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ABBREVIATIONS AND ACRONYMS

Å	Angstroms
AC	Alternating Current
ACE	Acceptance Checkout Equipment
ACQSS	Acquisition Sun Sensor
ACS	Attitude Control System
ADP	Acceptance Data Package
ALSA	Astronaut Life Support Assembly
AM	Airlock Module
APCS	Attitude & Pointing Control System
ARC	Ames Research Center
ASAP	Auxiliary Storage and Playback
ATM	Apollo Telescope Mount
ATMDC	Apollo Telescope Mount Digital Computer
BTU	British Thermal Units
CBRM	Charger Battery Regulator Module
CCB	Change Control Board
CCOH	Combined Contaminants, Oxygen, Humidity
CCS	Command Communication System
C&D	Control and Display
CEI	Contract End Item
CFE	Contractor Furnished Equipment
CG	Center of Gravity
C_L	Centerline
Cluster	SWS plus CSM (used synonymously with "Orbital Assembly")
CM	Command Module
CMG	Control Moment Gyro
CMGS/TACS	Control Moment Gyros Subsystem/Thruster Attitude Control Subsystem
C/O	Checkout
COAS	Crew Optical Alignment Sight
CO_2	Carbon Dioxide
COFW	Certificate of Flight Worthiness
COQ	Certificate of Qualification
cps	cycles per second
CRS	Cluster Requirements Specification
CSM	Command Service Module
C&W	Caution and Warning
DA	Deployment Assembly
db	Decibel
dc	Direct Current
DCS	Digital Command System
DCSU	Digital Computer Switching Unit
DDA	Drawing Departure Authorization
DDAS	Digital Data Address System
deg.	Degree
DTCS	Digital Test Command System
DTMS	Digital Test Measuring System

ECP	Engineering Change Proposal
ECS	Environmental Control System
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPCS	Experiment Pointing Control Subsystem
EPS	Electrical Power System
ERD	Experiment Requirement Document
ESE	Electrical Support Equipment
ESS	Experiment Support System
ETR	Eastern Test Range
EVA	Extravehicular Activity
°F	Degrees Farenheit
FAS	Fixed Airlock Shroud
fc	foot candles
FM	Frequency Modulation
fps	feet per second
FSS	Fine Sun Sensor
ft.	Feet
g	Acceleration due to Earth's Gravity
GFE	Government Furnished Equipment
Grms	G Level, root mean square
GSE	Ground Support Equipment
H_2O	Water
He	Helium
HSS	Habitability Support System
Hz	Hertz
ICD	Interface Control Document
IOP	In Orbit Plane
IU	Instrumentation Unit
IU/TACS	Instrument Unit/Thruster Attitude Control Subsystem
IVA	Intra-Vehicular Activity
JSC	Johnson Spacecraft Center
KHz	Kilohertz
KSC	Kennedy Spaceflight Center
LCC	Launch Control Center
LCG	Liquid Cooled Garment
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LRC	Langley Research Center
LV	Launch Vehicle
LVDC	Launch Vehicle Digital Computer
MDA	Multiple Docking Adapter
MGSE	Maintenance Ground Support Equipment
MHz	Megahertz
MRD	Mission Requirements Document
MS	Margin of Safety
m/sec.	Millisecond
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSOB	Manned Spacecraft Operations Building

N_2	Nitrogen
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook
NiCd	Nickel Cadmium
NM	Nautical Miles
O_2	Oxygen
OA	Orbital Assembly (SWS and CSM - Used synonymously with "Cluster")
OWS	Orbital Workshop
ΔP	Differential Pressure
PCM	Pulse Code Modulation
PCS	Pointing Control System
PMC	Post Manufacturing Checkout
POD	Planning Operational Dose
psi	pounds per square inch
psia	pounds per square inch absolute
psid	pounds per square inch differential
Q	Heat
RCS	Reaction Control System
RF	Radio Frequency
S-IB	First Stage of Saturn I-B Launch Vehicle
S-II	Saturn II
SAL	Scientific Air Lock
SAS	Solar Array System
SCN	Specification Change Notice
SL	Skylab Program
SM	Service Module
SWS	Saturn Workshop (PS/MDA/ATM/AM/OWS/IU/ATM Deployment Assembly)
ΔT	Differential Temperature
TACS	Thruster Attitude Control System
TCRD	Test and Checkout Requirements Document
TCSCD	Test and Checkout Specification and Criteria Document
UV	Ultra Violet
VAB	Vehicle Assembly Building (HI-Bay)
Vdc	Volts direct current
VHF	Very High Frequency
WMS	Waste Management System
WSS	Water Subsystem
Z-LV(E)	Z Axis in Local Vertical (Earth Resources Attitude Mode)
Z-LV(R)	Z axis in Local Vertical (Rendezvous Attitude Mode)

SECTION 3 - RELIABILITY PROGRAM

3.1 OBJECTIVE AND METHODOLOGY - The principle objectives of the MDAC Orbital Workshop (OWS) Reliability Program were to provide assurance that:

- System designs contained maximum inherent reliability consistent with Skylab (SL) program requirements and constraints;
- The as-built hardware retained its inherent design reliability;
- The OWS provided a reliable interface with other SL modules and/or equipment.

To attain these objectives a methodology was formulated premised on Apollo Applications Reliability and Quality Assurance Program Plan (NASA Document NHB 5300.5), Formal Reliability Program Plan, Saturn S-IVB System (MDAC Document SM-46863A) and other MDAC prior program experience. The subsequent formulation of this methodology culminated in the Orbital Workshop Reliability Program Plan (MDAC Document DAC 56701A) which was prepared for the NASA under Contract NAS9-6555, Schedule II and submitted under MSFC-DRL-171, Line Item No. G03.

The MDAC Reliability Program for OWS provided guidance, disciplines, and assessment applied to all phases, from design through test and delivery, to achieve a high quality, reliable, and safe OWS. MDAC organized the Skylab/Orbital Workshop (SL/OWS) Program in a manner that assured that reliability, quality, and safety requirements were determined and satisfied throughout all phases of contract performance. The salient feature of this program was an integrated engineering effort among the technology disciplines of Effectiveness (Reliability, System Safety and Maintainability), Design, Crew Systems and Logistics Support. The following paragraphs describe these interrelated functions and activities that enhanced the successful achievement of the Skylab mission. Figure 3.1-1 displays the interrelationship of these functions.

3.2 RELIABILITY - The Reliability Program was designed to assure delivery of a reliable system capable of successfully performing the planned OWS mission. The basic approach was to concentrate attention on hardware items critical to crew safety, mission success or launch operations. Table 3.2-1 presents the Reliability Program functions for the three basic development phases. Table 3.2-2 presents a list of criticality categories.

The following paragraphs briefly describe the various reliability program tasks and associated items that comprised the OWS reliability effort.

3.2.1 <u>System Reliability Analysis</u> - The basic analytical effort was the Failure Mode and Effect Analysis (FMEA). The FMEA for all mission phases used MSFC Drawing 10M30111A, Parts I and II, as a guideline except that all analyses were done on a single failure effect rather than a multi-failure effect basis. However, functions that were not critical single failure points only because of redundancy were identified and included in the documentation. Certain groundrules, as follows, applied to the preparation of the FMEA:

- o MSFC Document IN-P&VE-V-67-6 was used as a guideline for GSE analysis. One major exception was that the analysis began at rollout rather than at T-24 hours.

- o The analysis normally progressed to the replaceable component level. However, if the occurrence of a component's failure mode

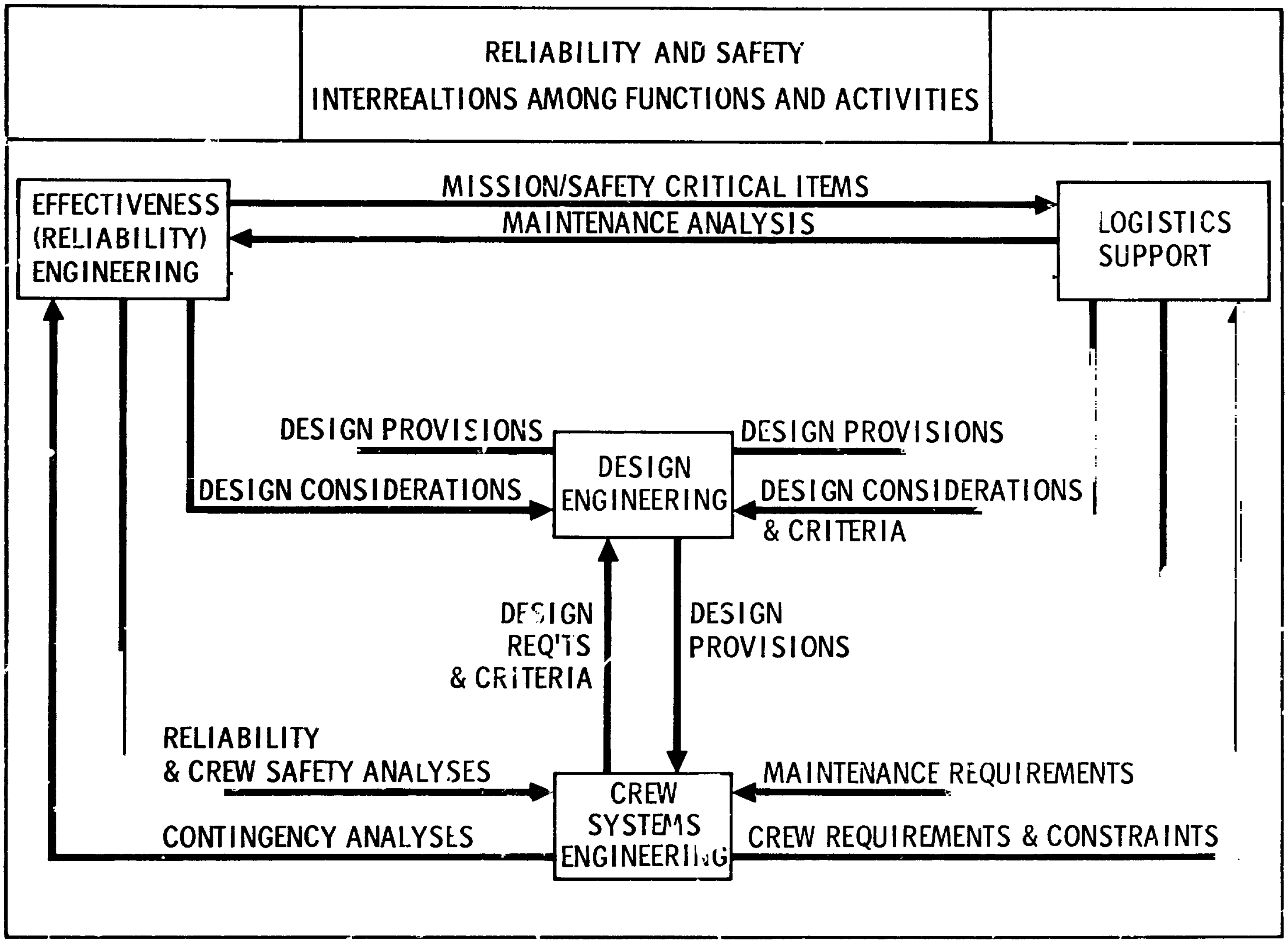

RELIABILITY AND SAFETY
INTERREALTIONS AMONG FUNCTIONS AND ACTIVITIES
EFFECTIVENESS (RELIABILITY) ENGINEERING
MISSION/SAFETY CRITICAL ITEMS
MAINTENANCE ANALYSIS
LOGISTICS SUPPORT
DESIGN PROVISIONS
DESIGN CONSIDERATIONS
DESIGN ENGINEERING
DESIGN PROVISIONS
DESIGN CONSIDERATIONS & CRITERIA
DESIGN REQ'TS & CRITERIA
DESIGN PROVISIONS
RELIABILITY & CREW SAFETY ANALYSES
CONTINGENCY ANALYSES
CREW SYSTEMS ENGINEERING
MAINTENANCE REQUIREMENTS
CREW REQUIREMENTS & CONSTRAINTS

Figure 3.1-1

TABLE 3.2-1

RELIABILITY PROGRAM FUNCTIONS BY DEVELOPMENT PHASE

Development Phase	Reliability Program Function(s)
Conceptual Design	Preliminary Failure Modes and Effects Analysis (FMEA)
	Reliability trade-off studies
	Internal Design Reviews (IDR's)
Detail Design	Updated FMEA's, Criticality Analyses (CA's), establishment of Mission/Safety Critical items (M/SCI), and establishment of Critical Components List (CCL) and Retention Rationale.
	Workshop Design Review (WDR)
	Supplier reliability requirements
	Drawing and specification approval
	Parts and materials usage control
Production, Test, and Operational Use	Test and assessment document, component acceptance status, and certificate of component acceptance
	Test procedure approval, test monitoring, and test report approval
	Review of failure reports, failure analyses and corrective action
	Engineering Change Proposal (ECP) and drawing change approval

TABLE 3.2-2
CRITICALITY CATEGORIES

General Category	Failure Description	SFP Category
1	Single failures of flight hardware which could result in loss of human life or incapacitating injury.	1
1R	Failures of redundant or backup flight hardware which exposes a single failure point, the subsequent failure of which would be categorized "1."	-
2	Single failures of flight hardware which could result in loss of mission or inability to achieve other primary mission objectives but would not create conditions hazardous to the safety of the astronauts.	2
2R	Failures of redundant or backup flight hardware which exposes a single failure point, the subsequent failure of which would be categorized "2."	-
2B	Failure of flight equipment which could cause a launch reschedule.	2B
A	Failures of MDAC supplied GSE which interfaces with crew life support functions or system functions during countdown and launch which could create hazardous conditions adverse to the safety of the ground/flight crew or the vehicle.	A
B	Failures of MDAC supplied GSE which interfaces with crew life support functions or system functions during countdown and launch which could either result in an inability to achieve primary mission objectives or cause a launch reschedule.	B
5	All other functional failures.	-

NOTE: Criticality category is based on the effect of the observed failure without knowledge of the cause. The failure must be considered to occur randomly. Categorization is based on a "worst case" analysis of the failed configuration and also of any similarly constructed configurations subject to the same mode.

would have created a crew safety hazard or lead to an orbital mission abort and a contingency procedure was not available or planned, the FMEA was extended downward until those circuits/parts which were the lowest level SFP's were identified.

- A schematic and logic block diagram accompanied the FMEA to identify the subsystem components, their function, their dependencies and their input-output requirements. Each function was analyzed for the following failure modes and their impact on the system.

  A. Premature operation

  B. Failure to operate at prescribed time

  C. Failure to cease operation at prescribed time

  D. Failure during operation

- Prelaunch operations were analyzed to identify those failures of OWS equipment not detectable on the ground which would have resulted in a mission loss after launch. The possibility of eliminating these conditions if identified was investigated.

A. Identification of Single Failure Points - A single failure point (SFP) was defined as a single item of hardware whose failure would have adversely affected crew safety or resulted in loss of OWS mission or primary mission objectives. Structural members which performed no function other than to provide structural integrity were excluded. Certain ground rules were established for determining whether or not specific failure modes were to be classified as SFP's. These were as follows:

1/ A failure mode was not an SFP if either of the following conditions existed:

a. Redundancy was available where two or more independent failures must occur before a critical effect results. Redundancy was defined as two or more elements available to provide the same function, either simultaneously (active) or by selection through automatic or manual switching (standby) by ground command or astronaut actions. When simple redundancy (only two elements to perform a given function) existed where otherwise the function would be a critical SFP, the FMEA contained the effect of failure, both with and without the redundancy.

b. A backup was available to accomplish the required function. A backup was defined as a contingency procedure available for use which required unscheduled astronaut actions (other than simple manual switchover) to render the system to an acceptable condition for use. Use of orbital spares was included.

2/ Loss of any or all experiments data was not considered critical. Loss of any other data was considered critical only if the data was mandatory for continuing the Skylab mission.

3/ Leakage failures resulting in loss of OWS atmosphere overboard were categorized as possible mission loss if the maximum leakage rate caused a loss greater than five pounds per day with all other leakage paths within limits. If the maximum leakage rate was sufficient to cause the Caution and Warning System to be energized, the failure was categorized as a crew hazard.

4/ A failure in the Solar Array System (SAS) must have reduced available electrical power more than 12-1/2 percent to have been classified as an SFP.

5/ Loss of one refrigeration loop, loss of one heating and ventilation duct and one electrical bus out were not considered to result in loss of mission and thus any single failure causing one of these conditions was not classified as critical.

B. Identification of Launch Critical Components - A Launch Critical Component (LCC) was defined as a component not classified as an SFP, but whose failure during launch pad operations would have resulted in a launch reschedule. A launch reschedule was defined as a delay of sufficient duration to require detanking of propellants and retanking to a new countdown sequence. LCC's met the following criteria:

1/ Functions actually operating prior to launch.

2/ Detection capability existed. This information was stated with detection method and measurement number if applicable.

3/ Only those failures which would have caused a launch reschedule (detank and retank) were to be included. Launch delay items were excluded.

C. Caution and Warning System Analysis - The Caution and Warning

(C&W) System was analyzed to identify those safety and hazard monitoring system components which, if individually did not function as required, i.e., positively indicating a failure in the operating system being monitored, would have caused a crew hazard.

D. Critical Redundant/Backup Components - During the performance of the FMEA, components which, if it were not for redundancy or availability of a backup means to perform their function, would have been an SFP were identified. Single redundancy only was considered. If two or more unrelated failures were required before a critical SFP was created, the component did not receive this classification.

E. Contingency Analysis - Concurrent with the preparation of the FMEA a contingency analysis was implemented. This analysis identified those contingency actions available to the astronauts to implement in the event hardware malfunctions occurred. This was essentially a feedback operation, where the FMEA identified the need for a contingency procedure and when the procedure was created and the facilities planned for its performance, the failure mode in the FMEA was downgraded to its ultimate effect on the system. In this manner, the final critical SFP list contained those failure modes which represented a degree of risk because they were still contained in the system.

F. Risk Acceptance Rationale - A statement justifying acceptance of the associated risk was prepared for the following hardware after application of the contingency analysis described above:

1/ SFP's with a criticality category of 1 or 2. The design goal was to eliminate, if at all practicable, all Category 1 SFP's.

2/ Launch Critical Components with a criticality category of 2B.

3/ GSE with a criticality category of A or B.

4/ Caution and Warning System Components identified as described in Paragraph C. above. There is no SFP criticality category for these components because by definition they were not SFP's for the total OWS system. They were, however, SFP's for the C&W system itself. These components complied with Criticality Category 1S as defined in Annex A of MSFC Program Directive MPD 8020.4, dated 16 July 1970.

G. Criticality Analysis - A Criticality Analysis was performed for all criticality 1, 2, and A SFP's and criticality B SFP's affecting primary mission objectives. This analysis used the factors contained in MSFC Drawing 10M30111A and IN-P&VE-67.6.

These factors were used to determine a Criticality Number (CN) for each SFP. Criticality, in this connotation, was that portion of the unreliability of an SFP associated with its failure mode which could have resulted in crew hazard, mission loss or primary mission objectives loss. The CN itself, represents the expected number of failures attributed to the SFP in one million mission attempts. If a given SFP could have resulted in more than one of these effects, a separate CN was computed for each SFP for each resulting effect.

H. Criticality Ranking - Criticality ranking was done to provide a convenient comparison of SFP's for their respective contributions toward crew/mission/primary objective loss. In the comparison, it was important to treat criticality numbers relatively rather than by actual quantitative values. The value of the ranking was that it identified the areas where the most unreliability existed as a guide to product improvement design efforts.

I. Government Furnished Property (GFP) and Experiment Data - The OWS FMEA and criticality analysis considered Government Furnished Property, including OWS corollary experiments. The Contractor included the analysis of GFP to the same depth and to the same criteria and groundrules as Contractor furnished equipment providing the necessary data was made available to the Contractor by NASA/MSFC.

J. Mission/Safety Critical Items (M/SCI) - The main objective of the analytical reliability task described in this section was to identify those items of hardware critical to the OWS mission and eliminate them or minimize their impact through the design and contingency action process. The associated risk for those remaining must be accepted. To help provide justification for this acceptance, a M/SCI list was created such that these critical items could receive special program disciplines during the design review, production, test, assembly and checkout phases of the program. The following groundrules applied:

1/ The M/SCI list contained all SFP's of Category 1, 2, A or B. The list also included SFP's having a criticality of 2B at the discretion of technical management. Non-SFP's were also included if they performed essential functions (though not critical), were advanced designs pushing the state-of-the-art, could have caused some degree of crew discomfort, or were in the more critical redundant systems. With this selectivity, these special program disciplines were imposed in a cost effective manner.

2/ The M/SCI was normally at the replaceable component level. The level was higher or lower, however, if more convenient and did not prevent the implementation of the necessary disciplines.

3/ Electrical cables and piping runs were excluded.

4/ Structural items having no function other than providing structural integrity were excluded.

The M/SCI list was maintained internally by the Contractor as a Design Requirements Drawing. Additions or deletions to the list were made by Reliability Engineering to continually reflect the latest FMEA.

3.2.2 Design Support - Premised on the output of the system reliability analysis effort, Reliability Engineering provided support to the design technologies in the generation of criteria and guidelines necessary to the development of a safe and reliable OWS.

A. Orbital Maintainability/Maintenance Evaluation - The analytical effort described in Paragraph 3.2.1 was used as a tool to determine what hardware items should have maintainability provisions as a design criteria and what maintenance provisions should be available to the astronaut to maximize their presence in order to attain a successful and non-hazardous mission. The feasibility or providing useful orbital maintenance was enhanced by the presence of the Caution and Warning System.

The maintainability/maintenance task was a joint effort among Reliability Engineering, Crew Systems, Logistics Support and the Design Technologies. The effectiveness engineering support of this effort included the following tasks:

1/ Identification of M/SCI's offering potential for improved mission capability through orbital maintenance.

2/ Identification of critical failure modes correctable through orbital maintenance.

3/ Assurance that maintainability as a design criteria was implemented through the design review process and day-to-day communication with designers.

These recommendations for orbital maintenance and the design features provided to accommodate this orbital maintenance were used to:

- o Establish in-orbit spares requirements.
- o Establish the tools required for performing orbital maintenance.
- o Assist in the preparation of crew contingency procedures which utilized this orbital maintenance capability.

B. Parts and Materials Program - The Contractor implemented a parts and materials program for the selection, control, and application review of parts and materials for items used in the OWS. Selection of electronic and electro-mechanical parts and materials for the OWS was based on proven capability of each part and material for its application. It was the Contractor's goal to minimize and control the existing number of parts and material types through the selection and subsequent design review process.

Where adequate specifications for parts and materials did not exist, the Contractor prepared them. These specifications were responsive to the requirements which resulted in a reliable system. These requirements were imposed in the form of readily measurable values which included:

- o Dimensional requirements
- o Performance requirements
- o Quality assurance requirements (inspection and production acceptance functional testing)
- o Special screening requirements which may include x-ray, seal leak tests, burn-in cycling
- o Manufacturing process restrictions or special controls
- o Toxicity and/or flammability requirements
- o Protective packaging

The adequacy of existing parts and materials test data were reviewed to assure that development and qualification testing was performed under environmental conditions equal to or more severe than anticipated in OWS applications. Test data were reviewed to assure that performance requirements and failure criteria were also applicable to those in planned OWS usage. Where adequate data was not available, the Contractor designed and conducted tests to provide the necessary data.

C. Parts Usage Control (Approved Parts List)

1/ MDAC Fabricated Items - An Approved Parts List (APL) was prepared utilizing the data derived from prior programs, parts application studies and testing. This APL governed parts application for MDAC fabricated flight and GSE items. It contained those parts specifications defined in paragraph B. which required that MDAC fabricated items contain screened electrical, electronic and electro-mechanical parts to insure maximum use reliability.

2/ Supplier Procured Items - Supplier procured items (higher than the part level) had the following parts usage controls imposed.

a. On all flight items, the procurement documentation required that each supplier submit a complete parts list, including his procurement specifications, to MDAC for review and approval. Changes thereto were subject to prior MDAC approval. The order of precedence was defined.

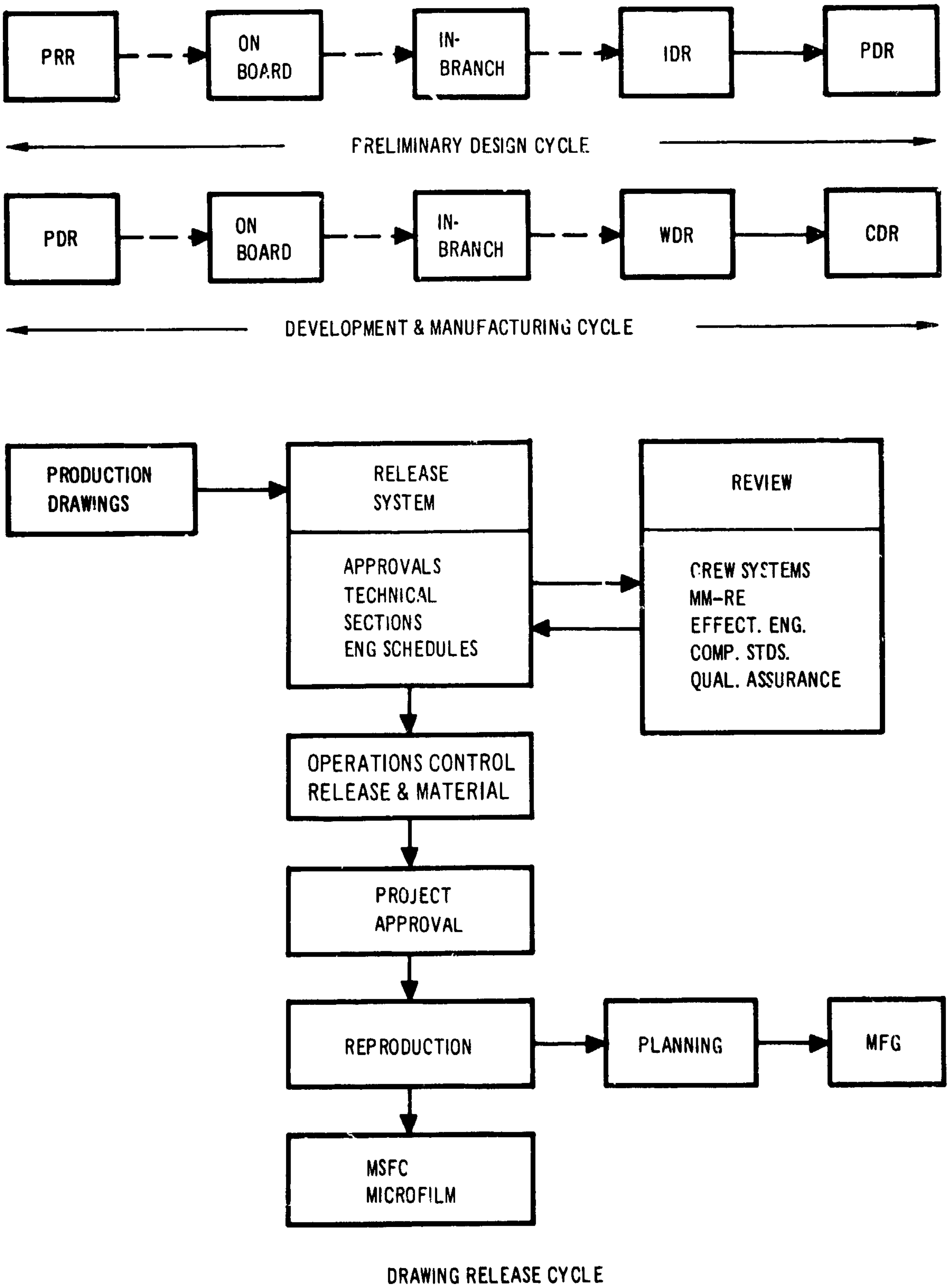
b. On all applicable supplier procured M/SCI's and selected supplier procured non-M/SCI's (both above the part level), a specification was imposed which contained requirements for selection, environmental screening and testing, quality assurance documentation and evaluation of the electrical, electronic and electromechanical parts to be used. This requirement applied to lower tier suppliers down to the part level.

D. Parts Derating Requirements

1/ MDAC Fabricated Items - Electrical, electronic and electromechanical parts used in MDAC fabricated flight hardware items were derated in accordance with established guidelines as required to achieve the long life capability of the OWS system.

2/ Supplier Procured Items - Selected supplier procured items, basically those containing electrical, electronic and electromechanical parts, had derating requirements imposed in that the derating criteria used by the supplier was subject to review and approval by MDAC. Items included in this parts derating effort included but was not limited to M/SCI's. The selection was made on a cost-effective basis considering past parts problems encountered in the Saturn/Apollo Program and the controls necessary to prevent their recurrence.

E. Design Review Program - The Design Review Program for the OWS was comprehensive and included several types of reviews depending upon the level of presentation and point in the development cycle. The program included informal reviews within the design technologies, formal design reviews by a single review board and the basic drawing release system which ensured review and approval by appropriate technologies and agencies during drawing release. The timing of design reviews and the drawing release system are depicted in Figure 3.2.2-1. Informal design reviews were held at the drawing board and the branch level to resolve component and subsystem design problems so that alternate approaches could be evaluated. Formal design reviews were conducted at the system level to ensure that the system met design and performance requirements. The



Design Review Flow Chart
Figure 3.2.2-1

formal design reviews were of two types:

1/ Internal Design Review (IDR) - An IDR was a review of the conceptual design following the NASA Preliminary Requirements Review (PRR) and prior to a Preliminary Design Review (PDR) with NASA. This review was held during preliminary design development to ensure in house coordination between the technologies and the program offices (e.g., Design Office, Project, Quality Assurance).

2/ Workshop Design Review (WDR) - A WDR was a review of the final design as depicted on engineering drawings. This type of review was held following the PDR and preceding the Critical Design Review (CDR) with NASA, and at a time when substantial numbers of production drawings were available. The review ensured coordination between the technologies at the detail level and ensured that production designs met PDR updated requirements. The design reviews were conducted by the Contractor on each OWS system. These reviews considered the design, system requirements, engineering analyses, reliability, crew safety, crew interfaces, systems interfaces, maintainability, spares provisioning, materials and processes, test data, producibility, and quality assurance provisions. During the review, presentations were made to a formally constituted Design Review Board whose membership possessed the technical capability and authority in the aforementioned review consideration areas. Some of the major objectives of the Design Review Board deliberations included elimination of SFP's, changing failure categories, and minimizing the attendant risks of M/SCI's. Documentation of the reviews included decisions and agreements, any action items, and assignments.

A large part of the supporting documentation for the review was obtained from FMEA's, specification reviews and parts and materials program activities.

F. Design Specification Review - Reliability Engineering reviewed and approved all M/SCI design specifications and drawings to assure that they included necessary provisions for reliability, maintainability and crew safety. This was in addition to a review by other analytical agencies for consideration of predicted environments, operating loads and safety margins (derating factors). The check list for this review covered:

- Proper reliability requirements specification callout
- Proper operating environments specified
- Output performance specified and compatible with the FMEA
- Adequate test requirements and test data documentation.

Revisions to these specifications and drawings in the form of Engineering Orders (EO's) were also reviewed and approved to assure maintenance of the required design integrity.

G. Engineering Change Proposal (ECP) Review - All ECP's were reviewed to the maximum extent possible with the design definition existing at the time of review. The following points were covered in this review.

- Effect on criticality

- Effect on single failure points
- Effect on systems safety
- Effect on redline parameters

After ECP approval, additional Reliability Engineering analysis was accomplished to the point of design release to support the design drawing and specification approval function.

H. Supplier Reliability Requirements - Procurement documentation for M/SCI's required that the supplier plan and implement an engineering reliability discipline which influenced the inhouse design process in the same manner as if this work was done within MDAC. The suppliers were required to selectively provide the following data as evidence of their analytical engineering reliability activity.

- A program plan containing such elements as organization, task descriptions and schedules
- A Failure Modes Cause Analysis
- Failure Mode Probability
- Specific design measures taken to minimize the probability of occurrence of these failure modes
- A joint MDAC-supplier design review to critique the suppliers design drawings and specifications. Test data and provisions for orbital repair/replacement.

Certain M/SCI items did not require all of the elements described above. Therefore, the requirements imposed on each M/SCI supplier was tailored to meet the need for the item being supplied.

3.2.3 Production and Test Support - The primary reliability effort in support of production and test was aimed at assuring that the as-built hardware attained and retained its inherent design reliability. In accomplishing this goal, Reliability actively participated in the functions described in this section.

A. Review of Test Plans, Requirements, Procedures and Reports - Reliability Engineering reviewed and approved all Mission/Safety Critical Items (M/SCI) Specification Control Drawings (SCD), Test Control Drawings (TCD), Test Procedure Drawings (TPD), MDAC and Subcontractor Test Plans, Production Acceptance Test Requirements Drawings (PATRD), Production Acceptance Test Procedures (PATP), test reports, and changes thereto.

The SCD, TCD, and PATRD were drawings originated by the cognizant Design Technologies to specify verification of design requirements by testing. The TPD, APTP, and Subcontractor Test Plans, were drawings originated by agencies outside of Design Engineering, which reflected the procedures used to meet the requirements of the engineering drawings.

Reliability participated in the definition, formulation and approval of these drawings for the purpose of assuring that the design and conduct of the test established th susceptibility to critical failure modes.

B. Electronic Module Screening - Reliability, early in the OWS Program conducted an investigation to determine if, based on previous program experience, environmental screening of electronic modules would be beneficial and cost effective and if so what selection criteria should be used. The results of this investigation were affirmative and led to the development of Product Acceptance Test Requirements drawing Vehicle Circuit Modules Screening (1B79368).

The affirmative recommendation for inclusion of post manufacturing controlled screening tests on selected electrical/electronic modules was based on the following rationale:

1. An investigation of SIVB Electrical Hardware Supplementary Failure Analyses disclosed approximately 10 percent of module functional anomalies occurred after the module post-encapsulation Production Acceptance Test (PAT). This test customarily does not include environmental tests.

2. Reliability of the module would be increased by reducing the portion of the overall module failure rate attributed to fabrication-induced anomalies.

3. Extended operational requirements of the Orbital Workshop (OWS) necessitated every effort be made to eliminate infant mortalility prior to module operation.

4. Other studies showed additional corrective action, other than upgrading workmanship and inspection techniques was needed.

Each module was considered independently to determine what post-manufacturing screening tests the module would be subjected to, e.g., thermal-cycling, operation burn-in, low-level vibration, etc. Determining factors in this decision were:

1. Complexity of the module.

2. Type of piece parts contained in the module and the type of internal structure, i.e., P.C. boards, I.C.'s etc.

3. Function of module in the OWS.

The basic investigation consisted of research of SIVB Supplementary Failure Analysis (SFA) files. Of the 173 electrical SFA's in the file, 18 functional anomalies met all of the following conditions:

1. Failures occurred after the module final PAT, i.e., in the system, on the stage.

2. Use of a screened piece part would not have precluded the failures occurring.

3. The anomaly would have been detected by a controlled screening test of the module.

4. Past corrective actions were primarily related to the areas of manufacturing and inspection.

Thus, the research disclosed approximately 10 percent of those electrical SFA's reviewed were performed on modules that contained either design or fabrication anomalies that would have been detected by controlled screening tests. Those anomalies consisted of:

1. Missed or inadequate welds.

2. Poor solder joints.

3. Handling damage to a piece part during the next assembly fabrication.

4. Wrong value piece part installed.

5. Piece part misinstalled (i.e., wrong polarity of capacitor).

6. Installation damage to a piece part during next assembly fabrication that was compounded by encapsulation stresses.

7. Marginal design.

Since reliability of a module is determined by the failure rates of the internal piece parts, design plus derating practices, and fabrication induced anomalies it was concluded that the reliability of the module would be increased in all three areas if controlled screening tests were performed on the module. The most significant improvement was in the area of fabrication-induced anomalies. The second most significant improvement was in the design and derating area.

The research also showed that since more complex modules are most susceptible to fabrication-induced anomalies and certain piece parts are more susceptible to fabrication-induced damage, all modules should not have screening tests. Also, the modules selected need not have all screen tests performed on them. This was dependent on complexity and the internal piece parts.

C. Loose Particle Detection Test (LPDT) - A loose particle detection test (LPDT) was imposed on selected electrical/electronic components used on OWS. This test was imposed at the component PAT level with the purpose of increasing overall system reliability. Components subjected to the test were relays and certain semiconductors. Basis for the selection was past failure history from the SIVB program on similar components and engineering judgement. The test consisted of acoustically monitoring the component while it is being vibrated sinusoidally at 20 Hz and 2g's. The program was considered highly successful. No particle related failures occurred in any of the screened components after installation into a next higher assembly.

D. Hardware Acceptability - Early in the OWS Program, it became apparent that hardware acceptability and verification would require special attention. This was due primarily to two main reasons, both of which were premised on cost effectiveness. One was that hardware that had been qualified on previous NASA programs would be utilized where ever possible. The second was that for the most part when testing was accomplished it would not attempt to qualify the hardware for the full duration SL mission.

This concept, while reducing development and qualification testing, did not however reduce the requirements to verify and validate the acceptability of all flight critical hardware. In attempting to define these requirements it was deemed necessary to establish two major categories for hardware qualification; test and/or assessment. This led naturally to the need for a single reference source which became known as the Test and Assessment Document (TAD).

The Test and Assessment Document (TAD) was a formal compilation of Contractor/Customer agreed to requirements for equipment acceptability. The TAD contained, for each applicable item, design and mission requirements in terms of exposed environments and stresses with the associated levels for each specific application. The TAD also included the verification method (test and/or assessment) which was to be employed to satisfy equipment acceptability in meeting the requirements. Where test was the verification method, the TAD iterated the specific test line item to be used to satisfy each requirement. Where assessment was the verification method the TAD provided rigorous rationale, contained therein or by reference to other accepted documentation, in terms of analyses, prior use in similar applications, and/or test documentation from other sources to show the equipment met each requirement.

Certification that the hardware had indeed met the requirement defined in the TAD became the function of the Certificate of Component Acceptance (CCA). Throughout the development phase the CCA was published monthly as a status report referred to as the Component Acceptance Status (CAS). Upon completion of testing and/or assessment of a given item the CCA was submitted to NASA/MSFC for signature approval that that particular item was indeed qualified and acceptable for the OWS.

The CCA was a multi-section document consisting of configuration history, test history, failure history and the certificate itself. The configuration history defined changes from the baseline reviewed during TAD negotiations. The test history, if applicable, defined the test line items being conducted, their status, the configuration under test, and the difference between the test and flight configuration. The failure history described the nature of all failures and their subsequent resolution and/or corrective action. The certificate section identified the mandatory flight configuration, the methods of qualification (test and/or assessment), applicable procedures and specifications including other pertinent documentation which supported TAD requirements. The certificate also provided for MDAC Design and Reliability Engineering signature approval in addition to NASA/MSFC Design and R-Qual.

E. Non-Conformance Reporting, Analysis and Corrective Action Control - A maximum effort was maintained throughout the OWS design, development, and production phases to provide management visibility and control of all non-conformances, failure analysis, and corrective actions. This section discusses the general system and techniques employed to this end.

Quality Assurance was responsible for the detection and reporting of non-conforming material. Upon detection, all nonconforming material was promptly removed from the system and impounded for disposition and completion of the non-conformance report.

NOTE: The system provided control through Failure and Rejection Report Supplements (FRR Supplements), and Test Problem Reports (TPR's) where immediate removal of nonconforming material was neither desirable nor practical. Such circumstances often arose during Qualification Testing and Checkout.

Quality Assurance utilized three basic documents to report nonconformances, i.e., Inspection Item Sheet (IIS), Failure Report (FR) and the Discrepancy Report (DR). The IIS was used to report temporary nonconformances and to disposition items which had exceeded their age/life limits. The IIS was initiated to authorize removal and replacement of nonconforming removable details/assemblies, or to authorize troubleshooting during acceptance testing, systems/subsystem test or checkout. Where a problem could be eliminated by allowable adjustment, the IIS was used.

The FR was used to report functional nonconformances occuring during qualification test, acceptance test and/or normal operation. The DR was used to report nonconformances such as dimensional discrepancies, improper processing and physical discrepancies (non-functional).

As defined, both the IIS and DR imply for the most part minor discrepancy categories. As such, these items were routinely dispositioned through the Material Review Board (MRB). The nonconformances which fell into the FR category presented a far greater potential of overall program impact and were considered priority one. Upon detection and initiation of an FR, Quality Assurance notified Development Engineering (DE) of the problem. DE immediately initiated a preliminary analysis and investigation of the reported problem. The chronology of this investigation generally followed the following format. Determination of the failure mode and effect if the reported problem had occurred during launch countdown and/or during flight. A record search for any previous similar or like failures. It was policy to require as a minimum an FRR Supplement for all failures whose effect could jeopardize personnel safety, Mission and or Vehicle launch. The preliminary investigation by DE normally included hardware retest prior to removal, supplemental tests (within operational spec) for additional data points and analysis of all performance data.

The FRR Supplement was an engineering initiated document defining failure history, failure effect, the preliminary investigative data (previous and current) and a cause conclusion. The primary purpose of the FRR Supplement was to provide a comprehensive data base in determining Supplemental Failure Analysis (SFA) requirements. The FRR Supplement therefore presented the total operational and performance history to program management, and Quality Assurance for their concurrence with engineering's SFA recommendation. Where this documentation revealed the cause of failure, no SFA was recommended, where the data failed to indicate the problem cause conclusively, an SFA was recommended.

Upon review and approval of the FRR Supplement recommendations by program management, the disposition of the failed hardware was reflected on the FR. In either case the FRR Supplement was attached and became a permanent part of the FR. Where data indicated the cause of the problem the FR was completed, indicating cause and corrective action to prevent recurrence and was submitted to the customer (USAF) for concurrence. When the problem required further and detailed investigation to determine failure cause an SFA was initiated. Of the 388 FRR Supplements on the OWS Program 109 resulted in SFA's.

The SFA as the name implies, was a supplement of the FR designed to control the failed hardware during investigation of the problem, and upon completion became a permanent part of the FR. The SFA defined in detail the scope of the investigation, who and where performed and served as a data record during the investigation. The SFA was carried out to the degree necessary to define cause of failure. Development Engineering at that point described their cause rationale and recommended any necessary corrective action. Upon completing the SFA documentation, the data was presented for review and concurrence of the SFA Review Board. Final closure of the SFA was withheld by the Board until proof that necessary corrective action had in fact been implemented. With closure of the SFA all documentation was attached and summarized on the FR which was submitted for Customer approval.

The foregoing discussion has been limited for the most part to hardware handling internal to MDAC-W. At least two other classes of nonconforming hardware should be mentioned that which was Government Furnished (GFP) and Supplier Furnished Material (SFM).

GFP nonconformances were reported and documented upon the FR or DR system. The cognizant government agency was then immediately notified and arrangements were made to return the subject hardware to that agency for investigation disposition. FR/DR was placed in suspense pending completion of the government directed investigation and corrective action documentation. Upon receipt of such information the FR/DR was completed and closed.

When MDAC elected to return nonconforming SFM to the manufacturer (this was often the case where failure occurred during acceptance testing) for analysis and corrective action it was accomplished via the MDAC "Supplier Rework and Recurrence Prevention Record" (SRRPR). This system worked much as the handling of GFP, where an FR/DR was initially written and held open pending receipt from the supplier of the SRRPR defining the cause and corrective action determined by the supplier. Following MDAC review and concurrence of the data submitted, the FR/DR was completed reflecting the SRRPR information and forwarded for customer closure approval.

The "Test Problem Report" (TPR) was used during OWS final assembly and checkout. The TPR was identical in format and intent to the previously discussed FRR Supplement. Differing only in that its utilization was confined to post manufacturing vehicle checkout.

It should be noted that integrated throughout the MDAC nonconformance system were provisions to input the IDEP Alert System. Each applicable OWS nonconformance occurrence was evaluated (both SFA and FRR Supplements required such notation) determining whether an alert should be requested. All nonconformances which were applicable to the alert system, resulted in requests for such alerts.

3.3 CONCLUSIONS AND RECOMMENDATIONS - The Orbital Workshop Program presented many challenging reliability problems which were the result of mission and operational requirements and constraints unique to the Skylab Program. Some of these were the "one-of-a-kind" concept, the "off-the-shelf" concept, the mission duration and the fact that this was the first operational space station.

Mission duration had probably the most significant influence on reliability. This parameter alone was the subject of many system engineering trade studies. Typical of these problems were loss of consumables due to leakage, level and types of redundancy, maintainability versus redundancy, manual versus automatic operation, ground versus on-board control, etc.

Leakage by itself was a major problem and eventually led to an engineering management decision to braze or weld all fittings whereever feasible. Where brazing or welding was not feasible special redundantly sealed and torque free joints were developed. The effectiveness of this approach was demonstrated by the Thruster Attitude Control (TAC) and Refrigeration Systems in that no measurable leakage was detected.

Levels and types of redundancy also presented a problem in that for missions of this length the probability of multiple failures was significantly increased. Yet on the other hand multiple redundancy increased system complexity, required detection and selection capability and complicated system checkout, all of which tended to oppose reliability. The basic solution to this problem was two independent systems either of which was capable of performing the function for the mission duration. Typical of this solution were the Refrigeration System which contained two completely independent loops and the electrical bussing concept which provided for two independent busses from the AM/OWS interface to all critical functions. Another example is the TACS system which incorporated series parallel thruster control valves in a quad-redundant configuration. Each parallel leg in the quad was controlled by a separate electrical bus. The series arrangement in each quad protected against leakage, inadvertant operation and/or failure of a single valve to close.

Maintainability was utilized in lieu of and/or in addition to redundancy where the overall effectiveness of the system dictated. Prime examples of this concept were the Waste Management Compartment (WMC) and Wardroom (WR) water dump probes. Since loss of cabin atmosphere was a program concern it was decided to limit the number of Habitation Area (HA) penetrations thus reducing the number of potential leak points. However, the WMC and WR water dump probes which exited the HA into Waste Tank (WT) offered a potential for clogging especially due to icing. To overcome this potential problem spare probes were stowed on-board and the SL crews were trained in the maintenance task of removing and replacing these probes. In fact during SL-3, the WMC probe did clog up and Astronaut Al Bean accomplished the task of removing and replacing it, thus restoring the system to a fully operational status. Subsequent to performing this task, Al Bean reported that the job had been easy to accomplish and that he wished he had done it sooner instead of wasting the time they had in attempting to free the clog.

In summary, the effectiveness of these concepts were evidenced by the success of the SL mission. In retrospect and in light of actual on-orbit operational experience there probably are things that would have been and should be done differently for future programs. One of these obviously has to be an increase in maintainability provisions for future manned space systems as evidenced by the ability of the SL crew to maintain and repair the systems under the most adverse of conditions.

SECTION 4 - SYSTEM SAFETY PROGRAM

4.1 GENERAL - The Contractor recognized the requirement to make a total commitment to provide experience, disciplines, and motivation to design and maintain through handling and operations, the highest possible level of safety.

The Orbital Workshop (OWS) System Safety Program (SSP) covered three basic areas: Design, Ground Operations, and Flight Operations. This overall program was implemented by the System Safety Program Plan (DAC-56759) per MSFC DRL-171, Line Item H02, December 1969, and supplemented by a combination of activities such as: those of an on-going nature within MDAC, those defined by various other Program Plans and/or Specifications, and special activities not included in these two primary categories.

MDAC on-going safety activities consist of those defined in the MDAC Employe Safety Manual (M5.057-AC) as well as other activities which implement the requirements of standard MDAC policies and procedures. Additional activities were defined by the OWS Crew System Integration Plan and various NASA and/or government directives/specifications, e.g., the KSC Range Safety Plan. A number of special activities not defined in the above were also performed, two of significance were the Contractor review and evaluation of the OWS, using: (1) the 266 space flight hazards contained in NASA/JSC Space Flight Hazards Catalog, and (2) the Skylab System Safety Checklists.

The MDAC OWS System Safety organizational responsibilities were basically in four areas.

A. All program personnel were responsible for seeing that safety governed their OWS efforts in all design and operational areas. In addition, three coordination and surveillance organizations assisted as noted below in paragraph B, C and D.

B. As a derivitive of the Saturn/Apollo Program management it was desired that a single interface be maintained with the customer in the interest areas relative to safety. To this end the Product Assurance organization was designated to fulfill this role and provided the overview to Industrial Safety, System Safety Engineering, and the Quality surveillance and control over OWS ground operations, such as manufacturing, handling and transportation.

C. Effectiveness Engineering, as part of development engineering, was primarily involved in design activities of flight hardware including a considerable expenditure of effort for the design of ground support equipment.

D. Employe Safety had responsibility for ensuring that MDAC Industrial Safety Standards and Federal, State and local safety regulations and ordnances were complied w

The above three activities operated as inter-dependent activities with substantial amount of coordination. Representatives from all three of the organizations were often times in attendance at appropriate OWS meetings to discuss safety related items.

The key elements in implementation of the overall System Safety Program are shown in Table 4.1-1. Each will be covered with respect to their use in subsequent paragraphs.

KEY ELEMENTS OF THE OWS SYSTEM SAFETY PROGRAM

- Failure mode effects analysis (FMEA)
- System logic analysis (SLA)
- Contingency analysis (CA)
- Hazard identification, assessment and resolution
- Design review
- Design change review
- Hazardous materials control
- Flammable materials control
- Contamination control
- Mission safety critical items (MSCI) control
- Hardware integrity reviews
- Review of operations with potential for damage to equipment or injury to personnel (Manufacturing, Handling & Transportation, Test, Pre-Flight)
- Test procedure reviews (Manufacturing, Acceptance, Pre-Flight)
- Operational procedure reviews (Handling & Transportation, Test, Pre-Flight, Flight)
- Man-machine interface verifications
- Nonconformance reviews
- Safety and safety related audits (Internal, Government)
- Accident/incident investigation, reporting and corrective action
- Alert processing
- Training (skills, operational, motivational)
- Subcontractor/supplier safety activities
- Special investigations and reviews (Spaceflight hazards catalog, System safety checklists)
- Safety surveillance and monitoring

TABLE 4.1-1

4.2 CREW SAFETY

4.2.1 Concept Phase - The crew safety program was consituted in the design phase with the incorporation of the manned mission awareness which became part of the design activity from initial concepts to final design. This design approach was directed toward the evolution of a design minimizing personnel hazards or mission loss conditions.

It became essential to affect the design as early as possible with the manned interface and to identify requirements stemming from the necessity to provide a habitable, safe atmosphere which would satisfy the total mission requirements. The concept adopted consisted of review of preliminary design and mission specifications by personnel principally involved in system safety within the engineering organization. This review was systematic and devoted to the early identification of potential crew hazards or mission loss conditions to the engineering activity for impact on design and testing. In addition the results of other analyses were reviewed with respect to safety such as the output of the reliability effort in assessing the effects of single failure points in terms of ground personnel or crew hazard potential.

4.2.2 Design Phase - Once the safety aspects were implemented in the design concepts this activity consisted of analysis of systems to module level including supporting GSE to identify and evaluate hazardous conditions existant during all phases of the mission. A cross matrix of elements was formed from the Gross Hazard Analysis leading to loss of life, physical injury, physical impariment, or early mission termination.

The conditions leading to the above which were considered were: toxicity, flammability, particulate matter, loss of cabin atmosphere, loss of vehicle attitude control.

The results of this activity were presented via a gross hazards analysis, and status update through Quarterly System Safety Progress Reports, MSFC-DRL-171A, Line Item H04, and communicated within the design department through internal media, as well as formally in the several levels of design review procedures.

In certain specific situations a System Logic Analysis was performed to set down the details of the failure mechanism, and to identify less obvious modes and effects.

As the design progressed and identifiable hazards were reduced, the potential developed to utilize crew contingency procedures as a method of reducing the effects of failures. To this end procedures were organized toward the definition of crew and/or ground command contingency action capability, and on the identification and evaluation of procedures to modify the criticality of a Single Failure Point (SFP) without eliminating the SFP itself. Inasmuch as the development of the crew procedures were within another jurisdiction, this effort was modified to an evaluation activity aimed at determining the effectiveness of crew/ground contingency procedures toward the elimination or downgrading of a SFP.

4.2.2.1 Key Studies and Controls

A. Hazardous Materials Control - This subsection describes the controls and assessment methods for material design usage in the OWS for the purpose of minimizing or eliminating potential and flight crew toxic hazards due to metallic and organic chemical contaminants in the breathing atmosphere.

1/ Design Controls - Material uses that did not meet the acceptability guidelines were reported to NASA/MSFC along with the appropriate rationale to substantiate the material usage or the need for an alternate material. MDAC initiated reporting form P0327, Material/Component Usage, to obtain approval from NASA/MSFC for the usage of these type materials. Each P0327 report was a supplement to MDAC Report MDC G0126. The primary guideline documents were the following for the control of metallic and non-metallic materials which offgassed carbon monoxide and/or other organic chemcials.

a. Metals - Design Memorandum Number OWS-46, Orbital Workshop Usage/Crew Systems Requirements. This document established the policies, responsibilities, and requirements for the control of metals, metallic oxides, and alloys used within the OWS.

b. Carbon Monoxide and Total Organics - The NASA control document was MSFC-SPEC-101A. The equivalent MDAC document 1B78110, Flammability, Offgassing, and Odor Requirements, Materials was issued to provide the engineering definition for contractual compliance, implementation, and control of MDAC internal designs and supplier designs.

Material Usage Computer Program, P0327, was used to calculate the total offgassing rates for carbon monoxide and total organics for each usage of non-metallic materials and the sum of all material offgassing products.

2/ Manufacturing Control

a. General Cleanliness - The control requirements were established by CEI Specification, CP2080J1C, and by the Contamination Control Plan, MDC G0384A. Contamination control and cleanliness requirements related to OWS hardware were applied throughout manufacturing, test, and checkout of the OWS module.

b. Mercury Contamination - Mercury contamination control requirements were in accordance with MSC Standard 120, Breathing Systems, Requirement to Test for Mercury Contamination. This requirement was implemented by the MDAC document, Orbital Workshop Mercury Control Plan.

3/ In-Flight Controls

a. Normal Operations

1. Atmospheric Contaminant Removal - The controls to prevent the buildup of gaseous and particulate

contaminants were a function of several ECS components. The major components included.

- o Carbon canisters in AM and WMC.
- o Molecular sieves.
- o Condensing heat exchangers.

2. Contaminant Monitoring Capacility - The inflight monitoring capability for airborne contaminants consisted of:

   - o Carbon dioxide sensors at inlet to molecular sieves.
   - o Carbon dioxide analyses with the mass spectrometer.
   - o Carbon monoxide periodic determination with manual Drager tubes.
   - o Experiment T003, Inflight Aerosol Analysis, for periodic sampling of atmosphere for particulate matter samples for return to earth.

b. SL-2 High Temperature Contingency - MDAC conducted several studies, both analytical and test, to assess the potential OWS high temperature contamination problems resulting from the launch loss of the meteroid shield. In the area of contamination, these studies had significant effects on decision making relative to the SL-2 mission. The new requirements most directly influenced included:

1. OWS atmosphere pump down procedures to remove toxic contaminants.

2. New capability for crew to monitor MDA, AM and OWS atmospheres for carbon monoxide and toluene disocyanate prior to entry.

B. Flammable Material Control - This subsection describes the controls and assessment methods for nonmetallic materials design usage in the OWS for the basic purpose of fire prevention. Flammable materials were used only in the absence of a suitable nonflammable material.

1/ Material Selection Control - The controlling document for selecting materials was MSFC-SPEC-101A. MDAC document 1B78110, Flammability, Offgassing, and Odor Requirements, Materials was prepared to provide the engineering definition for contractual compliance, implementation, and control of MDAC internal designs and supplier designs. MDAC drawing 1B86198, Flammability Batch/Lot Test Requirements, was a list of materials that were tested prior to OWS usage. The proposed usage of flammable materials was reviewed, documented, and reported on the P0327 usage form for NASA/MSFC approval.

2/ Material Classification - Materials were classified as Type I (nonflammable), Type II (self-estinguishing), or Type III (flammable). Type III materials were ranked into subcategories by functional application and spatial distribution.

3/ Types II and III Usage Map - Each Type II or Type III material or component was included as a part of the materials use map (MDAC drawing 1B77015). The usage map depicted the location of each item thus was an aid in determining the distribution of materials throughout the habitable OWS interior and their proximity to other flammable materials. This proximity information was used to segregate flammable materials (Type III) on the subcategory basis thus emphasizing the probability of contributing to the propagation of a fire. In summary, the grouping of materials in this manner provided the basis for meaningful fire hazard assessments.

4/ Stowage and Installation Approaches - Multiple installation and stowage approaches were utilized to ensure adequate safety provisions for flammable material usages to minimize potential fire propagation. The following examples illustrate the design utilization of this approach with respect to flammable material control.

a. Fixed Items

1. Charcoal filters were enclosed in metal canisters.

2. Water tank heaters enclosed in nonflammable fluorocarbon rubber impregnated fiberglass.

3. Tank polyurethane insulation covered with fiberglass liner and aluminum foil.

4. Refrigerant control (Coolanol-15) by use of

brazed tube joints, o-ring sealed boss fittings, and enclosure of active components in a sealed vacuum vented container.

5. Wiring inside OWS routed through closed metal troughs contained fire barriers.

6. Light assembly lamps installed in a metal housing.

7. Power control consoles compartmentalized.

8. Sealing of the habitable area foam insulation.

9. Extensive circuit protection with circuit breakers.

10. Encapsulated modules including switches and circuit breakers.

11. All anodized metal interior finishes of multiple colors wherever possible to preclude use of paint and satisfy color compatibility requirements.

12. Elimination of O_2 in steel piping in deference to N_2 for the pressurizing medium for water tank.

13. Extensive protection for maintenance of touch temperature requirements in galley and water systems.

b. Stowed Items - Flammability protection for stowed items was provided by the use of metal stowage cabinets and nonflammable glass fabric bags.

5/ Inflight Responses to Orbital Fires - A MDAC study was conducted (MDC G2190-P) to provide data for the training of the Skylab crews in responding to orbital fires. The information and recommendations documented by this study had a major impact on Skylab requirements in the following areas.

a. Crew ground training procedures.

b. Late addition of the water fire extinguishing system.

c. Crew inflight response and procedures for the control of orbital fires.

C. Microbial Contamination Control

1/ Baseline Design Requirements - The OWS design requirements for microbial control, as defined by CEP CP2080J1C, generally involved the application of earth open environment principles to a closed manned system. The following examples represent the major microbial growth control principles that were applied.

a. Water systems were treated with a biocide (iodine).

b. Hydrated food supplies were refrigerated.

c. Personal hygiene procedures were to maintain a normal body flora.

d. Crew housekeeping and waste handling procedures were to prevent the buildup of organic matter and liquid water.

e. The Skylab environmental control system was to provide the primary capability for controlling airborne bacteria in the carbon canisters, molecular sieves, and the condensing heat exchangers.

2/ Design Support - The Skylab Program Office on 14 August 1970 established the Skylab Intercenter Microbial Control Working Group (SIMCWG) to conduct a detailed study of the Skylab cluster microbial control problems and recommend design and procedural changes. The major SIMCWG support areas included:

a. Microbial sampling of OWS interior surfaces prior to shipment to KSC.

b. Microbial sampling by JSC of OWS, AM and MDA interior surfaces at KSC prior to SL-1 launch.

c. Inflight microbial sampling of crew skin and OWS surfaces during all missions with return of samples to earth for analyses.

d. Biocide wipe development by MDAC for inflight disinfection of Skylab surfaces with high potential for microbial growth. The flight biocide wipes consisted of pre-wet pads heat sealed under reduced pressure in conolam 6000. The water system contained 120 ml water and the equivalent of 5000 ppm of available iodine, as betodine, on a cottom guaze pad of Webril R-2201.

e. Pressure suit assembly drying station requirements for microbial growth control during stowage.

f. Flight plan requirements were established with respect to general housekeeping procedures, trash handling (normal and contingency), spare replacement schedules, biocide wipe usage, periodic crew inspection and clean-up of high potential microbial growth areas, etc.

4.2.2.2 Special Safety Studies

A. Experiment M509 Structural Impact Study - A special safety study was conducted to investigate the effects of an experiment M509 (Astronaut Maneuvering Unit) runaway condition on equipment within the forward compartment of the OWS. The study was postulated on an impact load of 94 ft/lbs (127.5 joules) of kinetic energy from the experiment. The results from the investigation provided a listing of approximately 30 items within the OWS which might suffer damage from an M509 impact. Data was also provided to indicate the probable effects of this damage on system performance as well as the likelihood of damage occurrence.

B. SAL Structural Integrity Review Study - In response to a request from MSFC, a study group was formed to investigate a possible malfunction situation in which it would not be possible to remove an experiment from the Scientific Airlock due to a failure to close the SAL outer door, thus the experiment would have to remain attached to the SAL and constitute part of the overall OWS structure. System Safety participated in this study and identified several potential hazards and recommended design changes as well as contingency procedures. The study approach was to review data from each of the SAL experiment suppliers and determine the capability of the equipment to withstand extended exposure to both a space vacuum as well as any problems which might develop within the OWS itself in terms of crew impact against the experiment.

C. Experiment Structural Support Fixture - A special investigation was conducted to review structural integrity considerations in the event of an astronaut impact against the T027 experiment while it was attached to the SAL. An analysis was performed which indicated that a 250 pound (1112 Newtons) load against the end of the 5 foot (1.5 meters) experiment attached to the SAL might exceed the ultimate load capability of the tank wall. The findings of the study demonstrated that the existing design constituted a definite hazard for crew safety in that a crew impact could result in damage to the wall and possible depressurization of the OWS. Consequently, System Safety recommended the design of a structural support fixture to anchor the experiment to the floor of the OWS. The design change was accepted and resulted in the fabrication of a portable experiment support fixture which could be installed and removed at the discretion of the crew during on-orbit operations.

D. Coolanol 15 Study - Coolanol 15 was used as the coolant in the OWS Refrigeration system. A safety study was conducted to determine the acceptability of the coolant in terms of its potential flammability and toxicity characteristics. In addition, the study investigated the likelihood of leakage occurring in the OWS. The study results indicated that the coolant was flammable and that it was also toxic at certain concentration levels. As a result of this study, special MSFC funding was made available to conduct an Oral Sensitivity test using 15 MDAC subjects to determine if a leak in the water chiller, which would permit coolant to get into the drinking water, could be detected by the crew. The study results were affirmative. In addition, as a result of this study findings, B-nuts in the refrigeration system plumbing were replaced by brazed fittings and the refrigeration pumps were enclosed in an evacuated container. Both of these design changes were intended to decrease the likelihood of coolanol leaking into the interior of the OWS.

E. Mercury Study - An investigation was performed to explore the safety considerations associated with the fluorescent lights which provided general illumination for the OWS. These lights utilize a small amount of mercury vapor and the focus of the study was to explore the likelihood of mercury leakage and the effect on the crew from the mercury released into the OWS atmosphere. In addition to an overall assessment of the adequacy of the existing design, recommendations were made to provide mercury vapor detection devices for the crew, periodically to energize the spare lights to check for leakage, and to exercise extreme care and caution in handling and transportation of the fluorescent devices. As an outgrowth of the study, MDAC generated an OWS Mercury Control Plan to identify the requirements and criteria necessary to assure that the OWS and GFP experiments are protected from and free of mercury contamination. The control plan identified each of the items of equipment which required the mercury checks and also described the detailed procedural steps required to ensure that the hardware was free from mercury contamination.

F. System Safety Checklists - MSFC directed that MDAC perform special safety studies utilizing customer supplied Skylab System Safety Checklists for both Ground Support Equipment (GSE) (SA-003-001-2H, dated July 1971) and Flight System Design (SA-003-002-2H, dated November 1971). These checklists were extremely comprehensive and served as a forcing function to ensure that, if possible, hazards had been eliminated and that the appropriate safety features in the equipment design were utilized. In the event of noncompliance items, it was necessary to list rationale for failure to comply with the safety item. Sixty-one items of GSE and sixteen flight systems were analyzed through these safety checklists.

G. Sneak Circuit Analysis - An analysis of conducting paths that could cause an unwanted function when power was applied to the space vehicle to achieve a desired function was accomplished on the OWS Program. The Sneak Circuit Analysis was accomplished at MSFC. Effectiveness Engineering analyzed any sneak circuit paths that were uncovered criticality impact on crew safety or mission. The sneak circuits were analyzed for both activation of unwanted functions and wanted functions. No sneak circuits were uncovered that would have resulted in danger to the crew or have had a mission impact.

H. Space Flight Hazards Catalog Review - A detailed review of the 266 hazards identified in the NASA/MSC Space Flight Hazards Catalog was conducted. The objectives of this voluntary review were to identify and document the means by which the OWS design, procedures, or operations provided for detecting, controlling, or circumventing the hazards. There were no cases where a listed hazard had been unrecognized or overlooked and there were no hardware changes found to be necessary as a result of the review; however, the review was considered beneficial and productive. In several instances, the OWS status relative to certain hazards was not immediately apparent and required further study, analysis, and/or test before the item could be positively categorized as resolved. This investigative effort brought about a greater awareness and recognition of those hazards and, in turn, an increased confidence that they had been adequately circumvented or controlled for the OWS application.

4.2.3 Test and Operations Phase - All test and operational procedures, excluding routine shop handling and transportation procedures, were reviewed for safety considerations. Included were Handling and Checkout Procedures (H&CO), Test and Checkout Procedures (TCP), Development Test Procedures, Qualification Test Procedures, Production Acceptance Test Procedures (PAT), and nonroutine shop Handling and Transportation Procedures.

Test and operational procedure documents were submitted to Effectiveness Engineering for review prior to final publication. It was the responsibility for the safety group to review the document to ensure that any hazardous activities were identified on a special page in the document which was devoted to safety considerations. In addition, it was necessary to review all of the procedural steps to ensure that any potential safety problems were preceeded by "Caution" or "Warning" statements. A "Caution" statement was used to flag out a potential accident which could result in damage to equipment. A "Warning" notice was used to indicate that the procedural steps had the potential to cause an injury to personnel. These recommended changes were subsequently transmitted by written memoranda to the originator and the OWS Safety Committee. The OWS Safety Committee reviewed all procedures containing "Operations with potential for damage to equipment or injury to personnel."

Approximately 800 procedures or changes thereto were reviewed for safety considerations with the great majority found fully acceptable. In a few cases, significant changes were found necessary to eliminate or minimize potential adverse safety affects and were implemented.

4.2.3.1 Review of Operations with Potential for Damage to Equipment or Injury to Personnel - These formal, documented reviews were accomplished in accordance with the requirements of MDAC Control Procedure "Operations with Potential for Damage to Equipment or Injury to Personnel." They were accomplished by the special committee created by MDAC and covered all manufacturing, handling, transportation, test and pre-flight operations identified by the committee as having the potential for damage or injury.

Each review involved a detailed study of the methods and purposes of the operation, the as-built configuration of facilities and equipment involved, including the OWS system, analysis of the design of affected tooling, facilities and equipment, analysis of applicable procedures, and review of personnel training and certification requirements and implementation.

Risks involved in each operation were assessed and necessary corrective action implemented. In selected cases, simulated operations were performed. A complete listing of these reviews (92) is shown in Table 4.2.3.1-1.

In general, there were no major problems and/or corrective actions found as a result of these reviews. A large number of minor changes and corrective actions as well as safety additions to equipment involved were implemented. During subsequent performance of these operations there were no incidents involving either equipment damage or personnel injury.

In addition to the formal reviews described above, a relatively large number of informal reviews were conducted by the System Safety Manager's Office. These documented reviews were based on the same considerations as those above; however, they were not accomplished in strict accordance with the noted MDAC procedures. A listing of major reviews of this type (30) is contained in Table 4.2.3.1-2.

4.2.3.2 The MDAC audit program included both internal and customer audits, and was implemented at all levels and within all organizations. All of the internal safety related audits accomplished (62) were reported in detail in Quarterly OWS System Safety Reports and are listed in Table 4.2.3.2-1. All corrective actions identified as "necessary"

REVIEW OF OPERATIONS WITH POTENTIAL FOR DAMAGE TO EQUIPMENT OR INJURY TO PERSONNEL

- Tank Cylinder External Painting
- Tank Interior Foil Liner Installation
- Side Access Door Installation and Removal
- Stage Handling Operations Related to Tower 8 Leak Checks
- Crew Quarters Floor Installation (Vehicle Horizontal).
- Water Bottle and Water Bottle Support Structure Installation (Vehicle Horizontal)
- Forward and Aft Skirt Foil Installation and Thermal Barrier Painting
- DTA Erection in Building 30
- Weight and Balance
- DTA Pressure Test in Building 30
- Tank Cylinder Foil Installation
- Operations Related to DTA Shipment
- DTA Access and Handling Equipment and Plans in Building 30
- OWS Tank Cleaning
- DTA Removal from Building 30
- DTA Operations at Michoud
- DTA Operations at MSC
- Revised Horizontal Work Platform OWS Interior
- DTA Erection in Building 30 (Reassessment for OWS)
- Operations Related to DTA Shipment (Reassessment for OWS)
- Access Controls and Procedures
- Contamination Controls and Procedures
- Personnel Safety Controls and Procedures
- Erection and Joining in Tower 2
- Interior Access in Tower 2
- AM/OWS Interface and SAS Mounting Bolt Drilling Operations
- Meteoroid Shield Installation
- Roll Cleaning (Prior to Erection in Tower 2)
- Meteoroid Shield Ordnance Operations
- Meteoroid Shield Deployment Test
- In-Place Brazing Operations (External)
- In-Place X-Ray of Brazed Joints
- Erection in Tower 6
- Crew Quarters Wall Installation

TABLE 4.2.3.1-1

- Interior Access Stand Installation and Operations
- TACS Bottle Installation
- Tooling Hoist Installation and Operation
- Documentary Photo Activities in the Habitation Area
- In-Place Brazing Operations (Internal)
- Observation Window Installation
- Tooling Conveyor Installation and Operation
- Water Bottle Installation (Vehicle Vertical)
- Film Vault Installation
- T020 Installation (Foot Controlled Maneuvering Unit)
- M074 Installation (Specimen Mass Measurement)
- M131 Installation (Human Vestibular Function)
- S149 Installation (Particle Collection)
- M172 Installation (Body Mass Measurement)
- GSE Dolly System Installation and Operation
- GSE Upper Interior Access Kit Installation and Operation
- GSE Hoist Kit Installation
- Meteoroid Shield Counterbalance System Installation and Operation
- Meteoroid Shield Ordnance Installation
- Trash Disposal Airlock Installation
- Refrigeration System Pumping Assembly Installation
- Meteoroid Shield Deployment Test (Manual)
- Meteoroid Shield Deployment Test (Ordnance)
- Habitation Area and Waste Tank Leak Checks
- TACS System Leak Checks
- Ground Pressurization System Leak Checks
- VCL Pneumatic Control Leak Checks
- Water System Leak Checks
- Meteoroid Shield Ordnance Handling
- Handling and Installation of Experiments:

ESS	S020	S073	M171
T002	T027	M092	S183
T003	S063	M093	S195
T013	M071	M133	M509
S019	M073	M151	

- Refrigeration System Test Procedures

TABLE 4.2.3.1-1 (Continued)

- OWS Transport, Tower 6 to Tower 2
- Final Preparations for Shipment
- OWS Removal from Tower 2 and Transport Loading
- Weight and Balance
- TACS System Proof Test at Seal Beach
- HFMU Handling and Shipping Operations
- Handling Equipment Operations Inside the Spacecraft (Reassessment for OWS Backup)
- SAS Loading on Guppy
- OWS Backup Handling and Shipping Operations

TABLE 4.2.3.1-1 (Continued)

- Removal of OWS from Tower 6
- OWS Habitation Area Personnel Occupancy Limits
- Methane Venting through the M171 (Metabolic Activity Experiment) Vacuum Vent Lint
- OWS Susceptibility to Damage During M509 (Astronaut Maneuvering Equipment) On-Orbit Operations
- Fluorescent Work Lights
- Forward Interior Work Stands
- Experiment GSE Design Concepts
- Waste Processor Module Fit Check
- Suit Drying Station
- OWS Radioactive Materials
- Hearing Protection During M509 Checkout Operations
- Inadvertent Use of Zinc Chromate
- OWS Backup Common Bulkhead Rework
- VCL Emergency Egress
- VCL Emergency Lighting
- VCL Power Outage Procedure
- VCL Use of Portable Gage Regulator Assemblies
- Fit Check - Waste Processor Module
- Production Test Plan - TACS System Proof Tests at Seal Beach
- OWS Pressure Integrity
- Coolanol Taste Odor Test
- Structural Integrity Review of the Scientific Airlock/Experiment Interface
- Energy Generating Sources near Potential Coolanol Leak Points
- Experiment S183 Ultraviolet Panorama use of Tritium Paint
- Portable High Intensity Light
- Program Manager's Review OWS Transport Tower 6 to Tower 2
- Program Manager's Review - OWS Removal from Tower 2
- Lower Body Negative Pressure Device (LBNPD) Operations
- Handling Equipment Operations and Procedures Developed on OWS-1 (Reassessment for OWS Backup)
- OWS Backup Aft Interstage Shipment

TABLE 4.2.3.1-2

SAFETY AND SAFETY RELATED AUDITS

- o Not-For-Production-Use (NFPU) System
- o Inspection Guage Production
- o Inspection Preplanning.
- o Testing
- o Surveillance Inspection
- o Repetitive Nonconformance Control
- o Process Control
- o Processing Operations/Planning Call-Outs
- o Heat Treating
- o Shipping Inspection
- o Intercomponent Work Orders (ICWO's)
- o Skylab Workshop (SWS) Program - Florida Test Center (FTC)
- o Controlled Material/Bulk Material Stockroom
- o Control of Mercury
- o KSC Orbital Workshop/Airlock Module Programs
- o Nondestructive Testing
- o Shipping Inspection
- o Acceptance Testing
- o Application of Standard Fasteners
- o Reliability Critical Items (RCI)
- o Recurrence Control
- o Surveillance Inspection
- o Training and Certification
- o Process Control - Cleaning
- o Control of Detailed Process Material (DPM's)
- o Sampling Plans

CUSTOMER

- o OWS Quality, Reliability and System Safety Survey
- o Annual Systems Safety Survey of OWS Operations
- o Pre-Delivery Turnover Review
- o Review of Nonconforming Supply and Corrective Action System
- o Quality System Survey
- o Hardware Integrity Review

TABLE 4.2.3.2-1

by these audits were accomplished. The Customer audits, with minor exceptions, found the system and/or operations under audit completely satisfactory.

4.2.3.3 Accident/Incident Investigation Reporting and Corrective Action - The contractor's Accident/Incident Investigation Reporting and Corrective Action activities were in accordance with requirements of the OWS System Safety Program Plan, as implemented by MDAC Standard Practice SP 1.004-ACN.

There were only seven reportable incidents involving damage; two of a serious nature, one of a significant nature, two minor, and two near misses. These incidents, all reported in Quarterly OWS System Safety Program Reports, are summarized.

A. Meteoroid Shield - During initial portion of Skylab I flight, the OWS Meteoroid Shield failed causing the loss of one SAS, high OWS internal temperatures, and considerable perturbation to flight operations. Failure was contributed to design deficiency by a formal NASA Review Board investigation and by parallel investigations conducted by the contractor.

B. Damage to GSE - Significant damage was incurred by GSE Model DSV7-314 (Vacuum Pumping Unit) during transportation at MDAC. Incident was the result of improper fork lift operation and resulted in appropriate changes to procedures and instructions regarding such operation.

C. Damage to GSE - Two items of unused GSE incurred minor damage during transportation at MDAC. The damage was the result of improper tie-down during truck transportation and resulted in changes to instructions and procedures related to tie-down.

D. Damage to Forward Dome - Very minor damage to the OWS forward dome occurred during removal of a bonded support bracket when technician failed to follow appropriate procedures. All affected technicians were reinstructed regarding such operations.

E. Gouges in Tank Structure - Several gouges were found in waste tank dome structure during routine inspection. No cause was identified. All technicians performing work in this area were were reinstructed with regard to need for care and surface protection.

F. Crane Overload - This near miss incident was potentially the most serious handling occurrence during the entire program and was the result of improper use and overload of a mobile crane during shipping preparations of the Dynamic Test Vehicle. Had overload been greater or the dynamics of the two crane operations been different, significant damage to the DTA would have resulted. This incident resulted in major changes to procedures involving the use of all cranes.

G. Winch Failure - This near miss incident involved failure of a hand operated reduction gear drive facility winch equipped with a ratchet type safety lock. Malfunction of the safety lock combined with failure of the drive handle freed the winch and allowed a large catwalk access assembly to fall free. Fortunately, no contact resulted. All reduction gear drive winches in critical applications were replaced with self-locking worm gear drive winches and technicians reinstructed regarding equipment maintenance.

The program experienced thirteen lost time injuries, all reported in Quarterly OWS System Safety Program Reports. Ten of these injuries were of a minor nature, e.g., employe tripped on stairway, employe strained back lifting routine load, etc.

One injury of a very serious nature resulted when an employe fell from a catwalk into the crotch area of the OWS Development Fixture Forward Interstage. The exact cause of this fall was never determined. However, protective handrails were modified to eliminate any possibility of recurrence.

Two fairly significant injuries occurred: One when an employe fell approximately six feet when a faulty work platform broke, and the other when an employe was struck on the legs by a mockup item which tipped over for reasons never determined.

One near miss injury occurred when astronaut Bruce McCandless fell shortly after participation as a test subject in tests of the M131 rotating litter chair. No connection between the fall and the chair test was established and the small ground access ladder involved in the fall was redesigned. In addition, procedures related to occurrence involving injury or potential injury to astronauts were revised to require immediate examination by a physician regardless of severity or outward appearances.

4.3 TRAINING

4.3.1 Skills Training - Throughout the life of the program, MDAC's on-going programs for both training and certification related to production skills continued. Basic training and certification of an on-going nature included soldering, torque and tubing, paste adhesives, and many others. Additional training, related to OWS peculiar skills, was incorporated in the overall program. These additions provided for training and certification of OWS Manufacturing and Quality Assurance personnel in such skills as tube induction brazing, refrigeration system insulation, wire harness fire proofing, and others. The relative absence of problems in the skills area provided confidence that the program implemented was adequate.

4.3.2 Operational Training - Special training of an operational nature was provided in several areas: safety, access control, contamination prevention, and system familiarization. Approximately 1400 personnel completed the safety, access control, and contamination prevention training. Over 300 personnel completed basic OWS familiarization/orientation training, including 80 MDAC FTC personnel and 127 NASA, NASA Contractor, and Air Force personnel. Most of these personnel also completed basic OWS systems training and one or more specialized courses in OWS subsystems.

4.3.3 Employe Motivation/Awareness - The Skylab Orbital Workshop Motivation/Awareness (M/A) Program was established in July 1970, as an activity to motivate both MDAC and supplier employes to produce defect-free hardware for the safety of the crew and the success of the Skylab mission. Primary emphasis was directed toward maintaining the highest standards of workmanship and avoidance of human errors in the manufacture, test and handling of mission/safety critical hardware. The program was aggressively pursued and is being actively sustained until the customer accepts and takes delivery of the OWS Backup Spacecraft in April 1974.

The scope of MDAC M/A program embraced all of the key elements of the NASA Aerospace Awareness Program as subsequently delineated in NPD 1700.3A and as recommended by the Office of Manned Space Flight. It was formally implemented per authority contained in MDAC Standard Practice 10.007-ACL, and directed by the OWS Program Manager for System Safety and Product Assurance.

To ensure that MDAC employes and critical suppliers were fully aware of the significance of the OWS program as well as the importance of their OWS efforts to mission success, and extended series of presentations were conducted. The presentations consisted of the following:

A. Top management program overview.

B. Two films: Quality Craftmanship (NASA film)
The Essential Factor (MDAC film)

C. Detailed briefing inside OWS full scale mockup.

D. Facility tour of OWS manufacturing area, payload shroud assembly area and space chamber simulator.

E. Handout material (crew photos, NASA Skylab brochure, detals).

By the time the OWS manufacturing phase had been completed, approximately 1300 personnel from in-house and selected suppliers had attended these presentations.

In September 1970, a Skylab OWS conference was conducted by MDAC at

Huntington Beach so that the collective managements of MDAC and suppliers of critical OWS hardware could jointly review their mutual obligations to the man-in space. Primary emphasis was devoted to the criticality of each invited supplier's hardware to crew safety and mission success. Invitations were extended to the Chief Executive and Project Director of twenty-six companies who were under contract to provide components for use in the OWS. The Vice-President-General Manager, Program Director and other members of the MDAC Skylab OWS management team addressed the supplier representatives and stressed the urgent requirement for on-time delivery of defect-free hardware. The supplier's executives were also enjoined to establish their own awareness programs and pass on the information to their people.

In order to maintain the momentum established by the Skylab presentations and supplier's conference, maximum use was made of the NASA and MDAC motivational material as it became available. Approximately 560 MDAC West Coast and MDAC/KSC personnel attended showings of the NASA film "Invitation to Overconfidence" and an additional 150 saw the film "Anatomy of an Accident." NASA and MDAC Manned Flight Awareness posters were conspicuously displayed in all OWS work areas continuously throughout the life of the program. New posters were displayed and/or rotated every two - three weeks and maintained current with the changing phases of the program. The principal themes that were emphasized included quality craftmanship, safety, care in handling, cleanliness, contamination control and human error avoidance. Another impressive display was a MDAC built 1/40-scale model of the Skylab Cluster in-orbit. This scale model was effectively used as the focal point of a larger show case exhibit which contained assorted space memorabilia, crew photos and other program information.

In September 1972, an Open House was held at Huntington Beach for all employes and their families. It featured the OWS Hi-Fi Mockup, Payload Shroud, several Skylab models, cutaways, pictorial displays. Several thousand persons toured the OWS work areas and the event was an outstanding success. Another one-time successful promotional event was the visit of the NASA Craftmanship Van in February 1973. During its stay at Huntington Beach, an estimated 4000 employes visited the exhibit.

A new error cause identification and removal system called Special Performance and Craftmanship Effort (SPACE) was formally initiated in February 1973, by C. R. Able, MDAC Chairman and Chief Executive Officer. This aspect of the motivation program, with top management emphasis, quickly took hold as a viable and effective program. As a side benefit, SPACE proved to be a definite stimulus to the Employe Suggestion program.

Recognition activities were maintained at a highly satisfactory level throughout all phases of the OWS program. Approximately 150 VIP citations were approved and awarded annually to program top performers. In addition two MDAC employes were selected as NASA Manned Flight Awareness Honorees for each of the Skylab launches and attended all associated activities at KSC as guest of NASA.

Special ceremonies were held at Huntington Beach to recognize the outstanding accomplishments of the Skylab I and Skylab II crews.

On each occasion the flight crews visited hundreds of employes in their work stations and 75 of the most deserving OWS team members were invited to witness the special presentation to the crew in the executive conference room. Subsequently, a color reproduction of the autographed Skylab photograph and flag, presented to the company by the crew, was in turn presented to the select group of OWS team members.

In addition to the foregoing motivational activities, a considerable amount of program literature and miscellaneous motivational material, received from NASA and generated in-house, was transmitted and circulated routinely to all MDAC departments and to critical suppliers. Material so distributed included Skylab booklets, MFA brochures, pocket inserts, crew photos, decals, bumper stickers, lapel buttons and Awareness Newsletters.

4.4 CONCLUSIONS & RECOMMENDATIONS - In retrospect, the Skylab OWS System Safety Program is considered to have attained its objectives by providing for the welfare of the crew and the eventual success of the Skylab mission. Specific areas where either new techniques were developed or the state-of-the-art was challenged are highlighted below with respect to their effectiveness as well as some do's and don'ts for future manned space programs.

A. Hazardous Materials Control - Methods were acceptable since crew toxicity symptoms due to airborne chemical contaminants were not reported for any Skylab mission. The initial OWS chemical contaminant load was greatly reduced due to the high temperature bakeout and the multiple venting of the OWS atmosphere prior to

SL-2 entry. This overheat contingency was a positive factor in minimizing the offgassing of carbon monoxide and total organics from the non-metallic materials for the life of the Skylab.

B. Flammable Material Control - This program was highly successful and resulted in maximum development and usage of many new non-flammable non-metallic materials; e.g., fluorocarbon rubber, impregnated fiberglass materials of different types, cardboard, etc.

Skylab design objective was to select the best non-flammable material for the intended purpose. When a non-flammable material could not be found, the recommended material was documented and coordinated with the customer for concurrance. Rationale was supplied to support this technical judgement. Part of the rationale included showing the placement of the material on the non-flammability map (MDAC drawing 1B77015) for assessment of potential flame propagation. Some materials, to meet flammability requirements, may compromise flight crew comfort and therefore necessitated early coordination with the crew.

C. Microbial Contamination Control - Microbial sampling of OWS surfaces prior to shipment to KSC demonstrated that the manufacturing cleanliness standards were very satisfactory in maintaining a normal microbial flora population in the OWS.

SECTION 5 - TESTING PROGRAM

5.0 INTRODUCTION - This section defines the scope of the Orbital Workshop test program performed by MDAC-W. This reflects the baseline scope of effort associated with the "Dry" launched Workshop concept and also identifies that effort common to either the "Wet" or "Dry" stage configurations.

The prime objective of the test program was to ensure that the hardware and equipment furnished by MDAC-W fulfilled the objectives stipulated in the NASA Mission Requirements Document I-MRD-001A and the requirements of the OWS Contract End Item Detail Specification CP2080J1C. The following testing was performed:

- Component and subsystem testing

  a. Development

  b. Qualification

  c. Production acceptance

- Structural testing
- Special and module testing
- Spacecraft system testing (post-manufacturing checkout)
- Integrated vehicle testing
- Mission support testing

The following rationale was used by MDAC-W in the formulation of the Orbital Workshop Test Plan:

- Orbital Workshop considered one-of-a-kind experimental vehicle.

- MDAC-W performed development and qualification tests on selected equipment and hardware to the extent necessary to provide or support the technical justification for usage. Testing was accomplished on specific flight hardware or equipment categorized as follows:

  Vehicle Mounted Equipment and Hardware

  - Category 1 - Equipment whose failure could adversely affect crew safety.
  - Category 2 - Equipment whose failure could result in not achieving a primary mission objective but would not adversely affect crew safety.
  - Hardware and equipment evaluated at the Workshop system level during vehicle or cluster checkout was considered ready for flight where successful fulfillment of the design and mission objectives and requirements were achieved. Where analytical models could be developed and evaluated for particular items of hardware and equipment, those items would not be subjected to component or subsystem level tests prior to vehicle installation.
  - Off-the-shelf hardware or equipment was not requalified to the Orbital Workshop levels where analysis was performed to justify their usage on the vehicle.

- Hardware or equipment qualified on the Saturn IVB environmental levels was not retested to the Saturn V vehicle levels, if assessment showed that previous test levels were satisfactory

- The test program was based on fulfilling the total Skylab mission life objectives; however, in interest of cost effectiveness full mission performance was verified by a combination of both testing and assessment, except where analysis showed a necessity for long life or full mission duration testing. The rationale for selecting testing and/or assessment to verify elements of mission performance was documented in the Test and Assessment Document (Reference MSFC-DRL-171A, Line Item G09).

- Checkout and integrated testing followed a logical progression to preclude invalidating tests or activities already accomplished, and to facilitate fault isolation without interference from other systems. Integrated system testing was performed at the highest level of assembly possible to ensure that all equipment, systems, and support equipment functioned properly in relation to the total mission.

- Verification of GSE design requirements was accomplished by Production Acceptance Testing. No separate development or qualification testing of GSE was accomplished.

- Test Program Objectives - Implementation of this Orbital Workshop Test Plan fulfilled the following objectives:

  - Performed all tests necessary to verify flight readiness of the Orbital Workshop hardware and equipment.

  - Demonstrated that the Orbital Workshop hardware/equipment fulfilled the requirements of the Contract End Item Specification CP2080J1C.

- Test Categories - The categories of tests described in this report are defined as: Development, Qualification, Production Acceptance, Special, and Spacecraft Checkout and Integration Tests. A brief description of each type is presented.

  - Development Tests - Hardware utilized during these test programs was either prototype or pre-production configurations depending on the particular phase of design evaluation at the time of program initiation. Development testing was performed to optimize hardware configuration and identify potential areas of marginal design or performance. These tests also served to determine and evaluate design feasibility, functional parameters and environmental limitations. Development Tests also demonstrated fulfillment of design objectives and requirements and identified areas where design improvements would be required prior to finalization of the production configuration.

- Qualification Tests - Qualification Tests were performed on production hardware to demonstrate that the design and production methods resulted in a product which fulfilled the design requirements established for usage.

- Production Acceptance Tests - Production Acceptance Tests were performed on all deliverable items of equipment to ensure that production methods and quality control produced an article which satisfied the design intent.

- Special Tests - The special test program consisted of those tests, usually conducted at government facilities and/or subcontractor facilities, and required MDAC-W hardware, software and technical supporting personnel during the performance of specific phases of each program.

- Spacecraft Checkout and Integration Tests - This activity included post-manufacturing checkout accomplished at Huntington Beach and system verification at the KSC. The integrated cluster systems testing was also performed at the KSC.

5.1 TEST REQUIREMENTS

5.1.1 General Requirements and Guidelines

o The primary objective of the component and subsystem test program was to ensure that the hardware configuration selected for flight usage fulfilled the design requirements.

- The determination to perform development or qualification tests on selected items of equipment and hardware was based on the complexity and criticality of the specific item of interest. Design verification of certain items was made following development testing only. The rationale used in establishing the depth and degree of testing was to ensure total verification of design at minimal program expenditure and schedule impact. The judgment to eliminate development testing and proceed directly into qualification was made by assessing the complexity and similarity of that item to existing design and adaptation for Workshop usage.

- Where certain items of equipment and hardware were not subjected to development or qualification testing, verification of design was made during experiment integration, spacecraft checkout and integrated system testing. Items verified in this manner included those that required higher levels of assembly to properly evaluate their performance.

- Hardware or equipment identified as requiring dynamic testing were subjected to the vibration and shock levels stipulated in the Orbital Workshop dynamic criteria document - DAC 56620-C (OWS mounted equipment). Any item of hardware and/or equipment selected for OWS usage based on similarity to existing Saturn IVB Configuration was reassessed to determine whether additional testing was required.

- Hardware and equipment provided was designed to fulfill the requirement of 8-months of orbital life (Reference CEI Specification CP2080J1C). Continuous operation environmental testing was generally demonstrated only for the initial 28-day habitation period; however, full or compressed mission duration life cycle testing was conducted when, the test assessment indicated further testing was required.

- Flammability testing at the components and subsystem levels were conducted. Material evaluation tests were performed in accordance with the requirements defined in CEI CP2080J1C. Some of these tests were performed in the MSFC facilities.

- The general policy for conducting Electromagnetic Compatibility (EMC) tests was to evaluate hardware and equipment at the highest level of assembly wherever possible. EMC testing conformed to the requirements delineated in MIL-I-6181 and MDAC Specification No. 7883817-501.

5.1.2 Documentation and Control Requirements of Component and Subsystem Testing

- Component Test Control Authority (CTCA) - The general testing requirement for any MDAC-W or supplier tested item was denoted on Forms 850-7 (CTCA) which were used as the control document during each specific test program. A CTCA was prepared for each item of hardware and equipment.

- Test Control Drawing (TCD) - A TCD was prepared for each of the items subjected to component or subsystem testing at MDAC-W. The TCD was the engineering requirements document used as the basis for the preparation of a Test Procedure Drawing (TPD), when required.

- Test Procedure Drawing (TPD) - The TPD, when required, was prepared by either the testing laboratory or design section. It outlined the detailed procedure for performance of the test and was prepared in accordance with the authorizing TCD.

- Specification Control Drawing (SCD) - An MDAC-W Specification Control Drawing was prepared for each item supplied by suppliers on deliverable items of equipment and hardware. Section 4 of the SCD defined those test requirements to be verified by the supplier to support design usage including Development, Qualification and Production Acceptance testing. For each test, a test procedure document was required to be submitted to MDAC-W for approval prior to start of testing. MDAC-W Engineering and Quality Control monitored the testing at the suppliers facility to verify all test requirements were met.

- Qualification Test Controls - The qualification tests were conducted by MDAC-W Development Engineering with optional surveillance by NASA or its representative in accordance with the following:

The TCD was prepared for each of the items to be subjected to testing. The TCD was the engineering requirements document defining each test condition and environment per CTCA form and used as the basis for preparing a TPD, as required. In certain cases, it was necessary to make redline changes during the test activity. These changes were reflected in a subsequent TCD revision. All redline changes were approved by a representative of the Contractor Design Technology and coordinated with an authorized NASA RMO Representative.

NOTE: When supplier tests were conducted, the procurement specification completely defined the engineering test requirements and provided for all anticipated environments to which the component may be exposed during the life of the component.

- Test Failure/Anomaly Reporting - When a failure occurred during development testing, the resolution was the responsibility of MDAC-W Development Engineering.

  During the Qualification Test Program, should a component/module fail to perform in accordance with test requirements of the TCD or TPD, the contractor would immediately instigate an investigation or diagnostic test to determine the cause of the anomaly. If it was determined by the contractor that a true failure existed, i.e., the component/module would not meet the test requirements when subjected to proper test conditions, the NASA RMO was verbally notified within one working day of the contractor's determination of failure. A Failure Report (FR) was generated by MDAC-W

Quality Assurance as requested by MDAC-W Development Engineering. Test anomalies other than failures were documented in the Test Log Book. Adjustments or equipment replacement was permitted during an operation only if they were part of the normal use cycle.

- Test Status - Test status of all component/module tests was provided to NASA on a monthly basis. The status was presented in the form of MDAC-W work plans. These plans were the in-house working plans utilized by the MDAC-W for program management and assessment of performance.

- Change Control - The test specimen quantity, configuration, and testing environments for each component and subsystem test adhered to the requirements defined in the appropriate CTCA form. MDAC-W changes occurring during the Development Test Program as to configuration, additions or deletions to test environments or specimen quantity were denoted in revision CTCA forms and submitted to the NASA Resident Management Office as information. Changes to Qualification Test CTCA forms and the addition or deletion of Development and Qualification Test line items were authorized by mutual approval of a revised CTCA under cover of a Test Plan Change Form. If MDAC-W notified NASA that the revision was a major change in scope, a change order was issued directing the change. Test Plan changes resulting from Class I OWS flight hardware changes were submitted to NASA by the ECP submitting the hardware change (reference paragraph 6.2.2.2 for Class I change definition).

- Certification of Component Acceptance - Certificates of Component Qualification were prepared for all items in criticality categories 1 and 2 prior to Pre-Flight Readiness Review.

- Data Submittal Requirements - Data submittal to the Contracting Agency during the MDAC-W period of performance was in accordance with the Data Requirements List MSFC-DRL-171 (DRL).

5.1.3 Documentation and Control Requirements - Spacecraft Systems and Integrated Vehicle Testing

- Documentation - In order to ensure a complete and adequate checkout was performed, a series of support documentation was provided. Documentation was as follows:

  - Checkout Control Plan - The 1B79321 Checkout Control Plan, an internal MDAC-W Engineering document, provided advanced checkout planning for both Huntington Beach (HB) and Kennedy Space Center (KSC).

    The final release of this document was an "A" Revision, dated 4 August 1970. Subsequent planning was incorporated in Test Outline Drawings (TOD's) and the 1B83429 Test and Checkout Requirements, Specifications and Criteria Document (TCRSC).

  - Test and Checkout Plan (TCOP) - The TCOP was a matrix listing which correlated the HB test requirements contained in the TCRSC, the TOD's and the Test and Checkout Procedures (TCP's). Each requirement identified in the TCRSC Document as applicable for HB checkout was listed in the TCOP. A matrix was completed which indicated the TOD's and TCP's that satisfied the requirements during HB checkout. Only the TOD and TCP numbers and titles were identified. Detailed paragraph identification was not included. A TCCP was also prepared at the KSC to verify all TCRSC requirements were met.

- Test and Checkout Requirements, Specifications and Criteria Document (TCRSC) - A TCRSC Document was prepared in accordance with Line Item J08 of Data Requirements List (DRL) - 171A. This document specified OWS test requirements for both Huntington Beach and KSC checkout. The test requirements were divided into sections for each OWS system and subsystem.

  The test requirements necessary to verify system and subsystem operations were listed along with associated acceptance criteria for both Huntington Beach and KSC. If a test requirement was not applicable at one of the test locations (HB or KSC), this was also indicated. These requirements included the necessary information to support OWS checkout in the HB Vehicle Checkout Laboratory (VCL) OWS checkout and prelaunch checkout operations at the KSC. The TCRSC required the NASA approval.

- Area Control Drawing (ACD) - ACD's were prepared and utilized to authorize, document and plan the conduct of the OWS and GSE testing in the VCL. All Test and Checkout Procedures and Handling and Checkout Procedures required to verify, handle and transport the Spacecraft and GSE were included. General test policy, objectives, safety requirements and test sequence were also included. Authorization for usage of ACD's was by Manufacturing Planning Assembly Outlines (AO's). ACD's were submitted to the Resident NASA Management for approval prior to utilization.

- Test Outline Drawings (TOD's) - TOD's were prepared in accordance with Line Item J24 of DRL-171A.

A TOD was prepared for each TCP that was accomplished during HB checkout. The TOD's were updated until the release of the corresponding TCP after which time no additional releases were required. These documents included the checkout flow and operations for each procedure to a depth necessary to specify the basic operations for each procedure to a depth necessary to specify the basic operations to be performed. Test prerequisites, facility support, ground support equipment (GSE) support, and other significant support information were included. Detail checkout operations (e.g., connect, disconnect) and GSE interface operations were included. The information contained in the TOD's provided the information from which the detailed TCP was prepared. In the case of automatic tests, the TOD contained sufficient detail information required to generate the automatic portion of the TCP.

The principal engineering design discipline responsible for each test was responsible for coordination of inputs from all other disciplines, the collation of the inputs, and the preparation of the respective TOD and TCP. Each design discipline ensured that its individual requirements for each test was recognized by the responsible discipline and incorporated into the test sequence. TOD's were submitted to the NASA for review. TOD's were prepared and utilized at the KSC in the same manner as noted.

- Test and Checkout Procedures (TCP's) - The TCP's were prepared in accordance with Line Item J01 in DRL-171A.

  These procedures identified the step-by-step checkout to be performed during the HB operations.

  The TCP's were used to perform the tests and provide the buyout documentation for acceptance of the OWS. TCP's were prepared and utilized at the KSC in the same manner as noted.

- GSE End Item Test Plan (EITP) - The GSE EITP was contractually required by Line Item J04 of DRL-171A.

  The GSE EITP contained a column listing of each item of GSE used to support OWS checkout and handling operations at HB. Included in the listing were the GSE model number and title along with identification of the procedure used to verify proper operation of the model.

- Test Management - The MDAC-W Development Engineering Vehicle Checkout Laboratory (VCL) functional organization, was responsible for managing and performing Spacecraft checkout operations at Huntington Beach (HB). This organization was responsible for:

- Verifying configuration before starting OWS checkout.
- Assuming and retaining custody of the OWS from initiation of checkout operations until turnover for shipment.
- Spacecraft modifications required to meet mission peculiar requirements.
- Planning, organizing, directing, and controlling assigned checkout tasks.
- Updating, modifying, maintaining, and testing test and support equipment, and assuring necessary calibration was accomplished.
- Ensuring safety of personnel and hardware.
- Maintaining an effective training level of checkout representatives.
- Planning and controlling checkout area cost and budget requirements.
- Maintaining liaison with the NASA Resident Management as designated in program requirements.
- Generating and retaining objective evidence in the form of test records to verify or establish that the test requirements were met.

The MDC G2427, Huntington Beach Vehicle Checkout Laboratory Operating Plan, identified: (1) applicable management directives associated with directing the VCL operations, (2) supporting MDAC-W elements who provided personnel, skills and services, (3) custody turnover requirements from manufacturing to the VCL, (4) applicable Test Plans/Specifications, (5) work scheduling requirements, (6) test team structure, (7) test conduct, (8) hardware configuration control, and (9) test problem reporting system, etc. This plan was a more comprehensive document than was normally required for a post-manufacturing checkout because of the many interfaces between the various NASA centers and experiment developers.

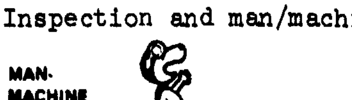
Special Operating Instructions (SOI's) were released to define operating procedures for use by all personnel assigned to the VCL. SOI's were written to interpret and implement the intent of MDAC-W Management Directives or to provide operating instructions where existing directives did not apply.

Safety aspects of the VCL operations were specified in the following:

- The 1B88179, B Revision, OWS Safety and Retreat Operating Instructions, A3-VCL, specified redline monitor instructions and retreat procedures to be followed in the event emergency action was required during OWS operations.

- The MDC GC937, OWS Safety Brochure of the Vehicle Checkout Laboratory, Huntington Beach, dated November 1971, specified the safety rules and procedures to be observed by all personnel engaged in checkout of the OWS in the VCL.

In order to ensure timely release of Test and Checkout Procedures (TCP's), verify all test requirements were included, and to improve TCP coordination with the NASA, an OWS Review and Revision Plan was implemented. Initial release of TCP's was scheduled no later than test minus four (4) weeks. TCP's implemented the requirements of Test Outline Drawings (TOD's), satisfied test requirements previously approved by the NASA, and were thoroughly reviewed by affected technologies. Test time minus three weeks a review meeting was held with representatives from affected technologies and the NASA. NASA approval letter was prepared and transmitted to MDAC-W approving TCP contingent on incorporation of initial review meeting agreements. Review comments were incorporated into TCP by firm letter change release. A final review meeting was held at test minus one (1) week. Procedure changes resulting from final review meeting were incorporated into all test team copies by Procedure Change Instructions (PCI's). Inspection and man/machine interface stamps (Snoopy)



were applied to TCP Inspection Master. The Snoopy was a symbol used to indicate that a crew systems engineer had a requirement to perform a functional test to properly evaluate whether the action met the loads and handling capabilities of a flight crewman. Inspection master procedure vellum was then approved by the NASA and MDAC-W personnel. Real time procedure changes were also incorporated by the PCI method.

Overall responsibility for the Saturn Workshop Skylab (SWS) program at the KSC was the NASA Kennedy Space Center (KSC) Spacecraft Operations (SO). Skylab Preflight Operations Procedures (POP's) were established to define Contractor Interface Guidelines for SWS Spacecraft Operations at the KSC.

5.1.4 Documentation and Control Requirements - Mission Support Testing

- Action Requests generated to solve Mission problems generally flowed from Johnson Space Center (JSC) Flight Operations Management Room (FOMR) to Huntsville Operations Support Center (HOSC); however, requests were sometimes phoned directly to the MDAC-W Mission Support (MS) Room Captain (RC). Each action was assigned a unique Action Item Number.

  Action Requests requiring use of the OWS Backup or Component and System Hardware to resolve a Mission problem resulted in preparation of a Mission Support Test Request (MSTR) by the RC. A responsible engineer was assigned. The engineer was responsible for preparation of the MSTR Test Plan, coordinating test requirements, within MDAC-W and with MSFC, participating in the test when required, providing the solution to the Mission problem, and completing the action item form. Action Requests and associated MSTR's are presented in Figure 5.1-5. The MSTR, with Test Plan included, was submitted to the VCL Program Manager and the NASA

Senior Vehicle Systems Checkout Representative for approval prior to commencing any hardware activities. The MSTR was then submitted to the affected technology Task Leader. The Task Leader implemented the requirements of the MSTR on a Test Preparation Sheet (TPS) and ran the test. All other agencies supported preparation of the TPS and performance of the test as required. At the completion of the test, the Task Leader was responsible for submitting the results of the test to the responsible engineer/Room Captain and preparing a final report.

The documentation utilized during Mission Support special tests were:

- Mission Support Area Control Drawing. MSACD's provided the means to authorize, direct, control and document special tests requested by a MSTR.

- Test Preparation Sheets - TPS's were generated by the Engineering Task Leader to implement the requirements of the MSTR. TPS's included but were not limited to the following:

  - Pre-test setups
  - Recording requirements
  - Test instructions
  - Temporary configuration changes
  - Authorization for removals/disconnections
  - Inspection buyout for applicable details associated with returning the Spacecraft back to original configuration, and retest of invalidated subsystems.
  - Identifying Manufacturing Planning requirements

- Non-Conformances - Non-Conformances were documented in accordance with Quality Assurance Standard Practices.

- Documentation - Mission Support Test documents were maintained by Quality Control during Mission Support (MS). At the completion of MS, all special test documentation was transferred to Quality Data Records File.

5.2 COMPONENT AND SUBSYSTEM TESTING

This section enumerates the development and qualification tests performed on the component and subsystems. Provided is a listing showing the quantity and types of tests with the corresponding report number that contains all of the test data. A brief is provided that describes the general purpose of the tests. For detailed test description and discussions on significant anomalies, reference is made to the Tests Section within each subsystem in Section 2.2 of this report.

5.2.1 Development and Qualification Testing - For purpose of clarity, the development and qualification testing which was performed is grouped in accordance with respective functional OWS hardware breakdown structure. Tests which were not compatible with this grouping because of scope and method of accomplishment are defined as special tests in Paragraph 5.4 of this report. Major functional groupings are listed below:

- Crew Accommodations
- Habitability Support Systems
- Electrical Systems
- Illumination System
- Communication System
- Data Acquisition System
- Thermal Control Systems
- Thruster Attitude Control System
- Corollary Experiment Accommodations

5.2.1.1 Crew Accommodations - This portion of the test program verified the integrity of the crew quarters, astronaut aids, crew safety provisions and the orbital maintenance provisions.

Testing of items in this category were initiated early in the OWS program and many completed prior to the conversion from the "wet" to "dry" concept. Twelve of these tests remained applicable to the "dry" version.

- Crew Quarters - Tests applicable to this area encompassed the floor, ceiling, compartmentization, viewing window and color scheme. Listed below are Test Line Items used to develop and qualify the crew quarters.

Title	Line Item	Type	Start	Completion	Report Number
Floor Panel	CA-1	Dev	08/14/67	10/06/67	TM-115
Floor & Wall (4.2 Grid)	CA-2	Dev	10/16/67	02/15/68	TM-123
Wall & Floor Grid Splice	CA-3	Dev	12/18/67	12/27/67	TM-124
Thermal Curtain & Ceiling	CA-4	Dev	12/15/67	12/31/68	MP-51694
Green Alodine Coating	CA-5	Dev	03/15/68	10/28/69	DAC-62115
Coating Al Foil MD-19	CA-6	Dev	08/04/67	12/05/67	DAC-62116
Color Anodic Films	CA-7	Dev	02/26/68	12/16/68	MP 51,386
Viewing Window & Instal	CA-18	Dev	11/16/70	08/20/71	G3865
Viewing Window & Instal	CA-19	Qual	08/18/71	12/07/71	G3761
View Window Int Shield	CA-27	Dev	09/27/71	04/07/72	G3372

- Astronaut Aids - Items tested in this category involved both fixed and portable aids including handrails, tether attachments and foot restraints. The tests noted below cover the development of these items.

Insulated Plug Assembly	CA-8	Dev	08/14/68	05/02/69	TM-131 R1
Portable Foot Restraints	CA-9	Dev	09/03/68	07/11/69	TM-190
Portable Hand Hold	CA-10	Dev	06/17/68	06/21/68	TM-188
Tether Attach Pin	CA-11	Dev	06/24/68	06/25/68	TM-184

o Crew Safety Provisions - Testing in support of crew safety provisions consisted of development and qualification of the fire protection and meteoroid shield deployment systems. Test Line Items CA-5, CA-6 and CA-7 noted under crew quarters, developed the fire retardant coating utilized. In addition, testing was accomplished on the foam insulation applied to the common bulkhead dome under Line Item CA-21

Title	Line Item	Type	Start	Completion	Report Number
Foam Insulation	CA-21	Dev	06/11/70	09/22/70	TM-138

Listed below are those Test Line Items that developed and qualified the deployment of the meteoroid shield.

Meteoroid Shield Rel Sys	CA-12	Qual	04/21/71	05/19/71	R689012
Exp Tube/CDF & EBW CDF	CA-13	Dev	06/23/69	07/25/69	R6573A
Exp Tube	CA-14	Dev	01/17/68	09/12/69	R6664
Exp Tube	CA-15	Qual	02/19/71	04/29/71	R6870A
*Expand Tube & Strap Assy	CA-28	Dev	07/12/71	09/04/71	G4022
Exp Tube/Strap Assy	CA-30	Qual	03/08/72	04/14/72	R7042A
Exp Tube/Strap Full Scale	CA-31	Qual	01/11/72	02/10/72	R7043
Meteoroid Shield Post Inst	CA-32	Dev	12/13/71	01/31/72	G3373
Meteoroid Shield Deploy Latch	CA-34	Dev	02/17/72	07/19/72	G3374

o Orbital Maintenance Provisions - Since most orbital maintenance logistics spares were stored in storage containers, it was necessary to demonstrate that this equipment could withstand launch and boost dynamic load environments. The Test Line Item noted below was utilized for this purpose.

Spare Equipment Stow Container	CA-16	Qual	09/20/71	05/13/72	C4112 Vol. I, II & III

*Tested at supplier.

5.2.1.2 Habitability Support System - The habitability system consisted of many major subsystems requiring extensive development and qualification testing prior to flight of the OWS. In addition to these test line items, Neutral Buoyancy and Zero-Gravity testing, identified in Paragraph 5.4 as Line Items ST-1 and ST-2, were conducted at MSFC. Some design verification was accomplished on the spacecraft with crew participation during post-manufacturing checkout.

For the prupose of this report, the Habitability Support System was composed of the following subsystems: Crew Restraints, Waste Management, Water, Personal Hygiene, Food Management and Refrigeration, Trash Disposal and Vacuum provisions.

- Crew Restraints - Crew restraints were evaluated and developed by Test Line Item HS-1. These included Food Management Compartment, Pressure Suit Foot, Portable and Fixed Foot, Sleep and Equipment Restraints. In addition to the one "G" tests at Huntington Beach, these restraints were tested in neutral buoyancy at MSFC facilities. Sleep restraint stowage testing was initiated under Line Item HS-69 and subsequently stopped due to material change and testing accomplished at MSFC. Below are Test Line items involved.

Title	Line Item	Type	Start	Completion	Report Number
Crew Restraints	HS-1	Dev	11/03/69	07/27/71	R6901
Sleep Restr Assy	HS-69	Dev	02/02/72	02/03/72	N/A

o Waste Management Subsystem - The subsystem provided the hardware necessary for safe, effective and hygienic collection, processing, stowage and return or disposal of all waste products for the three Skylab missions. Below are listed the development and qualification test line items applicable to this subsystem including some supplier tests.

Title	Line Item	Type	Start	Completion	Report Number
Waste Management Subsys	HS-2	Qual	07/15/71	11/21/72	G4176
*Zero-G Fecal Collector	HS-3	Dev	11/01/69	04/14/70	TM-192
*Waste Collector & Proc	HS-4	Dev	12/07/70	06/28/72	TM-198
*Urine Processor & Stor	HS-5	Dev	11/03/69	03/05/70	TM-199
Apollo Blower	HS-27	Qual	02/16/70	07/20/70	R6690A
*Apollo System	HS-28	Qual	07/08/70	08/17/70	TM-195
*Waste Management Odor Cont	HS-34	Dev	06/30/71	11/19/71	TM-203
*UCMSS - Prelim Spec Tests	HS-39	Dev	07/28/70	10/06/70	TM-193
Urine Freezer	HS-41	Qual	11/08/71	03/28/72	R7038
Urine Sample Return Stor Container	HS-42	Qual	04/28/72	07/13/72	G3973
*UCMSS - Two-Bag Urine	HS-51	Dev	10/27/70	11/13/70	TM-196
*Urine Centr Sep Assy	HS-55	Dev	06/21/71	01/28/72	TM-204
*Centr Sep (Plexiglass)	HS-60	Dev	07/20/71	09/21/71	TM-206
Two Bag Urine Tracer *Verification	HS-61	Dev	11/29/71	02/25/71	TM-205
Centr Sep Collect Subsys.	HS-62	Dev	09/18/71	08/16/72	G4132
Urine Freezer/Tray Frost	HS-64	Dev	06/09/71	06/15/71	R6888
Urine Freezer (Urine & Blood	HS-85	Qual	06/29/72	10/05/72	G4150
Urine/Blood Sample Return Storage Container	HS-86	Qual	10/16/72	10/27/72	G4152
Urine Subsystem-Redesigned	HS-89	Dev	10/25/72	12/15/72	G4198
Urine Subsystem-Redesigned	HS-90	Qual	12/08/72	04/09/73	G4199
Urine Bag Assy	HS-91	Qual	01/17/73	02/12/73	G4196

*Test accomplished at Supplier.

NOTE: Expendable storage and dispensing equipment which included collection bag supply module, bag dispenser, utility water dispenser, and storage containers were evaluated during the qualification test of Waste Management Subsystem, Line Item HS-2.

o Water Management Subsystem - Two separate installations of the Water Subsystem were made in the OWS - One for personal hygiene and one for food management. These provided capability for storage, supply, conditioning, dispensing for food and beverage preparation, drinking and body cleansing during all missions. Test Line Item HS-7 qualified the water management subsystem. Line Item HS-94 was the qualification test initiated on a redesigned water heater with CAL-ROD type element for use in the OWS Backup spacecraft. Listed below are the tests performed to develop and qualify this major subsystem.

Title	Line Item	Type	Start	Completion	Report Number
Water Subsystem	HS-7	Qual	11/02/71	06/15/73	G4194
Water Storage Assembly	HS-8	Dev	09/16/70	11/10/72	G4175 VOL I & II
Food Reconst Disp Unit	HS-10	Dev	03/02/70	07/07/71	R6915
Drink Water Dispenser	HS-11	Dev	02/10/70	08/16/71	R6938
*Water Heater	HS-12	Dev	09/29/71	06/04/71	G3945
Microbiological Eqp	HS-14	Dev	12/01/70	05/24/72	G4156
Per Hyg Water Disp	HS-16	Dev	07/22/70	09/16/70	R6760
*Water Storage Cont Bel	HS-32	Dev	12/17/70	03/12/71	G3611
Heater Controller	HS-46	Dev	03/29/71	06/11/71	R6875
Urine Sep Flush Disp Assy	HS-56	Dev	09/27/71	01/31/72	R6989A
Water Deionization Assy	HS-59	Dev	12/08/71	07/12/72	G4181
Water Heater	HS-94	Qual	08/02/73	11/27/73	R7228

*Tested at Supplier.

- Personal Hygiene Subsystem - There were two types of personal hygiene equipment utilized during the Skylab/Orbital Workshop missions. These were either individual or common personal hygiene equipment. Qualification was accomplished under Test Line Item HS-17 at the subsystem level. In addition, neutral buoyancy and zero gravity tests were accomplished at MSFC.

  The washcloth squeezer was developed under Line Item HS-48 but qualified during the water subsystem test, HS-7.

  Below are the tests conducted on this subsystem.

Title	Line Item	Type	Start	Completion	Report Number
Per Hygiene Subsystem	HS-17	Qual	09/10/71	01/19/72	R6993
Cleansing Solution Test	HS-33	Dev	02/23/70	04/03/70	R6703
Wash Cloth Squeezer Assy	HS-48	Dev	04/05/71	05/23/72	R7062
Biocide Wipes	HS-74	Qual	06/12/72	04/24/73	R7067

- Food Management and Refrigeration Subsystems - These subsystems provide the equipment and supplies required for the storage, preparation, consumption and preservation of food and disposal of food wastes and wrappers. The urine freezer tested as Line Items HS-41 and HS-85 is noted under the Waste Management Subsystem; however, it is functioned by the Refrigeration Subsystem. Below are noted the development and qualification testing of the elements of these subsystems.

Title	Line Item	Type	Start	Completion	Report Number
Refrig Subsystem	HS-19	Qual	02/05/71	01/12/73	G4180
Radiator & Plume Shield	HS-31	Dev	05/25/71	04/20/72	R7060
Pump Logic Control	HS-35	Qual	11/17/71	03/20/72	R6967
Radiator Bypass Valve Controller	HS-36	Qual	03/21/72	07/13/72	G4004
*Pr Rel Valve, RTC	HS-66	Dev	08/11/71	09/14/71	Sterer DTR-29450-5A
Bypass Control Monitor	HS-76	Qual	05/03/72	06/06/72	R7073A
Radiator & Plume Shield	HS-77	Dev	03/11/72	01/23/73	G4234
*Potable Water Chiller	HS-78	Dev	02/28/72	05/09/72	G4087
Coolant Pump Inverter	HS-88	Qual	01/02/73	02/08/73	G4193

- Trash Disposal Subsystem - This subsystem included the collection and disposal equipment necessary to remove trash and garbage from the LH_2 tank of the workshop and expel it into the LOX tank area. This was accomplished by means of an airlock located in the common bulkhead. Testing was performed on the bags utilized to contain liquids and solids expelled through the airlock (HS-67) as well as the screens, baffles, gage and the trash airlock itself. Below are listed the test line items utilized in verifying the design integrity of this subsystem.

Title	Line Item	Type	Start	Completion	Report Number
Trash Disp Airlock	HS-24	Dev	09/28/70	11/08/71	G3364
Trash Bags	HS-67	Dev	07/15/71	05/19/72	G4094
Waste Tank Screen	HS-73	Dev	10/15/71	01/14/72	R7040
Pressure Gage, Trash Disposal Airlock	HS-75	Dev	12/20/71	02/09/72	G3377
Waste Tank-Screen Baffle	HS-81	Dev	03/03/72	03/31/72	R7039

*Tested at Supplier.

o Vacuum Provisions - These provisions were provided in the Workshop to provide vacuum discharge and shutoff capability for various items of equipment and experiment support. 1-inch and 1/2-inch ball valves were utilized in the Waste Management Compartment to accommodate the urine and processor dump systems, waste management and wardroom water systems and the waste management dump system. These valves were also utilized for shutoff capability to the Lower Body Negative Pressure (LBNP) experiment, and vent refrigeration coolant leakage into the waste tank. Testing of the components and subsystems were accomplished by the following line items.

Title	Line Item	Type	Start	Completion	Report Number
Vac Outlet Valves	HS-25	Dev	08/29/68	03/19/70	R6358
Vacuum Outlet System	HS-26	Qual	10/18/71	05/20/72	G4117
1/2 Inch Vacuum Vlv	HS-65	Qual	01/17/72	04/26/72	R7065
Condensate Dump Syst	HS-80	Dev	06/30/72	08/15/72	G4203
Heater Probe/AM Cond Dump System	HS-87	Qual	10/19/72	01/26/73	G4204
Htr Probe Back-up	HS-92	Dev	01/14/73	01/31/73	G4205

5.2.1.3 Electrical Systems - The systems associated with the Workshop electrical power generation, distribution and control are contained in this section. There are three major divisional breakdowns involved: Launch Support Electrical System; Electrical Distribution and Control; and the Solar Array System.

o Launch Support Electrical System - This operated only during launch and ascent phases of the OWS mission and remained passive subsequent to orbital insertion and Instrument Unit (IU) power down. Hardware utilized was previously qualified for the S-IVB stage; however, the system was verified during cluster testing at KSC.

- Electrical Power Distribution and Control - Electrical energy is provided by the Solar Array System (SAS) with power conditioning accomplished by equipment installed in the Airlock Module (AM). Single voltage DC power is then regulated and transferred into the Workshop electrical power distribution and control system where final distribution to end items of equipment is made.

  The following tests were conducted to ensure design suitability and verification of the electrical system which supplies power to each of the Orbital Workshop components.

Title	Line Item	Type	Start	Completion	Report Number
LH_2 Wicking & Ign	ES-1	Dev	07/12/67	07/29/67	R6088
Cryo Mat Eval	ES-2	Dev	11/06/67	03/11/69	R6134
Zero G Conn	ES-3	Dev	02/06/69	07/30/71	R6548A
Zero G Conn	ES-4	Qual	05/06/70	02/03/72	R6970A
Forward Dome Test	ES-5	Dev	04/01/70	05/28/70	G2071
Cont & Displ Panel	ES-6	Dev	03/19/70	06/09/70	R6696A
Cont & Displ Panel	ES-7	Qual	10/11/71	06/15/72	G4023
OWS Relay Modules	ES-11	Qual	05/03/71	10/29/71	R6943
30 Amp G.P. Relay	ES-13	Qual	06/10/71	07/08/71	R6877
WMC C & D Panel	ES-14	Qual	10/21/71	12/16/71	R6939
Module, Isol. Diode	ES-15	Qual	05/09/72	06/09/72	R7053A
Series Reg Module	ES-16	Qual	05/15/72	06/06/72	R7054

- Solar Array System (SAS) - The Solar Array was the primary source of electrical power for the Orbital Workshop. The test program conducted to develop the SAS and finally qualify it for flight consisted of development testing and qualification testing of array panel assemblies, array deployment mechanisms, and passive vent module. This testing was followed by a qualification test of the entire SAS wing assembly to verify that mechanical integrity of the array structure and equipment would withstand the launch and ascent dynamics of vibration, shock and acoustics. The assembly was subjected to the launch dynamics in the stowed position and verified the deployment performance from initiation of the ordnance actuated beam/fairing release mechanisms to full extension of the SAS wing section. Counterbalances during extension were utilized to negate one "G" loads. The following is a list of all SAS testing.

Title	Line Item	Type	Start	Completion	Report Number
*Solar Cell Panel	SA-1	Qual	07/12/71	01/26/72	G4039
*One-Third Wing Assy	SA-2	Dev	07/01/70	03/21/72	G4078
SAS Pwr Unit & Conn	SA-3	Qual	11/22/71	01/07/72	G3999
*Solar Array System	SA-4	Qual	03/31/72	07/11/72	G4032
CDF Manif Install	SA-5	Qual	10/23/70	11/16/70	R6788A
Solar Cell Panel	SA-13	Dev	08/14/70	09/22/70	SAS4-3082
Wing Rel Mech Tube	SA-14	Dev	04/23/70	02/19/71	R6835
Wing Rel Mech Exp Tube	SA-15	Dev	07/12/71	08/30/71	G4049
*Hinge Assy Beam	SA-16	Dev	10/07/70	04/28/72	G4050
SAS Beam Rel, Exp Tube	SA-17	Dev	01/08/71	05/14/71	R6894
*Actuator/Damper	SA-18	Dev	10/12/70	03/25/71	TM-7
*Actuator/Damper	SA-19	Qual	02/18/72	07/18/72	G4047
*Act/Damper W/Brkn Spring	SA-20	Dev	06/02/71	06/15/71	G4000
Mag Rel Vent Module	SA-21	Dev	12/18/71	02/18/72	R7041
*SAS Vent Module	SA-22	Dev	01/03/72	05/30/72	G4046
*SAS Vent Module	SA-23	Qual	04/19/72	05/31/72	G3950
*Cinch Bar/Seal	SA-26	Qual	07/05/72	07/20/72	G3932

5.2.1.4 Ilumination System - The OWS illumination system which provides internal lighting units for crew quarters, work areas, emergency use and

*Tested at supplier.

experimental support operations utilizes a common lighting unit which was subjected to a component qualification test designed to demonstrate that the design objectives were fulfilled; however, a possible low input voltage operating mode was defined which could prevent light operation or cause possible damage to light. To overcome this problem, a design change was implemented to add a capacitor circuit and a case extension to house it. The redesigned lighting unit was qualified by Line Item IS-7. In addition to the component tests listed below, total system verification was accomplished during vehicle post-manufacturing checkout.

Title	Line Item	Type	Start	Completion	Report Number
Gen Illum Light	IS-1	Qual	05/07/71	12/17/71	R6924
Gen Illum Light	IS-7	Qual	06/19/72	09/26/72	G4155

5.2.1.5 Communication System - This section is concerned with elements associated with crew communications. The telecommunication system and inter-communication systems are both a part of the Airlock Module and were designed and tested as part of that effort. The interface of the two systems is by means of inter-communication (intercom) boxes supplied as GFP and installed in the Workshop area. Verification testing of the intercom was accomplished during post-manufacturing checkout defined in Paragraph 5.5.

The Caution and Warning (C&W) system is provided for alerting crew to out-of-tolerance and emergency conditions by visual and/or audible signals. This system was verified during spacecraft and integrated systems testing and since the alarms and displays are part of the control and display panel, these were verified during test Line Items ES-6 and ES-7.

The following test line item was conducted to verify the structural mounted components of the communication system.

Title	Line Item	Type	Start	Completion	Report Number
Structural Mtd Cons Comp	CS-3	Qual	06/14/71	05/24/72	G3996

5.2.1.6 Data Acquisition System - This system included transducers, excitation and signal conditioning, multiplexing, and on-board data displays. Data was acquired during the launch and ascent phase from various Workshop system operations as well as the caution and warning system. This data was transferred to the Airlock Module (AM) telemetry system or to the Workshop control and display panel. Electrical power for the data acquisition system was supplied directly from the AM and was electrically independent of the Workshop electrical power distribution and control system. The data acquisition system was made up of launch support data, Orbital Workshop (OWS) data, on-board data display and HSS data systems.

- Launch Support Data System - Monitored the launch, ascent and early orbit system parameters vital to the success of that phase of the mission. All components of this system, except the multiplexer, were previously qualified and flown on the S-IVB stage. The multiplexers were utilized during the Gemini program but additionally tested as Line Item DA-1 to meet the Workshop launch and ascent dynamics levels.

The forward signal conditioning panel was tested in four phases as Line Item DA-3. The first two phases included lightly loaded and fully loaded panels to various environments. The last two phases of this test were initiated to increase temperature ranges and to eval ate the redesigned 5Vdc excitation module.

Title	Line Item	Type	Start	Completion	Report Number
*Mult Sign Cond-Gen	DA-1	Dev	Unknown	07-07/69	EMR-2175-02
Fwd Sign Cond Panel	DA-3	Dev	08/19/70	02/08/71	R6763
			08/19/71	12/13/71	R6763

o Orbital Workshop (OWS) Data System - Monitored functions of the various Workshop systems which are important to crew safety, comfort and mission success. The following line items verified the capability of this system to meet mission requirements.

Title	Line Item	Type	Start	Completion	Report Number
Fuse, Cart, Slk Mini	DA-4	Dev	01/06/70	01/09/70	R6658
Data Acquisition Comp	DA-5	Dev	10/07/70	12/30/70	R6775B
*Absolute Press Transducer	DA-8	Qual	01/25/72	10/10/72	G4075
*Diff Press Transducer	DA-9	Qual	01/19/72	08/02/72	G4002
Data Acq Modules	DA-10	Qual	05/12/72	06/30/72	G4005

*Tested at supplier.

o On-Board Data Display System - This system was used to provide the flight crew with the information needed to indicate particular subsystem operational status and to provide visual indication of conditions sensed by the warning and emergency systems. These displays are presented on the control and display panels which were tested as Line Items ES-6 and ES-7. (See Para. 5.2.1.3). All other elements of the system were qualified for flight use by previous usage or by qualification in some other system.

- HSS Data System - Utilization of log books, etc. for data precluded the requirement for testing the items of this system.

5.2.1.7 Thermal Control System - This system consisted of three major elements: Pressurization and Pressure Control, Thermal Control, and the Ventilation Control Systems.

- Pressurization and Pressure Control - This system provided for pressure control of the habitation area (LH_2 tank) and waste tank (LO_2 tank) during ground holds, boost flight, tank venting during orbital insertion, and orbital pressurization.

  The habitation area vent and relief control equipment was S-IVB hardware modified to OWS requirements and were verified by Test Plan Line Items EC-13, EC-22, EC-38 and EC-15. The waste tank prelaunch pressurization was verified by PAT and post-manufacturing checkout. The vent and relief control of this tank consisted of pneumatically actuated caps over each of the two vent ducts which penetrates waste tank and aft skirt. These caps were released after spacecraft separation and remained off throughout the mission. This hardware was verified by Test Plan Line Item EC-32. It was also necessary to reverify waste tank pressurization line (stainless steel tubing and three bellows flex sections) to the higher dynamic environments of the OWS. This was accomplished by Line Item EC-40. Orbital pressurization provisions included the access hatch check valve which was qualified by Line Item EC-39, the functional and structural integrity which was verified by EC-2, and the airlock interface bellows seals which were verified by Line Item EC-3. After completion of EC-2 and EC-3, it was found necessary to subject the entry hatch to further testing to clear an anomaly. (One rod and bearing on a latch actuator rod for hatch closure came loose from the end, apparently due to vibration test which occurred during Line Item EC-2.) This was accomplished on Line Item EC-44. Line Item EC-46 was performed to accomplish functional leakage tests in order to qualify the hatch for possible EVA use. Line Item EC-4 was conducted to qualify the sealing device used to seal the habitation area vent line after astronaut entry.

The Test Line Items accomplished for this system are listed below.

Title	Line Item	Type	Start	Completion	Report Number
OWS Access Hatch	EC-2	Qual	07/12/71	11/17/71	G3363
Bellows Seal Airlock	EC-3	Qual	07/20/71	11/17/71	G3363
LH_2 Tank Seal Device	EC-4	Qual	04/21/70	12/11/70	R6823
Solenoid Vent Valve	EC-13	Qual	07/14/71	10/13/71	R6932
Fuel Tank Vent Duct Assy Ext.	EC-15	Qual	01/07/71	03/10/71	R6855
Hab Area Vent & Relief Latching Vent & Relief Valve	EC-22	Qual	02/20/71	09/30/71	R6878
Short Duct Waste Tank NPV System	EC-32	Qual	10/08/71	10/29/71	R6973B
Hab Area Vent Flex Line	EC-38	Qual	01/22/72	02/03/72	R6998A
Check Valve, Access Hatch	EC-39	Qual	02/16/72	03/15/72	G3375
Pipe Assy-Waste Tank Press	EC-40	Qual	02/07/72	02/16/72	R6999
Hatch Rod End Bearing Vib Test	EC-44	Qual	03/15/72	03/17/72	G3376
Entry Hatch-Repeat Cycle	EC-46	Qual	06/15/72	06/27/72	G3379

o Thermal Control - Thermal control of the Workshop was achieved by two methods - external passive thermal control and internal passive and active thermal control provisions.

The external passive thermal control provisions consisted of surface coating applied to meteoroid shield interior and exterior surfaces, meteoroid shield boots and extension surfaces and forward dome insulation. These coatings were verified by coupon testing in the materials laboratory both at MSFC and at MDAC and wherever possible coatings which were previously qualified for use on other space programs such as cat-a-lac 463-1-500, were utilized. Line Item EC-5 was a development test to verify thermal shield extension structural integrity when exposed to both high and low level sonic integrated loads.

The internal passive thermal control consisted of internal surface coating and heat pipes. Those coatings were selected to achieve both aesthetic qualities desired as well as provide the necessary emittance levels and were evaluated both by MSFC and MDAC-W for flame-proofing and emissivity qualities. This test activity is identified in Paragraph 5.2.1.1, Crew Accommodations. The interior heat pipes are utilized to transfer heat from warm side of vehicle to the cold side to prevent condensate to form within OWS. Test Line Item EC-41 was utilized to verify structural integrity when subjected to launch and boost dynamic criteria.

The active thermal control provisions include a radiant heater which was qualified by Line Item EC-6. The convection heaters in each of the TCS ducts were qualified by Line Item EC-7. The temperature control assembly design was supported by development test EC-11 and then qualified by test EC-12.

Ground thermal control was required to maintain the temperature between 40°F (278°K) and 80°F (300°K) for maintaining stowed food and film from the time they were loaded in the OWS to launch. Two heat exchangers in series, located in the entertainment console, were used to maintain this temperature. Development Test Line Item EC-26 was conducted by the supplier (AIResearch) and qualification testing by Line Item EC-27, was completed at MDAC.

Listed below are the test line items used to verify the capability of the thermal control system.

Title	Line Item	Type	Start	Completion	Report Number
Thermal Shield Ext	EC-5	Dev	07/03/69	10/29/69	TM-137
Tank Radiant Heater	EC-6	Dev	11/10/70	11/12/71	R6786
Duct Heater Assembly	EC-7	Dev	09/29/69	06/04/71	R6601
Thermal Control Assembly	EC-11	Dev	06/24/70	01/15/71	R6740
Thermal Control Assembly	EC-12	Qual	12/15/71	06/29/72	R6968
*Ground Thermal Cond Syst	EC-26	Dev	04/30/71	09/18/71	TM-207
Ground Thermal Cond Syst	EC-27	Qual	09/21/71	02/29/72	R7035A
Heat Pipe Installation	EC-41	Qual	11/02/71	02/11/72	R7037

*Tested at supplier.

o Ventilation Control System - The ventilation control system is comprised of a mixing chamber, where reconstituted air from the AM heat exchanger and contamination control equipment is mixed with air to be recirculated, and a 3-duct system which runs from mixing chamber to a plenum volume formed by a common bulkhead and ceiling. Each duct had a cluster assembly of four GFE fans, which provided the required flow rates and the air moved from the plenum into habitation areas through adjustable diffusers in the ceiling. The waste management area and food management areas were ventilated independently from the Workshop proper. These areas had identical systems which are comprised of a fan, filter, charcoal bed and sound suppression assembly. The fan cluster was verified by a Line Item EC-8. Line Item EC-9 was utilized to verify air distribution and EC-10 verified room fan filter assembly.

The atmosphere supply duct carried revitalized air from the AM/Environmental Control System (ECS) to the TCS filter mixing chamber. This duct was designed and qualified by MDAC-ED.

The atmosphere mixing chamber was a relatively simple design of a sheet metal structure and was qualified by analysis. Further evaluation was conducted during the systems tests described in subsequent paragraphs.

The recirculation ducts carried airflow from the mixing chamber to the fan cluster through the crew's quarters and convective heaters and into the plenum area above the ceiling. These ducts were qualified by analysis and part of Line Item EC-8.

The fan cluster assembly consists of pre-installed porous wall baffled resonant chamber, inlet and outlet muffler, and four GFE recirculation fans. Testing for this cluster was accomplished on Test Line Items EC-8, EC-33 and EC-36 as well as tests conducted at MSFC.

The recirculation duct diffusers and ceiling diffusers design verification was accomplished by analysis and Test Line Item EC-9.

The waste and food management ventilation system consisted of ceiling diffusers, filter odor removal canisters, recirculation fans and resonant mufflers. Testing for these items were accomplished by Line Items EC-10, EC-34 and EC-37.

Three portable fans allowed the astronauts extra ventilation velocity at selected locations within the OWS. Tests of these units were conducted by Line Items EC-30 and EC-42.

The following list constitutes the testing accomplished in support of the thermal control system. Further functional verification was obtained during post manufacturing checkout.

Title	Line Item	Type	Start	Completion	Report Number
Fan Cluster Test	EC-8	Dev	01/20/69	90/23/70	R6705
Air Distrib Ceiling	EC-9	Dev	11/03/69	11/13/69	TM-139
Rm Fan Filter Test	EC-10	Dev	06/29/70	11/30/70	R6753
Fan, Portable	EC-30	Dev	08/06/71	08/27/71	R6911
Fan Cluster Assembly	EC-33	Dev	10/11/71	10/21/71	R7022
Room Fan Filter	EC-34	Dev	04/26/71	09/17/71	G4177
Fan, Cluster Vib	EC-36	Qual	05/14/71	05/28/71	G4101
Fan, WMC Vibration	EC-37	Qual	04/24/71	04/30/71	R6885
Portable Fan - Vibration	EC-42	Dev	12/21/71	03/21/72	R7034

5.2.1.8 Thruster Attitude Control System (TACS) - The TACS was a blow down type system using ambient temperature nitrogen gas and was used for cluster stabilization prior to Control Moment Gyro (CMG) spin up as well as correction of spacecraft attitude as required. Development testing of the system was accomplished during Line Item TC-1 and additional test accomplished by the supplier on TC-12 to evaluate the effects of adverse tolerances, etc., on the valves. Qualification of the pressure switch was accomplished in Test Line Item TC-14 while satisfactory qualification of the temperature probe and switch was verified by TC-13.

This system is made up of four major functional subsystems; propellant storage and distribution, propellant distribution control, thruster modules, and thruster control.

- o Propellant Storage and Distribution - Titanium cold gas storage spheres were mounted to the thrust structure cone. These modified S-IVB spheres used a bi-metal joint as a transition section between the spheres and stainless steel manifold supply tubing. Development testing of this bi-metal joint was done during Line Item TC-10 while qualification of the sphere was accomplished through Test Line Item TC-9.
- o Propellant Distribution Control - The TACS system, being of the "blow-down" concept, had no regulation system; therefore, the plumbing and manifolding configuration was evaluated during post-manufacturing checkout.
- o Thruster Modules - Initial development of the valves were accomplished by the supplier but the TACS system, including the modules (four valves) were developed and qualified during testing of

Line Items TC-1 and TC-2 respectively.

- Thruster Control - Control was achieved with these quad redundant valves, the control switching assembly, TACS timer module and the TACS valve signal delay module. The total system was qualified by Test Line Item TC-2.

The Control Switching Assembly - This electronic switching device was used to supply command signals to the TACS and the critical items were qualified during the testing of Line Item ES-11 (see Paragraph 5.2.1.3).

The TACS timer module was a solid state switching device qualified by Test Line Item TC-8

The TACS valve signal delay module composed of four (4) 10 amp general purpose relays and two (2) independent electronic times was qualified by Test Line Item TC-11.

Tests noted below summarize the test line items utilized in developing and qualifying the thruster attitude control system.

Title	Line Item	Type	Start	Completion	Report Number
Thruster Module Assy	TC-1	Dev	04/11/70	12/03/71	R6868
Thruster Module Assy	TC-2	Qual	09/13/71	11/06/72	G4206 VOL I-VI
TACS Timer Module	TC-8	Qual	10/16/71	11/24/71	R6946
TACS Pressure Sphere	TC-9	Qual	06/07/71	08/06/71	G2119
Bi-Metal Joint TACS Syst	TC-10	Dev	03/01/71	05/05/71	G2113
TACS Timer Delay Module	TC-11	Qual	04/12/72	05/17/72	R6971

Title	Line Item	Type	Start	Completion	Report Number
TACS Temp Probe & Press Switch	TC-13	Qual	08/30/72	11/08/72	G4208
TACS Pressure Switch	TC-14	Dev	12/08/72	12/20/72	G4209
Supplemental TACS Ball Valve	TC-16	Dev	07/03/73	07/19/73	R7219

NOTE: Line Item TC-16 was accomplished after launch of the Skylab to develop a backup or supplementary TACS system. Hardware would be flown up on SL-3 if required. (This system was not needed so did not get implemented, but test results indicated its feasibility.)

5.2.1.9 Corollary Experiment Accommodations - The experiment accommodations consisted of both electrical and mechanical provisions.

- Electrical Provisions - Regulated, direct current electrical power for the corollary experiments was supplied through the Workshop power distribution panel with switching function provided by the panel circuit breakers. Typical Workshop wiring harness connections to the power distribution panel terminated in receptacles for the special electrical connectors designed for engagement or disengagement by the pressure suited crew. These receptacles were located to provide convenient plug-in power capabilities for the corollary experiments, TV camera, portable fans, etc. The equipment supplying these provisions was tested and described in Paragraph 5.2.1.3 of this document.
- Mechanical Provisions - These provide mounting, pneumatic, fluid and vacuum provisions for the experiments. The functional and structural integrity was accomplished by line items noted below. Experiment/accommodation interfaces were verified by post manufacturing checkout.

Title	Line Item	Type	Start	Completion	Report Number
Scientific Airlock	CX-1	Dev	07/10/70	10/08/71	G4115
PGA Air Flow Mod Syst	CX-5	Dev	07/30/71	09/26/72	G4178
Film Vault Humidity	CX-7	Dev	05/10/71	06/18/71	R6904
Film Vault Mat Compat	CX-8	Dev	7/01/71	09/23/71	R6930A
SAL/Experiments Desiccant Unit	CX-9	Dev	05/24/72	12/12/72	G4179
Film Vault Mat Compat	CX-11	Dev	03/31/72	05/26/72	R7051

NOTE: The accommodations for the lower body negative pressure (LBNP) system consisted of tubing which connected the experiment support section to the LBNP valve located in the Waste Management Compartment vacuum panel. This tubing did not require qualification testing but was subjected to PAT, proof and leak tests during checkout.

5.2.2 Production Acceptance Tests (PAT)

Production acceptance testing of contractor fabricated or assemblied items was performed in compliance with the production test requirements defined by Development Engineering in the applicable MDAC-W drawing. PAT of supplier items were defined by engineer in the procurement drawing. (Specification Control Drawing, Source Control Drawing or MDAC Standard Drawing.)

These requirements for PAT were determined by the design requirements and mission application. A study was conducted in 1970 at MDAC-W by the CWS Systems Engineering organization on Production Acceptance Testing (PAT) with induced environments. A significant number of OWS components, modules and assemblies were identified as being potential candidates for environmental PAT. The environments found to be most effective for this purpose were random vibration, low level sinusoidal vibration for loose partical detection and thermal cycling.

Most relays were subjected to loose partical detection (LPD) vibration tests during PAT and their next assembly modules (approximately 225) were thermal cycled between $-85^{\circ}F$ ($208.2^{\circ}K$) and $+160^{\circ}F$ ($344.3^{\circ}K$) for approximately five (5) cycles. In addicion, high reliability (HiRel) components were given operational burn-in tests to gain confidence in their acceptability to the Workshop environments.

All of these environmental requirements were defined in the engineering drawing and reflected in the subsequent Production Acceptance Procedure as indicated above.
Of signifiance, the entire solar wings (2) were given a vibration PAT prior to installation on the OWS.

5.3 STRUCTURES TESTING

OWS structures consisted of the following major components:

- Forward and Aft Skirts
- Tankage (Habitation and Waste Tank)
- Aft Interstage

Each of the above structural components were qualified separately during the Mainline Saturn Program. In addition to loading each of the above items to ultimate design loads, items were tested to failure. It was originally planned to utilize this data for design verification of the OWS structure. However, because of the many modifications and weight increase to 78,000 lbs (34,373 kg), MSFC authorized by Change Orders 116 and 147, a vibro-accoustic and static structural test program. This package also authorized the assembly of an Orbital Workshop Dynamic Test Article (OWS/DTA). These tests were performed in the vibration and acoustic test facility at the Manned Spacecraft Center in Houston, Texas, from January through May 1971.

The results of the acoustic tests were published in Volume I of Report No. MDC G2445, dated October 1971, and results of the low frequency vibration tests were reported in Volume II of this report. For this program, MSFC was responsible for overall test direction and MDAC-W provided technical support to MSFC. The DTA was constructed from existing fwd and aft skirts used in the Saturn V high force test program and existing Lox and LH2 tankage from S-IVB-1004, Facilities Checkout Vehicle. These major assemblies were assembled, reworked and modified to provide structural and mass simulation. The DTA included flight configuration crew quarters, ceiling, walls and access panel. Equipment racks, panels, and bracketing, as well as water container ring and stowage lockers, were configured in such a manner as to provide the stiffness, strength, and geometry of flight configuration. The mass of plumbing and wiring was integrated and added to associated equipment mass substitutes except for large ducts or wiring runs whose stiffness, and/or mass would have affected modal characteristics. All components installed on brackets, panels, basic structure and isolators were mass simulated.

The acoustic tests were performed at OWS acoustic qualification test levels and structural integrity of all flight type structure was verified to meet the flight dynamic environment. Several anomalous conditions were noted, bolts loosening or backing off, however, they were peculiar only to the DTA configuration.

The low frequency vibration tests utilized the DTA configurated as it was for the acoustic test. These tests simulated the maximum transient response expected to be experienced by the OWS during launch, engine cutoff and stage separation. Vibration response and strain were measured and recorded during test. Integrity of all flight type structure was verified to meet the flight dynamic environment.

Change Order 147 authorized the static test program performed at MSFC. MSFC was responsible for conducting and directing the tests and MDAC provided technical support to MSFC. Volume I of Report No. MDC G2785, dated August 1972, published the results of the combined loading tests where Volume II covered the ultimate pressure test. For these tests, the OWS Static Test Article (STA) was the same structure as previously designated DTA, but was updated to represent the increased weight of the 78,000-lb (34,373 kg) OWS.

The combined loading tests simulated ground wind and maximum αq flight loading test conditions, and tests were performed 21 October 1971 thru 23 November 1971. All test loads were based on latest vehicle weight and structural design criteria. Moment loads were applied using hydraulic jacks acting normal to vehicle centerline. Axial loads were applied using hydraulic jacks. The dead weight of the loading head and lead weights were placed inside of the STA. Specimen sustained all loads satisfactorily.

The ultimate pressure test to 32.5 psig (2.25×10^5 N/m^2) was performed at MSFC on May, 1972. The purpose of this test was to demonstrate the structural integrity of the habitation area cylinder penetrations, common bulkhead trash airlock penetration and to demonstrate that there were no detrimental yielding or other damage to the basic OWS structure under limit loads. No pressure loss was observed during the test and no yielding or other damage to the OWS tank penetrations were observed after test completion. The basic test objectives were met. However, a failure occurred in the meteoroid shield butterfly hinge on the window side of the main tunnel. Also, post test inspection revealed that three of the meteoroid shield hinges sustained heavy damage due to circumferential growth of tankage during pressurization. This failure resulted in a redesign of the shield butterfly. The redesign was reverified by special test ST-28 discussed in Section 5.4.

5.4 SPECIAL DESIGN SUPPORT AND VERIFICATION TESTS

There were tests that were considered "special" in nature and were identified. Some required special facilities such as large volume water tank, aircraft to produce zero-g affect and sunlight at altitude. Others were tests to evaluate unique problems. The following is a description of each special test line item performed:

- ST-1, Neutral Buoyancy Tests - These tests were performed from 2 July 1971 through 29 November 1971. The purpose of this effort was to evaluate habitability support and crew accommodation hardware equipment. The hardware was supplied by MDAC-W and was non-operational but did reflect the latest external configuration to insure proper astronaut interfaces. These tests were directed and conducted by MSFC at Huntsville, Alabama. The following hardware was evaluated:

  a. Waste Management Compartment Equipment

  b. Food Management Compartment Equipment

  c. Sleep Compartment Equipment

  d. Forward LH_2 Dome Equipment

  e. Experiment Interfaces

  f. Astronaut Aids and Restraints

  g. Trash Disposal Airlock

- ST-2, Zero-Gravity Test Program.- The primary objective of this test program was to perform operational evaluation of OWS equipment during limited duration zero-gravity exposure achieved during KC-135 aircraft flights. MDAC-W participation included design and fabrication of mockups simulating sections of the OWS and the test program. This program started 22 June 1970 and was concluded 2 August 1971. The following equipment was flown and evaluated:

  a. Waste Management Compartment Equipment

b. Food Management Compartment Equipment

c. Sleep Compartment Equipment

d. Forward LH_2 Dome Fixture

e. Astronaut Aids and Restraints

- ST-7, SAS Cell Sunlight Test - Test was performed to obtain sample current voltage curves of representative samples of glassed cells. Tests were run using a solar simulator at a constant intensity over full operating temperature range and then repeated in natural sunlight. The tests were run to obtain current and voltage temperature co-efficients for typical SAS cells. The tests were conducted 15 February 1971 through 14 January 1972 and results reported in Report No. MCR-71-320.

- ST-8, SAS Panel Sunlight Test - Sunlight testing of the SAS solar panels was performed on two groups of representation panels to determine the following electrical characteristics:

a. Determine the sunlight performance capability of two 30-module power groups.

b. Mismatch losses of modules.

c. The air mass equals zero (AMO) current-voltage (I-V) characteristics of modules.

d. The correlation factors to be used for extrapolating terrestrial data to AMO sunlight conditions.

e. Mismatch losses of power groups.

f. The basic design compatibility of the power source with the power control group (PCG).

Testing was performed outdoors in natural sunlight at a minimum sunlight intensity of 100 mw/cm^2 and when data was analytically corrected, the true solar array performance could be predicted. These tests were performed 26 July 1971 through 18 October 1971 and test results were reported in Report No. MCR-71-320.

- ST-9, SAS Module Shadow Test - Solar cell module shadow testing was performed on single cells and on module series/parallel strings using a solar simulator for cell energization. The test program was designed to study and evaluate cell failure mechanisms and module string configurations under changing shadow conditions.

  The test objectives of this test program were:

  a. To obtain confidence in the four separate string concept for the SAS Panels under shadow conditions.

  b. To understand the cell failure mechanism due to heat and reverse voltage, and to find possible cures.

  c. To determine which cell arrangement is the best technical solution for Z-Local Vertical shadows with the cell failure mechanisms known and either accounted for or cured.

  d. Establish the integrity of the interconnect and solder joints.

  This test included a simulated orbital sunlight exposure in conjunction with a SAS power distribution unit (PDU) and a power conditioning group (PCG). Modules were tested singularly, and in parallel, with loads/angle conditions simulated for the Skylab orbit, including the dark portion of the orbit. Tests were started 1 November 1971 and completed 17 November 1972. Results were published in TRW Report SAS 4-3142.

- ST-11, M487 Stowage Container Test - the M487 Stowage Container was vibration tested to verify that the container and the equipment within the container would not present a crew or mission safety hazard when subjected to the launch and boost vibration environment.

  The failure/rejection criteria for this test was a post-vibration examination to verify:

- Equipment and/or parts ejected from the locker compartment.
- Loose particles.

This test was started 1 December 1972 and was completed 29 February 1973. Results were published in Report MDC G4089.

- ST-12, Flowmeter Transducer Life Test - This flowmeter transducer was used in each of cabin atmosphere circulation ducts to measure output of fan units. The transducer consists of a flow sensor and associated electronics for the readout signal. This test was a 5700-hour life test at worst case humidity and temperature condition and was run 30 July 1971 through 3 March 1973. The results were published in MDC Report G4192.
- ST-13, Pneumatic Meteoroid Shield Release - Test was initiated to explore the separation characteristics of five (5) different configurations of pneumatic meteoroid shield release mechanisms. These tests were conducted 26 August 1971 through 3 September 1971. Test results were published in Report No. R69261.
- ST-14, Meteoroid Shield Deployment Test - Three (3) meteoroid shield deployment tests were conducted utilizing the STA at MSFC, Reference Section 5.3. These tests were accomplished in conjunction with tank pressure tests. Test program started 17 February 1972 and was completed 14 March 1972. Results were published in Report MDC G3369.
- ST-15, SAS Passive Vent Valve Module - Acoustically Actuated - Actuation of the Passive Vent Valve Module was accomplished by the acoustics field created by the booster engines at time of lift-off to demonstrate functional performance. Specimens were actuated at KSC by exposure to the Saturn 16 launch acoustics field. Preparations for the test included functional operation in an acoustics chamber prior to the KSC exposure. In addition to the KSC exposure, long term storage

the mechanism latched and subsequent actuation in the acoustics chamber was accomplished to simulate the latched time span between roll-out and launch, and to verify lack of stiction. Testing was accomplished 3 March 1973 through 15 July 1973 and results were published in MDC Laboratory Report TM-208.

- ST-16, Spring Loaded Mechanism, Magnetic Latch - The Magnetic Latch Mechanism Assembly for the SAS Passive Vent Valve Module consists of the acoustic panel, magnet, armature, armature support arm, and support arm actuating spring. The means of releasing the armature from the magnet is acoustics impingment on the acoustics panel. This test was performed to establish a confidence level for the latch mechanism. Testing consisted of repeated acoustics initiated latch releases on each of several production (flight quality) assemblies, and a pull force test after latched storage on others. Two specimens were used for reverberant chamber vs. progressive wave tube acoustic efficiency comparisons. This test was started 26 April 1972 and completed 15 July 1972. Results were published in MDC Report No. G3993.

- ST-17, Coolanol 15/Water Oral Sensitivity - Special test was performed using human test subjects to obtain information concerning the crew's capability for detecting Coolanol 15 in the potable water system. The test was conducted 17 February 1972 through 21 February 1972. Results were published in MDC Report G4227.

- ST-18, SAS Solar Cell Panel - Testing of specimens from different production runs was accomplished in this test effort to evaluate cell and solder joint performance in extended thermal cycling. Of particular interest is the ability to maintain electrical continuity during thermal stressing while in space vacuum. Electrical performance checks as well as microscopic and X-ray examination of all solder joints, were made periodically to establish solder joint integrity values. These tests were performed 1 March 1972 through 22 June 1972. Results were published in MDC Report G4039.

- ST-19, RSS Component Evaluation - Testing was performed to assess the RSS thermal capacitor's sensitivity to inlet fluid temperautre change (Specimen #1), to determine the combined performance of the radiator thermal control pressure relief valve utilizing a simulated radiator for valve crack and reseat and coolanol mixing characteristics (Specimen #2), to determine the effects of cold fluid temperature on radiator control valve (Specimen #3), and determine if talk-back switch in bypass valve affects valve operation after cycling (Specimen #4). Thermal capacitors were subjected to thermal evaluation testing as an individual unit (Specimen #5), and as an assembly (Specimen #6) to evaluate a new thermal capacitor design. Testing was performed 12 February 1972 thru 28 June 1972. Results were published in MDC Report G4135.
- ST-23, Film Equipment, GFP-25 - This special test line item was performed to qualify GFE film transport magazine that was stowed in film vault to the OWS dynamic levels. This testing started 2 June 1973 and was completed 13 June 1972. Results were published in MDC Report G4091.
- ST-24, Expandable Tube/SAS Tension Strap - This test was performed to assess the performance of the SAS beam fairing tie down ordnance links when functioned with expandable tubing having the minimum yield value per specification. Of particular interest was the possibility of loose tab generation when functioned under flight loading conditions with minimum yield limit tubing. This test was performed 11 May 1972 thru 13 May 1972. Test results were published in

MDC Report G4091.

- ST-27, Stowed Items Life Tests - A typical ring locker with contents listed below, was stored in a secured area at ambient temperature, pressure and humidity for 9 months. Examination was then performed on the contents to determine any degradation.

P/N	ITEM
1B83881-501	Hose Assy Water Supply
LT-80	Aluminized Tape
1B87724-1	Restraint General Purpose
TLC 691-3/4	Tape Pressure Sensitive
TLC - CJH	Duct Tape (49050 tape)
1B83847-1	Patch Repair Meteoroid Penetration
1B90481-1	Patch Repair
Q-1266	Quad-X seal
NM-1300	Batteries
1B91431-1	Transfer Hose Urine Sample
1B87477-525	Label Stowage
1B92262-501	Roy Stowage Waste
1B87307-1	Holder Assy Towel and Wash Cloth Drying
1B91613-507	Fillers, Fiberboard
1B91013-505	Filler, Fiberboard

Test was started 6 June 1972 and completed 3 March 1973. Results were published in MDC Report G4223.

- ST-28, Meteoroid Shield - Butterfly Hinge Test - This test was performed to obtain information for redesign of the butterfly hinge as a result of a failure which occurred on the STA at NASA/MSFC. Reference Section 5.3. Test was conducted on 7 May 1972 through 27 May 1972. Results were published in MDC Report G3605.

- ST-29, SAS Solar Cell - Special testing of SAS Solar Cells was performed to determine the cause of solder de-wetting and low solder joint strength in some of the production cells. Suspect cells from production panels were examined for solder joint failure modes. Special cells were manufactured with variation in material thickness, and in processing times and atmospheres during the metalization processes to ascertain the modes of potential failures. These tests were conducted 7 April 1972 through 9 June 1972. Test results were published in Report SAS4-3187.
- ST-31, Urine Collection Subsystem - Redesigned - The purpose of this test was to determine the feasibility of proposed urine collection subsystem redesign. Test was started 25 September 1972 and was completed 17 October 1972. Results were published in MDC Report G4161.
- ST-34, Mosite and Polyurethane Foam Odor Generation - Odor generator of mosite and polyurethane foam which is used as a packing material in the storage lockers became a concern late in the program. The purpose of this test was to obtain qualitative off-gassing data when subjected to OWS mission pressure profile. The test was conducted 29 October 1972 through 15 January 1973. Results were published in MDC Report G4159.
- ST-35, Trash Airlock Functional Compatibility - Test was performed to verify functional compatibility of trash lock when subjected to various contingency anomalous configurations of operational duty cycles with trash bags and disposal bags. Testing was started 11 March 1973 and completed 18 March 1973. Results were published in MDC Report G4228.
- ST-38, Meteoroid Shield, Debonded Butterfly Hinge - Test was conducted to investigate the debonded hinges found on OWS-1. The

test consistrd of tension pull tests on 4 specimens. Tests were accomplished 20 December 1972 through 3 January 1973. Test results were published in MDC Report G3616.

- ST-39, TACS Temperature Probe Leak Test - Testing of the TACS Temperature Probe to verify the integrity of the internal seals of the item was accomplished by this test line item. One specimen, consisting of a new transducer installed in the TC-9 test bottle, was proof tested. One specimen, consisting of two new swaged magnesium oxide filled tubes was leak tested. The third specimen consisting of the qualification test probe machined to expose the swaged tubing was leak tested individually for leakage through each swaged tube and through the body head bushing. The tests were conducted 1 January 1973 through [illegible] February 1973. Results were published in MDC Report G4120.
- ST-40, SAS Fairing Tests for De-orbit Loads - A special test of the SAS Fairing, utilizing test hardware from Line Item SA-16 was performed to demonstrate the structural integrity of the SAS forward fairing and beam fairing when subjected to ultimate loads for de-orbit condition. This test was conducted 18 April 1973 through 19 April 1973. Results were published in Report TM-171.
- ST-41, Meteoroid Shield Leading Edge Ballooning Test - Wind tunnel test program was performed to investigate shield lifting, due to airflow entering underneath, to determine bending loads on shield and to determine loading as shield lifts. These tests were run 25 June 1973 through 11 July 1973. Results are contained in Report AI-73-43.
- ST-43, SAS Fairing Test - De-orbit Loads - Test was conducted to verify that SAS beam fairing would withstand de-orbit condition

ultimate loads when applied in the deployed configuration. Existing hardware from Line Items SA-16 and ST-40 were utilized for this test. The test was started 25 June 1973 and completed 7 July 1973. Test results were contained in Report M-7315.

5.5 SPACECRAFT SYSTEMS TESTING

5.5.1 General - Post-manufacturing checkout of the OWS-1 was accomplished in the Huntington Beach Vehicle Checkout Laboratory during the period 6 November 1971 through 16 August 1972. The objective of this activity was to a) provide an OWS checked out and calibrated to an extent consistent with the ambient 1-G environment, and b) provide an OWS acceptable for planned, integrated cluster system testing at the Kennedy Space Center. Checkout was performed utilizing flight hardware within the constraints of hardware availability. Detail test requirements, acceptance criteria and operational constraints were provided in the 1B83429, OWS-1 Test and Checkout Requirements, Specifications and Criteria. An OWS-1 Timeline is presented in Figure 5.5-1.

The Ground Support Equipment required to check out the OWS was functionally verified prior to utilization for checkout of the spacecraft. The Automatic Checkout System was activated to support checkout and was used to provide continuous monitoring and automatic control of selected OWS systems. Provisions required to maintain OWS cleanliness and provide internal access control were included.

Checkout was initiated with the start of Continuity/Compatibility testing and continued through completion of the All Systems Test, Electromagnetic Compatibility (EMC), and residual subsystem retests. During this checkout period, all subsystems, Crew Compartment Fit and Function, and the AST and EMC tests were performed. Thousands of elapsed hours of manufacturing work were accomplished in parallel.

The spacecraft was moved from Tower 6 to Tower 2 on 16 August 1972. The significant Tower 2 checkout activities included a mercury certification of the habitation area and calibration of the meteoroid shield strain gauges. Mercury certification checks were conducted to demonstrate

Figure 5.5-1
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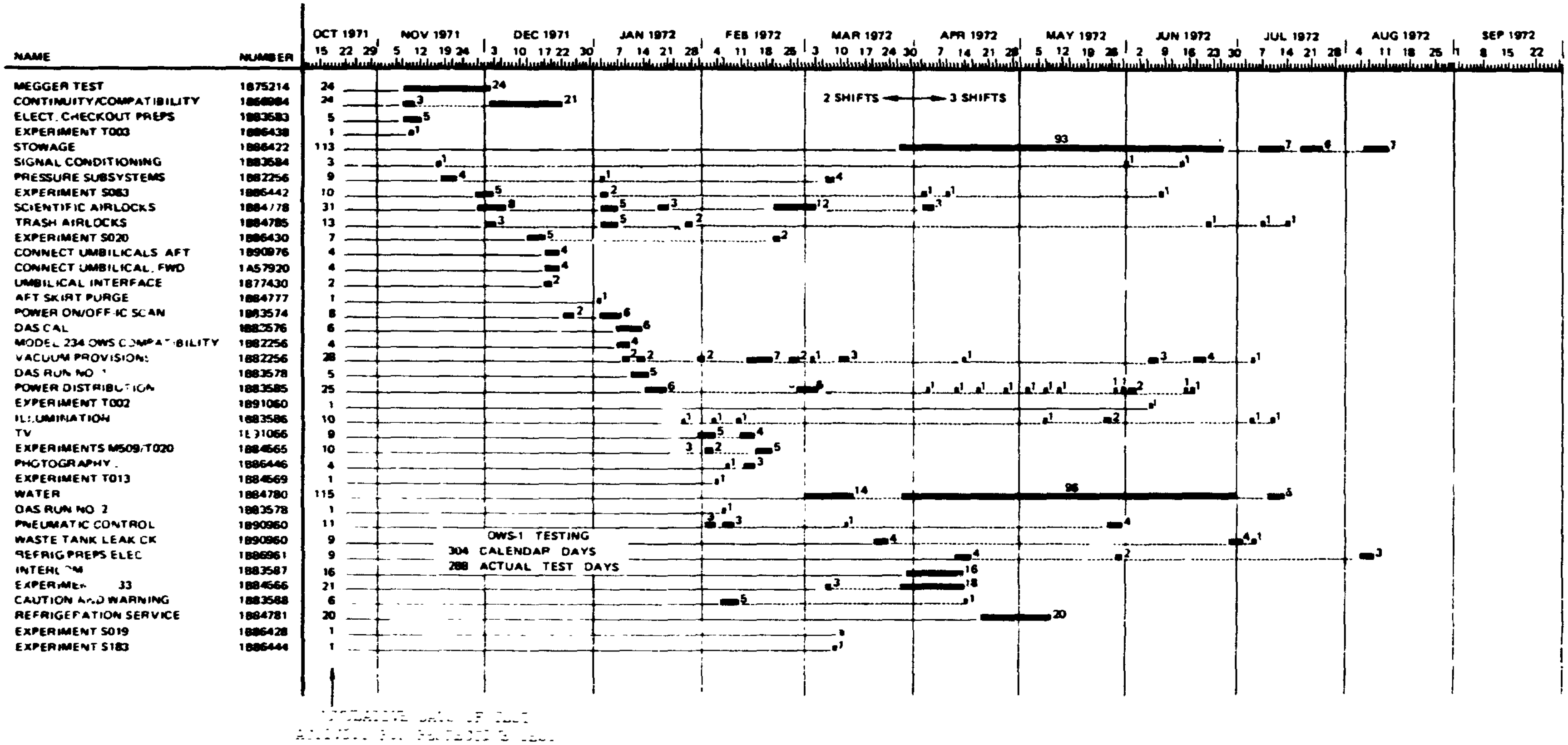
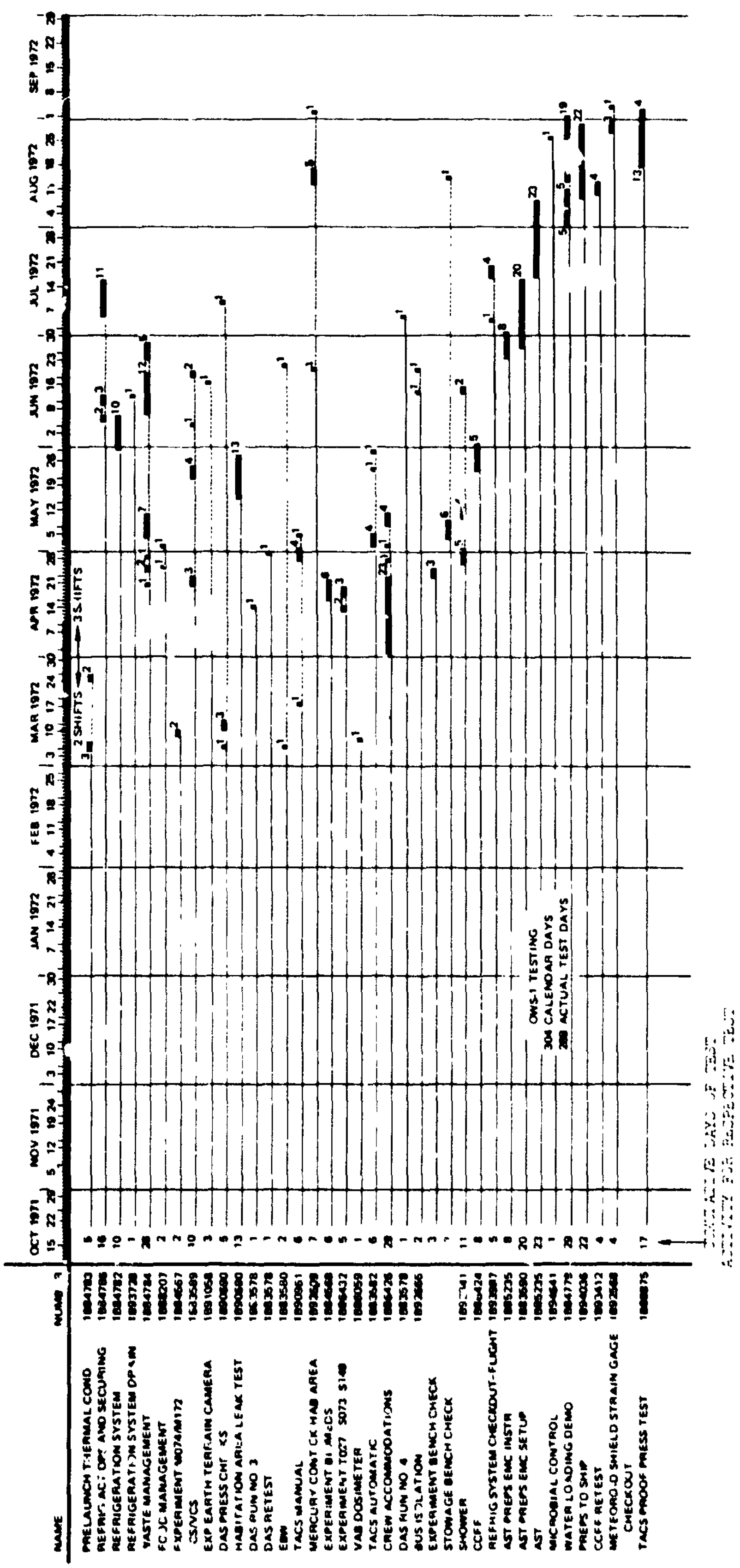


Figure 5.5-?
Page 2 of 2



compliance with MSC Standard 120 and MDAC-W System Safety and Product Assurance Plan 120, dated 22 October 1971. In general, the mercury checks implemented were:

- Habitation Area was certified free of contamination prior to pressurization.
- Huntington Beach gas supply, distribution systems, associated GSE and flight hoses were verified to be free of mercury prior to being connected to Experiments.
- Certain Experiments were verified externally during Receiving Inspection or prior to installation in the Workshop unless a mercury-free certification was received as part of the data package.
- In-flight spares were checked prior to stowage in the OWS.
- A final overall Habitation Area check for mercury was performed after a twenty-four hour lockup period.

Major manufacturing activity in Tower 2 was focused on modification of the meteoroid shield and clean-up activities associated with final inspection. The spacecraft was moved to Seal Beach for TACS proof testing on 31 August 1972, while final preparations for delivery continued at Huntington Beach.

Problems encountered during checkout were documented on Test Problem Reports (TPR's). Test problems that could not be closed at Huntington Beach because of unavailability of hardware, rework not accomplished, testing not completed, etc., were transferred to a Recap TPR (OW1-P-9999-X). The Recap TPR's described the problems being transferred, i.e., Failure Report, Discrepancy Report, Inspection Item Sheet, original TPR number and Removal number, and reason the problem was not resolved at Huntington Beach.

A Retest Assembly Outline documented the open retest and/or test requirements of incomplete Assembly Outlines (AO's), Discrepancy Reports (DR's), Failure Reports (FR's), Removals at the time of delivery, and the Recap TPR's noted above that were transferred to the KSC.

All items associated with open work were noted in Section 4.0 of the MDC G3078B, OWS Pre-delivery Turnover Review (PDTR) Report, Huntington Beach, except crew comments that did not involve hardware changes.

All test objectives were satisfied except those noted in the PDTR. Complete spacecraft test results, anomalies, test problems and hardware discrepancies were documented in MDAC G3069, Orbital Workshop Checkout - Vehicle Checkout Laboratory Report, dated November 1972. The checkout that was accomplished on the OWS-1 by system is outlined in the summary paragraphs below:

5.5.2 Structures - Structures consists of the following major components:

- Forward and Aft Skirts
- Habitation Tank
- Thrust Structure
- Meteoroid Shield
- Aft Interstage

Verification of the OWS Structures was demonstrated by successfully completing all subsystem testing.

The Ground Support Equipment associated with Structures were as follows:

- DSV7-302 Meteoroid Shield Handling Kit
- DSV7-371 Meteoroid Shield Counterbalance Kit
- DSV7-316 Mechanical Test Accessory Kit

Fit and function tests of the above were completed satisfactorily.

5.5.3 Environmental Control - The Environmental Control System (ECS) consists of the Ground Thermal Conditioning Subsystem (GTCS), the Ventilation Control Subsystem (VCS) and the Thermal Control Subsystem (TCS). The GTCS maintains the proper environmental conditions within the OWS while it was on the launch pad. The TCS maintains the proper environmental conditions during all orbital operations and the VCS provides the proper ventilation during manned orbital operations.

Checkout for the ECS consisted of two (2) major tests:

- 1B84783 Ground Thermal Conditioning, OWS Interior
- 1B83589 Thermal and Ventilation Control Subsystem

The 1B84783 test performed a functional checkout of the GTCS to a) verify the hermetic integrity of the plumbing and components, b) validate the operation of the on-board heat exchangers and fans, and c) confirm restart and purge capability of the Model DSV7-334, Environmental Control System. The test was initiated on 3 March 1972, and was completed on 28 March 1972. No major vehicle hardware problems were encountered and no retest was required. There were no open items against the GTCS.

The 1B83589 test performed a functional checkout of the OWS TCS and the VCS, including spares to:

- Verify functional performance of the TCS duct and radiant heaters, TCS thermal control assembly, VCS duct and portable fans and the fan filter assembly.
- Verify fit of the spare charcoal canisters, inlet filters, heaters and fans.
- Demonstrate adjustment capability of the VCS diffusers and dampers.
- Verify manual and automatic control of the TCS.

The test was initiated on 21 April and the final test was completed on 20 June 1972. There were three (3) significant hardware problems encountered during the test which were:

- Duct #2 flowmeter reading was out-of-tolerance low which was solved by a redesign of a section of duct to provide a more uniform contour at the flowmeter inlet.
- Floor diffuser dampers were binding, preventing actuation, which required rework of the damper to provide more clearance from the diffuser sidewall.
- The heat exchanger relay drive module failed to turn on the heat exchanger indicator light which required a redesign of the module.

Retest of the modified hardware was successfully completed. There were no open items against the Thermal Control and Ventilation Subsystems.

The ECS portion of the All Systems Test verified proper operation of the GTCS fans and heat exchanger, the TCS duct heaters, TCS control logic, and VCS fans. The ECS equipment functioned as required by the simulated mission timeline. The only significant AST ECS problem was in the GTCS. The pressure switch on the #2 fan-heat exchanger assembly failed to hold the electrical circuit energized. The pressure switch was tested and found to be within specification. A design change was made to add a tube from the existing high pressure static pressure tap on the fan-heat exchanger assembly to the exit of the fan. The design change increased the delta P sensed by the pressure switch by adding velocity pressure to the high pressure side of the switch. The new design was tested successfully. There were no open problems or items against the ECS resulting from the All Systems Test.

The Ground Support Equipment required by the ECS was Model DSV7-344, Environmental Control Distribution System and Model DSV7-334, OWS Interior Ground Thermal Conditioning System Kit. The -344 was the ground ventilation air distribution duct that was installed in the OWS during VAB operations. The -344 installation and flow balance test was completed wi h no problems encountered.

The -334 ground thermal conditioning unit supplied the coolant to the on-board heat exchanger and controlled the fan-heat exchanger unit. All fit checks were accomplished without encountering any problems, and the unit functioned properly.

5.5.4 Electrical

5.5.4.1 Continuity/Compatibility - The 1B66984 Continuity/Compatibility Test verified the integrity of OWS electrical wiring prior to application of power and prior to GSE/OWS interface connections as follows:

- End-to-end continuity of spacecraft wiring, applicable line and component load resistance series active elements such as circuit breakers, switches, relays, diodes and resistors, and powered activation of relays via a portable power source.
- Ground isolation of spacecraft power and return buses, separate return wires and relay coils.
- Bus-to-bus isolation, including power bus to return bus isolation of related buses, etc.

All anomalies/problems were satisfactorily resolved and retested.

There were no anomalies or problems encountered during this test except minor procedure problems. All resistance measurements were within tolerances.

5.5.4.2 Power Distribution - The OWS Power Distribution Subsystem is comprised of that hardware which is involved in routing electrical power from the AM/OWS interface to the various items contained within the Workshop. The primary function of this subsystem is to provide the required circuit protection and switching capability necessary to meet manned space flight requirements.

All Huntington Beach post-manufacturing checkout procedures associated with establishing the integrity of this subsystem were completed. Checkout for the Power Distribution consisted of the following:

- 1B66984 Continuity/Compatibility
- 1B77430 Umbilical/AM Interface Checks
- 1B83574 Power Setup, I/C Scan, Power Turnoff
- 1B83585 Power Distribution Acceptance Test
- 1B92665 Electrical Bus Isolation
- 1B86424 Crew Compartment Fit and Function
- 1B93589 All Systems Test - Preparations and Securing
- 1B83590 EMC - Preparations and Securing
- 1B93588 All Systems Test - Prelaunch, Boost, and Preactivation
- 1B93591 All Systems Test - Activation, Orbital Operations and Deactivation

There were no anomalies encountered during these tests that created any significant redesign. All checkout problems were resolved and all applicable test requirements were satisfied.

There was no open work pending on this subsystem as related to delivering a complete, functional subsystem to KSC. All subsystem hardware (i.e., wiring, circuit breakers, switches, etc.) installed in the OWS was flight qualified equipment. All Interim Use Material (IUM) was removed and replaced with flight equipment prior to beginning the All Systems Test. In addition, all subsystem hardware changes authorized during VCL checkout were completed.

5.5.4.3 Illumination - The OWS Illumination Subsystem is comprised of that hardware which is involved in providing lighting to support crew activities within the Workshop. The primary function of this subsystem is to provide the required illumination levels for planned mission functions and, in addition, provide sufficient lighting for crew activities under emergency conditions.

All Huntington Beach post-manufacturing checkout procedures associated with establishing the integrity of this subsystem were completed. Checkout for the Illumination Subsystem consisted of the following tests:

- 1B83586 Illumination Subsystem Acceptance Test
- 1B86446 Photography
- 1B91066 TV
- 1B86424 Crew Compartment Fit and Function
- 1B93589 All Systems Test-Preparations and Securing
- 1B83590 EMC-Preparations and Securing
- 1B93591 All Systems Test-Activations, Orbital Operations and Deactivation

There were no anomalies encountered during these tests that created any significant redesign. All checkout problems were resolved and all applicable test requirements were satisfied.

The DSV7-105, Internal Test Lighting Kit was verified during post-manufacturing checkout. There were no major problems encountered during the checkout of this item of Ground Support Equipment.

5.5.5 Instrumentation and Communications

5.5.5.1 Instrumentation Subsystem - The OWS Data Acquisition System provides real-time and delayed-time monitoring of OWS Subsystem flight parameters, as well as biomedical and scientific experiment data to ground tracking stations of the Spaceflight Tracking and Data Network (STDN). Designed as an integral part of the Airlock Module Data System, it consists of high and low level multiplexers, signal conditioning, transducers and umbilical prelaunch instrumentation.

All Interim Use Material (IUM) was removed and replaced with flight hardware prior to the All Systems Test (AST). Subsystem hardware installed in the spacecraft was flight qualified equipment.

The checkout procedures listed below identify the various post-manufacturing tests that were performed to establish the integrity of this subsystem:

- 1B83584 Signal Conditioning Setup
- 1B83574 Power Setup, IC Scan, Power Turnoff
- 1B83576 DAS Calibration, OWS
- 1B83578 DAS, Acceptance Test Procedure
- 1B93589 All Systems Test - Preparations and Securing
- 1B93591 All Systems Test Activation, Orbital Operations and Deactivation
- 1B93588 All Systems Test - Prelaunch, Boost and Preactivation
- 1B83590 EMC Setup and System Reverification
- 1B86424 Crew Compartment Fit and Function Check

Open work transferred to KSC related to a number of measurements that could not be functionally verified end-to-end at Huntington Beach because they were either not required to be installed (i.e., SAS, Meteoroid Shield, etc.) or the Subsystem/Parameters were not required to be exercised functionally (i.e., Water System, digital clock, etc.).

During spacecraft testing of the Data Acquisition System, per Acceptance Test Procedure (ATP) 1B83578, measurements randomly failed in responding to automatically programmed Remote Automatic Calibration System (RACS) commands to provide checkout verification levels. The problem was extensively investigated in both software and hardware areas. All measurements responded to manually initiated RACS commands. During subsequent runs of the DAS, no random failures of RACS responses occurred. This was documented as a Phantom Test Problem Report. The RACS hardware is installed for flight. However, the RACS is used for ground verification only and its isolation prevents any affect on the flight performance of the measurements.

A Phantom is defined as any problem for which a positive solution or explanation has not been reached but is thought to be an acceptable condition and risk. This includes intermittent problems which disappear or will not repeat.

5.5.5.2 Communication and Television Subsystems - The OWS Communication System is designed as a functional part of the Orbital Assembly (OA) Audio System for the Skylab Program and provides:

- Direct voice line between the OWS and STDN via the Command Module (CM) S-band.
- Biomedical Data to STDN through the AM PCM telemetry system.
- Intercommunication line between astronauts.
- Audio and visual displays of warning tones generated by the Caution and Warning System.
- Control for the operation of the voice and data recording system in the Airlock Module (AM).

There were no major problems encountered during checkout of the Communication subsystem and there was no open work transferred to the KSC.

The OWS Television Subsystem is an extension of the Orbital Assembly (OA) television system and provides video coverage of crew activities, equipment operation, and experiments. Transmission to STDN is made through the Command Service Module (CSM) unified S-band.

The subsystem hardware was qualified equipment; however, an updated configuration was installed but not tested at Huntington Beach.

The TV Input Station was provided as GFP and was qualified by Martin-Marietta Company (MMC), Denver, document MMC Environmental Test Report 3278.

The only open work transferred to the KSC was related to the testing required as a result of replacing the Televison Input Station (TVIS) with the latest configuration after All Systems Test. The KSC test requirements were defined in the KSC Test and Checkout Requirements, Specifications and Criteria Document. There were no major problems encountered during testing of this system.

The checkout procedures listed identify the various post-manufacturing tests that were performed to establish the integrity of the Instrumentation and Communication System:

- 1B83587 Intercommunication Subsystem
- 1B91066 TV System Acceptance Test Procedure
- 1B83590 EMC Setup and System Reverification
- 1B93589 All Systems Test - Preparations and Securing
- 1B93591 All Systems Test - Activation, Boost and Deactivation
- 1B93588 Prelaunch, Boost and Preactivation

5.5.5.3 **Caution and Warning Subsystem** - The OWS Caution and Warning Subsystem is a part of the Cluster Caution and Warning System. It consists of redundant monitor and repeater circuits to identify caution, warning and emergency parameters. The parameters monitored throughout the cluster are annunciated visually as well as by audio means. The status of the OWS bus voltages and fire surveillance within the compartments utilizing fire sensors are primarily for monitoring performed within the OWS. Solar flare activity which is monitored through the Multiple Docking Adapter (MDA) Solar Flare Panel is also annunciated within the OWS by an audio tone annunciator.

Subsystem hardware installed in the spacecraft was qualified equipment.

The checkout procedures listed identify the various post-manufacturing tests that were performed to establish the integrity of the subsystem:

- 1B83588 Caution and Warning Subsystem Test
- 1B83590 EMC Setup and Systems Reverification
- 1B93589 All Systems Test - Preparations and Securing
- 1B93591 All Systems Test - Activation, Orbital Operations and Deactivation

There were no problems encountered during testing of this subsystem that created any significant design changes and there was no open work deferred to the KSC.

5.5.6 Waste Management - The Waste Management Subsystem components consists of:

- Waste Processor
- Blower Unit
- Fecal/Urine Collector
- Vacuum Cleaner
- Urine Dump Station
- Mirror
- Trash Airlock
- Shower
- Suit Drying Station

Checkout consisted of the following tests:

- 1B84784 Waste Management
- 1B92841 Shower
- 1B84735 Trash Airlock
- Suit Drying Station - All Systems Test, Delta C^2F^2

The one significant problem encountered during checkout was the sticky operation and operational forces of the urine pressure plate. The pressure plate was redesigned by replacing the clock spring with a tension spring. The redesigned unit was reinstalled and verified in the spacecraft.

The Processor Chamber #2 heater plate temperature was also out-of-tolerance. Waiver Number OWS-2 was submitted to the Test and Checkout Requirements, Specifications and Criteria (TCRSC) to waive the 105°F $\pm$5°F (303.6 $\pm$13.1K) requirement and accept the maximum temperature of 113.1°F.(318.2K). This condition was considered minor and did not require hardware changeout.

The significant crew operation problem remaining at the completion of checkout was an odor in the fecal collector cabinet which was discovered during Delta C^2F^2.

Review of other units (qualification test, development test and SMEAT collectors) resulted in detection of a similar odor. The odor appeared to be coming from the acoustic insulation. The acoustic insulation was subsequently replaced by Fairchild Hiller.

GSE Model DSV7-373, Waste Management Checkout Kit, was the only item of Ground Support Equipment required for the Waste Management. It functioned properly with no significant problems.

5.5.7 Solar Array Subsystem - The Solar Array Subsystem (SAS) consists of two (2) wing assemblies with the major components being forward fairing, beam/fairing, deployment mechanisms, electrical harnesses and instrumentation, and three (3) wing section assemblies per wing. The wing sections are composed of ten (10) panels with solar cells. There is a total of 147,840 cells for the OWS. The SAS was manufactured and tested by MDAC subcontractor, TRW, Inc., in accordance with Specification Control Drawing 1B79083 for the System and 1B78822 for the Solar Cell Panel.

The SAS was qualified for flight by a testing program which included component as well as a system qualification test. The component testing was done on solar cells, solar panels, actuator/dampers, deployment mechanism, and the vent module.

System acceptance testing was accomplished on a wing assembly complete except for the thermal baffle and environmental seals and the two forward bays which had dummy masses simulating the wing sections. System testing included dynamics, deployments, and structural testing under induced worse case environments. All tests were completed satisfactorily.

Acceptance testing of the 60 solar cell panels was accomplished using TRW Procedure SA-14A-01. The acceptance criteria of 67.0 watts minimum per module was exceeded on all panels. No major or unresolved problems are known.

Acceptance Testing of the system was performed using the following TRW procedures:

- SA-01A-06 Acceptance Vibration Testing
- SA-01A-05 Ordnance Deployment Tests
- SA-01A-02 Wing Section Deployment Tests
- SA-01A-03 Beam/Fairing Deployment Tests
- SA-04A-02 Electrical Tests
- SA-01A-01 Weigh and Final Acceptance

All tests were completed with no major problems or unresolved discrepancies.

The types of problems that were encountered during the acceptance testing and their resolutions were as follows:

- During post-vibration electrical checks of wing Serial Number (S/N) 2, a shim between panel hard-point and panel substrate contacted solar cell causing an electrical short between the solar cell and the cinch bar structure. The shim diameter was reduced at all locations to provide clearance.
- During wing S/N 2, Pre-vibration Functional Wing Section Deployment Test, the power and instrumentation harness wires were pinched between hardpoint bushings at two (2) locations on the wing section which resulted in wire damage. This damage was repaired and procedure precautionary notes were added and placards were installed on the leading stabilizer beams to remind personnel of the necessary precautions.

- During post-vibration deployment of wing section S/N 3 on wing S/N 1, the truss and dummy panel failed to deploy to a flat position. The dimension between the second stabilizer beam to panel slide fitting and the hinge line between the first and second stabilizer beam sections was too short. Shims were added in the stabilizer beam hinge area to provide the necessary dimension. The wing section was again deployed and the panels deployed to an acceptable position.

The wings were prepared for delivery, at completion of testing, in accordance with TRW Procedure SA-01M-01 and SA-01M-02. GSE Models DSV7-304, Solar Array Hoisting and Handling Kit, DSV7-305, Solar Array Shipping and Storage Dolly Assembly, and DSV7-306, Solar Array Preservation Kit, were used in transporting and handling of the SAS wings. Model DSV7-1[illegible]9, Solar Array Component Test Set, was used in the electrical checkout of the wings at TRW.

5.5.8 Refrigeration - The Refrigeration Subsystem (RSS) provides for chilling and freezing of urine, chilling of potable water, and chilling and freezing of food during all OWS operational modes including Prelaunch and Orbital Storage.

All elements of this subsystem were verified for thermal and functional performance in both manual and automatic logic controlled modes of operation. The subsystem was proved to be leak-tight. Checkout for the RSS consisted of the following tests:

- 1B86961 Refrigeration System Electrical Preparations
- 1B84781 Refrigeration Subsystem Service
- 1B84786 Refrigeration System Activation, Operating and Securing
- 1B84782 Refrigeration Subsystem
- 1B93987 Refrigeration Subsystem Service-Flight

The major problems encountered during checkout operations were corrected and are described below:

- Pump Start Anomaly - During checkout loop switching verification, primary pump #1 did not start when commanded. The automatic logic then switched to primary pump #2 which started normally. This occurred one time out of a minimum of 147 pump starts accomplished during checkout. The flight invertors were adjusted to maximum current limit following checkout. Running current for all eight pumps was measured and data indicated all pumps to be consistent and satisfactory. Laboratory testing was conducted using a production invertor and a prototype invertor in conjunction with various pumps and motors. These test data indicated a torque capability from the motor of approximately 15 in. oz. (10.6 N cm). Additional data indicated the drive train looseness could allow the motor to start a pump having a static frictional torque of 18 in. oz. (12.7 N cm). Cycling tests with a 18 in. oz. (12.7 N cm) pump showed that if drive train looseness was unfavorable and a start did not occur, a second turn-on always started. Additional testing continued to verify that a second turn-on of a high friction pump would produce a start after a no-start turn-on. The problem was determined to be one of marginal start capacity due to the current limiter in the inverter. The inverter was subsequently redesigned and retested to correct this problem.

- Food Freezer Frost Buildup - During AST operations, frost was observed in several spots on the food freezer exterior. Additional FS-19-1 testing confirmed the formation of local areas of frost and ice; however, no condensation occurred. The frost/ice accumulation reached a steady state condition during the first 48 hours of test. This condition did not impair freezer door operation and all doors opened freely with no frost adhesion to the seal or door surfaces. This condition was subsequently dispositioned at the KSC as an acceptable anomaly.

The Ground Support Equipment required by the Refrigeration Subsystem were Models DSV7-301, Ground Thermo-Conditioning System - RSS, DSV7-315, Refrigeration System Service Unit, DSV7-314, Vacuum Pumping Unit, DSV7-316, Mechanical Test Accessory Unit, and the DSV7-122, Refrigeration Test Set. All units were verified with the exception of an out-of-tolerance flowmeter frequency controller module on the -301. The frequency controller was replaced and retested at the KSC.

5.5.9 Ordnance Subsystem - The Ordnance Subsystem Consists of the ordnance components and electronic circuitry required to function the following systems:

- Meteoroid Shield Release
- Solar Array Beam/Fairing Release
- Solar Array Wing Section Release
- S-II Retro-Rocket Ignition
- S-II/OWS Separation

Because all ordnance components were installed at KSC, checkout at Huntington Beach was limited to verification of electrical circuitry only on the OWS.

Checkout for the Ordnance Subsystem consisted of the following two (2) tests:

- 1B83580 EBW Subsystem, Meteoroid Shield and Solar Array
- 1B85235 All Systems Test (AST)

No significant problems were encountered during this checkout, and there were no unresolved problems.

All ordnance qualification tests were completed satisfactorily. Major areas of qualification were accomplished under line items ST-14 and SA-4.

- Test ST-14, "Full-scale Meteoroid Shield Deployment," was accomplished at MSFC on the Static Test Article. Repeated testing verified proper performance of the meteoroid shield release system, which had been redesigned following VCL deployment in May 1971, in which deployment was not total, and an expandable tube ruptured, releasing gas and debris.

- Test SA-4, "Solar Array System," was accomplished at TRW and included deployment tests which qualified both the solar array beam-fairing release and wing section release systems. All individual deployments were successful, the only ordnance system anomaly being the breaking off of small metal tabs along the fracture line of the tension straps during firing. This problem was resolved with a dual tape-wrap which had been satisfactorily tested in SAS Production Acceptance Tests. These tests, which incorporated flight ordnance, showed that all broken tabs were completely retained by the tape.

There were no outstanding ordnance qualification test problems.

5.5.10 Pneumatic Subsystem - The Pneumatic Subsystem consists of the following systems:

- Thruster Attitude Control System (TACS)
- Pneumatic Control System (PCS)
- Habitation Area (H.A.) and Waste Tank (W.T.) Pressurization, Vent Purge Systems
- Vacuum Provisions.
  - Wardroom and Waste Management Water Dump Systems
  - Urine Dump System
  - Refrigeration Pump Container Vent Line
  - Metabolic Analyzer (M.A.) and Lower Body Negative Pressure (LBNP) Vacuum System

Checkout for the Pneumatic Subsystem consisted of the following tests:

- *1B82256 Pressurization Systems and Vacuum Provisions
- 1B90960 PCS, H.A. and W.T. Leak and Functional Tests

*Includes DSV7-350, Vacuum Pump Demonstration Test

- 1B90961 TACS Leak and Functional Tests
- 1B83582 TACS Automatic Checkout
- 1B85235 All Systems Test
- 1B89875 TACS Proof and Leak Test, Seal Beach

The following significant problems were found during checkout:

- Metabolic Analyzer (M.A.) Sample Valve and Vacuum Outlet leakage exceeded Interface Control Drawing (ICD) allowable 0.4 liter/sec at 10^{-5} torr, a high vacuum could not be established at the M.A., and OWS skin interfaces. The M.A. was replaced with a flight unit. The OWS system, M.A., and Model DSV7-350 Vacuum Pump then performed nominally.
- TACS Temperature Transducer, P/N 1B79580-505 (C7262) and a leak at the miter weld joint. The transducer was removed and replaced. All eight (8) TACS Temperature Transducers were modified to have an externally applied bonded sheath
- TACS emergency vent command circuitry caused upstream valve (L1) to delay in closing. Circuitry was redesigned to eliminate the delay and the system operation was then normal.
- During All Systems Test, the TACS pressure switch "Airlock Module indication" did not come on during the first cycles of two (2) TACS thrusters. The response was nominal on the subsequent 102 cycles. Detailed troubleshooting, inspection, testing and analysis was performed. The problem was dispositioned as a Phantom for the following reasons:
  - The fault which caused the delayed talkback problem did not re-occur.
  - No evidence of a damaged component on the spacecraft or GSE was found to indicate the cause of the delayed talkback.
  - The TACS I-IV and I-II thrusters were successfully tested for

approximately 102 cycles subsequent to the malfunction.

Possible causes were delineated in Test Problem Report OW1-P-2052-0/C (P), dated 23 August 1973.

- During the Spacecraft Mass Decay Leak Test, individual component leakages were also measured. The Mass Decay Test met all leakage requirements, however, it was noted that the hatch and check valve individual leakages were less than their production test leakage values. Since all primary test objectives for the Mass Decay Test were met, it was concluded that the individual component leak test fixtures were leaking.

5.5.11 Crew Systems - MDAC-W Crew Systems personnel performed mission crew tasks in the subsystem tests to verify the crew interfaces. The checkout tests performed in the Crew Systems area were:

- 1B88207 Food Management
- 1B96426 Crew Accommodations
- 1B94641 Microbial Control Test Sample
- 1B86424 Crew Compartment Fit and Function (C^2F^2)
- 1B94312 Delta C^2F^2

No significant problems were encountered during checkout.

The testing of the portable foot restraints (triangle shoes) and the sleep restraints were deferred to KSC because late configuration definition prevented flight articles from being available at Huntington Beach.

The flight crew performed the C^2F^2 test in two (2) sessions and a final bench check of the Ring Stowage Containers on 30 August 1972. Fifteen (15) flight crewmen participated during these tests. There were no significant problems; however, a number of Test Problem Report (TPR) items were transferred to KSC for crew reverification because of insufficient schedule time at Huntington Beach. These were identified in the Pre-delivery Turnover Report. Significant sections of the C^2F^2 Test and Checkout Procedures that were not performed at Huntington Beach because of hardware unavailability were:

- M487 Experiment Verification
- M172 Experiment Verification
- Rescue Drogue Verification
- Stowage Fit Checks - Sleep Compartment
- 29 Stowage locations in other compartments

Crew Systems required no unique GSE. The interface with Model DSV7-303, Crew Quarters Vertical Access Kit, and DSV7-311, HSS Equipment Handling Kit, was successfully demonstrated.

5.5.12 Stowage - The Stowage Subsystem provides provisions for containment/restraint for loose equipment in the OWS during the launch/boost phase and zero-gravity. Stowage provisions consist of containers, lockers, cabinets, film vault, food freezer/chiller and miscellaneous restraint provisions.

Checkout for the Stowage Subsystem consisted of 1B96422, Stowage procedure, plus eighteen (18) additional procedures, mostly experiments and water subsystem hardware.

All stowage locations were fit checked during checkout except for approximately 28 locations which were completed at the KSC because of the hardware not being available. In addition, 96 locations were unstowed and the hardware was returned to the suppliers in accordance with contractual direction. Twenty-five (25) Ring Containers were delivered to the KSC outside the spacecraft. Fourteen (14) of the Ring Containers were fully stowed and five (5) were partially stowed.

A precision inspection of the eleven ambient food containers disclosed that some of the inside dimensions were outside the ICD tolerances. A Drawing Department Authorization was submitted. During checkout, the installation and removal of the GFP food racks were successfully demonstrated in all eleven containers.

Pressure tests of the Mozite packing material (a closed cell material) indicated a change of volume with pressure change. Since this volume change could affect support of equipment during boost and/or in orbit, a series of tests were conducted to evaluate OWS uses. The test consisted of selecting critical installations of packing materials (Mosite, urethane, and fiberboard) and subjecting it to launch-to-orbital pressure profiles. Results of the tests were as follows:

°	Launch pressure	Support of equipment deemed satisfactory.
°	Orbital Pressure	Design changes were requried on M487 stowage box to make it easier for the crewman to extract instruments supported by the foam.

Interface with DSV7-303, OWS Crew Quarter Vertical Access Kit, and DSV7-311, Habitability Support System Equipment Handling Kit, was successfully demonstrated.

5.5.13 Experiments Subsystem - The Experiments Subsystem consists of the hardware accommodations needed to integrate the experiment equipment into the OWS. These accommodations include structural attachments, electrical cabling, pressurization and vacuum plumbing provisions, and storage restraints.

The experiment/OWS interface accommodations were verified through a series of subsystem tests and the All Systems Test. Additional man/machine interface verifications were accomplished during Crew Compartment Fit and Function (C^2F^2) testing. The subsystem testing for experiments covered the period February through August 1972. The All Systems Test (AST) and C^2F^2 testing were completed in August 1972.

No significant problems regarding OWS experiment accommodations were encountered during OWS testing. The major problems encountered with experiment hardware are as noted.

A total of 14 subsystem tests encompassing 21 experiments were performed, including six (6) retests because of replacement of experiment hardware with new hardware after those tests were completed. Only a small number of test problems of any significance were encountered. These included:

- Out-of-tolerance electrical bonding interface for S063 and S183
- S190B stowage provisions
- T027 photometer extension rod failure
- T027 Sample Array leak check failure
- Displays did not illuminate
- M171 Exhale Sample Valve was opened beyond its limiting stop

Since no anomalies occurred during the AST, the out-of-tolerance bonding checks were acceptable and waivers from the Interface Cc rol Drawings (ICD's) were requested. The S190B stowage provisions were corrected by adding a new storage container for these items. The T027 extension rod was redesigned and successfully retested. The T027 Sample Array was returned to the supplier for evaluation and rework to correct the interface leakage problem. The T027 lights were replaced by the supplier. The Exhale Sample Valve opening did not require recalibration. Recalibration was needed only for "high accuracy" testing.

Only one (1) significant problem occurred during the AST - a failure of the M171 Metabolic Analyzer. This was attributed to a failure of the spirometer ball valve. This unit was returned to MSFC for rework and retest and was subsequently made ready for flight. No significant problems occurred during C^2F^2 except T027 Photometer extension rod failure. The extension rod was returned to the experiment developer for rework. The modified unit was returned to MDAC-W and retested.

The significant checkout open items remaining were summarized in the FDTR. Most of these items were open because the flight hardware was not available for checkout, or the hardware was scheduled for future modifications before delivery to the KSC. The experiments that were returned to the supplier(s) for rework were identified in MDC G3078, FDTR.

After completion of the AST, the biomedical experiments M171, M092, M093, ESS, were removed from the OWS and replaced with new flight hardware. A retest of the new hardware was successfully completed with no major anomalies noted. Checkout for the Experiments consisted of the following tests:

- T003 1B86438 Aerosol Analysis
- T013 1B84569 Crew/Vehicle Disturbance
- M074 1B84567 Specimen Mass Measurement
- M172 1B84567 Body Mass Measurement
- T027/S073 1B86432 Contamination Measurement/Gegenschein-Zodiacal Light
- S149 1B86432 Particle Collection
- S019 1B86428 UV Stellar Photography
- S020 1B86430 UV/X-ray Solar Photography
- M509 1B84565 Astronaut Maneuvering Equipment
- T020 1B84565 Foot-Controlled Maneuvering Unit
- S063 1B86442 UV Airglow Horizon Photography
- M092 1B84568 Lower Body Negative Pressure
- M093 1B84568 Vectocardiogram
- M131 1B84568 Human Vestibular Function
- M171 1B84568 Metabolic Activity
- ESS 1B84568 Experiment Support System
- M151 1B86446 Time and Motion Study

- S183 1B86444 UV Panorama
- M133 1B84566 Sleep Monitoring
- T002 1B91060 Manual Navigation Sightings
- S190B 1B91058 Earth Terrain Camera

5.5.14 Water - The OWS Water Subsystem provides for storage, pressurization, distribution, purification, thermal control, conditioning and dispensing of water required for the total mission.

Checkout of the Water Subsystem was satisfactorily completed per 1B84780, Water procedure. Two significant problems were encountered which were: (1) The water tank domes on several tanks were deformed. The problem was found to be related to the mechanical restraint method used for handling. The domes were reformed with gas pressure. The restraint system was redesigned to utilize a vacuum system, (2) dispensed water temperatures from the chiller were 15°F (8°K) higher than the specification requirements of 45°F (281°K). Changes to Contract End Item (CEI) and Food Interface Control Drawing (ICD) were processed. The TCRSC drawing was changed and approval obtained. The subsystem was prepared for shipment per 1B90436, OWS Mechanical System Preparation for Shipment.

A Water Subsystem/GSE service demonstration utilizing the DSV7-312, HSS Water Subsystem Sterilization Checkout Kit (GSE), was performed per 1B84779, Water Subsystem Service Demonstration, which included sterilization and filling of two (2) water tanks, a portable tank, and prelaunch conditioning of a deionization filter. The only problem encountered was the failure of a H_2O level transducer on one tank. This failure was attributed to its being used at a temperature which exceeded its design operational limits. The transducer was replaced and retested.

The DSV7-314 Vacuum Pumping Unit was used to evacuate the water networks prior to filling the system with water and to evacuate the portable water tank for leak testing. No problems were encountered to cause any design changes.

5.6 INTEGRATED VEHICLE TESTING - KSC

5.6.1 General - There were three primary areas of operations at KSC:

- Operations & Checkout Building (O&C) - general office area and Acceptance Checkout Equipment (ACE) rooms located on the third floor.
- Vertical Assembly Building (VAB) - office area, receiving inspection, equipment storage, assembly and test site; MDAC OWS-1 occupied some of the low bay area, High Bay 2, 20A & B, 24B, 25B, 26B of Towers A & B.
- Launch Complex 39A - OWS-1 Launch Site.

All pre-flight preparations and testing were conducted in accordance with the MDC Florida Test Center, Pre-Flight Operations Procedures (POP).

All High Bay 2 facilities, GSE, electrical, mechanical, and fluid systems were verified and certified as functional, clean, and mercury free prior to vehicle hookup.

The complete integrated schedule for all testing and prelaunch preparation for OWS-1 at KSC is presented in Figure 5.6.1-1.

All data for all tests have been evaluated. All tests were acceptable and all test objectives were achieved.

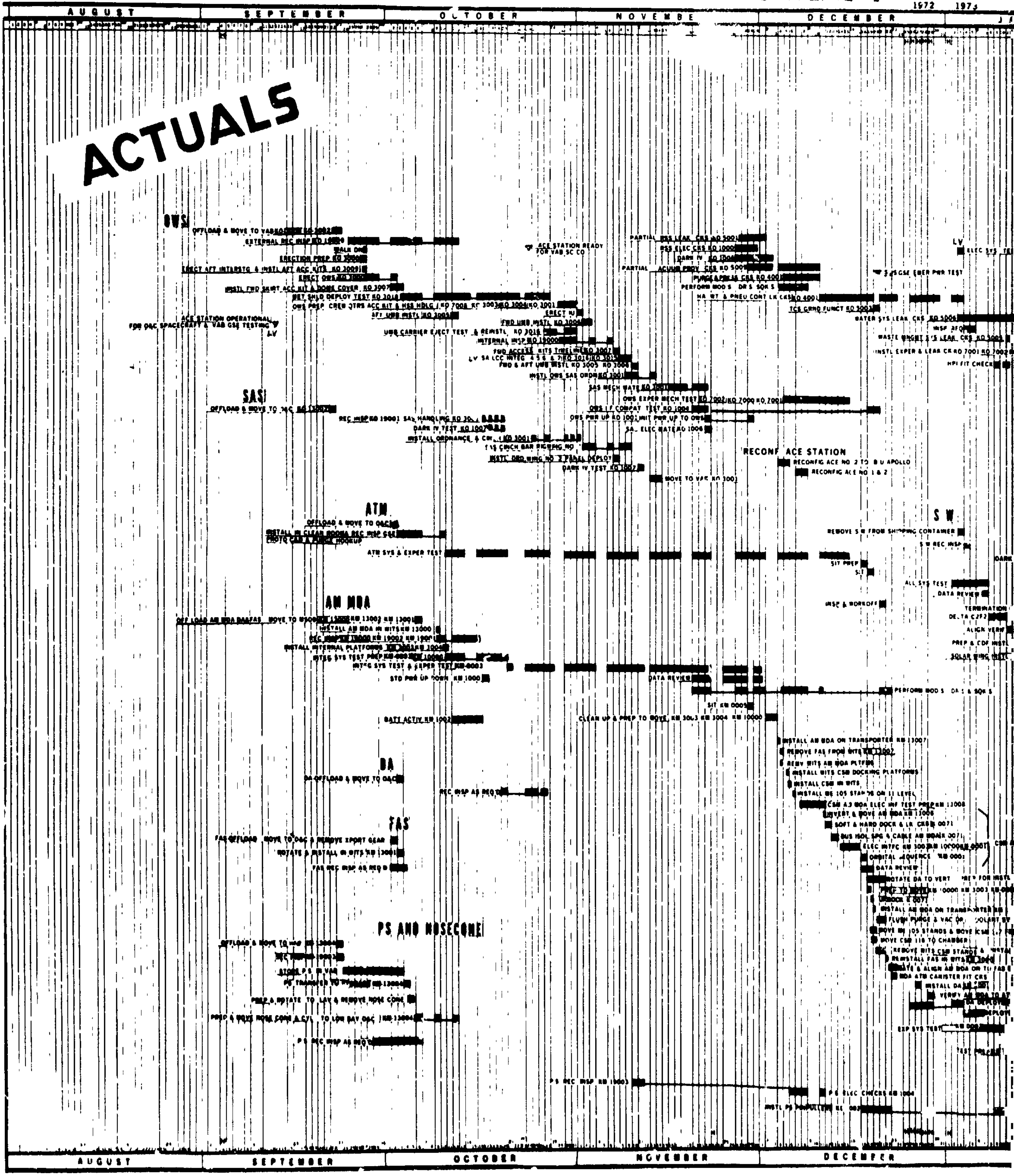
5.6.2 Vehicle Arrival, Inspection, and Vertical Assembly - The OWS-1 arrived at KSC on September 22, 1972. A walkdown inspection of the OWS-1 was performed to assess any damage which may have occurred during shipping and to ensure the OWS-1 was in a condition to erect. The Aft Interstage was erected and assembled onto the vehicle stack; access kits were installed; and the OWS-1 was erected September 28, 1972, and placed on the vehicle stack. The IU was

FOLDOUT FRAME

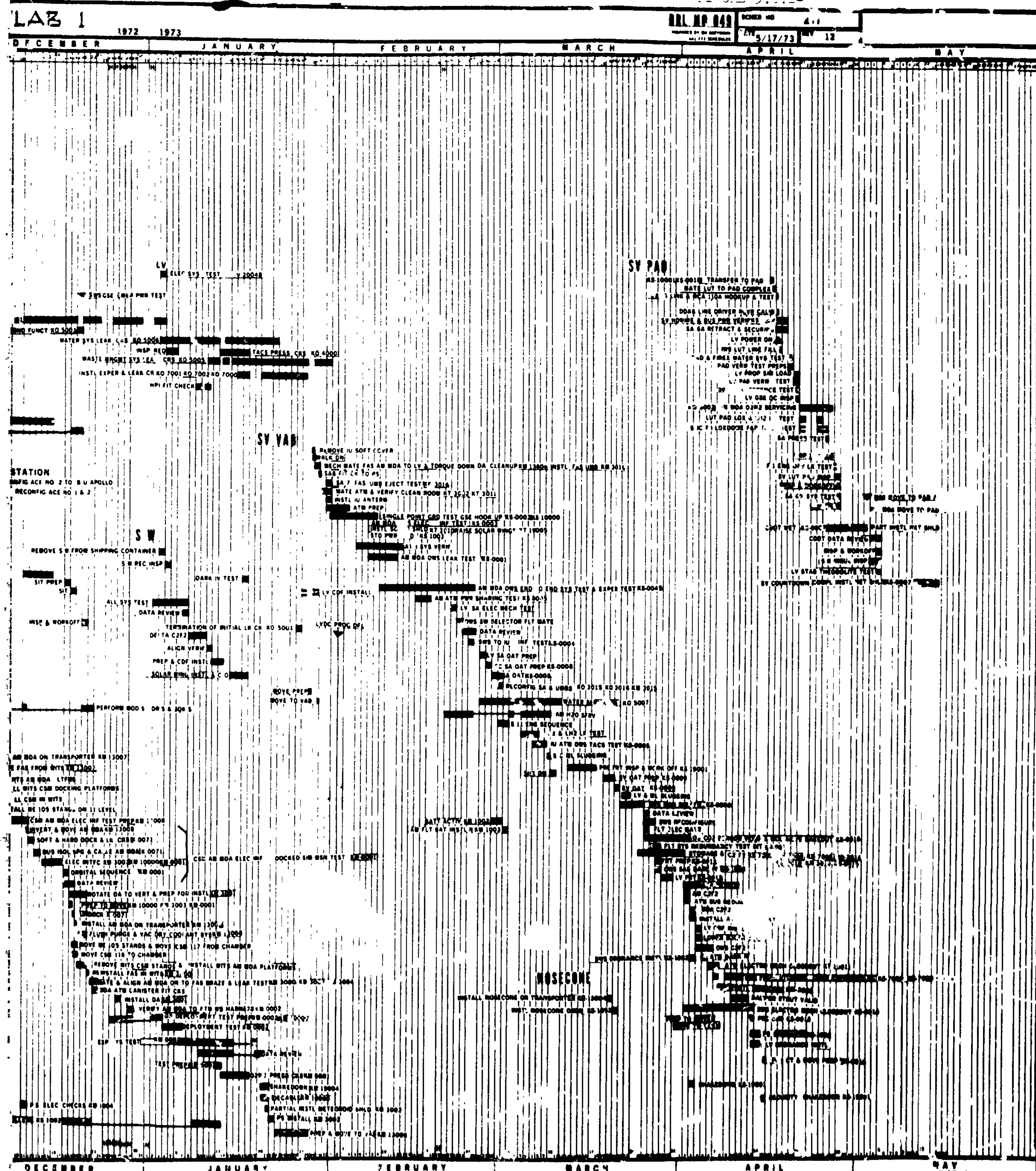
1

FOLDOUT

SPACECRAFT OVERALL SCHEDULE SKYLAB 1



FOLDOUT FRAME 2



erected November 1, 1972, and the Fixed Airlock Shroud (FAS), Airlock Module (AM), and Multiple Docking Adapter (MDA) were added to the stack on January 29, 1973. This completed the stack and the KSC activity shifted to subsystem verification. The following is a list of procedures which were used at KSC to prepare the OWS for subsystem verification:

KO-3000	OWS Erection
KO-3002	DSV-7-331, DSV-4B-368 Protective Cover Removal and DSV-4-324, DSV-4B-365 Desiccant Reconfiguration
KO-3003	OWS Facility Mate, Preparation for Habitation Tank Access and DSV-7-303 Crew Quarters Workshop Access Kit Installation and Removal
KO-3004	DSV-7-311 HSS Equipment Handling Kit Installation and Removal
KO-3005	DSV-7-327 Aft Umbilical Carrier Installation, Initial
KO-3006	DSV-7-375 Forward Umbilical Carrier Installation, Initial
KO-3007	DSV-7-328 Vertical Forward Skirt Access Kit and DSV-7-307 Dome Protective Cover Installation and Removal
KO-3009	DSV-7-326 Interstage Access Kit Installation and Removal

The OWS-1 was certified as mercury-free and any item taken into OWS-1 was certified to be mercury-free. Mercury contamination control at KSC was specified in Memorandum A41-787-M&M-M-012, dated November 29, 1972, and signed by the Mercury Control Officer.

5.6.3 Subsystem Verification

5.6.3.1 Structural System - There were no structural tests scheduled at KSC. For Structural Testing, see Paragraph 2.2.1.

The ordnance effort at KSC was administered in the structural group and the following procedures were employed:

- KS-1000 - OWS/DA/Payload Shroud (PS) Ordnance Receiving Inspection and Storage. This test was performed every time ordnance was received. Test objectives were to perform a receiving inspection on all ordnance required for the OWS, DA, and Payload Shroud. There were no significant Discrepancy Reports. All test objectives were achieved; all data were reviewed and found to be acceptable.
- KS-1001 - OWS/DA/Shroud Ordnance Lot Verification Test. The test began April 2, 1973, and was completed April 9, 1973. Test Objectives were to demonstrate ordnance acceptability for flight by lot sampling methods. All seven (7) tests were performed successfully on schedule and all test requirements were achieved. The flight ordnance on the Skylab I OWS/DA/Payload Shroud and S-193 Experiment Systems were verified flight worthy.

  NOTE: All ordnance which was flown on OWS-1 was from the same manufactured lot as the ordnance which was tested in the Ordnance Lot Verification Test.
- KS-1002 - OWS/DA/Shroud Ordnance Installation. The test began December 20, 1972, and was completed April 14, 1973. All ordnance detonators were installed by TCP KS-0007, CDDT/CD.

  Objective of the test was to install ordnance in SWS, specifically, LEA installation in the payload shroud, CDF assemblies, CDF manifolds, and pressure cartridges installation in ATM/DA, CDF assemblies installation in OWS meteoroid shield, and S-193 experiment ordnance installation.

  All installations were successfully accomplished per the TCP requirements. There were 9 IDR's generated of which 6 were upgraded to DR status. The test was successfully completed and all objectives were met. All test data were reviewed and found to be acceptable.

5.6.3.2 Meteoroid Shield System

- KO-3018 - Meteoroid Shield (MS) Mechanical Deployment Test. The test was begun October 3, 1972, and completed October 28, 1972. Test Objectives were to install the ordnance-released folded panel and rig the meteoroid shield for flight, verify proper deployment of meteoroid shield using a mechanically released folded panel as a test substitute for the ordnance released panel used in flight, and verify proper operation of MS sensors which report deployment and positioning.

  The real-time data and post data evaluation showed the objectives were accomplished as planned with the inclusion of the following specifications waivers:

  - Waiver MDAC OWS-WR-02 allowed any three of the four link latches to engage at deployment. Two of the four link latches did not engage during the first deployment test. One of the four latches did not engage during the second deployment test which conforms to waiver MDAC-OWS-WR-02. These discrepancies were documented on DR's OW1-02-0112 and -0118.
  - TCN OW-012 changed the tolerance on the torsion rod strain gage outputs.

  Significant IDR's/DR's encountered are noted:

  - Interferences occurred between the forward circumferential bulb scale and the swing links. The bulb seals were replaced by flat seals. These discrepancies were documented on DR's OW1-02-0039, -0069, -0095, -0096, -0108, and -0110.
  - The lower proximity switch magnet located on the right butterfly hinge interfered with the main tunnel cover during the first deploy-

ment test. The interference was eliminated. This discrepancy was documented on DR OW1-02-0067.

- At two (2) panel joints on the aft end of the meteoroid shield, the shield was away from the spacecraft approximately one (1) inch after the shield was rigged for flight. The splice plates at these panel joints were improperly installed. The attachment holes in the splice plates were slotted to permit proper installation. This was documented on DR OW1-02-0136.
- The hinge doublers bonded to tunnel straps were determined to have slight areas of debond per TPS OW1-02-0246. Tests were conducted at Huntington Beach and the condition was found not to be detrimental to the structural integrity of the S/C. This discrepancy was documented on DR OW1-02-0289.
- The hex of the torsion bar at position five (5) aft section was found to be twisted with a permanent set. This torsion bar was replaced. This discrepancy was documented on DR OW1-02-0066 and was performed prior to initial deployment.
- The contact area of the meteoroid shield with the habitation tank was determined to be 62% at zero ΔP. The contact area was checked at 8 psid during the performance of KO-4001 and determined to be 95%. This was documented on DR OW1-02-0180 and performed after flight rigging.
- Minor discrepancies occurred or were determined during the test. These included out-of-tolerance parts, chipped paint, damaged gold foil, improper installations, misalignments, bent, scratched and lost parts. These discrepancies are documented and resolved prior to launch on DR's OW1-02-0025, -0027, -0028, -0029, -0030, -0031, -0034, -0035, -0037 thru -0045, -0047 thru -0055, -0066, -0068, -0070

thru -0090, -0092 thru -0094, -0097 thru -01C7, -0109, -0111, -0113, -0117, -0119, -0126, -0129, -0132 thru -0134, and 03-0024.

In summary, all problems encountered during the test were resolved satisfactorily, all data were evaluated, and all requirements were met.

5.6.3.3 Thermal Control System - The active system was the Ground Thermal Control System (GTCS) which was controlled and conducted by KO-5003, OWS Habitation Tank Ground Thermal Conditioning System Functional and Operational Test. The test was begun December 20, 1972, and completed March 18, 1973. The purpose of the test was to - (a) leak check IGTC On-Board Heat Exchanger and associated plumbing; (b) verify On-Board fan operation and malfunction logic and indicators; (c) fill system with water-glycol; (d) perform Habitation Tank heating, stabilization, and cooling demonstrations with both primary and secondary systems, and (e) purge Heat Exchanger and re-cycle with ground system.

Major problems encountered were - (a) umbilical quick-disconnects were found to be susceptible to side loading and developed leaks. A line support bracket was added to the aft umbilical carrier and no further problem was experienced; and (b) GSE Model DSV7-334 was found to be marginal in its ability to refill the flight system following pre-launch purge. A seven-gallon supplemental reservoir (S14-140 bladder) was added and no further problem occurred.

The GTCS was put into operation following hatch closure (April 8, 1973) and operated to hold OWS internal temperature within specified limits throughout rollout, countdown demonstration test, countdown and launch. There were no significant discrepancies. All test objectives were met, and all data were reviewed and found to be acceptable.

Passive System handling at KSC was confined to the following procedures:

- KO-3012 - OWS Surface Optical Measurements. The purpose of the test was to determine if atmospheric contamination and handling degraded the surface optical properties of various selected portions of the OWS sufficiently to require cleaning. Solar absorptivity and emissivity measurements were taken on selected internal and external surfaces, components and coupons with Gier-Dunkle infra-red and solar reflectometers. There were no significant discrepancies. All test objectives were achieved, and all data were reviewed and found to be acceptable.

- KO-3011 - OWS Forward Dome High Performance Insulation Installation (HPI) and Purge. The purpose of this test was to install Habitation Tank forward dome high performance insulation (HPI). HPI segments were removed from shipping containers and carried into forward skirt. Sections of the forward skirt access kits were removed and HPI installed on forward dome. Lace HPI sections were laced together and HPI protective cover was installed. There were no significant discrepancies. All test objectives were met and all data were reviewed and found to be acceptable.

There were thirteen (13) waivers processed on the Thermal Control System and all were approved. These fell into meaningless categories, generally, such as time of measurement or number of measurements or unavailability of some measurements, etc.

5.6.3.4 Thruster Attitude Control System - This section addresses all pneumatic testing in addition to the TACS.

The following TACS/Pneumatic System procedures were performed at KSC in qualifying the various pneumatic systems and TACS:

- KO-5009 - Vacuum Provisions Checkout. This test was begun December 1, 1972, and was completed April 4, 1973. Test objectives were to perform a leak check of the vacuum systems. These included the urine dump, refrigeration pump container vent, waste management water dump, LBNP experiment vent, metabolic analyzer vent, wardroom water dump and water condensate dump subsystems line. Each subsystem vacuum line was evacuated using a mass spectrometer and each joint was sprayed with Helium to determine external leakage at each joint. The seat and stem leakage was measured for each vacuum valve and the opening and closing breakaway torque was determined. There were no significant discrepancies. The test was satisfactorily completed and the vacuum subsystem was accepted for flight. No significant problems nor anomalies were found during the test.

- KO-4001 - Pneumatic Pressure and Tank Leak Checks. The test was begun December 1, 1972, and completed January 3, 1973. Test objectives were to perform a leak and functional test of the various pneumatic systems aboard the OWS. The test was satisfactorily completed and the Pneumatic Pressurization and Tank Systems were accepted for flight. All specifications and criteria requirements were met except for the following:

    - Leakage at the LH_2 feed blanking flange exceeded the requirement - 1×10^{-3} sccs He allowed as against 1.25×10^{-3} sccs He actually measured. Waiver MDAC-OWS-WR-13, allowing the slightly out-of-tolerance leakage, was submitted and approved by NASA.

- Quantitative leak checks of the coupled quick disconnects (QD's) for the H/A pressurization system, waste tank pressurization system, pneumatic control system, and SAS purge system could not be satisfactorily accomplished because of accessiblity problems when the umbilical carrier was installed. Waiver MDAC-OWS-WR-30, substituting a qualitative leak check of these QD's, was submitted and approved by NASA
- Leak check of the Pneumatic Control System Monitor Port Cap was accomplished by a 24-hour pressure decay test instead of with leak detector solution required by the specifications and criteria document. This change was made to conserve schedule time. Waiver MDAC-OWS-WR-52 was submitted and approved by NASA for this change.

There were no significant discrepancies.

- KO-4000 - Thruster Attitude Control Systems Checks. The test was begun January 12, 1973, and completed January 17, 1973. Test objectives were to perform leak and functional checks of the Thruster Attitude Control System (TACS) to verify system integrity and demonstrate the system meets the design intent. The test was satisfactorily completed and the TACS was accepted for flight. All specifications and criteria requirements were met except for the following:
  - A leak at the 1B79580-515 Temperature Transducer located on TACS Bottle #9. The leakage requirement was 1×10^{-6} sccs Helium and the actual leakage measured was 7.04×10^{-5} sccs Helium. No leakage was noted when using the mass spectrometer in the sniffing mode. The leakage requirement was changed per KSC request to no leakage allowed using the mass spectrometer in the sniffing mode and the transducer was accepted for flight.

- Fifty-six (56) brazed joints out of approximately 400 brazed joints were leak checked using the mass spectrometer in the sniffing mode instead of in the vacuum mode as required by the specifications and criteria document. Waiver MDAC-OWS-WR-36, allowing leak check of these joints in the sniffing mode instead of the vacuum mode, was submitted and approved by NASA.
- Leak check of the TACS Q.D. was performed with Helium and the Uson Leak Detector instead of with GN_2 and bubble soap. Since the Helium test was a more stringent test, Waiver MDAC-OWS-WR-19 was submitted and approved by NASA.

5.6.3.5 Solar Array System - The Solar Array System (Wings #1 and #2) was handled at KSC by the following procedures.

- KO-3001 - OWS/SAS Mechanical Mate and Ordnance Installation. The test was begun October 17, 1972, and completed March 18, 1973. Test objectives were to (a) install ordnance for beam fairing release and solar panels release systems, (b) perform mechanical pre-load on solar panels subsequent to ordnance installation in SAS wings, (c) install Wing #1 and Wing #2 on OWS-1, (d) leak check purge subsystem and establish a GN_2 purge within the solar cell compartments, and (e) verify proper operation of the vent modules. All test objectives were met and all test data were reviewed and found to be acceptable.

During and subsequent to SAS wing installation, various minor changes were made to the specification and criteria requirements for the SAS purge system. These changes were made primarily to conserve schedule time and were documented in the following waivers which were submitted and approved by NASA.

- MDAC-OWS-WR-04 - Waived load sensors 13 and 14 cinch bar rigging adjustments because they were set per TCP values which were in error - 440 $^{+0}_{-25}$ lbs (1957 + 0,-112N) should have been 450 $^{+0}_{-25}$ lbs (200.2 + 0,-112N).
- MDAC-OWS-WR-06 - Waived the requirement to maintain 0.1 $\pm$ .01 psig ($1.02 \times 10^5 \pm 68.9$ N/$_m$2) in the SAS wings until the appropriate orifices could be fabricated (12/13/72).
- MDAC-OWS-DR-08 - Extended the date for installing the purge orifices from 12/13/72 to 12/22/72.
- MDAC-OWS-WR-07 - Increased the allowable relative humidity for the SAS wings from 60% to 68%. This change was allowed during the mechanical mate of the SAS to the OWS only.
- MDAC-OWS-WR-14 - Allowed a one-time deviation only of maximum SAS purge off-time of 67 minutes instead of 60 minutes.
- MDAC-OWS-WR-15 - Allowed use of GN_2 and bubble soap for leak test of the SAS purge system instead of helium and a mass spectrometer.
- KO-1007A - SAS Dark I-V Test. Pre-ordnance installation was begun October 17, 1972, and completed Octover 25, 1972. Post-ordnance installation was begun November 10, 1972, and completed November 11, 1972. Test objectives were to obtain dark current-voltage (I-V) data on the solar array wings before installation on the OWS. There were no significant discrepancies. All test objectives were achieved; all test data were reviewed and found to be acceptable.
- KO-1006 - SAS/OWS Electrical Mate and Dark I-V Test. The test was begun November 20, 1972, and completed December 6, 1972. Test objectives were to (a) verify the redundant electrical paths from each solar module to the solar array power unit, (b) obtain dark current and voltage (I-V) data on the solar array wings after installation on the OWS, and (c) connect the electrical interfaces between the SAS wings and the OWS. All test objectives were achieved; all test data

were reviewed and found to be acceptable. No major problems were noted. Only two minor problems were documented on DR's; two pairs of wires on test connectors were reversed. The DR's were dispositioned to re-identify wires to prevent future test problems. The noted DR's were: OWI-03-0227 and -0234.

- KO-1008 - SAS/OWS Dark I-V Test. The test was begun March 26, 1973, and completed April 4, 1973. Test objectives were to obtain dark current-voltage (I-V) data on the solar array wings after AM electrical mate. All test objectives were achieved; all test data were reviewed and found to be acceptable. This test was performed to obtain current and voltage data on the Solar Array Wings and verify electrical mate of SAS temperature measurements after Dark I-V Test. The procedure did not account for the temperature gradient across the SAS wings in excess of 2°F (256.4K). The data had to be evaluated using individual module voltage vs. temperature curves. A waiver (MDAC-OWS-WR-38) to the TCSRD was written to include the module curves as part of the acceptance criteria. A failure in the DSV7-109 caused modules 111 and 139 on both wings to give faulty readings. The wing modules were retested and found to be acceptable, using individual module voltage vs. temperature curves.

5.6.3.6 Electrical Power Distribution System - The Electrical Power Distribution System was re-verified at KSC after some modifications and all problems were resolved satisfactorily. All test objectives were met.

The following procedures were performed in the pursuit of electrical system verification:

- KO-1004 - OWS/IV/SII Continuity and Compatibility Checks. This test was begun November 20, 1972, and completed November 22, 1972. Test objectives were to verify the pre-power compatibility of the OWS electrical interface lines prior to application of power and prior to mating with the AM, IU, SII, and SAS. Also, establish the initial OWS switch and circuit breaker configuration. There were fourteen (14) IDR's generated during the performance of this procedure. Thirteen (13) were closed by deviations which revised tolerances, test meter polarity, meter range, dirty pins which were cleaned or test cables used not wired pin-to-pin. DR OWI-03-0469 which was transferred from KO-1004, IDR-013 documented a discrepancy on one of the signal lines from the S-IC to the IU. A higher-than-specified resistance through the OWS - 1.4 ohms rather than 1.0 ohms maximum was found. During investigation, one of the interface connectors was disconnected at the IU and upon reconnection, the out-of-specification reading was cured. During flight mate, the suspect connector was found to be contaminated. The contamination was removed by cleaning with alcohol. In summary, all test objectives were met and all data were reviewed and found to be acceptable.
- KO-1001 - OWS Power-Up Support. This test was begun November 22, 1972, and completed November 29, 1972. Test objectives were to power up and power down OWS electrical buses that were energized and controlled through the OWS/GSE umbilicals, in order to support OWS electrical tests prior to the integrated (AM/MDA/OWS) phase of checkout.

The following OWS buses were energized:

4D119 (talkback power)

RACS/RS (Refrigeration System)

Prelaunch Instrumentation

The power down portion of the procedure de-energized the noted buses. Prior to each power application, isolation resistance measurements were performed in order to verify that the power buses were safely above ground. In summary, all test objectives were met and all test data were reviewed and found to be acceptable. Run 1 of the procedure revealed that the ACE software for RACS HI and RACS LO commands was reversed. The ACE software was revised to correct the problem.

5.6.3.7 Illumination System - The verification of the Illumination System was incorporated into KS-0045, SWS End-to-End Systems Test and Experiment Test (see Paragraph 5.6.4).

5.6.3.8 Communication & Data Acquisition System - Verification of this system was incorporated into KS-0045, SWS End-to-End System Test (see Paragraph 5.6.4).

The following significant problems were encountered and resolved satisfactorily.

- Multiplexer Thermostat Installations, KR's OWI-03-0477, OWI-03-0476. During visual inspection, it was discovered that the multiplexer thermostats, P/N 1B75338, were installed in reverse; i.e., the thermostat sensing surface was installed away from the multiplexer surface.

  A thermal analysis was performed to determine the thermal response of the thermostats in the above configuration. The results indicated only a one degree difference in the switching points of the thermostats, with the thermostat sensing element installed next to the multiplexer case.

Drawing Change Request Serial Engineering Order (DCRSEO) 1B77021-A41-1 per Engineering Change Proposal (ECP) W003-122, was issued to clarify the installation drawing. The thermostat can be installed with either side toward the multiplexer case. TPS OWI-04-0479 was generated to reflect the above change. No retest was required.

- Speaker Intercom Assembly Removal, TPS OWI-06-0054. All Speaker Intercom Assemblies (SIA's) were removed twice from the spacecraft for design modifications. The first removal was to reduce the output level of the call potentiometer which minimized the possibility of squeal in the call mode. The second removal was the result of DR's related to the indexing of the channel switches and the looseness of the CCU receptacles. The SIA's were reinstalled and successfully retested per KS-0045, Sequence 14.
- TV Input Station Removal, DR OWI-06-856. The TV Input Station located at 404 was found to have an improper DC offset. This unit was replaced with S/N 00001 and successfully retested per KS-0045, Sequence 15.

5.6.3.9 Caution & Warning System - This system was verified during KS-0045, SWS End-to-End System Test. (See Paragraph 5.6.4)

5.6.3.10 Experiment Accommodation System - Experiment testing was conducted both off- and on-module. All test requirements were satisfied and four (4) waivers were written to accept discrepant items.

The following procedures were used to conduct off-module experiment tests:

KE-7005	Medical Experiments Off-Module
KE-7006	Experiments Off-Module Preparations
KE-7007	S019/S183 Off-Module Functional
KE-7008	Off-Module Periodic Operations

The following procedures were used to conduct on-module experiment tests or were integrated tests supported in whole or in part with experiment hardware:

KO-19003	Receiving Inspection
KO-7000	Experiment Leak Checks
KO-7001	Experiment Installation and Removal
KO-7002	Experiment Mechanical Tests
KO-7004	On-Module Periodic Operations
KS-0009	Simulated Flight
KS-0016	OWS Closeout
KS-0045	End-to-End Test
KS-7000	Experiment Stowage

The following paragraphs detail, by experiment, those tests performed and indicates any anomalies observed and the subsequent resolutions.

- Thermal Control Coatings (D024) - This is a passive experiment; only a receiving inspection and fit check were performed.

- Experiment Support System (ESS) - After receipt of the OWS at KSC; the ESS was removed and returned to MSFC for rework. After reinstallation in the OWS, no anomalies were detected.
- In-flight Blood Collection System (IBCS) - No anomalies were observed during IBCS testing.
- Specimen Mass Measurement Devices (M074) - On-Module testing was performed with no anomalies. Calibration of the devices could not be performed on-module because of low frequency vibrations present within the spacecraft. Calibration was successfully accomplished off-module.
- Lower Body Negative Pressure (M092) - Minor repairs were performed on the waist seal, iris plate and delta p gauge by MSFC representatives. Leak and function tests were performed on the device. Waiver MDAC-OWS-WR-02 was written to explain the out-of-tolerance readings of the leg volume measuring system.
- Vectorcardiogram (M093) - One vectorcardiogram umbilical was returned to MMC for rework and the electronics module in the ESS was reworked at MSFC. No other anomalies were detected.
- Human Vestibular Function (M131) - No test anomalies were observed.
- Sleep Monitoring (M133) - After receipt of the OWS at KSC, M133 was returned to MMC for rework of worn hardware and incorporation of design modifications. After return of the hardware, the backshell of the power cable was discovered to be loose. The shell was tightened and the discrepancy closed. Other test anomalies observed were associated with the M133 test sct.
- Metabolic Analyzer (M171) - After receipt of the OWS at KSC, the bicycle ergometer and metabolic analyzer were returned to MSFC for rework. After

reinstallation in the OWS, the ergometer performed unsatisfactorily and was again returned to MSFC. After reinstallation in the OWS a leak in the metabolic analyzer was discovered. The leak was isolated and fixed. All subsequent tests were satisfactory. Two (2) waivers (MDAC-OWS-WR-02 and MDAC-OWS-WR-11) were written to allow for a power-off period in excess of that specified in the test requirements. Waiver MDAC-OWS-WR-23 was written to explain an anomaly in the comparison of metabolic analyzer telemetry outputs versus displays.

- Body Mass Measurement Device (M172) - On-Module testing was performed with no anomalies. Calibration of the device could not be performed on-module because of low frequency vibrations present within the spacecraft. Calibration was successfully accomplished off-module.
- Habiability/Crew Quarters (M487) - This equipment generated numerous discrepancies due to cleanliness problems, label debonding and inadequate drawer inserts. All discrepancies were reworked and accepted. The digital thermometer output did not meet the acceptance test requirement. However, it was determined that the requirement exceeded the hardware design specification and the unit was accepted.
- Astronaut Maneuvering Equipment (M509) - No test anomalies were observed. The propulsion support system bottles were discovered to contain twisted valve stems. The bottles were reworked and retested by MMC personnel and reinstalled in the OWS.
- UV Stellar Astronomy (S019) - After receipt of the OWS at KSC and completion of tests, the film cannister and optical cannister were returned to the University of Texas for flight calibration and film loading. After reinstallation in the OWS, no anomalies were observed.
- X-Ray/UV Solar Photography (S020) - No test anomalies were observed.

- UV Airglow Horizon Photography (S063) - No test anomalies were observed.
- Micrometeorite Particle Collection (S149) - During testing, a loss of motor drive/cassette support unit motor temperature occurred. The problem was traced to a faulty socket on the photometer connector. The socket was reworked and the unit performed satisfactorily. No other test anomalies were observed.
- UV Panorama (S183) - No test anomalies were observed. The pupil on the unit was determined to have spots and scratches. The unit was cleaned and it was determined that the scratches would have no effect on the photographic data to be gathered by the experiment.
- Earth Terrain Camera (S190B) - No test anomalies were observed.
- Trans-Uranic Cosmic Rays (S228) - This is a passive experiment; only a receiving inspection and fit check were performed.
- Magnetospheric Particles Composition S230 - This is a passive experiment. Only a receiving inspection and fit check were performed. No anomalies were observed.
- Manual Navigation Sightings (T002) - No test anomalies were observed.
- In-Flight Aerosol Analysis (T003) - No test anomalies were observed.
- Crew Vehicle Disturbances (T013) - The suit was removed and returned to Langley Research Center for rework. After return of the suit, subsequent testing showed no discrepancies.

- Contamination Measurement and Gegenschein/Zodiacal Light (T027/S073) - Leak checks of the unit at both scientific airlocks produced leakage in excess of the test requirements. The cannister was removed from the OWS and leak testing was performed in the laboratory. Leakage was reduced to an amount acceptable for flight. A failure of the photomultiplier tube indicator resulted in replacement of the indicator. Additionally, the photometer connector was reworked (Reference Micrometeorite Particle Collection (S149) paragraph, above).
- Sample Array (T027) - The unit was rejected due to pitting and corrosion and returned to Martin Marietta Corporation (MMC) for rework. The backup sample array unit was upgraded for flight and installed in the OWS. Leak tests on this unit were successful and it was installed in the OWS. A functional failure on this unit occurred during system testing and it was returned to MMC. The original unit was returned to the OWS and system tests were completed. After rework of the backup unit and subsequent system tests, it was determined that the backup unit was more flight worthy, the flight optical samples were then installed in this unit, final off-module leak and functional tests were successfully completed and the unit was final stowed for flight.
- Van Allen Belt Dosimeter (VABD) - Irregular variations of certain telemeter indications were observed. Off-module tests showed these date variations were characteristic of the unit and the unit was accepted.

- Bacteria and Spores (ED31) - No functional testing was performed on this experiment hardware. Receiving inspection and fit check were performed. Some missing tape was noted and dispositioned.
- In Vitro Immunology (ED32) - No functional testing was performed on this experiment hardware. Receiving inspection and fit check were performed and no discrepancies were observed.
- Motor Sensory Performance (ED41) - Contamination was observed in the cable. The unit was cleaned, functioned satisfactorily and accepted.
- Web Formation (ED52) - No discrepancies were detected during functional tests.
- Plant Growth/Phototropism (ED61/62) - No functional testing was performed on this experiment hardware. Alignment/orientation information was not present. This discrepancy was dispositioned and the unit was accepted.
- Cytoplastic Streaming (ED63) - No functional tests were performed on this experiment hardware.
- Capillary Study (ED72) - No functional tests were performed on this experiment hardware. Some marks on protective coatings were noted and dispositioned.
- Mass Measurement (ED74) - Numerous discrepancies, including improper identification tags, inadequate packing, delamination and bent pins were noted and dispositioned. No anomalies were detected during functional tests.

- Neutron Analysis (ED76) - No functional tests were performed on this experiment hardware. Two neutron detector slides were accidentally exposed; however, this condition was dispositioned as acceptable. The unit did not have the required radioactive material decals; decals were applied.
- Liquid Motion in Zero-G (ED78) - No functional tests were performed on this experiment hardware. No discrepancies were observed.

  All experiment testing objectives were achieved; all test data were reviewed and found to be acceptable.

5.6.3.11 Habitability Support System

- Waste Management System - Subsequent to OWS-1 delivery to KSC, the WMS was redesigned to accommodate increased daily urine collection requirements. The redesign and hardware fabrication were accomplished at MDAC-W per ECP W659. Associated rework and installation at KSC were accomplished per the following TPS's: OWI-09-0139, OWI-09-0151, OWI-09-0181, OWI-09-0182, OWI-09-0185, OWI-09-0202, OWI-MDAC-0036 and OWI-MDAC-0040.

  TCP's KO-5005, KS-0045, KS-0010, KS-0009, and KS-0016 were rewritten and conducted using the redesigned WMS hardware.

  - KO-5005 - Waste Management System Verification and Checkout was begun January 10, 1973, and completed March 3, 1973. Test objectives were to perform a power-off mechanical test of the Waste Management Subsystem to ensure flight readiness, perform leak and functional checks of the Waste Management System in the processing and launch configuration, and perform a mechanical and functional checkout of the trash airlock. All test objectives were achieved; all test data were reviewed and found to be acceptable.

Major problems encountered and solutions are summarized below.

- DR-OWI-09-0802 Excessive Closing Forces on Urine Drawer #2 unacceptable to flight crew. Drawer was replaced with drawer from OWS-2 and retest yielded acceptable forces.
- DR-OWI-09-0852 Interference Between Chill Plate and Centrifugal Separator in Urine Drawer #2 scratched chill plate and created potential coolanol leak. Scratch depth was measured and analyzed and found not to create a leak hazard. Separator mounts on all three drawers were backed-off to provide adequate clearance and preclude repetition of problems.
- Airflow and pressure drops in collection module during KS-0045 test failed to satisfy TCRSCD requirements. This problem was attributed to clogged filter in GSE fecal bag. Retest of Drawer #2 using flight bag yielded acceptable results. Data analysis indicated no retest required on Drawers #1 and #3 (reference Waiver Request MDAC-OWS-WR-31).
- DR-OFS-0046 Centrifugal Separator mount assemblies (P/N 1B90271-501C) were found to have loose center cores resulting in index pin misalignment. Failure analysis by NASA malfunction investigation staff (MIS-039-73) concluded that debond condition was caused by "short shot" of center rubber material. Mounts were replaced with new mounts; however, a history of similar failures in the test program prompted development of a backup means by which the flight crew may re-align index pins on debonded mounts.

- Water Management System - To perform a functional check, sterilization and servicing operation for the HSS Water Subsystem, and to prepare the system for orbital operation, KO-5007 Water Subsystem Servicing and

Functional Test was performed. The test was begun February 23, 1973, and completed April 10, 1973. Test objectives were to perform a functional check, sterilization, and servicing operation for all the HSS water subsystems including portable tank, microbial control equipment, and shower, and prepare the system for orbital operation. Review of real-time data accumulated during this test indicated that all test objectives were met. The pressurization manifold transducer was successfully tested and the telemetry output verified. The ten water tank level transducers were evaluated during water loading. Reference data was obtained during bellows stroking to correlate bellows position with transducer outputs and meaningful results were obtained on 7 of 10 tanks. The specification requirement for 100 ± 2.4% was waived (MDAC OWS WR-33) since all transducers were intermittent, fluctuating between an on-scale reading and off-scale high. During performance of this test, sixty-three IDR's were written and of these IDR's, three were voided, one was transferred to an MDAC Discrepan y Report (DR) (Flight Crew Equipment), two were transferred to LUT 2 DR's, ten were transferred to DSV7-312 DR's and twenty-seven were transferred to Spacecraft DR's. The most significant anomalies are discussed below.

- Low Water Flowrate from Facility (Reference IDR 005) - Due to a restriction in the LUT 2 facility water filter bank, maximum flow delivered was 0.4 GPM (.0259 liter/sec), should have been 0.5 to 1.5 (.0315 to .0945 liter/sec). Waiver Request (WR) MDAC-OWS-WR-26 allowed completion of a test sequence with this low flowrate. The facility filter banks were reserviced subsequently to correct the problem.

- Shower Suction System Indicated Leakage (Reference IDR 014) - During shower suction system leak checks, the Uson leak detector indicated several apparent leaks. Waiver request MDAC-OWS-WR-28 allowed use of the mass spectrometer in the sniffing mode instead of the Uson, and all leakages in this mode were acceptable.
- Biocide Level Problems (Reference IDR's 009, 017, 020, 046) - Problems resulted during preparation of water/biocide solution in the GSE reservoir. Contributing factors were (a) incorrect biocide concentration in supply container, (b) binding of the injector assembly, (c) leaks in the injector needle, and (d) calibration of the injection system. These problems were resolved and correct biocide concentrations were achieved.
- H_2O Gun Hose Leakage (Reference IDR's 022, 023, 024) - After steam sterilization of the wardroom network and water servicing, leakage was noted at each of the three H_2O gun hoses. The hoses were replaced by TPS OW1-08-0446 and successfully retested by deviation KO-5007 No. 275. TCN 130 eliminated autoclave steam sterilization of the guns to avoid subsequent damage. Guns were maintained sterile using aseptic techniques.
- Portable Tank Biocide Level (Reference IDR 011) - Waiver request MDAC OWS-WR-27 was written to permit a biocide level of 3.8 ppm (S/B 6 ± 1 ppm) for the portable tank test. This water was loaded for demonstration test only and was subsequently drained from the portable tank.
- Water Tank Number 9 Low Volume - Water tank 9 was not completely filled during servicing. Waiver request MDAC OWS-WR-34 allows up to 55 lbs (24.94 Kg) of water to be off-loaded [was 25 lbs (11.33 Kg) maximum].

- Miscellaneous Specification Changes - The following TCN's were processed during this test:
  - TCN-136 changed the cation filter water sample requirement to delete discolved gas specification.
  - TCN-139 changed the cation filter final biocide conditioning requirement to 21 $\pm$ 1 ppm (was 14 $\pm$ 1 ppm).
  - TCN's 107 and 141 deleted requirements to run wet tests of the urine flush and contingency networks.

  All test objectives were met; all test data were reviewed and found to be acceptable.

- Personal Hygiene System - No testing was accomplished at KSC on this system. The only activity at KSC was the stowing in the OWS. (See Paragraph 5.6.3.13.)
- Body Cleansing System (Shower) - The KSC activity consisted of leak checking the shower, the inter-connect tubing, and the pump. The pump was functionally verified by operation and the whole system was stowed aboard the OWS (see Paragraph 5.6.3.13). The testing was completed and all results were satisfactory.
- Food Management System - No testing on this system was accomplished at KSC; this system was stowed aboard the vehicle (see Paragraph 5.6.3.13).
- Sleep Support System - The light baffles for each sleep compartment were retested at KSC to evaluate design changes made after the OWS was shipped to KSC. The retest resulted in several more design changes to minimize light leaks. The final evaluation of the sleep support system was acceptable.

- Refrigeration System - The mechanical Refrigeration System (RS) checkout spans the time from December 9, 1972, until Countdown Demonstration Test (CDDT), May 2, 1973 (KC-5001).
  - The RS electrical checkout started November 27, 1972, and was completed December 4, 1972 (KO-1000). Problems encountered and solutions are summarized below:
    - The Pressure Indicator Panel (PIP) was reassembled after cleaning and leak checked by bagging in lieu of a vacuum chamber check (a chamber large enough was not available). The bagging technique could not be used on the quick disconnects (QD's) which later became the source of leakage and caused a connection delay with the pump enclosure. These same QD's were susceptible to side loading and leaked (DR OW1-02-1013). A support bracket was fabricated and the QD's secured. No subsequent coolant leakage was reported after December 19, 1972, bracket installation. Protective aides were also fabricated to prevent gage glass breakage and calibration screw adjustments. QD handling procedures were developed to maintain lubrication in QD mating surfaces.
    - Refrigeration System (RS) Checkout (KS-0045) started February 12, 1972. Schedule delays were caused by the inadvertent use of "quarantined" Coolanol-15 heat transfer fluid (Batch QB4) in the RS Servicer (DSV7-315). A new supply of Coolanol-15 (Batch QB3) caused a new concern over the dark yellow fluid color. The yellow coolanol was filtered (1.25 microns), analyzed and counselled with the manufacturer and determined to be acceptable. A decision was made to use this fluid. The GSE was serviced, and Coolanol-15 dewatered and

degassed. A waiver (MDAC OWS-WR-25) was required to accept the GSE particle sampling (one particle approximately 190 microns). The decision to use the "yellow" Coolanol caused a resequencing of the RS checkout procedure which now started with chilldown and without the proper flight coolant level. All RS "cold" tests incorporated an insulating cover and a .013 ft ^{3}/min (6.13 X 10^{-6}m ^{3}/Sec) Gaseous Nitrogen (GN_2) trickle purge for the pump enclosure which allowed for the regenerator heater operation and the verification of chiller low loop switching using dry ice in the food chiller only.

The completion of RS coolant loading was delayed when the 1B93649-501 secondary loop jumper hose outlet QD operator did not retract. The fix was to disconnect the secondary jumper hose while maintaining a slight positive pressure on the pump enclosure secondary outlet QD [approximately 1 psig (1.08 x 10^5 N/$_m$2)] on disconnect. The primary jumper hose was used to off load the secondary coolant loop.

A waiver (MDAC OWS-WR-32) allowed for a refinement of the off loading temperature variable, the net result of which allowed the average coolant temperature in the primary loop to reach 94.2°F (307.7K) and the secondary loop to reach 91.1°F (305.9K) before completely extending the accumulator bellows.

GSE Model DSV7-301 supplied the proper water glycol flow rate temperature and pressure to the RS; however, the Temperature Control Units (TCU's) failed to refill the flight system after the launch purge. The first fix was to modify the GSE by adding two S14-140 bladders to add seven gallons of additional water glycol reservoir capacity to each TCU. Although the bladders were ultimately successful in refilling the TCU reservoir, the problem was found to be excessive glycol leakage in the TCU's. The RS ground serviced water glycol loop was over pressurized when incorrect operational steps were taken to reduce the pressure (IDR 119). Subsequent data review revealed that the GSE relief valves limited the maximum pressure to 310 psia ($2.137 \times 10^6 N/_m2$) [maximum proof is 400 psia ($2.757 \times 10^6 N/_m2$)]. Procedures, valve, switch positions, and relief valve settings were changed to prevent a further recurrence of overpressurization.

Umbilical QD's at find numbers (FN) A7679 and A7683 started leaking water glycol into the aft umbilical carrier (GSE DR-DSV7-301 0004). The QD's were removed and inspected. Normal seal wear was observed and the possibility of QD side loading, causing leakage, was confirmed. The fix was twofold: a coolant line support bracket was fabricated (1B72774-1) to support QD's and help maintain axial alignment. The QD's with new seals were replaced (after KS-008). There was no subsequent water glycol leakage reported from these umbilical QD's. KS-0045 was completed February 25, 1972. All RS flight and ground functional modes were verified except for water glycol ground refill with the DSV7-301.

Since the RS umbilical QD's were not available for the swing arm test (KS-0008) February 27, 1973, no ground functions using conditioned water glycol were verified. All GSE uplink functions were simulated. RS plus count activities (loop enables/disables, plume shield jettison/reset) were verified functional.

Umbilical QD's were installed and leak tested in time for the start of Space Vehicle OAT (KS-0009). All RS performance was acceptable during the test.

Current spikes were observed during post-test data review on the +4D111 Remote Automatic Calibration System (RACS) bus (DR OW1-09-1099). Fault isolation revealed an electrical noise sensitivity in the primary loop inverter. Current spikes did not affect the pump flow output or other parameters. The RS primary loop inverter was replaced March 25, 1973, with a unit tested at Huntington Beach and verified not to have a similar condition. Subsequent retest and observation of +4D111 current showed no further occurrence of current spikes. Corrective action on the inverter which was removed was to twist the clock line and its return to the shift register, twist the 5 vdc supply and its return to the shift register, and remove a capacitor across the clock line. Removal of the capacitor reduced the clock pulse fall time from 8 microseconds to 2 microseconds which minimized the clock output line exposure time to noise. These actions eliminated the current transients.

The Automatic Terminal Sequence Program (ASEP 1111) which sequences off the Interior Ground Thermal Conditioning System (IGTCS), RS and AM functions, was verified in the simulated Flight Test (KS-0012). Performance of the RS was acceptable.

RS responses to DCS commands and IU commands were verified in the Software Integration Test, March 27, 1973, (KS-0011).

RS pump enclosure tube support was found missing. Part was fabricated per OWI-02-1013 and support was bonded in place. The gold foil blanket was installed over regenerative heat exchangers and the pump enclosure door installed and enclosure purged with GN_2 (KO-5009) on March 13, 1973.

The RS was prepared for frozen food storage by TPS-OWI-09-029. Frozen food was stowed at 10:30 AM, April 8, 1973, and RS was operated continuously with all system data recorded a minimum of every half hour until launch.

The radiator backface insulation and thermal curtain were installed by KS-0016. Rollout (KS-0018, May 16, 1973) was uneventful except for facility transients during power transfers. RS was successfully controlled and monitored from Mobile Launcher panels 302-421A2 and 302-420A2.

RS performance during CDDT and CD (KS-0007) was acceptable. Water glycol purge and refill by DSV7-301 was successful during CDDT. The ASEP 1111 Terminal Sequencer Program sequenced AM IGTCS and RS functions properly. A nominal performance during countdown and launch was observed.

- KO-1000 - Refrigeration System Electrical Checks. The test was begun November 27, 1972, and completed December 4, 1972. Test objectives were to verify that electrical components of the RS were functional prior to the start of RS wet tests. The following were conducted:
  - Pump inverter and logic supply voltage checks
  - GSE input command checks
  - Logic unit checks

- Pump Sequencing
- Loop Transfers
- Logic Control
- OWS Display Indications

- Temperature Control Circuitry Checks for:
  - Freezer Inlet Temperature
  - Chiller Outlet Temperature
  - Regenerator Heater Controller
  - Radiator Bypass Controller
- Heater voltage and thermostat checks

All test objectives were achieved; all test data were reviewed and found to be acceptable. Leak checks on the RS were performed by KO-5009 and are recorded in Paragraph 5.6.3.4.

5.6.3.12 Pressure Garment Conditioning System - No testing was accomplished on this system. The suit drying station was installed in the vehicle.

5.6.3.13 Stowage System - Crew equipment stowage was handled at KSC by Test and Checkout Procedure (TCP) KO-3014. This test was begun March 25, 1973, and completed April 2, 1973. Test objective of this test were (1) to provide instructions for handling and pre-packaging flight crew equipment in the cleanroom to support subsystem testing, bench review, crew fit and function test, and flight stowage, (2) to provide instructions for stowage of flight crew equipment in the OWS spacecraft for CCFF and flight; and (3) to create an installation record of stowed flight crew equipment in support of launch operations. KO-3014 also provided CCFF procedures for the ring containers. All tests were conducted satisfactorily.

Six (6) procedure change requests (PCR's) were written due to stowage changes. Three (3) bench reviews were conducted with crew participation and all components or representative samples were reviewed. There were 1255 deviations written and 231 IDR's generated during the total test run. None of these were any major problem and all were closed or upgraded to DR's.

All test objectives of this sequence were satisfied and the test was acceptable.

5.6.3.14 Ground Support Equipment (GSE) - the GSE utilized at KSC was, for the most part, the same GSE used at Huntington Beach (A3) in the Vehicle Checkout Laboratory (VCL) for stage checkout, except where facility differences dictated a different test setup. A more complete account of the GSE exists in Paragraph 2.2.14.

Prior to performance of OWS interface checks, system verification and space vehicle integrated testing, the following SWS ESE TCP's were successfully completed to prove the integrity of the Ground Electrical Power and Control Systems.

- KS-9000 - LC39 Electrical Support Equipment Cable Validation. This test assembled all electrical equipment on the Mobile Launcher and Launch Control Center and performed electrical ring-out, meggering, and connection of GSE cables.
- KS-9001 - ACE to VAB GSE Integration. Verified the capability of ACE control room 2 to transmit commands and receive data from LC39 GSE and spacecraft umbilical systems. Each command and its associated indications were validated prior to use with the space vehicle.

- KS-9002 - SWS GSE Emergency Power Test. Verified the capability to transfer to and from emergency back-up power and confirmed which equipment was on emergency power.
- KS-9018 - VAB GSE Power System Activation. Verified all local controls in the Mobile Launch and provided a control procedure for daily use when not operating under ACE Station control.
- KS-9101 - EBW Pulse Sensor Functional. Verified the calibration of the EBW pulse sensors prior to spacecraft use.
- KO-9010 - DSV7-109 Solar Array Component Test Set Self-Test. This test was utilized to set up and run a self-test of the DSV7-109 Solar Array Test set prior to running each dark I-V test. There were three issues of this self-test; all were completed satisfactorily.
- KO-9016 - GSE Relay Module Test. Functionally tested GSE relay modules prior to installation in GSE racks. There were three issues of this test and all were completed satisfactorily.
- KO-9017 - GSE Diode Module Test. Functionally tested GSE diode modules prior to installation in GSE racks.
- KO-9018 - DSV7-122 Refrigeration System (RS) Checkout Kit. This test was utilized to set up and run a self-test of the DSV7-122 Refrigeration Test Set prior to accomplishing the spacecraft RS tests.
- KO-9019 - GSE Circuit Breaker Test. Functionally tested GSE circuit breakers prior to installation in GSF racks. There were three issues of this test; all were satisfactorily completed.

- KO-0004 - SWS to IU Interface Test. Test objectives were to (1) verify the OWS switch selector interfaces and the vibration and acoustical channels; (2) ensure that other systems operating during this test did not transmit false commands to the SWS switch selector MDA vent valve circuits; and (3) assure that the MDA vent valves operating commands via the SWS switch selector did not transmit transients to other systems in parallel operation.

  All of the channels were verified with the exception of Channels 108 and 109 which control the radiator shield jettison command. These commands were performed by deviation to KS-0008. Two (2) errors found in the switch selector counting ACE routine. The counter counted multi-malfunctions when the switch selector output was 2.4 vdc. The output voltage for a single channel was found to be a maximum of 2.7 volts instead of 2.4 vdc. The tolerance in the counting routine was changed to not more than 2.7 vdc. This solved the problem of receiving erroneous malfunction counts and multi-malfunctions. This procedure channel verified all ATM/AM/OWS vibration and acoustic sensors through the IU FM telemetry system with no problems.
- KS-0008 - SWS Operations for Space Vehicle Swing Arm Overall Test. Test objective was to verify the SWS/LV compatibility during countdown and an abbreviated plus count (9 min., 40 sec.) while in a minimum GSE/ESE cabling configuration. The test was satisfactorily completed.
- KS-0005 - IU/ATM/OWS TACS Test. Test objectives were to verify the capability of the IU and ATM to provide the necessary signals to the TACS to accomplish the required attitude control functions and to verify the proper TACS response to these controls. The test was satisfactorily completed.

complete and the Skylab mission was ready for launch. These tests were nearly trouble-free and any problems which occurred were quickly resolved and satisfactorily handled. All test data were satisfactory and all test objectives were achieved.

- KO-0003 - AM/MDA/OWS Electrical Interface Test. Test objectives were to perform flight mate of the OWS to the AM and verify the operational performance of the complete electrical and power distribution system. Six (6) DR's were written which involved cable routing. The cable routing was changed and the DR's were closed. The OWS Power Distribution Control System was functionally verified and no hardware problems were found.
- KO-0001 - AM/MDA/OWS Leak Test. Test objectives were to perform a leak test of the various systems aboard the AM, MDA, and OWS, and verify the integrity of the interfaces.
- KS-0045 - SWS End-to-End Systems Test and Experiment Test. Test objectives were to: (1) Verify OWS control circuits from ESE/GSE; (2) verify AM/OWS manual control of SWS systems; (3) verification of the caution and warning system including the ATM interface; (4) verification of on-board HSS equipment to the extent possible in a one "G" environment; (5) verification of the on-board illumination system; (6) verification of the experiments which could not be checked prior to OWS/AM/MDA mate; (7) verification of all ordnance circuits; (8) verify operation of the communications and instrumentation systems; (9) verify the combined operation of the EREP system; (10) M512-confidence level verification of the vacuum system; (11) RNBM-end-to-end verification of flight spare RNBM alert; (12) EREP-perform operational checkout of earth resources.

All tests were satisfactorily completed.

- KO-9020 - DSV7-502 Mass Decay Leak Test Kit and Associated GFP Validation. Performed an end-to-end verification of the DSV7-503 test set prior to installation for spacecraft checkout. Significant proplems encountered were: Mobile Launcher Noise (DR GSE-7-329-0014) - It was discovered during checkout operations, that Mobile Launcher noise was present and was being introduced into pressure transducer output lines. The transducers responded to this noise and caused an out-of-specification condition and/or noise in the measurement. The noise affected five OWS pressure measurements and approximately thirteen measurements within existing S-IVB pneumatic consoles. Consoles affected were: DSV7-301-MT 3 and 4; DSV7-329-MT 1, 2, 3, 4, 6, 10, and 14; DSV7-322-MT 8 and 9; DSV7-334-MT 3 and 4; DSV7-343-MT 1, 2, 3, 4, and 5.

  Only three OWS pressure measurements resulted in out-of-specification conditions. (High RACS indicated 2.56 vdc and should be 4.00 ± 0.40 vdc Low RACS indicated 0.7 vdc and should be 1.00 ± 0.050 vdc). An interim fix which consisted of a capacitor in the patch panel measurement test points was incorporated.

  As a final fix, filter cables were fabricated per ECP W003-65C. The filter cables were installed and successfully tested per KS-0009, Mission SIM Test.

5.6.4 System Verification - The following test procedures represent all the integrated system testing which was accomplished at KSC. These tests are listed chronologically and the general test philosophy was that upon successful completion of each of these tests, system verification was

- KS-0009 - SWS Operations and Space Vehicle Overall Test Mission Simulation/Flight Readiness Test. Test objectives were to (1) verify IU/SWS interface compatibility in the flight mode; (2) accomplish SL-1 countdown and countup functions in preparation for SWS simulated flight; (3) demonstrate electromagnetic compatibility between the individual SWS systems, and between SWS systems and associated experiments during SL-2 countup and orbital operations; (4) Perform docking drogue installation in MDA axial tunnel and closeout docking port hatch; (5) perform axial docking target installation; (6) perform an open loop VHF ranging test to CSM on Pad 39B.

  The test was satisfactorily completed.

- KS-0011 - SWS SIT Test. Test objectives were to verify the ATM/LV interface in the guidance system after electrical mate, demonstrate the compatibility of the space vehicle with the command network, demonstrate the suitability of the operational handbooks for the conduct of the mission, and verify operation of the backup command modes.
- KS-0012 - SWS Operations for Launch Vehicle Flight Readiness Test. Test objectives were to demonstrate compatibility of Saturn Workshop with the launch vehicle by participating in three plus counts. Part 1 required nominal support from the SWS. Part 2 validated TACS switch-over on IU guidance failure. Part 3 validated SWS functions upon normal IU command.
- KS-0010A - Integrated Crew Compartment Fit and Functional Test. The Crew Compartment Fit and Functional Test (CCFF) at KSC was performed to accomplish the verification of fit check and functional sequences that were not satisfied during the first CCFF (1B86424) at Huntington Beach due to lack of hardware or non-acceptable equipment requiring

modification and subsequent review. The specific tasks performed by the Flight Crews, under the direction of assigned Test Conductors were:

- Verification of the accessibility and operational suitability of the previously non-verified stowed and installed OWS module equipment provisions.
- Verification of applicable mechanical and certain electrical functions of certain stowed and installed equipment, including experiments at in-flight using locations within the OWS module.
- Verification of fit check and/or functional interface within the OWS module of certain equipment launched in other vehicles and designated for temporary or permanent OWS module occupancy.
- Verification of selected critical tool interfaces.
- Verification of selected in-flight maintenance tasks using orbital spares.
- Demonstrate and verify functional performance of designated Habitability Support System (HSS) operations as comprised by the test environment (1G, 14.7 psia, etc.).

- KS-0016 - SWS Electrical and Mechanical Closeout. Test objectives were to: (1) verify final stowage for flight; (2) verify the overall internal OWS launch configuration; (3) configurate all OWS switch panels and valves for flight; (4) closeout of the OWS dome and side hatches; (5) Perform a leak check of the OWS side hatch, waste tank vent caps and purge and monitor ports; (6) perform fit check of S009 detector package; (7) M131 rotating litter chair, installation of chair to base; (8) T020 interior pictures.

- KS-0018 - SWS Operations for Space Vehicle Transfer to the Pad. Test objectives were to provide the required AM/MDA/OWS support functions while transferring from the VAB Complex to the pad complex (rollout).

5.6.5 Final System Test and Launch - KS-0007, Countdown Demonstration Test (CDDT)/Recycle/Countdown (CD) test was begun April 26, 1973, and completed May 2, 1973. It was the final system test procedure which demonstrated launch readiness and prepared the vehicle and the launcher for the actual launch operation. Test objectives were to perform the sequence of operations and tests required to prepare SL-1 for launch and provide operational plans for launch recycle if required.

After the vehicle was transferred to launch pad 39A, and all facility and pad preparations and hook-ups were accomplished, the KS-0007, Wet CDDT, was initiated. The CDDT consisted generally of closing out the vehicle for flight - removal of access kits from the vehicle, final installation of ordnance, pressurizing vehicle systems for flight, etc. The CDDT was trouble-free and proceeded smoothly. All test objectives were met, and all data were reviewed and found satisfactory.

The only significant problem encountered during performance of CDDT was the habitation area dew point maximum temperature requirement of 0°F (255.3K) per the specifications and criteria document could not be maintained without schedule impact to the test. Waiver MDAC OWS-WR-54, allowing dew point excursions up to +4°F (257.5K) was submitted to and approved by NASA.

° KS-0007 (Countdown (CD). CD was initiated for launch May 10, 1973, and flowed smoothly down to launch. The Skylab was launched on May 14, 1973, from Complex 39, Pad A. The spacecraft was boosted into a 234 nautical mile (433 kilometer) orb by a Saturn V launch vehicle. Liftoff time was 1730:00.586 Greenwich Mean Time (GMT).

5.7 MISSION SUPPORT TESTING

5.7.1 OWS Backup - The OWS Backup was utilized many times in its mission support role as a functional real-time test equipment entity. Procedures were verified and system anomalies investigated to provide rapid and realistic solutions. The Backup was utilized by a crewman to develop a procedure to extract coolanol from the OWS Refrigeration System for servicing the AM cooling system. In addition, hardware was removed from the OWS Backup for logistic resupply to the Skylab via the Command Service Module.

The Mission Support activities utilizing the OWS Backup are outlined in the paragraphs below:

5.7.1.1 Water Heater Test (MSTR 001)

- o Problem/Anomaly - Tests indicated there was a possibility the water heater life would not extend through SL-4 mission.
- o Action was to determine temperature and voltage/current characteristics of Wardroom and Waste Management Compartment water heaters.
- o OWS Backup action was to remove the heaters from OWS-BU, perform the test in Engineering Laboratory and ship heaters to the KSC. Results of the laboratory tests are presented in Paragraph 5.7.2. The heaters were flown as spares on SL-1.

5.7.1.2 Wardroom Window Cover Pressure Decay (MSTR 010)

- o Purpose - Concern was expressed that pressure could be trapped between wardroom window and cover.
- o Action was to remove the window/cover assembly from the Backup and check for pressure decay in the Spacecraft.
- o Results - The window cover seal relieved at a relatively low pressure and, therefore, did not present a problem.

5.7.1.3 SAS Wing Output Measurements (MSTR 011)

- o Problem/Anomaly - Inadequate power supplied from SAS and indications were that the SAS did not deploy.

- Action was to 1) determine deployment status of SAS Wing #2, 2) analyze available flight data, and 3) simulate flight data on OWS Backup.
- Conclusions - SAS Wing #2 position data indicated SAS Wing #2 on OWS #1 had been separated from Skylab.

5.7.1.4 Duct Fans Operation by Ground Command (MSTR 017)

- Problem/Anomaly - Because of elevated OWS temperature, due to lack of power, it may have been necessary to operate duct fans during unmanned periods.
- Action was to develop hardware and procedures and demonstrate capability to operate duct fans. Cables were developed connecting from radiant heater to duct fans. Procedure and successful operation were demonstrated.
- Result - A decision was made by NASA, not to fly up these cables.

5.7.1.5 Bus Crossover Investigation (MSTR 030)

- Problem/Anomaly - Buses 1 and 2 low voltage caution and warning lights came on even though bus voltages were normal. It was also noted that the caution and warning low voltage sense breakers were open.
- Action was to trace wire harness routing in Backup to determine if crossover points existed which would allow a potential short path.
- Conclusions/Results - Interbus short was ruled out and troubleshooting indicated circuit breaker position was probably the problem.

During the crew debriefing, it was stated numerous breakers and switches were inadvertently actuated until they became accustomed to the cluster configuration and zero-G.

5.7.1.6 Restraint Adapters (MSTR 038)

- Problem/Anomaly - Use of Waste Management Compartment (WMC) foot restraints required removal of triangle shoes by flight crew.
- Action was to 1) develop a procedure so flight crew could install a newly designed triangle shoe adapter, 2) perform fit/function check on adapter, 3) determine dimensional capability and determine fit/function of triangle shoe and redesigned restraint on OWS Backup.
- Conclusions/Results - Test of the redesigned restraint was successful. JSC design was flown on SL-3.

5.7.1.7 Wardroom Window Drying Procedure (MSTR 045)

- Problem/Anomaly - Condensation and ice had formed on Wardroom Window.
- Action was to 1) determine on-orbit hardware available to crew which would allow evacuation of Wardroom Window enclosure, and 2) determine routing and fit check of hose attachments and fittings necessary to connect vacuum source.
- Results - Routing was established, and a new adapter was designed and flown up on SL-3, to allow SL-3 crewman to perform evacuation.

5.7.1.8 Refrigeration System Radiator Bypass Valve Lockup (MSTR 052)

- Problem/Anomaly - Skylab Refrigeration System temperature was elevated. Cause was believed to be partially open bypass valve resulting from a potential contaminant.
- Action was to 1) simulate radiator surface temperatures and initial RSS conditions, 2) activate loop enable/disable commands, 3) monitor bypass valve talkback indicators, and 4) ascertain delta time to prevent lockup in bypass position under no flow conditions.
- Conclusions/Results - Delta time between enable/disable commands must exceed 2.6 seconds for proper bypass operation. This information was utilized by HOSC and JSC to formulate new procedures.

5.7.1.9 Refrigeration System Ground Command Initiated Flushing Procedure (MSTR 054)

- Problem/Anomaly - Skylab Refrigeration System temperature was elevated. Cause was believed to be partially open bypass valve.
- Action was to 1) activate enable/disable commands to determine valve lockup in bypass position, 2) determine when valve would respond properly to temperature sensor inputs from radiator and thermal capacitor, 3) perform combined ground DCS command and manual circuit breaker open/closing flushing procedure, 4) perform flushing procedure with pumps operating for both the primary and secondary loops, 5) demonstrate capability for ground dual loop operation, and 6) demonstrate crew accessibility to RSS connections.
- Conclusions/Results - 1) delay time between enable/disable commands must be greater than 5.6 seconds for consistent results to prevent lockup in bypass position, 2) a combined ground DCS and manual circuit breaker opening/closing procedure was feasible, 3) circuit breaker on Panel 611 must be closed for valid TM indications, 4) demonstrated crew capability to access and remove RSS electrical connectors which allow primary and secondary loops to function independently, 5) verified that the OWS can be left in a configuration which would allow use of both loops simultaneously should the need arise even during unmanned storage time.

5.7.1.10 Refrigeration System - Crew Operational Procedure Verification - Radiator Bypass Controller (MSTR 055)

- Problem/Anomaly - Skylab Refrigeration System temperature was elevated. Potential transient resulting from crew actions.
- Action was to verify that crew task of opening and closing bypass controller circuit breaker would not cause transients that could alter bypass valve positions and verify that radiator bypass valve flushing procedure could be performed by the crew.

- Conclusions/Results - 1) a feasible flushing procedure was established, 2) crew operations did not generate transients during bypass controller opening, 3) optimum flushing procedures techniques require combined crew and ground monitors, and 4) opening the logic circuit breaker for 10 seconds on Panel 611 returns the bypass monitor control module to its proper state.

5.7.1.11 Radiator Bypass Valve Flushing (MSTR 059)

- Problem/Anomaly - Possible contamination in bypass valve.
- Action was to develop and perform a procedure that could be utilized during Skylab Manned operations.
- Conclusions/Results - 1) the procedure was developed and successfully accomplished, 2) time required to run simulation was 16 minutes per loop, and 3) verified TM indication is bypass when radiator bypass controller circuit breaker was open.

5.7.1.12 Intercom System Feedback (MSTR 062)

- Problem/Anomaly - Feedback in Skylab Intercom System.
- Action was to determine methods and develop procedures to reduce feedback effect by 1) determining maximum and minimum volume settings, 2) determining groups of Speaker Intercom Assemblies (SIA's) that may exhibit interactions resulting in feedback and 3) determine the results of reducing the total number of SIA's.
- Results - Optimum volume control settings were established which eliminated feedback problem.

5.7.1.13 Verify NASA MSFC Refrigeration System Flushing Procedure (MSTR 063)

- Problem/Anomaly - Possible contamination in bypass valve.
- Action was to perform and verify NASA MSFC procedure prior to submission to JSC.
- Results - The procedure operated the system satisfactorily.

5.7.1.14 Condensate Dump Fit Check (MSTR 067)

- Problem/Anomaly - Requirement was established to develop an alternate method of venting gas side of condensate dump tank.
- Action was to establish tools, prepare and verify a procedure to verify hardware compatibility for a method of venting the gas side of condensate tank through the SAL.
- Results - The procedure was verified but because of hardware configuration, alternate means were recommended.

5.7.1.15 Pump Package Cover Photographs (MSTR 070)

- Problem/Anomaly - Coolanol leak in airlock module cooling system.
- Action was to develop crew training photographs which depicted the series of operations required of the SL-3 crew to withdraw coolanol from the OWS Refrigeration System.
- Results - The photographs were obtained and transmitted which depicted hardware appearance and relationships to surrounding equipment.

5.7.1.16 Refrigeration System Flushing Procedure (MSTR 071)

- Problem/Anomaly - Possible contamination in bypass valve.
- Action was to establish flight setup initial conditions and perform combined ground flight RSS flushing procedures.
- Results - The combined ground flight RSS flushing procedures were acceptable.

5.7.1.17 Malfunction Noted During Performance of JSC/Flight RSS Flushing Procedure (MSTR's 071, 071-1, -2)

- Problem/Anomaly - Ground monitors noted bypass valve position talkback did not indicate radiator position during flushing procedure.
- Action was to determine probable cause by performing JSC/Flight RSS Flushing Procedure utilizing different delay times and determine if circuit breaker flight operational sequences or simultaneous closing and opening of the circuit breakers could cause bypass valve lockup.

- Results - The bypass valve did not lock up in the bypass position for times greater than one (1) second. Reversed circuit breaker operation sequences, sequentially closed and reversed circuit breaker operational sequences simultaneously, closed did not cause a lockup.

5.7.1.18 Airlock Module Coolanol Servicing (MSTR 072)

- Problem/Anomaly - Coolanol leak in Airlock Module cooling system.
- Action was to verify crew access capability and develop a procedure for extracting coolanol from OWS Refrigeration System into OWS portable water tank for transport to airlock module and injection into cooling system.
- Results - SL-3 hardware could be utilized to accomplish transfer of coolanol from OWS Refrigeration System to airlock module cooling system.

5.7.1.19 Trash Airlock (TAL) Turnbuckle Interlock (MSTR 081)

- Problem/Anomaly - Turnbuckle interlock between the inner door latch and the valve/outer door handle was damaged (bent) to the extent that airlock operation was difficult but not impossible.
- Action was to determine whether MDAC-W recommended any maintenance on the interlock.
- Conclusions - Maintenance of the TAL was not recommended. This recommendation was the result of a procedure accomplished in the OWS Backup which indicated the bent turnbuckle rod was not the cause of the difficulty to close lid and latch. The cause could have been the result of latch torsion spring moving out of the slot when fully unlatched and then jamming during latching operation. It was recommended that the crew inspect the spring position and if the spring was out of position, to remove the spring as the latch can be operated without the spring. If spring was not out of position, a troubleshooting procedure was provided.

5.7.1.20 Wardroom Table Top to Function as a Desk (MSTR 083)

- Purpose - Ascertain the design requirements to convert the Wardroom table top to function as a desk top.
- Action was to remove 1B86448-1, Food Table Cover and four (4) 1B87579-1 Bungees from OWS Backup and perform engineering evaluation to allow conversion of Wardroom table top to function as a desk top.
- Results - 1B96431-1, Adapter Restraint was designed and the test part was hand carried to JSC for evaluation.

5.7.1.21 Dual-Loop Refrigeration Operations (MSTR 086)

- Purpose - Demonstrate capability of performing dual-loop Refrigeration System (RS) operation.
- Action was to verify the RS logic unit interface connector 436A49W1P1 could be disconnected from the primary loop logic connector 436A49A1J5 without damaging the RS in order to perform dual-loop RS operations.
- Conclusions - Both primary and secondary loops will work independently of each other when RS logic unit interface connector 436A49W1P1 is disconnected from primary loop connector 436A49A1J5 (Dual Loop Operation).

  Manned flushing and unmanned flushing procedures can be accomplished for dual loop operation.

  Application of +28 vdc (from pins on the interconnecting harness) to any other pins on the interconnecting harness, or the grounding of any of the pins, will not damage either the primary or secondary loop logic units.

5.7.1.22 Fit Check Lower Leg Restraint and Adapter (MSTR 089 and 078)

- Problem/Anomaly - Fit of lower leg restraint and adapters in the Waste Management Compartment on door of Locker No. 829.

- Action was to verify fit of leg restraint and adapters.
- Results - Parts performed adequately. Screw length discrepancies were noted and corrected. Parts are considered ready for flight.

5.7.1.23 Adapter Assembly Fit Check (MSTR 093)

- Purpose - Verify the satisfactory fit check operation and integration of 1B96363-1 adapter with the Quick Disconnect (QD) on Panel 500 and hose assembly.
- Action was to perform fit check of adapter in OWS Backup per Assembly Outline (AO) 1B96363-AN2D-B01 to support SL4 Airlock Module coolanol reservicing.
- Results - The adapter was successfully fit checked. No problems were encountered.

5.7.1.24 Waste Management Compartment Foot Restraint Fit Check (MSTR 096)

- Problem/Anomaly - Fit of WMC foot restraint.
- Action was to perform fit check of WMC foot restraint in OWS Backup.
- Results - Fit check of left foot restraint (1B86723-503) and adapter 1B96414-502 in both positions (in front of water module and in front of collector) was successful. A tightening technique was developed in that if the set screws start from a flush position (point end)--placed on foot restraint--and then set screws tightened four (4) 180° turns of Allen wrench, a good attachment was obtained. The -504 and -506 right restraints were not satisfactory. The -504 adapter after being tightened, popped off and the -506 could not be properly installed. The right restraints had a bend or curve in the sole plates. Discrepancy Reports (DR's) were prepared and dispositioned to straighten the sole plates. The set screws were moved to a lower position per 1B96412-503, Revision D. The straightened restraints and reworked adapter were retested successfully.

5.7.1.25 Acoustical Feedback Elimination (MSTR 097)

- Purpose - Determine feasibility of utilizing a variable load to control acoustic feedback in the OWS Intercom System.
- Action - Activate Intercom System in the OWS Backup.
- Connect the variable load connected to CCU connector of SIA at P901.
- With variable load set to maximum and connected at P401, determine volume setting required to produce feedback when speaking into SIA at P702. The test was then repeated while speaking into P540.
- Results - The SIA volume control developed for eliminating acoustical feedback in the Skylab performed more than adequately in eliminating acoustical feedback.

5.7.1.26 T027 Sunshield Interference (MSTR N/A)

- Problem/Anomaly - Plus (+) Z SAL was covered by the sunshield through which T027 had to project.
- Action was to determine substitute methods of utilizing T027 from minus (-) Z SAL.
- Results - A plan was prepared to fit and function cables to utilize T027 on minus Z SAL and route cabling to Panel 544 or Panel 518.

5.7.1.27 Telemetry Anomaly During Pre-launch Tests at the KSC (MSTR N/A)

- Problem/Anomaly - Noise affecting TM during pre-launch tests at the KSC.
- Action was to determine a method to eliminate noise in Skylab data system. Photograph various TM signals on the OWS Backup for comparison with signals observed on OWS-1.
- Results - A capacitor was added to each spacecraft low level multiplexer to suppress the noise (ECP W003-24C).

5.7.1.28 SAS Wing Substitute (MSTR N/A)

- Problem/Anomaly - Insufficient spacecraft power because of missing SAS Wing.
- Action was to develop interface equipment and a plan to provide for

an on-orbit installation of a SAS wing.

- Results - The plan was prepared for implementation when required.

5.7.1.29 Installation of Dosimeters in Backup (MSTR 102)

- Problem/Anomaly - There was a noted discrepancy in the dosimeter readings during SL-3 and SL-4 missions.
- Action - Four (4) dosimeters were shipped from JSC to MDAC-W for installation in the Backup spacecraft. Two (2) in the film vault for a two week exposure.
- Results - These dosimeters were returned to JSC for analysis.

5.7.1.30 CMG Heater Adapter Cable Development (MSTR 104)

- Problem/Anomaly - Unstable operation of CMG's during mission- One CMG inoperative and one intermittent instability.
- Action - Develop a cable to supply heat to the CMG in order to stabilize gyro operation.
- Results - The M509 cable connector was disconnected and cable harness cut on the Backup vehicle. Tool clearances verified that procedure could be performed on the spacecraft.

5.7.1.31 Fit Check Urine Trays in Return Container (MSTR 105)

- Problem/Anomaly - During SL-4, the urine trays were not fitting into the return container satisfactorily.
- Action - A fit check was made in the Backup vehicle using various methods of stowing.
- Results - Several methods were tried using Teflon, removing compartment dividers, etc. and results indicated task could be accomplished in spacecraft satisfactorily.

5.7.2 Laboratory - Laboratory test results provided valuable data in support of each workshop habitation. The test hardware used for qualification testing of waste management subsystem, Line Item HS-2, was utilized prior to first habitation to determine operation characteristics without power. In addition, the Refrigeration Subsystem Qualification Test Hardware, Line Item HS-19, was utilized almost constantly during first and second habitation period for the investigation of problems and their solution as required.

The following is a listing of laboratory tests instigated in support of the OWS mission(s):

5.7.2.1 Freezer Temperature Decay Test (MSTR RS0001)

- Purpose - Develop a temperature curve with which to determine allowable hold time (TCU Ground Cooling not available) as a function of storage freezer temperature.
- Action - Utilized HS-19-1 hardware in Space Laboratory to accomplish testing and record measurements.
- Results - Satisfactorily accomplished prior to the launch of SL-1.

5.7.2.2 Orbital Insertion Performance Data for Refrigeration System (MSTR RS0002)

- Purpose - Obtain plots as required for data noted in title to support launch of SL-1.

- Action - Utilized HS-19-1 hardware in Space Laboratory to accomplish testing and record measurements.
- Results - Satisfactory for three possible launch times giving intersection points for the insertion-to-solar inertial case and the corresponding solar inertial orbital case.

5.7.2.3 Window Metal Cover Pressure Tests (MSTR 009)

- Purpose - Verify structural integrity of the Rosen Insert installation in the Fluorogold Ring.
- Action - Three specimens of inserts were used to determine the pull-out strength and the load/strain characteristics of the insert installation at different load levels. Phase two was to simulate a cabin blowdown condition in which the cavity between the window protective cover and the glazing of window assembly had reached the pressure of the habitation compartment prior to blowdown.
- Results - Achieved prior to launch of SL-1 and indicated no degradation in the sealing capability of the cover assembly.

5.7.2.4 SAS Beam Fairing Actuator/Damper Break-away Force (MSTR 002)

- Problem/Anomaly - SAS wing not fully deployed and possibility of A/D being exposed to abnormally low temperatures making it necessary to break A/D loose before full deployment of SAS wing could be achieved.
- Action - Required several test runs on qualification test Hinge Assembly varying temperature on A/D to achieve deployment.
- Results - When A/D was cooled to -100°F, (199.79°K) a force of 114 lbs. (507 N) was applied at the apex of the deployment frame and broke the hinge loose. Failure occurred in the clevis fitting of the forward fairing. The A/D did not fail nor extend.

5.7.2.5 SAS Beam Fairing Cold Actuator Damper Deployment Durations (MSTR 003)

- Problem/Anomaly - SAS wing not fully deployed and possibility of actuator/damper being cold, will increase deployment time.

- Action - To determine 1) lowest temperature of the A/D at which the beam fairing can deploy in one orbit, 2) time to fully extend at 0°F (255.3°K) and 20°F (266.45°K).
- Results - Indicated that -20°F (244.24°K) was lowest temperature for one orbit deployment and that deployment at 0°F (255.3°K) took 4 min. 48 secs (208 sec.) and at -20°F, (244.24°K) 3 min. 22 secs. (202 sec.). These results indicated a need for further tests and under refined test procedures. (Reference MSTR 028)

5.7.2.6 Internal Insulation Outgassing (MSTR 004)

- Problem/Anomaly - Loss of meteoroid shield created an increase of the spacecraft's internal temperature which could create a degradation of the internal insulation.
- Action - To test 4 specimens in a bell jar at 5.5 psia oxygen atmosphere using temperatures of 175°, 290°, 350° and 400°F, (352.56°, 416.44°, 449.77°, and 477.55°K) for 11-1/2 hours (4.14×10^4 sec). Specimens were evaluated for structural, thermal and off-gassing qualities.
- Results - Specimens subjected to temperatures above 175°F (352.56°K) became debonded. This was well above the temperatures within the OWS.

5.7.2.7 Waste Processor Test (MSTR 005)

- Problem/Anomaly - With SAS undeployed, power limitations may require processing of feces without use of the heaters in the waste processor.
- Action - Testing was accomplished at Fairchild Hiller and MDAC. The backup processor was used to run a 14-phase test program at MDAC.
- Results - The processor can accomplish its function without power but processing time is longer dependent on specimen and mass.

5.7.2.8 Iodine Container and Reagent Container (MSTR 006)

- Problem/Anomaly - Elevated temperatures within the OWS created by loss of meteoroid shield caused concern as to temperature vs. pressures within the containers noted above.

- o Action - Run an elevated temperature test on the iodine and reagent containers (loaded to flight levels). Temperatures to be 160° - 180°F (344.23° - 354.22°K) approximately.
- o Results - Iodine container was exposed to temperatures from 99° - 180°F (310.34° - 354.22°K) with internal pressures of from 9 psi (62046.0 N/m^2) to 156 psi (1.075×10^6 N/m^2). The reagent container saw temperatures from 99° (310.34°K) to 165.5°F (347.28°K), and pressures from 15 psi (1.034 x 105 N/m^2) to 36 psi (2.48×10^5 N/m^2). Water was expelled from iodine container at 165.5° (347.28°K) and 180°F (354.22°K). All results on both containers were satisfactory.

5.7.2.9 Determine Bond Strength of 3D Tile at Elevated Temperature (MSTR 006.1)

- o Problem/Anomaly - Continuation of MSTR 004 as elevated temperature test of internal insulation. Specimen was 3D foam attached to aluminum plate by Lefkoweld and wrapped in foil.
- o Action - Determine bond strength of the specimen at temperatures of 300°F (422.0°K) on aluminum skin side and aluminum foil side at 200°F (366.45°K) over a total 8-hour (2.88×10^4 sec) period of constant temperatures followed by a pull test (at ambient temperature), of embedded attach fittings in the 3D foam.
- o Results - Indicated cracks first appearing in Lefkoweld after 2 hours 40 minutes (9.6×10^3 sec) of an intended 12-hour (4.32×10^4 sec) run. Temperatures were at 194.5°F (363.39°K) on foil side, and 292.5°F (417.83°K) on aluminum sheet side. Test was stopped after 10 hours 10 minutes (3.66×10^4 sec) when temperature on metal side was 300.5°F (422.27°K) and 201.8°F (367.45°K) on foil side. Lots of cracks in adhesive. Debonding at plate and discoloring at bond line noted. The embedded fittings withstood design ultimate loads when subjected to tension loads.

5.7.2.10 Pressure Regulator Test for Pneumatic Heat Shield (MSTR 008)

- Problem/Anomaly - Loss of the meteoroid shield created overheating problems on the interior of the spacecraft (OWS). It was necessary to establish a protective sun shade that alleviated the overheating conditions. In the design of the heat shield, it is required to utilize pressure regulators.

- Action - A test on 4 regulators was made to verify regulation could be maintained from 5 psia (3.447×10^4 N/m^2) to .5 psia (3.447×10^3 N/m^2) with a vacuum as reference.

- Results - All regulators performed satisfactorily; data was with 5.0 psia (3.447×10^4 N/m^2) inlet conditions.

5.7.2.11 Hand Tool Rupture of SAS Wing Section Ordnance Straps (MSTR 012)

- Problem/Anomaly - SAS wing failed to deploy at the proper time, therefore, alternate methods were surveyed to determine if the astronauts could manually deploy the wing.

- Action - Could the ordnance straps be a binding element holding the wing in place, devise a method using all actual recommended hardware and determine actual force required and technique.

- Results - Successfully ruptured one ordnance strap groove which partially released the ordnance strap but not enough to deploy. Successfully ruptured opposite groove which provided the complete release. Actual forces applied to 12 inch (30.48 cm) pry bar handle were not measured, but "not very much."

5.7.2.12 Early Cinch Bar Release of SAS (MSTR 012.1)

- Problem/Anomaly - Failure of SAS to release on scheduled command transmitted to SL-1.

- Action - Build an 8" x 10" x .020" (20.32 cm x 25.4 cm x .0508 cm) piece of 6061T6AL and attach to a piece of 3" (7.62 cm) square tubing to simulate meteoroid shield skin. Release cinch bar assembly simulating early release to determine cinch bar/shield skin interaction.

- Results - Release of assembly simulating the projecting adjustment screw penetrated the .020" (.0508 cm) stock full length of the exposed screw thread, and the stock sheared over a length of 1-1/4" (3.175 cm) where the cinch bar edge attempted to penetrate the stock. The penetrated screw required between 5 and 10 lbs. (22.24 and 44.48 N) of force to remove from the .020 (.0508 cm) stock.

5.7.2.13 Meteoroid Shield Swing Bar Restraint to the Beam Fairing Deployment (MSTR 012.2)

- Problem/Anomaly - Indications were the SAS beam fairing was held in its present position preventing deployment by interference or restraint by a swing bar from the meteoroid shield.
- Action - Determine where the meteoroid shield swing bar and associated bar can restrain the beam deployment.
- Result - 1) the swing arm alone, because of its configuration, does not offer any means of restraining beam fairing deployment, 2) with undistorted shield frame angle still attached, damage could be done to the solar cells, but there would be no beam fairing deployment restraint, 3) with distorted shield frame and/or distorted or torn shield panel skin, there are many ledges and flanges which could be snagged, restraining beam fairing deployment.

5.7.2.14 Auxiliary Tunnel Aft Section Pressure Test (MSTR 014)

- Problem/Anomaly - Due to the loss of meteoroid shield, a possible source of differential pressure lifting the end shield could be in the auxiliary tunnel aft section.
- Action - A test was performed with a 2" (5.08 cm) diameter vacuum line and later changed to a 3" (7.62 cm) diameter and test re-run.
- Results - Using the 2" (5.08 cm) vacuum line, a differential pressure of 2.5 psi (1.732×10^4 N/m^2), with a flow rate of 297.335 cubic feet per minute (.14029 m^3/sec) was obtained. With the 3" (7.62 cm) diameter line, a differential pressure of 4.9 (3.378×10^4 N/m^2) was obtained with a flow rate of 1,514 cubic feet per minute (.71435 m^3/sec).

5.7.2.15 Meteoroid Shield Failure Anomaly Investigation (MSTR 014 R1)

- o Problem/Anomaly - Reference MSTR 014, see preceding investigation.
- o Action - Re-run boot test previously described above to determine an accurate picture of a leak area vs. boot ΔP.
- o Results - A curve of leak area vs. boot ΔP was transmitted to MSFC via Mission Support Room.

5.7.2.16 SAS Beam Fairing Deployment Test (MSTR 015)

- o Problem/Anomaly - Establish method for astronaut to deploy SAS beam fairing.
- o Action - Determine forces, energies, and reactions of the SAS wing assembly in crew deployment effort using the qualification test wing in zero-G fixture. Approximately 8 tests were conducted under various conditions.
- o Results - It was discovered that if debris were removed from restraining the SAS wing, the outboard tip would immediately move approximately 48" with no external force applied. With the actuator broken loose, it was entirely possible to deploy the SAS beam fairing to a latch-up position by using a small amount of external force.

5.7.2.17 Humidity Generator Test Plan (MSTR 016)

- o Problem/Anomaly - It was suspected the internal humidity inside the Workshop was too low.
- o Action - Pump a nozzle from the humidity generator into a vacuum chamber and operate under anticipated workshop conditions.
- o Results - The nozzle created a fine mist that raised the humidity of the test chamber according to calculations.

5.7.2.18 High Temperature Degradation and Outgassing of Tank Insulation (MSTR 018)

- o Problem/Anomaly - Interior of the OWS overheating due to lack of meteoroid shield acting as a sun shade.
- o Action - Using a 2' x 2" (60.98 cm x 5.08 cm) tank section in test line item CA-30, OWS Insulation (2 specimens) install in vacuum chamber and determine the outgassing rate of carbonmonoxide and total hydrocarbon output throughout heat/vacuum environments. Vacuum chamber to have 100% oxygen. Outer skin surface temperature, 300°F; (422.0°K) inner surface 200°F (366.45°K). Chamber pressure approximately 5 psi (3.447×10^4 N/m^2). Gas samples to be taken throughout a 72-hour period (2.592×10^5 sec).

o Results - Test indicated there would be no structural degradation of the internal tank insulation or emission of toxic gases to any degree of danger to the astronauts welfare.

5.7.2.19 SAS Beam Fairing Bent Angle Captivation Simulation Test (MSTR 019)

o Problem/Anomaly - TV films indicated the beam fairing was captivated by a bent angle remaining as a result of loss of the meteoroid shield.

o Action - Perform a test to determine force required to clear bent angle.

o Results - Four tests were conducted to simulate the conditions noted on the TV films. A procedure was established to apply astronaut loads to remove the angle clear of the beam fairing.

5.7.2.20 SAS Beam Release - EVA (MSTR 020)

o Problem/Anomaly - Establish a procedure for an astronaut to release the SAS beam fairing during an EVA utilizing on-board tools.

o Action - Utilize pinch bar and handrail as a pry bar.

o Results - Tests demonstrated capability of using established pry bar to release restraining bent angle.

5.7.2.21 Water Tank Iodine Reading Low (MSTR 021)

o Problem/Anomaly - Possible iodine depletion within the OWS water tanks due to high internal temperatures.

o Action - Analyze a 6 ppm water/iodine solution at 70°F, 100°F, and 120°F, (294.23°, 310.9°, and 322.0°K) to determine elevated temperature effects on the OWS onboard readout.

o Results - Tests indicated on-board iodine level evaluation method is not reliable at elevated liquid temperatures. There is no crew problem. The iodine level taken out of the water chiller indicated a good sample reading.

5.7.2.22 SAS Beam Fairing Restraint Pry Away Test (MSTR 022)

o Problem/Anomaly - Constraint created by angle holding SAS beam fairing from being deployed.

o Action - Determine methods and force required to pry the restraining angle out of the way. Document step-by-step procedure and measure force required for each developed technique.

- Result - Test was successfully accomplished on test specimen.

5.7.2.23 SAS Beam Fairing Deployment Using Pneumatic Washcloth Squeezer (MSTR 024)

- Problem/Anomaly - S/S beam fairing failure to deploy.
- Action - Demonstrate feasibility of deploying SAS beam fairing by means of pneumatically pressurizing a washcloth squeezer bag installed beneath the SAS beam fairing.
- Results - Test showed that the actuator damper could be broken free utilizing this method.

5.7.2.24 SAS Deployment Simulation Test Using the Washcloth Squeezer Bag (MSTR 024.1)

- Problem/Anomaly - SAS beam fairing failure to deploy.
- Action - Determine the ballooning effect of the external vacuum on the washcloth squeezer bag after it has been prepared for placement under the SAS.
- Results - Feasibility of this method of deployment was established.

5.7.2.25 Inflatable Heat Shield Test (MSTR 026)

- Problem/Anomaly - Develop design feasibility of a sunshade to protect the OWS from elevated temperatures.
- Action - Verify design approach of a pneumatically deployed shade by performing a series of tests.
- Result - Present design concept for the inflatable interior shield cannot be installed in a 1-G atmosphere, although it is possible that it might deploy in zero-G environment. Test results indicated the shield will not meet the structural requirements imposed by the environments anticipated during an orbital mission.

5.7.2.26 Recommendation for Vehicle Attitude for SAS Wing Deployment (MSTR 028)

- Problem/Anomaly - SAS beam fairing failure to deploy.
- Action - Verify actuator/damper extension time after a minimum period

of 4 hours (1.44×10^4 sec) at -40°F (233.12°K). Pitch 40-50° and hold for 4-1/2 hours (1.62×10^4 sec) fully extended after release in 605 seconds.

- o Results - Test was conducted. Actuator damper held at depressed position at -40°F (233.12°K) for four hours (1.44×10^4). Actuator damper was fully extended after release in 605 seconds.

5.7.2.27 Shoulder Deploy SAS with Fireman's Pole Tether (MSTR 029)

- o Problem/Anomaly - Failure of SAS to fully deploy.
- o Action - Conduct a series of tests and develop a technique where one crewman inserts fireman's pole tether into the SAS vent and acts as a support bracket for other crewman to pull tether and break actuator damper; thereby, releasing the SAS beam fairing.
- o Results - Technique did not develop into SL-2 crewmen capability to deploy SAS beam fairing; however, when the crewman substituted for the pole and moved from crouched to full standing position, the actuator damper clevis was easily fractured. (Note: This method was used to deploy the OWS wing.)

5.7.2.28 Squeezer Bag Temperature Susceptibility (MSTR 031)

- o Problem/Anomaly - SAS beam fairing failure to deploy.
- o Action - Conduct test on wash cloth squeezer bag at low temperatures to see if it was possible to deploy simulated SAS beam fairing load of 400 pounds (1779.2 N) and determine what pressure was required to accomplish a successful deployment.
- o Results - Test results were satisfactory with an average bag temperature of -57°F, (223.68°K) the squeezer bag fully deployed at approximately 6.0 psig (1.427×10^5 N/m^2).

5.7.2.29 Water Purification Elevated Temperature (MSTR 032)

- o Problem/Anomaly - Possible loss of iodine and starch in the purification equipment at elevated temperatures.
- o Action - Determine the effect of 200°F (366.45°K) on 30,000 ppm iodine solution and starch in the OWS purification equipment for a period of 24 hours (8.64×10^4 sec).

- Result - Testing indicated that the loss of iodine in the purification equipment at the temperatures existing in the OWS was not significant.

5.7.2.30 Meteoroid Trunnion Pull Test (MSTR 033)

- Problem/Anomaly - Loss of meteoroid shield.
- Action - Conduct a pull test on the trunnion strap taking measurements at the applied low levels in 250 lb (1112.0 N) increments, until failure was achieved.
- Result - Failure occured at 3,350 lbs (1.49×10^4 N). Failure mode was tear-out of the meteoroid shield skin between the two rows of rivets on the strap. Rivets on the trunnion strap were still intact. Conclusion also indicated that the trunnion straps met the design requirements.

5.7.2.31 SAS Beam Fairing Release Using the Squeezer Bag at Various Pressures (MSTR 034)

- Problem/Anomaly - SAS beam fairing failure to deploy.
- Action - Several tests were conducted between 5 psi (3.447×10^4 N/m^2) internal bag pressure and 20 psi (1.3788×10^5 N/m^2).
- Result - 20 psia pressure (1.3788×10^5 N/m^2) maximum because of beam fairing structural capability limitations. Energy imparted to the SAS beam by bag expansion will be dissipated by tether. Two tethers required: One long (40'), (12.192 m) one short (10') (3.048 m). Hands-off approach feasible.

5.7.2.32 SAS Actuator Damper Cold Deployment Tests and Analysis (MSTR 035)

- Problem/Anomaly - SAS beam fairing not deployed, and low temperature indicated on actuator damper.
- Action - Determine the response of the actuator damper at -50°F (227.57°K) when held in compressed position and then released.
- Result - Actuator damper held in compressed position at -50°F (227.57°K) for 2 hours (7.2×10^3 sec), then released. Time for extension 845 seconds. Same conditions, only for 5 hours (1.8×10^4 sec), time for extension 1125 seconds.

5.7.2.33 Abrasion Test of Fluorocarbon Rubber Shoe (MSTR 040)

- Problem/Anomaly - Extensive wear on the astronaut shoe at the toe.

- Action - Run an abrasion test using fluorocarbon rubber sheet of .060 in. (0.152 cm) thickness.
- Result - Tests were run with a STM 0564-0304 rubber sheet with no loss in thickness after 2,700 cycles. Houston had already tested Durette BW-P-586, using a 500 gram weight and a CS-17 wheel. Fabrication was penetrated in 1,345 cycles.

5.7.2.34 Auxiliary Tunnel Vent Measurement (MSTR 042)

- Problem/Anomaly - Resolve a discrepancy between MSFC measurements on STA tunnel vent in Backup measurement at MDAC-W.
- Action - Make measurements on the vent forward and side seals and compare what the results obtained at MSFC on the STA were.
- Result - Discrepancy probably due to MSFC using test part and MDAC-W using production part to make measurements.

5.7.2.35 Biocide Wipe Iodine/Thermal Temperature Degradation Test (MSTR 043)

- Problem/Anomaly - Possible depletion in biocide wipes on SL-1 due to elevated temperatures.
- Action - Make analysis of three biocide wipes received from Houston that were subjected to elevated temperatures for extended lengths of time.
- Result - Increase in iodine depletion rate was not considered to be very significant for several reasons: 1) JSC test temperatures were higher than the biocide wipe of SL-2 exposure, 2) An acceptable iodine concentration is 2,500 ppm.

5.7.2.36 Quick Disconnect (QD) Sealing Capability in a Vacuum (MSTR 044)

- Problem/Anomaly - Question was asked concerning condensate dump system. Is the pressure cap portion of P/N 1B79636-611 an adequate seal in a vacuum?
- Action - Measure leakage of the QD pressure cap.
- Results - Leakage rates considerably less than anticipated, therefore, problem did not exist.

5.7.2.37 Waste Management Compartment (WMC) Water Dispenser from SL-2 (MSTR 046)

- Problem/Anomaly - Clogging of the SL-2 WMC water dispenser.
- Action - Perform a failure analysis of the WMC water dispenser returned by the crewmen on SL-2.
- Results - The seal from this water dispenser proved to be made of Neoprene which is not compatible for use in the hot iodine water as it swells and reduces water flow. Material should have been Viton as specified on Change Letter "F". The Neoprene seals were removed from spare valves, and Viton seals were inspected and installed in two dispensers to be carried up on SL-3.

5.7.2.38 Meteoroid Shield Leading Edge Ballooning Test (MSTR 047)

- Problem/Anomaly - Investigation of the cause of a loss of meteoroid shield.
- Action - Conduct a wind tunnel test as noted on Test Line Item ST-41.
- Results - A total of 29 runs were completed (2 MACH numbers per run). Tests show that at 0 shield deflection (i.e., the meteoroid shield in contact with the tank wall), there is a net negative differential pressure on the shield. At shield deflections in excess of 0.1" (.254 cm), positive differential pressure occurs. This positive differential pressure would tend to lift the shield.

5.7.2.39 SAS De-Orbit Load Test (MSTR 049)

- Problem/Anomaly - No de-orbit loads have been derived by MSFC greater than previously tested under Line Item ST-40.
- Action - Prepare Mini TCD for Test Line Item ST-43 and conduct a test with a new de-orbit load, using Test Line Item SA-16 hardware to the new loads as furnished by MSFC.
- Results - The tests verified that the structural integrity of the SAS beam fairing and forward fairing could withstand the ultimate de-orbit loads without structural failure.

5.7.2.40 Refrigeration System (MSTR 048)

- Problem/Anomaly - Sudden change in ability of OWS Refrigeration System to maintain extreme cold conditions in freezer compartments.
- Action - Perform tests on components such as the radiator bypass valve and the pressure relief valve, and on the system as a whole, in the space chamber, using all components including freezers, and capable of simulating all orbital conditions except zero-G. Test objectives were to duplicate anomaly, to determine the cause, and to prove out recommended corrective actions.
- Result - The component tests indicated that the radiator bypass valve could give rise to the anomaly under conditions of partiuclate contamination or certain electrical control signals.

  In the systems tests, the anomaly could be duplicated by mechanical manipulation of the bypass valve to simulate the particulate contamination or the erroneous electrical control signals. From this base, test results verified some of the corrective action concepts, and provided operational limitation and capabilities data for the system while in the anomalous condition.

5.7.2.41 SL-2 Returned Biocide Wipes Test (MSTR 050)

- Problem/Anomaly - Concern still expressed about the degradation of the biocide contents to the wipes onboard the OWS.
- Action - Conduct a test and analysis similar to that of MSTR 043, utilizing biocide wipes removed from spacecraft and returned with SL-2.
- Result - Elevated SL-2 temperatures did not result in a detectable change in the depletion rate of available iodine in Skylab biocide wipes. Resupply of biocide wipes was not required for SL-3 or SL-4.

5.7.2.42 EREP Constraints - Refrigeration System HS-19-1 Testing (MSTR 051)

- Problem/Anomaly - Concern expressed on the impact to the frozen food temperatures based on spacecraft maneuvers.
- Action - Conduct test obtaining temperature plots of various spacecraft attitudes to gain constraints such that no degradation in performance of the refrigeration system would occur.
- Results - There was minimum impact to frozen food temperatures. Constraints were not expected on EREP maneuvers, assuming no more than two EREP's per day.

5.7.2.43 Radiator Bypass Valve Lockup Test (MSTR 052)

- Problem/Anomaly - Concern over the anomaly occurring in the spacecraft with the refrigeration system related to MSTR 048.
- Action - Conduct a test in the OWS Backup vehicle on the radiator bypass valve to verify that it could be locked in a bypass condition and allowed full operation.
- Result - It was possible to maintain the valve in a bypass mode, even though the controller was generating a radiator mode command.

5.7.2.44 Supplemental TACS Ball Valve Development Test (MSTR 053)

- Problem/Anomaly - Excessive use of TACS system during SL-2 maneuvers made it advisable to supplement the existing TACS system with a manually operated TACS system deployed through the SAL. (Reference Action Item No. 280.)
- Action - Determine feasibility of using existing designed ball valve for supplemental TACS system. Conduct a proof, leak, functional, life cycle and burst test on the ball valve from Test Line Item HS-26, reworked to a -501 valve configuration (stem seal facing pressure) and reidentify as test hardware for Line Item TC-16.

- Result - Hardware withstood all environments necessary to perform this function of a supplementary TACS system control valve satisfactorily. Present position is that it probably will not be flown because TACS usage has subsequently decreased.

5.7.2.45 Trash Airlock Leakage Test (MSTR 058)

- Problem/Anomaly - Leakage noted in trash airlock with the trash disposal valve assembly in intermediate position.
- Action - Run a test to: (1) measure valve leakage with valve handle in worstcase position; (2) establish range of valve handle positions between pressurize and vent where significant leakage (cabin to vacuum ports) occurs.
- Results - Procedure was established to alleviate further leakage of trash airlock for crew implementation. Leak rates vs. handle position were also determined.

5.7.2.46 Refrigeration System Dual Radiator Loop Operation Test (MSTR 060)

- Problem/Anomaly - Warmup of spacecraft Refrigeration Subsystem.
- Action - Demonstrate thermal performance improvement through dual radiator loop operation on HS-19, qualification test hardware.
- Results - Refrigeration System "dual loop" HS-19 test results indicated substantial improvement in system performance can be anticipated when the radiator bypass valve, bypass poppets, are in partially open positions with both refrigeration subsystem loops running. Increased radiator flow was the cause for the improved performance.

5.7.2.47 Cold Coolanol Test (MSTR 064)

- Problem/Anomaly - Resolve refrigeration system warm up.
- Action - 1) Evaluate the effect of extremely cold coolanol on pressure drop. While flowing coolanol and at starting flow of static conditions. 2) investigate effect of increased radiator delta P, due to cold coolanol, on relief valve crack and reseat.
- Result - The bypass valve and relief valve operated normally throughout the test.

5.7.2.48 OWS Refrigeration Subsystem Leak Analysis Verification (MSTR 068)

- Problem/Anomaly - RSS warm up anomaly.
- Action - Perform Refrigeration Subsystem HS-19-1 specimen testing to verify RSS analytical leak detection capability.
- Result - Review of HS-19 data provided sufficient information which obviated the requirement to run the test.

5.7.2.49 Pump Box Vent Test (MSTR 069)

- Problem/Anomaly - Determine if the RSS pump box can be pressurized from the OWS.
- Action - Determine if the "Swiss Army" knife could be used to cut 1/4" (.635 cm) tube to allow cabin pressure to pressurize the refrigeration pump box.
- Results - In two tests, both showed ready penetration of the stainless steel tubing wall.

5.7.2.50 SL-3 Coolant Transfer Hardware Test (MSTR 073)

- Problem/Anomaly - Leakage indicated in the AM thermal conditioning system.
- Action - Use HS-19 hardware to demonstrate how much "well bleed" or air-free coolanol can be transferred from one RSS loop of the OWS on SL-3 into the SL-3 portable water tank.

- Results - This method of coolanol transfer entirely feasible, but only a portion of loop content available in air-free condition.

5.7.2.51 Water Bottle Drying and Residual Determination Test (MSTR 074)

- Problem/Anomaly - Requirement to establish procedure to dry the water hoses to levels satisfactory for coolanol transfer.
- Action - Conduct tests to determine: 1) potential particulate contamination level in OWS #1 hardware; 2) level of drying that can be obtained using proposed vacuum technique; 3) time to accomplish training and drying using .02 psia (137.88 N/m^2) as a goal for residual iodine level; 4) residuals from condensate fluid; 5) vacuum level vs. time after drying.
- Results - Tests were completed, documented, and considered satisfactory to resolve the problem.

5.7.2.52 Coolanol/Silicone Compatibility Test (MSTR 075)

- Problem/Anomaly - Coolanol transfer capability from OWS refrigeration coolanol loop to portable water bottle in order to service the AM thermal conditioning system.
- Action - Determine the compatibility of coolanol with silicone seals present in the condensate hose couplings and portable water tank plug valve.
- Result - Deterioration of silicone seals occurred after 57 hours exposure to coolanol.

5.7.2.53 Valve Life Cycle with Coolant (MSTR 077)

- Problem/Anomaly - Will the valve meet the life cycle testing with new seals and torque limits within the leakage requirements after life cycling?
- Action - Perform a pressure leakage torque measurement in life cycle test on the outlet plug valve of the portable water tank. Tests will be initially GN_2 and then coolanol.

- Result - Seal life under exposure to coolanol is still considered time critical. No leakage or apparent wear to the valves and packing were encountered.

5.7.2.54 SL-3 AM Coolanol Servicing Procedure Revisions (MSTR 079)

- Problem/Anomaly - Determine that the RSS pump filter can be removed and that MC160C4 union, with 3165-1-0424, can be installed without having a clearance notch cut in the support block.
- Action - Conduct tests to see if this fit check is possible with no interference in the support.
- Result - A required filling was .020" (.0508 cm) at 45° from the fiberglass support edge for worst case tolerance conditions.

5.7.2.55 Additional Heat Sink for Refrigeration System (MSTR 084)

- Problem/Anomaly - Refrigeration anomaly was discovered on the SL-1 mission.
- Action - Determine the wardroom thermal response to ambient temperature (70°F) (294.23°K) water-filled urine bags placed in Compartment No. 2, which is controlled to flight operational temperatures.
- Result - The use of water-filled urine chiller bags will not significantly increase refrigeration system troubleshooting time (less than 5 minutes) (300 sec).

5.7.2.56 Skylab TACS Valve Thermal Tests (MSTR 085 R1)

- Problem/Anomaly - It is possible the OWS TACS valves may be exposed to temperatures approaching 200°F (366.45°K). Previous testing was only accomplished up to 165°F (347.0°K). In order to anticipate possible degradation under these environments, testing was requested.
- Action - Conduct tests at elevated temperatures to determine external leakage, response time and internal leakage at various pressures.
- Results - The TACS valves passed all test environments. No problems were encountered.

5.7.2.57 Urine Separator Suction Line Washer Replacement and Test (MSTR 088)

- Problem/Anomaly - SL-3 crew reported one washer had debonded and fallen off separator line.
- Action - Redesign washers and test in life cycle sufficient to provide confidence that the washer will sustain the duration of the mission.
- Results - Test was conducted in Space Systems Laboratory and results were considered satisfactory.

5.7.2.58 Vibration Effects of Cycling Radiator Bypass Valve (MSTR 090)

- Problem/Anomaly - Concern expressed that cycling of secondary loop bypass valve might cause sufficient vibration transfer to the primary loop bypass valve to cause valve poppet movement.
- Action - Conduct a vibration test at levels experienced during bypass valve actuation to determine the level required to unseat the valve.
- Results - It was concluded the bypass circuit of the unactuated valve will remain in contact with the seat when the other valve is actuated.

5.7.2.59 Bypass Valve Controller Test (MSTR 091)

- Problem/Anomaly - Bypass valve lock-up/unlock capability not good during power on/power off at low temperature levels in the thermal capacitors. This could create a problem in the refrigeration system performance.
- Action - Perform a limited PAT on the bypass valve controller to obtain refrigeration system operating data point support of OWS.
- Results - Confirmed requirement to raise thermal capacitor temperature to 32.8°F (273.57°K) or higher to command radiator mode by power off-on cycl

5.7.2.60 Non-Propulsive Vent System Torque Test (MSTR 092)

- Problem/Anomaly - Perform fit check of hoses required to connect the LBNP checkout vacuum "tee" to the urine dump probe fitting on the waste tank bulkhead. Also, determine "B" nut torque requirements.

- Action - Use OWS Backup hardware to perform fit check. Make laboratory setup to determine torque vs. leakage.
- Results - Fit check test was performed with satisfaction. Torque value for LBNP "B" nut was established at 200 ±25 in. lbs (2259.6 N·cm).

5.7.2.61 M092 Hose Collapse Test (MSTR 094)

- Problem/Anomaly - Loss of meteoroid shield LBNP vent caused overboard to be propulsive. A new installation utilizing onboard hoses will be used to vent the LBNP experiment to waste tank; thereby, eliminating propulsive vent condition.
- Action - Run test on Hose, P/N 1B83881 (.41 ID), at approximately 5 psid (3.44×10^5 N/m^2) and demonstrate that no collapsing of the inner liner occurs.
- Results - The hose was subjected to differential pressures of 5, 10, and 14.7 psid (3.447×10^4, 6.894×10^4, and 1.013×10^5 N/m^2) and no collapsing of the inner liner was detected. A 0.34" (.864 cm) diameter ball was used to detect if collapsing of the hose occurred. A vacuum pressure of 2mmH mercury was maintained within the hose for 2-1/2 hours, (9.0×10^3 sec) without detrimental effect. Note: 0.344" (.8738 cm) diameter ball is maximum size that will pass through .350 (.889 cm) ID of hose

5.7.2.62 M092 NPV System Flow Test (MSTR 092 R2)

- Problem/Anomaly - Loss of meteoroid shield caus LBNP vent overboard to be propulsive. A new installation utilizing onboard hoses to be developed to vent the LBNP experiment to waste tank; thereby, eliminating propulsive vent condition.
- Action - Run four flow tests of the LBNP non-propulsive vent system. MSTR 095 R1 authorized removal of 1B83881-507 hose from Backup vehicle for this test. R2 revision initiated to authorize removal of QD's on the system flex hoses, the installation of unions between each flex hose, and the repeat of the flow test per MSTR R1 change.

- o Results - At the specified flowrate of 0.13 lb/min. (9.83 kgm/sec) of air, the back pressure at the LBNP interface was 2.70 psia, (1.86×10^4 N/m^2) using unions vs. 3.28 psia (2.261×10^4 N/m^2) with QD's.

5.7.2.63 Heat Pipe Test (MSTR 098)

- o Purpose - Obtain heat transfer coefficient data for 1/2" (1.27 cm) square bar immersed in water to support a potential SL-4 heat pipe experiment.
- o Action - Conduct a test of an instrumented 1/2" (1.27 cm) square aluminum bar one-foot (30.48 cm) long immersed in water on one end (thermo-couples on both ends). Record temperature histories on an X-Y plotter.
- o Results - The heat transfer coefficients obtained during water agitation ranged from 160 to 500 BTU/Ft^2 - HR °F (907.78 to 283.8 watt/m^2/K) with no dependence on $T_{water} - T_{bar}$. There was no noticeable difference in heating or cooling.

5.7.2.64 Methods for Compressing Frozen Urine Samples (MSTR 106)

- o Problem/Anomaly - Stowing urine in return container presented problem to crew.
- o Action - Fresh urine was frozen in the laboratory and installed in the return container. Protrusion above lip was about 3/32, of an inch (.238 cm) above tray lip. Height was reduced by tapping/pounding with flight type hammer and a blood sample spacer with varying degrees of force.
- o Results - The recommendation was to use loose end of blood spacer in pounding as a technique to prevent leaks. Do not use flat side of spacer or hammer only.

SECTION 6 - ENGINEERING PROGRAM MANAGEMENT

6.1 PLANNING AND SCHEDULING

The management of technical resources, to plan and control the engineering tasks on the Orbital Workshop Program, was basically oriented to two major activities:

- o Design and development pre-CDR
- o Design changes post-CDR

6.1.1 Design and Development - In the evolution from the Wet Workshop to the Dry Workshop, an OWS Development Engineering Work Statement was utilized to depict the technical requirements/configuration as ultimately reflected in the CEI Specification, CP2080J1C, dated 26 November 1969. At that point in time, definition of design was very fluid, many technical discussions/meetings between MDAC and MSFC resulted in definition and/or re-definition affecting other organizations. This led to various organizations working to different requirements and/or configurations. In order to provide singular technical work definition, Engineering Management directed that the baseline work statement could only be amended by issuance of Development Engineering Plans (DEP) as shown in Figure 6.1.1-1.

Another form of management directive to control design criteria was the establishment of OWS Design Memorandums. They depicted design philosophy, design loads and factors, materials selection, etc. These memoranda were the medium by which the technical community was unified in the design approach to the OWS.

Engineering management established the means to monitor all technical work effort in requiring an Engineering Work Order (EWO) number on every job The EWO required the signature of the Project Engineer for approval. Every design job had a Job Drawing List (JDL) assigned to the EWO and every released drawing required the signature of the Project Engineer on the Engineering Order (EO) prior to release. Through these means the design job was defined, and statused against that

M E M O R A N D U M

Date: Oct 08, 1969
A3-250-KK00-M-095

To: All H. B. Development Engineering Orbital Workshop Supervision

From: A. P. O'Neal, A3-250 (Ext. 2458)

Subject: ORBITAL WORKSHOP CONFIGURATION DEFINITION

Copies to: L. F. Starlof, A3-126; H. E. Bauer, M. C. Button, G. V. Butler, R. C. Dineen, G. F. Hanson, S. Yarchin, A3-850; File

The purpose of this memorandum is to clarify the authority to which the H. B. Development Engineering Department is to adhere for the configuration of the Saturn V Workshop. There has been much confusion as to system description emanating from many sources; viz, Orbital Workshop Development Engineering Work Statement, Integrated Work Statement, Contract End Item (CEI) Specification, System Engineering study results, Customer contacts, meetings, rumors, etc.

The H. B. Development Engineering Department shall work to the Orbital Workshop Development Engineering Work Statement, dated August 11, 1969, as a baseline and the Development Engineering Work Statement shall only be amended by H. B. Development Engineering Plans (DEP's). These are the sole definition documents that the design technologies are to follow. Due to the current backlog of revisions to the Development Engineering Work Statement, DEP issuance may lag in an untimely fashion. To fill that gap, Records of Discussions (ROD's) resulting in changes to the Development Engineering Work Statement shall be issued and distributed to the appropriately affected groups. In order to authenticate these changes to the Development Engineering Work Statement, the ROD's shall carry advance DEP numbers.

Responsibility for the Development Engineering Work Statement and the DEP's remains in the Project Office. In addition, the Project Office has the responsibility to represent the H. B. Development Engineering Department in achieving compatibility among the Development Engineering Work Statement, the Integrated Work Statement, and the CEI Specification. In achieving this, the Project Office will need the support of all other engineering agencies to bring to its attention incompatibilities in any of these documents. Detail changes not affecting the Development Engineering Work Statement are not within the scope of this memorandum.

In summary, the Development Engineering Work Statement, supplemented by DEP's and ROD's carrying the DEP numbers, is the sole document depicting system changes. Your compliance is required to minimize confusion and to implement our Work Plan.

A. P. O'Neal
H. B. Development Engineering Director
Saturn/Apollo & Apollo Applications Programs

APO:WBS:md

Figure 6.1.1-1

definition and against the design completion schedule.

These management techniques provided the program with an effective communication system so that all of the engineering departments were kept "up to date" during the design development phase. This assured all personnel working to the same ground rules and the same configuration of the various OWS subsystems. It also provided visibility of drawing schedules so corrective action could be implemented as required.

6.1.2 Design Changes - Internal Design Reviews (IDR) and the Preliminary Design Review (PDR) led to a baseline configuration, as established with completion of the Critical Design Review (CDR), consisting of the basic contract plus approved Engineering Change Proposals (ECP). Thereafter, all design changes were reviewed for approval and program impact. Class I changes resulted in ECP submittal to the Customer, other changes that caused significant internal effects were presented to the CCB for authorization approval. All implementing drawing changes, Engineering Orders (EO), were submitted to the resident NASA Office for information and concurrence with Class II classification. Tracing a hardware change from MDAC initiation to installation illustrates the technical management system utilized after CDR.

A. Upon discovering a problem, the designer prepared a description and justification of the proposed change on MDAC Form 850-60, "Skylab-OWS Change Request" (CR), as shown in Figure 6.1.2-1. The designer and the Engineering Scheduler planned the design and drawing work arriving at a proposed drawing release date.

B. The designer presented the CR at a daily meeting, chaired by the Project Engineer and attended by representatives affected in implementing the change. The CR was completed for submittal to the Program Manager, Chief Engineer, and Operations Manager for their approval. Those CR's for which approval was not recommended were also reviewed for their concurrence. The approved CR's constituted a commitment of all departments to the Work Plan and Schedule developed during these sessions.

1 ECP/PCP NO.

2 MODEL NO.

SKYLAB-OWS CHANGE REQUEST

REV

DATE:

3 FEC NO.

4 CEI NOMENCLATURE

5 CONTRACT SPECIFICATION(S) AFFECTED

6 TITLE OF CHANGE

7 RECOMMENDED CHANGE PROPOSAL PRIORITY ( ) EMERGENCY ( ) URGENT ( ) ROUTINE ( ) COMPATIBILITY

8 DESCRIPTION OF CHANGE (ATTACH SKETCH & JDL)

9 JUSTIFICATION

10 AFFECTS:

YES	NO		YES	NO	
( )	( )	ELECTRONICS	( )	( )	OWS CONTROL DWG 1B77075
( )	( )	LOGISTICS	( )	( )	IP&CL
( )	( )	MECHANICAL/CREW	( )	( )	P0327 FORM
( )	( )	PROPULSION	( )	( )	AGE CONTROL SIGNIFICANT ITEMS
( )	( )	STRUCTURES	( )	( )	STOWAGE, RCN, NCN
( )	( )	TIME CYCLE SIGNIFICANT ITEMS	( )	( )	KSC TEST & CHECKOUT PROCEDURES (TCB)
( )	( )	ENGG CRITICAL COMPONENT LIST IN CEI	( )	( )	FIT CHECK MATRIX
( )	( )	MISSION CRITICAL ITEM ON DWG 1B75304	( )	( )	KSC TCRSC
( )	( )	TEST AND ASSESSMENT DOCUMENT	( )	( )	QUAL TEST (IF YES, INDICATE
( )	( )	INTERFACE CONTROL DWGS (ICD)	( )	( )	CTCA NO._____ & LINE ITEM NO._____
			( )	( )	PRODUCTION TEST

11 SERIAL NUMBER EFFECTIVITY AND LOCATION (IDENTIFY GSE TO LOCATIONS)

12 MOD INSTRUCTION REQD

( ) YES ( ) NO

13 RETEST REQUIRED

( ) YES ( ) NO

14 RECOMMENDED CHANGE PERIOD – FTC DESIGNATION ( )

2A (2A) _____ 4 (4, 5) _____ 7 (11) _____

2B (2B) _____ 5 (6, 7, 8) _____ OTHER _____

3 (3) _____ 6 (9, 10) _____

15 SCHEDULE PARTS AVAILABLE

OVERTIME REQUIRED

ENG – OPS –

16 ORIGINATOR:

NAME

EXT DATE

BRANCH CHIEF/DESIGN ENG

CONCURRENCE

COMMENT:

OPERATIONS MANAGER – OWS

COMMENT:

CHIEF ENGINEER – OWS

18 ACTION/DISPOSITION

APPROVED	( ) YES	( ) NO
IN SCOPE	( ) YES	( ) NO
IMPLEMENT BY WRO	( ) YES	( ) NO
PREP ECP/PCP	( ) YES	( ) NO

COMMENT:

PROGRAM MANAGER – OWS DATE

FIGURE 6.1.2-1

FORM 860-60 (OCT 72)

C. As the design progressed, the Engineering Scheduler was responsible to alert Engineering Management of any jeopardies to the Work Plan. Correcting action was then taken. In the event the Work Plan was about to be violated, the CR was revised and resubmitted for review and approval.

D. Every EO was required to have an identifier noting the approval of a CR and a verifying signature of the Project Engineer.

E. The drawing number and change letter was posted in the manufacturing area and status reported daily. Engineering representatives attended these meetings to assure prompt responses when technical activity was desired. During the period when the OWS No. 1 was in final assembly, Engineering Management also attended these meetings to monitor technical modes of operation and to develop methods to further foreshorten response times when required to solve hardware problems. Management was applied in implementing methods to reduce time to process paper accompanying the hardware while assuring judicious adherence to proper activity and documentation. These activities occurred in all areas of fabrication, assembly and installation. Some examples of management "English" are:

1/ The normal system to obtain technical assistance in clarifying or requesting a design change of a released drawing is for the requestor to prepare a Process Action Request (PAR). Normally prepared in the manufacturing area, the PAR book is posted at a specific location. This is visited a few times a day, or on demand, by a Liaison Engineer, who logs it and sends it to the appropriate technical organization via the Engineering Schedules Group for disposition. The designer answers the PAR and sends it back to the originator, essentially, via the same route. The lapsed time may be five days while the hardware is put aside awaiting some resolution.

In early 1971 the OWS Program Manager recognized that "normal activities" could not meet program needs and as a result identified sixteen "OWS Action Teams." One of these, "War Board, Shortage Management, and Tooling" assigned the Chief Project Engineer as the engineering team member. The team established their headquarters in the fabrication area at the Santa Monica plan, available to PAR requestors. The Engineering representative then handled the PAR "on the spot" thereby minimizing hardware delay. This was accomplished by a phone call to the designer to obtain immediate attention and answers, or concurrence, to solve the problem. If a drawing change was required, the PAR was dispositioned to provide the answer and identify the drawing change letter to be issued. The EO was expedited and hand-carried to the fabrication area. This allowed the continuation of fabrication while the EO was enroute for proper documentation of the fabrication and inspection.

In the installation area at Huntington Beach, in late 1971, the same problem of normal routing of PAR's was slowing the operation. Since it was an installation problem, the part obviously was past the fabrication process, hence, there was little or no drawing change activity - which allowed a more direct solution. Here the engineering representative on the Action Team, with appropriate coordination with other organizations, directed that the PAR be replaced with the EO. When the problem was written the resolution was to be prepared by engineering on the same piece of paper and, when possible, within minutes of each other. This was called the Engineering Change Request (ECR), and was released to the shop immediately and processed later for finalizing through normal EO channels.

2/ In the electronic module fabrication area we were faced with delays when a problem and its solution, resulting in a drawing change, occurred after the first shift working hours (nights or week-ends). Although the operations and technical people were present, the personnel who perform the functions that process EO's from the technology to the shop were not. This involved Check, Weights, Stress, Schedules, Project, Release within Engineering, also, Reproduction and Change Control. Since the personnel who perform these functions were not present, the fabrication process, with many interim inspection points, would normally await their presence to process the EO. The program could ill affort such delays, however, it was not practical to institute a three shift, seven day shift of these functions. The Action Team Engineering Representative, by proper coordination with appropriate organizations, authorized the engineers on the floor to release the EO's, marking them "SSNA" (Standard System Not Available). These EO's were processed later through normal channels to maintain proper documentation.

3/ When Procurement received a request from the supplier for a change in technical requirements it was via a Supplier Information Request (SIR). The normal routing was similar to that of the PAR noted earlier. With creation of the OWS Action Team, the Procurement representative would ask the Engineering representative for "on the spot" answers. This was accomplished again by a call from the Chief Project Engineer to the designer for immediate attention and solution. This was then written on the SIR and, rather than route through for signatures, the coordinated designers name was noted and signed by the Action Team Engineering representative. Similarly, Material Substitution Forms were processed. Many days were thus saved.

4/ It was normal procedure upon receiving a non-conforming shipment in Receiving Inspection to return it to the supplier for reconciliation. In order to protect the program schedule the Procurement and Engineering representatives of the Action Team initiated a twice daily review of the packages to be returned to the supplier. A significant magnitude of return shipments were stopped or split to retain the hardware in plant to allow faster supply to the using department. Some involved rework, and the supplier was brought to the hardware rather than vise versa. Some were cosmetic rather than functional non-conformances, wherein, the parts could be accepted for use. In those cases when technical requirements were not met, the requirements were reviewed for practicality and/or effect. This activity saved many delays in supplying parts to the using department.

The management system used to evaluate, plan and schedule design changes proved very effective in absorbing the many design changes so necessary in the development of a complex space system. It provided the contractor and Customer management early visibility of impending program changes which was the initial key to successful change management.

Formation of the "OWS Action Teams" provided technical management in the hardware problem area as it occurred and was very effective in minimizing delays.

6.1.3 <u>Recommendations for Future Programs</u> - The OWS Program was not necessarily unique but changes from the "wet" to "dry" concept created some special problems of schedule and cost control. It was recognized that the established and documented operating policies would not likely provide the quick reactions, rapid communications, and on-the-spot decision-making needed. Therefore, new techniques of management were developed to proceed and additional new inovations were developed plus some old techniques previously used under similar conditions were applied. Most of the techniques described could be used on any program. It must be realized that such uses would require retraining the people being assigned, since the high percentage of technical people would not normally be familiar with these procedures. The recommendation would be to use these procedures again if conditions were similar to those that existed on OWS.

6.2 CONFIGURATION MANAGEMENT

The requirement for implementation of Configuration Management (CM) disciplines was included in the initial Workshop contract as part of the Schedule II work statement. DAC 56689 was designated as the initial Configuration Management Plan and was to be the repository for the contractually imposed CM requirements and procedures applicable to the Saturn I (Wet) Workshop. This CM plan was updated as DAC 56689A to convert from Saturn I (Wet) Workshop to Orbital Workshop (Dry) requirements per direction of Supplemental Agreement #2 to contract NAS9-6555. The 23 January 1970 issue of DAC 56689A was designated by NAS9-6555 Supplemental Agreement 84 as the applicable CM document for the Orbital Workshop program.

6.2.1 Configuration Identification

6.2.1.1 Specifications - The OWS Contract End Item Specification (CEIS), CP2080J1C, was designated as the document to contain the OWS design and performance baseline requirements. The CEIS was revised by MDAC and NASA approved Specification Change Notices (SCN) when needed to remain current with the contract design and performance requirements. The OWS Ground Support Equipment (GSE) requirements were maintained in DAC 56692A, Ground Support Equipment Model Specification. This document was also maintained current by SCN's processed through MDAC to NASA for approval. These two documents reflected the total contractual design/performance requirements baseline for the OWS Program and were conscientiously maintained current. For this reason they were extremely useful throughout the program, including at the board design engineer level.

Changes to the CEIS and the GSE Model Specification were identified to the authority for the change by SCN vs authority logs maintained in the document and by anotating each changed paragraph with the SCN number. This provided the information needed to allow ensuing engineering document changes to be identified to the applicable change identity.

6.2.1.2 Interface Control Drawings (ICD) - ICD's were included by reference as requirements in the CEIS, but were maintained separately on drawing format. The ICD's were prepared by contractors designated by NASA, were coordinated with the affected associate contractors, were issued by NASA, and subsequently were placed on the appropriate contractor contracts. The total listing of the applicable ICD's was maintained in MSFC document CM-023-003-2H, Skylab OWS Interface Control Documentation Contractual Index and Status Report, which was listed in the CEIS.

There were two levels of ICD's used on the OWS Program. Those which affected only one NASA center and contractors for which that one NASA center was responsible were called Level B ICD's; and those ICD's which affected more than one NASA center or their contractors were called Level A ICD's.

MDAC was designated by NASA as the responsible contractor for ICD's reflecting OWS to Experiment interface requirements. This was a sizeable task which resulted in MDAC preparation, coordination and maintenance of 70 ICD's (50 Level A and 20 Level B).

In addition to those prepared by MDAC, there were 46 additional applicable ICD's which represent requirements upon the OWS design. MDAC's task related to these ICD's was to review, accept, or propose changes, and when placed on contract, to control the OWS design thereto. This same task of review, acceptance, and control also was required of MDAC for the 70 ICD's prepared by MDAC.

Once it was established that an interface existed that would be documented on an ICD, a specific design technology organization was assigned the responsibility for that particular interface. This responsibility, in addition to the design aspect included:

- o Establishment of a single contact for coordination with each affected associate contractor and NASA,

- The marking of each affected design drawing to identify that it could not be changed without prior approval via the ICD change system,
- Establishment of central records regarding all interface transactions,
- Responsibility for initiation of designs to comply with the interface requirements,
- Responsibility for initiation of changes to the ICD to keep it current or to insure proper functioning of the interfacing hardware,
- Responsibility for assessment of all changes proposed by NASA or an associate contractor relative to that interface,
- Responsibility for coordination of that set of interface requirements with all other MDAC agencies affected.
- Responsibility for keeping management appraised of the status of the compatibility of that interface design.

Each ICD change carried the identity of the change authority on the Interface Revision Notice (IRN) which described the change. This change authority identity was carried down through the engineering documents which were subsequently revised to reflect the ICD changes.

6.2.1.3 Design Drawings - The OWS and GSE design drawings were required to and did comply with MIL-D-70327, Class II, in format and content. Strict rules governing part numbering were observed and the designs, when released for manufacturing/test were identified to the approved design requirement baseline established by the CEIS and/or the GSE Model Specification.

The release records were centrally maintained in the engineering release group and the release file for each drawing contained the information required to determine the total released engineering requirements. Likewise, the release records contained the information necessary to be able to determine the total design configuration of the OWS and of the GSE at any point in time in the program.

6.2.1.4 Design Reviews - Once the design requirement baseline was established, design reviews were planned and performed to assure that the design baseline was established which conformed with the requirements. There were reviews conducted internally by MDAC and reviews conducted by NASA. The latter were required by the CM plan:

- o To resolve design baseline requirements,
- o For acceptance of design concepts, analysis, and preliminary design,
- o For authorization to proceed with final design,
- o For approval of final design baseline.

The NASA reviews were conducted in two phases. The Preliminary Design Review (PDR) was required prior to proceeding with the final design, and the Critical Design Review (CDR) was required to obtain NASA approval of the final design.

The PDR was initially held in May 1967 and was completed in a delta PDR in December 1967; however, both of these reviews related to the Saturn I Workshop (Wet) configuration. The CDR (OWS dry configuration) was held in September 1970 and thereafter MDAC was authorized to proceed with completion and closeout of NASA assigned Review Item Discrepancies (RID) and to release the approved baseline design for production. Both of these reviews were major milestones in the OWS development cycle and each system was reviewed in-depth for all affected NASA centers and associate contractor personnel.

Separate PDR's and CDR's were conducted by MDAC of the major subcontractor developed portions of the OWS; namely, the Solar Arrays and the Waste Management hardware. NASA participated in these and closely monitored both the reviews and the RID closeout activities.

To assure compliance with the baseline requirements, MDAC conducted internal company reviews of each OWS system and subsystem, and redirected the design as needed, prior to presentation to NASA at the CDR. NASA attendance was invited at these sessions to aid in communication of progress status and system details between the various technical organizations.

6.2.2 Configuration Control

6.2.2.1 Configuration Control Board (CCB) - The MDAC OWS CCB was chartered as a senior management committee to direct MDAC response to contract directives and to implement and control appropriate action relative to OWS baseline changes generated within MDAC. The CCB was established early in the program (July, 1970) at a time, prior to the OWS CDR, when formal change traffic was just beginning to become a factor that required management attention and control.

The CCB was chaired by the OWS Program Manager and the Directors of the functional organizations were members. The board convened regularly each week on a schedule tailored to the change traffic. The early sessions were less frequent than later when the change traffic increased to a level such that it was necessary for the CCB to convene each workday.

The CCB was supported by an internal MDAC change analysis board (CAB). This team, consisting of representatives from each OWS department, performed the staff work, for each directed or proposed change, such as establishing the description, cost, schedule, impact, recommended actions, and associated documentation. The CAB relieved the CCB members of this preparatory staff effort and provided them with firm, factual information upon which to base their decisions. This arrangement was significantly beneficial in that it improved the timeliness of CCB decisions as well as assuring that they were founded on facts.

The CCB operated to strict guidelines relative to proposed changes and approved only:

A. Necessary changes resulting from:

- o A change in NASA requirements
- o A design deficiency necessitating a "Make-it-work" change

B. Cost saving changes resulting in:

- o Significantly reduced recurring cost in design, manufacturing, or test, without unacceptable effect on schedule

C. Desirable changes resulting in:

- o Significant increase in reliability, system safety or schedule accomplishment.

The CCB activities provided the top management control needed in the OWS activities. The timely decisions of this management team kept the OWS design change traffic from becoming excessive and costly to the point where it would have jeopardized the aims of the program.

It is important to note that the CCB decisions were the responsibility of the chairman. The members made recommendations and gave advice to him, but they did not decide the final issues by vote. This method placed the final control with the program manager and the decisions were thus made with consistency and with full benefit of his total OWS experience.

6.2.2.2 Engineering Change Control - The OWS Configuration Management Plan required any Class I change to be proposed to NASA via an Engineering Change Proposal (ECP) for approval prior to implementation. A Class I change was defined as - Any proposed engineering change to NASA accepted or unaccepted prime equipment end items (flight hardware and launch critical GSE) which affected one or more of the following documents or caused a listed action:

- o CEI Specification

- Interface Control Documents
- KSC portion of Orbital Workshop Test and Checkout Requirements Specification and Criteria Document (1B83429)
- Orbital Workshop portion of the Saturn Workshop Power Allocation Document (40M35631)
- OWS portion (I-SL-008) of the Skylab Stowage List
- OWS Stowage Capability Document (1B85808)
- OWS Alignment Control Drawing (10M03934)
- OWS Operational Nomenclature Document (MDC G0387)
- OWS Snaps/Velcro Restraints Document (MDC G2439)
- Government Furnished Property
- Camera and Photolight Locations Drawing (1B94616)
- Retrofit at KSC
- A change in required requalification testing
- A change of vendors of mission/safety critical components
- A change to contract price or fee, contract guarantee, contract delivery or test schedules
- A change in electrical interference to communications or to electronic equipment, or a change in electromagnetic radiation hazards
- A change in materials which come into contact with urine
- Instrumentation Program and Component List (1B68467) additions, deletions or changes to measurement number, name range or channelization therein

All other changes were designated as Class II type; i.e., those required to correct errors or to correct the designs to be able to meet the baseline requirements without affecting the items listed in the Class I definition. These did not require formal NASA approval, but did require the NASA Resident Manager Office concurrence with their classification. MDAC submitted copies of all Class II drawing change Engineering Orders (EO) to the resident NASA office to fulfill this requirement. There were virtually no mis-classified EO's which MDAC was required to change to Class I type.

A. ECP Initiation - The requirement that stipulated the need for approved ECP's prior to implementation of Class I changes was one of the prime controls imposed on the OWS engineering department by the CM plan and by the program/engineering management. Consequently, there was a particular emphasis throughout engineering to assure compliance.

Once a design has been prepared and reviewed/approved/released, each proposed change to that design was screened by design technology and engineering project management for proper change classification (I or II) and for need. Once the need for the change was established, the Class II type change was completed and released and the Class I type change was held while an ECP was initiated to gain the approval to implement that change.

The OWS, being designed to accommodate a large quantity of parallel developing experiments and to mate with and operate compatibly with an equally large quantity of parallel developing multidisciplined crew support systems, spawned an exceedingly large quantity of proposed changes. Class I changes were approved as part of the CWS CDR baseline and thereafter an average of 72 Class I changes were processed each month until the initial Skylab launch (8/1/70 through 5/30/73).

The quantity listed above is only of changes approved by the MDAC CCB, and indicates the high degree of compliance of MDAC with the CM Class I change ECP requirements.

The total number of changes processed per month by MDAC was much higher when Class II and disapproved changes are considered.

B. ECP/PCP Preparation/Processing - Each change, approved by the MDAC CCB for preparation and processing to NASA utilizing the long form change format, was required, by the CM plan, to include the following specific data and information:

- o Description of effect of the change on prime equipment
- o Description of effect of the change on non-prime equipment
- o Description of effect of the change on other OWS program elements such as the test program, GSE, High Fidelity Mockup, Neutral Buoyancy Hardware, One-G Trainer, Crew Systems Engineering Laboratory, and Dynamic Test Article
- o Effect on MDAC contractual software
- o Effect on designated NASA software
- o Cost of implementation
- o Schedule for implementation - including retrofit at KSC
- o Contractor recommendations related to approval

To eliminate unneeded effort and to speed the flow of information and approval, certain types of changes were allowed to be identified within "family" change numbers. Some of these family series changes were then allowed to be prepared and processed to NASA utilizing a special short form format containing only certain specified data pertinent to that family of changes. The change families established were:

	Family No.	Type	Format
o	ECP W003-X	OWS Compatibility change	Short Form
o	ECP W004-X	OWS Compatibility change - that affects the stowage system only.	Short Form
o	ECP W005-X	Document only change to OWS CEIS	Short Form

o	ECP W006-X	OWS stowage system only change that affects NASA document I-SL-008.	Short Form
o	ECP W007-X	Change proposed to NASA that is on OWS contract.	Long Form
o	ECP W008-X	Change to OWS on-orbit Snaps and Restraints	Long Form
o	ECP W009-X	Change to OWS operational nomenclature.	Long Form
o	ECP WXXX	Change to OWS prime equipment.	Long Form
o	PCP WXXXX	Change to OWS equipment/ program that does not affect prime equipment.	Long Form

Every effort was made to provide the required data with each ECP processed to NASA. Many times, however, the required technical decisions were not available from associate contractors (actual dimensions needed to reflect ICD changes, for example) or from MDAC design technologies (factual power requirements, for example) because the design required to obtain these facts may not have proceeded that far.

To hold ECP's until such data was available would have caused significant, undesirable delay in change approval. Therefore, as an expedient, many ECP's were processed lacking some of the desired knowledge. This did necessitate additional change board activities to process the ECP revisions that updated previous submittals to include the omitted information.

Several methods were used to fill the information gap for NASA.

when this type of ECP was reviewed by their change board:

1/ The MDAC on-site engineering group at MSFC furnished representatives to the MSFC CCCB and was able to hand carry data and information, as it became available after initial ECP submittal, to cognizant MSFC personnel to supplement the ECP.

2/ During the MSFC CCCB meeting, wherein ECP's were being discussed and dispositioned, an MDAC management support team was in attendance via telephone conference hookup. This MDAC team was able to answer CCCB member questions and supply latest knowledge on information regarding any area of the ECP. This included not only information that may have been omitted completely, but amplification or explanation of information presented within the ECP.

These support efforts were very effective, particularly during the peak ECP traffic periods as OWS designs were jelling.

C. Drawing Change Control - The configuration of the OWS approved at the CDR consisted of a design which conformed with the 26 November 1970 CEIS requirements as modified by the approved ECP's listed in Table 6.2.2.2-1. Once this design baseline had been established, OWS engineering imposed a hard and fast rule that restricted all drawings from being revised unless because of an approved Class II or Class I change. The OWS Engineering Integration Office was the approval agency for Class II changes while the MDAC CCB gave ECP submittal approval and the NASA CCCB gave implementing approval for Class I changes.

All drawing changes after the CDR were identified to the approved ECP causing the change and upon release separate lists, of the drawings affected by each change, were maintained.

The release records of each drawing contained each approved ECP number, obtained from the drawing releasing paper (Engineering Order - EO) on a real time basis. The release records were

CDR APPROVED DESIGN BASELINE

CP2080J1C, dated 24 July 1970 as modified by the following listed ECP'S:

W020 R1
W023 R1
W024 R1
W030 R1
W033 R1
W034 R1
W035 R1
W036 R1
W041 R1
W043 R1
W048 R1
W052 R1
W054 R1
W061
W069 R1
W070 R1
W082 R2
W084 R1
W085 R1

W087 R1
W091
W092 R1
W093
W096 R1
W097
W099
W100
W101 R2
W105 R1
W110 R1
W111 R1
W116
W119 R1
W122
W127 R1
W129
W144
W145

W146
W147
W149
W168 R1
W169
W171
W172
W173 R2
W174
W191
W199
W209
W209 C1
W215
W218
W244
W245
W303

TABLE 6.2.2.2-1

automated and thus were capable of producing listings of design drawings affected by any authorized, released ECP. These listings were called Engineering Change Identity Parts Lists (ECIPL).

Prior to the ECIPL printout which occured after drawing release, an estimated list of drawings to be affected by an approved ECP was maintained in a sub-routine of the automated release record system. This sub-routine was called the Job Drawing List system (JDL). It was used to great advantage by simultaneously providing drawing change and scheduled release visibility to manufacturing departments. The JDL system also maintained in-system location of each drawing and change, thus providing the important release status function that engineering management needed to monitor design progress.

6.2.3 Configuration Accounting

6.2.3.1 Configuration Accounting Records - MDAC maintained records within the OWS program departments as required to maintain complete configuration visibility and status. Maintained were:

A. Approval records and change incorporation status information of all configuration specifications/documents and changes thereto (i.e., Contract End Item Specification, Ground Support Equipment Model Specification, Government Furnished Property Requirements, Quality Program Plan, Reliability Program Plan, Test Plan and Configuration Management Plan). Each document included a change log which listed the SCN number and date, ECP number, contract authority number and date, document pages affected, and other pertinent information.

B. Approval records of all deviations and waivers to the approved configuration specifications/documents. These records were maintained in the engineering contract specification section.

C. Listings and release status of all drawings/documents of which the OWS design baseline was comprised. These records were maintained within the engineering release section (Refer to 6.2.1.?).

D. Listings and approval status of all Class I changes (ECP's) to the design baseline. These records were maintained in an on-line automated system which included data relating to initiation, internal MDAC approval, submittal to NASA, approval by NASA, approval authorities, and modification kit information.

E. Records of all Class II changes. These records were maintained in the engineering release section drawing release record files. Each drawing change was identifiable as to its classification as Class II or to its ECP number if Class I.

F. Verification records relating to baseline or Class I change (ECP) identities. This information was also maintained in the automated system noted in D above.

6.2.3.2 Configuration Accounting Report Certification - MDAC, in addition to compilation and maintenance of internal records, reviewed and suggested changes/corrections to the following NASA prepared configuration management oriented documents:

A. Skylab Configuration Identification Index and Modification Status, CM-020-001-2H. MDAC reviewed monthly and responded to NASA with suggested changes.

B. Skylab OWS Interface Control Documentation Contractual Index and Status Report, Part I of CM-023-003-2H.

C. Skylab OWS Stowage List Status Report, Part II of CM-023-003-2H.

D. Skylab Stowage List, I-SL-008.

6.2.4 Change Traffic - The OWS design baseline underwent many changes from the time of CDR (Table 6.2.2.2-1) through SL-4 splashdown. There were several reasons for this high rate of change:

- The change from the Wet Saturn I Workshop to a Dry Skylab Orbital

Workshop was a major change.

- The OWS program sustained several "stretchouts" for funding reasons. This gave extra time for many desirable redesigns - from all agencies.
- The inter-center reviews developed needed changes.
- **The OWS design included a huge volume for stowage of mission required items - by an order of magnitude greater than on any program before. This new design field also brought forth many crew/NASA initiated changes related to on-orbit operation of the many experiments.**
- **The trainers, mockups, and neutral buoyancy and dynamics test articles were utilized effectively and continuously. A natural fallout of this effort was change traffic.**

Between September 1969 (CDR) and November 1973, the following quantities of changes were processed by MDAC on the OWS program:

Change Family	1969	1970	1971	1972	1973
ECP W003-X	0	0	0	10	109
ECP W004-X	0	0	0	7	156
ECP W005-X	0	37	28	24	3
ECP W006-X	0	29	244	301	140
ECP W007-X	0	0	215	299	114
ECP W008-X	1	0	0	6	5
ECP W009-X	1	0	1	19	23
ECP WXXX	18	364	412	247	121
PCP WXXXX	27	140	127	107	18
SUB-TOTAL	47	570	1027	1020	689

TOTAL CHANGES = 3353

6.2.5 Conclusions and Recommendations - The configuration management disciplines used were adequate and fulfilled the desires for the OWS. A lot of effort was spent obtaining a mutual understanding of an operable system structured to meet CM requirements with the OWS schedule and cost control problems. A lot of emphasis and participation was required of top management for change board and change control activities. The disciplines used for OWS are applicable to any future programs. However, the implementation methods are not necessarily optimum and depend on the program schedule conditions.

SECTION 7 - MISSION OPERATIONS SUPPORT

7.1 GENERAL

Support of the Skylab (SL) mission was provided by many NASA and Skylab contractor personnel from various locations throughout the country. MDAC-W provided mission operations support for the Orbital Workshop (OWS) from its facilities at Huntington Beach, California, and through its on-site personnel located at MSFC, Huntsville, Alabama. This support was provided to MSFC who supported the JSC flight control team from the Huntsville Operations Support Center (HOSC).

MDAC-W monitored all mission activities and provided around-the-clock support to NASA for the final four months of launch preparations and for the entire 9-month mission period.

An OWS mission support team was established at MDAC-W which included senior systems engineers for all OWS systems and representatives from all supporting program organizations. All mission support actions were assigned to the OWS mission support team which operated out of the OWS Mission Support Center at Huntington Beach. Coordination with MSFC was accomplished through the MDAC-W mission support personnel on-site at MSFC which operated out of Conference Work Area (CWA) No. 6 in the HOSC.

Whenever an OWS problem was identified or whenever JSC and/or MSFC generated a mission support action request related to the OWS, MDAC-W would generate an internal action item to respond to the problem or action request. Responses to these action items received an internal technical and program review and were forwarded to the MSFC Mission Support Groups (MSG's) for their consideration and use when responding to the JSC flight control team. One thousand twelve (1012) such actions were processed by MDAC-W during the course of the mission.

The OWS Backup spacecraft and OWS component and system test setups at Huntington Beach played a prominate role in providing test data in support of many of the OWS action items. In addition, a significant amount of hardware was developed at Huntington Beach during the mission period for fly-up on SL-3 and -4 and for test or crew training use by MSFC and JSC.

7.2 MDAC-W SUPPORT AT MSFC

7.2.1 Overview of MDAC-W's Role at MSFC - MDAC-W's role at MSFC was as follows:

A. To provide a team of qualified engineers that could advise their MSFC Mission Support Group (MSG) leaders on technical matters pertaining to their responsible Orbital Workshop (OWS) system.

B. To manage the technical support, insure coordination and integration across technical interfaces, and timely response to action items.

C. To insure that the MDAC-W technical position on OWS action items was properly represented to the MSG leaders and OWS Project Office.

D. To provide to MDAC-W, Huntington Beach, real time data on key OWS parameters on a frequency sufficient to allow assessment of systems status.

The organizational structure and interface relationship are discussed in Section 7.2.2. Individuals assigned to the team were responsible for working shifts as assigned by their MSG leaders. Duties generally included console monitoring and action item coordination. In some cases, and particularly during times of heavy action item traffic, the ability to properly coordinate technical responses was compromised by console monitoring duties. Two senior representatives were assigned to MDAC-W, Huntsville, to insure technical coordination and continuity of responses. Coverage was provided during the manned mission phases seven days a week to properly represent MDAC-W technical positions. A staff was formed (varying initially from seven to four at the end of the mission) to provide around-the-clock coverage in the Huntsville

Operations Support Center (HOSC) to assist in the specific action tracking and coordination system. All actions assigned to or potentially affecting the OWS were assigned a number for tracking purposes and responses distributed to affected MSFC personnel.

7.2.2 MDAC-W/MSFC Mission Support Interface - The interfaces between MDAC-W and MSFC can best be viewed on an organization-type chart, considering MSFC's overall responsibility during the Skylab mission (see Figure 7.2-1). MSFC was organized to accomplish two basic functions with regard to hardware and experiments under their development responsibility; monitor real time systems status and provide solutions to problems. To accomplish these functions MSFC established several MSG's that had technical responsibility for the status monitoring and problem solution. These MSG's were headed by the individuals designated on the charts. To ensure continuity and timeliness of technical response, an Operations Director (O.D.) position was established full time at HOSC, reporting to a senior O.D. Staff systems engineers were assigned to the O.D. to assist in technical integration and coordination across MSG overlapping responsibilities. The OWS Project Office had individuals assigned to support the various MSG's and advise the Project Manager of the status of OWS systems and actions required.

The MDAC-W interfaces were officially from the Huntington Beach Duty Officer (Program Manager/Chief Engineer level) through the on-site Huntsville Senior Representative to the affected MSG's. Thus, all problems or actions affecting the OWS were responded to through the Huntington Beach Mission Support Room (MSR) under approval of the cognizant Duty Officer. Responses were reviewed and coordinated with the MSG's with copies distributed to local MDAC-W MSG personnel and the OWS

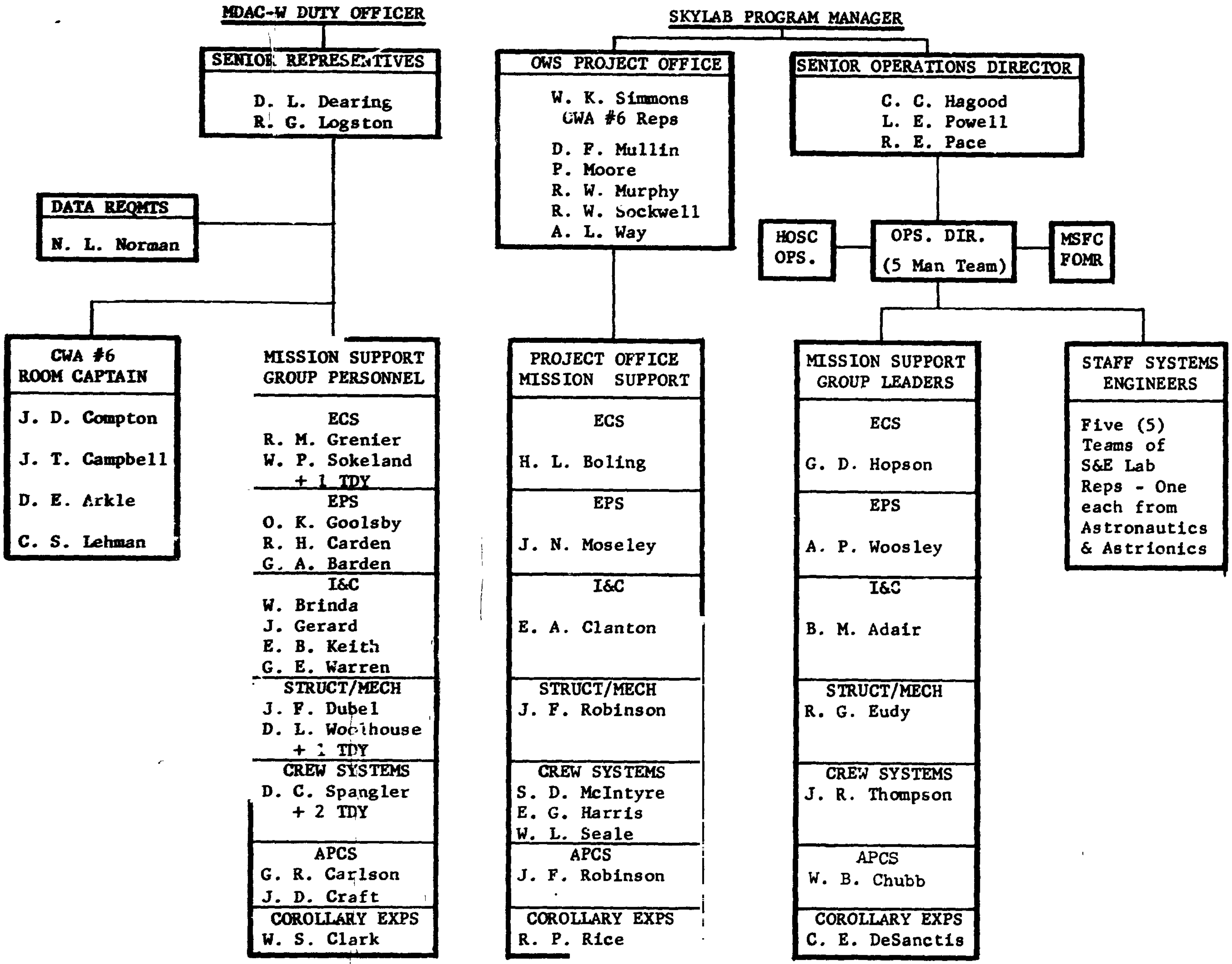

MDAC-W DUTY OFFICER
SENIOR REPRESENTATIVES
D. L. Dearing
R. G. Logston
DATA REQMTS
N. L. Norman
CWA #6 ROOM CAPTAIN
J. D. Compton
J. T. Campbell
D. E. Arkle
C. S. Lehman
MISSION SUPPORT GROUP PERSONNEL
ECS
R. M. Grenier
W. P. Sokeland
+ 1 TDY
EPS
O. K. Goolsby
R. H. Carden
G. A. Barden
I&C
W. Brinda
J. Gerard
E. B. Keith
G. E. Warren
STRUCT/MECH
J. F. Dubel
D. L. Woolhouse
+ 1 TDY
CREW SYSTEMS
D. C. Spangler
+ 2 TDY
APCS
G. R. Carlson
J. D. Craft
COROLLARY EXPS
W. S. Clark
SKYLAB PROGRAM MANAGER
OWS PROJECT OFFICE
W. K. Simmons
CWA #6 Reps
D. F. Mullin
P. Moore
R. W. Murphy
R. W. Sockwell
A. L. Way
PROJECT OFFICE MISSION SUPPORT
ECS
H. L. Boling
EPS
J. N. Moseley
I&C
E. A. Clanton
STRUCT/MECH
J. F. Robinson
CREW SYSTEMS
S. D. McIntyre
E. G. Harris
W. L. Seale
APCS
J. F. Robinson
COROLLARY EXPS
R. P. Rice
SENIOR OPERATIONS DIRECTOR
C. C. Hagood
L. E. Powell
R. E. Pace
HOSC OPS.
OPS. DIR. (5 Man Team)
MSFC FOMR
MISSION SUPPORT GROUP LEADERS
ECS
G. D. Hopson
EPS
A. P. Woosley
I&C
B. M. Adair
STRUCT/MECH
R. G. Eudy
CREW SYSTEMS
J. R. Thompson
APCS
W. B. Chubb
COROLLARY EXPS
C. E. DeSanctis
STAFF SYSTEMS ENGINEERS
Five (5) Teams of S&E Lab Reps - One each from Astronautics & Astrionics

Figure 7.2-1

Project Office representative. Requests for MDAC-W support originated from several sources: MSG's through MDAC-W MSG personnel to Conference Work Area (CWA) No. 6 (MDAC-W/OWS HOSC Control Room); directly to CWA No. 6 from MSG's' to CWA No. 6 from OWS Project Office personnel; and CWA No. 6 initiated through monitoring voice conversation and JSC action requests.

All MDAC-W action requests requiring hardware fabrication, utilization of the Backup OWS or conduct of testing required authority of the OWS Project Manager (or his designee). Details of the overall action system are discussed in Section 7.2.6, however, for interface discussion purposes there was an official authority interface with the Project Manager

The MDAC-W senior representatives to HOSC interfaced with all the personnel or positions identified on the chart with the exception of Flight Operations Management Room (FOMR) (MSFC representatives to JSC FOMR). The day-to-day interface was basically coordination with the MSG leaders and the OWS Project Office representative to CWA No. 6. Interface with the O.D.'s or senior O.D.'s was more periodic, depending on the events and circumstances. The MDAC-W CWA No. 6 Room Captains provided the on-site full time capability for coordinating action requests and responses (with Huntington Beach and MSFC) as well as a single point of contact for MDAC-W personnel location and notification of problems.

7.2.3 <u>Facility Definition</u> - The Skylab mission support facility is located primarily in the HOSC. The facilities available to MDAC-W were as follows:

A. CWA No. 6 - CWA No. 6 (Figure 7.2-2) was used by MDAC-W to provide

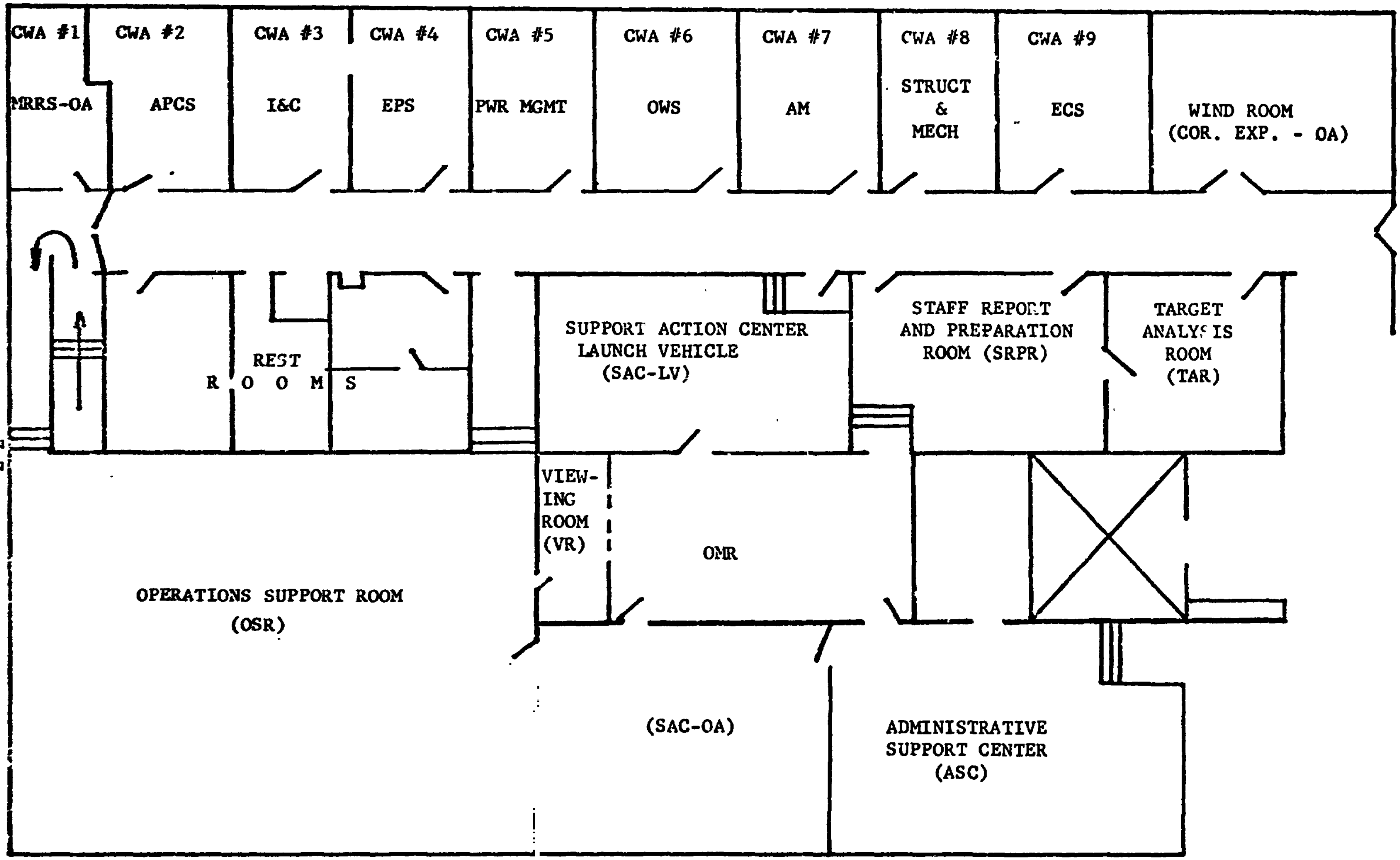


FIGURE 7.2-2

HOSC SKYLAB OPERATIONS SUPPORT FACILITY LAYOUT a focal point for disseminating action requests and action responses, to provide a work area to work on problems, to maintain communications with MDAC-W, Huntington Beach, as well as the on-site MDAC-W MSG personnel. The equipment within CWA No. 6 included desk, work table, filing cabinet, technical library, three phones, TV monitor, plus hardcopier and communication loops to monitor Flight Director (FLT DIR), Ground Operational Support System (GOSS), HOSC, FOMR, O.D., plus several internal lines.

B. Administration Support Center (ASC) - The ASC provided magnafax support, reproduction, limited typing, mail distribution, and an extensive library of documents and photos.

C. Operations Support Room (OSR) - The real time data display consoles, Mission Operations Planning System (MOPS) terminals, data hardcopiers, and strip charts were located within the OSR and were manned by MDAC-W personnel as required by their respective mission support leader.

D. Support Action Center-Orbital Assembly(SAC-OA) - The SAC-OA was manned by the Operational Support Manager (OSM) from which HOSC/FOMR business was conducted. MDAC-W supported the OSM by participating in status meetings and all technical meetings affecting the OWS.

Other facility areas included:

A. Building 4481 - MDAC-W Office - The MDAC-W office provided all of the MDAC-W typing, additional magnafax transmission, complete MDAC-W drawing file, reproduction and normal MDAC administrative services.

B. Crew Systems Facilities - The MDAC-W Crew Systems support personnel worked out of the Crew Systems War Room. Available to them were TV monitor, communication monitors, and phones. Also, the Hi-Fi Mockup was available next to the War Room for mockup of problem solutions. The Neutral Bouyancy Facility was used by the Crew Systems personnel to work crew training procedures using simulated zero "G" conditions.

C. Experiment Work Area - TV monitor, voice monitor, and phones were available within the Experiment Work Area to support problem coordination.

7.2.4 MSFC Skylab Data System

7.2.4.1 General - Although many similarities existed between Apollo and Skylab data systems, the long duration mission, with the resultant large quantities of data, required significantly new approaches to data processing. The most notable of these was the compression (or compaction) of data such that only changes in data values were transmitted from the ground stations to the data network. During final data reduction, the "missing" static data bits were reinserted for a "continuous" data curve. The downlinked data was recorded at the remote sites in both an analog and digital format. The analog instrumentation tape recording was utilized as "prime" data on the Apollo Program but the Skylab Program utilized the digital tape recording. These digital recordings were stripped of all redundant data samples by using an editing technique (zero-order-predictor) at the remote site. These edited data [All Data Digital Tape (ADDT)] were then transmitted to JSC where they were available in the Skylab Data Base. The ADDT computer terminal at JSC inserted tape recorder data, time sequenced the data, removed overlaps from the remote sites, and then transmitted the data to MSFC. Figure 7.2-3 shows a simplified flow of Skylab data to MSFC with each of the major elements described in the following sections.

7.2.4.2 Real Time Data - The on-board telemetry and command response data were downlinked at the remote sites, processed through the Remote Site Telemetry Computer (RSTC) and transmitted to JSC via Goddard Space Flight Center (GSFC) and the Apollo Command, Communications, and Telemetry System (CCATS). At JSC these data were available in the Skylab Data Base via the Mission Operations Computer (MOC). These real time CCATS data were also transmitted to MSFC via a 50 kilo-bit line where they were received at the HOSC, processed through computers and Digital-to-TV (D/TV) generators to drive the video matrix for the television and console displays.

Originally, real time data were to be received and displayed 8 hrs/day with an option to call up additional data within one hour to assist in solving urgent problems. However, because of complex difficulties encountered in transmitting the ADDT to MSFC and because of the state of the Skylab following launch, it became necessary to perform the mission operation functions utilizing the real time data as a "prime" data source. This was performed by manning the HOSC in an "around-the-clock" operation. This mode of operation placed very great demands on the D/TV hardcopy capabilities during the first manned mission, as well as requiring additional personnel to man the consoles continuously. Certain data formats were hardcopied and transmitted by telephone to Huntington Beach for tracking critical system performance.

7.2.4.3 MOPS - Four MOPS terminals were available in the HOSC, at least one of which was operated around-the-clock. These terminals provided direct

SKYLAB DATA FLOW

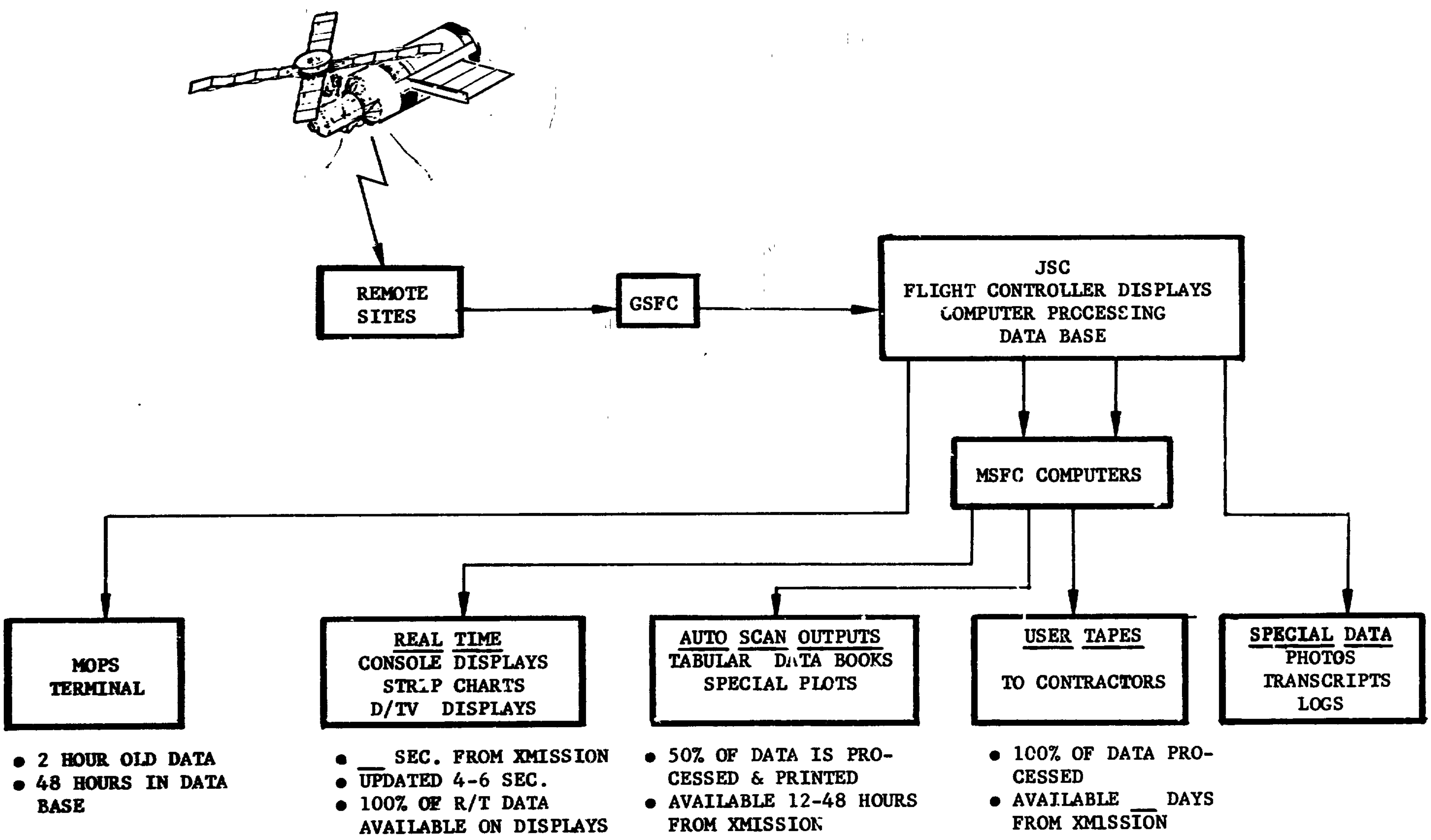


FIGURE 7.2-3

access to the Mission Data Retrieval System (MDRS) Data Base at JSC. The data base normally contained the most recent (from about 2 hours old) 48 hours of data (real time plus recorded) which could be retrieved in fixed, predetermined plot or tabular formats in selected time slices and sample rates. The older data (more than 48 hours) was stored on magnetic tape and catalogued into a historical data base which could be retrieved at a later time. The system (MOPS) proved to be the prime source of data for contingency analysis until the data books were available since real time data "slices" at time points selected by the console monitor over ground stations. MOPS provided continuous data tabulation within certain limitations.

7.2.4.4 Auto Scan - The Auto Scan Program was a software program system of smaller programs, any one or all of which could be resident in the computer simultaneously. The Auto Scan main program performed a limit search, discrete event search, detected time of acquisition and loss of signal, and output three tapes:

A. The Behavior History Tape (BHT) contained the times at which measurements exceeded and returned to their predetermined limits, the maximum deviation, and total number of points outside the limits as well as the status and times for discrete event measurements. (A minimum of five consecutive data points outside the scan limits were required for a measurement to be processed onto the BHT and after eleven deviations were discontinued). A tabular output report (Event Report and Limit Scan Report) was printed for engineering review.

B. The Statistical Data Tape (STDT) contained the actual data that required more thorough study as determined by the limit search of the main program. This allowed special processing to be performed as determined by the requestor.

C. The data tabulation keying tape contained the measurement number and times that these exceeded and returned to their limits as a criterion to provide the start and stop times for further non-Auto Scan processing. This was used in conjunction with a compressed data tape to produce special plots and/or tabs.

During the storage period between SL-2 and SL-3, the limit search portion of the Auto Scan Program output was deleted and only batches 3 and 4 [1200 to 2400 hours Greenwich Mean Time (GMT)] of the ADDT data were routinely processed to the data book format. This time interval covered the waking hours of the crew and any of the remaining batches were processed on a contingency basis. These changes resulted in a more realistic output schedule such that the data books were available within 12 to 48 hours.

7.2.4.5 User Tapes - Skylab user tapes were provided to each contractor using compressed data and a special user format. These tapes were used by the contractors for detailed system evaluation or module performance analysis for final evaluation reporting.

7.2.4.6 Special Data - Telemetry was not the only source of data that was used to evaluate the OWS. Crew voice transcripts were made from tape recorded air/ground communication and from airborne tape playbacks. These were available on a "quick-look" basis in about 24 hours and on an "edited" basis in 2 to 4 weeks. Copies of the crew debriefings and crew logs were also available.

Photographs made by the crew were selected for review based on the OWS systems photographed. Video transmissions from the crew were recorded at the Mission Control Center (MCC). An "enhanced master merge" video tape was prepared and transmitted to MSFC where a kinescope was then prepared. Copies of this kinescope were then provided to the contractors. The sound track was deleted from the kinescope prior to the SL-3 manned missions due to cost and availability considerations.

The problems encountered early during the launch of Skylab involving the loss of the Meteoroid Shield (MS) and the secondary problems of overheating resulted in contingency data requirements. Analog tapes containing the launch and OWS telemetry links through insertion were requested. An analog tape from the Madrid tracking station was also required to investigate an anomaly of the refrigeration system.

Video tapes were requested on two occasions; the rendezvous and "fly-around" of SL-1/SL-2 and the trash airlock operations conducted during Day of Year (DOY) 253. A 16mm movie film to perform an analysis of crew systems operations was requested.

7.2.5 MDAC-W Support Structure and Manning Schedules - The support structure was described in Section 7.2.2 and shown in Figure 7.2-1. The team working out of CWA No. 6 manned 24 hours a day, seven days a week during manned and unmanned phases. Two senior representatives provided coverage for seven days a week during manned operations (in HOSC during major crew activity periods and on-call the other times) and a normal shift, five days a week and on-call on weekends during unmanned operations. The MSG support team schedule was variable, depending on the needs of the individual groups. During the manned phase, the Electrical Power System (EPS), Structural/Mechanical and Crew Systems support personnel covered two shifts a day, seven days a week. The

Environmental Control System (ECS), Attitude Pointing and Control System (APCS), and Instrumentation and Communication (I&C) support personnel covered three shifts daily while the experiment support individual covered a single shift 5 days a week. During unmanned mission phases, ECS supported two shifts a day, seven days a week, and I&C supported one shift a day, seven days a week.

Temporary Duty (TDY) support during the mission varied considerably from the SL-1/SL-2 period through the SL-4 mission. This was basically because of two factors: the launch problem activity and a normal learning curve. Subsequent to the initial launch and meteoroid shield failure, several individuals were in Huntsville on TDY to aid in developing solutions to the thermal shield and SAS deployments as well as program management. During the remainder of the mission, TDY was generally as shown on Figure 7.2-1 with the exception that two TDY individuals rotated to cover the I&C and EPS console monitoring until the middle of the SL-3 mission. Experience gained in CWA No. 6 operations allowed release of two electrical engineers with subsequent discontinuance of the I&C and EPS TDY. In general, it was viewed preferable to have individuals on a long term field assignment as opposed to rotating several individuals to fulfill a requirement. This better maintained continuity of operations.

7.2.6 Action Request Flow - The method used by the OSM to satisfy the actions requested by the various agencies was as follows: the Action Request (AR) form was used to document requests initiated by MSFC; and the FOMR/Mission Action Request (MAR) form was used by FOMR personnel at JSC.

Any agency requesting information, solutions to problems or recommendations, documented their request on one of the forms and submitted it to the OSM at HOSC. After coordination with and approval of the O.D. the OSM would then assign the request to the appropriate MSG or groups for disposition. On some occasions, the contractors were assigned an action. However, most contractor support was requested through the MSG, either verbally or written. When an action request was assigned affecting the OWS, a MDAC-W action number was assigned to the request which was transmitted to Huntington Beach by magnafax for disposition. The response by MDAC-W was then submitted to CWA No. 6. The action response was reviewed by the senior representatives and coordinated with the appropriate MSG. Distribution was also made to various MSG's, MSFC personnel, the OWS Project Office, and MDAC-W Huntsville, personnel. A log and copy of action requests and responses were kept on record in the CWA No. 6. This overall system is shown on Figure 7.2-4.

ACTION REQUEST FLOW

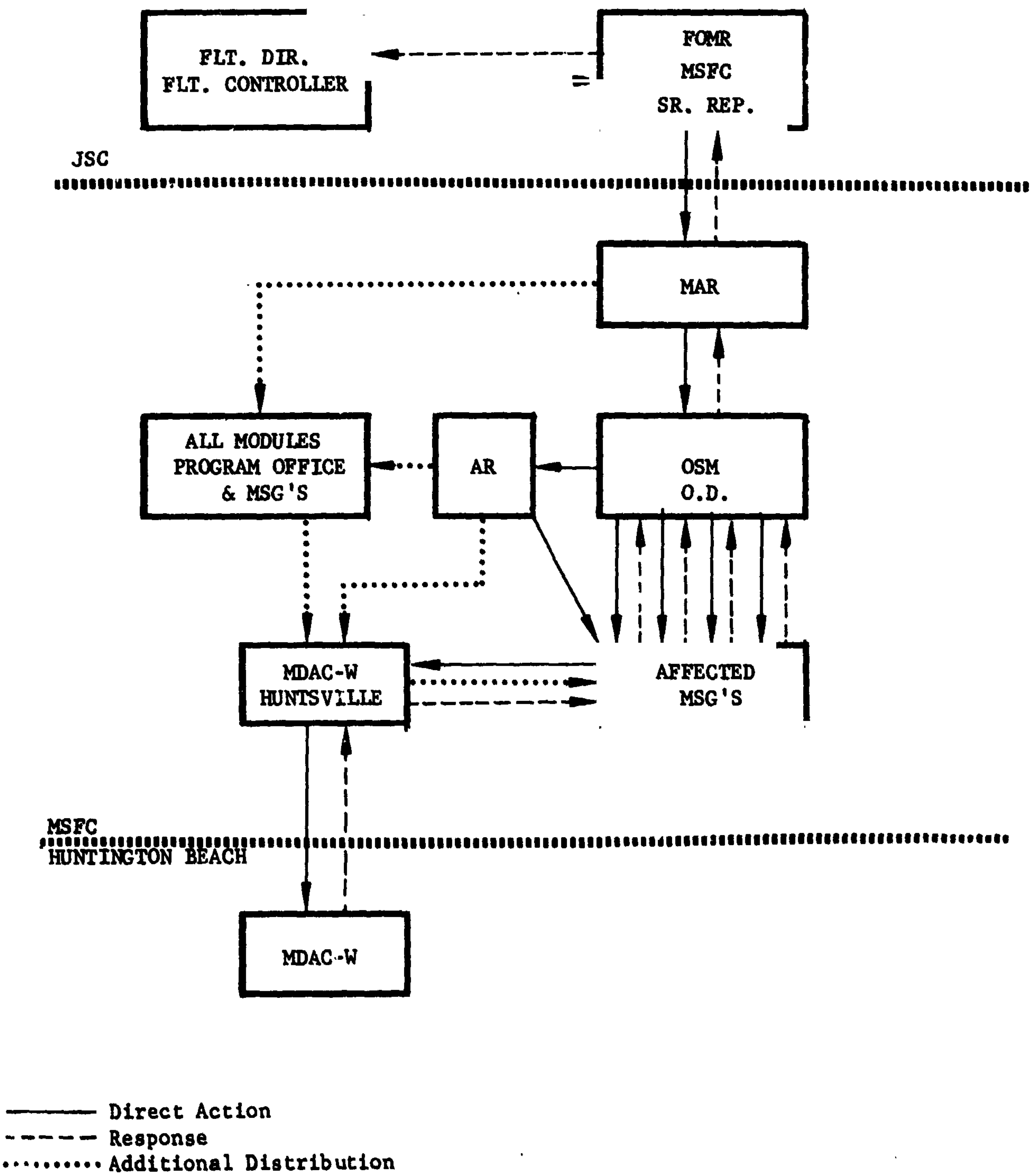


FIGURE 7.2-4

7.3 MDAC-W SUPPORT AT HUNTINGTON BEACH

7.3.1 Overview - Mission support activities at Huntington Beach were concentrated in the Mission Support Room (MSR), a part of the four-room complex comprising the Huntington Beach Mission Support Center. The MSR was the focal point for communications between MDAC-W, Huntington Beach, and the other Skylab (SL) launch and mission support organizations. Primary support consisted of providing a minimum manning crew of technology personnel consistent with the mission phase for real time problem/action item solution. The on-duty crew was responsible for keeping abreast of mission activities/anomalies by monitoring crew and flight director voice loops and through telephone coordination with Huntsville Operations Support Center (HOSC), JSC, MDAC-E, etc., and for providing a coordinated technical position in support of JSC, HOSC, or internally generated action items.

The Huntington Beach MSR was activated in January, 1973, to support mission simulations originating at JSC. Continuous support was provided for the duration of individual simulations and key KSC countdown activities. Around-the-clock support continued through SL-4 splashdown 08 February 1974. MSR manning levels during this period varied in accordance with the requirements of the different mission phases.

7.3.2 Mission Support Team Definition/Organization - The OWS mission support team was formed from Skylab OWS technology engineers and OWS program support organizations to provide an organization capable of monitoring the mission activity and solving all OWS anomalies/associated action items during the Skylab mission. Organization of the team, including the person in charge of each functional area, is depicted in Figure

7.3.2.1. Personnel from the various support groups were assigned to provide real time MSR manning. Figure 7.3.2-2 shows mission support team in relationship to other MDAC-W mission support organizations.

7.3.3 Summary of Huntington Beach Prelaunch Operations Support

A. Mission Simulation Support - Mission simulations originating at JSC were held during the period of 17 January 1973 through 05 May 1973. The Huntington Beach MSR was operated in as close to the anticipated mission mode as possible. Ground Operational Support System (GOSS) and flight director voice loops were operational at the outset of the mission simulation period and the various other items of MSR equipment were phased in as they became operational. The simulations provided an excellent training opportunity to familiarize the mission support team with action item solving and mission monitoring, and the intent was to utilize as many personnel as possible. A total of 23 mission simulations, expending approximately 4500 man-hours, were supported by the Huntington Beach mission support team. The overall system for solving action items and coordinating with HOSC and JSC was developed and improved during this period.

MDAC-W participation in mission simulations was as follows:

- Orbital Operations Simulations - 170 Hours
- Deactivation Simulations - 50 Hours
- Activation Simulations - 25 Hours
- SL-1 First Day Simulations - 90 Hours

OWS action items worked during the simulations were as follows:

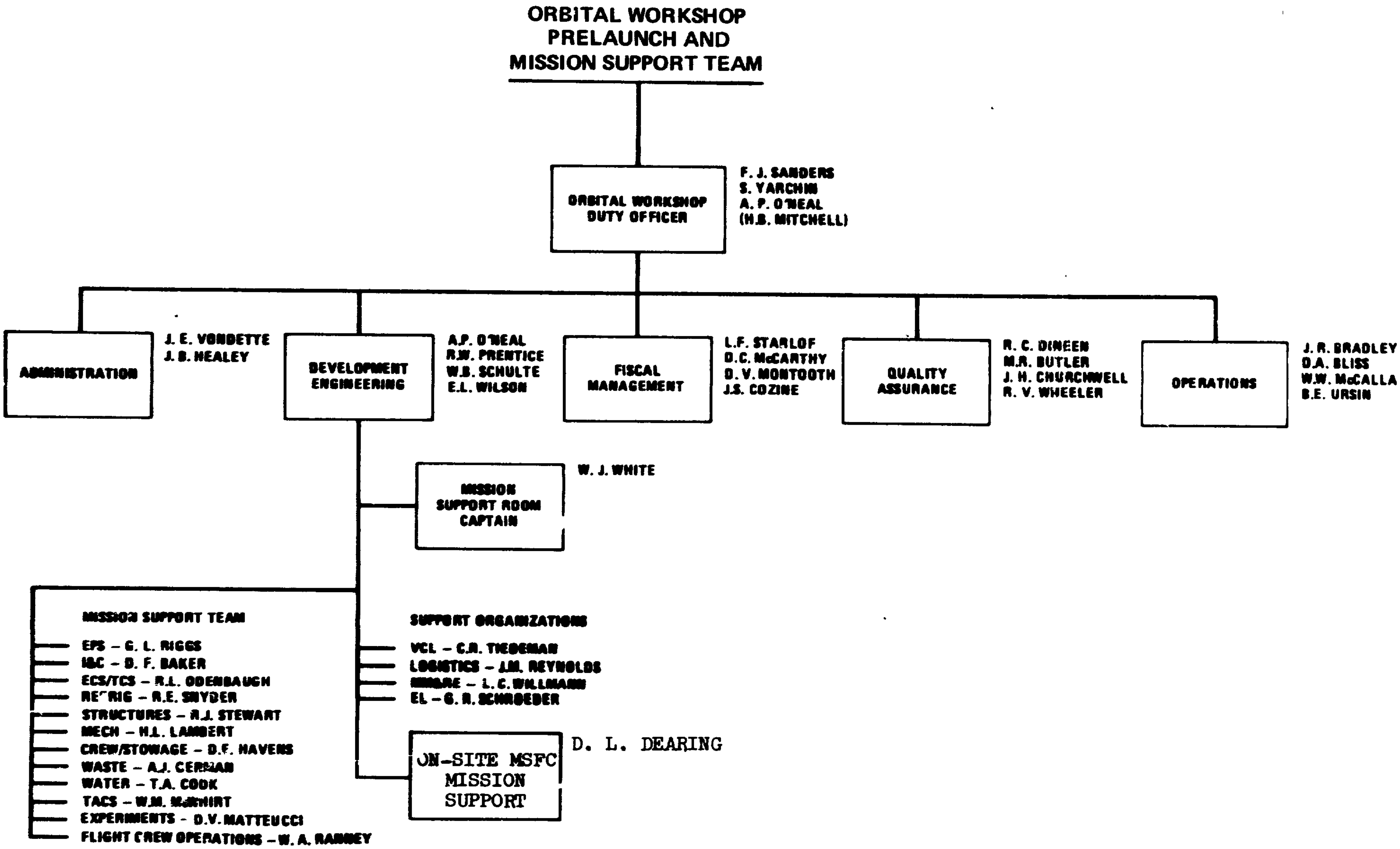

ORBITAL WORKSHOP PRELAUNCH AND MISSION SUPPORT TEAM
ORBITAL WORKSHOP DUTY OFFICER
F. J. SANDERS
S. YARCHIN
A. P. O'NEAL
(H.B. MITCHELL)
ADMINISTRATION
J. E. VONDETTE
J. B. HEALEY
DEVELOPMENT ENGINEERING
A.P. O'NEAL
R.W. PRENTICE
W.B. SCHULTE
E.L. WILSON
FISCAL MANAGEMENT
L.F. STARLOF
D.C. McCARTHY
D. V. MONTOOTH
J.S. COZINE
QUALITY ASSURANCE
R. C. DINEEN
M.R. BUTLER
J. H. CHURCHWELL
R. V. WHEELER
OPERATIONS
J. R. BRADLEY
D.A. BLISS
W.W. McCALLA
B.E. URSIN
MISSION SUPPORT ROOM CAPTAIN
W. J. WHITE
MISSION SUPPORT TEAM
EPS – G. L. RIGGS
I&C – D. F. BAKER
ECS/TCS – R.L. ODENBAUGH
REFRIG – R.E. SNYDER
STRUCTURES – R.J. STEWART
MECH – H.L. LAMBERT
CREW/STOWAGE – D.F. HAVENS
WASTE – A.J. CERMAN
WATER – T.A. COOK
TACS – W.M.
EXPERIMENTS – D.V. MATTEUCCI
FLIGHT CREW OPERATIONS – W. A. RAMSEY
SUPPORT ORGANIZATIONS
VCL – C.R. TIEDEMAN
LOGISTICS – J.M. REYNOLDS
– L. C. WILLMANN
EL – G. R. SCHROEDER
ON-SITE MSFC MISSION SUPPORT
D. L. DEARING

FIGURE 7.3.2-1

OWS MISSION SUPPORT

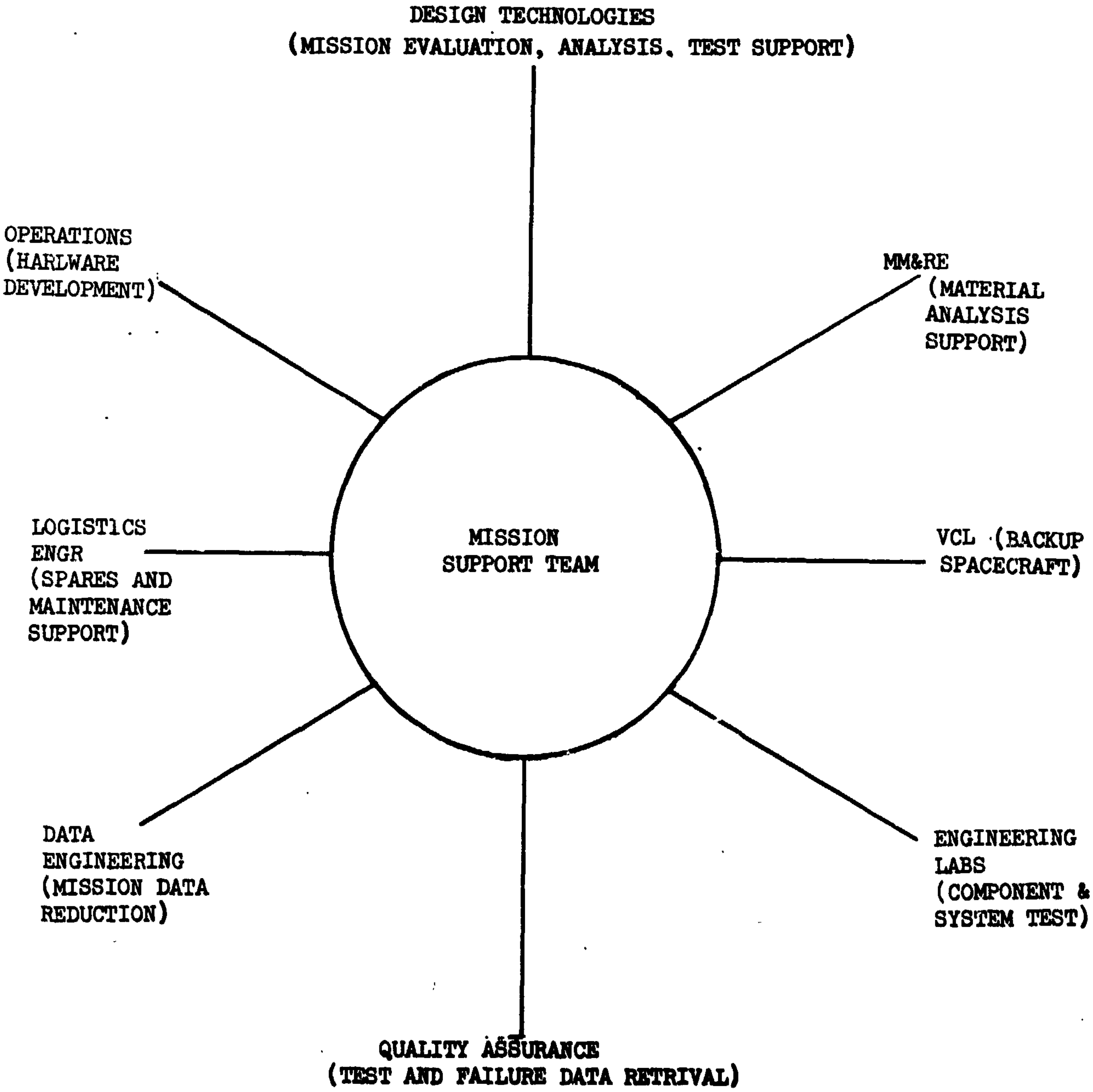


FIGURE 7.3.2-2

OWS SYSTEM		NO. OF ACTION ITEMS
Instrumentation and Communication (I&C)	-	12
Electrical Power System	-	4
Environmental Control System (ECS)	-	19
Attitude Pointing and Control System (APCS)	-	10
Refrigeration System (RS)	-	20
Water System	-	9
Waste Management System (WMS)	-	3
Mechanical Systems	-	9
Structures	-	9
Crew Systems	-	3
Experiments	-	12
TOTAL MISSION SIMULATION ACTION ITEMS	-	110

B. KSC Prelaunch Support - Huntington Beach MSR support of KSC prelaunch activity consisted of providing appropriate technology personnel in the MSR to support specific key KSC prelaunch tests. For these tests the voice channels normally used for capcom and flight director were switched at HOSC to the KSC Operational Intercom System (OIS) channels running the test. In this manner the MSR personnel assigned to support the KSC test could monitor and follow the test as it progressed. Due to the lack of anomalies during the major prelaunch tests, very few action items were assigned. The KSC tests supported were as follows:

1/	21-24 March 1973	Flight Readiness Test (FRT)
2/	27 March 1973	Systems Integration Test (SIT)
3/	29 March 1973	Launch Vehicle FRT
4/	27 April 1973	Countdown Demonstration Test (CDDT)
5/	02 May 1973	CDDT
6/	14 May 1973	Countdown

In addition to the specific test support noted above, MDAC-W provided around-the-clock "locator-type" service at Huntington Beach in support of all KSC OWS operations. This service was used to aid in the expediting of replacement hardware required at KSC and for establishing teleconference setups between MDAC-W personnel at KSC and various Huntington Beach engineers and management personnel to discuss technical problems.

7.3.4 Identification and Management of OWS Problems/Action Requests - Figure 7.3.4-1 depicts the overall flow which action items followed from origin to completion. This section of the report will cover the functions performed and the paperwork utilized within the Huntington Beach MSR to accomplish the tasks from (A) - (B) on Figure 7.3.4-1. Action item initiation was the responsibility of the MSR Room Captain and he initiated action items based upon the following sources:

A. Flight Operations Management Room (FOMR) - Mission Action Request (MAR).

B. HOSC Support Action Center - Orbital Assembly (SAC-OA) - Action Request (AR).

C. HOSC Conference Work Area (CWA) No. 6 - Action Request.

D. Other - This category includes MDAC-W management, MDAC/JSC, HOSC MSG, MSR real time mission monitoring of voice loops.

Regardless of the source, all MSR formal action items were initiated, and the response documented, by the standard OWS MSR action item form. After completion of the action item form copies of the action item would be distributed and the action item log and status board would be annotated.

The action item log provided control over action item number issuance and comprised an index which assisted in retrieving action item information subsequent to closeout. The action item status board was a management tool providing a quick-look assessment of current action items. Color coding was utilized to provide emphasis and easy recognition of proximity to the due time. A responsible engineer was selected for each action item. The responsible engineer selected,

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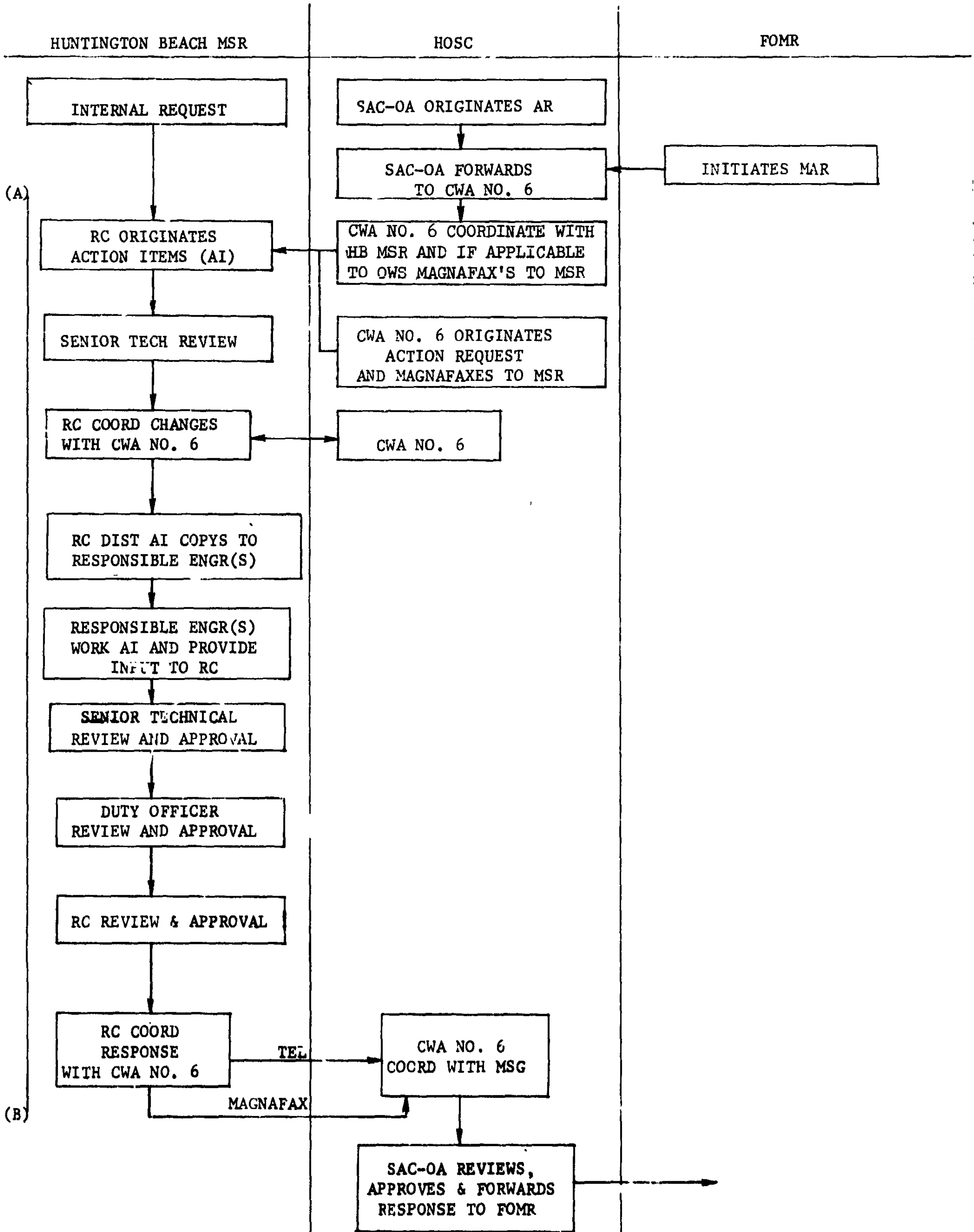

HUNTINGTON BEACH MSR
HOSC
FOMR
INTERNAL REQUEST
SAC-OA ORIGINATES AR
SAC-OA FORWARDS TO CWA NO. 6
INITIATES MAR
(A)
RC ORIGINATES ACTION ITEMS (AI)
CWA NO. 6 COORDINATE WITH HB MSR AND IF APPLICABLE TO OWS MAGNAFAX'S TO MSR
SENIOR TECH REVIEW
CWA NO. 6 ORIGINATES ACTION REQUEST AND MAGNAFAXES TO MSR
RC COORD CHANGES WITH CWA NO. 6
CWA NO. 6
RC DIST AI COPYS TO RESPONSIBLE ENGR(S)
RESPONSIBLE ENGR(S) WORK AI AND PROVIDE INPUT TO RC
SENIOR TECHNICAL REVIEW AND APPROVAL
DUTY OFFICER REVIEW AND APPROVAL
RC REVIEW & APPROVAL
RC COORD RESPONSE WITH CWA NO. 6
TEL
CWA NO. 6 COORD WITH MSG
MAGNAFAX
(B)
SAC-OA REVIEWS, APPROVES & FORWARDS RESPONSE TO FOMR

FIGURE 7.3.4-1

generally, was the senior system engineer as listed in Figure 7.3.2-1 having cognizance over the component/subsystem involved. Action items involving more than one technology were assigned to a senior technical representative as prime responsiblity for integrating all inputs into a single response. Action item responses completed by the responsible engineer were reviewed and approved by the senior technical representative, OWS Duty Officer, and Room Captain prior to transmittal to CWA No. 6. This review cycle formalized the action item response and established it as a company position.

Informal responses and telephone conversations not requiring a formal action item were documented by using a Dire Response Record (DRR) form. Completed DRR's were filed with the related action item if one existed or in the Room Captain's Log under the day of year that the DRR was written.

Action items involving testing were handled in such a manner that the test authorization was processed and test results tracked by a separate system. Two types of tests were utilized in support of MSR action items (OWS Backup Vehicle and Component Tests). The Mission Support Test Request (MSTR) was used to authorize, initiate, and document results of both types of mission support tests.

7.3.5 Summary of Mission Support Action Items

A. A total of 1012 action items were assigned during the entire mission. As a point of interest, the greatest activity in any one day occurred DOY 135 in which 22 action items were opened and 20 closed out. Responses to all action items were magnafaxed to MSFC and distributed to effected personnel

B. Action item distribution by OWS system vs. mission period is provided in Table 7.3.5-1.

C. Action item distribution by initiating agency vs. mission period, [i.e., JSC (FOMR-MAR's), MSFC (HOSC-AR's), or MDAC-W] are provided in Table 7.3.5-2. It should be noted that many of the actions initiated by MDAC-W were a result of informal requests by the MSFC MSG's.

D. Action item distribution by OWS system vs. type of action item are provided in Table 7.3.5-3. Many action items involved more than one type of action. Action items were classified by placing them in the category where most of the effort was concentrated except that all action items which provided hardware were placed in the "hardware" category regardless of the amount of effort expended in the other categories.

E. Action items worked in support of the Skylab mission are typical of the following examples:

1/ Investigated the meteoroid shield anomaly including an assessment of the effect of high temperatures on OWS equipment and food, internal insulation, and optimum attitudes for thermal and electrical control. Also, investigated alternate methods for thermal control such as deployable sun shade.

2/ Investigated Solar Array System (SAS) Wing No. 1 deployment problems including analysis of video tapes to develop procedures and hardware required to make the SAS operational.

3/ Reviewed operational documentation, such as activation and deactivation checklists, command procedures, and flight mission

OWS MISSION SUPPORT ACTION ITEM SUMMARY
NUMBER OF ACTIONS BY OWS SYSTEM VS. MISSION PERIOD

OWS SYSTEM \ MISSION PERIOD (DOY)	SL-1 (134-144)	SL-2 (145-173)	STORAGE (174-208)	SL-3 (209-268)	STORAGE (269-319)	SL-4 (320-039)	TOTAL MISSION
INSTRUMENTATION & COMMUNICATION	6	6	5	12	4	6	39
ELECTRICAL POWER SYSTEM	29	14	5	8	1	2	59
ENVIRONMENTAL CONTROL SYSTEM	41	22	14	40	21	20	158
THRUSTER ATTITUDE CONTROL SYSTEM	3	13	5	6	0	4	31
REFRIGERATION SYSTEM	5	3	43	80	15	12	158
WATER SYSTEM	2	7	5	2	0	16	32
WASTE MANAGEMENT SYSTEM	2	8	2	4	13	9	38
CREW SYSTEMS	30	33	16	31	20	7	137
MECHANICAL SYSTEMS	2	6	10	19	2	1	40
STRUCTURAL SYSTEMS	50	51	2	5	0	5	113
EXPERIMENT ACCOMMODATIONS	3	5	4	3	2	4	21
ACTIONS AFFECTING ALL SYSTEMS	32	33	25	58	17	21	186
TOTAL	205	201	136	268	95	107	1012

TABLE 7.3.5-1

OWS MISSION SUPPORT ACTION ITEM SUMMARY
NUMBER OF ACTION ITEMS BY INITIATING AGENCY VS. MISSION PERIOD

INITIATING AGENCY \ MISSION PERIOD (DOY)	SL-1 (134-144)	SL-2 (145-173)	STORAGE (174-208)	SL-3 (209-268)	STORAGE (269-319)	SL-4 (320-039)	TOTAL MISSION
JSC VIA MSFC	22	29	16	33	3	20	123
MSFC	104	129	74	171	70	73	621
MDAC-W	79	43	46	64	22	14	268
TOTAL	205	201	316	268	95	107	1012

TABLE 7.3.5-2

OWS MISSION SUPPORT ACTION ITEM SUMMARY
NUMBER OF ACTION ITEMS BY OWS SYSTEM VS. TYPE OF ACTION ITEM

OWS SYSTEM \ TYPE OF ACTION ITEM	INFORMATION	ANALYSIS	CREW PROCEDURES	TESTING BACKUP SPACECRAFT	TESTING COMPONENT & SUBSYSTEM	HARDWARE	TOTAL
INSTRUMENTATION & COMMUNICATION	0	31	3	3	0	2	39
ELECTRICAL POWER SYSTEM	1	39	4	2	8	5	59
ENVIRONMENTAL CONTROL SYSTEM	4	122	14	6	7	5	158
THRUSTER ATTITUDE CONTROL SYSTEM	1	23	4	0	1	2	31
REFRIGERATION SYSTEM	22	68	24	9	19	16	158
WATER SYSTEM	0	23	2	0	5	2	32
WASTE MANAGEMENT SYSTEM	1	17	2	1	3	14	38
CREW SYSTEMS	3	54	24	1	7	48	137
MECHANICAL SYSTEMS	1	30	2	1	3	3	40
STRUCTURAL SYSTEMS	6	64	4	2	11	26	113
EXPERIMENT ACCOMMODATIONS	0	17	1	0	1	2	21
ACTIONS AFFECTING ALL SYSTEMS	15	137	4	2	3	25	186
TOTAL	54	625	88	27	68	150	1012

TABLE 7.3.5-3

rules, for compatibility with the OWS configuration.

4/ Developed procedures for removing ice formation in Wardroom window cavity allowing continuation of experiment and astronaut observation activities.

5/ Evaluated wearout of the triangle shoes and provided the necessary hardware for fly-up on SL-3 and SL-4.

6/ Routinely evaluated Earth Resources Experiment Package (EREP) pie charts for compatibility with OWS systems. As a result of this review, it was determined that the OWS insulation outgassing temperature limit of 200°F would be exceeded for extended Z-LV EREP maneuvers. As a result of test data provided by MDAC-W the outgassing temperature limit was raised to 300°F allowing for increased flexibility in EREP planning.

7/ Evaluated the loss of OWS low-level multiplexer "B" and identified instrumentation which could be utilized in lieu of the low-level multiplexer "B" data.

8/ Investigated the Waste Management Compartment (WMC) H_2O dispenser failure, identified the failure mode, and developed and shipped spares to KSC for fly-up on the SL-3 command module.

9/ Developed the necessary procedures and hardware required to route experiment M092 vent into the waste tank resulting in a non-propulsive vent which decreased Thruster Attitude Control System (TACS) usage.

10/ Developed RS flushing and dual loop operational procedures in an attempt to alleviate the RS radiator bypass valve anomaly.

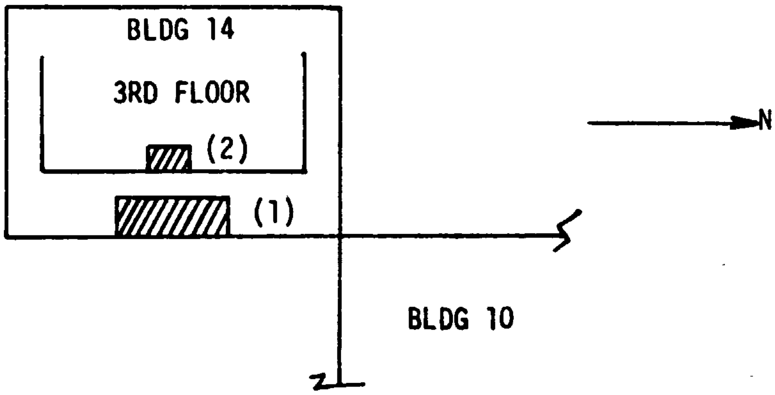
7.3.6 Facility Description/Evaluation

7.3.6.1 Mission Support Center

A. Description - The OWS Mission Support Center consisted of a four segment interconnected complex plus a separate data room all located on the east end of the third floor of Building 14. Figure 7.3.6-1 is a sketch of the OWS Mission Support Center showing the relative position of the various areas.

1/ Mission Support Room (MSR) - The MSR was the focal point of OWS mission support activities and was the normal duty station during mission support activities for assigned personnel. The MSR was organized as shown in Figure 7.3.6-1. Nineteen direct support positions were provided, however, the room accommodated up to 30 persons during high activity periods. Table location assignments for normal operations were as follows:

OWS MISSION SUPPORT CENTER
LOCATION AND GENERAL LAYOUT



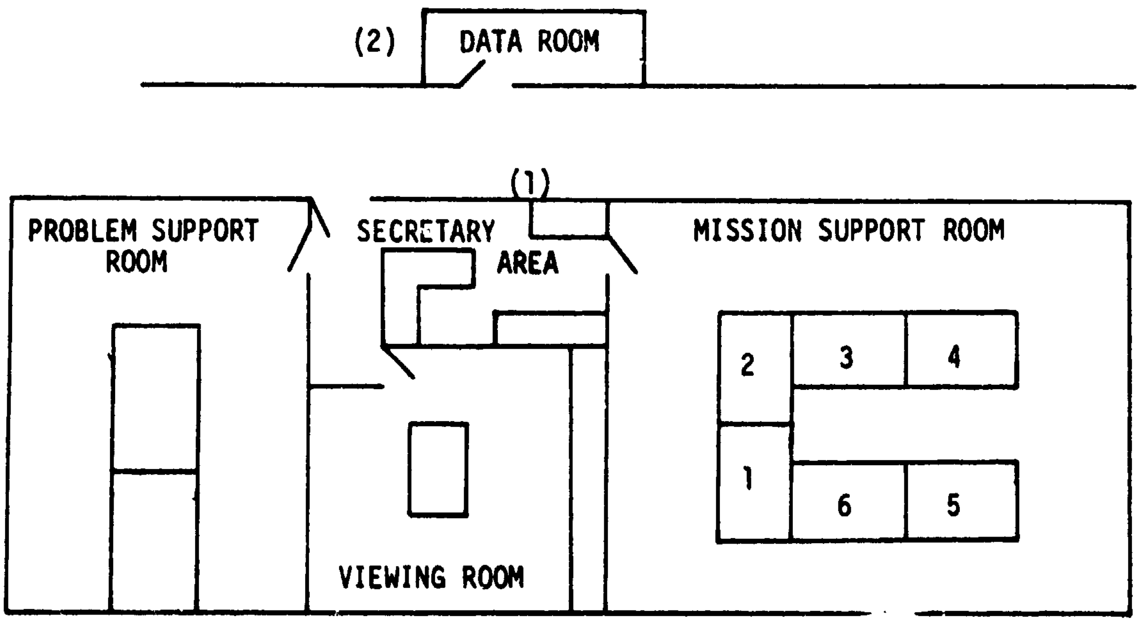


FIGURE 7.3.6-1

Tables 1 and 2: Room Captain

Mission Operations Representative

Senior Technical Representative

NASA Representative

Duty Officer

Experiments

Tables 3 and 4: Mechanical

Crew Systems

Aero/Thermal

Propulsion

Tables 5 and 6: Electronics

Structures

Flight Mechanics

Historian

Facilities were available in the MSR for display of significant data (schematics, detailed flight plans, spacecraft panel layouts, photographs, etc.) and storage of mission documentation and essential support data frequently used during mission operations.

2/ Secretarial and Access Control Area - This area provided all facilities and supplies for secretarial support and magnafax transmitting and receiving capability.

Access to the MSR could only be obtained through this area and was limited to those required for mission support. The Room Captain had complete authority for access control.

3/ Problem Support Room (PSR) - The PSR was used for mission problem solving activity when group activities would interfere with normal operations of the MSR. The PSR had limited support facilities in terms of display space, chalkboards, etc.

4/ Viewing Room - This room was utilized for observation of the OWS mission support activities without interfering with those operations. The room accommodated up to 20 people during peak activity periods and was also used as a second Problem Support Room

5/ Data Room - This room was utilized for storage of mission support type data (i.e., selected as-run test procedures, design drawings, real time voice tapes, crew voice transcripts, etc.) A Xerox reproduction machine was located here for support of OWS mission support activities.

B. Evaluation - The mission support center was adequately sized and arranged to support mission monitoring and problem solving activities.

7.3.6.2 Communications

A. Description - Communications within the OWS Mission Support Center complex were as follows:

1/ Telephone - Eighteen telephone instruments were installed in the OWS Mission Support Center with 11 different extensions. These included two Federal Telephone System (FTS) lines and four MDAC Type 1 (direct dial) lines.

2/ Magnafax - A magnafax terminal was installed in the secretarial area which provided 24 hours/day sending and receiving capability. The magnafax was connected to an FTS telephone line (additional to the two MSR FTS lines).

3/ Television - Commercial color TV sets were located in the MSR and Viewing Room. These sets were utilized to monitor commercially broadcast Skylab activities.

4/ Launch Information Exchange Facility (LIEF) Voice Circuits - Three speakers were installed which were patched into the LIEF Board at Huntsville. One speaker broadcast the launch director loop during KSC prelaunch activities and was switched to the JSC flight director's loop at launch of SL-1. The second speaker broadcast the KSC OIS during prelaunch activities (switchable at HOSC to any of 16 KSC OIS circuits) and was switched to the JSC GOSS at launch for monitoring of crew voice conversation with JSC. The third speaker was used when S-IVB mission support activities required use of the other two lines during SL-2, -3, and -4 launches.

5/ Data Displays - Two Cathode Ray Tube (CRT) data displays were installed in the MSR. These displays each had a separate keyboard and provided the capability of displaying data in various formats from the Data Engineering Tape Library (OWS checkout data and user mag tapes supplied by MSFC during the missions). The two CRT displays were tied to a Timeshare computer so that both worked independently and simultaneously on different tapes. A single hardcopy device was installed in the same area as the displays and was shared between the two displays. This device provided a hardcopy of the data being displayed on either CRT. A single intercom in the same area provided two-way conversations between the MSR and the Data Engineering Laboratory.

6/ Time - Clocks were installed along the north wall as follows:

Ground Elapsed Time (Digital Clock)	MSFC/JSC
Greenwich Mean Time (GMT)	Local Time
KSC Time	

7/ A remotely activated "Beeper" system was established whereby key personnel were contacted when away from their normal telephones to assist in solving mission problems/action items. The MSR part of the system consisted of 30 Beeper units each with a unique 4 digit code number assigned to key individuals and a special touch pad telephone. The touch pad telephone could access a central computer and input a 4 digit code activating the desired Beeper. In addition, an operator was on duty 24 hrs/day at the Beeper facility for voice requests by regular telephone.

B. Evaluation - Communications were generally adequate and properly sized to support mission activities except as noted in the following:

1/ Due to extremely high activity in the first part of the mission telephone capacity and arrangement was found to be inadequate, and the following changes were accomplished: two new extensions were added to the Problem Support Room (PSR), a single line speaker phone was added to the Room Captain's position and was dedicated for use between the MSR and CWA No. 6.

2/ The vast majority of magnafax activity was transmittal of action item information between the MSR and HOSC CWA No. 6. A great deal of time was wasted in this communication loop due to the slowness of magnafax (6 minutes per page) and due to the fact that CWA No. 6 did not have a magnafax machine and all transmittals had to go through the HOSC Administrative Support Center. The main problems occurred when sending from the Huntington Beach MSR to HOSC since an automatic machine was used to receive and often large action items would have to be sent 2 or 3 times just to get one readable set of pages. A manual magnafax machine in CWA No. 6 would have greatly improved this loop.

3/ As the mission progressed beyond the early stages, very little Skylab TV was broadcast commercially. For the TV to be effective on future programs a data link would have to be provided to supply real time TV which is received at JSC.

4/ The CRT data displays did not get as much utilization as expected. One problem with this system was that the data displayed was generally old. A more desirable system would have been a real time data link to HOSC.

7.3.7 Mission Support Manning Schedules (Manned/Unmanned) - The quantity and types of personnel required in the MSR during any particular time period depended upon the type of mission activity taking place in that time period. Generally, minimum manning levels were adjusted downward as the mission progressed and action item activity decreased. The following discusses the manning during each mission period.

A. KSC Prelaunch Operations - The MSR was utilized as a focal point for Huntington Beach support of KSC checkout and prelaunch activities. The room was manned by a Locator 24 hrs/day during the last four months prior to launch. On-call personnel were available to be contacted by the Room Captain/Locator to initiate work on the KSC problems. The Locator was replaced by a mission support team dur- specific high activity and launch tests. The team consisted of a Room Captain and the appropriate technology personnel necessary to support each individual test. During normal KSC operations the MSR was available for Huntington Beach personnel to monitor KSC tests on the voice loops.

B. SL-1 - This period began at approximately T-4 hours and continued to SL-2 launch. Manning for this period was per Table 7.3.7-1.

C. SL-2, SL-3, and SL-4 Manned Activation/Deactivation - Manning for SL-2, SL-3, and SL-4 activation/deactivation was per Table 7.3.7-2.

D. Normal Manned Orbital Operations (SL-2, -3, and -4) - This period consisted of normal manned operations subsequent to the activation period and stabilization of OWS systems. Minimum MSR manning during these periods was per Table 7.3.7-3.

E. Unmanned Orbital Operations - This period started at the end of the applicable deactivation period and lasted to the start of the next activation period. During this period the MSR was manned 24 hrs/day by a Room Captain. No preplanned design technology manning was necessary during this period, however, technology representatives were required to visit the MSR daily to be abreast of mission activity. Personnel necessary to solve specific mission problems were called in as necessary.

F. Extra Vehicular Activity (EVA) Periods - A minimum crew was required consisting of the following: Room Captain, Historian, Propulsion, Electrical, Mechanical, Aero Thermal, Structures, Crew Systems.

TABLE 7.3.7-1
SL-1 MANNING

POSITION	MSR DUTY PERIOD
ROOM CAPTAIN	CONTINUOUS
MISSION OPERATIONS	CONTINUOUS
EPS	
SENIOR SYSTEM ENGINEER	FIRST 10 HOURS
SYSTEM ENGINEER	CONTINUOUS
I&C	
SENIOR SYSTEM ENGINEER	FIRST 10 HOURS
SYSTEM ENGINEER	CONTINUOUS
ECS	
SENIOR SYSTEM ENGINEER	FIRST 10 HOURS
SYSTEMS ENGINEER	CONTINUOUS
FLIGHT MECHANICS	
CONTROL SYSTEM ENGINEER	THROUGH ORBIT STABILIZATION
KINETICS SYSTEM ENGINEER	THROUGH ORBIT STABILIZATION
MECHANICAL	
SENIOR SYSTEM ENGINEER	FIRST 10 HOURS
SYSTEM ENGINEER	CONTINUOUS
ORDNANCE ENGINEER	THROUGH DEPLOYMENT SEQUENCES
REFRIGERATION	
SENIOR SYSTEM ENGINEER	FIRST 10 HOURS
SYSTEM ENGINEER	CONTINUOUS
PROPULSION	
SENIOR SYSTEM ENGINEER	FIRST 10 HOURS
SYSTEM ENGINEER	CONTINUOUS
STRUCTURES	
SENIOR SYSTEMS ENGINEER	FIRST 10 HOURS
SYSTEM ENGINEER	CONTINUOUS
SAS DESIGN ENGINEER	FIRST 10 HOURS
METEOROID SHIELD ENGINEER	FIRST 10 HOURS
HISTORIAN	CONTINUOUS
SENIOR TECHNICAL REPRESENTATIVE	CONTINUOUS
OWS DUTY OFFICER	CONTINUOUS
SECRETARY	6:00 AM TO 7:00 PM DAILY

TABLE 7.3.7-2

SL-2, SL-3, SL-4 ACTIVATION/DEACTIVATION MANNING

POSITION	MSR DUTY PERIOD
ROOM CAPTAIN	CONTINUOUS
MISSION OPERATIONS	CONTINUOUS
ELECTRICAL	CONTINUOUS
ECS	CONTINUOUS
MECHANICAL/REFRIGERATION	CONTINUOUS
CREW SYSTEMS	CREW AWAKE PERIOD
EXPERIMENTS	CONTINUOUS DURING EXPERIMENT ACTIVATION/DEACTIVATION
PROPULSION	CONTINUOUS
STRUCTURES	CONTINUOUS
HISTORIAN	CONTINUOUS
SENIOR TECHNICAL REPRESENTATIVE	CONTINUOUS
OWS DUTY OFFICER	CONTINUOUS
SECRETARY	6:00 AM TO 7:00 PM DAILY

NORMAL ORBITAL
OPERATIONS MSR MINIMUM MANNING

POSITION	MSR DUTY PERIOD			
	SL-2	SL-3	SL-4	SL-4 11-25-73 -- 02-09-74
ROOM CAPTAIN	CONTINUOUS	CONTINUOUS	CONTINUOUS	CONTINUOUS
MISSION OPERATIONS	0600-2200 DAILY	0600-2200 DAILY	0600-2200 DAILY	0600-2200 DAILY
ELECTRICAL	0600-2000 DAILY	0600-1800 DAILY	0600-1800 DAILY	0600-1700 5 DAYS/WK*
ECS	0600-2000 DAILY	0600-1800 DAILY	0600-1800 DAILY	0600-1700 5 DAYS/WK*
MECHANICAL/REFRIG	0600-2000 DAILY	0600-1800 DAILY	0600 1800 DAILY	0600-1700 5 DAYS/WK*
CREW SYSTEMS	0400-2000 DAILY	0400-2000 DAILY	0600-2000 DAILY	0600-1700 5 DAYS/WK*
EXPERIMENTS	0600-1800 DAILY*	0600-1700 DAILY*	0600-1700 DAILY*	0600-1700 5 DAYS/WK*
PROPULSION	0800-1700 DAILY	0800-1700 DAILY	0600-1800 DAILY	0600-1700 5 DAYS/WK*
STRUCTURES	0800-1700 DAILY	0800-1700 DAILY	0600-1800 DAILY	0600-1700 5 DAYS/WK*
HISTORIAN	CONTINUOUS	CONTINUOUS	CONTINUOUS	0400-2000 5 DAYS/WK*
SENIOR TECH REP	CONTINUOUS	0600-1800 DAILY	0600-1800 5 DAYS/WK	0600-1700 5 DAYS/WK*
OWS DUTY OFFICER	0600-1800 DAILY	0600-1800 DAILY	0600-1800 5 DAYS/WK	0600-1700 5 DAYS/WK
SECRETARY	0600-1900 DAILY*	0600-1900 DAILY*	0600-1900 5 DAILY*	0800-1642 5 DAYS/WK

*0600-1400 SAT & SUN

TABLE 7.3.7-3

G. Unplanned Contingency Periods - On-call personnel were recalled to MSR by Beeper system (Reference Section 7.3.6 B.7.) as required to support contingency.

7.4 CONCLUSIONS AND RECOMMENDATIONS

7.4.1 General - The overall MDAC-W Orbital Workshop (OWS) mission support activity was conducted per the pre-mission plan. The resultant support was effective in providing NASA the technical information, test information, and hardware required to support mission operations. All actions directed to MDAC-W were completed in a timely fashion with responses directed to the appropriate MSFC technical [Mission Support Group (MSG)] personnel through the MDAC-W MSFC on-site personnel.

7.4.2 Prelaunch Support - From mid-January, 1973, to Skylab-1 (SL-1) launch, around-the-clock "locator type" support was provided at Huntington Beach in support of KSC checkout and launch preparations. While KSC support requirements were relatively light compared to mission support, several hardware support requests were coordinated through the support room which resulted in expedited handling and shipping of replacement hardware to KSC. Use of teleconference capability to allow various Huntington Beach engineers and management personnel to discuss technical problems with MDAC-KSC personnel during Huntington Beach non-working hours proved fruitful. As we approached launch and time to solve problems became more critical, this service received increased activity. Prelaunch support is concluded to have been adequate as conducted.

7.4.3 Mission Simulations - Pre-mission participation by MDAC-W in the NASA mission simulations proved beneficial in the development of in-house operating systems and procedures and in developing communication channels with the NASA mission support organizations. It is believed that additional benefits could have been derived from these mission simulations had (1) NASA real time data processing and data handling been included as a part of the simulations, and (2) MDAC-W been permitted to participate more actively in the simulation debriefings.

7.4.4 Mission Support Organization and Manning - The OWS mission support team included members from all program support organizations and was formed to assure an integrated and total response to all launch and mission support demands. This team concept proved effective for dealing with all mission support problems by providing technical support, test support and hardware development support. Huntington Beach mission support was provided around-the-clock for the entire mission period. Manning levels in the MSR varied dependent upon mission periods and level of activity. The manning levels were adequate to support the NASA requirements in a timely manner. Making "on-call" assignments and use of radio controlled paging systems proved very effective in contacting personnel during off-duty hours. Integration of key MDAC launch and support personnel into the mission support team proved beneficial to the mission support activity and helped to maintain the capability for a backup launch should this have been required.

7.4.5 Mission Support Facilities - The facilities at Huntington Beach as described in Section 7.3 were utilized to their fullest capability and proved to be a significant factor in the overall capability to provide effective support. Of significant importance were the flight director and crew real time voice transmission loops which provided the capability to maintain cognizance of mission progress and problems.

The magnafax machine traffic was very heavy and quite often caused delay of required information due to slowness of transmission (six minutes per page). Higher speed transmission equipment is strongly recommended. The presence of a magnafax station in Conference Work Area (CWA) No. 6 at the Huntsville Operations Support Center (HOSC) would have proved beneficial, especially during high activity periods when the HOSC central machine was busy or unattended in the automatic mode causing a requirement for re-transmission of many pages due to "page-splitting" or other transmission problems.

The lack of real time data at Huntington Beach diluted the capability of the technical people to provide thorough and timely response to many problems. Telephone communication of real time data from MSFC helped to fill this gap but expediting of hard data (data tapes, etc.) through normal system and transportation channels was ineffective in supporting real time problems. The delay for this data was normally 7 to 10 days making it useful only for long term mission evaluation. A real time data source, Mission Operations Planning System (MOPS) terminal or equivalent, would have proved beneficial.

7.4.6 Action Item Assignment, Tracking, and Response - A total of 1012 action items were assigned to the OWS mission support team with responses to all actions provided to the MSFC in a timely manner as required to support the on-going mission operations. These actions involved the following type of activity:

150	Hardware Delivery Actions
68	Component Test Support Actions
27	OWS Backup Test Support Actions
54	Engineering Information Actions
88	Crew Procedures Actions
625	Engineering Analysis Actions
1012	Total OWS Mission Support Actions

The MDAC mission support action item system for assignment, tracking, and responding to mission support requirements was basically sound and remained intact throughout the mission. This system provided the necessary integration, tracking, and management surveillance to maximize timeliness and quality of action item responses. During the early mission period, the action item traffic was so heavy that both timeliness and quality of some action item responses was less than desired. Additional resources and time (neither of which were practical) may have alleviated this problem. In many cases a better definition of the problem would have been beneficial but was difficult to obtain because of the same heavy workload burden on the NASA personnel at MSFC and JSC. A more formal NASA (both MSFC and JSC) feedback system to document the final disposition of action items [Mission Action Requests (MAR's), Action Requests (AR's), and OWS Action Items (AI's)] would have proved beneficial. Quite often we would learn of problem disposition by monitoring crew voice or flight director loops, reading crew transcripts, or through direct requests through MSFC of JSC mission support group personnel.

Maintaining a good action item index and tracking system was difficult during the early mission period as many related actionswere assigned new action item numbers with no reference to previous actions addressing similar activity. This was generally corrected by greater use of action item dash numbers to group related actions.

7.4.7 Hardware and Test Support - The inclusion of manufacturing operations and the various MDAC test support organizations as part of the OWS mission support team and the assignment and control of hardware and test support activity through the basic mission support action assignment system proved very effective. Hardware and test activities were accomplished in concert with mission support requirements and were provided in a timely manner. Delivery and control of MDAC hardware to MSFC during the early mission period caused some problems. A system for single point (one individual) delivery and control was established and alleviated many of the problems.

7.4.8 MDAC-W On-Site Support at MSFC - The general approach used by NASA/MSFC and supported by MDAC-W to provide mission support at MSFC was sound and worked. Shortly after the initial launch, however, the need for operational improvements became evident and a series of changes were implemented. The most notable of these were: (1) a substantial increase in level of attention to real time monitoring of systems via data display consoles in the HOSC and establishment of plans and criteria for collecting and evaluating data (consoles were monitored on a 24-hour a day basis rather than the before-launch plan of 8 hours a day), and (2) a substantial increase in the numbers of personnel and the technical depth of talent required real time in the HOSC, including the establishment of an Operations Director and Senior Operations Director to act as both technical and operational management for all HOSC resources.

The assignment by the MSG leaders of some MDAC-W support engineers to console monitoring positions diverted their attention from technical coordination of OWS actions and responses. It is believed that the on-site MDAC-W support personnel could have provided better support in the coordination role. To accommodate this would have required additional personnel for assignment to the console positions.

In the action item system the contractor was excluded from direct action item response requirements other than as a support role when requested by the MSG. While MDAC-W chose to respond to all actions affecting the OWS, this was not true for all contractors. Action item submittal utilization was thus the perogative of the MSG. It is believed that the prime contractors could have been of greater service if utilized more directly in the action response system and given the opportunity to review responses affecting their systems.

Major technical discussions were often carried out on the Operations Director (OD) networks or Flight Operations Management Room (FOMR) loops without the contractor, and the contractor was not involved unless they were called into the Support Action Center - Orbital Assembly (SAC-OA) room to participate. In addition, the contractors home facility was rarely tied into a conference loop. This exclusion occasionally resulted in incomplete information being related on a particular question. It is believed, in the future, that better contractor support can be realized by inclusion in action discussed teleconferences and meetings.

The CWA No. 6 was generally inadequate. The size was too small to fully accommodate supporting material, work areas to lay out drawings and discuss problems, as well as monitor voice and data loops. Each contractor should have a two-room complex with at least three times the square footage of area. One room should house a library with pertinent data, handbooks, procedures, etc., to support problem evaluation, while the other room should be utilized strictly for voice monitoring and teleconferences. The data room should have microfilm drawing file and printer along with an Long Distance Xerox (LDX) machine. The absence of drawings within HOSC often placed an unnecessary burden on personnel to drive the one mile to the MDAC-W office at MSFC, locate the microfilm and print a drawing. The available phone lines were often busy and difficult for incoming callers. A phone with a rotary of four numbers would have greatly relieved the congestion.

The volume of data and magnitude of the data handling and processing systems for Skylab were probably under estimated. The differences and changes from the Apollo systems are much more profound in the areas of data reduction and analysis than in the display and monitoring of the real time data.

Problems were encountered in the processed All Digital Data Tape (ADDT) data during simulations conducted before liftoff which caused a very low confidence level in this data system. However, many of these problems were resolved during the mission such that "erroneous data" became the exception rather than the rule. Using relatively new "state of the art" techniques like the zero order prediction at the remote Spaceflight Tracking and Data Network (STDN) sites added to the already complicated, complex system. Although the data compaction that was actually achieved was not what was expected, the Skylab data system performance should form a good basis for further investigation and studies. The development of the Auto Scan Program to assist the systems engineers in spotting and analyzing anomalies were rendered almost useless by the lack of confidence in the ADDT data. Perhaps the overwhelming task of processing the Skylab data could have been performed with more confidence if more systems checkout time could have been allowed or if the burden were shared with each module contractor.

SECTION 8 - NEW TECHNOLOGY

The Skylab (SL)-Orbital Workshop (OWS) evolved from the Saturn S-IV/S-IVB, the Manned Orbital Laboartory (MOL), and the Gemini and Mercury programs over a time span of fifteen years. A considerable amount of new technology has been developed during this time which is applicable to current and future aerospace programs and to the commercial sector of the USA economy. These new technologies include patent disclosures, hardware with associated test and operational data, and design fabrication, test, checkout and/or mission support computer programs. These items can be applied as currently established or can provide a cost effective basis for conversion to the desired configuration.

8.1 AEROSPACE APPLICATIONS

The applicable new technologies will be identified in the following two sections: Patent Disclosure Listing and Hardware and Design Concepts.

8.1.1 New Technology Patent Disclosures - MDAC-W, under the provisions of the New Technology Clause, made 104 New Technology disclosures during the years 1969 through 1974. Table 8.1.1-1 is a tabulation of these disclosures. All new technology reports received by NASA are reviewed and those having commercial potential are disseminated to all sectors of the U.S. industry by NASA. As noted in the tabulation, NASA has filed Patent Applications on some of the items. Six items have been filed for patent by NASA and 22 items are of notable use.

8.1.2 Applicable Hardware and Design Approaches - The OWS design represents a state-of-the-art which resulted from an evolution of manned spacecraft technology from the early days of the Mercury and Gemini designs, continuing through the giant step taken by the Apollo program, then through the further improvements necessary to sustain long duration manned space missions required by the Skylab program.

Table 8.1.1-1

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER
NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
1	R-4486	Non-Contaminating Shroud Separator #1	30 Jan 70	Extension of Commercial Separator
2	R-4487	Non-Contaminating Shroud Separator #2	30 Jan 70	Extension of Commercial Separator
3	R-4531	Dental Hygiene Device	27 Feb 70	
4	R-4621	Trash Disposal Airlock	3 Jun 70	Patent Application Filed by NASA
5	R-4624	System Leakage Indicator	3 Jun 70	NASA Showed Special Interest
6	R-4717	Urine/Water Dump Probe	14 Aug 70	
7	R-4732	Power Management Computer Program	4 Sep 70	Computer Program Made Available Thru COSMIC
8	R-4746	Food Water Dispenser	25 Sep 70	Patent Application Filed by NASA
9	R-4753	Fecal Bolus Separator	25 Sep 70	
10	R-4780	Drinking Water Dispenser	23 Oct 70	Patent Application Filed by NASA
11	R-4781	L101 Wire Harness Program	23 Oct 70	Computer Program Made Available Thru COSMIC
12	R-4802	General Illumination Floodlight	12 Nov 70	
13	R-4815	Interchangeable Shear	23 Nov 70	
14	R-4953	H.P.I. Fastener	28 Apr 71	

Table 8.1.1-1 (Continued)

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER
NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
15	R-4962	Straight Tube Fitting	13 May 71	
16	R-4971	High-Performance Insulation Fastener	17 May 71	Commercial Use Anticipated
17	R-4987	Fastener Retaining Wrench	24 May 71	
18	R-4996	Liquid Gas Separator	8 Jun 71	
19	R-5002	PK Screw Installation	24 Jun 71	
20	R-5007	Preload Indicating Turnbuckle	24 Jun 71	Patent Application Filed by NASA NASA Tech Brief
21	R-5027	Load Indicator, Variable	9 Nov 71	Patent Application Filed by NASA
22	R-5034	Pressure Control System	15 Jul 71	
23	R-5040	Remote Weighing Device	15 Jul 71	Patent Application Filed by NASA NASA Tech Brief
24	R-5052	Swaging Tool	28 Jul 71	Part of Commercial Aircraft Program
25	R-5064	Nonflammable Fiberboard	12 Aug 71	NASA Showed Special Interest
26	R-5094	Flexible Thermal Device	14 Sep 71	
27	R-5104	Orbital Exercise Track	17 Sep 71	
28	R-5106	Zero "G" Bidet	21 Sep 71	
29	R-5107	Self Sealing Valve	21 Sep 71	

Table 8.1.1-1 (Continued)

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
30	R-5108	Re-Circulation Valve	21 Sep 71	
31	R-5111	Tube Positioned Radioisotope Heaters	21 Sep 71	
32	R-5114	Diffuser Assembly	24 Sep 71	
33	R-5116	Zero-G Washcloth Squeezer	24 Sep 71	
34	R-5117	Ball Detent Mechanism	24 Sep 71	
35	R-5119	Hygiene Water Dispenser	24 Sep 71	
36	R-5122	Container Support System	24 Sep 71	
37	R-5125	Cable Strain Relief	7 Oct 71	
38	R-5131	End Closure	14 Oct 71	
39	R-5132	Liner, Polyethylene	14 Oct 71	
40	R-5143	Checkout Integrity Sort	12 Oct 71	Computer Program Made Available Thru NASA
41	R-5158	Explosively Severed Strap	27 Oct 71	
42	R-5159	SAS Release Mechanism	27 Oct 71	
43	R-5160	Explosive Severance System	27 Oct 71	Extension of Commercial Separator
44	R-[illegible]	Humidity Control Protection	11 Nov 71	
45	R-5173	CO_2 Swept Leak	11 Nov 71	

Table 8.1.1-1 (Continued)

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER
NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
46	R-5174	Waste Tank Vent	11 Nov 71	
47	R-5176	Trash Ejector	11 Nov 71	Useful in Commercial Area
48	R-5179	Jumper Test, Special	11 Nov 71	
49	R-5185	Resettable Break-Away Strut	11 Nov 71	
50	R-5187	Transducer, Water Level	23 Nov 71	
51	R-5190	Coiled Metal Tube	23 Nov 71	
52	R-5209	Expandable Closure Pads	23 Dec 71	
53	R-5211	Air Flow Measurement	23 Dec 71	
54	R-5212	Flameproof Sensor Installation	23 Dec 71	
55	R-5213	Fusible Material Program	23 Dec 71	Available Thru COSMIC
56	R-5214	Universal P.O.E. Program	23 Dec 71	Available Thru COSMIC
57	R-5215	Fire Break Fitting	23 Dec 71	
58	R-5216	H.P.I. Material Removal	23 Dec 71	Commercial Use Anticipated
59	R-5222	Electronic Module Encapsulant	23 Dec 71	
60	R-5225	Protective Nozzle Cover	23 Dec 71	
61	R-5227	Fluid Dispenser	24 Dec 71	
62	R-5228	Color Comparator	24 Dec 71	Commercial Satellite Use

Table 8.1.1-1 (Continued)

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER
NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
63	R-5229	Fluid Sampler	24 Dec 71	
64	R-5230	Fluid Injector	24 Dec 71	
65	R-5233	Feedthrough Junction Module	24 Dec 71	
66	R-5234	Trash and Stowage Bags	24 Dec 71	Useful in Commercial Area
67	R-5235	Fill and Vent Quick Disconnect	24 Dec 71	
68	R-5236	Individual Wire Identification	24 Dec 71	Commercially Useful
69	R-5237	Continuity/Compatibility Procedure	24 Dec 71	
70	R-5242	Clamps, Tie Down	17 Jan 72	Commercially Useful
71	R-5243	Ventilation Unit	17 Jan 72	
72	R-5244	Fusible Control Material	17 Jan 72	
73	R-5245	STI Computer Technique	17 Jan 72	Available Thru COSMIC
74	R-5262	Latch-Container	17 Jan 72	
75	R-5267	Indexing Cleat	17 Jan 72	
76	R-5277	OWS Thrust Inbalance	3 Feb 72	
77	R-5281	Propulsion Hardware Statistic	3 Feb 72	
78	R-5294	Bi-Metal Joint Doubler	15 Feb 72	

Table 8.1.1-1 (Continued)

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER
NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
79	R-5300	Wobble Damping System	28 Feb 72	
80	R-5305	Deployable Meteoroid Shield	28 Feb 72	
81	R-5306	Adjustable Experiment	28 Feb 72	
82	R-5319	Starch-Iodide Reagent	8 Mar 72	
83	R-5336	Blueprint Roller	20 Mar 72	
84	R-5349	Hydrophobic Trash Bag	7 Apr 72	
85	R-5350	Radiator Control Valve	7 Apr 72	
86	R-5356	Flange Receptacle Retainer	7 Apr 72	
87	R-5360	Foot Restraints	12 Apr 72	
88	R-5363	Water Servicing System	25 Apr 72	
89	R-5384	Lens Protection System	9 May 72	
90	R-5386	Zero G Chair	9 May 72	
91	R-5409	Torknob, Hand Valve	22 May 72	
92	R-5431	Dip Brazing Technique	9 Jun 72	
93	R-5439	Nonflammable Webbing	22 Jun 72	
94	R-5442	Strap Tension Meter	22 Jun 72	

Table 8.1.1-1 (Continued)

NEW TECHNOLOGY PATENT DISCLOSURES DEVELOPED UNDER NASA CONTRACT NAS9-6555 ORBITAL WORKSHOP

ITEM NO.	MDC PATENT DISCLOSURE DOCKET NO.	TITLE	DATE REPORTED	REMARKS
95	R-5505	3-D X-Ray Analysis	28 Aug 72	
96	R-5506	Retainer	28 Aug 72	Commercially Useful
97	R-5565	Computer Program G347-R	26 Oct 72	Available Thru COSMIC
98	R-5614	Computer Program SAGP-E	26 Oct 72	Available Thru COSMIC
99	R-5803	Hydrophillic Screen Separator	15 Jan 73	
100	R-5661	Acoustic Release Mechanism	13 Mar 73	
101	R-5679	Heat-Gun Temperature Indicator	18 May 73	
102	R-5733	Biocide-Water Prediction	14 Jun 73	
103	R-5762	L101 Line Sort	7 Aug 73	
104	R-5773	Dark EI Test Set	13 Aug 73	

OWS design is composed of several phases of technological development:

A. Existing flight-qualified hardware subsystems from the Gemini program.

B. Apollo-era technology uprated in several areas to accommodate the extended duration of zero-g flight conditions.

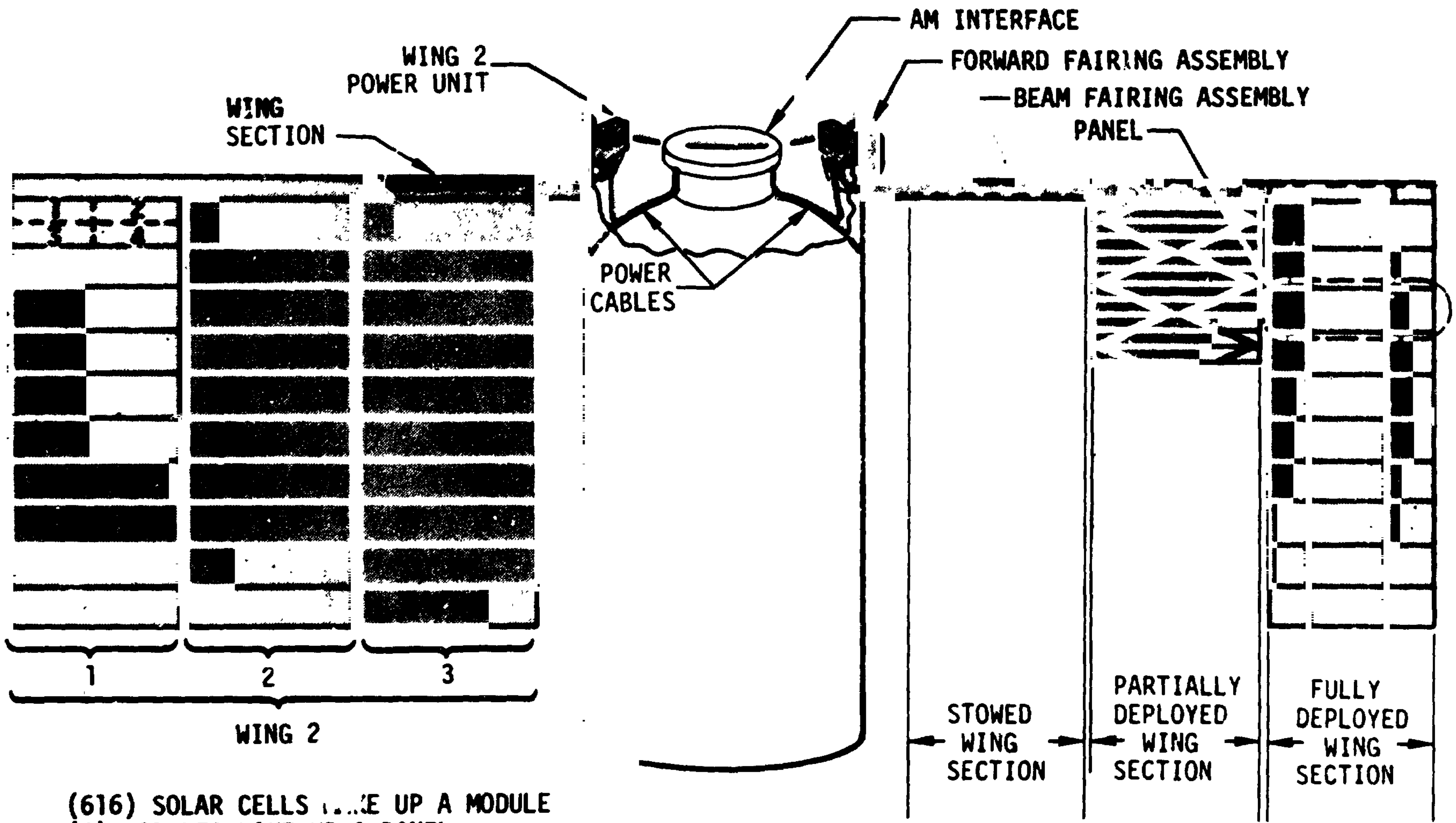
C. New systems developed to accommodate needs not previously experienced representing current state-of-the-art.

Several of the technology advancements are, in part, due to the large volume within the habitable quarters of the spacecraft. Sufficient room is available for the design of individual sleeping quarters, a wardroom for preparing and eating meals, a waste management compartment, and an entertainment center. All are separate from the area designated for conducting experiments.

The following OWS systems provide a reservoir of hardware, operational use data and analysis/design approaches which can provide cost effective solutions for current and/or future manned/unmanned spacecraft.

Electrical Power System (EPS) - The OWS power source consists of approximately 1,200 ft^2 (111.5 m^2) of solar cells. Mission duration and redundancy requirements precluded the use of fuel cells, the prime power supply for Apollo. Under normal operating conditions the workshop arrays supply power to the Multiple Docking Adapter, Airlock Module, and Orbital Workshop; the Apollo Telescope Mount arrays supply power for the experiments and control system located in that mount only. In addition, bidirectional power transfer capability is provided by means of transfer busses to allow either array system to power the entire Skylab cluster.

The OWS Solar Array System (Figure 8.1.2-1) consists of externally mounted and deployable wing assemblies which unfold after insertion into orbit to expose the solar panels to sunlight. The sun side of the solar array is covered by 147,840 solar cells connected in series to satisfy the voltage requirements, and in parallel to satisfy the current and power requirements. These cell-groups are combined into modules and panels. Modules are connected electrically in 8 groups and located on the wings in a specified



(616) SOLAR CELLS MAKE UP A MODULE
(4) MODULES MAKE UP A PANEL
(10) PANELS MAKE UP A WING SECTION
(3) WING SECTIONS PLUS BEAM FAIRING
MAKE UP A WING

Figure 8.1.2-1. ORBITAL WORKSHOP SOLAR ARRAY SYSTEM pattern to compensate for the effects of potential shadows and variations in array temperature. This technique helps maintain a balance in the use of the power conditioning groups, thus equalizing the life of the numerous onboard batteries. The average available power from the array during the sunlight portion of the orbit is approximately 10,500 watts while in the solar inertial mode. However, due to the day/night operation, vehicle orientation, and system efficiency, the power output capability is approximately 3,750 watts. The mechanical and electrical buildup of the system to maintain redundancy and to minimize the impact of single point failures is a unique design feature which was beyond the state-of-the-art at the time the preliminary designs were initiated.

Refrigeration System - To provide freezers and chillers for food, water, and urine for the extended stay in orbit, an active refrigeration system was required (Figure 8.1.2-2). The simpler thermal control system used in earlier manned spacecraft could not provide the low temperatures desired, the redundancy or duration required for the Skylab mission. The refrigeration system consists of a circulating single phase liquid coolant (Coolanol), a large radiator, and a phase changing wax compound heat sink (Undecane) which acts as a thermal capacitor. The radiator is sized to provide an energy rejection rate to space equal to the average OWS excess energy load. The peak energy demands are satisfied by the thermal capacitors which absorb excess thermal energy during the daytime orbital pass.

Film Vault - The large amount of highly sensitive photographic film required for the Skylab mission resulted in a unique design problem. Return of the film to the ground was limited to the scheduled deorbiting of the Command Module and crew, necessitating a relatively long storage period. The high radiation levels encountered at the Skylab orbital altitude dictated an extreme shielding requirement, consisting of a thick-walled aluminum vault approximately 15 ft^3 (.42 m^3) in volume (Fig. 8.1.2-3). To protect the packaged film magazine/cassettes from damage due to moisture, special desiccant salt packs are stowed in the film vault. These salt packs are calibrated to maintain a relative humidity of approximately 45 percent throughout the mission duration. The shielding requirement resulted in a vault weighing about 3,000 pounds. This large concentrated weight required

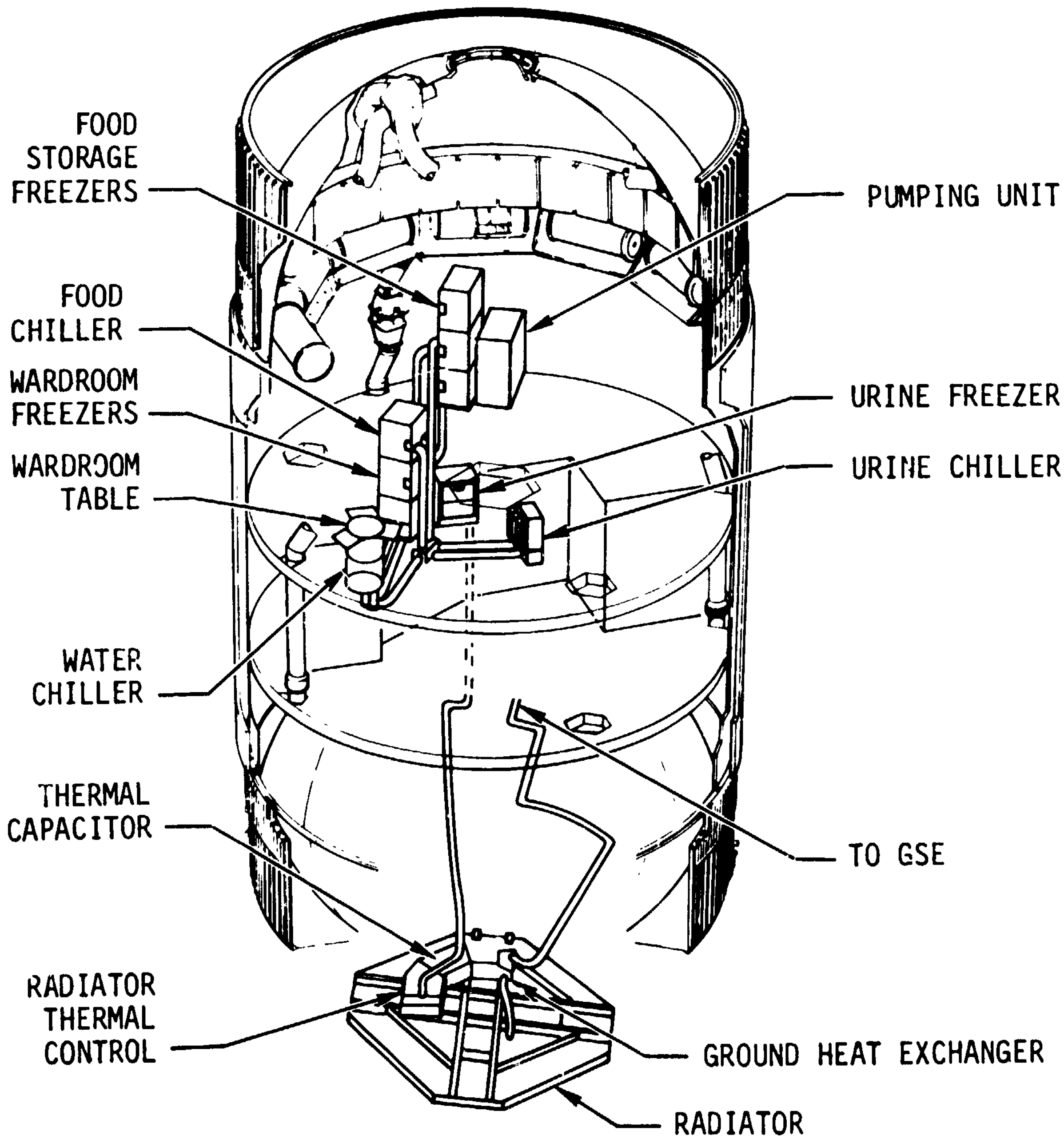


Figure 8.1.2-2. REFRIGERATION SYSTEM

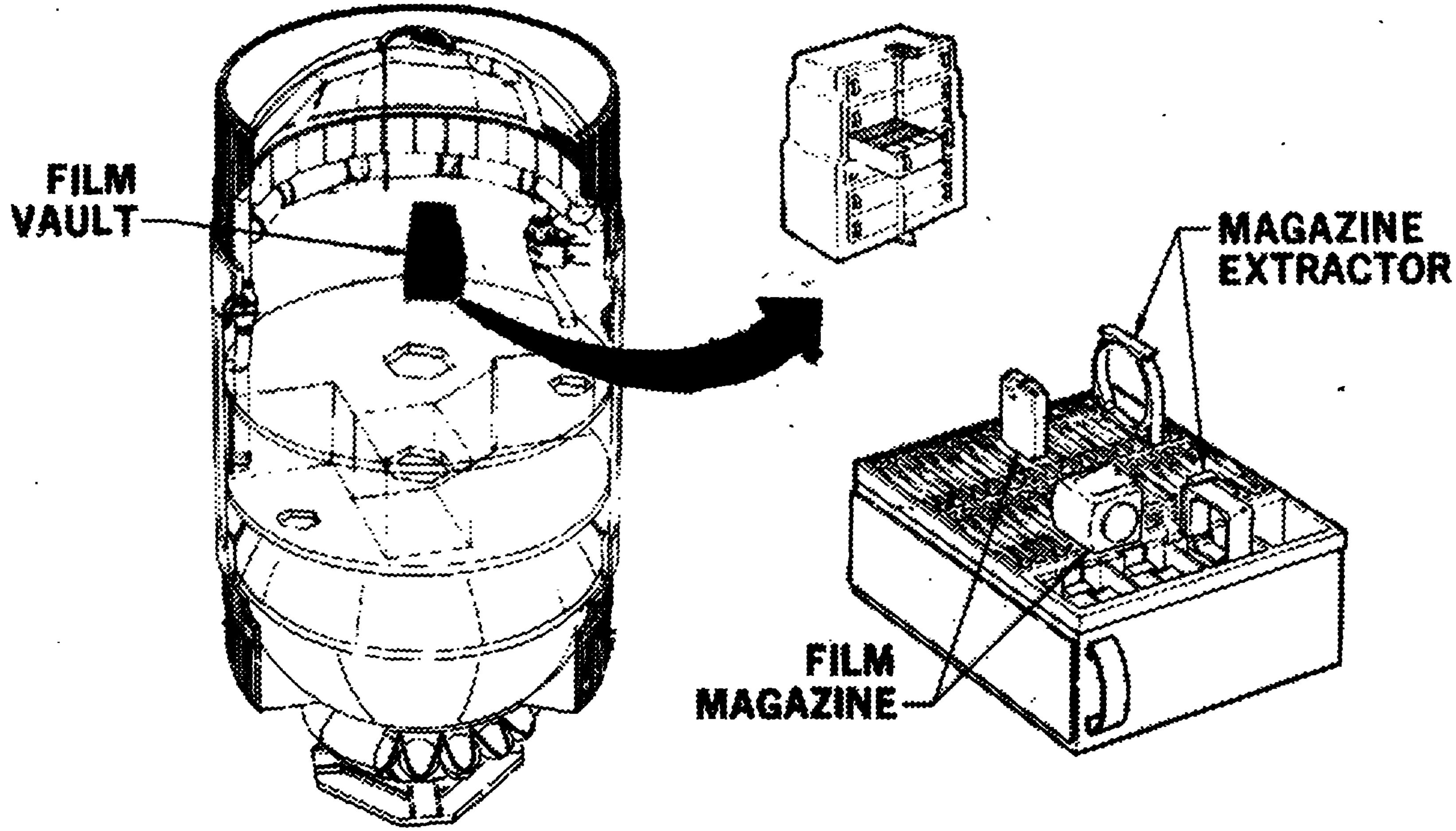


Figure 8.1.2-3. FILM VAULT PACKAGING

significant structural support to accommodate the loads encountered during launch.

Vehicle Attitude Control System - The Skylab represents the largest spacecraft ever placed in Earth orbit, the Orbital Workshop "laboratory" alone being about 50 times larger than the Apollo capsule. Relative to past manned spacecraft, the physical size of this vehicle imposed requirements which are unique. Accurately controlling and maneuvering this 100-ton (90.718 kg) space station, and maintaining a comfortable environment throughout the entire volume presented challenging design considerations.

During the eight-month coast period the Skylab was required to accurately point the telescopes in the Apollo Telescope Mount experiment package to desired locations on the solar disc, as well as to provide three-axis attitude control and maneuverability. To satisfy these rigid requirements a dual control system was designed, consisting of control moment gyros for the prime moment source and supplemental reaction control thrusters.

The supplemental system (i.e., the OWS Thruster Attitude Control System) consists of a non-contaminating, gaseous nitrogen blow-down system which provides primary control of the cluster until the control moment gyros are spun-up (Figure 8.1.2-4). The nominal pressure in the 22 nitrogen spheres at liftoff is 3,100 psi (2.137×10^7 N/m^2). This system provides supplemental control for control moment gyros desaturation, for maneuvers, and for docking transients. Components of the system were designed for rapid response (minimum impulse bits) and extremely low leakage by use of all brazed joints in the high pressure part of the system to provide maximum orbital capability.

Environmental Control System (ECS) - The ECS for the Skylab cluster provides atmospheric gas composition, pressure and temperature control, electronics equipment thermal control, atmosphere contaminant control, and crew compartment radiant thermal environmental control (Figure 8.1.2-5). The atmospheric gas composition for the Skylab has a dual gas system (O_2/N_2). An enriched oxygen atmosphere is used in the Skylab resulting in a partial pressure of approximately 3.6 psi (28×10^3 N/m^2) of oxygen and 1.4 psi

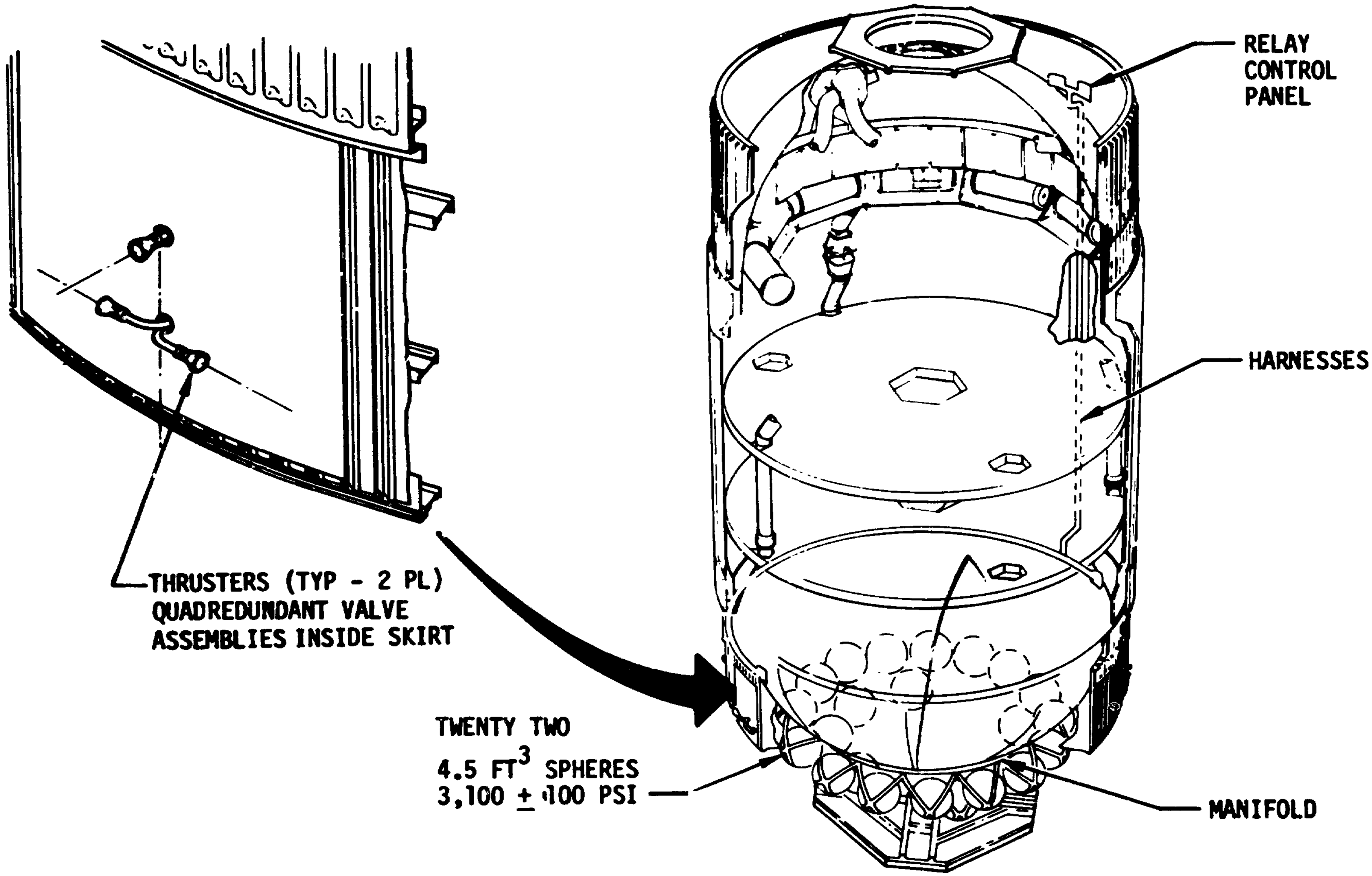


Figure 8.1.2-4. THRUSTER ATTITUDE CONTROL SYSTEM

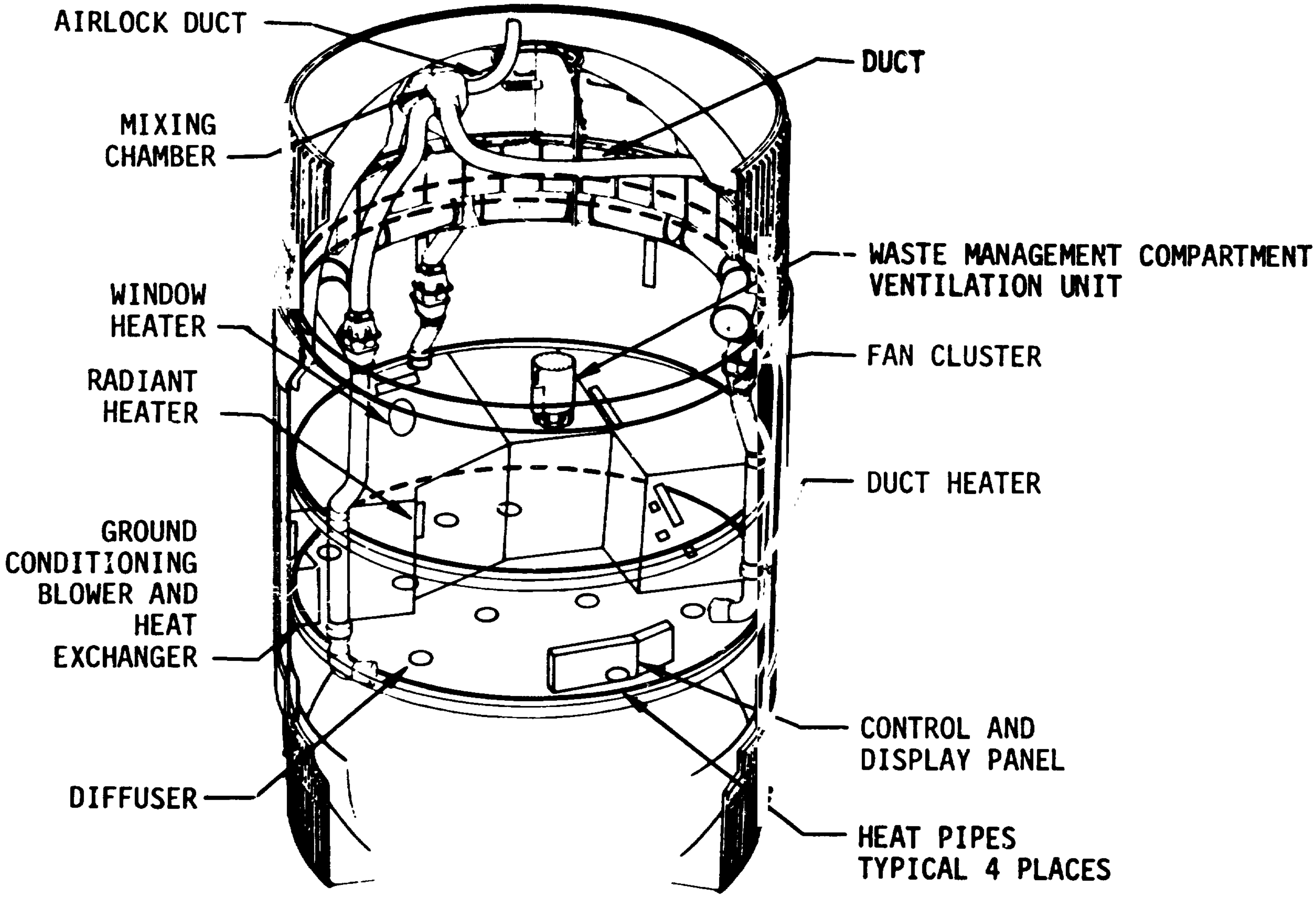


Figure 8.1.2-5. OWS ENVIRONMENTAL CONTROL SYSTEM

(11×10^3 N/m^2) of nitrogen. Atmosphere heating is accomplished using electric heaters in the Orbital Workshop. The atmosphere is cooled by heat exchangers in the Airlock Module.

Odor and trace gas removal is accomplished by a molecular sieve/ charcoal cannister system.

The primary vehicle thermal control system relies on the extensive use of passive thermal control coatings such as gold tape/foil and various paints and paint patterns. Local thermal control to preclude condensation is provided by a system of heat pipes. A unique feature of the Orbital Workshop is a large multilayer insulation blanket on the forward dome which used a ground purge and environmental system to maintain the insulation free of moisture until launch.

Living Quarters - As opposed to being a basic transportation vehicle, the Skylab was designed to provide the conveniences of a long duration habitable spacecraft. It was designed to include a kitchen, three bedrooms, bathroom, and two levels of laboratory work space. It also provides a volume of sufficient size to allow considerable mobility by the crew, which in itself created unique design problems.

Personal Hygiene - Skylab personal hygiene equipment provides for the maintenance of skin health, personal cleanliness, grooming, and the collection and disposal of body particulate matter. This equipment is unique in that it provides many more items than previous manned spacecraft, and allows the crew more privacy in a more near Earth-type facility.

The Skylab personal hygiene system (Figure 8.1.2-6) includes common equipment such as tissues, wipes, towels, washcloths, mirrors and trash bags; also individual equipment (for each individual astronaut) such as tooth brushes, combs, shaving eouipment, etc. Other unique hardware for crew hygiene includes a whole-body shower, which uses a vacuum arrangement to contain the water in a zero-g environment, warm water dispenser, and washcloth and towel drying equipment.

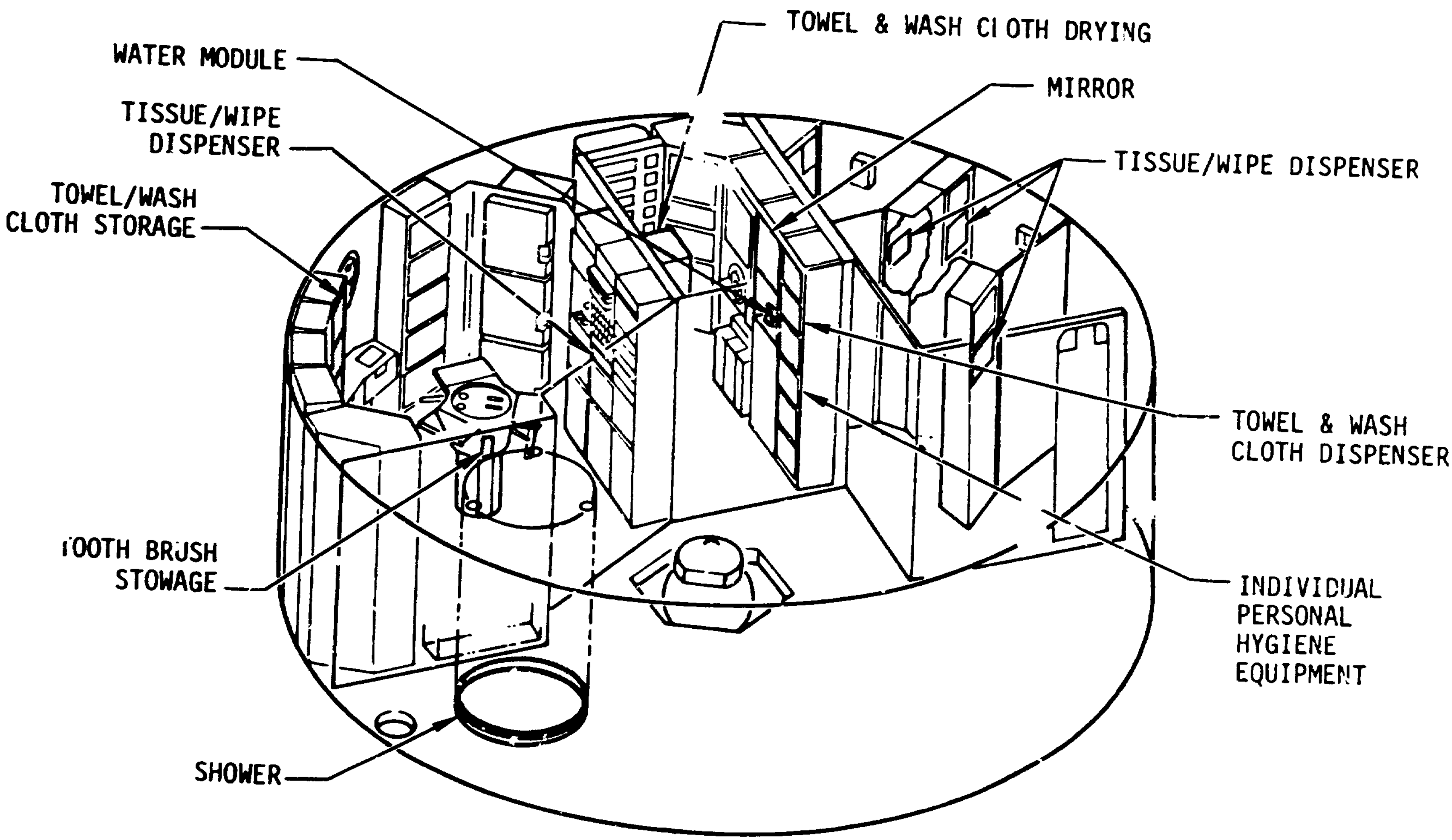


Figure 8.1.2-6. SKYLAB PERSONAL HYGIENE SYSTEM

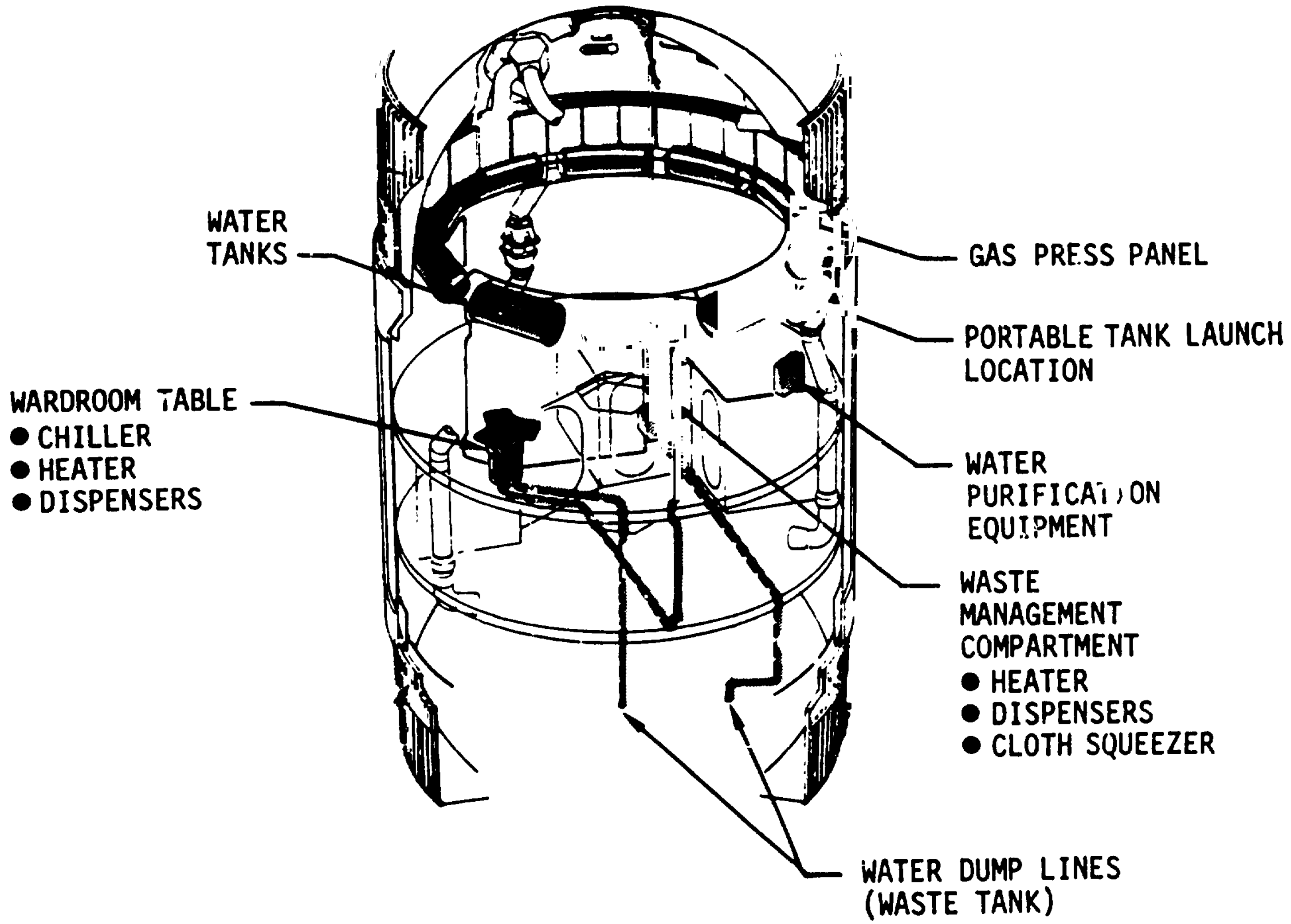


Figure 8.1.2-7. WATER SYSTEM

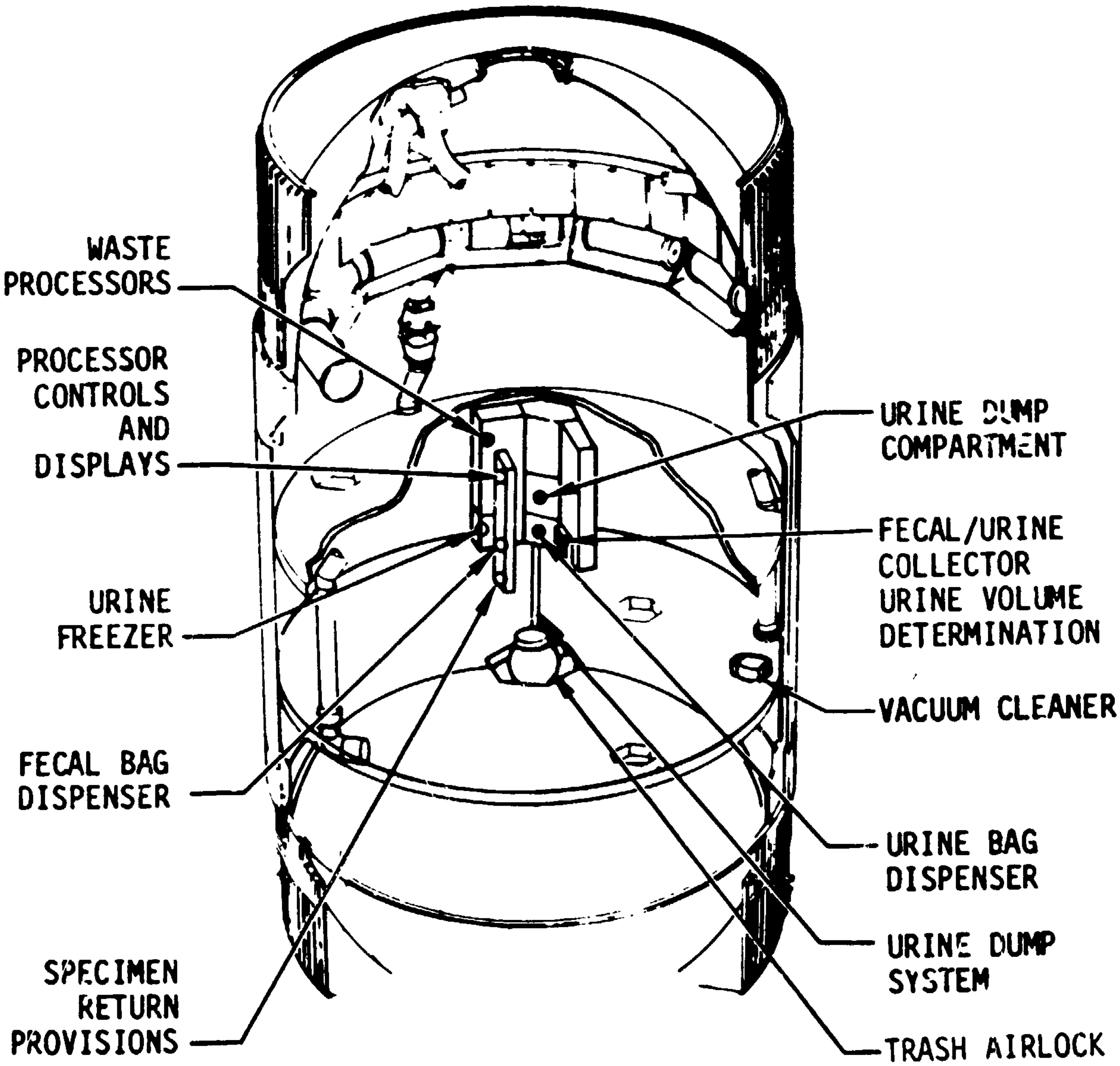


Figure 8.1.2-8 WASTE MANAGEMENT SYSTEM

Water System - Water for the entire eight-month mission is stowed in tanks aboard the Orbital Workshop prior to liftoff. Approximately 6,000 lbs (2721 kg) of water was available through the water system (Figure 8.1.2-7) for drinking and personal hygiene, including allowance for each crewman to take a weekly warm-water shower.

Three independent and isolated water distribution systems were utilized (potable, personal hygiene, and urine flush). For biomedical purposes, a highly accurate dispensing system was designed for measurement of the potable water.

Ten identical water tanks with pressurized nitrogen gas expulsion bellows provides sufficient water pressure throughout the Orbital Workshop.

An iodine monitoring and injection system has been designed to maintain the proper biocide level throughout the entire mission. To ensure the health of the crew an iodine level of 2.0 to 6.0 ppm is maintained. This level is well above biocide levels found in the average metropolitan water supply system.

Waste Management System - This system is composed of several subsystems designed to provide for collection, storage and/or disposal of body waste and debris (Figure 8.1.2-8). The OWS concept utilized the existing S-IVB oxidizer tank by converting it into a 2800 ft^3 (79.27 m^3) vented waste tank. The tank was separated into compartments for solid, liquid and gaseous wastes with stainless steel screen material capable of filtering to a particle size of 10 microns absolute. In so doing, the capability was obtained for holding all solid waste products on board that were generated during the mission; thus assuring the contaminate-free environment required to accommodate sensitive optical and atmospheric experiments. The sanitary collection of urine, feces, and vomitus, precluding cross contamination between crewmen's specimens, and the preparation for return of samples to Earth presented unique design problems. A gas-flow system used in the waste collector and processor assists in the collection of urine (Figure 8.1.2-9), which is then subjected to a centrifugal separation of urine and gas. Urine samples are extracted every 24 hours and frozen in preparation for subsequent analysis. A "thermal wax" (Dodecane) is contained in the bottom compartment of the urine sample trays, providing needed temperature control to prevent thawing during return to Earth in the Command Module. Feces and vomit are dried using heat and vacuum prior to stowage.

A vacuum cleaner module is provided for collection of loose waste throughout the Orbital Workshop. A debris bag is used in the normal vacuum cleaner manner. These bags are subsequently sealed, and are disposed in the waste (LOX) tank through the Trash Airlock. The waste tank also serves as a repository for residual urine trash bags, solid wastes (food cans, wipes, etc.) and liquid wastes (wash water, activation water, etc.). In addition to the Trash Airlock there is a port through the bulkhead to accommodate gas dumps (fecal dryer) and a heated probe to serve as a secondary system for urine disposal.

Data Transmittal for European Spacelab Project - In response to a request from the NASA data on OWS material and equipment which could be applicable to the European Spacelab project was transmitted to the NASA/MSFC by MDAC-W Letters A3-850-AZC5-LW-1201 (September 10, 1973) and A3-250-AZC5-LW-1216 (September 21, 1973).

8.2 OTHER APPLICATIONS

Areas in the commercial sector of the economy along with the technology which will have application will be identified in the following material.

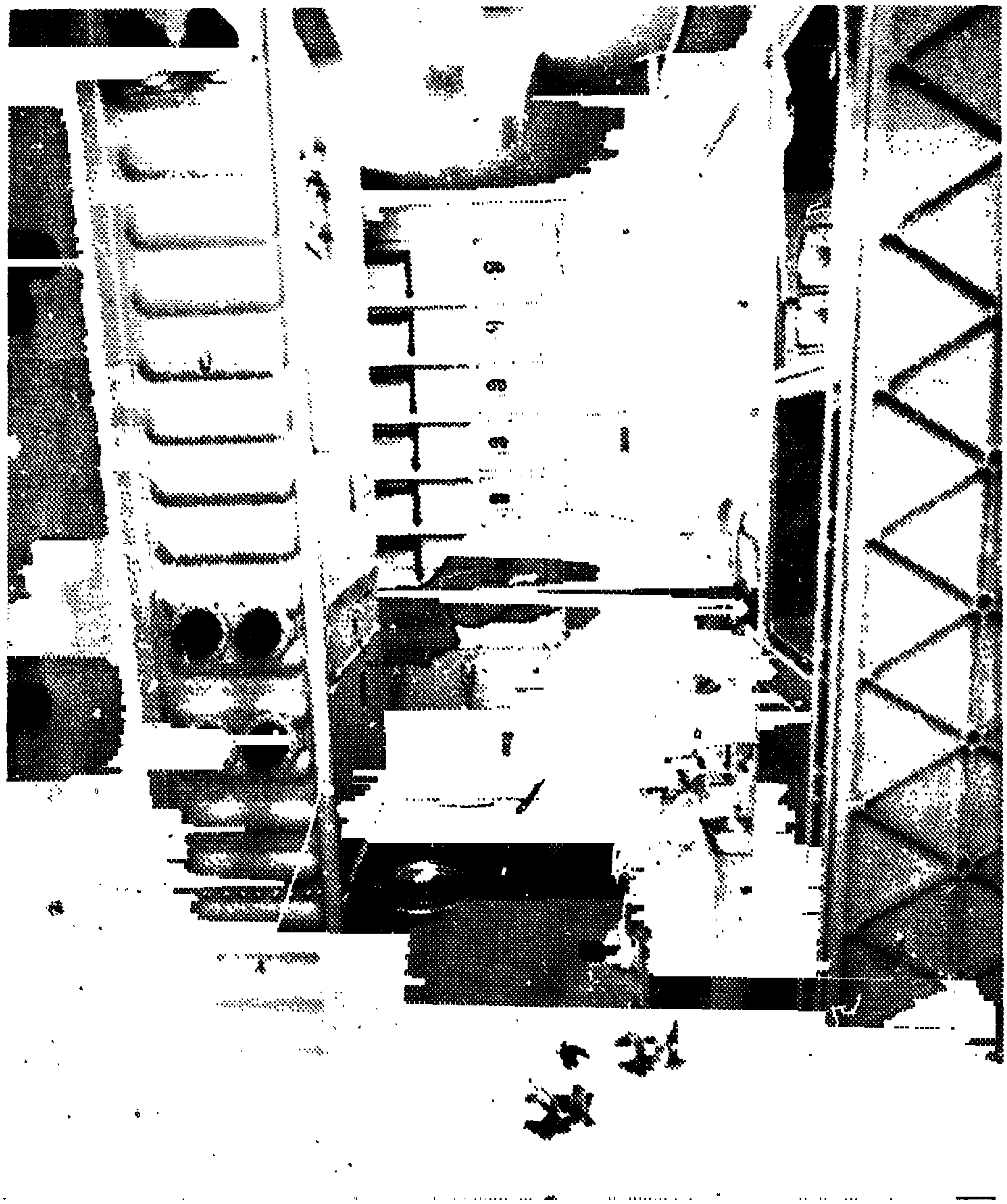


Figure . . . - . WASTE COLLECTOR AND PROCESSORS

8.2.1 Electronic/Electrical - A considerable amount of new electronic/electrical technology has been developed that has direct potential utilization to current areas of interest.

Solar Array Systems - With the energy crisis all possible energy sources have to be explored and the sun is a real candidate. One possible use would be the conversion of the sun's energy, through the use of large solar array farms, into electrical power. The Skylab solutions in the following technology areas provide the initial step towards producing a feasible, cost effective earth bound solar conversion system.

- o N-on-P silicon cell construction
- o Minimization of shadowing effects through cell interconnection techniques and diode isolation
- o Passive thermal control
- o Super-flex cable construction
- o Manufacturing panel repair techniques at the assembly level
- o Fault isolation capability through development of Dark EI tests
- o Correlation of solar versus pulsed xenon performance

General Illumination Light - There are many non-aerospace areas that will benefit from the Skylab technology identified in the following:

- o Shatterproof bulb
- o Low power consumption (12 watts)
- o Fast starting
- o Easy removal (one-hand operation in zero-g)
- o Vibration/shock protected
- o High illumination efficiency (mercury-vapor)
- o Long life capability [tested to 10,000 hrs (3.6×10^8 sec) and 2,750 start cycles]
- o Operates from 0 to 26 psia (0 to 1.792×10^5 N/m^2).
- o Not affected by 100% oxygen atmosphere or 100% relative humidity
- o EMI suppression design

These areas include hospital special treatment and surgery facilities, mines, undersea operations, manufacturing operations that utilize hazardous gases, etc.

Overall Electrical Hardware Construction - The Skylab techniques that evolved out of the program can have direct benefit to commercial interests in the four following areas:

- Flammability and outgassing control
  - Plasma arc coating of electronic modules
  - Sectionalized cable troughs
  - Non-flammable wire harness "boots"
- Crew hazard prevention
  - Touch temperature control on display panels
  - Hazard bonding
  - Teflon coating of meter faces and lenses
  - Explosion proof connectors
  - Guards around switches and circuit breakers
  - Elimination of sharp edges
- Elimination of electromagnetic interference
  - Single point grounding system
  - RF filters
  - Physical separation of system functions (e.g., power, signal, etc.)
  - Shielding
- System reliability
  - Redundancy
  - Interchangeability
  - Lightning protection
  - Component/wire derating
  - Transient protection
  - Specialized thermal screening

8.2.2 Fireproof Materials - MSFC Specification 101 forced an extension of the "state-of-the-art" in production and fabrication of fire resistant materials. Many of these have potential application in industrial and consumer utilization.

Non-Flammable Fiberboard - This material is similar to ordinary corregated cardboard. It is light and easily fabricated but will not support combustion. Potential applications are:

- Record storage boxes
- Facing materials for rigid foam (flammable and non-flammable)
- Storage boxes for use in hazardous environments
- Trash containers for flammable materials

Fluorel Moldings and Coatings - Moldings and coatings of non-flammable fluorel were used extensively on the Skylab program. Design and fabrication knowledge gained can be utilized in industrial and consumer applications. Spray coatings of flammable materials would be a major utilization in such applications as commercial aircraft and other transportation modes.

Armalon Fabric Fabrication - The extensive use of non-flammable armalon, a teflon coated fiberglass fabric in the Skylab program resulted in a wealth of fabrication technology. Utilization of this technology in industrial and consumer applications could make armalon a cost effective fabric for applications requiring a non-flammable material.

8.2.3 Zero Gravity Restraint Equipment - The zero gravity environment of Skylab is quite similar to the buoyant environment found in the developing field of underwater technology and habitation. The problem of restraining a crewman to perform a task in zero gravity is the same as for a diver performing a task while submerged. In fact, the prime method of simulating zero gravity, in order to test and develop hardware for spaceflight, is the use of neutral buoyancy test facilities. The design technology and equipment developed on Skylab can be directly utilized in its counterpart underwater programs, which it is anticipated will grow as undersea mining, oil exploration and farming of the sea activities increase.

8.2.4 Structural Technology - A considerable amount of expertise in the structural technology has been developed and is applicable in the following commercial areas:

- Design and fabrication of large and small pressure vessels of various shapes and materials for use in industrial application for gas or liquid storage. Includes insulation systems and testing.
- Development of commercial type of isogrid structure for use in industry for trusses, stiffened panels, open torque boxes, shells, and beams. This structure could be used in ship building, all types of vehicles, bridges, buildings, and many other applications for low weight/high strength and reduced assembly time.

- o Handling, transportation, erection, and maintenance equipment design for systems requiring special care and support.
- o Design and fabrication of environmental storage systems for industrial use. This could apply for many commercial products where controlled conditions are required for long time periods.
- o Structural system design analysis and synthesis including tradeoffs, documentation, and recommendations. This would be applicable to many industries concerned with pollution, transportation and the energy crisis.
- o Structural static and dynamic engineering and testing of industrial components, subassemblies, and assemblies. MDAC-W Huntington Beach structures and space test labs can provide this service to many industries who normally subcontract for their testing.
- o Design, fabrication and test of Skylab type optical window for possible industrial use.

8.2.5 Fire Detection, Prevention and Suppression - The fire detection and warning technology developed for the Skylab could very well be used in various industrial, computer and commercial applications. The general area of fire prevention was treated as a system engineering problem in the OWS and the same techniques are applicable to many terrestrial and naval situations. The basic technique is identification of ignition sources and combustibles by location and concentration and providing proper shielding for both, the elimination of propagation paths, and the identification by modeling of catastrophic situations.

The prevention analysis is directly applicable to developing the required equipment and procedures to suppress a fire. MDC G2190-P, Criteria and Tolerances for Determining Responses to Orbital Fires, is an example of this technique.

8.2.6 Biocide Wipes - The biocide wipes developed for the Skylab program have been qualified for a long time storage life and have proven not to deteriorate at elevated temperatures. The pre-moistened wipes are sealed in a film package and have 5000 ppm available iodine. These wipes would be usable in first aid kits and for various operations where microbacterial contamination needs to be removed.

8.2.7 Thermal Mechanical - With the energy crisis, solar energy and energy conservation are two areas of activity where Skylab technology can be applied. The analysis and design techniques developed for the Skylab refrigeration system with regard to heat rejection to space via a radiator surface can be applied to collecting heat from the sun in a solar heating system. In addition the insulation design techniques for the radiator, freezers and plumbing developed on Skylab could be used to optimize terrestrial heating and/or cooling systems to minimize the loss or gain of heat in a system, thus conserving energy.

8.2.8 Potable Water Sterilization - Providing a large quantity of high grade potable water in pre-sterilized OWS flight tanks for long duration storage led to the development of a mobile item of ground support equipment referred to as the DSV-7-312 water sterilization and checkout kit. This equipment was capable of receiving water from any source and processing it through organic contamination filtration, deionization and microscopic filtration and biocide treatment. It also had the capability of providing steam for self-sterilization as well as sterilizing an external spacecraft system and also contained an autoclave. A possible non-aerospace application of this development could be a smaller, compact, portable piece of equipment which could be transported by truck, plane, helicopter, boat, etc., into remote areas or disaster areas (or battlefields) for any immediate temporary supply of not only potable water but a source of sterilization for emergency operating rooms.

8.2.9 Noise Control - Acoustic insulation techniques applied to noise producing rotating equipment such as fans, blowers and pumps to minimize noise output are applicable to industrial and consumer use.

8.2.10 Pneumatic Valve Design

A. Pneumatic Valve Performance Simulation Computer Program - Due to specific response and reaction problems encountered in the development of the series/parallel valve cluster in the Thruster Attitude Control System, a computer program was developed to provide a simulation of all valve functions. This program was successfully used to isolate response problems, valve interactions, and to optimize component development.

   The program is readily adaptable to accomplish these items on many types of pneumatic valves in single, parallel, series and redundant combinations.

B. Redundant Mechanical (Pneumatic) Actuator - To provide high reliability actuation of the OWS waste tank vents, a redundant pneumatic actuation system was developed. This mechanism would be applicable to any similar application where a position one-shot operation is desired (the mechanism can be manually re-set for multiple operations).

8.2.11 Product Safety Evaluation - Skylab Documentation Techniques present some record formats that can be used for product safety evaluation by commercial hardware manufacturers.

- Test and Assessment Document - This type document presents a perfect display for comparison of hardware design requirements to test environments to actual environments. Failure to design and/or test for an environment could result in product failure with resultant user injury.

SECTION 9 - CONCLUSIONS AND RECOMMENDATIONS

9.1 MISSION PERFORMANCE - This section is a narrative discussion of the mission performance of each Orbital Workshop (OWS) system with emphasis on performance that was above and below nominal. Included in this section are recommendations for future systems. In general, if more detail is desired the reader can refer to SECTION 2 - SYSTEM DESIGN AND PERFORMANCE.

9.1.1 Structural System - The basic shell structures [forward skirt, aft skirt, Habitation Area (HA), and aft interstage] withstood critical launch and ascent loadings without any problems. The failure of the Meteoroid Shield (MS) and Solar Array System (SAS) Wing No. 2 during ascent did not affect structural shell performance although their failures introduced some unexpected load conditions and subsequent orbital activation problems. The failures did suggest that built-in restraints be considered for Extravehicular Activity (EVA) to certain areas on new space vehicle shell design, especially for access to deployment mechanisms. Planned manual deployment of external mechanisms in lieu of automatic deployment may prove to be design and cost effective for future manned spacecraft. At least, restraints should be considered in development of contingency plans.

With no MS, the design limit temperatures for some materials were exceeded. Although the bonded phenolic discs on the interior insulation had a lesser load carrying capability, adequate margin existed for orbital conditions. The Lefkoweld adhesive for insulation saw 200°F but no debonding was reported by the crew. This type of bonded installation should be seriously considered for future systems which require internal insulation.

The aft structure performed as predicted. The Thruster Attitude Control System (TACS) and Refrigeration System (RS) components mounted thereon functioned properly after experiencing the critical launch dynamic load environment. The S-II/OWS separation was nominal.

The HA leak rate was much better then the 5 lbs/day (2.3 kg/day) allocation [approximately 2 lbs/day (.9 kg/day) was experienced for the entire Saturn Workshop (SWS)] indicating good sealing on all tank penetration leak sources. Seals developed and sealing methods used on OWS should be considered on future space vehicles.

The Wardroom window had an ice spot form on the inner surface of the outer glazing prior to activation. It was cleared by evacuating the cavity between panes by the Skylab-3 (SL-3) crew. The first evacuation through the anti-solar Scientific Airlock (SAL) vacuum outlet utilized on-board hardware plus hardware taken up by the SL-3 crew, and was followed by a backfill with air through the SAL desiccant canister. Ice reappeared and subsequent evacuations left the cavity locked up with a vacuum without backfilling through the SAL. Ice continued to form in the window cavity which required periodic evacuations by the crews. Crew comments on the window were good with a desire for more and larger windows. The window construction (2-pane) proved structurally sound and it was not contaminated from outgassing of pane seals. Therefore, its use for visual observation and as a photographic aid was good. In future spacecraft, windows should be established early in the design phase so that optimization can occur between window size and structural support design. The 18-inch (45.7 cm) clear pane used was the optimum as a modification to an existing S-IVB shell. An improved technique should be developed to control the environment betwee the glass panes to prevent ice or fogging.

The entry hatch was used for 9 EVA's without any functional or leakage problems. During the pressurization cycles prior to habitation, OWS pressure was bleeding into the Airlock Module (AM). The SL-2 crew made make-shift flapper valves with mosite and tape on the OWS side of the hatch check valves. Leakage to the AM did not occur again after initial hatch opening and installation of the make-shift valves.

The SAL's functioned properly with no leakage or malfunctions reported. The JSC parasol was in the solar SAL through the entire Skylab mission. The airlocks proved to be flexible in usage and as a result suggests that additional airlocks of larger sizes could create multiple uses. In addition to experiment use, they might be considered usable for deployment or for contingency repair and maintenance external to the spacecraft.

Performance of internal structures (floors, water bottle and stowage container support, fasteners, walls, etc.) could only be measured by crew comments. Structurally, there were no failures as a result of the boost phase of flight. Some recommendations would be to design the floor and walls into integral closet/bookcase type structures, standardize fasteners used by astronauts, increase grid size in floor with larger corner radii for handhold use, and give more consideration to contingency repair of functioning systems.

Dome and forward compartment handholds and handrails were used occasionally for stability, orientation, and translation when carrying equipment. The handhold located near the SAL's were not used. The fecal collector handholds were used extensively as were handrails in in the Waste Management Compartment (WMC) ceiling and at the hand washer/washcloth squeezer module. No handhold/handrail problems, malfunctions or failures were noted. Future programs should incorporate more hand restraints into equipment design.

Light duty foot restraints in the Wardroom and WMC provided adequate restraint when used as intended, i.e., with bare, stocking, or soft slippered feet. The crew rated the Pressure Garment Assembly (PGA) foot restraint as excellent and indispensible during EVA activities. The triangle shoes, used extensively, were most useful and versatile restraints. This was also true for their use with the water tank foot platform. C[illegible] cleats in place of the triangles tended to slip out [illegible]h in the grid. The triangle shoes were subject to toe abrasion which was caused by astronaut dragging one foot or the other. Tape was used to reinforce worn areas on SL-2, Fluorel toe caps were flown up on SL-3, and spare uppers were flown up on SL-4. Future missions should have well constructed universal foot restraints suitably constructed for on-orbit use.

The Fireman's Pole was used to good advantage during activation on SL-3 and -4 with no problems reported. It was removed after activation. Such a device is recommended for future large volume space vehicles for transfer of bulky items.

Food table restraints, thigh and foot, provided effective means for relaxed restraint. The triangle cutouts for the triangle shoe were oversize causing some interface problem. Future missions might need only one restraint - a larger contact thigh restraint or just a foot restraint. Lower leg restraints, used at ring lockers to install the condensate tank on forward dome, worked satisfactorily. Portable handholds and tethers were not used because the open grid provided inherent handhold and tether attach point capability. The adjustable tethers worked relatively well but did not provide the stability afforded by the Fireman's Pole.

9.1.2 Meteoroid Shield (MS) - MS failure occurred at approximately 63 seconds after launch. The film vault accelerometer indicated an onset of vibration just prior to 63 seconds followed by temperature measurement losses; ordnance breakwire separation, and SAS Wing No. 2 tiedown failure. Other than the loss of SAS Wing No. 2 electrical power, and SAL (solar side) experiment capability, no other functional system failures were caused by the loss of the MS. No meteoroid hits resulting in HA pressure loss occurred during full mission duration; however, electrical power monitoring and thermal control was affected by the MS anomaly. Future spacecraft should attempt to avoid use of thin shell deployable shields.

9.1.3 Thermal Control System (TCS) - All components of the active thermal control subsystem performed as expected and met the design requirements. The control system performed as expected; however, for future design a tighter control band is recommended since the astronauts used the thermostat to manually control the OWS internal temperature. The radiant heaters were not required to maintain storage temperatures because the use of the sun shades rather than the MS passive system, which was lost, caused the OWS to operate at higher temperature levels. The duct heaters were not required or used during habitation for the same reason that the radiant heaters were not used. The duct fan performance resulted in adequate velocity in the crew quarters without using the portable fans. One portable fan was used periodically in the experiment compartment to provide additional flow to the crew member using the ergometer.

The MS with its coatings and paint pattern was an integral part of the passive thermal control subsystem. Its loss caused HA walls, ambient food and film temperatures, and all internal environment temperatures to exceed their maximum temperature limits. Deployment of the JSC parasol sun shade on Day of Year (DOY) 147 resulted in a marked cooling of the OWS and on DOY 153 the internal environment met the comfort criterion. The internal environment remained in the comfort box until DOY 170 near the end of the SL-2 mission. At this time the beta angle exceeded 60 degrees and the average internal temperature increased and peaked at 98°F (319°K) on DOY 177. The high temperatures during this period were due to incomplete deployment of the sun shade [approximately 135 ft^2 (12,54 m^2) of HA sidewall gold coated surface were exposed to direct sunlight] and the high beta angle (greater than 70 degrees for three days). As the beta angle decreased, the temperature also decreased and stabilized at approximately 80°F (300°K) where it remained until DOY 218. On DOY 218 the MSFC solar shade was erected over the top of the JSC parasol. The additional shading reduced the temperature to the 72°F (295°K) to 75°F (297°K) level for the remainder of the SL-3 mission.

The forward dome Multi-Layer Insulation (MLI), the internal foam, and the remaining control coatings (excluding the lost MS coatings) functioned within predicted levels. The loss of instrumentation on low-level multiplexer "B" resulted in a loss of some measurements and has prevented comparisons at essentially similar conditions to determine small performance changes. The evaluation to date could only detect large changes and none were identified. For future design, it is recommended that the thermal control system be independent of deployable systems or a redundant system capable of operation with any type of failure be utilized.

9.1.4 Thruster Attitude Control System (TACS) - The TACS successfully fulfilled all vehicle control demands imposed upon the system throughout the mission. Impulse consumption significantly exceeded the predictions during the early portion of SL-1/SL-2 and during SL-4. The excessive usage was attributed to a delay in Apollo Telescope Mount/Control Moment Gyro (ATM/CMG) switchover due to rate gyro drift early in the SL-1/SL-2 mission; flight plan changes during the SL-1/SL-2 mission due to the loss of the MS [i.e., "unplanned" maneuvers to attitudes for vehicle thermal conditioning; CMG momentum cages performed while maintaining the "unplanned" attitudes; perturbations associated with Standup Extravehicular Activity (SEVA) and EVA activities to deploy SAS Wing No. 1]; several unsuccessful "hard dockings" attempts, and failure of CMG No. 1 during SL-4.

No detectable system leakage was observed in a series of mass calculations during each of the storage periods. The negligible leak rate of the TACS has verified the adequacy of bi-metal joints and "in place" induction brazing for long term storage systems. The ability of the TACS valves to remain leak tight after extensive orbital usage has verified the adequacy of the valve design, materials, and testing program.

The unanticipated high propellant consumption during the early part of the mission caused concern that TACS might be depleted prematurely. Future designs should include the capability to interconnect systems using similar working fluids such as the TACS and the AM N_2 supply which had ample reserve.

9.1.5 Solar Array System (SAS) - The OWS SAS design, manufacture, and test program resulted in a system which equaled or exceeded all performance specification requirements. Investigation and analysis of the Skylab ascent anomaly concluded that the loss of SAS Wing No. 2 and the failure to deploy SAS Wing No. 1 on time was a direct result of the MS failure. The primary and backup command sequences, ordnance, Exploding Bridgewire (EBW) electronics units, and associated instrumentation and interlock circuits functioned as designed. Deployment mechanisms in SAS Wing No. 1 deployed the wing sections to the full open position after removal of the MS obstruction. Venting of the fairing during ascent was as planned.

End of Mission (EOM) requirements for the SAS was 10,496 watts. SAS Wing No. 1 met its contribution to the requirement of 5,248 watts minimum average power, and a voltage between 51 volts and 125 volts at the AM/OWS interface were fulfilled. Minimum average array power ranged between 6,500 watts and 7,050 watts at +145°F (335°K), with the variation being attributed to (1) measurement inaccuracies, (2) changes in solar flux which reached a maximum approximately 1974 DOY 005, and (3) the absence of any measureable performance degradation. Throughout the mission, Solar Array Group (SAG) voltages remained between 51 volts (during peak power tracking) and 125 volts (at sunrise). SAG voltages typically ranged between 58 volts and 99 volts. Predicted SAS performance degradation from all causes was 8.3 percent for the mission (flight data indicated no measureable degradation); the major contributor being thermal cycling effects, followed by charged particle and ultraviolet radiation. It is concluded that the orbital environment encountered by the SAS was very nominal, and in particular, the extremes of thermal environment were less severe than those assumed in in preflight analyses and testing.

Following are recommendations for application of future solar arrays.

Actuator-Dampers - The actuator-dampers, used to both deploy and control the rate of deployment of the wings, used an orificed fluid for damping. The damping characteristics of the fluid were highly dependent upon the thermal environment of the dampers. It is recommended that a method of temperature control be employed on designs of this type. In the case of Skylab, the wing deployment damper was frozen after being in orbit without full deployment long after the design period. The damper was finally broken loose by the crew EVA allowing wing deployment. Any design using a damper or similar device should also contain a capability of breaking the damper loose by crew EVA forces.

Vent Modules - The requirement to maintain a purge atmosphere on the wings prior to liftoff was made late in the SAS development program. As the mating electrical interfaces were already designed and fabricated, a decision was made to design the vent valves to operate mechanically with no interface between the SAS/OWS structure. An acoustic actuated valve was designed and developed to provide the venting function. The disadvantages of this type of valve were the lack of capability to close the valve in the case of premature opening and lack of an automatic talkback on valve position. The valve operated at liftoff and did not prematurely open. It is recommended that the use of this type of valve be limited because of its inherent disadvantages.

Thermal Control Paint - The increased power (approximately 130 watts) did not justify the difficulties encountered in the application, maintenance, and repair of the Z-93 paint used on the rear of the solar panels. Its use in future applications of this type is not recommended.

Ordnance Release Systems - The completely contained expandable tube ordnance system used for release of the beam fairing and panels provided a reliable, redundant release system. Further use of this type of gas-contained system on future space programs is recommended especially where equipment, such as that with optically critical surfaces, cannot tolerate the contamination producted by ordnance systems.

9.1.6 Electrical Power Distribution System (PDS) - The OWS PDS subsystem has performed as designed and its operation during the mission has verified the data obtained in checkout/analysis to be very close to actual mission conditions. In review of the various subsystem problems and crew comments obtained during the mission, the following modification/improvements are presented for consideration.

- System design should include a one-for-one ground control capability for every voltage sub-bus [enable/disable via Digital Command System (DCS)].
- Voltage and current telemetry (TM) parameters should be available for every sub-bus; high resolution for all TM current/voltage parameters (i.e., if range 0-140A, provide a low and high range measurement) is desirable; provide multi-scale meter (range selection switch) for on-board voltage and current measurements; provide local power ON/OFF control at all utility outlets; provide more utility (LO/HI power) outlets; and provide circuit breakers that are not easily (inadvertently) activated/deactivated (maybe push-button type).

9.1.7 Illumination System - The OWS lighting system met all design requirements. There were no light failures. All general purpose lights were used in the HIGH mode only. The difference between high and low modes was slight. Future general lighting fixtures should be limited to a single light level for simplification and cost reduction. Special low level lights should be installed for emergency, night lights, etc.

Supplemental lighting was required for close work, i.e., item repair, shaving, reading, etc. Specific area(s) should be designated as a repair/maintenance facility and provided with sufficient illumination for close detail work. In areas where reading and/or record keeping is performed, i.e., Wardroom, Sleep Compartments, and Experiment Area, higher illumination levels (higher intensity and/or additional lighting) should be provided.

9.1.8 Communication and Data Acquisition Systems (DAS) - All audio equipment of the OWS communication system performed with no failures except for the Speaker Intercom Assembly (SIA) located at Panel 540 which sustained a broken Intercom/Transmit (ICOM/XMIT) switch; the SIA unit was replaced. Based on crew debriefing reports, the OWS communication system provided adequate volume level and quality during mission operations. However, some audio feedback problems were encountered. The problem manifested itself as a nuisance to the crew and it is attributed primarily to the interaction between SIA's, as well as the total gain characteristics of the cluster audio system. Audio system redesign and/or relocation of SIA's should be considered if this or a similar system were to be used in the future. Both channels of the OWS communication system provided adequate intercommunication for activities within the OWS as well as uplink and downlink communication.

The overall performance of the OWS DAS throughout the Skylab mission was very good. Despite the failure encountered by the low-level "B" multiplexer data, optimization of reliability through distribution of a system measurement to separate multiplexers avoided the total loss of data from any one particular system.

The following recommendations would improve the DAS: The OWS DAS instrumentation panels located in the OWS forward skirt area should be provided with temperature measurements which measure the panel thermal environment to facilitate malfunction analyses. The actual measured temperature environment would provide a fundamental assessment of the actual thermal environments of the system's major components. The OWS instrumentation and heater power buses should be instrumented for current monitoring. Many of the system analyses performed during the mission required such measurements. Load current changes are very significant analytical data in evaluating system performance or anomalies. Future space missions similar to Skylab should incorporate a data management system so that measurements required only for boost, deployment and initial activation (i.e., EBW, positions, events, etc.) would be deactivated after their usefulness. On-board data compression would be another method of implementing better data management. These approaches would reduce the quantity of data, speed up the data processing, enable better quality control of the data and allow for the data to be disseminated in a more timely manner. The OWS DAS could increase its data acquisition versatility, especially within the OWS HA, by having remote interface panels with patching-type connections or connectors for accessing the unused multiplexer channels. The usefulness of this concept was made obvious by the addition of new equipment, work-arounds, and anomalies which made it necessary to accommodate additional data during the Skylab missions.

The OWS television (TV) system accommodations consisting of the TV Input Stations (TVIS), and its associated wire harnesses, performed very well in support of the Skylab TV system in transmitting video information during the manned Skylab mission as well as during the ground checkout activities. Future design of TV system accommodations should take into consideration provisions to permit the astronauts to control the operations of the video tape recorder from the TVIS or the TV camera. In other words, the astronauts should be provided with remote control capability within the OWS. During the Skylab missions the astronauts were required to activate the Video Tape Recorder (VTR) in the Multiple Docking Adapter (MDA) and it was a major inconvenience when TV activities were being performed within the OWS.

9.1.9 Caution and Warning (C&W) System - The OWS C&W system design and installation satisfactorily supported the SL mission without failure. All design goals of the subsystem have been met. False alarms which occurred during the mission were attributed to other sources. The OWS repeater panel and SIA portion of the C&W system gave the crew the desired mobility while providing the necessary monitoring function. High temperatures early in the mission caused only temporary undesired operation from one fire sensor. Crew comments during debriefings indicated satisfaction with the system and inflight tests proved to be satisfactory. There are no recommendations or suggestions made to alter the C&W system.

9.1.10 Experiment Accommodations System - This system performed to design requirements except for the following anomalies:

OWS experiment accommodations anomalies which occurred on SL-2 are as follows: The crewmen were unable to obtain the proper calibration adjustment of -0.9K factor for the M487 Sound Level Meter. -0.7K factor was obtained. The readings on the instrument is ±2 db so the 0.2 db correction was not considered to present a problem. The backup SAL tripod, which was bolted to the adapter plate, was drilled in a mirror image with the holes misaligned about two inches. The crewmen had to rotate the SAL tripod legs and had to realign the adapter under the photometer canister to accomplish the tripod installation. The tripod did perform its intended function although two of the tripod legs were bolted to open grid floor, instead of using the fixed nut-plate locations. During the SL-3 mission, the backup tripod was transferred to the solar SAL where all the legs were successfully bolted into the fixed nut-plates on the floor.

The crewmen stated that the SAL pressurization and repressurization times for experiment hardware installed in the SAL were greater than anticipated. The actual pressurization and depressurization times were five to eight minutes vs. two minutes anticipated. MDAC analysis verified that the longer times were realistic and the flight plans were revised to allow more crew time for these operations.

The M092 vent was propulsive with the meteoroid shield gone and this venting resulted in additional spacecraft attitude correction. A decision was made to correct this problem. The problem was alleviated by the SL-4 crew by rerouting the vent to the waste tank through the common bulkhead using a penetration previously used by a urine dump probe. No additional experiment accommodation anomalies were reported during the SL-4 mission.

The OWS film vault was successful in providing temperature, humidity, and radiation protection to the over 600 lbs (272 kg) of film used for the Skylab experiments. Future programs which require protection of hardware from humidity and radiation could successfully use the same approach of potassium-thiocyanate salt pads and aluminum walls. The use of standard commercial fasteners such as a "dialatch" should be scrutinized carefully and tested thoroughly before use.

MDAC was successful in adapting a previously designed Apollo SAL to meet all the objectives of the Skylab Program. The SAL repressurization system performed its function of preventing condensation from forming on experiment hardware. In regards to things to be done differently in future missions, the Skylab crew has recommended that two SAL's are not sufficient and consideration should be given to having more on any future spacecraft.

9.1.11 Habitability Support Systems (HSS's)

9.1.11.1 Waste Management - All waste management systems performed successfully in flight. The flight crew comments during and after the mission were complimentary. There were no damaged fecal bags and only minor urine spills. Samples of dried feces and frozen urine were returned for post flight analysis. Urine collection was simple and easy. Daily sampling and bag changeout proved to be an acceptable task in flight. The only significant anomaly was the low volume returned in the urine sample bags. Procedure revisions were used by the SL-3 crew which increased the volume slightly. Fecal collection was very successful. It was the one area of waste management which could not be adequately tested in 1-G or in the simulated zero-G of the KS 135. For future spaceflight a higher airflow and a softer seat for a better seal would provide better results. Fecal processing gave the crew no problems. During SL-2 mission, the processing was accomplished successfully without power. The vacuum cleaner worked well but was not used to pick up wet debris. Again, the flight crew stated that increased airflow would be required on future spacecraft. The trash airlock performed successfully; however, in two cases it was difficult to eject the trash. The case of major concern was during deactivation of SL-2 when the crew attempted to dispose of the Molecular (MOL) sieve canister and two pairs of suit golves in the same bag. For a while, the trash airlock was stuck, however, they were able to free the unit with additional force.

9.1.11.2 Water System - The water system performance during the entire mission was highly successful. The water properties and iodine level at the dispensers were maintained within specification. Temperatures and quantities of heated and chilled water were also satisfactory. There were reports of air in the water at the start of two missions. In SL-3 the problem was with the food packages. In SL-4, after switching tanks, the crew reported that there was no longer gas in the water. After noticing a decrease in flow from the WMC dispenser, the crew replaced the assembly and reported flow to be normal. Evidence of contamination on the replaced unit was reported and the unit was returned for failure analysis. The ground failure analysis disclosed that the contamination was a result of an improper seal being installed. New seals of the proper material were installed on a spare dispenser launched on SL-3. Near the end of SL-3 the washcloth squeezer seal was replaced to eliminate leakage. The seal was found to be folded back in at least one area, allowing water leakage past the piston. The squeezer was beginning to get difficult to operate because of "grit, grime, dirt, or soap" on the moveable parts. A procedure was supplied for cleanup and lubrication during SL-4. Also, three additional seals were sent up as spares. The performance of the washcloth squeezer was reasonably successful, however, there is room for improvement. A future scheme should allow wringing of a washcloth is much the same was as in 1-G. A high flow air supply and liquid air separator might be the best approach. On future spacecraft the drink dispensers could be simplified to an on-off valve design if medical experiments are not involved. The crew reported some difficulty holding the food packages on the reconstitution dispenser. Future food packages should include an improved holding area.

As a result of qual testing, it was determined that with time the iodine in the water system would attack the water heater element resulting ultimately in failure of the heating element. The [illegible] and Wardroom water heaters from OWS-2 were flown as spares on OWS-1 and although some degradation was noted during the latter part of SL-4, the spare heaters were never required. The water heaters for OWS-2 were redesigned to eliminate iodine errosion by furnace brazing the heating element between two stainless steel tubes and then welding the element unit. Any future application should consider the OWS-2 redesigned water heater.

9.1.11.3 Personal Hygiene System - The general purpose tissues and utility wipes were adequate. The second mission crew reported using rags (old shirts and shorts) for cleaning instead of a general purpose tissue. On future flights, a cloth should be considered for wiping up spills and cleaning tasks.

The biocide wipes left an iodine coloration on a wiped area that comes off easily. The second mission crew reported that their hand became yellowed during deactivation biocide cleaning but that it faded away several days later. The iodine solution used in the biocide wipes is an acceptable biocide.

Hygiene kits were satisfactory. However, the crew requested personalized kits. Mirrors were positioned well for the activities requiring their uses. The polished stainless steel mirror surface was adequate. The soap was used with no apparent medical problems. The metal disc in the soap held the soap bar to the magnetic post in the water module sufficiently for zero-G application. Because of bacteria growth reported on terrestrial samples, investigations should be made into this possible problem before Neutrogena soap is used for future space flights.

9.1.11.4 Body Cleansing - The washcloths and towels were very adequate. There were 89 extra towels launched on the SL-3 flight and 30 extra towels on the SL-4 flight. Towel allocations for future missions should consider this. The drying station provided a convenient and effective means of drying the towels and washcloths. The restraint approach should be standard equipment on future missions for towel and washcloth drying as well as general fabric restraint. The washcloth squeezer and water dispenser provided a satisfactory method for partial body cleaning and housekeeping. An enclosed water module for more convenient handwashing on future missions was desirable.

9.1.11.5 Food Management System - Although the primary elements of the food management system performed satisfactorily, minor operations became sources of irritation to the crew. The food table, when not used for

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food service, was the center of mission operations activity. Because of this potential usage, similar to the traditional kitchen table, future designs should be based on total needs and not limited to those solely associated with food management. Since the operation of food storage and preparation facilities is so subjective, a high degree of flexibility should be a design requirement. It should be possible for each crew to rearrange the pantry to suit their own needs and desires. As a result it is recommended that a realistic evaluation through repeated usage of prototype hardware and operational procedures in a high fidelity interior mockup be accomplished.

9.1.11.6 Sleep Support System - The sleep restraints provided an excellent means for providing restraint during sleep. The crews had no difficulty in obtaining comfortable, restful sleep. The adjustable features of the restraint accommodated most of the individual preferences of the various crewmen. On future missions an additional adjustable blanket for more thermal control should be provided. Also, additional adjustable straps and/or adjustable blanket would add variation of restraint and minimize dead space inside the restraint for thermal control. The light baffles were effective in blocking light from entering the sleep compartments. The fabric airflow louvres had a tendency to collapse and restrict airflow. The light baffles are probably unique to the OWS configuration. Future mission sleep compartments should have inherent capability to provide a dark environment. The privacy curtains and privacy partitions performed satisfactorily. They provided visual privacy and light control. Sound control was not a requirement but future missions should provide for reasonable sound isolation.

9.1.11.7 Refrigeration System (RS) - The RS operated satisfactorily and maintained the food, water, and urine within required temperature limits except for an anomaly which occurred on DOY 173. Lower than specified freezer temperatures occurred during SL-3 storage and a high temperature excursion (approximately 13 hours) occurred during SL-4 mission. Assessment of the flight data indicates no apparent performance degradation or malfunction in any of the refrigeration components other than the occurrence of the anomaly attributed to the radiator bypass valve on DOY 173. There was no detectable coolant leakage from either the primary or secondary loop. On DOY 173 a continuing increase occurred in the food freezer and radiator inlet temperatures. Assessment of the data indicated that a split flow condition existed between the radiator and radiator bypass branches. Probable cause was determined to be a malfunctioned radiator bypass valve in which both radiator and bypass poppets were in a flow position. "Cycling" of the valve was performed which resulted in an increase of performance apparently due to a partial closing of the bypass poppet. The RS continued to operate satisfactorily in this mode. The system performance from the standpoint of temperature control was equivalent to the nominal performance observed prior to the anomaly.

Data obtained during the SL-3 storage period indicated that the wall temperature of the coldest freezer compartment decreased to the specification limit of -20°F (244°K) by DOY 270, and by DOY 277 decreased to its lowest value of -23.6°F (242.5°K). Thereafter, until SL-4 activation (DOY 320), the freezer wall temperature oscillated between -20°F (244°K) and -23.6°F (242.5°K). This freezer performance resulted from the following: (1) opening of the radiator bypass valve circuit breaker by the SL-3 crew which prevented the valve from switching from the radiator position, and (2) disabling the OWS ventilation fans during SL-3 deactivation. Consequently, the freezer temperatures varied as a function of the OWS internal temperature which, during the SL-3 storage period, decreased to approximately 63°F (290°K). No food was stored in this freezer, however, it was reserved after SL-2 for stowage of filled and frozen urine trays. Following SL-4 activation, the coldest freezer temperature returned within the specification limits due to an increase in OWS internal temperatures. On DOY 018/019 the warmest freezer warmed to +1°F (256°K) which exceeded the specification limit for 13 hours. No food, however, is known to have been stored in this freezer at that time and other freezers were within temperature specifications.

Evaluation of the flight performance of the refrigeration system resulted in the following recommendations: (1) a 15-micron filter should be added upstream of the radiator bypass valve (RBV), (2) the existing radiator bypass branch orifice should be reduced in size to increase the radiator flow in the event of a split flow condition, caused by either a relief valve open malfunction or a RBV poppet position anomaly, (3) the 100-micron filter should be removed from the downstream flow side of the thermal capacitor. This filter is a potential source of pressure increase due to ice plugging the filter element as the water in the coolant freezes out. The filter is not required in the system since its original purpose was to protect the radiator control valve which was deleted, (4) the negligible leakage detected during the mission has verified the adequacy of "in place" induction brazing for consideration of long term storage system, and

(5) since essentially only one pump of the eight on-board (4 in each loop) was required during the mission, future systems design need not be as conservative if pump performance can be predicted with confidence or an operating life test can be performed prior to design.

9.1.11.8 Atmosphere System - The pneumatic vent valves in the atmosphere system fulfilled all ground and orbital design requirements. The only anomalies in the solenoid vent system performance were slow venting on DOY 145 due to a clogged filter and failure of Valves 1 and 3 to give a closed indication on DOY 146 probably caused by particulate contamination. The use of an inlet screen with a finer mesh (finer than 100 microns) allowing more flow area might have prevented both problems.

The overall low cabin atmosphere leakage rate verified the manufacturing and testing techniques used to assure OWS HA pressure integrity.

9.1.11.9 Vacuum Systems - All vacuum systems performed as expected and without significant anomalies, except that the waste tank pressure reached the triple point pressure of water during some large quantity dumps apparently due to a higher than expected rate of sublimation of the ice formed during the dumps (no adverse effects have been observed because of this high pressure), and the WMC water dump probe orifice became blocked during SL-3. The dump probe was replaced with an on-board spare and no additional problems were experienced with this system. Subsequent investigation indicated that the problem was temporary blockage with ice and the probe could be kept on-baord as a spare. The liquid urine dump system was used on SL-4 only and performed satisfactorily except for a brief temporary blockage on DOY 005 of SL-4.

9.1.12 Pressure Garment Conditioning System - Suite drying was accomplished satisfactorily. The suits were always dried adequately and there was no evidence of bacterial growth or odor. The desiccants were dried in the waste processor. The noise level during the extended operation of the blower was not objectionable. There were no changes in procedures or hardware recommended by the flight crew. During the SL-2 mission, the suit drier power module was reported too hot to touch. The unit was being operated with the ring compartment door closed per procedure. Crews were instructed to leave the door open for additional cooling and no further problems were reported.

9.1.13 Stowage System - In general, the stowage compartments performed their intended functions very well. They were versatile and provided ease of access. The ability to complete the stowage of the ring containers (and the ambient food containers) outside the vehicle prior to launch minimized the impact of stowage operations on vehicle time. This feature should be strongly considered for future vehicles. The restraint straps in the compartments, even though adequate, should be more flexible, stronger, and easier to adjust. This will require development of new materials that will meet flammability requirements. The armalon/sponge bags and the non-flammable fiberboard proved very effective as a packing material and vibration dampening device. These had the added advantage of being lighter than other materials available that would have satisfied the flammability requirements.

All dispensers performed satisfactorily. The towel dispenser did not require the versatility it had. The trash containers performed very well. The concept of standard compartments with standard door attachments lent itself to inter-changing trash containers as desired. The bag/door interface provided easy replacement of trash bags.

The food box concept was satisfactory. No problems were encountered in relocating the boxes on-orbit. Placing round cans in rectangular boxes was an inefficient use of space. The food freezers and food chiller performed as designed. They maintained the food at the required temperatures. Chillers and freezers on future vehicles should have a general restraint capability to provide the flexibility to handle preflight and flight requirement changes.

The film vault performed satisfactorily and met all requirements. The large amount of unplanned equipment stowed in the vault drawers suggests a system or universal restraints should have been incorporated.

The bungees appeared to be the best concept for on-orbit temporary restraints. A better attaching method could have been developed. Permanent attachment or snap attachment would have been desirable but would have added weight to the vehicle. The snaps and velcro performed satisfactorily. A higher shear strength and longer life velcro would have performed better but none was available that would meet the flammability requirements.

The tool and repair kits performed satisfactorily. The utilization of standard tools proved to be effective and should be continued on future vehicles. On future vehicles a basic comprehensive tool kit should be established early in the design phase. Specific tools would have to be added where the design dictated but the change in the basic kit would be minimized.

The computer program was an excellent vehicle for tracking the various stowage items, restraint hardware, and required drawings. No previous program of this magnitude and numbers of stowage items exists from which a comparison can be made between manual and computerized management of numerous stowage aspects, but manual preparation would have produced a much higher magnitude of errors. Future programs should find advantages in this type of approach to stowage control.

9.1.14 Marking System - Since no comments from the flight crews were received regarding the methods chosen for the markings or the adequacy of same, it is assumed that no significant problems were encountered. However, as a result of the experience gained during the silkscreening of the various OWS panels, certain recommendations can be made for future application. The panels silkscreened with uniglaze ink were not able to withstand normal wear. For future applications, it is strongly recommended that an ink more suitable for silkscreening, e.g. MDAC STM 0248 catalyzed silkscreen ink, be used. This ink has proved to be easily applied using normal practices and stands up very well to normal wear.

The metal-foil labels proved to be an excellent method of identifying stowage content and for procedural labels. For future applications it is recommended that the .008 inch (.203 mm) thickness be used for all labels applied to a flat surface. In general, the application of labels on a curved surface is not recommended. However, if this cannot be avoided, the .003 inch (.076 mm) thickness should be specified.

9.2 PROGRAM PLANNING

9.2.1 Organization - The OWS Engineering organization was separate from but an extension of the Saturn/Apollo matrix organization; however, this matrix management technique was utilized in a way which was tailored to the special needs of the program. It was, for example, recognized early in the program that there would be a need to place special emphasis on the "system" aspect of the design, since the OWS was only one component of the total Skylab Cluster, and contained many inter-related, internal systems. Systems that were to provide for and to support crew habitation on-orbit, to accommodate launch provisions and on-orbit operation of Associate Contractor designed/Government Furnished Experiments, and to provide monitoring and control capability to assure proper functioning of all systems in orbit. The organization recognized the "one-of-a-kind" (one launch spacecraft) and the need to make the transition from concept to design, to fabrication, to qualification, to spacecraft system tests, to launch site testing and launch with firm continuity. This caused the identification of key technical people to become involved through the transitions and these people were identified to the NASA as focal points for working group meetings and exchange of technical questions and directions.

To assure proper emphasis on this system aspect, three methods were employed:

- The System Engineering Organization was strengthened and chartered to work closely with NASA and the MDAC-E Airlock engineering department to concentrate on the systems engineering aspects of the design.

- Special system managers were assigned to focus particular emphasis on major system hardware which was being designed and supplied by subcontractors or associate contractors; to wit: Habitability Support System, Solar Array System and Government Furnished Equipment.

- Subsystem engineers were assigned to assure that the system design aspects were properly studied and accounted for in each OWS design; to wit: Crew Support, Electrical, Environmental Control, Experiments, Ground Support Equipment, Instrumentation & Communication, Ordnance, Pneumatics, Refrigeration, Solar Array, Stowage, Structures, Waste Management, and Water. To maintain the continuity from design through launch, the subsystem engineers, which also included the special system managers, were identified as the key technical people to follow the respective systems and actively participate through all its phases. Where appropriate, these key people were identified to go to the field site, engage in the final test and launch, and then go to mission support sites.

These assignments carried with them an across the department responsibility for design and mission performance.

To further reduce communication paths the OWS engineering organization was brought together as a centralized unit, physically located in one large working area. Within the same area were key representatives and working personnel from all program elements such as Manufacturing, Tooling, Procurement, Planning and Quality. This technique provided early inputs to engineering to effect simplification and reduced cost. It also provided rapid response from engineering on problems encountered by other program elements, and eliminated false starts.

9.2.2 Establishing Requirements - The OWS design evolved from the S-IVB stage of the Saturn/Apollo vehicle. It was first envisioned as a regular propulsion stage with additional "SCARS" (OWS equipment attach fittings) added within the hydrogen tank portion. The SCARS were to allow utilization of the stage in orbit, after the fuel had been expended, as a habitable workshop. During this period the design was known as a "Wet Workshop" design since it was to have been launched with fuel - or "Wet". The design progressed from "Wet" to "Dry". The Dry Workshop, being the final design wherein the OWS no longer performed as a propulsion stage during launch, and consequently was launched without fuel or "Dry" with all provisions built in for on-orbit use as a Workshop. During this period of OWS evolution, engineering management provided a close relationship between MDAC and NASA technical people to establish and develop the design requirements for the program.

This close working relationship had been established and promulgated during the S-IV/S-IVB design period and was particularly effective in previously good communication paths between government and contractor personnel.

Another planned technique employed by NASA and fully supported by engineering management, to assure development and wide dissemination of technical requirements with a minimum of communication barriers, was the establishment and conduct of frequent, regular sessions of requirement/design working groups. These working groups included the flight crews and their representatives to assure that their flight experience provided the necessary influence where appropriate.

The design requirements, once established were formally maintained in the Contract End Item Specification and attendent documents (Systems Engineering Requirements Document, Development Engineering Plans, Engineering Work Orders, Design Requirements Document, etc.).

A major requirement determination effort was accomplished on the Skylab program in the area of interface requirements. NASA and contractors alike recognized the need for interface requirements development, since Skylab brought together literally hundreds of newly designed and developed items of hardware. Interface Control Drawings (ICD) prepared by assigned contractors and formally controlled and issued by NASA became the prime means for communication of design requirements between the many associate contractors supporting the OWS. Each prime contractor in the Skylab program actively supported the ICD approach to requirements definition. It had been anticipated that many significant fit and function problems would develop during OWS final assembly and test but the ICD program proved to be a prime technical management tool.

9.2.3 Controlling to Requirements - It is mandatory to establish a good set of requirements, and equally mandatory that the designs produced are controlled in a way that assures their conformance to the requirements once established.

The OWS engineering management recognized early in the program this need for control to requirements, and several management methods were employed to focus attention on this control aspect:

A. The system managers and subsystem engineers were established in the organization, as previously outlined in 9.2.1, and were chartered to assure compliance to the design requirements. Each system/subsystem engineer conducted frequent reviews of the design against the requirements, and through the assigned team members, accomplished the technical coordination with NASA and Associate Contractors to effect complete compliance to requirements. This was a very effective team approach that focused the engineering effort where and when needed to control designs to the requirements.

B. An interface management office was established and a working team assembled, comprised of representatives from each design technology, to define and control the OWS designs in the interface areas. This team made direct contact with NASA and Associate Contractor representatives and made certain that each interface requirement was known and followed. Design drawings were identified to the ICD's and formal ECP submittal and approval was required in order to change a design of the interface identified as affected by the change. The result of this effort was very effective control of interface designs to the approved ICD requirements.

C. Design reviews - internal and external - were a prime method employed to assure total compliance to recognized OWS requirements.

The OWS Design Engineer office conducted extensive internal reviews of each system to ascertain requirement compliance and assure capability for total mission performance.

The OWS joint NASA reviews were comprehensive and searching - and more frequent - as launch time approached. OWS engineering management committed fully to support of these affairs and every facet of the design including test data was made available to the NASA teams conducting these reviews. The major reviews conducted are shown in Table 9.2.3-1.

D. Special types of reviews and groups which NASA managed, relating to the total Skylab Cluster, were also actively supported by OWS engineering management. These (see Table 9.2.3-2) were a vital part of the overall NASA plan to develop, disseminate and control Cluster requirements across the program. OWS engineering provided data and representatives to these sessions regularly; and followed them up by responding to assigned action items.

These sessions were invaluable to OWS designers since they provided a way to gain insight into the workings of the other Cluster hardware and to the compatibility of the flight crew with the hardware design.

9.2.4 Improvements for Future Programs - The management methods stated in 9.2.1 through 9.2.3 were a major contributor to the OWS success in meeting its design and performance objectives. Following are some suggested improvements which should be considered for new programs:

A. Increased utilization of the subsystem management concept should be made throughout the total program management structure. This is equally applicable to Contractor and NASA organizations. Assigned subsystem engineers should clearly be made responsible

Table 9.2.3-1
OWS REVIEWS

REVIEW	DATE
OWS Preliminary Design Review (PDR)	May 1967
OWS Delta PDR	December 1967
OWS Preliminary Dry Requirements Review (PRR)	July 1969
Habitation Support Systems Preliminary Design Review	August 1969
OWS Critical Design Review (CDR)	September 1970
OWS Solar Array System CDR	January 1971
OWS Subsystem Reviews	March 1971 thru June 1972
OWS Systems/Operations Compatibility Review	June 1972
OWS Design Certification Review (DCR)	October 1972
OWS Hardware Integrity Review (DCR)	March 1973
OWS Flight Readiness Review (FRR)	April 1973

Table 9.2.3-2

Cluster Reviews

REVIEWS

Cluster Requirements Reviews

Progressive Crew Station Reviews

Experiment Integration Reviews

Crew Equipment Fit Checks

Customer Acceptance Readiness Reviews

Monthly Management Reviews

WORKING GROUPS

EVA Operations Planning Group

Change Integration Working Group

Stowage Working Group

Contamination Control Working Group

Microbial Working Group

Transfer (on-orbit) Working Group

Checkout Working Group

Electrical Working Group

Mechanical Working Group

Instrumentation and Communication Working Group

ICD Working Group

Mission Evaluation Working Group

Maintenance (in-flight) Working Group

only for the technical aspects of analysis, design, fabrication, test and assembly and they should remain free of administrative activities. The types of people assigned to these roles are key engineers and are often also given administrative responsibilities. This should be avoided.

B. More emphasis and effort should be expended to assure the earliest possible definition of design requirements for each subsystem of the flight items.

C. Once defined, each design technology should maintain an engineering document which is the repository for each set of system/subsystem requirements.

D. Design reviews should be planned and scheduled for each system in a way that will assure an orderly progression and with no schedule conflict with another system review. Review participation should be defined and considered mandatory, to assure maximum communication of system knowledge and plans for meeting the requirements.

E. Analytical and design engineers should be encouraged to become significantly more involved with the hardware. This could be accomplished by more review of basic raw and final data, observance of test runs and initial production operations, and by participation in first article and delivery acceptance inspection.

F. The NASA intercenter working group panels should be structured compatible with the program systems and should convene frequently. Contractor assigned representatives should be obligated to present frequence concise reviews of the design features of their related product, and should be afforded member status to enable them to present problems deemed appropriate.

G. GFE should be subject to the same requirements for design, review, and documentation as are imposed on the contractor in whose product it is used. The drawings and design information regarding the GFE should be made available to the using contractor and his agreement should be required in any decisions regarding flight worthiness of the GFE.

9.3 TESTING

9.3.1 ° Development and Qualification - The Orbital Workshop, a follow-on development of the S-IVB Program, was designed to use common, qualified hardware to the extent possible. Components unique to the OWS program were designed with the intent to minimize required testing. Methods such as factored safety margins and system redundance to reduce criticality were used. Wherever possible, analysis or similarity to previously qualified hardware was used as the verification method.

Initially, because the OWS was approached as a low-cost ("bare bones") program, the test program and its associated documentation were developed on a minimal basis. This concept left much to be desired in developing the required confidence by MDAC Management and the Customer that all design and mission operation requirements were being satisfied. At this point, it was mutually agreed that a Test and Assessment Document (TAD) be employed to provide traceability of requirements through necessary verification.

The "Off the shelf" concept while eliminating a complete redesign, development and retest of much hardware, did not reduce the requirements to verify and validate the qualification of all Flight Critical hardware. In attempting to utilize both new and previously qualified hardware in the OWS Program, the contractor found that three (3) major categories were required to define the hardware test history; i.e., hardware qualified by test; analysis, similarity and/or any combination thereof. To certify the hardware was qualified by the above methods, the contractor required evidence of the previous test records, current and/or previous analysis data, similarity rationale and/or combinations of all.

In addition to the above items, data to satisfy program requirements, the desirability of a single reference document to record, validate and control this multitude of data points lead the contractor to the development of a Test and Assessment Document (TAD). The TAD evolved around these major data points.

The initial work was begun on the TAD early in 1970, by defining hardware lists, establishing ground rules and area of responsibility. This effort was coordinated with Customer representatives in working group meetings. By early summer of 1970, the basic ground work was finalized to initiate the TAD "First Draft.' DRL MSFC 171A, Line Item G09, released 10 August 1972, identified minimum TAD data and established a release date which had been agreed upon during the Customer/Contractor working meeting 3 through 7 August 1970.

During the "First OWS Mechanical Assessment Review Meeting" (eleven Mechanical and 6 Electrical meetings were subsequently held), it was agreed that all Mission Safety Critical Items (MSCI) would, as a minimum, be included in the TAD. The Customer further stipulated additional hardware items, collectively designated as "Engineering Critical Items" would also be added to the TAD list when identified. It was also agreed two (2) separate TAD Volumes would be issued and maintained. Volume I would contain the Mechanical items and Volume II the Electrical items. Engineering critical item inclusion in the TAD presented the contractor a substantial schedule problem, in that the TAD hardware list was in a continual state of expansion. This was born out in growth of the original 188 items of the first TAD issue compared with the 291 items of the final issue.

During the duration of the OWS Program, three (3) complete revisions of the TAD (Volumes I and II) were issued. The first issue was made in February 1971, being preceded by a Preliminary Volume I, dated September 1970. First submittal of Volume II was dated 6 April 1971. The final revised issue of Volumes I and II was made on 1 May 1973. This final issue incorporated the contractual data requirements for OWS as well as OWS Backup baseline requirements.

The TAD was expanded well beyond the original intent of a component test validation document by becoming a master test index during CDR's, Vehicle checkout and CDDT. It served well as an indispensable Engineering tool throughout the Program. It was considered by most as the controlling document for other contractural functions such as the Certificate of Component Acceptance (CCA), as well as significantly influencing the entire OWS test program.

To facilitate a reasonable degree of visibility of test status between TAD items and the multitude of tests performed, a FORTRAN computer Test Matrix was developed. This matrix provided first an alphanumeric tabulation of all TAD items and a corresponding list of test line items associated with the qualification/development testing of the item.

Both the item and the test line item were suffixed to indicate testing status, i.e., complete or incomplete.

A second tabulation "matrix of OWS-1 components tested under test line items," listed all test line items. Beneath each specific line item the part number and nomenclature of each TAD item tested were listed.

As the development and qualification testing progressed, Certificates of Component Acceptance were prepared for all critical items listed in the TAD. At this time, acceptance test procedures were developed to assure the flight hardware was built to the proper quality and design standards. Virtually all hardware assembled into the OWS was subjected to a Production Acceptance Test (PAT) prior to installation. Many systems received an additional PAT after installation--for example, after brazing pneumatics systems.

9.3.2 ° Spacecraft Systems Testing - Spacecraft systems testing was initially approached as a low cost, low profile program with the same type of management and controls utilized to checkout SIVB stages. Very early in the checkout, the Contractor and the Customer decided the established practices were not sufficient. A more comprehensive management and controls system was established because of the many interfaces between the NASA centers, experiment developers, and participation of crewmen in the tests. The expanded system proved to be quite satisfactory.

Checkout was a finite plan. Changes were carefully controlled and authorized.

The checkout was completed within the required schedule, thousands of elapsed hours of manufacturing work were accomplished in parallel and the flight integrity of the spacecraft was verified.

Division of work, applicable contractor policies and procedures, working agreements established by the Customer and Contractor, etc., were specified in the MDC G2427, Huntington Beach Vehicle Checkout Laboratory Operations Plan, dated July 1971.

Procedures utilized during checkout were prepared in accordance with requirements of 1B83429, Test and Checkout Requirements, Specifications and Criteria Drawing. Special constraints and remarks were noted. The TCRSC changes were very carefully controlled and required the NASA approval. It proved to be a very valuable document not only for specifying the requirements but also the mechanism to verify all requirements were met.
Spacecraft checkout objective was to verify operational capability by exercising each spacecraft element in such a manner as to assure operation within allowable test specifications and criteria as a component, subsystem and all systems operating together.

Checkout was accomplished subsystem by subsystem to ascertain 1) all components were properly installed and unctioned properly throughout normal sequence of operation, 2) appropriate system leakage requirements were met, and 3) each command response was within test specification and criteria established for each system/subsystem.

An All Systems Test was accomplished subsequent to completing subsystem testing. The AST simulated a compressed OWS-1 Mission, including Prelaunch, Boost, Preactivation, Activation, Orbital Operations and Deactivation. It was a functional test with all OWS systems active in the required boost or orbital flight configurations, within the constraints of ground testing. The AST was the final demonstration at HB of OWS flight readiness.

The OWS was tested for lack of electromagnetic interactions, safety margin of induced RF interference, and experiment/OWS radiation susceptibility. Acoustical noise measurements were also included as part of the AST.

Spacecraft checkout at Huntington Beach contributed greatly toward successful integrity verification of the spacecraft and launch preparation activity of the Skylab.

9.3.3 Conclusions and Recommendations

9.3.3.1 Component and Subsystem - The emphasis on qualification testing was to develop a "low cost"/"bare bones" program. Criteria were: reduce testing, reduce formality of testing, and reduce formal documentation requirements. There was a continuing increase in demand for technical justification to substantiate the need for a test and more technical analysis was required to support rationale for qualification without testing. Assembly or system level tests were performed in lieu of some component level testing. This action created at least two problems: (1) more components had to be gathered to complete the higher level assembly/system tests and, therefore, test delays were evident, (2) tests were entered at a recognized higher risk because of the lack of component level test. This caused further delays in the test program.

The emphasis of reduced formal documentation was recognized as a misjudgment. The background, rationale, and judgments made by the designers was not readily available to the technical and program management people who had the responsibility to assess the validity of the program to make the spacecraft ready to fly. This problem was eventually corrected by the development of the Test Assessment Document (TAD) as discussed in paragraph 9.3.1.

In conclusion, the test approach taken did make the spacecraft ready to fly. In-flight performance did show that in three significant cases, more testing should have been done. Those three were (1) meteoroid shield which was lost during boost, (2) the refrigeration system radiator by-pass valves that failed. While they did not cause a loss of the systems, anxiety was created, (3) late ground test results predicted that the Wardroom and waste management heaters would fail. At the last minute spare heaters were launched. Inflight data indicated a change in performance of the heaters, however, both did supply needed hot water through the entire mission.

Recommendations to consider for improvements in the qualification approach are (1) a systematic approach should be developed to assess each subsystem until all elements of the spacecraft have been analyzed and documented to show the rationale to verify ready for flight by use of tests, analysis, and similarity, (2) during the assessment phase the components having a relative high risk of failing tests and causing redesign should be identified as candidates for individual component level testing as early as possible. This could help prevent test stoppages and/or delays.

9.3.3.2 Post Manufacturing Checkout - The spacecraft checkout was performed in detail to meet the Test and Checkout Requirements Specifications and Criteria (TCRSC). The MDAC-W proposed concept of formalizing the TCRSC for MSFC concurrence and preparing Test Outline Drawings (TOD's) for early review and comment by MSFC, KSC, JSC, and in-house checkout related organizations proved beneficial to establishing a solid foundation for detailed procedure preparation. Adequate attention had been paid to the technical content of the tests. All procedures were worked through the procedure working group review teams and finalized prior to testing. Therefore, there were no significant technical problems.

The significant checkout problem was the misjudgment of the timing and magnitude of actual flight crew participation. The premise on which the start of checkout was prepared for and started, was - the spacecraft would be functionally checked first and then the flight crew would do the things they planned separately. After the major part of the checkout procedures had been prepared, it was decided that the flight crew would participate in subsystem checkout. They stipulated what tests they desired to participate in and what parts of the test. In addition, it then became a requirement to reformat the procedure into a crew operating format. The format was to be as near identical to the inflight procedure as possible. This then increased the crews familiarity with systems and hardware functions and also allowed them to function as near as possible to the anticipated flight procedure. After this initial changeover the crew participation became routine and helpful.

The other significant problem was in attempting to get all the equipment aboard for the Crew C^2F^2 (Crew Compartment Fit and Function). This spacecraft had significantly more equipment aboard than any previous spacecraft. There were hundreds of storage items, many of which were still undergoing modification, and there were many pieces of experiment equipment not readily available. The ultimate solution was performance of the C^2F^2 in increments with that not performed being deferred to the launch site.

The following recommendations should be considered on future programs of a similar nature. The checkout plan should clearly recognize the degree of flight crew participation desired so that checkout procedures are formated properly and consistently and are as near identical to inflight procedures as possible.

9.4 PRELAUNCH AND MISSION SUPPORT - The Orbital Workshop (OWS) prelaunch and mission support provided by MDAC-W was effective in providing the technical analysis, ground testing, and support hardware necessary to support the NASA in the successful conclusion of the Skylab mission.

The organization of an MDAC-W OWS Prelaunch and Mission Support Team including representatives from all program support organizations was effective in providing an integrated and total response to all launch and mission support demands. The use of program and engineering personnel with in-depth experience in the design, development and prelaunch verification of OWS systems proved invaluable in the rapid assessment and complete response to mission support requests. The inclusion of manufacturing operations and the various MDAC-W test support organizations as part of the OWS mission support team and the assignment and control of hardware and test support activity through the basic mission support action assignment system proved very effective. Hardware and test activities were accomplished in concert with mission support requirements and were provided in a timely manner.

OWS mission support requests were formally documented by an MDAC-W action request and assigned to the appropriate mission support team representative for response. Responses received a technical and program review to verify their completeness and accuracy prior to transmittal to MSFC. During the Skylab (SL) mission one thousand twelve (1012) action requests were processed by MDAC-W. The system developed for action item assignment, tracking, review, and response was effective in providing accurate and timely support.

The OWS mission support facilities at Huntington Beach proved to be satisfactory in providing the communication channels and work areas necessary for mission monitoring and action response coordination. Of particular benefit were the NASA provided mission voice networks for real time monitoring of the air-to-ground crew conversations and the JSC flight directors communication loop. Real time data availability at Huntington Beach was limited to what could be received via telephone from MSFC. This resulted in a constraint to understanding and providing fast response for some of the more complex technical problems. Another significant constraint was the inability to transmit written material in a timely manner. There was a large volume of written material requiring transmission between MSFC and Huntington Beach. The magnafax transmission equipment provided was too slow (6 minutes per page) and very often caused delay of required information.

The following recommendations should be considered for future programs: provide a data terminal at each support location which would allow receipt of real time or near real time flight telemetry data for support of problem resolution, and provide a capability for timely transmission [e.g., Long Distance Xeroxgraphy (LDX)] of written material between all mission support locations.

SECTION 10 - BIBLIOGRAPHY

10.1 SPECIFICATION'S/PROGRAM DOCUMENTS

DOCUMENT	DATE OF ISSUE	TITLE
CP2080J1C	26 November 1969	Contract End Item Deatil Specification (Prime Equipment), Performance/Design Requirements
DAC-56618A	26 September 1969	Quality Program Plan
DAC-56689A	23 January 1970	Configuration Management Plan
DAC-56692A	26 September 1969	Ground Support Equipment Model Specifications
DAC-56697A	26 September 1969	Test Plan
DAC-56701A	26 September 1969	Reliability Program Plan
DAC-56724A	26 September 1969	Government Furnished Property Requirements
MDC G0837C	17 September 1971	Operational Nomemclature
MDC G0945	June 1971	Critical Components List
MDC G2439	October, 1971	Snap/Velcro Restraints
MDC G0397	August, 1971	High Fidelity Mockup Program Requirements
MDC G0174A	24 February 1970	Engineering Mockup/One-G Trainer Program Requirements
MDC G0017	26 September 1969	Dynamic Test Article Program Requirements
40M35631E	18 March 1970	Power Allocation Document

10.2 SYSTEMS ENGINEERING STUDY REPORTS

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0031-P	1-15-70	SATURN V WORKSHOP WATER SYSTEM
SUMMARY:	Trade Study directed toward establishing the configuration of the water system for the "Dry" Orbital Workshop. Study is divided into three basic sections: Water Distribution System; Water Storage Container; Water Storage Container Installation	
MDC G0033-P	2-17-70	ORBITAL WORKSHOP PRESSURIZATION AND VENT SYSTEM REQUIREMENTS
SUMMARY:	Study documents the selection of a system for pressurization and venting of the OWS tanks during launch and orbital coast.	
MDC G0041-P	2-2-70	INTELSAT IV ANTENNA INSTALLATION FEASIBILITY STUDY
SUMMARY:	Study initiated to establish the feasibility of installing both the refrigeration subsystem radiator and the intelsat antenna in the aft interstage area of the Saturn Workshop. Study was terminated by NASA prior to completion.	
MDC G0047-P	3-17-70	OWS PASSIVE THERMAL CONTROL STUDY
SUMMARY:	An evaluation of the thermal control requirements for the OWS made to define potential passive system changes to meet CEI Specification habitation temperature criteria. Primary emphasis was on external tank and meteoroid shield "optical" coatings.	
MDC G0052-P	2-16-70	SOLAR ARRAY SYSTEM DESIGN DESCRIPTION
SUMMARY:	Document summarizes the results of a Preliminary Design Study on the Workshop Solar Array System.	
MDC G0053-P	1-15-70	SCIENTIFIC AIRLOCK (SAL) INSTALLATION STUDY
SUMMARY:	Study reviews the SAL design and documents the structural and and mechanical modifications required to meet OWS requirements.	

REPORT NUMBER	DATE ISSUED	TITLE
MDG G0055-P	1-29-70	WINDOW INSTALLATION IN OWS WARDROOM

SUMMARY: Study compares window designs already made and in some cases flown on existing Apollo craft. Window location information is derived for optimum viewing. Several alternate designs are presented along with a discussion of their relative merits to aid in eventual selection.

MDC G0056-P	1-21-70	A GASEOUS OXYGEN RECHARGE SYSTEM TO SUPPORT SVWS EXPERIMENTS M509/T020

SUMMARY: Study provides definition of a Gaseous Oxygen recharge system for use in conjunction with experiments M509 and T020.

MDC G0058-P	12-29-69	AM/OWS TRANSIENT GENERATION AND SUSCEPTIBILITY LEVEL DISPARITY

SUMMARY: Study documents the impact of increasing susceptibility levels to ± 50 volts.

MDC G0059-P	3-31-70	OWS ORBITAL STORAGE TRADE STUDY

SUMMARY: Study to determine if the OWS internal hardware could be stored in orbit between habitation periods at near vacuum conditions and remain functional for subsequent use. Electrical and Habitability Support System equipment, sealing devices, and experiments were considered.

MDC G0060-P	1-29-70	ORBITAL WORKSHOP PERSONAL WASH SYSTEM

SUMMARY: Trade study to evaluate wash systems for the personal hygiene of the OWS crew. Failure to find a satisfactory filter for the baseline system air-water separator required a study of alternate approaches to crew hygiene and wash water collection methods.

MDC G0061-P	1-29-70	THRUSTER ATTITUDE CONTROL SYSTEM (TACS)

SUMMARY: Trade Study compares the use of the Saturn Control Relay Package (CRP), P/N 1B57731, to a design concept which uses relay modules containing the general purpose 10 Amp relays, P/N 1B66900, used on the Mainline Saturn Program.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0062-P	1-16-70	URINE POOLING STUDY, TECHNICAL (REVISED 5 FEB. 70)

SUMMARY: Trade Study to analyze a 24-hour pooled urine sample technique with optional processing of:

(a) 100% dried
(b) 120 ML sample dried
(c) 120 ML frozen sample

Study takes these options and compares them to the Baseline System to develop the measure of advantages in volume, electrical energy and return weights.

MDC G0064-P 2-18-70 ORBITAL WORKSHOP POSIGRADE ΔV SYSTEM STUDY TO ELIMINATE SHROUD RECONTACT POSSIBILITY

SUMMARY: Trade Study of Propulsive Venting Systems to determine the most promising design approach for imparting a posigrade ΔV to the OWS. A delta velocity of four feet per second was used to avoid recontacting the payload shroud.

MDC G0065P 1-22-70 TACS MISSION IMPULSE INCREASE USING ELECTRICAL HEATERS

SUMMARY: Study on a means of maximizing Thruster Attitude Control System (TACS) impulse by utilizing active thermal control.

MDC G0067-P 1-29-70 FILM VAULT STUDIES

SUMMARY: Study of design approaches to the storing of film.

MDC G0068-P 1-29-70 OWS EXPENDABLES

SUMMARY: Study to identify required quantities of expendables for the dry version of the OWS and document the ground rules and rationale used in their determination.

MDC G0069-P 2-19-70 LIGHT BAFFLING STUDY

SUMMARY: Study to determine the optimum method or methods of providing a means for light baffling in the sleep compartment and wardroom. Total darkness was chosen as a design goal.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0070-P	2-11-70	TRADEOFF STUDY GAS SUPPLIES FOR WATER SYSTEM PRESSURIZATION & METABOLIC ANALYZER FOR SATURN WORKSHOP #1

SUMMARY: Study to evaluate alternate methods and configurations for supplying gas for pressurizing the water system that supplies the OWS with water for metabolic and hygienic needs, and secondly, to evaluate alternate methods of connecting the gas supply lines into the Airlock Module Supply System.

MDC G0071-P	2-10-70	IMPACT ASSOCIATED WITH REVISED ACOUSTIC, SHOCK, AND VIBRATION CRITERIA FOR THE SATURN V ORBITAL WORKSHOP

SUMMARY: Study documents the effect of the increased environments, resulting from the conversion to a "dry" Workshop, on the OWS Test Program. Design procedures which minimize the impact of the increased environments are recommended.

MDC G0074-P	2-24-70	URINE FREEZING STUDY

SUMMARY: Study to determine the optimum method to implement a urine sampling and freezing system. Consideration was given to the following:

(a) Total mass determination
(b) Alternative methods and procedures for obtaining measured samples
(c) Methods of freezing and storing samples
(d) Methods of packaging samples for return
(e) Available space in CSM for sample return

MDC G0075-P	3-13-70	TRASH AND DISPOSAL STUDY

SUMMARY: Trash Disposal System Study used to develop a current "trash model" procedure for trash disposal and determine the size of the screen in the LOX tank.

MDC G0076-P	4-3-70 (Revised 6-30-70)	ISOLATION OF GAS SUPPLY FOR SWS THRUSTER ATTITUDE CONTROL SYSTEM TRADE STUDY (REVISED 30 JUNE '71)

SUMMARY: Study addresses TACS Gas Supply Isolation of the systems presented, selects the optimum with respect to performance, hardware development, reliability, development and qualification testing, cost and schedule. The primary objective was to complete the 236 day mission or, in the event of a leak, complete as much of the mission as possible.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0077-P	3-25-70	PRELIMINARY DESIGN/TRADE STUDY FOR CONTINGENCY ACCESS TO SATURN WORKSHOP ON LAUNCH PAD
	SUMMAFY:	Preliminary design/trade study which led to development of a design concept for adapting the catwalk end to the stage side.
MDC G0078-P	3-31-70	USE OF APOLLO SCIENTIFIC AIRLOCK ORBITAL WORKSHOP
	SUMMARY:	Study to identify changes to the SAL to assure that the Experiment/SAL interface is operationally compatible. Study established structural and dimensional limitations to be included on experiment ICD's.
MDC G0079-P	5-4-70	STUDY TO DETERMINE THERMAL CONTROL SYSTEM REQUIREMENTS FOR A 50° INCLINATION ORBIT VOL. I TECHNICAL REPORT
	SUMMARY:	Study determines the impact of a change in mission inclination angle from 35° to 50° and recommends system changes to the OWS to satisfy crew comfort criteria.
MDC G0080-P	5-4-70	STUDY TO DETERMINE THERMAL CONTROL SYSTEM REQUIREMENTS FOR A 50° INCLINATION ORBIT VOL. II APPENDICES
	SUMMARY:	Study presents supplemental data used to assemble the results contained in MDC G0079-P.
MDC G0081-P	4-14-70	DELETION OF THE S-IVB ULLAGE ROCKETS
	SUMMARY:	Study identifies advantages and disadvantages associated with the deletion of the S-IVB ullage rockets. A summary of all potential problem areas and their final assessment is presented.
MDC G0088-PA	12-18-70	EFFECT OF EARTH RESOURCES AND RENDEZVOUS MANEUVERS ON THE ORBITAL WORKSHOP
	SUMMARY:	Study assessed the compatibility of components with the X-IOP/Z-LV attitude required for rendezvous and defined the OWS subsystem performance and limitations during the revised earth resources X-IOP/Z-LV maneuvers.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0089-P	6-19-70	380,000 LB. SEC. THRUSTER ATTITUDE CONTROL SYSTEM

SUMMARY: Study presents a design for a 380,000 pound-second cold Gas Attitude Control System for the Saturn V Workshop. The selected impulse was based on a back-up capability requirement for a control moment gyro failure. Also, this impulse level is believed to represent the practical upper limit of a cold gas system for workshop applications.

MDC G0090-P	7-13-70	SOLAR ARRAY SYSTEM (SAS) DEPLOYMENT CONSTRAINT STUDY

SUMMARY: Investigation of all factors influencing the time when the SAS could be deployed. Study recommended a sequence of events for the identified influencing factors including actual SAS deployment and detailed the constraints dictating this sequence.

MDC G0092-P	7-27-70 (Revised 9-9-70)	LOOSE ITEMS AND DEBRIS DETECTION AND REMOVAL FROM ORBITAL WORKSHOP

SUMMARY: An analysis of the impact of tumbling or rolling the OWS to dislodge, detect, and recover loose articles for contamination control.

MDC G0093-P	9-8-70	METHODS TO REDUCE POSSIBILITY OF REFRIGERANT LEAKAGE IN THE OWS

SUMMARY: Trade-off Study to evaluate means of reducing or eliminating a possible fire hazard resulting from leakage of OWS refrigerant.

MDC G0083-P	4-27-70 (Revised 9-28-70)	ORBITAL WORKSHOP VENTILATION AND COOLING DURING GROUND OPERATIONS

SUMMARY: A study to (1) determine the optimum method of ground conditioning. Assuming OWS internal temperature requirements are 40°F to 80°F and that ground conditioning should maintain this temperature level for the 20 days preceding launch, (2) define the aft interstage prelaunch temperature purge requirements, and (3) identify the nominal purge gas temperature and the required tolerance band.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0084-P	7-27-70	ORBITAL WORKSHOP LEAK DETECTION AND REPAIR

SUMMARY: Study defines requirements for a hand held portable leak detector. Established C&W displays, meteoroid penetration probability, and evaluated present availability of leak detection device.

MDC G0085-P	5-25-70	LIGHTNING PROTECTION - OWS

SUMMARY: Study to investigate possible effects of lightning on the OWS hardware. Applicable review of the Apollo 12 incident were utilized to explain where similarity exists between the S-IVB stage and the OWS. Capability of the OWS to withstand any induced transient voltage or current was evaluated.

MDC G0086-P	6-10-70	NITROGEN GAS SUPPLY FOR WATER SYSTEM PRESSURIZATION FOR ORBITAL WORKSHOP

SUMMARY: Study identified the optimum method of supplying N_2 gas as pressurant to the OWS water bottles.

MDC G0087-P	7-27-70 (Revised 3-15-71)	ORBITAL WORKSHOP COMPLIANCE EVALUATION TO THE MANNED SPACECRAFT CENTER STANDARDS & CRITERIA DOCUMENT MSCM 8080

SUMMARY: Review of "Manned Spacecraft Criteria & Standards" (MSCM 8080), dated January 8, 1969, and determination of OWS compliance or noncompliance for each requirement.

MDC G0094-P	8-3-70	DESIGN REQUIREMENTS FOR THE ORBITAL WORKSHOP (OWS) REFRIGERATION SUBSYSTEM

SUMMARY: Study the refrigeration logic unit to determine if the logic is too complex. Study documents investigation and updates, evaluates, and clarifies the design requirements.

MDC G0095-P	8-20-70	FIRE DETECTION SYSTEM STUDY

SUMMARY: Trade study aimed at selecting sensor coverage - double or voting, and definition of the sensor quantities. Study defines coverage area and logic.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0096-P	8-12-70	ORBITAL WORKSHOP STOWAGE DESIGN REVIEW JUNE 26, 1970
SUMMARY:	Documents stowage PDR conducted on June 26, 1970.	
MDC G0098-P	8-28-70	RESIDUAL WATER EXTRACTION FROM THE ORBITAL WORKSHOP WATER TANKS
SUMMARY:	Trade Study to determine the optimum method of extracting and using residual (unused) water from each water tank.	
MDC G0099-P	9-8-70	SKYLAB A OPERATIONAL ACOUSTIC NOISE STUDY
SUMMARY:	Trade Study to determine if special methods of controlling (limiting) on-orbit noise level and acoustic characteristics in the OWS to attain the limits specified in the CEI, were required. Recommended methods were to be compatible with interior decor, flammability requirements, thermal heat balance, etc. Minimum change to the equipment sources generating noise was desirable.	
MDC G0100-P	8-28-70	ORBITAL WORKSHOP WASTE/TRASH DISPOSAL GENERAL REQUIREMENTS
SUMMARY:	Tabulation and incorporation of Cluster Trash into a trash model.	
MDC G0101-P	9-14-70	METHODS OF CLUSTER ODOR CONTROL WHICH CAN BE INCORPORATED INTO THE OWS
SUMMARY:	Definition and evaluation of methods of Cluster Odor Control which can be incorporated within the OWS.	
MDC G0102-P	1-28-71	CREW TASKS EVALUATION "POTABLE" WATER SYSTEM IMPROVEMENT
SUMMARY:	Review existing OWS water system design and identify changes which would simplify crew tasks and procedures. Identify potential design improvements and make recommendation relative to their incorporation.	
MDC G0103-P	10-9-70	STAINLESS STEEL/OXYGEN COMPATIBILITY
SUMMARY:	Study established design practices for oxygen-stainless steel systems. Assembled currently available data on metal combustion properties with oxygen. (Considered system pressures, temperature melting points, and any other pertinent data).	

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0104-P	11-13-70	MICROBIOLOGICAL CONTROL/OWS ATMOSPHERE CONTROL SYSTEMS

SUMMARY: Review of NASA request for microbiological control of Atmosphere Control System. Study analyzed problem and OWS system capabilities and provided conclusions and recommendations.

MDC G0105-P	9-29-70	ORBITAL WORKSHOP (OWS) PRODUCTION ACCEPTANCE TESTING (PAT) WITH INDUCED ENVIRONMENTS

SUMMARY: Study to determine OWS production acceptance environmental testing requirements.

MDC G0106-P	10-16-70	FILM VAULT HUMIDITY CONTROL

SUMMARY: Study examined candidate methods and recommended means of maintaining film vault humidity at 45 $\pm$ 15%.

MDC G0107-P	11-3-70	PRELIMINARY DESIGN CONCEPTS OF WASTE MANAGEMENT COMPARTMENT ATMOSPHERIC FILTRATION

SUMMARY: Study develops several preliminary design concepts for catching hair, fingernails, dandruff, whiskers, etc. in the waste management compartment. Consider as a high priority, placing adequate filtration in the WMC ventilation fan for this purpose.

MDC G0108-P	10-26-70	SIMULATED OWS FORWARD DOME FOR VIBROACOUSTIC PAYLOAD TEST (PHASE II)

SUMMARY: Determine the most feasible and economical means of providing an OWS Forward Dome Assembly including the OWS hatch to meet the technical requirements of the vibro-acoustic payload test program (Phase II).

MDC G0109-P	11-9-70	RETRO-ROCKET PLUME IMPINGEMENT ON SOLAR ARRAY SYSTEM

SUMMARY: Study examines candidate methods and recommends means of preventing retro-rocket plume impingement upon and through the solar array fairing assembly purge vent valves which might cause damage or degradation of their on-orbit performance.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0110-P	1-11-71	METHODS OF PRESERVING SURFACE OPTICAL PROPERTIES OF S-13G COATING ON ORBITAL WORKSHOP

SUMMARY: Determine the likelihood of having to clean the low solar absorbence coating on the OWS (S-13G) to remove excessive dirt and bring the thermal characteristics back to an acceptable level.

Determine if it is more efficient to inspect and subsequently clean the coating if required or install a protective cover that would be removed just prior to launch.

Considerations should include but not be limited to the following:

- o Length of time the OWS will be on the pad
- o Accessibility of coated areas
- o Total area coated with S-13G
- o Complexity of a cover designed to withstand wind, rain, etc.
- o Past experience with mainline vehicles
- o Duration of tasks as opposed to available time

Summarize the preceding and recommend a course of action.

MDC G0111-P	11-19-70	ORBITAL WORKSHOP SUIT CONDITIONING STATION - ALTERNATE BLOWER AND CONCEPT STUDY

SUMMARY: Study evaluated blowers other than the high cost waste management unit and investigated an alternate concept of utilizing the environmental control system as a source of blown air for the pressure suit conditioning station.

MDC G0112-P	12-28-70	CLUSTER WEIGHT/MASS REDUCTION BY WATER REMOVAL

SUMMARY: Determination of the optimum water bottles to be removed (and/or launched empty) to avoid mass saturation of the Skylab control moment gyros during X-LV gravity gradient.

MDC G0114-P	2-4-71	ORBITAL WORKSHOP CONDENSATION CONTROL STUDY

SUMMARY: Perform conceptual design and prepare gross impact for systems to backup/enhance or replace the existing heat pipe system.

MDC G0115-P	2-1-71	TRASH AIRLOCK CONTINGENCY/MALFUNCTION STUDY

SUMMARY: Conduct a study to evaluate contingency actions in the event of a failure of the trash disposal airlock. Evaluate test program.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G0116-P	02-05-71	EVALUATION OF METEOROID REPORT KIT

SUMMARY: Review existing meteoroid penetration repair techniques and comment on their adequacy. Recommend new techniques where appropriate. Evaluate the list of maintenance and operational tools/materials contained in Design Requirements Drawing 1B80699. Identify additional tools required.

MDC G0117-P	03-01-71	EVALUATION OF METHODS OF PREVENTING ICING OF THE WASTE TANK NPV SYSTEM

SUMMARY: Conduct further studies to substantiate the decision that control venting of the LOX tank will not be implemented. Present to MSFC the substantiating analysis to assure that no problems will be encountered by using the LOX tank for waste disposal will not occur.

MDC G0118-P	02-19-71	TRANSFER AND DISPOSAL OF SERVICE MODULE FUEL CELL GENERATED WATER

SUMMARY: Determine methods of draining CSM fuel cell water into an OWS water tank. Consider hardline and drag through hose concepts.

MDC G0119-P	02-25-71	ON-ORBIT TRANSFER STOWAGE STUDY

SUMMARY: Perform the stowage studies requested by SED-208-07-00204.

MDC G2161-P	03-01-71	SATURN SYSTEMS ENGINEERING TRADEOFF STUDY REPORT IN-FLIGHT SERVICING OF EXTRAVEHICULAR ACTIVITY UMBILICALS

SUMMARY: Perform a trade study relative to in-flight servicing of the dry AM EVA umbilicals. Prepare data relative to the design and operational characteristics of the water system. Data will be used in an MDAC-East presentation to NASA.

MDC G2162-P	04-26-71	PRELIMINARY TEST PLAN ORBITAL WORKSHOP CONTINGENCY TRASH PROCESSING VERIFICATION TESTS

SUMMARY: Study and present a preliminary design relative to contingency trash disposal via ejection through the Scientific Airlock (SAL).

REPORT NUMBER	DATE ISSUED	TITLE
MDC G2163-P	06-09-71	PROCEDURES FOR DETERMINING THE EFFECTS OF ORBITAL WORKSHOP WEIGHT CHANGES ON ATTITUDE CONTROL MARGINS

SUMMARY: Develop graphical aids which can be used to determine the effect of a weight change upon attitude control margin.

G2164-P	07-02-71	FIXED METEOROID SHIELD STUDY

SUMMARY: Generate the appropriate data and prepare viewgraphs on the feasibility/merits of a fixed meteoroid shield.

MDC G2165-P	07-26-71	PRELIMINARY DESIGN OF THE NITROGEN PURGE SYSTEM FOR THE ORBITAL WORKSHOP SOLAR ARRAY SYSTEM

SUMMARY: Determine methods of maintaining suitable environmental conditions for the solar cells in the beam/fairing during operations at the following locations:

1. Within the VAB.
2. During rollout.
3. On the launch pad prior to LOX chilldown in the S-II stage.
4. During cryogenic chilldown and until liftoff.

MDC G2166-P	07-23-71	ORBITAL WORKSHOP METEOROID SHIELD RELEASE SYSTEM DESIGN ALTERNATES

SUMMARY: Evaluate alternate methods of meteoroid shield deployment.

MDC G2167-P	07-28-71	EFFECT UPON OWS SYSTEMS OF ACCOMMODATING EARTH RESOURCES EXPERIMENT PASSES AT ANYTIME

SUMMARY: Assess or define the OWS subsystem performance and limitations during the revised earth resources X-IOP/Z-LV maneuvers.

MDC G2168-P	09-16-71	EVALUATION OF CONTAMINATION GENERATED BY WASTE DISPOSAL THROUGH THE WASTE TANK NPV DUCTS

SUMMARY: Conduct a survey to establish performance of all materials dumped into and vented out of the waste tank. The survey is to be summarized in two forms:

1. A viewgraph presentation.
2. A Systems Engineering Study Report.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G2169-P	10-11-71	EFFECTS OF CMG DESATURATION MANEUVERS AND Z-LV MANEUVERS UPON WORKSHOP SYSTEMS PERFORMANCE
	SUMMARY:	Determine the effect of CMG desaturation maneuvers during Z-LV on the refrigeration subsystem. Determine necessary desaturation maneuver constraints and/or system performance deviations required to accommodate specified maneuvers.
MDC G2170-P	09-30-71 (Preliminary)	AN EVALUATION OF MEANS TO CONTROL OWS SAS GROUND PURGE, ASCENT VENTING, AND RETRO ROCKET PLUME CONTAMINATION
	SUMMARY:	Update preliminary study on SAS vent valve and plume impingement protection.
MDC G2171-P	10-05-71	ORBITAL WORKSHOP METEOROID SHIELD PNEUMATIC SEPARATION SYSTEM
	SUMMARY:	Evaluate alternate methods of meteoroid shield deployment.
MDC G2172-P	11-12-71	RATIONALE FOR THE SELECTION OF THE URINE SAMPLE RETURN TRAY CONFIGURATION
	SUMMARY:	Document the trade-offs and selected design that led to the chamfered tank urine sample tray and separate dodecane tanks.
MDC G2173-P	11-11-71	ELIMINATION OF EXTERNAL OPTICAL CONTAMINATION FROM AM AND OWS FREE WATER DUMPS
	SUMMARY:	Conduct a study to identify methods to eliminate free water dumps from the waste management compartment and wardroom lines into the OWS waste tank.
MDC G2174-P	11-30-72	OWS HABITABLE COMPARTMENT MAXIMUM PARTIAL PRESSURE OF OXYGEN
	SUMMARY:	Determine the maximum partial pressure of oxygen that may be encountered in the OWS habitable compartment.
MDC G2175-P	01-07-72	GROUND COOLING AND PURGE REQUIREMENTS FOR THE OWS HABITATION AREA
	SUMMARY:	Re-evaluate the adequacy of the present purge system for the OWS habitation area. Compare the present method with alternate methods.

REPORT NUMBER	DATE ISSUED	TITLE
MDC G2176-P	12-22-71	ORBITAL WORKSHOP ATTITUDE CONSTRAINTS STUDY (INTERIM REPORT)
	SUMMARY:	Determine the effects of short term worst case attitudes and associated attitude constraints.
MDC G2177-P	01-25-72	STUDY OF CONTRAINTS ON MANEUVERING OF EVA CREWMEN AND A CSM TO AVOID SHADOWING DAMAGE TO THE OWS SAS
	SUMMARY:	Determine all constraints required to be imposed on planned missions to prevent unnecessary damage to the OWS SAS that could occur as a result of array shadowing. Primary items to be studied are (1) shadowing from CSM fly-around of the OWS and (2) shadowing from EVA crewmen.
MDC G2178-P	01-27-72	PLUME SHIELD DELETION STUDY
	SUMMARY:	Determine the effect on the performance of the refrigeration subsystem due to removal of the plume shield.
MDC G2180-P	04-20-72	REFRIGERATION SUBSYSTEM LEAK ISOLATION REPAIR
	SUMMARY:	Determine techniques of isolating and repairing leaks in the refrigeration subsystem coolanol lines prior to launch.
MDC G2181-P	05-01-72	REDUNDANT RELEASE ACTUATOR FOR RADIATOR SHIELD JETTISONING
	SUMMARY:	Examine the existing single failure point in the radiator shield jettison mechanism and determine methods of providing redundancy.
MDC G2784	11-10-70	OWS REFRIGERATION SUBSYSTEM ALTERNATE COOLANT STUDY
	SUMMARY:	Determine necessary equipment changes and desirability of utilizing a fluid other than coolanol.
MDC G2814	01-31-72	COOLANOL ASSURANCE PLAN
	SUMMARY:	Define the overall approach used by MDAC-W to insure the leak tight integrity and safety of coolanol-15 related systems in the OWS.

10.3 TEST PLAN DAC-56697A, DEVELOPMENT TESTS

TEST LINE ITEM	TITLE CREW ACCOMMODATIONS	REPORT NUMBER RELATED/VENDOR	REPORT DATE
CA-1	Floor Panel	A3-860-KBBB-TM-115	1 January 1968
CA-2	Floor & Wall (4.2 Grid)	A3-860-KBBB-TM-123	14 February 1968
CA-3	Wall & Floor Grid Splice	A3-860-KBBB-TM-124	27 December 1967
CA-4	Thermal Curtain & Ceiling	MP 51591, MP 51692, MP 51691 MP 51593, MP 51600 MP 51690, MP 51694	4 August 1970
CA-5	Green Alodine Coating	DAC-62115 (PHASE I AND II)	4 August 1970
CA-6	Coating Al Foil MD-19	DAC-62116	March 1968
CA-7	Colored Anodic Films	MP 51, 386	14 February 1969
CA-8	Insulated Plug Assembly	A3-250-KBBB-TM-131	27 August 1968
CA-9	Portable Foot Restraints	TM-DSV-ACCB-190	May 1970
CA-10	Portable Hand Hold	TM-DSV-ACCB-188	April 1970
CA-11	Tether Attach Pin	TM-DSV-ACCB-184	April 1970
CA-13	Exp Tube/CDF & EBW CDF	TM-DSV-4B-MECH-R-6573 A	10 November 1969
CA-14	Exp Tube	TM-OWS-MECH-R-6664	13 February 1970
CA-18	Viewing Window & Instl	MDC G3365 MDC G3865	May 1972 October 1972
CA-21	Foam Insulation	A3-250-ABA8-TM-138	15 January 1971
CA-23	OWS Acoustic Evaluation	A3-253-ABD4-TM-004	17 June 1971
CA-27	View Window Int Shield	MDC G3372	May 1972
CA-28	Expand Tube & Strap Assy	MDC G4022 Jet Research 1617 & 1618	January 1973
CA-32	Meteoroid Shield Post Instrumentation	MDC G3373	July 1972
CA-34	Met. Shield Deply Latch	MDC G3374	May 1972

EXPERIMENT ACCOMMODATIONS

CX-1	Scientific Airlock	MDC G4115 TM-DSV-7-SSL-R6952 A	March 1973
CX-5	PGA Air Flow Mod System	MDC G4178 TM-DSV7-F&M-R7049	April 1973
CX-7	Film Vault Humidity	TM-DSV7-SSL-R6904	24 August 1971
CX-8	Film Vault Mat Compatibility	TM-DSV7-SSL-R6930 A	7 February 1972
CX-9	SAL/Experiments Desiccant Unit	MDC G4179 TM-DSV7-F&M-R7050	April 1973
CX-11	Film Vault Mat Compat	TM-DSV7-SSL-R7051	18 July 1972

DATA ACQUISITION

DA-1	Mult Sign Cond-Gen	MDAC-ED REPORT 2175-02 2175-02 ADDENDUM 1, REV. A	25 July 1969 10 October 1969
DA-3	Fwd Sign Cond Panel	TM-DSV-7-EE-R6763 B (Phase 1 and 2) TM-DSV-7-EE-R6763 SUPPLEMENT 1 (3) TM-DSV7-EE-R6763 SUPPLEMENT 2 (4)	10 September 1971 10 November 1971 4 February 1972
DA-4	Fuse, Cart, Slk Mini	TM-DSV7-EE-R6658	December 1969
DA-5	Data Acquisition Comp	TM-DSV7-EE-R6775 B	15 April 1971

ENVIRONMENTAL CONTROL

EC-4	LH2 Tank Seal Device	MP 50, 885	3 April 1968
EC-5	Thermal Shield Ext	A3-290-ABF5-TM-137	March 1970
EC-6	Tank Radiant Heater	TM-DSV7-EE-R6786	24 February 1972
EC-7	Duct Heater Assembly	TM-DSV7-PROP-R6601 TM-DSV7-EE-R6601-1 A	12 November 1969 4 May 1972
EC-8	Fan Cluster Test	TM-DSV7-ENV-R6705 TM-DSV7-ENV-R6705-1 TM-DSV7-MECH-R6705-2	2 August 1970 23 December 1970 17 June 1970

EC-9	Air Distrib Ceiling	TM-250-ACMO-69-TM-189	December 1969
EC-10	Rm Fan Filter Test	TM-DSV7-F&M-R6753	20 July 1971
EC-11	Thermal Control Assembly	TM-DSV7-EE-6740	30 March 1971
EC-26	Ground Thermal Cond Syst	A3-250-ACM1-TM-207 AIRESEARCH 71-7741, REV 2	14 August 1972
EC-30	Fan, Portable	TM-DSV7-F&M-R6911	21 July 1972
EC-33	Fan Cluster Assembly	TM-DSV7-F&M-R7022	19 September 1972
EC-34	Room Fan Filter	MDC G4177 TM-DSV7-F&M-R6899	April 1973
EC-42	Portable Fan - Vibration	TM-DSV7-F&M-R7034	14 July 1972

ELECTRICAL SYSTEM

ES-1	LH2 Wicking & Ign	DSV-4B-PROP-R6088	30 October 1967
ES-2	Cryo Mat Eval	DSV-4B-EE-R6134 DSV-4B-EE-R6134, Supplement-1 TM-SIW-ENV-R6134-1	15 December 1967 11 April 1969 11 July 1969
ES-3	Zero G Conn	TM-SIW-EE-R6548 A TM-SIW-ENV-R6548-1 TM-SIW-SSL-R6548-2 TM-DSV7-EE-R6906	23 September 1970 16 September 1969 29 August 1969 15 September 1971
ES-5	Forward Dome Test	MDC G2071	March 1971
ES-6	Cont & Displ Panel	TM-DSV7-EE-R6696 B TM-DSV7-ENV-R6696-1 A	22 April 1971 24 July 1970

HABITABILITY SUPPORT

HS-1	Crew Restraints	TM-DSV7-SSL-R6901	23 August 1971
HS-3	Zero G Fecal Collector	TM-192, Vol I & II	24 July 1970
HS-4	Waste Col & Process	A3-250-ACM2-TM-198 AE-250-ACM2-TM-201 A3-250-ACM2-TM-202 Fairchild MS115T0123 Fairchild MS115T0122	19 April 1972 September 1972 September 1972
HS-5	Urine Process & Stor	TM-DSV-ACM2-191	May 1970

HS-8	Water Storage Assembly	MDC G4175 TM-DSV7-F&M-R7057, Vol. I and II	April 1973
HS-10	Food Reconst Disp Unit	TM-DSV-F&M-R6915	14 April 1972
HS-11	Drink Water Dispenser	TM-DSV-F&M-R6938	17 April 1972
HS-12	Water Heater	MDC G3945 Hamilton Standard SVHSER 5728, Vol. I and Supplement I, Vol. II and Vol. III	November 1972
HS-14	Microbiological Eqp	MDC G4156 TM-DSV7-F&M-R7058	April 1973
HS-16	Per Hyg Water Disp	TM-DSV7-F&M-R6760	15 October 1970
HS-24	Trash Disp Airlock	MDC G3364	March 1973
HS-25	Vac Outlet Valves	TM-SIW-SSL-R6358 TM-SIW-SSL-R6358-1 TM-DSV7-SSL-R6358-2 TM-DSV7-SSL-R6358-3	14 March 1969 11 April 1969 7 January 1969 30 April 1970
HS-31	Radiator & Plume Shield	TM-DSV7-F&M-R7060	11 October 1972
HS-32	Water Storage Cont Bel	MDC G3611	19 October 1972
HS-33	Cleansing Solution Test	TM-OWS-SSL-R6703	8 May 1970
HS-34	Waste Management Odor Cont	A3-250-ACM2-TM-203 Fairchild MS115T0086, Barneby Cheney 2341-4 and NASA Ltr. PM-SL-256-72H	October 1972
HS-39	UCMSS - Prelim Spec Tests	TM-OWS-ACM2-193 FH/RAD MS115T0029	20 November 1970
HS-46	Heater Controller	TM-DSV7-EE-R6875 TM-DSV7-EE-R6875 A	6 July 1971 18 August 1971
HS-48	Wash Cloth Squeezer Assy	TM-DSV7-SSL-R7062	31 August 1972
HS-51	UCMSS - Two-Bag Urine	TM-OWS-ACM2-196 FH/RAD MS115T0056	7 July 1971
HS-55	Urine Centr Sep Assy	A3-250-ACM2-TM-204 Hamilton Standard SVHSER 5965, Vol. I, II, III, Book 1 and 2	September 1972

HS-56	Urine Sep Flush Disp Assy	TM-DSV7-F&M-6989 A	23 June 1972
HS-59	Water Deionization Assy	MDC G4181 TM-DSV7-F&M-R7063 (S)	April 1973
HS-60	Centr Sep (Plexiglass)	A3-250 ACM2-TM206 Hamilton Standard SVHSER 5909	September 1973
HS-61	Two Bag Urine Tracer Verification	A3-250-ACM2-TM-205 Fairchild MS115T0092	19 September 1972
HS-62	Centr Sep Collect Subsystem	MDC G4132 TM-DSV7-SSL-R7064	March 1973
HS-64	Urine Freezer/Tray Frost	TM-DSV7-SSL-R6888	13 July 1971
HS-66	Pr Rel Valve, RTC	Sterer DTR-29450-5 A	6 October 1971
HS-67	Trash Bags	MDC G4094 TM-DSV7-SSL-R7066 A	February 1973
HS-69	Sleep Restraint Assy	Deleted by C.O. 745	
HS-73	Waste Tank Screen	TM-DSV7-SSL-R7040	21 September 1972
HS-75	Pressure Gage, Trash Disposal Airlock	MDC G3377	April 1973
HS-77	Radiator & Plume Shield	MDC G4234 A TM-DSV7-F&M-7068 A	September 1973
HS-78	Potable Water Chiller	MDC G4087 AiResearch 72-8439, Rev. 1	March 1973
HS-80	Condensate Dump Syst	MDC G4203 TM-DSV7-SSL-R7069	April 1973
HS-81	Waste Tank - Screen Baffle	TM-DSV7-SSL-R7039	13 April 1972
HS-89	Urine Subsystem - Redesigned	MDC G4198 TM-DSV7-SSL-R7146 and Supplement I	April 1973
HS-92	Htr Probe Back-up	MDC G4205 TM-DSV7-SSL-R7167	April 1973

SOLAR ARRAY SYSTEM

SA-2	One Third Wing Assy	MDC G4078 TRW SAS.6-3189, SAS. 6-3189-1, SAS. 3189-2, SAS. 6-3189-3, SAS. 6-2088 A	February 1973
		MDC G3958, VOLS. I & KK TRW SAS. 6-2846 VOLS. I, II, & III	February 1973
SA-13	Solar Cell Panel	TRW SAS. 4-3082 Apprendices: A-8222.8-1875, SAS.6-1590 B-8222.8-1876, SAS.6-1591 C-8222.8-1881, SAS.6-1595 D-EOS 3127-TVTR	13 July 1971 24 September 1970,
SA-14	Wing Release Mech Tube	TM-DSV7-F&M-R6835	1 September 1971
SA-15	Wing Rel Mech Exp Tube	MDC G4049 TRW-SAS.6-2983 A	September 1972
		MDC G3958, Vols. I & II TRW SAS.6-2846 Vols. I, II & III	September 1972
SA-16	Hinge Assembly Beam	MDC G4050 TRW-SAS.6-3188	September 1972
SA-17	SAS Beam Rel, Exp Tube	TM-DSV7-F&M-R6894	9 September 1971
SA-18	Actuator/Damper	A3-250-ACAB-TM-7 TRW-SAS.6-2643	8 November 1971
SA-20	Act/Damper W/Brkn Spring	MDC G4000 TRW-SAS.6-3285 TRW-SAS.6-2367, 8221.18-22, Add R612	January 1973
SA-21	Mag Rel Vent Module	TM-DSV7-ENV-R7041	30 June 1972
SA-22	SAS Vent Module	MDC G4C46 TRW-SAS.6-3193, SAS.6-3193-1, SAS.6-3193-2	January 1973

THRUSTER ATTITUDE CONTROL

TC-1	Thruster Module Assy	TM-DSV7-F&M-R6868, Vols. I, II & III	November 1972
TC-10	Bi-Metal Joint TACS Syst	MDC G2113	September 1971
TC-12	TACS Valve Collar & Seal Evaluation	MDC 4207 Valcor MR27700-3671-368-1 & -2	April 1973
TC-14	TACS Pressure Switch	MDC G4209 TM-DSV7-F&M-R7150	April 1973
TC-16	BALL VALVE	TM-DSV7-P/M-R7219	21 Dec 1973

10.4 TEST PLAN DAC-56697A, QUALIFICATION TESTS

TEST LINE ITEM	TITLE CREW ACCOMMODATIONS	REPORT NUMBER RELATED/VENDOR	REPORT DATE
CA-12	Meteoroid Shield Rel Syst	TM-DSV7-F&M-R6890 A	11 August 1972
CA-15	Exp Tube	TM-DSV7-F&M-R6870 A TM-DSV7-SSL-R6874 A	28 June 1972 28 June 1972
CA-16	Spare Exp Stow Container	MDC G4112, Vols I, II, & III TM-DSV7-ENV-R7048 A	March 1973
CA-19	Viewing Window & Instal	MDC G3761 Actron DSV7-DI-029	July 1972
CA-30	Expand Tube/Strap Syst	TM-DSV7-F&M-R7042 A	28 July 1972
CA-31	Expand Tube/Strap Full Scale	TM-DSV7-F&M-R7043	22 June 1972

COMMUNICATION SYSTEM

CS-3	Struct Mtd Cons Comp	MDC G3998 TM-DSV7-EE-7028	November 1972

DATA ACQUISITION

DA-8	Absolute Press Transducer	MDC G7045 Statham 4308 & 4308B	February 1973
DA-9	Diff Press Transducer	MDC G4002 Celesco Industries QTR.630937, & Add. 1 Rev. A Dynacciences Corp. QTR.630937, Rev. A	March 1973
DA-10	Data Acq Modules	MDC G4005 TM-DSV7-EE-R7052	December 1972

ENVIRONMENTAL CONTROL

EC-2	OWS Access Match	MDC 3363	May 1972
EC-3	Bellows Seal Airlock	MDC 3363	May 1972
EC-4	LH2 Tank Seal Device	TM-DSV7-F&M-R6823 MP-50, 885	11 June 1971
EC-12	Thermal Control Assembly	TM-DSV7-EE-R6968	2 October 1972
EC-13	Solenoid Vent Valve	TM-DSV7-F&M-R6932	17 February 1972
EC-15	Fuel Tank Vent Duct Assy Ext.	TM-DSV7-F&M-R6855	11 June 1971
EC-22	Hab Area Vent & Relief Latching Vent & Relief Valve	TM-DSV7-F&M-R6878	18 February 1972
EC-27	Ground Thermal Cond Syst	TM-DSV7-F&M-R7035 A	25 September 1972
EC-32	Short Duct Waste Tank NPV System	TM-DSV7-F&M-R6973 B	20 October 1972
EC-36	Fan, Cluster Vib	MDC G4101 TM-DSV7-ENV-R6889 A	March 1973
EC-37	Fan, WMC Vibration	TM-DSV7-ENV-R6885	25 July 1971
EC-38	Hab Area Vent Flex Line	TM-DSV7-F&M-R6998 A	27 October 1972
EC-39	Check Valve, Access Hatch	MDC G3375	June 1972
EC-40	Pipe Assy - Wate Tank Press	TM-DSV7-F&M-R6999	3 April 1972
EC-41	Heat Pipe Installation	TM-DSV7-ENV-R7037	3 April 1972
EC-44	Hatch Rod End Bearing Vib Test	MDC G3376	May 1972
EC-46	Entry Hatch - Repeat Cycle	MDC G3379	October 1972

ELECTRICAL SYSTEM

ES-4	Zero G Conn	TM-DSV7-EE-R6970 A	23 August 1972
ES-7	Cont & Displ Panel	MDC G4023 TM-DSV7-EE-R6931	February 1973
ES-11	OWS Relay Modules	TM-DSV7-EE-R6943	11 April 1972

ES-13	30 Amp G.P. Relay	TM-DSV7-EE-R6877	11 November 1971
ES-14	WMC C & D Panel	TM-DSV7-EE-R6939	28 April 1972
ES-15	Module, Isol. Diode	TM-DSV7-EE-R7053 A	28 September 1972
ES-16	Series Reg Module	TM-DSV7-EE-R7054	9 August 1972

HABITABILITY SUPPORT

HS-2	Waste Mgmt Subsystem	MDC G4176, Vols I, II, III, IV & V TM-DSV7-SSL-R7055-1, -2, -3, -4, -5 Rev A, -6 & -7	9 April 1972
HS-7	Water Subsystem	MDC G4194, Vols I, TM-DSV-SSL-R7056-4	March 1973
		MDC-G4194 Vols II, III, IV, VI & VII TM-DSV7-SSL-R7056-2, -3, -5, -6, -7, 8 & 9	April 1973
		MDC G4194 Vol VIII TM-DSV7-SSL-R7056-10	October 1973
		MDC G4194 A Vol V TM-DSV7-SSL-R7056-1 A	October 1973
HS-17	Per Hygiene Subsystem	TM-DSV7-SSL-R6993	10 March 1973
HS-19	Refrig Subsystem	MDC G4180 Vols I, II, III, IV & V TM-DSV7-SSL-R6940, -5, -7 & -8 TM-DSV7-F&M-R6940-2 & -6	April 1973
		TM-DSV7-SSL-R6940-1	9 December 1971
		TM-DSV7-SSL-R6940-3	24 March 1972
		TM-DSV7-F&M-R6940-4	9 August 1972
		TM-DSV7-F&M-R7060	10 November 1972
HS-26	Vacuum Outlet System	MDC G4117 TM-DSV7-SSL-R7059B	February 1973
HS-27	Apollo Blower	TM-DSV7-EE-R6690 A	10 March 1971
HS-28	Apollo System	A3-250-ACM2-TM-195	22 January 1971
HS-35	Pump Logic Control	TM-DSV7-EE-R6967	28 June 1972
HS-36	Radiator Bypass Valve Controller	MDC G4004 TM-DSV7-EE-R7027	February 1973
HS-41	Urine Freezer	TM-DSV7-SSL-R7038	2 May 1972

HS-42	Urine Sample Return Stor Container	MDC G3973 TM-DSV7-SSL-R7061 A TM-DSV7-ENV-R7061 & Supplement 1	March 1973
HS-65	1/2 Inch Vacuum	TM-DSV7-SSL-R7065	22 May 1972
HS-74	Biocide Wipes	MDC G4233 TM-DSV7-SSL-R7067	April 1973
HS-76	Bypass Control Monitor	TM-DSV7-EE-R7073 A	9 November 1972
HS-85	Urine Freezer (Urine and Blood)	MDC G4150 TM-DSV7-SSL-R7110	April 1973
HS-86	Urine/Blood Sample Return Storage Container	MDC G4152 TM-DSV7-SSL-R7111	April 1973
HS-87	Heater Probe/Am Cond Dumm System	MDC G4204 TM-DSV7-SSL-R7144 (S)	April 1973
HS-88	Coolant Pump Inverter	MDC G4193 TM-DSV7-EE-R7145	April 1973
HS-90	Urine Subsystem - Pedesigned	MDC G4199 TM-DSV7-SSL-R7147 (S)	April 1973
HS-91	Urine Bag Assy	MDC G4196 Hamilton Standard SVHSER 6048	April 1973
HS-94	Water Heater	TM-DSV7-P/M-R7228 TM-OWS-ENV-R7210	

ILLUMINATION SYSTEM

IS-1	General Illumination Light	TM-DSV7-EE-R6924	26 May 1972
IS-7	General Illumination Light	MDC G4155 TM-DSV7-ENV-R7107	March 1973

SOLAR ARRAY SYSTEM

SA-1	Solar Cell Panel	MDC G3958, Vols I & II TRW-SAS.6-2846 Vols I, II, III	February 1973
		MDC G4039, Vols I, II, III & IV TRW SAS. 4-3130 A, Vols I, II & III SAS. 62707 (71-8224.5-42); 6-3023; SAS.6-3225	February 1973

SA-3	SAS Pwr Unit & Conn	MDC G3999 TM-DSV7-EE-R6951	December 1972
SA-4	Solar Array System	MDC G432, Vols I, II, III & IV TRW SAS. 6-3179, -1, -2, & -3	January 1973
SA-5	CDF Manif Instal	TM-DSV7-F&M-R6788 A	19 February 1971
SA-19	Actuator/Damper	MDC G4047, Vols I & II TRW SAS.6-3192, -1 -2, -3 & -4	January 1973
SA-23	SAS Vent Module	MDC G3950 TRW SAS.6-3194, -1 & -2	November 1972
SA-26	Cinch Bar/Seal	MDC G3932 TRW SAS.6-3191, -1 & -2	November 1972

THRUSTER ATTITUDE CONTROL

TC-2	Thruster Module Assy	MDC G4206, Vols I, II, III & IV TM-DSV7-F&M-R7072	April 1973
TC-8	TACS Timer Module	TM-DSV7-EE-R6946	19 April 1972
TC-9	TACS Pressure Sphere	MDC G2119	May 1972
TC-11	TACS Timer Delay Module	TM-DSV7-EE-R6971	26 July 1972
TC-13	TACS Temp Probe & Press Switch	MDC G4208 TM-DSV7-F&M-R7149	April 1973

10.5 TEST PLAN DAC-56697A, SPECIAL TESTS

* REPORT NOT TRANSMITTED TO CUSTOMER

TEST LINE ITEM	TITLE CREW ACCOMMODATIONS	REPORT NUMBER RELATED/VENDOR	REPORT DATE
*ST-1	Neutral Buoyancy Tests	Test performed by MSFC	----
*ST-2	Zero G Test Program	Test performed by MSFC	----
ST-7	SAS Cell Sunlight Test	Martin Marietta MCR-71-320, Vols I & II	13 April 1972
ST-8	SAS Panel Sunlight Test	Martin Marietta MCR-71-320, Vols III, IV & V	13 April 1972
*ST-9	SAS Module Shadow Test	TRW-SAS.4-3117, Vol II & Append. A SAS. 4.3132	November 1971 April 1972
ST-11	M-487 Stowage Container	MDC G4089 TM-DSV7-ENV-R-7033 A	9 February 1973
ST-12	Flowmeter Transducer	MDC 4192 Quantum Dyn 482-11 and 482-12	April 1973
ST-13	Pneumatic Separator Syst Meteoroid Shield	MDC G2171-P TM-OWS-F&M-R6926	5 October 1972
ST-14	Meteoroid Shield Depl STA	MDC G3369	August 1972
ST-15	Vent Mod Test @ KSC	MDC G3378 A3-250-ACAB-TM-208 TRW SAS.6-3190	January 1973
ST-16	Spring Loaded Mech	MDC G3993 TRW SAS.6-3195 TM-DSV7-ENV-R7071 A	February 1973
*ST-17	Coolanol 15/Water Oral Sensitivity	MDC G4227 TM-DSV7-SSL-R7029	April 1973

ST-18	SAS Solar Cell	MDC G4039 TRW-SAS.4-3130 A Vols I, II & III SAS.6-2707 (71-8224.5-24) SAS.6-3023 SAS.6-3225	February 1973
ST-19	RSS Component Evaluation	MDC G4135	16 March 1973
ST-20	M-487 Stowage Container (Modified)	TM-DSV7-ENV-R7046	12 June 1972
*ST-23	Film Equipment, GFE	MDC G4090 TM-DSV7-ENV-R7098	February 1973
*ST-24	Expandable Tube/SAS Strap	MDC G4091 Jet Research, Report 3	February 1973
ST-27	Stowed Items Life Test	MDC G4223	6 April 1973
ST-28	Butterfly Hinge, Met Shield	MDC G3605	September 1972
ST-29	SAS Solar Cells	TRW SAS.4-3187	June 1972
ST-31	Urine Subsystem - Redesign	MDC G4161 TM-A3 250-ACM2-TM-209	April 1973
ST-34	Mosite & Polyfoam Odor Generation	MDC G4159 TM-DSV7-SSL-R7148	28 February 1973
ST-35	Trash Lock Funct. Compatibility	MDC G4228 TM-DSV7-SSL-R7168	April 1973
ST-38	Met. Shield-Debonded B/F Finge	MDC G3616	March 1973
ST-39	TACS Temp. Probe - Leak Test	MDC G4120 MP 52, 244	March 1973
*ST-40	SAS Fairing Test-Deorbit Loads	Structures TM 171	24 April 1973
*ST-41	Meteoroid Shield Leading Edge Ballooning Test	A3-250-AAAO-AT-73-43	13 July 1973
ST-43	SAS Fairing Test-Deorbit Loads	A3-250-ABF5-M-7315	12 July 1973

10.6 MISCELLANEOUS REPORTS

DOCUMENT	DATE OF ISSUE	TITLE
DAC-56695B	March, 1970	Man/System Integration Plan
MDC G0384B	September, 1972	Contamination Control Plan
MDC G3069	November, 1972	OWS Checkout Report
DAC-56759	December, 1969	Safety System Program Plan
DAC 56698A	January, 1971	Production Plan
MDC G2423A	November, 1971	OWS Backup Implementation Plan
N/A	November, 1972	Microbial Test Sample Report
MDC G3077	24 May 1972	OWS C^2F^2 Stowage Configuration
MDC G3820	12 August 1972	OWS Delta C^2F^2 Stowage Configuration
N/A	September, 1972	SAS-SA23 Vent Door Module Flow Test
DAC-56620C	May, 1971	Acoustic Shock and Vibration Test Criteria
SA-003-001-2H SA-003-002-2H	MSFC Document	Skylab System Safety Check, Input

APPROVAL

MSFC SKYLAB ORBITAL WORKSHOP

FINAL TECHNICAL REPORT

Orbital Workshop Project

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.

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