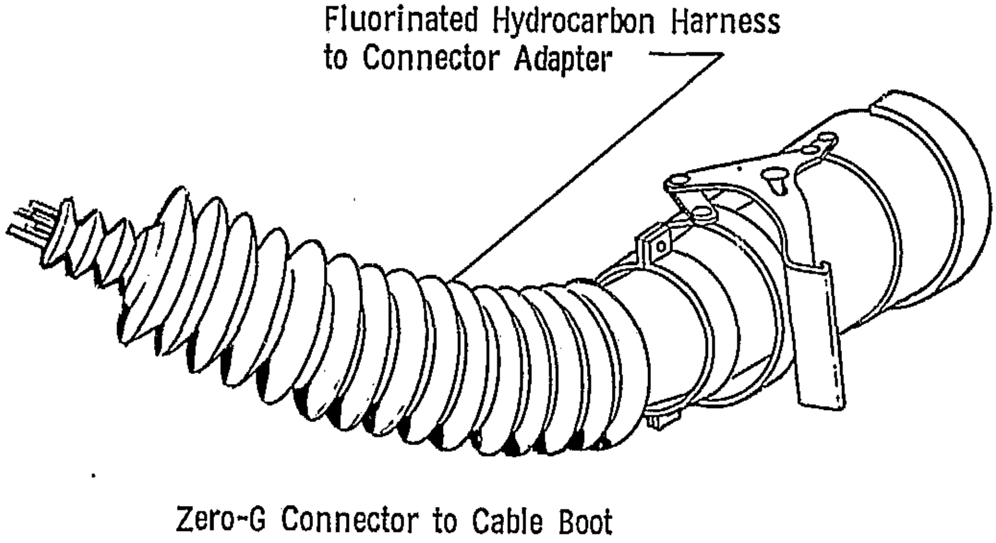


Figure 2.2.4-6 Termination of Zero-G Connector

Physical damage protection of the interior harness was provided through the maximum use of cable trays, cable covers, ducting, routing techniques and sleeving.

Flammability protection of the MDA cable assemblies was in accordance with MSFC-SPEC-101A. Cables were completely enclosed in fluorel coated fiberglass tubing. Tubing junctions and cable junctions were formed as shown in Figures 2.2.4-7 and -8. The backup article tubing junctions were improved for handling and dressing by use of a telescoping method with a string tie in lieu of the Butt Junction. To complete the enclosure at the connector ends, fluorel coated fiberglass, teflon coated fiberglass, convoluted viton tubing, fluorinated hydrocarbon boot, or approved combinations of these were utilized. See Figures 2.2.4-9 and 2.2.4-10.

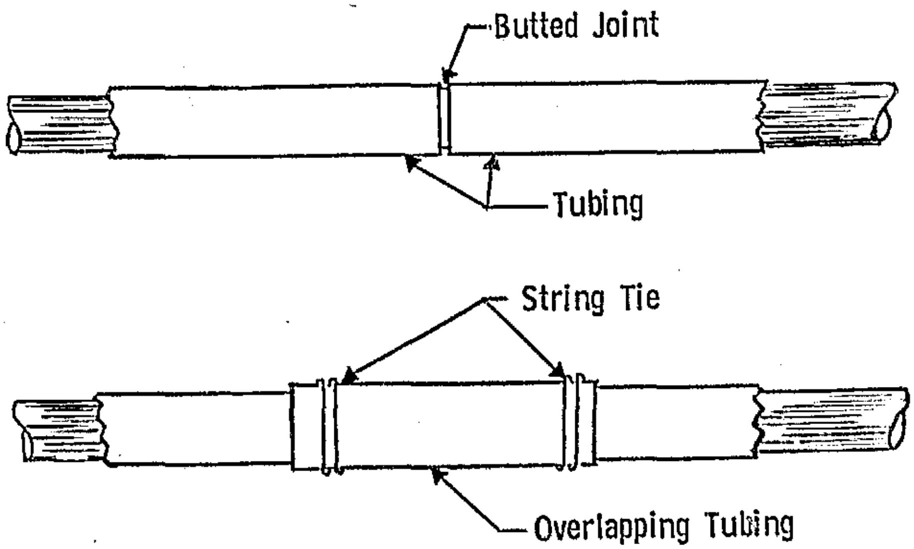
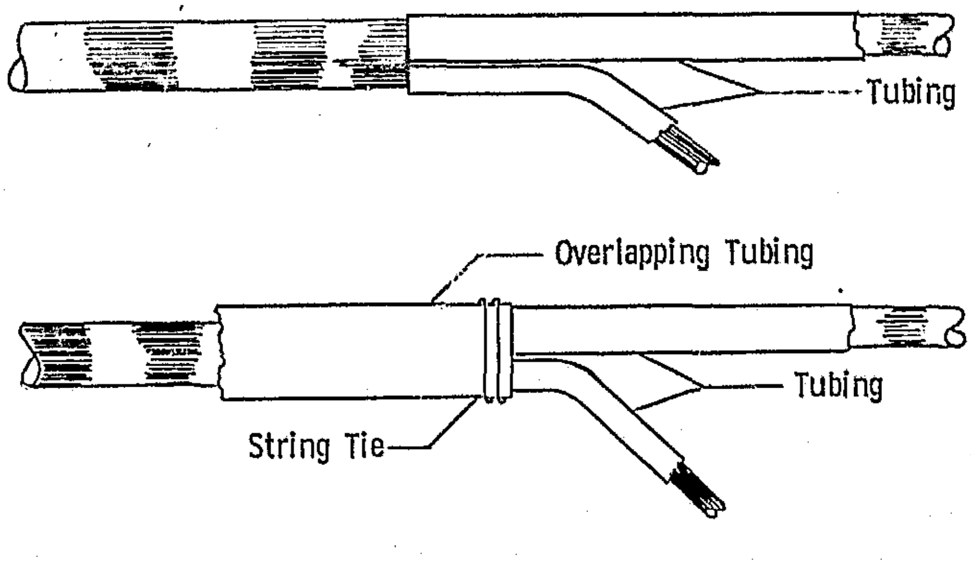
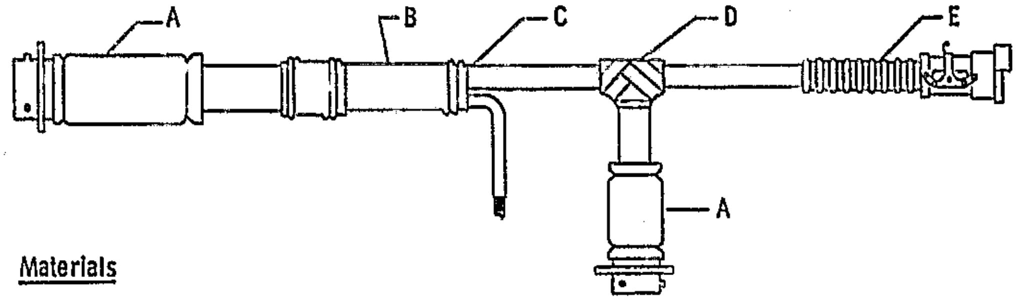


Figure 2.2.4-7 Tubing Junctions



"Y" Type Breakout Joint

Figure 2.2.4-8 Cable Junctions



Materials

A Teflon Coated Fiberglass Cloth (Used to Make Flameproof Covers for Areas Not Covered by Tubing. Covers Are Called Beta Bags).

B Fluorel Coated Fiberglass Tubing - 3 ft Lengths

C Liquid Fluorel Overcoating Material for Sealing Raw Edges of Tubing and for Sealing of Taped Junctions

D Fiberglass Tape - 1/2 and 1 Inch Wide - No Adhesive

E Fluorinated Hydrocarbon Harness to Connector Adapters

Figure 2.2.4-9 Cable Flammability Protection

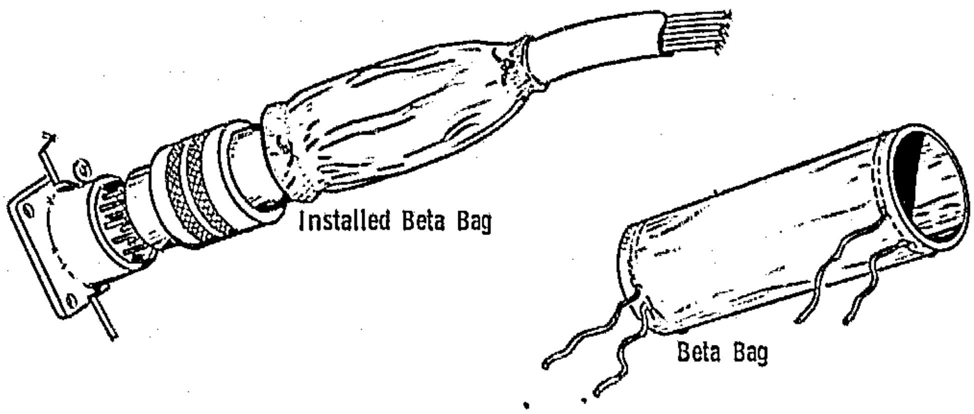


Figure 2.2.4-10 Cable to Connector Flammability Protection

B. Functional Description - The MDA Electrical cabling provided the following functions: interconnection of various electrical subsystems within the MDA itself; and power and signals transfer between equipment and subsystems located within the MDA and other cluster modules.

The contingency cables for the video switch power and the video loop hook-up, MMC drawing 82000042920, were designed, built, and tested to the same criteria as the flight functional cables, and stowed in the MDA.

The BI/LCA cabling system was a mod kit consisting of cable harness, patch panel and 8 shorting plugs. The mod kit was designed to be incorporated with minimal effect or rework on the existing MDA cabling. Proper selection and installation of (4) shorting plugs determined whether the I/LCA or BI/LCA system operated. Installation of the mod kit, on the flight article was accomplished at St. Louis and functionally tested and verified at KSC.

C. Test - Continuity and megger testing of all harness wire was done prior to power application. Testing was performed after harness removal from the development unit and again after installation on the flight article. The same test procedure was used on the harness for the backup unit. The test was accomplished using the Hughes Analyzer and was tested to 1500 VDC breakdown and 50 megohm isolation criteria.

NOTE: Requirement to meet the 1500 VDC breakdown testing was directed by MSFC. Ref: NASA letter PM-SL-AL/MDA-1461-70.

The L-Band cables were subjected to the same 1500 VDC breakdown and 50 megohm isolation testing.

Additional test activities resulting from design changes and connector problems were as follows:

(1) Microdot/Airlock connector tolerance buildup; (NASA Alert 72-03), brought about the design and fabrication of test equipment to test all the affected connectors throughout the cluster.

(2) Structural ground continuity on the docking port heaters was found inadequate on the backup article.

This resulted in additional grounding wires being added to both the backup and the flight article.

(3) Isolation of and/or crew handling requirements of coax connectors ST82D28, ST82D29, and ST82D32 prevented safety wiring of receptacles and/or plugs. Vibration testing was performed on affected connectors to determine the required torque values for mounting the receptacles, as well as for the mating of the plugs.

NOTE: The incorporation of any and all mods into the MDA vehicle resulted in the retesting (continuity and megger) of all affected cables and connectors. This was effective at Denver, St. Louis and KSC.

D. Mission Results - The MDA Electrical cabling, having been designed, constructed and finished in a quality manner consistent with manned space flight operations, demonstrated its integrity throughout all the Skylab missions.

E. Conclusions and Recommendations - The MDA Electrical Cabling System performed satisfactorily. An evaluation of MDA connectors was performed as part of the postflight data analysis and crew debriefings. The results were that all MDA connectors (NB, Micro-dot Airlock and Zero-G) were functional in space environments. For in-flight mating and demating the crew expressed a preference for both the Micro-dot and Zero-G connectors. The crew also suggested that in future space applications the in-flight maintenance connectors should be standardized throughout the spacecraft.

2.2.4.4 Interior Lighting

The MDA Interior Lighting system (see Figure 2.2.4-11) was designed to provide illumination at the crew work stations and for general illumination of the MDA using the General Illumination Floodlight Assemblies.

A. Design Requirements - The design requirements for the MDA lighting system were defined in CP114A1000026 - MDA Contract End Item Specification. The basic requirements were as follows:

(1) General Illumination System -

- An illumination level of 3.5 foot-candle (fc) minimum along the X-axis of the MDA

- A minimum of 5 fc illumination at the work stations and consoles.
- Lights near the ATM C&D Panel were required to have variable illumination with a maximum of 90% illumination.
- The lights were to be controlled individually at the light as well as remotely from the AM.
- All lights were to be simultaneously controlled from the axial docking port.

(2) Emergency Illumination System -

- Automatically controlled and powered from AM.
- An illumination level of 0.5 fc to 2.0 fc along the X-axis of the MDA.
- Lights to come on automatically when AM bus voltage falls below 23 VDC.

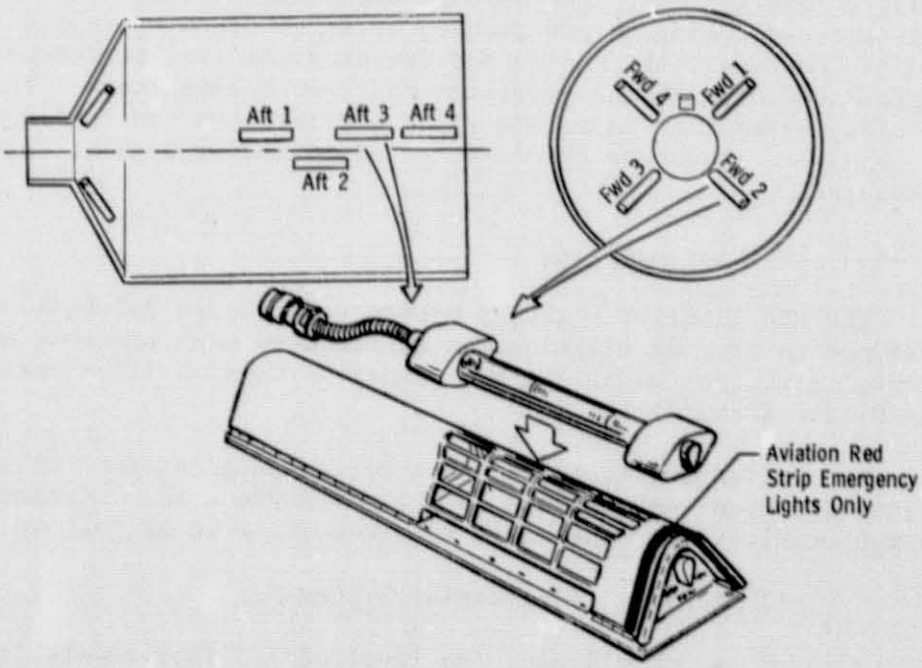


Figure 2.2.4-11 MDA Interior Lighting System

(3) The Light Assembly and the Light Switch Assembly (see Figure 2.2.4-12) were developed to meet the overall system requirements. The specific design requirements of the units were as follows:

(a) Light Assembly (P/N 1B69364) - This unit was supplied to the MDA as GFP equipment. It met the specificacion 1B69364 written by MDAC-W. The requirements of the specification are as follows:

- Assembly shall be hermetically sealed.
- All switching devices shall be hermetically sealed.
- The power shall not exceed 12.5 watts at 28 VDC.
- Each assembly shall have a local control of "OFF", "LOW", and "HIGH".
- Minimum operating life of 4500 hours.

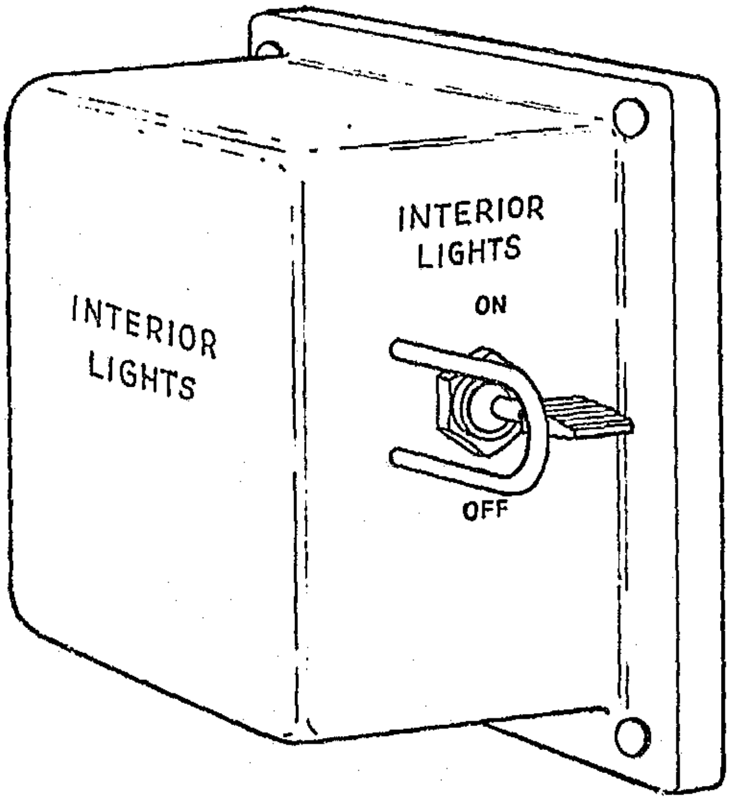


Figure 2.2.4-12 MDA Interior Light Switch Assembly

(b) Light Switch Assembly (P/N 82000001800-009) - The unit was designed and fabricated at MMC. It met the requirements of the equipment specification, 82000001816. Some of the more pertinent of these are listed below:

- Two pole-three position switch (momentary-maintain-momentary).
- Contact rating of 10 amperes at 28 VDC.
- Voltage to unit of 28 $^{+2}_{-4}$ VDC.
- Operating life of 10,000 cycles and storage life of three years.

B. Functional Description - The interior general illumination floodlight assemblies provided crew work station illumination. There were eight interior floodlight assemblies, four on the forward dome and four aft along the air ducts. Each of the eight lights had a local switching capability of "OFF", "LOW" and "HIGH". Each light had an output of 315 lumens minimum before installation into the light fixture. A switch (Panel 101) for On-Off lighting control for all eight lights simultaneously shall be provided near the axial docking port of the MDA for easy access control during astronaut engry. However, the individual light switches had to be in either the "HIGH" or "LOW" position for proper operation. The MDA Lighting Control System was designed such that all AM remote control switches (STS Panel 207) were independent of each other and functioned in pairs of two lights per control. Control power switching of the lights was accomplished through latching relays in the PDAs (82000000900-010). The two lights above the ATM C&D Panel (Aft 3 and Aft 4) were provided with removeable and adjustable light filters for the purpose of attenuating illumination levels at the ATM C&D panel. Two lights (Forward 2 and Aft 3) functioned as emergency lights and were controlled from the AM.

C. Test

(1) Development Tests - The number of lights in the MDA and their location was determined by simulating the flight light output with commercial fluorescent lights and then conducting illumination tests in the MDA Engineering Mockup Unit (EMU). Evaluation included:

- Mechanical Characteristics
- Electrical Characteristics
- Performance Characteristics

Each Light Switch Assembly was acceptance tested at MMC for verification of the following:

- Physical Examination
- Functional Test
- Vibration, Low Level

(2) Qualification Test

(a) Light Assembly - The qualification testing for the Light Assembly was accomplished by MDAC-W.

(b) Light Switch Assembly - The Light Switch Assembly was qualified by MMC. The results are contained in MMC Qualification Test Report No. 3178. All requirements were successfully met except for EMI. The EMI testing was completed in conjunction with the Power Distributor Assembly, see Paragraph 2.2.4.2 C(2)(b) for EMI waiver information. The qualification test covered the following:

- Performance
- Vibration
- Thermal Vacuum
- CCOH (Corrosion Prevention Criteria)
- Shock
- Temperature, Altitude, Storage and Transportation

(3) Acceptance Test - Acceptance tests were completed by Sylvania Corporation (MDAC-W's vendor) and consisted of:

o Functional Verification
o Mechanical Verification (dimensional analysis)
o Illumination Verification

(4) Lighting System Functional Verification

(a) Denver - After installation of the lighting system in the MDA, functional verification and illumination level tests were performed to procedure MDA-OCP-D-60002 "Electrical System Functional". During functional verification testing of the individual light assemblies, two lights drew excessive current in the "LOW" mode. The lights were removed and replaced with flight spares. The removed lights were then returned to MDAC-W for failure analysis and modification. The remaining functional verification tests were completed satisfactorily. The illumination level test was completed successfully except for the ATM C&D Panel and Aft General Illumination.

(b) St. Louis - A functional verification test of the individual light assemblies was accomplished at St. Louis as part of the PDA reverification test (refer Paragraph 2.2.4.2 C(4). During this test, one light exhibited the same malfunction as the two in Denver. The light was replaced and returned to MDAC-W. During SEDR D3-E72, "Systems Assurance", an illumination test was conducted. The illumination level at the ATM C&D panel was again below specification. The decision was made to have a crew evaluation of the lighting during SEDR D3-E76. This was accomplished along with a remeasurement of the illumination level on the ATM C&D panel. The crew evaluation indicated that the lighting was low but adequate. The illumination measurement met the specification at the ATM C&D, it was determined that the light meter was very sensitive as to where it was pointing which could have been the reason for the previous measurements not meeting the specification. Prior to altitude chamber testing, all MDA interior lights were replaced with modified lights received from MDAC-W. The electronics of the lights had been modified as a result of the failure analysis performed by MDAC-W. Remaining tests were completed satisfactorily.

D. Mission Results - The MDA interior lights functioned properly during SL-2.

During the SL-3 flight on DOY 232, the Aft 2 and 4 MDA lights were reported out by the crew. The light assemblies were replaced and switches cycled, but the lights would not come on. Possible causes of the failure could have been an intermittent 'Aft 2·4' light switch on STS Panel 207, inadvertent operation by the crew, or an intermittent relay in an MDA power distributor.

Trouble shooting procedures were accomplished by the crew on DOY 243. The crew completed the first three steps of the procedure and reported that Aft Lights 2 and 4 were "ON" and that the switch on STS panel was intermittent. To preclude any further loss of Aft 2 and 4 lights, the lights were controlled from their local switches instead of the switch on Panel 207. To prevent operation of the light circuit in question during deactivation of SL-3 and activation of SL-4, the SL-3 crew opened the "MDA Light 2" circuit breaker on STS Panel 202. During SL-4 activation the "MDA Light 2" circuit breaker was closed and the Aft 2 and 4 lights were controlled by their local switches.

MDA interior lights performed satisfactorily for missions SL-2, SL-3 and SL-4.

2.2.4.5 Exterior Lighting

A. Design Requirements - The design requirements for the MDA exterior lights were defined in CP114A1000026 - MDA Contract End Item Specification. The basic requirements were as follows:

- One set of four Gemini type running lights is to be used. (See Figure 2.2.4-13)
- Provide illumination to the crew rendezvous from 2,000 feet to 50 feet.
- Sensitivity of each light must be at least 0.25 foot-candles.
- Location and color:

Axis*	Color
+Y	Green
-Y	Red
+Z	Amber
-Z	White

* (Based on mass properties coordinate system)

- Red and green light powered from one electrical bus and white and amber powered by the other AM bus.

B. Functional Description - External running lights were used for gross vehicle attitude determination. They were controlled and activated via the AM/DCS. Running lights were provided to allow determination of coarse vehicle attitude alignment by the crew during rendezvous and docking of the CSM. The running lights were located radially near the MDA outer skin line, but did not interfere with the deployment of the ATM truss as defined in 13M20726. The +Z axis (amber) light was partially obscured by the L-Band truss assembly.

Figure 2.2.4-13 MDA Running Light

C. Test - The MDA running light system was functionally verified at Denver to procedure MDA-OCP-D-60002, at St. Louis to procedure D3-E72 and at KSC to procedure KS0003. All tests were completed satisfactorily.

D. Mission Results - The MDA running lights performed without failure as required in support of rendezvous and docking maneuvers.

E. Conclusions and Recommendations - MDA running lights performance was satisfactory.

2.2.4.6 Rate Gyro Six Pack Cabling

During mission SL-2, the Rate Gyro system reflected an unstable operating condition caused by overheating of individual Rate Gyro assemblies. A new hardware requirement was generated to build a contingency Rate Gyro system (Rate Gyro Six-Pack) to be incorporated into the airborne system for use during missions SL-3 and SL-4. As a result of this new requirement, the MDA Electrical group designed, fabricated, tested and delivered three cable sets needed to incorporate the Rate Gyro Six Pack into the MDA:

- 1-flight
- 1-DAT/flight backup
- 1-Zero-g trainer

A. Design Requirements - Refer to Section 2.2.4.3 A.

B. Functional Description - A complete cable set consisting of:

(1) One power and control distribution cable assembly between the Rate Gyro Six-Pack distributor and the individual gyros (6).

(2) One Y-cable assembly connecting between the control distributor of the Rate Gyro Six-Pack, the MDA cable connector 807W46P1 and receptacle 807W44J21 of the ATM C&D distribution panel (807W46P1 was launched mated with 807A44J21).

(3) One power cable assembly connecting between the Rate Gyro Six-Pack distributor and the MDA High Power Accessory Outlet No. 2 to provide 28 VDC (AM Bus 2) operating power.

NOTE: An additional external cable was designed and built by MSFC.

C. Test Requirements - Refer to Section 2.2.4.3.C.

D. Mission Results - Operation of the ATM Rate Gyro system, using the Rate Gyro Six-Pack and associated cabling, met all requirements during the SL-3 and SL-4 missions and subsequent orbital storage periods.

E. Conclusions and Recommendations - The Rate Gyro Six-Pack Cabling performance was satisfactory.

2.2.4.7 Rate Gyro Six Pack Meter Checkout Cables

A capability to evaluate operational characteristics of each Rate Gyro was required. The operational checkout cable set consisted of two (2) cable assemblies.

A. Design Requirements - Refer to Section 2.2.4.3.A.

B. Functional Description - By using the two cable assemblies and a digital voltmeter, the output signals from each gyro and the internal operating temperature of each gyro could be measured/monitored, as desired. The checkout cables mated with the Rate Gyro Six-Pack Control distributor and a digital voltmeter.

C. Test Requirements - Refer to Section 2.2.4.3.C.

D. Mission Results - During missions SL-3 and SL-4, the performance of the cables met all requirements.

E. Conclusions and Recommendations - The Rate Gyro Six-Pack Meter Checkout Cables performance was satisfactory.

2.2.4.8 TV Mini-Monitor Power/Signal Cable

During mission SL-3, ATM TV Monitor No. 1 system failed. A requirement was generated to provide capability to use the onboard TV Mini-Monitor to replace the failed ATM TV Monitor No. 1 during mission SL-4.

A. Design Requirements - Refer to Section 2.2.4.3.A.

B. Functional Description - The power/signal cable was a Y configured cable. The cable mated with the MDA Low Power Outlet #2 (Panel No. 134), the TV Mini-Monitor and with the ATM MON 1 Cable connector 80/W51P4 that mated to J-1 of the MDA Video Switch Selector Assembly.

C. Test Requirements - Refer to Section 2.2.4.3.C.

D. Mission Results - Due to CSM storage priorities, the TV Mini-Monitor cable was not carried up on SL-4.

E. Conclusions and Recommendations - No mission data for conclusions and recommendations.

2.2.4.9 Adapter Power Cable/Modified Lunar Drill (Electric Nibbler)

A power cable was designed and fabricated to be used with a modified Lunar Drill. The assembly was to be used as a metal cutting tool in support of mission SL-2. The concept was to use the CSM as a power source for the modified Lunar Drill during an EVA to aid in releasing the malfunctioned OWS Solar Wing Panel.

A. Design Requirements - Refer to Section 2.2.4.3.A.

B. Functional Description - The power cable configuration was a two-wire cable sheathed in convoluted scuff resistant tubing approximately 20 feet in length. One cable end terminated into a Zero-G connector, type ZG6E2525-19PA, permitting mating to CSM Panel 230 to provide 28 VDC power. The other cable end terminated into a "Yardney battery" drill interface connector which required a special backshell. The backshell allowed for potting of the connector and attachment of the convoluted tubing. The cable/connector assembly was secured to the Lunar Drill battery interface adapter plate. The cable/adapter plate then became an integral portion of the modified Lunar Drill (Electric Nibbler). Usage was to be in conjunction with a CSM flyaround and a standup EVA.

C. Test Requirements - Refer to Section 2.2.4.3.C.

D. Mission Results - The modified Lunar Drill (Electric Nibbler) and power cable were prime candidates for mission SL-2, however, an alternate method was developed which deleted the requirement for the "Electric Nibbler".

E. Conclusions and Recommendations - No mission data for conclusions and recommendations.

2.2.4.10 MDA Engineering Mockup Unit (EMU) Article

A. Design Requirements - The design requirements for the finalized MDA EMU Article was to provide an MDA test article of suitable fidelity to work component, systems, crew and vehicle relationships. To achieve that objective, the components and cable bundles were representative in visual appearance and manual operation to their flight counterparts. The specific "defined" requirements for the EMU are defined in MSFC MOD, MSFC-165.

B. Functional Description - The MDA EMU electronic system consisted of nonfunctional as well as functional prototype equipment and circuitry.

(1) Electrically Functional Equipment - The electrically functional equipment which MMC provided for the MDA EMU was as follows:

- Interior Lights (8)
- Entry Light Switch
- Utility Outlet, Low Power (4)
- Accessory Outlet, High Power (2)
- Speaker Intercom Assemblies (3)

(2) Nonelectrically Functional Equipment - The nonelectrically functional equipment which MMC provided for the MDA EMU was as follows:

- TV Outlet Unit
- TV Control Unit
- UV (Fire Sensor)
- Inverter/Lighting Control Assembly
- UV (Fire) Sensor Control Panel
- 16 MM Camera Cables
- Window Heater Control Switch
- Intervalometer
- Radio Noise Burst Monitor (2)
- Window Heater Limit Switch

- Backup D.A.S.
- Wall Heaters
- Pressure Sensor PSIA
- Pressure Sensor

(3) Electrically Functional Circuitry - The electrically functional circuitry which MMC provided for the MDA EMU was interfaced by facility power at the EMU Rack. The electrically functional circuitry and EMU Rack functions and their interfaces were as follows:

- Interior Lights (8) 75 VAC to 117 VAC, 60 Hz
- S009 28 VDC (GFP S009)
- Utility Outlets, Low Power (4) 28 VDC
- Accessory Outlets, High Power (2) 28 VDC
- External Acquisition Lights (4) 28 VDC (GFP Lights)
- Area Fans (2) 28 VDC (GFP Fan)
- Entry Light Switch 28 VDC
- CSM Fan (1) 28 VDC (GFP Fan)

The electrical and facility interface requirements for the EMU Rack and its interconnecting cabling were as follows:

- Provide individual ON, OFF, and LOW brightness control for each of the eight interior lights.
- Provide a relay to interface with the MDA entry light switch, simulating the function of the flight article's Power Distributor Assembly.
- Provide intercom with subjects in vehicle.
- Provide 28 VDC power to the electrically functional MDA equipment.
- Provide MDA EMU equipment with facility power, 28 VDC and intercom.

C. Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

D. Mission Results - Prior to the launch of Skylab the EMU article was converted to the One-G Training Article under a new MSFC MOD (See Section 2.2.4.11).

E. Conclusions and Recommendations - The EMU article provided its required functions satisfactorily.

2.2.4.11 MDA One-G Training Article

A. Design Requirements - The Design requirements for the MDA One-G Training Article were: adequate and proper training of the astronauts and the generation of suitable crew procedures and flight problem workarounds. Component and system fidelity was required to be representative in visual appearance and manual operation. The specific component requirements are defined in MSFC MOD, MSFC 322 "MDA One-G Trainer Definition".

B. Functional Description - The MDA One-G Trainer electronic system consisted of nonfunctional as well as functional equipment and circuitry. Due to training requirements being unique, NASA along with MMC support, established a fidelity matrix (Table "A" and "B" of the above referenced mod) to be adhered to in component and system design.

(1) Electrically Functional Equipment - The electrically functional equipment which MMC provided for the MDA One-G Trainer was as follows:

- Interior Lights (8)
- Entry Light Switch
- Utility Outlet, Low Power (4)
- Accessory Outlet, High Power (2)
- Video Switch
- Television Input Stations
- External Acquisition Lights (4)

(2) Nonelectrically Functional Equipment - The nonelectrically functional equipment which MMC provided for the MDA One-G Trainer was as follows:

- UV (Fire) Sensor (2)
- UV (Fire) Sensor Control Panel
- S190 Window Heater Control Panel
- S190 Window Heater Cable with Temp Sensor
- Radio Noise Burst Monitor
- Backup D.A.S.
- Temperature Transducers (2)
- Window Cover Limit Switch
- S190 Window Sensors and Electronics
- Docking Port Heaters (2)
- Docking Port Thermostats (2)

- Wall Heaters 40 watt (4)
- Wall Heaters 20 watt (3)
- Wall Heater Thermostat $+45^{o}F$ (2)
- Wall Heater Thermostat $+70^{o}F$ (2)
- Gas Temperature Sensor - Cone
- Auto Transformer (BI/LCA)(2)
- DC-DC Converter (BI/LCA)(2)
- Shorting Plugs - I/LCA(4)
- Shorting Plugs - BI/LCA(4)

(3) Inflight Maintenance equipment which MMC provided for the MDA One-G Trainer was as follows:

- Video Switch - Nonelectrically functional
- Television Input Station - Nonelectrically functional
- S190 Window Heater Cable with Temp Sensor - Nonelectrically functional
- Video Switch Contingency Power Cable - Electrically functional
- Revision of ATM C&D Console cable interface to facilitate astronaut training toward expedient on-orbit installation of the carry up Rate Gyro Six Pack system.

(4) Electrically Functional Circuitry - The electrically functional circuitry which MMC provided for the MDA One-G Trainer was interfaced with the training facility at the Training Interface Panel (TIP). The electrical and facility interface requirements for the TIP and its interconnecting cabling were as follows:

- TIP Functional Requirements - Provide simulation of AM Bus 1 or AM Bus 2 failure causing MDA component(s) loss. Provide individual ON, OFF and LOW brightness control for each of the eight interior lights. Low brightness was accomplished by a rheostat which allowed varying voltages to be applied to the lights instead of the normal 117 VAC.
- Provide a relay to interface with the MDA entry light switch, simulating the function of the flight article's Power Distributor Assembly.
- Provide power and control for the external acquisition lights. Provide 28 VDC power to the electrically functional MDA equipment.

The electrically functional circuitry TIP functions and associated interfaces were as follows:

- Interior Lights (8) - 75 VAC to 117 VAC, 60 Hz
- Television Input Station - 28 VDC and Speaker Intercom Assemblies (2) - 28 VDC Signal
- Rate Gyro Six-Pack (SL-3) - 28 VDC and Signal
- S009 - 28 VDC
- Utility Outlets, Low Power (4) - 28 VDC
- Accessory Outlets, High Power (2) - 28 VDC
- External Running Lights (4) - 28 VDC
- Entry Light Switch - 28 VDC
- Rate Gyro Checkout Cables (2) - Signal

C. Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

D. Mission Results - The One-G Training Article provided the high-fidelity necessary to successfully support the Skylab mission. The Article was used extensively during the mission to develop astronaut procedures and assist in developing new cables for crew on-orbit installation and checkout.

E. Conclusions and Recommendations - The One-G trainer successfully provided its required functions throughout all phases of the MDA program.

This Page Intentionally Left Blank

2.2.5 Instrumentation System

The instrumentation system consisted of a signal conditioner, temperature transducers and a pressure transducer. The temperature transducers were platinum resistance elements which sensed the temperature at various locations internal and external to the MDA. The signal conditioner consisted of power supplies and bridge completion networks of which one leg was the temperature transducer. The measurement output range of the signal conditioner was a 0 to 20 mv signal corresponding to the temperature at the temperature transducer. The pressure transducer was a potentiometric device which measured the internal MDA pressure. The output of the transducer was a 0 to 5 volt signal corresponding to MDA absolute pressure.

2.2.5.1 Signal Conditioner

The Signal Conditioner, P/N 82000001000, provided signal conditioning for the MDA instrumentation system temperature measurement sensors.

A. Design Requirements - The specific design requirements were not specified in an ICD. The Equipment Specification 82000001016, gave all the details necessary for the design. The signal and loading are described in ICD 50M13122. Following is a list of drawings and specifications needed for the build of the Signal Conditioner:

82000001000	Top Assembly, Signal Conditioner
82000001016	Equipment Specification, Signal Conditioner Assembly
82000001018	Test Specification - Range Cards
82000001026	Range Card Assembly
82000001027	Range Card Schematic

B. Functional Description - The Signal Conditioner provided to the AM PCM system, electrical signals proportional to the ambient temperature of platinum sensors electrically connected to it (See Figure 2.2.5-1). The basic Signal Conditioner circuit design came from the ATM I&C subsystem and required synthesis of the bridge resistors for use on the MDA. The Signal Conditioner weighed 16 pounds, was 475 cubic inches in volume and required 2.5 watts at 28 VDC for operation.

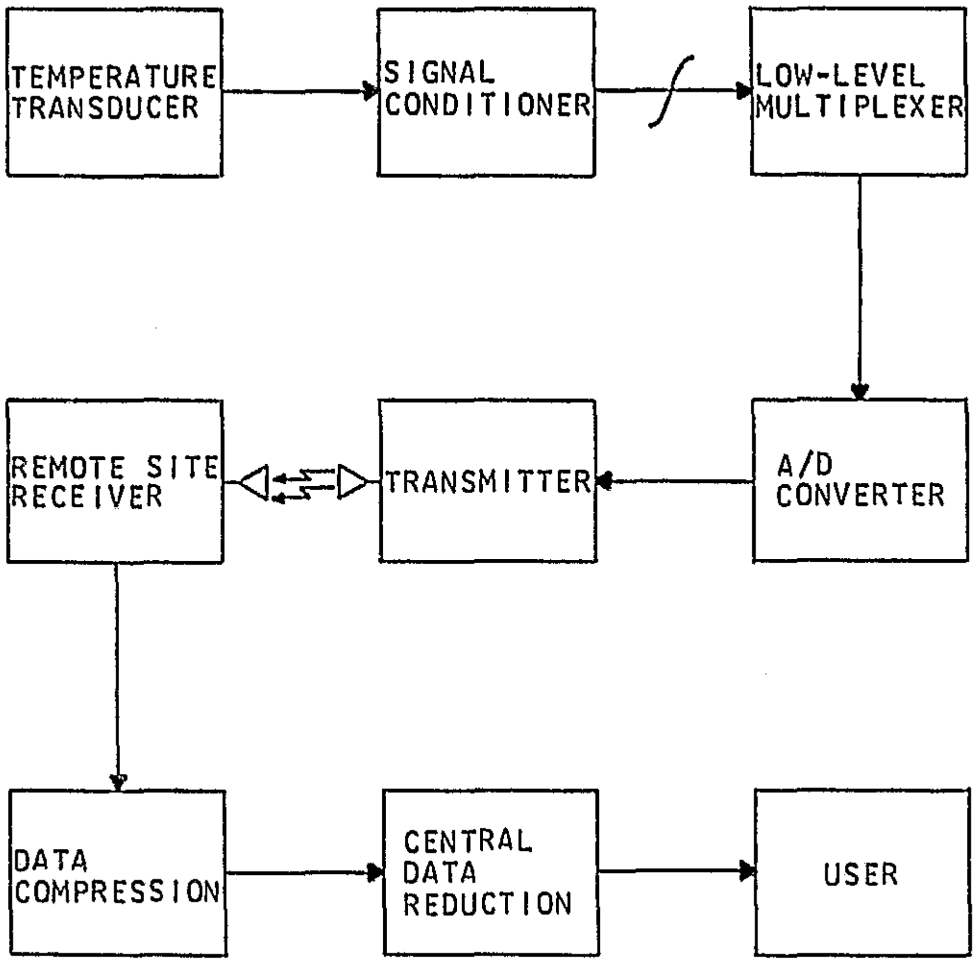


Figure 2.2.5-1 MDA Temperature Measurement System Block Diagram

The Signal Conditioner consisted of 40 bridge completion circuits, of which 37 were actively used (See Figure 2.2.5-2) and four power supplies. There were three unique bridge circuit designs which conditioned measurements to the three required temperature ranges. The Signal Conditioner was divided into four groups of 10 bridge circuits and one power supply each. The four power supplies provided identical voltages (8-9 volt open circuit) to each bridge circuit with the actual bridge voltage and the maximum output voltage determined by a zener diode and a voltage divider network consisting of R1, R2, R3 and the bridge itself. The bridge was designed such that the lowest temperature to be measured produced a null voltage condition. The null voltage adjustment was provided by R8. The maximum

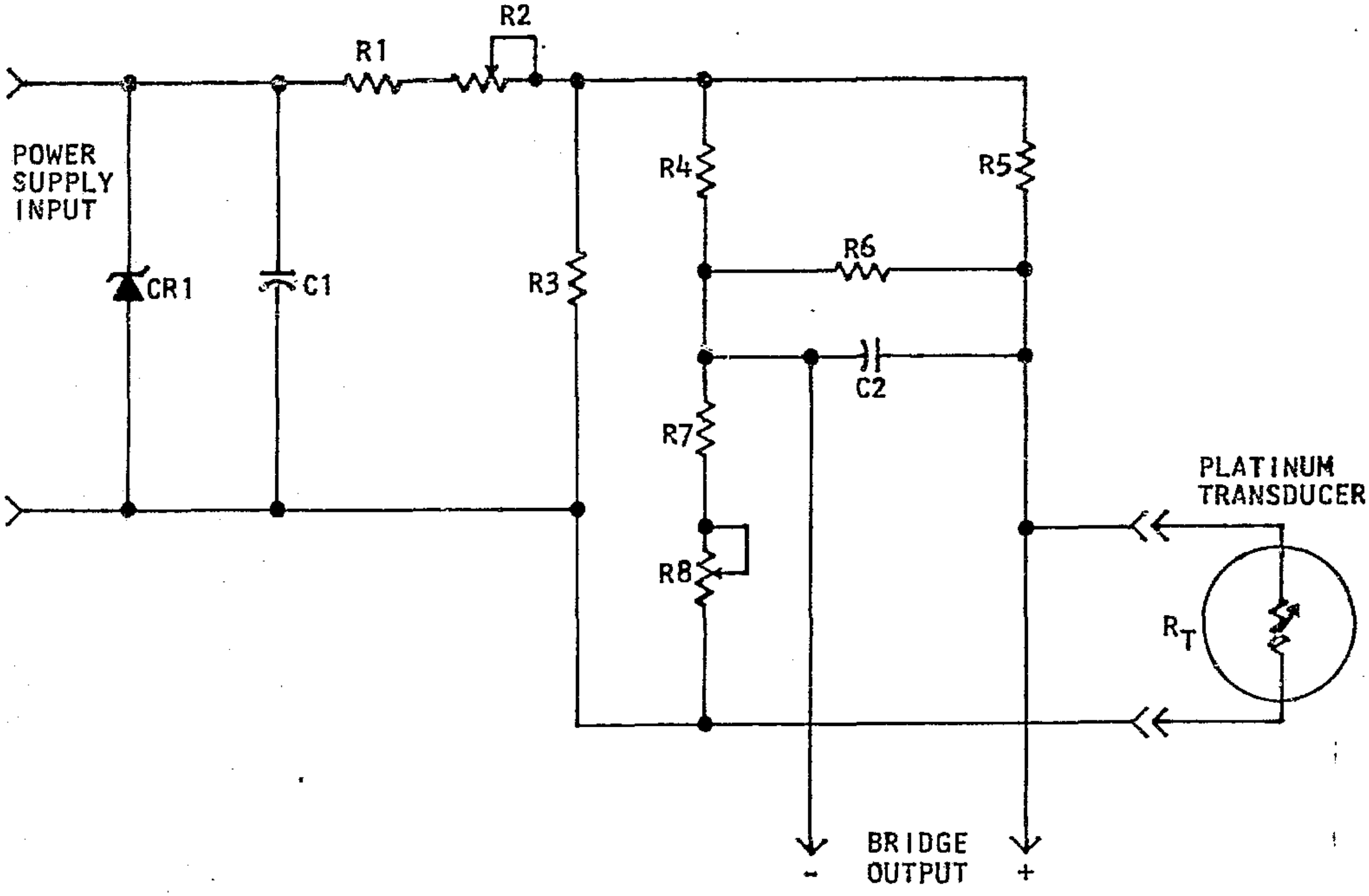


Figure 2.2.5-2 Bridge Completion Network Schematic

nominal output voltage corresponding to the highest temperature to be measured was 20 mv. The maximum nominal output was obtained through adjustment of R2.

C. Test-

(1) Qualification Test - Due to the similarity with the ATM Signal Conditioner only a delta qualification test was performed. This consisted of a shock and vibration test. The primary reason for this was the lack of shock requirements on the ATM. The MDA shock requirement was 380 g's and the vibration was 7 g rms maximum. The operations are called out in the Equipment Specification 82000003816, Paragraphs 3.2.?.5.2.5 and 3.2.2.5.2.6. A delta test was later performed to verify environmental temperature requirements compliance. During the test, 10 signals were monitored while the temperature varied from -40°F to +150°F. The average delta was 0.4 mv over the full range.

The Signal Conditioner passed all tests successfully. The results were recorded in Qualification Report #3179.

(2) Systems Test - All systems tests were performed with the only failure being out of specification temperature readings resulting from the use of Vamistor resistors. Due to contamination during the build process, these resistors progressively shifted in resistance causing a corresponding shift in bridge output voltage. The Vamistor-type resistor drift problem was solved by recycling the signal conditioner-printed circuit boards and assemblies through manufacturing and acceptance testing. The Vamistor resistors were removed and replaced with Mepco and Ward Allen type resistors and re-tested at the board level. Each signal conditioner assembly was then reacceptance tested without failure.

After the rework and reinstallation of the Signal Conditioner in the flight article, new calibration data for each signal conditioner bridge circuit was calculated using the new ATP test data and the bridge offset caused by the resistance of the wire connecting the sensor to the Signal Conditioner. This resistance was determined by subtracting the original ATP test data (signal conditioner/cable interface) from the KSC system level test (cable/sensor interface). This difference was directly attributable to the interconnecting wire resistance.

An end-to-end system level calibration test was not possible due to the configuration of the mated AM/MDA at KSC.

D. Mission Results - The Signal Conditioner performed exceptionally well throughout the Skylab mission. It was operated continually from the launch of SL-1 through SL-4. It provided accurate data well within the predicted values and no failures were attributed to the hardware.

In support of the mission, the following analyses were performed:

(1) Error Analysis - An analysis was performed to establish the three sigma (99.7 probability) error band, considering calibration, environment and mission life, from the transducer to the data user. The total error was obtained by calculating the error attributable to the MDA Signal Conditioner, obtaining the best available PCM system error data from MDAC-E and using transducer acceptance test procedure data. No data reduction error was included because an errorless conversion from PCM to temperature or pressure was assumed.

The analysis entitled "Skylab MDA Engineering Report: Temperature and Pressure Measurement Error Analysis" was submitted to NASA in MMC letter 73Y-80,796, dated 21 May 1973.

(2) Corrected Calibration Data - During SL-1/2 it became apparent that the calibration data being

used for data reduction of temperature and VTR 'tape-remaining' measurements were incorrect. MMC derived the correct calibration data utilizing a third order curve fit computer program, with data inputs from sensor and signal conditioner tests. The corrected data vs both digitized counts and incorrect data (then in use) were published and distributed to NASA and MMC (73Y 80,837 - Identification of Calibration Data Certification Responsibility) users. Similarly derived corrected calibration data were put into the MSFC data reduction computer prior to SL-3 launch. While the data processing system has occasionally reverted to the incorrect calibration data, the predominant amount of MDA data has been correctly processed.

(3) Trend Analysis - A continuing trend analysis was performed throughout the Skylab mission. The purpose of the analysis was two-fold: First; detect measurement failures and second; detect measurement trends which would eventually lead to a failure condition. For internal temperature measurements, the analysis consisted of calculating the MDA mean wall temperature and comparing each measurement to the mean. Limits were established based on system errors, measurement location and special conditioners (e.g., MDA thermal gradient, equipment operation and the addition of the Rate Gyro Six-Pack). External temperature measurements were compared to the average external temperature. Evaluation of the MDA pressure measurement was accomplished by comparing it to measurements D217-540, Lock/Amb Delta P and D218-540, Aft/Amb Delta P. No failures or failure trends were identified.

(4) Noise Analysis - During the manned phases, the activation of the AM Caution and Warning System coupled noise onto several temperature measurements. The peak noise and average peak noise were determined for those channels where the noise peaks exceeded 1% of signal range. Noise, even at the 6% level proved not to be a problem, as the true reading could be determined by scanning several sequential data points.

E. Conclusions and Recommendations - The Signal Conditioner performed satisfactorily throughout the mission without any signs of failure. Future missions should consider using state of the art design and components to greatly decrease size, weight and power.

2.2.5.2 Temperature Transducer

Variable resistance temperature transducers were installed in the MDA to provide instrumentation measurements for the MDA external and internal wall and atmospheric gas temperatures.

A. Design Requirements - Design requirements for the MDA temperature transducer were included in PD7400082 and based on the requirements specified in SP113A1000026D, MDA CEI.

B. Functional Description - The PD7400082-009 temperature transducer was a variable resistance device with a platinum resistive element mounted in a stainless steel case. The unit included stainless steel sheathed cable and a three pin NASA-type connector which interfaced with the MDA electrical cabling. The units measured 500 ± 0.5 ohms at $0^{\circ}C$ and were calibrated over an operating range of -125 to $+150^{\circ}C$.

Vendor for the transducer was: Hy Cal Engineering, Santa Fe Springs, California.

Transducer type was RTS-4565-A.

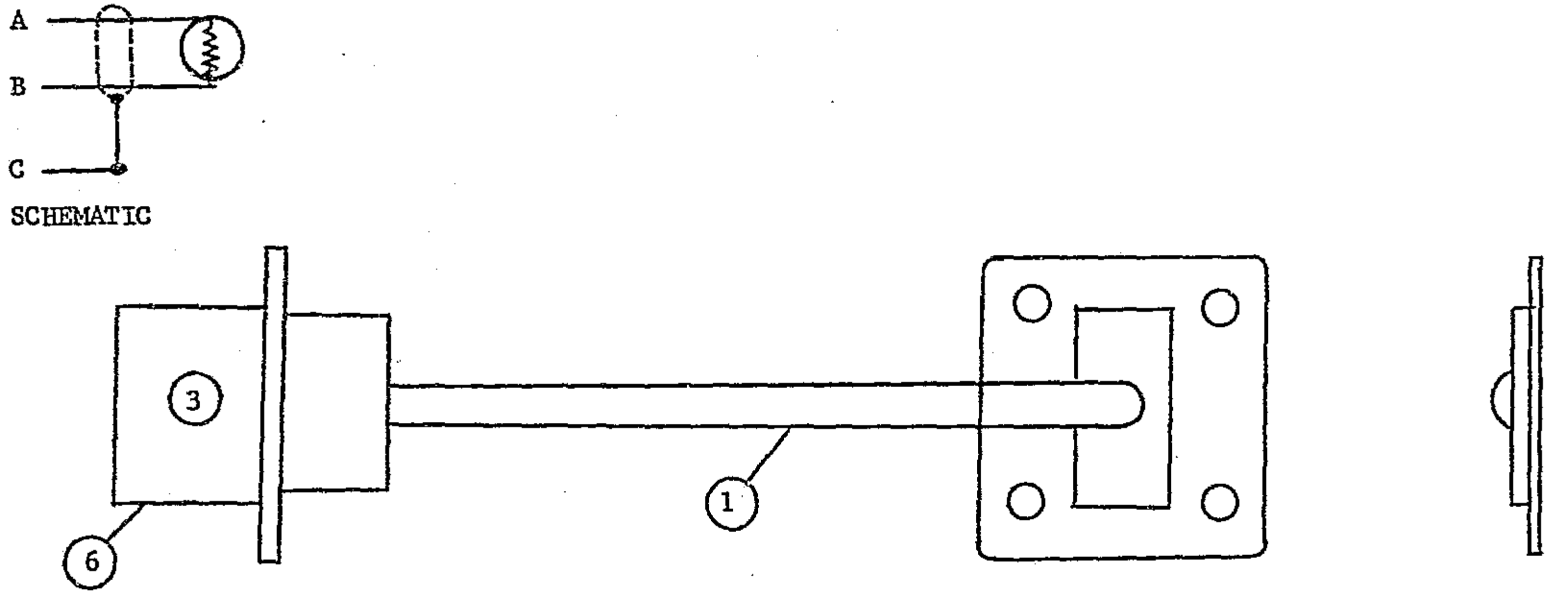
The transducers were bonded with a thermally conductive adhesive at various locations inside and outside the MDA or to mounting adapters that were subsequently installed within the MDA. See Figure 2.2.5-3.

The resistive element of the sensor formed a leg of a bridge circuit within the MDA signal conditioner. Bridge circuit components permitted adjustment to operating ranges of:

- Internal $+23^{\circ}F$ to $+113^{\circ}F$
- External $-193^{\circ}F$ to $+212^{\circ}F$
- Proton Spectrometer $-103^{\circ}F$ to $+167^{\circ}F$

C. Test -

(1) Qualification Test Document - Hy Cal Engineering Document 70-522A.



1. STAINLESS STEEL SHEATH CABLE
2. CASE MATERIAL: AUSTINETIC STAINLESS STEEL
3. ELECTRICAL CONNECTOR: NASA TYPE NB7H9-98PN PER MSFC-40M39569
4. ELEMENT MATERIAL: 99.999% PURE PLATINUM
5. 0°C RESISTANCE: 500 ± 0.5 OHMS
6. CONNECTOR COVER NO. G1109E8B4-1

Figure 2.2.5-3 Temperature Transducer

(2) Testing - Qualification testing of the temperature sensors was accomplished at the vendor's facility and was performed on Serial Numbers 0000001 and 0000002. Both units failed to read within limits at the icepoint after temperature cycling. Thermal cycling tests were passed by S/N 0000003, 0000004, and 0000083. See Table 2.2.5-1 for qualification test satisfaction and component disposition.

Table 2.2.5-2 reflects usage of the temperature transducers and disposition of components not installed on the flight or backup article.

D. Mission Results - The temperature transducers were used continuously during manned and unmanned flight of the Skylab. All transducers performed satisfactorily through SL-4, with the exceptions noted below:

On DOY 295, MDA tunnel wall temperature measurement (C0052) exhibited erratic output indicating a possible sensor/signal conditioner/multiplexer and/or associated wiring failure. The measurement as observed on strip charts and tab runs increased in magnitude rapidly and erratically (12°F fluctuations) to a level approximately 25°F above the apparent tunnel wall temperature at the time. The measurement level did not decreased below the apparent wall temperature during any of the fluctuations.

A lab test utilizing a spare MDA signal conditioner, flight temperature transducer and the signal conditioner test box was performed with the following conclusion:

- Introduction of 50 ohms in series with the sensor causes the measurement output to go off-scale, high (113.9°F)

Analysis of the signal conditioner bridge circuit showed that the above phenomenon, can occur with a proportional change in value of the bridge components associated with measurement C0052.

The MMC support group at MSFC performed a sneak circuit analysis of the involved circuitry and concluded that the problem could be caused by drift of the integrated choppers in AM multiplexer (P). However, they felt that the problem was more likely (see page 259)

S/N	ATP	Repeat-ability	Self Heating	Time Constant	Vibration	CCOH	Shock	Thermal Cycling	Disposition
0000001	9/4/70	9/8/70	9/8/70	9/8/70	9/16/70	10/2/70	10/13/70	10/13/70 Failed MARS B67461	- F/A - Scrap
0000002	9/4/70	9/8/70	9/8/70	9/8/70	9/17/70	10/2/70	10/13/70	10/14/70 Failed MARS B67461	- F/A - Repair - Delivered Spare
0000003	11/4/70 11/13/70							11/4/70 Failed MARS B77463 11/13/70	- Repair - Delivered
0000004	11/4/70							11/4/70	- Delivered
0000005	11/13/70							11/13/70	- Delivered

Table 2.2.5-1 Temperature Transducer Qualification Test Results and Disposition

S/N NO.	Location/Disposition				S/N NO.	Location/Disposition		
	FLT	BU	MISC			FLT	BU	MISC
1			Scrapped		25	C0018		
2			MMC-DEN Surplus		26	C0045		
3			Consumed DEN TEST		27			Scrapped
4			MMC-DEN Surplus		28	C0048		
5	C0030				29	C0049		
6	C0032				30			Failed KSC Scrapped
7	C0015				31	C0004		
8	C0035				32	C0051		
9	C0046				33	C0024		
10	C0052				34	C0031		
11	C0033				35	C0038		
12	C0034				36	C0022		
13	C0005				37	C0040		
14	C0003				38	C0002		
15			Failed ST. LOUIS		39	C0043		
16	C0037				40		C0031	
17	C0042				41		C0052	
18	C0041				42		C0033	
19	C0050				43		C0046	
20	C0039				44			
21	C0044				45		C0043	
22	C0021				46		C0015	
23	C0047				47		C0023	
24	C0016				48		C0044	

Table 2.2.5-2 Transducer Location/Disposition

(Sheet 1 of 2)

S/N NO.	Location/Disposition FLT	BU	MISC	S/N NO.	Location/Disposition FLT	BU	MISC
49		C0037		73		C0002	
50		C0051		74		C0032	
51		C0005		75		C0042	
52		C0041		76		C0035	
53		C0045		77		C0021	
54		C0040		78		C0016	
55		C0036		79	C0023		
56		C0048		80		C0038	
57		C0047		81		C0022	
58		C0003		82		C0024	
59			Spare MMC-DEN	83			MMC-DEN Surplus
60			Spare MMC-DEN	84			
61			Spare MMC-DEN	85			Spare MMC-DEN
62			Spare MMC-DEN	86	C0019		
63		C0039		87			
64		C0018		88			Spare MMC-DEN
65		C0034		89	C0036		
66		C0004					
67			MMC-DEN Surplus				
68			MMC-DEN Surplus				
69		C0049					
70		C0050					
71		C0019					
72		C0030					

Table 2.2.5-2 Transducer Location/Disposition (Cont.)
(Sheet 2 of 2)

due to variations in component characteristics in the signal conditioner circuitry. Evaluation of strip chart and MOPS data indicated a possible correlation between the erratic indications of C0052 and the tunnel wall heaters. Extensive analysis of available data revealed the following:

- Initial C0052 anomaly - C0029 and M0516 also exhibited some erratic movement but C0029 and M0516 became stable shortly thereafter and remained stable.

- C0033 provided reliable tunnel wall temperatures in the absence of C0052, even though it read slightly lower than C0052 because of its location and the vehicle attitude with respect to the sun.

- C0052 became erratic when tunnel heaters were turned on and/or when the tunnel temperature increased in an erratic fashion.

- Measurement C0052 became more erratic when primary tunnel heater #1 was on, than when primary tunnel heater #2 was on, although both affected the output on an intermittent basis.

Contact with the sensor vendor (Hy Cal, Santa Fe Springs, California), revealed that no similar phenomenon had been experienced with that particular device. Efforts to correlate the anomalous phenomenon with a cause were unsuccessful. It was recommended to the Denver Support Room Systems Area that the parameter should be considered unreliable and all data users were so informed.

On DOY 349 excessive noise was noted on low level multiplexer (P) measurements C0028, C0029, C0052, M301, M302, M303 and M304. MDAC-E concluded the most probable cause for the problem was a change in turn-on characteristics of the second tier switch associated with the noisy parameters. On DOY 357, measurements on all AM low level multiplexers became erratic. MDAC-E concluded the problem was caused by a double failure, but could not exactly duplicate the problem at the STU/STDN facility at St. Louis.

These additional problems associated with the low level multiplexer raised doubts that the C0052 measurement anomaly was a transducer or signal conditioner failure, but rather, may have been an indication of an incipient multiplexer failure.

E. Conclusions and Recommendations - There have been no confirmed temperature transducer failures since qualification testing. The component has proven itself as a high-reliable device for monitoring temperatures over a wide range of applications.

2.2.5.3 Pressure Transducer

A potentiometric pressure transducer was installed in the MDA to provide for measurement of the MDA ambient pressure.

A. Design Requirements - Design requirements for the MDA pressure transducer are included in PD7400081 and based on the requirements specified in CP114A1000026D, MDA CEI.

B. Functional Description - The PD7400081-010 pressure transducer was a potentiometric device housed in a stainless steel case. One end was a pressure port with a MS33656-4 pressure fitting. The other end had an electrical connector of weld-mount hermetic design to mate with Deutsch P/N NB6E-8-98-SNC. A wiper arm was positioned to sweep across a precision wirewound resistance element of 5000 ohms ±250 ohms, picking off a voltage ratio directly proportioned to applied pressure. Calibration was based on direct proportionality, 0% VR representing 0% pressure, and 100% VR representing 100% pressure. The instrument had a 1.7% static error band which included the effects of nonlinearity, hysteresis, resolution, repeatability and friction. The range of the transducer was 0 to 6 pounds per square inch - absolute.

Vendor for the transducer was: Servonic Division, Gulton Industries, Inc., Costa Mesa, California.

Transducer type was: 3031-11801.

The transducer was installed behind the ATM C&D console.

The transducer, not requiring signal conditioning, was connected directly to AM high level multiplexer B.

C. Test

(1) Controlling Test Documents were Qualification Test Procedure QTP-3031-11801 and Acceptance Test Procedure, ATP-3031-11801.

(2) Testing - Qualification testing of the pressure sensors was accomplished at the vendor's facility.

Two test units, SN0000013 and SN0000014, were subjected to the bench operating test. Post Bench Operating Calibration indicated test unit S/N 0000013 error band was +2.1% and -2.3%. Maximum allowed is +1.7%. Two new test units, SN0000018 and SN0000019, were constructed and submitted into the Qualification Test Program. During shock test at 1500 g's, both test units exhibited output error in excess of specification limits. Specification limits are +1.7% full scale 10 milliseconds after completion of shock pulse (shock pulse duration approximately 480 milliseconds). Test unit SN0000019 post shock calibration failed to operate beyond 4.7 psia. Investigation revealed that wiper arm resonance and total energy absorbed during shock testing resulted in a relaxation of the wiper tension. Test unit SN0000019, was readjusted, submitted to ATP, and then reinserted into the Qualification Program at the Shock Sequence. Concurrently, the transducer location became better defined and as a result the peak shock load was reduced from 1500 g's to 380 g's. SN0000018 showed no post shock functional out-of-tolerance condition after shock testing. Reappraisal of shock data taken while the test unit was run using new criteria indicated SN0000018 passed the higher shock level. Therefore, this unit was not rerun to the reduced shock level.

It was concluded that the two test units, serial numbers 0000018 and 0000019, passed all qualification test requirements and were qualified.

A summary of pressure transducer failure analyses (not including SN0000013 and SN0000014) is included in Table 2.2.5-3.

D. Mission Results - The pressure transducer was operated continually and performed nominally throughout the Skylab Mission.

SERIAL NO.	MARS NO.	TEST OBSERVED IN	FAILURE OBSERVED/CORRECTIVE ACTION
0000015 (Flight)	B-74494	Acceptance	Thermal coefficient of sensitivity - Input to output ratio excessive at +160°F. Reference cavity resealed to eliminate minute leak path through weld, seal-off area.
	B83419	Receiving Insp.	Part received needed cleaning. Vendor error-cleaned at Denver
0000016 (Backup)	B-91656	Acceptance	Excessive deviation from last calibration. Tolerance too tight. PD changed to reflect new requirement.
	B-93320	Final Insp.	5% positive shift in calibration-due to overpressurization during test. Unit scrapped.
0000017 (Spare)	No Mars written against this unit.		
0000018 (Qual)	B-66925	Acceptance	Unit failed dimensional inspection. Error in vendor drawing. Drawing Revised.
	B-66926	Qualification	Excessive error band in post bench operating cycle calibration test. Drive band assembly was redesigned and assembled using less loading at weld off of the band to the drive frame.
	B-73818	Qualification	Exceeded max tolerance condition during and after shock exposure. Shock requirement of PD7400081 and QTP-3031-11801 revised.
	B-75188	Acceptance	Thermal coefficient of sensitivity excessive at +160°F. Failure resulted from insufficient outgassing time during seal off process. Engineering drawing 118-480 revised to specify adequate outgassing time.
0000019 (Qual)	B-73819	Qualification	Exceeded max tolerance condition during and after shock exposure. Shock requirement of PD7400081 and QTP-3031-11801 revised.
	B-75189	Acceptance	Unit failed dimensional inspection. Error in vendor drawing. Drawing revised.
	B-75190	Acceptance	Thermal coefficient of sensitivity excessive at +160°F. Failure resulted from insufficient outgassing time during seal off process. Engineering drawing 118-480 revised to specify adequate outgassing time.

Table 2.2.5-3 Failure Analysis Summary - Absolute Pressure Transducer

E. Conclusions and Recommendations - There have been no pressure transducer failures since Qualification and Acceptance Testing.

This Page Intentionally Left Blank

2.2.6 Communcations System

The Speaker Intercom Assemblies (SIAs), which were the major components of the MDA Communications System, were supplied to MMC as Government Furnished Property (GFP) for installation in the MDA.

A. Design Requirements - The design requirements for the MDA Audio Communications subsystem were identified in the following documents:

- 50M13136 - Skylab Orbital Assembly Audio System Requirements
- RS003M00003 - Cluster Requirements Specifications, Appendix E
- CP114A1000026 - MDA Contract End Item Specification, Page 3-9a, Paragraph 3.1.1.2.6.3
- Instrumentation & Communication (I&C) Design Criteria 8200004005

Interface Control Documents (ICDs) which defined the design parameters are listed below:

- 50M13122 - AM to MDA Instrumentation and Communication (I&C)
- 50M13125 - CSM to MDA Instrumentation and Communication (I&C)
- 50M13146 - Ancillary Equipment to Saturn Workshop I&C
- 50M13148 - Speaker Intercom Assembly to MDA and Orbital Workshop (OWS)

The SIAs were designed and tested in accordance with "McDonnell-Douglas Astronautics E-0065, Design Requirements".

Accessory equipment to enable the crewmen to interface with the intercom was also supplied as GFP and consisted of:

- Crewman Communication Umbilical (CCU)
- Lightweight Crewman Communication Umbilical (LCCU)
- Crewman Communication Control Head Assembly (CCCHA)

- Communication Carrier Headset Assembly
- Lightweight Headset Assembly

B. Functional Description - The MDA Communications subsystem provided the Skylab unsuited crewmen with a voice communication capability within the MDA and interfaced with the Saturn Workshop (SWS) audio system. It enabled the crewmen in the MDA to communicate with each other in the MDA and throughout the SWS and permitted real-time voice communication between the crewmen and the Spacecraft Tracking and Data Network. In addition to the voice communication capability, it included visual and audio provisions to alert the crewmen when emergency and warning parameters of the SWS Caution and Warning (C&W) systems were exceeded. The subsystem also included provisions to support the collection of the biomedical data.

The MDA Communications subsystem consisted of three Speaker Intercom Assemblies (SIAs) as shown in Figure 2.2.6-1.

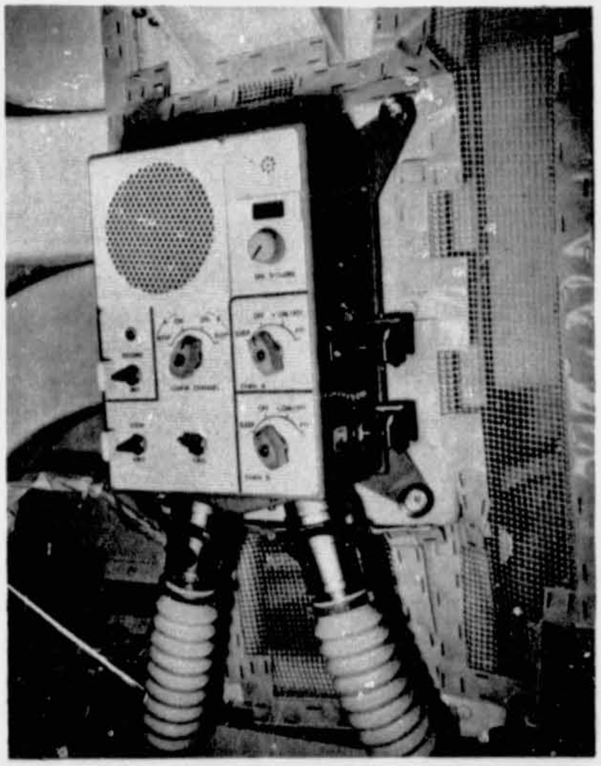


Figure 2.2.6-1 Speaker Intercom Assembly

C-4

The three MDA SIAs were identified as PNL 102, PNL 116, and PNL 131. PNL 102 was located at the Earth Resources Experiment Program (EREP) console; PNL 116 was located at the M512 facility; and PNL 131 was located at the ATM Control and Display (C&D) console.

The MDA SIAs were inoperative until the crew entered the MDA for the first time on Flight SL-1/2 and made the required connections. The connections involved the following:

- Transfer of PNL 102, stowed in the Structural Transition Section (STS), to its MDA location, where it remained throughout the program;
- Connection of PNL 102 to the communication cable provided at the EREP location in order to activate both PNL 102 and PNL 116;
- Activation of PNL 131 by reconnecting the cable formerly attached to PNL 102 at the STS location, to PNL 131 in the MDA.

Fundamentally, each SIA served three purposes: 1) as an intercom facility; 2) as a junction box for connecting the crew communication umbilicals and biomedical communications umbilicals to the SWS communication network; and 3) provided audio warning tones from the Caution and Warning (C&W) System.

Functionally, the three MDA SIAs were connected in parallel via two Audio Load Compensators (ALCs) located in the AM, to the CSM communications network, as shown in Figure 2.2.6-2. There were two independent communications channels; i.e., Channel A and Channel B were each served by a separate ALC. Channel A was connected to the CSM Pilot (PLT) Audio Center while Channel B was connected to the Commander (CDR) Audio Center.

The normal intercom signal flow in the SIA-ALC-CSM audio center network was as follows: a microphone signal, originating from an SIA, was amplified by the ALC and sent to the CSM. Where it was again amplified by the CSM Audio Center microphone amplifier, as shown in Figure 2.2.6-3. Through proper switching circuits the signal was routed to the CSM A/C headset amplifier and then returned as a speaker (or earphone) signal through the same ALC to any SIA monitoring that channel.

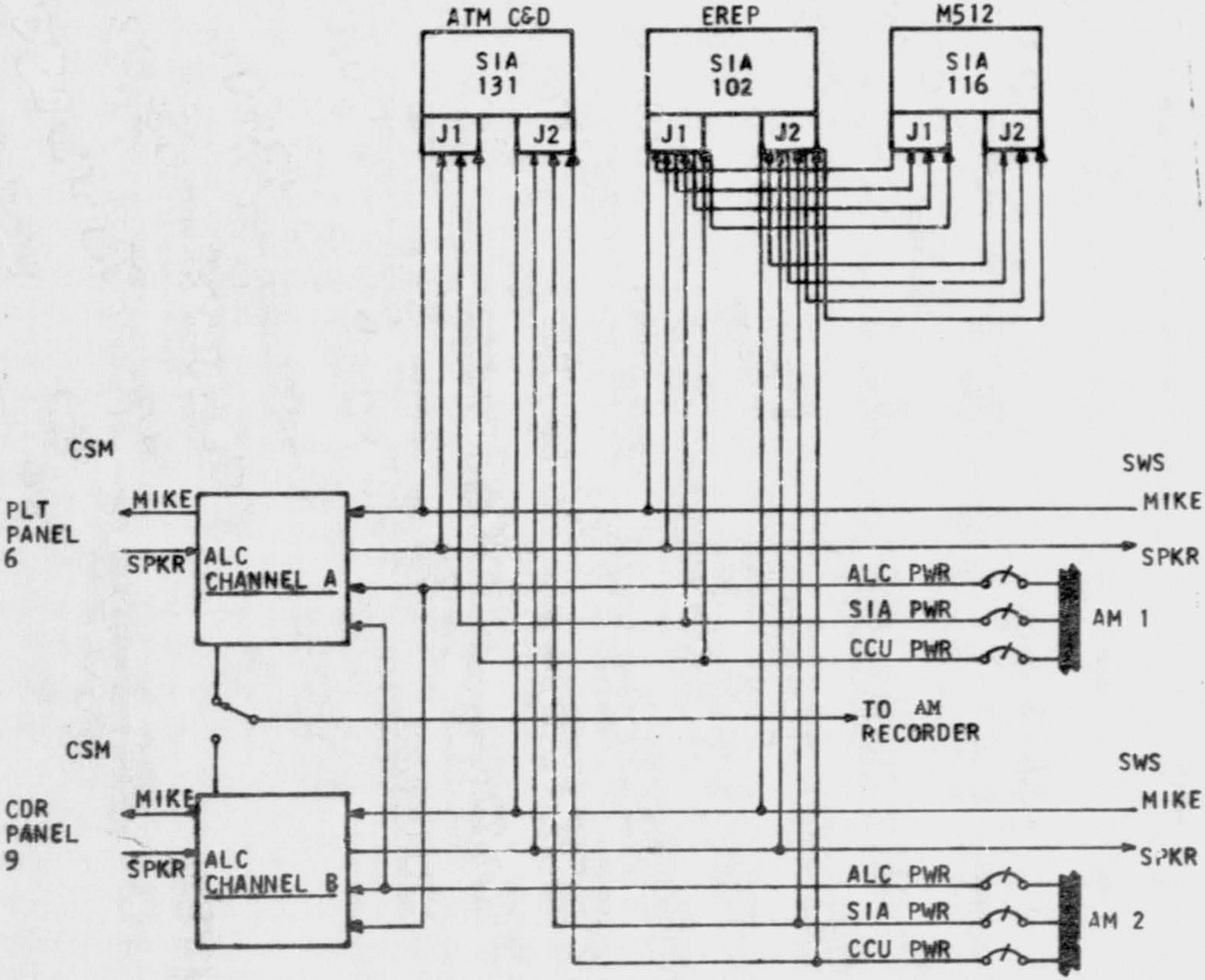


Figure 2.2.6-2 MDA SIA Network

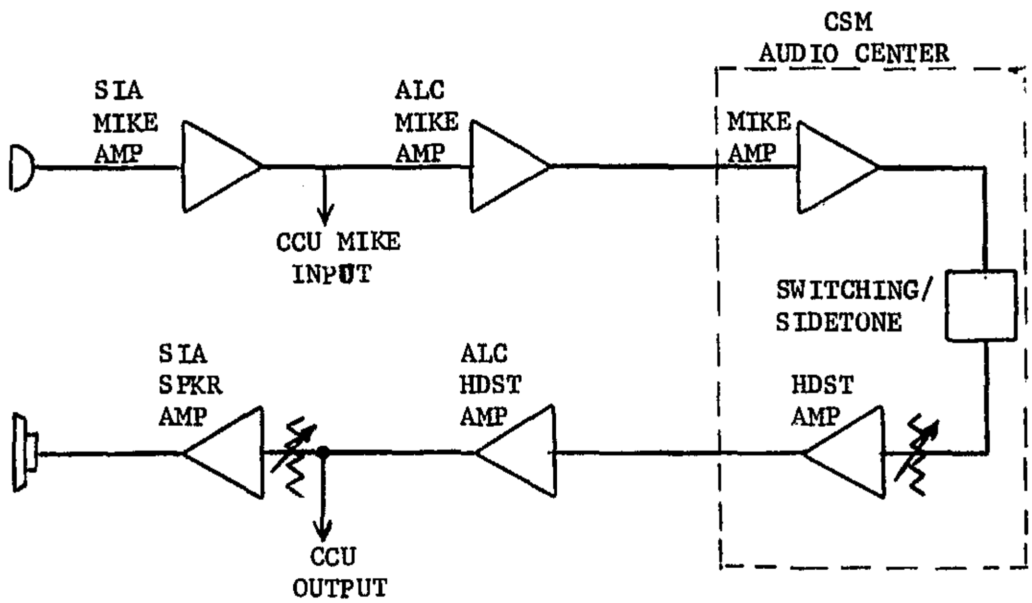


Figure 2.2.6-3 SIA Signal Flow

In this mode, private on-board intercom and voice record capability was maintained without an active ground communcation loop. The normal mode of operation required one of the channels to be configured as above, while the other channel was interconnected to the CSM S-Band transmitter/receiver to allow real time communication with the ground.

An over-view of the CSM-MDA audio subsystem configuration is shown in Figure 2.2.6-4. It should be noted that the SWS intercom was inoperative in the normal configuration when the CSM Audio Center was off. Only in an emergency mode configuration was it possible to operate the SWS intercom independently from the CSM audio center.

(1) Speaker Intercom Assemblies - Each SIA contained the following major components and controls: speaker, speaker amplifier, SPKR VOL control, mike, mike amplifier, COMM CHAN sw, ICOM/XMIT sw, CHANNEL B sw, and a MASTER ALARM and a Record light. The functions of the above components were, in brief, as follows:

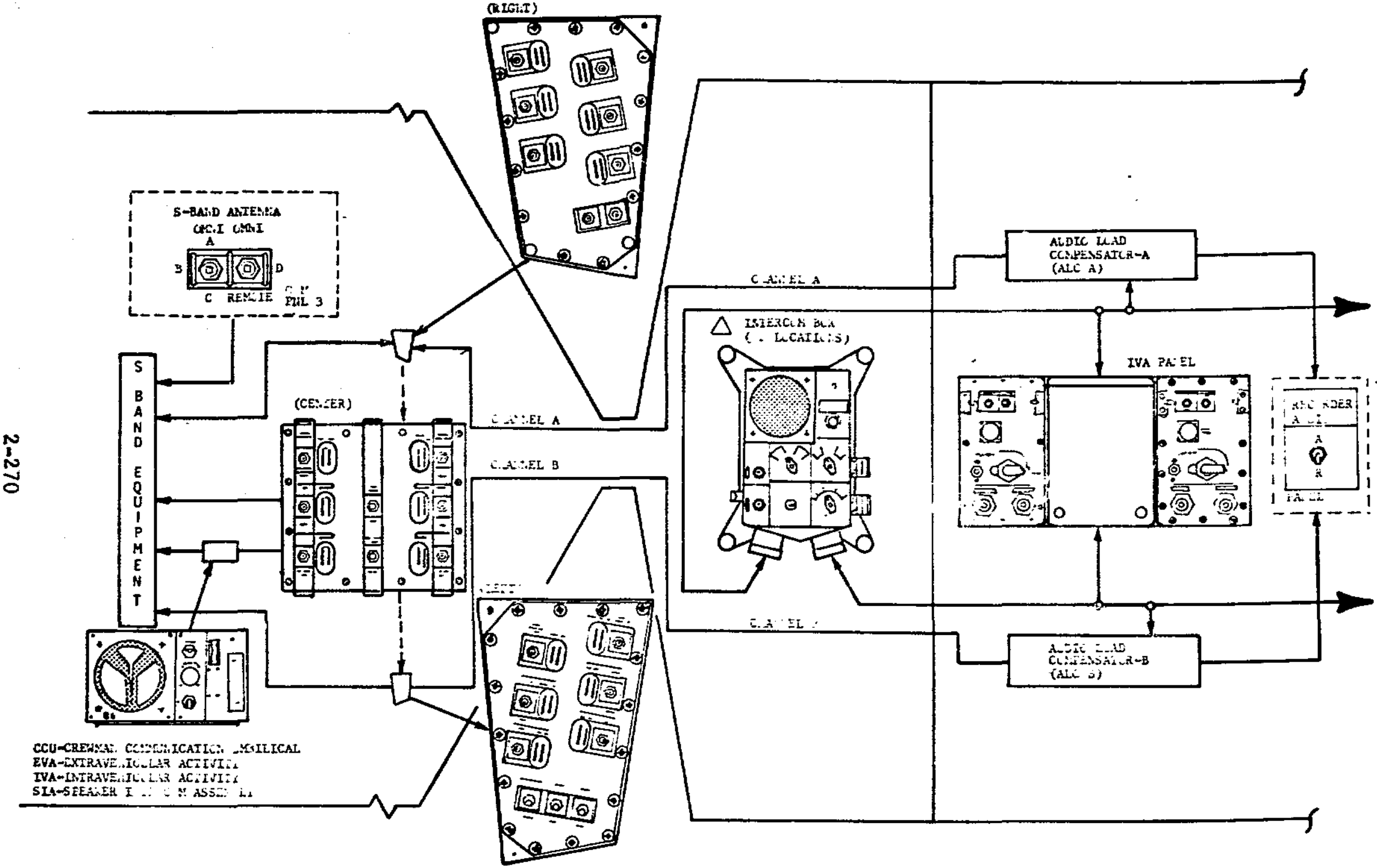


Figure 2.2.6-4 CSM/MDA Audio System

(a) Speaker/Speaker Amplifier - The speaker responded to two input sources: a high level alarm signal direct to the speaker and a signal via the speaker amplifier for voice and Low Level Alarm.

(b) SPKR VOL - Controlled the level of voice but not the Low and High Level Alarm Signals.

(c) Mike/Mike Amplifier - Provided input to ALC mike amplifier for simplex mode of communication.

(d) COMM CHAN sw - Enabled selection of Channel A or B to the ON or SLEEP mode. In the ON mode, power was applied to speaker amplifier and the Push to Talk (PTT) relay. In the SLEEP mode, both the speaker amplifier and the PTT relay were disabled.

(e) ICOM/XMIT sw - With COMM CHAN sw Channel A or B ON, the ICOM position activated the mike amplifier and, to avoid audio feedback, inhibited the local speaker amplifier (simplex communication). The XMIT position enabled voice transmission to ground in addition to the ICOM functions stated above.

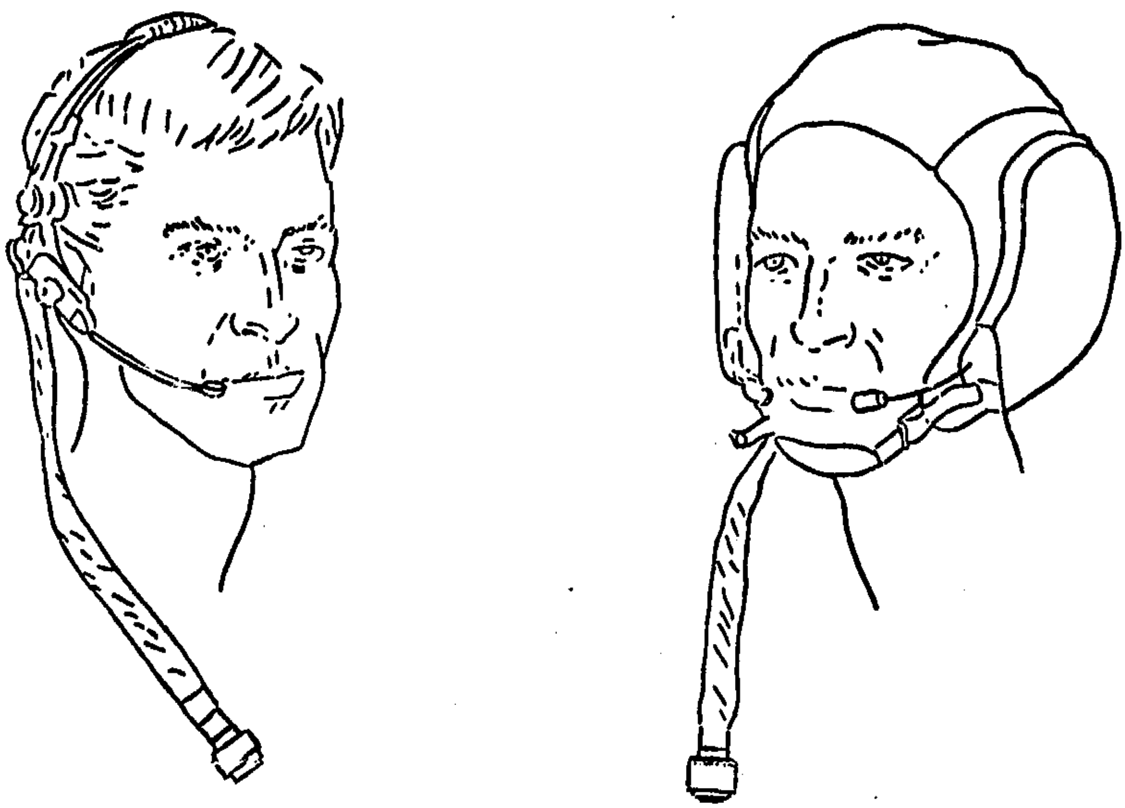
(f) CALL sw - Enabled all speaker amplifiers in the OA with the exception of local speaker amplifier and ICOM/XMIT relays (including those in SLEEP mode). At the same time, enabled the local mike amplifier and connected its output to both Channels A and B, simultaneously.

(g) RCD/OFF sw - Enabled or inhibited tape recording of Channel A or Channel B audio signal (as selected by the [illegible] SYS RCDR AUDIO sw on AM Panel 204). SIA Record light was ON whenever voice recording was in progress, except when SIA was in SLEEP mode.

(h) CHAN A (B) sw - Selected the operating mode of the CCU/headset connected to the Channel A (B) connector.

(i) RECORD Light - See RCD/OFF sw function.

(2) CCU Functional Characteristics - The Crewman Communication Umbilical (CCU) was used to connect the crewman Personal Communication Assembly (Figure 2.2.6-5) to the intercom Channels A or B. The CCU, as shown in Figure 2.2.6-6, interfaced with a T-adapter which separated and routed the audio and biomed functions to the headset and the crew's bioinstrumentation assembly respectively.



LIGHT WEIGHT HEADSET   SOFT HAT

Figure 2.2.6-5 Personal Communications Assembly

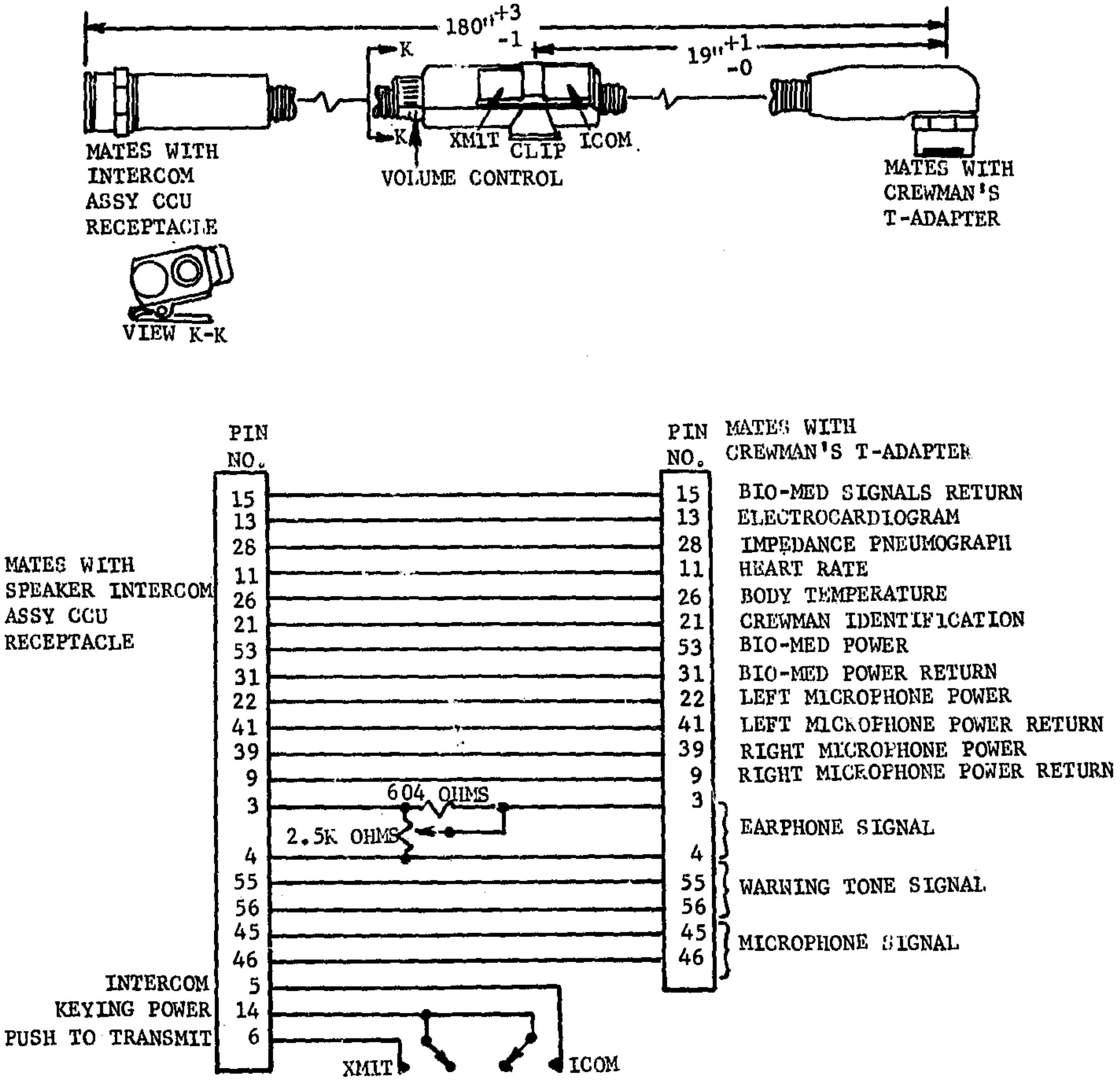


Figure 2.2.6-6 Crewman Communications Umbilical

(3) LCCU Functional Characteristics - The LCCU contained audio cabling to connect the crewman Personal Communication Assembly (Figure 2.2.6-5) to the Intercom channels at the SIA. The LCCU, as shown in Figure 2.2.6-7, connected to the Crewman Communication Control Head Assembly (CCCHA), Figure 2.2.6-8, which in turn mated with the Personal Communications Assembly.

(4) CCCHA Functional Characteristics - The CCCHA contained a volume control for the headset and a switch for intercom or PTT (transmission to ground). Two LCCUs could be connected in series if a longer umbilical was required.

(5) Special Mounting Criteria - Shock and vibration criteria defined in the MDA CEI exceeded the qualification testing levels imposed on the SIA. The SIA installed at the ATM C&D console (Panel 131) was shock mounted to attenuate the levels imposed on the SIA.

C. Test - As stated previously, the SIAs and associated communication accessory equipments were furnished to MMC as GFP.

(1) Qualification Tests - All of these equipments, except for the headset, were qualification tested by the developing contractor. However, the SIAs were subjected to a delta vibration qualification test because the MDA vibration and shock environmental requirements exceeded those to which the SIAs had been initially qualified.

A special qualification test was performed to verify the attenuation of the SIA Isolation System. Accelerometers were installed on the SIA which measured the vibration levels received at the SIA with the following levels inputted to the base of the isolation assembly.

High Level Random Criteria - 9.6 g rms, 1 min/axis

Low Level Random Criteria - 4.8 g rms, 4 min/axis

ICD 50M13148 was revised to specify the increased random vibration levels for the SIA and the tests were successfully performed.

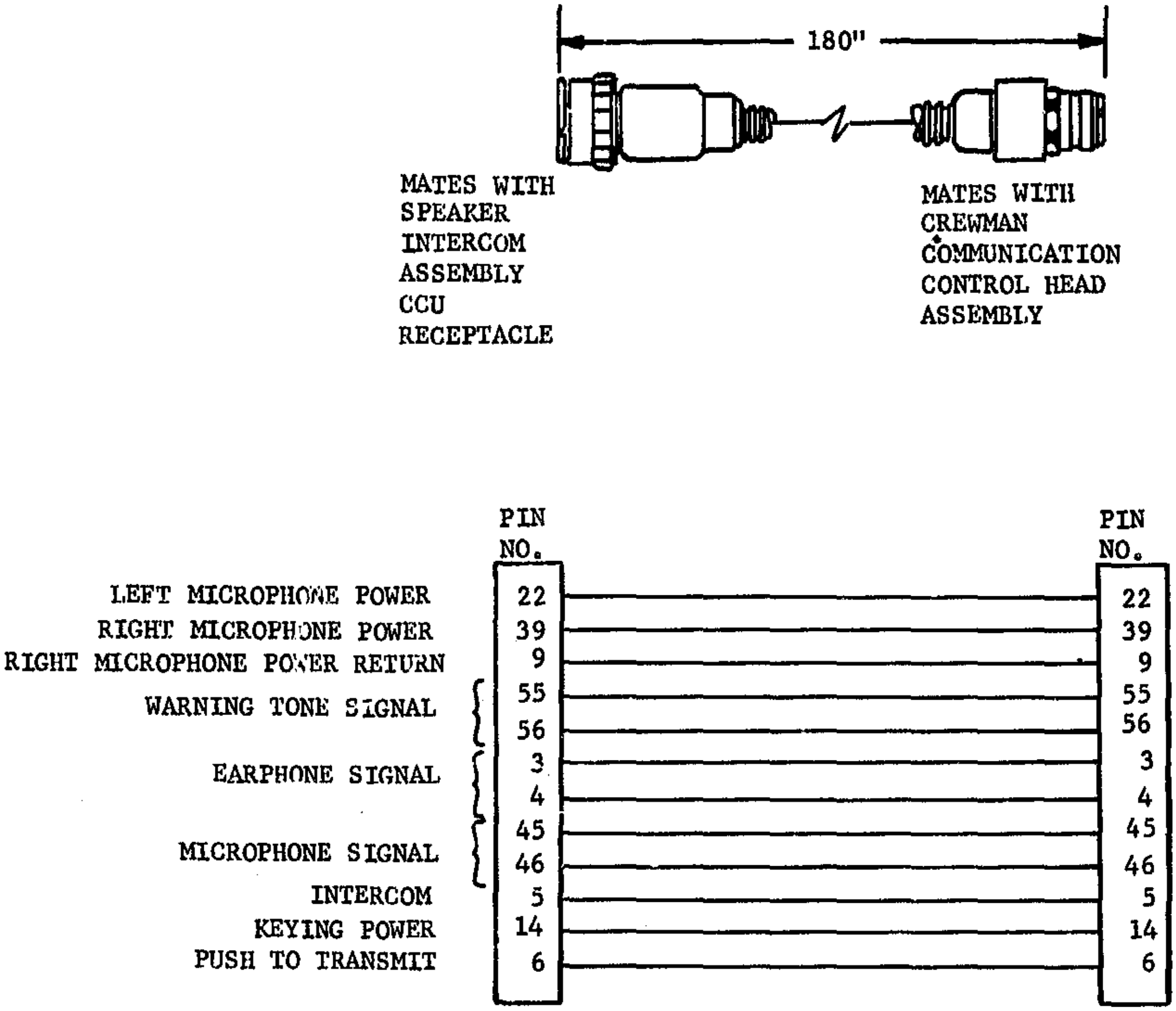


Figure 2.2.6-7 Lightweight Crewman Communications Umbilical

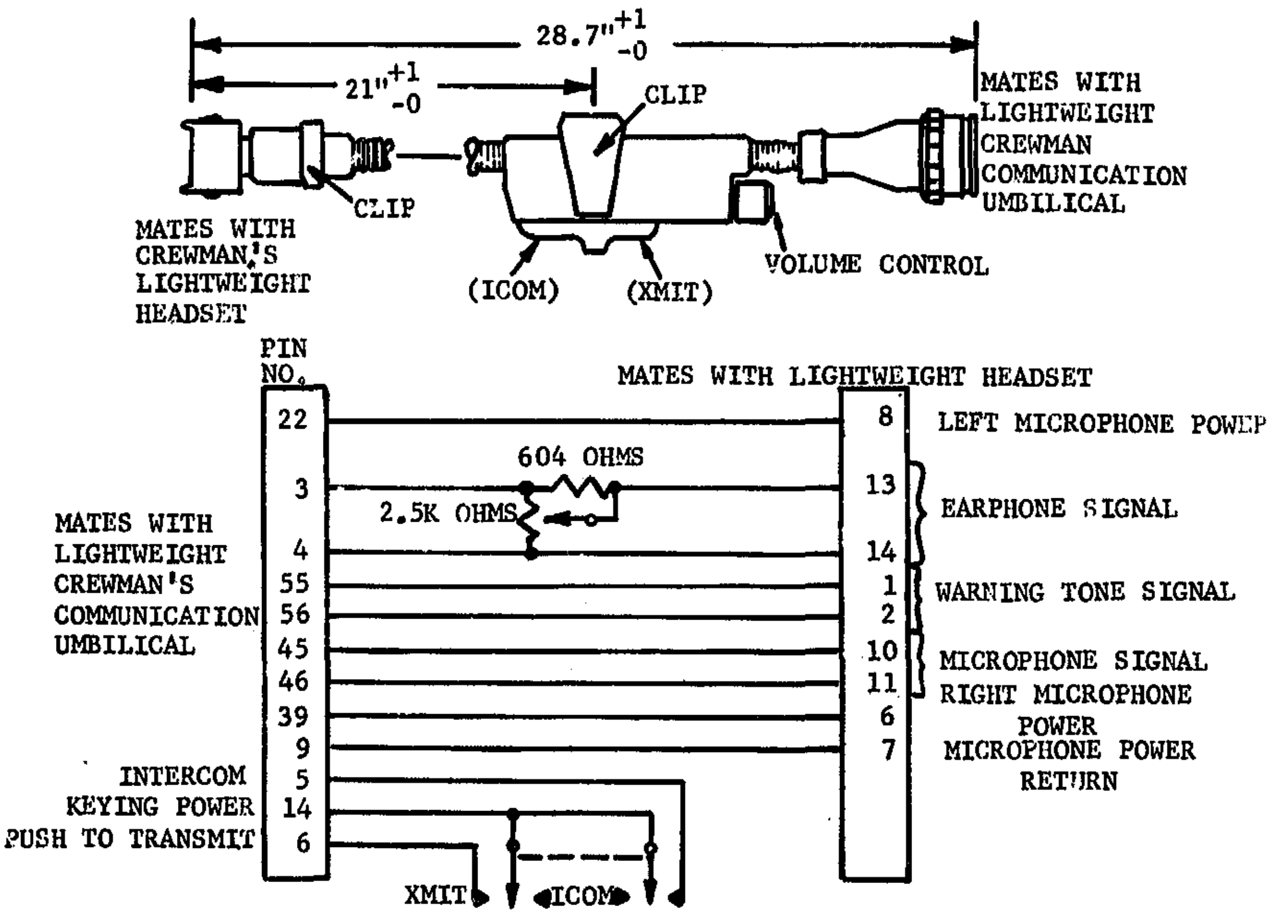


Figure 2.2.6-8 Crewman Communications Control Head Assembly

(2) MDA Module Test at MMC, Denver - The MDA communications system was successfully tested in accordance with Operational Checkout Procedure, OCP-D-40001. Results of this test are included in Section 7.0 of this report.

(3) AM/MDA tests at St. Louis and Cluster tests at KSC - Results of these tests are included in Section 7.0 of this report.

D. Mission Results -

(1) SL-1/2 - The communication system within the MDA provided the communication and data transmission capability for which it was designed. There were no anomalies reported by the SL-2 crew, nor were there any malfunctions reported by the ground stations. However, because of the proximity of the SIAs in the MDA, feedback would invariably occur when using the SIA microphone if more than one SIA was powered on. Operational discipline was required to mitigate this condition.

Audio difficulties were reportedly experienced by the SL-2 crew while conversing directly with each other between SWS compartments. Crewmen in the OWS could not be readily heard by a crewman in the MDA or AM without shouting. The poor sound-carrying condition was attributed to the 5 psi cabin pressure. Usage of the ICOM mode on the SIAs was mandatory under these conditions.

Functioning of the Caution and Warning System (C&WS) input to the SIA audio and visual alert presentation was demonstrated through the activation of a "Service Propulsion System" (SPS) Pressure Low warning triggered in the SWS and properly identified in the C&WS panel in the Structural Transition Section (STS).

(2) SL-1/3 - The Communication system within the MDA provided the communication and data transmission capability for which it was designed. There were no anomalies reported by the SL-3 crew, other than the SIA feedback problem evident in the SL-1/2 mission which caused occasional degradation in the communications.

Due to the close proximity of the SIAs in various sections of the SWS, audio feedback occurred and interferred with crew communications, especially with the ground. A partial resolution to the feedback problem was made by reducing the gain of the SIA speaker amplifiers on Skylab missions SL-1/2 and SL-1/3. This wasn't completely satisfactory, however, so a change to the audio system was incorporated into SL-4. This change consisted of the addition of an electrical load to the microphone and earphone lines between the CSM and the MDA reducing the overall system gain. The load on the earphone line was active only when the PTT switch was activated.

(3) SL-1/4 - During the SL-4 mission the feedback reduction network provided a significant improvement to the audio feedback problem. On DOY 333 SIA Panel 131 microphone circuit failed. The cause of the failure was never determined and could have been associated with any of the following electrical components:

- o Microphone transducer
- o Electronic component within microphone channel assembly
- o Output transformer
- o PTT relay
- o ICOM/XMIT switch contacts
- o Comm Channel (rotary switch) contacts

The unit was removed and replaced. No further problems were experienced by any of the SIAs in the MDA.

E. Conclusions and Recommendations - The crew reported during the SL-2 debriefing that they believed they lost some recorded voice data due to mistakenly operating the SIA ICOM/XMIT for the RECORD/OFF switch. They suggested that for future designs, the switch should be shaped differently or should operate in different directions. For future programs it is also recommended that the design of speaker systems include testing in a full scale mockup at flight ambients and subsequent design of the system to prevent feedback problems. Some consideration should also be given to design of the SIA to facilitate operation from any angle in a zero-G situation.

It is also recommended that portable, wireless communication assemblies be developed for use by crew members to allow more freedom of movement and positive communication with each other and/or ground personnel.

2.2.7 Caution and Warning (C&W) System

The MDA C&W subsystem was supplied to Martin Marietta as GFE for installation in the MDA.

A. Design Requirements - Design requirements for the C&W System were specified in the Cluster Requirements Specification, RS003M00003, Appendix H. System and component design was performed by the SWS Integrating Contractor. Requirements levied on the MDA consisted of:

- A study to determine the number and location of Fire Sensor Assemblies (FSA) required to assure optimum coverage of the MDA.
- Provide mechanical interface for installation of the FSAs and the Fire Sensor Control Panel (FSCP) (50M16147).
- Provide cabling information to electrical design area to assure compatibility with OWS C&W system functional requirements and the AM/MDA Electrical ICD (40M35662-2).
- Provide the capability of verification and checkout of the subsystem at the MDA module level.

B. Functional Description - The C&W system monitored the CSM, ATM, AM, and OWS for malfunction (out-of-limit) conditions categorized as caution, warning or emergency, and identified malfunctions by visual and distinctly coded audible alarms. Functionally, the caution and warning system was divided into a Caution and Warning (C&W) subsystem and an emergency subsystem. The C&W subsystem monitored OA systems performance parameters categorized as caution and warning conditions. The emergency subsystem monitored two hazardous conditions: fire in the MDA, AM and OWS, and a rapid decrease in pressure (rapid ΔP) within the OA. Each subsystem was further divided into two subsystems, providing redundant parallel parameter monitoring and malfunction indicators. The C&W system was active only when the SWS was manned. No ground control of the C&W system was provided.

The components used to detect and initiate a caution and warning alarm (high or low limit detection) consisted of C&W sensors, C&W detector module and C&W signal conditioning display converters. Emergency condition detection was provided by two rapid delta-P sensors located in the STS, and 22 fire sensors installed throughout the SWS. The two Fire Sensors, one Fire Sensor Control Panel (FSCP), and the Master Alarm lights located on each Speaker Intercomm Assembly made up the C&W subsystem in the MDA. (See Figures 2.2.7-1 and 2.2.7-2.)

All circuit breakers for the emergency subsystem were located on Panel 202 in the AM. Power on/off control was provided by POWER EMERGENCY 1 switch (Panel 206) for subsystem 1 and POWER EMERGENCY 2 switch (Panel 206) for subsystem 2. EPS control bus 1 supplied power to emergency subsystem 1 and EPS control bus 2 supplied power to subsystem 2. Either subsystem could be disabled and the remaining operative subsystem would provide monitoring of all emergency parameters, however, all fire sensor power switches would have to be configured to the operative subsystem (BUS 1 or 2). All circuit breakers and control switches, except for the Fire Sensor Control Switch, were in the AM STS.

(1) Ultra Violet Fire Sensor Assemblies - Each UV fire sensor used + 28 vdc for internal power and provided two output signals upon sensing a flame within its coverage zone or application of test signal (Figure 2.2.7-3). One signal latched on the fire sensor identification light on the fire sensor control panel, and the other drove a relay in the fire sensor control panel as long as a flame was sensed. The coverage zone by each sensor was a 120-degree cone with the apex being the sensor element. An external sensitivity adjustment (requiring a slot screwdriver) set the sensor electronics sensitivity. Numerals 0 through 5 provided a range of 75 to 25 counts per second with position 4 (35 counts/sec) being the normal setting. The shielded background sensor provided protection against false alarms due to high energy particles in the South Atlantic anomaly.

(2) Fire Sensor Control Panel (FSCP) - The FSCP provided controls for operation and test of the fire sensor assemblies. See Figure 2.2.7-4.

The FSCP had the capability of controlling both sensors in the MDA. Two power switches were provided, one for each sensor, which allowed manual selection of one of two normally energized

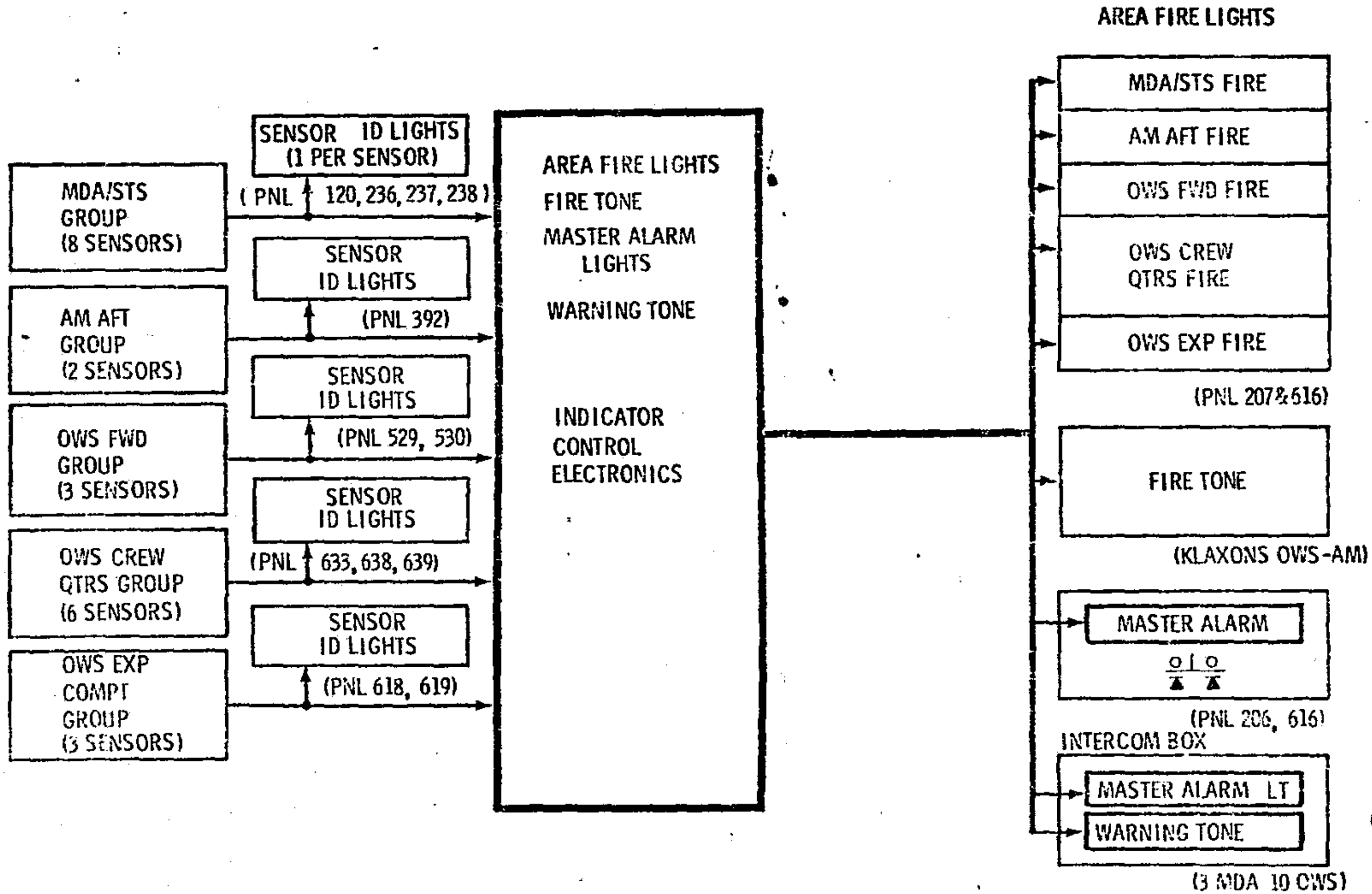


Figure 2.2.7-1 Fire Detection Subsystem

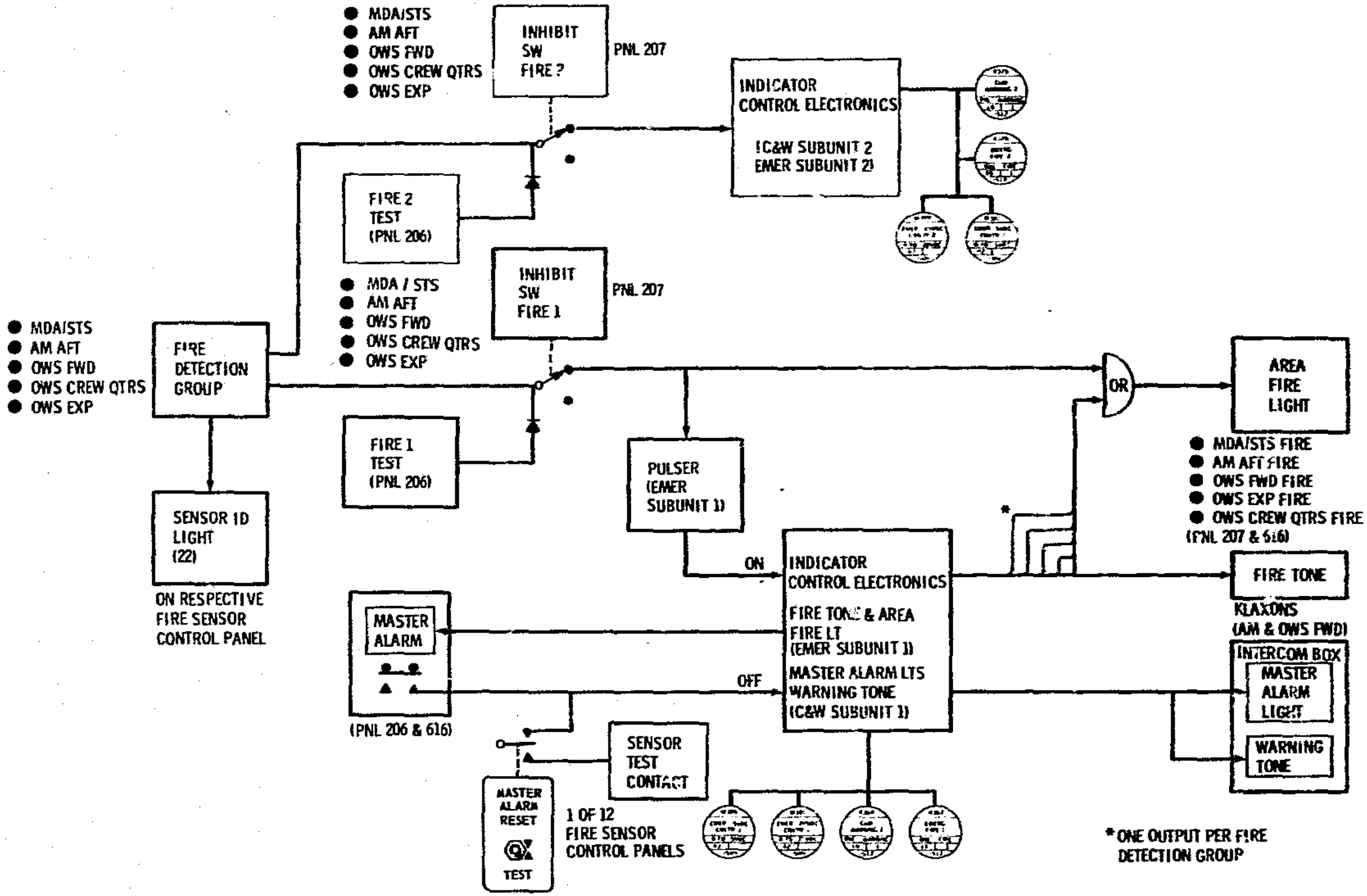


Figure 2.2.7-2 Fire Detection Functional

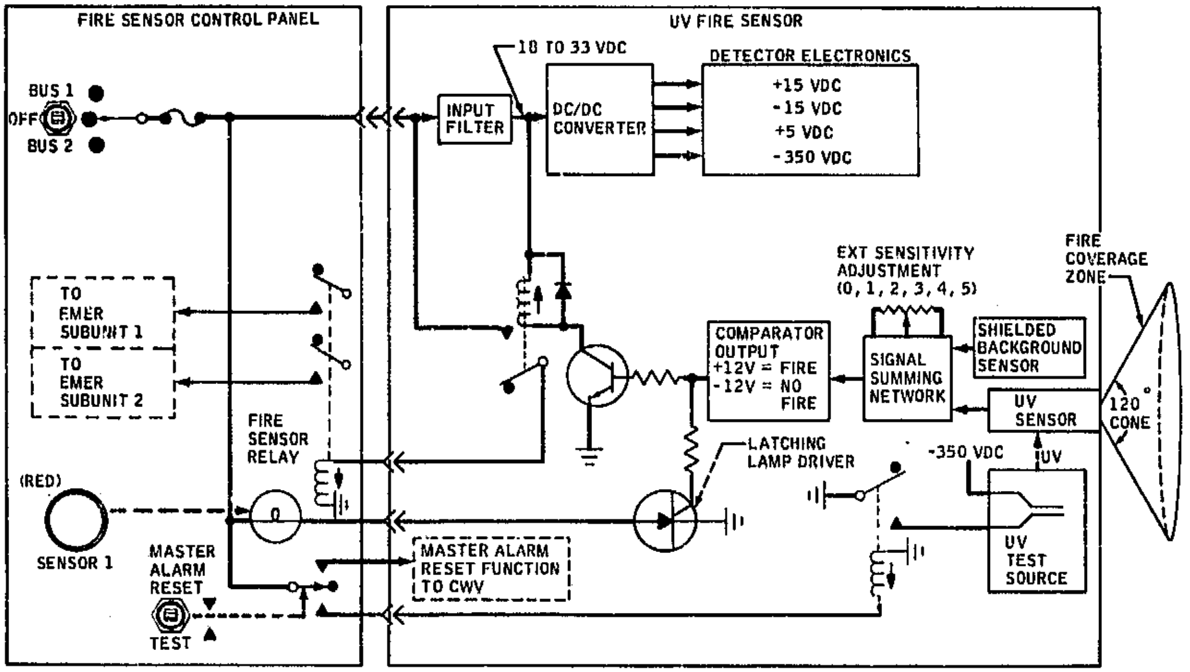


Figure 2.2.7-3 UV Fire Sensor

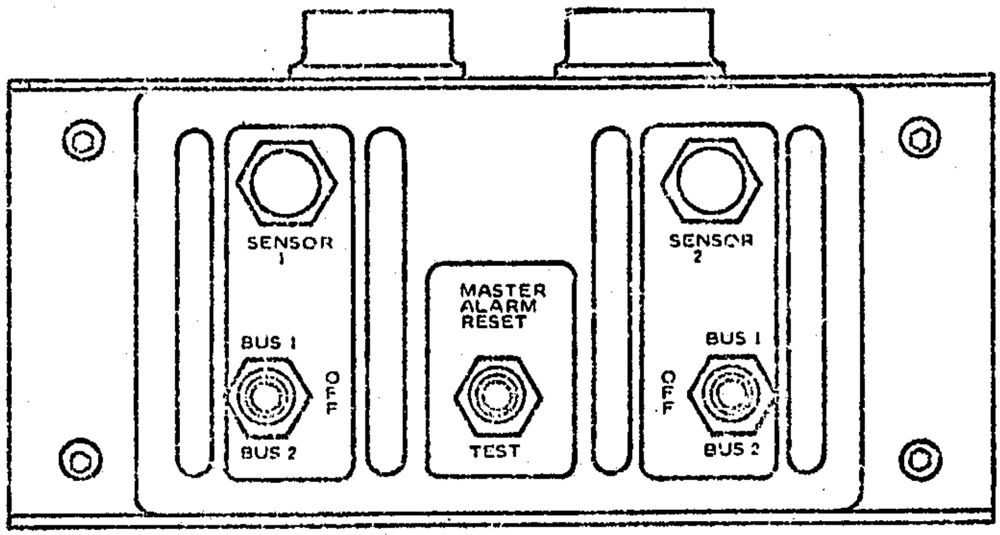


Figure 2.2.7-4 Fire Sensor Control Panel

buses capable of supplying power to the respective sensor. A master alarm reset/test switch was provided for testing the sensor(s) and resetting the SWS C&W system. A red display lamp was provided for each of the two sensors and remained illuminated until power was momentarily removed from the sensor. Each display contained one bulb which drew 40 milliamperes of current when illuminated. The bulbs and lenses on the panels and the panels themselves were in-flight replaceable. When both sensors were energized, the panel dissipated 5.5 watts of power. The FSCP weighed 1.4 pounds.

(3) Fire Sensor Test - Individual fire sensor testing was accomplished by the MASTER ALARM RESET/TEST switch on the respective remote fire sensor control panels (Figure 2.2.7-5). Actuation of the MASTER ALARM RESET/TEST switch to TEST applied a test signal to an UV test source in sensors 1 and 2. Individual fire sensor testing was accomplished by turning power off to either sensor 1 or 2 as desired prior to performing the test.

MASTER ALARM reset and cycling of the sensor power switch to off and back to the bus 1 or 2 position was required after each sensor test.

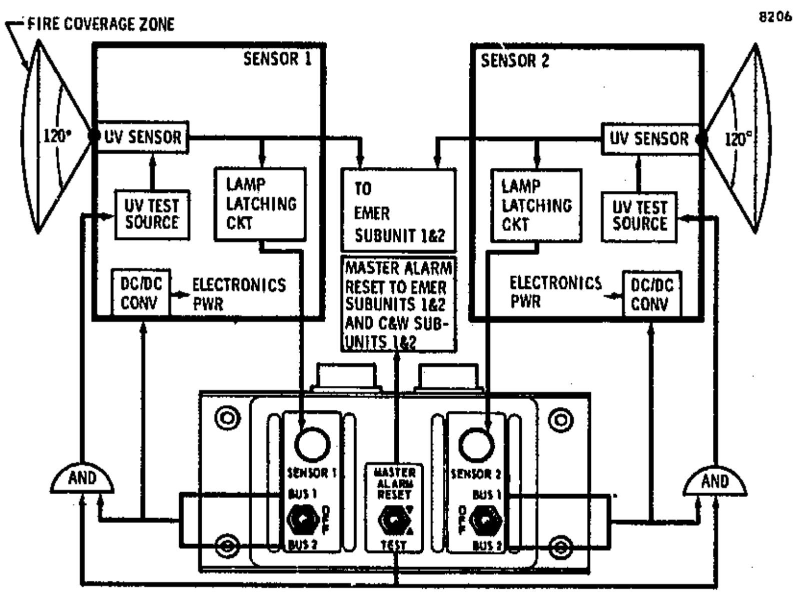


Figure 2.2.7-5 Fire Sensor Test

(4) Performance and Design Data - UV Fire Sensor Assembly

• Input Voltage	18 to 33 vdc
• Input Power	3.6 watts standby, 6 watts active
• UV Spectrum Sensitivity	1850 to 2650Å
• Response to Test	Approximately 1 sec
• Size	5.3 x 5 x 3.15 inch
• Weight	5.8 pounds

For a more complete description of the Skylab Caution and Warning System, see MSFC 40M35701, Skylab Caution and Warning Technical Manual.

C. Test - The FSCP and FSA were provided to MMC-Denver as GFE to be installed in the MDA. Subsystem testing was accomplished on-board the MDA per MDA-OCP-D-10001. An ultraviolet light test tool was designed and functionally tested per SK820DM6020 OP125.

Two fire sensors failed subsystem testing. The units indicated the presence of a fire during a background noise verification test. The units were bench tested and all hardware functioned per specification. The test requirement and procedure were subsequently rewritten.

The MDA C&W subsystem was satisfactorily tested in St. Louis and at KSC per STACR ED-2002-2020.

There were no other failures in the C&W subsystem during Denver Testing.

D. Mission Results - C&W hardware components in the MDA functioned satisfactorily throughout the Skylab mission.

E. Conclusions and Recommendations - The Caution and Warning system performed its intended function adequately. However, it is recommended that future designs provide sufficient isolation to prevent intra-system noise from inadvertantly coupling into other systems. For example, the converter switching spikes associated with the emergency power system caused data perturbations on MDA Temperature measurements. Modifications were incorporated but the problem was never totally eliminated.

This Page Intentionally Left Blank

2.2.8 Television (TV) System

Major TV system components installed in the MDA included a Video Switch, Television Input Station (TVIS) and a Video Tape Recorder (VTR). (Ref. Figure 2.2.8-1). A discussion of each of these components, including their contribution to the performance of the OA TV System, is included in the following paragraphs.

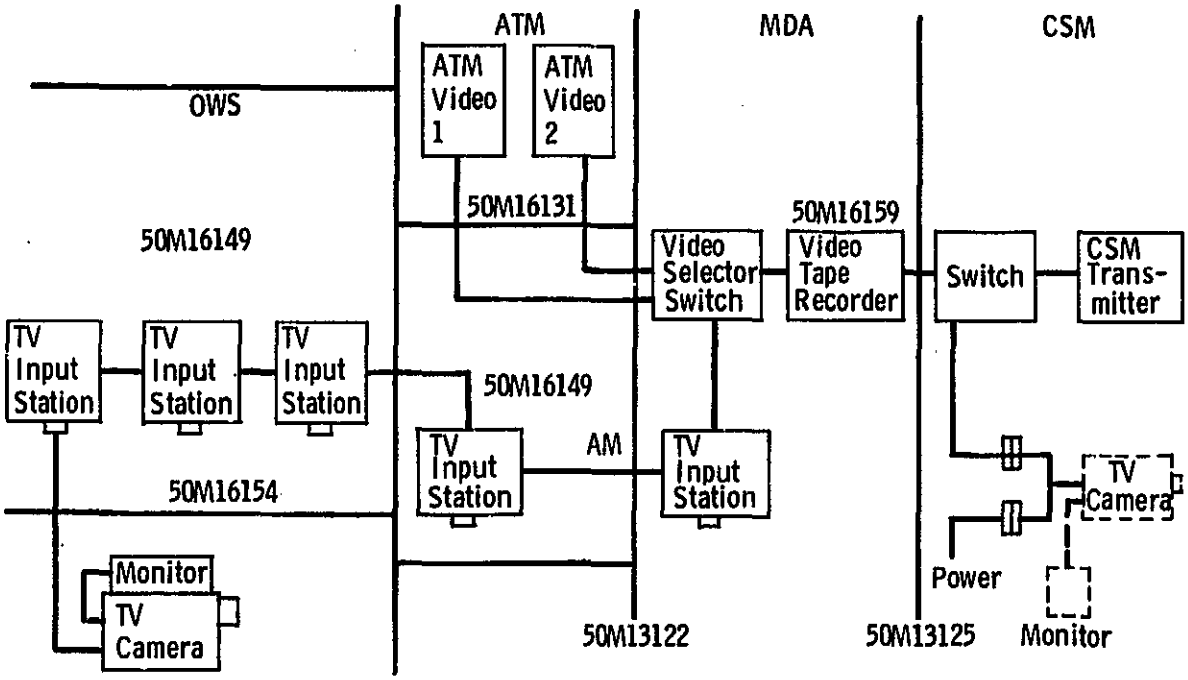


Figure 2.2.8-1 Skylab TV System

2.2.8.1 Video Switch

A. Design Requirements - The design requirements for the Video Switch were specified in Drawing PD7100078. The system requirements applicable to the Video Switch were specified in the following ICD's:

- 50M16132 - Skylab Orbital Assembly Television System Requirements
- 50M16139 - Multiple Docking Adapter Measurement List
- 50M16131 - ATM to AM I&C Interface
- 50M13122 - AM to MDA I&C Interface
- 50M13125 - CSM to MDA I&C Interface

B. Functional Description - The Video Switch, Figure 2.2.8-2, provided manual switching and conditioning of TV video signals from the ATM or the MDA/AM/OWS TV bus.

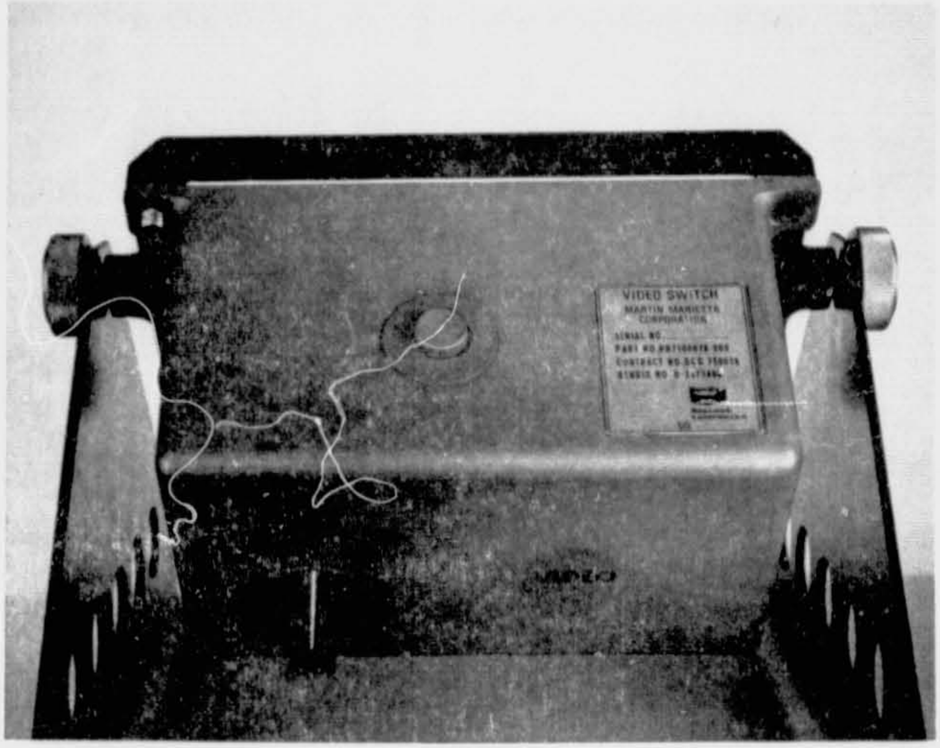


Figure 2.2.8-2 Video Switch

The switch was a three-position rotary switch with positions for ATM MON 1, ATM MON 2, and TV. The switch was hardwired to two 75 ohm coax cables from the AM/ATM interface and one 93 ohm cable from the MDA TVIS. Another 93 ohm coax connected the video switch output to the VTR and through the VTR to the CSM unified "S" band transmitter. Power (28 VDC) was supplied from the Airlock Circuit Breaker Panel 202. The unit had no local power switch. The unit conditioned the video signals as follows: ATM impedance of 75 ohms was converted to 93 ohms and the ATM video signal bias and amplitude were adjusted so as to be compatible with the S-band transmitter. The portable TV camera bus signal was not conditioned.

The ATM signals were isolated from each other, each having a separate power supply and conditioning circuitry. Adjustments were provided for both gain and bias.

The ATM TV camera video for each of the two channels was selected at the ATM C&D panel from one of five TV cameras in the ATM. The video being viewed on the ATM C&D TV monitor #1 could be routed to the VTR and/or transmitter by placing the video switch in the ATM MON #1 position. Likewise, selection of ATM MON #2 permitted that video being viewed on ATM C&D TV monitor #2 to be routed to the VTR and/or transmitter.

In the TV position a relay was activated which connected the output of the TV bus through the video switch to the VTR and transmitter. When in either ATM position, the TV bus coax was connected to a 93 ohm load internal to the video switch, with the shield being connected to structure. This provided a fault current path in the event of a short in the portable camera.

The Video Switch had three event measurements which indicated switch position to the ground controller via the AM telemetry system. These were 28 V indications to the TM system and were displayed on the ground console as ATM MON 1, MON 2 and TV.

C. Test - The test requirements for the Video Switch were specified in the PD7100078 drawing. Bendix Corporation Report No. 5426A covered the qualification testing. There were no anomalies reported in the following tests:

- EMI: MIL-I-6181 and CE01, CS06 of MIL-STD-461
- Thermal Vacuum: Temperature - +40°F to 90°F; Pressure - 321 mm Hg to 5 mm Hg
- Vibration: 7.4 grms for 1 min/axis; 3.7 grms for 2 min/axis
- Shock: 60 gs - 6 shocks/axis
- CCOH: 1 percent salt solution followed by oxygen and humidity
- Temperature, Altitude, and Storage: Temperature -40°F to +160°F; Pressure, Sea level to 35 K ft

Because of the addition of the TV bus relay which provided a ground connection for the shield, a Delta Qualification Test was performed which consisted of Acceptance Tests and Delta Qualification Vibration. There were no failures reported. The results of these tests are covered in Bendix Corporation Report MT-17,701, dated October 1972. The system testing at Denver and St. Louis was minimal. The unit received comprehensive system test at KSC with the complete flight OA TV system.

The two ATM channel gain and DC offset settings were preset at KSC during testing with video signals. The settings could not be verified during test since the ATM TV cameras could not be activated while in the VAB cluster test configuration. Minimal stimulation of the XUV MON, XUV SLIT, and WLC VIDICONS was provided to verify that video was transmitted as selected, and that the DC offset was correct.

There were no anomalies during KSC testing. One system problem, where the shields of the TV bus were found to be grounded through 475 ohms, was traced to a safety wire configuration on the Deployment Assembly. The 475 ohm reading was traced to resistive elements in the Video Switch and enabled isolation of the fault to the Deployment Assembly. The Video Switch proved to be easily adjustable and performed as required during all testing prior to launch.

During backup article testing at St. Louis, a failure occurred in one of two amplifiers in S/N 6. The failure was found to be a broken wire internal to a potted module. The wire had apparently been stressed during the build cycle and had broken under thermal cycling during shipping and storage. Other units, including the second amplifier of S/N 6, were thermal cycled to gain confidence as to the reliability of the flight units. All units were twice cycled over the range of 30° F to 90° F with no failures observed. Therefore the flight units were not removed from the vehicle. No other anomalies occurred during backup article testing.

D. Mission Results - During the first manned mission there were no reported anomalies. However, a problem was noted with the knob on the Video Selector Switch (VSS). The crew requested the ground to advise them of the position of the switch on one occasion. They then reported the knob was loose. No further discussion was heard or reported, and the switch was observed to be working normally during subsequent passes by monitoring the TM indication of switch positions. Apparently, the Allen set screws worked loose and were retightened by the crew.

E. Conclusions and Recommendations - The Video Switch proved to be a very reliable component of the television system. Except for the one incident of the loose knob, there were no anomalies during the operating life of the unit.

Some recommendations which are applicable to the Video Switch are as follows:

(1) The gain and bias pot adjustments were too deeply recessed and the A-1 amplifier packaging design made alignment of these pots difficult. A larger, more rugged pot should also be used to avoid adjustment screw breakage. Repackaging the A-1 amplifier as recommended above should also include a new mounting technique for the pot that will place it closer to the external surface of the Video Switch case.

(2) A post ATP thermal cycle should be introduced into the test program for new Video Switch builds.

(3) High torque operated rotary switches (70 in.-oz. or more) should have a special knob attachment so that repeated operation does not overstress the set screws and cause the knob to loosen.

2.2.8.2 TVIS

A. Design Requirements - The requirements governing the design of the Television Input Station (TVIS) were imposed by the following Interface Control Documents (ICD's):

50M13125	CSM to MDA Instrumentation and Communication Requirements
50M16132	Skylab Orbital Assembly Television System Requirements
50M16149	TV Input Station to AM and OWS Requirements
50M16154	Portable Television Camera Assembly to SWS Interface

The design requirements are summarized in the MMC document, "TV Input Station; Equipment Specification, 82000003816". The detail drawings which were used in the build of the TVIS are listed in Table 2.2.8-1.

82000003800	TOP ASSEMBLY - TVIS
82000003801	TOP ASSEMBLY SCHEMATIC - TVIS
82000003816	EQUIPMENT SPECIFICATION - TV INPUT STATION
82000003818	TEST SPECIFICATION - TV INPUT STATION
82000003826	CASE AND COVER
82000003827	INPUT FILTER
82000003828	INDUCTORS - INPUT FILTER
82000003829	PRE-REGULATOR - CONVERTER - TVIS
82000003830	TRANSFORMERS AND INDUCTORS - DC-DC CONVERTER
82000003831	OUTPUT FILTER
82000003832	INDUCTORS OUTPUT FILTER
82000003833	AMPLIFIER - TVIS

Table 2.2.8-1 TVIS Build Drawings

B. Functional Description - The TV Input Stations accepted video signals from the portable TV camera, amplified and signal conditioned the signals and routed them to the SWS video bus. A variable gain adjustment was included to enable the TVIS to be utilized throughout the SWS. The variable gain was used to maintain a constant signal level at the MDA/CSM interface.

The TV system maintained a single point ground at the CSM. Isolation of the signal return from both the case and the power return was required in the TVIS. The former was accomplished by development of a bulkhead connector which, by means of a teflon insulating sleeve, maintained this isolation. The latter was maintained by use of a transformer isolated DC-DC converter.

The interface with the Portable Camera was by means of an Air-Lock microdot connector. This connection supplied +28 VDC system power to the camera. The video signal from the camera was also carried on a coax pin in the same connector.

The final flight TVIS configuration was an 82000003800-020 (see Figure 2.2.8-3). The units built for the One-G Trainer were of the same configuration, with one exception. The EMI filters which were replaced on the flight units, (2.2.8.2.C.4), were not replaced on the One-G Trainer units. The reason for this was that the form and function of the filter was not changed; only additional testing was added to improve reliability. A total of five units were built for the One-G simulators.

The TVIS units were built for operation in the Skylab environment for a minimum period of eight months. The unit itself was electronic in nature with the only mechanical part, the power switch, rated at 20,000 cycles at full load. All other parts were adequately derated and heat sinks were provided to extend the life of the unit to its maximum.

The unit's design was discussed at various NASA and MMC reviews. The purpose of the reviews was to verify that the unit met all specifications and to familiarize using agencies with the electrical and mechanical interfaces.

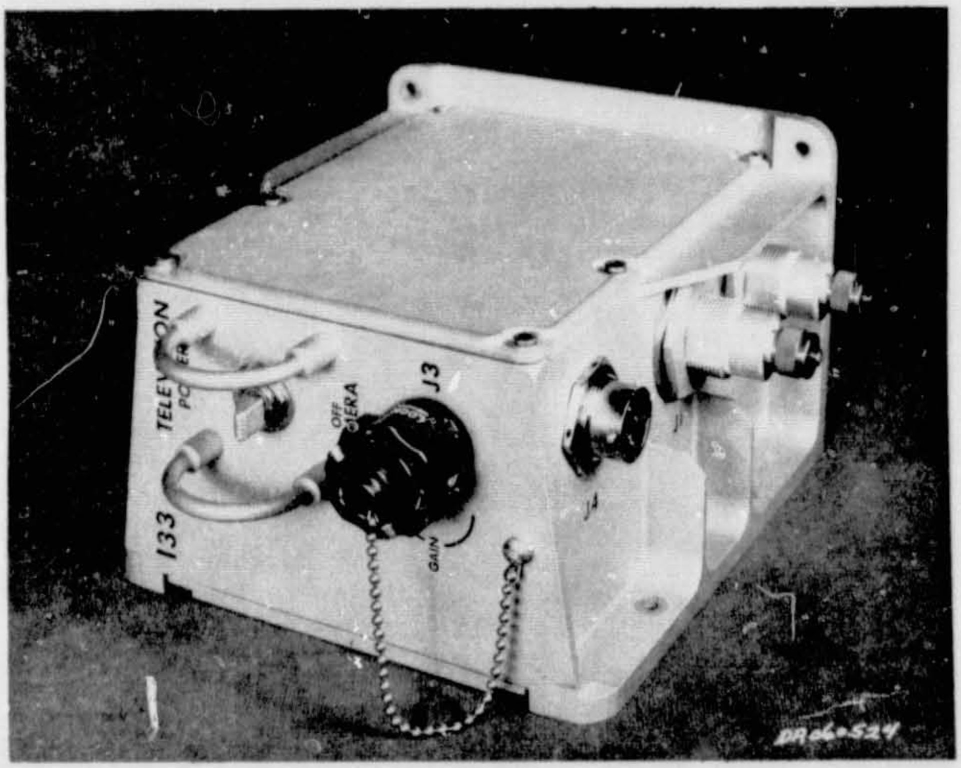


Figure 2.2.8-3 TV Input Station

As a result of the build cycle, three deviations were requested and granted:

DAR-MDA #7 - Approved use of an increased plating thickness of solder on PC boards (deviation from MSFC-STD-154A).

DAR-MDA #13 - Approved use of plated-through holes for qualification PC boards (deviation from MSFC-STD-154A).

DAR-MDA #20 R1 - Approved EMI test deviations as discussed in paragraph 2.2.8.2-C(2) below.

C. Test - Summary - There were two (2) specific programs of testing performed on the TVIS at the component level. These were the development and qualification testing programs. Each unit was also subjected to the required acceptance tests.

(1) Development Tests - The purpose of these tests was to prove out the design prior to fabrication of the first production unit. It was decided to test the TVIS in the most severe environments; i.e., random vibration, shock, and temperature. The vibration test was run to 32 grms for 1 minute per axis and was followed by a run of 28 grms for 2 minutes per axis. The TVIS was shock tested at 380 gs. A temperature test was performed to verify the D.C. bias drift and gain stability over the range of -50°F to +180°F.

During vibration, two parts failed due to improper bonding and mounting. Rework was accomplished and a successful vibration and shock test was run. No problems occurred during shock or temperature testing. Over the temperature range tested, -50°F to +180°F, the D.C. bias drift totalled 97.6 millivolts. However, over the operating range of the unit, +25°F to +125°F, the drift was 4.4 millivolts.

(2) Qualification Test (Report #3278) - The purpose of the qualification test was to assure flight environment compatibility of the TVIS using worst-case cluster-assigned environments. The tests included the following:

- Temperature, Altitude, and Storage: Temperature, -50° F to $+180^{\circ}$ F; pressure, Seal level to 35K ft.

- Vibration: 32 grms/axis for 1 min/axis; 26.6 grms/axis for 2 min./axis.

- Shock: 380 g's - 6 shocks/axis.

- EMI: MIL-STD-461 and MIL-STD-462.

- CCOH: 1 percent salt solution followed by oxygen and humidity.

- Thermal Vacuum: Temperature 25° F to $+120^{\circ}$F; Pressure 1 X 10^{-6} psia.

The TVIS successfully completed all tests with the exception of EMI and vibration. There was no evidence of contamination due to salt or oxygen. The drift of the TVIS during thermal vacuum test was 12 millivolts. During vibration, an internal connector, P1, backed off during the first test. This connector was located in a position where it could not be torqued adequately. Bonding compound was placed across the plug and receptacle. The tests were continued successfully. However, the unit failed portions of the EMI tests (see Table 2.2.8-2) as follows:

(a) Radiation Susceptibility - Out of specification at 59 MHz to 62 MHz.

(b) Narrow Band Interference - Out of specification at 120 MHz, 436 MHz and 800 MHz.

(c) Broadband Interference - Out of specification due to input power switching.

A deviation was received for the following reasons:

- (a) and (b) - There were no transmitters operating at these specific frequencies in the OA.

- (c) - Broadband interference occurred only when the TV was switched on. Since this was infrequent, it was not felt advisable or necessary to redesign.

EMI DEVIATION	SPEC LIMIT	MEASURED	REMARKS
1. Conducted interference + 28 V lead to TVIS Broad band audio + 28 V return to TVIS Method CE01 + 28 V load to TV Camera load	90 db 90 db 90 db	140 db 140 db 119 db	Violation only occurs when power switch is actuated
2. Conducted interference + 28 V lead to TVIS Broad band method CE03 + 28 V return to TVIS + 28 V lead to camera load		70 db out of spec 66 db out of spec 40 db out of spec	Violation only occurs when power switch is actuated.
3. Conducted narrowband + 28 V to TVIS Method CE03 + 28 V to TVIS		11 db above spec limit 13 db above spec limit	The emission was found to be common mode 123 KHz and peaks of 2 ma.
4. Radiated interference from 14 KHz to 240 KHz Broad band method CE03 at 25 MHz		25 db above spec limit	Violation only occurs when power switch is actuated.
5. Radiated interference at 436 MHz Narrow band method RE02 at 880 MHz		18 db out of spec 7 db out of spec	
6. Radiated susceptibility Exceeded level from Method R503 59 MHz to 62 MHz	1.0 Volt/Meter	Reduced RF level to .25 Volt/meter or 12 db below required level to pass.	

NOTE: TVIS is ON only when camera is plugged in and TV system turned ON.

Table 2.2.8-2 TVIS EMI Deviation Report

(3) Delta Qualification - Report #3512 - Due to a revision in the vibration requirements, a delta test was performed. While the overall composite level was lower (27.7 grms), there was much more energy concentrated at the lower frequencies. This was the main reason for the performance of the test. The test was successfully completed using S/N 7 TVIS with no anomalies.

(4) Acceptance Test - The purpose of the acceptance test was to prove out the assembly of the production units. The test consisted of a thermal cycle test and a vibration test at 7 grms/axis. A functional test was also run before and after each environment. The results of the ATP tests were successful. The major anomalies consisted of the following:

- ST88D8 EMI filters had a shorted capacitor. The problem was traced to foreign matter inside the filter. All filters were returned to the vendor for additional tests to update the part to "hi-rel" status. All filters in the TVIS were replaced.

- The bottom shell of the ST82D29 connector (J1 and J2) became loose. This was corrected by the addition of a small amount of "Locktite" to the threads as well as torquing the bottom shell to 8 to 10 in.-lb.

The above changes were incorporated into the drawings. The functional tests and the final checkout of the TVIS consisted of the following:

Impedance
Isolation
Gain and Bias
Frequency Response
Insertion Loss
Power

(5) System Test - The system test program took place at Denver, St. Louis, and KSC.

At Denver, all tests were completed successfully with the exception of an isolation test. This test showed a short between the +28 VDC power return and structure. The problem was traced to a shorted EMI filter (see C.(4), herein). As noted, all EMI filters were retested and replaced.

At St. Louis no anomalies occurred. However, during a system development test excessive reflections were noted. The problem was traced to the impedance mismatch caused by the 10 ohm output impedance of the TVIS and the impedance characteristics of the RG 180 coax at these relatively low frequencies. All TVIS's were returned to Denver and the output impedance raised to 93 ohms. During subsequent system testing at St. Louis, no further anomalies were reported.

At KSC, a series of anomalies occurred. One was a reported gain change. The output of S/N 11 was reported to have been set to 3.72 VP-P. After a period of time it dropped to 3.24 VP-P. Subsequent burn-in testing, thermal cycling and vibration testing with 100 percent monitoring could not verify the failure. The unit was sent to St. Louis as the inflight maintenance unit for the backup article.

The next anomaly was reported against S/N 16. This unit was located in the OWS which was tested for the first time at KSC. The offset voltage was reported to be high and out of specification. In testing and investigation at Denver it was discovered that a selected value resistor was chosen incorrectly. Reselection of the resistor corrected the problem and retest resulted in no further anomalies. All other TVIS records were checked to verify correct resistor values.

The next problem that occurred at KSC was mechanical. It was discovered that the portable camera cable did not mate with S/N 13 TVIS. The problem was traced to a tolerance build-up of the camera cable connector. However, the solution was to tighten the tolerances allowed on the TVIS side and use shims under the Airlock adapter where necessary. This approach was chosen because it was the quicker solution and would not require retest. No further anomalies occurred during the rest of the system testing at KSC

(6) Backup System Testing - As a result of the flight system and development testing programs no significant problems occurred during the TV testing that could be attributed to the TVIS. Backup system

testing was the same as that performed on the flight vehicle.

All anomalies encountered during the entire testing phase were analyzed and proper design adjustments were made. These changes were all incorporated into the qualification and production units.

(7) Special Testing

(a) Relay Moisture Test - An alert against Teledyne RF relays was concerned with inoperative conditions due to moisture internal to the relay. At the time a requirement was made to test all relays (CCBD800-70-0859) prior to installation, only two TVIS units were left to build. As a result, only two relays were tested. The test consisted of energizing the relay at 140 percent of rated coil operating voltage for a period of two and one half minutes. An electrical check of the relay was performed before and after the stress test. The primary characteristic observed was the insulation resistance. A change in the resistance before, during, and after the test would show the presence of moisture. In the test no change was noted and the relays were installed in S/N's 17 and 18.

(b) Gain vs Turns - Due to the interchangeability of the TVIS units it was decided to run tests to determine the gain adjustment when moving the unit from one position to another in case of a failure. The results were first found analytically using specified cable losses. The analytical results showed the adjustments were needed. However, tests both at Denver and at St. Louis showed that the total adjustment was less than 3/4 of a turn. This was felt to be so nominal an adjustment that it would not be needed if it became necessary to perform a change-out. During SL-4 this was proved to be true when the spare was used as a replacement for the TVIS in the OWS. No adjustment was made and the video received was satisfactory.

D. Mission Results

(1) SL-1/2 - No anomalies occurred during the first Skylab mission which could be attributed to the

TVIS. All units, with the exception of the AM TVIS, were used during real time TV transmission. The units in the OWS were subjected to higher wall temperatures as a result of a meteoroid shield loss during launch. However they still operated properly with no observable problems. Flight performance was analyzed by viewing flight video data. Nominal performance by all units was indicated.

(2) SL-3 - During this mission all units were used. The AM unit was used during the EVA of DOY 236. During this EVA the camera failed due to overheating. To verify that it did not cause a problem with the TVIS, the AM unit was used at a later date. No problem was observed.

(3) SL-4 - During the mission all units were again used. On DOY 361 the crew reported a broken pin in the Airlock/Microdot connector on the TVIS located in the OWS. At the crew debriefing it was stated that the pin had been broken while attempting to straighten it. No explanation of how the pin was bent was given. The unit was replaced and the mission was completed with no further anomalies.

E. Conclusions and Recommendations - The prime areas of improvement for the TVIS would be:

- Increase in the gain-bandwidth product
- Use of a potentiometer for bias adjustment
- Use of smaller connectors for J1 and J2.

(1) The need for the increase in gain-bandwidth became evident when the output impedance was raised to 90 ohms. The original design had a 10 ohm output impedance. Analysis had shown that there would be little reflection due to the mismatch. However, actual system tests showed that reflections were greater than expected. To reduce the reflection, the output impedance was raised to 93 ohms. As a result, the gain needed to maintain the required output was increased. The effect of this was more roll-off from 2 MHz to 4 MHz. The exact roll-off is shown in Report ED-2002-1550. For future usages, thought should be given to improving this design.

(2) A potentiometer could have been used for the bias adjustment. Possible movement during vibration was the main reason for not using it. However, the use of a gain potentiometer provided an example of satisfactory stability of a cermet potentiometer. If the bias potentiometer had been used, time would have been saved when the R7 (bias select) was replaced as a result of specification change.

(3) In the design of the TVIS a new coax connector was developed which provided isolation of both center pin and shield from chassis ground. The connector worked well, however, it was very bulky for a unit of the TVIS's size. A TNC bulkhead mounted on fiberboard would have been adequate and would have reduced the overall envelope.

2.2.8.3 Video Tape Recorder (See Figure 2.2.8-4)

A. Design Requirement - The Video Tape Recorder (VTR) was a modified version of the RCA ERTS VTR originally built for Goddard Space Flight Center. The Interface Control Documents which describe the VTR are:

ICD 50M16159	-	Video Tape Recorder and Audio Splitter to Multiple Docking Adapter Interface
ICD 50M16132	-	Skylab Orbital Assembly Television System Requirements

B. Functional Description - The Video Tape Recorder consisted of a tape Transport Unit (TU) and an Electronics Unit (EU), each in its own separate package. The TU was installed in a 21.5" X 15" X 6.5" hermetically sealed housing. The EU was packaged in a 16.75" X 16" X 7" housing. These two units were connected together via four cables and had a combined weight of approximately 74 pounds exclusive of interconnecting cables. The transport contained 2,000 feet of special two-inch-wide video recording tape which was scanned transversely by a rotating head with a head to tape speed of 1,964 inches per second. The tape was recorded or played at a tape speed of 12 inches/second resulting in a 30-minute minimum record time. The rewind speed was four times faster. The wide-band recording electronics were functionally similar to those used in conventional broadcast television recorders. The recorder had a bandwidth of 4 MHz.

All circuitry was designed to insure an operating life performance of three years.

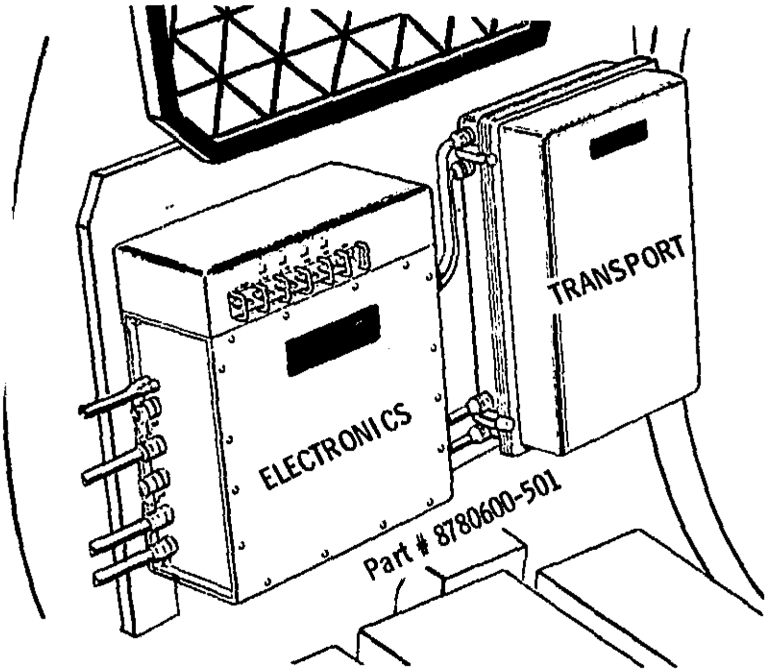


Figure 2.2.5-4 Video Tape Recorder

The recorder electronics included circuitry for control and telemetry. The VTR could be controlled manually or by ground command with the exception of playback, which could only be controlled by ground command. The command system had been designed such that command sequencing was performed internal to the recorder, thus deleting prerequisite commands from most VTR operating modes. The following functions could be commanded from the ground:

- Headwheel Drive Motor On,
- Headwheel Drive Motor Off,
- Fast Forward,
- Rewind,
- Playback,
- Record.

The VTR provided an output signal to the MDA for telemetry transmission of tape position. This signal was a 0 to 5 volt signal in which five volts indicated no tape had been used, and zero volts indicated that all tape had been used.

The VTR was connected to a Speaker Intercom Assembly (SIA) in the Skylab audio system. The VTR accepted a voice signal from the earphone circuit and interleaved it with the recorded video such that a single composite signal was available for transmission to the STDN.

In the event that one or more external VTR command lines became disabled, a separate device called the Command Transfer Unit (CTU) could be used to sacrifice less important commands and restore necessary ones. The CTU was essentially an in-line patchboard which permitted cross-patching of command functions.

C. Test - A nonflight VTR was installed in the MDA at St. Louis. During isolation testing the 28 vdc return line was found to be only 10 ohms above structure ground instead of the required isolation. The VTR was returned to the manufacturer for rework. After rework the unit was reinstalled into the MDA at St. Louis and tested briefly. During this test, data was recorded and played back through a CSM simulator and transmitted to an S-Band STDN receiver. This nonflight unit was then returned to RCA.

The flight VTR was installed in the MDA at KSC. Isolation tests determined that an audio cable shield was grounded. This was traced to a VTR connector pin which was grounded internal to the VTR. Although this ground was in conflict with the controlling ICD, the module cable shield termination was changed in the interest of speed and simplicity.

Subsequent testing revealed that the "tape-remaining" telemetry channel calibration was incorrect. A problem also developed between the VTR and the audio splitter. The audio splitter was GSE equipment whose purpose was to recover the audio recorded on the VTR. The bias in the VTR was not compatible with the audio splitter and the voice recordings were not intelligible. As a result, the VTR was returned to RCA for rework.

During retest, streaks were occasionally seen across the monitor. The problem was traced to the interleaved audio. However, since it was only observed when the audio levels were high and the monitor was set up for high contrast, it was judged acceptable. No further anomalies occurred during testing.

D. Mission Results - VTR

(1) Skylab 1/2 - The VTR operated properly throughout the SL-1/2 mission. All uplink commands were successfully exercised except the RECORD function. The RECORD function was always operated by the crew. Since all commands operated satisfactorily it was not necessary to utilize the CTU during SL-1/2.

(2) Skylab 1/3 - The VTR operated properly until mission day 6, when it failed during a playback. On-board troubleshooting, using ground-formulated procedures, isolated the probable cause to the EU. The crew replaced the flight VTR with the inflight maintenance unit and restored video recording capability. It was thought that the TU may have been damaged, either by the EU failure or the fact that it had been left ON for approximately 13 hours. Skylab Test Unit (STN)/STDN testing revealed that only the failed EU need be replaced on the next mission (SL-4). The EU from the backup MDA VTR was being prepared for launch on SL-4 when a loose connector was discovered on the unit. It was found that the connector nut had not been epoxied in place. The connector was tightened and epoxied, and the unit was shipped to KSC for launch on SL-4.

Failure mode analysis on the ground led to the decision to have the crew remove four printed circuit boards from the failed VTR EU. This was done according to a procedure developed on the ground. Upon return of the four printed circuit boards to the manufacturer, failure analysis isolated the failure to an inductor on the Video Demodulator board. The failed inductor was replaced and all four cards were inspected, X-rayed, temperature-cycled and tested. These four boards were launched on SL-4 for replacement in the failed VTR EU.

The inflight maintenance VTR operated properly throughout the SL-1/3 mission after its installation on mission day 6.

The CTU was not used during SL-1/3.

(3) Skylab 1/4 - The VTR operated properly during the entire SL-1/4 mission. The four P.C. boards carried in the CSM by the crew were not used. The unit installed on mission day 6 of SL-1/3 operated successfully and so there never was a need to repair the unit which failed. No problems were indicated with the uplink commands. As a result the CTU was not used during SL-4.

E. Conclusions and Recommendations - The flight VTRs adequately performed the required functions throughout the manned Skylab missions. However, the following recommendations would enhance the capability and usability of the VTR.

(1) Remote switching would allow a crew member to start and stop the recorder without going to the VTR location in the MDA.

(2) A visual readout of tape position, which could be read by a crew member, would aid in tape management.

This Page Intentionally Left Blank

2.2.9 Crew Systems

2.2.9.1 Crew Stations

A. Design Requirements - The design requirements for the MDA Crew Stations were delineated in the Cluster Requirements Specification (CRS) RS003M00003. The following is the Crew section from the CRS, Appendix G:

> Crew Stations - The crew stations established for accomplishment of mission activity are generally located as shown in Figure G-1 (figure not included herein).
>
> Multiple Docking Adapter (MDA)
>
> a. In addition to those requirements specified in paragraph 3.1.1.1.4.2.2 of the basic Cluster Requirements Specification, the following items shall be provided in the MDA:
>
> 1) Lighting and associated controls.
> 2) Caution and Warning System (audio only).
> 3) Communication stations.
> 4) Ventilation fans.
> 5) Astronaut mobility/stability aids.
> 6) Utility outlets (high and low power).
> 7) Experiment and viewing windows.

Also applicable were Sections 3.1.1.1.4.2.2 Multiple Docking Adapter (MDA) which specified the basic requirements for cluster integration of the MDA, and 3.1.3.7 which referenced MSFC-STD-267, 10M32447, and MIL-STD-1472 as guides for standards and practices for human engineering design for new hardware and Appendix G, Crew System Design Requirements, Section 2.1 System Requirements.

B. Functional Description - This section described the crew stations of the MDA. The MDA had crew work stations at the ATM C&D console, EREP C&D panel, EREP Viewfinder Tracking System (VTS), and the M512/479 Material Processing in Space Facility (MPF). Because of its small volume, the MDA module was also treated as a crew station in the evaluation.

This crew station section will discuss work space, work space layout, reach envelopes, habitability factors, and compatibility between crew stations.

The term crew station was rather a generalized term. Originally it was associated with control panels and experiment installations but as the MDA received additional installations such as the EREP experiment, the VTR and numerous stowage containers, the whole of the MDA was looked on as a crew station by the flight crew. With the growth of the MDA installed experiments, it became obvious that task and volume sharing was required and this requirement became part of the crew station definition. The primary criteria for defining a crew station was the provisioning required for long duration, two-handed tasks. Where these requirements were identified a foot restraint was provided; i.e., EREP C&D Panel, ATM C&D console, and the M512/479 facility. The single exception was the VTS crew station for EREP. The foot restraint for this station was deleted at the astronauts' request. The rationale for the VTS was that handholds mounted on the VTS panel would adequately position the operator and give him the freedom to quickly move away from the station and back again. The crew believed this would be easier to do if they did not have to disengage their feet from the foot restraint grid.

Each crew station was evaluated by task analysis to establish the operator's functions. His reach and work envelopes were major constraints for positioning the foot restraint at the crew station. Tradeoffs and compromises were made as required and on occasion, equipment was re-positioned, e.g., the positioning of SIAs at EREP, M512/479 and ATM C&D console. Where operator volume sharing was required, the scheduling of the experiments was studied to assure no conflict existed such as between EREP VTS and the M512 which share the same work envelope.

(1) ATM C&D Crew Station (Ref. Figs. 2.2.9-1 and 2.2.9-2) - The ATM Crew Station hardware consisted of the C&D Panel, the ATM foot restraint, the chair and a speaker intercomm assembly. The ATM C&D console was originally designed for seated operation and installation in the Lunar Module (LM). Although changes were made in the panel for Skylab, its basic size and shape did not change.

At crew reviews early in the program, the astronauts elected to operate the ATM C&D Panel from a standing position. This decision was based on two considerations, 1) that two operators may be required at the ATM, and 2) the requirement to monitor the STS control panel while physically oriented at the ATM C&D Panel. Neither of these requirements remained by the time the Skylab was being readied at KSC and the

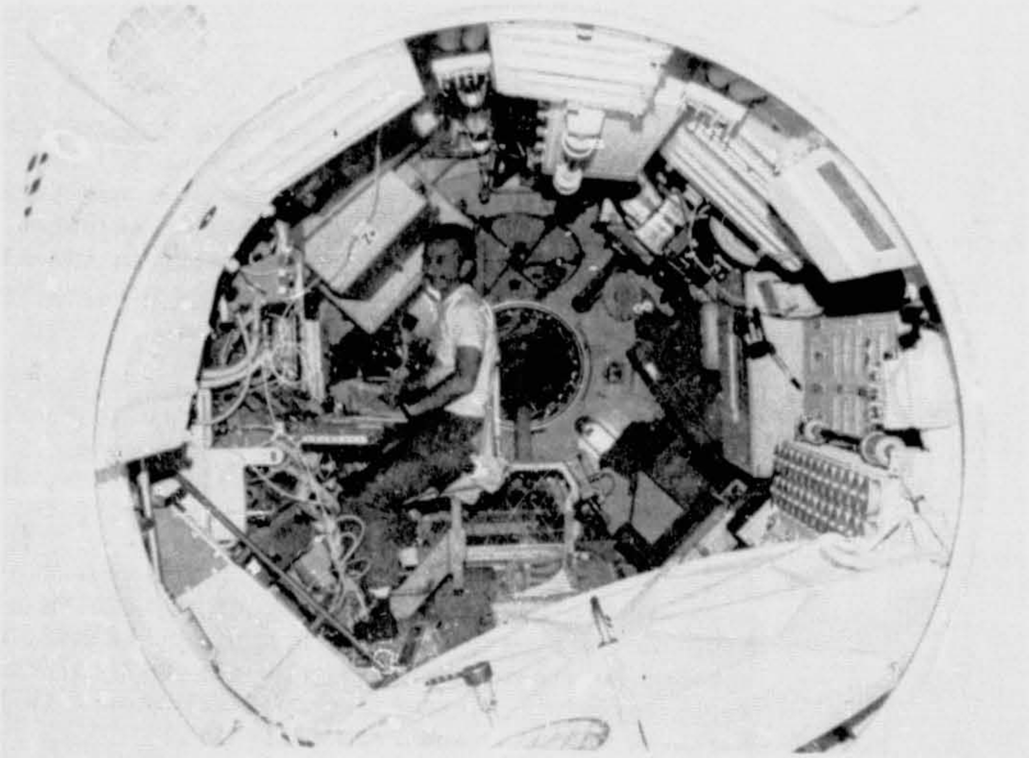


Figure 2.2.9-1 - Crewman at ATM Crew Station (left view)

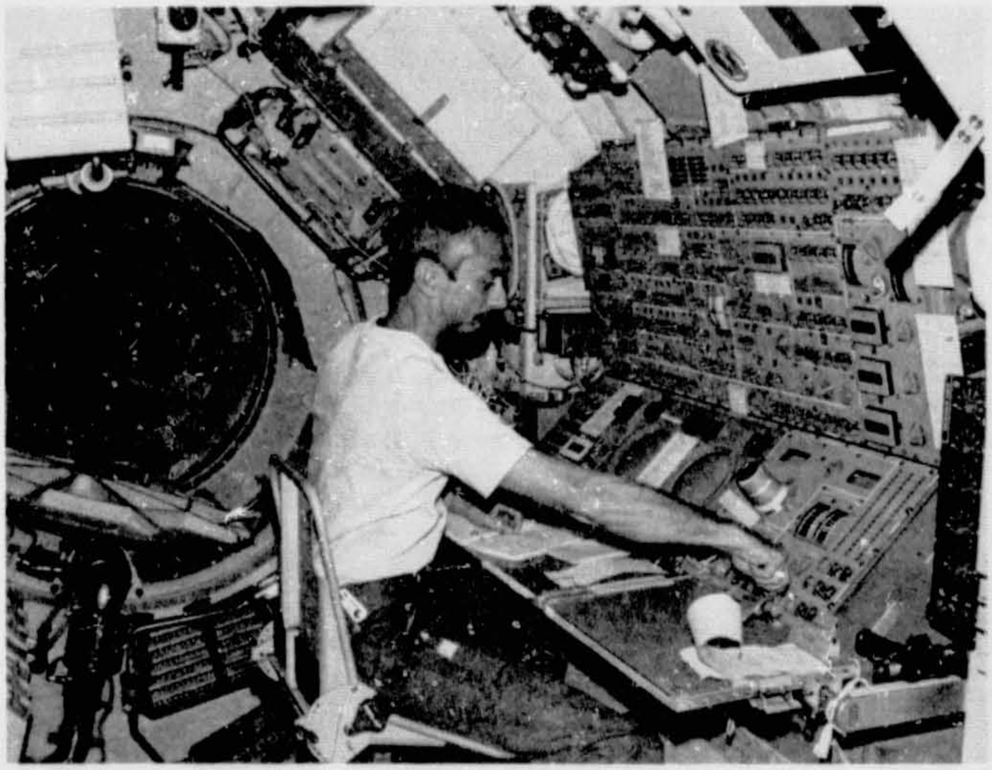


Figure 2.2.9-2 - Crewman at ATM Crew Station (right view)

decision was made by the flight crew commander (CDR) to install a chair at the ATM C&D console. To provide flexibility in the chair, its seat and back angles could be changed and its height adjusted. It was mounted with captive connectors in the ATM foot restraint grid and stowed in the Orbital Workshop (OWS) for launch.

The ATM C&D foot restraint was composed of the Skylab triangular grid; it was the same length as the console width and approximately 20 inches wide. The foot restraint was adjustable in 3 positions, at 6-in. increments, vertically to the panel face.

(2) EREP C&D Crew Station (Ref. Fig. 2.2.9-3) - The EREP crew station hardware consisted of the C&D Panel, the S190 camera array, the S190 stowage container, a speaker intercomm assembly, and the M512/497/EREP foot restraint. The major crew interface with MDA hardware was with the foot restraint.

The original foot restraint concept for the EREP C&D console was a grid platform, serving both the EREP C&D Panel and the VTS. Functions on the C&D Panel were not fully developed and were quite limited at that time so it was decided to remove the C&D Panel foot restraint but leave the VTS foot restraint. However, during this design period a crew review reversed this concept placing the foot restraint back at the C&D Panel and removing it from the VTS. It was at this crew review that the recommendation was made to use a combined M512/479 and EREP C&D Panel restraint. This is the concept that was ultimately designed and flown.

The EREP C&D Panel foot restraint fitted into mounting brackets and provided a standing orientation of the operator to the panel with the center of the panel chest high to a 50th percentile astronaut. This restraint was not adjustable in its vertical orientation to the panel. It was removable for positioning and utilization at the M512/479 experiment.

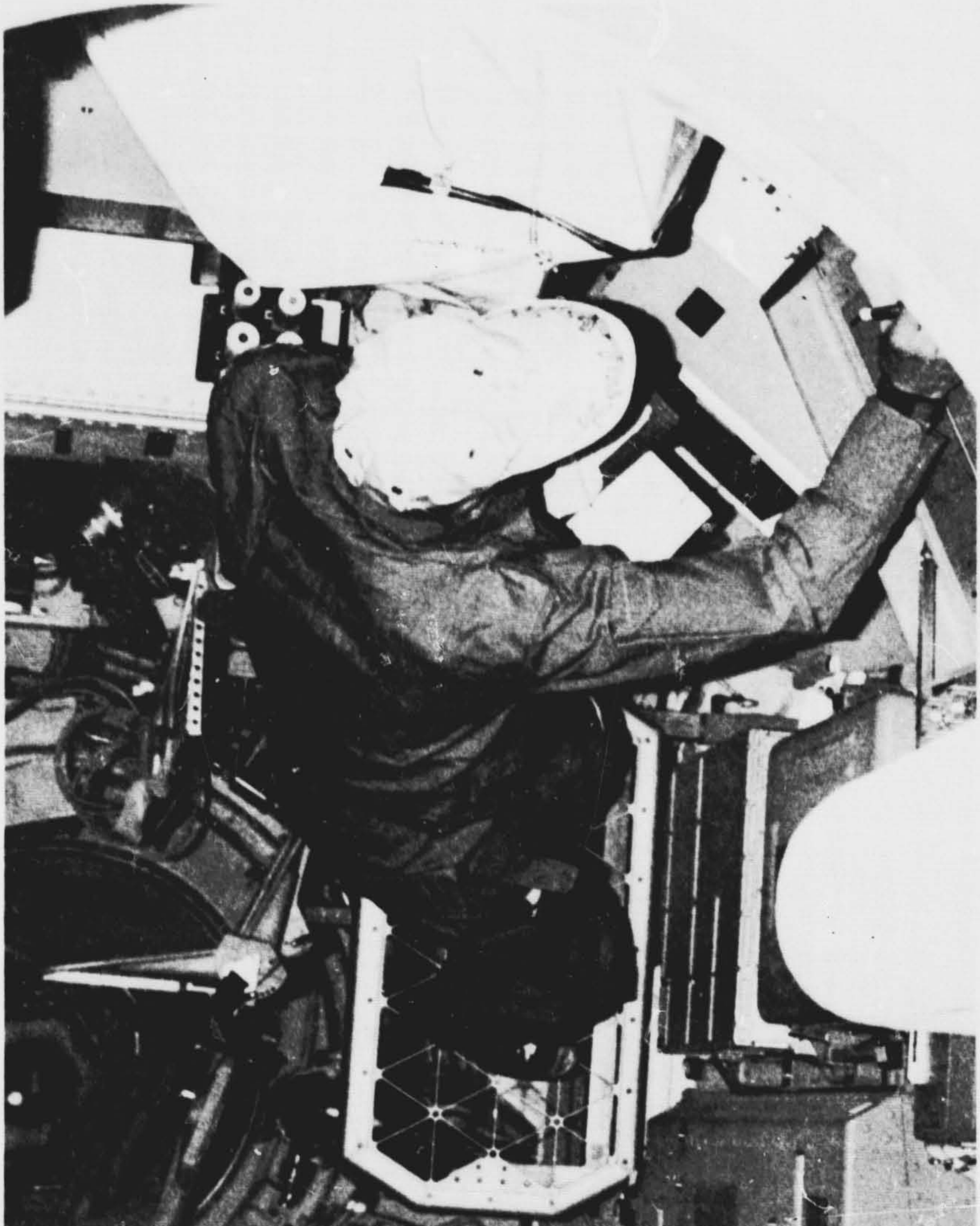


Figure 2.2.9-3 - Crewman at EREP C&D Crew Station

(3) EREP VTS Crew Station (Ref. Figs. 2.2.9-4 and 2.2.9-5)- The VTS crew station hardware consisted of the Viewfinder/Tracking System, its associated control and display panel and a clipboard restrained on the S191 closeout cable cover. A crewman at this station utilized the SIA located adjacent to the MPF.

No foot restraint was provided at the VTS crew station. Handholds on the VTS panel were provided for crew positioning and operation at this station. The operator needed to interface with the EREP SIA and the C&D Panel. Neither of these units were positioned to provide this capability from a foot restraint. (A major modification to the MDA equipment arrangement would have been required to configure this station for that capability. A modification of this magnitude was deemed undesirable at that time.)

(4) M512/479 Material Processing Facility Crew Station (Ref. Fig. 2.2.9-6) - The design of the M512/479 crew station foot restraint utilized the same restraint platform provided at the EREP C&D console, but repositioned to the M512/479 experiment. The placement of the restraint in the MDA provided the operator with access to all the pallet-mounted M512/479 equipment, the M512/479 SIA and the two 4-inch vent valve handles controlling the experiment furnace venting. Due to the wall mounting of the M512/479 and the positioning of the mounting pallet, it was not possible to position the operator to the M512/479 in a standup position. The resultant operator position was a compromise between a standup attitude and a position wherein the operator leaned slightly forward to operate the experiments. In effect he assumed a bent-over "hovering" position. This presentation to the experiments was evaluated in the Neutral Buoyancy Facility (NBF) and determined to be satisfactory.

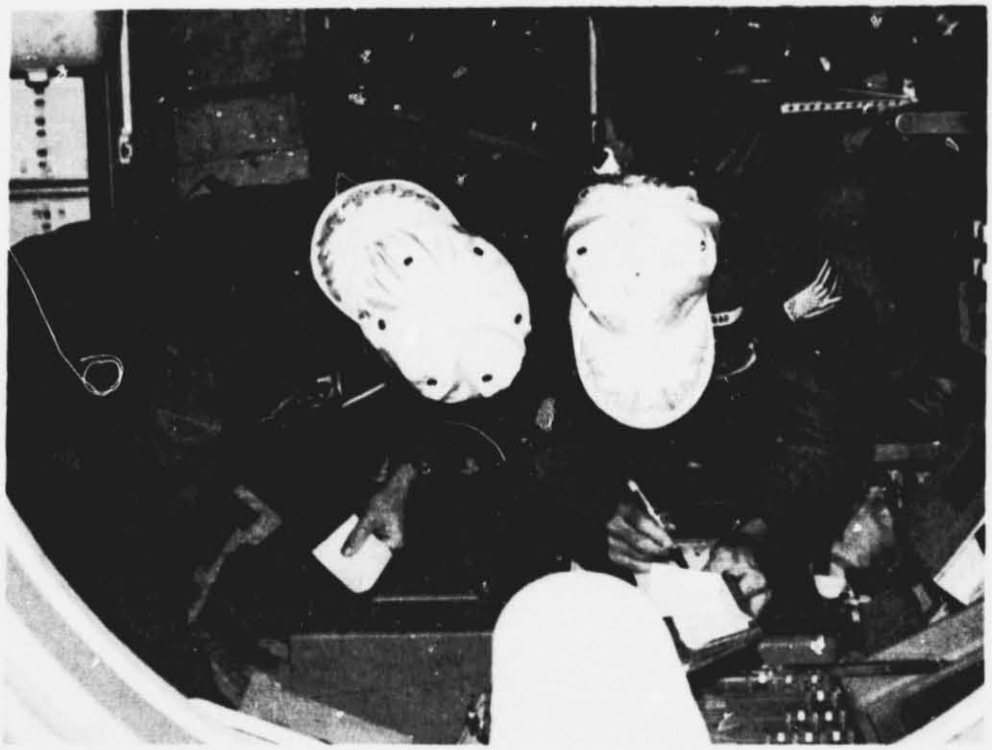


Figure 2.2.9-4 - Skylab Crewmen at EREP VTS and C&D Crew Station

Figure 2.2.9-5 - Crewman at VTS Crew Station

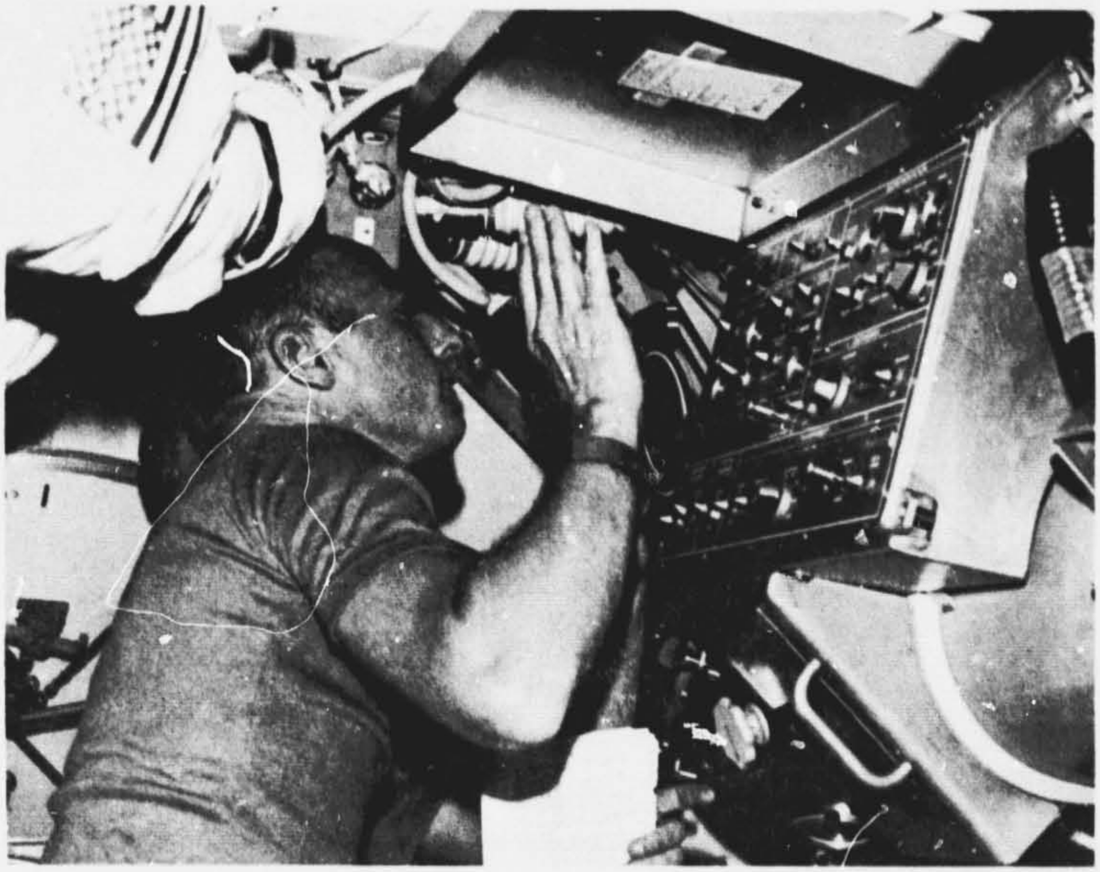


Figure 2.2.9-6 - M512/479 Experiment Crew Station

(5) MDA Module Work Space (Ref. Fig. 2.2.9-7) - The significant feature of the MDA as a crew work area was its cylindrical layout of hardware and crew stations as opposed to the OWS floor-ceiling arrangement of equipment and crew work stations. The evolution of the MDA from a five port docking adapter to the two-port docking adapter and experiments/stowage module resulted in an add-on approach to interior layout. This prevented a dedicated area approach to MDA layout of experiments and stowage. Experiment work stations were laid out according to space available rather than with a specific orientation in mind.

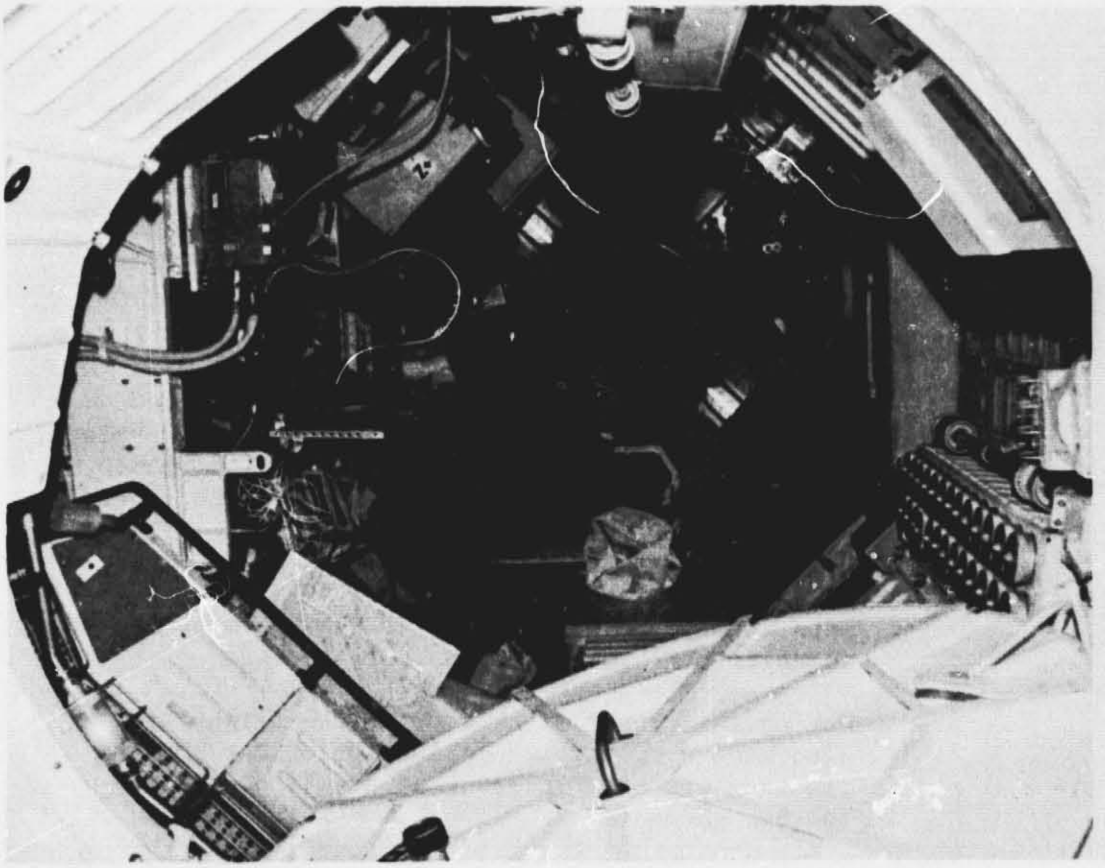


Figure 2.2.9-7 - Total MDA Workspace

The crew interfaced with the MDA in the following areas:

- Passage between the AM and the CSM.
- Stowage of hardware and support equipment for experiments.
- Performance of experiments at the respective crew stations.
- Stowage of probe and drogue during activation.
- Photography and TV recording of IVA activities.

C. Test - Crew station reviews were held at Denver, St. Louis, and KSC as discussed below:

- 18 Discrepancies dispositioned rework to engineering
- 30 Discrepancies against GFP/Experiment hardware
- 13 Discrepancies requiring flight crew nomenclature changes
- 21 Discrepancies requiring hardware changes.

The most significant hardware changes involved captivating screws, addition/modification of Velcro, stowage relocation of an S056 magazine to reduce interference and the extension of inflight stowage straps to ease operational access.

The intent of this test was to have a total C^2F^2 with items not accomplished in Denver to be tested in delta C^2F^2 tests at St. Louis and KSC.

During the course of this test, the flight crew also made a subjective evaluation of the MDA lighting with the result that it was considered low but adequate.

(3) St. Louis Crew Compartment Fit and Functional (C^2F^2) Test - The St. Louis C^2F^2 test was a composite of four events utilizing a common test procedure, MDA-OCP-S-80001. The first two events were incremently held in February 1972 utilizing the vehicle in a vertical orientation. The third event was a bench review held in May 1972 with the final event a combined AM/MDA C^2F^2 held in June 1972 with the AM/MDA horizontal.

The culmination of all crew tests held at St. Louis resulted in 40 discrepancies. The breakdown of these discrepancies follows:

- 20 Discrepancies against GFP/experiment hardware
- 3 Discrepancies dispositioned no item
- 4 Discrepancies dispositioned rework to engineering
- 6 Discrepancies requiring flight crew nomenclature changes
- 7 Discrepancies requiring hardware changes.

The most significant hardware changes involved captivating washers to bolts designed for in-flight removal changing the mounting hardware for the TV input station and video switch, adding a 1/16 Allen wrench to the MDA tool kit and adding additional restraints to the miscellaneous stowage container.

(4) KSC Crew Compartment Fit and Functional (C^2F^2) Test - The KSC C^2F^2 was held in April 1973 for the MDA portion of the SL-1. The test was conducted utilizing the MDA portion of KSC-0010 Integrated C^2F^2 Test. Prior to the test, all available flight crew and experiment equipment available at KSC was launch stowed in accordance with MDA stowage procedures KM-3014 and KM-7000.

At the conclusion of the test, 13 discrepancies were recorded. Their breakdown follows:

- 7 Discrepancies against GFP/experiment hardware
- 2 Discrepancies dispositioned no item
- 1 Discrepancy requiring flight crew nomenclature changes
- 3 Discrepancies requiring hardware changes.

The three hardware changes consisted of removing the blue paint from the ATM handrail due to chipping, stowage configuration changes for EREP attenuators and the MDA tool kit launch pip pins.

D. Mission Results -

(1) ATM C&D Crew Station - The comments made by the SL-2 crew on the ATM C&D crew station were generally favorable except for the layout of the controls and displays. The SL-2 Science Pilot (SPT) commented in detail on his reach envelope at the ATM C&D station while using the chair (Dump Tape 154-03).

The SL-2 SPT further states that the ATM C&D in his opinion was designed to be worked in a one-g environment (Dump Tape 155-12). He goes on to say that they did not want to sit at the C&D station, but neither did they want to stand on the foot restraint.

During the SL-2 crew debriefing, the CDR and Pilot (PLT) said that the ATM integral panel lighting gave a nice effect when the MDA floodlights were shut off, but the lighting was not necessary. When the floodlights were turned on the ATM edge lighting effect disappeared and when the ATM lights were used alone they couldn't read the checklists.

The crew further stated in their debriefing that, because of the similarity between the S082A and S082B panels, control and displays on one panel were often mistaken for those on the other panel.

The Skylab 3 crew in all their comments about the ATM crew station indicated that they preferred to use the triangular grid foot platform alone without the ATM seat/backrest assembly. The SL-3 CDR gave a complete description of how the crew arranged their checklists and portable equipment around the ATM work station. He also said:

> "We know where everything is and - I think that works pretty well - it's a nice area to use."

The SL-3 CDR further stated that it was really pleasant to work the ATM. (Ref. Final Dump Tape 251-11)

The SL-3 SPT evaluating the ATM work station stated that the foot restraint at the ATM work station was very adequate and worked well but added that the lighting was poor for reading or updating checklists.

The SL-4 crew also considered the ATM foot restraint to be very adequate. They did not consider the ATM seat/backrest an acceptable work station restraint. The SL-4 crew preferred the freedom of having just one foot fastened to the restraint and the shoulders and body unrestrained.

The SL-4 SPT made one comment saying that he would have liked the foot restraint to be just a bit lower (Dump Tape 022-06, Pg. 13 of 24). No other comments were located to suggest that other crewmen would like to have had a lower platform.

The SL-4 crew, explicitely by the SPT, made suggestions that the addition of a trash bag at the ATM station and in general a bag in the MDA would have aided operations in the MDA (Dump Tape 361-03, Pg. 4 of 17).

(2) EREP C&D Crew Station - The SL-2 crew operated at the EREP C&D station as planned and no major problems were indicated, however, the arrangement of the experiment controls (from top to bottom: S192, S191, S190, S193, S194) was a source of minor irritation.

The SL-3 CDR and the PLT gave evaluations of the EREP crew station. The CDR said (Final Dump Tape 251-11):

> "The foot restraint there, that's the greatest thing since popcorn."

The SL-3 PLT's comment on the EREP crew station was:

> "You've got to have the ability to get your feet locked down at the EREP panel. The C&D does have that ability. It's easy to work that."

The SL-4 comments were very similar to the SL-2 and SL-3 comments. The EREP C&D crew station posed no problems and again the foot restraint was considered a very adequate restraint (Dump Tape 365-07, Pg. 3 of 21).

(3) EREP VTS Crew Station - The kinescopes of the VTS passes showed the ease at which the VTS operator acquired and tracked the target site. The SL-2 crew described the VTS as working better than the simulator. They did feel, however, for future designs a wider field-of-view would be desirable. The only bothersome problem on the SL-2 mission associated with this crew station had to do with the clipboard mounted on the EREP experiment S191 closeout cable cover. The clipboard was attached to the cable cover by two snaps and was utilized to hold checklists, maps, photographs of target sites, etc. The clipboard came unsnapped several times when used by the crewman.

The significant comment the Skylab 3 crew made relative to the VTS crew station was the lack of a foot restraint for the VTS operator. The CDR said of the work station (Final Dump Tape 251-11):

> "One of our biggest mistakes in EREP was not having one of those (foot restraints) for the VTS. Sure you can hold on by your hands, but then you can't grab your map cause you are holding on."

As with the SL-3 crew the SL-4 crew thought that the VTS station needed a foot restraint (Dump Tape 365-07, Pg. 3 of 21):

CDR: "I think we need more of the grid-work sort of thing, like the ATM C&D and the EREP C&D foot grid restraints. Those are very, very useful and very versatile and very handy.... I think the VTS Operator needs some sort of foot restraints. The way it's working right now, you - we're wrapping our feet around the restraint system that holds the - the elephant trunk that goes over the sill into the Command Module down through the tunnel, the AID."

(4) M512/479 Materials Processing Facility Crew Station- There was little SL-2 crew comment on this experiment station. The SL-2 crew did not report using the M512/EREP foot restraint in the M512 position. In review of the SL-2 kinescopes it was noted that the suit which was stowed near the M512 operator's head appeared to cause minor infringment into the operator's work space. Stowage of a suit in this area was not nominal and was assumed to have resulted from stowage constraints due to the extra equipment brought up for the repair operations and the early EVAs. Also, it was seen from viewing the SL-2 kinescopes that the furnace door evidently had some unanticipated forces acting on it. The door would not remain open, causing minor inconvenience to the operator.

The M512/479 crew station appeared to have adequately provided for the tasks performed by the crew. The SL-2 crew stated in their debriefing (14-117) that using the M512 was just like working on the trainer.

The only reference to this station by the SL-3 crew was during the crew inventory. The CDR pointed out that the M512/EREP foot restraint was in the M512 position to perform the M518 experiment operations. The M518 Multipurpose Electric Furnace Experiment was the only M512 series experiment that was performed by the Skylab 3 crew. Therefore, this crew station was not heavily used by the SL-3 crewmen and did not receive a significant evaluation on this mission.

The most significant comment from the SL-4 crewmen concerning the M512/479 Materials Processing Facility crew station come from the PLT (Dump Tape 356-010, Pg. 15 of 17):

PLT: "When you use the foot restraint for 512 it's not very good. It - in fact I stopped using it, it was so bad, I could get along better without the thing. It holds your body in the wrong position."

However, the PLT did say that the station was operable without the restraint.

(5) MDA Module Work Station - The SL-2 CDR (TAB 154-02) stated that there was disorientation upon initially entering the MDA from the AM early in the mission. The SL-2 SPT (Dump Tape 155-12) stated that the MDA size was very good for hanging onto things, but that it was not too good for traffic, in that if two crew members were working in the MDA the third had problems getting past them.

The add-on type evolution of the MDA module layout generated such descriptive crew comments as "hodgepodge" and "boiler room".

The SL-2 PLT (Dump Tape 159-13) stated:

"Orientation is all right, I've come to learn to accept it during training. The general arrangement is kind of helter-skelter and hodgepodge...It's not good, you come in here and things are - you have trouble finding things in here...The volume is good, more than adequate."

The crew preference was strongly in favor of a one-g floor-ceiling orientation of spacecraft modules. This was evidenced by comments like the CDR's:

> "Trouble with the MDA is it's not oriented like a room...Also by having circular rooms, you end up having a problem knowing where different cabinets and things are stowed. It's much better to have rooms, like down in the workshop where you've got a floor and you've got cabinets; you've got certain places to put certain things, and it just seems to work better."

The floor-ceiling orientation seemed to be largely a matter of crew preference rather than an operational necessity. The fact that the crew had no problems working in the MDA was pointed out by such comments as the SL-3 CDR's (Final Dump Tape 229-13):

> "Now this is certainly acceptable for what we're doing. We don't have any trouble in there except bumping into each other unless things accidently slide into spots and maybe, who knows, maybe that's a thing of the future. But right now, my feeling would be that you want to stick to something that you put things of a similar nature in the same place: Put all stowage against one wall; put all this against another wall; put all the equipment in a little corner. In other words, it gets everything in a spot where it can be useful and not have to try to hunt for it."

The SL-3 PLT expressed a similar opinion about improving the arrangement in a cylindrical vehicle. He said (Final Dump Tape 232-05):

> "Next time we build something like that we ought to make it so things are faired in better and there's not so many nooks and crannies for stuff to get lost into, so many head knockers and sharp objects sticking out from lack of things to grab on to and to fasten yourself down to."

In evaluating the total volume of the MDA the SL-3 PLT said (Final Dump Tape 232-05):

> "The volume of the MDA is probably about right, but it's so cut up it's hard to really evaluate the volume in there. The volume is, in my case, is unusable because its small sections of volume tucked down behind boxes and around boxes. And a lot of volume in the MDA is not available for use."

The SL-4 crew was the first Skylab crew to describe to some degree the MDA arrangement as having other than a "hodgepodge" or "boiler room" effect.

Comments relating to the MDA by the CDR are as follows:

> "MDA/STS, general arrangement and orientation of compartment, I would say given the size and volume you got to work with, it's rather well oriented and arranged and compactly done so; the volume is acceptable, adequate." (Dump Tape 356-05, Pg. 17 of 19).

> "The MDA is fairly adaptable to other uses, but it's kind of crowded there." (Dump Tape 347-11, Pg. 2 of 16).

Comments relating to the MDA and STS by the PLT are as follows:

> "Boy, both of those are so lousy, I don't even want to talk about it until I get back down to the ground, because everytime I think about how stupid the layout is in there I get all upset. You can't even find numbers on panels . . . That MDA is really bad." (Dump Tape 356-06, Pg. 14 of 17).

Although the SPT did describe the relationship of working spaces to stowage spaces in the MDA as a hodgepodge, his additional comments are as follows:

> "Now there's one thing I do like about it. General arrangement and orientation of compartment. Come people, I guess, do knock it, but I kind of like having the walls as working space." (Dump Tape 361-03, Pg. 3 of 7).

"That's one feature I do like about the MDA, is that at least they co-manage, it seems, to use up all the walls. The walls are the working area. (Dump Tape 361-02, Pg. 6 of 6)

The SL-4 crew also experienced difficulty in locating panels and stowage locations in the MDA. Typical comments noted are as follows:

PLT "...This is one of the reasons that they got in trouble - of course they just didn't make the numbers big enough in a lot of cases." (Dump Tape 365-10, Pg. 14 of 22)

SPT "The MDA/STS is one of the biggest mysteries of the world when you go in there to find a panel. ... The guy - when he did that, it looks as though he just kind of flipped numbers up in the air and scattered them all around and whatever way they came out, that's the way it was." (Dump Tape 361-03, Pg. 3, 4 of 7)

E. Conclusions and Recommendations -

(1) ATM C&D Crew Station - The ATM C&D console design was predominantly a result of the evaluation of this crew station. The ATM C&D Panel was originally designed to fit the unique limited confines of the LM. Another design constraint which greatly influenced the layout of this station after it was moved to the MDA was a potential requirement for two-man operation. This consideration rules out having a wrap-around console suited to one operator. However, despite these design constraints in the evolution of this crew station, the operator was apparently able to perform his duties quite well.

To minimize the confusion between S082A and S082B, color coding decals were launched with the Skylab 3 crew to be applied on-orbit. The SL-3 crew stated in their debriefing that the color coding decals were added to the ATM C&D Panel and further suggested that more color coding would improve the operation of a C&D panel like the ATM C&D Panel.

The final layout of the ATM crew work station proved to be troublesome to the Skylab 2 crew. The Skylab 3 crew was not inconvenienced by the one-g design influences referred to by the SL-2 crew. The only known major difference in operating at the ATM work station between the SL-2 and SL-3 crews was the use of the ATM "chair" by the SL-2 crew. The lack of adverse comment by the SL-3 crew was attributed to their greater freedom and range of motion by use of the foot restraint platform alone while working at the ATM C&D Panel. The conclusion was that the ATM seat/backrest assembly while providing additional restraint also restricted freedom of motion and the reach envelope of the crewman.

The SL-4 recommendation of a platform having more flexibility at work stations should be considered for future designs. This would enable more flexibility for individual crewman comfort.

It is recommended that in future designs of C&D Panels with multiple experiments like the ATM C&D Panel that color coding be used to differentiate the individual experiments and separate functions on the panel. It is further recommended that a seat/backrest "chair" type restraint undergo further evaluation to determine the degree of its usefulness or necessity at a crew work station.

(2) EREP C&D Crew Station - The Skylab crews had no problems working at the EREP C&D work station. The SL-3 crew saved setup time at the EREP work station by leaving the communication cables and communication soft caps connected to Channel A on the Speaker Intercomm at the EREP work station.

The Skylab 3 crew was pleased with the use and operation of the EREP C&D foot restraint.

The crew station appeared to have adequately fulfilled its design function of control of the earth resources experiments.

(3) EREP VTS Crew Station - The only crew criticism of the EREP VTS work station was the lack of a foot restraint for the VTS operator.

A crew review eliminated the foot restraint at the VTS work station. The original foot restraint concept for the VTS crew station was a grid platform which folded out from the MDA wall and rotated over the radial hatch.

The Skylab crews when evaluating work stations repeatedly expressed a need for a foot restraint type device so that they could use both hands to operate C&D panels and handle charts and checklists.

(4) M512/479 Materials Processing Facility Crew Station- In accord with the concept of negative reporting the lack of SL-2 and SL-3 crew comments on this crew station indicated satisfactory performance.

The SL-4 comments concerning the M512 foot restraint should again emphasize a need for a foot restraint at each work station and the possibility of designing a restraint with position flexibility for complimenting different crewmen.

(5) MDA Module Work Station - The MDA evolved from a multiple port docking adapter to include experimental and stowage provisions. This evolution generally entailed "add-on" of an item at a time and was governed by a "minimum impact" groundrule. Consequently installations were made where space and system interfaces were readily available. Crew convenience and optimum work station groupings of equipment were compromised. The addition of stowage items to the MDA continued following closeout of the OWS. This mode of evolution in the development of the MDA configuration resulted in a somewhat disassociated arrangement of the MDA installed hardware and equipment.

The performance of the Skylab crews proved that man can function effectively in a cylindrical spacecraft module with a zero-g orientation and layout of hardware. There existed, however, a longer period of adaptation to working in the cylindrical layout of the MDA than the floor-ceiling layout of the crew and experiments modules in the OWS. Each of the Skylab crews thus far expressed a problem of orientation when arriving in the MDA until they found a familiar piece of experiment hardware to key on. Most crewmen found that they used the ATM C&D Panel or the EREP experiment hardware to orient themselves in the MDA. It also took the crewmen longer to locate a particular stowage container in the MDA than in the OWS where the stowage containers are laid out in floor to ceiling shelf-type cabinets.

Each of the Skylab crews felt the volume of the MDA was good for working in and hanging onto things, but expressed problems with traffic when two crewmen were working in the MDA and a third crewman tried to get past them. The volume of the MDA, 17 feet long and 10 feet in diameter, was suitable for its functions as a multiple docking adapter to a larger space station and experiments/stowage module. The volume ideally should be larger for a module similar to the MDA that is used as a single space station experiments module for a crew of three.

The floor-ceiling layout of a spacecraft module was preferred by the Skylab crews but more than preference, the floor-ceiling layout is more efficient. The Skylab crews adapted faster to the floor-ceiling layout and were able to locate stowage containers quicker than in the cylindrical layout of the MDA. This would suggest that in future spacecraft it would be efficient to layout experiment and stowage hardware in a one-g orientation even in small cylindrical vehicles like the MDA. At the very least the early design concept for a small cylindrical vehicle like the MDA should provide for functional grouping of similar hardware. Stowage containers should be grouped along one axis like the OWS experiment compartment stowage containers, or around the radius in a particular location like the ring lockers in the OWS.

In the development of future modules of this type, opportunity for a more analytical, systematic design approach to crew integration considerations should be afforded. The design process obviously should include application of established human factors techniques and simulations utilizing both one-g mockups and a neutral buoyancy facility to develop optimum crew interfaces with the installed equipment and systems. Future design concepts would capitalize significantly on the experience and crew insights to be gleaned from the Skylab missions.

2.2.9.2 Stowage

A. Design Requirements - For the purpose of normal and contingency resupply and to support specific operational equipment, a number of items were required to be stowed on Skylab. To accomodate these items, stowage containers were designed to secure and protect the stowed equipment from prelaunch, launch and docking loads and to provide convenient locations for orbital storage. Specific requirements for latches, restraints, operation, interfaces, sharp edges, etc., are set forth in the following documents.

- Contract End Item Specification, CP114A1000026, Rev. E

- Human Engineering Design Requirements for AAP, 10M32447

B. Functional Description - Flight crew equipment, consisting of communication equipment, tools, film magazines and cassettes, camera filters and assorted experiment equipment and supplies were stowed in the MDA in forty-three (43) different stowage locations. The MDA was assigned a block of stowage location numbers from 100 thru 199, inclusive although all of the numbers were not used. To differentiate stowage numbers from panel numbers, the prefix (M) was added to the stowage numbers. A total of 418 items were stowed for launch in the MDA. Most of the items were stowed inside containers which were designed to provide restraint and protection for launch and docking environments as well as zero-g restraint once the container was opened. The film vaults additionally provided radiation shielding for the ATM film contained therein. One panel location (SIA 131) provided stowage for two dust caps.

Fifteen of the stowage locations were containers. The remainder were wall-mounted locations, use locations or experiment locations. The containers utilized basically four types of equipment restraints:

- Equipment nested in Mosites foam (Ref. Fig. 2.2.9-8)

- Equipment stowed between partitions padded with Mosites foam (Ref. Fig. 2.2.9-9)

- Mechanically clamped and secured with Calfax fasteners (Ref. Fig. 2.2.9-10)

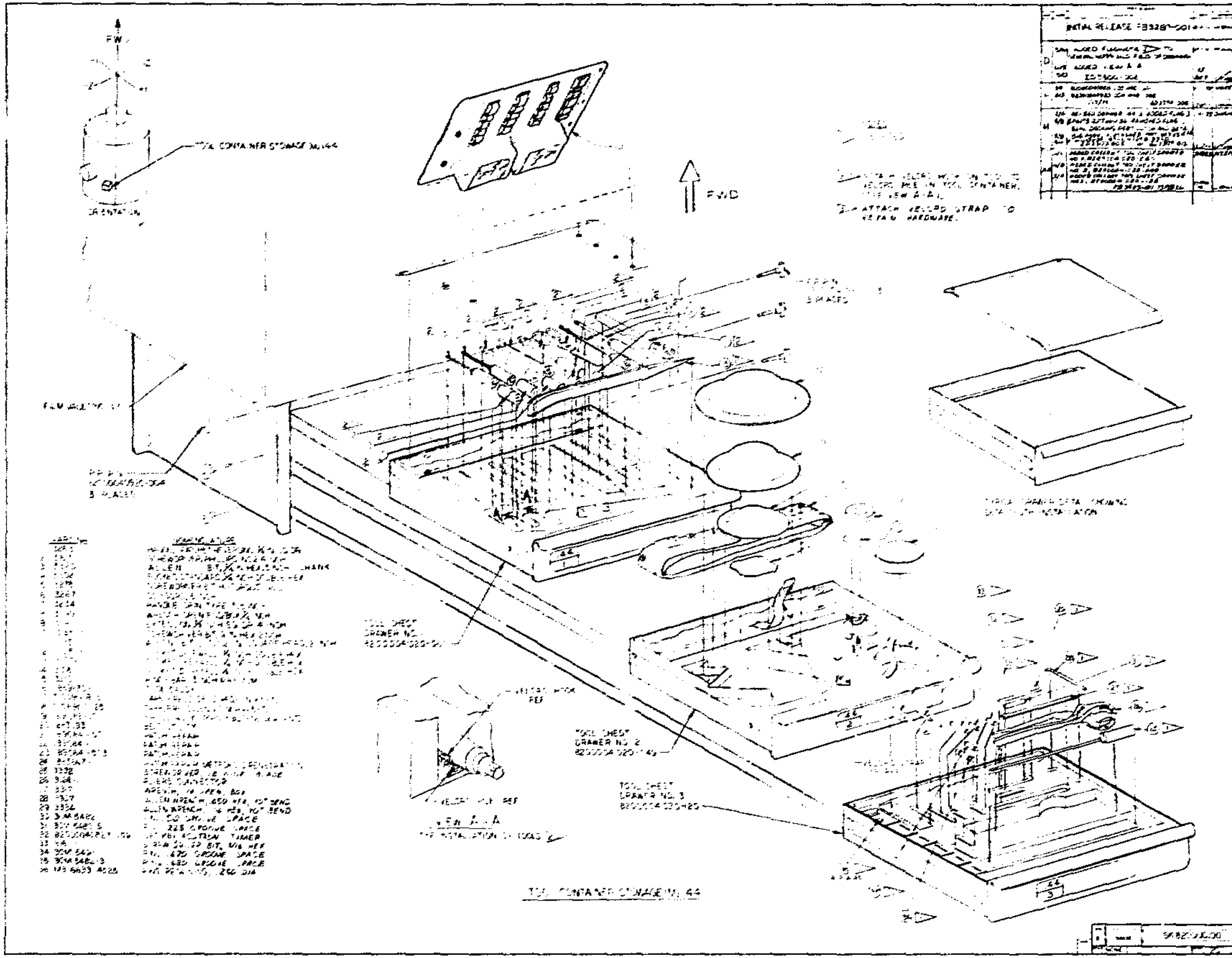


Figure 2.2.9-8 - Equipment Nested in Mosites Foam

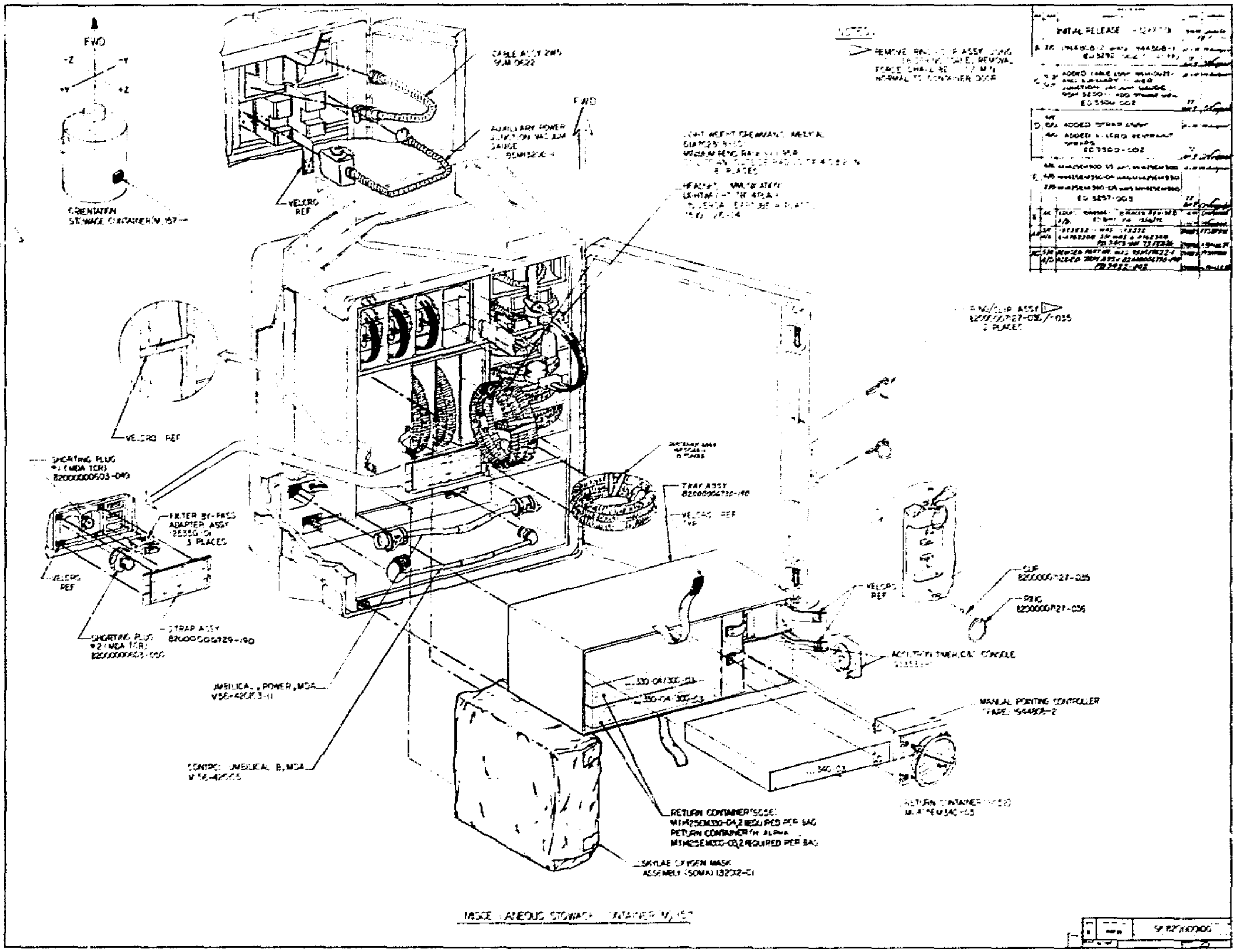


Figure 2.2.9-9 - Equipment Stowed Between Partitions Padded with Mosites Foam

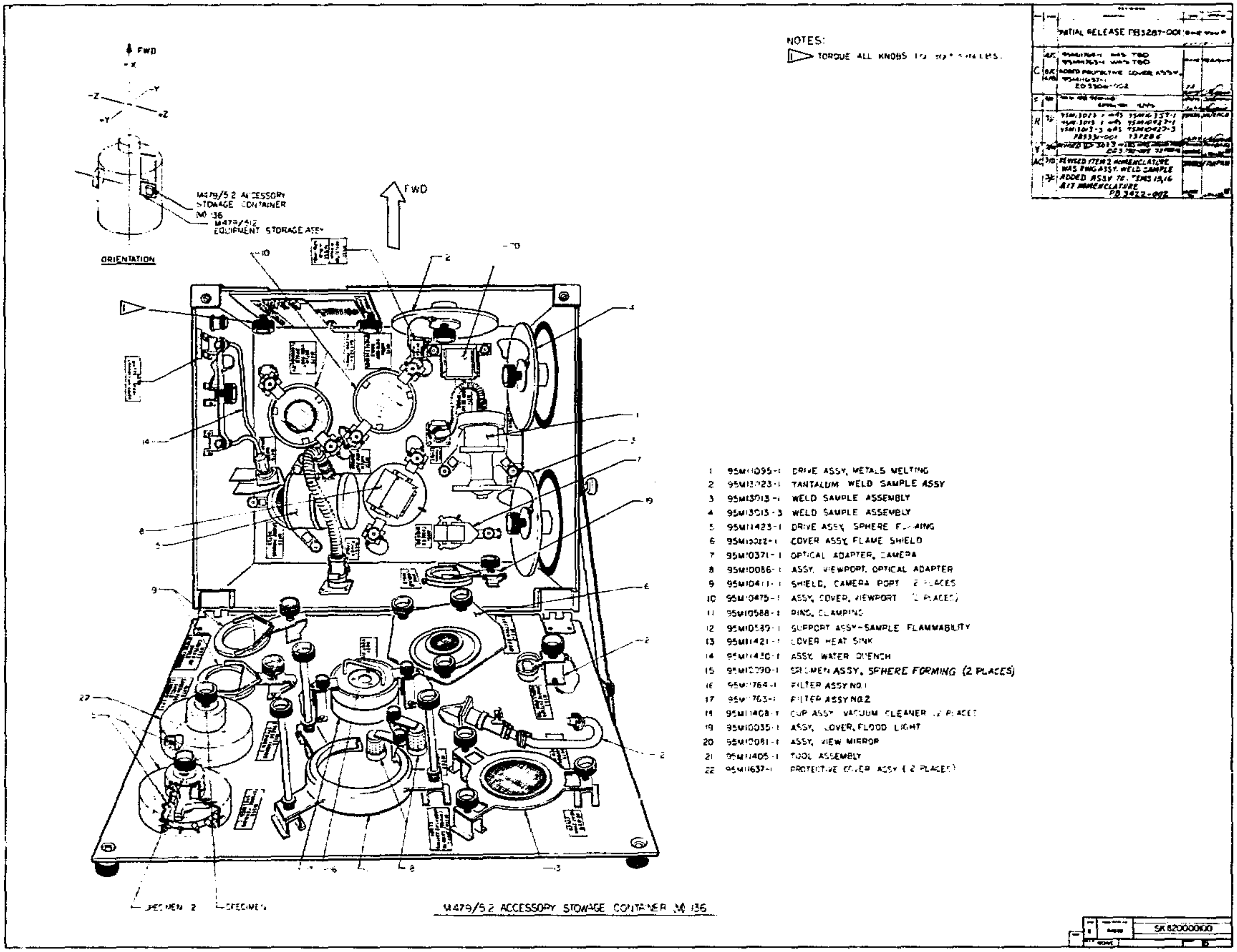


Figure 2.2.9-10 - Equipment Mechanically Clamped and Secured with Calfax Fasteners

- Equipment with clevis/lug interfaces secured with expandogrip pin (Ref. Figs. 2.2.9-11 and 2.2.9-12)

There were a variety of container door latches, hinge frictional devices, and equipment restraint designs.

There were several last minute stowage items added to the MDA after the vehicle was on the launch pad. Two spare water heaters were mounted to a plate that was added to the outside surface of the door of film vault No. 2 (M152). Two Scientific Airlock (SAL) window-covers were added to the M512/EREP foot restraint (M127). An EVA hatch window cover and the S183 kick plate were attached to the ATM C&D console foot restraint (M175). One earth terrain camera magazine was added to film vault 3 (M143).

A complete listing of MDA stowage may be found in the Skylab Stowage Locker List (MDA) #1-SL-012 which lists the items by stowage location number or #1-SL-007 which lists the items by stowage list item number.

C. Test - Final stowage of the MDA was accomplished by performance of test and checkout procedures (TCPs) KM-3014, KM 7000, and test preparation sheets (TPSs), written in real time, to accomodate revisions to the original stowage plan as well as last minute additions. The MDA Stowage Installation Drawings (SK820000100) were used extensively detailing and clarifying the TCPs and TPSs. No waivers were required to be written, although 273 deviations were written against TCP KM-3014 and 101 against TCP KM 7000.

D. Mission Results - Based on all reports available, the overall stowage program was entirely adequate and went smoothly. No launch stowage anomalies were reported by the crew; everything was secure as stowed when the MDA was activated. The sticky back Velcro strips were the only temporary stowage/restraint devices reported to be totally inadequate throughout the entire spacecraft. The Velcro which was bonded to the vehicle before launch performed satisfactorily. The crew stated a dislike for the dialatch fastener. Although swelling mosite was a major problem during the altitude chamber test at St. Louis, the subsequent modifications made to such containers proved excellent as stated by the crew at their debriefing of July 1973.

During the SL-2 mission, destowing and restowing of headsets, IWCCUs, film magazines, cassettes, etc., from the 15 MDA stowage containers went "as advertised".

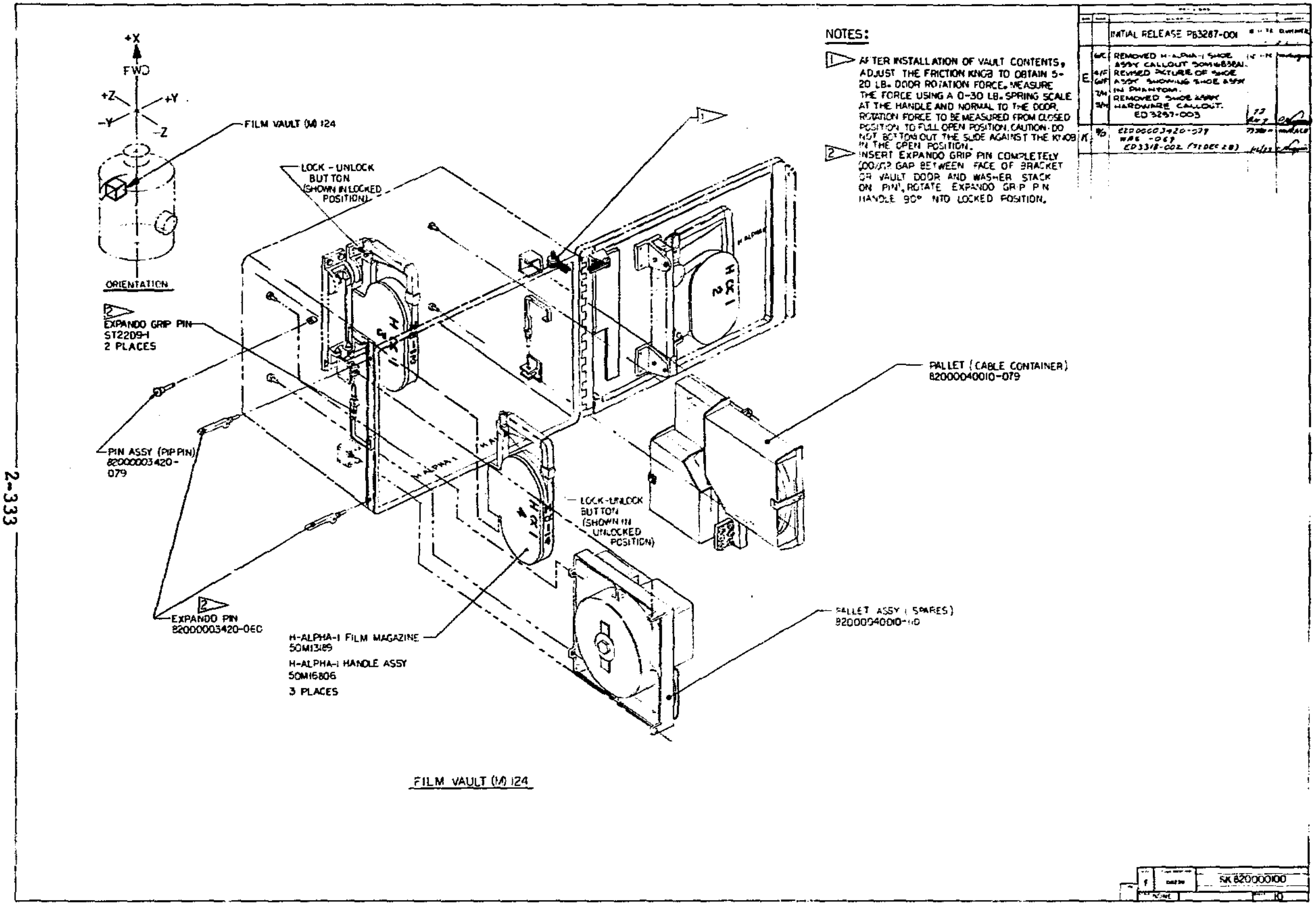
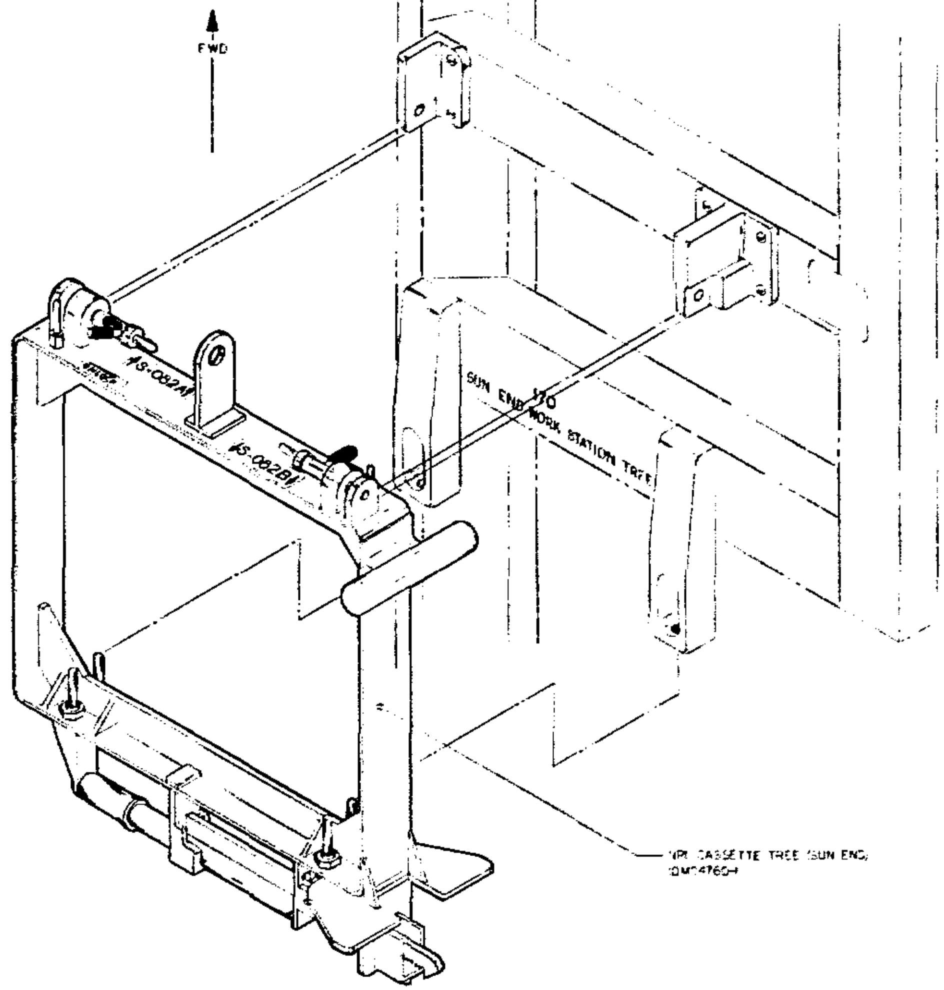


Figure 2.2.9-11 - Equipment with Clevis/Lug Interfaces Secured with Expandogrip Pin



NPL CASSETTE TREE (SUN END) STOWAGE (M 70)

Figure 2.2.9-12 - Equipment with Clevis/Lug Interfaces

E. Conclusions and Recommendations - Standardization of latches and hand operated fasteners related to stowage compartments should be of prime concern for future spacecraft design. Customizing of latches and hand-operated fasteners should be avoided in favor of off-the-shelf products to the maximum extent possible. Use of the Dialatch type of latch should be avoided as these were considered too complex and awkward to operate (and too numerous per container) by both the SL-2 and SL-3 crews. Calfax fasteners need to be improved with regard to the reliability of the retainers intended to keep them captive.

Containers or drawers stowing like items of varying sizes such as tools should be designed to present these items in order of size to expedite selection of proper item, i.e., allen wrenches, sockets, and screwdriver bits. Attention should also be given to categorization of tools with respect to their application.

More temporary stowage devices should be provided in the spacecraft of the future rather than requiring the crew to improvise. In conjunction with general temporary stowage devices, the design and location of planned operational temporary stowage aids should be considered.

2.2.9.3 <u>Habitability (Comfort Evaluation)</u>

A. Design Requirements -

(1) Noise - The design requirements for the MDA noise levels were detailed in the Cluster Requirements Specification, Appendix A, Paragraph 2.12.2a. Sound pressure level limits were identified for various frequency ranges including an overall internal sound pressure level no greater than 72.5 db when the summation of the individual sound pressure levels from all sources is considered at any given time.

(2) Illumination - The paragraph below was taken from the CRS, Appendix G, Section 2.8 and gives the general crew systems lighting requirements. The details of the interior lighting requirements were presented in Section 2.8.1 of the CRS.

"The lighting system shall provide general interior lighting during the mission to allow the crew members to locate, operate, and read all displays, controls, and nomenclature, to provide visual access to interior visual surfaces, allow storage and retrieval of all articles of crew equipment, and provide for location and orientation of the crew members within the various crew areas."

(3) Thermal and Atmospheric Habitability - The MDA Crew Thermal Design requirements were called out in the Thermal Comfort Tolerance Design Criteria BRO DB-57-67, Rev. B. The crew comfort criteria was determined by a "comfort box" area on a plot of wall temperature versus air temperature. See the Thermal Control System, Section 2.2.3 of this report for a plot of the comfort box. The maximum surface touch temperature of 105°F was also specified in the above referenced design criteria document.

The air flow velocity design requirements for crew systems was defined in the CEI Specification CP114A1000026 which specifies velocity at the MDA crew stations of 15 to 100 fpm.

B. Functional Description -

(1) Noise Sources - The primary sources of MDA internal ambient noise were the three circulation fans and the Rate Gyro Six-Pack. Intermittent noise sources emanating from the MDA were the EREP (S190 Camera Array) and the Nuclear Emulsion experiment (S009). However, the predominant source of noise in the MDA emanated from the Rate Gyro Six-Pack which was installed in the MDA by the SL-3 crew.

Also contributing to the MDA internal ambient noise was the Airlock Module's Environmental Control System. In this system the noisiest sources were the Molecular Sieve fans and the Cabin Heat Exchange Module fans.

A cluster wide analysis of noise sources was conducted which effected the development of acoustic mufflers for the MDA circulation fans and produced predicted on-orbit noise levels. The predicted ambient noise level in the MDA (including noise sources in the AM but excluding intermittent noise generated by experiments), with all MDA circulation fans operating at high speed was approximately 60 decibels overall.

(2) Illumination - The interior of the MDA was illuminated by eight interior floodlight assemblies that provided an illumination level of five foot candles (fc) minimum at the ATM Control and Display (C&D) console, EREP C&D console, and experiment M512 work stations, and a general illumination level of 3.5 fc minimum when measured along the X-axis of the MDA. The two lights nearest the ATM C&D console were provided with removable light attenuators. Each of the eight lights had a local switching capability of "OFF", "LOW", and "HIGH". The above stated illumination levels were met with all lights on "HIGH". A switch for on-off lighting control of all MDA lights was provided near the axial docking port of the MDA.

(3) Thermal and Atmospheric Habitability - Three cabin heat exchangers located in the STS provided cooling to the MDA/STS area. Three circulation fans located in the MDA provided air circulation for the MDA and the CM interiors. Each fan could be operated at high or low speed or could be turned off. Two of the circulation fans had their inlets and outlets in the MDA with adjustable diffusers at the outlet.

The third fan forced air through a removable duct into the Command Module interior. Thermostatically controlled electric wall heaters could be set to actuate based on MDA air temperature in either the $70^{o}F$ range or the $45^{o}F$ range. An air temperature sensor was located at the inlet to the "CSM" fan which provided telemetric data.

There was a ground capability to select, through telemetry, the heating range. The integrated system (wall heaters, air heaters, circulation fans and control systems) was designed to be capable of keeping the MDA atmosphere within a prescribed astronaut comfort range. This range assumed the astronaut had some capability to adjust to the temperature through clothing, metabolic rate, and circulation fan control.

C. Test -

(1) Noise - The Skylab crews during prelaunch tests made a few subjective comfort evaluations of individual

noise sources and found all MDA noise sources acceptable. See Section 2.2.2, Environmental Control System, of this report for sound pressure level test results in the MDA.

(2) Illumination - The one lighting test performed with the flight lights resulted in the crew stating that the light levels were low but acceptable. See Section 2.2.4.3, Lighting, for illumination test results.

(3) Thermal and Atmospheric Habitability - There was no subjective evaluation by the Skylab crews of temperature and air velocity in the MDA during prelaunch tests. See Section 2.2.3, Thermal Control System, and Section 2.2.2.1, Ventilation System, for prelaunch test results of temperature and air flow.

D. Mission Results -

(1) Noise - During the SL-2 mission, noise measurements were taken by the crew (Dump Tape 152-05).

The overall sound pressure level (reported as "ambient noise level") was 53.5 db. The SL-2 PLT evaluated the MDA noise level as satisfactory, but stated that it got high when EREP was operating.

Comments and evaluation by the SL-3 crew indicated that the noise environment throughout the cluster was quite comfortable.

On Dump Tape 230-03, Page 3 of 3 on mission day 22, the SL-3 pilot commented:

> "Noise levels are all satisfactory everywhere."

Later on mission day 24, the SL-3 pilot further elaborated (Final Dump Tape 232-07):

> "Noise level is quite low. It's higher in the STS area than anywhere because the fans on the mol sieves are running but otherwise it's quite quiet. There is no objectionable noise. It just hums along with a very comfortable noise level. That's throughout the whole spacecraft ..., so I don't have any complaints about the noise at all."

Commentary relative to the noise induced by the rate gyro six-pack was provided on mission day 49 and appears on a transcript of the communication, wherein the pilot's answer to a query from Cap Comm was:

> "No, I wasn't turning anything on and off, Bruce, probably the rate gyros. They do a lot of humming back here and that's the thing that makes the most noise up here in the MDA, when EREP is not with us."

A comparison of the sound pressure level measurements recorded by the SL-3 crew and the internal noise spectrum shape over nine frequency ranges specified as the design goal maximum in the Cluster Requirements Specification, MSFC Document RS003M00003, substantiated the subjective evaluation describing a comfortable noise level environment.

The SL-4 crew reported that unacceptable noise levels in the MDA affected them in areas of communications, concentration and work as explained in the following crew comments.

CDR "Noise: ... has affected our recordings. And the people on the ground have complained on several occasions about the recording situation and the fact that there's a lot of background noise." (Dump Tape 365-07, Pg. 4 of 21)

SPT "Noise: ... I find that it gets to me when I'm trying to concentrate." (Dump Tape 003-01, Pg. 3 of 11)

SPT "The noise ... used to get to me when we're working in the MDA." (Dump Tape 003-01, Pg. 3 of 11)

Some sources of noise are pointed out by the SPT on Dump Tape 361-03, Pg. 6 of 7.

> "Aside from the pump which I mentioned, we've got rate gyros in there. And they're both making so much racket, I can't tell what noise level exists under either two of these."

(2) Illumination - The SL-2 mission power problem caused the SL-2 crew to operate with reduced lighting in the MDA for a portion of the mission.

The SL-2 PLT rated MDA illumination as adequate to poor (Dump Tape 159-13). The SPT stated, "Illumination is low in the MDA and a little bit confusing in a circular compartment" (Dump Tape 159-12). The SL-2 PLT also said, "The lighting bugs me a little bit. I think the light level is too low ... the color temperature or quality of the light is too harsh ..." (Dump Tape 155-12). After splashdown, the PLT evaluated the MDA lighting as adequate but stated that since the first two weeks were spent with reduced lighting, when the lights were completely turned on everything looked good.

During the SL-3 mission power-down requirements imposed on SL-2 as a result of EPS (Electrical Power System) anomalies were not necessary. However, crew comments indicated that in general they still felt the lighting levels should be increased. Some trouble-shooting and maintenance tasks required the crew to work in out-of-the-way places ("Nooks and crannies") where adequate lighting could only be provided by handheld flashlights and penlights. This prompted a recommendation for head-mounted lights which would leave both hands free to perform the desired task.

For a short period during SL-3 lighting within the MDA was somewhat restricted due to an outage of aft floodlight assemblies 2 and 4.

The general impression regarding cluster illumination was well summed up in the following comments expressed by SL-3 pilot in Tag Tape 232-07, Pg. 5 of 7:

> "Okay, illumination seems to be generally a little bit low. It could be higher everywhere, I guess, although we're able to accomplish our work with the illumination that we have ... Just to work around in here and throw switches and so forth, it seems adequate, but if you want to read a book or something, it's best to find yourself near the window or something like that so that you've got illumination. But for

just working and moving around and doing your job, why the illumination is adequate although it could very easily be higher and make everybody happier."

The subjective evaluation of the SL-3 crew that the cluster illumination level should be increased reiterates the recommendation expressed by the crew of SL-2. Lighting levels were apparently adequate for the performance of scheduled tasks.

The SL-4 crew was somewhat more tolerant of the illumination level than previous crews as the following comments indicate.

CDR "Illumination in the airlock MDA/STS is - is more than adequate, quite adequate." (Dump Tape 356-05, Pg. 18 of 19)

PLT "Illumination is satisfactory." (Dump Tape 356-06, Pg. 15 of 17)

SPT "Adequacy of lighting. No problem." (Dump Tape 025-05, Pg. 7 of 28)

(3) Thermal and Atmospheric Habitability - The SL-2 mission habitability of the MDA was affected by the total Skylab thermal and power problems. The SL-2 crew wore their jackets at times when working in the MDA because the heaters were kept on low range to conserve power.

The thermal problem in the OWS caused PLT Weitz to sleep in the MDA for two nights until the sleep compartment temperatures cooled down enough to be comfortable. The SL-2 crew said that the air flow in the MDA, as in the whole Skylab vehicle, was excellent. The CSM fan was operated almost continuously to provide air flow to the CM while the MDA area fans were used as required when the crew was working in the MDA.

A unique feature of the zero-G air flow system is its ability to transport items to the intake duct of the ventilation system. The following comments express some crew thoughts. These comments were made at the SL-2 Technical Crew Debriefing June 30, 1973.

CDR "Any time you are handling a lot of little pieces of stuff, you really have to take your time or you will lose it. The way the circulation system was blowing air into the Command Module, if something got away from you and you didn't see it, it would quickly be up in the middle of the MDA. This was because the airflow was out the tunnel. The duct blew it down the side of the tunnel and ducted it in. There was a nice little flow down the bottom and right back out. If something got out in the middle of the command module you would look out and see that the thing would be 15 feet down there in the MDA heading for the workshop."

The following conversation occurred at the same debriefing as above:

CDR "But as soon as fans are going in there, that circulation system causes everything that's floating to line up on a fan screen someplace."

SPT "This is a very good design point in the vehicle. You don't lose things. If it's properly closed down and you have good fans, everything winds up on a screen."

PLT "That's right. We agonized a lot, especially Bob Overmeyer on those closeouts in the MDA. But it was worth it, because it kept stuff from getting lost back there."

Through telemetry the wall temperatures and air temperatures in the MDA were monitored on the ground and the plotting of air versus wall temperature revealed that the MDA met the design comfort box criteria for only three days of the SL-2 mission. The reason for this was that the MDA wall heaters were kept off to conserve electrical power.

Review of the SL-3 crew comments and subjective evaluations indicated that the thermal environment was essentially quite comfortable.

The SL-3 PLT in a M487 Habitability Experiment debriefing recorded the following on Final Dump Tape 232-07.

PLT Thermal comfort. The temperature has been quite satisfactory in here. It was a little warm in the workshop when we first got here; the sail took care of that. It gets cool in the night when we're sleeping and most of the stuff is powered down. Wind up putting a little extra blanket over late in the mornings. The MDA is always quite cool, and it's uncomfortable to come up here, matter of fact, for me anyway, without any - or in my underwear, which is sometimes the way you work up here because you have to work up here before you go to bed. And you come up here to get the pads and do some other things. So the MDA is a little cool but tolerable; in fact, sometimes a pleasant place to come when things get a little warm down in the workshop.

Reduction of the telemetered thermal data recorded during SL-3 mission is presented in a plot of module gas temperature versus wall temperature. This plot of the crew comfort criteria in the MDA is reported in the Thermal Control System section of this report (Section 2.2.3). It shows that the MDA met the "comfort box" criteria for the entire SL-3 mission from DOY 209.8 through 268.9.

SL-4 comments also agree with previous comments.

PLT "Thermal comfort is cold, but it's sort of a nice relief from the workshop, which is hot." (Dump Tape 356-06, Pg. 15 of 17)

E. Conclusions and Recommendations -

(1) Noise - Quantitative recordings of the overall sound pressure level within the MDA indicated that the MDA complied with the specified requirement for the acoustic environment. The rate gyro six pack was the only noise producing installation that exceeded the design sound pressure levels in some of the frequency ranges. However, it was lower in ambient noise level than the design specification.

The rate gyro six-pack was launched with the CSM for SL-3 to provide a contingency installation as backup for the basic rate gyro system due to gyro module failures in the basic system, which had occurred during the SL-2 mission. This consideration would tend to qualify the criticality of this induced noise environment. Likewise the sound pressure level measurements recorded by the commander were afforded some degree of qualification in his accompanying comments on the dump tape - 251-14.

> "Remember that these were taken in the environment with other equipment running. And so sometimes you're not getting a pure sound level on this except for pointing the instrument at it."

A qualitative assessment established that the acoustic environment was within comfortable limits based on the subjective evaluations reported by the crew of SL-3.

(2) Illumination - Throughout the test program, with the exception of one lighting test performed in St. Louis very late in the program, all crew tasks were performed using GSE lighting.

The reason for this was to minimize operating hours on the flight lights. The one lighting test in St. Louis resulted in the crew stating that the lighting was acceptable but low. This test involved reading checklists and photos, not performing specific flight tasks. This leads to the recommendation that future designs be given evaluation under flight-type conditions performing typical orbital tasks.

(3) Thermal and Atmospheric Habitability - The MDA was cold most of the time during the SL-2 mission and there are numerous references to this by the crew.

Because of the electrical power conservation required during most of SL-2, evaluation of the thermal comfort in the MDA during this mission did not reflect the MDA's capabilities.

Obviously the individual preferences of the crew members and their personal comfort criteria was reflected in the subjective evaluations provided by the crew as recorded on the Tag Tapes and the Dump Tapes.

Considering the individual crew comfort preferences future manned space vehicles should give the crew a maximum control over their thermal environment in the spacecraft modules. The circulation of air in the MDA was adequate based on crew comments. The air diffusers were set at "wide" on launch and no further adjustment was required on orbit by the SL-2 crew.

The circulation system in the MDA was designed to eliminate pockets of stagnant air and to equalize temperatures throughout the MDA and CM interiors. The crew had few comments on these functions. What interested the crew more about the air flow was its capability to move loose objects in zero gravity. There were numerous comments on this subject. Quantitative evaluation of the air flow velocity at the MDA crew stations was not accomplished by either SL-2 or SL-3 crews.

The consensus of the SL-3 crew commentary relating to air flow was that this aspect of internal atmosphere conditioning was satisfactory.

The utility of the circulation air flow as a means of capturing lost items and debris on vent screens was again noted by the SL-3 crew.

This Page Intentionally Left Blank

2.2.10 Experiments/ATM C&D to MDA Interfaces

2.2.10.1 Earth Resources Experiment Package (EREP)

The Earth Resources Experiment Package in the MDA System consisted of a selected group of remote earth survey sensors designed to obtain earth resources data (see Figure 2.2.10-1). The sensors accomplished this objective by remote sensing in various regions of the electromagnetic spectrum.

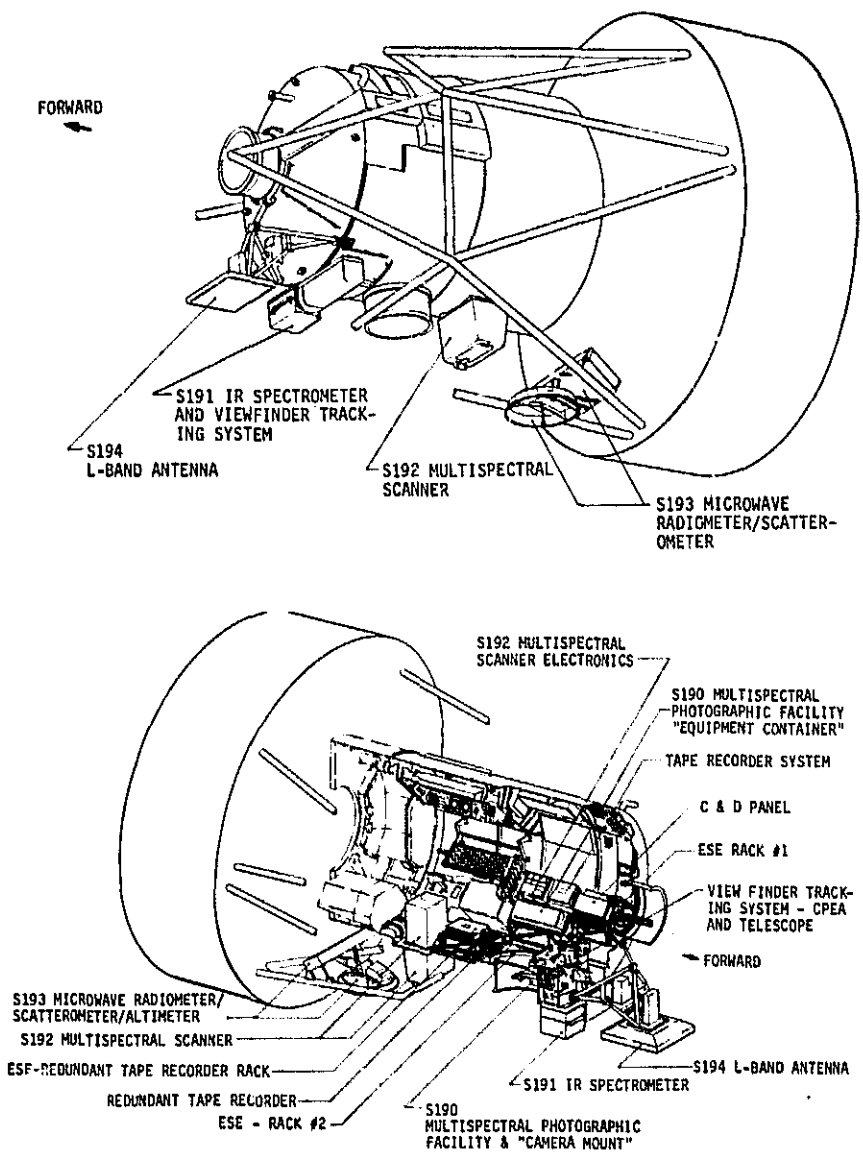


Figure 2.2.10-1 EREP Installation

Specifically the experiments and the regions of the spectrum they covered were as follows (see Figure 2.2.10-2):

- S190A Multispectral Photographic Facility-Visible and near infrared.
- S191 Infrared Spectrometer-Visible, near infrared and thermal infrared.
- S192 Multispectral Scanner-Visible, near infrared and thermal infrared.
- S193 Microwave Radiometer/Scatterometer/Altimeter - 13.9 GHz.
- S194 L-Band Radiometer-Microwave - 1.4 GHz

The major components required to support these experiments were the following:

- EREP System Control and Display Panel (C&D)
- EREP Data Recording System
- Interconnecting cabling
- EREP Diagnostic Downlink Unit (E[illegible])

A. EREP Design Requirements -

(1) Location - The five data taking sensors were mounted such that the sensor viewing line-of-sight was on the OA geometric Z axis to permit earth viewing while the MDA was in the Z-LV(E) pointing mode. EREP experiments S190, S191, S192 and S194 were mounted in and/or on the MDA and S193 was mounted on the DA.

(2) Control and Display - The EREP system required a centralized control and display panel mounted in the MDA with room to allow operation by one crewman in a shirt sleeve environment. The C&D panel was required to provide for the complete control and display of the five data taking sensors and the EREP data recording system. It also was required to provide power distribution and control of MDA power, sensor calibration control, sensor operational mode selection and display pertinent data to verify proper sensor operation and interface with the MDA TV input station. The panel provided signal conditioning for certain of the EREP experiments and accepted and routed EREP data to the data recording system. It also provided proper signals to the MDA TV input station for dumping over CM TV downlink for ground analysis.

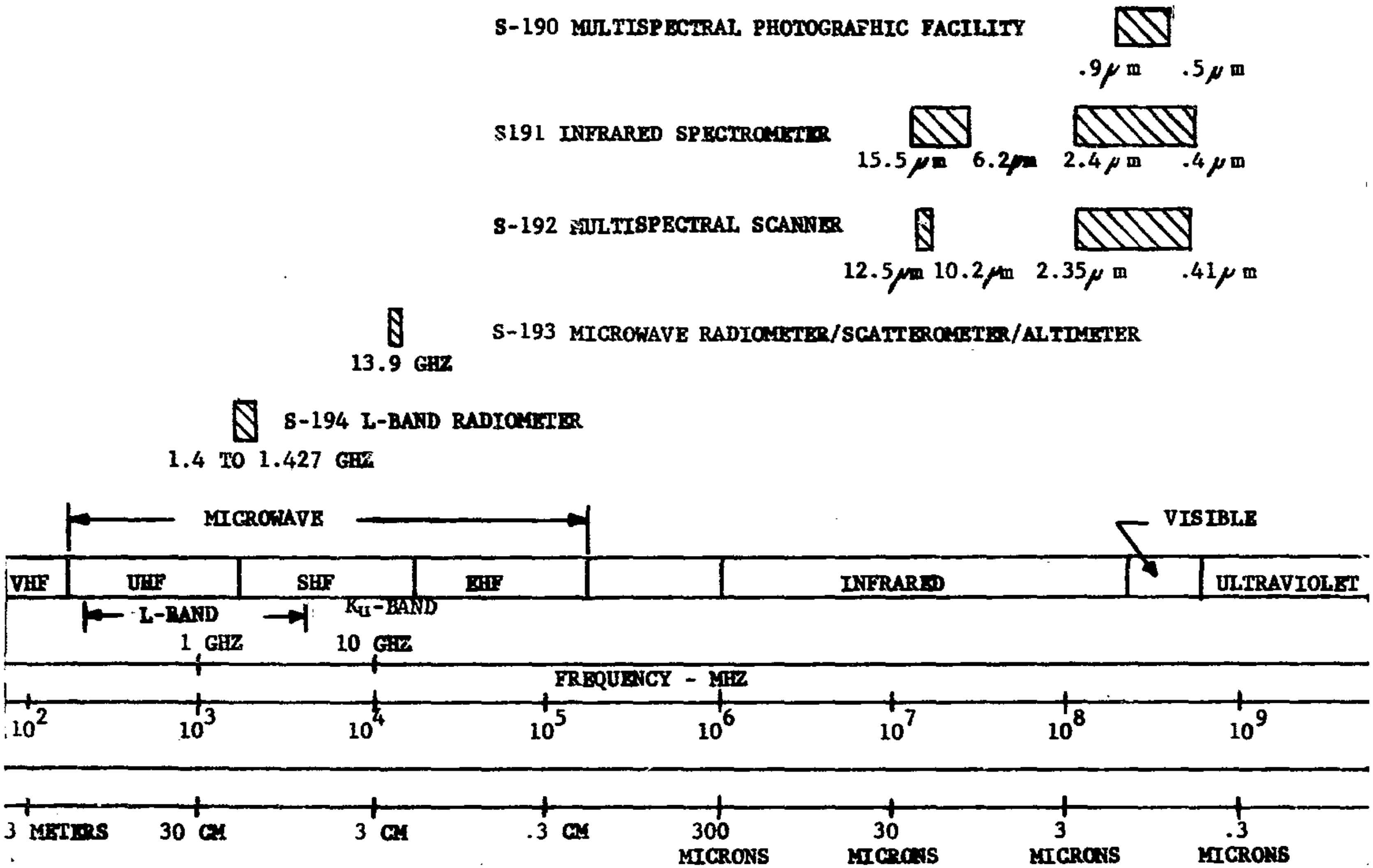


Figure 2.2.10-2 EREP Data Frequency Spectrum

(3) Cabling - MDA cabling between sensors and the data electronics within the C&D Panel was required to handle the following capabilities:

(a) Transmit analog signals from sensors to the C&D and Tape Recorder (T/R) with a maximum frequency of less than 0.2 Hz, with a voltage range from 0 to 5 VDC and 250 ohms, or less, source resistance.

(b) Transmit on-off signals between sensor, T/R and C&D as required for display.

(c) Transmit a 36 bit time signal from the AM/MDA interface to the C&D. The signal was time multiplexed into an NRZ-L PCM format and run at a nominal bit rate of 8.192 KBPS.

(d) Transmit DC power of the quality described in paragraph (7) below.

(e) Transmit discrete control signals, as required, of three types:

- Contact closure - switching for loads up to 0.5 ampere at 28 VDC.
- Logic - differential discretes to provide the capability to operate properly with up to 10 volts DC of common mode voltage between the driver and receiver circuits.
- Multidiscrete Level - voltage discretes to provide a voltage scaling network within the panel.

(f) Transmit PCM NRZ-L wave forms at 0 & 5V from the sensors to the C&D Panel. Each PCM signal was accompanied by a synchronizing signal, where required, at twice the PCM bit rate. The unit frequency multiplexed, or encoded the PCM NRZ-L signals as Miller Code.

(4) Data Recording System - The EREP system required a capability to record and store data generated by the system. The data recording was accomplished by mounting two (one primary and one backup) magnetic tape recorders in the MDA. The MDA was

required to provide wiring between the C&D panel and these T/Rs for the following data transmission and control capabilities:

(a) 1.0 MBPS Maximum - Miller Code Data - 24 lines

(b) 60 KBPS Maximum - Miller Code Data - 2 lines

(c) A composite signal consisting of one 200 BPS (maximum) PCM signal, one 8 KBPS (maximum) PCM signal and one 10 KBPS (maximum) PCM signal and one 10 KBPS (maximum) PCM signal; each PCM signal frequency shall modulate a Voltage Control Oscillator (VCO). The three VCO outputs would be mixed by mixer amplifier - 2 lines.

(d) Control signal to select servo controlled speeds of 7-1/2 and 60 inches per second.

(e) Transmit Miller encoded or FM multiplexed signals from the Control and Display Panel for recording on magnetic tape. The bit error rate for these signals would not exceed an average of 5 bits in 10^6.

The MDA was required to provide for crew access to permit tape changing and head and guide rollers cleaning, a shirt sleeve environment, and cooling of either T/R when manned (see item (5) below).

(5) Special Thermal Requirements - The EREP System required a liquid coolant loop to thermally control the C&D Panel, the primary and secondary tape recorders and the S192 Electronics Assembly. This coolant loop was connected downstream of the ATM Control and Display Console coolant system and performed as a dependent part of that system. A means was required in the MDA to isolate the EREP coolant loop from the ATM C&D Console coolant system.

The EREP coolant loop required high purity inhibited water as the working fluid:

(a) Maximum supply pressure: 37.2 psia

(b) Maximum Δ P from EREP inlet to outlet: 2.0 psid @ 220 lb/hr

(c) Minimum flowrate: 220 lb/hr

(d) Inlet Temperatures - EREP operating: +40°F to +81°F
- EREP not operating: no flow thru system

(e) Maximum heat dissipation to coolant loop: 810 btu/hr @ 81°F inlet temperature

The coolant loop was required to maintain surfaces of the equipment being cooled (which were likely to contact the crew) between 50°F and 105°F. The maximum allowable leakage from the EREP coolant loop was not to exceed 17 cubic inches from final fill to the end of a 240-day mission.

The MDA wall temperature in the vicinity of the S192 mounting plate was required to be greater than 65°F prior to operation of the S191 cooler.

(6) Structural Requirements - The EREP system was constructed to operate after being subjected to the dynamic environments of the MDA. The MDA provided mounting space and crew restraints in a controlled environment. The MDA also provided mounting plates, trusses and windows for various pieces of EREP equipment.

(7) Electrical Requirements - The MDA was required to transmit power to the EREP system from the AM power system with the following characteristics at the experiment interface:

(a) DC Steady-State Voltage Limits: 30 volts maximum at zero power transfer to 24 volts minimum at rated power transfer.

(b) Ripple Voltage Limits: composite ripple voltage, superimposed upon the DC steady-state voltage, not exceeding 1.0 volts peak to peak from 20 Hz to 20 KHz.

(c) Under Voltage: not less than 21 VDC returning to the steady-state voltage within one second under normal conditions.

(d) Over Voltage: not exceeding 33 VDC returning to the steady-state voltage within one second under nominal conditions.

(e) Transients: transient voltage at the interface not exceeding plus or minus 50 volts with a pulse width not greater than 10 microseconds.

(f) Reflected Ripple: reflected ripple meeting the requirements of MIL-STD-461, CE 01.

(g) Power Consumption: power consumption used to size the transmission system in the MDA system are given in Table 2.2.10-1.

ITEM	ELECTRICAL POWER - WATTS AT 28 VDC		
	PEAK	STANDBY	AVERAGE
S190	580	60	153 (1) (2 sec interval)
			85.5 (1) (8 sec interval)
			72 (1) (20 sec interval)
S191 (2)	481	90	150
S192	266	124	117
S193	300	59	131.5
S194 (3)	35.4	20.4	35.4
C&D Panel	298	130	117.6
Tape Recorder	N/A	N/A	260

(1) Intervals shown are between camera exposures.
(2) Includes the V/TS.
(3) Includes heater power.

Table 2.2.10-1 EREP Power Allocations

(8) Alignment Requirements - The mounting provisions of the MDA were required to keep the line-of-sight (viewing axes) of the EREP data taking sensors perpendicular to the MDA X-Y reference plane within ±0.5 degrees.

(9) Window Requirements - Experiments S190, S191, and S192 required viewing windows set into the MDA shell. The particular optical requirements of each window are specified in the paragraphs below.

(10) Weight Allocations - The total weight of the EREP system within the MDA was 2159 pounds. This was exclusive of the MDA cabling, windows, the S193 experiment and film and magnetic tapes.

(11) Thermal Allocation - The acceptable heat dissipation required by the MDA atmosphere from the EREP system was 2740 btu/day. The heat dissipation from the EREP system to the EREP coolant loop provided by the MDA did not exceed 2740 btu/day.

B. System Description - The EREP System is pictorially illustrated in Figure 2.2.10-3. The following (Table 2.2.10-2) is a list of the contract end items that comprised the EREP system:

EXPERIMENT	SUPPLIER	NAME	END ITEM
S190	ITEK	S190 M/S Photo Ass'y	173200
		Boresighted Camera Array	173150
		Magazine Assembly	173160
		Cassette Assembly	173155
		Flight C/O & Support Equip.	N/A
	MMC	S190 Supplemental Hardware	220401A
S191	Block Engineering	S191 IR Spectrometer Module	PL-950167
		Electronics Module	PL-950139
	MMC	S191 Viewfinder/Tracking Sys	220301A
S192	Honeywell	External Scanner Assy	DJK11A1
	Radiation Center	Internal Scanner Assy	DLK79A1
		Digital Electronics Assy	KHK9A1
S193	G.E.	Microwave Rad/Scat/Alt	3240
S194	AIL	L-Band Electronics Box	375668
		Microwave Radiometer	375584
		Antenna	375667
ESE	MMC	Control and Display Panel	220601A
		Data Recording System	220101A
		ESE Subsystem	220201A

Table 2.2.10-2 EREP System End Items

(1) S190 Multispectral Photographic Facility (MSPF) - The S190 MSPF was a six camera system with a forward motion compensator. The six cameras had a matched distortion and provided photographs, in the visible and near infrared regions, of the earth's features. The specific objectives of the S190 MSPF were to:

- provide a photographic facility to study the value of multispectral photography using various film/filter combinations for the identification and assessment of the earth, oceans and cloud features.
- determine to what extent multispectral photography could be applied to detailed analysis in earth resources.

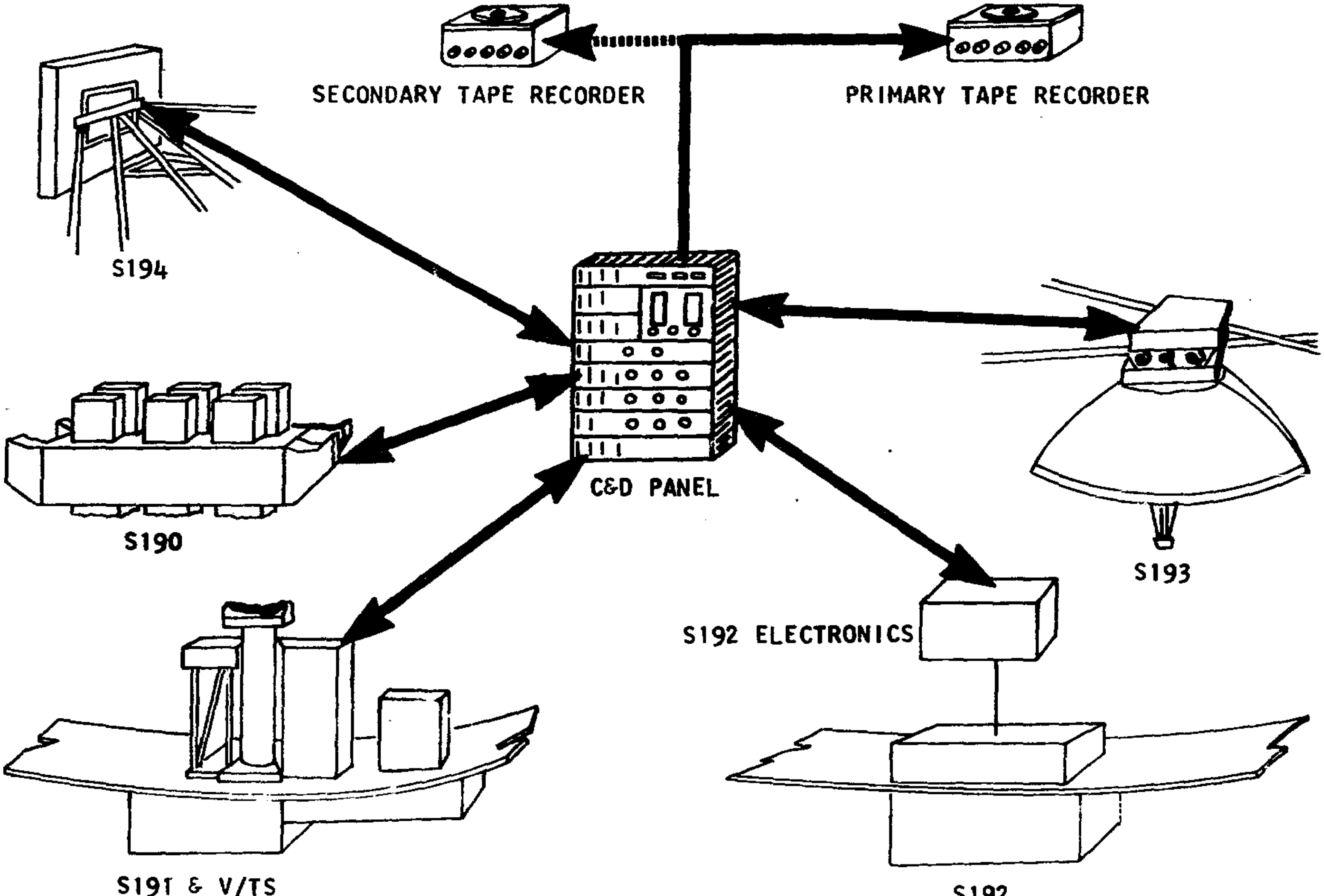


Figure 2.2.10-3 EREP Hardware Interfaces

The S190 MSPF consisted of a boresighted camera array with a Forward Motion Compensator (FMC), a Mount Support Assembly (MSA) and a viewing window in the MDA shell.

(a) S190 Boresighted Camera Array (BCA) - The S190 BCA employed six camera stations, each using 70 mm film. The six camera lenses were distortion matched so that the impage points fall within a 20 Tan Θ micrometers (tangential dimension) by 10 micrometers (radial dimension) elliptical envelope. The BCA was boresighted to position the optical axis of each camera station parallel to each other within a cone of 60 arc seconds full angle. The spectral region covered, the film type used and resolution of each of the camera stations, are given in Table 2.2.10-3.

STATION	WAVELENGTH (MICROMETERS)	FILM TYPE	RESOLUTION LP/MM STATIC	DYNAMIC
1	.5 - .6	PanX Aerial	116	102
2	.6 - .7	PanX Aerial	130	115
3	.7 - .8	IR Aerographic	55	50
4	.8 - .9	IR Aerographic	50	45
5	.5 - .88	Ektachrome IR	45	40
6	.4 - .7	Aerial Color (SO242)	130	116

Table 2.2.10-3 S190 Sensor Specifications

The BCA was capable of sequencing exposures from one frame every two seconds to one frame every 20 seconds, controllable at 2 second intervals.

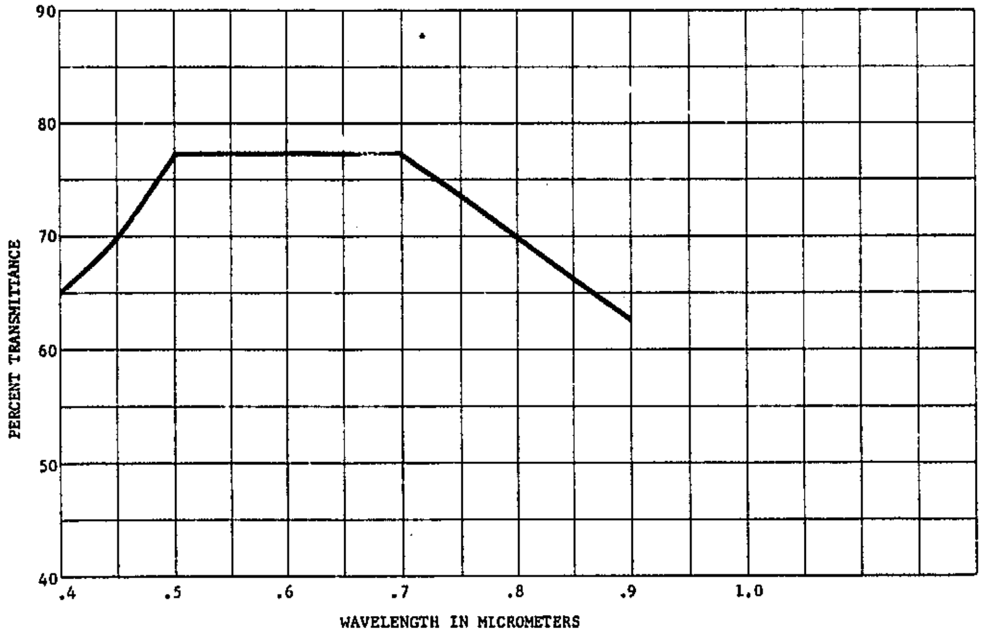


Figure 2.2.10-4 S190 Window Transmittance Requirements

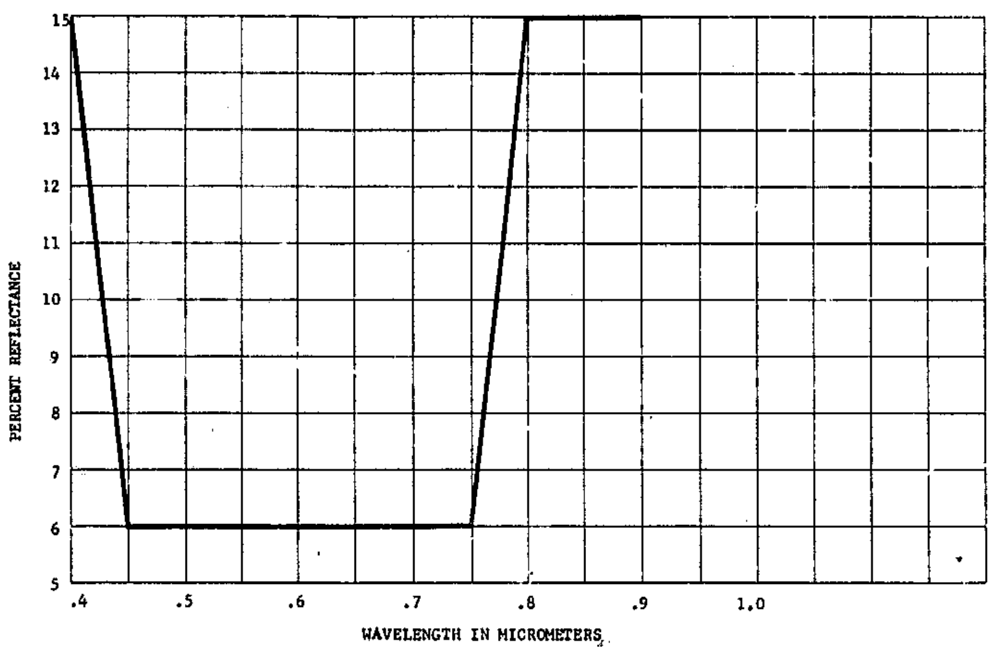


Figure 2.2.10-5 S190 Window Reflectance Requirements

(b) S190 Window - The S190 window was mounted into the MDA hull and performed a photographic function, an astronaut viewing function, a structural function and a sealing function. The area of optical quality was a minimum of 13.5x19.76 inches with the following characteristics:

- Wavefront Variation - Less than 0.06 micrometer from original plane, less than 0.012 micrometers from best RMS fit plane (any 3 inch diameter area)
- Transmitting 1/4 Figure 2.2.10-4
- Reflectance - Figure 2.2.10-5
- Parallelism - The exterior surfaces of the window parallel to within 2.0 arc seconds over the entire window area.

The window was provided with external and internal covers. The external cover was mechanically operable from within the MDA.

(c) S190 Mount Support Assembly (MSA) - The MSA was the member that attached S190 to the MDA shell. The MSA positioned the S190 camera array over the MDA window during launch, during sensor operation, rotated the camera array to a stowed position to clear the window for crew viewing and filter changes, and provided an intermediate position for camera checkout. The MSA mounting in the MDA positioned the BCA over the center of the S190 window assembly during photographic operations with the optical axes positioned within ± 0.25 inches of the center of the MDA window. The MSA was capable of holding the BCA such that the Forward Motion Compensation device (FMC) axis was perpendicular to the MDA X-Z plane within 0.060 inch and parallel to the window within 0.057 inch.

(d) Functional Interfaces Description - The operation of the S190 experiment was controlled at the EREP C&D Panel, with the exception of certain basic controls which were located on the BCA. The S190 housekeeping and timing signals were recorded on magnetic tape by the EREP Data Recording System.

(2) S191 Infrared Spectrometer System - The S191 IR Spectrometer had the capability of acquiring spectra of small (approximately one nautical mile diameter) ground targets with a one milliradian spatial resolution from orbital altitudes of 200 to 260 nautical miles. The IR Spectrometer scanned through the spectral regions .4 to 2.4 micrometers (visible to near IR) and 6.2 to 15.5 micrometers (thermal IR). The acquisition and tracking of the specific ground targets was accomplished by the utilization of an astronaut controlled Viewfinder/Tracking System (V/TS). The IR Spectrometer had the same line-of-sight as the V/TS by the manipulation of a two-axes hand controller. Once the ground target was being tracked, the EREP Data Recording System would record the spectrometer outputs. Concurrent with tracking the target and recording data, the V/TS provided the capability to take photographs of the target area. The specific objectives of the S191 IR Spectrometer were to quantitatively evaluate earth resources sensing in the above spectral regions from near orbit and to evaluate the use of an astronaut controlled tracking system to acquire ground sites.

The S191 IR Spectrometer consisted of the Infrared Spectrometer, a Viewfinder/Tracking System and precision machined mounting plate, set in the MDA shell.

(a) S191 Infrared Spectrometer Description - The S191 IR Spectrometer consisted of a filter wheel design utilizing circularly variable interference filters as the spectral bandpass selection elements. The spectral resolution of the spectrometer is shown in Figure 2.2.10-6. The IR Spectrometer completed one spectral scan per second through the entire wavelength range. The IR Spectrometer had full internal calibration in radiance, and employed sandwich detectors of silicon and lead sulfide for the short wavelength channel and mercury-cadmium-telluride for the long wavelength channel. The mercury-cadium-telluride detector was cooled to below 90°K by a closed cycle cooling engine.

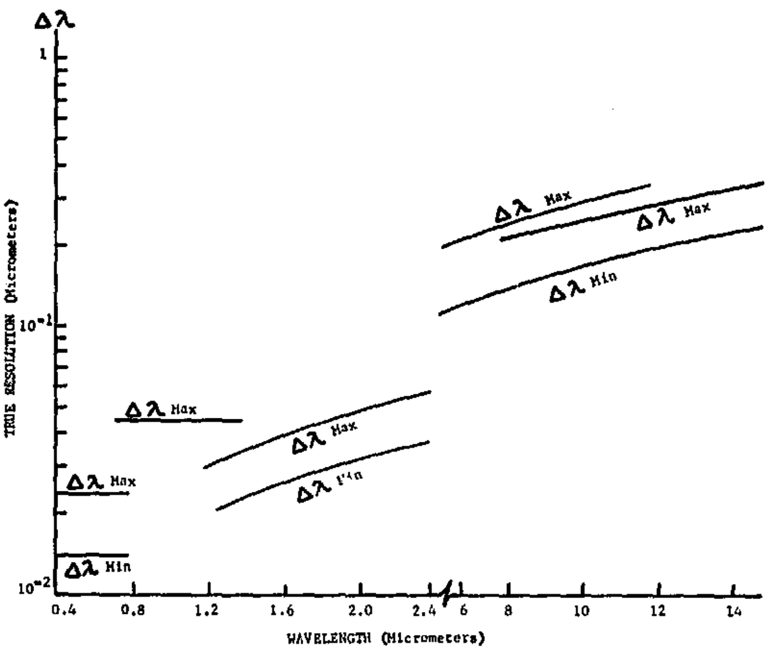


Figure 2.2.10-6 IR Spectrometer Spectral Resolution

Appropriate electronics were provided to output the various signals in a form compatible to the S191 pulse code modulation (PCM) system. The PCM system sampled each spectral channel (5) and the filterwheel angular position at a rate of 684 samples per second (SPS) and 31 housekeeping channels at a rate of 21.375 SPS. The PCM system had a 10-bit accuracy. A clock output was provided to allow the PCM data stream to be Miller encoded.

(b) S191 Viewfinder/Tracking System Description - The V/TS permitted an astronaut in the MDA shirt-sleeve environment to visually acquire a selected ground target, direct the field of view of the IR Spectrometer within the target area, then maintain this condition during one second of data acquisition. The system provided a structural/environmental enclosure for the externally mounted portions of the S191 Experiment.

Key characteristics of the V/TS were as follows:

- The magnification of the astronaut viewing telescope was adjustable between 2.25 power and 22.5 power.
- The field-of-view ranged from 70 $\pm$ 4 nautical miles at minimum magnification to 7 $\pm$ .4 nautical miles at maximum magnification from a 235 nautical mile altitude.
- The static ground resolution of the V/TS telescope was:

Maximum magnification:	On-axis	73 ft/cycle
	0.85^{o} from the center of FOV	105 ft/cycle
Maximum magnification:	On-axis	660 ft/cycle
	8.5^{o} from the center of FOV.	930 ft/cycle

- The V/TS was designed for in-flight alignment of the telescope line-of-sight to the IR Spectrometer detectors.
- The V/TS had the capability to direct the line-of-sight 10 degrees aft to 54 degrees forward along the ground track and 23 degrees left and right measured from the +Z axis. These angles are defined for the center of the field-of-view with the entire field of view unobstructed.
- The telescope field-of-view displayed time, gimbal angles, and an alignment light for V/TS and IR Spectrometer alignment.
- The V/TS provided all controls and displays necessary for complete operation of the system. The controls and displays were located at the V/TS station.
- The external environmental enclosure was equipped with an electrically operated aperture cover. The cover was designed to open or close at a rate of 2.0^{o} per second and had an automatic electrical/mechanical latching mechanism.

- The V/TS accommodated a camera, either TV or Data Acquisition Camera (DAC), and incorporated a pick-off mirror to allow the camera to photograph the field-of-view of the V/TS. It was also possible to dump photographic data to the ground via TV.

(c) S191 Mounting Plate Description - The S191 mounting plate provided the internal and external mounting of all S191 components. The mounting plate provided feedthrough connection for transmission of all data, power and control signals between the various portions of S191. The mounting plate also provided a viewing window (which was a part of the optics of the telescope gimbal mirror system) for the V/TS telescope and a thermal sink for the S191 Infrared Spectrometer. The window had, as a minimum, the following optical qualities:

- Transmissivity - In the wavelength range from 4,000 Å to 7,000 Å, a minimum of 95 percent transmission at normal incidence. An anti-reflection coating was provided.
- Parallelism - 5 arc seconds or less.
- Wavefront - Peak-to-peak variation did not exceed $\frac{\lambda}{2}$ for λ = 6,000 Å over a total window area.
- Clear Aperture - Three-inch diameter, minimum.
- Index of Refraction Variation - The index of refraction of the glass measured at λ = 6,000 Å would not vary by more than $\pm 5 \times 10^{-6}$ over the clear aperture.

(d) Functional Interface Description - The S191 equipment operation required two crewmen (one at the C&D for power, and spectrometer operation and one at the V/TS). All S191 data along with housekeeping data, was transmitted to the C&D panel to be recorded on magnetic tape by the EREP system.

(3) S192 Multispectral Scanner - The Multispectral Scanner was capable of gathering high spatial

resolution and quantitative line scan data on the radiation reflected and emitted by selected test sites. The data was taken in 13 spectral regions of the visible, near infrared, and thermal infrared regions of the spectrum. The Multispectral Scanner could gather the data in these spectral bands with a high signal-to-noise ratio in a spatially registered manner. The data was digitized to maintain the information content and spatial registration of the data as it passed through the system electronics to the EREP C&D panel and to the EREP recorder.

The S192 Multispectral Scanner employed 13 detectors to gather information in the 0.4 micrometer to 12.5 micrometer region of the spectrum and separated the spectral information into the following 13 bands:

Band	Wavelength (Micrometers)	Band	Wavelength (Micrometers)
1	0.41 - 0.46	8	0.98 - 1.08
2	0.46 - 0.51	9	1.09 - 1.19
3	0.52 - 0.56	10	1.20 - 1.30
4	0.56 - 0.61	11	1.55 - 1.75
5	0.62 - 0.67	12	2.10 - 2.35
6	0.68 - 0.76	13	10.2 - 12.5
7	0.78 - 0.88		

The S192 Multispectral Scanner consisted of an internal and external scanner, a digital electronics assembly and a mounting plate in the MDA shell.

(a) S192 Multispectral Scanner Description - The external scanner was provided with a remotely actuated cover for the objective aperture. The instantaneous field-of-view (IFOV) for all detectors was 0.182 milliradian times 0.182 milliradian or 260 feet by 260 feet, from a 235 nautical mile orbit. The total scan overlap was less than 5% of the area scanned. The variations in the scan pattern were less than 0.1 times the dimension of the smallest IFOV in both the in-track and cross-track directions. The spatial registration between any two bands was maintained to one-tenth the dimension of the IFOV of the two bands. The angular coverage (swath width) was 120° of rotation of a 5.5° of a half angle cone.

The optical resolution of bands 1 thru 12 was such that the diameter of the blur circle of the optics was smaller than one-half the dimension of the IFOV. For band 13, the optical resolution was essentially diffraction limited. The Multispectral Scanner had a cooler/detector/preamplifier assembly replacement and realignment capability. The replacement assembly was stowed in the internal scanner assembly.

The Multispectral Scanner had the capability to calibrate each spectral band radiometrically, once each scan line.

(b) S192 Digital Electronics Assembly (DEA) - The DEA accepted the video outputs from the detectors and digitized/formatted this data. The DEA also distributed MDA power, controlled S192 gains and provided circuit protection. The output of the electronics assembly was 22 channels of digital scientific data and a single channel of housekeeping data at a rate of .970 megabits per second per channel. Each scan line (data frame) was divided into subframes with synchronization signals at the beginning of each frame and subframe. The digital data output was coded in pure binary and was then Miller encoded in the C&D panel before being recorded on tape.

The DEA also digitized and multiplexed all electrical signals necessary to define the instrument status, at a rate of once each scan line; such as operating conditions and calibration source conditions. These signals were routed through the EREP C&D Panel at the same rate as the scientific data to be recorded by the EREP Data Recording System. This housekeeping data was redundantly recorded on T/R tracks 1 and 27.

The electronics assembly also provided selected analog signals for display on the C&D panel.

(c) S192 Mounting Plate - The S192 Mounting Plate provided for the mounting of the internal/external portions of the scanner. The mounting plate provided a thermal sink for the external portion and provided feedthrough connectors for all data, control and power transmission between the internal and external portion of S192. The mounting plate included two windows for sensor viewing. The window material for spectral bands 1 thru 12 was T17 Infrasil I. The window had as a minimum the following characteristics:

- Clear Aperture: 2.0 inches in diameter by 0.25 inch in thickness.
- Transmittance: 93% minimum at any wavelength between 0.4 and 2.4 micrometers; 96% minimum at wavelength of peak transmittance; uniform within 0.5% over any 1/4-inch diameter.
- Coating: Single layer of magnesium fluoride anti-reflection coating to both sides with 1/4 wavelength optical thickness for peak transmittance at 0.6 micrometers per MIL-C-675.
- Wavefront Variation: Variation not to exceed 1/4 wavelength for a wavelength of 0.6 micrometers over the total window area.

The window material for spectral band 13 was germanium with the following minimum requirements.

- Clear Aperture: 2.0 inches in diameter by 0.25 inch in thickness.
- Transmittance: 92% minimum average over the 10.2 and 12.8 micrometers; band uniform within 0.5% over any 1/4 inch diameter.
- Coating: Multilayer anti-reflection coating to both sides.

(d) Functional Interface Description - The S192 Experiment was controllable from the EREP C&D Panel and required only one crewman for operation during data passes. The experiment used 24 recording tracks of the EREP Data Recording System; 22 for scientific data and 2 (1 redundant) for housekeeping data. The Digital Electronics Assembly was supported on equipment rack no. 2 and used cooling water from the EREP coolant loop.

(4) S193 Microwave Radiometer/Scatterometer/Altimeter - The S193 Experiment was a combination radar altimeter, radar scatterometer and passive microwave radiometer. The S193 Experiment measured near simultaneously, the radar differential backscattering cross section and the passive microwave emissivity of the land and sea surfaces. The microwave radiometer and scatterometer were capable of operating independently of each other and of operating independently of the altimeter. The system used a single antenna which was gimbaled to scan in various modes.

The S193 Experiment also consisted of a gimbaled (pitch and roll) antenna and an electronics package mounted externally.

(a) S193 Microwave Radiometer/Scatterometer/Altimeter Description - The S193 System was designed to operate on a single frequency of 13.9 GHz. A single antenna was used for all operations. The antenna exhibited a pencil beam of approximately 1.5 degrees and was gimbaled to allow for scanning up to 48 degrees on either side of the flight track and 48 degrees forward along the flight track relative to the Z axis of the MDA. The system was electronically controlled from the EREP C&D Panel to perform the various modes for the altimeter radiometer and scatterometer. In addition, the altimeter range gate was set from the C&D panel.

The S193 electronics data output was digital and adaptable to a 10-bit word PCM format. It was 10 KBPS for the altimeter mode and 5.333 KBPS for any radiometer/scatterometer mode. All data was redundantly recorded on the EREP Tape Recorder System, tracks 14 and 15.

The flight hardware, antenna and electronics box, was provided for mounting directly to the AM DA truss.

(b) Functional Interface Description - The entire S193 Experiment was mounted to the AM DA truss. It received power directly from the AM power bus. All S193 controls were contained in the EREP system in the MDA. The AM also provided survival heater power for the unit.

(5) S194 L-Band Radiometer - The S194 L-Band Radiometer was a microwave radiometric sensor, utilizing a fixed planer array antenna, oriented toward Nadir. The system measured the earth's thermal radiation and provided a digital representation of 0 to 350°K input temperature range to an accuracy of 1°K, at a center frequency of 1.413 GHz. The antenna beam provided a nominal 60x60 nautical mile footprint coverage of the earth. The energy received by the antenna was integrated at a rate that ensured a minimum of 80 percent ground coverage overlap.

The S194 L-Band Radiometer consisted of the antenna, an electronics box and a mounting truss.

(a) S194 L-Band Radiometer Description - The S194 L-Band Radiometer was a modified Dicke type radiometer with gain modulation utilizing a tuned radio frequency receiver. It had an integration time of [illegible] second and a band width of 27 MHz (1.400 to 1.427 GHz). The radiometer measured the effective antenna temperature by comparing it to a reference at a Dicke switch rate of 105 Hz. The electronics had a dynamic range of 0°K to 350°K with an accuracy of ± 1°K. The system included two automatic calibration intervals; one cycle calibrated every four minutes and the other every 34 minutes. A manual calibration could be initiated by the crewmen from the EREP C&D panel.

The data output of the radiometer was a slowly varying DC voltage sampled at a rate not to exceed 200 KBPS.

The mounting truss supported both the antenna and the electronics box. It was designed to maintain the alignment requirements of the sensor and withstand the MDA dynamic enviroments.

(b) Functional Interface Description - Control for the S194 L-Band Radiometer was contained in the EREP C&D Panel and all scientific and housekeeping data was routed from the sensor through the C&D Panel and recorded on the EREP Data Recording System.

C. Test - The component tests were performed by the experiment developer prior to being delivered as GFE. For details refer to the Experiment Final Program Report. For systems testing see section 7 of this report.

D. Mission Results - All aspects of MDA and AM/MDA interface requirements affecting the EREP experiments were satisfactorily met. Concerns that developed at the EREP system level were possible loss of Flight Time Reference System (TRS) in the AM and possible loss of AM coolant loop. The severe electrical power restrictions during the earliest part of the mission were successfully worked around. Results of individual experiments performance during the mission can be found in the Experiment Final Program Report.

(1) S190A - Interfaces were satisfied. Concerns with malfunctioning lights, with "dust or bubbles" inside the lens assembly and, later, with slowing or inoperative shutter drive were internal to the experiment.

(2) S191 - All interfaces were satisfied. A substantial concern that an S191 door failure was eminent developed early in the mission and persisted until the operation was demonstrated to be complete, including proper latching. The first opening of the door, reported at 3 minutes (in contrast to nominal KSC test value of 1:45) was the basis of this concern; door operations were absolutely minimized throughout the mission in the belief that total failure might occur at any time. As a

result of leaving the door open or unlatched:

- alignment could not be performed as had been scheduled
- colder temperatures were presented to the Malaker cooler
- longer warmup time was required.

These matters were routinely handled by the MDA Mission Support/EREP Support Operations.

(3) S192 - MDA interface requirements were met. The cooler-detector-preamplifier assembly (CDPA) was installed at the beginning of the first manned mission and the CDPA did not, it was later found, mate properly. This created considerable crew difficulties and confusion in alignment procedures and final readings. The second crew readjusted the CPDA and normal procedures worked and expected values were observed. A noise in the 18-20 Hz range was present in the flight and in the St. Louis test data as modulation on the expected data. It appeared that this noise was built into the experiment design.

(4) S193 - Mechanical, electrical and operational interfaces with the orbital assembly and the EREP C&D Panel were satisfactory throughout the mission. The crew interface with S193 C&D Panel presented a more complex situation than usual as a result of constraints on sequence and timing of S193 switches and sights. After the first operations by each crew, the problems were mastered and operations became routine.

The gimbal system of S193 exhibited an abrupt failure during the SL-1/3 mission. A short in the power circuits to the gimbal systems rendered the pointing uncontrollable. A test-and-fix box was taken up on SL-4 and ·sed during EVA. The existence of a short was confirmed and the box was used to open the circuit to the short restoring the remaining functions employing the power system. The gimbal launch-lock pin was also installed locking the inoperative axis. The S193 operations during the SL-1/4 mission were performed within this additional constraint. The mechanism which could have caused the short was considered, and speculation seemed to suggest that thermal blanket material may have moved into the gimbal pot near the high end (with respect to ground) of the electrical sensor winding around the structural member.

(5) S194 - Mechanical, electrical and operational interfaces with the orbital assembly and the EREP C&D Panel were satisfactory. The rare, unexpected operations of indicators were the result of out of tolerance temperatures or insufficient time to reach in-tolerance temperatures.

E. Conclusions and Recommendations - All EREP interfaces with MDA hardware and subsystems were satisfactory. The crew interface at the EREP C&D panel was highly successful, confirming this approach of a centralized nerve center for all the EREP experiments. Centralized power distribution, sensor control and data processing is highly recommended for future experiment operations of this nature.

2.2.10.2 Materials Processing in Space Facility (MPF)

A. Design Requirements - The Materials Processing in Space Facility consisted primarily of a sphere for vacuum environment, an electron beam source, and associated mechanical and electrical hardware. The facility was utilized for numerous experiments which were performed in the Zero-G and vacuum environment.

The MDA/Experiment interfaces required for these experiments, and the correct environments were:

(1) Mechanical - The MPF was shock-mounted in the MDA. The entire facility was mounted on honeycomb panels and then installed in the MDA. The stowage container was mounted in the same manner.

(2) Electrical - The MPF required only the 28 VDC interface for its operation. When the M518 Multipurpose Electric Furnace (MEF) was added, it also required power from the hi-power utility outlet and telemetry data interface utilizing the Speaker Intercom System.

(3) Vacuum -

(a) The MDA provided a 4-inch line to the external vacuum environment. This line was controllable with two 4-inch valves placed in series between the MPF and the MDA bulkhead.

(b) A Battery Vent Line was provided for overboard' dump of battery gas.

(4) Water - The MDA was compatible with a flex line water hose from the OWS to provide quenching water for M479.

(5) Vacuum Cleaner - Access around the MPF was necessary for using the vacuum cleaner attached to the vacuum cleaner port.

B. Functional Objectives - The objective of the MPF was to provide a facility (see Figures 2.2.10-7 and -8) in which to demonstrate and evaluate the merit of performing various repair and assembly techniques and numerous procedures needed to process certain materials research projects in a Zero-G and vacuum environment. Molten metal flow, freezing patterns, thermal

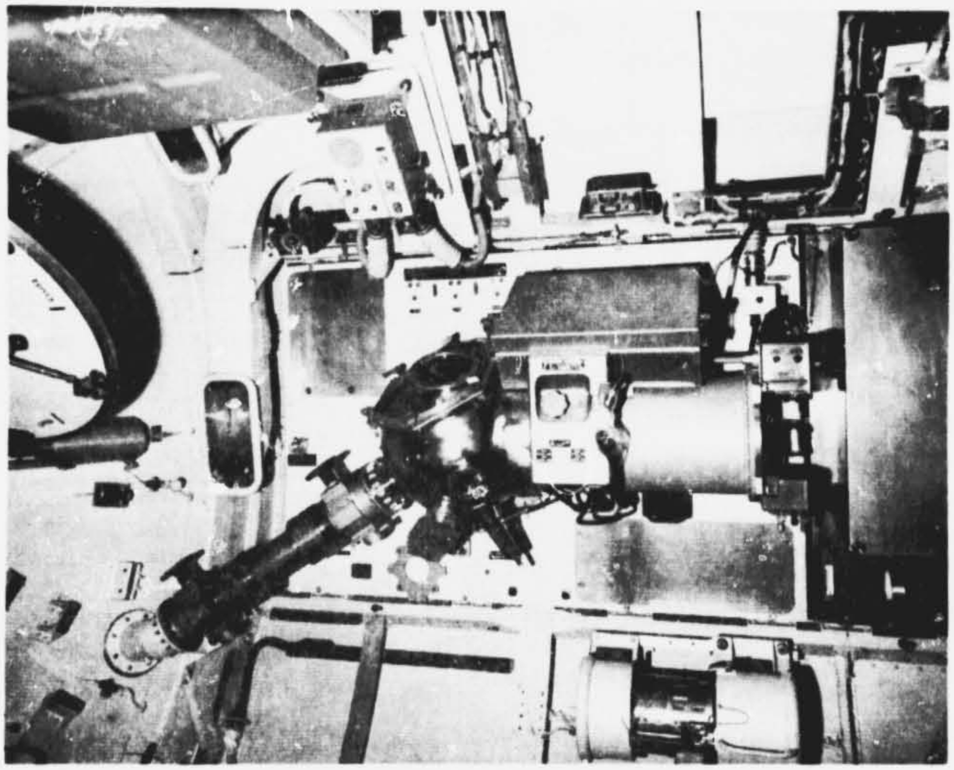


Figure 2.2.10-7 M512 Materials Processing in Space Facility

Figure 2.2.10-8 M512 Equipment Stowage Container

stirring, fusion across gaps and surface tension were examined.

The Experiment objectives were met by performing various experiment tasks within the facility. The following is a listing of the experiments and their objectives by number and title:

(1) M479 Zero Gravity Flammability - Ignite various materials in Skylab cabin atmosphere to determine:

- Extent of surface flame propagation, flashover to adjacent materials, etc.
- Rates of surface and bulk flame propagation under zero convection.
- Self-extinguishment.
- Extinguishment by vacuum or water spray.

(2) M551 Metals Melting -

- Study behavior of molten metal in micro-gravity.
- Establish means of materials joining and cutting in space, and maintenance of orbiting structures.

(3) M552 Exothermic Brazing -

- Study behavior of molten metal in reduced gravity (in particular, surface wetting and capillary flow)
- To demonstrate a heat source for melting metal in space.
- To test and demonstrate a method of brazing components for space repair and maintenance operations.

(4) M553 Sphere Forming -

- To evaluate segregation in binary alloys and pure metal solidified in micro-gravity.
- To determine amount of supercooling of a pure metal solidified in micro-gravity.
- To determine the smoothness of metal surfaces solidified in micro-gravity.

The M518 Multipurpose Electric Furnace (Figure 2.2.10-9) experiment system was approved for the Skylab Mission in June 1972 to provide necessary thermal parameters for the following experiments:

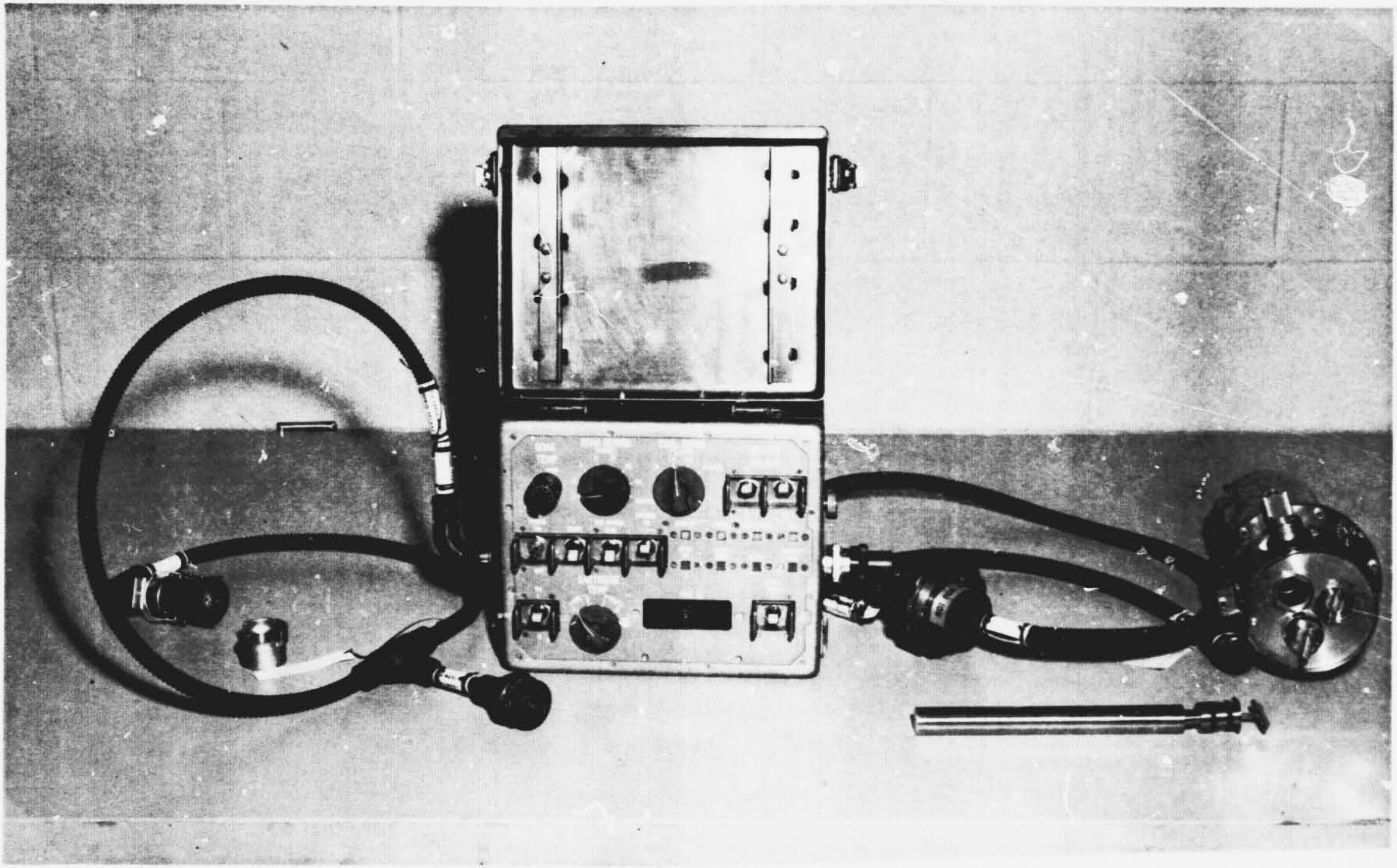


Figure 2.2.10-9 M518 Multipurpose Electric Furnace

(1) M556 Vapor Growth of IV-VI Compounds - To determine the degree of improvement that can be obtained in the perfection and chemical homogeneity of crystals grown by chemical vapor transport under weightless conditions.

(2) M557 Immiscible Alloy Compositions - To determine the effects of near Zero-Gravity on the processing of material compositions which normally segregate on earth.

Solidification of immiscible metal liquids under isothermal conditions with a third sample to be solidified in a temperature gradient.

(3) M558 Radioactive Tracer Diffusion - To measure self-diffusion and impurity diffusion effects in liquid metals in space flight and characterize the disturbing effects, if any, due to spacecraft acceleration.

Specifically, determine the diffusion coefficient of radioactive zinc in natural zinc.

(4) M559 Microsegregation in Germanium - To determine the degree of microsegregation of doping impurities in germanium caused by convectionless directional solidification under conditions of weightlessness.

(5) M560 Growth of Spherical Crystals - To grow doped indium antimonide (InSb) crystals of high chemical homogeneity and structural perfection and study their resulting physical properties in comparison with theoretical values for ideal crystals.

(6) M561 Whisker-Reinforced Composites - To produce void-free samples of silver reinforced with oriented silicon carbide whiskers.

(7) M562 Indium Antimonide Crystals - To produce doped semiconductor crystals of high chemical homogeneity and structural perfection and to evaluate the influence of weightlessness in attaining these properties.

(8) M563 Mixed III-V Crystal Growth - To determine how weightlessness affects directional solidification of binary semiconductor alloys and, if single

crystals are obtained, to determine how their semiconducting properties depend on alloy composition.

(9) M564 Halide Eutectics - To produce highly continuous controlled structures in samples of the fiber-like NaF-NaCl eutectics, and to measure their physical properties.

(10) M565 Silver Grids Melted in Space - To determine how pore sizes and pore shapes change in porous structures when they are melted and resolidified in space.

(11) M566 Aluminum - Copper Eutectic - To determine the effects of weightlessness on the solidification of Lamellar structure in an eutectic alloy when directionally solidified.

C. Test - Component level tests were performed by the experiment developer prior to being delivered to the MDA as GFE. For details refer to the Corollary Experiments Final Technical Report, TMX-64809. MDA systems level testing results are included in Section 7 of this report.

D. Mission Results -

SL-1/2 - Experiments M551, M552, and M553 were performed as scheduled. Slightly longer than anticipated times to achieve the desired working pressures in the chamber, and a malfunction in the circuitry controlling the shutoff of the electron beam were the only events marring the successful operation of the facility. The extended time to achieve the pressures impacted the number of samples completed on M553 (21 of the scheduled 28). The malfunction of the electron beam gun was successfully corrected through an operational procedure using the battery circuit breaker to terminate the beam when necessary.

SL-1/3 - The M518 series of experiments was scheduled to be performed on the SL-1/4 mission, but due to the availability of mission time and the crew's request for additional work, approval was granted by the Flight Management Team to perform as many of the M518 experiments as possible on SL-3. Thus, the entire series of eleven experiments (3 samples each) was performed. The system performed as designed with two exceptions, neither of which created a problem or was considered an anomaly. First, the heat-up times were generally shorter than expected. This was due to the AM Bus 1 voltage being slightly higher (but well within tolerance) than that used to predict the heat-up time. Second, there was an apparent "slip" in the "Soak Temp" potentiometer, resulting in slight variations in the furnace soak temperatures obtained.

SL-1/4 - Seven of the M518 backup experiments were launched, performed, and returned successfully. The heat-up times were slightly longer than anticipated, again due to minor variations of the AM Bus 1 voltage.

M479, "Zero-G Flamability" was performed as scheduled. All samples were performed, with the only significant problem being the performance of the water quench system. The system did not operate as intended, but it could not be determined whether the problem was procedural, or a hardware malfunction.

A more detailed discussion of the results obtained during the three manned mission can be obtained by referring to the Corollary Experiments Final Technical Report, TMX-64809.

E. Conclusions and Recommendations - See the Corollary Experiments Final Technical Report, TMX-64809.

2.2.10.3 S009 Nuclear Emulsion

A. Design Requirements - MDA support to the S009 consisted of physical support, a controlled environment and electrical power. The experiment consisted of a detector package, an experiment housing assembly and the support structure furnished by the experiment developer, the Naval Research Laboratory (NRL). The detector package was launched in the OWS film vault and transferred on orbit to the experiment housing which was permanently mounted in the MDA.

The support consisted of two beams attached between two longerons in the forward section of the MDA. This aligned the experiment housing such that the detector pointed along the -Y axis. The skin of the MDA, between these two longerons, was then chem-milled to 0.076" from a nominal thickness of 0.250", to allow a uniform skin as thin as possible to "look" through. The MDA provided the controlled environment required by the detector package emulsion and 28 VDC at a maximum of 1.25 amps.

Further details concerning the design requirements and interface requirements can be found in the Experiment Requirements Document (SE-010-022-2H) and the appropriate ICDS:

- Mechanical - 13M12191
- Electrical - 40M35652

B. Functional Description - The objective of the experiment was to study the charge spectrum of primary cosmic rays, obtain detailed chemical composition of the heavy primary nuclei, search for rare particles, and study these phenomena as a function of the solar cycle.

This was accomplished by exposing a stack of layers of emulsion and studying the tracks left by the cosmic rays as they passed through. Two actions were taken to eliminate unwanted particle tracks such as protons in the South Atlantic Anomaly. First, the detector package containing the emulsion was hinged along one edge much like an open book. This allowed the package to be closed or put in a "data reject" mode. Thus, any track that could be traced across the interface between the two halves could be considered to have occurred during the data reject mode and was not analyzed. Second, the detector package was oriented so that it "looked" essentially perpendicular to the orbit plane. This was to eliminate secondary particle tracks resulting from collisions between the primary cosmic rays and the earth's atmosphere.

These two functions were accomplished by the detector housing assembly mounted to the wall of the MDA (see Figure 2.2.10-10). The opening and closing of the package was controlled by a stepping motor activated through a timing circuit. The period of the orbit was set, then the fixed open and closing cycle insured that the package was closed whenever the OA was north of 30 degrees north latitude or south of 25 degrees south latitude. Orienting the package perpendicular to the orbital plane was accomplished by the astronaut. His participation was required because the pointing of the experiment varied with the beta angle of the orbit. Thus, he was required to make an adjustment to the experiment pointing anywhere from once a day to once every six days, depending on what part of the beta angle versus time curve the mission covered.

C. Test - Component tests were performed by NRL prior to being delivered as GFE. For details refer to the Corollary Experiments Final Technical Report, TMX-64809. MDA systems level testing is included in Section 7 of this report.

D. Mission Results - The S009 Nuclear Emulsion Detector Package was transferred from the OWS Film Vault on MD5 (DOY 149) of SL-2 and was successfully deployed, although the crewman commented at the time that the package was very difficult to install because of tighter-than-expected tolerances between the package and the Experiment Housing. The package was exposed for 21 days, and then on MD26 (DOY 170) it was removed on schedule from the experiment housing and stowed in the CM for return.

The experiment did not perform as well as expected, and the data was degraded due to:

(1) High temperatures in the OWS Film Vault during the first 13 days of SL-1.

(2) Late deployment due to the delay of the launch of SL-2.

(3) The tendency of the package to stall on the close cycle of the automatic open/close sequence. This problem was noted on MD17 (DOY 161).

The first two of these problems were related to the loss of the OWS meteoroid shield with the resultant high temperatures and late scheduling of the SL-2 launch. The OWS temperatures climbed far above nominal and remained there for several days. The Nuclear Emulsion Package resided in Drawer J of the OWS Film Vault during this period. Although there was no temperature

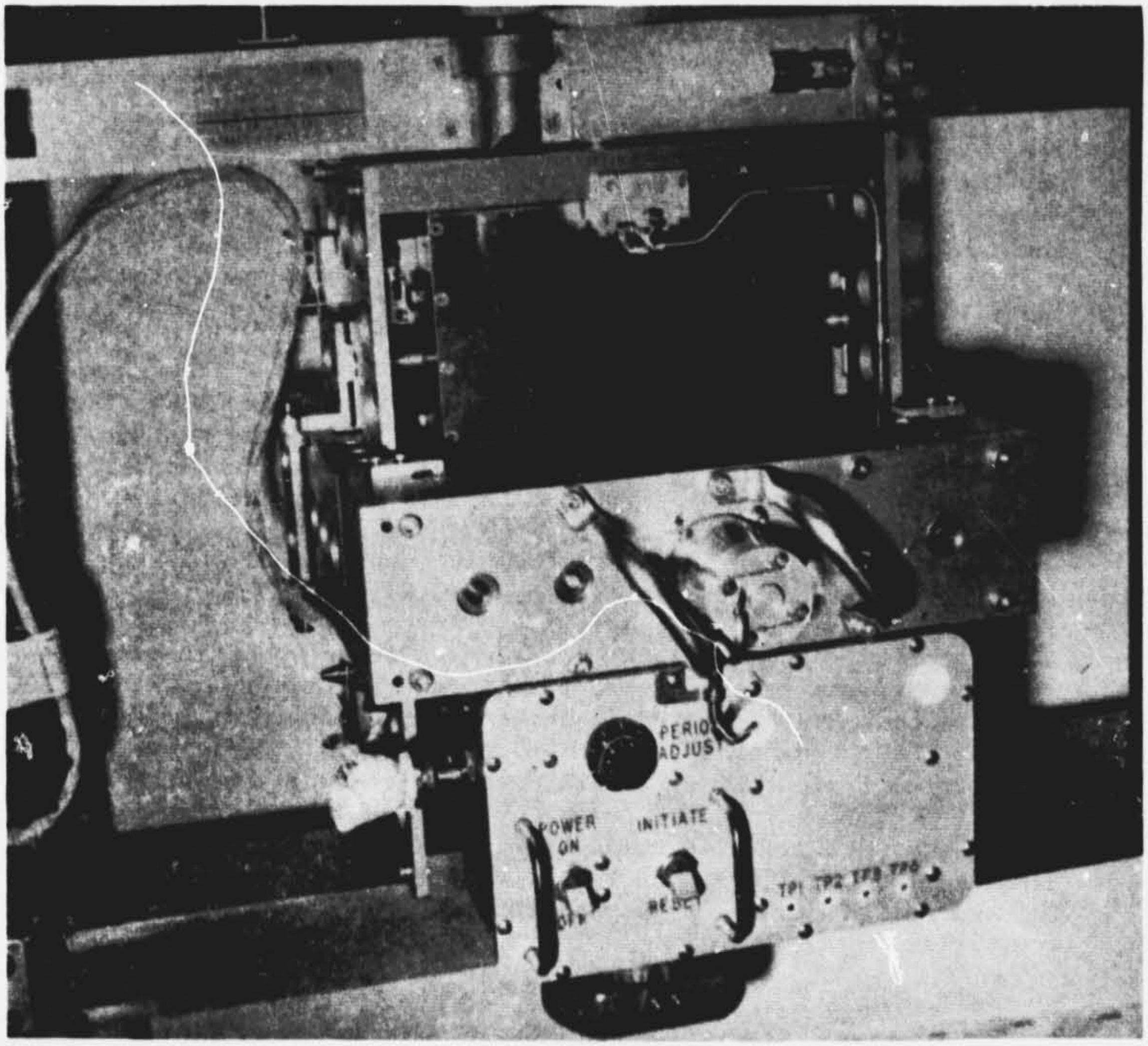


Figure 2.2.10-10 S009 Nuclear Emulsion

sensor in the Film Vault, the temperature could be closely estimated by use of the sensors in the vicinity of the vault. The temperature was above 90°F, the nominal maximum, from DOY 136 to DOY 149. From DOY 142 to DOY 147, the temperatures were between 120°F to 125°F. These extremely high temperatures led to the softening and sticking together of the individual layers of the emulsion to such an extent that they were deformed when separated for analysis. In addition, the background fogging level increased by a factor of 2.

Late deployment was deleterious because the Nuclear Emulsion Package begins to gather data (cosmic ray tracks) from the day the film is made until the time it is processed. In space, of course, the effect is much greater since there is no shielding atmosphere. Therefore, the additional ten days that the package spent in orbit in a data reject mode (package closed) added to the background "noise" that had to be eliminated during the postmission analysis.

On MD17, the motor/drive train proved incapable of closing the Emulsion Package. This condition interrupted the timing sequence of the package openings and closings that were accurately synchronized with 30° north and 25° south latitude crossings. The decision was made to turn off the motor and deploy the Emulsion Package open, but with the continued manual pointing updates. This mode of operation continued through MD26.

In order to evaluate the motor/drive train condition, a set of questions were uplinked to the crew and later a malfunction procedure was prepared in a coordinated effort with NRL, JSC and MSFC. The procedure called for the cycling of the motor/drive train through several opening/closing sequences without a package present, but with the crewman actuating limit switches manually. When tried by the crew, the motor closed the emulsion package with some hesitation at the midway point. It then opened, but when the attempt was made to close it again, it stalled.

A backup package was prepared for launch on SL-2, but was not launched due to limited CM stowage. It was then approved to be launched on SL-3, but was again deleted due to stowage considerations. It was launched and performed on SL-4.

A replacement motor assembly was launched on SL-3 to replace the degraded unit on orbit. Inflight maintenance was performed prior to the activation of the experiment on SL-4.

E. Conclusions and Recommendations - Skylab experience has shown the importance of supplementing Telemetry over and above information gathered through voice contact with the crew. The anomalous condition of S009 could have been discovered at its first occurrence and possibly converted had telemetry been provided to indicate when the motor was operating. This also would have allowed the ground support personnel to relieve some of the duties of the crew, such as requiring them to adjust the experiment only when required, rather than on a regularly scheduled basis.

Testing of the experiment could have included zero-G simulation. This would have allowed investigation of the effects of the high mass of the detector package on the open and close cycle. It also would have provided an evaluation of the adequacy of the motor to perform this function.

Overload protection on the motor itself might have detected those times when it is predicted that the package stalled.

2.2.10.4 Proton Spectrometer

A. Design Requirements - The Proton Spectrometer required support from the MDA in the form of physical support, electrical power, and instrumentation and communication. Specifically, the instrument was mounted to the L-band truss (see Figure 2.2.10-11) such that the detector had a clear field of view (a 45° acceptance cone) along the Y axis. The instrument was, in addition, bonded to the structure through the truss. Electrically, the MDA provided 28 VDC at 5.9 watts maximum load. The I&C interface accommodated:

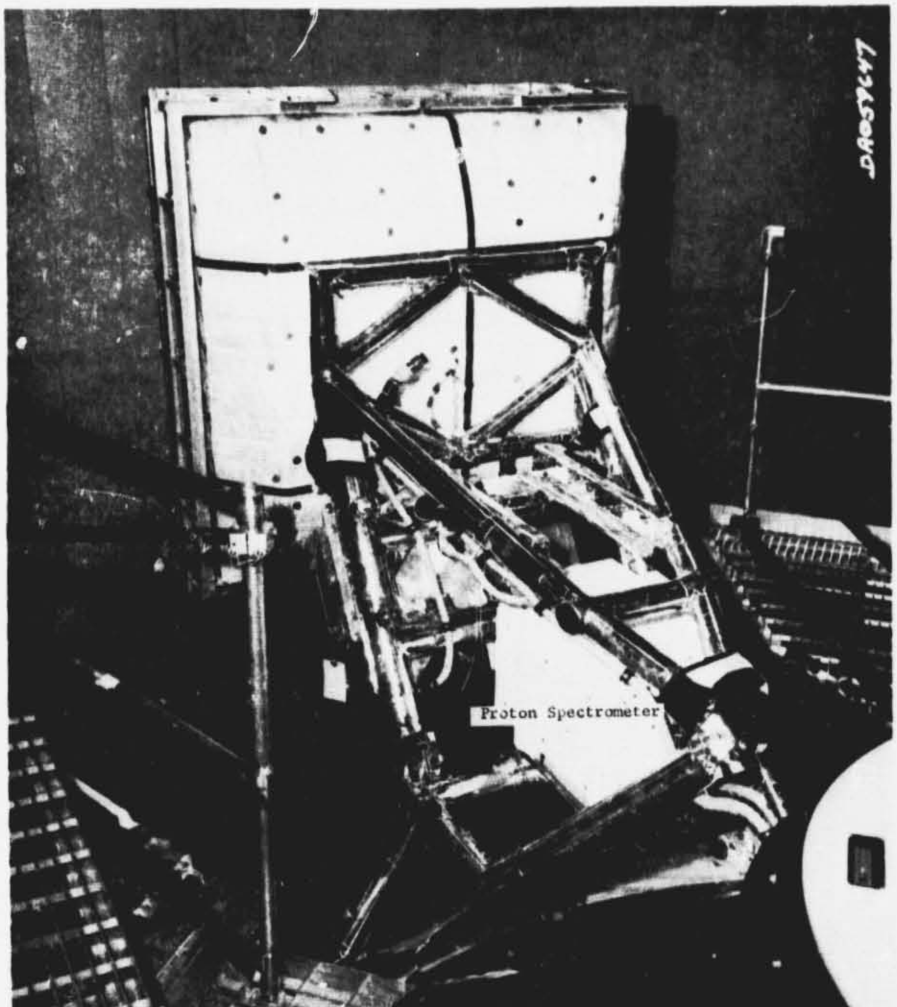


Figure 2.2.10-11 Proton Spectrometer Installation

- A 6 VDC count/calibrate threshold change signal.
- Detector head, and electronics temperature measurements.
- Transmission of a 12-bit digital word.
- Two particle rate counting measurements.
- A spacecraft clock signal for data synchronization.

Further information can be found in the Instrument Requirements Document for the Proton Spectrometer (Repository No. SE-010-050-2H), or the applicable ICDs.

- Mechanical - 13M13513
- Electrical - 40M35664
- I&C - 50M16134

B. Functional Description - The objective of the experiment was to determine the energy spectrum and intensity, as well as the pitch angle distribution, of electrons and protons trapped in the radiation belts of the South Atlantic Anomaly. Time variations of these measurements over long periods should help in the analysis of solar modulation of the radiation belts. Solar flare radiation was also recorded. This knowledge of the energy spectrum of the particles should aid in the design of shielding, the choice of films and film developing procedures, and the determination of radiation dosage being received by the crew.

The Proton Spectrometer was a charged particle spectrometer mounted on the L-band truss external to the MDA. It measured electrons from 1.2 to 10 MEV and protons from 20 to 400 MEV. The spectrometer consisted of a detector head, and electronics housed in a single instrument.

The detector head was a particle-identifying and measuring device (see Figure 2.2.10-12). It measured specific energy loss in two thin solid state detectors and energy in a cesium iodide crystal detector. These three detectors were surrounded by a fourth detector, a plastic scintillator, which operated in anti-coincidence. The scintillation counters were viewed by photomultiplier tubes.

When in the South Atlantic Anomaly, the intense electron radiation environment resulted in a very high counting rate in the individual detectors despite heavy shielding. Therefore, very fast electronics were used and multiple coincidences and anti-coincidences were required before a particle was counted.

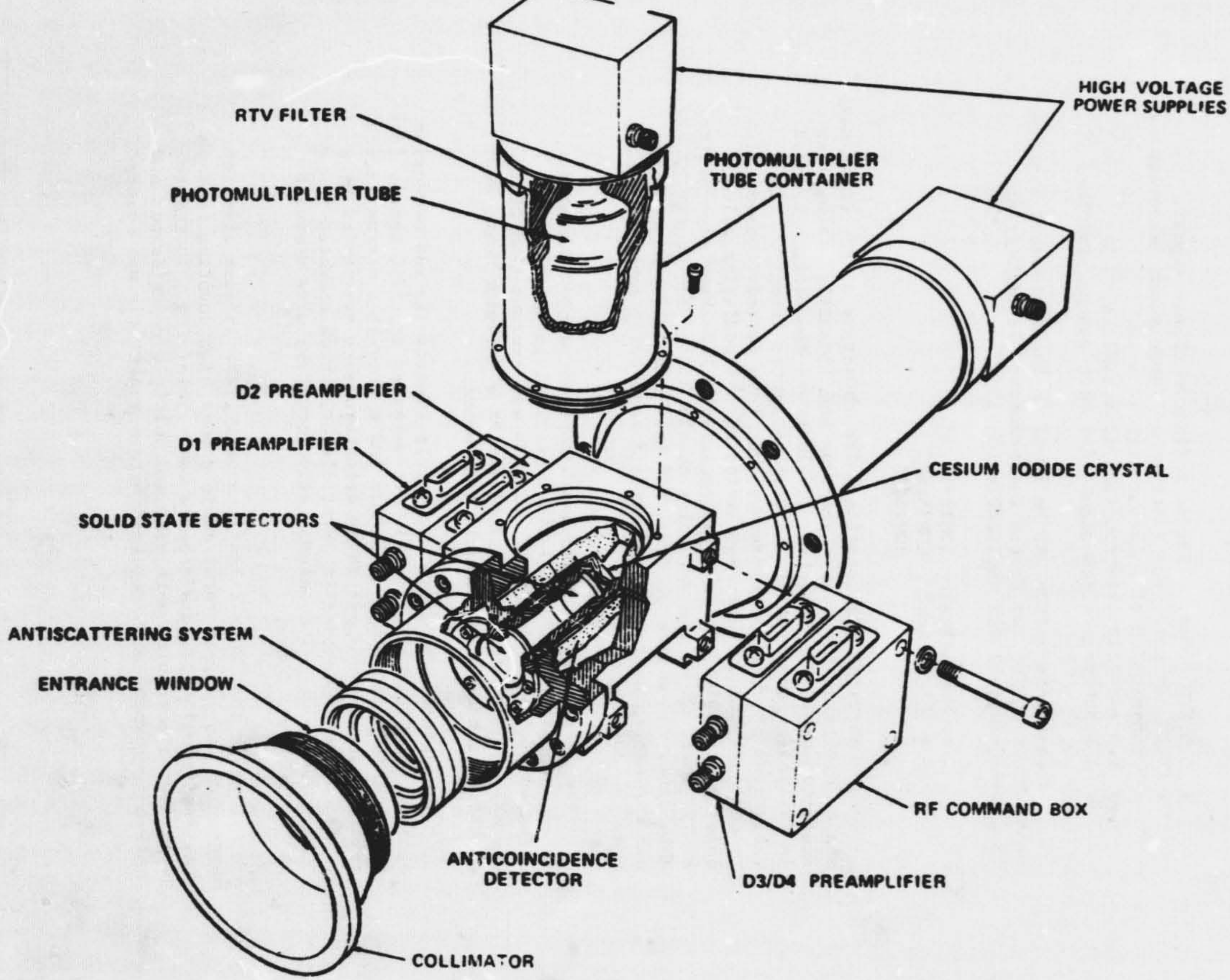


Figure 2.2.10-12 Proton Spectrometer Detector Head Assembly

The instrument was normally acquiring calibration data, using an alpha source grown into a cesium iodide crystal as a reference. Both scintillation detectors sensed the radiation environment continuously. One scintillation detector signal was sent to a threshold discriminator. The discriminator was used by the control logic to bring the detector system into its counting mode automatically.

This method of automatic count-calibrate mode changes required initial knowledge of radiation to be measured in order to properly set the reference threshold voltage for the discriminator. Therefore, a ground command was used to change this reference voltage, as well as providing a ground command capability for turning the instrument on or off. The status of the reference voltage was changed in steps by repetition of the ground commands.

The Proton Spectrometer, due to the layout of the coincidence and anti-coincidence detectors, had an acceptance cone angle of 45° from both the front and rear of the instrument. Knowledge of the orientation of the OA while passing through the South Atlantic Anomaly yielded information about the pitch angle distribution of the spiraling particles.

The output of the instrument consisted of two analog temperature measurements, two analog count measurements (indicating the total flux of the radiation field) and a 12-bit digital word. The digital output was updated at a 10 per second rate and provided the complete data frame of 12 words in 1.2 seconds.

The complete data output per orbit was reconstructed after the orbit. Real time data recorded by the ground stations was combined with AM recorder dump data covering periods when no ground coverage existed. Real time monitoring was limited to the four analog measurements. Near real time monitoring could be accomplished by addressing the mission data retrieval system via MOPS.

C. Test - Component level tests were performed by the Experiment Developer prior to delivery as GFE. Details of these tests are contained in the Corollary Experiment Final Technical Report, TMX-64809. MDA systems level testing is discussed in Section 7 of this report.

D. Mission Results - The instrument was scheduled to be turned on approximately five hours after the launch of SL-1 by ground command. The activity caused by the loss of the meteoroid shield delayed instrument activation until approximately twelve hours after launch. By this time, the temperature of the instrument had dropped to -23°F. The design condition low temperature was +14°F. Data output during this period indicated that the instrument was not calibrating itself.

Efforts were then undertaken to lower the OWS temperatures by taking the cluster out of the solar inertial orientation, basically pitching the X-axis toward the sun. This resulted in some radiant heat input to the instrument, and the temperature increased to approximately +40°F and stabilized there for the next eight days. The data during this period indicated some improvement in instrument performance.

The third period of the instruments thermal history occurred with the assumption of solar inertial attitude (returning the Proton Spectrometer to the shade) and the hard dock of the CSM. The temperatures were within ±5°F of -25°F for the detector head and -15°F for the electronics.

The result of this lower than predicted thermal environment is discussed in HOSC Action Request AR-444, and a Failure Analysis Report prepared by the experiment manager, George Detko, S&E-SSL-S.

Briefly, the internal gain of the instrument dropped so low that it could not calibrate itself, rendering only two of the thirteen data channels useful. All of the proton channels and two of the three electron channels were lost. The remaining data consisted of one channel of low energy electrons and one channel indicating the total flux of the field through which the instrument was passing.

The lower internal temperature resulted due to a design error concerning the value used for the emissivity of the inner face of the thermal shroud. An emissivity 0.05 was used rather than the actual value of 0.88. Thus the instrument did not retain as much of its internally generated heat (both from the electronics and two small heaters) as was predicted. The low temperature was predicted to have caused a mechanical failure within the detector head. Specifically, the scintillation detectors (protons or electrons striking them create small flashes of light - scintillation) were light coupled to a photomultiplier tube by RTV 615. The coefficient of thermal expansion and contraction was believed to be responsible for a gap at the interface either between the detector and the RTV or the RTV and the photomultiplier tube. Either way the end result would be an effective loss of gain in the instrument. Thus, the instrument was incapable of determining the energy levels of the electrons or protons.

The failure could possibly have been reversed by raising the temperature of the detector head to bring the RTV into contact with the surface. It was proposed to install a thermal blanket to accomplish this, but due to the complexity of installing it on orbit and limited launch stowage, the effort was terminated.

The Proton Spectrometer continued to transmit the two useful channels of data throughout the Skylab missions.

E. Conclusions and Recommendations - It is likely that had the Proton Spectrometer been subjected to a thermal vacuum test, the error in the thermal shroud emissivity value would have been detected and corrected. Although one was planned, a failure of the qual unit prior to the thermal vacuum test necessitated qualification by analysis. Schedules for the development of space hardware should include adequate time to allow a failed unit in test to be analyzed and all scheduled testing completed.

2.2.10.5 Solar Radio Noise Burst Monitor (RNBM)

A. Design Requirements - The ATM Solar Radio Noise Burst Monitor receivers were mounted on an MDA panel above the ATM C&D panel (see Figure 2.2.10-13). The two identical units were mounted such that the two cables (one antenna, and one power and signal) could be connected to either unit, the flight or spare.

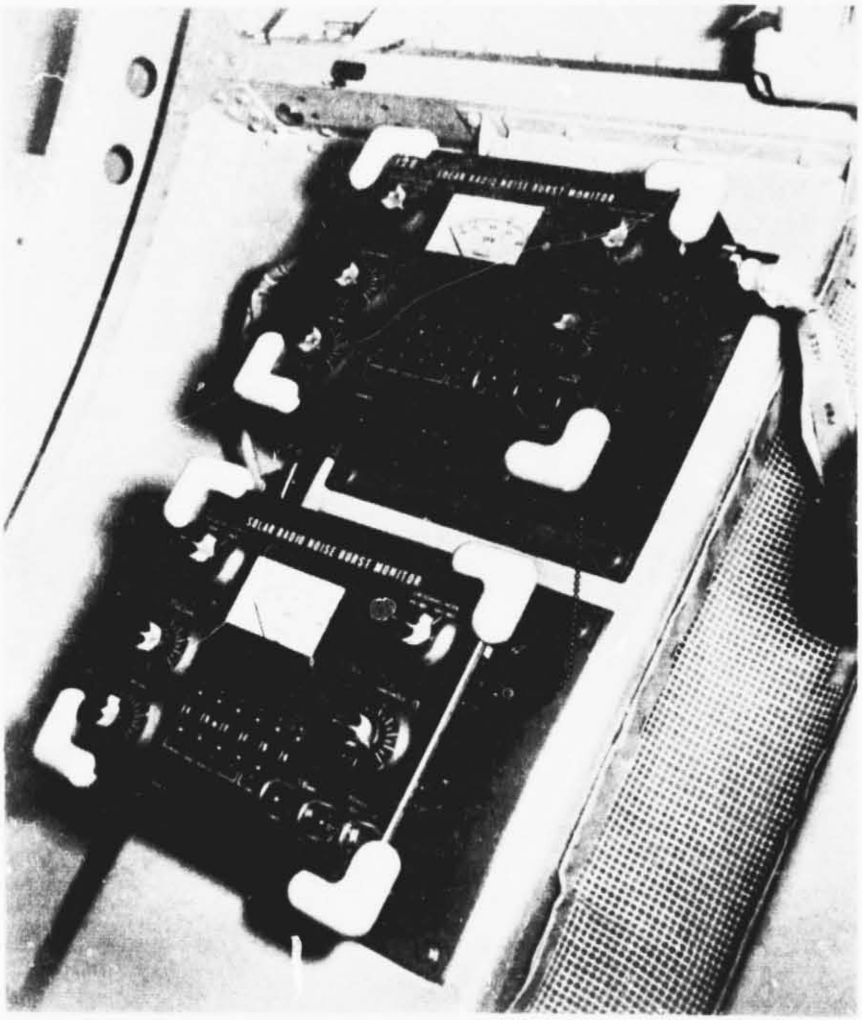


Figure 2.2.10-13 Solar Radio Noise Burst Monitor Installation

The MDA, in addition to physically supporting the receivers, provided approximately 1.4 amps of 28 VDC power, and a signal interface with the ATM C&D console for an analog output to a history plotter and a discrete to an alarm.

B. Functional Description - The ATM Solar Radio Noise Burst Monitor system received solar electromagnetic radiation in the 5 GHZ frequency range, and indicated the absolute intensity of this radiation relative to an internal noise source calibration.

The system consisted of a two-foot diameter parabolic antenna mounted on the AM truss, and a receiver mounted in the MDA, connected with low loss coax cable. The operation of the system was based upon the detection of an increase of approximately 5 solar flux units (SFU) to accompany most significant solar events.

The receiver accepted the signal from the antenna and displayed its intensity on a 0-5 volt meter on the face of the instrument. In addition, it presented an analog signal to a history plotter on the ATM C&D console and, when the intensity exceeded a threshold set by the astronaut (which corresponded to the ambient solar radio noise), it delivered a 28 volt DC signal to an alarm circuit.

The receiver had a built-in calibration noise source and a mode switch that allowed the selection of either the antenna or this cal source. A system gain adjustment and balance adjustment was provided to allow calibration relative to this noise source. It also contained an internal clock that allowed the period of the orbit and the "on time" to be set. Thus, the instrument could be adjusted to be activated only when the cluster was in the view of the sun.

C. Test - The component level tests were performed by the experiment developer prior to being delivered as GFE. For details refer to the Corollary Experiment Final Technical Report, TMX-64809. For systems level testing, see Section 7 of this report.

D. Mission Results - The RNBM was activated at approximately 16:40 on DOY 163. The activation occurred later in the mission than scheduled due to power conservation efforts in the early phases of the mission. Dr. Kerwin reported that "it calibrated very nicely."

As the mission progressed, it was reported that the paper had jammed in the history plotter and could not be repaired. It was also noted that the threshold setting was fairly critical to preclude false alarms at sunrise and sunset.

Since the calibrated signal to the history plotter was no longer required, the Principle Investigator, Dr. Owen Garriott, revised the sensitivity adjustment to maximum.

On SL-3 Dr. Garriott utilized this same calibration system. In the crew debriefing he reported that the RNBM was a useful tool as a backup to the X-ray sensors as an early indicator of solar flare activity.

E. Conclusions and Recommendations - Refer to the Corollary Experiments Final Technical Report, TMX-64809.

2.2.10.6 ATM Control and Display Subsystem

A. Design Requirements -

(1) The ATM Console supplied the necessary controls and displays for conducting the following experiments.

- High Altitude Observatory (HAO) White Light Coronagraph (WLC) Experiment
- American Science and Engineering (AS&E) X-Ray Spectroheliograph Experiment
- Naval Research Laboratory (NRL) Extreme Ultraviolet (XUV) Coronal Spectroheliograph and Spectrograph Experiments
- Harvard College Observatory (HCO) Ultraviolet (UV) Scanning Spectrometer Experiment
- Goddard Space Flight Center (GSFC) X-Ray Telescope
- Hydrogen-Alpha (H α) Filter Experiments

(2) Controls and displays were also provided for monitoring and/or operating the ATM Attitude and Pointing Control System (APCS), Power Supply System, Lighting System, Telemetry System, Computer System, Experiments Closed-Circuit Television (TV) System, Canister Thermal System, Event Timer and Alert Subsystem. A cooling system was provided to control the console thermal characteristics.

(3) The overall Console dimensions were in accordance with 40M37870.

(4) The console weight was limited to the value specified on 40M37870 (630 lb max.)

(5) Thermal cooling of electrical components was accomplished through the use of active (liquid) cooling. The coolant was circulated through cooling lines attached to structural members in those areas of the Console that were thermally critical.

(6) The console colors were in accordance with 40M37871.

(7) Inverter/Lighting Control Assembly (I/LCA) - The I/LCA provided regulated and unregulated electrical power, both alternating current and direct current, to the ATM C&D Console. The I/LCA used electrical power provided by ATM busses.

(8) Backup Inverter/Lighting Control Assembly (BI/LCA) - The BI/LCA provided fixed and variable AC backup power and fixed DC backup power to the ATM C&D Console in the event of failure of the primary power source, the I/LCA.

(9) Digital Address System (DAS) Backup Device - Expansion of console DAS requirements to provide functions addressable only by the DAS keyboard necessitated the addition of a backup capability.

The functions provided by the console DAS keyboard and the DAS Backup Device included the following:

(a) Backup capability for control of critical subsystem functions.

(b) Control of critical functions addressable only by the DAS to the ATM Digital Computer, e.g., command vehicle attitude change, command TACS pulse width, etc.

(c) Capability for power malfunction isolation of the ATM subsystems, e.g., AS&E main power ON, AS&E main power bus no. 1 OFF, AS&E main power bus no. 2 OFF. The AS&E main power ON-OFF switch did not provide the capability for removing a single power bus.

(d) Subsystem operational flexibility, e.g., the telemetry subsystem was provided with approximately 125 commands through the DAS.

(e) Commands to display APCS parametric information.

(10) EVA Rotation Control Panel (RCP) - The ATM EVA RCP enabled an astronaut to control the rotation of the canister to gain access to the camera doors for film loading and removal. Rotation of the RCP handle in the left or right direction caused canister rotation in the respective direction. The RCP consisted of a housing, control handle with appropriate mechanical assembly, and electrical equipment. The unit conformed to Drawing 40M37795.

The RCP also supplied switching for redundant panel input power, roll control activation, and S082 doors control. A separate visual position-status display for each of the two S082 doors was provided.

B. Functional Description - The Control and Display Subsystem, consisting of the C&D Console, the I/LCA, the BI/LCA, the DAS Backup Device, and the RCP provided the crew interface for the operation and management of the ATM experiments and subsystems. This interface was provided primarily by the C&D Console on which the controls and displays required to operate the ATM experiments and subsystems (see Figure 2.2.10-14) were located. Commands were provided to the ATM by toggle and rotary switches, the Manual Pointing Controller and the DAS. Monitoring

Figure 2.2.10-14 ATM C&D Console

was accomplished by the use of status lights and flags, alert lights, dual scale vertical meters, pulse counters, digital displays, an activity history plotter, and TV displays. Additionally, the C&D Console interfaced with the MDA RNBM, providing data recording and monitoring capabilities, and interfaced with the OWS Thruster Attitude Control Subsystem (TACS), providing status monitoring and thruster inhibit command capabilities. All critical command and display functions were implemented through redundant wiring and switching contacts, alternate displays, or were available through the DAS.

A summary description of the major C&D subsystem components is provided in the following paragraphs:

(1) ATM Control and Display Console - The C&D Console contained all components required for commanding and monitoring the following ATM experiments and subsystems.

(a) Experiments

- Hydrogen-Alpha (H α) 1 and 2 Telescopes
- X-Ray Telescope (S056)
- XUV Spectroheliograph (S082A)
- White Light Coronagraph (S052)
- UV Scanning Polychromator Spectroheliometer (S055A)
- X-Ray Spectrographic Telescope (S054)

(b) Subsystems

- Attitude and Pointing Control System (APCS)
- Telemetry (TLM)
- Power System
- TV System
- Canister Thermal
- Ground/DAS
- Alert

C&D components were arranged on nine panel assemblies, each removable for servicing during ground checkout operations. The experiment controls and displays were centrally located in a row-column matrix configuration wherein rows contained experiment controls and displays and columns contained controls and displays having a common function. Subsystem controls and displays were functionally grouped around the periphery area.

Time sequenced controls ran from left to right within each experiment and subsystem grouping.

A History Event Recorder, located in the lower left-hand corner of the console, provided an onboard record of solar activity. The device provided for simultaneous recording of two channels of analog data. One channel recorded the X-Ray Telescope (S056) X-Ray Event Analyzer (X-REA) outputs; the other channel recorded RF activity as provided by the Solar Radio Noise Burst Monitor.

The controls and displays for the Attitude Control System provided for activation and mode selection of the Experiment Pointing Control System, Star Tracker, and momentum dump. They also provided override controls for the CMG subsystem and the ATMDC, TACS inhibit commands and thruster status, and Fine Sun Sensor experiment bias enter controls.

The Manual Pointing Controller (MPC) allowed manual control of the Experiment Pointing System and the Star Tracker. The MPC could be replaced in orbit with a spare provided onboard. (MDA Misc. Stowage Container, M157)

The controls and displays for the telemetry system provided for activation of the system and mode control. Mode control allowed the activation of the ATM tape recorders in the record or playback mode, the selection of tape recorder or real time inputs to the ATM transmitters, and the selection of forward or aft antennas for each transmitter.

The power system displays provided status monitors for the individual ATM CBRMs, status flags which cued the operator to off-nominal conditions, and dual scale vertical meters to monitor parameters of the ATM main busses and individual CBRMs.

The TV controls provided for the activation of the ATM TV system and for the operation of the individual experiment TV cameras. Two TV monitors were provided, each of which displayed any of five TV signals from ATM experiments; Hα -1, Hα -2, XUV MON, WLC and XUV Slit.

The canister thermal controls allowed selection of PRIMARY/OFF/SECONDARY pumps and controllers and heater power AUTO/OFF. A dual scale vertical meter was provided for display of system parameters.

The Digital Address System (DAS) keyboard provided the command and data entry capability for functions which were not allocated a dedicated control and provided the backup command capability for control of critical subsystem functions.

The alert advisory indicators warned the astronauts of a low level malfunction of an ATM experiment or subsystem. The system was independent of the Cluster Caution and Warning System and the functions monitored did not require immediate crew attention.

The location within the console of major C&D components required direct structure mounting. A distributor assembly, located at the bottom of the console accommodated interpanel and subassembly wiring. All panel connections were routed directly to the distributor or interface connectors by means of an interconnecting harness, thereby eliminating inter-panel connector interfaces. Power distribution, signal conditioning and relay switching required by the panels was provided by the distributor.

Power was provided to the console by redundant main ATM load busses. Circuit breakers, located on the console power distribution panel, provided current overload protection. The use of power distribution switches and/or circuit breakers provided a flexible power distribution scheme, therefore, console single point failures were capable of being isolated to insure against the loss of parts of more than one experiment or the loss of an entire experiment or subsystem.

Electroluminescent Lighting (EL) was utilized for panel nomenclature, integrally illuminated displays, and for numeric readouts. The numeric displays utilized green EL lamps which contrasted with the immediate background when energized.

The lamps were designed for an operating life expectancy of 2000 hours, with end of light brightness defined as 0.2 foot-lamberts for integral and 1.8 foot-lamberts for numeric lighting.

Vibration isolation of the entire console was used to protect components from the severe dynamic environments of the MDA. A four-point, vibration-isolation, mounting scheme was used with the console CG in the plane of the isolators and equidistant to the isolators in that plane.

Thermal control was provided by a liquid coolant loop which used an open cycle cold rail, fluid supplied externally by the AM coolant system. The console structure (frame) served as an intermediate heat sink, transferring component heat loads to the coolant loop for removal from the console.

Inverter/Lighting Control Assembly - The I/LCA provided regulated and unregulated electrical power, both alternating current and direct current, to the ATM C&D Console. These various types of power were required for the operation of the console display components and the electroluminescent lighting of the console nomenclature and display components.

- Operational power was provided to the unit by ATM power busses with input and output circuit breakers located on the ATM C&D Panel.
- A Pulse Width Modulator was used to satisfy the requirements of variable output and high efficiency for four AC outputs. Regulated DC outputs were generated from a ripple regulator type preregulator that provided the power to three separate regulator circuits.
- The I/LCA thermal control was accomplished by a combination of active heaters, selected case finish, and thermal isolators.
- The I/LCA was located externally on the forward conical section of the MDA and mounted on the L-band antenna truss.

(3) Backup Inverter/Lighting Control Assembly - The BI/LCA consisted of two DC to AC inverters, two auto-transformers, two 5 volt DC to DC converters, and a connector patch panel used in transferring the C&D Panel from I/LCA to BI/LCA. The BI/LCA system, in the primary mode of operation, provided a fixed and variable AC power by using one inverter and the two auto-transformers. In the secondary mode the BI/LCA provided only fixed AC power from the other (secondary) inverter. A fixed 5 VDC was supplied to the C&D Panel in both the primary and secondary modes by employing one of the two DC to DC converters. The BI/LCA components were installed in the MDA as illustrated in Figure 2.2.10-15.

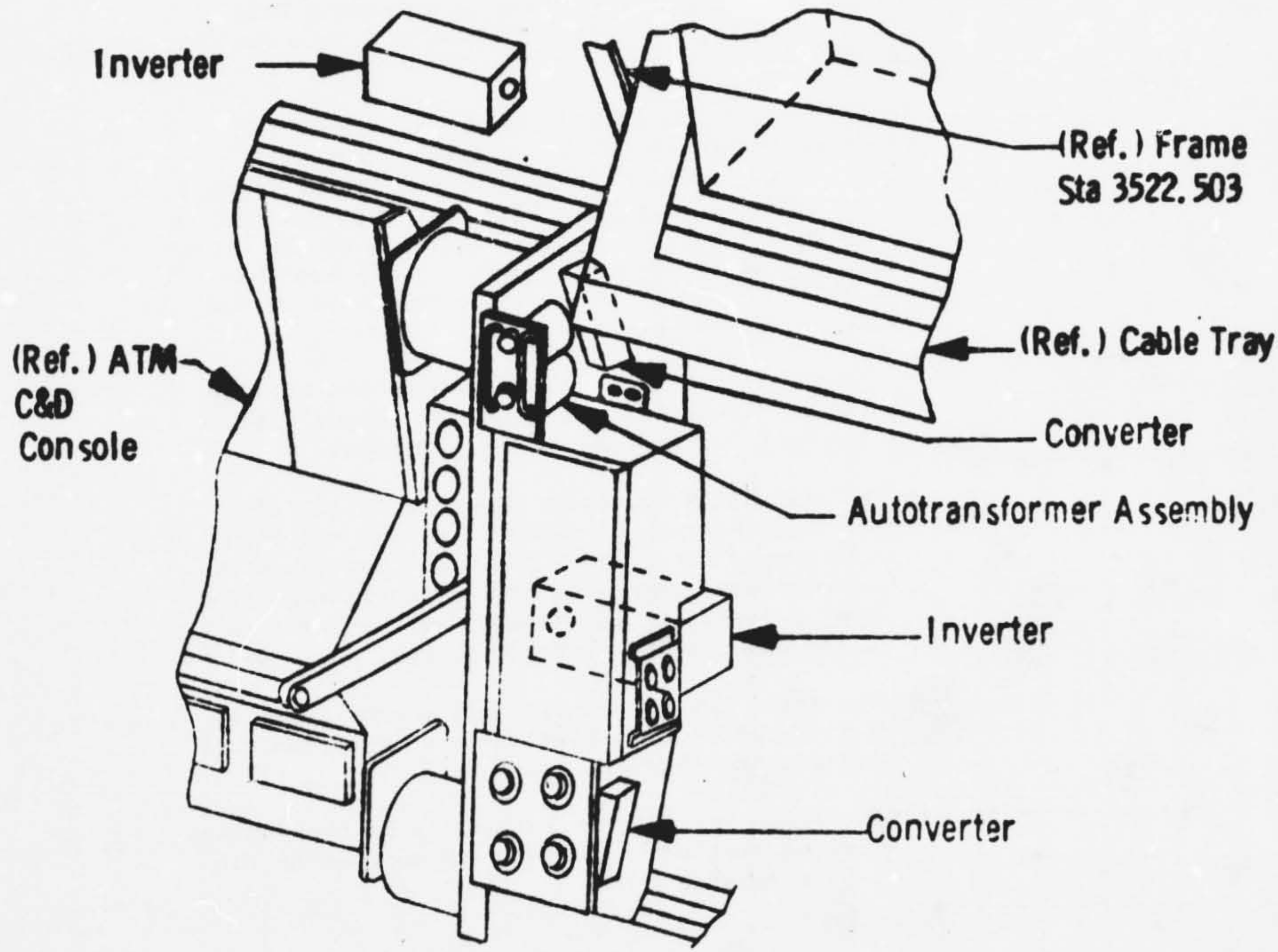


Figure 2.2.10-15 BI/LCA Installation

(4) DAS Backup Device - The DAS Backup Device was installed in the MDA, adjacent to the right of the console, to provide command redundancy. This was a manual switching unit which utilized five rotary switches to format each command. Unlike the Console DAS, feedback from ATM was not available to verify command transmission. The positions of the rotary switches were the only indications to the crew of the command transmitted.

(5) EVA Rotation Control Panel - The EVA Rotation Control Panel was located at the ATM Center Workstation. It was used to rotate or roll the ATM experiment canister to any desired position within a range of $\pm$ 120 degrees from a mechanical zero roll reference position. During EVA 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 and ATM experiment film camera assemblies could be replaced.

Full rotation control capability existed at the Control and Display Console and provided a backup to the RCP. Thus, should the RCP control handle become completely disabled, ATM film retrieval could be accomplished by controlling canister rotation from the console under the direction of the EVA astronaut.

C. Test - Component level tests were performed by the console developer prior to being delivered to the MDA as GFE. Refer to the ATM Final Technical Report, TMX-64811, for systems level testing results.

D. Mission results and recommendations are included in the ATM Final Technical Report, TMX-64811.

This Page Intentionally Left Blank

2.2.11 Ground Support Equipment (GSE)

The GSE described in this section is limited to those equipments provided by the Martin Marietta Corporation as Contractor Furnished Equipment (CFE) under the MDA contract. A more detailed description of each specific CFE end item accompanied by a brief description of MDA related GFP GSE can be found in the MDA GSE Description Document, ED-2002-2002.

2.2.11.1 Structural

The Ground Support Equipment (GSE) described herein was provided by the Martin Marietta Corporation under the MDA contract. Structural GSE for the MDA flight article evolved from just five items in the original MDA proposal to a total of 83. The initial items were: one handling fixture and sling; one transportation fixture; two access platforms; and one package handling kit. A hoist and track, two docking port protective covers, and an STS sealing plate were supplied as GFP with the MDA.

As program requirements were defined, it became necessary to modify the GFP items. The hoist and track, being supported inside the conical end of the MDA, was relocated to clear dome installations and its capacity was upgraded to lift heavier objects. The docking port covers were provided with adapters for use with the desiccant breathers and the internal heaters which were used during transportation of the MDA. The STS sealing plate, initially intended as a closure during pressurization and leak testing of the MDA, was modified to accept a support adapter during transportation, rotation, and trunnioning of the MDA.

Additional program directives identified structural GSE for installation and removal of EREP, VTR, I/LCA, and M512, protection of sensitive areas and equipment, contingency activities, and MDA test peculiar requirements.

In addition to providing for handling and transportation of the MDA and access inside the MDA, structural GSE was frequently used to perform special functions, and was designed specifically for unique activities and tasks. Some notable ones were:

- Support equipment used during horizontal rotation of the MDA and during weight and center-of-gravity determination of the MDA.

- Hoisting and handling equipment (with the MDA in the horizontal attitude) used for contingency installation of EREP, Video Tape Recorder, I/LCA, the M512, and the L-Band truss and antenna.

- Crew support equipment inside the MDA during the altitude chamber test.

- Crew support, access, and ingress equipment used inside the MDA during the inverted docking test.

A. Horizontal and Vertical Handling

(1) Design Requirements - The handling fixture was designed as a very rigid frame for lifting and transportation. A lifting load factor of 2.0 was used for design, with material safety factors of 3.0 on yield and 4.0 on ultimate stress. In order to prevent transmission of bending moments or externally induced forces into the MDA structure, spherical sockets were incorporated into the support legs of the fixture to mate with special lifting fittings on the MDA.

The assembly was also designed as the MDA forward support during transportation and rotation of the MDA, and during inverting of the AM/MDA. See Figure 2.2.11-1. Since the most critical loading conditions occurred during transportation of the MDA, the handling fixture design was also based on the load factors defined in the General Specification for Air Transportation, MIL-A-8421B and Aero Space Lines Cargo Loading Schedules ASL-30 and ASL-46.

The design requirement for the strongback beam used with the handling fixture was to support the outfitted MDA during hoisting and provide a co-planar MDA interface when mating to the AM. Due to limited headroom at the MDAC-E facility, the beam was designed for use without slings or spreaders. See Figure 2.2.11-2.

The lifting fixture was also required to support the mated AM/MDA during trunnioning and hoisting and to provide a true co-planar interface when stacking the AM/MDA onto the FAS. See Figure 2.2.11-3.

(2) Description - Hoisting and handling of the MDA was assisted with the use of the Handling Fixture and Sling Assembly. The assembly consisted of three major components; i.e., a handling fixture that was secured to special fittings on the conical end of the MDA; a strongback beam for mating the MDA to the AM; and a lifting fixture for stacking the mated AM/MDA to the FAS.

The function of the handling fixture was to distribute the hoisting, handling, and transportation loads through four fittings on the MDA and provide the forward support for the MDA during transportation or horizontal rotation, and when trunnioning the MDA or the mated AM/MDA to the vertical or horizontal attitudes, and during inverting of the AM/MDA.

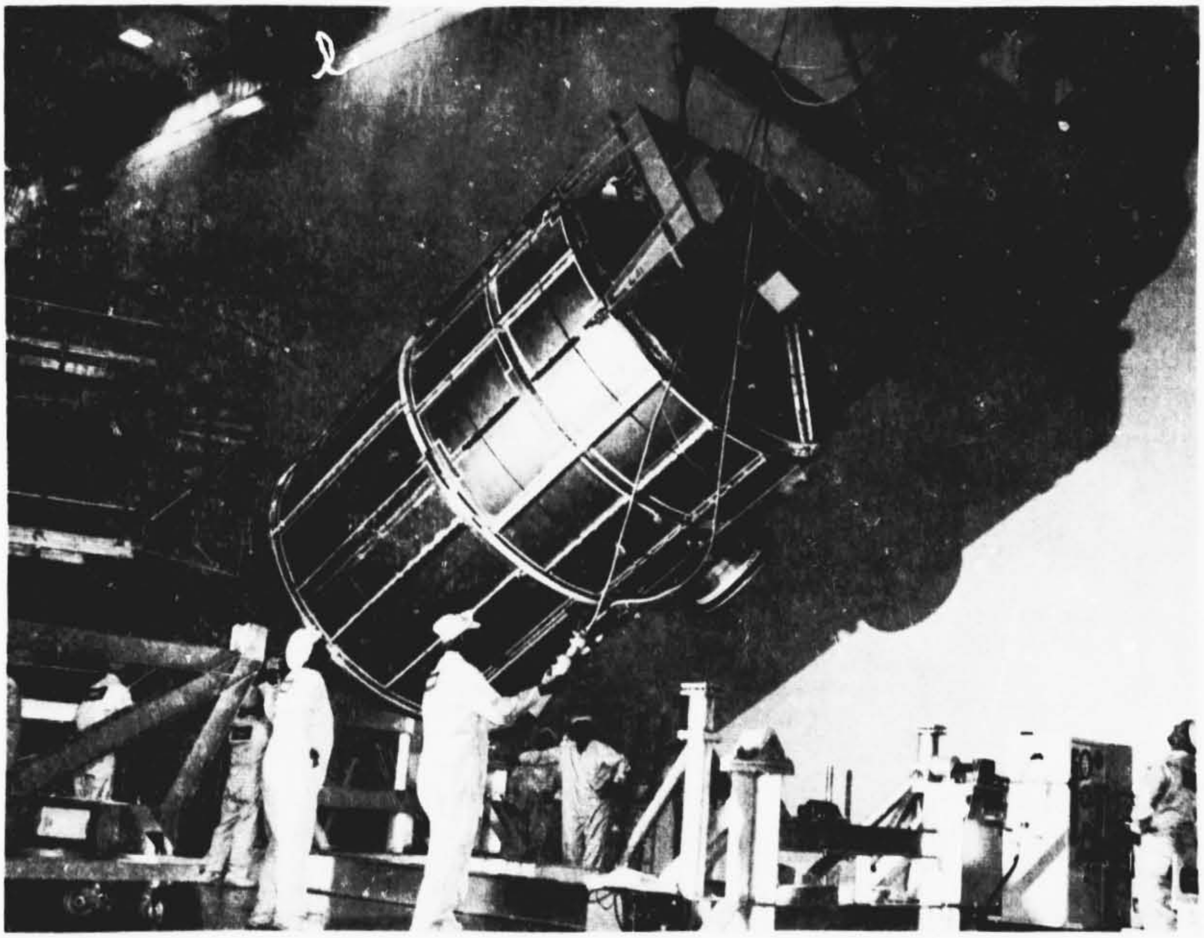


Figure 2.2.11-1 MDA Trunnioned Onto Rotation Fixture

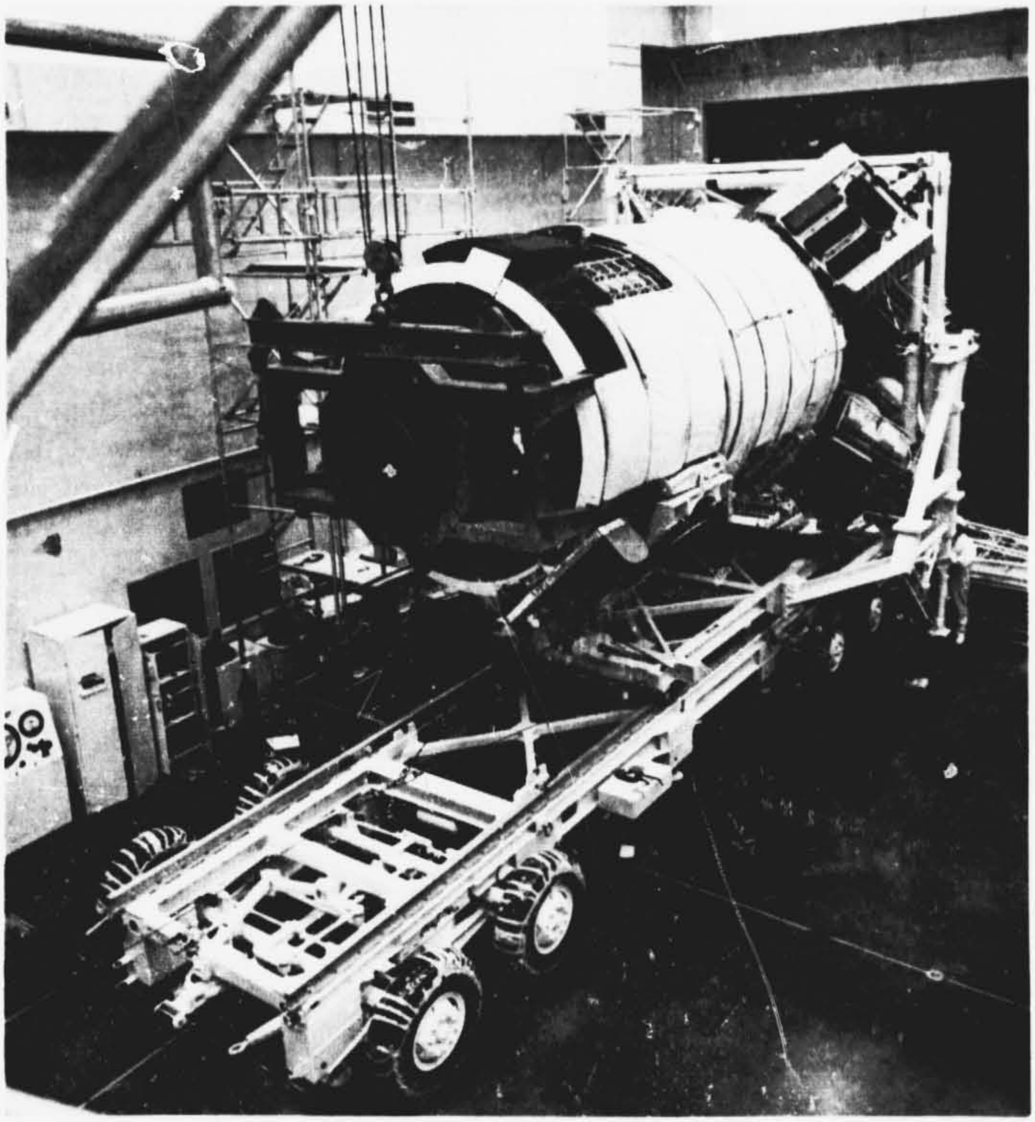


Figure 2.2.11-2 MDA Trunnioned to Horizontal Attitude after Mating to AM

The function of the strongback beam or the lifting fixture was to supply the connecting link between the handling fixture and the hoisting facility during hoisting of the MDA or the AM/MDA.

(3) Design/Test Verification - During the manufacture, and upon completion of the assembly, the units were examined to verify conformance of the product to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

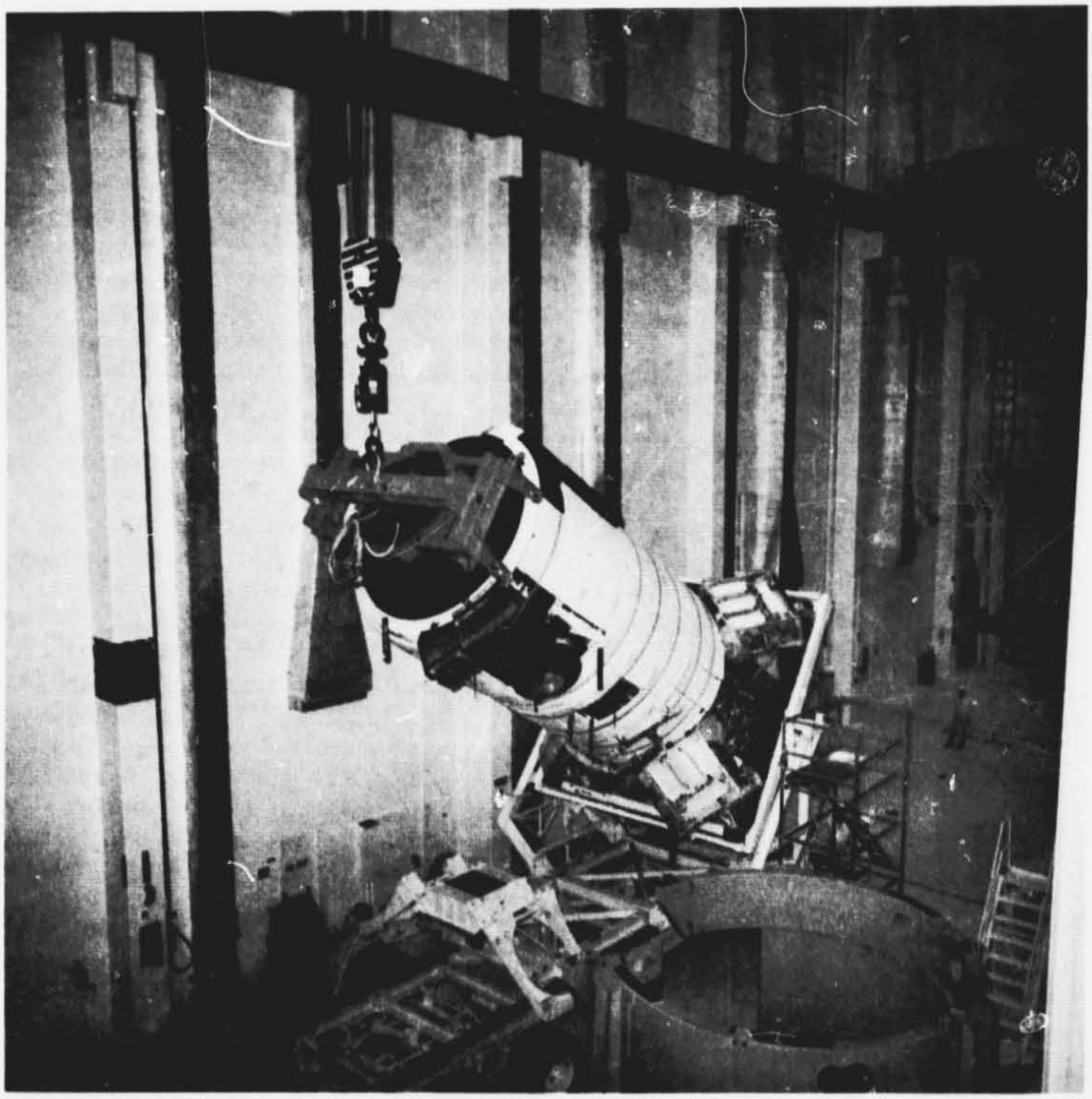


Figure 2.2.11-3 AM/MDA Trunnioned to Vertical Attitude for Stacking to FAS

Proof load testing of the assembly was conducted by statically loading the assembly to 200 percent of its design loads, with no evidence of failure or deformation.

Fit checking of the fixture to the MDA was not possible prior to delivery and first use of the product.

(4) Program Usage - First usage of the Handling Fixture and Sling Assembly was made at MSFC. The units were Delivered to MSFC for fit checking, match drilling of

the fixture, and mating to the MDA. The fixture was used for initial handling and loading of the MDA in preparation for shipment to the Martin Marietta facilities at Denver. The assembly was used repeatedly during handling, as the forward support during transportation, and during mating of the MDA to the AM. The versatility of the handling fixture was demonstrated in its varied uses. In Denver, the fixture was adapted to the rotation fixture, as shown in Figure 2.2.11-1. At St. Louis and KSC, the fixture was used in conjunction with associate contractor GSE for trunnioning the AM/MDA during inverted docking and stacking of the AM/MDA. Since a prior fit check had not been possible, high confidence was placed on previously verified interface examinations. Also used successfully on a first-time basis for providing co-planar interfaces were the strongback beam for mating the MDA to the AM, and the lifting fixture for stacking the AM/MDA to the FAS.

(5) Conclusions -The Handling Fixture and Sling Assembly encountered no significant problems in the design, build, or use. The assembly met and satisfied the design, functional, and interface requirements imposed by the Skylab program. The GSE performed as planned in all its uses and proved to be a highly reliable and safe set of handling equipment.

B. Transportation

(1) Design Requirements - The Horizontal Transportation Fixture was designed as a rigid support cradle for the MDA during air and ground transportation. The fixture was designed to prevent external forces from being induced into the MDA. The design loading criteria were contained in the General Specification for Air Transportation, MIL-A-8421B and Aero Space Lines Cargo Loading Schedules ASL-30 and ASL-46. Material factors of 2.0 on yield stress and 3.0 on ultimate stress were used.

The assembly was designed to distribute the transportation loads to an aircraft pallet or to a flat bed trailer.

(2) Description - Transportation of the MDA was accomplished on the Horizontal Transportation Fixture. See Figure 2.2.11-4. The assembly consisted of an aft trunnion and support, a forward support, and a main frame. The assembly was used in conjunction with the MDA handling fixture attached to the forward support.

The function of the Horizontal Transportation Fixture was to provide support for the MDA during air or ground transportation and to permit the MDA to be trunnioned from the horizontal to the vertical or the vertical to the horizontal attitudes.

The fixture provided support for the desiccant breather assembly during transportation. (See Section 2.2.11.2).

(3) Design/Test Verification - During the manufacture, and upon completion of the assembly, the fixture was examined to verify conformance of the product to the engineering drawings with respect to materials, dimensions, construction, and identification.

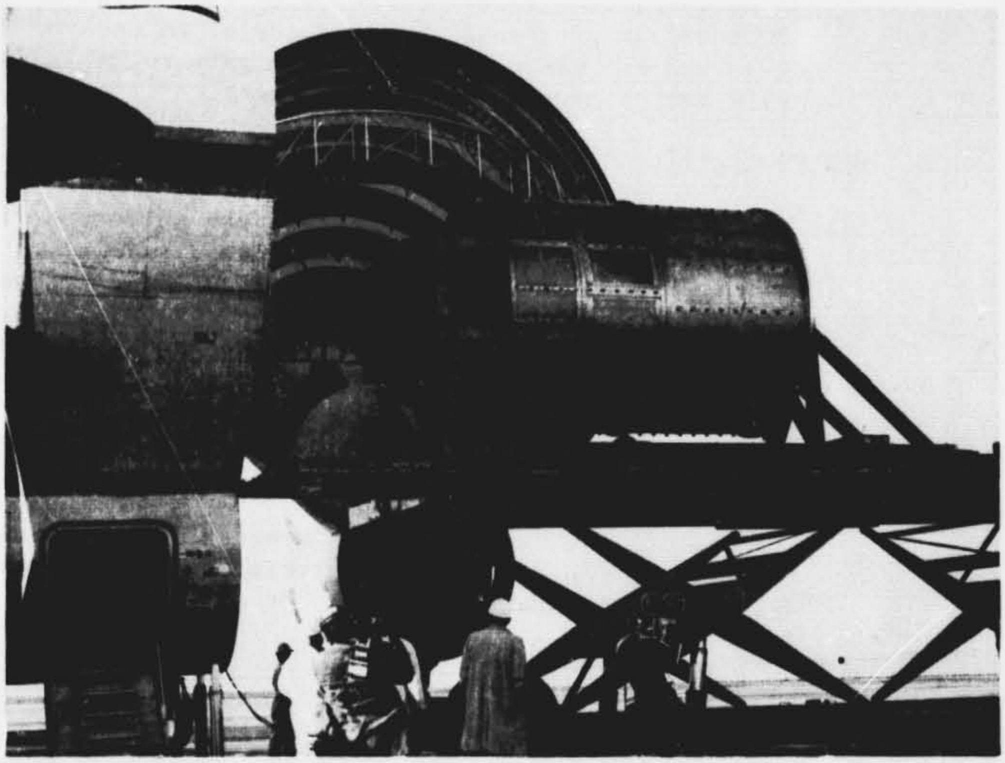


Figure 2.2.11-4 MDA in Transportation Fixture Offloaded from Guppy

Proof load testing of the fixture was conducted by statistically loading the assembly to 150 percent of its design loads, with no evidence of failure or deformation.

The fixture was fit checked and match drilled to the aircraft pallet, but fit checking to the MDA and handling fixture was not possible prior to delivery and first use of the product.

(4) Program Usage - First use of the Horizontal Transportation Fixture was made at MSFC. The assembly was delivered to MSFC for fit checking, longitudinal alignments, and mating to the MDA. The assembly was used repeatedly during movements of the MDA for MSFC to Denver, and between the manufacturing, test, thermal, and high bay facilities. Also, the fixture was used during MDA weight and C.G. determination. See Figure 2.2.11-5.

(5) Conclusions - The Horizontal Transportation Fixture encountered no significant problems in the design, build, or use. The assembly met and satisfied the design and functional requirements imposed by the Skylab program. Performance of the GSE was successful in each of its uses and the GSE proved to be a highly reliable and safe set of transportation equipment.

C. MDA Protection

(1) Design Requirements - In general, the philosophy for the design of protective devices was based on its location inside the MDA. If a cover could be stepped on, it was designed for a stepping load of 300 pounds. Otherwise, the cover was designed for a pushing load of 150 pounds from any direction. Since the MDA could be oriented to the horizontal, vertical upright, or inverted attitudes, the design of the protective covers was required to satisfy loading from any direction.

It was not made a design requirement to impose impact factors to the covers, but material factors of safety of 2.0 on yield stress and 3.0 on ultimate stress were used.

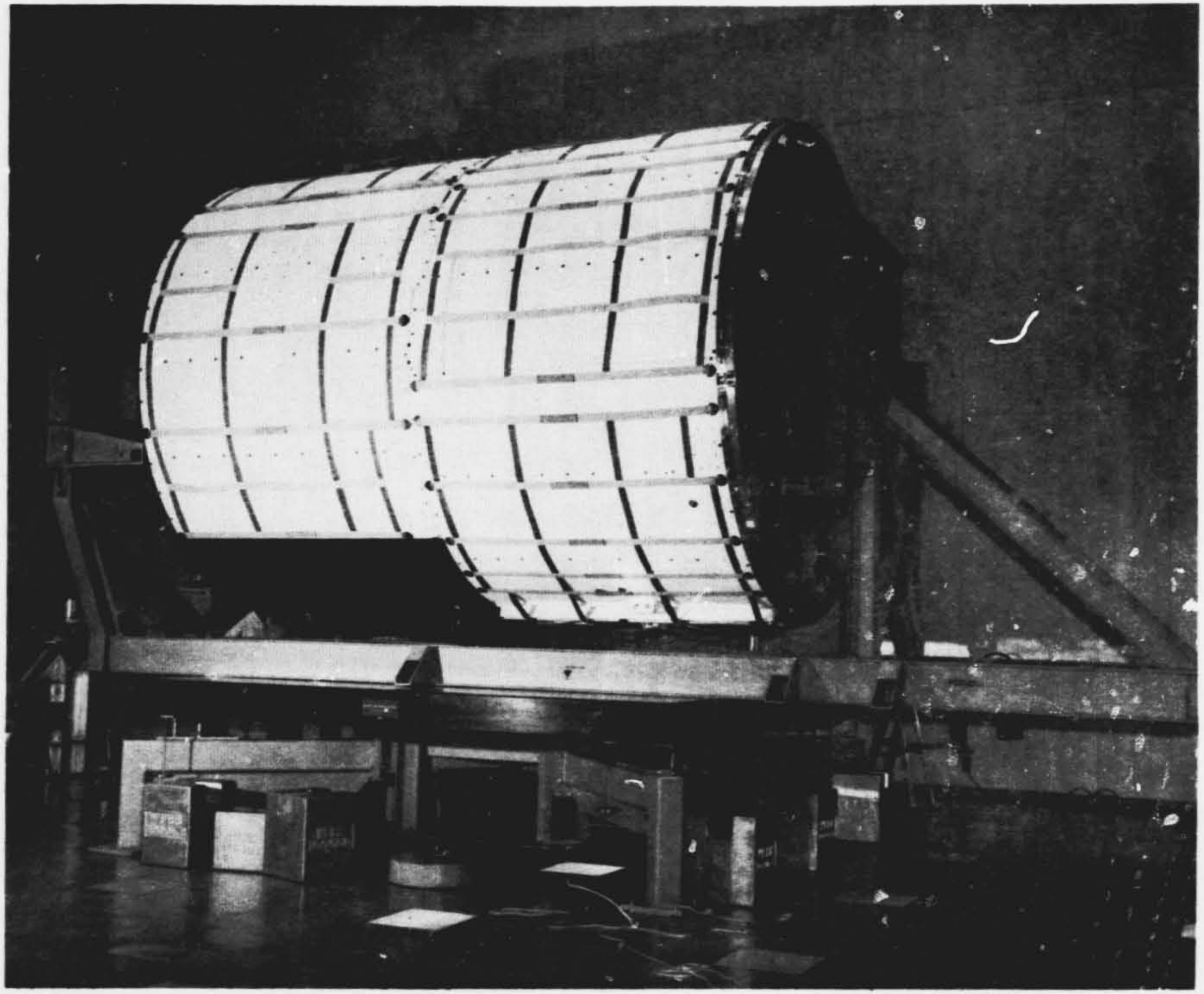


Figure 2.2.11-5 MDA on Weight and C. G. Table

(2) Description - Protection for sensitive areas and equipment in the MDA was provided by GSE. Covers were installed over the S190 window, the hatches and hatch seals, and the docking ports. A sealing plate protected the AM/MDA interface surface. During equipment installations, checkouts, and other activities in the MDA, protective covers were provided for the EREP components, I/LCA,the M512, fire detectors, RNBs , valves, and gages. Also, a safety net and a debris catcher were installed to prevent damage to equipment or injury to personnel from dropped objects.

(3) Design/Test Verification - During the manufacture and upon completion of the assemblies, they were carefully examined to verify conformance of the products to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

In general, proof loading of the covers was not required. An exception was the docking port protective sleeves. These flanged covers lined the full length of the tunnels while providing protection to the docking surfaces and the hatch seal. Used extensively during equipment ingress to the MDA, they also became the sole means of access for personnel into the MDA after the MDA was mated to the AM. See Figure 2.2.11-6.

(4) Program Usage - Extensive use was made of the protective equipment. Once the covers were installed they remained in place at all times that personnel were working on the MDA. During those times when access to controls or displays was required, covers were removed to facilitate those activities. While handling or transporting the MDA, protective covers were always in place over the S190 window and the docking ports. During air transportation, special environmental protection was provided.

(5) Conclusions - The protective devices encountered no significant problems in the design, build, or use. They met and satisfied the design, functional and interface requirements imposed by the Skylab program. Performance of the GSE was successful, and as planned.

Figure 2.2.11-6 Equipment for Protection and Access
at the Radial Docking Port

D. MDA Experiment Installation

(1) Design Requirements - The criteria used to determine which experiment packages would be provided with handling and installation equipment was based on NASA human engineering requirements contained in MSFC-STD-267. In general, if the package to be installed weighed more than 35 pounds or required a reach of more than two feet, GSE was provided.

Handling loads were as defined in appropriate ICD's. The GSE was designed for a load factor of 1.5 and a material safety factor of 2.0 on yield stress and 3.0 on ultimate stress. In order to maintain the MDA cleanliness environment, the GSE was required to be cleaned to Class 100,000 compatibility. All parts such as pins, bolts, and small assemblies were tethered or made captive to the main assembly to prevent dropped objects inside the MDA.

(2) Description - The function of the MDA experiment installation equipment was to provide a mechanical means for handling the experiment packages from the bench to the MDA, and the capability to make the final installation.

A special set of GSE was required to install and remove EREP experiments. The size, weight and awkward location of the equipment precluded manual handling and dictated basic design requirements. Since the MDA was to be positioned in two attitudes, GSE was designed to accommodate both the horizontal posture of the MDA at MDAC-E, St. Louis, and the vertical (upright) position at Martin-Denver, and at KSC.

GSE was also provided to permit loading experiments into the horizontal MDA, through the radial docking port. This equipment consisted of a rail and cart assembly to winch equipment into the MDA and a hoist and track inside the MDA to remove and position the experiments. See Figure 2.2.11-6. For access to the equipment locations, a platform assembly for the full length of the MDA was provided. See Figure 2.2.11-7. A system of handling slings and counterbalances was employed to permit installations on the sides of the MDA. For equipment mounted on the exterior of the MDA, an adjustable lifting fixture was provided.

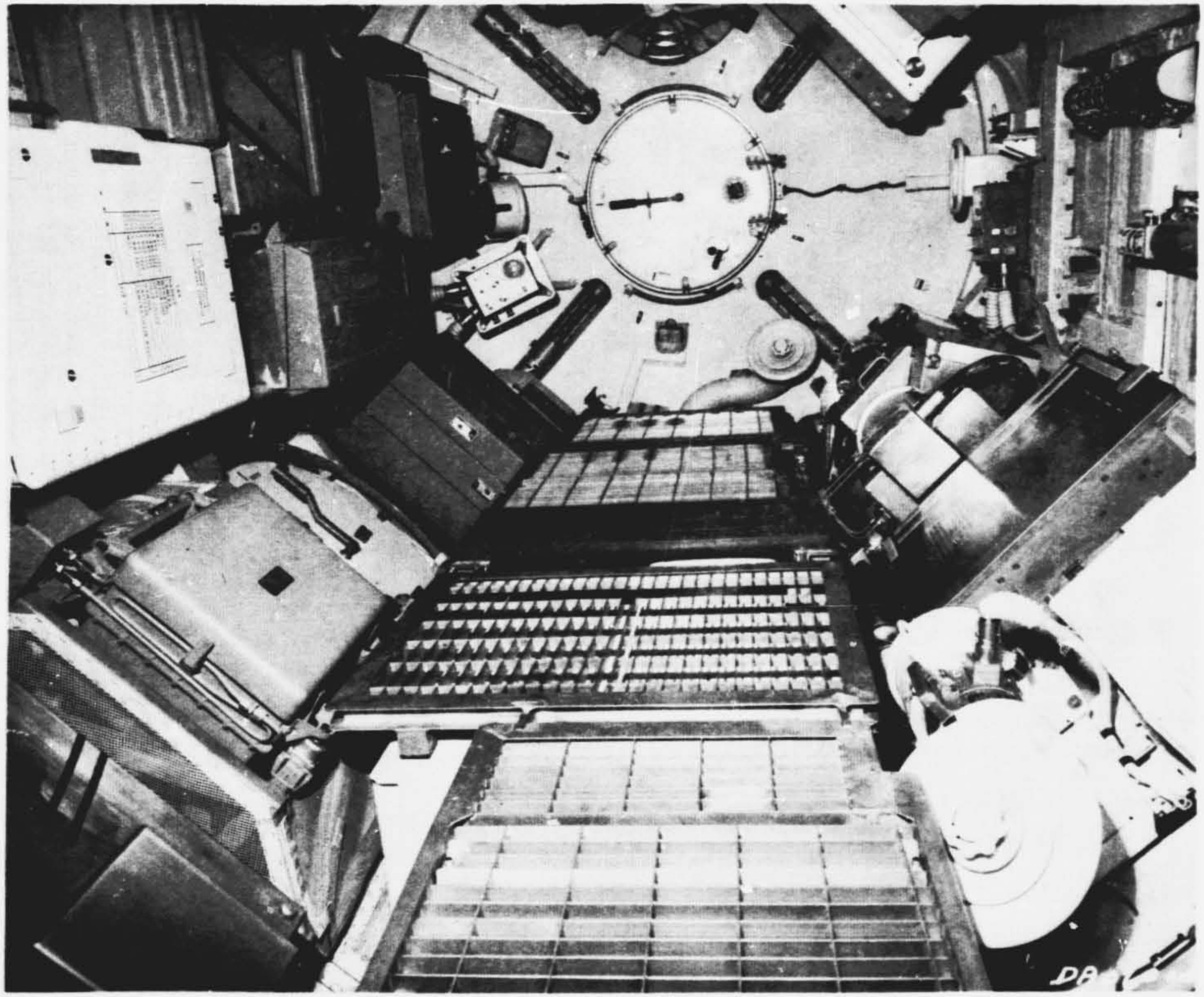


Figure 2.2.11-7 Horizontal Access Platform

For the MDA in the upright position, a hoist and track were secured to the underside of the dome. See Figure 2.2.11-8.

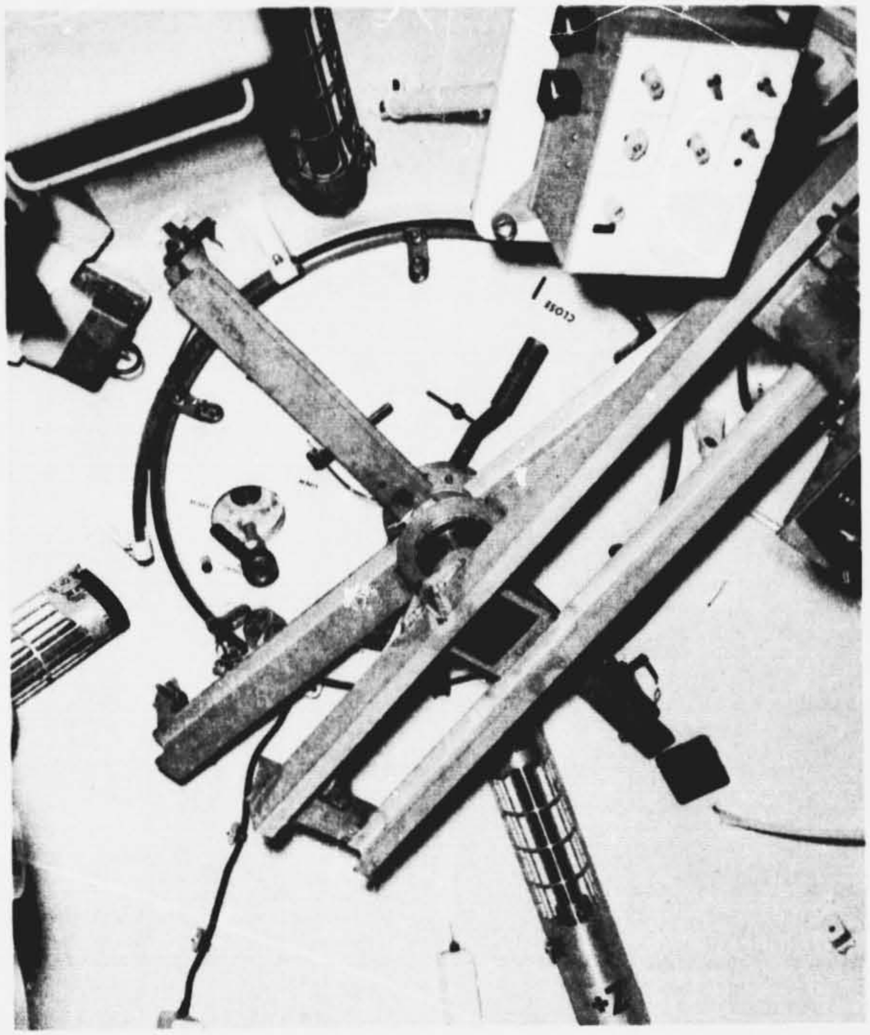


Figure 2.2.11-8 Hoist and Track Installation

Equipment was moved vertically through the AM tunnel and out the EVA hatch opening. These operations required a set of slings and counterbalances to be used with handling frames and fixtures. Access inside the MDA was provided from two platform levels. See Figure 2.2.11-9.

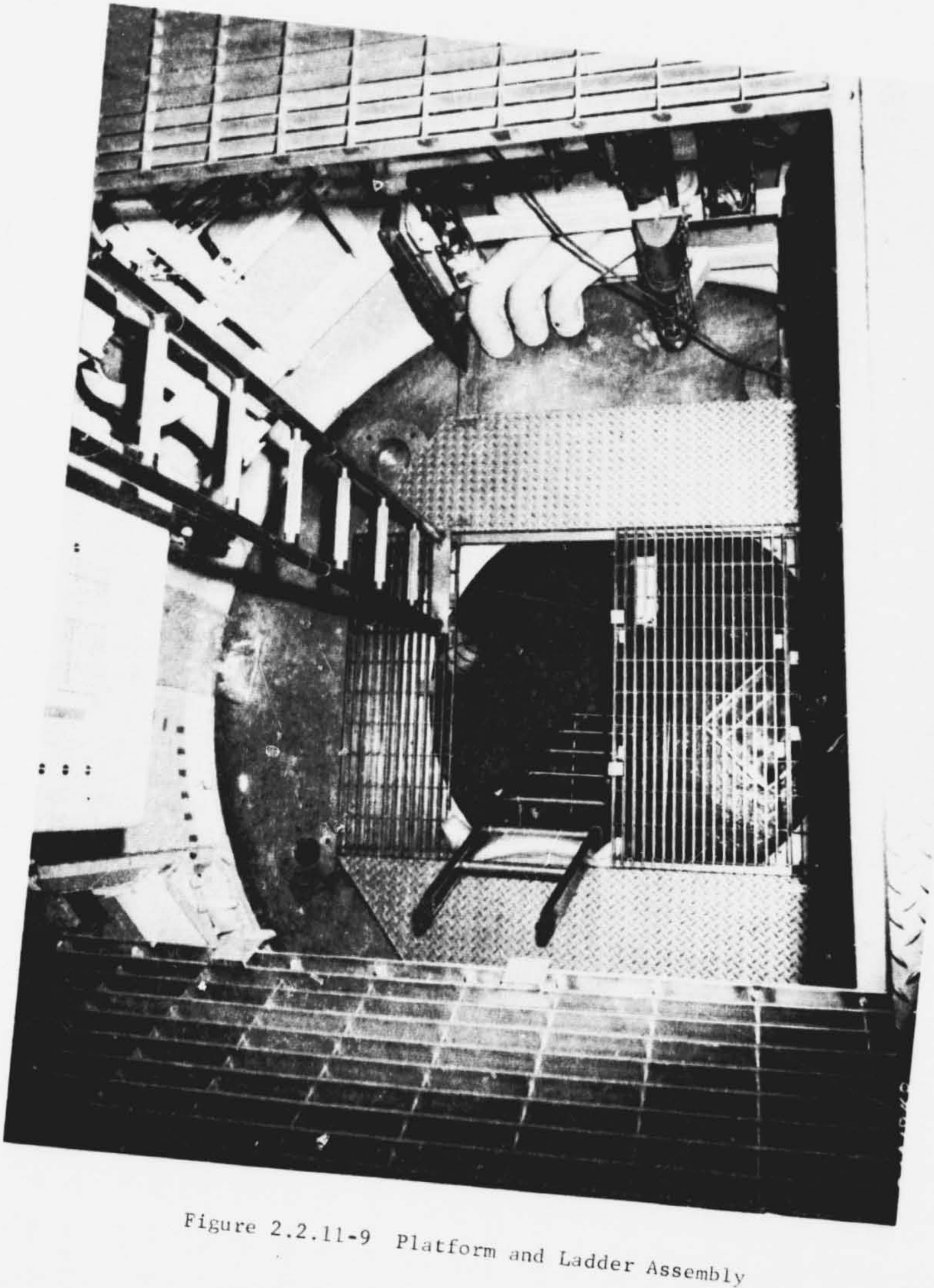


Figure 2.2.11-9 Platform and Ladder Assembly

Special universal handling frames and fixtures were designed and sling/counterbalance attachments were made to permit rotation of the experiment into any desired attitude.

(3) Design/Test Verification - During the manufacture, and upon completion of the assembly, the equipment was examined to verify conformance of the product to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Proof load testing of the assemblies was conducted by statically loading them to 150 percent of their design loads with no evidence of failure or deformation.

Fit checking of the equipment to the experiments and the MDA was usually made prior to delivery and first use of the items. A notable exception is described in the following section.

(4) Program Usage - First use of the installation equipment was normally made at Denver, as most of the experiments were available. Some experiments were installed, checked out, and then removed from an upright MDA in Denver, and were later reinstalled at St. Louis when the MDA was in the horizontal attitude. Thus, all items of GSE that were designated as contingency hardware for use at MDAC-E were utilized in planned activities.

Removal of the M512 prior to the MDA being mated to the AM posed a challenge at MDAC-E. Reinstallation was required to be made of the M512 intact into the horizontally positioned AM/MDA. As a consequence, a plan was devised to insert the M512 through the radial docking tunnel. This required a new set of GSE. Because a fit check could not be made of the GSE prior to usage, high confidence had to be placed in the design and build verifications, resulting in a successful first-time installation.

Also used successfully on a first-time basis without a prior fit check were the internal access platform and ladder assemblies during inverted docking tests.

(5) Conclusions - The hardware encountered no significant problems in its design, build, or use. It met and satisfied the design, functional and interface requirements imposed by the Skylab program. Performance of the GSE was as planned. The hardware proved to be highly reliable and safe equipment, and resulted in the successful installation of all the experiment packages.

E. One-G Trainer GSE

(1) Design Requirements - Since the One-G Trainer was to be capable of supporting flight crew procedures development and flight crew training exercises for those experiments performed in the MDA, the Trainer had to have the capability of being placed in either a horizontal position or in a vertical position. When in the horizontal position, the capability to rotate the Trainer about the longitudinal axis was required.

Ground handling for loading, erection and transportation of the Trainer by air or ground was required. Design loading conditions were the same as those used for flight hardware GSE.

(2) Description - To satisfy these criteria, the following set of GSE was identified:

- A handling and installation set - to provide the capability of lifting and positioning the MDA Trainer through the horizontal and vertical positions. See Figure 2.2.11-10.

- A vertical support stand - to support the Trainer in the vertical (launch) position, to permit personnel entry through the aft end of the MDA, and to provide access to the experiments inside the MDA. See Figure 2.2.11-11.

- A horizontal rotation fixture - to support the MDA Trainer when mechanically interfaced with the AM/STS Trainer in the horizontal position and provide manual roll capability of the Trainer about the X-axis.

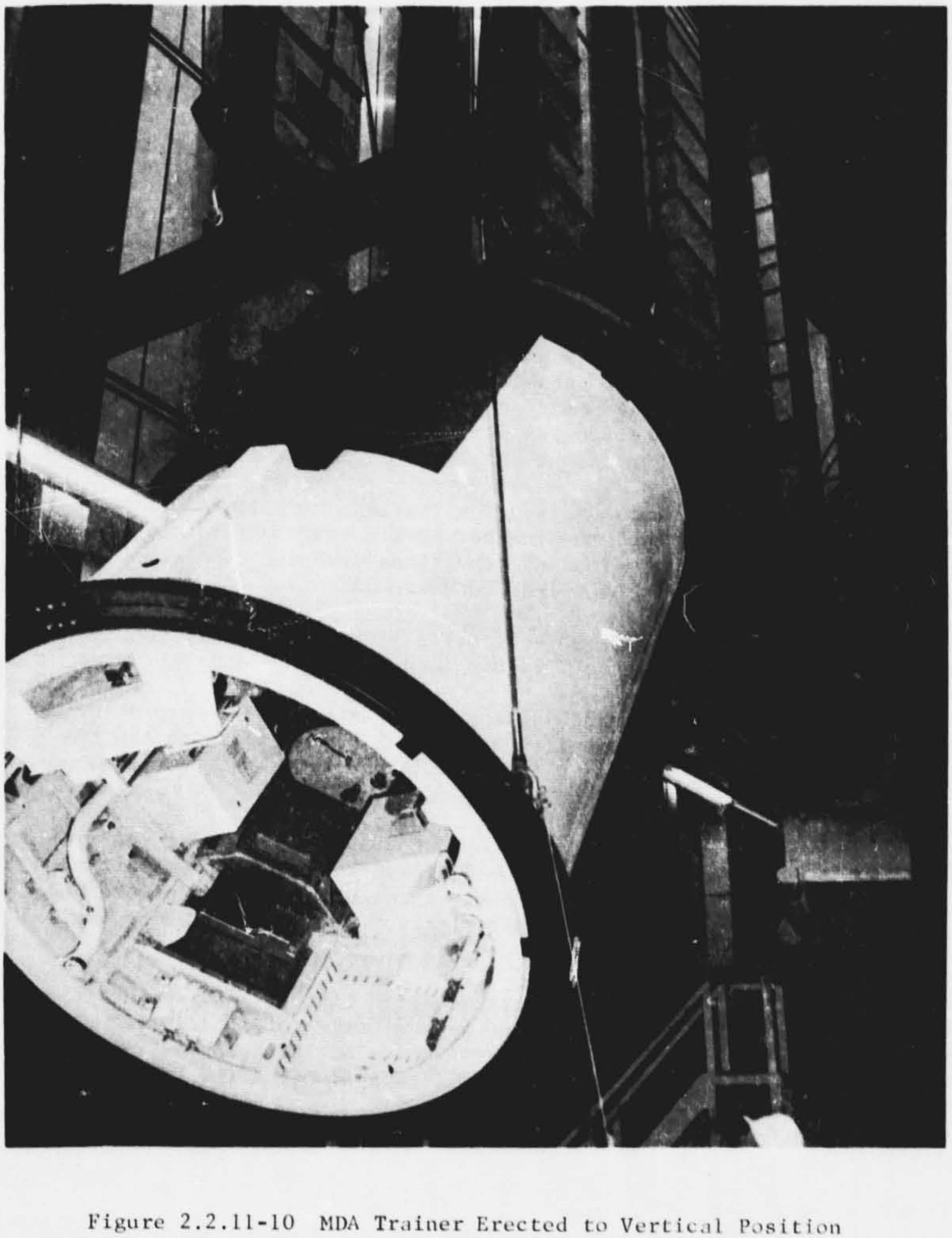


Figure 2.2.11-10 MDA Trainer Erected to Vertical Position

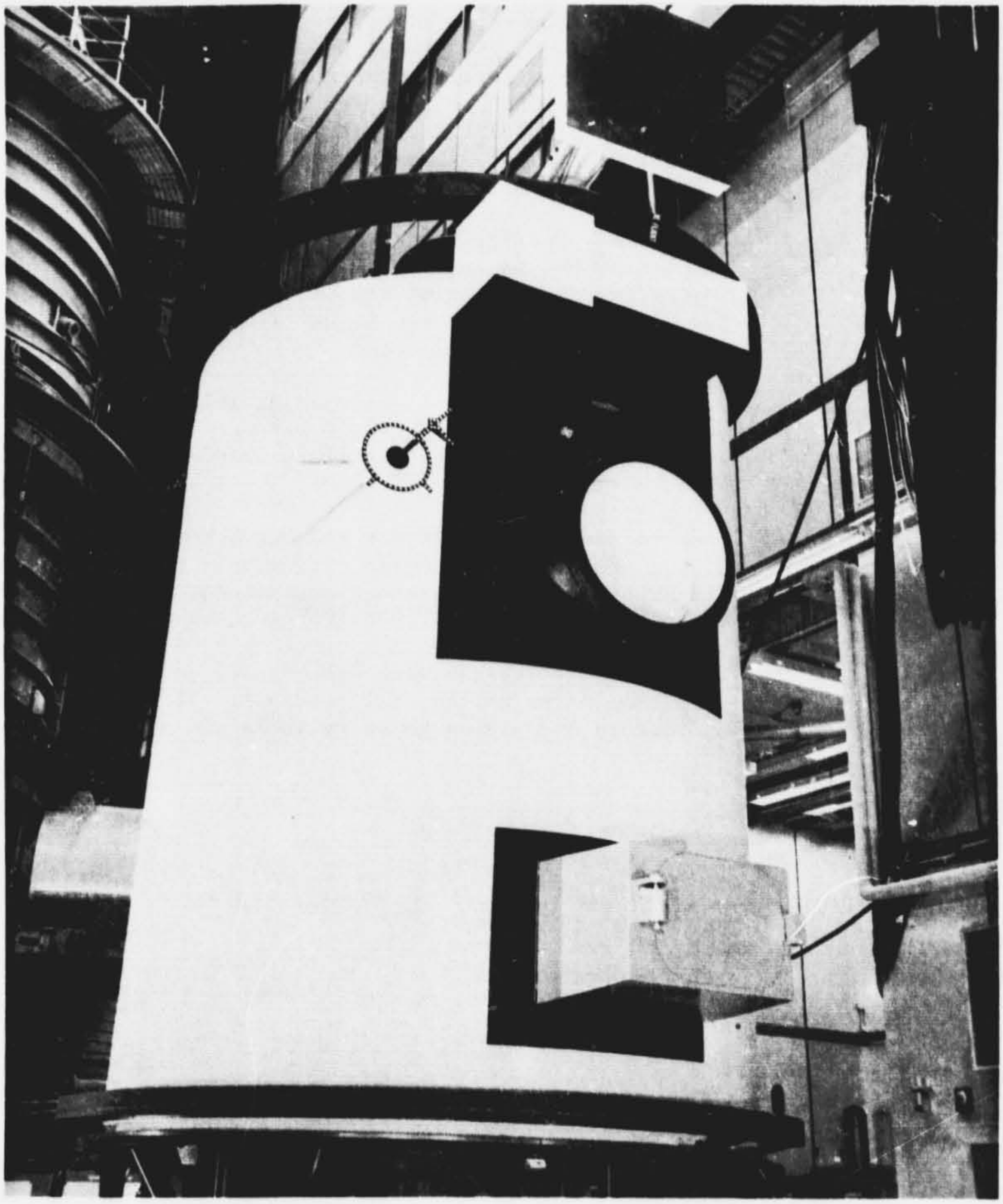


Figure 2.2.11-11 MDA Trainer on Support Stand

- A Trainer access stand - to permit personnel access into the aft end of the trainer while on the rotation fixture.

- A handling fixture and transportation fixture (similar to those provided for the flight article) - for handling and transporting the MDA Trainer by air or ground. This set was jointly shared with the MDA Dynamic Test Article.

(3) Design/Test Verification - During manufacture, and upon completion of the assembly, all equipment was examined to verify conformance of the product to the engineering drawings with respect to materials, dimensions, construction and identification.

Proof load testing was conducted on all assemblies by statically loading them to 150 percent of their design loads with no evidence of failure or excessive deformation.

(4) Program Usage - All GSE for the One-G Trainer was delivered to JSC and was used extensively throughout all phases of One-G Trainer operations. The equipment contributed substantially to the success of the Trainer.

(5) Conclusions - The hardware encountered no significant problems in its design, build or use. It met all requirements and proved to be reliable and safe equipment.

2.2.11.2 Mechanical

Mechanical GSE provided by MMC as CFE started with 3 end items per the original proposal and expanded to eleven deliverable end items as the MDA program progressed. The original three pieces of mechanical GSE were the Pneumatic Checkout Console, the Desiccant Breather Assembly, and MDA Shipping Cover Assembly. The other units all evolved from new requirements as the program developed. The mechanical GSE items categorized as transportation support, module support, and experiment support are discussed below.

A. Transportation Support - The following items were provided for protection of the MDA during transportation from Denver to St. Louis and St. Louis to KSC and during any storage modes:

- Desiccant Breather Assembly SK820FL5300
- Shipping Cover Assembly SK820FL5500

The breather assembly and the shipping cover assembly were designed to protect the MDA from environmental damage or contamination during ground handling and transportation from Denver or during any storage modes of the MDA outside of a controlled environment. The breather was also designed to provide protection of the AM/MDA during air transportation to KSC.

(1) Design Requirements - The design requirements for the breather assembly and the shipping cover assemblies were based on requirements derived from the MDA End Item Specification, CP114A1000026, NASA Technical Memorandum TMX 53328 for natural environments, and Aerospacelines Report ASL-30 for air transportation criteria. A preliminary design criteria was prepared for each to establish pressures, temperatures, and general configuration of the hardware for preliminary design reviews since no end item specs were available.

(a) The Desiccant Breather Assembly was designed to protect the MDA during handling, transportation, and storage against structurally harmful atmospheric pressure changes and to maintain a clean, dry interior environment within the MDA and its shipping cover. Design considerations were mainly concerned with drying capability, filter requirements, maximum air flow conditions vs pressure drop, and interface criteria.

(b) The Shipping Cover Assembly was designed to protect the MDA from the environments and normal transportation hazards. The assembly was designed as an inner cover to be sealed to maintain a dry and clean environment around the MDA and an outer cover of more rugged material to protect the inner cover from external damage. Design considerations were concentrated on compatible materials and proper configuration and size for installing and removing the covers in the areas prescribed for this operation.

(2) Functional Description - The breather and cover assemblies (See Figures 2.2.11-12 and 2.2.11-13) were designed to function together for protection of the MDA. The breather allowed the MDA and the inner cover to breathe clean dry air by directing all air through a desiccant bed and filter assemblies of proper size and capacity for the air inside to be dry and the pressure drop at maximum flow rates to be less than 0.5 psid (maximum allowable ΔP per the MDA-CEI). Prior to connecting the breather assembly to the system, the interior of the MDA and the inner cover were purged to a low dew point to remove moisture inside and assure no condensation would occur. A brief description of each unit is as follows:

(a) The Desiccant Breather Assembly consisted of a desiccant canister assembly, a humidity indicator, filter assemblies, flex hoses, adapters, and other miscellaneous hardware such as clamps.

The Air Carry Unit was a large unit designed to meet the higher-capacity requirements during air carry; the smaller Ground Handling Unit could remain attached to the MDA during ground handling operations.

The desiccant canister assemblies consisted of a desiccant container sized to flow the required air to or from the AM/MDA and maintain the humidity level within the MDA and the AM/MDA while preventing the outside-to-

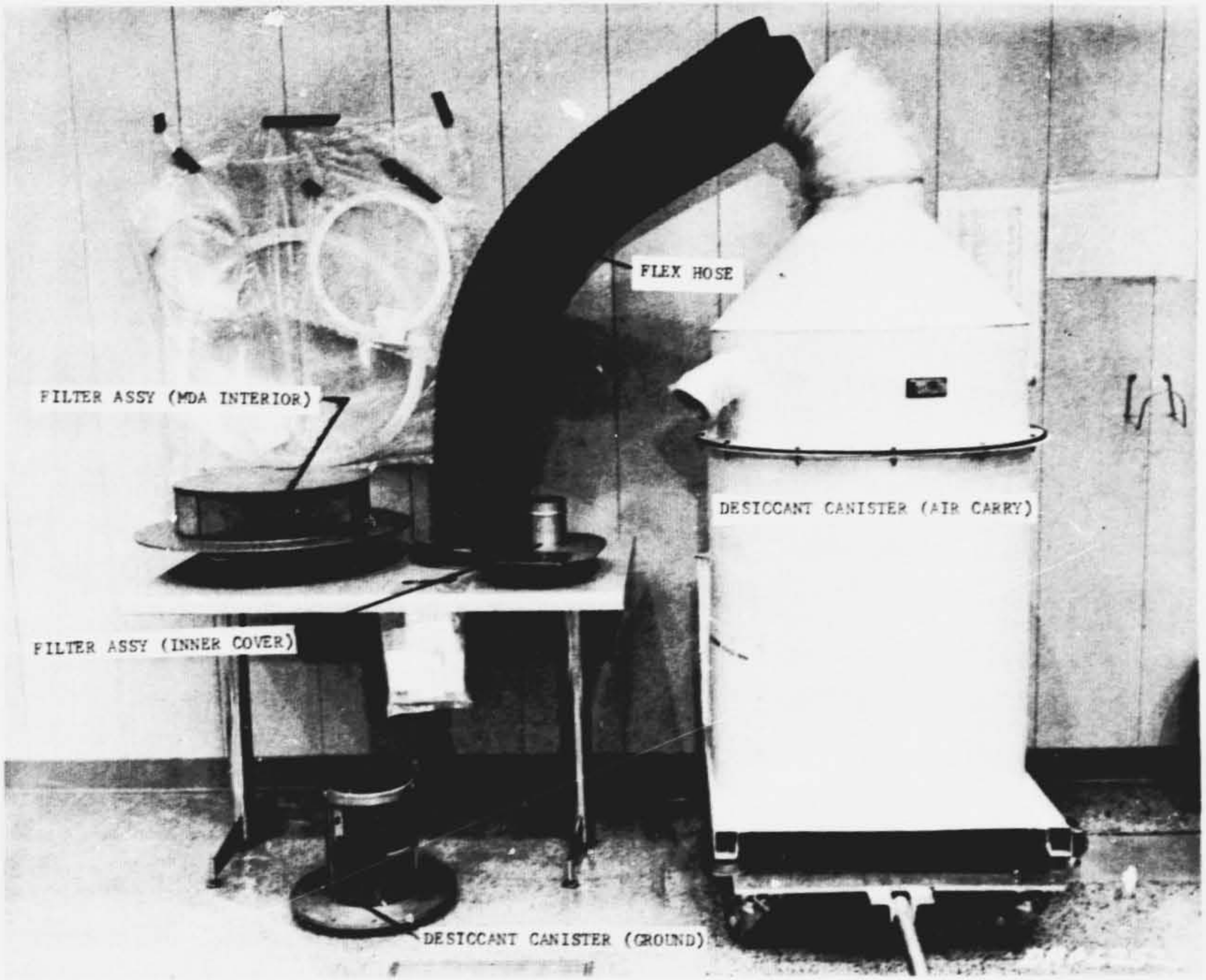


Figure 2.2.11-12 Desiccant Breather Assembly (SK820FL5300)

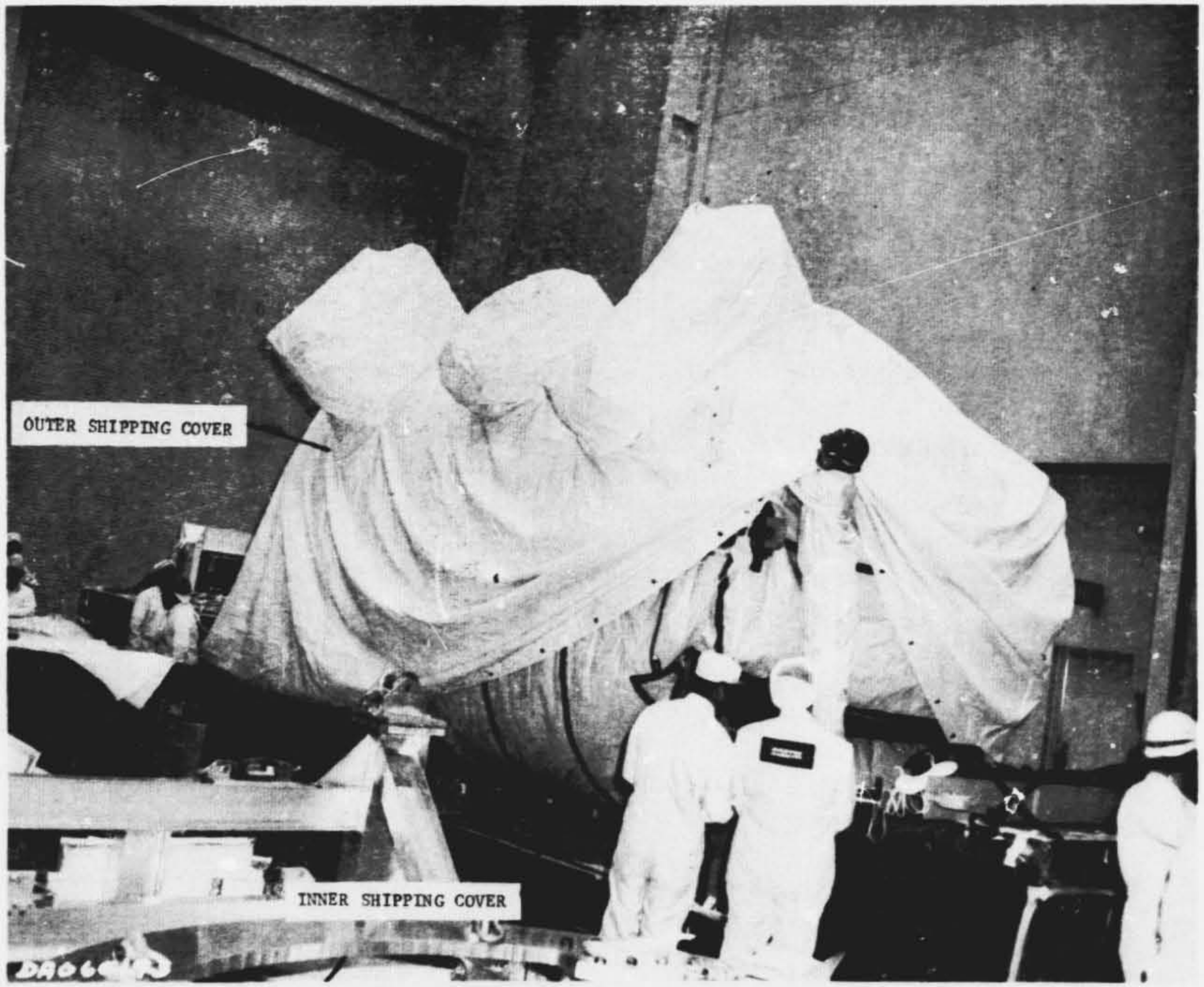


Figure 2.2.11-13 Shipping Cover Assembly (SK820FL5500)

inside pressure differential from exceeding 0.5 psid. The Air Carry Unit also provided a separate outlet to supply dry air to the MDA Shipping Cover Assembly.

(b) The MDA Shipping Cover Assembly consisted of inner and outer covers. The inner cover was a water-proof enclosure of plastic film (VELASTAT) designed to eliminate moisture and other contaminants from contacting the outer surfaces of the MDA. The MDA Desiccant Breather Assembly was attached to the inner cover during ground and air transportation.

The outer cover was installed over the MDA Inner Cover to provide protection against physical damage resulting from weather and dirt conditions encountered in transit and storage. It was made of durable waterproof and flame resistant material (HYPALON) that provided maximum protection during shipment. It attached to the Horizontal Transportation Fixture by ropes thru eyelets in the cover and hooks on the transportation fixture.

(3) Design/Test Verification - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item. The breather assembly was tested for its capability to meet flow vs pressure drop, moisture removal and general assembly configurations and interface verifications. The shipping cover tests included proof pressure and leak test of the inner cover and complete inspection of all units for compliance with engineering drawings. Fit checks on the Breather and Cover Assemblies for the flight and backup articles were also completed. Some alterations to inner cover were required as a result of the fit check and retests were conducted. All tests were completed successfully for each assembly.

(4) Program Usage - First usage of the breather assembly and the shipping cover assembly was during preparation of the flight article for shipment from Denver to St. Louis. The assemblies were used again in the same configuration for the backup article. The breather assembly was incorporated into a shipping plan provided by MDAC-E for the AM/MDA configuration.

(5) Conclusions - The breather assembly and the cover assembly encountered no significant problems during design, build or use. The assemblies met and satisfied the design, functional, and interface requirements imposed by the Skylab Program.

B. MDA Module Support - The following items were provided for support of the MDA Module testing at Denver, St. Louis, and KSC:

Volumetrics Leak Detection Unit (VLDU)	SK820FL5010
Pneumatic Checkout Console	SK820FL5100
MDA/CSM Leak Detection Kit	SK820FL5200
MDA Fan Test Set	SK820FL5400
Coolant System Checkout Unit (CSCU)	SK820FL5700
Water Chiller Unit	SK820FL5800
M512 Vent Adapter Assembly	SK820FL5900
Leak Detection Adapter Kit	SK820FL6464

Some of the above items were used for support of experiment testing as well as MDA module support. Design of each item was based on the known usage requirements at the time of design.

(1) Design Requirements - The design requirements for each of the end item assemblies were based on requirements derived from the MDA End Item Specification, CP114A1000026, applicable ICDs, and actual usage requirements for the unit. A preliminary design criteria was prepared for each item to establish criteria such as pressures, temperatures, and general configuration of the hardware for preliminary design reviews since no end item specifications were available. In some cases trade studies were completed to determine which method of leak measurement would be used. Some of the units were initially designed as non-

deliverable GSE and later converted to deliverable GSE in which case changes were worked to upgrade the units for more universal usage. In general each unit was designed using standard off-the-shelf components wherever possible, with similarity to previously used hardware for added design assurance without special qualification testing.

(2) Functional Description - A brief description of each unit is as follows:

(a) (VLDU) and the Leak Detection Adapter Kit - The VLDU (SK820FL5010) was used to measure the leakage rate of MDA subsystems and experiments. The Leak Detection Adapter Kit (SK820FL6464) provided the hose assemblies, filters, and adapters required to connect the VLDU to the flight article being tested and to the facility gaseous nitrogen (GN2) supply. The VLDU also interfaced with facility 115 VAC, 60 Hz, single-phase electrical power.

The VLDU was approximately 25.5 inches wide by 27.25 inches deep by 36.5 inches high and weighed approximately 150 pounds. Major subsystems were a pneumatic system and an electrical/electronic system. Basically, the VLDU utilized a volumetrics micrometer to measure the precise volumetric change required to neutralize the pressure change resulting from leakage of the test article. Charge pressures from zero to 60 psig could be used. The VLDU had the capability of determining the test article leakage rate by maintaining a constant differential pressure or by determining the drop in pressure over a timed interval. Leakage rates from 100 scc/min to 1.0×10^{-3} scc/sec could be measured.

(b) Pneumatic Checkout Console - The Pneumatic Checkout Console (SK280FL5100) was used to control, measure, and monitor the facility nitrogen gas used during the Leakage Rate Measurement and Purge Manifold tests on the MDA. It consisted of the console, reference volume kit, flex hoses and flowmeter kit.

The console contained the controls, indicators, and pneumatic circuits required to perform the test functions. The pneumatic circuits consisted of high flow circuit, a low flow circuit, and a differential pressure circuit. The differential pressure circuit was isolated from the high and low flow circuits. The reference volume kit assembled to the STS Simulator Sealing Plate Assembly on the MDA and was connected to the console by flex hoses. A flex hose assembly was used to connect the console to the facility gaseous nitrogen supply. The flowmeter kit consisted of a portable flowmeter and a 15 foot length of clear vinyl tubing.

The Pneumatic Checkout Console operated in a clean environment located within 65 feet of the test article and 35 feet of the facility nitrogen supply because of the flex hose lengths. The hoses were restrained when pressurized and, when laid across floor areas,were protected by barricades or covers to avoid damage from vehicular or personnel traffic over them. Facility nitrogen used met the requirements of MIL-P-27401B and was capable of supplying a flow of up to five pounds per minute at a pressure of 150 to 475 psig for the duration of the tests.

(c) MDA/CSM Leak Detection Kit - The MDA/CSM Leak Detection Kit (SK820FL5200) was used to measure gas leakage from the MDA and Command and Service Module (CSM) interface. This leakage test was performed during the AM/MDA inverted docking test with the CSM in the WITS of the O&C Building at KSC.

The kit was housed in a portable aluminum carrying case approximately 15 by 12 by 13 inches. Components assembled and installed in the bottom of the case were a thermowell assembly, two flowmeters, a thermometer, a three-way valve, and associated plumbing and hardware. Removable components stored in the stowage space in the upper half of the case that completed the kit were:

- Spring - to provide a flow channel for leakage gas at the MDA/CSM interface,
- White vinyl tape that laid over the spring to form a leakage collector cavity,
- Tee assembly that mated with the spring and tape to form a leakage connection point from the leakage collector cavity,
- A piece of flex tubing that connected between the tee assembly and inlet fitting of the kit,
- Flowmeter that could replace one of the flowmeters installed in the case if additional flowmeter range was required,
- Spare disc filters,
- Leather punch used to punch a hole in the tape for the tee assembly installation, and
- GS-43 sealant that provided a seal for the assembly.

The test setup was obtained by creating and then connecting a leak collector cavity at the MDA/CSM interface to the gas flow measurement equipment in the carrying case.

(d) MDA Fan Test Set - The MDA Fan Test Set (SK820FL5400) was used to check the performance of the fans in the MDA ventilation system. It consisted of an Air Velocity Meter Set, an Inlet Adapter Assembly, an Electrical Set, and a Shipping/Storage Container Assembly.

The Air Velocity Meter Set consisted of a velometer, range selector, diffuser probe, pilot probe assembly, and tubing. It was used at the air inlet to the CSM duct fan to measure the CSM air supply and at the MDA diffuser outlet to determine the MDA cabin fan air velocity.

The Inlet Adapter Assembly was used to position the diffuser probe during measurement of the CSM air supply. It interfaced on the screen side of the inlet muffler assembly and was held in place with tape.

The Electrical Set was used to control and measure electrical power to the applicable MDA fan during the testing functions. It was inserted between the MDA airborne wiring and the applicable fan and supplied electrical power of 26 ± 0.1 VDC and approximately 350 MA via the airborne wiring.

The Shipping/Storage Container Assembly was a light weight aluminum carrying case filled with Scott Pyrell foam. Cutouts were provided in the foam for test components to restrict movement to a minimum during handling and shipping.

(e) (CSCU) and Water Chiller Unit - The CSCU (SK280FL5700), was used to check out the MDA coolant loop. It consisted of a mobile cabinet containing a liquid reservoir, pump, interface fittings and hoses, and the associated control and measuring components. It used facility nitrogen and 115 VAC, 60 Hz, single phase power.

The CSCU was designed to circulate a flow of coolant fluid through the MDA coolant loops and to measure the flow versus differential pressure. A pneumatic circuit was included to permit purging and drying of the liquid flow circuit. An auxiliary Water Chiller Unit (SK820FL5800) was connected into the coolant return lines between the MDA and CSCU for tests requiring cooling capability.

The Water Chiller Unit was used to maintain the temperature of the MDA coolant system fluid between 40°F and 78°F during testing functions. It was a cast cooler package manufactured by Dunham-Bush, incorporated and modified by MMC. It was approximately 27 inches high by 21.5 inches wide by 24 inches deep, with two rigid and two swivel casters to provide easy movement, and operated on 115 VAC, 60 Hz, single phase facility power.

(f) M512 Vent Adapter Assembly - The M512 Vent Adapter Assembly (SK820FL5900), provided an interface connector between the pressure supply or vacuum pump and the M512 Experiment vent system. It was used for the leak check, experiment vacuum tests, and for protection during transportation. The assembly consisted of an aluminum cylinder with one end threaded and one end flanged, gaskets, a blind flange, a tube fitting with cap, and mounting hardware for the blind flange.

The cap was removed and the pressure supply connected to the tube fitting during the leak check. The blind flange was removed and the vacuum pump connected to the adapter flange interface for vacuum testing.

(3) Design/Test Verification - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

All end item units were subjected to tests such as proof pressure, leakage, functional, flow and temperature control, as applicable to verify design capability versus usage requirements.

When schedule allowed, fit check were conducted prior to actual usage to verify interfaces.

(4) Program Usage - Usage of the GSE items described herein was as follows:

(a) The VLDU was used at KSC for the M512 leakage tests, M512 battery vent leakage, and tunnel leak tests. A similar unit of capital equipment (non GSE) was used for similar tests at Denver and KSC and was not available for use at KSC.

(b) The Pneumatic Checkout Console was used at Denver only for the MDA leakage tests, insulation purge tests and various other unscheduled usages requiring nitrogen within the clean room area during the flight and backup test periods in the high bay at Denver.

(c) The MDA/CSM Leak Detection Kit was used at KSC during the inverted docking test to measure the leakage at the MDA/CSM interface.

(d) The MDA Fan Test Set was used at St. Louis with the flight article and at Denver with the backup article to measure air capacity of the MDA fans.

(e) The CSCU and the Water Chiller Unit were used at Denver and St. Louis during all usages of EREP & ATM C&D coolant system on flight and backup articles to supply coolant as well as to verify flow and pressure drop data on the system. The units were used also at St. Louis during bench tests on the EREP system.

(f) The M512 Vent Adapter Assemblies were installed at Denver on the flight and backup articles. These units remained on the MDA until after completion of tests at KSC. The flight article unit was removed before flight at KSC. The backup article unit remained installed through storage. These items were used for M512 leakage and vacuum tests conducted at Denver, St. Louis and KSC and also provided interface protection during all other times.

(5) Conclusions - None of the GSE items described herein encountered any significant problems in design, build or use. The units met and satisfied the design, function, and interface requirements imposed by the Skylab Program.

C. MDA Experiments Support - One item, the Internal Scanner Ground Coolant Adapter Kit, SK820FL5600, was only provided for experiment support. Other units mentioned above, however, were used in support of various experiment tests mostly on module with some off module tests supported. The SK820FL5010, SK820FL5900, and SK820FL6464 were used to support M512 on-module tests; SK870FL5100, SK87FL5700, SK820FL5800, and SK870FL6464 were used to support on module and off module EREP tests at Denver and St. Louis.

(1) Design Requirements - The Internal Scanner Ground Coolant Adapter Kit was required to furnish a supply and return flex hose from the axial docking port closure plate to the inlet and outlet fittings at the S192 Internal Scanner Heat Pipe Condenser and Cover for use during the Altitude Chamber Test in St. Louis. Two standard off the shelf hoses of correct length were provided for this use.

(2) Functional Description

(a) The Internal Scanner Ground Coolant Adapter Kit supplied the cooling flow loop within the MDA.

During the tests the atmosphere in the MDA varied from sea level ambient atmospheric conditions to an oxygen enriched atmosphere at approximately 5.0 psia. The two coolant hoses were ½ inch in diameter, 21 feet long, and consisted of an inner teflon liner with a wire braided outer jacket and corrosion resistant AN hose fittings. One end of each hose had a straight swivel nut flared fitting and the other end had a 90° swivel nut flared fitting.

The Internal Scanner Ground Coolant Adapter Kit was part of the GSE required to provide coolant to the S192 Internal Scanner during the Altitude Chamber Tests at MDAC-E. It consisted of two hoses that connected the inlet and outlet fittings at the S192 Internal Scanner Heat Pipe Condenser and Cover

(F21005807) to pass through fittings in the MDAC-E Axial Docking Port Closure Plate (61E010044). MDAC-E tubing, hoses, and fittings, completed the supply and return flow loop to the Heat Pipe Condenser Water Cooling System (F21005644-102) on the outside of the altitude chamber. The completed assembly transferred heat from the Cooler-Dewar-Preamp Assembly Engine Cooler by circulating distilled water at 0.5 gpm minimum through a heat exchanger attached to the wall of the engine cooler.

(b) The VLDU and the Leak Detection Adapter Kit were used for leak testing of the M512 experiment at KSC. Reference 2.2.11.2.B for details on these units.

(c) The CSCU and Water Chiller provided coolant flow during EREP testing at St. Louis for on-module and off module tests. Reference 2.2.11.2.B for details on these items.

(3) Design/Test Verification - The hoses of the Ground Coolant Adapter Kit were proof pressure tested, leak tested, and inspected to meet the engineering drawing requirements for proper identification, cleanliness, and packaging.

(4) Program Usage - The Ground Coolant Adapter Kit was not used since the S192 was not installed for the altitude test at St. Louis.

(5) Conclusions - The Ground Coolant Adapter kit was provided with no problems encountered during design or build and tests verified the item would function as required. This unit employed commonly used flex hoses and could be used for many other purposes where flex hoses are required.

2.2.11.3 Electrical

A. Test Lighting, SK820FL6461 (Figure 2.2.11-14)

(1) Design Requirements - Provide electrical lighting for operations within the MDA.

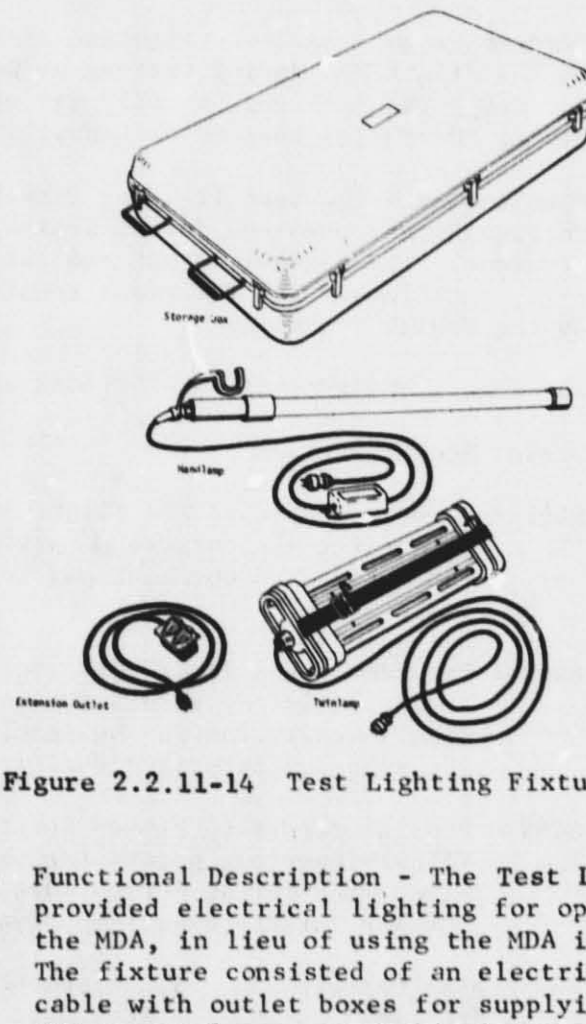


Figure 2.2.11-14 Test Lighting Fixture

(2) Functional Description - The Test Lighting Fixture provided electrical lighting for operations within the MDA, in lieu of using the MDA internal lights. The fixture consisted of an electrical extension cable with outlet boxes for supplying 115 VAC for MDA internal use. Portable lamps provided with the fixture connected to the outlet boxes, as applicable, to supply lighting in the MDA.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The test lighting assembly was used in the Flight MDA during testing at Denver, St. Louis and KSC. The lighting assembly was used in the Backup MDA during testing at Denver and St. Louis.

(5) Conclusions - The test lighting assembly encountered no significant problems during design, fabrication or usage. The assemblies met and satisfied the design, functional, and interface requirements imposed by the Skylab Program.

B. Breakout Boxes, SK820FL6462, SK820FL6463 and SK820FL6465

(1) Design Requirements -

6462 - Provide access to MDA flight interface points for the purpose of signal monitoring during MDA checkout and verification tests.

6463 - Provide access to EREP/AM power bus and timing interface points for the purpose of signal monitoring during initial EREP checkout and interface verification tests.

6465 - Provide access to Proton Spectrometer/MDA flight interface points for the purpose of signal monitoring during initial MDA checkout and interface verification tests.

(2) Functional Description - All breakout boxes provided "in line" access for diagnostic test equipment to troubleshoot and monitor individual circuits during initial checkout and interface verification testing.

6462 - The MDA Checkout Fixture consisted of two packing trunks containing eleven inline and end-line breakout boxes used to provide access to MDA flight interface points. The utility C/O box and CCU simulator C/O box contained load resistors and switches to provide the capability for special tests (Figure 2.2.11-15).

6463 - The EREP Checkout Fixture consisted of a packing trunk containing six in-line breakout boxes used to provide access to EREP/AM power bus and timing interface points (Figure 2.2.11-16).

6465 - The Proton Spectrometer GSE mating fixture consisted of an in-line and end-line breakout box. The box was kept in a "kudl-Pak" vac-u-form carrying case when not in use (Figure 2.2.11-17).

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The breakout boxes were used to checkout the Flight MDA at Denver, St. Louis and KSC. They were also used on the Backup MDA during testing at Denver and St. Louis.

(5) Conclusions - The breakout boxes encountered no significant problems during design, fabrication or usage. The boxes met and satisfied the design, functional, and interface requirements imposed by the Skylab Program.

C. Television GSE, SK820FL7100 - 7400 (Figure 2.2.11-18)

(1) Design Requirements - Provide a signal source to the Skylab television systems to assure the functional integrity of the system.

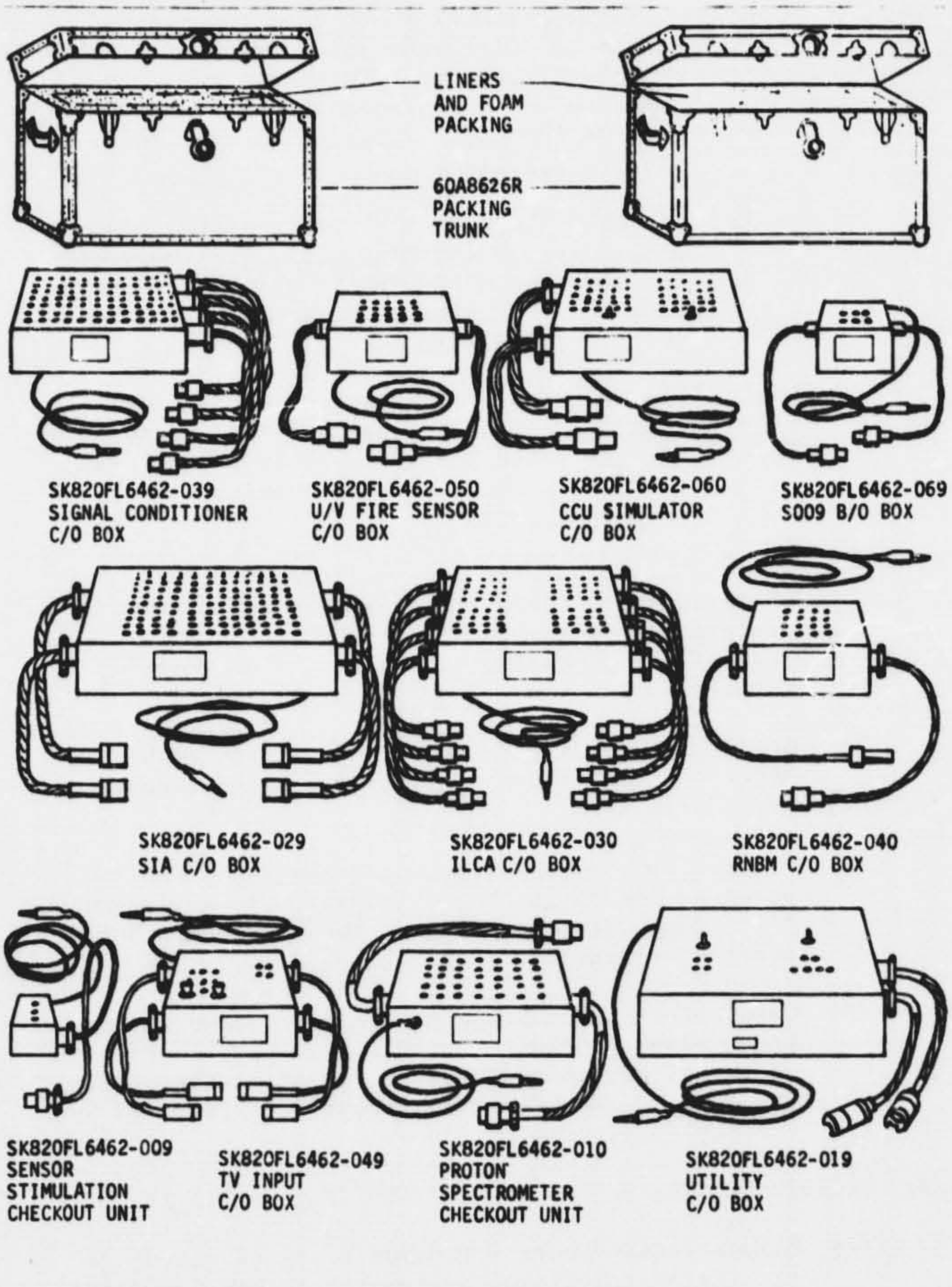


Figure 2.2.11-15 MDA Checkout Fixture

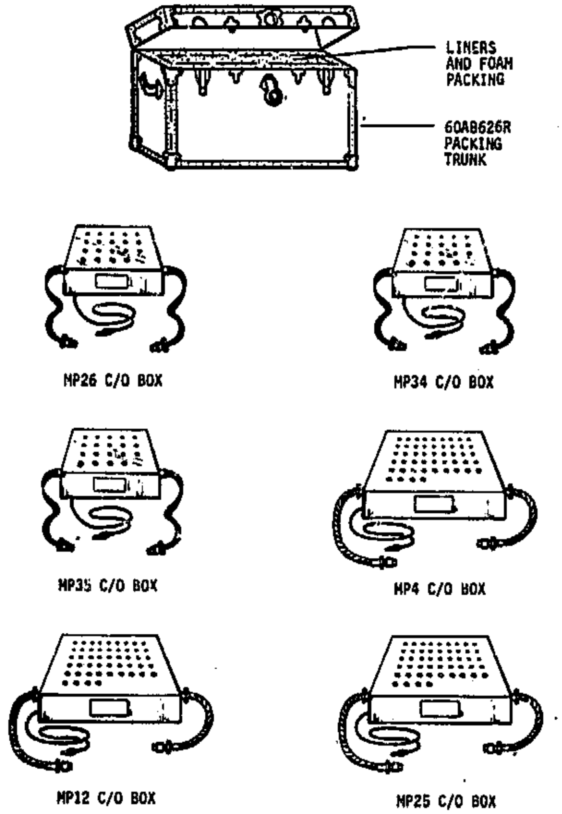


Figure 2.2.11-16 EREP Checkout Fixture

(2) Functional Description - The TV GSE provided sine^2 2T, stairstep, and multiburst signal sources to the Skylab TV system to assure the functional integrity of elements of the system. It was designed to test parts of the Skylab TV System in the development lab. It consisted of a monitor, a box of signal sources, cables, and a storage case.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The Television GSE was used for development of the TV system in Denver.

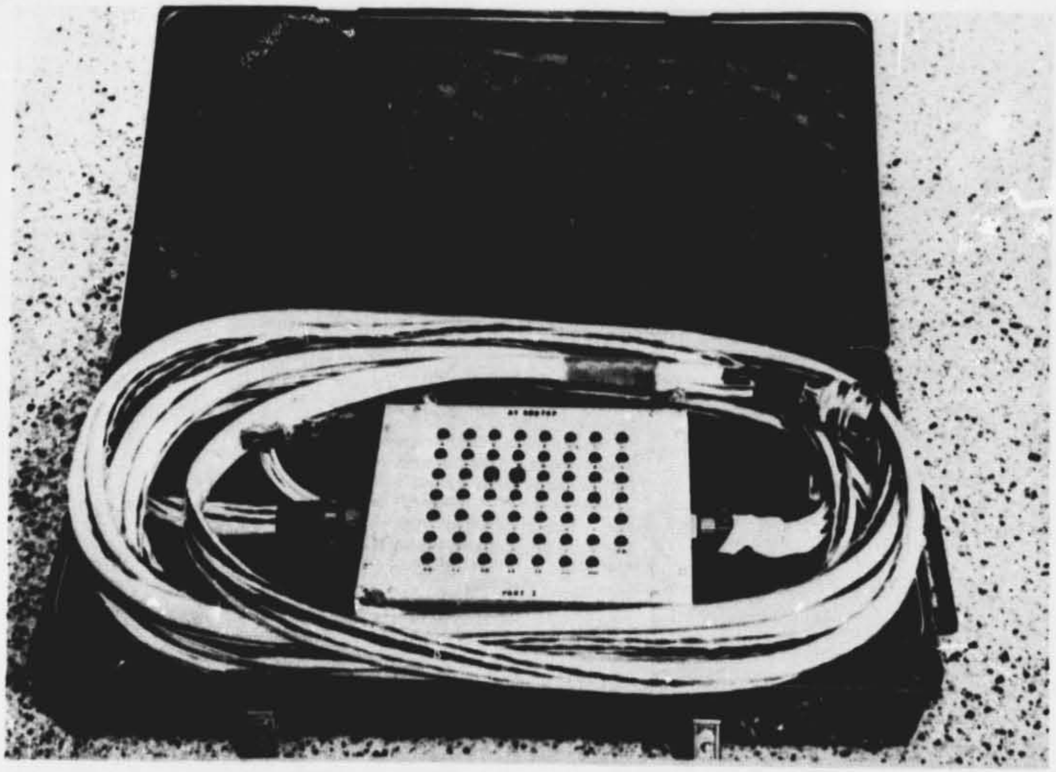


Figure 2.2.11-17 Proton Spectrometer GSE Mating Fixture

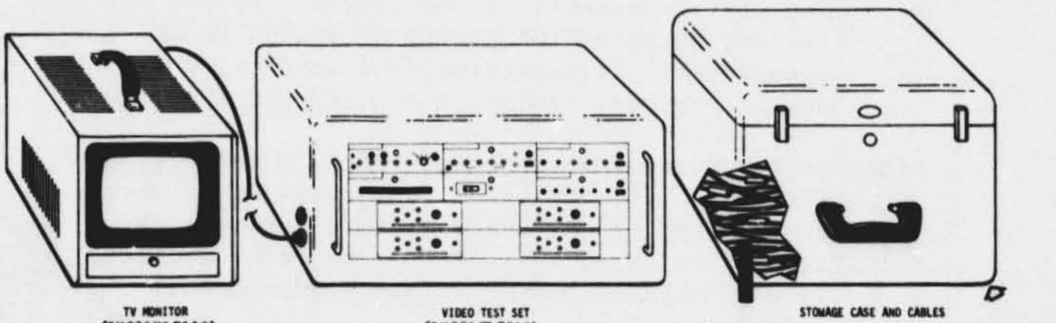


Figure 2.2.11-18 Television GSE

(5) Conclusions - The Television GSE encountered no significant problems during design, fabrication or usage.

D. EMC Test Adapters, SK820FL7500

(1) Design Requirements - Provide capability to perform MDA system Electromagnetic Compatibility (EMC) tests.

(2) Functional Description - This set consisted of seventeen test adapters that provided in-line monitoring of MMC furnished experiments for purposes of assessing, with GFP EMC equipment, the electromagnetic energy characteristics of individual critical circuits. Sheet 9 of SK820FL7500 illustrates the connections of the adapters for EMC testing at St. Louis.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The EMC Test Adapters were used on the Flight MDA during testing at St. Louis.

(5) Conclusions - The EMC Test Adapter encountered no significant problems during design, fabrication or usage.

E. Transportation Heater, SK820FL7700

(1) Design Requirements - Provided environmental protection during transportation of the MDA.

(2) Functional Description - The set consisted of a Portable Generator Plant, a Heater Control Box, six (6) 500 watt Heaters, two Thermoswitches, Electrical Cables and a Sensor Readout Adapter.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The heaters were used during transportation of the Flight MDA from Denver to St. Louis and St. Louis to KSC. The Backup MDA used the heaters during transportation from Denver to St. Louis and St. Louis to Huntsville.

(5) Conclusions - The transportation heaters encountered no problems during design, fabrication or usage.

F. Cable Set - AM to MDA, SK820FL7760

(1) Design Requirements - Provide capability to breakout all EREP functions at the AM/MDA interface to allow checkout of EREP components independent of the AM after electrical mate of the AM/MDA.

(2) Functional Description - This set consisted of four cable assemblies, each a Y configuration with three connectors. These cables permitted isolation of the MDA EREP bus and ground after AM/MDA electrical mate. The cables interfaced with EREP connectors MP4, MP12, MP25, and MP26.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The cable set was used on the Flight and Backup MDA during testing at St. Louis.

(5) Conclusions - The cable set encountered no significant problems during design, fabrication, or usage.

G. S190 Window Assembly Pre-Flight Tester, SK820FL7770 (Figure 2.2.11-19).

Figure 2.2.11-19 S190 Window Assembly Preflight Tester

(1) Design Requirements - Provide functional checkout capability for the S190 Window Heaters and Controls either on or off module to assure functional integrity of the system.

(2) Functional Description - The tester was a portable suitcase type test set consisting of a panel assembly and test cable. The panel assembly contained a selector switch and voltmeter to monitor the heater control outputs and resistors. It also

contained switches to simulate heater high-low range and over temperature signals. Test points were provided to monitor heater error signals.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The S190 Window Tester was used on the Flight MDA during testing at St. Louis and KSC, and on the Backup Article at St. Louis.

(5) Conclusions - The tester encountered no significant problems during design, fabrication or usage. The tester met and satisfied the design, functional, and interface requirements imposed by the Skylab Program.

H. Television Test Set, SK820FL8000 (Figures 2.2.11-20 and 2.2.11-21).

(1) Design Requirements - Provide the appropriate stimulus to and monitoring of the Skylab Television Systems to assure the functional integrity of the system.

(2) Functional Description - The Television Test Set (SK820FL8000) was used to test the Skylab TV System on a module and partially integrated system level at the manufacturer's facilities and on a system level at KSC. It consisted of an input rack and two output racks and a set of interconnecting and adapter cables with a storage case. Miscellaneous items included patch cords, termination resistors, panel adapters, and film cameras which were stowed in drawers in the racks and the cable stowage case when not in use.

Functionally, the Television Test Set consisted of an input rack to generate test signals and an

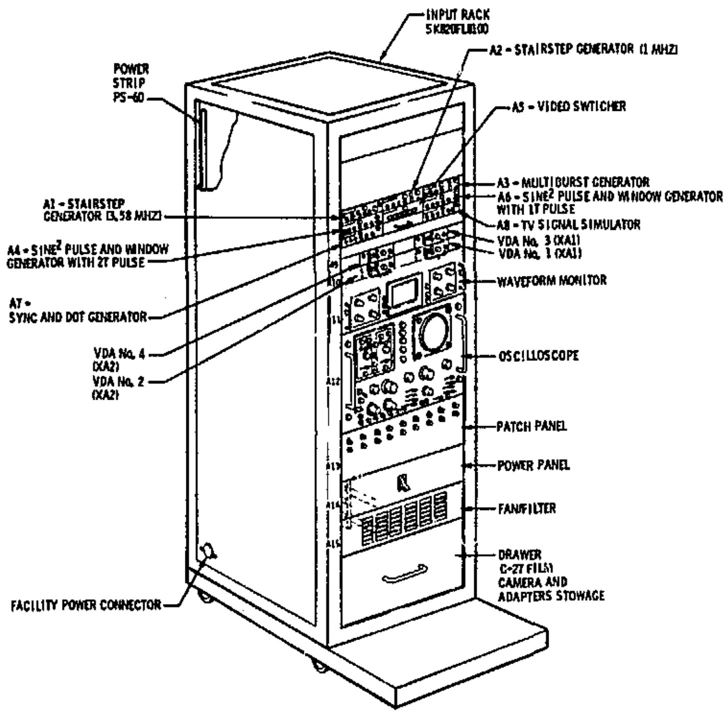


Figure 2.2.11-20 TV GSE Input Rack

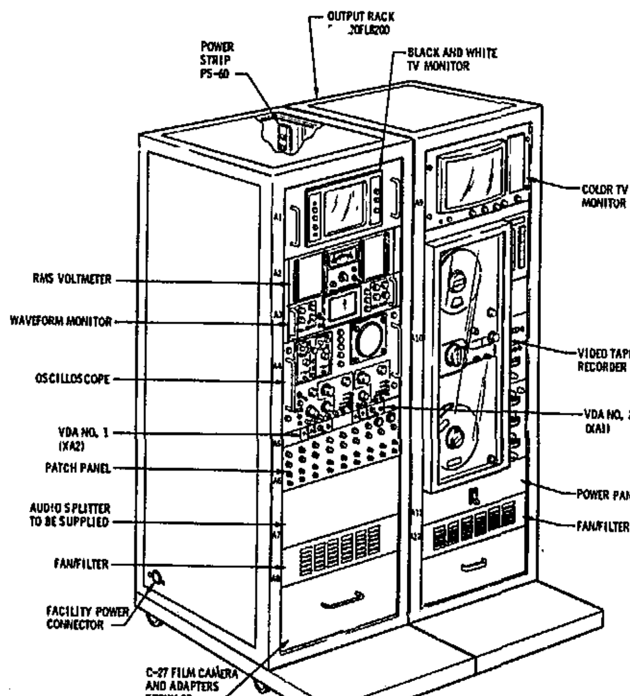


Figure 2.2.11-21 TV GSE Output Rack

output rack to monitor the results. Six standard video test signals, stairstep, $sine^2$ pulse and window, and multiburst of both the 100/40 and 100/28 formats; plus a simulated sequential TV signal, were generated in the input rack. A selected test signal from the input rack was transmitted to the Skylab TV system module and/or integrated system under test and the resulting outputs were compared and evaluated on the output rack's oscilloscope, waveform monitor, RMS voltmeter, and TV monitors. The stairstep test signal was required to verify amplifier linearity and signal to noise. The $sine^2$ pulse and window test signal was required for DC response verification. The multiburst test signal was required for frequency response verification. The field sequential TV signal was required for sequential color verification. An audio splitter/interleaver was provided to separate the audio from the video and for self test.

The Television Test Set was used to verify the video bus performance on a module level and to identify potential problem areas. It was used at KSC to verify the video bus performance on the module level after shipment from the manufacturer's facility, and to verify system capability and performance at the various levels of system integration. The input rack provided selectable video test signals to the TV Input Stations, Video Switch, and associated test points on the MDA, AM, ATM and OWS. The output racks displayed field sequential color or black and white video data, monitored video signals up to 4.0 volts peak to peak and provided for amplitude measurement of signals in excess of 4.0 volts peak to peak. Output racks also provided for test signal evaluation and the recording and playback of test data. The following system parameters were monitored to assure functional integrity of the system:

(a) Frequency Response
(b) D. C. Response
(c) $Sine^2$ Pulse
(d) Linearity
(e) Differential Gain
(f) Noise

(g) Interface Signal Levels
(h) Color
(i) Audio

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The Television Test Set was used on the Flight MDA at KSC, and the Backup MDA at Denver and St. Louis. During the Skylab Mission the test set was used for mission support at St. Louis. One of the Television Test Sets has been delivered to JSC for use during the Russian and United States joint Spacelab flights.

(5) Conclusions - The Television Test Set encountered no significant problems during design, fabrication or usage.

I. MDA Dust Cover Kit, SK820FL8500 (Figure 2.2.11-22)

(1) Design Requirements - Provide protection for demated MDA electrical connectors during altitude chamber testing

(2) Functional Description - The kit consisted of a lockable lightweight stowage and shipping container containing environmental dust covers which were oxygen and contamination compatible.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

(4) Program Usage - The MDA Dust Cover Kit was used on the Flight Article during testing at St. Louis.

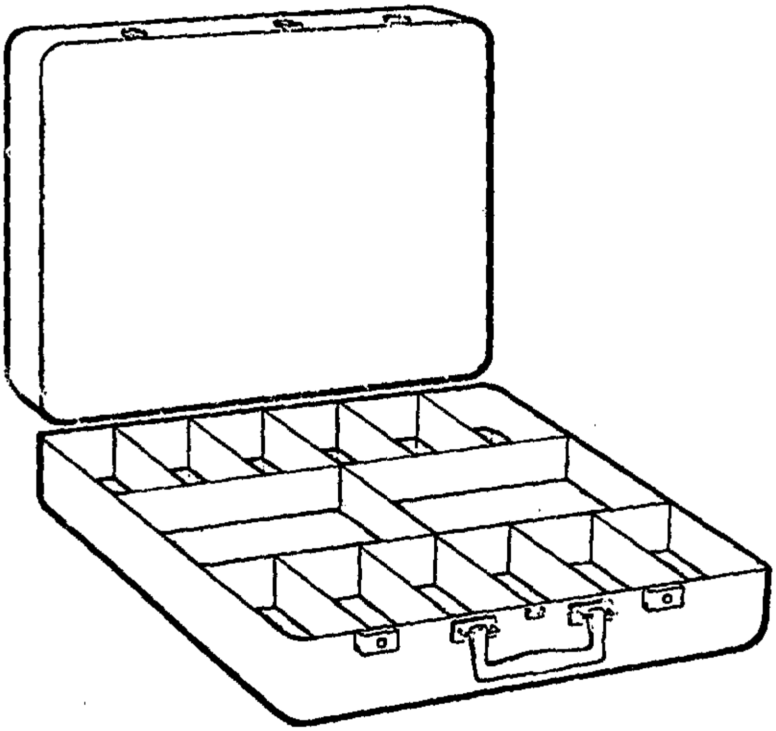


Figure 2.2.11-22 MDA Connector Dust Cover Kit

(5) Conclusions - The Dust Cover Kit encountered no significant problems during usage.

J. BI/LCA Functional Test Set, SK820FL8600 (Figure 2.2.11-23)

(1) Design Requirements - Provide electrical loads and simulations to checkout MDA BI/LCA systems.

(2) Functional Description - The BI/LCA Functional Test Set (FTS) consisted of a 22" X 17" X 9" box containing all components and a front panel with test and display points.

The BI/LCA FTS provided a loads network capable of supplying 28 VDC and 115-130 VAC simulation of 9 electrical loads to the BI/LCA and the I/LCA systems.

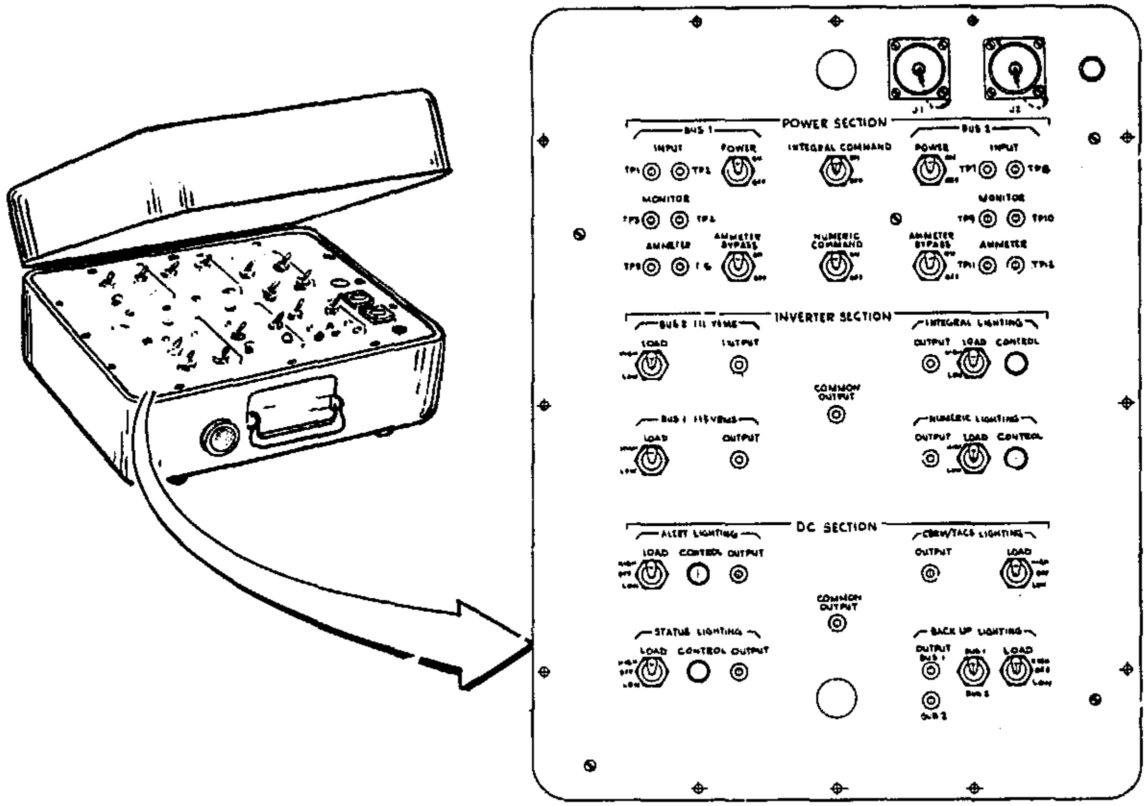


Figure 2.2.11-23 BI/LCA Functional Test Set

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

(4) Program Usage - The BI/LCA Functional Test Set was used on the Flight MDA during testing at KSC, and on the Backup MDA during testing at St. Louis.

(5) Conclusions - The BI/LCA Functional Test Set encountered no significant problems during design, fabrication or usage.

K. T027 TV Test Adapter, SK820FL8700 (Figures 2.2.11-24)

(1) Design Requirements - Provide a means to monitor voltage and to control camera/lens movement during T027 checkout and interface verification tests.

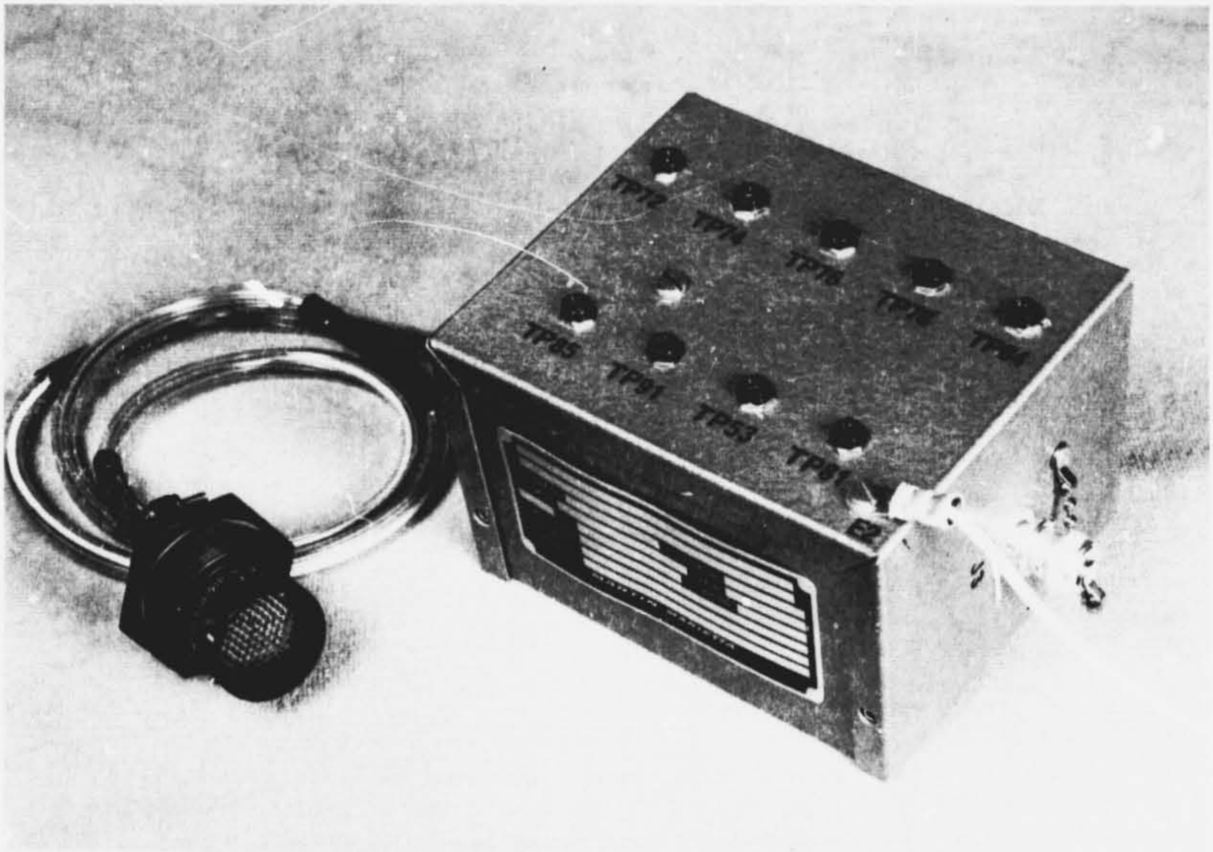


Figure 2.2.11-24 T027 TV **Test** Adapter

(2) Functional Description - The T027 Test Adapters consisted of a T027 TV Camera Test Adapter and a T027 Control Panel Test Adapter. Both adapters were small electrical boxes sized approximately 3" X 4" X 6", with nine tip jacks, a three foot cable with connector, and a ten foot ground cable with alligator clip.

Connector (J1A) on T027 Camera Test Adapter interfaced with T027 Camera connector (P1) and connector

(J9A) on T027 Control Panel Test Adapter interfaced with T027 Control Panel Connector (P9) during testing functions.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The test adapters were used on the Flight Article during KSC testing.

(5) Conclusions - The test adapters encountered no problems during design, fabrication or usage.

L. S193 Heater Control Breakout Box, SK820FL8800

(1) Design Requirements - Provide access to the S193/AM heater interface connection and provide a means to check for AM voltage on the pins of the S193 A3 P1 connector during EREP checkout and interface verification tests.

(2) Functional Description - The S193 Heater Control Breakout Box was a small electrical box, sized approximately 4" X 5" X 6" with fifteen banana jacks, a ground stud, and a five foot electrical cable with connector.

(3) Test - During manufacture, and upon completion of each assembly, the units were examined to verify conformance to the engineering drawings with respect to materials, dimensions, construction, identification, and interface requirements.

Acceptance tests were also conducted on each assembly to assure design verification with intended use of the item.

(4) Program Usage - The breakout box was used during test of the Flight MDA at Denver, St. Louis and

KSC. The Backup MDA used the breakout box at Denver and St. Louis.

(5) Conclusions - The breakout box encountered no problems during design, fabrication and usage.

NASA TMX-64812

APPROVAL

MSFC SKYLAB MULTIPLE DOCKING ADAPTER FINAL TECHNICAL REPORT

AIRLOCK/MULTIPLE DOCKING ADAPTER 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.

J. McCool

J. McCool
Project Manager, Airlock/Multiple Docking Adapter

R. Ise
Program Manager, Skylab Program Office