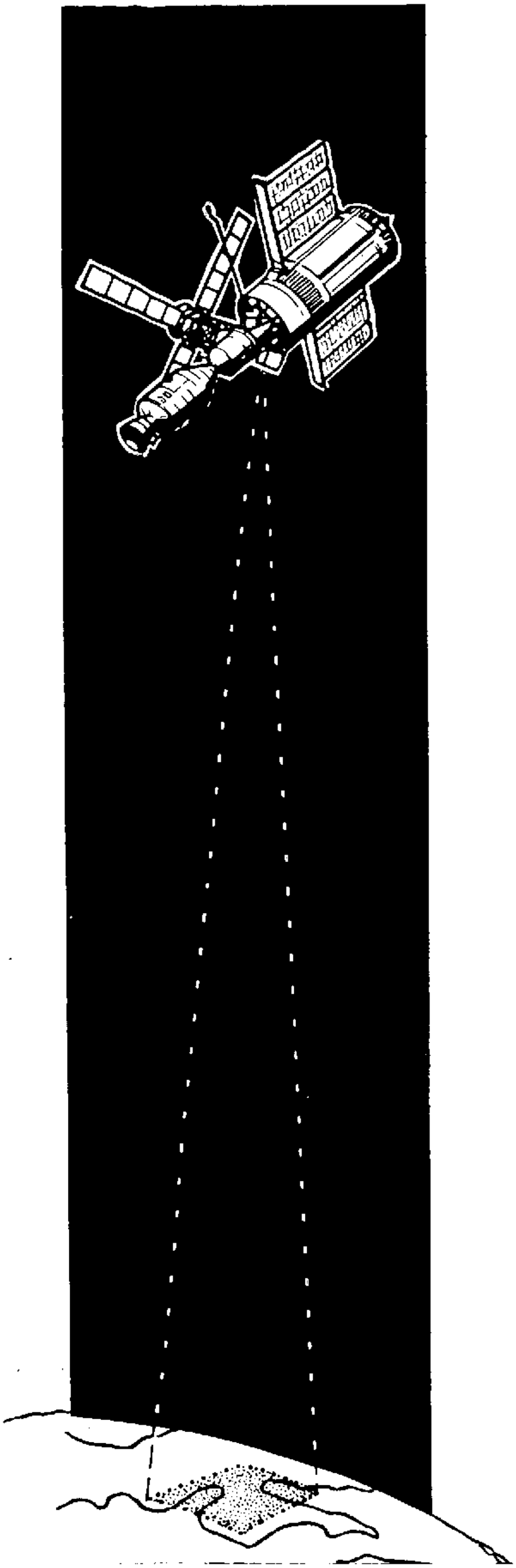
VOLUME II
PROGRAM IMPLEMENTATION
AND MATURITY



REPORT TO THE ADMINISTRATOR BY

DRA

THE NASA AEROSPACE SAFETY ADVISORY PANEL

ON THE SKYLAB PROGRAM

JANUARY 1973

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ERRATA SHEET

for

Volume II Panel Report on Skylab Program

Page No.	Location and Correction
60	1st line, top of page. Change "rodent" to "rod end". 2nd line from bottom. Change "pure" to "purge".
71	3rd paragraph, 2nd line. **Change** "there" to "these"
90	1st line, top of page. Change "stickly" to "Sticky". 4th line from top. Eliminate the word "Minor". Should read "Items open at....."
103	Item 2. Environmental and Thermal Control. Item (b) (1), remove "ECD". Item (b) (4) change "head" to "heat".
118	2nd paragraph, 4th line. Change "CSC" to "KSC"
127	Item 4 above "Multiple Docking Adapter". Remove "life test" at the end of the line.
129	3rd paragraph, 2nd line. Change "utilization" to "Integration".
145	2nd paragraph, 2nd line. Change "influence" to "Influenced"
146	1st line under "Crew Operations". Change "experimental" to "experiment".
151	2nd paragraph, 6th line. Change "assured" to "assessed".

SKYLAB PROGRAM

A REPORT TO THE ADMINISTRATOR

by

THE NASA AEROSPACE SAFETY ADVISORY PANEL

Volume II - Program Implementation and Maturity

January 1973

PREFACE

This volume discusses the maturity of the modules as evidenced during the design and manufacturing reviews, and reviews the scope of the cluster risk assessment efforts and their results. Inherent in this discussion is an assessment of the technical management system and its capability for assessment and resolution of problems.

The detail in volume II supports the conclusions and recommendations in volume I.

In addition, a number of specific "open items" are identified during the course of the discussion. While it is anticipated that they will be closed as the program progresses, the Panel is asking for a formal disposition to assure themselves closure was in fact achieved.

CONTENTS

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SUMMARY

Volume II provides the detailed material on which the Panel's conclusions and recommendations are based. In addition, the material presented in the SUMMARY represents significant areas taken from the details of this volume. To assure that the Administrator is provided adequate background on the Skylab mission items such as those noted here should be covered in Skylab presentations to him.

1. Reliability, quality, and safety: Open items at the time of the Panel reviews include the following:

   (a) Completion of the sneak circuit analysis for the total space vehicle

   (b) Completion of the testing associated with corona assessments

   (c) Problems associated with the suit drying station and the availability of the suits in case of emergencies

   (d) Crew procedures for reaction to the loss of cluster pressure

   (e) Further studies on the susceptibility of crew to dangers due to the inhalation of particulate matter during earth orbit conditions

2. Manufacturing, workmanship, and vendor control: At each contractor visited by by the Panel a self-assessment was provided by the contractor in terms of the recommendations made by the Centaur and Thor/Delta Review Boards (reports issued in 1971). Obviously, no self-assessment can give the full assurance that would result from a detailed onsite audit. However, the Panel found that, in fact, these self-assessments when backed by NASA audit teams and astronaut comments did provide confidence in workmanship and vendor control aspects of contractor's activities.

3. Fire prevention, control, and extinguishment: The reviews of individual modules, mission operations, and associated areas indicate that these most important safety areas have been, and continue to be, a mainstream effort throughout the program. The philosophy of fire prevention appears to have been adhered to strictly. Thus, while there are significant quantities of flammables on board the cluster (for example, OWS wall insulation, Coolanol-15 as a refrigerant, various materials contained in experiments), there has been a careful and thorough effort to minimize the quantities of such materials. Where they do exist the effort has been toward their isolation from each other and from both ignition sources and flame propagation paths. However, since this is not completely possible, fire escape plans and fire extinguishment techniques take on added significance. There is every indication that this area is receiving the necessary

emphasis. Nonetheless, continued attention is required to maintain awareness and those necessary communications between personnel and organizations which will preclude anything entering the system that would adversely affect the fire situation. Housekeeping involving thousands of items is of course critical to control of the hazards leading to fires.

4. Results of Skylab medical experiments altitude test (SMEAT): This test subjected three crewmen to the rigors of a 56-day simulated Skylab mission. Data reduction and handling proved adequate. Experiment operating procedures, medical team training, and pre- and postmedical flight data and procedures were evaluated. A medical baseline was established and principal investigator participation was explored. The test, based on available data, was most successful. It did, however, surface numerous operational procedures which were cumbersome as well as a large number of hardware problems. This of course is the reason for running the test in the first place. At the time of the Panel's review of the SMEAT data five items were still in work, not counting the documentation requirements being factored into the operational data. These five items were

(a) Ergometer anomalies

(b) Urine collection insufficiencies

(c) Metabolic analyzer anomalies

(d) Food system problems (minor nature)

(e) Erratic operation of the blood pressure measuring system (minor nature)

Those manned altitude tests conducted after SMEAT will no doubt be used to verify the resolution of most of the SMEAT aired problems.

5. Microbial control: Apparently an exact definition of system requirements for microbial thresholds under Skylab environmental conditions, zero-G and low pressure, cannot be provided. Therefore, the objective of the microbial control program is to minimize the implantation of microorganisms and their growth rate. The establishment of the Skylab intercenter microbial control working group in 1970 has gone a long way toward meeting these objectives. Methodology has centered on pinpointing those areas where relatively large numbers of organisms could accumulate and receive nutrients. This area of endeavor will require operational surveillance during the mission itself as well as strict premission controls.

6. Contamination control: The Skylab organization, with the continuing support of the contamination control working group, has directed a steady effort to identifying contamination sources, assuring adequate material controls, and maintaining hardware cleanliness. To further assure clean conditions the premission and mission operational documentation and mission training efforts are directed toward the same goals. Test programs over the last year have provided valuable data on sources of contamination and possible solutions for the protection of susceptible hardware.

7. Experiments: The number, type, and sophistication of the experiments carried in the Skylab cluster present a very complex technological and administrative task. Problems encountered during the development and testing of the experiments have been as diverse and difficult as any found on the basic Skylab modules themselves. The management systems operating at each Center now appear to be doing the necessary job of providing proper experiment hardware and operating procedures. Those experiments involving two sponsoring Centers, of course, require more detailed coordination and specific documentation. With the experiments being delivered to the KSC it is also necessary that the principal investigators are appropriately involved during the test and checkout periods at KSC. This is a must to ensure that their experiment hardware is properly exercised and that any problems are resolved quickly and with the least perturbation on the overall KSC schedule. The system for defining priorities for the experiments and the assessment of payoff during the mission warrants particularly greater attention. This area has not been defined as far as the Panel reviews are concerned.

8. Command and service modules: Since the Skylab CSM's constitute a modification to the very successful Apollo CSM's and the contractor appears to be maintaining adequate skills and engineering capability, there is a high degree of confidence in the CSM's ability to do its assigned job. Apollo 17 problems will of course need to be evaluated for their impact on Skylab. The following items were noted by the Panel during its reviews:

(a) Adequacy of the tension-tie cutter and explosive charge system

(b) Qualification of the descent battery

(c) The discharge and/or safing of the RCS propellant system during reentry

9. Qualification tests: Those qualification tests still incomplete at the time of the Panel's review (November 1972) included the following number of tests against each of the modules:

Module	Number of tests
Orbital workshop	28
Airlock module	10
Apollo telescope mount	4
Payload shroud	1
Multiple docking adapter	0

ABBREVIATIONS, ACRONYMS, AND DEFINITIONS

The following are abbreviations, acronyms, and definitions used in this volume:

Skylab orbital assembly (OA):

AM	Airlock module
MDA	Multiple docking adapter
OWS	Orbital workshop
CSM	Command and service module
ATM	Apollo telescope mount
IU	Instrument unit

Major module systems:

ECS	Environmental control system
TCS	Thermal control system
EPS	Electrical power system
HSS	Habitability support system
CAS	Crew accommodation system
SAS	Solar array system

Other major hardware:

PS	Payload shroud
L/V	Launch vehicle
SAT-V	Saturn V launch vehicle
SAT-IB	Saturn IB launch vehicle
GSE	Ground support equipment
CFE	Contractor furnished equipment
GFE	Government furnished equipment
MCC-H	Mission Control Center - Houston
LCC	Launch Control Center
EREP	Earth resources experiment package
C&D	Control and display

Skylab reviews, mission terms:

SOCAR	Systems/operations compatibility assessment review
DCR	Design certification review
PDTR	Predelivery and turnover review
COFW	Certificate of flight worthiness
FRR	Flight readiness review
FMEA	Failure mode and effects analysis
SFP	Single failure point
SMEAT	Skylab medical experiments altitude test

EVA	Extravehicular activity
SL-1	First Skylab launch: Saturn V and orbital assembly less CSM
SL-2	Second Skylab launch: Saturn IB with CSM 116
SL-3	Third Skylab launch: Saturn IB with CSM 117
SL-4	Fourth Skylab launch: Saturn IB with CSM 118

NASA and industry organizations:

OMSF	Office of Manned Space Flight, Washington, D.C.
MSFC	Marshall Space Flight Center, Huntsville, Alabama
MSC	Manned Spacecraft Center, Houston, Texas
KSC	Kennedy Space Center, Florida
MDAC-W	McDonnell Douglas Astronautics Company, Huntington Beach, California
MDAC-E	McDonnell Douglas Astronautics Company, St. Louis, Missouri
MMC	Martin Marietta Corporation, Denver Division, Denver, Colorado
NR	North American Rockwell Corporation, Downey, California

Definitions:

Saturn workshop	Inorbit space assembly which includes the orbital workshop (OWS), airlock module (AM), multiple docking adapter (MDA), and the Apollo telescope mount (ATM).
Orbital assembly or cluster	Saturn workshop plus the docked CSM.
Group-related experiments	Experiments that are closely related to each other either through common focus of study or by integration into a single subsystem. These are the medical experiments, solar astronomy (ATM), and Earth resource experiments.
Corollary experiments	Experiments other than group related or passive type that require significant in-flight crew support and are not closely related to each other.
Passive experiments	Experiments whose associated in-flight crew support requirements are almost nonexistent.
Constraint	Restriction that influences the mission profile, or timeline, and for mission planning purposes cannot be violated.
Single failure point (SFP)	Single item of hardware which, if it failed, would lead directly to loss of a part, system, mission, or crew member.
Principal investigator (PI)	Individual NASA has contracted with for the development and delivery of experiment hardware, analyses of returned data, or both.

PANEL ACTIVITIES SCHEDULE

Phase I

September 14-15, 1971	Washington, D.C. (OMSF and Skylab Program)
October 18-19, 1971	McDonnell Douglas, Huntington Beach, California
November 8-9, 1971	McDonnell Douglas, St. Louis, Missouri
December 13-14, 1971	Washington, D.C. (Life Sciences Division)
January 10-11, 1972	Martin-Marietta Corporation, Denver, Colorado
February 14-15, 1972	North American Rockwell Corp., Downey, California
March 13-14, 1972	Chrysler/Boeing/MSFC Launch Vehicle, Michoud, Louisiana

Phase II

April 10-11, 1972	MSFC, Skylab Program Office, Huntsville, Alabama
May 8-9, 1972	MSFC, Skylab Program Office, Houston, Texas
June 12-13, 1972	KSC, Skylab Program Office, Cape Kennedy, Florida
June 19-23, 1972	OWS Pre-DCR, MDAC-West, Huntington Beach, California
July 13, 1972	MSFC Skylab Experiments Pre-DCR, Huntsville, Alabama
July 27, 1972	Saturn I-B Turnover Meeting, Michoud, Louisiana
August 10-11, 1972	Formal DCR for CSM and Selected MSC Experiments, MSC, Houston, Texas
August 31 - Sept. 1, 1972	Pre-DCR Mission Operations, MSC, Houston, Texas
September 5-6, 1972	OWS PDTR at MDAC-West, Huntington Beach, California
September 12-14, 1972	ATM Product Turnover Review, MSC, Houston, Texas
September 15, 1972	DCR for Mission Operations, MSC, Houston, Texas
September 28, 1972	SMEAT Review, MSC, Houston, Texas
September 27-29, 1972	AM/MDA Acceptance Review, MDAC-East, St. Louis, Missouri
October 2-3, 1972	DCR-Module and Experiment Hardware, MSFC, Huntsville, Alabama
November 9-10, 1972	Washington, D.C. (Skylab program update)

RISK ASSESSMENT

RELIABILITY, QUALITY, AND SAFETY

The reliability and safety program defines and integrates the activities of Headquarters, the operating Centers (MSFC, MSC, KSC), and the contractors. It provides guidance, disciplines, and assessment during all phases of design, manufacturing, test, preparation, and mission operations. The experience of NASA and its contractors in both manned and unmanned space missions has been applied at each level of the program. Experience as documented in the MSC 00134 Report "Space Flight Hazards Catalog" and the MSC "Manned Spacecraft Criteria and Standards" along with similar launch vehicle material was used extensively. The results of the Centaur and Thor/Delta Review Boards were factored into the program in late 1971 to assure appropriate workmanship. Contractors developed system safety program plans and instructions on their implementation. Each affected organization throughout the program had dedicated personnel in these areas. Motivational programs have been continued and strengthened during the lifetime of the Skylab program.

The purpose herein is to discuss the procedures and their implementation. In so doing the report assesses the extent that this provides confidence in the hardware and documentation. Related efforts, discussed elsewhere in this report, include sneak circuit analysis; falut current protection; habitation area pressure integrity review (covered in each module); cluster materials; fire detection, control, and extinguishment; and contamination control.

For each design review and "turnover" acceptance meeting, a reliability and safety analysis has been provided by both the contractors and NASA. These appear to be thorough. They follow the basic system originally used during the Apollo program with excellent results. MSC and the crews have instituted very thorough safety efforts on anything relating to "man." Some of these efforts are borne out in MSC's "Manned Safety Assessment for Skylab" reports concerning each item of MSC responsibility as well as the operational aspects of the mission. MSC has produced an "Index of MSC System Safety Studies" (Report No. SN-5-71-43 Rev. B, May 1, 1972) which serves as a baseline for such work. MSFC through its resident offices has exerted continuing pressure to assure that reliability and safety goals were practical and were met to the maximum degree. A part of any reliability and safety program is the support obtained from the configuration management (CM) systems. This assures that reliability and safety groups have the opportunity to assess all changes, know the "as-designed" versus "as-built" hardware, and assure the traceability of hardware and component materials. Thus, CM plays a role in any discussion of reliability, quality, and safety.

Management policies have been initiated at the Headquarters level. Implementing policies and procedures have been developed by NASA centers and contractors. As an example, the following directives are issued and interpreted by the Program Office in Washington:

P.D. #9	Reliability, Quality, and Safety Auditing
P.D. #10A	Nonconformance Reporting and Corrective Action
P.D. #11A	Sequence and Flow of Hardware Development and Key Inspection, Review and Certification Checkpoints
P.D. #13	Failure Mode and Effect Analysis - Single Failure Point Identification and Control
P.D. #16A	Skylab Materials Policy
P.D. #31	Implementation of System Safety Requirements

The Program Office maintains visibility and control by participation in reviews and conduct of audits:

Intercenter panels, CCB participation
Formal reviews, DCR's, etc.
Safety technical interchange meetings
RQ&S quarterly meetings of Centers and Headquarters
Audits of center safety related activities
Participation in NASA-wide panels and advisory groups such as the Spacecraft Fire Hazard Steering Committee, NASA Hazards Identification Committee, NASA Parts Steering Committee, Contamination Working Group

Reliability

The basic approach is to concentrate attention on hardware and operational items critical to crew safety, mission success, and launch operations. These efforts could be classed under the following subheadings: system reliability analysis, design support, and production and test support.

The basic analytical efforts are the failure mode and effect analyses (FMEA). Based on the FMEA, the following work is carried out:

Identification of single failure points
Identification of launch critical components
Caution and warning system analysis

Critical redundant/backup components

In-flight maintenance

Single failure point retention rationale

Criticality analysis

Criticality ranking

Identification of mission/safety critical items

Design support includes those activities associated with in-flight maintenance evaluations, parts and material programs, design review programs, configuration control, and supplier reliability requirements and implementation. The results of systems reliability analyses are used as the basis for determining what hardware items should have in-flight maintenance. This is the foundation on which in-flight spares, tool requirements, and crew contingency procedures are established. The parts and material programs provide for the selection and control of parts and materials used in each module: These include selection and standardization, specifications, qualification tests, parts usage control, and derating requirements. The design review program includes informal reviews within the design technologies, formal design reviews by a single review board, and the basic drawing release system which ensures review and approval by appropriate technologies and agencies during the drawing release. Also included is the review and approval of design specifications. The reliability effort includes the review of all engineering change proposals and attendance at Configuration Control Boards to assure proper attention to the RQ&S areas. Supplier reliability requirements and their implementation are imposed and audited to meet program specifications.

Production and test support provided in the reliability area includes those activities tied to the test documentation, failure reporting system, failure analyses, problem control centers, monitoring of all testing, and the necessary followup to assure resolution of hardware test anomalies.

Based on the material presented to the Panel during its reviews at the contractor plants and at NASA centers, the efforts noted previously appear to be well founded on the experience of prior programs and implemented by experienced and competent personnel. For example, when checked against the findings and recommendations of the Centaur and Thor/Delta Review Boards, the reliability efforts on the Skylab are adequate.

Because of the importance of the FMEA work it is well to further discuss and understand it. The mission level FMEA has several important functions. It doublechecks, evaluates, and validates lower level inputs for adequacy and accuracy (modules, subsystems, components). It examines failure modes across interfaces to discern critical effects. The mission level FMEA, as distinct from the lower level FMEA, is based on composite schematics across the module interfaces. This enables an analysis of the functions required to cause all mission events to occur. These data are then analyzed for the failure modes that can cause loss of those functions. This type of knowledge is considered of prime importance to mission planning and operations. The dispositioning of single failure points is delineated by means of a Pert-type system which typifies the relationship of the module and mission level FMEA events and activities. MSFC Directive MPD 8020.4 shows the necessary activities that take place as a result of contractor, intra-, and intercenter interfaces to dispose not only of single failure points identified but all other action items resulting from these analyses. This then indicates that a closed-loop system does indeed exist. It is an iterative management control process embracing survey, audit, and monitoring activities. These data are then used by the design, quality assurance, test, operations, and safety discipline areas.

Quality Assurance

The prime objective of the quality programs is to provide those functions necessary at the NASA/contractor sites to produce Skylab hardware that meets the requirements of the specifications and is defect-free. The basic NASA documents used in this are NPC 200-2, NHB 5300.5, and NHB 5300.4. Here again the activities and methods used indicate that the Centaur and Thor/Delta problems do not significantly exist on Skylab. The audits conducted by the NASA quality groups and the contractors of their suppliers support this conclusion. The results of tests and the failures noted by the Panel at its reviews are also indicative of quality workmanship equal to that found on the later Apollo hardware. The fact that one can point to many problems with the manufacture of integrated circuits (cracked solder) and other similar types of workmanship problems is more indicative that the system is good enough to catch these problems before they reach the final "ready-to-launch" hardware. The screening of hardware from the initiation of manufacture through the prelaunch checks should provide confidence that only good quality items will appear on the vehicles.

Safety

Safety tasks were evident in the design, development, manufacturing, assembly, checkout and acceptance, and operational mission planning. Tasks associated with the system safety effort include safety analyses and postanalyses actions, safety reports, safety review functions, explosive and ordnance safety, ground handling and transportation, tests, training and certification, and systems installation.

System safety analyses of the modules and supporting GSE are performed to identify and evaluate hazardous conditions that may exist during all mission phases. The hazard criticality of module components, critical functions, and critical operations have been determined and evaluated. Appropriate corrective measures to eliminate or alleviate the hazard to an acceptable level have been effected in most cases. The following hazard identification techniques have been employed:

Review of the FMEA for safety significant items

Review of ECP's for safety impact

Review of all prior safety related history for impact

Special safety studies in support of design, test, and operations

Direct and continuing participation in test plans and operations, reviews, etc.

Safety assessment of failure reports

System safety checklist development and implementation

The results of system safety analyses and reviews noted previously are documented safety assessments and "alert system" reports. Documentation and test plans are reviewed to identify safety significant operations and methods.

Ground handling and transportation, an important phase of Skylab, has encompassed a wide variety of efforts. These include training of personnel, design of equipments for transport of hardware, and maintenance of cleanliness standards.

An integral part of the safety program is the training of personnel at all levels to be proficient in the performance of their jobs. This includes the motivational programs within the factory and at KSC.

An example of the safety office role in support of the Skylab program is that of the MSC Safety Office. Basically this office plans, directs, and coordinates the development and implementation of the MSC Skylab safety program in line with established directives. Of particular note is their support of milestone reviews, safety analyses, participation in test activities, and the monitoring of mission activities.

They have established a flexible but comprehensive approach to hazard identification and control. This includes the following:

1. Contractor provided safety program (fig. 1). Here the contractor provides the total safety plan and performs design hazard analysis, operational hazard analysis, and provides a final safety assessment.

2. Contractor assisted safety program (fig. 2). Here the contractor provides a safety representative and the hazard summary with NASA carrying the main burden.

3. MSC Safety Office provided safety program (fig. 3). Here the MSC organization conducts the design hazard analysis, safety assessment, and crew procedure reviews. MSC makes extensive use of independently prepared safety analyses by safety professionals.

MSFC, with the support of their integrating contractor MMC, developed a series of Skylab system safety checklists. The objective of this program was to summarize the actual status of the Skylab design and operational conditions which could result in systems failure, equipment damage, or personnel injury. These checklists also provide management visibility of the effectiveness of hazard identification and control activities. It also is an aid for effective implementation of followup actions. Typical source data

CONTRACTOR PROVIDED SAFETY PROGRAM

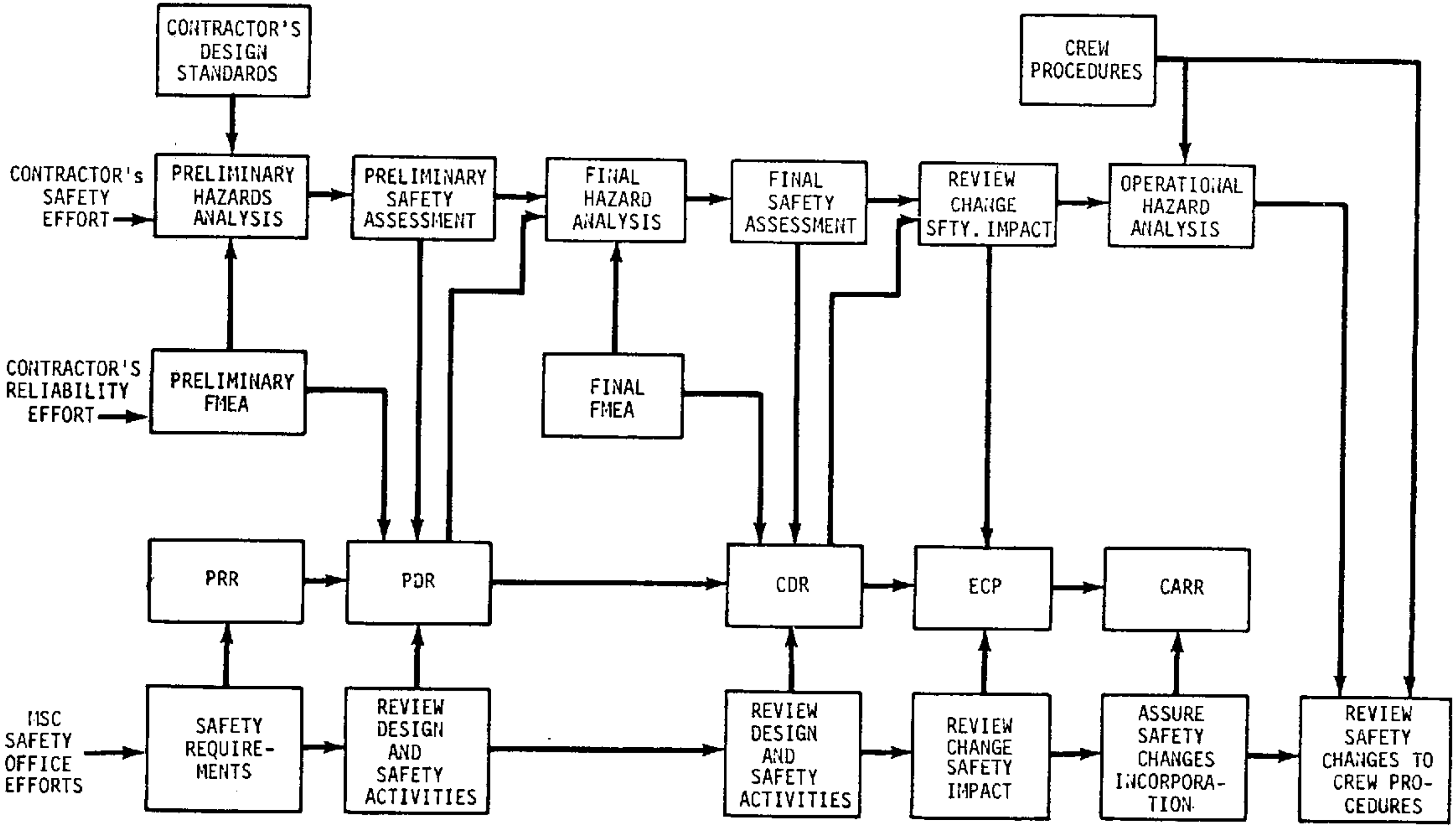


FIGURE 1

CONTRACTOR ASSISTED SAFETY PROGRAM

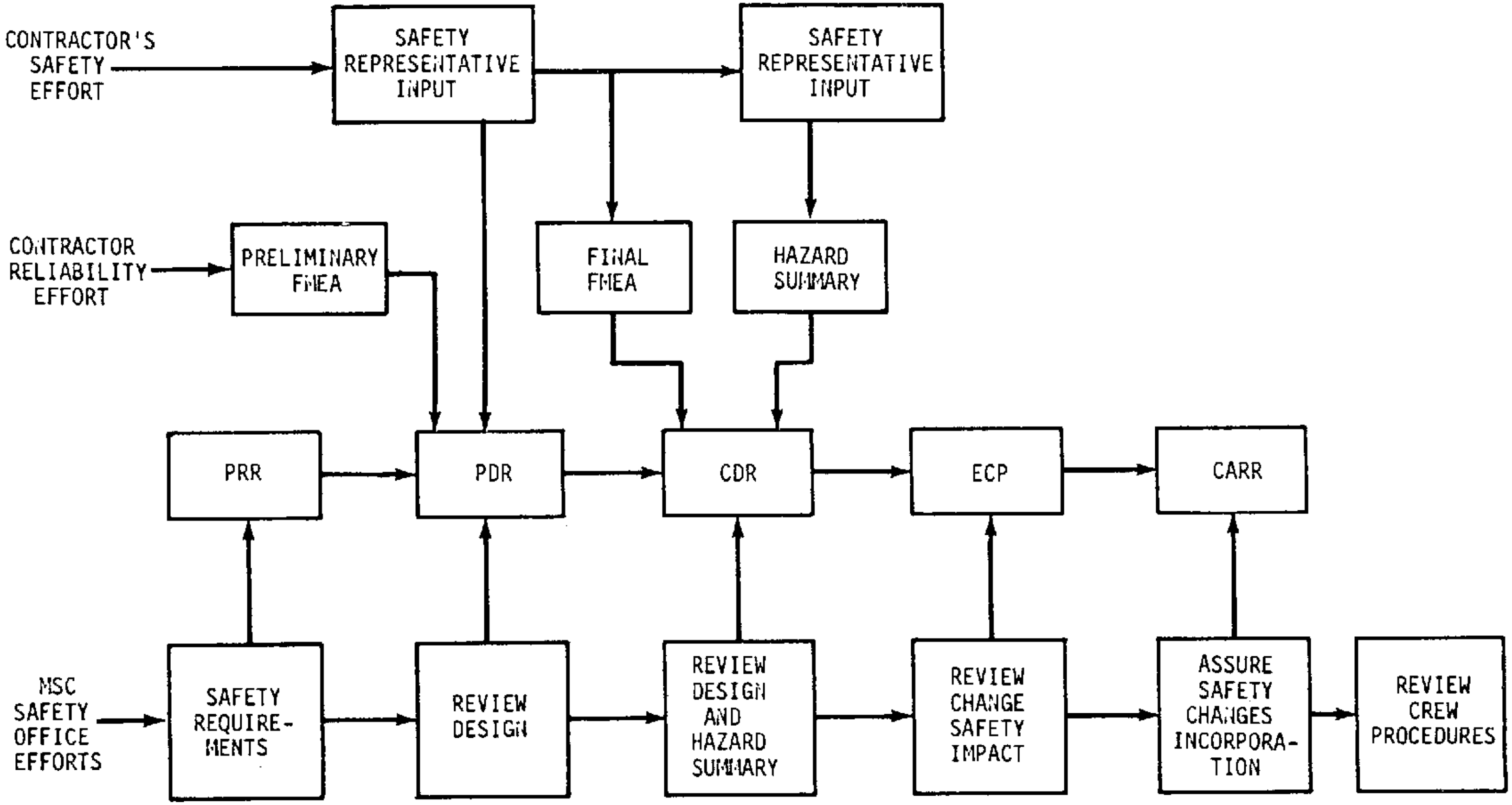


FIGURE 2

SAFETY OFFICE PROVIDED SAFETY PROGRAM

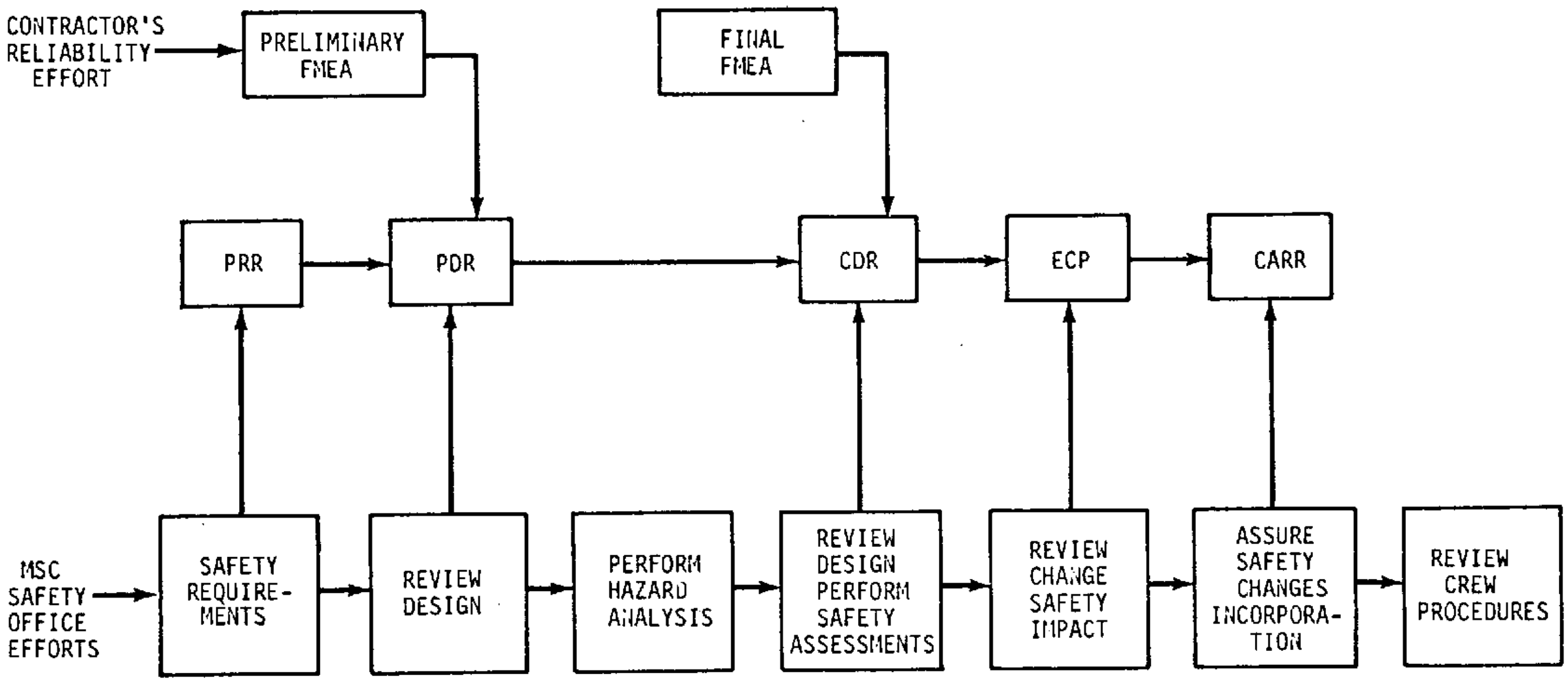


FIGURE 3

for the checklist development were derived from the documents shown in table I.

Safety assessments have been made for individual modules and launch vehicles as well as the Skylab systems across the cluster (total orbiting hardware). This activity, done in support of the design certification reviews, will continue through launch preparation and the mission as required. Manned safety assessments of the operations area are still being conducted as the mission documentation is prepared and hardware moves through KSC test, checkout, and launch preparation. If all available material from hardware assessments is used, this work will identify potentially hazardous operations, provide substantiating data that safety requirements are satisfied, and will indicate where additional contingency procedures development may be required for crew safety. Program management is currently emphasizing this aspect of the safety work to assure completion on time and with adequate coverage. At the time of the review by the Panel, 88 safety tasks had been identified. These tasks covered the mission events from prelaunch through landing, recovery, and rescue. Of these 88 safety tasks, 48 are still to be completed. The incomplete tasks include analysis of lightning strikes, solar heating of service module reaction control system during rendezvous and docking, and some of the cluster on-orbit operations in the fields of activation, habitability, emergency operations, and subsystem operations.

Among the "open items" of interest are the following:

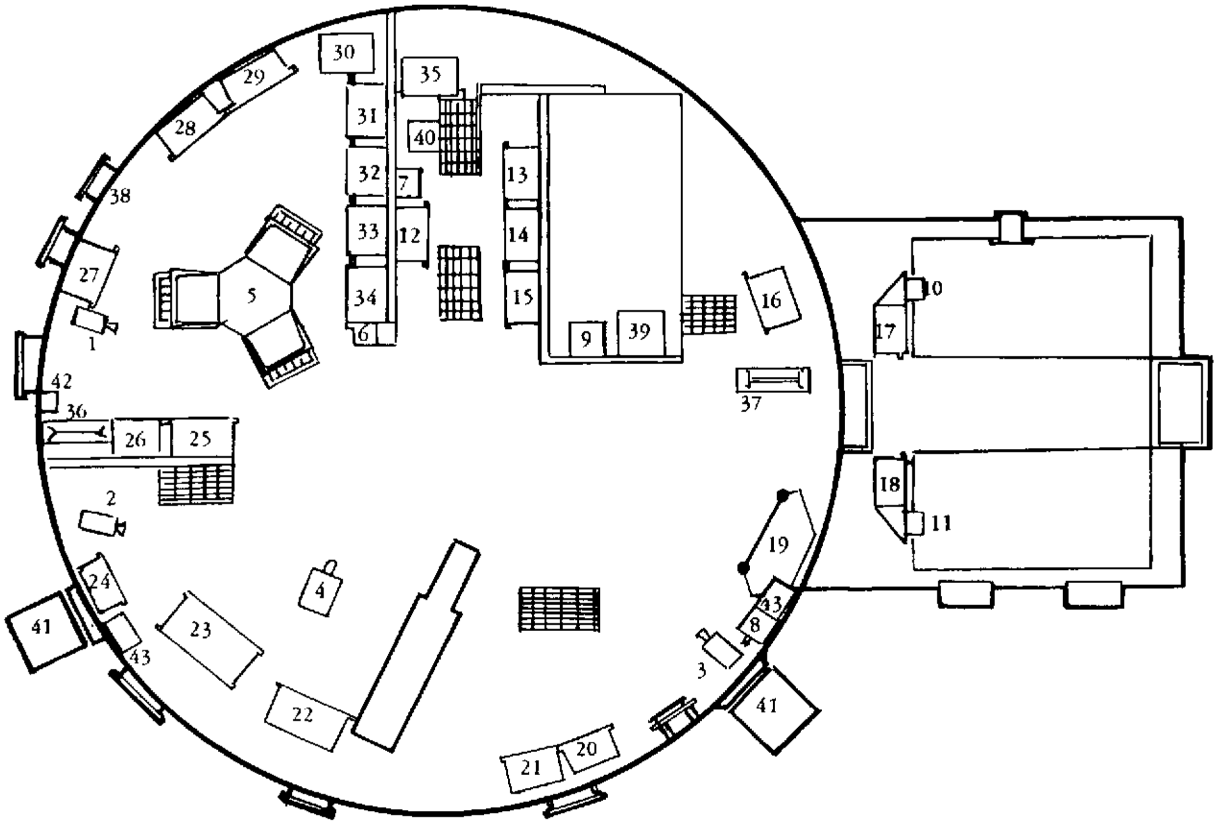
1. Sneak circuit analysis
2. Corona assessment
3. Susceptibility of crew inhalation of particulate matter within the cluster during Earth orbit
4. Suit drying system problems and suit availability for emergencies
5. Safety analysis of partial loss of solar array power and the definition of candidate loads for a power down
6. Detailed crew procedures for reaction to ΔP alerts

Skylab rescue is discussed in the MISSION OPERATIONS section of this report. From the safety standpoint the rescue is not considered to be time critical since it is assumed the cluster is habitable. Identified hazards in the rescue spacecraft include the couch assemblies installed in the lower bay, center couch ballast, and the oxygen umbilicals and "Y" adapters. Tests and analysis indicate minimal risk.

SKYLAB MEDICAL EXPERIMENTS ALTITUDE TEST (SMEAT)

Test Description and Objectives

The Skylab medical experiments altitude test was a 56-day chamber test performed at MSC. It used the Crew Systems Division's 20-foot-diameter altitude chamber. Skylab



1,2, & 3 - TV Camera (overhead installation)
4 - M 171 Ergometer
5 - Food preparation table
6,7,8,9,10, 11 - Intercoms
12,13, & 15 - Stowage (head area)
14 - Sink
16,17, & 18 - Stowage (personnel sleep area)
19 - Off-duty equipment
20 & 21 - Stowage (lounge area)
22 - ESS rack
23 - M 171 MA rack
24 - Experimental trash stowage
25 - Camera and photo stowage
26 - Medical stowage
27 - NASA Hdq stowage
28 - Fecal bag stowage
29 - Vac bag, hygiene, and thermoglove stowage
30 - Refrigerator/freezer
31 - Tools and trash stowage
32 - Galley
33 - Trays and food stowage
35 - Urine chiller
36 & 37 - Ladder
38 - Transfer lock
39 - M 133 sleep monitor
40 - Head
41 - TV display
42 - CO monitor
43 - Speaker entertainment stations

FIGURE 4. CHAMBER ARRANGEMENT

environment and protocol were duplicated as closely as possible.

The test objectives were as follows:

1. The primary objective was to obtain and evaluate baseline medical data for 56 days on those medical experiments which reflect the effects of the Skylab environment. This included microbiological data and additional biomedical data unobtainable in flight.

2. The secondary objectives were to (1) evaluate selected experiments hardware, systems, and ancillary equipment, (2) evaluate data reduction and data handling procedures in a mission duration time frame, (3) evaluate preflight and postflight medical support operations, procedures, and equipment, (4) evaluate medical in-flight experiment operating procedures, and (5) train Skylab medical operations team for participation during real orbiting flight.

The test started on July 26, 1972 and was completed on September 20, 1972. A final report is expected in January 1973.

The layout in the MSC 20-foot chamber was similar to the lower deck of the OWS. It included a waste management area, galley, crew sleeping quarters, and an experiment operation area. These are shown in figure 4. An upper deck area was set up for off-duty crew activities. Chamber modifications affecting the human medical data were made as close to Skylab flight hardware as practical. Other chamber modifications had Skylab hardware appearance but did not function as the flight hardware in order that costs could be held down. Crew activities were conducted according to the mission-like flight data file which was modified to fit the SMEAT test configuration. Communications conducted during the test period followed Skylab protocol except for equipment repair and safety activities.

The medical experiments and other Skylab equipments used and evaluated during the test are defined in table II.

During the Panel's attendance at the various DCR, PDTR, and spacecraft acceptance activities the impact of the SMEAT results during and after the completion of the test were noted. Most of the problems that surfaced during the SMEAT have been, or are in the process of being, factored into the flight hardware at this time.

Experiment Support Medical Requirements

Flight-type qualification preflight and postflight physical examinations were performed prechamber and postchamber. In-chamber exams, administered by physician crewman, were required for in-flight medical support system (IMSS). Vision and audiometry testing and chest X-rays were done prechamber and postchamber.

The SMEAT surfaced both operational and hardware problems. This of course is the reason for such development tests. A partial list of these problems is noted here. The Panel is awaiting the release of the SMEAT report for further data.

M092 - Lower body negative pressure experiment:

1. Differences between BPMS reading and blood pressure obtained by clinical techniques. (Problem may not be real - tests to be done to verify.)
2. BPMS occasionally reads 001 for systolic pressure.
3. Leg bands require calibration and incorporation of foam spacers.
4. Waist seal subject to leakage and damage. May need to carry in-flight spare.
5. Problem with isolation from VCG signals.

M093 - Vectorcardiogram experiments:

1. VCG cable length needs to be increased for use on ergometer.
2. Electrode sponges have caused variation in electrode impedance.
3. Heart rate readout occasionally hangs up at upper limit.

M074 - Small mass measuring device:

1. Elastomer retention sheet tore loose in use.

M133 - Sleep monitoring experiment:

1. Cap sizing critical to comfort. Must provide correct size for designated crewmen.
2. Electrode material caused allergic reaction on some crewmen.

M171 - Metabolic activity experiment:

1. Mode 1 operation is unsatisfactory.
2. Calibration shifts have occurred at 5 and 14 psia.
3. High CO_2 readings indicate high RQ.
4. High water vapor content entering mass spectrometer.
5. Minute volume and initial capacity readings erroneous or inoperative.
6. Moisture accumulates in expiration hose. Need method of cleaning and drying.
7. Ergometer pedals require rework to prevent them from coming off in use.
8. Load module failed in use (may have been nonflight configuration). Evaluation in process.
9. Temperature probe being redesigned for oral use.
10. Mass spectrometer outlet requires standpipe extension.

M487 - Temperature sensor:

1. Temperature sensor failed in use.
2. Stowage container mosites material expanded at 5 psia.

OWS waste management system:

1. 2000-Milliliter capacity of urine collection bags is inadequate.
2. Accuracy of mechanical system for measuring urine volume does not meet specification limits of ±2 percent.

3. Fecal bag seal design is unsatisfactory because of procedural complexity to close bag after use.

4. Fecal bag tare weights are not constant.

5. Minor problems exist with recirculation door latch, recirculation hose connections, and sample bags.

OWS vacuum cleaner:

1. Vacuum cleaner brush modification is required to provide effective operation at 5 psia.

2. Vacuum cleaner airflow is marginal at 5 psia.

The panel was assured that a concerted effort was underway to resolve all of these problems and any others which have arisen since the Panel viewed this area. The Panel fully intends to examine this area further to assure that the system is in fact adequately covering this most important facet of the Skylab development program.

CLUSTER FAULT CURRENT PROTECTION

A review of "Fault Current Protection" for the OWS, AM, MDA, and ATM was initiated in the fall of 1970. Its purpose was to eliminate or reduce possible crew and mission hazards resulting from electrical distribution system failures.

Fault currents in the power feeder lines (cluster solar arrays to the first line of internal circuit protection) can be of the order of hundreds of amperes, yet total protection is neither directly feasible nor practical. Consequently, any power feeder or bus not having overload protection must be physically protected and electrically isolated to the maximum degree possible to obtain lowest probability of fault occurrence. This can be accomplished by appropriate routing of circuits, proper installation and inspection procedures during fabrication, use of protective covers, and potting of buses.

Following this philosophy the practical approach taken by the Skylab program was to size the returns for a maximum fault current that is possible "downstream" of the first line of circuit protection. The maximum fault current based on this approach is 63 amperes.

The following power feeders from the power source to the first line of circuit protection have been identified:

Power feeders from the regulator bus to the AM bus

Power feeders from the regulator bus to the overload transfer bus

Power feeders from power conditioning units to the regulator bus

Power feeders in the regulator bus TIE circuit

Power feeders from the ATM solar array to the ATM battery regulators

Power feeders from the OWS solar array to the AM power conditioning units

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ELECTRICAL SYSTEMS APPROACH

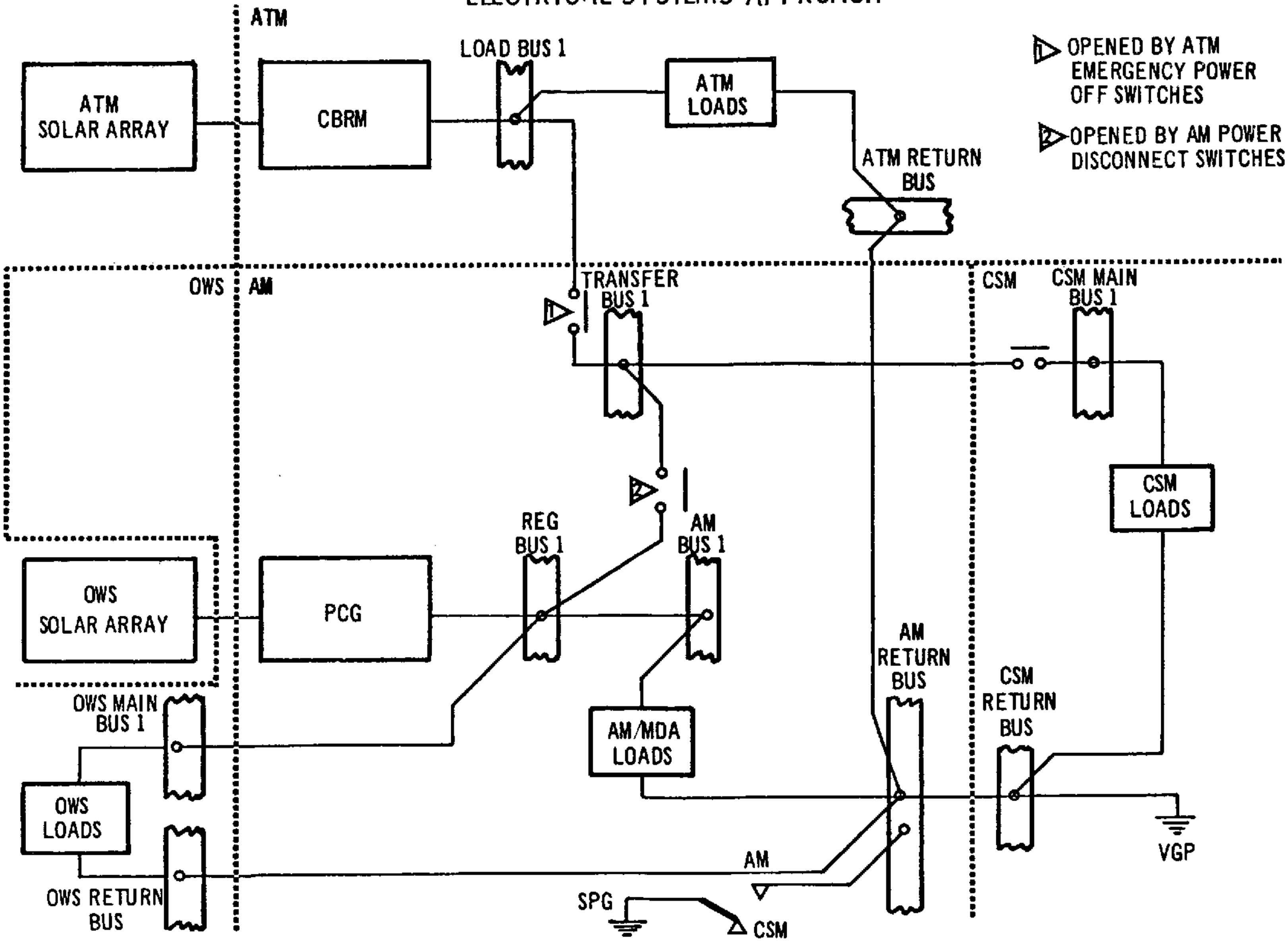


FIGURE 5

The MSFC and MSC Program Offices set up teams and dispatched them to the contractor plants for the major modules. The teams were to review and provide recommendations for electrical system protection. These activities were initiated in 1970 and were completed in the late spring of 1972. During this time several visits to each module contractor's site were made in order to maintain a current picture of this area. Each finding developed by the MSFC/MSC/contractor teams was acted on in what appears to be a responsible manner. Changes to the electrical circuit were made under a management discipline similar to a configuration change board.

The documentation and material presented to the Panel indicates that this area has been adequately covered.

Figure 5 indicates the cluster electrical systems approach.

SNEAK CIRCUIT ANALYSIS

A sneak circuit is an electrical or electromagnetic conducting path which causes an unwanted function (either activation or inhibition) when power is applied to an element of the space vehicle to achieve a desired function. Skylab sneak circuit analyses are conducted by the Boeing Company on a subcontract to the Martin Marietta Corporation. It is accomplished at MSC with the aid of a computerized system developed on the Apollo program. The computer-aided sneak circuit analysis program is shown schematically in figure 6. The purpose is to surface such circuits and alert appropriate programmatic organizations to assure resolution. Skylab Sneak Circuit Bulletins are circulated not only to Skylab organizations but to Apollo and other activities which may also have use for the information.

The sneak circuit program is scheduled for completion just prior to the launch of the SL-1/2 mission in the spring of 1973. Thus, at this time it is estimated that about 35 to 45 percent of the analysis is complete. The SOCAR team and the DCR material reviewed by the Panel indicate that, though the analyses conducted to date have uncovered numerous sneak circuits, none have been identified which would be hazardous to the crew or abort the mission.

Allied areas of corona analysis and electromagnetic interference and compatibility are discussed in the RELIABILITY, QUALITY, and SAFETY section.

COMPUTER-AIDED SNEAK CIRCUIT ANALYSIS

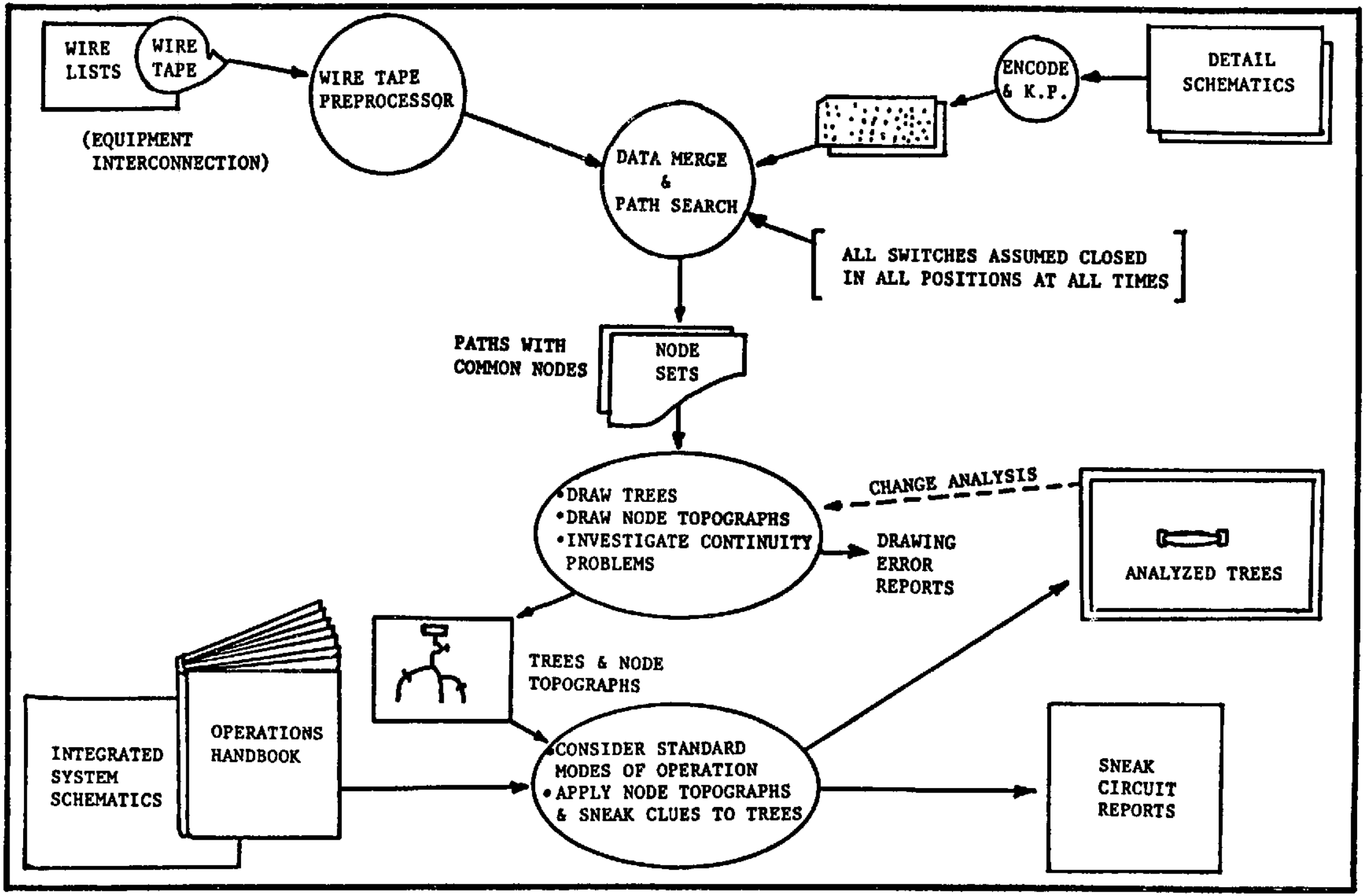


FIGURE 6

MICROBIAL CONTROL

Microbial contamination can occur during both the ground and mission phases. During ground activities, crew and ground personnel can bring organisms into the hardware. During the mission, crewmen will release organisms into an environment that may be supportive of growth. Based on this the program has emphasized source and propagation control.

The Mil Spec concerning fungus certification testing is the only requirement imposed in the cluster and module end-item specifications. Other than that there is apparently the requirement that only general visual cleanliness be achieved during the manufacturing and delivery process. Certain items of hardware such as experiments have very tight cleanliness requirements to prevent degradation of data.

The design of the Skylab had advanced to a rather late stage before the Skylab Program Office authorized the establishment of the Skylab intercenter microbial control working group (SIMCWG). This group consisted primarily of microbiologists and biomedical personnel from MSC, MSFC, and the major contractors. They held an organizational meeting on August 14, 1970. Since that first meeting the SIMCWG has been active and effective in meeting its charter. Essentially, this charter defined microbial control as an overall Skylab cluster program and requires the working group to maintain a continuous monitoring and consulting service for all phases of the Skylab program. From manufacture through the mission they provide assessments of the real and potential microbial problems that may arise, and they make recommendations for microbial control of the problem areas.

The SOCAR microbial control activities provided a most comprehensive review, while other reviews such as the DCR's and PDTR/SAR's carried the SOCAR effort to its logical conclusion by analyzing and following through on the recommendations made by SOCAR.

The primary purpose of the SOCAR team was to analyze all aspects of the Skylab program that could potentially result in significant microbial growth problems and the measures, both design and operational, presently implemented or planned for the control of the microbial growth. The review did not result in the identification of a major microbial control problem. However, several areas were uncovered in which the design or procedures were considered to be inadequate. Obviously, the determination of threshold values at which point microorganisms can be considered a detriment to the crew and/or mission is most difficult if not impossible. Therefore, the objective centered on pinpointing those areas where relatively high numbers of organisms could accumulate and propagate.

Another area covered under the microbial control issue is that of flight crew health stabilization. The purpose here is to establish basic requirements for the preflight, postflight, and in-flight mission phases. Protection of the crew against disease agents is, of course, critical to source control. Owing to the press of time the Panel was limited in its review of this area.

The Panel also reviewed analyses from other sources. The first was "An Etiological Study of Phthalate Self-Contamination or Spacecraft and Contamination From Their Earthly Environs" (NASA Technical Note TN D-6903, August 1972). The second was "Human Factors in Long-Duration Spaceflight" (National Academy of Sciences publication, 1972). They were examined to further understand the possible problems inherent in Skylab and the ability to resolve them.

The following excerpts from these documents are of value in placing the current Skylab posture with respect to microbial control in the proper perspective.

From the NASA technical note:

> All optical experiments are subject to degradation by contamination; however, the vacuum ultraviolet experiments are the most sensitive because nearly all organics absorb in this spectral region. Degradation of star-tracker optics could jeopardize orientation and guidance systems. . . . Contamination of other optical experiment and particle detectors on board can result in false data acquisition or failure of that module.
>
> Those working on the development of a manned orbiting laboratory such as Skylab must consider not only these problems but in addition the problems of long-term environmental stabilization and control for the well-being of personnel. As a result of these developments it can be anticipated, and, in fact, preliminary evidence exists, that phthalate as well as other types of contamination problems will emerge on even a larger scale than previously experienced. This does not seem like the type of problem for which there is any straightforward solution; therefore, people connected with all aspects of the space program must be made fully aware of the contamination pitfalls and work to minimize them so that they will no longer pose a threat to the success of a program.

From the National Academy of Sciences' document:

> Interestingly, observations to date on confined populations indicate that adequate hygienic measures in space crews should minimize buildup and transfer of microorganisms among individuals. . . . There will always be a risk of developing allergies to food and other allergenic agents in spacecraft during long-term missions.

Ground Handling

In general, all contractors have similar procedures for cleanliness and environmental controls during ground handling of their modules and equipments. During this time, for example, relative humidity is maintained at less than 60 percent and temperature is maintained between 40° and 80° F to prevent condensation on component parts. Materials and personnel moving in and out of the hardware work areas practice procedures required for class 100,000 cleanliness. The definition of a clean room class such as "100,000" is shown in figure 7. A 100,000 class room is one in which there are no more than 100,000 airborne particles of 0.5 micron diameter or larger per cubic foot of air with approximately 200 particles per cubic foot larger than 10 microns. On arrival at KSC all modules are to be protected from microbial contamination by procedures outlined in "Cleanliness Requirements for Kennedy Space Center Operations, Skylab I Hardware," SE-014-002-2H, Revision A, April 24, 1972.

STATISTICAL PARTICLE SIZE DISTRIBUTION IN CLEAN ROOMS

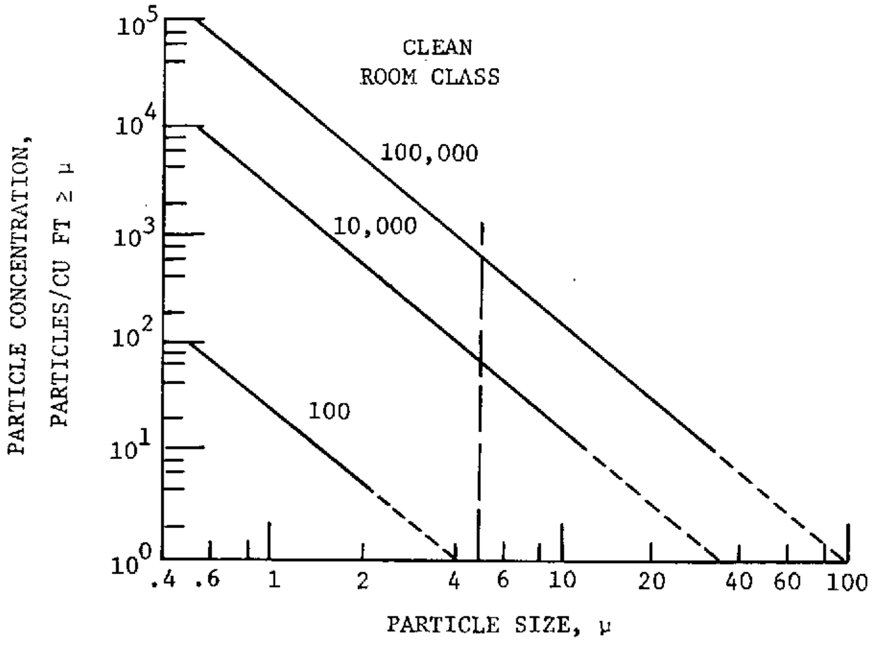


FIGURE 7

In-Flight Systems

Subsystem microbial control analyses have been conducted on the following systems and subsystems: water, food, waste, thermal and ventilation, personal hygiene, trash disposal, and suit drying. Each of these areas, except suit drying, has been discussed elsewhere.

The suit drying station is located on the upper or forward portion of the OWS near the water tank ring. The system is required to recirculate closed-loop cabin atmosphere to dry three suits within 48 to 60 hours. The potential for fungal growth in the interior of the suit arises during the between-use intervals when it is stowed in the CM. Inadequate drying or failure to maintain the appropriate humidity inside the suit may result in unacceptable fungal growths. A suit drying test was conducted at MSC during January and February 1972. The results of the test indicated that the drying procedure was not adequate. The hardware and the procedures were changed and the system retested. Closure of this item will be noted in the next report.

The SIMCWG apparently has developed cleaning and decontamination procedures to maintain a clean crew environment. The SOCAR team reviewed all of these and resolved any problem areas revealed during their examination. The SOCAR did identify two areas of concern. Due to initial management philosophy there are limitations on adequate in-flight monitoring and decontamination procedures. Since these cannot be resolved at this time their impact is under review.

It appears that the continuous attention being paid this area will assure inherent risks remain at an acceptable level.

CLUSTER CONTAMINATION CONTROL

Contamination of spacecraft and associated experiments occurs as a result of a complex interplay between onboard generated components, the environments encountered during construction, testing, launch, mission operations, and the hardware itself. As noted in NASA Technical Note D-6903, ". . . Multimillion dollar spacecraft have often been contaminated by such mundane things as fingerprints, plasticizers from vinyl gloves, plastic tubing or protective covers, and residues from improper cleaning solvents."

The Panel in examining contamination control reviewed effects of (1) materials offgassing, (2) waste dumping, and (3) rocket motor firings on experimental optical surfaces, thermal coatings, and solar arrays.

The contamination control working group, SOCAR team, and supporting in-house activities have directed a continuous effort to

1. Identify contamination sources
2. Assure adequacy of controls on materials and hardware
3. Eliminate vents (overboard) where feasible
4. Verify by test and analysis that remaining vents are acceptable
5. Assure that the Skylab environment (external and internal) is compatible with experiments
6. Assure adequacy of operational documentation

In addition, other agencies have been contacted and their expertise used wherever possible. These agencies include the National Bureau of Standards, the Atomic Energy Commission, and the Air Force Cambridge Research Laboratory.

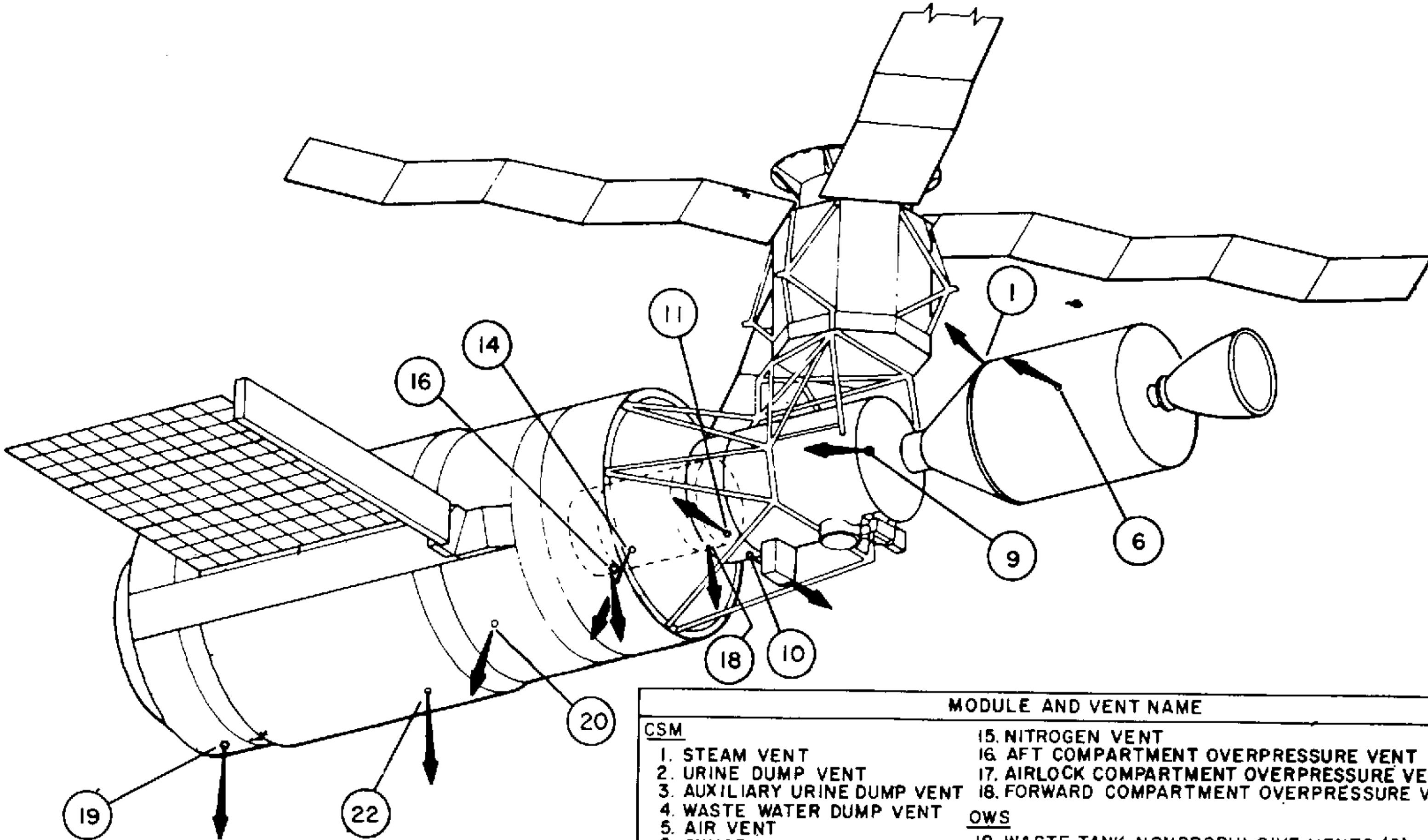
The SOCAR team reported the status of the contamination control activities (including tests) during the review. From their analysis the primary open area is the establishment of acceptable contamination levels for experiment operations. This activity is to be worked by the contamination control working group with the principal investigators. On the whole the cluster modules have been treated in several ways to eliminate possible contamination or reduce it to acceptable levels. The active vents have been designed so that their impingement on critical optical and thermal surfaces is precluded. Major hardware changes have been made to achieve this. This includes the conveyance of condensates into the waste tank rather than overboard, the use of waste tank filters, and the elimination of CSM waste water dump. Figure 8 indicates the location and type of vent. Table III indicates the major vent characteristics. Contamination controls are not relaxed up to the time of launch. The "Contamination Sources Report" ED-2002-879 is a compilation of all contamination sources for the Skylab hardware. This document will receive periodic updates. The contamination baseline will be used as the input and output guide for operational documentation and activities.

The contamination test program has been in progress for some time and is reviewed for necessary updating. Such updates occurred during the May to August 1972 period. Test results will be factored into the operational documentation as required. As an example, reaction control system plume effects and deposition tests are scheduled. Of particular interest here are the effects on the EREP.

Skylab has installed specific contamination sensing devices and experiments to provide real time data and record long term effects. These primary sources of information include the following:

Quartz crystal microbalance
Apollo telescope mount ion gages
Photometers (T027/S073)
Coronagraph (T025)
Proposed mass spectrometer to be mounted on T027 boom

This effort is supported by a ground test program.



MODULE AND VENT NAME

CSM
1. STEAM VENT
2. URINE DUMP VENT
3. AUXILIARY URINE DUMP VENT
4. WASTE WATER DUMP VENT
5. AIR VENT
6. OXYGEN PURGE VENT
7. HYDROGEN PURGE VENT

MDA
8. VACUUM VENT
9. EXPERIMENT VENT

AM
10. MOLECULAR SIEVE VENT
11. MOLECULAR SIEVE VENT
12. CONDENSATE VENT
13. EVA DEPRESSURIZATION VENT
14. AFT COMPARTMENT VENT
15. NITROGEN VENT
16. AFT COMPARTMENT OVERPRESSURE VENT
17. AIRLOCK COMPARTMENT OVERPRESSURE VENT
18. FORWARD COMPARTMENT OVERPRESSURE VENT

OWS
19. WASTE TANK NONPROPULSIVE VENTS (2)
20. HABITATION AREA NONPROPULSIVE VENTS (2)
21. EXPERIMENT VACUUM SOURCE VENT
22. SCIENTIFIC AIRLOCK VACUUM VENTS (2)

FIGURE 8

The manner in which these data are used is discussed in the MISSION OPERATIONS section. The SOCAR team indicated that there is a deficiency in the contamination data capability because no measurement of the composition of the Skylab environment is available. Knowing the contaminates composition would serve a threefold purpose: Combined with the quartz crystal microbalance output it would help establish "go-no-go" criteria for experiments in real time; it would provide a basis for a correction factor to experiment data affected by environment; and it would enable a more direct determination of the sources of contamination. The proposed mass spectrometer noted in the previous listing is suggested for this purpose. The decision on this suggestion will be noted in the next report.

CLUSTER MATERIALS

Skylab management has given considerable attention to controlling materials and the hazards they present.

Material controls for the Skylab program are based on Skylab Program Directive No. 16A and MSFC Memorandum PM-SL-TQ-17-72. In addition, MSC applied document MSC-DA-D-68-1, "Apollo Applications Program Experiment Hardware General Requirement." Beyond these documents there are numerous NASA and contractor documents specifying the details necessary to meet the overall material requirements. Certain categories of Skylab hardware are necessarily controlled somewhat differently. All methodologies, however, attempt to achieve the same goals.

Material Flammability and Toxicity

Basic to fire prevention and control of toxicity is the control of the materials used and their geometry and location. The Panel's role is not to second guess management judgments but to assure that there is an adequate system in support of it. As viewed by the Panel, the Skylab program has established a system for the identification and management assessment of flammable materials. They have used the data on hazards from past manned programs in their selection and evaluation of materials. All modules and experiments have now essentially been certified by this system. Those items that remain are small in number and they will receive the same thorough treatment as previous items. This does not mean that flammable materials have not been used; however, where they are used it is by conscious management decision. They have taken such actions as they thought possible to minimize the risk through isolating ignition sources, flammables and propagation paths.

The question of materials selection for toxicity of combustion products is actually a paradoxical one. Skylab has selected materials that are primarily either nonburning or self-extinguishing. The paradox lies in the fact that generally the better a material's nonflammability characteristics are, the more toxic its combustion products. Skylab has chosen to use the selection approach, which either will eliminate or limit the size of the fire. The proposed contingency action to counteract toxic combustion products is to isolate the crew from such products. This includes the use of portable masks and oxygen bottles, venting the cluster atmosphere, and a bakeout of the molecular sieves and repressurization with a new atmosphere. At the request of the Panel, MSFC tested a group of widely used, typical spacecraft materials for the effects of their combustion products on ECS components. The tests validated the operational solution and these results were presented to the Panel. Major combustion products of some Skylab materials are shown in table IV. In addition to the normal program activities, material flammability questions have been directed to the NASA Safety Office (Washington, D.C.) and the Spacecraft Fire Hazard Steering Committee.

Of particular interest has been the question of the flammability of crew clothing. Durette is used for the major outer clothing and it is flame retardant with good wear characteristics. The undergarments are made of cotton which has excellent comfort and moisture absorbing characteristics. To date no suitable substitutes have been found for the undergarment material. These materials are equivalent to or better than Apollo clothing. The choice of cotton and Durette has been examined and approved through a waiver. Improved materials are currently under evaluation. If tests work out and the material is available, these new materials could be used as replacements for durette and cotton.

An area of some concern centers on the large quantities of flammable material that must be used and restowed.

There appears to be a concerted, continuous effort to control each and every item that goes into the space vehicle. The requirements are stringent and the implementation if maintained should preclude problems stemming from the use of flammable materials.

Packing Materials

Treated cardboard has been placed in many stowage containers to alleviate the launch environment. These large quantities of cardboard are then discarded. The manner in which this is to be accomplished still appears to be unresolved. A secondary problem attendant to this material is the problem of "shedding" when the material is handled. The Panel understood several groups were working on this and should have resolved this problem as well. Obviously this is not just a hardware concern but also an operations concern since the crew interfaces with this material. The status of this item will be noted in the next report.

The problem posed by the Mosite packing material is different. During tests of the OWS, MDA, and perhaps the AM, the Mosite material had a volume change due to a variation in the pressure surrounding it. Mosite is installed at 14.7 psia and subjected to pressures up to 26 psia during launch. There are pressures of 5 psia during inhabited mission periods and less than 1 psia during quiescent periods of the mission. The material is cut and fitted at 14.7 psia and placed on doors and drawers of the stowage cabinets. When the pressure is reduced to 5 psia and lower, the material expands or swells since it is a cellular material. This makes it difficult and in some cases impossible to open or close cabinets. The Mosite material has been changed to a solid or near solid type. This, of course, has added additional weight to the vehicles. The problem appears to be solved.

Corrosion, stress corrosion, material outgassing, aging, creep, fatigue and cold-flow, and hydrogen embrittlement have apparently been given adequate attention.

FIRE DETECTION, CONTROL, AND EXTINGUISHMENT

This section of the Skylab report discusses the "fire" area in terms of the total cluster view and the relevant management systems. The area of extinguishment is covered in some detail. The main purpose is to assess the process by which the current posture on detection, control, and extinguishment has been reached.

The fire detection system has been described in each of the module sections of this report. Briefly the detection system consists of 22 ultraviolet sensors and 12 caution and warning panels. They are located throughout the cluster, except for the CSM. The basic elements of the fire detection system are ultraviolet sensors, memory recall capability, and distinct tones to identify alert by category. These are newly developed items, being used on Skylab for the first time. Because of this and the need to assure detection capability a rigorous test program was carried out. These tests appear to have proven the ability of the system to operate under simulated flight conditions. It had been indicated at one time that the sensor coverage of the OWS forward compartment was marginal due to the viewing distance of the sensors and the ability of the three sensors to adequately cover this large volume. Analysis, test, and crew evaluations indicate that this system for the forward compartment is acceptable. An area that has received considerable study is that of maintenance, since there is little redundant sensor coverage of cluster. Each sensor has the capability of being tested in flight. Spare sensors are carried during the mission for replacement of a failed unit. The test-and-replace capability is an adequate substitute for redundancy if a rigorous test and maintenance schedule is followed during the mission.

Fire control is accomplished by minimizing or eliminating flammable materials, reducing ignition potential, and inhibiting fire propagation paths. This too has been discussed under the sections devoted to each module as well as the CLUSTER MATERIALS section of this report. There is no question in the Panel's mind that this area has been under constant analysis and surveillance by all levels of management and working forces. The learning process that occurred during the design and development period resulted in knowledge that was spread across the entire program to support all NASA and contractor organizations. Materials used in the Skylab modules, experiments, and government furnished equipment have been and will continue to be reviewed for their flammability and toxicity characteristics using a number of proven control methods: (1) material usage agreements requiring NASA approval, (2) material usage maps indicating the location, surface area, and weight of flammable materials, (3) detailed material lists, and (4) computerized programs to assure completeness and consistency throughout the program. As a part of the control system the material application evaluation board plays a most important role in maintaining a full-time information desk through which all deviation requests must pass. The board is then convened as required to evaluate these requests. The board in turn notifies the appropriate design organizations and appropriate program managers of the disposition of each request. The data are entered into the control system. Examples of the thoroughness of cluster control by MSFC, MSC, and their contractors are many. The Panel thus feels it is worthwhile to present several cases which provide confidence in the system.

Early in the AM program, testing was conducted to determine the flammability characteristics of silicone/phenolic fiberglass laminates. This testing indicated that no ignition of these materials would result when tested with the standard ignition source. However, subsequent testing identified these materials to be "configuration sensitive." In addition, it was determined that once ignited, these materials will sometimes propagate to completion rather than self-extinguish. Since major module covers and ducting were fabricated of these materials, it was determined that the applications represented "fire propagation paths" and should be eliminated. As a result, a design change was made which utilized polyimide fiberglass laminates in lieu of the silicone/phenolic fiberglass laminates.

As a result of Apollo experience and the constant pressure to reduce ignition sources and their ability to reach flammables, a closed trough system was developed to carry all internal wiring. This is seen in the OWS design. The closed trough system consists of rigid troughs, flex troughs, interchange boxes, convoluted tubing, and connector boots. In addition, within these troughs flame barriers have been installed as an integral part of the isolation design to further prevent flame propagation and to cause the flame to self-extinguish. Figures 9 to 11 are indicative of the efforts taken in this design. Tests and analysis indicate that possible ignition source to flammables has been minimized as have been the flame propagation paths.

ORBITAL WORKSHOP
CLOSED TROUGH SYSTEM
(GENERAL CONCEPT)

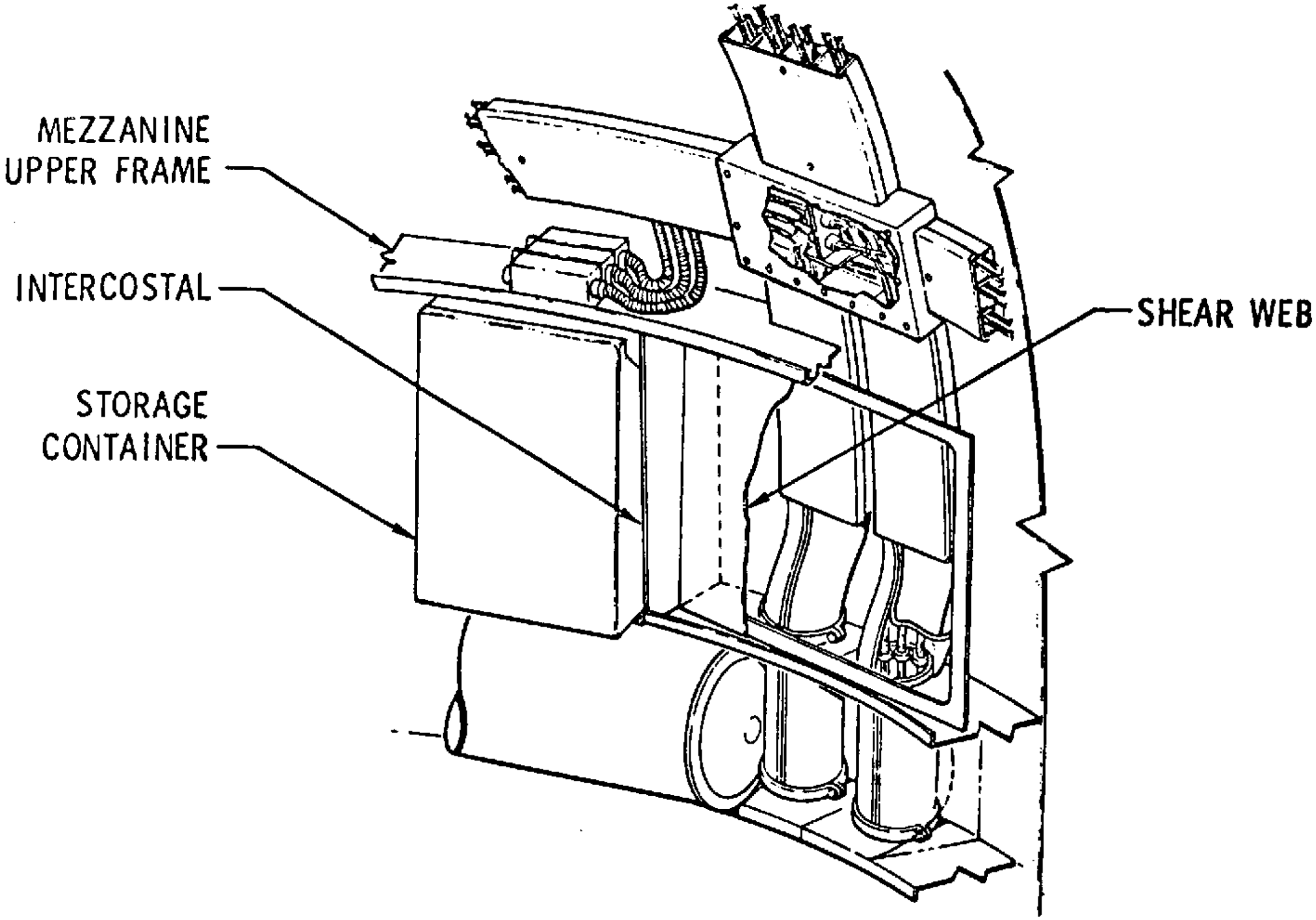


FIGURE 9

ORBITAL WORKSHOP
RIGID TROUGH

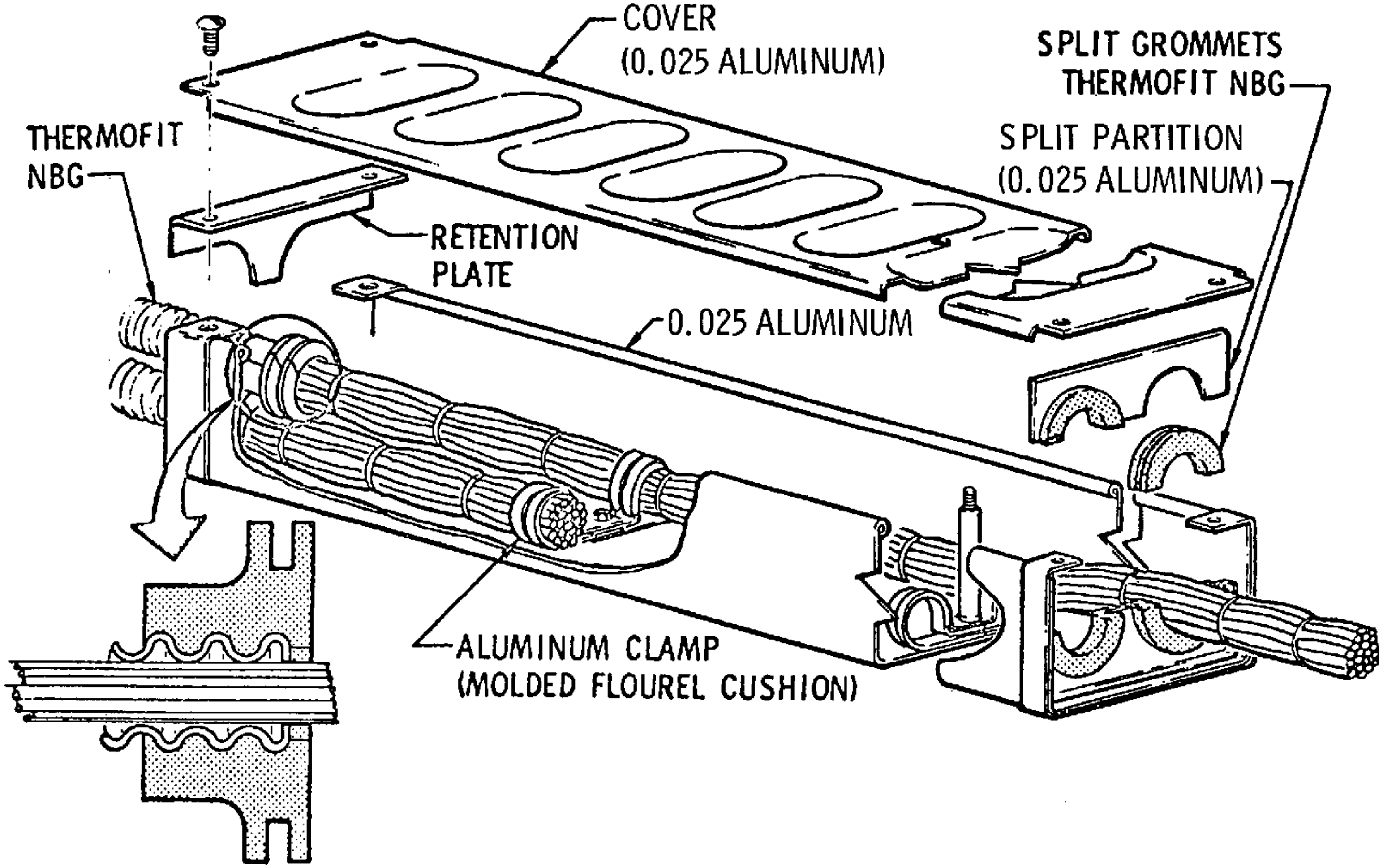


FIGURE 10

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ORBITAL WORKSHOP FLEX TROUGH USAGE
(GENERAL CONCEPT)

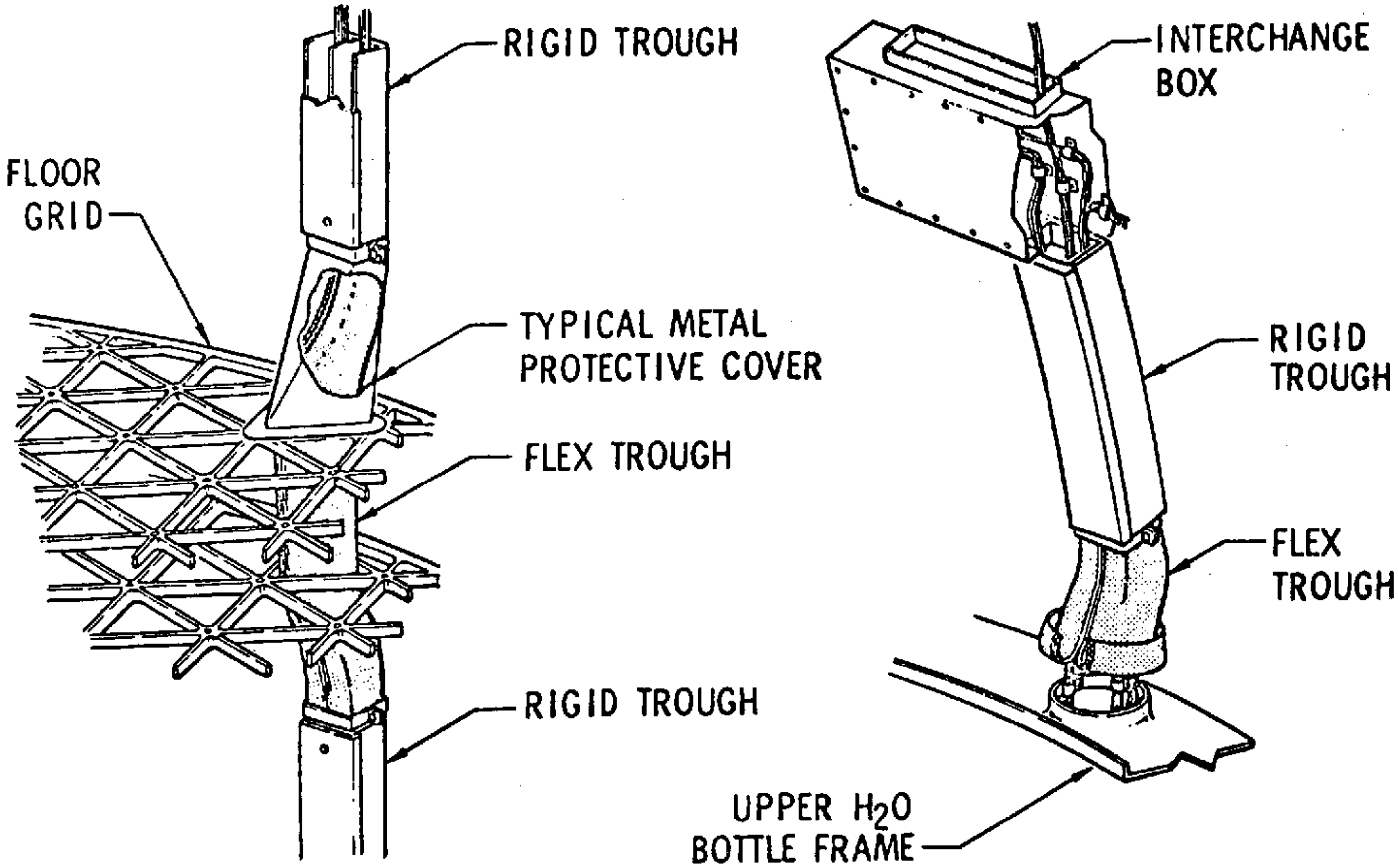


FIGURE 11

Coolanol-15, used as the working fluid in the refrigeration system, could present a critical crew hazard because of the fire potential and presence of toxic vapor. Extensive testing and analysis have been reviewed by management in its decision to accept the risk of using Coolanol-15. Recently, an intercenter Coolanol review team completed an investigation of all potential problems concerning its use. This included a consideration of fabrication, quality control, materials testing, training, safety, and overall system verification of all components and subsystems in the Coolanol loops. It appears to the Panel that the management systems and their implementation have resulted in adequate consideration and understanding of the use of Coolanol-15 and the procedures to alleviate problems if they should arise during testing and the mission itself.

In the event of a fire during the Skylab mission there appear to be four methods of effecting extinguishment: (1) fire extinguishers, (2) use of stored water, (3) shutdown of the atmospheric control system (reduce internal flow or pressure), and (4) shutdown of electrical power system. The Panel's reviews in this area indicate that shutdown of the atmosphere control system and electrical power should effectively allow a fire to self-extinguish. Additionally, fire extinguishers will most likely be used to extinguish the fire as rapidly as possible to minimize propagation and pyrolysis products. No provisions are known for the use of water directly as an extinguishment aid.

The Apollo fire extinguisher was modified for use on the Skylab vehicle. These modifications include the design for one hand use and a flare nozzle attachment to reduce foam velocity. There are five fire extinguishers onboard the cluster, four of these in the OWS and one in the AM/MDA. The CSM carries the same fire extinguisher as used during the Apollo program. MSC, MSFC, and the contractors have conducted comprehensive reviews on the subject of extinguisher locations, required volumes, and degradation with storage time. Further studies have covered the crew training procedures, crew translation times in moving from one point in the cluster to another, and the need and location of access holes in panels and equipment covers. With respect to the crew, fire procedures are being developed based on when to fight a fire, what to use, and when to evacuate. The quantity of expelled foam volume of the extinguishers degrades with storage in a one-G condition. Nominal installation of these extinguishers is made 18 days prior to launch. Concern exists that during that time, as well as during zero-G storage in orbit the yield of foam may degrade to an unacceptable level. This appears to be under study at this time, but no resolution is currently known. Fire extinguisher access holes were to be placed in the AM molecular sieves to accept the extinguisher nozzle. The status of both items will be noted in the next report.

A more detailed discussion of the crew procedures associated with fire extinguishment and crew protection is included in the MISSION OPERATIONS section of this report.

In summary then, the Skylab program organizations indicate that they have made a thorough analysis of the fire detection, control, and extinguishment areas, and there is confidence that those items still open will be adequately resolved.

HARDWARE/SOFTWARE ASSESSMENT

MISSION OPERATIONS

Mission operations is a broad category. It includes flight control operations, ground support systems, crew training programs and associated hardware, crew procedures, integration of medical operations, MSFC operations support, flight plans, and contingency analysis and mission rules. Mission operations activities are the summation of hardware performance, flight and ground crew needs and abilities, and the Skylab user requirements.

The Panel centered its attention on the ability of the Skylab program organization and management systems to achieve intercenter cooperation, needed data flow and understanding of hardware capabilities, and realistic planning to translate mission requirements into mission ready documentation and mission ready personnel.

The basic documentation of interest to the Panel includes the Skylab Program Directive No. 43B (March 27, 1972) and the following subordinates: Skylab Operational Data Book, Skylab Operations Handbook, Skylab Systems Handbooks, Flight Plan, and Flight Mission Rules.

The Skylab Operations Directive 43B is a plans and requirements document. It is used as the baseline on which program policies and requirements, mission objectives, and mission planning instructions are issued to the implementing Centers. Several points relevant to an understanding of the mission operations policy need to be clarified. First, if for any reason the Program Director is unable to carry out his duties for delaying a mission (para. 1.4.2 (8)) it is assumed some other individual must be delegated this authority. Second, in the same paragraph it is noted that "if a mandatory item cannot be corrected to permit liftoff within the launch window, . . . has the authority to downgrade an item from mandatory . . .. and to proceed with the launch . . ." The possibility of duality in the meaning of "mandatory" may create problems. Last, in Panel discussions at the NASA Centers on the possibilities of setting priorities for the experiments the "Flight Scheduling Precedence Number" discussed in this directive was not mentioned.

The major operations interfaces between MSFC and MSC in developing and implementing operational plans is shown schematically in figures 12 to 15. SOCAR and the many joint design and operational reviews conducted throughout the life of the program provided a valuable opportunity to define relationships and assure mutual indepth knowledge of the flight systems. Those difficulties that have arisen as to roles and responsibilities in the mission operations area appear to be resolved or are in the process of resolution at this time.

MSFC/MSC INTEGRATION RELATIONSHIPS (TYPICAL)

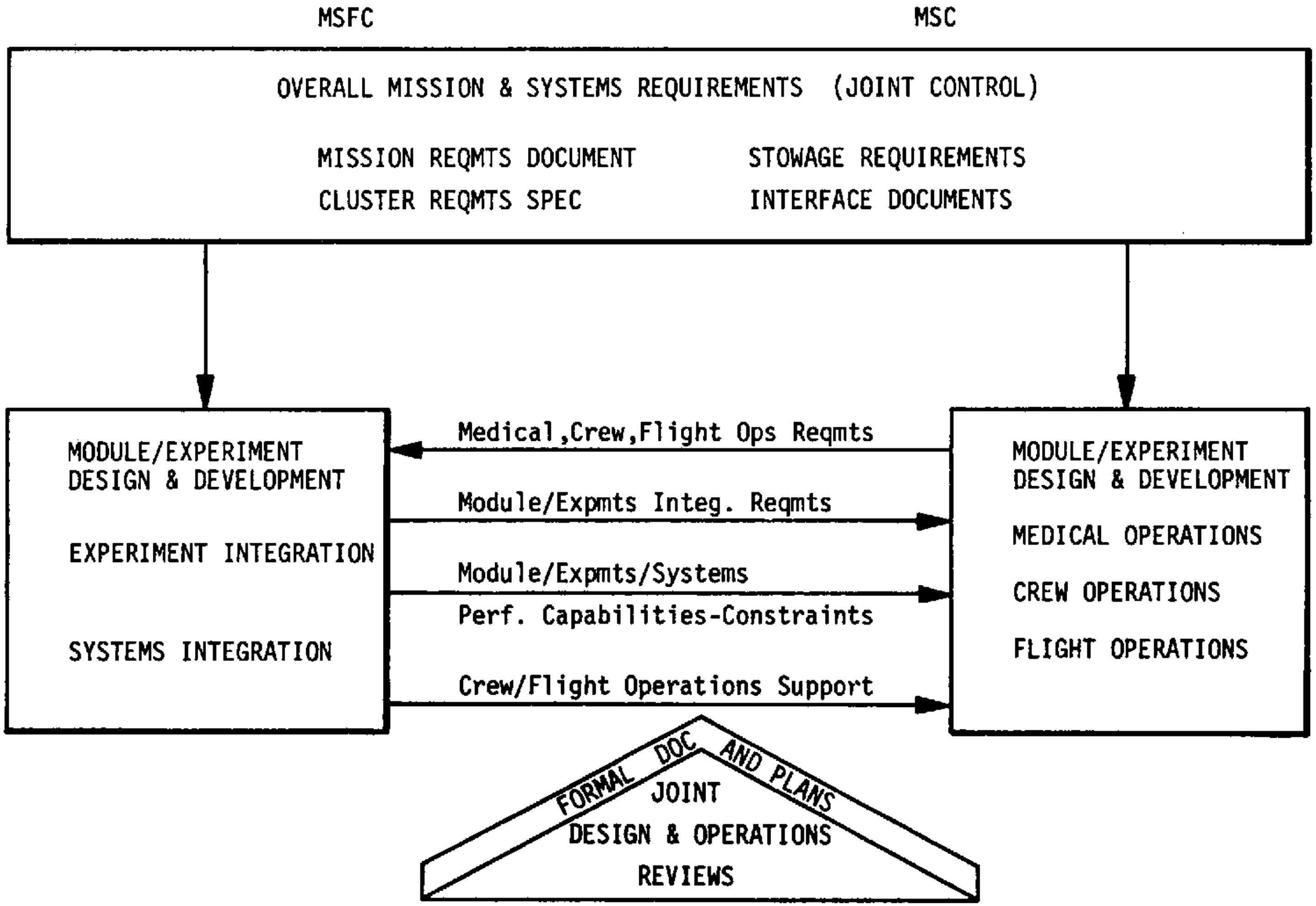


FIGURE 12

CREW OPERATIONS INTERFACES (TYPICAL)

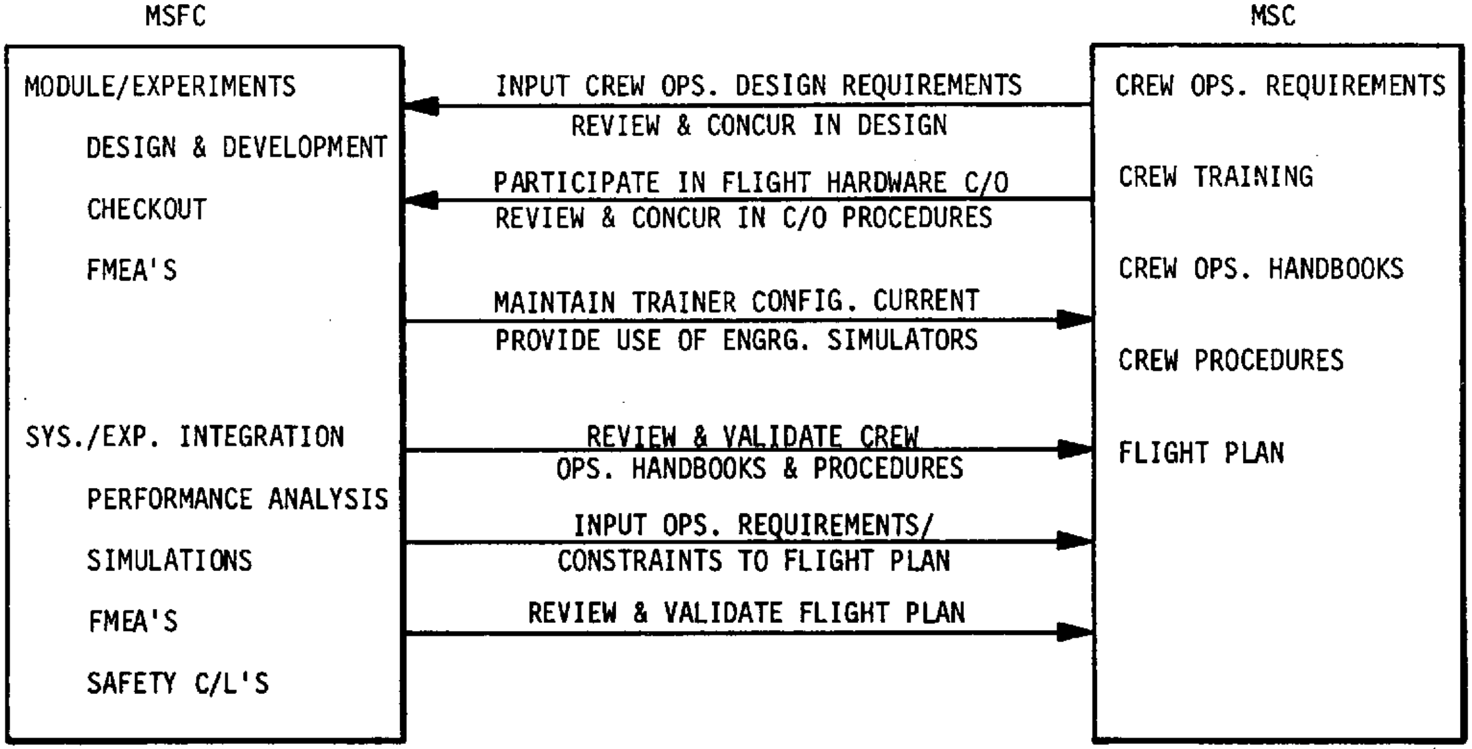


FIGURE 13

FLIGHT OPERATIONS INTERFACES (TYPICAL)

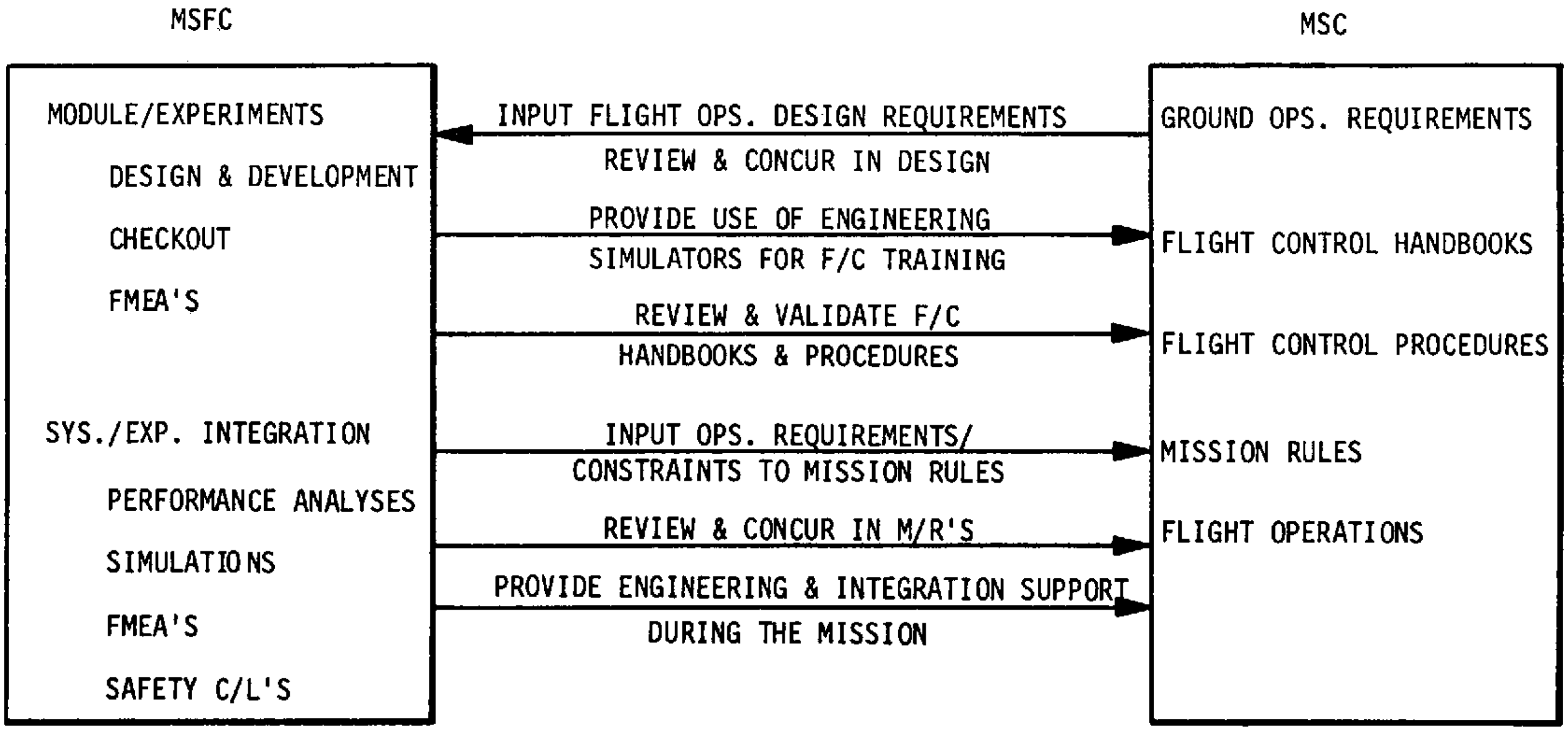


FIGURE 14

MISSION OPERATIONS SUPPORT

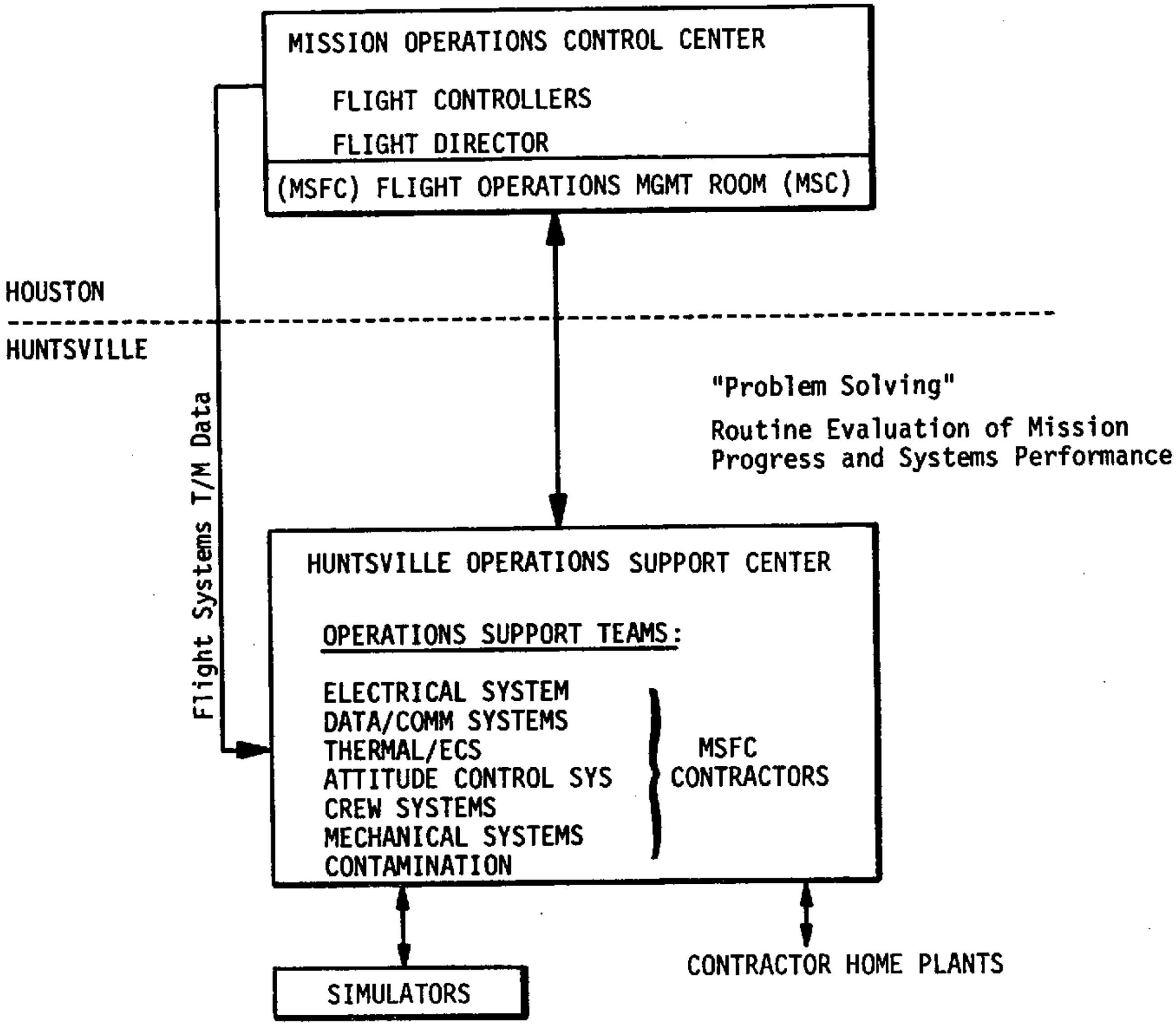


FIGURE 15

The RELIABILITY, QUALITY, AND SAFETY section of this report discusses the manned safety aspects of the Skylab mission operations. Where necessary this area is covered here.

The major portion of the mission operations work is accomplished at MSC through the following organizations: Flight Crew Operations, Flight Operations, Life Sciences, Science and Applications, Safety and R&QA - all of these, of course, under the direction of the Skylab Program Office at MSC. Support contractors tasks pertinent to this area include training hardware maintenance, training instruction, systems/operations handbooks, ground support simulations, mission planning, and so on.

Flight Crew Operations

Crew training. - Crew training is the core of achieving real-time mission operational objectives. The effectiveness of crew training concepts and procedures has been proven on prior manned programs. The Skylab missions are able to take advantage of those lessons learned, but there is one disadvantage of no prior "development flights" for SL-2 and only short periods between SL-2 and SL-3, and SL-3 and SL-4. Furthermore, all of those things which set Skylab apart from previous manned programs bring an extra burden to bear on the training requirements. Using an astronaut mix of seasoned veterans with new personnel, the crew training commenced approximately 2 years ago in the November 1970 period. As trainers became available and mission requirements better known the specific task training and integrated crew and mission team training began in 1972. Support training was also in fact ongoing throughout the Skylab program because of astronaut participation in the design, development, and testing phases. The planned training and hours assigned for each segment are shown in brief in table V. These hours represent the total hours for a crew of three. At this time the percent of training hours accomplished for the crews is about 60 percent of the total. Training at the KSC was somewhat restrained by the Apollo 17 activities.

Fire/evacuation training for Skylab missions encompasses about 76 hours per man, split between "on-orbit emergencies" and "ground emergencies." One might question the sufficiency of such training to meet the stringent time requirements to move from any given station in the cluster to another while determining actions to be taken. On the other hand, the many hours of training applied in other areas is often directly applicable to the fire/evacuation effort. This will be discussed further in another part of the report.

The SMEAT and other simulations conducted recently have added immeasurably to the training of the crews through a better understanding of the workings of the hardware and the problems involved in their use. There is, of course, the inherent limitation in the use of nonflight hardware. It may not show up all the little idiosynchrosies of flight hardware.

PROCEDURES DEVELOPMENT PROCESS

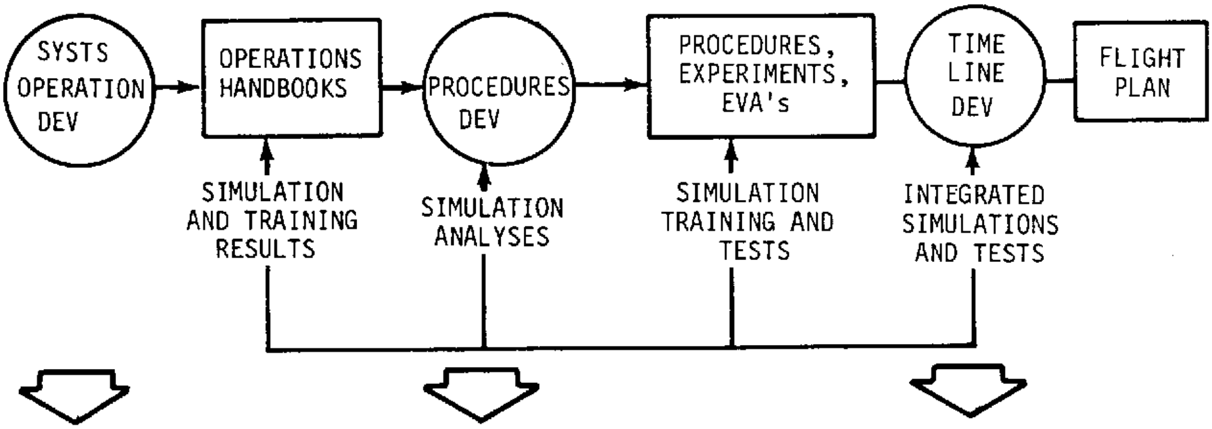
DATA SOURCES

DESIGN DATA
SYSTEMS DATA
EXPERIMENT INFORMATION

TRAJECTORY
MISSION REQUIREMENTS
MISSION RULES
OPERATIONAL DATA BOOK

FLIGHT CREW
TEST DATA
MISSION REVIEWS
CONSUMABLES

DEVELOPMENT PROCESS



FLIGHT DATA FILE

SYSTEMS CHECKLISTS
SYSTEMS DATA
SCHEMATICS
ACTIVATION/DEACTIVATION
SYSTEMS MAINTENANCE
SYSTEMS REPAIR
MALFUNCTION PROCEDURES

LAUNCH, ENTRY RENDEZVOUS BOOKS
EXPERIMENTS OPERATIONS
EVA CHECKLISTS

FLIGHT PLAN
CREW LOGS
STAR CHARTS
MAPS
GRAPHICS

FIGURE 16

An area of particular interest to the Panel is that of Skylab cluster housekeeping. Associated with almost every experiment and most day-to-day operations is the myriad items of loose equipment and discarded materials that must be accounted for and properly restowed. Such efforts as the activities scheduling program, crew flight plan, stowage in-flight management system, and mission operations planning system are used in part or totally in the housekeeping effort. Based on the various programs to control and account for these items, the Panel believes that adequate attention is currently being paid to this area. This does not preclude surprises in flight. Because of its importance to the overall operation of the Skylab mission continued attention must be given to housekeeping.

Maintaining simulation equipment in the in-flight configuration is a continuing problem. This was a problem encountered and managed on Apollo. Different than the Apollo program, though, is the very large number of items and experiments that are still undergoing changes, sometimes subtle in nature. The availability of some of the experiment training hardware appeared to be open at the time of the Panel reviews. The current use of trainer hardware is of the order of 40 hours per week for the OWS and 20 to 30 hours per week for the AM/MDA/ATM. This leaves limited time for further modifications or new requirements.

The crewmen have worked directly into the design, development, test, and operations areas as the program has progressed. Thus, in addition to the many thousands of hours of specific training, the crews also are trained through direct familiarization with the hardware at every phase of its development.

Crew procedures and flight planning. - These activities provide for the organization of crew time, preparation for contingencies, and definition of training and flight data file requirements. Figure 16 indicates the process through which procedures and flight planning are accomplished. The final Flight Data Files are scheduled for completion about 30 days before each launch to assure the most up-to-date file. The process to produce these documents has been planned. But the achievement of this schedule is dependent on the resources and the number of changes introduced into the system over the next few months. This suggests that it behooves the Skylab program organization to restrict changed requirements which affect the crew procedures and flight planning to an absolute minimum consistent with meeting the mission objectives.

Skylab Flight Operations

Flight operations include those activities associated with operational mission planning and the overall direction and management of flight control and recovery. This involves the implementation of manned space flight network instrumentation requirements, configuration and operation of the Mission Control Center, and operational evaluation and testing of landing and postlanding systems. Skylab flight operations have taken into account the very real differences between Apollo and Skylab and the difficulties imposed by constrained resource availability. The flight team and ground support system differ substantially from the Apollo arrangement due to large PI involvement, unmanned mission phases, and the long duration. They have also considered the Skylab peculiar requirement for manned phases, crew time scheduling, and the ability of the ground to monitor the orbiting vehicle on a less than 100 percent time span.

Mission characteristics affecting flight operations. - Ground system design and the flight operational requirements for the Skylab mission are affected by the "unique" character of the Skylab noted previously. In addition, there are such items as (1) the mass of data to be returned and its analysis, (2) the necessity of real-time flight planning, (3) no background of development flights, (4) intercenter hardware responsibility throughout the flight, (5) the housekeeping requirement, and (6) stringent requirements for the removal of "perishables," urine and feces samples, as soon after recovery or splashdown as possible.

Principal investigators. - The PI's form a part of the flight control team. PI mission support has been placed in four separate support categories:

Category I - PI is present in the MCC during experiment execution. His nonavailability (or that of previously designated alternate with same capability) is a constraint on the carrying out or conduct of the experiment. Currently no experiments are in this category.

Category II - PI is present in the MCC during conduct of experiment. He performs analysis of experiment data and makes recommendations for subsequent experiment operations.

Category III - PI is present in the MCC during conduct of experiment and is available for consultation. He maintains mission status visibility and provides assistance to flight controllers as required.

Category IV - The PI is not in MCC but is available via telecon for consultation.

The PI's have specific rooms (ATM science room, aeromed experiment room, EREP room, and science room) assigned for their use. In some cases there appears to be an underlying feeling discerned by the Panel that there is still a good deal of effort yet to be accomplished in setting up these arrangements with all of the necessary PI's. If this is the case, further effort should be extended to make these arrangements as quickly as possible.

MSFC operations support. - The purpose of the MSFC operations support is stated as "Continue to fulfill the MSFC hardware design/development and systems engineering and integration responsibility through active support in the operations phase of the Skylab program." Some concerns in this area are discussed in the PANEL REVIEWS section of volume I.

MSFC will provide qualified senior personnel to the Flight Operations Management Room and Mission Evaluation Room at MSC while maintaining the Huntsville Operations Support Center at MSFC. The concept appears quite sound. With the exercise of good management and cooperation between the two Centers (MSFC and MSC) the MSFC operational support arrangement should provide a valuable and needed function to assure the success of the Skylab mission. Nonetheless, because there are two Centers separated by large geographic distances, it would be unusual if operational problems did not crop up from time to time. These must be minimized or eliminated as quickly as possible.

Flight control training, documentation, and schedules. - The Flight Operations Directorate at MSC published an integrated training plan in October of 1971 defining the types of training, the certification program for each flight controller, and the training for non-Flight Operations Directorate personnel working in support of the basic team. It was interesting to note that videotapes of the classroom sessions were being made to allow additional sessions to be held with new personnel and to refresh the baseline groups as required.

Based on the data presented it appears that much of the training has yet to be accomplished.

Flight control documentation posture was indicated to the Panel as follows:

Document	Preliminary document	Final document
Systems Handbooks	Complete	March 1973
Mission Rules	Complete	February 1973
Flight Control Operations Handbook	October 1972	February 1973
Branch Console Handbooks	October 1972	April 1973
SL-1 Operations Handbook	October 1972	March 1973
Command Procedures Handbook	September 1972	February 1973
Branch Photo Support Albums	--------------	October 1972

Flight control manning plan. - The personnel assigned to the various operations activities, as to type and numbers, is crucial to the success of the MSC operations and efforts and is currently under review. The reason for the difficulty in selecting the number of teams and their mode of operation appears to stem from the smaller number of flight controllers and support personnel available and the cost of ground system hardware. This is not just a function of the current economic posture but is due to the requirement for continuous operations for 8 months versus 2 weeks for the Apollo missions. It has been indicated that the optimum number of mission operations teams would be five. Due to the practical aspects this cannot be achieved. The question now revolves around whether there should be three or four teams. From the material reviewed by the Panel, four teams seems most logical. It allows for a reasonable amount of sick time and leave time for the team members, whereas the three team system does not. It is estimated that 207 people will form a flight control team with specialty personnel used as needed, for example, when retrofiring and recovery. Of these 207 all will be NASA except for 50 to 60 contractor specialists. The number of "new" people, that is, those who have never sat at a console before, will be quite large - as high as 60 percent of the total. This, of course, is a further reason for the detailed and arduous training program envisioned by the MSC organization. Obviously, manning requires further study, and quickly at that, to assure that the personnel with their adequate training are available for the initiation of the Skylab major flight simulations and actual mission.

Ground support systems. - The Skylab ground support equipments includes both hardware and required software. The following differences between the Apollo and Skylab program are indicative of the new requirements that had to be met:

(1) Noncontinuous real-time data retrieval
(2) Continuous data recorded onboard and dumped during periods of real-time communications
(3) Greater variety and extent of data to be communicated up-and-down link
(4) Longer duration of support required
(5) Experiment activity to flight test activity far greater on Skylab
(6) Extent of experiments interaction with space vehicle power, ECS/TCS, vehicle attitudes, and orbit position

As a result of these new requirements the ground support systems have been designed to provide greater system reconfiguration flexibility and to require minimum time for preventative maintenance. In addition, the equipment should also provide data more directly to the users and eliminate remote site tape handling and shipping. It has been indicated that the deliveries of portions of ground equipment have slipped in schedule and that the mission simulations that were to have started in September may slip over into the November-December time period. This, combined with the obvious impact of supporting the Apollo 17 launch in December 1972, will require greater emphasis and effort on the part of both management and working flight controller personnel over the next few months. The reason for the Apollo 17 constraint is that some 50 percent or so of the people will come from there and obviously can work only one program at a time. The communications and telemetry network for Skylab (STDN, NASCOM) appear to be in good shape. Some areas are still under discussion to resolve minor problems. These include the use of ARIA (Apollo range instrumented aircraft) to support the Skylab and scheduling of site usage during the 8-month Skylab mission due to other vehicles on other missions.

To support Skylab requirements the following validation and test and checkout schedule was instituted:

Test description	Estimated completion dates
Mission control center internal validation tests:	
With mission operations computer	November 18, 1972
With real-time computer complex software	December 1, 1972
MCC external validation tests:	
With Merritt Island area	February 1973
With worldwide network	April 1973
Goddard network readiness test	April 1973
MCC simulations readiness test	November 1972
MCC pad readiness date	November 1972
MCC/network simulation	January 1973
Network on mission status	April 1973

Medical operations. - Medical operations support is provided for the preflight, mission, and postflight phases. The Mission Control Center medical team is formulated as shown in figure 17. Planning and documentation in this area appears to be progressing satisfactorily. Yet, as noted in the Panel's preliminary report contained in the Third Annual Report to the Administrator, there still appear to be some problems with staffing for medical support. This, though, is under continual study and it is hoped that the problem will be resolved in the near future.

Fire evacuation procedures. - Fire in any location of the Skylab cluster is a critical crew hazard requiring immediate and correct response from the crew. As a result of fire location, materials, and extinguisher studies, crew procedures have been prepared and to some extent tested through crew/equipment simulations. Procedures associated with the onset of fire warnings or known fires on board the vehicle are based on the philosophy that the crew should always move toward the command module obtaining life support and fire fighting equipment enroute. The fire is to be fought only if it blocks the route to the command module, is visible, and can be assessed as containable. The prime concern is crew protection rather than equipment protection or mission continuation.

MISSION CONTROL CENTER MEDICAL TEAM

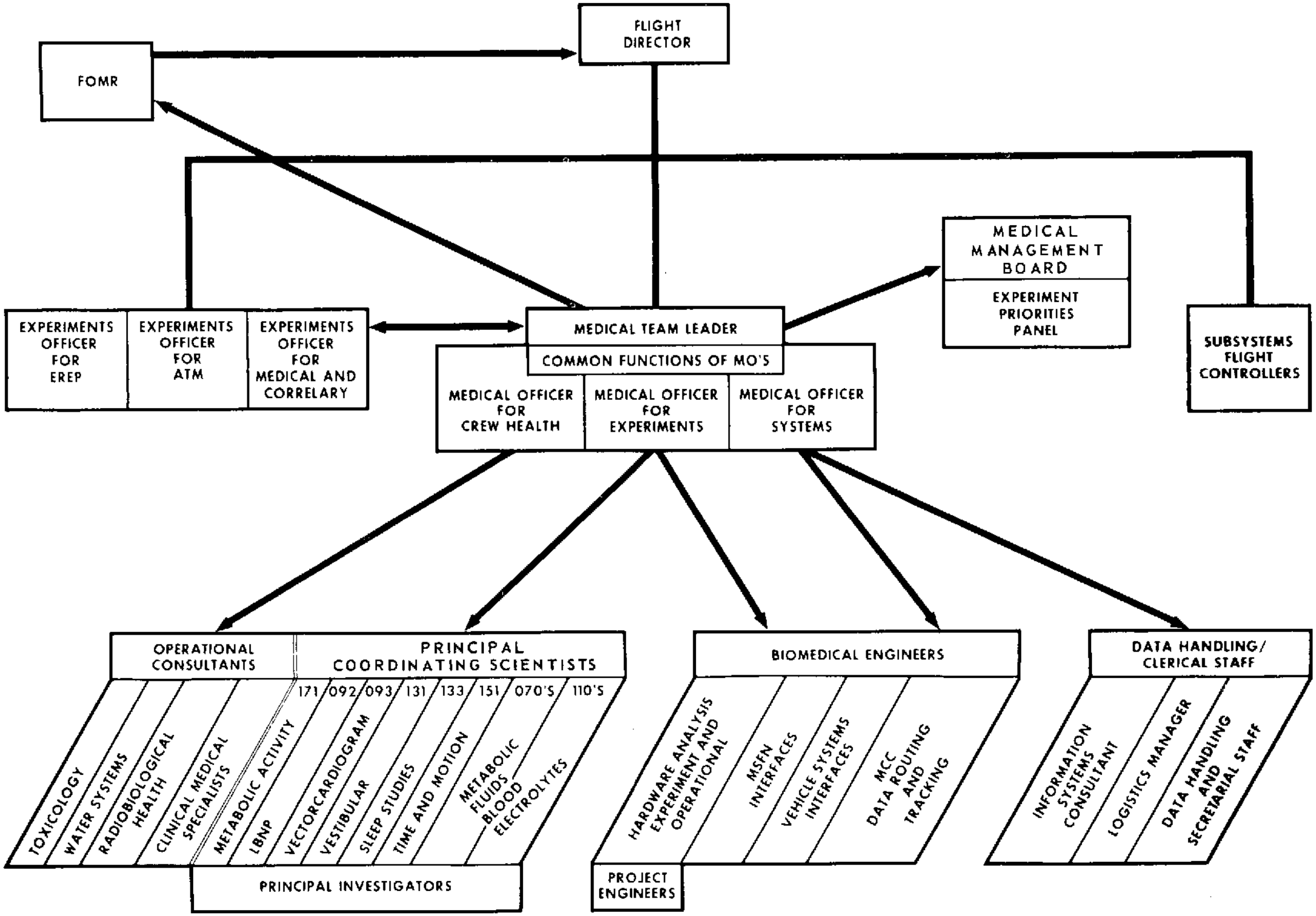


FIGURE 17

As the crew moves toward the CM the procedures indicate they should respond as follows if possible:

Obtain fire extinguisher.

Obtain oxygen mask.

Obtain suit.

Locate and assess fire.

Shut off power to fire area.

Shut off fans.

Shut off coolant loops in fire area.

Enable Manned Spaceflight Network (MSFN) control.

Break fire propagation paths.

Fight fire.

Remove atmospheric contamination if fire is extinguished.

Space suit availability for crew emergencies and crew translation times has received a good deal of study and testing to assure that the maximum protection is afforded the crew in case of emergencies. Based on the material presented to the Panel and that provided through reports it appears that the current procedures for evacuation and fire fighting are acceptable and should provide a good measure of confidence in the system that provides guidance and requirements.

In April 1971 the Safety Office at MSC completed "Skylab Orbital Assembly Fire Study" (MSC-04048, 1971) which covers the following overall aspects of fire protection. Fire prevention requires emphasis on housekeeping aspects of flammable materials control. Those systems using Coolanol-15 are to be monitored to assure their continuing acceptability. Fire detection requires acceptable fire sensor tests and maintenance procedures, coverage, maintenance, and replacement capability. These appear to have been accomplished.

Skylab space rescue. - Although rescue is covered to some extent in the RELIABILITY, QUALITY, AND SAFETY section of this report, it may be well to explore further to gather greater understanding and consequently more confidence.

In the Mercury and Gemini programs, the spacecraft could not be used for rescue because of their restricted size and life support capability. A different and unique spacecraft would have been necessary to retrieve stranded astronauts. In the Apollo program, rescue capability was again not feasible because of the limited life-support capacity of the lunar module coupled with the time required for the CSM to travel from Earth to the Moon. A rescue vehicle standing by in lunar orbit would have been necessary for lunar orbit rescue but still could not pick up astronauts on the lunar surface.

With Skylab, the orbital workshop offers long-duration life support in Earth orbit and a practical rescue capability is feasible. In each of the three Skylab visits, the astronauts fly to the space station in a modified Apollo CSM. It is then powered down after docking, but remains available for life support and crew return in the event of cluster failure. Therefore, the only failures to be considered for rescue requirements are the loss of CSM return capability or the loss of accessibility to the CSM. In this event, a second CSM would be launched carrying only two men with room for the three astronauts to be picked up in orbit, and the rescue CSM would then return with a crew of five. Therefore, after each of the first two manned launches, the next vehicle in normal preparation for launch would be used for rescue if needed. After the third and final launch (SL-4), the Skylab backup vehicle would be made ready for possible use as a rescue craft.

Just how long the Skylab astronauts would have to wait for rescue depends on the point in the mission when the emergency develops. The wait in the well-supplied orbiting cluster could vary from 48 days to 10 days. If, for instance, the need for rescue arose on the first day of the Skylab's occupancy or reoccupancy, present plans indicate that it might take 48 days for the launch crews to ready the rescue vehicle. This would include approximately 22 days to refurbish the launch tower following the previous launch. During this period the rescue kit or modification hardware would be installed in the CSM. The entire vehicle would then be moved to the launch pad for launch requiring about a week.

The later in a mission rescue is needed, the sooner the vehicle would be ready for launch. The response time from the "rescue alarm" to launch is reduced to about 28 days and 10 days at the end of the first and third missions, respectively.

Providing rescue modes for all conceivable emergency situations would obviously require instantaneous response. This is a capability not practical or feasible with the present space vehicle because of the preparations mandatory for a successful launch.

Based on the material presented to the Panel during the reviews the projected rescue techniques for Skylab appear to cover the most likely emergency situations.

ASSESSMENT OF MISSION OPERATIONS

Activities associated with mission operations planning and implementation appear to be proceeding satisfactorily. The schedules are admittedly tight and the resources limited. At this point in mission planning there are naturally a number of items of potential impact:

Clarification of the Skylab Operations Directive No. 43B, paragraph 1.4.2.(8), on delegation of authority for scrubbing missions and the meaning of the term "mandatory" is necessary. These may become more significant as the launch time grows near when all possible areas of misinterpretation should be minimized.

The continuance of open lines of communication is needed between the NASA Centers to assure understanding of their respective roles and responsibilities during the mission.

Flight crew operations:

- Defining realistic Skylab cluster housekeeping
- Limitations of nonflight hardware during training, particularly experiments
- Limited availability of hardware for training
- Control of program changes (hardware/requirements) and their impact on crew procedures and flight planning

Flight operations:

- Ability to integrate the PI's into the mission
- Ability and adequacy of flight control documentation
- Personnel staffing limitations
- Deliveries of needed hardware and software for ground systems support

COMMAND AND SERVICE MODULE

Because of mission differences, duration, and fixed attitude constraints of the Skylab program, several major modifications had to be made in the CSM's allocated for the Skylab program. The CSM's were modified to accept electrical power from the workshop. One of the three power-generating fuel cells on the CSM was deleted. Three batteries were added to the SM to provide power for descent from the workshop since the cryogenic reactants that power the fuel cells will have been depleted during its long Earth orbit stay. Two of the four service propulsion system propellant tanks and one helium tank were not required for the missions and so were deleted. A propellant storage module was incorporated into the SM to increase the quantity of reaction control system propellants, thus enhancing in-orbit attitude maneuvering and providing a backup method of deorbit propulsion.

The caution and warning system was modified. The warning tone was carried to the workshop to allow the entire crew to pursue activities in the OWS and still monitor the CSM.

The CSM audio system was hard-lined to the OWS and will serve as the communications center for the workshop. Stowage provisions in the CM have been vastly increased to allow for the greatest degree of resupply as well as return of experiments, film, biological samples, and other needed material. The thermal control system was significantly modified to meet the requirements of the fixed attitude dictated by the workshop cluster and the need to minimize condensation within the CM while maintaining CSM components and propellants within allowable temperatures.

A tank was added to the SM to allow water generated by the fuel cells after docking to be stored rather than vented overboard. An overboard hydrogen dump system was incorporated into the SM cryogenic system to allow maintenance of the hydrogen tank pressures within safe limits after the fuel cells are shut down. A nonpropulsive vent was used. A similar nonpropulsive vent was installed in the CM hatch to allow venting of surplus oxygen. These vents were necessary and the material ejected through them has been examined for contamination of experiments.

CSM vehicles designation and their assignment to the Skylab missions are CSM 116 for SL-2, CSM 117 for SL-3, CSM 118 for SL-4, and CSM 119 as a backup and rescue vehicle if required. A contingency modification kit for converting a Skylab CSM to a rescue vehicle in the event a crew becomes stranded in the workshop is also being provided. The rescue kit could be installed in any of the Skylab CSM's. Further information on the rescue plan is discussed in the RELIABILITY, QUALITY, AND SAFETY section.

SLA 23, 24, 6, and 25 go with CSM's 116, 117, 118, and 119, respectively. All of these SLA's are in storage at KSC.

The rescue vehicle kit components consists of -

Two aft bulkhead mounted crew couches

Two oxygen umbilicals and hose connector assemblies

Two oxygen masks and hose connector assemblies

Two crew communications umbilicals with cables and connectors

Crew equipment and stowage items to support additional crew

Ballast for required center of gravity

Postlanding vents and associated air ducting assemblies

Experiment return pallet assembly

Probe and drogue modifications

All of these items, along with modification instruction documents, are placed in bonded storage at KSC and are to be made available if required.

The rescue kit has been verified. Fit and function will be checked at KSC.

Since the Skylab CSM's constitute a modification to the very successful Apollo CSM's and the contractor appears to be maintaining adequate skills and engineering capability, there is a high degree of confidence in the CSM's capability to do their job. Apollo anomalies that apply to the Skylab CSM's are being resolved on the same basis as was done for the Apollo program.

The following discussions of the individual major onboard systems is intended to point out the activities which provide confidence in the system and those areas requiring closure.

Thermal Control System

In general, the approach used to verify the capability of the thermal control system involved the construction of a transient computer program. Using the essentials of the

Apollo program, the computer program predicts the temperatures and temperature transients experienced for any given sequence of mission events. It also verifies the predicted responses through exposure of a full-scale vehicle in thermal-vacuum test chamber. In addition, it defines mission constraints, and provides them for incorporation in mission rules and operational handbooks. While the CM shows adequate margin, the SM shows that only a small margin exists in some "worst case" conditions. There appears to be no concern here based on the material presented to the Panel.

Environmental Control System

In conjunction with the thermal control system, the environmental control system (ECS) provides the flight crew and electronic equipment with a conditioned atmosphere. The ECS is operated continuously during undocked mission phases. Except for the primary glycol system, it is shut down during docked operations in orbit. Apollo flight experience has indicated a high degree of reliability under similar flight conditions. For instance, the secondary coolant loop has been operated during boost, deactivated for the entire mission, and reactivated prior to reentry. The major portion of the ECS was subjected to an augmented system Skylab mission test. The test was designed to demonstrate the performance of the ECS during several mission simulations with normal and off-limit conditions. Approximately 1500 hours of testing were accrued. A further test of 120 days under a quiescent mode of operation similar to that occuring while the CSM is docked to the cluster was conducted. Maintenance of wall surfaces above the dewpoint temperature to preclude condensation appears to have been a problem. The Panel understands that condensation has been minimized by system control set-points but is still not clear on whether the condensation that is predicted to occur during docked condition will or will not cause problems which have yet to be resolved. During ground operations prior to launch the GSE must also be capable of precluding the formation of condensates. With respect to SM, thermal control tests were conducted to assure adequacy of current paint system as a result of paint blisters observed during CSM 112 EVA on Apollo. The closure of this potential problem will be noted in the next report.

Structural Systems

Changes to the Apollo configuration caused by the deletion of CM handholds and handrails, repositioning of support structures, and deletion of various portions of onboard systems and their impact on structural adequacy were checked by a combination of structural analysis, similarity with previous vehicles, and extensive testing (particularly for the SM which had far more structural changes). There appeared to have been few problems surfaced by these tests.

Mechanical Systems

The only mechanical system item requiring modification for the Skylab mission was the uprighting system. The uprighting system places the command module in a stable position upon Earth landing. The system consists of three air bags with their associated inflation and retaining hardware. The Skylab system differs from the Apollo in that the two intakes for the air used to pressurize the bags are interconnected in such a way that if one intake is submerged a water trap allows the onboard compressors to continue operating at full output. This system was successfully tested and no further problems were encountered.

Stowage and Crew Equipment

Skylab CSM stowage capability has been revised to support orbital workshop operations with particular attention to increasing the volume available for storage. Crew equipment additions involved are fire extinguisher, optical alinement sight mount, return mission water provisions, and tie-down straps. Crew compartment fit and function (C^2F^2) tests and other tests and analyses indicate no significant problems.

Service Propulsion System

The service propulsion system provides the impulse for X-axis velocity changes throughout a mission. It also provides the service propulsion system abort capability after the launch escape tower is jettisoned. The Skylab mission requires less helium and propellant than the Apollo missions. Therefore, one helium storage bottle and the propellant storage tanks were removed from the Skylab spacecraft. As a result of the extended duration Earth orbit in a fixed attitude (docked), an active thermal control system is required to maintain system temperatures. As presented, the verification program indicated few problems and these appear to have been resolved.

Reaction Control Systems

Skylab, like Apollo, has two separate reaction control systems, one set for the CM and one for the SM. The CM system is essentially unchanged from the Apollo while the SM system was supplemented with an additional 1500 pounds of stored propellant. There appear to be no open items in these systems.

Electrical Power System

The Skylab EPS conditions and distributes power to the CSM during its docked mode. During independent operation the CSM derives its power from fuel cells and batteries depending on the segment of the mission. Through the SOCAR and the DCR system the electrical power systems of the CSM and the cluster have been verified as being compatible. This included that time period during which both the EPS' would be operating in parallel. Parallel operation occurs during the beginning and end of each Skylab mission segment and is estimated to be no more than 4 minutes each time. MSFC, MSC, and contractor studies were conducted to assure this point. The descent battery cases cracked after qualification vibration testing. As a result of this, the cases were strengthened and internal changes made. The results of retest of these improved batteries has not been seen by the Panel. The nonpropulsive vents used to vent the hydrogen and the oxygen were discussed, and it appears that only the hydrogen vent was tested to assure its adequacy. The oxygen vent was assumed to work on the basis of similarity. One could question the validity of such an assumption since the working fluids are different. A clarification of this will appear in the next report.

Displays and Controls/Caution and Warning Systems

The displays and controls provide an integrated arrangement of like functions to control and monitor the various operational systems. The caution and warning system, which is included in the displays and controls, provides a means by which the crew receives a timely alert to actual or potential CSM system failures or out-of-tolerance conditions. The unchanged and modified displays and controls were verified compatible with the Skylab mission by similarity with demonstrated Apollo performance. The new items, not similar to Apollo, were verified by qualification tests and supported by analysis. There appeared to be no major problems in these systems.

Communication System

The communication system equipment and configuration are identical to those of the basic Apollo. It is augmented by a speaker box and configuration changes to facilitate cluster operation. The unique Skylab requirement is again in the extended operating time for a portion of the communications system. This includes the audio center, unified S-band equipment, premodulation processor, and up-data link. These units all use solid-state devices, having 100 percent derating, and preusage burnin screening as well as equipment burnin of 100 hours. Based on this justified extrapolation of previously demonstrated operating life to meet Skylab requirements was possible.

Ordnance Systems

Of the numerous devices used on the CSM, the Panel's interest centered on the CM-SM separation system. This system is located external to the CM and between the aft heat shield of the CM and forward bulkhead of the SM. CM separation from the SM takes place during all abort phases and after orbital flight before CM reentry. The Apollo RDX type tension tie cutter did not pass the Skylab thermal vacuum verification test. Detonation energy available for cutting was low. The RDX was replaced with a HNS silver sheathed shaped charge. At the time of Panel review the replacement was undergoing test certification. Failure of the tension tie cutter to separate the CM and SM is critical, and a qualified tension tie cutter must be available. The closure of this item will be enclosed in the next report.

Based on the material presented to the Panel, management controls are still in effect to assure hardware of high quality.

ORBITAL WORKSHOP

Background Description

The orbital workshop is a two-floor structure providing accommodations for the crew and a primary experiment area. The first floor is divided into four sections: the sleep compartment, the waste management compartment, the wardroom, and the experiment work area. The biomedical experiments are performed in the experiment work area. The second floor is devoted primarily to experiments which require relatively large volumes or which use either of two scientific airlocks for external viewing or exposure. The remainder of the space is occupied by subsystem and storage compartments. These arrangements are shown in figures 18 and 19.

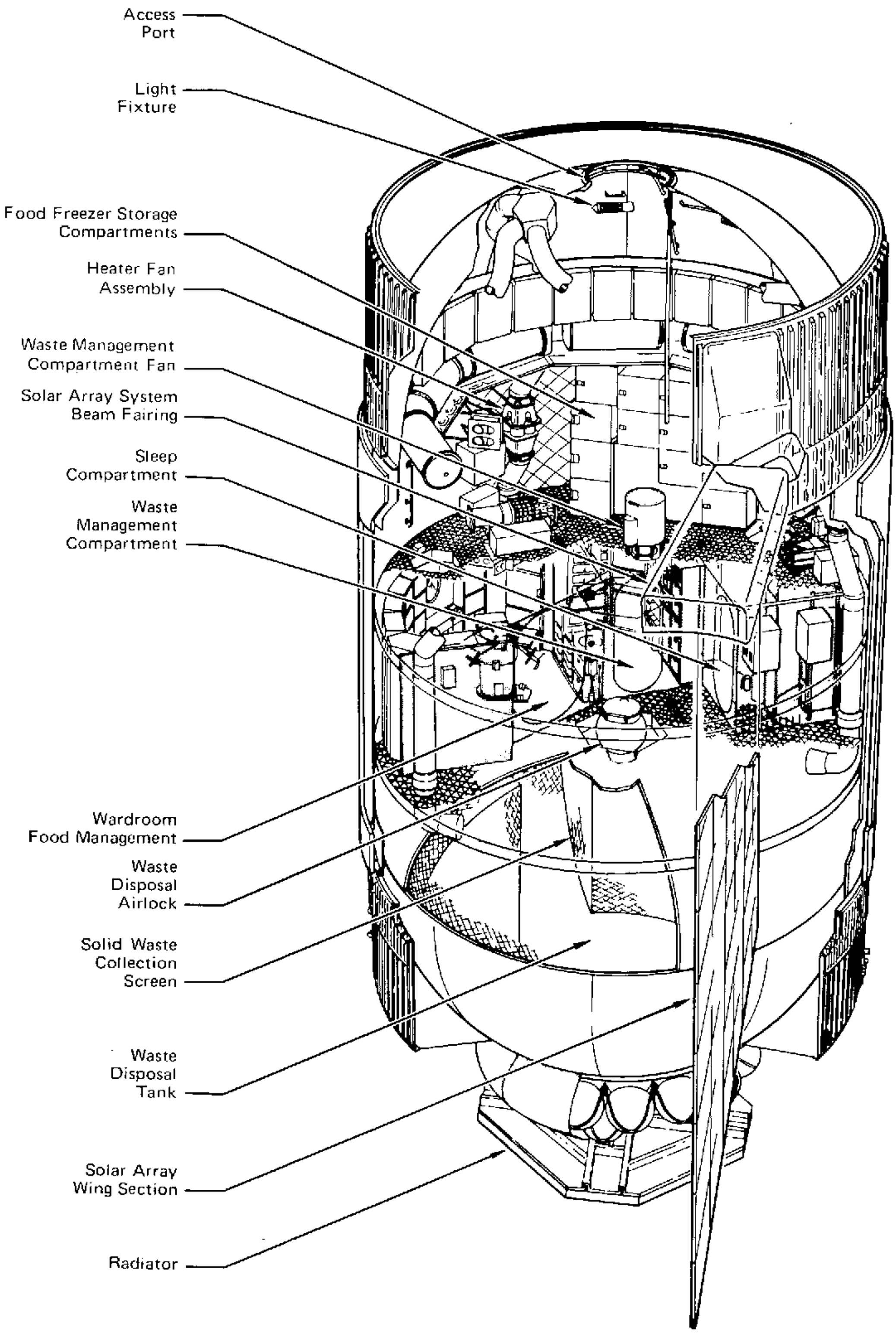


FIGURE 18 - ORBITAL WORKSHOP

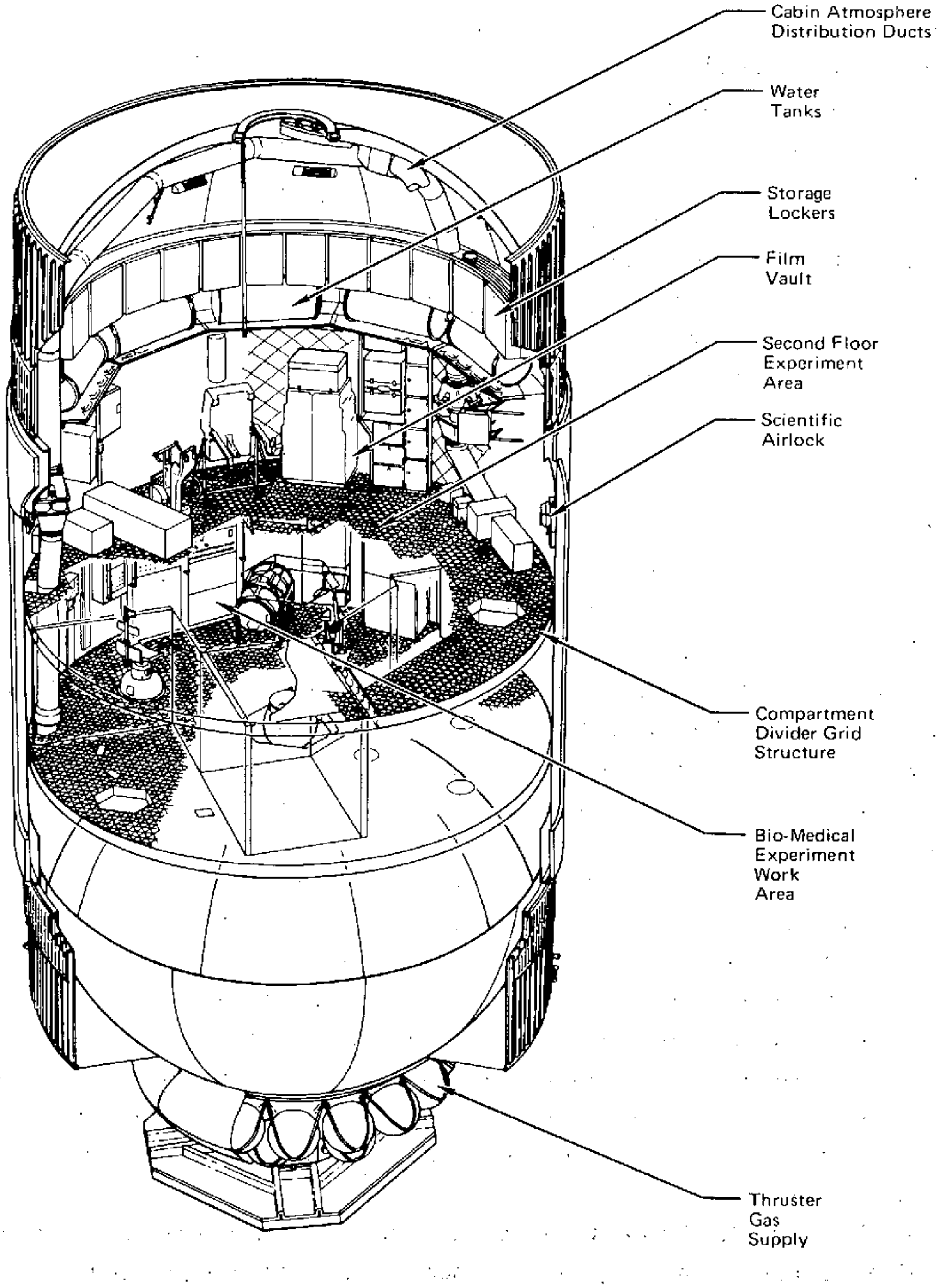


FIGURE 19 - ORBITAL WORKSHOP

The workshop also is the storage area for crew supplies, such as food, water, and clothing, as well as providing for personal hygiene and waste and trash disposal.

The OWS is an S-IVB stage of the Saturn V launch vehicle that is ground outfitted to be suitable for manned habitation.

The OWS structure provides for

1. Habitable environment with crew provisions and consumables
2. Capability for experiment installation
3. Support for conducting experiments
4. Propulsive capability for attitude control
5. Solar array power source, mounting provisions for the array, and routing of power to the airlock module
6. Storage for cluster waste material
7. Capability for orbital storage and reuse
8. Two scientific airlock installations, one on the cluster -Z axis (Sun side) and one on the cluster +Z axis (dark side)
9. Capability for television transmission via MDA video selector and CSM transmitter
10. No scheduled or planned activity requiring access into the habitable volume of OWS after closeout in the Vehicle Assembly Building

For launch, the OWS consists of an S-IBV/S-V forward skirt, S-IVB propellant tanks with preinstalled crew and experiment accommodations, and an S-IVB-S-V aft skirt and interstage. The forward skirt interfaces with the IU, the forward tank dome interfaces with the AM, and the aft interstage interfaces with the S-II stage. The in-orbit configuration is essentially the same. The only changes are that the interstage separates with the S-II stage, and the solar array and meteoroid shield are deployed.

Significant changes to the S-IVB structure have been caused by Skylab requirements. Provisions have been made for an OWS vacuum outlet, scientific airlock (SAL), and attachments for crew quarters, experiments, and equipment stowage. A waste dump airlock has been provided in the common bulkhead area for disposing of wet and dry waste through the common bulkhead from the LH_2 tank to the LOX tank.

A meteoroid shield is designed as a structurally integrated part of the OWS and protects the cylindrical portion of the tank. After deployment, the shield extends about 6 inches radially from the outer surface of the LH_2 tank. Deployment is accomplished during orbit by a signal from the IU.

The S-IVB is divided into a two-level crew quarters by a structure serving as a floor/ceiling installed in the LH_2 tank, perpendicular to the longitudinal axis of the S-IVB stage. The section aft of the floor/ceiling provides the crew with accommodations for sleeping, food and waste management, hygiene activity, off-duty activity, data management, and the implementation of corollar experiments.

Astronaut mobility/stability aids have been installed to assist the astronauts in performing tasks associated with activation, crew habitation, experimentation, and deactivation. These aids are of two basic types - fixed and portable. Fixed astronaut aids include handrails, tether attach devices, and the central handrail. They are permanently installed in locations throughout the LH_2 tank where it is expected that heavy traffic or task loading will occur. Portable astronaut aids include handholds, tether attach brackets, and foot restraints.

OWS interior lighting allows for crew equipment installations, normal and emergency crew activities, and experiment operations. The interior lighting system consists of initial-entry lights, general-illumination lights, emergency lights, and special-purpose lights. Orientation (running) lights are provided for determining the gross attitude of the passive vehicle and movement relative to a line of sight through the window of the docking vehicle. In addition, white floodlights will be used to illuminate the exterior of the cluster and the exterior of the AM within the thermal curtains. A portable floodlight is used by the astronaut during EVA.

The subsystems comprising the total OWS include the following for our purpose:

Panel examined in detail	Panel made cursory examination
Structures subsystem	Thruster attitude control subsystem
Environmental and thermal control subsystem	Solar array subsystem
Electrical power subsystem - (EMC and corona)	Ordnance subsystem
Communications and data acquisition system	Ground support equipment subsystem
Caution and warning subsystem	
Habitability support subsystem	
Crew equipment subsystem	

Three systems were reviewed on the following occasions: (1) MDAC-West, October 1971, (2) Marshall, April 1972, (3) PDTR, April 1972, and (4) DCR, October 1972. The Panel in its factfinding was interested in the evident effectiveness of the technical management systems, the maturity of the design, and the quality of the hardware. The following discussion is based on these factfinding reviews.

Note should be made that experiments and other modules are discussed here only as they present interface requirements. They are discussed in detail elsewhere.

Orbital Workshop Hardware

The OWS flight hardware checkout began November 6, 1971 with the start of continuity/compatibility testing. It continued through completion of the all systems test, electro/magnetic compatibility test, and residual subsystem retests August 16, 1972.

During this period, all subsystems, crew compartment fit and function (C^2F^2), and the combined all systems test and electro/magnetic compatibility (AST and EMC) test were performed.

The crew compartment fit and function was conducted in two increments. The first increment ran May 22 through 28, and the second increment August 12, 1972. Some C^2F^2 checkout remains to be accomplished at KSC primarily because of lack of hardware, notably in the stowage area.

The combined AST and EMC test was performed July 17 through August 7, 1972. This test functioned each OWS system on a simulated prelaunch, launch, and orbital time line to verify systems compatibility throughout the mission profile.

Further checkout activities included a mercury certification of the habitation area and calibration of the meteoroid shield strain gages. Major manufacturing activity focused on modification of the meteoroid shield and cleanup activities associated with final inspection. The spacecraft was moved to Seal Beach for thruster attitude control system proof testing on August 31, 1972. Final preparations for shipment followed at Huntington Beach.

Problems encountered during this checkout were documented on test problem reports. A summary of the closeout status of these reports is shown in table VI. Some test problems could not be closed at Huntington Beach because of unavailable hardware and unfurnished rework and testing. These are transferred to a recap test problem report which identifies the problem being transferred to KSC, the reason the problem was not resolved at Huntington Beach, and the applicable documentation (i.e., failure report, discrepancy report, inspection item sheet, original test problem report).

The retest outline is the document that identifies, at the time of shipment, open retest and/or test requirements of incompleted assemblies, discrepancy reports, failure reports, and removals and requires quality assurance verification for final buy-off. It contains three categories:

(1) Retest required as a result of assemblies, failure reports, discrepancy reports, and removals that were worked after factory testing

(2) A listing of unworked assembly outlines, engineering orders, etc.

(3) A line item to identify the recap test problem report and associated test or retest requirements that must be transferred to KSC

All items associated with open work are listed in the data package contained as a part of the certificate of flight worthiness and DD250 form.

There were 27 OWS design certification review (DCR) review item discrepancies (RID's). Essentially all are closed at this time.

All test objectives have been satisfied except those noted in table VII.

Orbital Workshop Structures Subsystem

The OWS structures subsystem consists of the following major components:

1. Forward skirt which serves as structural continuation between OWS habitation area tank and the IU. It provides space for mounting electrical and electronic equipment as well as providing support for the solar array system wing assemblies. There appeared to be no unique fabrication techniques or new technology applied here. The major items requiring assurance were the SAS attachment provisions which support these most important electrical power generating components. At the time of the formal DCR there were no open items, waiver, or deviations associated with the forward skirt, and it complied with the MSFC hardware safety checklist. McDonnell Douglas-West expects little or no work to be done at the KSC on this item.

2. Thermal shield. The thermal shield, attached to the aft 34 inches of the forward skirt, functions as a radiator barrier to aid in stabilizing the habitation area temperature. There appear to be no constraints to mission or crew safety attached to this item.

3. Aft skirt and thermal shield. The aft skirt is a modified Saturn V/IVB aft skirt. Structural capabilities apparently were not changed by OWS modifications. The attachment of the aft thermal shield is similar to that for the forward thermal shield. This skirt also has attachments to support the SAS installation. The OWS flight loads are indicated as lower than those for the S-IVB aft skirt and there was no indication of any problems. During development of this structure, the thruster attitude control subsystem nozzles which are hard mounted to this structure had to be modified to a shock-mount to preclude damage to nozzle valves. Analysis and test results show no waivers or specification deviations required.

4. Aft interstage. This is a frustum-shaped assembly which transmits loads between OWS aft skirt and S-II stage and provides the OWS radiator assembly protection during launch. It remains with the discarded S-II stage. There appear to be no constraints caused by this item.

5. Thrust structure. This is a multipurpose structure using the basic S-IBV stage with modifications to support the thruster attitude control subsystem's nitrogen gas storage spheres and associated piping, the subsystem's meteoroid protection shield, and the refrigeration system radiator with its impingement shield and structural support. Some items of note are the single failure points associated with the thruster attitude control system.

   (a) Rupture or bursting of the thruster attitude control subsystem's storage and manifold could jeopardize the safety of the crew.

   (b) Radiator shield actuator assembly release mechanism failure could preclude jettison of radiator shield adversely affecting OWS thermal control system operation.

These single failure points appear acceptable based on the added manufacturing and quality controls imposed, tests and analysis conducted, and similarity to prior use on Saturn launch vehicles.

6. Meteoroid shield. This shield for the habitation area is composed of cylindrical sections. When deployed they act as the outer barrier with the OWS main tank wall as the inner barrier. The standoff distance of this meteoroid shield is approximately 5 inches. It is deployed on-orbit by severing tension straps with expandable ordnance tubes and moved outward by 16 links powered by independent torsion bars.

Meteoroid shield deployment was successfully demonstrated at NASA/MSFC. However, during pressure testing one of the shield hinges failed structurally. The hinge subsequently was redesigned and the strength capability verified by tests. These design changes have been incorporated into the OWS. The static test article (STA) is to be reworked and retested at NASA/MSFC during the October to November time frame and these test results should be verified.

Verification of the structures subsystem was demonstrated by the satisfactory completion of all subsystem testing.

A further deployment production acceptance test is expected to be conducted at KSC.

7. Habitation tank. This "habitation or crew area" consists of a forward dome, main cylindrical section with window and door openings, and an aft common bulkhead forming the "lower floor." The interior is insulated with polyurethane foam covered with an aluminum foil-fiberglass-teflon type liner. In addition, the external surface of the forward dome is covered with insulation consisting of some 95 layers of aluminized mylar with interspersed layers of separator sheets, while the cylindrical portion is coated with a reflective coating.

The Panel's interest here was the structure's ability to support onboard equipment particularly through the SL-1 launch period and to maintain onboard pressure within the allowable atmospheric gas leakage (OWC decompression). The allowable leakage rate has been set at no more than 5 pounds mass per day in orbit. Table VIII indicates the expected leakage allowances for hatches and penetrations. In line with this approach the Panel identified the following areas which are discussed here:

1. Scientific airlock. It is used with experiments S-063 and S-190B. The scientific airlock provides vacuum source and allows deployment of experiments outside the habitation area. There are two ports, one on the solar side and one on the anti-solar side.

2. Forward dome entry hatch. It is located at the apex of the dome and provides for workshop entry in orbit. It functions as a structural part carrying pressure loads during boost.

3. Side access panel. It provides ground access into the OWS module for installation and work on such items as experiments, water containers, food containers, etc.

4. Wardroom viewing window. It is of a double pane construction approximately 18 inches in diameter to allow simultaneous viewing by two crewmen. The design includes thermal and meteoroid protection when not in use.

5. Trash disposal airlock. It is a passthrough chamber built into the waste tank common bulkhead. A failure poses both a potential pressure loss and microbial contamination problem.

6. Water bottles and stowage container support structure. It provides for large mass loads subject to static and launch acceleration loads. This is a good representation of all such structural loads.

The scientific airlock has a window which is the refurbished Apollo window and its failure, as with the scientific airlock doors, would jeopardize the safety of the crew. The inboard face of the scientific airlock has an opening which can be sealed by an experiment or a window cover. Because of this the Panel feels that procedures for both flight and ground operations must be explicit in the use of the scientific airlock. For example, flight procedures should specify that the crew must be certain that the experiments are indeed tightly situated against the scientific airlock to preclude leakage as the experiment becomes a part of the airlock pressure vessel.

Since the inner and outer surfaces of the assembly have highly effective antireflective coatings, special care is required during ground operations.

The low temperatures on the anti-solar side made a desiccated repressurization necessary to preclude humidity problems. Recent authorization for this resulted in a new design which is still undergoing qualification tests. These are scheduled for completion in November and to date indicate no problems are expected.

Precise alinement of the individual scientific airlock is apparently difficult because of deflections due to thermal, gravity, and pressure environments. Alinement must be done at KSC.

KSC is aware of the measurement work which they have to accomplish. In reviewing the scientific airlock structure it appears that it is capable of meeting its design requirements.

However, an item to be noted is that some scientific airlock components were made from material which had relatively low stress corrosion threshold levels. Stress corrosion analysis indicate susceptibility of the scientific airlock's aluminum 2014-T652 housing and aluminum. The 2024-T4 supports will possibly experience stress corrosion cracking, but since the housing and struts will be under a compressive load, the cracks should have little impact on the scientific airlock's operations. It was indicated that if cracks develop to the point where leakage occurs the scientific airlock integrity could be maintained with the outer door closed. There is also a possibility of closing any such leaks by using aluminum pressure sensitive tape or polybutane sealant putty indicated as part of OWS in-flight kit.

Subsequent to the completion of the forward dome entry hatch a rodent bearing failure during vibration was discovered. The failure apparently did not affect operation of the hatch. Failure analysis is still continuing; indications point to the cause being an improperly adjusted link (human error). Inspection of the spacecraft links is scheduled during subsystem checkout at KSC. A further check will result from integrated checkout requirements which specify a functional test with 25-pound maximum handle loads. If the hatch does not operate properly, tools are available in the tool kit. Procedures and tools have been verified on the test hatch. Leakage through the hatch seal has been analyzed. Prior proven application materials and special controls indicate that it is an acceptable single failure point.

Based on the analyses and test results presented to us, the side access panel as well as the opening into which it fits are structurally adequate. Tests indicate that no excessive leakage problems.

Two leakage problems were encountered. They were the wardroom window cover and the SAS wing cavity. Both are currently being redesigned and are identified as open work at KSC.

The protective cover leakage exceeded the allowable rate. Window redesign incorporates an O-ring seal in the cover plate (discussed subsequently) as well as on the support ring and window frame. When complete this will be installed and tested at KSC. With regard to the viewing window installation, the only major problem encountered involved the type of vent system used to vent the cavity between glazings to relieve the pressure. When the vehicle is launched, the cavity is sealed with an internal pressure of 14.7 psia. When the vehicle reaches orbit the differential pressure across the external glazing would be essentially 14.7 psi. There would be a pressure of about 10 psi across the inner glazing. Optical requirements dictate a pressure of no more than 6 psi. The original automatic one-way check valve provided a 5 psi pressure differential from the cavity to the cabin. Furthermore, analyses conducted by both the contractor and the NASA Center showed that should the valve "chatter" or freeze open a 26 psi differential could exist across the outer glazing. Eventually this would result in glass failure. To preclude this the window vent area was redesigned with a positive seal on the glass-to-glass cavity along with a manually operated valve. A removable metal cover plate was installed over the inside of the inner or cabin side glass window to carry the 26 psi OWS atmosphere during launch. This cavity between the new metal protective plate and the inner glass also required a similar manual vent valve. It is this cover plate that must be sealed to prevent leakage. This is an example of the extent of effort necessary to (1) meet the design requirements for both safety and mission utilization and (2) maintain the structural integrity of the basic OWS shell and reduce or eliminate hazards.

During factory checkout of the SAS wing cavity or support structure on the basic OWS, it was noted that there was excessive leakage of pure gas. If this occurred during KSC operations and launch it could lead to contamination within the cavity. It also means a chance of moisture. It was indicated that redesign was underway that would seal most leak paths. A leak test is then to be performed at KSC prior to SAS mating. This is not assumed to be a significant problem. One of the questions for the phase III review is whether moisture can or has seeped in and could when frozen impact the deployment mechanism. The closure of this question will be identified in the phase III or final report.

The trash disposal airlock is perhaps one of the most important items of operational hardware in the orbital workshop. It is in daily use and failure would most likely compromise primary mission objectives. Development and qualification tests were completed satisfactorily. They verified the structural integrity of the item (e.g., proof and burst pressures, leakage, vibration, etc.). Problems and corrective action are noted in table IX. One item noted by the Panel was that the hatch lid lock handle forces appeared high. It was understood that while the specification called for forces up to 25 pounds it requires as much as 45 pounds on the inboard hatch. The handle operating load for the outboard hatch is some 35 pounds.

The water container support structure (WCSS) provides support for ten 600-pound capacity stainless-steel containers within a circular ring structure. Stowage container support structure provides support for some 25 containers in a circular ring structure attached to the WCSS forward frame. The test results from the OWS dynamic test article and static test article, as well as analytic results, indicate adequate factors of safety and structural integrity.

Environmental and Thermal 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 Skylab is on the launch pad. The TCS maintains the proper environmental conditions during all orbital operations. The VCS provides the proper ventilation during manned orbital operations. Figures 20, 21, and 22 indicate the general arrangement of the hardware involved.

In general, quality testing on the ECS/TCS has been successfully completed. Components still under test are in the refrigeration subsystem and condensate dump line to the waste tank.

OWS
PRESSURIZATION AND PRESSURE
CONTROL SYSTEM

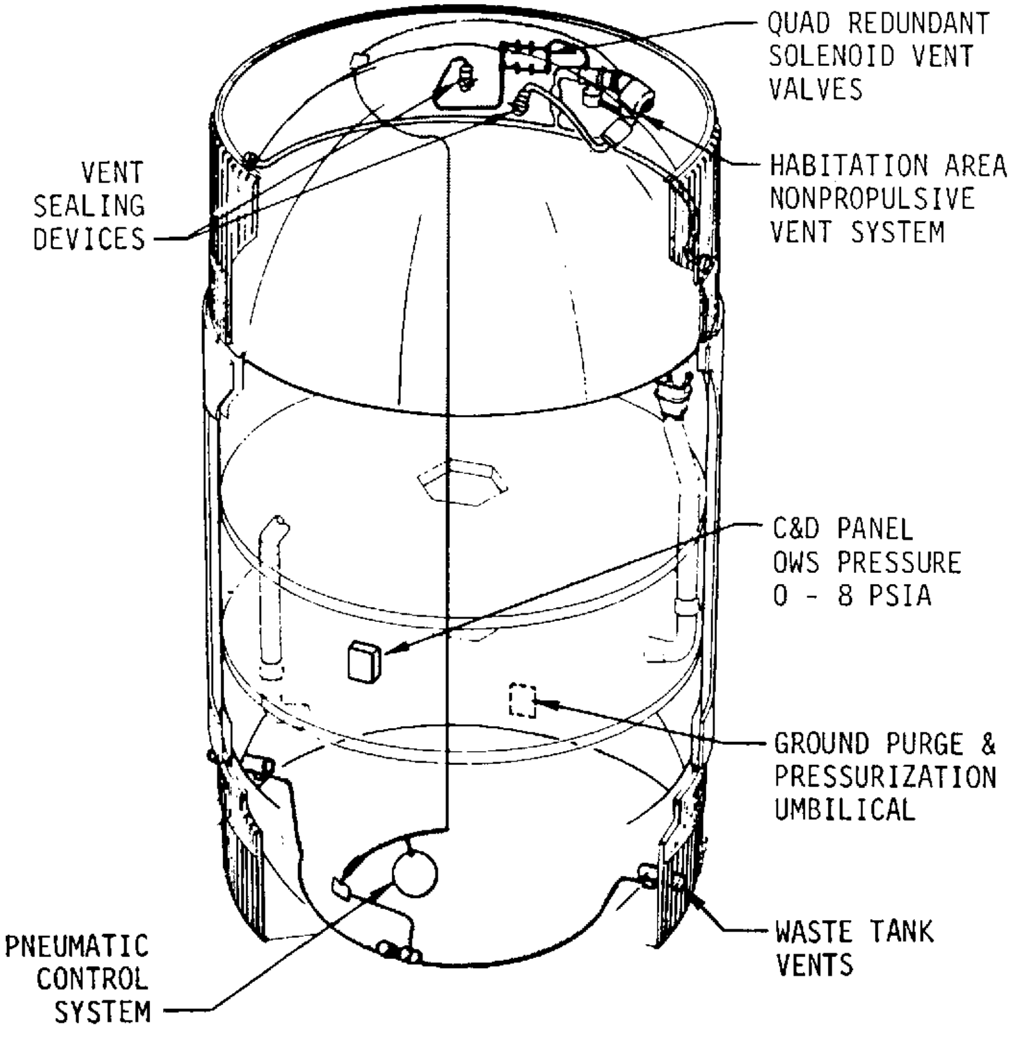


FIGURE 20

OWS
REFRIGERATION SYSTEM

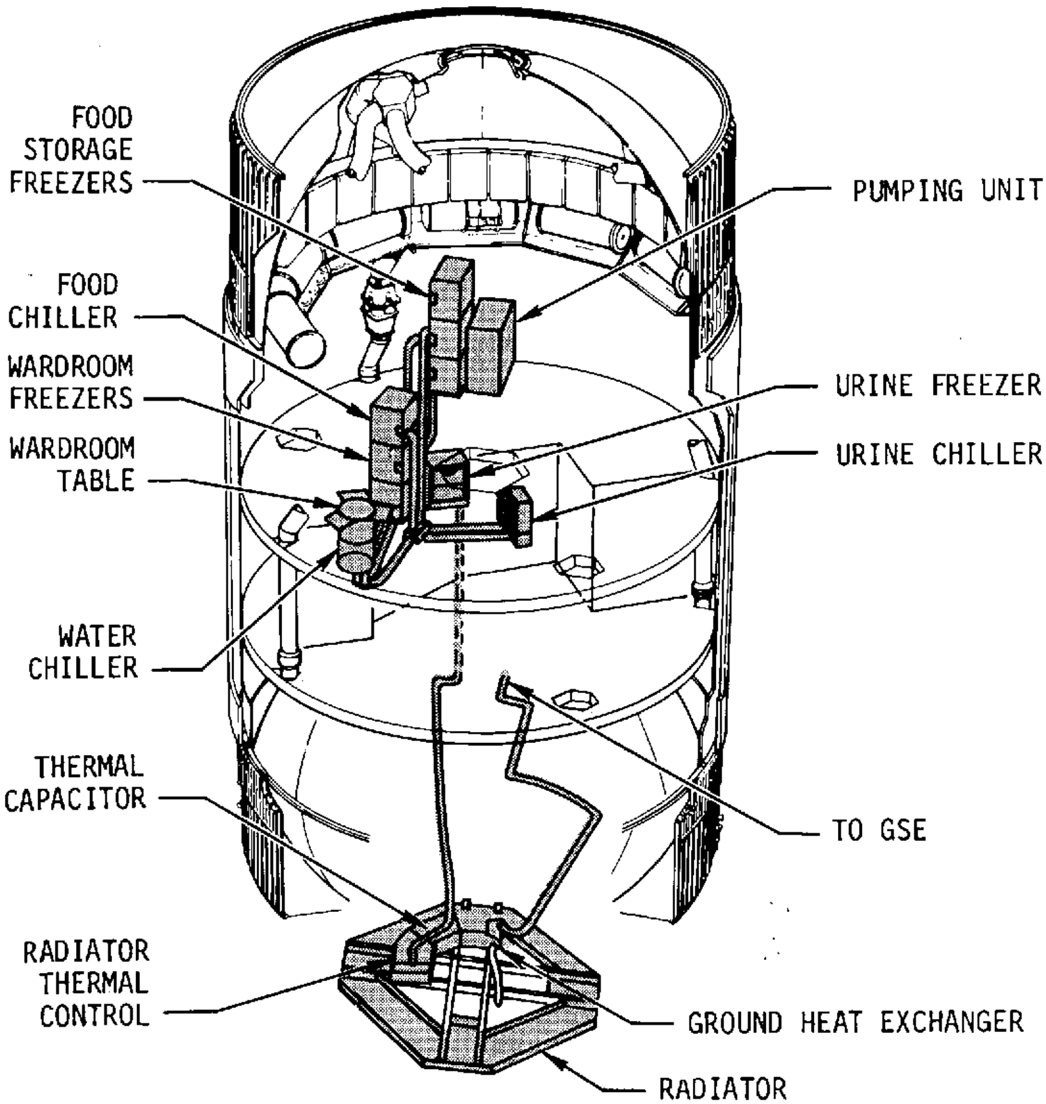


FIGURE 21

OWS
ATMOSPHERE CONTROL SYSTEM

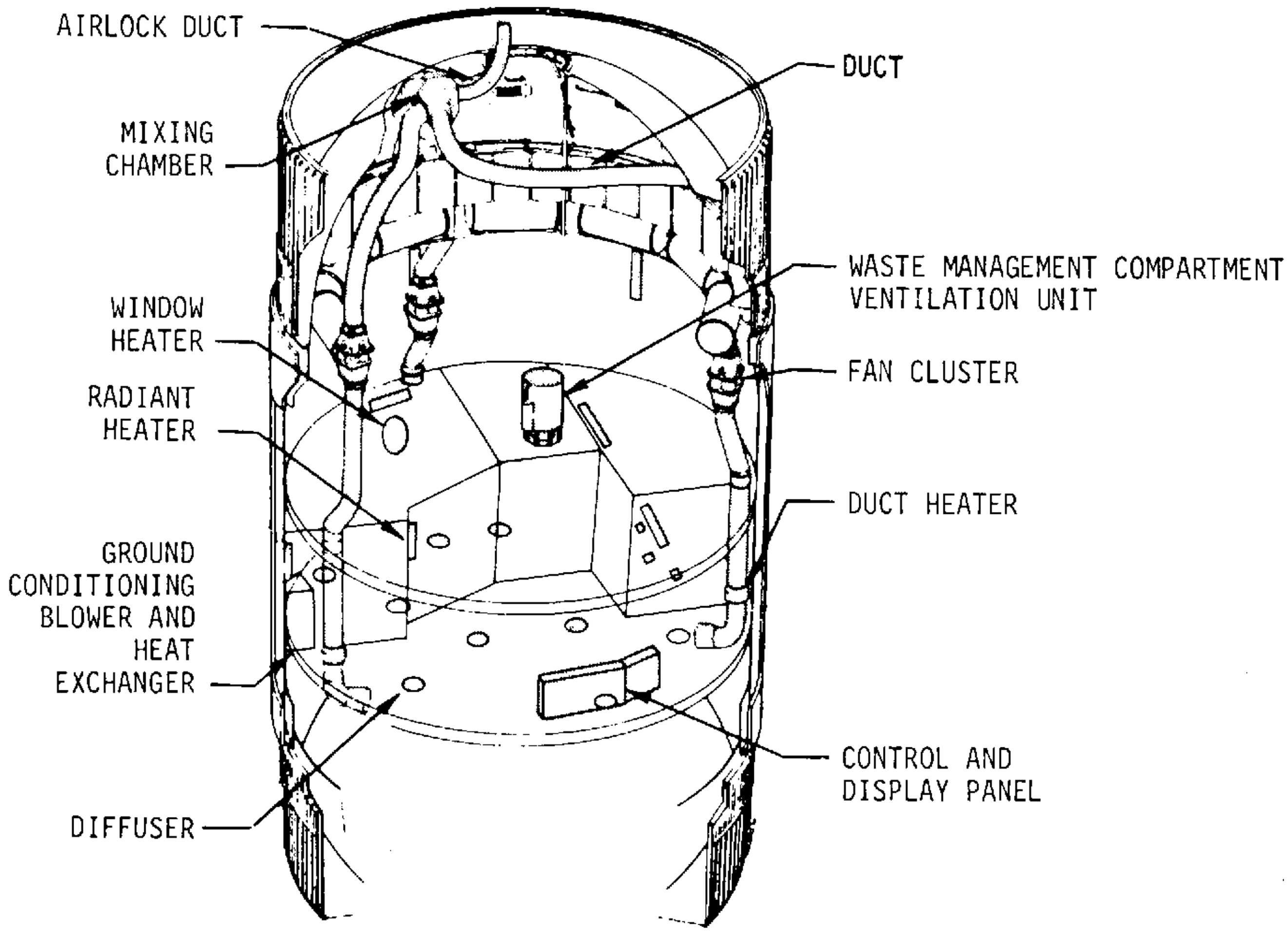


FIGURE 22

Panel interest in those subsystems directly related to crew operations has been emphasized throughout this review. Consequently, all aspects of the ECS were examined. As a result this section covers the following:

1. Habitation area atmosphere control
2. Waste tank as affects pressure control system
3. Thermal control ventilation and odor removal
4. Thermal control system
5. Refrigeration system
6. Ground conditioning and purge

The qualification test program for the remainder of the ECS equipment appears to have been successfully completed. There were numerous qualification tests, development tests, all systems' tests, etc., whose results were used to substantiate the qualification of the components.

Habitability area atmosphere control. - This portion of the ECS comprises the (1) vent system to provide overpressure protection during ground and flight operations, (2) pressurization provisions includes plumbing and pneumatic supplies for prelaunch pressurization from a GSE source and for in-flight pressurization from the AM supply, and (3) leakage control which herein is an extension of the material presented under OWS structures section.

The minimum allowable habitation area pressure during launch is 22 psia, based on structural requirements with a one-engine-out malfunction. Maximum pressure for the habitation area is 26 psia. Higher pressure will produce excessive discontinuity stresses in areas of the tank where reinforcement is required for floor, ceiling, and other equipment attachments. Prior to liftoff, the habitation area is to be pressurized with nitrogen from a ground source to between 23 and 26 psia.

The habitation area when in orbit is pressurized to 5 psia with oxygen by the AM pressurization system. The OWS part of the system consists only of the connecting lines from the AM/OWS interface to the gas inlet port located in the electrical feedthrough collar. Initial pressurization occurs through a system separate from that used to supply oxygen and nitrogen during habitation. This procedure permits flow of oxygen only and assures accurate knowledge of the oxygen and nitrogen concentrations for initial occupation. Pressurization will be initiated by ground command at about 1.6 hours after liftoff and will require about 9 hours to reach 5 psia. A pressure integrity check will be conducted prior to Skylab-2 launch.

During the 28-day Skylab-2 mission the AM pressurization system will control the habitation area pressure at 5.0 ± 0.2 psia with an oxygen partial pressure of 3.6 ± 0.3 psia.

At termination of the Skylab-2 mission, the solenoid vent port sealing device will be removed by the crew. The ground will then command the solenoid vent valves open to vent the orbital assembly from 5 to 2 psia to prevent condensation of water vapor during storage. Leakage will tend to reduce the pressure. Prior to reaching the minimum allowable of 0.5 psia, the ground will command the pressurization system on until the pressure is 1 psia. This sequence will be repeated as required. Prior to Skylab-3 launch the habitation area will be pressurized to 5 psia. Procedures for deactivation after Skylab-3 and activation prior to Skylab-4 will be identical.

The habitation area configuration during periods of leakage control is the normal manned orbital configuration (i.e., OWS/AM hatch open, and pneumatic and solenoid vent port plugs installed). There was a proposal to leave the solenoid vent port unplugged. A change to the specification permitting habitation area pressures below 22 psia during launch and a common bulkhead ΔP larger than 7.5 psia were being considered. The closure of this problem will be identified in the phase III or final report.

All habitation area penetrations use current state-of-the-art techniques to prevent leakage. Induction brazed fluid and gas lines are used wherever possible. Conoseals are used on large static components and in many cases are backed up by use of a sealant. Standard O-rings and B-nuts are used in other areas. There appear to be no new materials nor state-of-the-art advancements in this system.

The pneumatic system provides the means for opening and closing the habitation area vent valves, opening the waste tank vents, and jettisoning the refrigeration system radiator protective shield. The system consists of a 4.5 cubic foot pneumatic supply sphere from the S-IV-B. It is pressurized to 450±60 psia with nitrogen.

There are four S-IV-B actuation control modules for redundancy. One actuation control module supplies pneumatics to open the vent valve. Another actuation control module also supplies pneumatics to open the vent valve and serves as a pneumatic system vent. The third actuation control module is used for the waste tank vent duct cap release. The fourth actuation control module is used for the refrigeration system radiator protective shield jettison.

The pneumatic sphere is pressurized prior to launch. Following completion of all pneumatic functions but prior to the end of IU lifetime, the pneumatic sphere will be vented or dumped to safe the system. Failure to safe, however, is not considered critical since the 450±60 psia operating pressure is well below the sphere safety limits.

The method of calculating the orbital leakage rates based on ground tests conducted near ambient pressure and using a variety of gases (nitrogen, helium, and so on) may prove to be a difficult correlation. The Panel feels this area, being basic to consumable flow, should be thoroughly understood.

There appear to be no time/life critical components in this system, and most potential leak paths are of a static nature.

Waste tank as affects pressure control system. - The waste tank receives liquids and gases dumped through probes and penetrations through the common bulkhead. The waste tank is first pressured to 22 psia, then to 26 psia during launch, and finally vented to space once in orbit.

A problem that is apparently still open deals with the AM condensate dump line which transfers excess water collected in the AM from the OWS atmosphere. The dump system is shown in figure 23. Freezing during dumping of the airlock condensate has occurred during tests. Tests were then conducted to understand cause and solution. The cause is lack of driving pressure during two-phase flow - approximately 50 percent gas - 50 percent H_2O by volume. The current solution is to provide a pressure of at least 3 psia at the dump valve. Many approaches are being evaluated in order to select the best system for minimum impact on hardware, qualification testing, and crew timelines.

Thermal control ventilation and odor removal. - The ventilation control system (VCS) consists of the air supply duct, air circulation ducts, fan clusters (one per duct, four fans per cluster), a mixing chamber, distribution plenum, floor diffusers, and portable fans. The VCS transports revitalized air which has been purified and dehumidified from the airlock module (AM). It mixes the air with the OWS atmosphere and circulates the mixture throughout the habitable area. Revitalized air is brought from the AM to the dome of the OWS via the AM/OWS interchange duct. This duct is attached to the mixing chamber (plenum) located in the forward compartment near the OWS dome. Three OWS ventilation ducts are routed from the mixing chamber to the plenum chamber, which is between the crew quarters and the waste tank. The air flow is produced by fan clusters mounted in each duct. The crew quarters floor is equipped with adjustable diffusers which allow the air to circulate through the crew quarters and back to the forward compartment. A portion of that air then goes to the AM for revitalization.

Each ventilation duct contains four Apollo postlanding ventilation (PLV) fans. They are mounted in a baffled cluster assembly. Portable fans are included in the OWS. They consist of three of the postlanding ventilation fans mounted in central fixtures which can be located anywhere on the OWS grid, on handrails or the fireman's pole, and can be connected to utility outlets for electrical power.

Odor removal in the OWS is provided by the waste management compartment (WMC) ventilation unit. This unit is mounted on the forward compartment floor. The assembly is composed of a fan, charcoal bed, filters, and sound suppressor assembly. The fan is an Apollo postlanding ventilation fan. It is replaceable. The charcoal cannister, which contains activated charcoal, is also replaceable.

Removal of particulate matter, hair, and lint from the OWS atmosphere is provided by the combination of a fine and coarse filter at the inlet to the assembly. The fine inlet screen is upstream of the coarse inlet screen. The upstream restraining screen for the activated charcoal is 60 mesh. The downstream restraining screen is a 10-micron filter. All of the atmosphere flowing through the waste management compartment is drawn in through the circular diffuser in the floor of the waste management compartment, passes through the fan/filter assembly, and is discharged into the forward compartment.

The thermal control subsystem design is based principally on passive thermal con-

OWS
WASTE TANK DUMP PROVISIONS

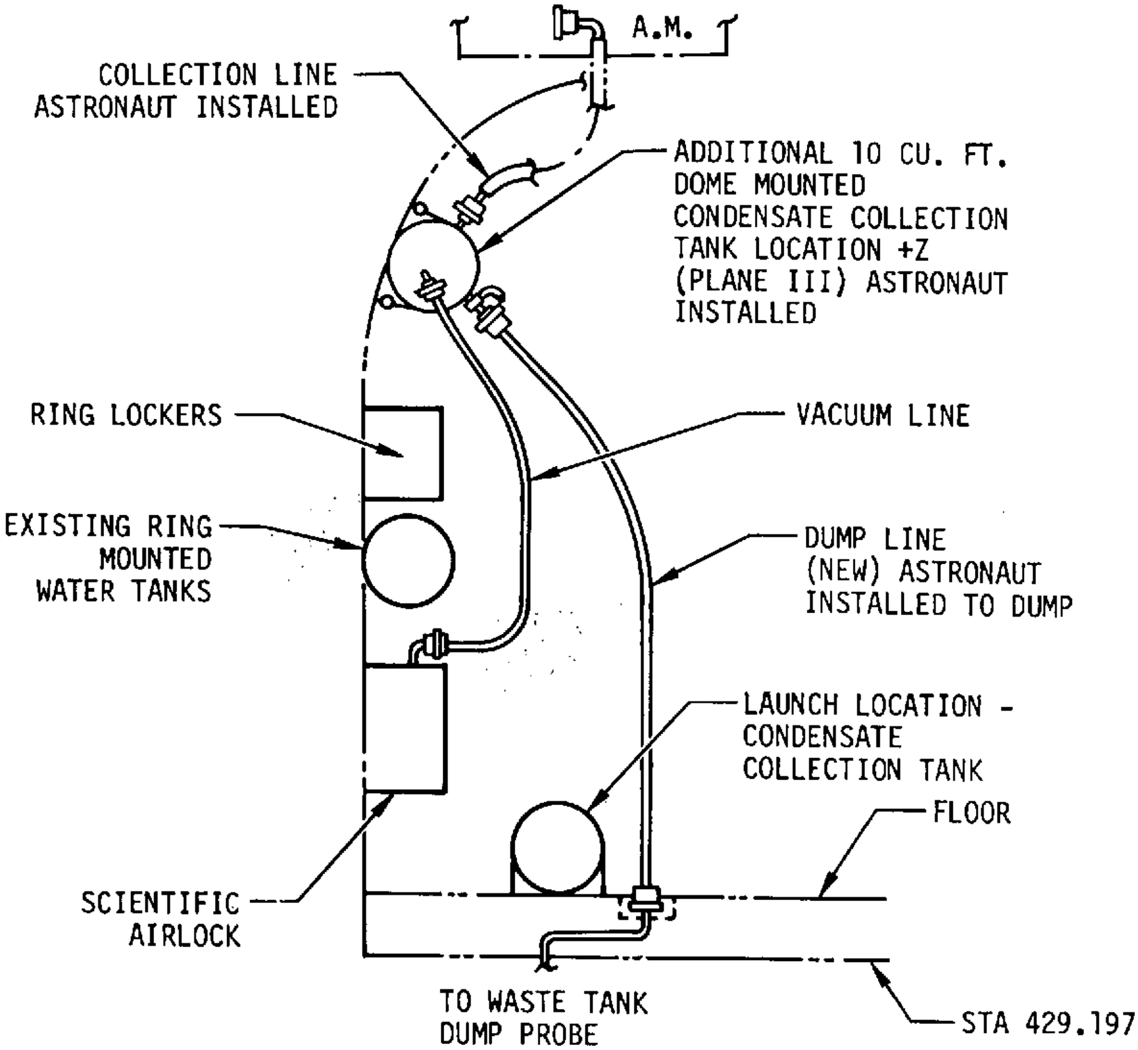


FIGURE 23

trol of the OWS environment. It is augmented by convective heating and cooling of the atmosphere during manned phases. Radiative heating of the internal structure due to the lack of atmosphere is the main thermal aspect to be controlled during unmanned phases. The thermal control subsystem is thus made up of two basic subsystems and a passive thermal control subsystem.

The active thermal control subsystem provides continuous control of the OWS internal environment during periods of astronaut habitation. The cabin gas temperature is controlled by cabin gas heat exchangers in the airlock module (AM) and by convective heaters in the three ventilation control system ducts. Reconstituted air from the airlock module is mixed and recirculated air in the OWS. Prior to habitation, radiant heaters maintain temperatures above the minimum levels that satisfy food and film storage requirements.

The passive thermal control subsystem consists of optical property control of the OWS interior and exterior surfaces. Also included in the passive system is the high performance insulation (HPI) blanket on the forward dome, polyurethane insulation lining the inside of the OWS pressure shell, and heat pipes attached to structural penetrations of the interior insulation. The exterior surface finishes and the high performance insulation blanket control the net energy balance between the OWS and the external space environment. The heat-transfer rates from the habitation area to the meteoroid shield and from the forward and aft dome areas are regulated by surface finish control. The interior habitation area wall temperatures are made more uniform through optical property control of these surfaces and use of heat pipes.

A functional checkout test was performed on the OWS, thermal control subsystem, and the ventilation control system, including spares. This served to (1) verify functional performance of the thermal control subsystem duct and radiant heaters, thermal control subsystem thermal control assembly, ventilation control system duct and portable fans, and the fan filter assembly, (2) verify fit of the spare charcoal cannisters, inlet filters, and heaters and fans, (3) demonstrate adjustment capability of the ventilation control system diffusers and dampers, and (4) verify manual and automatic control of the thermal control system. The test was initiated on April 21, 1972, and the final test was completed on June 20, 1972. There were three significant hardware problems encountered during the test. A duct flowmeter reading was out-of-tolerance on the low side. This 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. This required rework of the damper to provide more clearance from the diffuser sidewall. A heat exchanger relay drive module failed to turn on the heat exchanger indicator light. A redesign of the module was required. All retest of the modified hardware has been completed.

Problems under consideration at the time of the Panel's review are included here. The closure of these problems will be identified in the phase III or final report:

1. Flowmeters are currently undergoing life tests for 5700 hours with an estimated completion date of February 17, 1973.

2. The relationship of inoperative vent fans versus the possibility of a CO_2 problem, particularly in and around the sleep compartments, is being investigated.

3. It is understood that during SMEAT unexpected odors surfaced, and the source of the odor was identified as insulation material.

4. SOCAR indicated an area where further data might be needed. Data may be required to substantiate that cabinets, lockers, and vaults had adequate vent area/ structural strength to preclude inadvertent opening.

Thermal control system. - Heat pipes are defined as a closed structure containing a working fluid which transfers energy by means of liquid vaporization at a high temperature source, vapor transport driven from high to low temperature, and vapor condensation at a low temperature source with a subsequent return of the condensate by capillary action to the evaporator point. Heat pipes represent first-time applications (Freon 22 as working fluid, out-of-plane bends) of a technology that has flown before in different configurations. The Panel does not have information on prior use. Since the performance of the thermal control system as a complete system is based solely on analysis and heat pipes do not normally operate in a one-G environment, the temperature monitoring of these pipes may be worthwhile during orbit.

Internal water condensation at any time during mission is of concern. If there are operating conditions that can cause this condition they should be fully investigated.

Refrigeration system. - The refrigeration system is a low-temperature thermal control system that uses Coolanol-15 in a closed-loop circuit dissipating heat through a ground heat exchanger cooled by GSE during prelaunch operations and through an external radiator in orbit. This system has dual coolant loops and redundant components where necessary.

The refrigeration subsystem 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 (see table X).

The refrigeration subsystem has successfully completed checkout and all systems test (AST). All elements of this subsystem have been verified for thermal and functional performance in both manual and automatic logic controlled modes of operation. The subsystem has been proven leaktight. Checkout for the refrigeration subsystem consisted of the following tests:

Refrigeration system electrical preparations
Refrigeration subsystem service
Refrigeration system activation, operating, and securing
Refrigeration subsystem
Refrigeration subsystem service flight

The refrigeration system qualification test has been underway in the McDonnell Douglas Space Simulation Laboratory since August 4, 1972. The system has performed within specification under all orbital conditions imposed to date. This includes the hot orbital mode and the coldest orbit, a 3σ case at the highest specified Beta angle of 73.5°. Full radiator operation under orbital conditions has been achieved. No subsystem problems are anticipated in the balance of this test since the performance in worst-case conditions has already been verified.

Nonetheless, the following components are still under test or tests have recently been completed. Therefore, the Panel was not familiar with all results as of this writing.

Pump assembly (1B79778) life test

Radiator bypass valve (1B79878) qualification test

Pressure relief valve (1B89613) qualification test

Full and drain valve assembly (1B93271) qualification test

Redesigned thermal capacitor (61A830371) qualification test

Redesigned thermal control assembly with cold plate (1B92904) qualification test

Redesigned thermal control assembly with housing radiator control valve qualification test

The major problems encountered during production acceptance testing and qualification testing have been corrected. There are now described:

1. Thermal capacitor leak. The original thermal capacitor failed during thermal cycling in January 1972. This was a result of expanding undercane (wax) being unable to force a flow path to ullage when the unit was tilted. A redesign was undertaken at McDonnell Douglas-East which resulted in a successful honeycomb configuration which places distributed ullage in each individual cell. The new capacitor assembly is installed on the spacecraft.

2. Radiator control valve. A mixing valve formerly used to regulate Coolanol temperature to the OWS showed a tendency to oscillate at high temperature and pressure differentials. Bellows leakage of the temperature control element was also a major problem during its development. Concern over these problems resulted in the adoption of an alternate method of temperature regulation by either diverting flow through the radiator or bypassing it. The mode was based on the temperature range sensed coming out of the first segment of the thermal capacitor. This "bang-bang" temperature control was proven successful in the test facility and in checkout and was adopted as the baseline configuration, thus eliminating the radiator control valve.

The major problems encountered during checkout operations have been corrected. They are as follows:

1. Pump start anomaly - A pump start anomaly was encountered during checkout loop switching verification in the refrigeration subsystem checkout. The primary pump did not start when commanded. This occurred one time out of a maximum of 147 pump starts accomplished during checkout. Questionable start torque margin was found during

off module investigation. This problem has been attributed to the current limiter in the inverter. The inverter will be redesigned to provide a 100 percent margin.

2. Food freezer frost buildup - During factory and AST operations, frost was observed in several spots on the food freezer exterior. The occurrence of frost has since occurred in testing. The problem will not present a problem in flight.

Ground conditioning and purge. - The ground thermal conditioning and OWS interior test performed a functional checkout of the GTCS to (1) verify the hermetic integrity of the plumbing and components, (2) validate the operation of the onboard heat exchangers and fans, and (3) confirm restart and purge capability of the ground environmental control system. The test was initiated on March 3, 1972, and it was completed on March 28, 1972. No major vehicle hardware problems were encountered and no retest was required.

The ECS portion of the AST verified proper operation of the GTCS fans and heat exchanger, the thermal control system control logic, and ventilation control system fans. The ECS equipment was functioned as required by the simulated mission timeline. The only significant AST ECS problem was in the GTCS. The pressure switch on one of the fan-heat exchanger assemblies 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 ΔP sensed by the pressure switch by adding velocity pressure to the high pressure side of the switch. The new design was tested successfully. There are no open problems or items against the ECS resulting from the AST.

The ground support equipment required by the ECS includes the OWS interior ground thermal conditioning system kit and the environmental control distribution system. The OWS kit is the ground ventilation air distribution duct that is installed in the OWS during VAB operations. The installation and flow balance test is complete and there were apparently no problems encountered.

The environmental control distribution system is the ground thermal conditioning unit that supplies the coolant to the onboard head exchanger and controls the fan heat exchanger unit. The unit functioned properly and all fit checks were accomplished without encountering any problems. A modification is planned to add switch guards to the fan control switches on the manual control console (MCC) panel.

The ground support equipment required by the refrigeration subsystem are the ground thermoconditioning system, the refrigeration system service unit, vacuum pumping unit, mechanical test accessory unit, and the refrigeration test set. All units were verified with the exception of an out-of-tolerance flowmeter frequency controller module on the ground thermoconditioning system. The frequency controller is to be replaced as soon as procurement of a replacement module can be obtained through the supplier, North American Rockwell. Exchange is planned after delivery to KSC.

Thruster Attitude Control System (TACS)

The Panel reviewed this area to a lesser degree than those systems which directly interfaced with the crew. Consequently, our remarks here are limited to the qualification test area and SFP's which could compromise crew safety. The TACS high pressure storage spheres and adjunct lines were discussed in the structures portion of this section.

The qualification line item tests for the subsystem have been completed except for the following:

1. TACS valve panel tests have been completed with the exception of thermal vacuum testing. The TACS valve modules have demonstrated satisfactory performance during qualification testing. The number of cycles completed is in excess of 32,000.

2. A bonded metal sheath has been applied externally to the temperature transducer body in order to have a redundant leak seal to the miter weld. Development testing of the new configuration, with a known weld leak, to 8000 psig has been successfully completed. Proof and leak test of the flight hardware on OWS-1 was satisfactorily accomplished at Seal Beach.

3. The pressure switches were redesigned to eliminate a potential diaphragm leakage problem. All vehicle switches have been replaced. Development testing including cycle and burst testing have been completed. The flight hardware was successfully proof, leak, and functionally tested at Seal Beach.

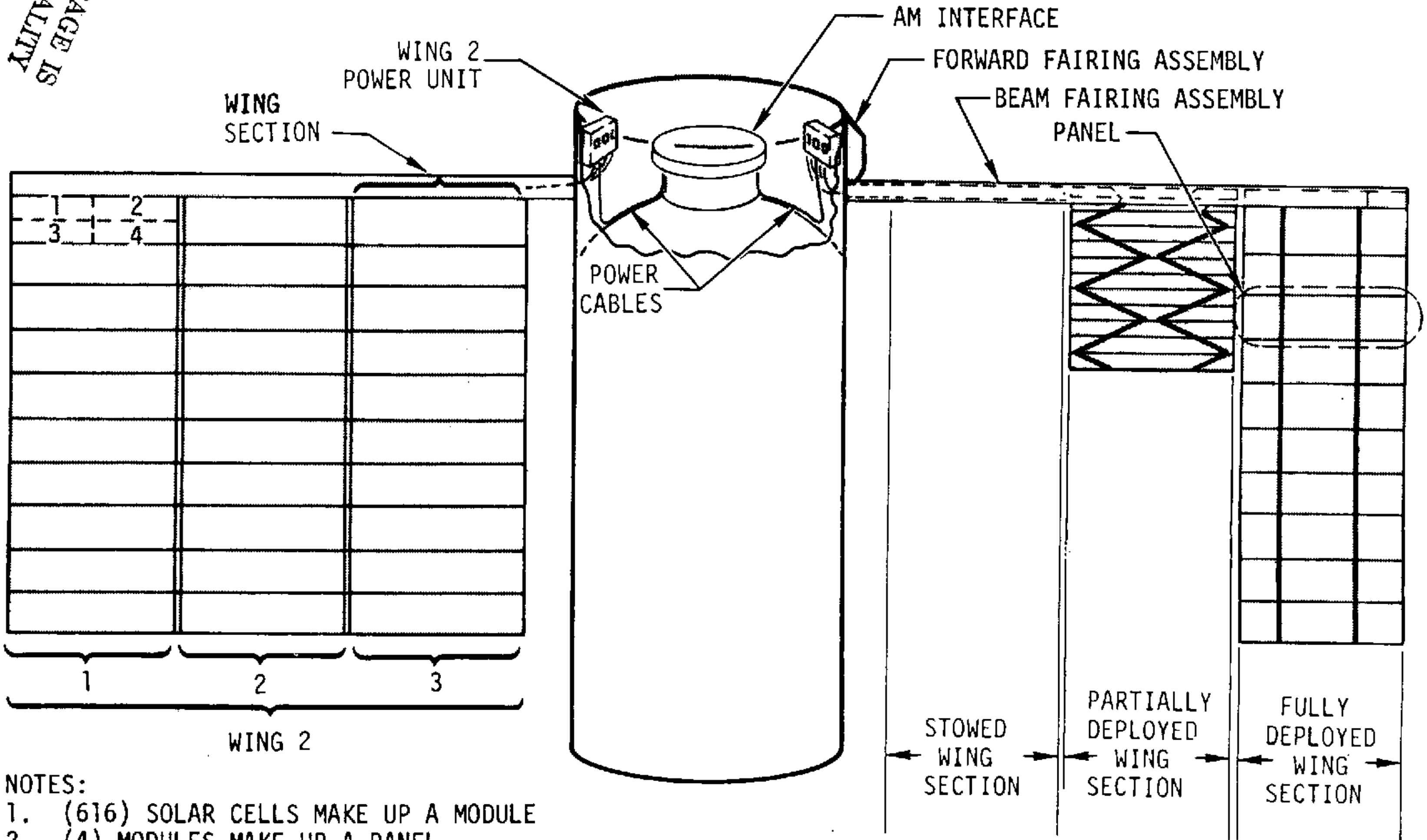
Solar Array Subsystem (SAS) (fig. 24)

The solar array subsystem (SAS) consists of two wing assemblies. The major components include the forward fairings, beam/fairing, deployment mechanisms, power units electrical harnesses and instrumentation, and three wing section assemblies per wing. The wing sections are composed of 10 panels with solar cells. There is a total of 147,840 cells for the OWS supplying an average of 10,496 watts during sunlight portions of orbit. The SAS is manufactured and tested by TRW, Inc.

The SAS has been 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 testing was accomplished on a wing assembly complete except for the thermal baffle and environment seals; the two forward bays had dummy masses simulating the wing sections. System testing included dynamics, deployments, and structural testing under induced worst case environments. All tests appear to have been completed satisfactorily.

OWS
SOLAR ARRAY SYSTEM



NOTES:

1. (616) SOLAR CELLS MAKE UP A MODULE
2. (4) MODULES MAKE UP A PANEL
3. (10) PANELS MAKE UP A WING SECTION
4. (3) WING SECTIONS PLUS BEAM FAIRI'G MAKE UP A WING

FIGURE 24

From a structural standpoint a number of items are of interest. Design modification of the actuator/dampers was required in the spring of 1972. The time required in the specification for full deployment changed. It originally was to be deployed in 6 to 9 minutes at 20 minutes after liftoff. This was changed to 10 to 14 minutes at 105 minutes after liftoff.

The beam fairing release and deployment system and the wing section release and deployment system are considered mission critical functions. These have received concentrated attention, both analytically and empirically. No major or unresolved problems are currently known.

From the point of electrical power generation there have been some problems. The following have all been resolved or the condition found to be acceptable:

1. Qualification solar array panel exhibited open circuits in solder joints between cell "prayer" tabs. Such open circuits could result in significant reductions in module power output. This problem was resolved by improved soldering methods, tab-to-tab joints inspected by mechanically "tweaking" them, and replaced long turn-around ribbon with ribbons having stress relief loop.

2. Actuator/damper storage test to be conducted at McDonnell Douglas-West. The actuator/damper is at KSC and will be returned to McDonnell Douglas in January 1973 for inspection.

Electrical Power Subsystem (EPS) (fig. 25)

The OWS is considered a load for power supplied from the AM. Such power is distributed by the OWS power distribution system. The primary function of the power distribution system is to provide circuit protection and switching capability for the various loads within the workshop. Circuit protection is provided by circuit breakers and fuses. Their primary purpose is to protect wiring from exceeding the maximum temperature limits specified to prevent fires and excessive outgassing within the OWS. Circuits are designed to provide the necessary redundancy and to limit the voltage drop within the system to prescribed levels. This is necessary to prevent the OWS loads from receiving voltages below their minimum operating voltage levels.

The distribution system provides power to operate internal OWS subsystems such as

Thermal control system
Internal lighting system
Experiment support system
Habitability support system
Communication system
Caution and warning system
Urine dump heater system
Refrigeration system

OWS
ELECTRICAL POWER DISTRIBUTION SYSTEM

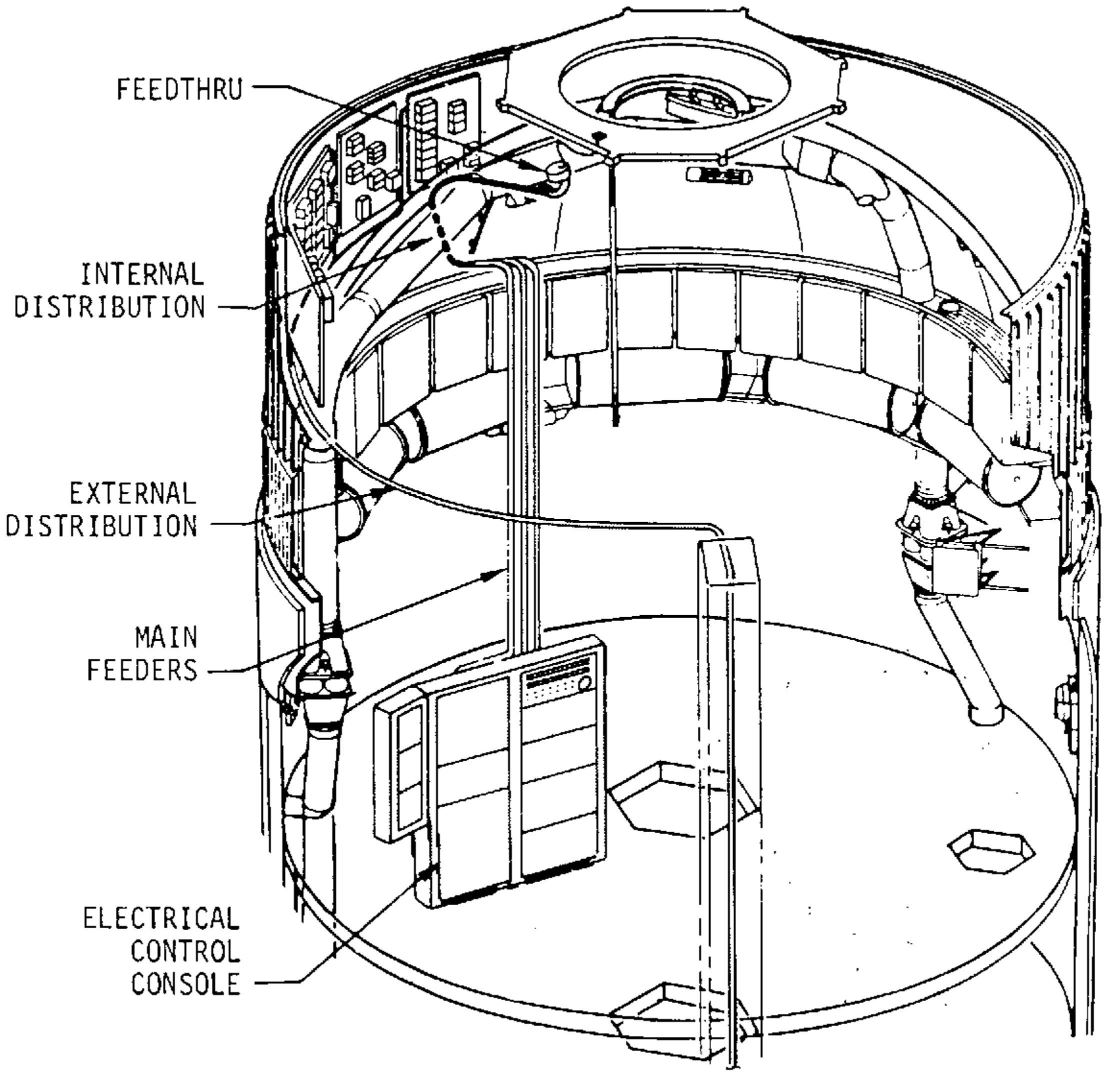


FIGURE 25

Viewing window heater system

Utility outlets

Essentially all wiring is installed external to the pressurized compartment for the following equipment and systems:

Instrumentation system

SAS

TACS

Meteoroid shield system

Switch selector

Airlock module umbilical requirements support system

The OWS receives 28 + 2, -2.5 volts dc from the AM at the OWS/AM interface.

All development and qualification testing has been completed. This includes such tests as the following:

Continuity/compatibility

Umbilical/AM interface checks

Power setup, I/C scan, power turnoff

Power distribution acceptance test

Electrical bus isolation

Crew compartment fit and function

All systems test - preparations and securing

EMC - Preparations and securing

All systems test - prelaunch, boost, and preactivation

All systems test - activation, orbital operations, and deactivation

Areas that require particular management viability and control include the following:

1. Individual wire identification was deleted to save cost and buildup time. There is the possibility that testing and work done at KSC may be hampered to some degree by this lack of identification.

2. Circuit breakers have been a source of failure during qualification tests. There are some 215 such units on OWS and malfunctions could cause spacecraft damage if another failure (circuit overload) occurred in the circuit.

3. The Panel understands that there are some exceptions to the protection of wires in the pressurized or inhabited section of OWS. These appear to be at the number 1 and 2 buses where wires are electrically unprotected between the circuit breakers and the bus. The length of wire is apparently very short and internal to the OWS panel.

4. The Panel noted there was a possible conflict between OWS specification and cluster specification over voltage requirements.

5. The wire harness running from the IU to the OWS and S-II stage interface are considered single failure points. The harness from the IU to lower stage may affect S-II performance if open or shorted. The harness from the IU to the OWS may affect

venting of waste tank if open or shorted. These have been identified as "critical hardware for Skylab" to ensure careful handling and will receive checks at KSC for integrity.

At the time of turnover there was no open work pending on this subsystem. Thus, a complete, functional subsystem was to be shipped to KSC. The subsystem hardware (i.e., wiring, circuit breakers, switches, etc.) presently installed in the OWS is flight-qualified equipment. All interim use material was removed and replaced with flight equipment prior to beginning the AST. In addition, all subsystem hardware changes authorized during factory checkout (e.g., replacement of switches, circuit breakers, and meters due to low insulation resistance; replacement and/or thermal cycle of modules due to encapsulation separations) have been completed.

The OWS data acquisition system provides both real-time and delayed-time monitoring of OWS subsystem flight parameters. This includes biomedical and scientific experiment data sent 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 was removed and replaced with flight hardware prior to the AST. Subsystem hardware presently installed in the spacecraft is flight-qualified equipment.

All qualification testing has been completed except for the following test line items:

1. Absolute pressure transducer life test. Anticipated completion date is November 1972.

2. Flowmeter transducer life test. Anticipated completion date is April 1973.

The following checkout procedures have been performed to establish the integrity of this subsystem:

Signal conditioning setup

Power setup, IC scan, power turnoff

DAS calibration, OWS

DAS, acceptance test procedures

All systems test - preparations and securing

All systems test - activation, orbital operations, and deactivation

All systems test - prelaunch, boost, and preactivation

EMC setup and system reverification

Crew compartment fit and function check

The only open work transferred to KSC relates to a number of measurements that could not be functionally verified end-to-end at Huntington Beach because they were either not installed (i.e., SAS, meteoroid shield, etc.) or the subsystem/parameters were not exercised functionally (i.e., water system, digital clock, etc.).

Communication and Television Subsystems (fig. 26)

The OWS communication system is designed as a functional part of the orbital assembly (OA) audio system for the Skylab program and provides

1. Direct voice line between the OWS and STDN via the command module (CM) S-band
2. Biomedical data to STDN through the AM PCM telemetry system
3. Intercommunication line between astronauts
4. Audio and visual displays of warning tones generated by the caution and warning system
5. Control for the operation of the voice and data recording system in the airlock module

Subsystem hardware presently installed in the spacecraft is flight-qualified equipment. There were no test plan line items prepared by McDonnell Douglas-West for development testing of components used in this subsystem.

The speaker intercom assembly is provided as government furnished property (GFP), and it is qualified by McDonnell Douglas-East.

There were no major problems encountered during checkout of this subsystem and there is no open work being transferred to KSC.

The OWS television subsystem is an extension of the orbital assembly television system and provides video coverage of crew activities, equipment operation, and experiments. Transmission to STDN is made through the command service module unified S-band. The subsystem hardware presently in the spacecraft is flight-qualified equipment. The updated configuration is to be installed, but not tested, at Huntington Beach. There were no requirements for development testing of television subsystem components. The television input station is provided as government furnished property and is qualified by Martin-Marietta Company, Denver. There were no major problems indicated. The only noted open work transferred to KSC relates to the testing required as a result of replacing the television input station with the latest configuration after AST. The KSC test requirements have been defined in the KSC test and checkout requirements, specification, and criteria document.

The instrumentation subsystem, while integral to this system, has been discussed elsewhere in the report.

The SOCAR team in reviewing test results indicated a desire for improvement of the general audio quality of the audio subsystem. This involved modifying lightweight headset to provide greater signal level and high output impedance. We understand this improvement has not been completed.

OWS
COMMUNICATION SYSTEM

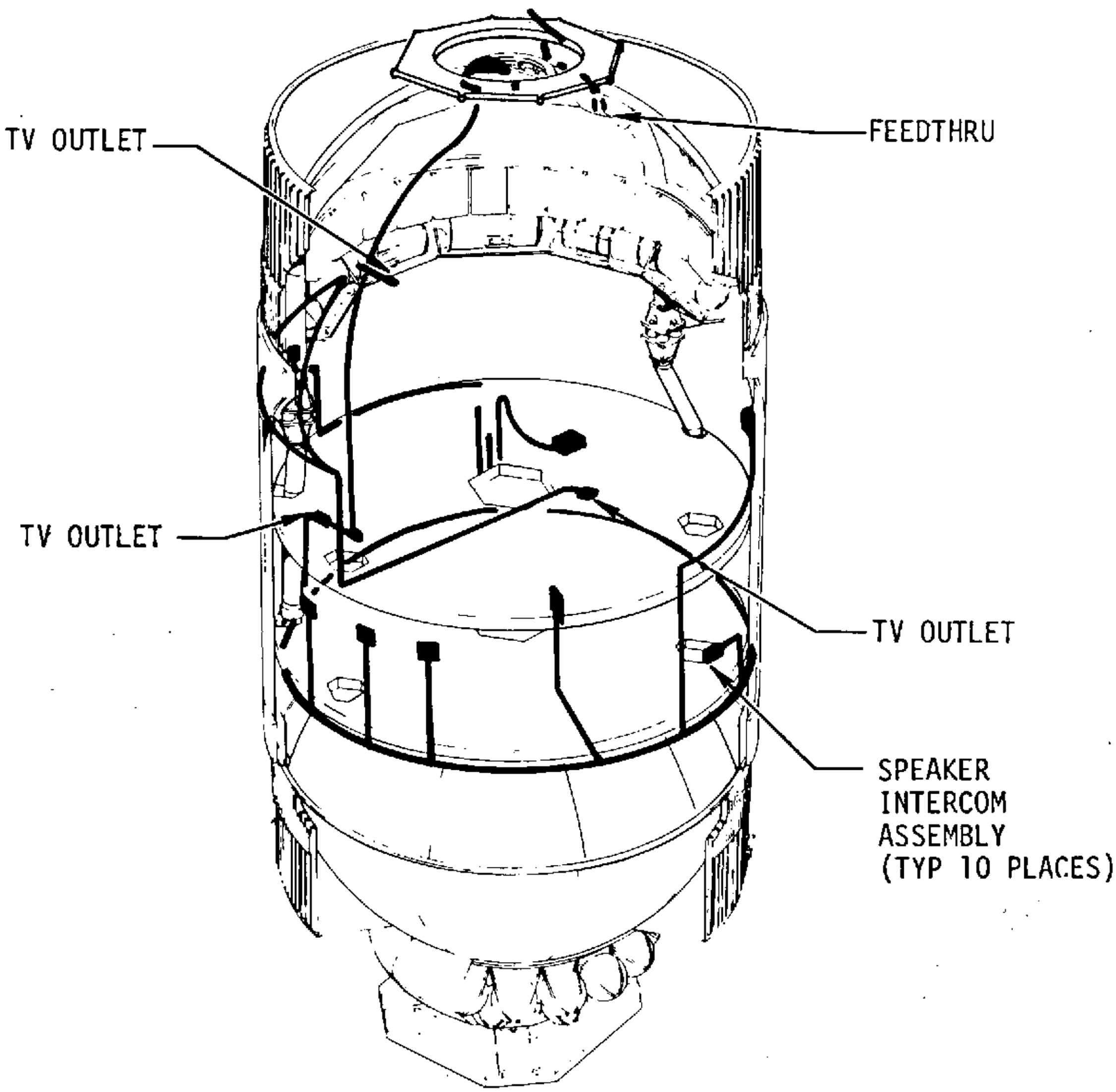


FIGURE 26

Caution and Warning Subsystem

The OWS caution and warning (C&W) system is a part of the cluster C&W system. It is completely redundant and not affected by a single failure point. The OWS portion of C&W inputs signals to and receives command signals from the AM C&W logic unit.

It consists of completely redundant monitor and repeater circuits to identify caution, warning, and emergency parameters. The parameters monitored throughout the cluster are annunciated by audio/visual alarms and indicators as required. The parameters monitored by the C&W are categorized as either emergency, warning, or caution. The criticality and crew response used to determine the category of a parameter is defined as follows:

Emergency. Any condition which can result in crew injury or threat to life and requires immediate corrective action, including predetermined crew response.

Warning. Any existing or impending condition or malfunction of a cluster system that would adversely affect crew safety or compromise primary mission objectives. This requires immediate crew response.

Caution. Any out-of-limit condition or malfunction of a cluster system that affects primary mission objectives or could result in loss of cluster system if not responded to in time. This requires crew action, although not immediately.

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.

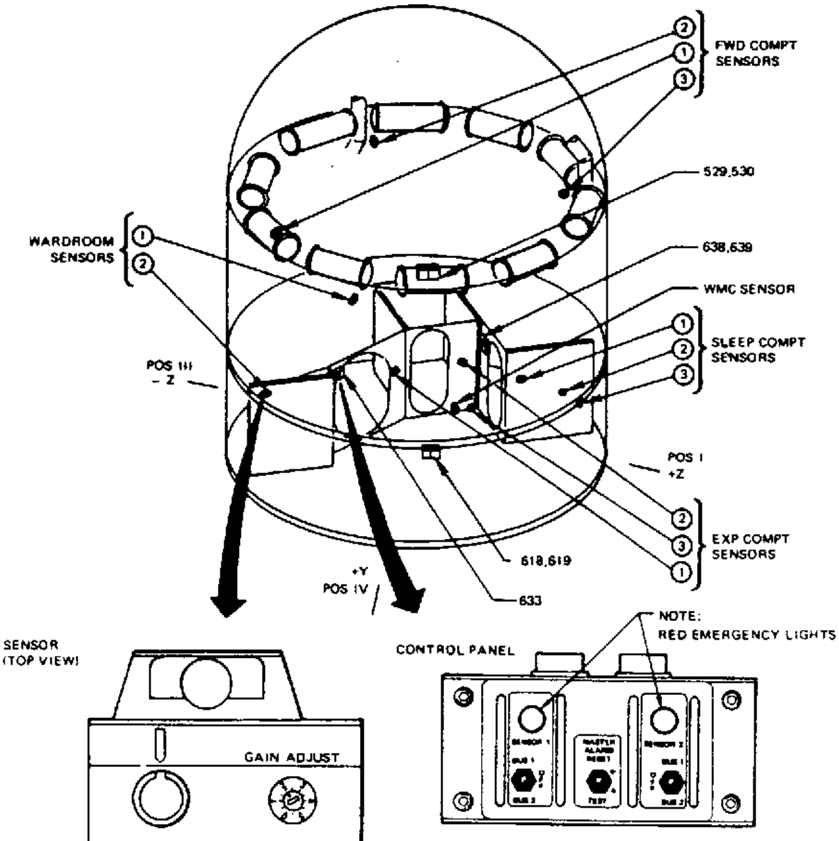
Specifically, the system is to provide warnings with respect to fire (table XI), rapid decompression, low pressure conditions, and OWS bus voltage changes. The fire sensors cover about 85 percent of the OWS volume and about 92 percent of the outer walk between aft floor and water bottle ring on top of the forward compartment. There are 12 ultraviolet sensors in the OWS, located as follows (fig. 27):

OWS forward (top compartment)		3
OWS crew quarters:		6
Wardroom	2	
Waste management compartment	1	
Sleep compartment	3	
OWS experiments		3
Total		12

The design of the OWS C&W system appears to be based on proven design practices which should preclude human errors.

The rapid ΔP alarm system is designed to alert the Skylab crew and the flight controllers to a decrease in cluster pressure at a rate equal to, or greater than, 0.1 psi per minute.

SKYLAB - ORBITAL WORKSHOP FIRE DETECTION SYSTEM AND PANELS 529, 530, 618, 619, 633, 638 & 639



PANEL	FIRE DETECTION SENSORS
529 (LEFT)	FWD COMPT 1, 2
530 (RIGHT)	FWD COMPT 3
618 (LEFT)	EXP COMPT 2, 3
619 (RIGHT)	EXP COMPT 1
633	WARDROOM 1, 2
638 (LEFT)	WMC AND SLEEP COMPT 1
639 (RIGHT)	SLEEP COMPT 2, 3

FIGURE 27

The first question that would naturally be raised is the possibility of an inadvertant fire alarm due to ultraviolet light from a nonflame source (e.g., through a window). Two methods were applied here to prevent that. The windows were coated to delete ultraviolet from solar radiation, and a time delay was added to avoid false triggering. A system constraint was added for the three fire sensors in the OWS forward compartment which must be powered down during operation of experiment SO63, ultraviolet airflow horizon photography. Tests were performed in the McDonnell Douglas-West hi-fidelity mockup to simulate energy conditions. These tests showed that such a modification was necessary to preclude false alarms. The rationale which permits this includes the fact that crew members are in the immediate vicinity of these powered-down sensors.

The fire sensors and fire sensor control panel are provided as GFP and are qualified by McDonnell Douglas-East. The solar flare alert is provided as GFP. These checkout procedures have been performed to establish the integrity of the subsystem:

Caution and warning subsystem test

EMC setup and systems reverification

All systems test - preparations and securing

All systems test - Activation, orbital operations, and deactivation

Ordnance Subsystem

The ordnance subsystem for the following systems are of diverse configurations:

Meteoroid shield release (figs. 28 and 29)

Solar array beam/fairing release

Solar array wing section release

S-II retrorocket ignition

S-II/OWS separation

The Panel understands that underlying this diversity were common design guidelines and criteria. These were greatly influenced by the operational success of the McDonnell Douglas-West launch vehicle stage hardware. Some typical examples of these concepts are given. All ordnance systems should use (1) a high-energy exploding bridge wire-type initiation for crew and pad safety, (2) common ordnance components, (3) minimum quantities, and (4) redundant ordnance trains.

Because the installation of all ordnance components has been planned for KSC, checkout and AST activity at Huntington Beach was limited to verification of electrical circuitry on the OWS. Checkout for the ordnance subsystem consisted of the following two tests:

EBW subsystem, meteoroid shield, and solar array

All systems test (AST)

OWS
METEOROID SHIELD

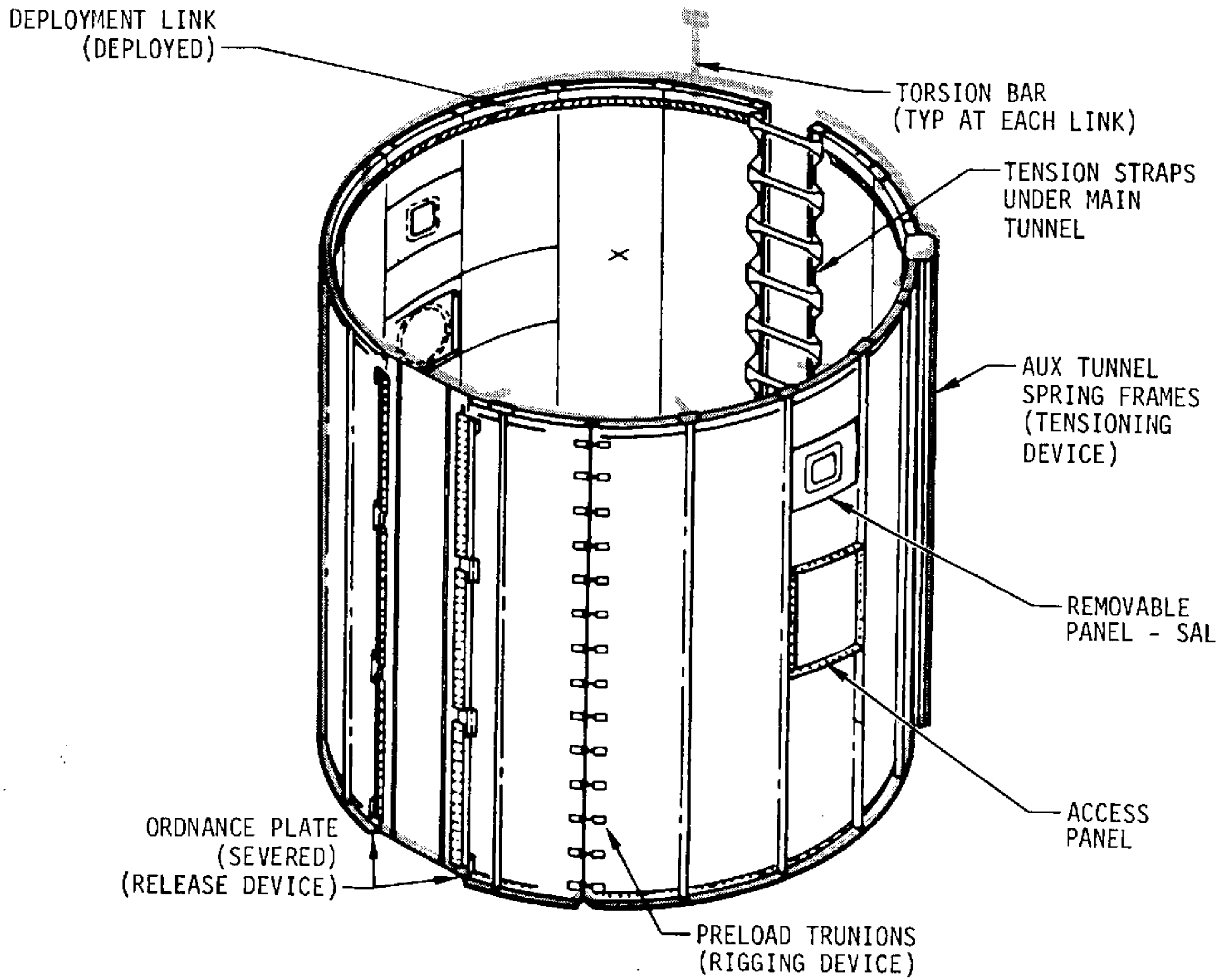


FIGURE 28

OWS
METEOROID SHIELD RELEASE ORDNANCE

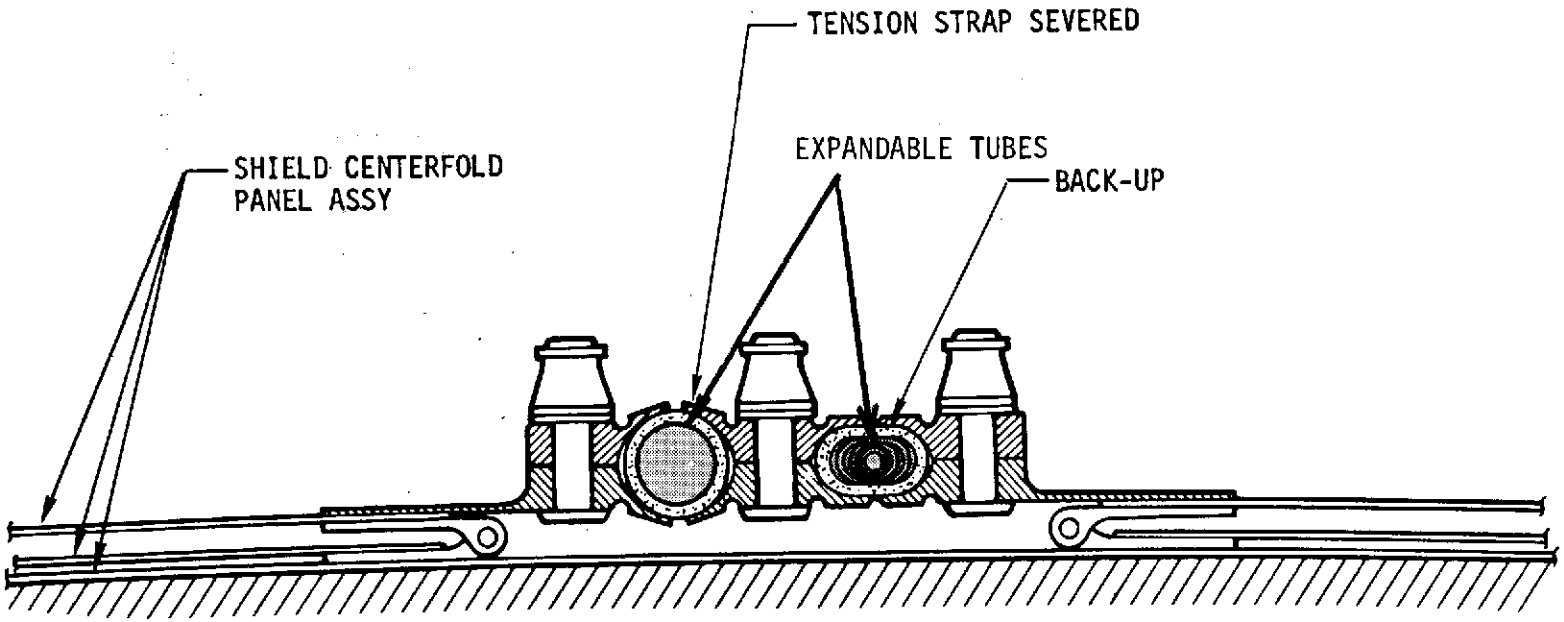


FIGURE 29

Problems encountered during this checkout were resolved, and there are no unresolved problems. Currently all ordnance qualification tests appear to have been completed satisfactorily. Major areas of qualification were the following:

1. Full-scale meteoroid shield deployment. This was accomplished at MSFC on the static test article. The meteoroid shield release system had been redesigned after a factory deployment test in May 1971. An expandable tube ruptured and released gas and debris. Reported testing has verified the performance of the redesign.

2. Solar array system. These factory deployment tests qualified both the solar array beam-fairing release and wing section release systems. All individual deployments were successful. The only ordnance system anomaly was the breaking off of small metal tabs along the fracture line of the tension straps during firing. This problem has been completely solved with a dual tapewrap that has 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.

Habitability Support Subsystem (HSS)

Habitability support encompasses a number of vital crew related systems because they sustain the crew on a day-to-day basis and are susceptible to the most subjective study and comment; the Panel examined this area in some detail. During the actual mission the public would probably relate most to an area in which they themselves are daily confronted. For our purposes the HSS consists of the following:

1. Waste management system. This provides for the collection, processing, storage, and/or disposal of the feces, urine, and vomitus as well as debris, particulate mater, and free water from the atmosphere. It also provides support for experiments MO71 (mineral balance) and MO73 (bio-assay of body fluids). At the end of each orbiting stay period this system provides for transferring of processed and identified samples to the CM for Earth return.

2. Water subsystem. This provides for storage, pressurization, distribution, purification, thermal control and conditioning, and dispensing of water. Water is provided for such items as food reconstitution, drinking, crew hygiene, housekeeping, urine separator flushing, life support unit used in EVA, ATM C&D Panel, EREP cooling loop, M-512 facility experiment, and the shower.

4. Food management subsystem. This provides specially selected foods, mineral supplements, fecal marker capsules, wardroom food preparation table, and galley.

5. Illumination subsystem. This provides interior lighting for normal and emergency crew activities, and experimental operations in the forward and crew quarter compartments. The fluorescent floodlight assembly is flight replaceable.

The habitation subsystems, of course, interface with other systems within the OWS. In this section the Panel limits itself to equipment not covered in other areas and which are primarily considered an integral part of HSS.

Waste Management

As is true of most all systems on board Skylab, the hardware capability must endure nominally for one 28-day and two 56-day manned mission periods during an 8-month time span. The waste management system components and general location are shown in figure 30 and 31.

The waste processor consists of six identical processing units capable of individual operation. They vacuum dry and thereby preserve fecal and vomitus collections for medical analysis.

The processor demonstrated its capability based on a series of detailed development and qualification tests. The significant problems have either been resolved or accepted based on their low order of impact on safety and/or mission success.

1. A processor chamber heater plate temperature was found to be out-of-tolerance. A waiver was submitted to the test and checkout requirements, specifications, and criteria (TCRSC). The specification requirement is 105° F maximum to conform to touch temperature requirements, since this heater plate exceeded the requirement by 5° F. This condition was considered minor and the hardware change has been made.

2. The processor indicator lights also exceeded touch temperatures by some 15° F. Since the lights are recessed in a protective cover to prevent access, a waiver was requested.

3. The processor drawer timer tended to "skip" in 1/2-hour increments during qualification tests. Voltage surges from the test setup apparently damaged the timer units. Timers were reworked and successfully retested.

The fecal/urine collection units are considered open items. Prior to the SMEAT, component qualification tests were still to be completed on the urine separator, fecal/urine collection module, urine volume determinator, chiller compartment, and urine bladder. These were essentially system performance and life cycle tests. They involved such factors as size and residual in separator.

There was a problem in achieving the accuracy required of the urine measurement device. Test results indicated that the original method of vertically calibrating the pressure plates resulted in error greater than ±2 percent allowed by specification. Horizontal calibration results indicate significant improvements. Spacecraft pressure plates will be removed and horizontally calibrated before flight.

WASTE MANAGEMENT SUBSYSTEM

THE WASTE MANAGEMENT SUBSYSTEM PROVIDES THE HARDWARE ITEMS NECESSARY FOR SAFE, EFFECTIVE, AND HYGIENIC COLLECTION, PROCESSING, RETURN, AND/OR DISPOSAL OF WASTE PRODUCTS (FECES, URINE, VOMIT, AND DEBRIS) FOR THREE CREWMEN.

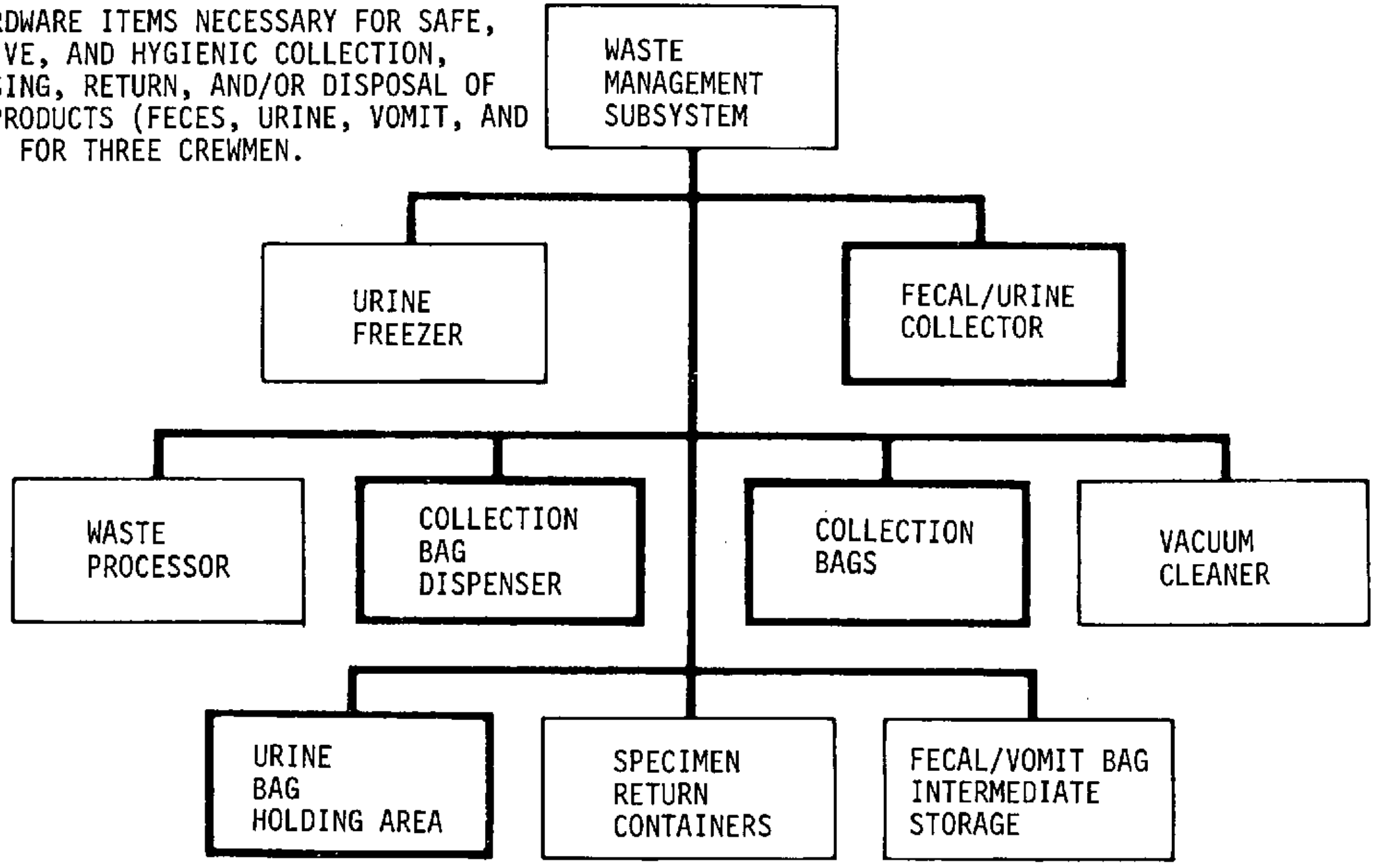


FIGURE 30

OWS
WASTE MANAGEMENT SUBSYSTEM

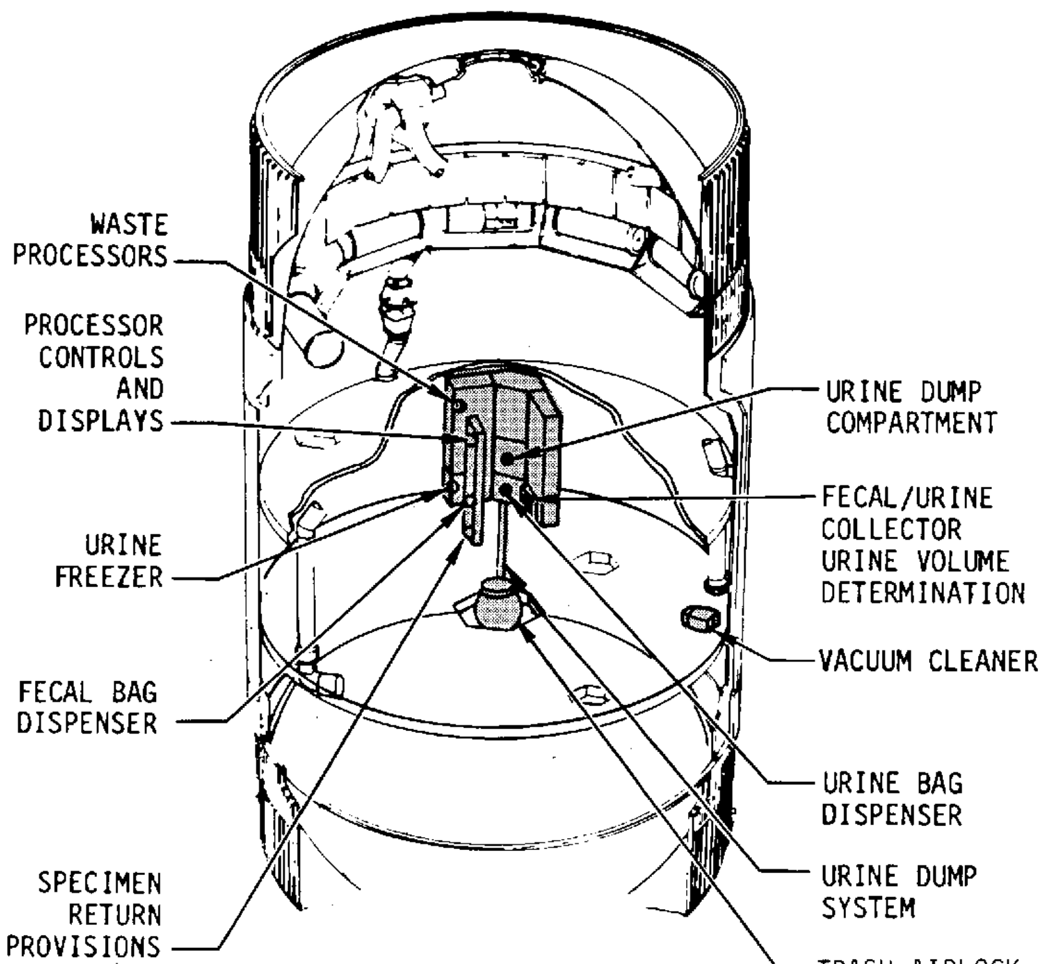


FIGURE 31

ORIGINAL PAGE IS
OF POOR QUALITY

One significant problem in checkout was the stickly operation of the urine pressure plate. The pressure plate was redesigned by replacing the clock spring with a tension spring and the redesigned unit was reinstalled and verified in the spacecraft.

Minor items open at time of PDTR were the following:

1. Fecal and contingency bags tare weight. The bag tare weight was found to be discrepant during pre-SMEAT test operations. Three discrepancies and their solutions are as follows:

(a) Weighing equipment was inadequate at Fairchild/Dielectric. The bags will be reweighed.

(b) Testing indicated that moisture content of bags due to humidity was a small influence but must be accounted for. Reweighing fecal and contingency bag will be accomplished in a controlled environment.

(c) Green peel tape weight was not adequately accounted for. Statistical weighing of green peel tape is expected to prove tape weight dispersion is within tolerance.

2. The SMEAT test crew exceeded 2000-milliliter capacity of the urine system. The system is therefore being modified to increase the capability of the urine system to 4000-milliliter capability. Hardware and development testing is to be completed in January 1973. Qualification testing is to be completed in March 1973.

An objectionable odor in the fecal collector cabinet was noted during delta C^2F^2. The odor appears to emanate from the collector acoustic insulation. The insulation, which is not mandatory, will be removed from the cabinet.

The trash disposal system shown in figure 32 deals with collection, disposition, and storage of cluster wet and dry waste. Two areas are discussed here since they constitute either open work or a problem to be resolved. The trash disposal system uses 420 trash bags for collection, 349 disposal bags for trash airlock disposition into a 2195 number 3 waste tank, 28 bags for cardboard packing used during launch, and the remainder 46 bags for contingency. With respect to the collection bags the open item is a shelf-life test with an estimated completion date of November 30, 1972.

The nonflammable cardboard is used extensively in OWS lockers to alleviate vibration impacts. Two problems have arisen here: (1) the cardboard sheds particles, and (2) it must be removed from the lockers and stored. The closure of these problems will be identified in the phase III or final report.

Other waste management areas, such as the vacuum cleaner, are covered within the discussion on SMEAT.

OWS
TRASH DISPOSAL SUBSYSTEM

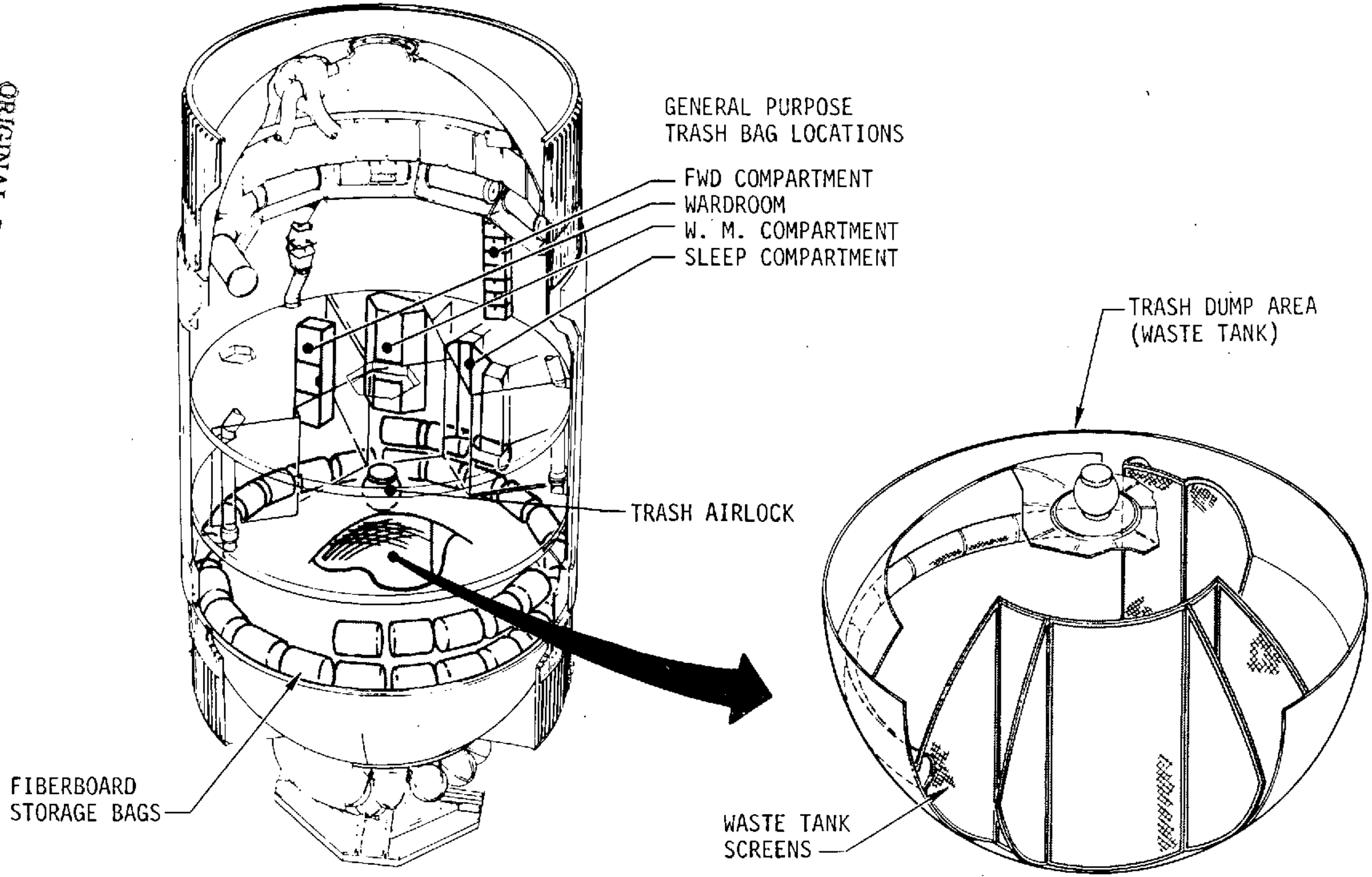


FIGURE 32

Water Subsystem (fig. 33)

The water system provides 6000 pounds of water, packaged in 10 tanks of GN_2 at 35 psig for pressure distribution. Iodine is the biocide.

The major problem during development testing occurred in the water deionization assembly test. It showed that the deionization resin absorbed an excessive amount of iodine from the water and the required iodine concentration levels could not be significantly increased by reducing the resin volume. The cartridge was redesigned to reduce the resin volume to 30 percent of the original design with influent iodine level at 8 ppm. Test completion is scheduled for April 1973.

System performance is being verified by the water subsystem qualification test. The estimated completion date is December 1972.

1. Leakage was observed from the valves in the iodine container, iodine injector, sampler, reagent container, and portable water tank. An investigation revealed that the food grade viton O-ring seals had taken a large amount of compression set. There are only two known food grade seals that can be used in the water system and are compatible with iodine, viton, and silicone. The silicone seals are known to have better compression set characteristics than viton. However, these are normally not used in dynamic applications because of poor abrasion and tear resistance. Tests have been conducted that indicate these seals are acceptable for low cycle, low pressure applications. All affected viton seals have been replaced.

2. Operation of the food reconstitution dispensers created a water pressure spike causing the relief valves to expel water. The problem was resolved by adding an orifice to each dispenser inlet and raising the relief pressure.

3. During life cycle testing of the iodine injector, water leakage was observed on the 38th cycle. The unit was disassembled and two cracks were found in the weld beads of the bellows assembly. The unit is being redesigned to add a pressure limitor to the bellows assembly.

During checkout for the water subsystem two significant problems were encountered. The water tank domes on several tanks were deformed. The problem was the result of the mechanical restraint method used for handling. The domes were reformed with gas pressure. The restraint system was redesigned to use a vacuum system. Temperature of water dispensed from the chiller was higher than the specification requirements. The CEI and Food ICD specifications and the TCRSC drawing were changed. Waivers or deviations to specifications had been given where touch temperatures had exceeded the specification on the personal hygiene water heater dump quick disconnect. However, further testing indicated that the original requirement of 105° F was in fact met and the deviations were not necessary.

OWS
WATER SYSTEM

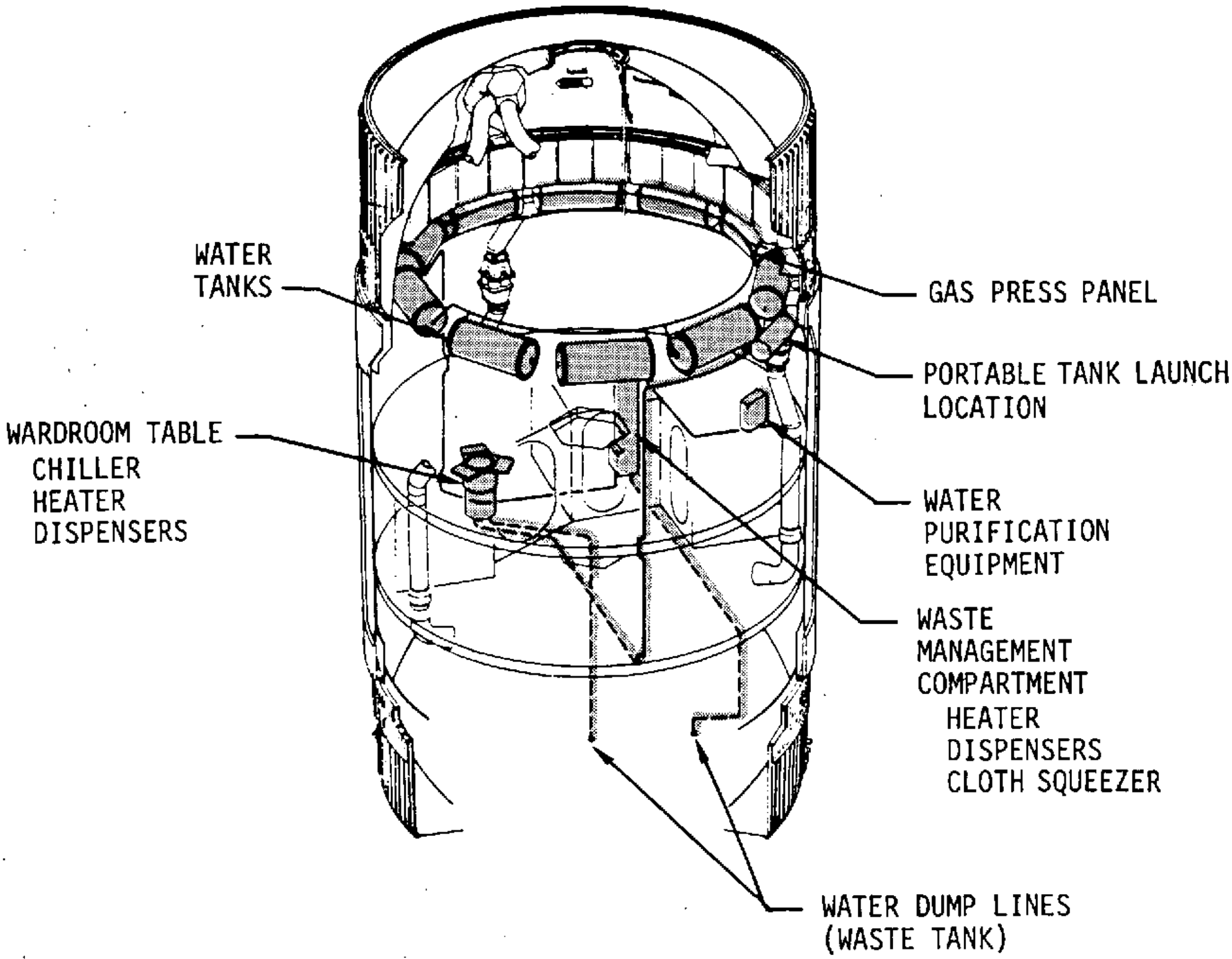


FIGURE 33

Food Management Subsystem

The Skylab food system appears to be still evolving. A reference menu, formulated some time ago as a driver for galley design, provided good engineering data. Galley design appears to be sensitive to the relative proportion of different food packages. The unique food safety problems of Skylab differ from Apollo in that the mission causes increased length of storage, food variation, new packaging, and medical experiments interface.

The basic system is shown in figure 34. The containers provide storage of 2200 pounds canned food and 252 pounds of frozen food. The food table has restraints and heating devices. This area is discussed in further detail under the OWS C^2F^2 activities.

Illumination System

The OWS illumination subsystem (see fig. 35) is comprised of that hardware which is involved in providing lighting to support crew activities within the workshop (see table XII).

All development testing associated with this subsystem has been completed.

All Huntington Beach postmanufacturing checkout procedures associated with establishing the integrity of this subsystem have been completed. Checkout for the illumination subsystem consisted of the following tests:

Illumination subsystem acceptance test

Photography

Television

Crew compartment fit and function

All systems test - preparations and securing

EMC-preparations and securing

All systems test - activations, orbital operations, and deactivation

There were no major anomalies encountered during testing. All checkout problems have been resolved and all applicable test requirements have been satisfied.

The only open work still pending at the time of the PDTR is a modification to the two GFP portable high intensity photolamps to incorporate EMI filters. In addition, all subsystem hardware changes authorized during factory checkout (e.g., replacement of lights due to inconsistent low mode starting) have been completed.

The GSE internal test lighting kit was verified during postmanufacturing checkout but was not used during the balance of VCL testing. Facility lighting was used instead during all postmanufacturing checkout. There were no major problems encountered during the checkout of this item of ground support equipment.

OWS
FOOD MANAGEMENT SYSTEM

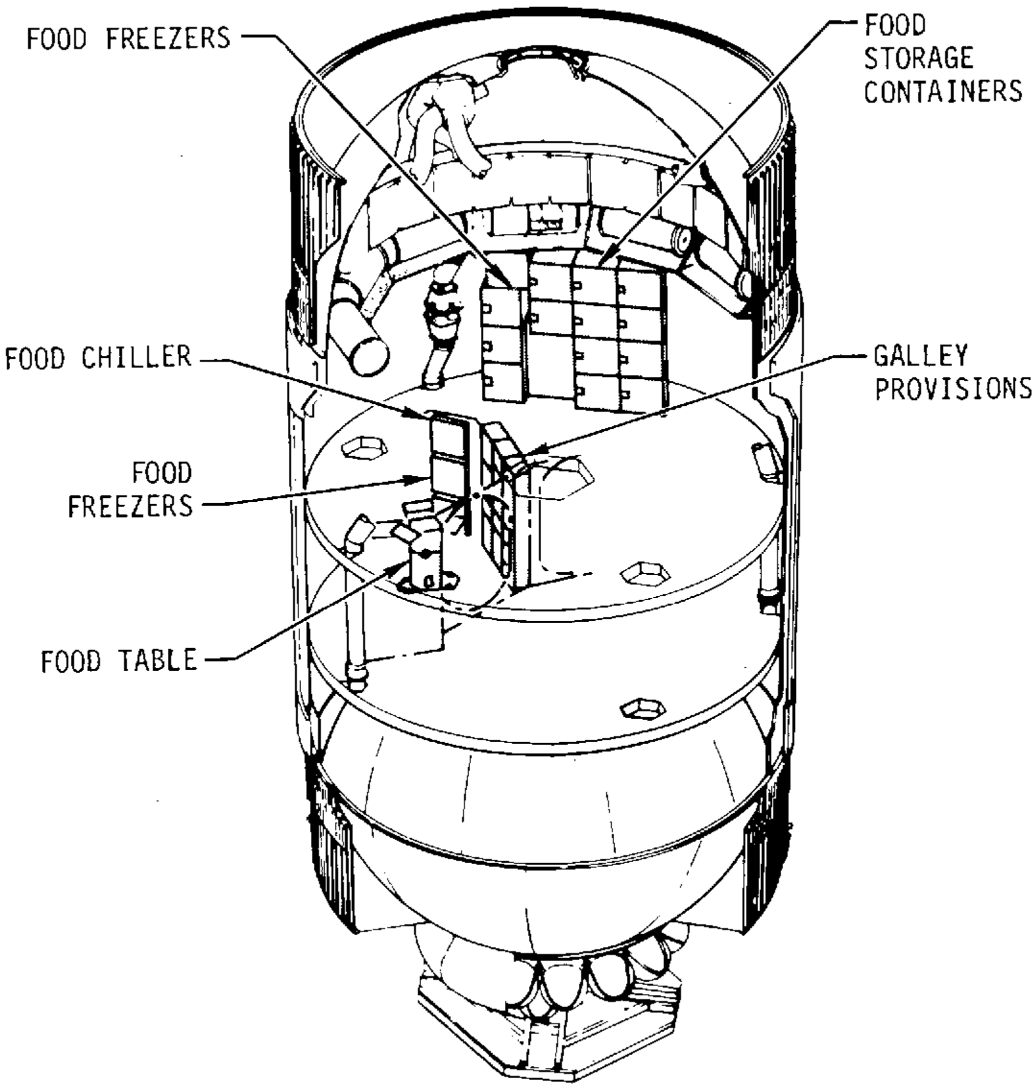


FIGURE 34

OWS
GENERAL ILLUMINATION SYSTEM

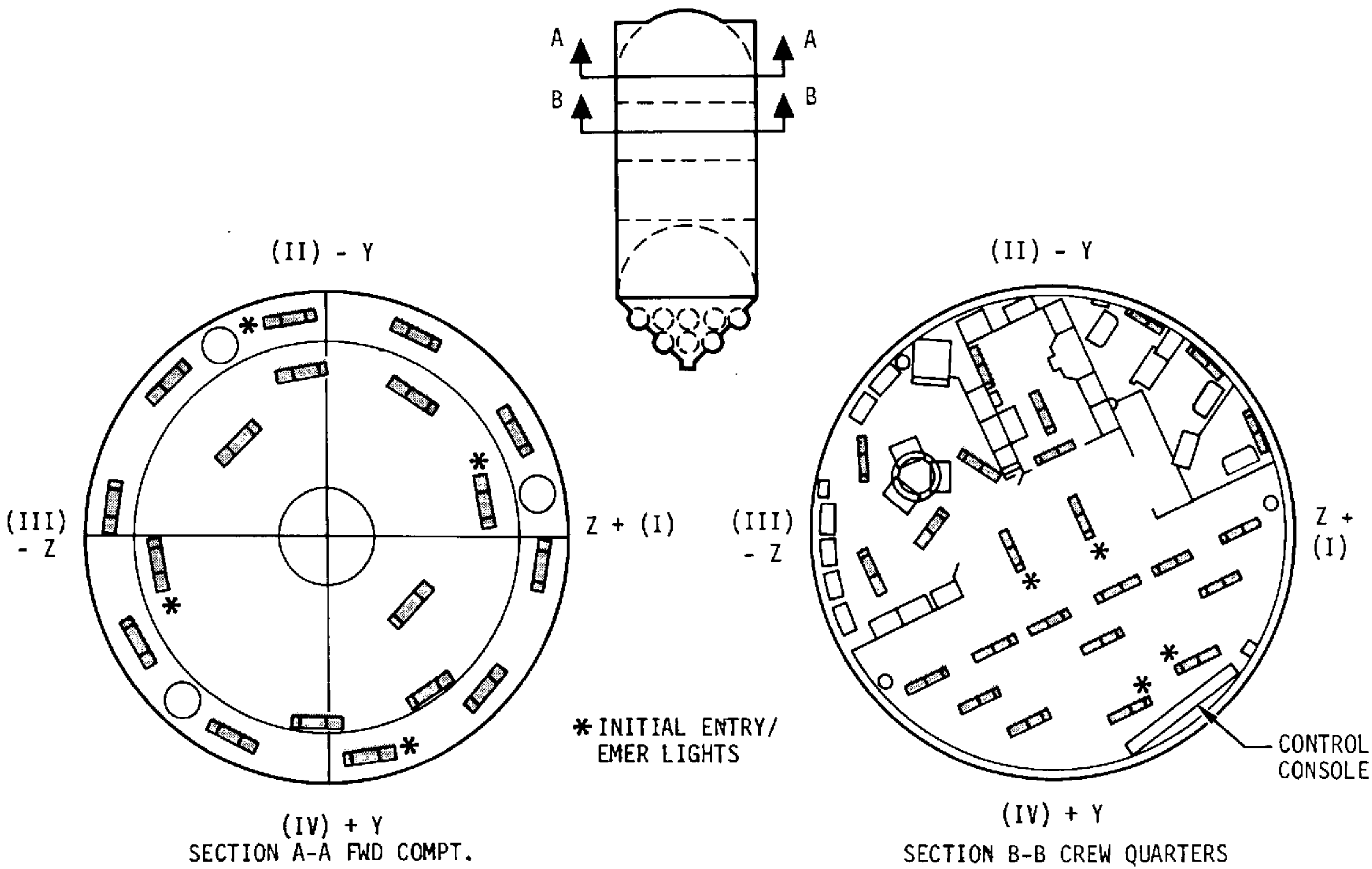


FIGURE 35

Crew Equipment Systems

Panel reviews in this area include discussions at MSFC, MSC, Headquarters, and the OWS contractor McDonnell Douglas-West. Of particular interest were the crew accommodations and stowage areas.

The Panel gave particular attention to the role of crew compartment fit and function activities in establishing design adequacy and mission readiness of the hardware. The materials control aspects are covered in the CLUSTER MATERIALS section.

Crew accommodations include the personal hygiene equipment, sleep hardware, and foot restraints (see figs. 36, 37, and 38). The stowage system (fig. 39) provides a total volume of 583 cubic feet.

Included in the stowage are two materials - nonflammable cardboard packing and mosite linings - which have been the occassion of much discussion. Cardboard was noted before as part of the trash control problem and will be covered in more detail under MICROBIAL CONTROL and MISSIONS OPERATIONS sections of this report. Mosite is discussed under the CLUSTER MATERIALS section of this report.

Problems under consideration at the time of the Panels review include the following:

1. The type of hook velcro used in the OWS may wear off and particles could float in zero-G.
2. Flight tools were getting worn as a result of use in C^2F^2.

The testing of the portable foot restraint (triangle shoes) and the sleep restraints have been deferred to KSC because late configuration definition prevented flight articles from being available at Huntington Beach. McDonnell Douglas-West noted that significant sections of the C^2F^2 test and checkout procedures were not performed at Huntington Beach because of hardware unavailability. Therefore, the following activities will have to be completed at KSC:

M487 experiment verification

M172 experiment verification

Stowage fit checks - sleep compartment

29 Stowage locations in other compartments

Crew systems required no unique GSE. The interfaces with the crew quarters vertical access kit, and the HSS equipment handling kit have been successfully demonstrated.

All crew systems qualification tests are complete except for the biocide wipe packaging.

This is an 8-month shelf-life test scheduled for completion in March 1973. It is to determine the stability of the Betadine solution used to prewet the wipes. The data after 73 days still show an acceptable iodine concentration. However, a consistent loss trend

OWS
PERSONAL HYGIENE EQUIPMENT

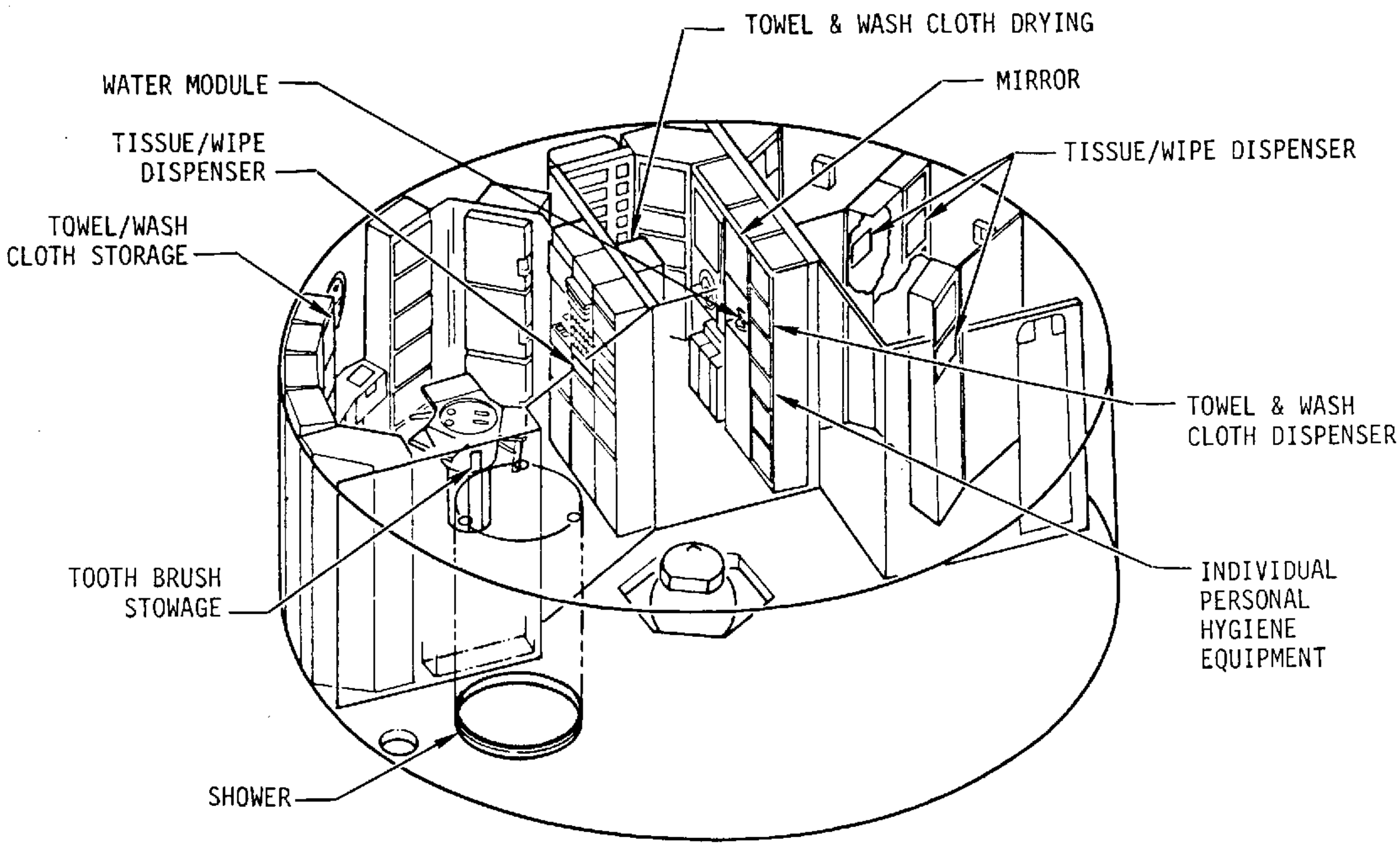


FIGURE 36

OWS
SLEEP COMPARTMENT EQUIPMENT

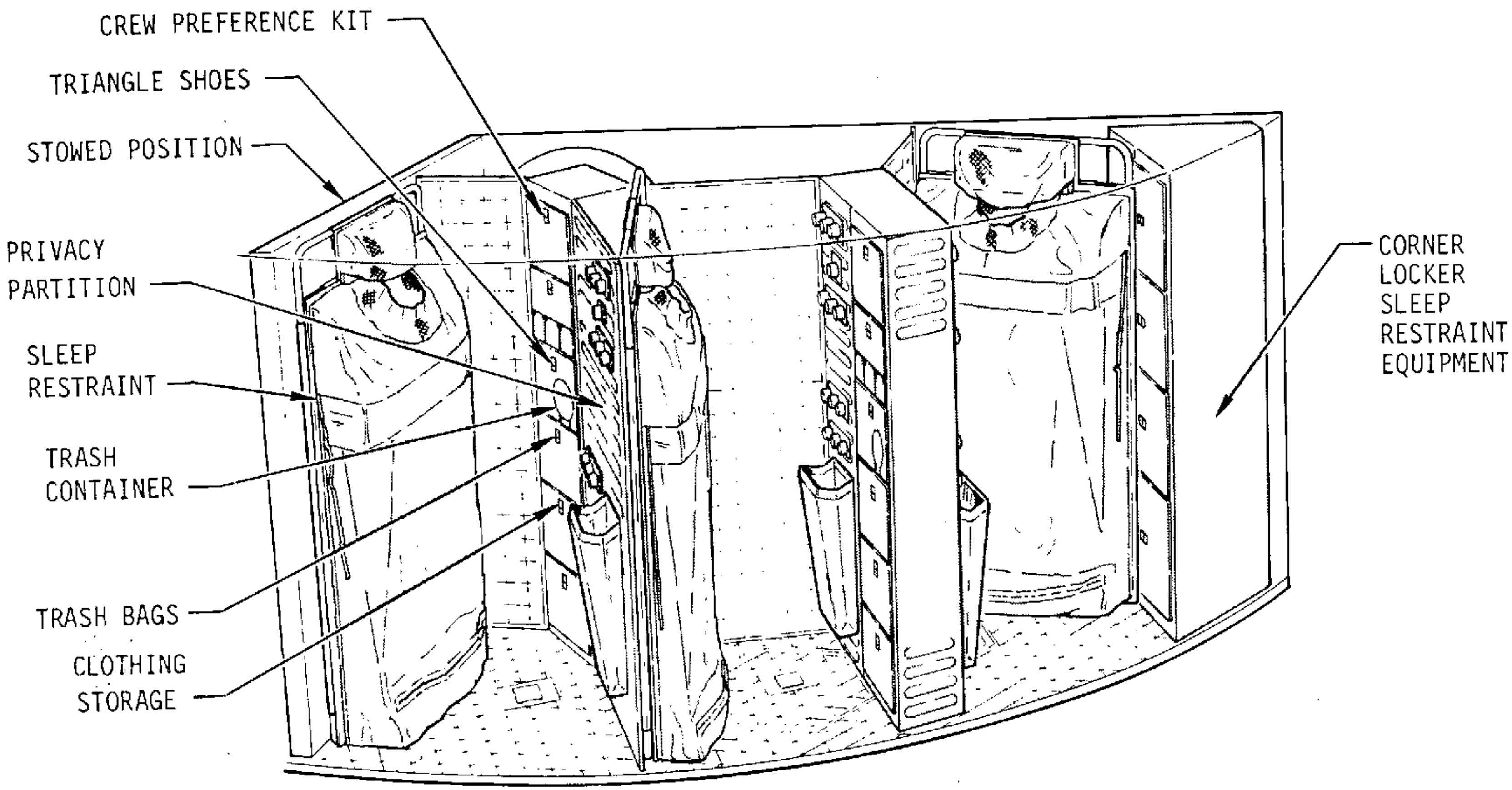


FIGURE 37

OWS
MAINTENANCE

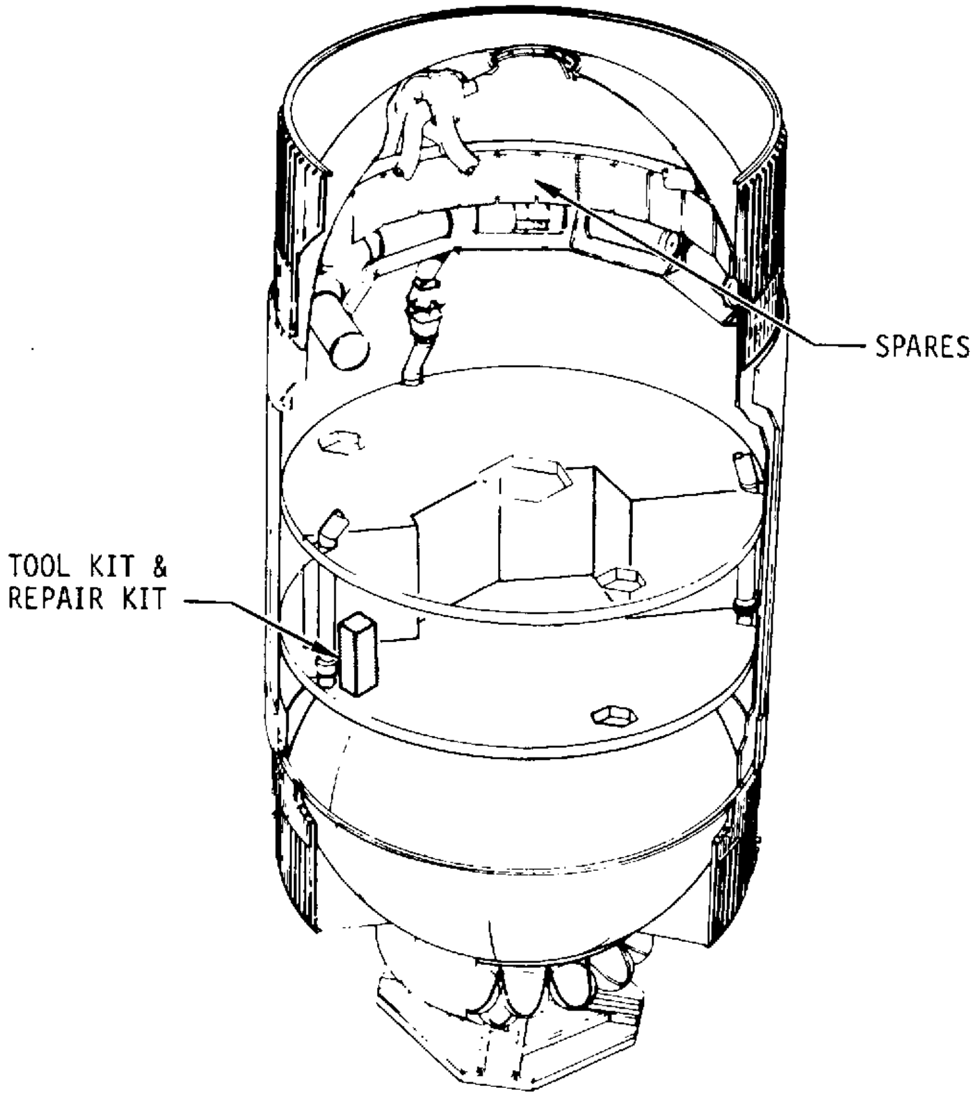


FIGURE 38

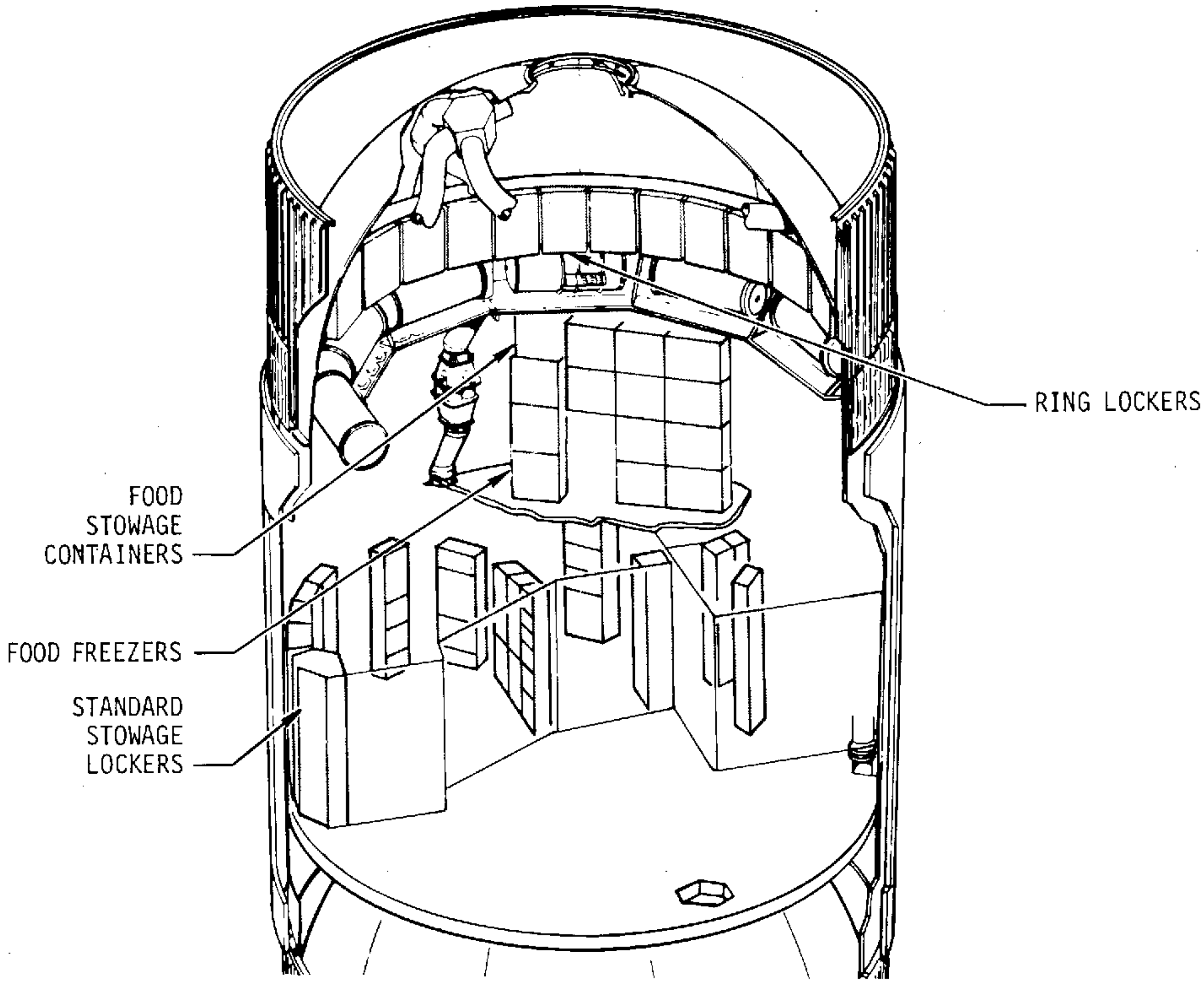

RING LOCKERS
FOOD
STOWAGE
CONTAINERS
FOOD FREEZERS
STANDARD
STOWAGE
LOCKERS

FIGURE 39

indicates that complete depletion will occur in approximately 160 days. If the trend does continue, one of the following solutions will be instigated:

1. Change the biocide to Zephyrin
2. Supply wipes for each mission

Checkout for the stowage accommodations and procedures dealt mostly with the experiments and waste system. All stowage locations were fit checked during checkout except for approximately 28 locations where equipment was not available. Checks will be completed at the KSC. In addition, equipment in 96 locations was unstowed and will then be restowed at the KSC. Twenty-five ring containers will be delivered to the KSC outside the spacecraft. Fourteen of the ring containers are fully stowed and five are partially stowed.

A list of stowage lockers not reviewed at McDonnell Douglas at PDTR and hardware not reviewed during OWS checkout at McDonnell Douglas are shown in table XIII.

Ground Support Equipment

The Panel has not had the opportunity to look into this area in depth. Based on the results of SOCAR and the OWS DCR and PDTR's it appears that OWS unique GSE including mechanical, electrical, and special handling has received a reasonably thorough examination. In most cases this equipment was used during the in-house development and qualification testing (all systems, dynamic test articles, subsystem tests, C^2F^2, and so on). It appears that where problems were encountered they have been resolved. Of interest at the KSC will be those items of GSE which are shipped incomplete or require further modification. A second point is the necessity of maintaining GSE, including separate cables and ducts, to the necessary cleanliness standards. Based on prior Apollo experience the Panel wishes to reiterate the necessity of having adequate GSE procedures and knowledgeable personnel to preclude overexcitation of flight hardware.

Current Assessment of Technical Areas

The Panel has observed factory buildup and test activities along with SOCAR, module DCR, PDTR, and cluster DCR reviews. These activities and reviews provide the basis for the Panel's assessment. This assessment identifies areas that require particular management visibility. Discussions of the individual systems follow.

1. Structure

(a) The thrust structure contains two single failure points. The TACS high pressure and storage spheres and one radiator shield jettison mechanism would jeopardize the mission and the crew if they failed. Furthermore, these components support not only the OWS but the total cluster and other individual module operations. It is important that these items be properly identified to the KSC test and checkout personnel to assure proper handling and control of ground excitation.

(b) The meteoroid shield deployment system was reworked; it was to be retested in the October-November 1972 time frame. Results of this test and further deployment tests expected at KSC should prove this system.

(c) The pressure integrity of the main habitation tank is subject to many perturbations during test, checkout, and while in orbit. Currently, the leakage problems are confined to secondary areas such as the wardroom window cover and SAS wing cavity. Nonetheless, there are so many structural penetrations and hatches that extreme care must be exercised during transport and handling as well as during test and modification activities. The Panel understands that the total OWS was not pressure tested. Pressure testing was limited to the original SIVB and each subsequent penetration.

2. Environmental and thermal control

(a) The waste tank receives fluids from the AM. In the case of condensates the fluid has frozen during dump tests.

(b) Thermal ventilation and odor removal subsystems are still under consideration.

(1) The results of the flowmeter life tests to be completed in ECD February 1973.

(2) The possible CO_2 concentrations because of inoperative ventilation fans in and around crew sleep compartments were covered in SOCAR and in the DCR, but the Panel did not have the results of the data presented.

(3) Objectionable odors emanating from feed collector (not from fecal matter) resulted in a determination that cabinet acoustic insulation caused the trouble. Solution was to remove it from cabinet. An assessment of the impact due to acoustic excitation with the insulation removed was under consideration.

(4) OWS head pipes use, for the first time in a space application, Freon-22 as the working fluid and out-of-plane pipe bends. The performance of the TCS as a whole is based on analysis; therefore, in-flight sensors are probably necessary for verification.

(c) Development tests continue on the suit drying station. The suit drying activity is significant because of its impact on the crew's planned activities and emergency egress.

3. Refrigeration system

(a) The inlet pressure of Coolanol-15 circulating pump is a "red-line" measurement. The Panel understands that the transducer currently in place is not operating properly and should be either replaced or bolstered with a redundant sensor.

(b) The following items are still undergoing life or qualification tests and test results should be monitored:

Pump assembly

Radiator bypass valve

Relief pressure valve

Fill and drain valve assembly

Thermal capacitor

Cold plate

Housing radiator control valve

(c) The inverter associated with the coolant pump was under redesign to assure adequate start torque margin. Tests at KSC should prove this unit. Hardware availability is December 1972.

4. Solar array system

This unit built by TRW for McDonnell Douglas-West is a complex structural, mechanical, and electrical unit. It requires special handling with a controlled environment while at KSC. Condensation in the stacked or stored configuration should be precluded for reasons of system deterioration and possible jamming of deployment mechanism. These subjects have been monitored by McDonnell Douglas and NASA, and the Panel has been assured that all precautions will be taken.

5. Electrical power system

(a) Wiring does not contain individual identification sleeves to depict their terminal points. This can hamper the KSC work effort if mods or test anomalies occur.

(b) Wire harness support and proper bend radii are of concern if modifications occur at the KSC in which wire bundles are moved, replaced, or operated on in any way. Procedures should assure that proper support and bends are maintained throughout test and checkout.

6. Caution and warning system

The rapid ΔP alarm system, unlike the fire warning system, does not indicate location of leaks. The alarm only indicates a rate equal or in excess of 0.1 psi per minute. Crew and flight controller procedures will have to be devised to support this system.

7. Habitability support subsystem

(a) SMEAT results will have a decided effect on the HSS areas of waste management, water, and food, while the specifics of SMEAT are discussed in that section devoted to it. The results include the following:

Urine collector system was redesigned to accommodate 4000-milliliter capability.

Fecal collector odor, noted in earlier tests as well as SMEAT, is determined to come from acoustic insulation which will be removed.

Current design of fecal bags is under consideration due to difficulty in using and closing them.

(b) Component qualification testing is in process or to be accomplished on the following:

Urine separator

Fecal/urine collection module

Urine volume determinator

Chiller compartment

Urine bladder

(c) Resolution of problems associated with disposal of cardboard used for packing appears to still be in process.

(d) The trash collection bag shelf-life tests are still in process. So far there are no problems.

(e) The water system has a number of component qualification tests in process on currently available hardware and redesigned hardware:

Food dispenser

Quick disconnect

Fluid filter

Iodine injector assembly

Water deionization filter assembly

8. Crew equipment systems

Most of the crew accommodation, storage, and C^2F^2 items are covered under other sections of this report (e.g., CLUSTER MATERIALS, MICROBIAL CONTROL, and RELIABILITY, QUALITY, AND SAFETY).

(a) The biocide wipe packaging is being subjected to an 8-month shelf-life test to assure maintenance of acceptable iodine concentrations. If depletion does occur, then the biocide will be changed or wipes will be supplied for each mission.

(b) Protective covers (also called "shop-aids") on OWS hardware and supporting equipment for use at KSC was discussed at the PDTR. There appears to be a need for either more covers or a better use of those currently available.

9. Ground support equipment

The majority of the GSE associated with the Skylab cluster modules and launch vehicles has been used in factory testing prior to shipment to KSC.

Where the equipment has not been used previously or is used in a different mode, it has been evaluated to assure usage compatability with the flight hardware. McDonnell Douglas-West and MSFC's general conclusion was that the few problems or descrepancies in hardware, documentation, and planning would not have a program impact.

An end-to-end functional assessment of all GSE systems operations was made during SOCAR using interface documentation, schematics assembly drawings, and other engineering planning documentation. All signal or operational paths associated with electronic and mechanical equipments were verified from initiating activity up through the first recipient function on the vehicle. The team also reviewed the impact of potential GSE failure modes on launch preparations, flight hardware, and personnel safety. Their conclusion was that there was low probability of failure in critical items because of demonstrated performance and no significant effect because of redundancy or adequate time to repair.

Risk Assessment and the Management System

For the past year MSFC has maintained a resident task team at McDonnell Douglas-West. This has included MSC and KSC personnel as required. The purpose was to assure the timely and proper resolution of both manufacturing and test problems in order to meet the Skylab schedule, funding limitations, and program design specifications. Because of such efforts the orbital workshop design reviews were well documented and the hardware presented for acceptance by NASA was reasonably "clean." In addition to the normal reviews, NASA had an OWS engineering "walk-through" inspection of the OWS on August 18, 1972 to inspect (with a team of MSC and MSFC specialists) wiring, sharp corners, and general fabrication techniques. The walk-through team expressed their satisfaction with the OWS spacecraft and were impressed with the overall condition of it, particularly the quality of construction. The routing of wire harnesses and tubing runs were especially well engineered and fabricated. This type of inspection will be repeated at KSC. The data packages used to support the turnover meetings were thoroughly reviewed by KSC quality engineering and quality assurance personnel.

McDonnell Douglas-West in support of this effort established an engineering test team with manufacturing expediting assistance to improve the development and qualification test schedule and establish engineering subsystems managers to work across the board from design through procurement, manufacturing, assembly, checkout, etc.

Essentially the task team members supplemented efforts of the NASA Resident Office in areas of individual specialties and could provide significantly improved communications regarding all types of problems and their timely resolution.

The OWS programmatic review cycle and methodology during the phase II Panel review period provided a measure of confidence that OWS hardware and software have been examined thoroughly and by a capable NASA/McDonnell Douglas-West team. The SOCAR system end-to-end analysis, pre-DCR's, and PDTR's provided open forums for frank discussions and surfacing of problems and their resolution.

Some concerns did arise on the management systems governing SFP's, use of backup hardware, control of retest requirements, and the control of contractor supplied data packs. The process by which SFP's are handled must be available to alert all concerned parties of their existence, background, and justification. This assures, for example, that the TSCRD would have a special note of such items and that the proper approvals are secured when a change is made involving SFP's. The Panel feels that a closed-loop system must be assured. The ability to use the Skylab OWS backup hardware for in-flight and on-the-pad anomaly resolution, similar to that done on the Apollo program, appears to be in question at this time and the extent of the problems probably needs further examination. The documentation and control of retest requirements, which are to be implemented at KSC, did not appear clear to the Panel although it may be under control.

Fire prevention and extinguishment. - The Panel was concerned with the possibility of fire because of the AS 204 and Apollo 13 incidents. The philosophy of the Skylab program is fire prevention. Thus, while there are significant consumables onboard (e.g., OWS wall insulation, Coolanol-15), there has been a careful and thorough attempt to minimize such materials or to define the rationale for their use, and to isolate ignition sources and propagation paths. MDAC noted that all materials were checked against a list of acceptable material and that all possible steps have been and will be taken to assure the risks are minimized.

Manufacturing, workmanship, and vendor control. - McDonnell Douglas-West had no direct experience in building such a complex manned spacecraft for the Skylab cluster. Thus, there was a learning curve which involved the manufacture of in-house piece parts and the development of in-house test procedures. The Panel feels comfortable with the quality of the hardware workmanship based on prior reviews and the NASA statements made during the DCR and PDTR's. McDonnell Douglas-West further tried to identify and use the relevant lessons from Apollo experience.

The "Lessons Learned on Apollo Spacecraft Reliability Program" was reviewed for applicability of its recommendations to the Skylab program. The recommendations have been generally implemented in the Skylab-OWS program. The exceptions are those cases where the task is considered to be applicable to a production or multivehicle program as opposed to the one-of-a-kind OWS.

"NASA/MSC Space Flight Hazards Catalog" describes 266 hazards which have been identified during prior space flight programs. The catalog was used by McDonnell Douglas's OWS departments and design technologies to voluntarily perform a comprehensive review. Results of the review have been incorporated into the systems safety presentations given to MSC and MSFC representatives. The final assessment and evaluation of all of the hazards was made by a special committee chaired by the director of system safety and product assurance.

The history on "Apollo Electrical, Electronic and Electromechanical (EEE) Parts Problems and Solutions" has also been used in a comprehensive review. This contributes to confidence that OWS electronics design has recognized prior pitfalls and will avoid or design around the conditions identified in the report. Concurrent with this review, McDonnell Douglas-West conducted independent but related studies relative to

McDonnell Douglas designed and manufactured electrical components. This study included a review of failure history, design analysis, manufacturing, and reliability considerations. The study concluded that the problems which had been identified and/or experienced on related programs had been given adequate consideration in the design, manufacturing, planning, and inspection of like OWS components.

Motivation. - In recognition of the human element and its vital influence on product quality, a positive and continuing vendor and in-house "awareness" program was planned and implemented. It features an OWS overview/orientation briefing. Some 1300 personnel from McDonnell Douglas and critical OWS suppliers attended. Primary emphasis during the orientation was devoted to the importance of each individual's contribution to mission success and the need for defect-free hardware that will operate reliably for the planned 8-month orbital mission. During the tour of the Crew System Evaluation Laboratory, the participants were shown the crew quarters and work areas, and they were briefed on several of the experiments to be performed in the OWS. The program has given OWS personnel a fuller appreciation of the application and importance of their work for OWS.

Other motivative aids have been introduced. Over 1000 plastic plastic pocket inserts with the designation "Skylab Team" were distributed to personnel working on the program. Approximately 500 1972/1973 Skylab calendar/facts pocket booklets have been passed out as have Skylab astronaut team photographs.

NASA and McDonnell Douglas produced films such as "Invitation to Confidence," "Anatomy of an Accident," "Quality Craftmanship," and "Human Factor." These have been widely shown at Santa Monica, Huntington Beach, and the Florida Test Center to further motivate OWS employees and acquaint them with the importance of the OWS mission. NASA and McDonnell Douglas Manned Flight awareness posters have been prominently displayed in all OWS work areas and changed as frequently as new posters were available. Posters and films have likewise been made available to suppliers. In addition, special OWS awareness stamps were procured and instructions prepared for all suppliers of mission/safety critical hardware to stamp all shippers, ship travellers, rejection tags, and any other inprocess paper "critical hardware for Skylab/OWS."

Hardware cleanliness. - Special precautions are being taken to maintain the required levels of OWS cleanliness. All items are and will be logged in and out of the vehicle. Such areas as the "crotch" (where the forward area meets the dome as well as where the floor meets the wall) were and will be X-rayed and fiber-scoped as well.

Acceptance testing. - Acceptance testing at both the manufacturer's site and at KSC have much in common and are vital to the receipt of known hardware at each site. The plan for carrying these acceptance tests at KSC for the OWS and ancillary equipment is shown in figure 40.

OWS
ACCEPTANCE TESTING
TEST SITES

KSC VAB CHECKOUT OPERATIONS

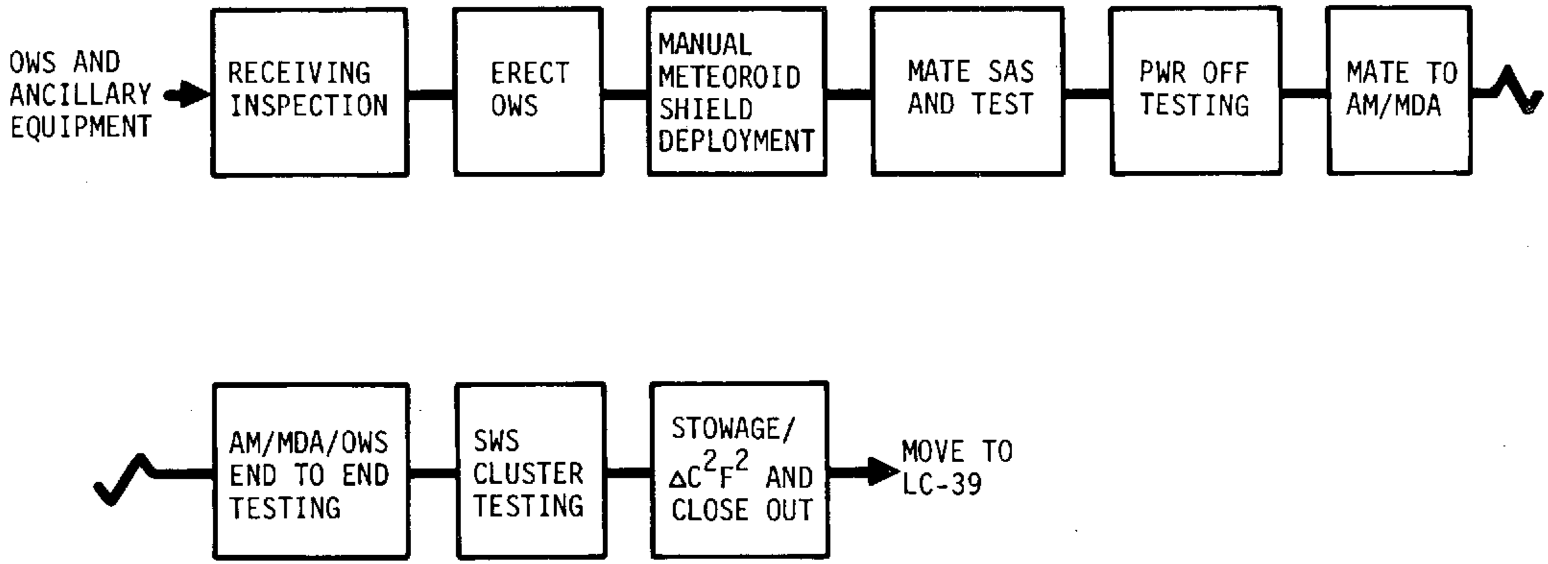


FIGURE 40

AIRLOCK MODULE

The airlock module (AM) is the module containing the hatch through which astronauts egress when performing extravehicular activity (EVA). It also contains systems for environmental control, instrumentation, electrical power, communications, and operational management for the orbiting assembly (OA) or cluster. It is attached to the forward end of the orbital workshop and provides structural support to all modules mounted forward of the OWS (MDA, ATM, CSM). The AM consists of two concentric cylinders with truss structures bridging the annular gap. This is illustrated in figures 41 to 44. The outer cylinder, or the fixed airlock shroud covering the high pressure gas bottles and encircling the outer AM structure, has the same diameter as the OWS (22 ft). The inner cylinder, or tunnel, contains the airlock and constitutes the passageway through which the Skylab crews move between the CSM and MDA on one side to the OWS on the other. The forward end of the fixed airlock shroud is the base on which the tubular structure supporting the ATM is mounted.

The airlock itself is the central portion of this module. It has two hatches that close off each end of the cylinder and a third hatch located in the outer wall that is the EVA hatch. Closing the two end hatches before opening the EVA hatch ensures that the atmosphere within the rest of the cluster is retained. High pressure gas containers store the oxygen and nitrogen which provide the internal atmosphere throughout the mission.

The payload shroud, covered in a separate section, fits over the AM as it does over the MDA and is supported on the fixed airlock shroud.

As with the OWS, the Panel has elected to discuss the AM from two points of view to better provide an assessment of the adequacy of management systems and their implementation. Thus, the first portion discusses management systems of the NASA Centers and McDonnell Douglas Astronautics Company, Eastern Division. The second portion discusses their implementation as mirrored in the technical aspects of the program.

Management

The basic system of management applied by NASA to the airlock program is similar to that used on other modules. Variations were necessary however due to the unique handling of the AM and MDA as a unit during the major phases of testing accomplished at the MDAC-East plant in St. Louis, Missouri. The airlock has more major interfaces than other modules. Last and certainly not least is the background of the MDAC-East organization. They have been involved in manned space flight through two programs prior to Apollo (i.e., Mercury and Gemini). The basic approach may be the same for each module contractor, but in the case of MDAC-East the emphasis was placed differently. Furthermore, there was a requirement to use existing hardware where possible. The

AIRLOCK

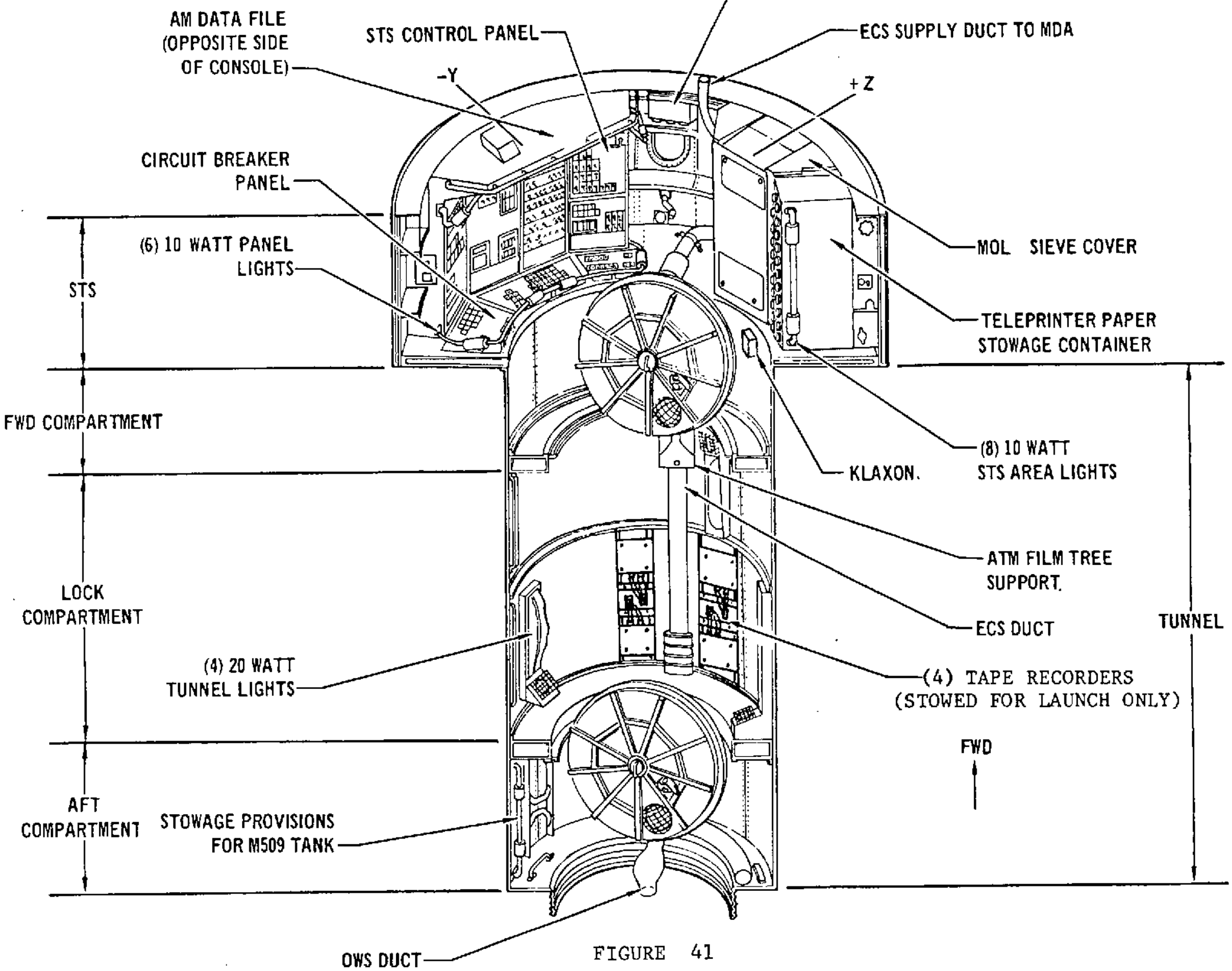


FIGURE 41

AIRLOCK

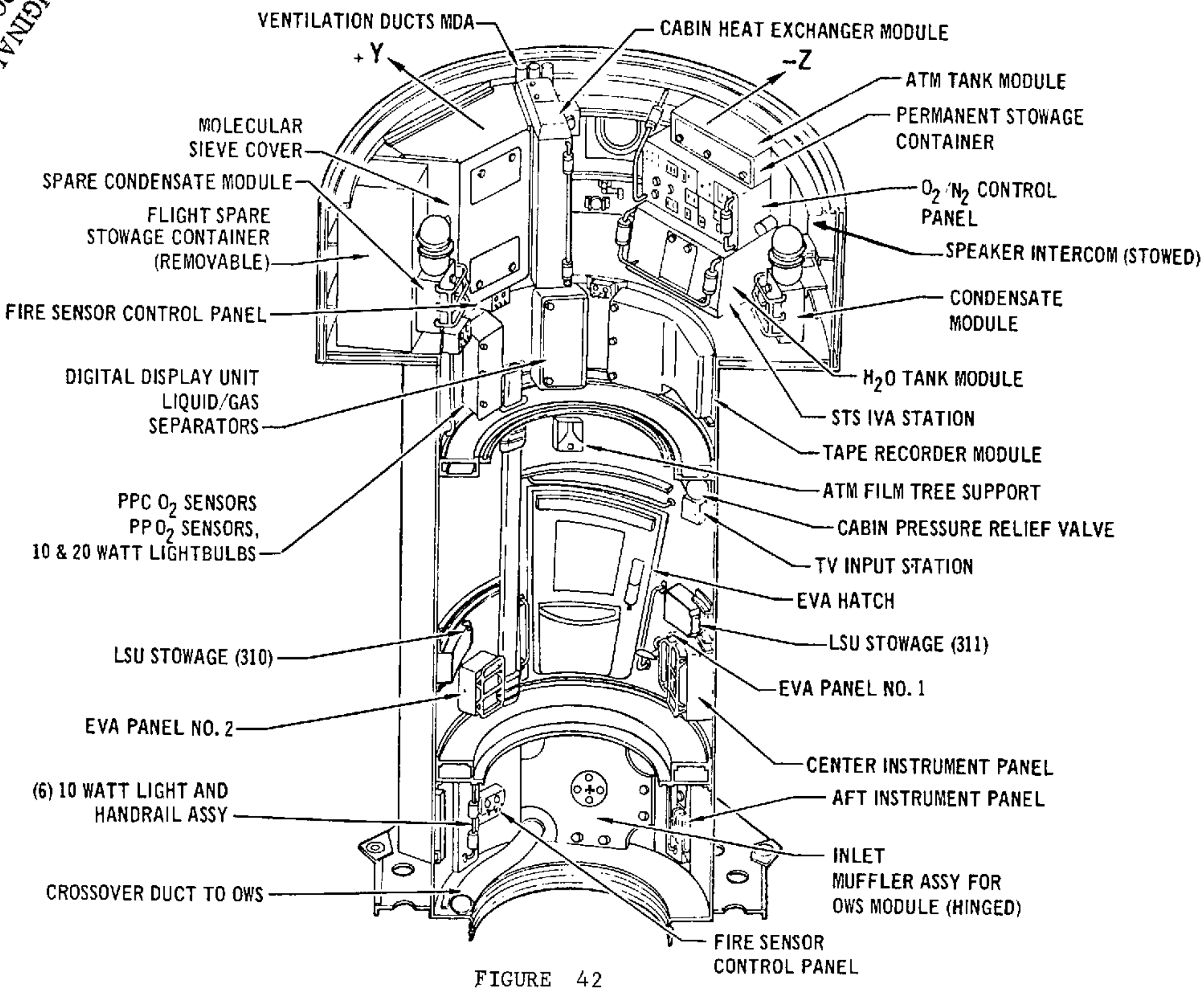


FIGURE 42

EXTERNAL EQUIPMENT

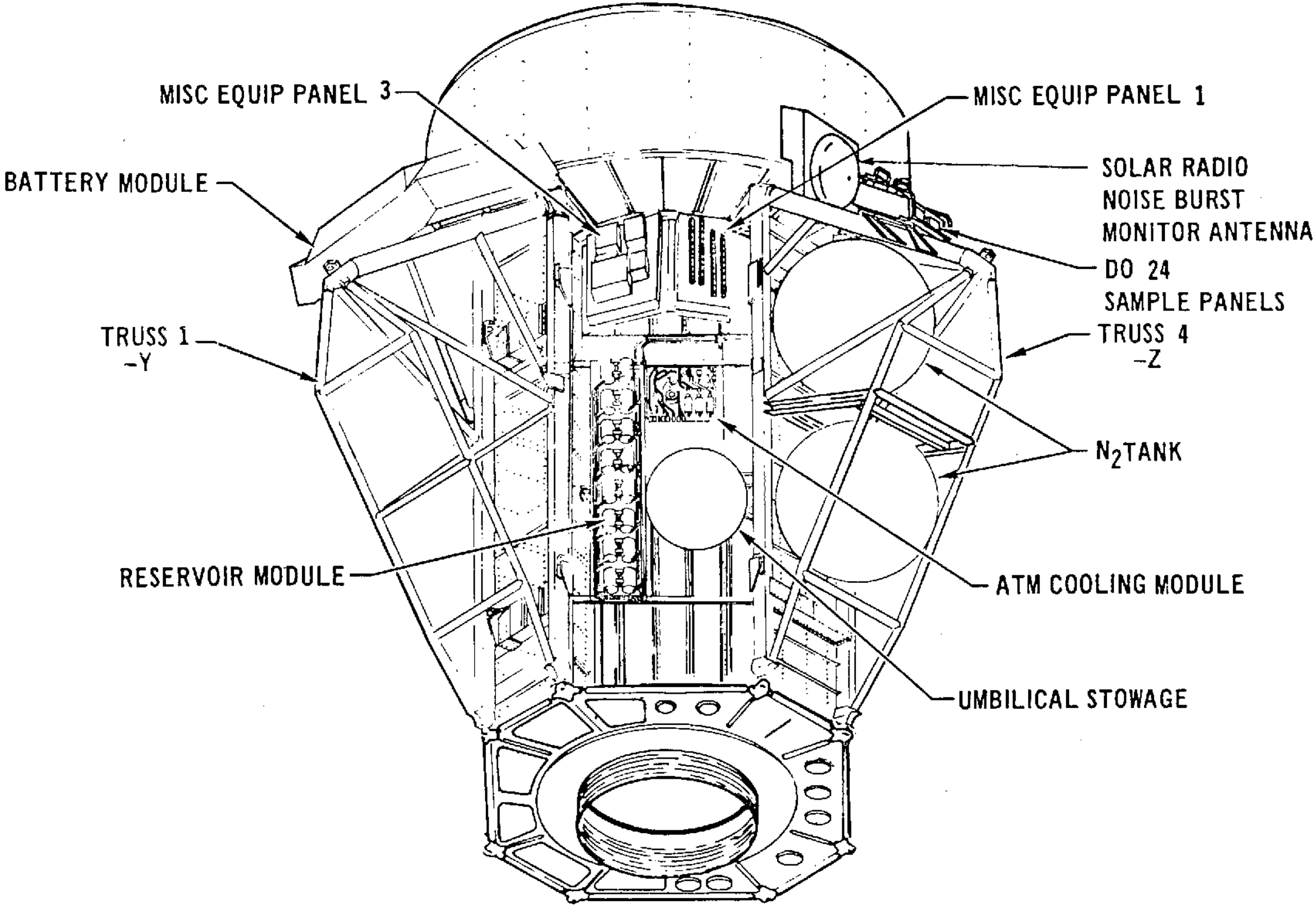


FIGURE 43

EXTERNAL EQUIPMENT

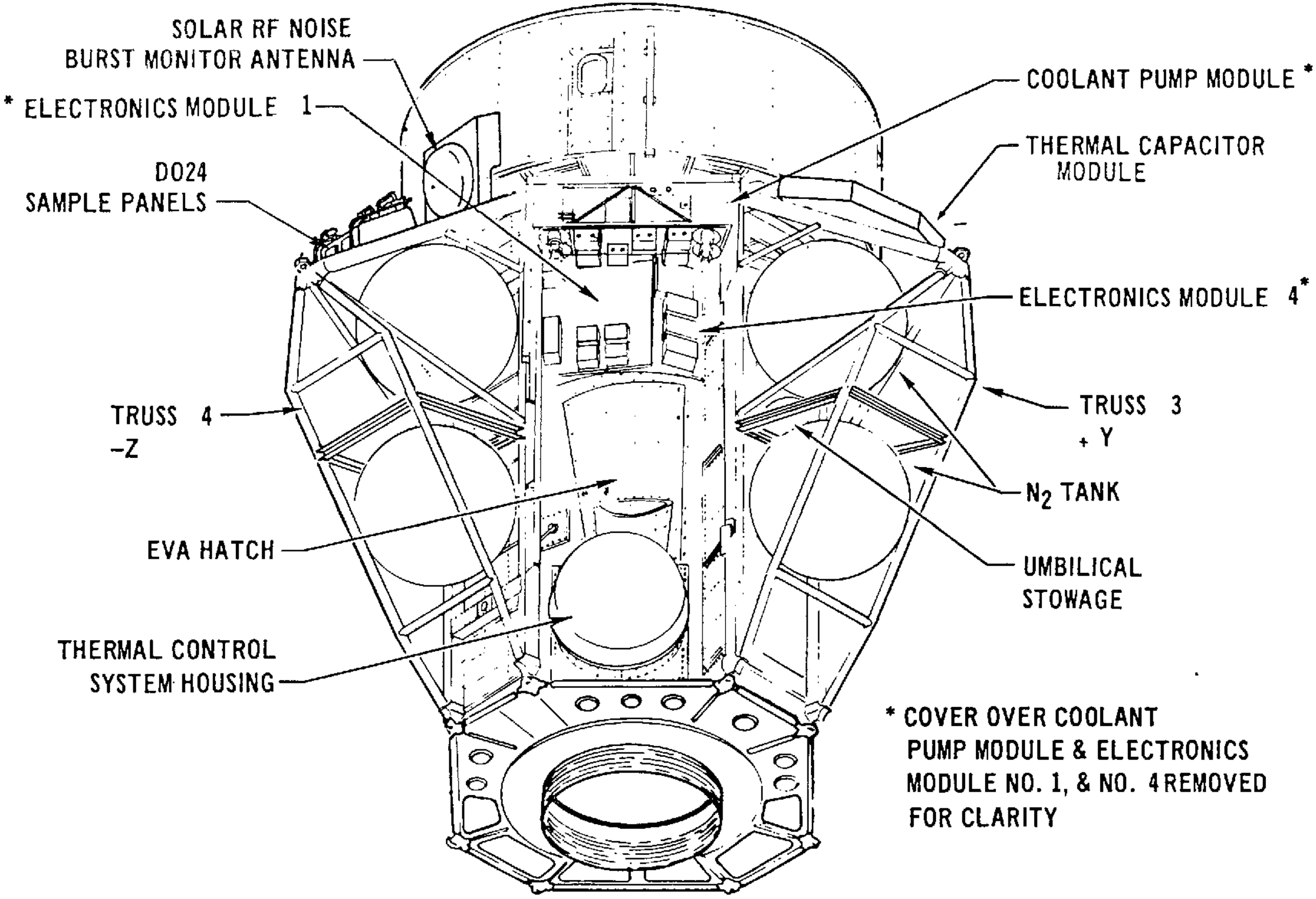


FIGURE 44

airlock module was designed to incorporate the Gemini hatch for EVA, Gemini latch assemblies on internal hatches, and Gemini ground support equipment as possible. As a result of all of these, NASA and the contractor were able to place more emphasis on hardware component assessment methods using similarity and analysis, and integrated testing between the MDA and AM. Vendor control of course was supported by the strength in related business activities as well. There were some difficulties encountered during the initiation of joint operational activities with MMC and MDAC-East and this was noted in the Panel's third annual report to the Administrator. The current posture is noted in the section "Response to the Preliminary Skylab Report."

Technical Implementation

The material discussed here was derived from Panel and staff attendance at the airlock modules DCR's and SAR's and the SOCAR.

Structures subsystem. - The basic structure is welded aluminum and consists of three sections: the structure transition section (STS), the tunnel, and the trusses. Added to these are the fixed airlock shroud and the deployment assembly for the ATM. The enclosed volume for the STS is 279 cubic feet and for the tunnel 345 cubic feet. A metallic convolute flexible bellows (42. 5 in. internal diameter and 13 in. long) joins the AM to the OWS. This bellows provides continuity of the pressurized passageway between the AM and OWS. The bellows material is 0. 025-inch aluminum. A fluorocarbon coating on the inside surface provides further pressure sealing capability. There are four ports provided for crew and experiment use. Other significant structural components include the EVA hatch, meteoroid protection, radiators, high pressure gas bottles and their attachments, and the various mechanisms used to activate and support AM operations.

The structural/mechanical aspects of the AM appear to have been carried through from design, fabrication, and test in a manner which resulted in a few problems of significance. Normal developmental problems occurred as they have for all the other Skylab modules.

Airlock penetrations, the ATM deployment assembly, and the meteoroid shield/ radiator were areas of specific interest to the Panel.

Airlock penetrations include major areas such as hatches, windows, and pressure equalization valves in internal hatch doors, and the interface surfaces between the AM and the OWS and MDA. Particular attention has been given to maintaining leakage rates at or below the required level. This is because of the significance of the AM in meeting EVA pressurization demands and the number of windows. Hatch seals were a problem at the beginning. They have been redesigned and retested with new material and appear to have successfully completed all qualification testing. It might be well to mention here that the material used by the AM for hatch seals is now different than that used in the MDA seals. The windows as in the case of the OWS had venting provisions added to control the differential pressure in the cavity between panes. These were requalified successfully. These pressure/leak tests were completed during the past few months prior to the spacecraft acceptance reviews.

The ATM deployment assembly is a complex unit consisting of numerous "mechanisms" over and above the basic truss structure. Because of its criticality the deployment assembly was designed so that a single mechanical failure would not impair its operation. A significant point of interest is that the deployment reels are the only life cycle critical items on the AM. However, it is not expected that ground usage will require changeout. The pyro components are, of course, shelf-life critical; pyro appears to be no problem for the AM based on data supplied to the Panel. Rotary joint corrosion was considered the major possibility of a "hang-up" in deployment.

At NASA's request MDAC-East was to establish, through analysis and test, the minimum margin for deployment when one or both trunnion bearings are jammed or "frozen," forcing slippage of the entire bearing unit. They were to determine the maximum eccentricity of the latch engagement resulting from a single "frozen" bearing slipping as a unit. Based on analysis it was projected that no adverse impact would occur. Tests were initiated to verify the analysis. The closure of this will be noted in the next report.

The structures and mechanical system performance summary as presented at the formal DCR is shown in table XIV. The factor of safety appears to exceed the specification.

Environmental/thermal control system. - This system consists of gas supply, atmospheric control, thermal control, ATM control and display and EREP cooling, suit cooling, and purge. The ECS/TCS is shown schematically in figure 45. The 8-month endurance test which was completed in April 1972 provided much of the substantiation for the total system. Prior to examining the material presented at Panel reviews and at those programmatic reviews attended by the Panel it is well to look briefly at the part that each of the subsystems plays in the total ECS/TCS.

The gas supply provides about 5600 pounds of oxygen and 15 pounds of nitrogen from the high pressure bottles. This maintains a 74 to 26 percent oxygen to nitrogen atmosphere at a nominal pressure of 5 psia. The atmospheric control system provides moisture control, carbon dioxide and odor control, ventilation, and cabin gas cooling. Moisture is removed from the atmosphere by condensing heat exchangers and molecular sieve systems. They also remove CO_2 and odors. Ventilation is provided by GFE fans and condensing heat exchanger compressors. The thermal control consists of active and passive elements in much the same fashion as found on the other cluster modules. Active equipment consists of suit cooling heat exchangers, condensing head exchangers, cabin heat exchangers, and an oxygen exchanger. Equipment cooled by coldplates includes tape

ENVIRONMENTAL CONTROL INTERFACE

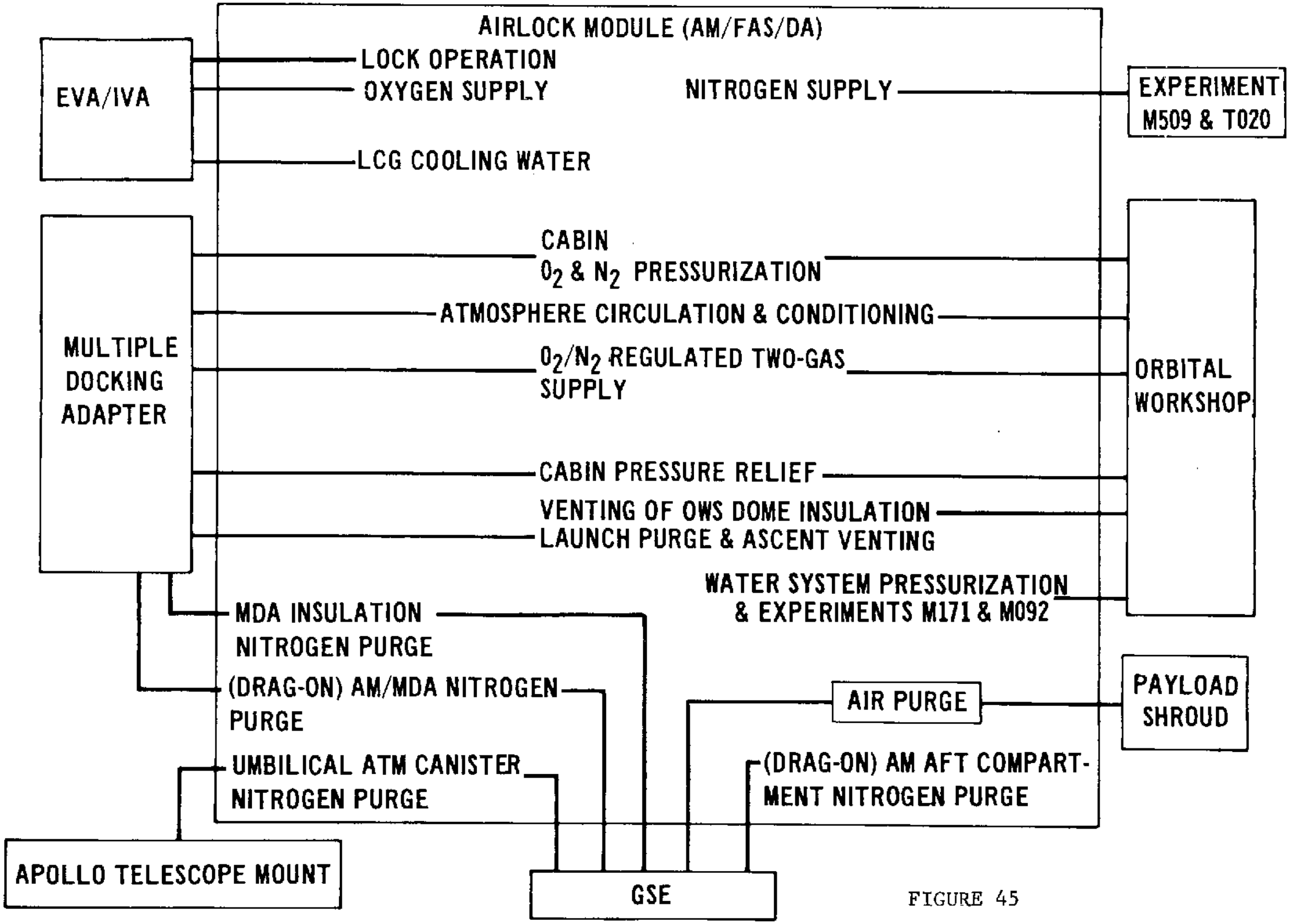


FIGURE 45

recorders, C&D panels, battery modules, EREP components, and electronic modules. Two separate coolant loops are provided for redundancy. The passive portion of the system includes thermal coatings, insulation, and curtains acting as insulation. The suit cooling system provides astronaut cooling during EVA and IVA by circulating temperature controlled water through suit umbilicals to the liquid cooled garments. Ground cooling and purge are provided by GSE cooling loops interfacing with in-flight heat exchangers and nitrogen purse gas introduced through a special fitting in the aft portion of the AM tunnel.

The test also included the related electrical communication and instrumentation components. The basic purpose of the test was to validate that the components had the endurance to function properly for a complete mission. The test system was designed to load the components under expected flight conditions. Factory and CSC procedures are the same.

The data were provided to the Panel on the development, qualification, and endurance tests at the component, module, and subsystem levels. These data indicated the system could meet the requirements. There are, however, a number of items remaining open from the test program and studies conducted by NASA and the contractor. The most significant items are noted here:

1. Thermal capacitor. The primary AM hardware problem has been due to a required redesign of the liquid cooling system thermal capacitor. The redesign was necessitated by structural problems caused by phase change wax expansion. A new capacitor was designed and built. It is undergoing qualification test with an estimated completion date of December 1, 1972.

2. Condensing heat exchanger separater plates. It appears that the separater plate assemblies started gas leakage long before they were expected. Redesign and retest were initiated. The qualification test was completed. A 140-day life test is being conducted with expected completion on December 27, 1972.

3. EVA suit coolant loop pumps. During acceptance tests all four pumps failed to start after 1 week dormancy in coolant loop fluid. Apparently interaction between loop materials and additives caused formation of nickel orthophosphate octalhydrate deposits (K_2HPO_4 with nickel from heat exchanger). These deposits prevented pump startup. NASA and contractor organizations are intensely investigating this problem. There is hope for a test start on December 15, 1972.

4. Condensate dump system. This was mentioned in the section of the report covering the OWS. It is, though, an AM problem. The problem is indicated as failure to dump condensate formed in the condensation heat exchangers into the OWS waste tank. This is due either to freezing in the exit port to one waste tank or entrapment of air in the water line. Design changes are still in process and testing is scheduled for completion around January 1973.

To better understand and predict ECS/TCS performance additional studies have been instituted. These include (1) definition of the coolant loop performance, (2) recommendations on flight procedures when providing water cooling for the three crewmen during EVA for various combinations of water loop operation, and (3) assessment of the impact of the rescue mission on AM ECS/TCS. There appeared to be some discussion concerning the GSE interface data needs and their control between KSC and MSFC. The extent of this question and its resolution are not known. The question of how long the crew can use the cluster if the ECS fails is one that must be answered in contingency planning. Such contingency planning will be reviewed further in the next report.

The successful completion of all component-level qualifications testing coupled with successful completion of the system level testing should provide the necessary confidence in the AM environment and thermal control systems.

EVA/IVA subsystem crew hardware. - The Skylab EVA currently involves all three crewmen for periods of up to 3 hours. During the first visit, 28-day occupancy, one EVA is planned. The second and third visits require 3 and 2 EVA missions, respectively. It is our understanding that there are no contingency EVA's planned at this time although they are under consideration.

The EVA hardware includes such items as an exterior workstation, lighting, film transfer mechanisms, handrails, oxygen, electrical power, and communications for the three suited crewmen. The Panel did not examine EVA hardware in any detail other than to assure that the cognizant organizations were delving into these systems to root out the problems and resolve them. There appear to be no major problems, and those items that were still open at the time of the formal DCR did not seem to be significant (i.e., EVA foot restraint functional tests and requalification of the film transfer boom device).

Electrical power system. - The EPS conditions power received from a solar array, mounted on the OWS, charges the nickel-cadmium batteries and supplies load requirements. During orbital dark periods, power is supplied to the load from the nickel-cadmium batteries. System output voltage is adjustable for proper load sharing periods of parallel operation with other cluster power sources. AM power system normally operates in parallel with the ATM power system to satisfy cluster power requirements.

The electrical power distribution system is comprised of positive isolated buses with a common return. The negative bus is tied to the vehicle structure at only one point (single point ground). The isolated buses may be tied together through two circuit breakers by the crew when necessary. Overvoltage protection is supplied by bus shunt regulators. The electrical power system protection is further discussed in the CLUSTER FAULT CURRENT PROTECTION and SNEAK CIRCUIT ANALYSIS sections. The EPS is shown in figure 46.

Because of prior spaceflight history and the fact that EPS is generally accepted as the major, if not only, ignition source available on board the Skylab vehicles, the Panel

SKYLAB ELECTRICAL POWER DISTRIBUTION

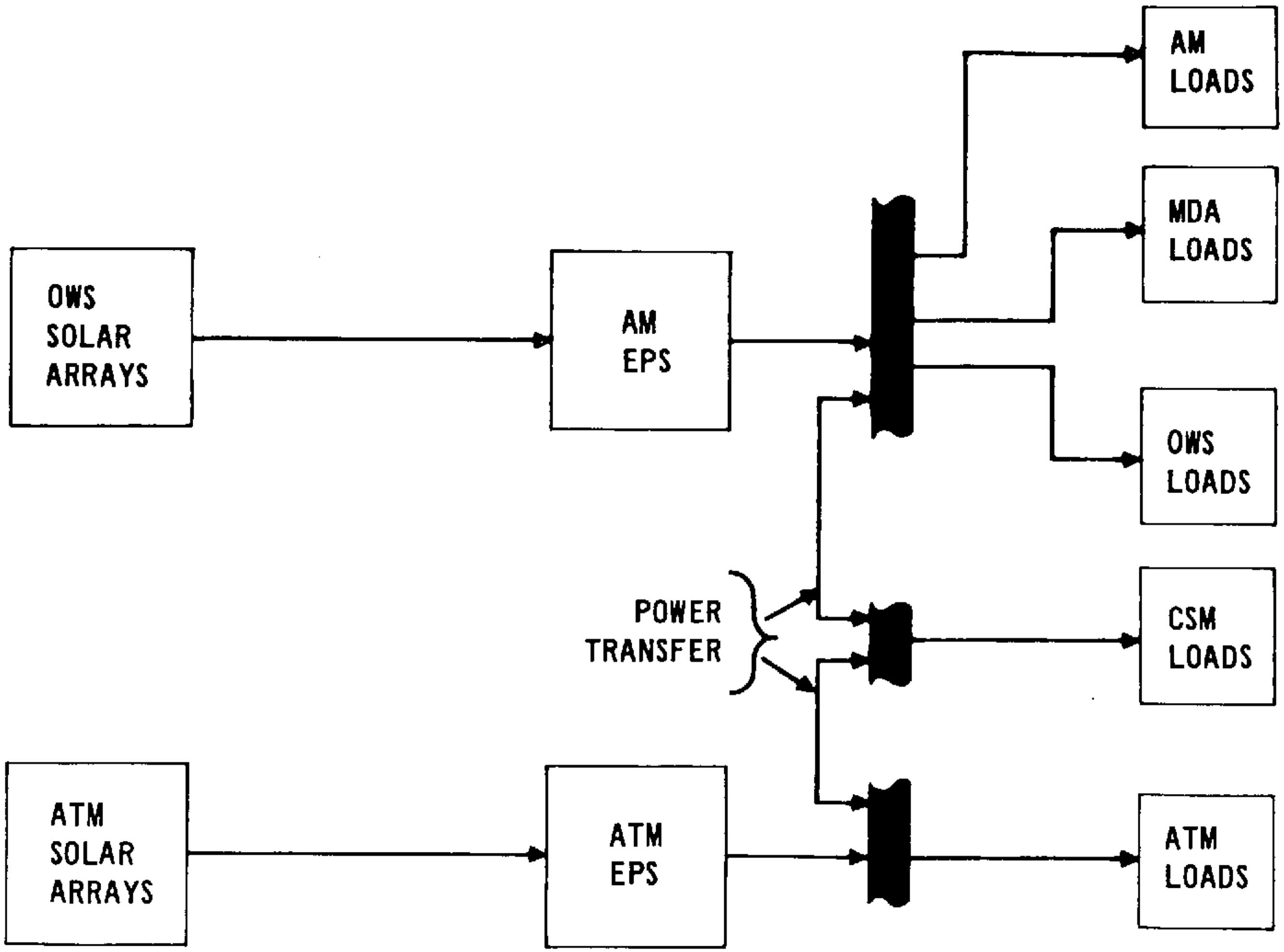


FIGURE 46

exerted additional effort in examining this system. The Panel specifically was interested in the wiring harness design and installation, the system tests and their results, and the FMEA and SFP analyses.

The wiring design, fabrication, and installation were watched very closely by not only the contractor but NASA as well. It is pertinent to point out unique fabrication techniques used as well as important details which point up the extra care taken. This takes the form of a tabulation, but it will, no doubt, increase the readers confidence in the EPS:

1. During fabrication the harnesses were "layed-in" rather than fed through the module. This reduced installation time essentially eliminated wire damage due to scuffing and cutting, avoided "captive" wire harness problems, and allowed access for inspections.

2. Redundant wiring through separate routing paths was used to ensure that damage which may occur to one line is not likely to occur to the other.

3. Where connectors were involved sufficient wire slack was left to effect easy equipment removal. Connector clearances were made sufficient to preclude the need for special removal tools. Adjacent connector interchangeability was avoided wherever possible.

4. Insulation and buffering provided the following:

   (a) A structural insulation barrier for unprotected power feeders
   (b) 360^0 fiberglass reinforced silicon or fluorel wedge-type cushion clamps
   (c) Protected positive terminal strips with nylon dome nuts on terminal studs and molded potting overall
   (d) Protection of interior wiring not behind enclosed panels by polyimide, aluminum, and NBG convolute covers

5. Special wire bundle restraint methods control wire runs and possibility of damage.

The AM went through an exhaustive series of tests: development tests, qualification tests, spacecraft acceptance tests, supplier hardware acceptance tests, and special tests to verify specific items of concern. Only the nickel cadmium battery life cycle qualification test is incomplete. Its purpose is to requalify the redesign of the cells. The test was initiated October 15, 1972.

Caution and warning system. - Various aspects of this system have been covered under other sections of this report. The important point here is that the AM contains the chief center or master unit for the cluster C&W system. This system is shown schematically in figure 47.

During testing the rapid ΔP alarm was activated several times while the vehicle was being illuminated with radiofrequency energy from the radiation simulator system. This problem was resolved by replacing the existing wire bundle tied to the ΔP sensor

AM CAUTION AND WARNING SUBSYSTEM

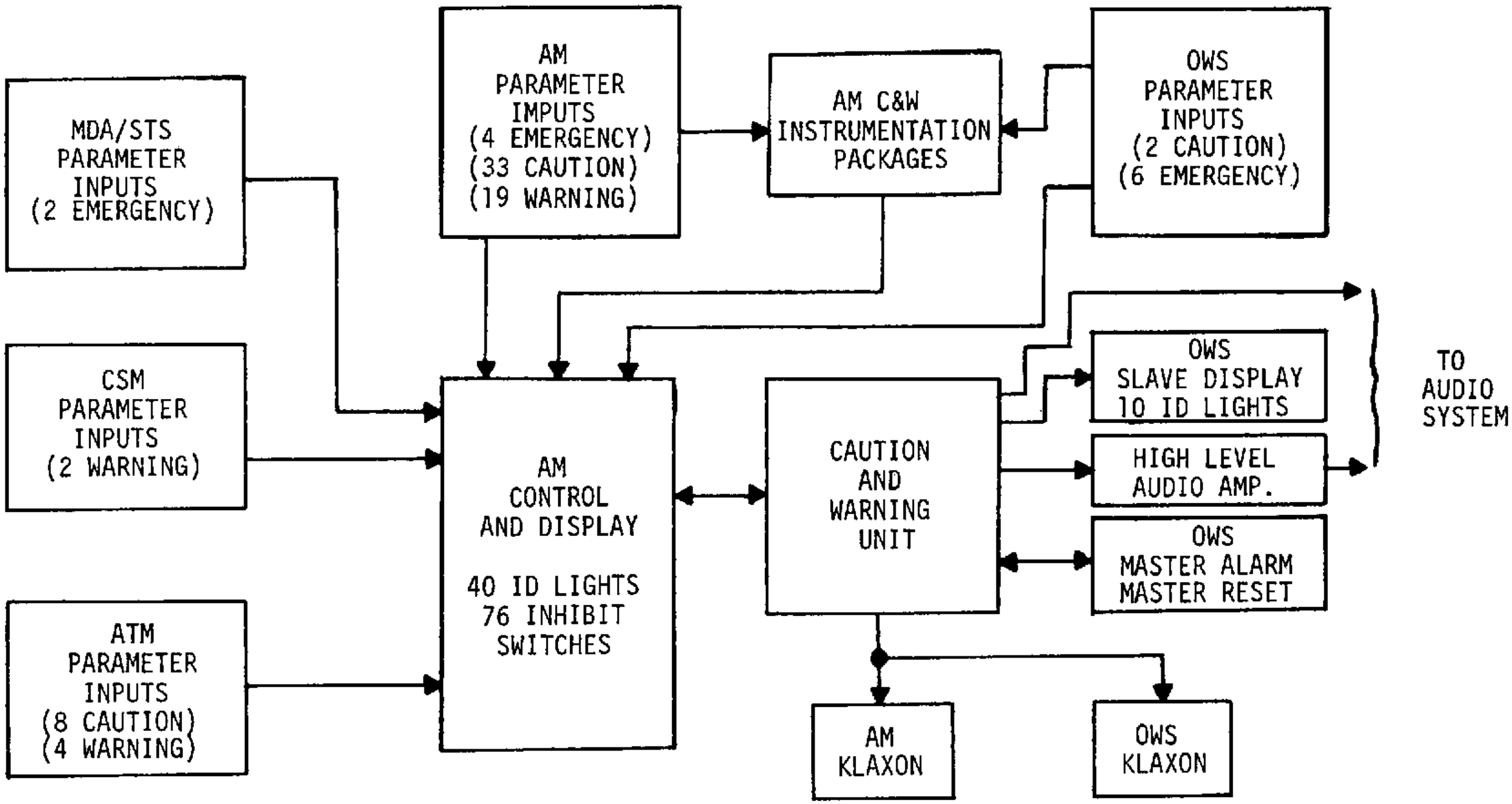


FIGURE 47

with a new cable. It is double shielded with ferrite beads installed on each wire within the cable.

The C&W system monitors fire and rate of pressure drop as well as bus voltages throughout the cluster, critical temperatures, partial pressure of oxygen, cluster attitude, etc. From the material reviewed by the Panel this system appears to be in good shape. The controls exercised by management and technical personnel indicate that this confidence is well placed. A further check of this system will occur during end-to-end testing at KSC.

Crew equipment. - This system consists of control and displays, mobility aids, lighting, stowage, communications and utility power outlets, and in-flight maintenance equipment. Essentially all of the problems identified in the SOCAR, DCR, and SAR have been closed or plan developed to achieve proper resolution. In the area of instrumentation and communications there are numerous qualification status reports still awaiting completion and approval by NASA. These should be accomplished as quickly as possible to assure proper documentation is available where and when it is needed. The same problem appears to exist with respect to a number of I&C intercenter ICS's. Another item to be closed out at KSC in February 1973 is the AM data recorders since acceptance testing was not complete at the time of AM turnover. A system performance summary chart used at the DCR provides additional data on the AM data subsystem (table XV).

During altitude chamber testing the Mosite packing material used in stowage containers swelled and contracted due to entrapped gas in the interstices of the Mosite. This material problem is applicable to both the AM and MDA. It is discussed more fully in the CLUSTER MATERIALS section. The problem is being resolved by changing material and reworking current locations to preclude interference between Mosite and hardware.

The in-flight maintenance program was reviewed in detail during the SOCAR activities. There were three significant results from the in-flight maintenance team report:

A. At the present time the IFM activity integrates all onboard tools to ensure availability and to preclude duplication. However, there is no formal method for cluster tool requirements, other than for in-flight maintenance tasks, to be transmitted to personnel involved with IFM. Consequently, the SOCAR Team Chairman recommends that action be taken to have the IFM program expanded to include activation, deactivation and operational tasks which involve tools, spares and/or servicing. He will also ensure that extravehicular mobility unit (EMU) and microbial contamination control tasks are adequately covered in the operational documentation.

B. Level II CCB approval of new IFM tasks requires too much time. A crew IFM procedure, in addition to other task data, will be provided by module contractors. MSC will review the procedure and other task data and verify the task as necessary. This will reduce approval time, changes, and revisions later on in the program.

C. Many inconsistencies exist in IFM program documentation. These differences are primarily between the IFM baseline document (LS-005-003-2H) and the Operations Handbook.

The Panel, as a result of its review of data presented at the DCR's and SAR's, feels that these problems are well in hand and envisions few difficulties in the future.

Risk Assessment and the Management System

MDAC-East's management systems effectively used Mercury and Gemini experience. They also made efficient use of NASA and intracompany support.

MDAC-East has used a series of tools to assist in the identification and solution of technical problems in a manner much the same as other contractors. These tools include FMEA, design reviews, use of NASA alerts, continuous management review of designs and procedures for hazard identification and resolution, personnel motivation programs, test and development organizations, and tight vendor control. The result is our confidence in management and the flight systems.

MDAC-East used meetings of in-house and NASA personnel on a daily, weekly, and monthly basis to discuss status, problems, solutions by engineering, manufacturing, test, and management.

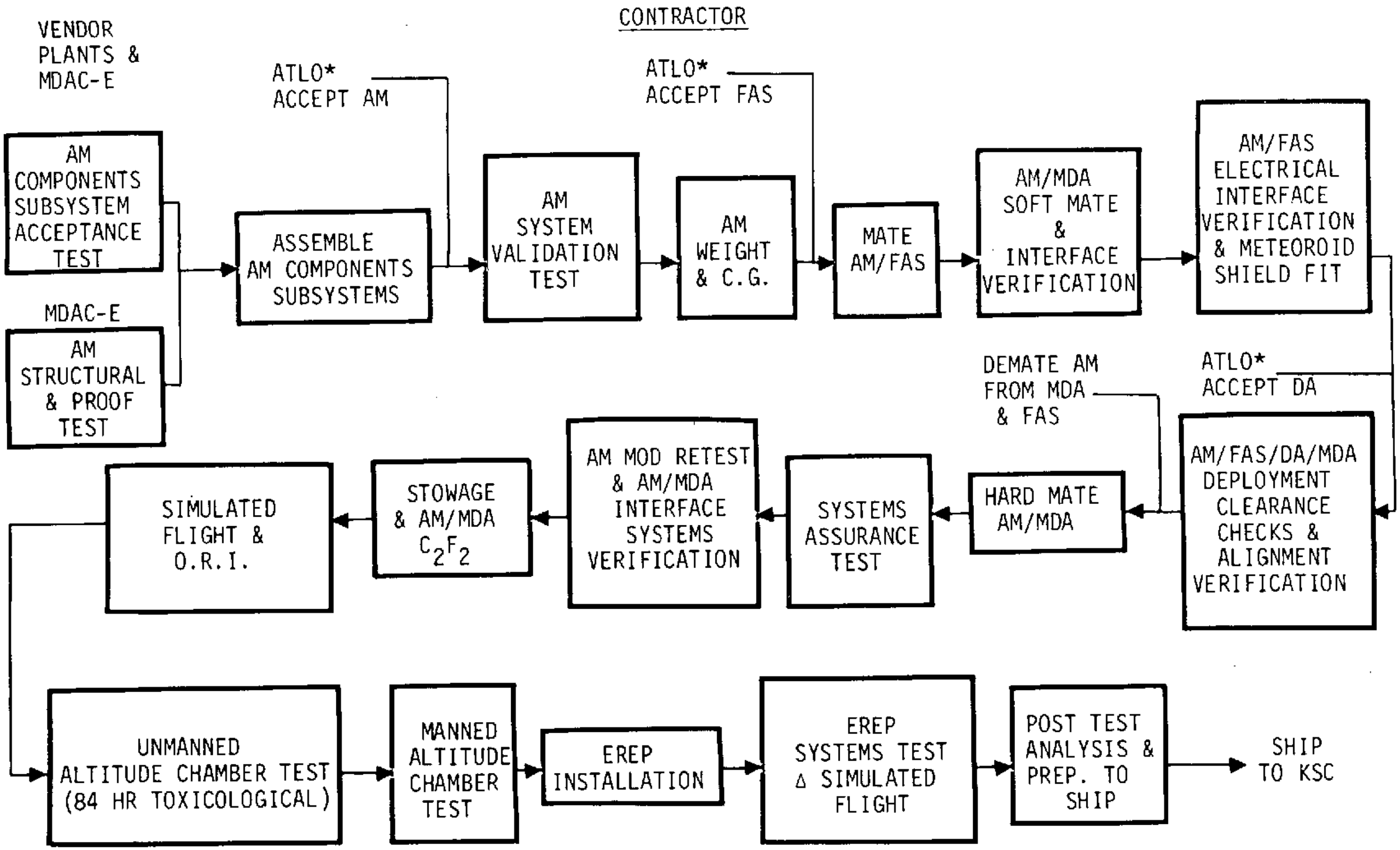
Test procedure formulation and actual test activity appears to have been closely coordinated with and monitored by NASA. Where anomalous conditions were encountered and corrected it again appears to have involved a high degree of coordination and information interchange with NASA. The test program is carried out at the factory and at the test site as shown in the schematics (figs. 48 and 49).

MDAC also conducted a self-assessment in terms of the findings and recommendations of the Centaur and Thor-Delta report. They noted the key personnel, including all engineers, have been given motivation and orientation lectures, and that NASA/MDAC motivation material is used to maintain continuous attention to this area. Vendors were furnished the same material. Vendor hardware penetration surveys concentrated on how the vendor personnel actually design, fabricate, test, and handle the hardware. As deficiencies were noted they were quickly examined and corrected to preclude further impact on the factory design, test, and fabrication. Internal AM reviews were structured to take into account ease of assembly based on the need to inspect and test.

To further understand and reduce the hazards on the AM, MSFC directed MDAC-East to expand the on-going AM and AM/GSE FMEA program to include the following failure modes: (1) relays and switches with respect to premature operation and failure to cease operation, (2) circuit breakers with regard to short to ground on unprotected side, and (3) connectors with regard to open and shorted pins. This expanded program resulted in

AIRLOCK MODULE

ACCEPTANCE TESTING



*ACCEPTANCE TEST AND LAUNCH OPERATIONS DIVISION

FIGURE 48

AM/MDA/FAS/DA/PS
ACCEPTANCE TESTING

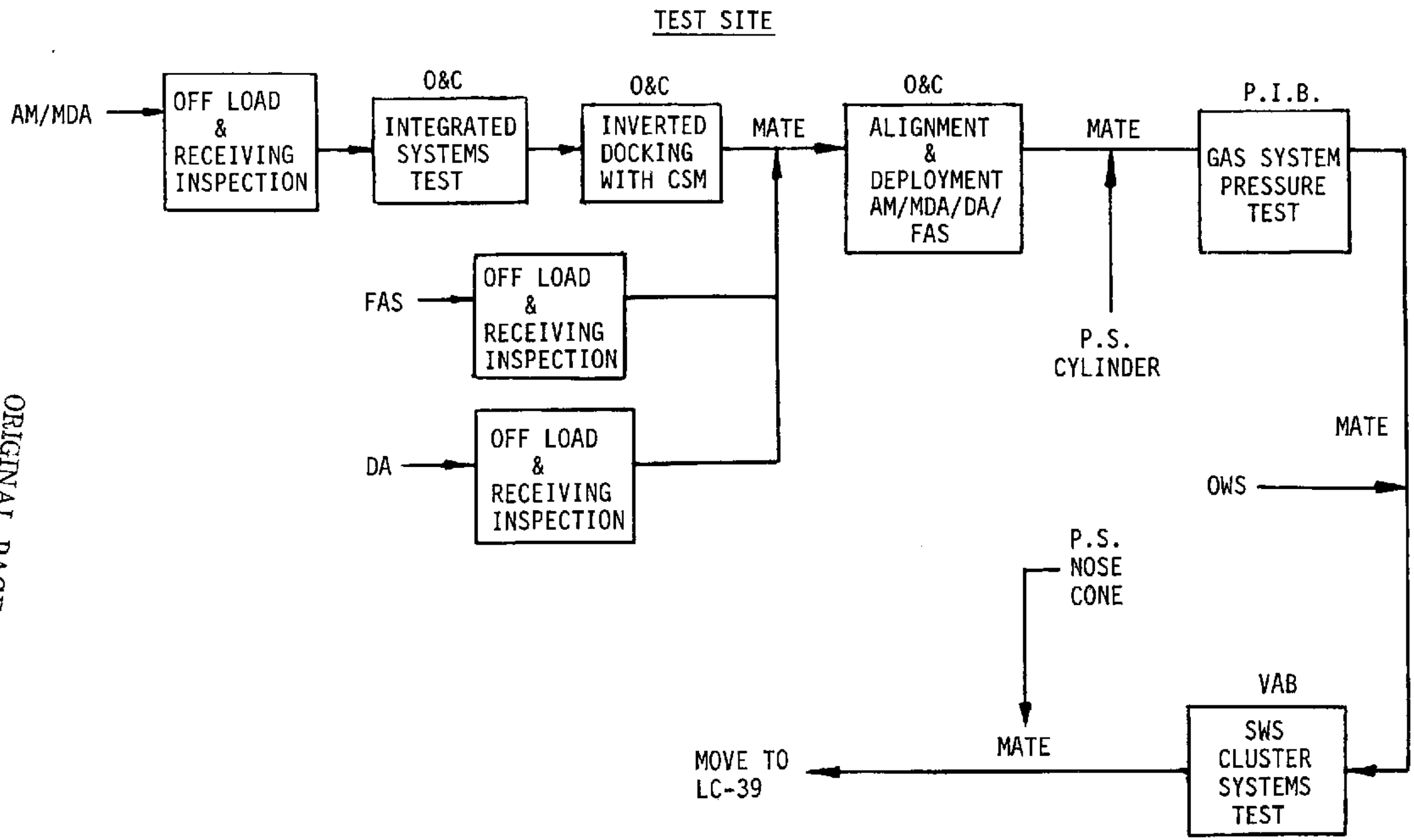


FIGURE 49

the evaluation of approximately 29,000 additional conditions of failure. Completion of this effort is expected by February 1973.

Meetings have been held periodically with Martin Marietta Corporation integration personnel and appropriate NASA personnel to resolve safety problems and noncompliance items encountered during system safety checklist analyses. As an example, special analyses were conducted to determine the flammability characteristics of flame propagation in the condensing heat exchanger and the molecular sieves modules.

The Panel asked about the high pressure gas system which carries nitrogen and oxygen into the onboard systems. It appears that the high pressures from the storage bottles surrounding the AM are carried to the basic AM structure (internal) before a pressure reduction valve system comes into play to reduce pressures to those needed. Prior experience has indicated that such pressure reductions should take place as close to the high pressure source as possible. If this is the case, the rationale for this design decision should be included in the SAR.

Inspection of the AM by the walk-through NASA group indicated that there were several instances of electrical cables in close proximity to sharp corners and edges and that some wiring was "squeezed" into containers and trays.

In summarizing the discussion of the AM systems the following open items are noted:

1. ATM deployment mechanism tests on jammed or "frozen" trunnion bearings
2. In the ECS/TCS -
   (a) Thermal capacitor requalification test
   (b) Condensing heat exchanger life tests
   (c) EVA suit coolant loop pump corrosion problem
   (d) Condensate dump system design change and retest in process
3. Nickel cadmium battery requalification test
4. Life test of the partial pressure oxygen transducer life test

The material presented to the Panel indicated an adequate AM management system. Again it is of the greatest importance to maintain the same high level of motivation and competence on the program as the AM moves through the test, checkout, and launch preparations period at the KSC.

MULTIPLE DOCKING ADAPTER

The multiple docking adapter (MDA) is the control center for Apollo telescope mount (ATM) and Earth resource experiment package (EREP) experiments. It is mounted on the forward end of the airlock module, and provides a docking post for the CSM's and a structural support to docked spacecraft. The MDA is a 10 1/2 foot diameter cylinder and is slightly over 17 feet long (see fig. 50).

The primary port for docking the CSM is axial and located at the forward end. The

MDA

HARDWARE ELEMENTS - EXTERIOR

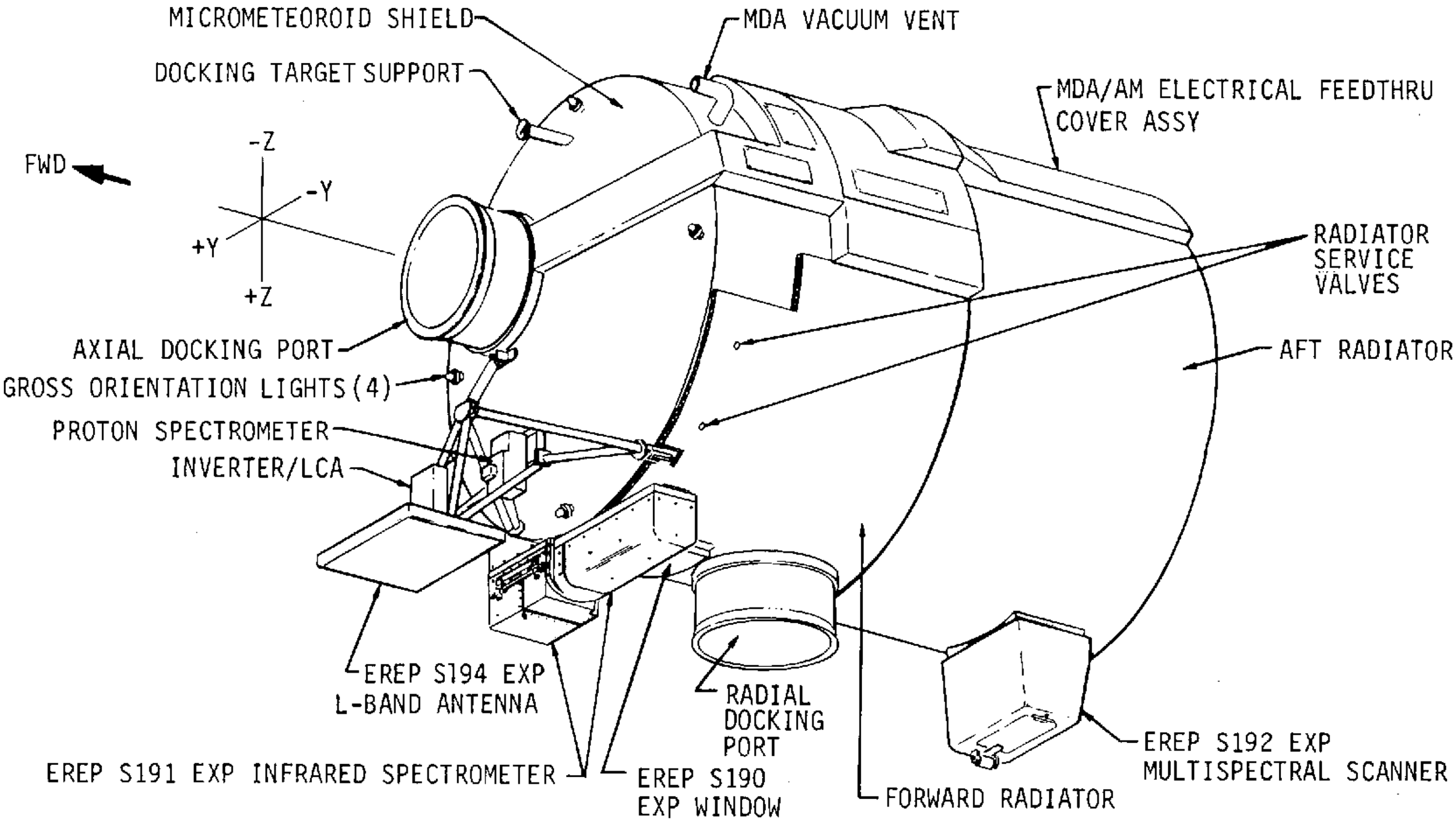


FIGURE 50

alternate port is located on the side of the module. Cameras and EREP sensors are located adjacent to the alternate docking port. Some look through a window in the wall, others actually protrude through the wall. Vaults are provided for storage of cameras and film for the ATM experiments. These vaults protect the film from the radiation environment experienced at orbiting altitudes.

The control and display console for the ATM is located in the rear of the module. It contains all the controls and instruments required for operation and observation of the ATM solar astronomy experiments. This control and display console also contains the instruments and controls for the ATM attitude control system and for the ATM electrical power system.

The MDA presented unique management challenges. It was initially designed and partially manufactured at Marshall. Then the utilization contractor in support of Marshall assumed responsibility to complete and equip the module. Finally, it was shipped to another contractor site for mating with his module and integrated testing. Thus, transfers of work and joint operating agreements had to be well defined. This is one illustration of the variety of contractual and operational situations in Skylab. That these arrangements were managed as well as they were speaks well for the contractor and NASA.

Management Aspects

The MMC-Denver did not have direct experience with management of manned space vehicles. However, they had substantial background in both manned (Gemini) and unmanned vehicles as well as manned spacecraft studies (Dynasoar, MOL). They have achieved a high degree of proficiency in carrying out their roles and responsibilities. In its review the Panel examined the pattern of problems encountered and the problem solving mechanisms. We also reviewed mechanisms to assure (1) senior management visibility of in-house operations, (2) assimilation and use of prior hazard knowledge and overall risk assessment experience, (3) quality assurance, (4) vendor control, and (5) intercontractor/NASA coördination. Activities to integrate the MDA into the cluster were of particular interest because of the contractors' overall integration role and the interfaces between the MDA and MSFC's Apollo telescope mount and the MSC Earth resources experiment package.

Special attention had been given to personnel responsibility, attitudes, and skills. MMC considers the PIE concept as one of the major contributors to goals of excellence in design, test, manufacturing, and change control. The PIE is a highly qualified, specialized engineer assigned by the program manager. He has the responsibility for a specific area of emphasis on a continuous basis. Specific areas of emphasis include subsystems, major components, test, materials and processes, etc. He has the responsibility for the technical integrity of all phases of design, development, fabrication, test, and operations. In his work of preventing, recognizing, and solving problems he provides upper levels of management with the required visibility for them to make adequate and sound decisions. Specific procedures were issued to cover the PIE concept and its implementation. From the material presented to the Panel it appears that this system has worked well and provides both vertical and horizontal control of the MDA program.

The training and certification program is much like that of other Skylab contractors and appears to be thorough and consistently implemented.

The results of the Centaur/Delta boards were reviewed in depth by the managers assigned to manufacturing, test, and quality. MMC made special efforts to contact specific members of the Centaur board who could be helpful in providing MMC with more detailed insight into the workmanship and management problems that might be applicable to their own program. It was apparent that MMC initiated steps to achieve improvements in their system wherever warranted. This willingness to accept the problems and solutions of others indicated an openness that most certainly would aid in achieving successful hardware.

In its early reviews of MMC, the Panel noted that the normal problems inherent in any large scale program were evidenced here, but that, like any of the other contractors, they were aware of them and resolving them as quickly as possible. The fact that MMC was the system integration contractor provided them with greater visibility of the program and the on-going problems. This in turn permitted them to look into their own operations with more knowledge. On the whole, the management systems and their implementation at MMC appeared to be in good shape and provided further confidence that not only their own hardware but the integrated cluster hardware would more nearly meet its requirements.

The interfaces illustrate the depth of MMC's penetration into the program. These interfaces involve EREP support equipment, medical and scientific experiments, associated GSE, Skylab experiment GFE and ICD configuration management, mockups and training equipment, and engineering support.

To assure that adequate skills continue to be available, key personnel are identified by discipline and name for retention to provide failure/anomaly review and analysis, test site support, and mission support. Furthermore, MMC is involved in the logistic support area dealing with spares and repair depot efforts. Skylab postdelivery support covered the following four areas:

Medical and scientific experiments at MDAC-West	October 1971 through August 1972
EREP and scientific experiments at MMC and MDAC-East	June 1971 through August 1972
KSC experiment support	August 1972 through December 1973
Denver engineering support	Current through December 1973

Hardware Aspects

In the design of the MDA, as in the other Skylab modules, the use of prior manned space programs experience and hardware played a very prominent part. For example, the design specifications, materials data, cleanliness, and general safety criteria were derived from Apollo and Gemini programs. In the case of hardware the following items were used:

Fire extinguisher (Apollo)	Docking drogue (Apollo)
Connectors (Apollo)	Docking targets (Apollo)
Flex lines (Apollo)	4-port selector valves (Apollo)
Fans (Apollo)	ΔP gages (Apollo)
Equalization valve (Gemini)	Running lights (Gemini)

The experiments mounted in and on the MDA are covered in the EXPERIMENTS section of this report. The ATM C&D panel is covered under the APOLLO TELESCOPE MOUNT section of this report.

Throughout the design, fabrication, and testing of the MDA there has been crew participation. This close coordination and consultation has been most helpful in producing a vehicle to meet the hardware and crew requirements in an optimum manner.

Some of the program concerns noted in the January 1972 review by the Panel are still present in the program. This is particularly true of the amount of deferred work due to nonflight hardware used in place of flight equipment.

Structures

There have been no significant design changes to the basic structure since the critical design review. Items of structural interest which are indicative of the ability to meet and resolve problems include the L-band antenna truss, pressure hatches (axial and radial), windows, window covers, and stowage containers.

The MDA proof pressure and leak test indicated that the actual leakage rates were some 20 percent of the allowable (1.097 lb/day versus 5.280 lb/day). All of this occurs through the MDA shell and the axial tunnel with no unacceptable losses through the radial tunnel area. When tested with the AM in a combined mode at St. Louis the total leakage was less than 2.2 pounds per day at 5 psi differential for both modules.

Structural verification methods for the cluster state that "Hardware that has calculated factors of safety of 3.0 or above and those that are similar to previously tested and used hardware are to be verified by analysis only. Hardware designed with factors of safety below 3.0 shall be tested to demonstrate structural integrity." While the windows have calculated factors of safety in excess of 3.0 they were tested none the less because of their criticality.

The L-band antenna truss structure is not in itself a critical item. It does, however, support the inverter lighting control assembly which is controlled by both the critical and limited life listing. There is a constraint to installation. The truss cannot be installed on the MDA at the same time as the MDA handling fixture because they both attach to the same fitting. This becomes a matter to be covered by the handling and associated procedures documents to assure no inadvertant impact on this truss.

The removable hatches provided for each docking port are functionally interchangeable. Hatch handles are provided on both sides of each hatch so that a hatch can be manually opened or closed from either side of the hatch. A positive lock is provided on the hatch handle (CSM side) to preclude inadvertent actuation. This lock permits contingency mode operation of the hatch from inside the MDA. Each hatch contains delta pressure gages and a pressure equalization valve. The hatch lip rests on a silicone rubber seal to achieve a pressure tight closure. Due to problems with this seal material becoming sticky under test the material has been changed. It is currently undergoing long term qualification testing. Testing was initiated August 5, 1972, with completion set for April 1973. Interim inspections will be made of the seal material in September, November, and early April (1973) to ascertain its state. This will provide time if necessary to institute corrective measures. It is interesting to note that the seal materials used by MMC and MDAC-East are not the same. These hatches because of their criticality have received a good deal of emphasis from both the design and proofing standpoints.

The Panel examined the glass and window designs in the MDA. Currently the S190 safety shield is undergoing delta qualification testing as a result of design changes made to meet leak rate requirements. Estimated completion date is December 1972. There was an ECP in process to make the safety shield (which is a tempered glass) a complete structural backup for S190 window. The status of this ECP is to be noted in the next report. If this ECP were approved the resultant changes would most likely require some form of delta qualification and perhaps other associated documentation changes.

Environmental/Thermal Control Systems

The MDA uses the active ECS and TCS of the airlock module. The MDA contains its own passive system along with heaters as required. The passive thermal system consists of insulation blankets, paints, and coatings. The active system includes ducting and fans to circulate the atmosphere, heaters and associated thermostats, and coolant loops for the ATM C&D console and the EREP water loop and MDA radiator. The environmental control system consists of vent valves, equilization valves, mufflers, ducting, diffusers, and the like. Problems in this area have in general involved the ATM C&D and the EREP equipments. The basic MDA ECS/TCS hardware and test program appeared to offer few problems. The SOCAR determined that some minor hardware and documentation discrepancies existed. To our knowledge they have all been resolved. There were however some cases where flow tests were not conducted and the test deviation accepted on an analytical base. Typical were the flow and pressure drop test of ATM/EREP coolant system. The SOCAR indicated that the only discrepancies were associated with the valves and ΔP gage. This indicated few concerns here.

Electrical Power System and Caution and Warning

The MDA electrical system interconnects all electrical hardware between CSM/AM/ATM and other MDA loads. There are some 40,000 feet of wire with approximately 8,000 connections. As in the case of the other modules the wiring, when not conducted external to the manned areas, is covered in sleeves and trays that eliminate to the greatest extent possible proximity of flammables and ignition sources and propagation paths. Figure 51 is a simplified schematic of the cluster EPS. Of interest here is the relative dearth of equipment in the MDA in comparison to other modules. There appeared to be few areas of concern in this EPS and all are indicated to be closed.

The fire detection system in the MDA is comprised of two ultraviolet fire sensors (identical to those used throughout the cluster) and one fire sensor control panel. No anomalies were apparent in this system during the various phases of the acceptance review cycle. Any SOCAR actions have been closed. MMC's attention to the actions taken by MDAC-East, MDAC-West in their C&W systems seems to have paid dividends in their MDA efforts.

SIMPLIFIED DIAGRAM OF THE
ELECTRICAL POWER SYSTEM

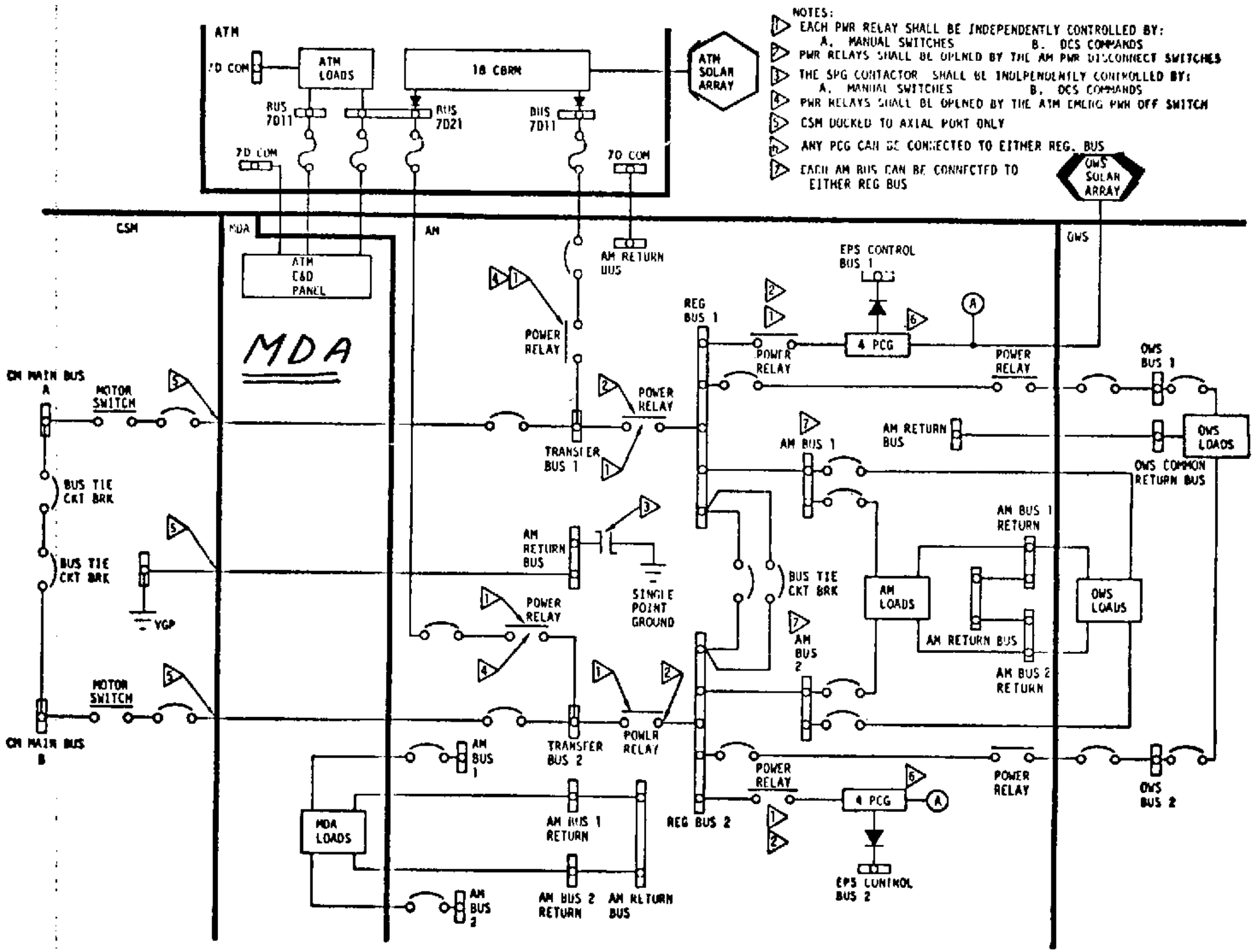


FIGURE 51

Instrumentation and Communications

The instrumentation system includes 89 measurements for temperature, hardware and experiments, and internal pressure. The communication system includes speaker intercoms, headsets, voice down-link via the CSM, and television input station and adjunct equipments. The MDA provides for all cluster television input stations. It includes a television video switch which permits selection capability in the television system and couples the video signal to the FM S-band transmitter in the CSM. In addition, it signals conditions and amplifies the ATM signals. Because of these multiple interfaces the interface control documentation system is most important. There were a number of open PIRN's to the basic ICD's. These should be closed as quickly as possible to preclude problems at the KSC during test and checkout operations. The history of the television systems, both on the Skylab program and prior manned/unmanned programs, indicates that this area requires a special effort on the part of management to assure that all will be in readiness by launch time.

Crew Equipment System

There are stowage areas using the Mosite material which has been discussed elsewhere. Repair materials and in-flight maintenance tools are also found in the MDA. One problem that still exists is the inverter/lighting control assembly. It generates noise at a level which appears to disturb the crew. The status of this problem will be noted in the next report. Test activites at KSC appear routine except for the evaluation of new mods to the axial hatch. This requires a crew test with MDA in the horizontal position.

Ground Support Equipment

The GSE, including that supplied by NASA, has been used during the process of testing the MDA at both Denver and St. Louis. There are a few significant items of note which should probably be resolved prior to extensive testing at KSC. These involve the Skylab television test set, an electronic test set (GFP), and data quick look system and fit checks. There have been no indications that the GSE has over-exercised the flight hardware during the testing to date.

Management and Risk Assessment

While there were no doubt "growing pains" and learning experiences the quality of the MDA basic hardware reflects well on the individual skill, dedication, and thoroughness of management. A characteristic of the MMC efforts is the early and strong partici-

MDA

FLIGHT ARTICLE FLOW DIAGRAM

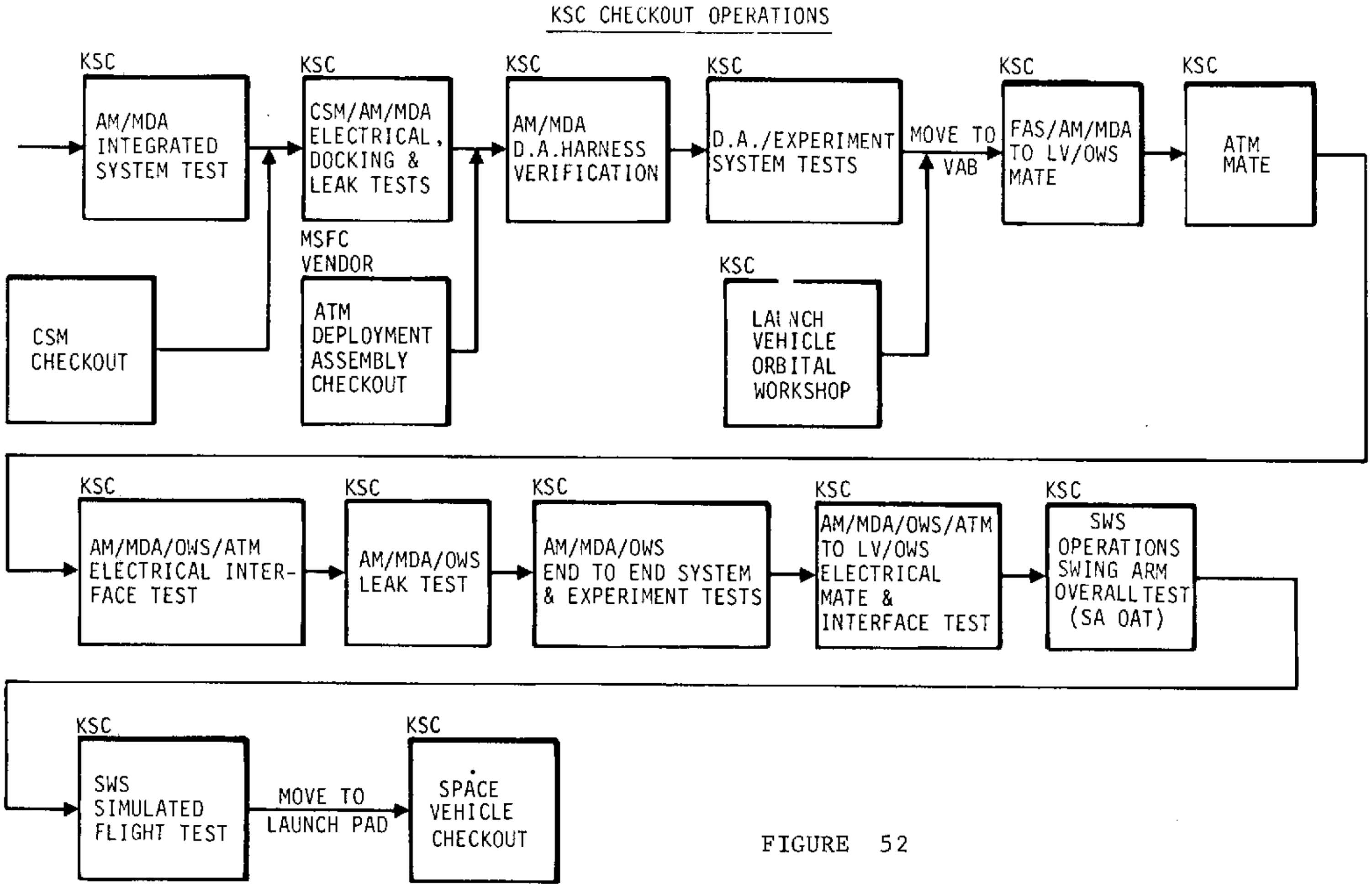


FIGURE 52

pation of the flight operations people in the hardware development program, again due in part to the integration working groups.

The MDA is expected to progress through its KSC cycle in the manner shown in figure 52. The open items noted in the preceeding discussion indicate no particular problems of significance should be expected during the KSC period. The experiments contained within the MDA are not a part of this discussion but are handled separately in the EXPERIMENTS section of this report.

PAYLOAD SHROUD

The payload shroud (PS) is designed to provide an environmental shield during the final stage of assembly/checkout and launch. It is also an aerodynamic fairing for launch and boost phases. Finally, it provides structural support to the Apollo telescope mount during prelaunch, launch, and boost phases.

The PS separates on command into four discrete segments. Radial velocities are sufficient to prevent recontact with the payload. Separation is effected through segment joints containing an explosive/bellows linear thrusting device located along the longitudinal segment separation lines. The shroud is unlatched prior to separation by explosive operated latch actuators. These are located at the segment joints for structural continuity. Separation is further aided by the use of tension cleats and bolts which fasten the lower end of the PS to the fixed airlock shroud.

This unit is handled in somewhat different fashion than other modules contracted to the MDAC-West and East divisions. The airlock payload shroud is contracted to MDAC-East as part of the airlock program. However, the shroud was manufactured by the MDAC-West special space programs office. This arrangement has not hampered the development and interface efforts in any way.

The general configuration of the PS is a double angle nose cone mounted on a 260-inch diameter cylindrical section 350 inches long. The forward nose cone has a 25° cone angle and is 182 inches long. The aft cone is 142 inches long with a 12.5° cone angle. The total length of the shroud is 674 inches long and it weighs approximately 25,000 pounds.

ATM launch loads are reacted by the PS support structure located at 90° intervals on the forward end of the cylindrical section. Provisions are made in the PS for access doors. The Saturn V damping system will be attached for use during transit from the VAB to the launch pad and for servicing while on the pad.

The PS acceptance review was conducted on August 10, 1972, and the Material Inspection and Receiving Report (Form DD250) was signed on August 31, 1972. It was received at KSC on September 22, 1972, well in advance of the KSC need date.

The jettison system for shroud separation in orbit was verified through component and full scale testing at the Plum Brook Facility, Cleveland, Ohio, vibro-acoustic testing at MSC, as well as other needed tests for qualification.

At this time one item remains to be qualified in the separation and ordnance subsystem. The diode modules are inaccessible for removal before flight. While they are now a nonfunctional flight item, assurance is required that they will not contaminate the payload.

The only open problem is the resolution of the shrinkage in the linear explosive assembly as a result of environmental conditions during storage prior to shipment to KSC. It is assumed that the new thermal conditioning process and environmental control of the shipping and storage modes should take care of the shrinkage problem.

APOLLO TELESCOPE MOUNT

The ATM houses a sophisticated solar observatory. It also provides attitude control to the cluster, and, by means of its solar arrays, provides about half the electrical power used by the cluster. The ATM consists of two concentric elements. The outer element, the rack, is an octagonal structure 11 feet from side to side and 12 feet high. The inner structure is the solar experiment canister and is about 7 feet in diameter and 10 feet long. Figure 53 shows the ATM and its component parts in relation to the total Skylab cluster.

The rack, in addition to supporting the canister, supports the four ATM solar arrays and contains the components of the attitude control system, the ATM communications system, and the thermal control system that maintains the temperature of ATM equipment within required limits. The canister is mounted in the rack on gimbals which allow it to rock 2° about two mutually perpendicular axes. A roll ring allows the canister to rotate about its axis. These features make it possible to point the experiments at their targets with greater precision than can be accomplished with the cluster alone.

During launch and ascent to orbit, the ATM rack is directly supported by the PS. When the shroud is jettisoned, the support structure assumes the structural support task. The ATM support structure, which connects the rack to the forward end of the fixed airlock shroud on the AM, incorporates a deployment mechanism that rotates the ATM 90° from its launch position in front of the MDA to its operating position alongside the MDA. Two work stations are provided so that an astronaut can perform the EVA task of changing the cameras and film magazines for the solar telescope.

The ATM is the major in-house development task that is performed at MSFC. MSFC has the total responsibility for the design and development including the experiments produced by a number of different PI's and their contractors. From the point of view of the total mission, the ATM experiments are supported by a ground-based ob-

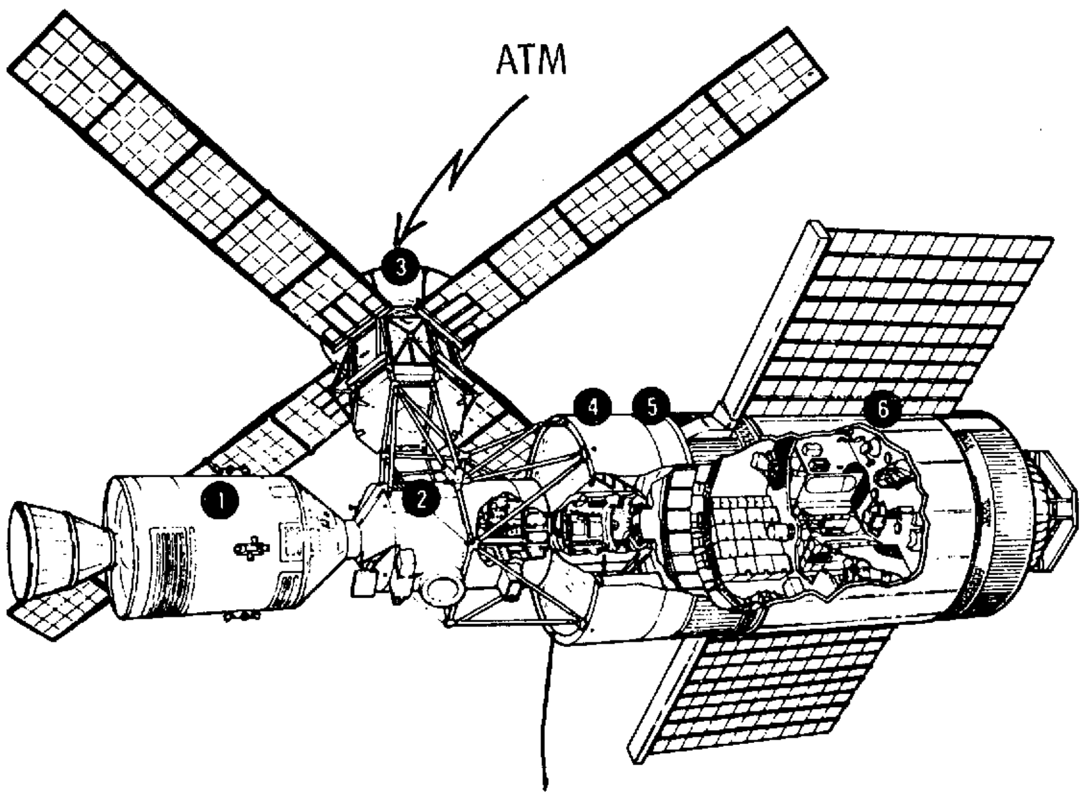


FIGURE 53

servatory astronomy program. As in any major hardware program the ATM program included a one-G trainer, thermal vibration unit, ATM prototype unit, and the necessary adjuncts.

The discussion of the ATM will include the associated experiments only as they impact the basic ATM as a module. The experiments themselves are covered in the EXPERIMENTS section of this report.

Management Aspects

A project office was set up under the Skylab Program Manager at MSFC. It used the various MSFC organizations such as engineering, astrionics, astronautics, manufacturing, and other groups. Subcontractors and vendors supplied many of the components. Because it was in-house the coordination and information flow between MSC and other affected NASA Centers was quickly and adequately set up. The geographical distribution of major elements of the ATM program are shown in figure 54. The management systems used an integrated team effort, configuration management and interface engineering, review process as well as a dedicated team of specialists to follow the ATM through testing program and the KSC test and checkout program right through launch preparations. While this was an MSFC in-house effort the same formal documentation was required as for the other modules.

The manpower varied from a high of over 2000 NASA/contractor personnel to a current number of something over 1000. The ATM program activities are shown in figure 55.

The ATM was subject to the problems inherent in a program starting in one direction in the early days of the Apollo application program and then being reoriented as the Skylab program was becoming more clearly defined. On the whole the ATM management systems and their implementation appear to be good and working well. An area that will have to be emphasized throughout the launch preparations at KSC is the cleanliness requirements in and around the ATM module.

Hardware Aspects

In its review of the ATM the Panel concentrated on the electrical power system, the attitude control system, EVA, and thermal control system. Other systems such as structures, mechanical, instrumentation, and communications were covered to a lesser extent. As in all its reviews the transferred work to KSC was a special area of interest. At the ATM preboard turnover the number of actual manhours of work to be transferred to KSC was 26 hours.

GEOGRAPHICAL DISTRIBUTION OF MAJOR ATM EFFORT

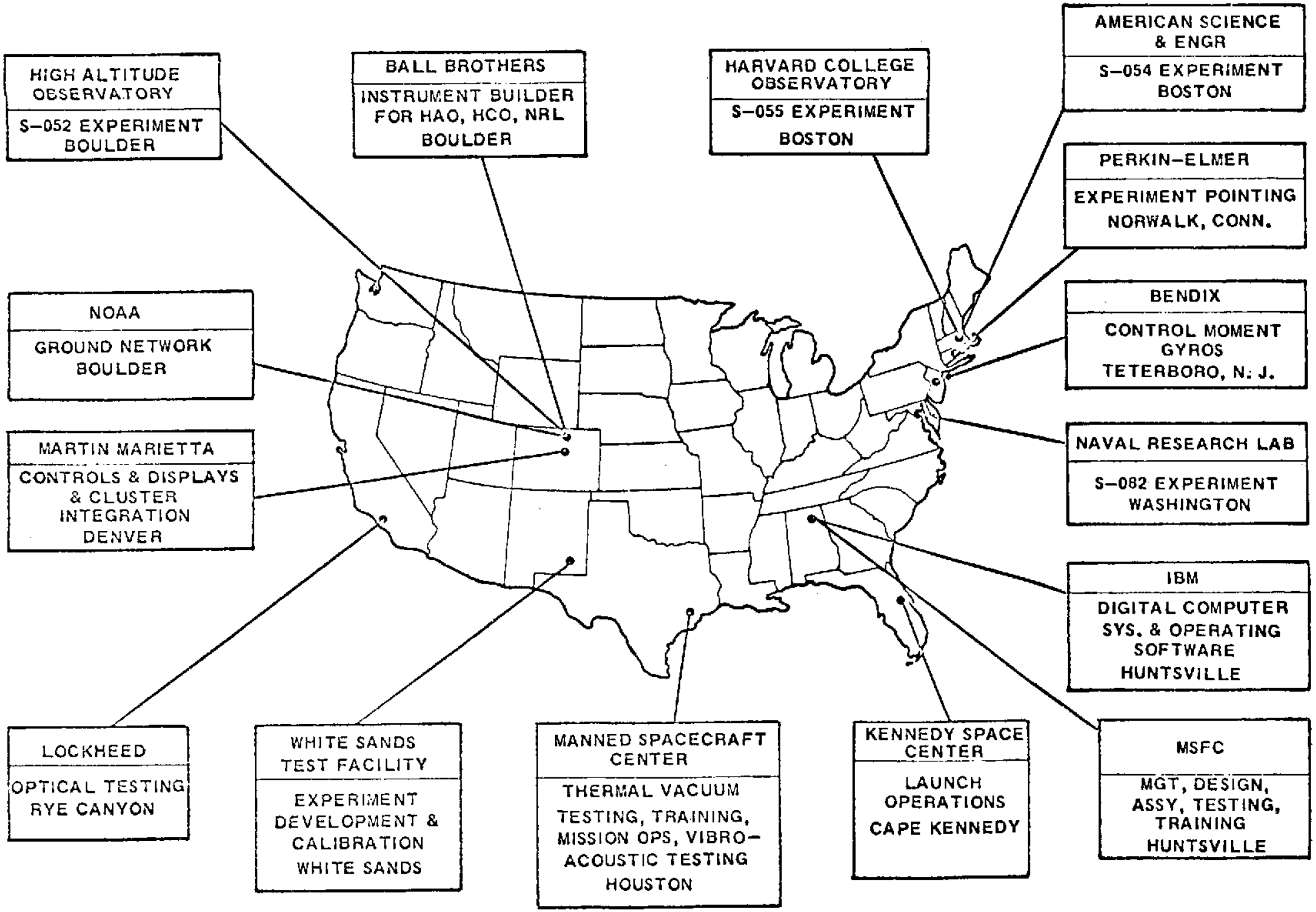


FIGURE 54

ATM CONFIGURATION DEFINITION & ASSOCIATED ACTIVITIES

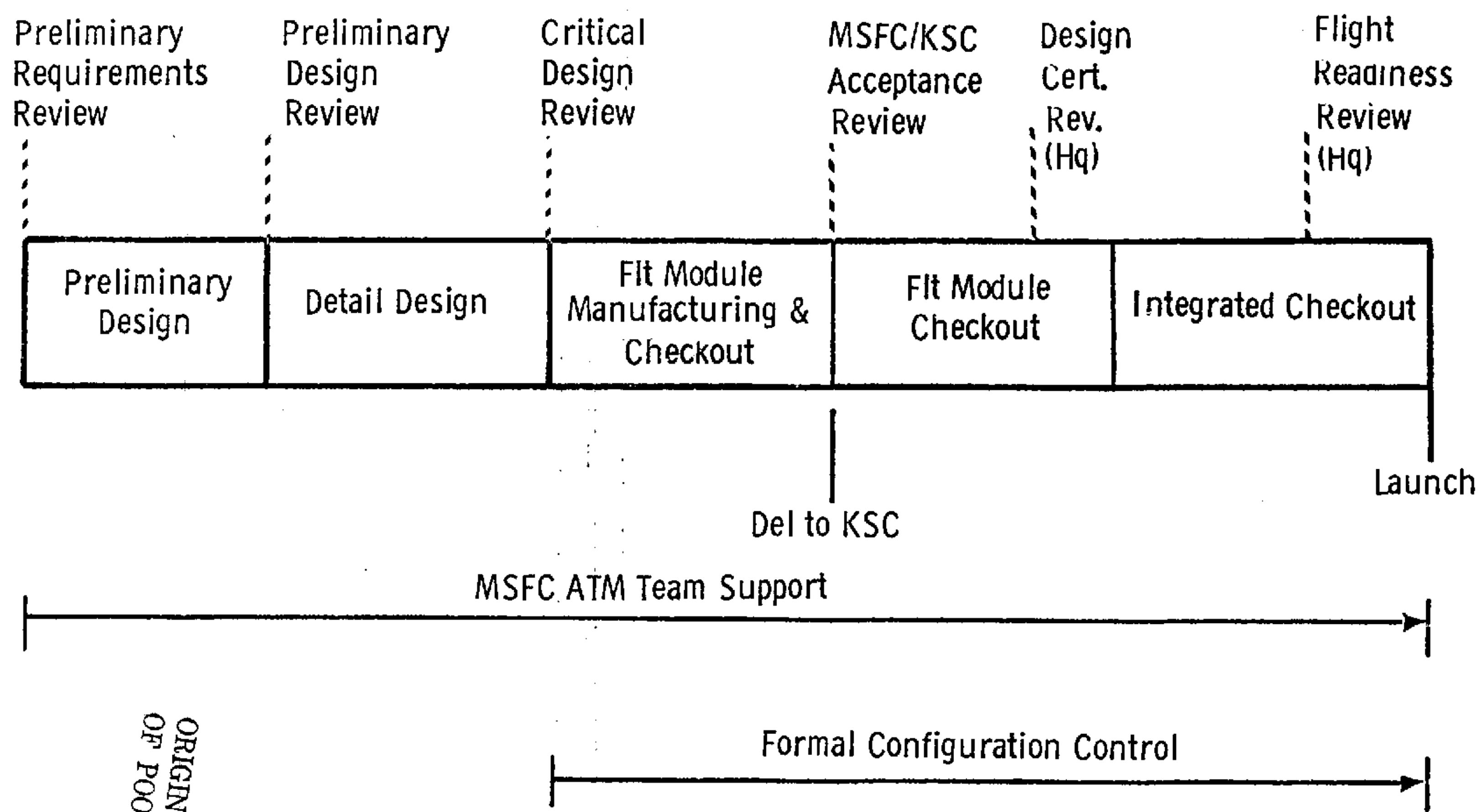


FIGURE 55

Open items at the time of the DCR included the following (closure will be noted in the next report:

1. Attitude pointing control system (APCS). Control moment gyro shutdown was due to high temperature of spin bearing during flight unit postthermal vacuum AST. Additional rate gyro processor failures were encountered during flight unit postmanufacturing checkout. Failure analysis is now in work. Test at KSC in December 1972 should close this out.

2. Electrical power system. ATM C&D logic distributor delta qualification was due to redesigned component. Expected qualification completion is in November 1972.

Other known open items are of minor impact. In examining the material issued by the Mathews team in late 1970 there were a number of items dealing with the ATM that required clarification. These included the procedures used by MSFC to check the designs, rationale for differences between the OWS and ATM solar arrays, and clarification of specific design decisions, thermal control aspects, and the reliability of the pointing system. These areas were all resolved to the satisfaction of the Mathews team.

The ATM control and display panel received a good deal of attention not only from the Panel but from the Skylab astronauts during C^2F^2 and hardware review activities. The Panel's purpose here is to use the discussion of the ATM C&D panel as indicative of the extent of coordination and effort expended by both NASA Centers (MSFC, MSC) involved in Skylab in identifying problems and resolving them. It is applicable to the entire spectrum of similar problems encountered during the development period of the Skylab and, the Panel hopes, will be the manner in which problems will continue to be resolved.

During the MSC briefing to the Panel on May 9, 1972, an assessment by the flight crew included some concerns in this subject area as noted in a memo to the Skylab Program Director:

> As a result of recent test participation, the Skylab flight crews had identified a substantial number of idiosyncrasies of the ATM C&D which required special crew procedures, or work arounds, to compensate for the actual hardware characteristics. It was pointed out that the planned ATM flight operations are already sufficiently complex that the burden of these additional workarounds would substantially reduce crew efficiency. The net effect was indicated as a very undesirable decrease in the return of ATM scientific data. Since the corrective action for these hardware idiosyncrasies was still in the consideration stage, Captain Conrad recommended strongly in favor of correcting the hardware rather than burdening the crew with the workarounds.
>
> In recognition of the adverse effect of these numerous hardware peculiarities, the ATM project personnel at MSFC have worked diligently

to correct the hardware whenever such action could be accomplished within the major program constraints. Concurrently our flight crew personnel have been directly involved in the day-by-day delibrations to achieve the most economical solutions to the hardware issues. The net result of this mutual effort is summarized in MSFC letter PM-SE/ATM-784-72 of June 12, 1972, which lists 34 ATM hardware idiosyncrasies and the corrective action planned. Of this total, MSC agreed with the resolution of 31, accepted the disposition of two without further comment, and recommended one for forwarding to the Level I CCB for resolution. . . . Subsequently, MSFC ATM engineering personnel worked out a relatively simple hardware modification with no schedule impact, and this modification has been approved for incorporation in the flight ATM C&D during the present thermal vacuum testing activities at Houston. Accordingly, this Center and the assigned Skylab flight crew personnel are now satisfied that the proper corrective hardware action has been taken to avoid any significant additional burden on the crew in operating the ATM.

EXPERIMENTS

Management of the Skylab experiments is complex because of (1) the variety of the experiments, (2) the design/fabrication requirements generated by data requirements, (3) the late definition of some experiments, (4) the requirements for integration and interface management, (5) the number of organizations involved, and (6) the data storage and retrieval requirements. The Panel sought to understand the evolving management system in response to these factors. Particular attention was given to the maturity of the system for risk assessments. Thus, the panel reviewed experiment design and fabrication, NASA/contractor responsibilities, NASA policies affecting experiment development and utilization, experiment integration and compatibility with module hardware, safety assessments, current posture of the experiment program, and projected operations at KSC.

The Skylab Program Office has overall authority. Both MSFC and MSC have responsibility for the development of individual experiments. MSFC has the integration responsibility. This ultimately involves a complex of people and organizations including experimenters, contractors for the experiments, and module contractors where interfaces are involved.

As a point of background information, the policy for scientific investigation is noted here:

The following statements constitute the Skylab policy for scientific investigations which is applicable to all Skylab principal investigators. It is a general NASA policy that the principal investigator is to insure the timely processing, analyses and publication of experiment results and findings. Applicable requirements and constraints on the principal investigators for the Skylab program are as follows:

1. Principal investigators will be funded by the Skylab program for a maximum of 1 year from the time they receive the last of their flight data from the NASA Experiment Development and Operations Centers in the format as previously agreed to.

2. The principal investigators proprietary rights to the original scientific data will normally expire at the end of the 1-year period when such rights are granted in the original agreements by the experiment sponsoring program offices. NASA does not plan to grant proprietary data rights to the EREP principal investigators.

3. All original experiment data and reduced data will be available at all times for review and study by NASA by arrangement in which the principal investigators proprietary rights are fully protected.

However, NASA reserves the right to disseminate the results of any experiment or group of experiments if it can be shown that this is in the best interest of the Government. Such action would be taken only by joint direction of the Office of Manned Space Flight and the Associate Administrator of the experiment sponsoring program office.

This policy obviously effects the method of NASA/PI operations during the mission and in some cases has influence the basic working agreements with regard to the experiment hardware itself.

The management systems applied to the experiments area follow the pattern set for the modules and in the case of MSC it varies little from that used on the Apollo program scientific experiments effort. Management systems and controls consist of the following:

- Program baseline/authority
  - Program plan
  - Resources management plan
  - Configuration management plan
  - Management guides
- Status reporting and controls to assure measurement of progress against plans (performance, cost, schedule)
  - Program reviews (internal, NASA Centers, NASA/contractor)
  - Problem control and resolution
  - Intercenter and internal panels

Safety assessments

Hazard identification

Risk assessment

Verification program

Development tests

Qualification tests

Integrated tests

Reliability and quality program

The development and integration sequence used for the experiments is shown in a simplified form in figure 56. The DCR's have been completed and the experiments are essentially in checkout at KSC. Some have had to be returned to the contractor for modification. The SOCAR and the DCR efforts were obviously most valuable in determining hardware readiness and problems in both hardware and the operational documentation. An example of the areas covered during the SOCAR are shown in table XVI. The Panel has, in its reviews, received every indication that the technical management systems can resolve the existing problems. The material that follows discusses some of the hardware, problems, and status as known at this time. The purpose here is to indicate the problem solving mechanism and its ability to provide confidence in experiment risk assessment with regard to both the crew and the mission.

Crew Operations

Crew time for experiments is a prime resource in the Skylab experimental program. Use of available crew time and skill must be optimized by effective and realistic scheduling of crew activities. The problem of available crew time versus experiment requirements appears to be one that is still to be resolved during the evolution of the mission control documents. It has been noted that as a result of such tests as SMEAT the time required to accomplish certain of the experiments may be well beyond what was originally anticipated. This requires an evaluation of the policy on scheduling the crew time line. It is evident from a consideration of the variety of experiments that each crewman must be versed in several skills but that it appears best to have only one crewman selected as an expert in a given major discipline. With different experiment emphasis for each segment of the mission, the type of training and delegation of responsiblities will vary from crew to crew. Further information obtained from the Panel reviews indicates the following:

1. Because of the crews role in the biomedical program, they must have a thorough understanding of the medical experiments. A qualified observer must act as the experiment conductor when the "medical" astronaut is used as the test subject. This requires extensive cross-training in the medical area.

EXPERIMENT DEVELOPMENT & INTEGRATION SEQUENCE

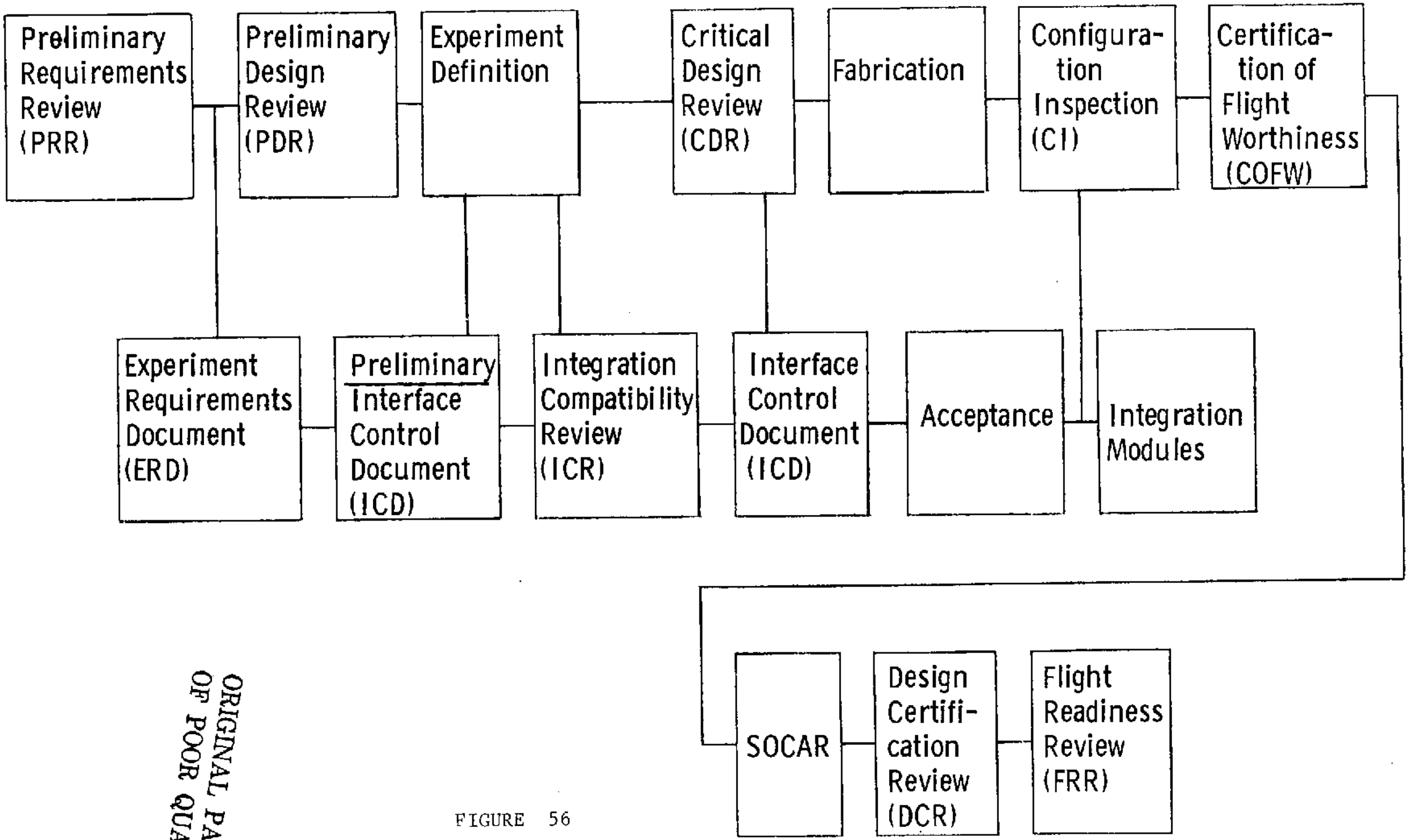


FIGURE 56

2. All three crewman must be trained to operate the ATM due to the extended periods of time planned.

3. It appears that EREP experiments require two men to operate the equipment, and attitude control operations probably require the efforts of all three crewmen.

Experiments

The experiment program consists of more than 50 items representing virtually every field that has been recognized as being able to benefit from operations in near-Earth orbit. The instruments, sensors, and other equipment for these experiments are located in various parts of the cluster, inside and outside. In addition to the permanently mounted items, there are two airlocks in the OWS through which scientific instruments can be operated outside the vehicle.

Medical Experiments

These experiments, including the specialized support equipment are the following (* indicates experiments integrated into the module hardware):

M071	Mineral balance
M073	Bioassay of body fluids
*M074	Specimen mass measurement
M078	Bone mineral measurement
*M092	Lower body negative pressure
*M093	Vectorcardiogram
M111	Cytogenetic studies of blood
M112	Man's immunity, in-vitro aspects
M113	Blood volume and red cell life
M114	Red blood cell metabolism
IMSS	In-flight medical support system
M115	Special hematologic effect
*M131	Human vestibular function
*M133	Sleep monitoring
M151	Time and motion study
*M171	Metabolic activity
*M172	Body mass measurement
*S015	Effects of zero-G, human cells
*S071	Circadian rhythm, pocket mice

*S072 Circadian rhythm, gnat

*ESS Experiment support system

*IBCS In-flight blood collection system

The ESS provides a central source from which medical experiments are supported with regulated electrical power, control and display panel, calibration, etc. This unit is mounted in the OWS in close proximity to the experiments it serves.

The remaining vehicle tests that impact the medical experiments are the end-to-end system tests, the experiment test at KSC, and the mission simulation/flight readiness test at KSC. The results of the SMEAT have been described, as known by the Panel at this time in the SMEAT section of this report. (M131 and M172 were not included in the SMEAT test.) Qualification tests remain to be completed on the M133 and ESS.

Experiment M071, mineral balance, is impacted by the increased requirements for urine collection noted in the SMEAT discussion. A procedure is required to use the new 4000-milliliter urine void in the mineral balance test. The complexity of the overall experiment operation and its impact on crew timeliness is a concern. The appropriate organizations at MSC and MSFC have indicated that this problem is being worked and will be covered in the operational documentation. This also applies to M073.

Experiment M092, lower body negative pressure device, has received special emphasis because of the implications for crew safety. Factors to consider include flammability, crew egress, vacuum environment, and physical crew restraint while in use. In addition, it is considered one of the most important of the medical experiments. This experiment is actually divided into three pieces of individual hardware: the lower body negative pressure device, blood pressure measuring system, and limb volume measuring system. The LBNPD prime contractor is the Marshall Space Flight Center. The prime contractor for the BPMS and LVMS is the Martin Marietta Corporation, Denver. The responsibility for the overall medical experiment M092 belongs to MSC. This experiment is indicative of those experiments involving a number of different organizations, geographically diverse, where extensive cooperation is required. Tests, FMEA, configuration control reviews, and EMI reviews have indicated problems during the development and testing of this hardware. These problems appear to have been resolved to each program element's satisfaction. The system performed well during SMEAT. Various body seals were tested. Operating limits were better defined.

The metabolic analyzer, M171, determines the metabolic rate in terms of oxygen consumption and carbon dioxide production. It is used during periods of rest and calibrated exercise. Components include an ergometer, metabolic analyzer, body temperature measuring system, and breathing apparatus. This is probably the most complex hardware of all the medical experiments. Testing of these units during AST on the OWS and the SMEAT uncovered a number of problems. These have been resolved or are in process of resolution with no other forseeable problems. It is interesting to note that the ability of the SMEAT crew to exceed expected energy inputs did cause failure of the bicycle ergometer. The operational acceptability of the oxygen consumption analysis at 5 psia appears to be somewhat of a problem. The resolution of this shall be noted in the next report.

The prime contractors for experiment M131 are the Naval Aerospace Medical Research Institute and the Applied Physics Laboratory of Johns Hopkins University. This is basically a chair device used to rotate the subject at several optional angular velocities and it will be used to determine the effects of prolonged weightlessness on man's susceptibility to motion sickness and on his judgment of spatial coordinates. Inherent in this type of device are many potential hazards. The safety activities have identified 28 of them: mechanical, -8; electrical, -7; pneumatic, -4; and operational, -9. Each has been investigated, understood, and considered acceptable. Apparently the chair velocity was erratic after 3 months of storage and the assessment of this appeared to be open at the time of the Panel's review. The resolution of this shall be noted in the next report.

The in-flight blood collection system had not been finalized at the time of the last Panel review. Only the prototype and development units have completed testing. Flight type hardware was not expected to be available for testing until October 1972. Prototype hardware was tested in the SMEAT.

Those experiments requiring no in-flight hardware, such as M111, 112, 113, 114, 115, and others, do not have direct hardware impacts. However, they do affect the operations area. The Panel has no specific comments on these at this time. The M487, habitability/crew quarters hardware, is used for these experiments. The posture of documentation and acceptability of the small hardware elements of M487 are not known by the Panel at this time. The closure of this shall be noted in the next Panel report.

The following documentation needs to be updated. The closure of these items will be statused in the next report:

1. The Skylab biomedical failure mode and effects analysis (FMEA) documentation for the hardware components
2. The mission level FMEA documentation
3. The operational data book

Apollo Telescope Mount (ATM) Experiments

These experiments provide data on solar activities beyond that available from Earth-based observatories. Experiments included in this group are the following:

S052 White light coronagraph

S054 X-ray spectrographic telescope

S055 Ultraviolet scanning polychromator spectroheliometer

S056 Dual X-ray telescopes

S082 XUV spectrograph/spectroheliograph H-alpha telescope

The ATM as an in-house program at MSFC used the management systems described for the basic program modules. The experiment interfaces shown in figure 57 also indicate the management controls necessary to execute this program. Contamination control is vital to these experiments both on the ground and while in Earth orbit. Contamination would cause scattering and absorption in orbit and degradation of critical surfaces.

The crew interface with the ATM is extensive involving them in the operation of the experiments from inside the vehicle and the EVA required to retrieve film. The time spent by a crewman in the MDA at the ATM C&D Panel can run as high as 10 hours in a 24-hour period. The amount of time assigned to the ATM experiments in the crew timeliness can be a problem if requirements are in excess of the available time to carry them out. The problem is being assured by both the MSC/MSFC and Headquarters personnel. The following items will have to be monitored closely in the months ahead:

1. Film and camera stowage including associated C^2F^2 activities
2. Damage to AM while traversing to MDA for film loading activities
3. Resolution of problems with image clarity on the S055A

In the fabrication of these experiments a number of new and/or unique techniques were employed. These involved lubrication methods and materials, electrical discharge machining, grating fabrication, development of heat rejection windows, and film strip camera development. In all of these areas the development testing and acceptance testing indicated that the workmanship and management controls produced the desired product.

Earth Resources Experiment Package (EREP)

The EREP system includes equipment used for observing and analyzing Earth phenomena from space. These phenomena include agriculture, forestry, geology, geography, air and water pollution, and land use. The equipment includes the following:

S190A Six camera multispectral photographic facility

S190B Long focal-length Earth terrain camera adapted from Apollo

S191 Infrared spectrometer boresighted with a viewfinder and tracking system

S192 13-Channel multispectral scanner (this spectral range overlaps the S190 and S191 camera capabilities)

S193 Microwave radiometer/scatterometer and altimeter (K-band)

S194 L-Band microwave radiometer

ATM EXPERIMENT INTERFACES

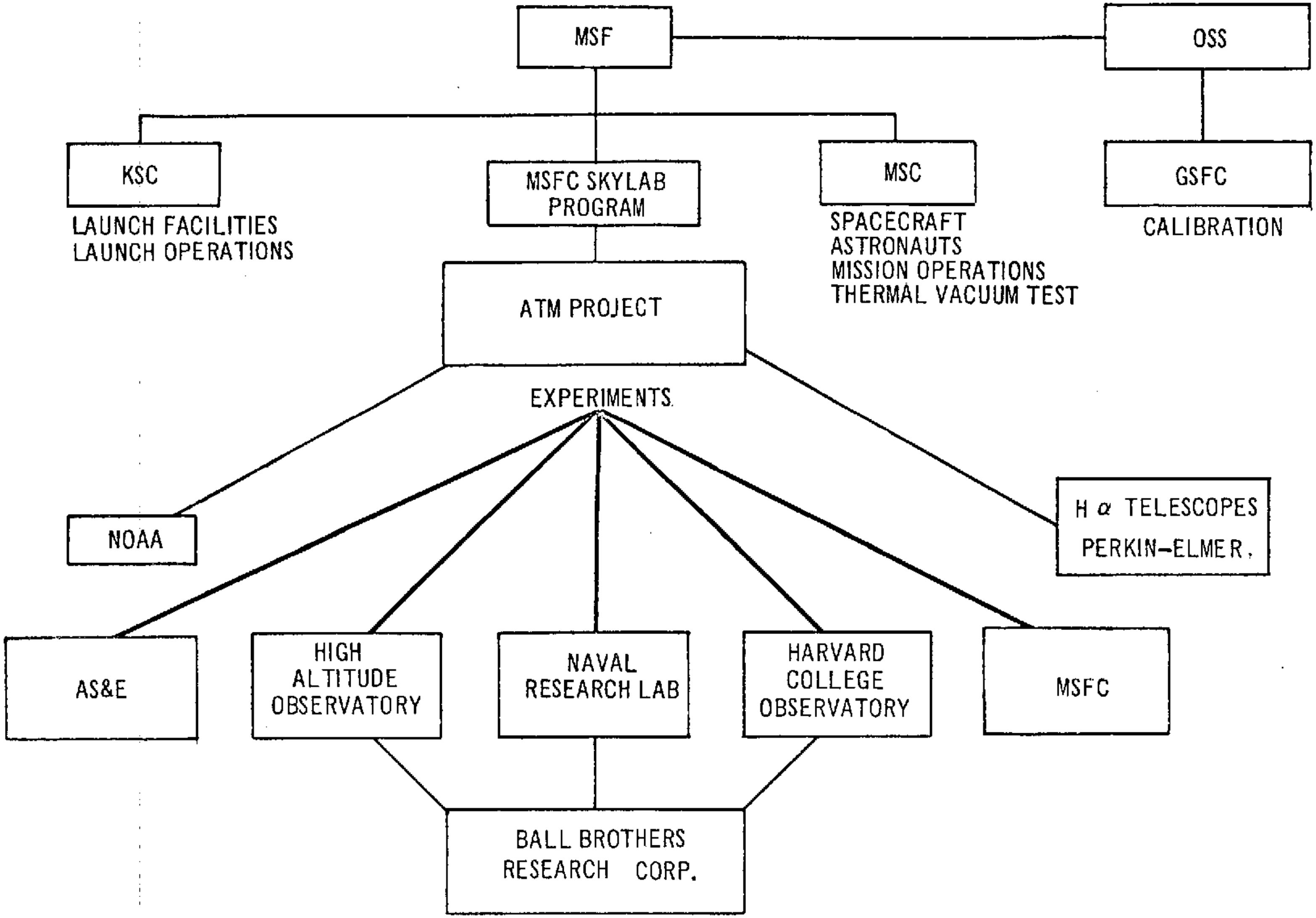


FIGURE 57

Some 106 PI's have been selected for experiments using the EREP system. These include 23 scientists from other nations. The equipment for these experiments is located in the MDA with S193 located in the AM and the S190B in the OWS. Development NEREP instruments began relatively late in the program. This resulted in the late selection of PI's and later evolution of the management systems necessary to conduct this segment of the program. These aspects of the EREP program had a salubrious effect. Greater emphasis was placed on EREP than might otherwise have been the case. On the other hand, the impact of EREP hardware problems late in the program tended to cause adverse impacts on the testing and development aspects. It also presented difficulties in maintaining a balance between operational compatibility evaluation and analysis and the activity directed toward obtaining a basic knowledge of the flight systems and the flight objectives.

The EREP support equipment include the control and display panel, tape recorder, viewfinder tracking system, S190 supplemental hardware, coolant system, structural support, etc. Indicative of the complexity and sophistication of the EREP hardware are the stowage requirements:

SL-1	Launch of the OWS, AM, MDA	188 items stowed
SL-2	Launch of the CSM	60 items stowed
	Return with CSM	157 items stowed
Each successive CSM Launch		60 items stowed

The EREP management structure to meet the requirements of this program is shown in figure 58. The major organizations involved in the hardware development are shown in figures 59 and 60. This arrangement indicates the attention given the EREP system by MSC.

Among the items still open are the following:

1. Descrepancies on S192, S193, and S194 require rework at the vendors.

2. ESE and functional interface verification for S192 and 193 will have to be completed at KSC.

3. Flight filters and desiccants for S190B have to be delivered; qualification testing has to be completed.

The closure of these items will be noted in the next report. The earlier major concern about the tape recorder and Malabee cooler appears to be resolved.

Based on the material presented to the Panel, we believe the actions being taken are appropriate. However, this is an area that will continue to require careful attention from contractors, PI's, and the NASA organizations involved. This requires continued control of ECP's, waivers, and IRN's as well.

EREP MANAGEMENT STRUCTURE

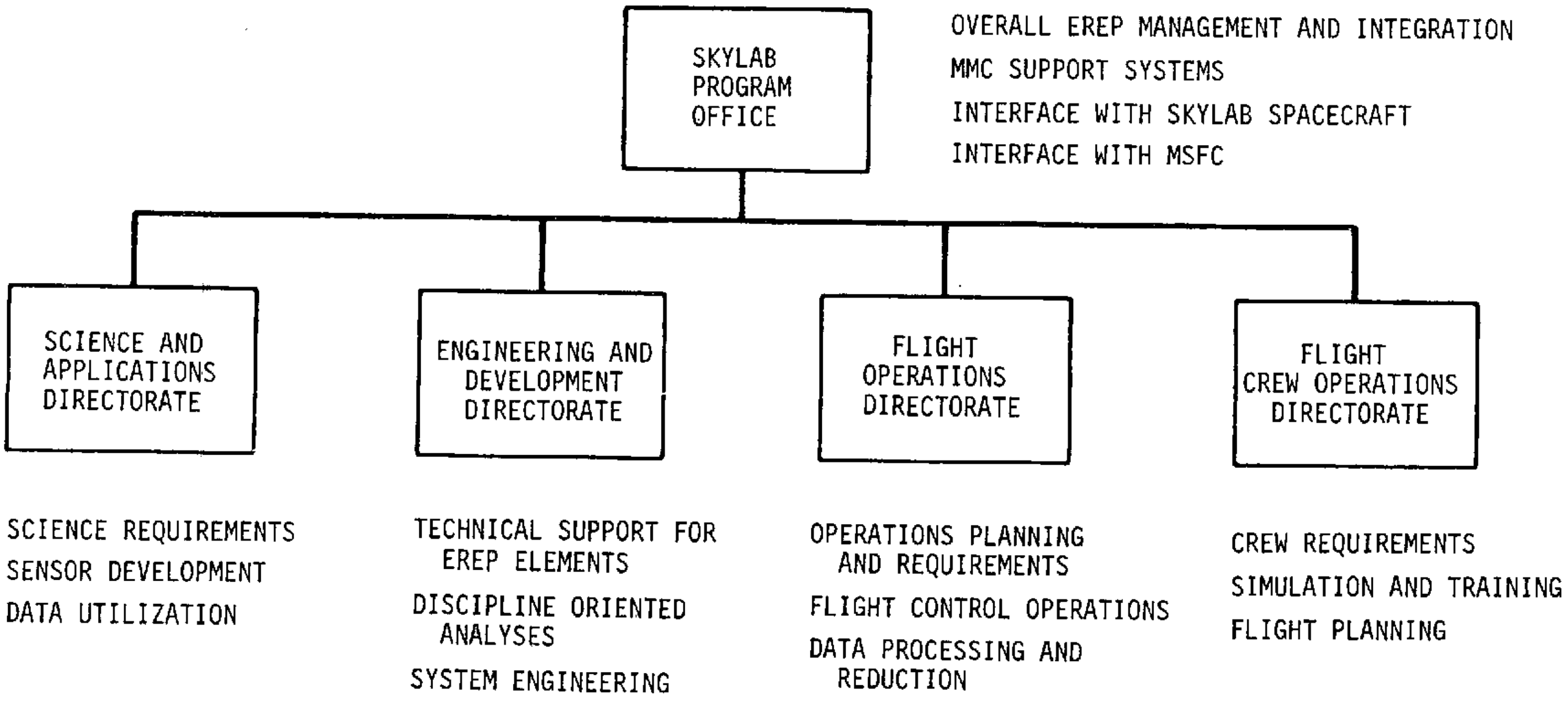
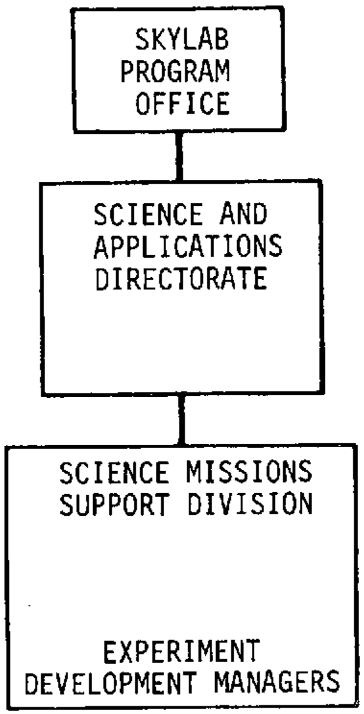


FIGURE 58

EARTH RESOURCES EXPERIMENT PACKAGE (EREP)
MANAGEMENT RELATIONSHIPS



RESPONSIBLE FOR OVERALL EXPERIMENT MANAGEMENT

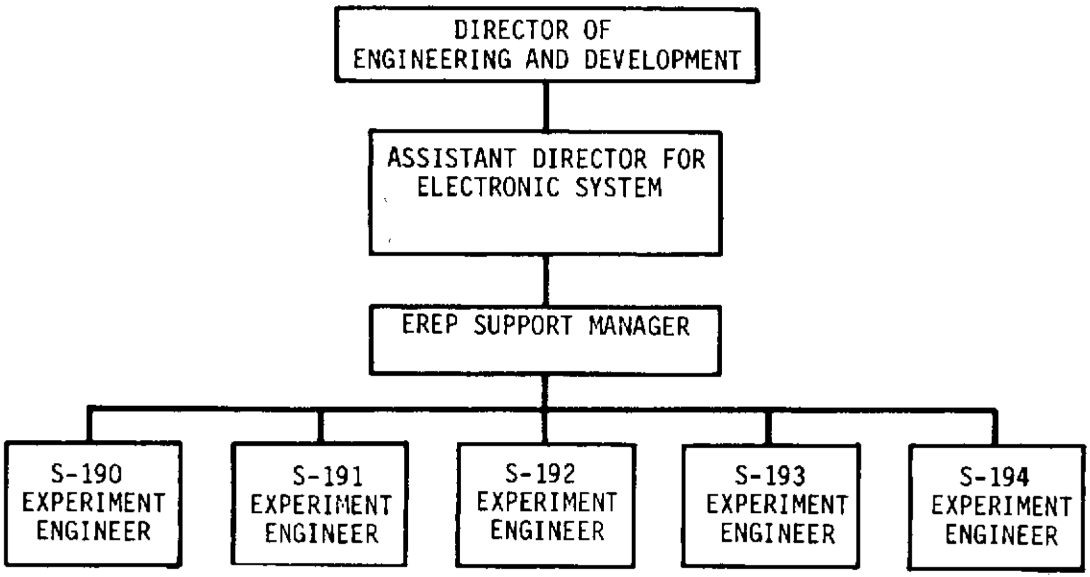
RESPONSIBLE TO SKYLAB PROGRAM OFFICE FOR SKYLAB SCIENCE EXPERIMENT MANAGEMENT

RESPONSIBLE FOR ESTABLISHING SCIENCE REQUIREMENTS AND IMPLEMENTING S&AD SUPPORT FOR SKYLAB

- EXPERIMENT HARDWARE DEVELOPMENT
- DEFINITION OF SCIENCE REQUIREMENTS
- SCIENCE EXPERIMENTS MISSION PLANNING
- ASSISTANCE IN CREW EXPERIMENT TRAINING
- REAL-TIME OPERATIONAL SUPPORT
- MSC POINT OF CONTACT FOR PI's

FIGURE 59

ENGINEERING AND DEVELOPMENT DIRECTORATE



1. ELECTRONICS CIRCUITRY AND PACKAGING
2. STRUCTURAL/THERMAL
3. GSE
4. INTEGRATION
5. TESTING
6. DATA SYSTEM
7. OPTICS
8. POWER DISTRIBUTION

FIGURE 60

Corollary Experiments

This group of experiments consists of all those experiments that do not fit into the three group-related classifications already discussed: -ATM, biomedical, EREP. All of the scientific airlock (OWS), astronomy, and photographic experiments are included in this category. These experiments are located throughout the cluster in the OWS, AM, and MDA. A thermal control coatings experiment (passive) located on the IU. Each of the modules provides the necessary accommodations for electrical, mechanical, and other support. One of these experiments is developed by the French Government, S183 Ultraviolet Panorama. Ten additional experiments in metals and materials processing were recently made possible by the development of the M518 multipurpose electric furnace system to replace the composite casting furnace. The Skylab experiments in M518 will explore and pioneer some of the potentially practical uses of manufacturing and processing techniques not possible on Earth.

All of these experiments and their supporting hardware have been subjected to the same review cycle applied to the modules and experiments. The SOCAR effort involved a specific team to cover the corollary experiments. The crews have gained a detailed understanding of experiment hardware, and they have provided much needed support in the development of those items through participation in reviews, C^2F^2 tests, training, and simulations. A large number of special studies have been conducted to assure the adequacy of design and operations. These cover

Unattended SAL experiment operations

Retraction, extension, and ejection of SAL experiments

Capability of the universal extension mechanism system

Velocity hazards from operations of T020, M509, and T013

FMEA's

The SOCAR and DCR's, including the activities leading up to them, identified problems and established means for solving them. Much has yet to be accomplished in preparing the operational documentation. This will continue to require management attention. However, the management structure gives us confidence that the hardware and operations planning will support mission requirements.

BIBLIOGRAPHY

Because of the vast number of documents associated with the Panel's reviews, only those of specific note are given here. The remainder are simply noted under the four titles of SOCAR, DCR, PDTR, and SAR.

"Third Annual Report to the Administrator," Aerospace Safety Advisory Panel, Feb. 1972.

"Skylab Design Certification Reviews," Skylab Program Directive No. 17, March 7, 1972.

"Establishment of Skylab Program Interface Panel Organization," Skylab Program Directive No. 7A, March 18, 1970.

"Reliability, Quality & Safety Auditing," Skylab Program Directive No. 9.

"Nonconformance Reporting & Corrective Action," Skylab Program Directive No. 10A.

"Sequence and Flow of Hardware Development and Key Inspection, Review and Certification Checkpoints," Skylab Program Directive No. 11A.

"Failure Mode and Effect Analysis - Single Failure Point Identification and Control," Skylab Program Directive No. 13.

"Skylab Program Materials Policy," Skylab Program Directive No. 16A.

"Implementation of System Safety Requirements," Skylab Program Directive No. 31.

"An Etiological Study of Phthalate Self-Contamination of Spacecraft and Contamination From Their Earthly Environs," NASA Technical Note D-6903, 1972.

"Human Factors in Long-Duration Spaceflight," National Academy of Sciences, 1972.

"Skylab Orbital Assembly Fire Study," MSC-04084, April 15, 1971.

"Skylab System Safety Checklists" SA-003-002-XX. This series of documents issued by MSFC to determine status of GSE, flight systems, and experiment hardware.

SOCAR Reports, May and June 1972.

DCR Documentation, May-Oct. 1972

PDTR Documents, Aug./Sept. 1972

SAR Documents, Sept. 1972.

TABLE I. - SKYLAB SYSTEM SAFETY CHECKLISTS

[Typical source data for checklist development]

Manned Space Programs Accident/Incident Summaries	NASA, Director of Safety, March 1970
System Safety Accident/Incident Summary	NAR, Space Division, July 1967
Air Force Eastern Test Range Safety Manual, Vol. 1	AFETRM 127-1, January 1, 1969
Minutes, System Safety Network Technical Interchange Meetings	
Space Flight Hazards Catalog	MSC 00134, Revision A, January 1970
Management Manual Technical Information Bulletins	MSC-M8081, January 1970
Space Flight Hardware Accident Experience Report	MSFC, October 14, 1966
Apollo 14 Safety Assessment	MSC-SN-1-174-10, December 2, 1970
Air Force Systems Command Design Handbook, series 1-0	DH 1-6, July 20, 1968; Revised July 20, 1970
Report of Apollo 204 Review Board, all appendixes	1967
Report of Apollo 13 Review Board, all appendixes	June 15, 1970

TABLE II. - EXPERIMENT/SYSTEMS DESCRIPTION

Experiment	Description
M071 - Mineral balance	Measure the gains and losses of various metabolic constituents from the body; measure changes in circulating levels of several metabolites to assess nutritional status and muscular-skeletal function.
M073 - Bioassay of body fluids	Evaluate the endocrinological inventory before, during, and after exposure to simulated spaceflight environment, foods, fluids, and workloads for extended periods.
M074 - Specimen mass measurement	Weigh feces, vomitus, and food residue generated in the simulated space environment and evaluate the measurement device for Skylab use; supports M071 and M073 analyses.
SMEAT food system	Evaluate the SMEAT/Skylab food system in a simulated space environment. Provide crew with controlled Skylab diet for successful evaluation of medical experiments that are based on nutritional intake.
M092 - Inflight lower body negative pressure	Obtain baseline ground-based data concerning the time course of cardiovascular deconditioning during long-term confinement and predict the degree of physical impairment that is to be expected upon return to normal activity. Obtain verification of procedures and crew operational capability.
M093 - Vectorcardiogram	Determine reference data and changes in the electrical activity of the heart caused by exposure to the SMEAT atmosphere and other specific stressors. Correlate the changes that are detected with those known to occur after specific stress in normal environments.
M171 - Metabolic activity	Evaluate the metabolic rate measurements of man while resting and doing work during prolonged exposure to the SMEAT atmosphere and compare these results with those obtained in normal sea level environment.
M133 - Sleep monitoring	Evaluate sleep quality and quantity during extended simulated space environment.
Operational bioinstrumentation system	Evaluate response parameters and operational adequacy in the simulated space environment.
SMEAT shower	Evaluate shower for operational suitability and adequacy as a body bathing system.

TABLE II. - Concluded. EXPERIMENT/SYSTEMS DESCRIPTION

Experiment	Description
SMEAT sleep restraint	Evaluate the Skylab baseline sleep restraint and the alternate sleep restraint for crew comfort and operational suitability.
Skylab urine system	Evaluate and verify proposed in-flight procedures, operational suitability, and design adequacy of the Skylab urine system prototype.
Chamber environmental microbial monitoring	Provide habitability, environmental aerosol, surface bioburden information.
SMEAT environmental noise	Evaluate quantitatively and qualitatively the effects of continued exposure to noise in the simulated space environment.
Atmosphere analyses	Identify and quantify trace contaminants encountered during the chamber test.
In-chamber CO_2 measurement	Use and evaluate the Skylab CO_2/dewpoint monitor; obtain knowledge and control of in-chamber CO_2 levels.
In-chamber CO measurement	Provide capability for crew monitoring and warning of out-of-tolerance in-chamber CO levels.
T003 - Aerosol analysis	Measure and collect in-chamber aerosol particulate matter as a function of time and location.
M487 - SMEAT habitability/crew quarters	Establish protocol and optimize subjective rating scales for elements of SMEAT/Skylab habitability and evaluate equipment use.
M151 - Time and motion study	Evaluate crew activities during performance of operational and experimental tasks in the simulated space environment.
Skylab data acquisition simulation	Evaluate mission rules and operations documents/Flight Operations Division data evaluation and handling procedures in a real time Skylab mission time frame with simulated manned space flight network (MSFN) coverage.
SMEAT housekeeping	Obtain information on frequency, duration, and crew acceptability of housekeeping requirements during a simulated long-duration mission; confirm predicted timelines for Skylab housekeeping activities.
SMEAT personal hygiene	Evaluate personal hygiene activities in the simulated space environment for extrapolation to the Skylab mission, crew evaluation of hygiene hardware, and consideration areas.
M078 - Bone mineral measurement	Measure any loss of bone mineral content during the simulated space environment to provide baseline information for Skylab mission use - prechamber and postchamber requirements only.

TABLE III. - VENT CHARACTERISTICS

Vent number	Vent	Effluent	Flow rate, lb/sec	Frequency	Days per mission	Velocity, m/sec	Vent size, in. diam.	Remarks
6	Oxygen purge	Oxygen	0.01	2 min/24 hr	14 to 18	300	0.21	No particulate
7	Hydrogen purge	Hydrogen Water vapor	0.012 .012	4 min/48 hr	14 to 18	300	0.21	No particulate
9	M512	Metallic vapors, nitrogen, oxygen, exothermic reaction products	0.001 to 0.05 (over short time intervals)	5 times total	6 to 10	300	4	Acceptable
	M479	Combustion products, nitrogen, oxygen, water vapor, particles	0.0001 to 0.1 (over short time intervals)	37 times total	2 to 6	Particles - 0.3; Gasses - 300	4	Testing
10	MOL sieve	Water vapor, oxygen, nitrogen, carbon dioxide	0.01 average (continuous)	Continuous (15-min cycles)	All	300	2 vents, 3 (each)	No particulates testing
13	EVA depress vent and hatch	Oxygen, nitrogen, carbon dioxide, water vapors	0.14 average for 30 sec	SL 1/2 - 1 SL 1/3 - 2 SL 1/4 - 2	1 to 2	300	2.75	Acceptable
19	Waste tank	Water vapor, hydrogen, oxygen, urine, sweat, food components, respiration products, biocides	16.7 lb/day normal; 29.4 lb/day full contingency	Continuous	All	Vapor - 300; Particles - 1-20	$1\frac{1}{2}$	New filter testing
21	M092 LBNP	Cabin atmosphere, sweat	0.05	9 times/mission	3	300	0.4	Acceptable
	M171	Breath products	Infinitesimal	2 to 3 times/day	All	300	0.4	Acceptable
22	SAL	Cabin atmosphere	0.001 to 0.05	6 to 12 times/mission	All	300	0.125	Acceptable

TABLE IV. - MAJOR COMBUSTION PRODUCTS OF SOME SKYLAB MATERIALS

Test material	Major combustion products
Polybenzimidazole (PBI)	Carbon monoxide, carbon dioxide, nitrogen dioxide, nitric oxide, cyanogen, methane, and benzene
Nylon fabric	Nitrogen dioxide, nitric oxide, carbon monoxide, carbon dioxide, methane, and ethylene
Paper	Carbon monoxide, carbon dioxide, and methane
Rayon terry cloth	Carbon monoxide, carbon dioxide, methane, ethylene, normal butanol, acetylene, and ethane
Methyl vinyl silicone	Carbon monoxide, carbon dioxide, methane, ethylene, and normal butanol
Teflon sheet	Carbon tetrafluoride, carbonyl fluoride, carbon monoxide, and carbon dioxide (minor constituent)

TABLE V. - SKYLAB FLIGHT CREW

TRAINING PROGRAM (HR PLANNED)

Activity	SLM-1	SLM-2	SLM-3
Briefings/reviews	450	450	450
Systems training	350	250	250
EVA/IVA	156	184	161
Medical	98	98	98
Simulators	695	695	695
Experiments	430	461	381
Total	2179	2138	2035

TABLE VI. - SUMMARY OF THE TEST PROGRAM REPORTS CLOSEOUT STATUS AS OF 9/1/72

FOR ORBITAL WORKSHOP

Items	Test program reports	Items	Closed	MDAC open	NASA open	NASA/MDAC open
Combined subsystem	933	933	920	[a]10	1	2
C^2F^2 experiment bench check	1	67	36	1	30	0
C^2F^2 stowage bench check		75	55	[b]15	4	1
C^2F^2		203	192	[b]8	2	1
Delta C^2F^2		42	21	[c]19	2	0
Delta C^2F^2 dome locker		31	2	[c]26	2	1
All systems test	119	119	116	3	0	0

[a]Subsystem TPR's are closed except for a few items waiting completion of inspection records.
[b]Stowage bench check and C^2F^2 items are open for decal changes, missing hardware, etc.
[c]Delta C^2F^2 items were opened within the past few days and are still being worked.

TABLE VII. - TEST OBJECTIVES NOT YET SATISFIED

	Subsystem open items	Remaining components to be qualified
Crew equipment	1	0
Ordnance	0	
Caution and warning		
Electrical power		
Solar array system		
Structures	3	
Communication and data acquisition	0	2
Thruster attitude control system	0	4
OWS experiments	0	6
Environmental/thermal control	1	7
Habitability support system	6	10

TABLE VIII. - LEAKAGE ALLOCATION SUMMARY

	lb/day of oxygen/ nitrogen at 5 psia during habitation		lb/day of oxygen/ nitrogen at 5 psia during storage
Allocations for component leakage			
Total		3.513	3.617
Dumps and purges (HSS usage):			
Waste processor (4 operations/day)	0.037		
Trash airlock (5 operations/day)	.650		
Liquid urine purge (3 operations/day)	.020		
Total		0.707	0
Contingency (including leakage from welds and other elements of basic structure)			
Total		0.780	1.383
Total (lb/day)		5.000	5.000

TABLE IX. - WASTE TANK - TRASH DISPOSAL AIRLOCK PROBLEM SUMMARY

Problem	Solution
Absolute pressure gage - failed in first phases of vibration testing	Made more rugged; retested successfully
Outboard hatch - drifted from its exact center after cycling due to brinnelling of aluminum hub for antirotational bolt	Tension strut was added; retested successfully
Pressurization valve plug - plug land galled causing valve handle load increase, bore also galled	Land was turned down to give clearance with bore; handle load reduced to acceptance level; continued testing with no further problem
Inboard hatch latch - galling between latch eccentric and mating part due to lack of proper lubricant caused excessive latch loads	Solid film replaced with krytox grease; testing continued successfully

TABLE X. - REFRIGERATION SYSTEM

System provides equipment for	Temperature, $^{\circ}F$
Frozen food	-20 to +0
Food chilling	+33 to +45
Water chilling	+33 to +45
Urine chilling	+59 (max)
Urine freezing	-2.5 (max)

TABLE XI. - FIRE SENSOR LOCATION AND READOUT LOCATION

Sensor location	Readout location	Fire location
Wardroom sensor 2 Wardroom sensor 1	Control panel	OWS crew quarters
Waste management compartment Sleep compartment 1	Control panel	
Sleep compartment 2 Sleep compartment 3	Control panel	
Experiment compartment 3 Experiment compartment 2	Control panel	OWS experiment compartment
Experiment compartment 1	Control panel	
Forward compartment 3	Control panel	OWS forward compartment
Forward compartment 2 Forward compartment 1	Control panel	

TABLE XII. - OWS GENERAL ILLUMINATION SYSTEM PROVIDES GENERAL ILLUMINATION AT AVERAGE LEVELS

[System provides initial entry and emergency mode illumination of 0.5 footcandle (min) in crew quarters and forward compartment.]

Area	Footcandle (min)
NASA sleep compartment	4.5
Wardroom	5.0
Head	9.0
Experiment compartment	5.5
Forward compartment	1.0

TABLE XIII. - OWS STOWAGE LOCKERS NOT REVIEWED AT HUNTINGTON BEACH (8/31/72)

[Those stowage lockers which have been reviewed and have open TPR items against them at time of shipment are not included in this list.]

Stowage lockers	Reason for no review
D420	No flight data file maps, no ergometer restraints
D448	No triangle shoes
F507	No A9 locker contents
F517	No blood sample spacers, etc.
F519	No blood sample spacers, etc.
F567	Redesign ETC window bracket not available
F573	No ETC stowage locker
W703	No high school student experiment equipment
W704	Inadequate quantity of food supplements available
W714	Final flight entertainment equipment contents not available
W749	M487 flight hardware not available
W754	On-orbit configuration not reviewed (food cans plus IMSS)
W769	No fecal tracers
H810	No blood sample equipment
H820	Squeezer bag stowage so unacceptable needs complete rereview
H823	Urine bag dispenser locker not available
S901	No sleep restraints
S902	No sleep restraints
E610	Final flight biomedical equipment contents not available
E615	Final flight biomedical equipment contents not available
S903	No sleep restraints
S909	No triangle shoes
S921	No triangle shoes
S931	No triangle shoes

TABLE XIV. - STRUCTURES AND MECHANICAL SUBSYSTEM

SYSTEM PERFORMANCE SUMMARY

Component/subsystem	Factor of safety, actual minimum effective[a]
Airlock module:	
AM basic structure (STS, tunnel, trusses)	1.25
EVA hatch: compartment (including internal hatches)	2.15
Nitrogen bottles mounting	2.00
AM/OWS bellows	2.00
STS windows	3.79
Mechanisms (latches, etc.)	2.00
AM/MDA radiators	[b]13.00
Transportation and handling equipment (as affects flight hardware)	[b]4.00
Apollo telescope mount deployment assembly:	
ATM/DA basic structure	[b]5.0
Deployment mechanisms	[b]3.0
Rigidizing mechanisms	[b]5.0
FAS attachments	[b]8.0
Transportation and handling equipment (as affects flight hardware)	[b]4.0

[a]Effective factor of safety defined here as factor of safety that will result in a zero margin of safety: Effective factor of safety = Capability/Applied load.

[b]No structural verification tests.

TABLE XV. - INSTRUMENTATION AND COMMUNICATION SYSTEM PERFORMANCE SUMMARY FOR AM DATA SUBSYSTEM

Basic requirements	Capability	Verification
Monitor and process signals from experiments and module subsystems	575 Transducers and 250 signal conditioners provide outputs to approximately 1250 telemetry channels, 80 displays, and 25 C&W channels	All subsystem requirements have been verified by analysis and test program which includes development, qualification, acceptance, and special functional compatibility and interface testing
Multiplex and encode data from experiments and module for transmission to STDN	Programmer, interface box, and 25 multiplexers provide 1298 analog and discrete channels, 1035 of which are recordable	SWS/STDN compatibility testing was performed at GSFC All testing has been completed except:
Record voice and data	Each of three tape recorders provide 180 minutes record capability with playback in 8 minutes per recorder	Mission support engineering, will be completed by April 1, 1973 Intrasubsystem waveform, will be completed by January 15, 1973
VHF transmission link to STDN via antennas which provide coverage during all mission phases	One launch and three on-orbit transmitters modulated by six different sources provide launch and on-orbit coverage via discone and UHF stub antennas; hardline cable provides prelaunch data coverage	Tape temperature, will be completed by March 1, 1973 Qualification of -- PPO_2 sensor, will be completed by November 7, 1972 TACS temperature sensor, will be completed by October 31, 1972 TACS pressure sensor, will be completed by October 20, 1972 OWS gas flowmeter, will be completed by April 13, 1973 Delta qualification of tape recorders, will be completed by December 31, 1972 Systems acceptance of tape recorders, will be completed at KSC by February 5, 1973

TABLE XVI. - SKYLAB SYSTEMS/OPERATIONS

COMPATIBILITY ASSESSMENT REVIEW

(SOCAR) PLAN REVIEW TOPICS

Systems design
Systems performance predictions
Systems operation constraints and limitations
Systems interfaces - functional
Waivers and deviations
Test and test anomalies
FMEA/SFP
Safety checklists
In-flight maintenance tasks
Contingency analyses