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TABLES

ABBREVIATIONS AND ACRONYMS

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

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

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

2.2.4 Thruster Attitude Control System (TACS)

2.2.4.1 Design Requirements - For most of the nine-month long Skylab mission, the primary source of attitude control was the control moment gryos (CMG's) which provided the pointing accuracy and stability necessary for many Skylab astronomical and earth resources experiments, and which maintained the solar inertial attitude necessary for the Skylab solar arrays. A propulsive attitude control system (ACS) was needed to provide control during CMG spinup (the first ten-hours of the mission), to handle docking transients and large maneuvers beyond the capability of the CMG's, to desaturate the CMG's when necessary, and to provide a contingency capability in case of CMG failure. This system, designated TACS (thruster attitude control system), was required to provide a total of 61,000 lb-sec (271 x 10^5 N-sec) of impulse. A high thrust level of 50 lbf (222 N) was required at the start of the mission for separation transients, a 20 lbf (89 N) thrust minimum was required for each of the three dockings with Apollo command modules, and a 10 lbf (44 N) minimum was specified for the rest of the mission.

Because of the ample payload capability of the Saturn V Booster, the design was not subject to the severe weight constraints normally imposed on such a system. This permitted selection of an ambient gas system to minimize development costs and maximize reliability. Nitrogen was selected as the propellant to minimize contamination of Skylab external equipment and to avoid the complexity of preventing condensation in cold propellant lines that would have resulted from use of a heavier gas. The thrust requirement permitted deletion of system pressure regulators. Thrust level was allowed to decay with bottle pressure in a simple blowdown mode.

TACS thrust requirements and predicted system performance are shown on Figure 2.2.4.1-1.

2.2.4.2 System Description - The schematic shown in Figure 2.2.4.2-1 identifies the major TACS components: 6 thruster nozzles, 24 solenoid valves with integral filters (6 quad-redundant assemblies), 2 supply line filters, 22 propellant storage spheres, and a fill disconnect. The location of the TACS on the Skylab spacecraft and the mounting of key components are shown in Figures 2.2.4.2-2 and 2.2.4.2-3.

The thruster nozzle has a 50:1 expansion ratio and a bell-shaped expansion contour. These features were selected to maximize specific impulse while confining the exhaust plume to minimize impingement on the vehicle which could cancel part of the thrust.

The TACS solenoid valve is illustrated in Figure 2.2.4.2-4. A small pilot poppet, integral and coaxial with the main poppet, controls pressure forces that open the main poppet. The pilot poppet and main poppet are linked mechanically so that energizing the solenoid coil opens the valve against the springs at low supply pressure. When the solenoid is deenergized, both poppets are pressure-unbalanced closed to assure leaktight sealing.

The supply line filters utilize a multilayer etched-disk construction to provide 10 micron nominal filtering capability.

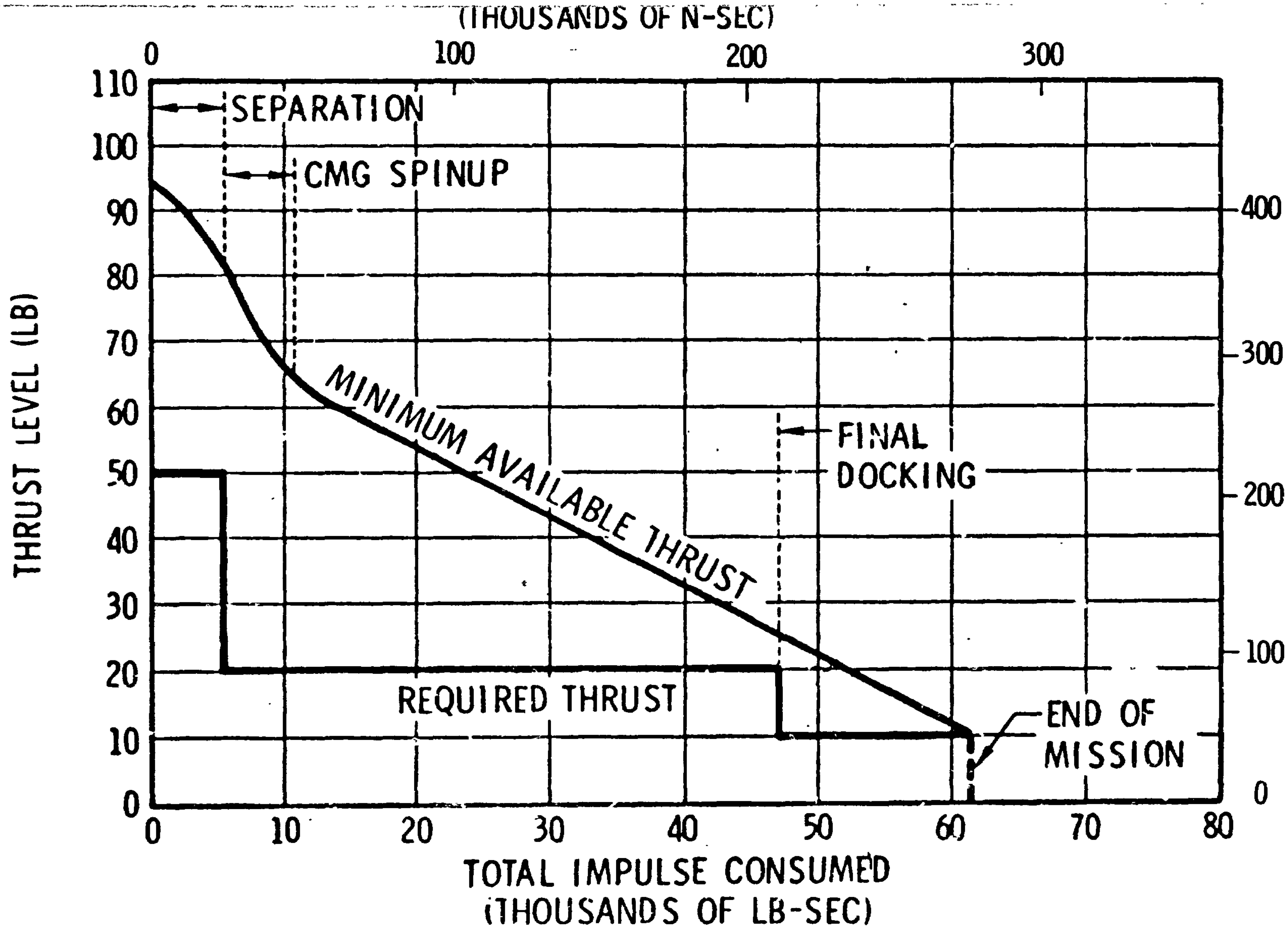


Figure 2.2.4.1-1. TACS Minimum Thrust Versus Total Impulse Consumed

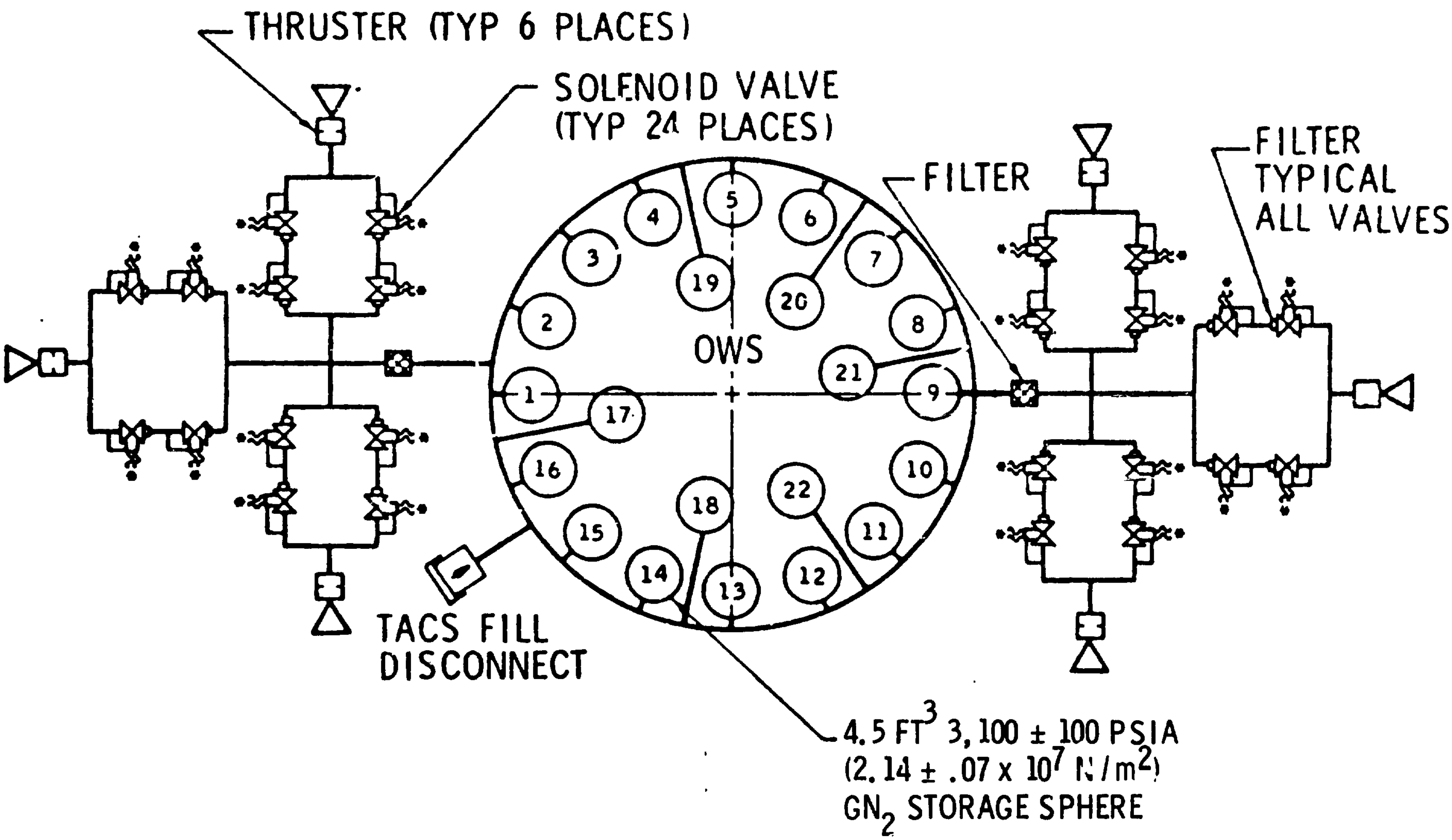


Figure 2.2.4.2-1. TACS Schematic

SKYLAB - ORBITAL WORKSHOP
TACS - COMPONENT LOCATIONS

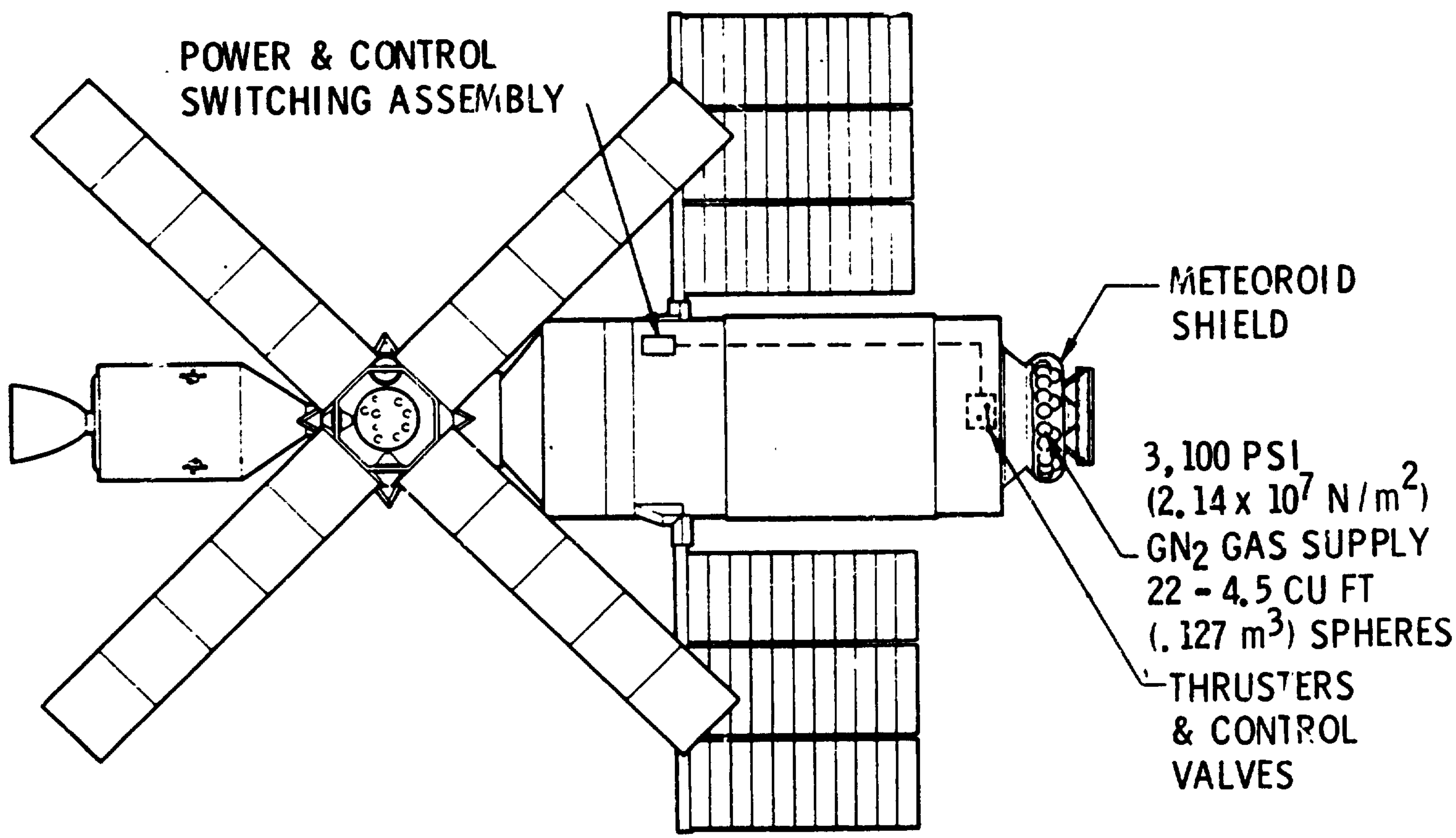
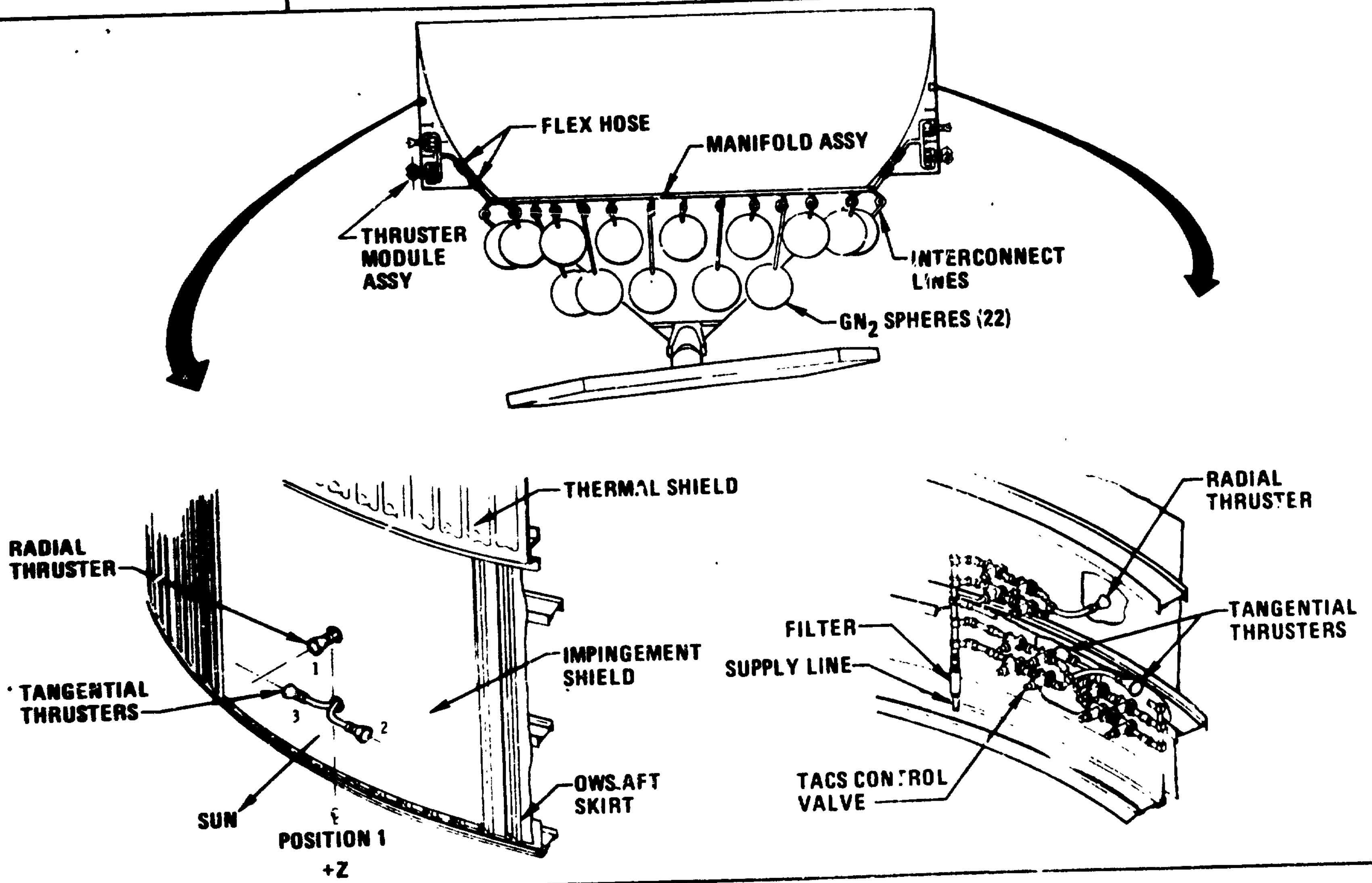


Figure 2.2.4.2-2

SKYLAB - ORBITAL WORKSHOP TACS INSTALLATION



SKYLAB - ORBITAL WORKSHOP
TACS CONTROL VALVE

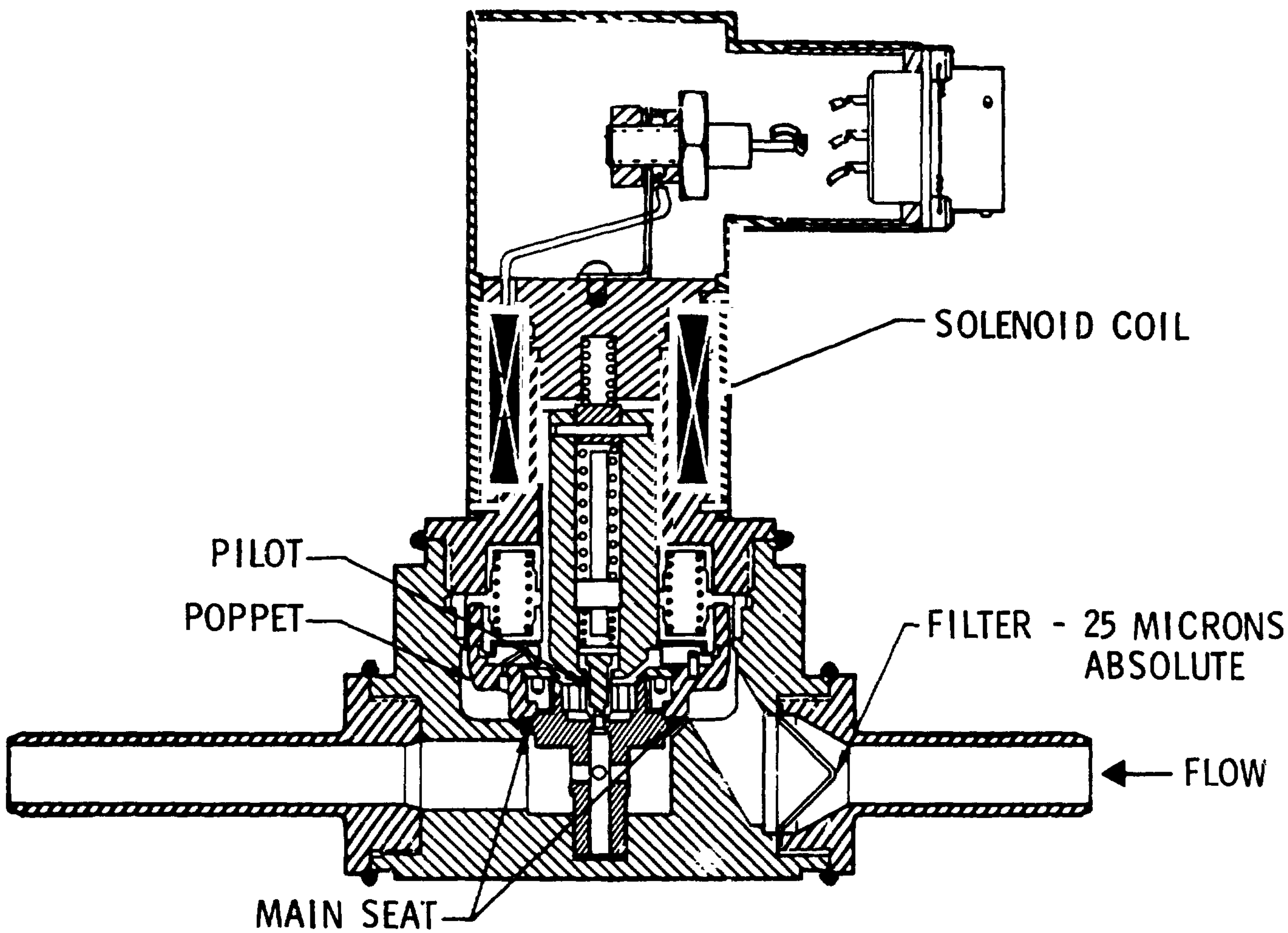


Figure 2.2.4.2-4

The nitrogen supply spheres are of the same design as those used in the S-IVB ambient helium repressurization system. They are constructed of welded titanium segments, and are qualified for operating pressures up to 3200 psia (2.2×10^7 N/m^2). The maximum loading pressure of the TACS supply was therefore established at 3200 psia. The storage spheres were loaded through a self-sealing disconnect located at the vehicle skin. The disconnect was hard-capped prior to launch to provide extra protection against leakage.

The propellant supply and distribution system was induction brazed (Figure 2.2.4.2-5) at all tubing connect points to minimize leakage. A modification to the inlet fitting of each sphere and the addition of a bi-metal joint (Figure 2.2.4.2-6) provided the capability of "in-place" brazing. Fluxless induction brazing provided a lightweight leakproof joint.

The TACS electrical subsystem was developed to (1) utilize Airlock Module (AM) power; (2) accommodate command or control signals from the Apollo Telescope Mount (ATM) Digital Computer, the Instrument Unit (IU) Flight Control Computer, the AM Digital Command System and the OWS switch selector (depending on the mode of operation and the phase of the mission); and (3) provide instrumentation measurement capabilities for telemetry and Skylab panel display monitoring requirements.

The electrical system utilizes separate redundant circuits and components to protect against single-point failures and employs high reliability in parts selection and design while ensuring compatibility of command signals, control signals and power measurement signals with the interfacing system and equipment.

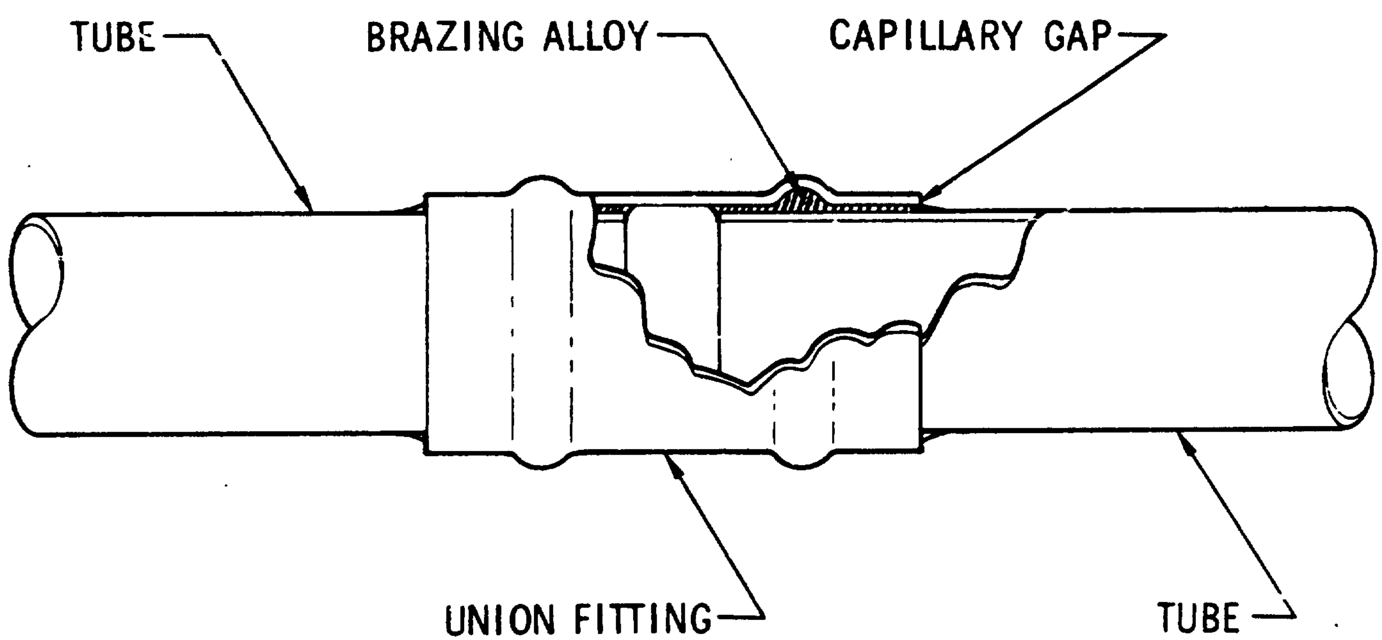


Figure 2.2.4.2-5. Typical Detail cf Brazed Joint

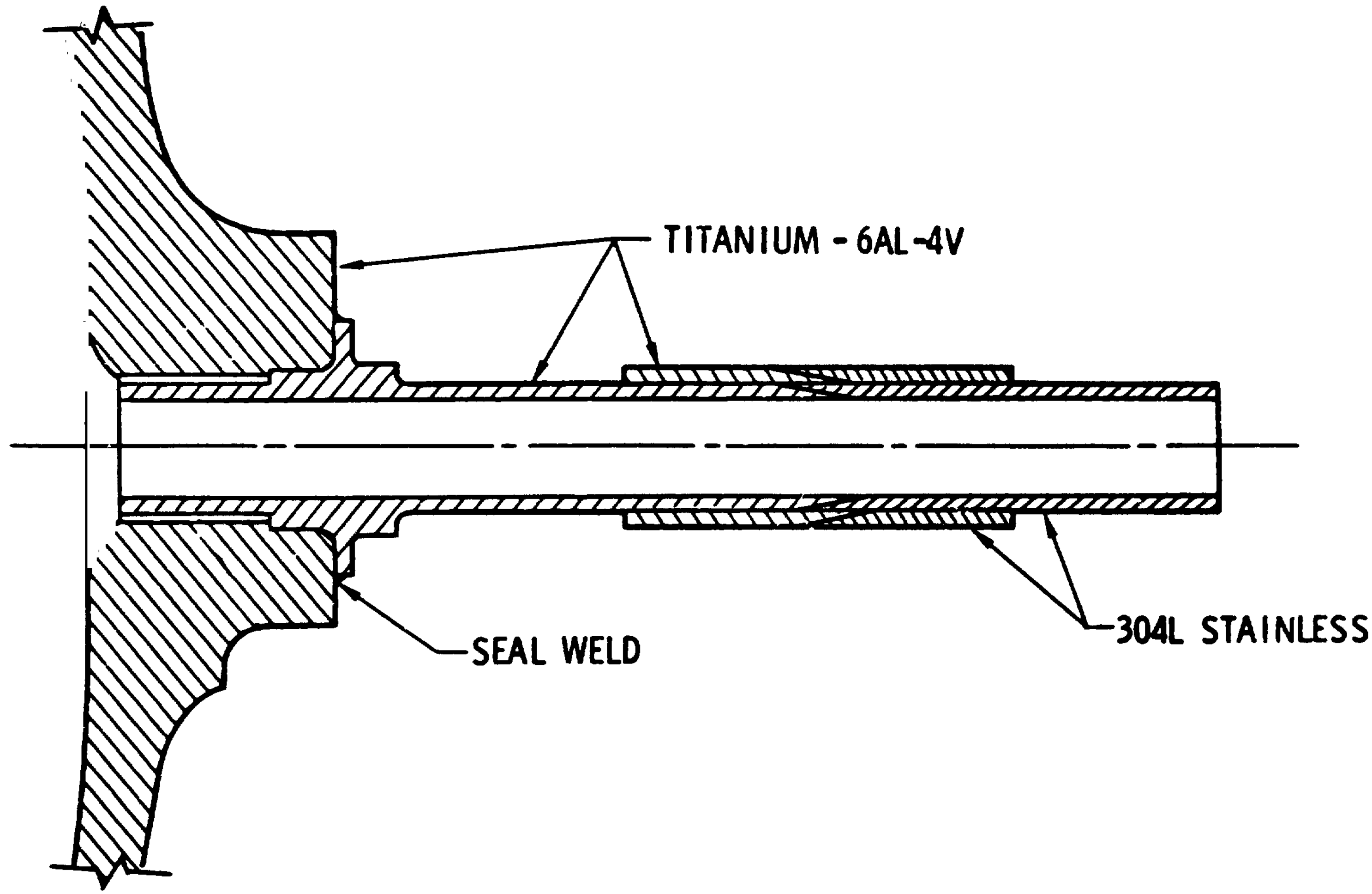


Figure 2.2.4.2-6. TACS Bimetallic Joint

Relay logic and control circuits, with solid-state time-delay circuits, were selected as the electrical configuration. Relays were chosen because of:

- o High reliability, based on past experience
- o Excellent isolation features for interface compatibility
- o Nonloading circuit features
- o No status change from loss of power
- o Compatibility with the installation environment and structural load conditions.

2.2.4.3 Testing - The TACS was certified for the Skylab mission after successful completion of the following development and qualification test programs:

- o Development Test

TC-1 Thruster Module Assembly (single valve, dual valve and module)

TC-10 Bi-metal joint

TC-12 TACS Valve -

Phase I Lip seal evaluation

Phase II Production module life cycle

Phase III Backup seal evaluation

TC-14 TACS pressure switch

o Qualification Test

TC-2 Thruster module assembly

Phase I Manifold assembly

Phase IA Pretest evaluation - single and dual valve

Phase IIA Pre-vibration and shock

Phase III Modules and manifold

TC-9 TACS pressure sphere

TC-13 TACS pressure switch and temperature transducer

The purpose of each test program, problems uncovered and resolutions are listed as follows:

A. TC-1 Thruster Module Assembly - The purpose of the test was to evaluate and establish a production configuration for the TACS valve. The development valves were tested at the valve, dual valves and module levels to evaluate: functional, performance, and dynamic characteristics under various environmental and system conditions. The major problems uncovered during the test program and resolutions were as follows:

1/ Internal Leakage - Redesigned seat and poppet configurations and change material to vespel. Increased pre-load on main poppet springs and chemical de-burring of all machined parts.

2/ Response Anomalies - Increased vent holes in plunger from 2 to 4 and micro-lube lip seal.

3/ Loss in Suppression - Changed to high reliability diodes and new supplier.

4/ Erratic Response - Added secondary seal to the lip seal to minimize the leakage rate into solenoid chamber and a physical stop to limit the main poppet travel.

B. TC-2 Thruster Module Assembly - The purpose of this qualification test was to establish the flight worthiness of the TACS valve, module and cluster (3 modules). The TACS pressure switches, temperature transducer, filter, flex tubings and manifold were included in the test specimen. The test hardware was subjected to and successfully met all the design parameters except for pressure switches which were sequentially qualified under Line Item TC-13. The problems and resolutions are listed below.

1/ Main Seat Crack - One of the 12 valves in the test program failed after being subjected to 3000 cycles. The failed valve was replaced and all 12 valves completed 35,000 cycles under all launch and orbital environments. After extensive analysis the cracked seat was determined to be a random failure and the valve was considered acceptable for flight since the maximum expected operating life was 3100 cycles.

2/ Pressure Switches - The components were deleted from this line item and qualified under Line Item TC-13 due to external leakage and failure to respond during repeat cycling of the TACS module.

3/ Temperature Transducer - The component failed to function during pretest and was deleted from this line item. The component was qualified under Line Item TC-13.

C. TC-9 TACS Pressure Sphere - The purpose of this test was to qualify the TACS pressure sphere installation for OWS usage. The test specimen included a TACS pressure sphere assembly with temperature (transducer) probe, bi-metal joint and a segment of the thrust structure. The test specimen was qualified without any problems.

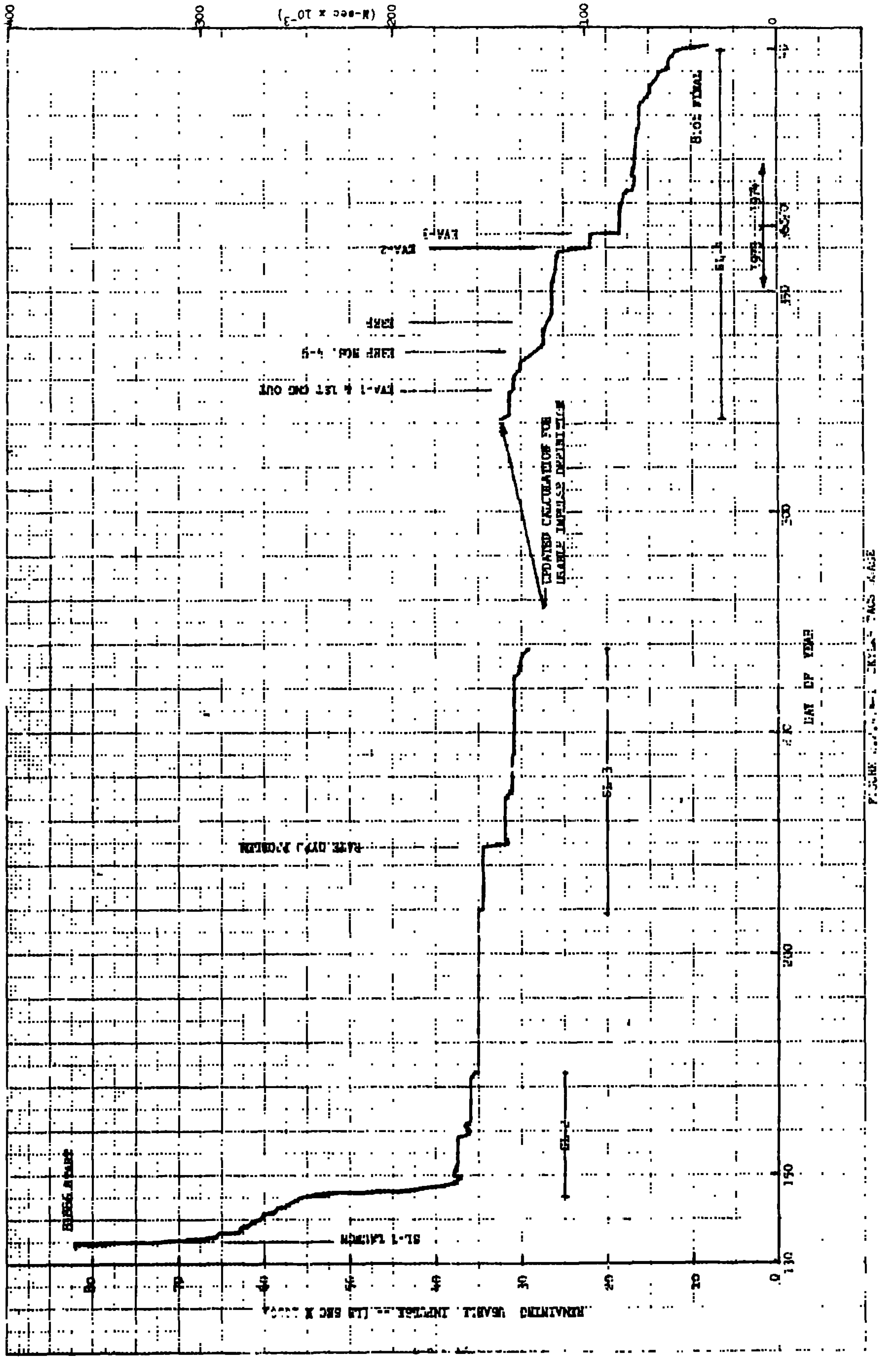
D. TC-10 TACS Bi-Metal Joint - The purpose of this test was to evaluate the design configuration of the joint and the suitability for production use. Special purposes were to determine the redundancy of the joint, pressure and load capabilities, weld joint and sphere neck configuration, and tooling and welding procedures. Six test specimens were successfully tested to demonstrate the acceptability of the bi-metal joint configuration for production usage.

E. TC-13 TACS Pressure Switch and Temperature Transducer - The purpose of this test was to qualify the TACS pressure switch and temperature (probe) transducer for OWS usage. The components were demonstrated to be adequate for the OWS mission requirements since both the pressure switch and temperature transducer functioned properly after being subjected to vibration, shock, and cyclic testing. The only problem was with the pressure switch.

Pressure switch had external leakage and failed to function properly after accumulating approximately 6300 cycles or approximately 4300 cycles after being subjected to vibration and shock. This was considered an acceptable service life since the maximum operational life would be 3100 cycles and the talkback parameters were not critical.

F. TC-14 TACS Pressure Switches - The purpose of the development test was to evaluate the performance of the TACS type pressure switches with diaphram materials made from CRES 302 and Kapton. Four pressure switches, two with CRES 302 and two with Kapton diaphram, were subjected to proof, leak, functional and 35,000 cycles at the expected orbital temperatures. The results appeared to indicate that the pressure switches with Kapton were better than with CRES 302 diaphram. Both test specimens with Kapton diaphram completed the test program without any problems. One of the test specimens with CRES 302 diaphram developed a leak after 8261 cycles and the other specimen successfully completed the test program without any problem. There were no pass/fail criteria for this test program.

2.2.4.4 Mission Results - The TACS successfully fulfilled all vehicle control demands imposed upon the system throughout the mission. The TACS was the primary system for attitude control following S-II separation until the CMG's were sufficiently spun-up to permit transfer to ATM/CMG control. Following transfer to CMG control, the TACS continued to function as a supplemental system to correct large attitude error rates and provide momentum relief for the CMG's. Figure 2.2.4.4-1 shows the TACS usage history.



(N-sec x 10^-3)
400
300
200
100
0
EVA-3
EVA-2
EREP
EVA-1 & 1ST CMG OUT
UPDATED CALCULATION FOR USABLE IMPULSE DEFINITION
RATE GYRO PROBLEM
SL-1 LAUNCH
SL-2
SL-3
SL-4
1973
1974
150
200
300
DAY OF YEAR
REMAINING USABLE IMPULSE

Impulse consumption significantly exceeded the predictions during the early portion of SL-1/2 and during most of SL-4. The excessive usage was attributed to the following mission anomalies:

A. ATM/CMG switchover occurred ten-hours later than scheduled due to rate gyro drift which resulted in a higher than normal rate of CMG momentum buildup.

B. Due to the loss of the meteoroid shield, several "unplanned" attitude maneuvers were conducted for vehicle thermal conditioning purposes.

C. Periodic CMG momentum cages were performed while maintaining the off-nominal vehicle attitude (i.e., -45° pitch) for thermal conditioning prior to JSC parasol sunshield deployment.

D. Large vehicle perturbations were associated with the SEVA and EVA activities to deploy the malfunctioned SAS panel.

E. Several unsuccessful "hard dockings" were attempted.

F. Failure of CMG No. 1.

Total usable impulse at liftoff was approximately 82,000 lb-sec (3.64×10^5 N-sec). This was 21,000 lb-sec. ($.93 \times 10^5$ N-sec) greater than the minimum requirement of 61,000 lb-sec (2.71×10^5 N-sec).

On DOY 327, CMG No. 1 failed. The predicted TACS usage during the planned EREP and Kohoutek Observation Program and during EVA's was significantly higher for two CMG operations. This raised concern as to the accuracy with which TACS remaining impulse was known. A comparison of apparent and actual TACS specific impulse was made using APCS momentum data from 80 pulses along with thruster flowrate data from Qual Testing. At a TACS storage pressure of 1280 psia (8.82×10^6 N/m^2), the average Isp was 78 seconds on the hot side (113°F, 318°K), and 66 seconds on the cold side (-59°F, 222°K). These values were respectively 2 percent and 7 percent higher than the nominal predictions. The estimated accuracy of the results is ±6 percent.

No detectable system leakage was found in a series of mass calculations during each of the storage periods.

2.2.4.5 Conclusions and Recommendations - The negligible leak rate of the TACS system has verified the adequacy of bi-metal joints and "in-place" induction brazing for long term storage systems. The ability of the TACS valves to remain leak tight after extensive orbital usage has verified the adequacy of the valve design, materials, and testing program.

The unanticipated high propellant consumption during the early part of the mission caused concern that TACS might be depleted prematurely. Future designs should include the capability to interconnect systems using similar working fluids such as the TACS and the AM O_2 and N_2 supplies which had ample reserves.

2.2.4.6 Development History

A. The TACS system flown on the OWS was the basic system conceived when the Skylab concept evolved from utilization of a passivated propulsive stage to a completely outfitted Workshop. Although little TACS system evolution occurred, many studies were made and tests accomplished to make sure that the system chosen would fulfill all mission requirements and provide maximum reliability. Some of the major studies made were as follows:

1/ Many different gases were considered as propellants. Nitrogen was chosen, although a comparatively large storage volume was required. Handling and performance familiarity, availability, compatibility and safety considerations were decisive factors in choosing nitrogen as the propellant.

2/ Several system configurations were considered:

- o Regulated system
- o Blowdown system
- o Regulated plus high pressure blowdown system
- o Pressure switch (bang-bang) system
- o Regulated plus pressure switch solenoid valve system

The blowdown system was chosen primarily for system simplicity (high reliability).

3/ System redundancy and gas supply isolation (in addition to quad redundant control valves which were a part of the basic system concept) were extensively studied. Among the systems studied were:

- o Completely independent redundant systems
- o Gas supply isolated with pyrotechnic valves
- o Gas supply isolated with parallel solenoid valves and check valves
- o Gas supply isolated with combinations of the above

It was found that the basic system reliability could be improved as much as 13 percent; however, the overall attitude control system improvement would be only a fraction of one percent. In light of schedule impact and cost, it was decided to stay with the simple, existing baseline system.

4/ In addition to the foregoing items, miscellaneous development items occurred as follows:

a. Vibration isolators were installed on the thruster modules when it was found that launch vibration tended to bounce the valve poppets and cause temporary leakage.

b. Redundant sleeves were added to the bimetallic joint (titanium to steel) when problems were encountered on other programs with a similar joint.

B. The heart of the TACS system was the quad redundant TACS valves. These valves were pilot operated solenoid valves specifically designed for this application to meet fast response and very low leakage requirements. Brief development history comments on these valves are as follows:

1/ Several different main poppet seal materials and configurations of the TACS valve were evaluated in the initial phase of testing. The configuration that displayed the optimum combination of sealing characteristics was a conical poppet with an "L" section sealing surface made from du Pont Vespel seal material. This configuration was used in all development valves and subsequently on production valves.

2/ It was noted that when the valves were tested in the quad redundant module, the upstream valves did not seal effectively with a high inlet pressure and low ΔP. However, all valves exhibited sufficient sealing characteristics at moderate (approximately 10 percent of inlet pressure) or high ΔP's. This problem was solved by assuring the presence of a moderate to high ΔP across the upstream valve, by slowing the closing response of the downstream valve. This was accomplished by shunting the Zener diode in the valve's voltage suppression circuit.

3/ During high temperature testing, electrical shorts developed in the magnum solenoid coil wire. This problem was resolved by changing the coil wire to constantan, changing the insulation from teflon to polyimide, wrapping the wire on an aluminum spool, and potting the entire assembly to provide greater heat dissipation.

4/ A problem with plunger flanges bending was found in the downstream valves. It was determined that pressure surges from upstream valves caused rapid acceleration of the main poppet which resulted in impact loads imparted to the plunger flange. This resulted in slow pneumatic response within the valve. This problem was resolved by incorporation of a main poppet stop which precluded impact of the plunger flange.

5/ Repeat cycle testing revealed the existence of a leak path around the backside of the lip seal. This leakage adversely affected valve response at pressures between 1750 to 3200 psig. This problem was resolved by incorporation of a static seal behind the primary lip seal.

2.2.5 Solar Array System - In this section the Solar Array System (SAS) design requirements, system description, testing, mission results and development history are presented. The SAS is made up of a structural beam/fairing assembly, solar panels, deployment mechanism, ordnance deployment devices, power units, and associated wiring and cabling. The system supplies the electrical power to the Airlock Module (AM) for distribution to the power-using equipment. The SAS design requirement was to provide an average of 10,496 watts between 51 and 125 volts during the sunlight portion of each orbit.

2.2.5.1 Design Requirements - The SAS was designed for installation on the OWS. Structural modifications were made to accommodate mounting the solar array panels. A dry nitrogen gas purge system was provided for pre-launch purge of the solar array panels. The SAS was designed to satisfy the following requirements:

- o During the primary deployment mode, the SAS shall be capable of being deployed starting at any time from 20-minutes after liftoff to 105-minutes after liftoff. Total deployment time shall vary from nine minutes maximum for deployment initiation 20 minutes after liftoff to fourteen minutes maximum for deployment initiati 105-minutes after liftoff.

- o Deployment of the SAS shall be automatic.

  a. Primary control shall be from the OWS switch selector.

  b. A backup deployment command shall be available at the OWS and AM interface.

- When deployed, the panel surfaces shall be in the OWS Position II - Position IV plane with the active surfaces facing in the direction of the Position I plane.

- The ordnance devices used to initiate deployment of the array wings shall not damage the OWS structure, contaminate the solar panels, or deter the proper operation of the solar array.

- The solar array panels shall consist of a number of separate groups of connected modules whose outputs shall be routed to the OWS/AM interface by a two-wire (positive and return) circuit.

- The average available power from the array if measured at the AM/OWS interface and integrated over the sunlight portion of the orbit at the end of the mission shall not be less than 10,496 watts with the Skylab in solar inertial orientation. This power shall be distributed over 8 individual sources (groups of modules) with an available average of not less than 1,312 watts each. This power shall be available at a minimum voltage of 51 volts at the AM/OWS interface and the voltage shall not exceed 125 volts. Each module shall be diode isolated from all other modules within its group. Each group shall be electrically isolated from all other groups.

- The packaged solar array wing assemblies shall be capable of withstanding dynamic environments, induced by transportation by land (truck), water (including barge on ocean), and air without experiencing system degradation.

o The SAS beam/fairing shall protect the solar panels and deployment mechanisms and be self-venting through the induced environments of the Skylab ascent trajectory.

o The SAS shall be capable of withstanding the vibration and shock levels associated with SWS maneuvers and docking operations.

2.2.5.2 System Description - The SAS for the OWS is made up of two wings, each consisting of a forward fairing, beam/fairing, three wing sections and mechanical and ordnance systems required to deploy the SAS in orbit.

Each wing section contains ten identical active solar panels for a total of 30 panels per wing or 60 panels per system. Two additional panels are included in each wing section to provide spacing between active panels and the beam fairing; one is a truss panel and the other a "dummy" panel. A typical SAS wing assembly is shown in Figure 2.2.5.2-1.

A. Electrical - The solar panels are approximately 27 by 121-in. (68.6 by 307.3 cm). Each panel contains four separate and electrically isolated solar cell modules. Each module contains 616 2 x 4 cm solar cells made up of four parallel strings, each with 154 cells connected electrically in series. The four strings are connected electrically in parallel at the module output terminals. Figure 2.2.5.2-2 shows a typical solar module - four per solar panel.

SOLAR ARRAY WING ASSEMBLY

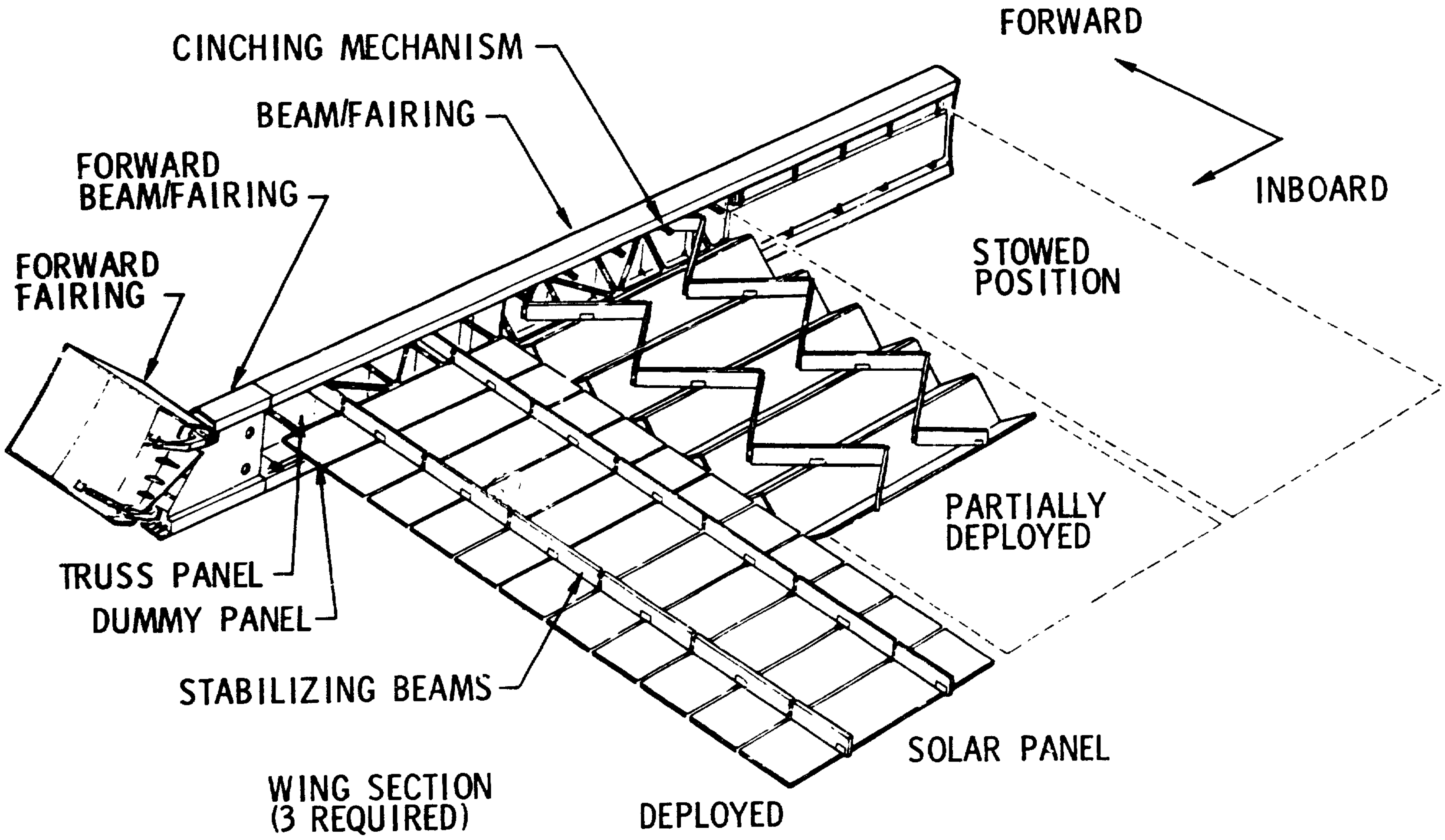


Figure 2.2.5.2.1

SKYLAB - ORBITAL WORKSHOP
SOLAR CELL MODULE

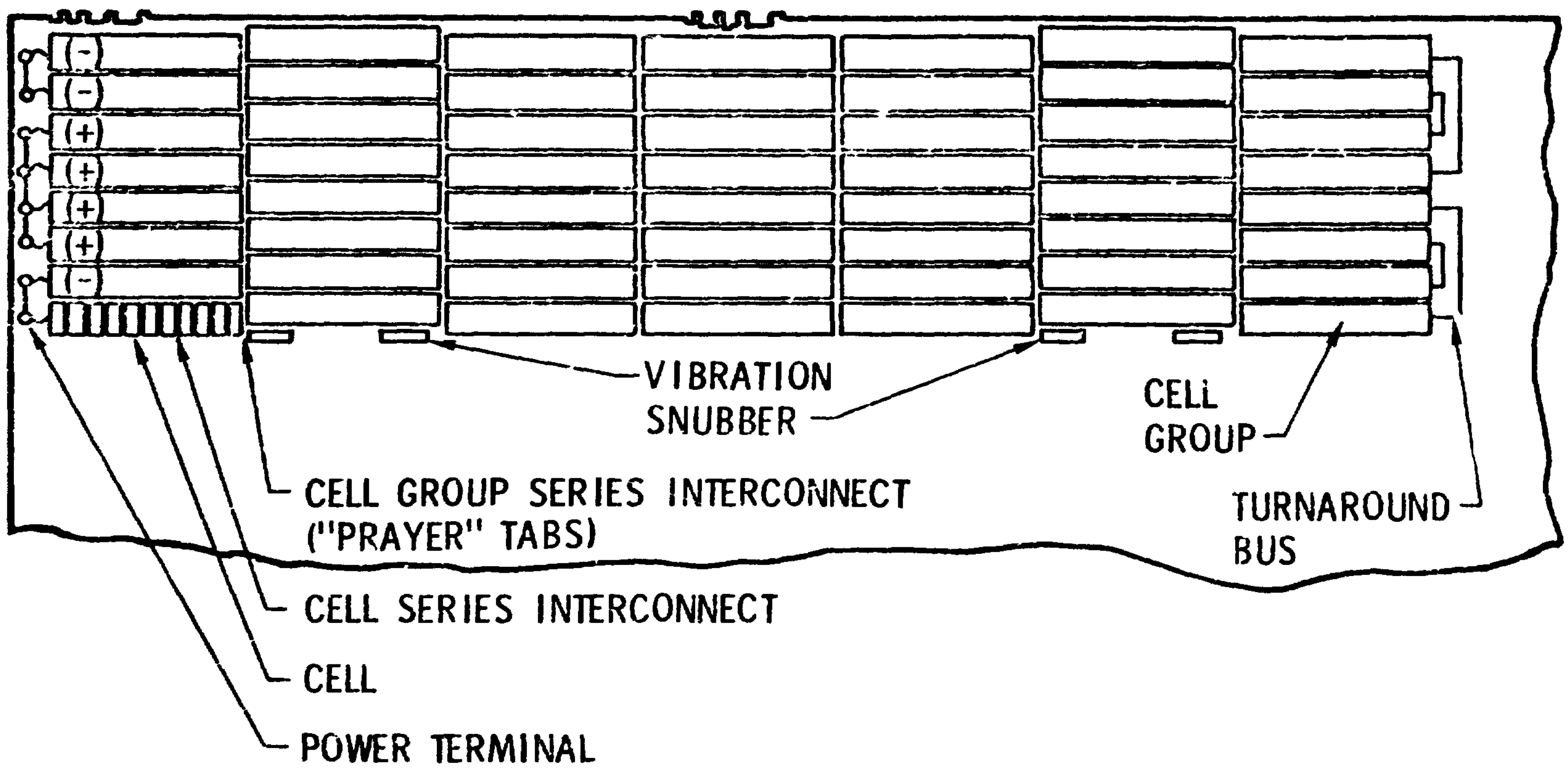
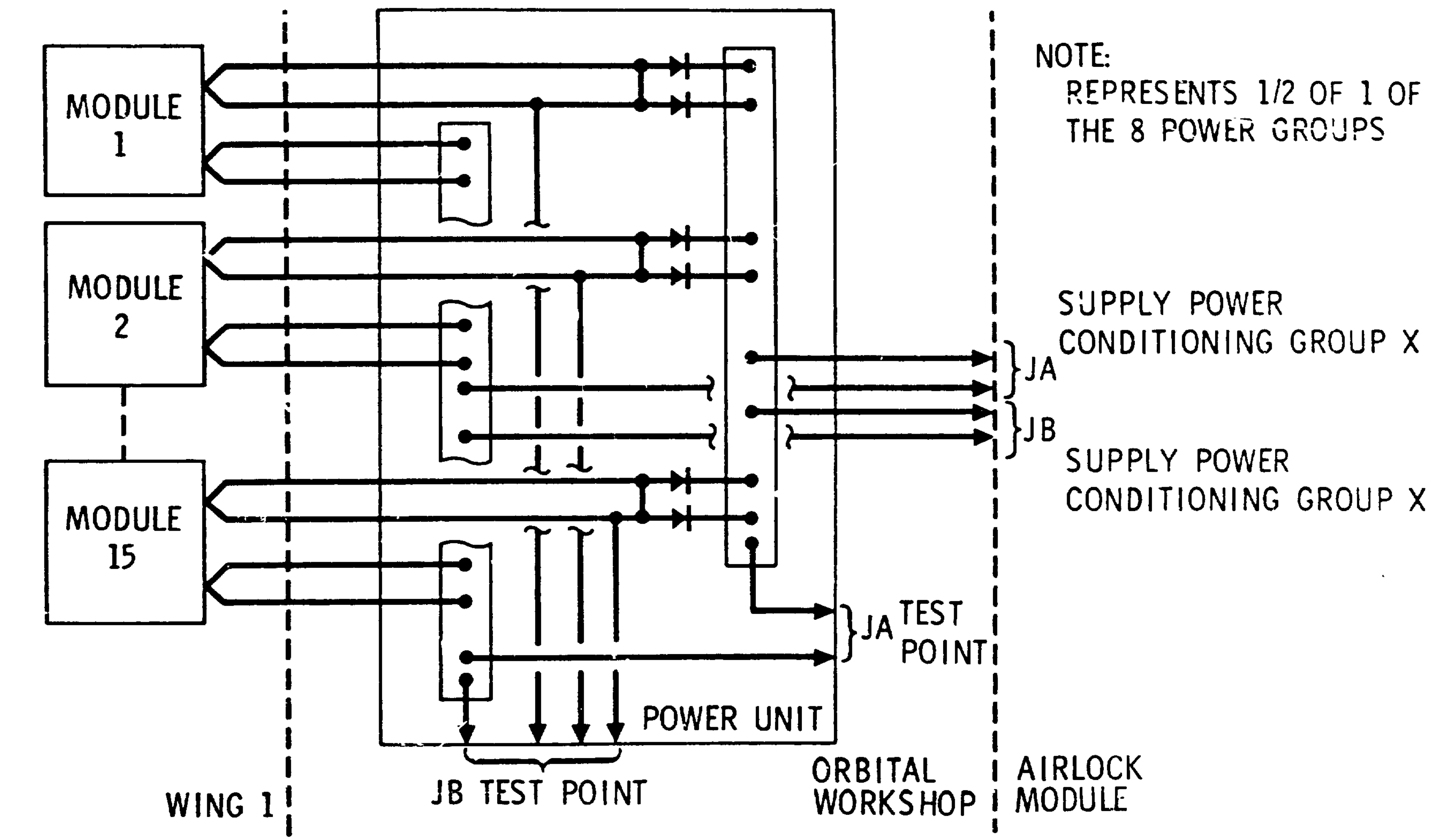


Figure 2.2.5.2-2

The electrical power is routed from each solar cell module through stabilizer beam channels on the backside of each wing section, inside the beam fairing, and then into the forward skirt of the OWS. Inside the forward skirt, solar module power enters the power unit which provides diode isolation and bussing into eight groups of 15 modules each. Power is then routed from the power unit to the OWS/AM interface. The eight 15 module groups from each wing are paired to make eight solar array groups (SAG) of 30 modules each. Each of the eight groups is in turn connected to one of the AM power conditioning groups (PCG) to form the OWS/AM electrical power system. Figure 2.2.5.2-3 illustrates a typical SAG/PCG interface.

Solar array temperature is determined by 20 temperature transducers, ten on each wing. Transducer locations were defined based upon predicted temperature profiles for each wing.

B. Mechanical/Deployment - The beam/fairings are deployed at about 42 minutes after liftoff. Release of beam fairings is accomplished by means of an ordnance system. The beam fairings are held against the OWS by means of six tie-down modules, each of which contains a frangible tension link and two explosively actuated expandable tube assemblies (Figure 2.2.5.2-4). The tie-down modules are installed between the OWS and the beam fairings at the time the SAS is installed on the OWS. Mounting holes on the outboard side of the tie-down modules mate with fittings on the beam/fairing. The inboard side of each tie-down module is equipped with a track and slide and has a mounting-hole pattern

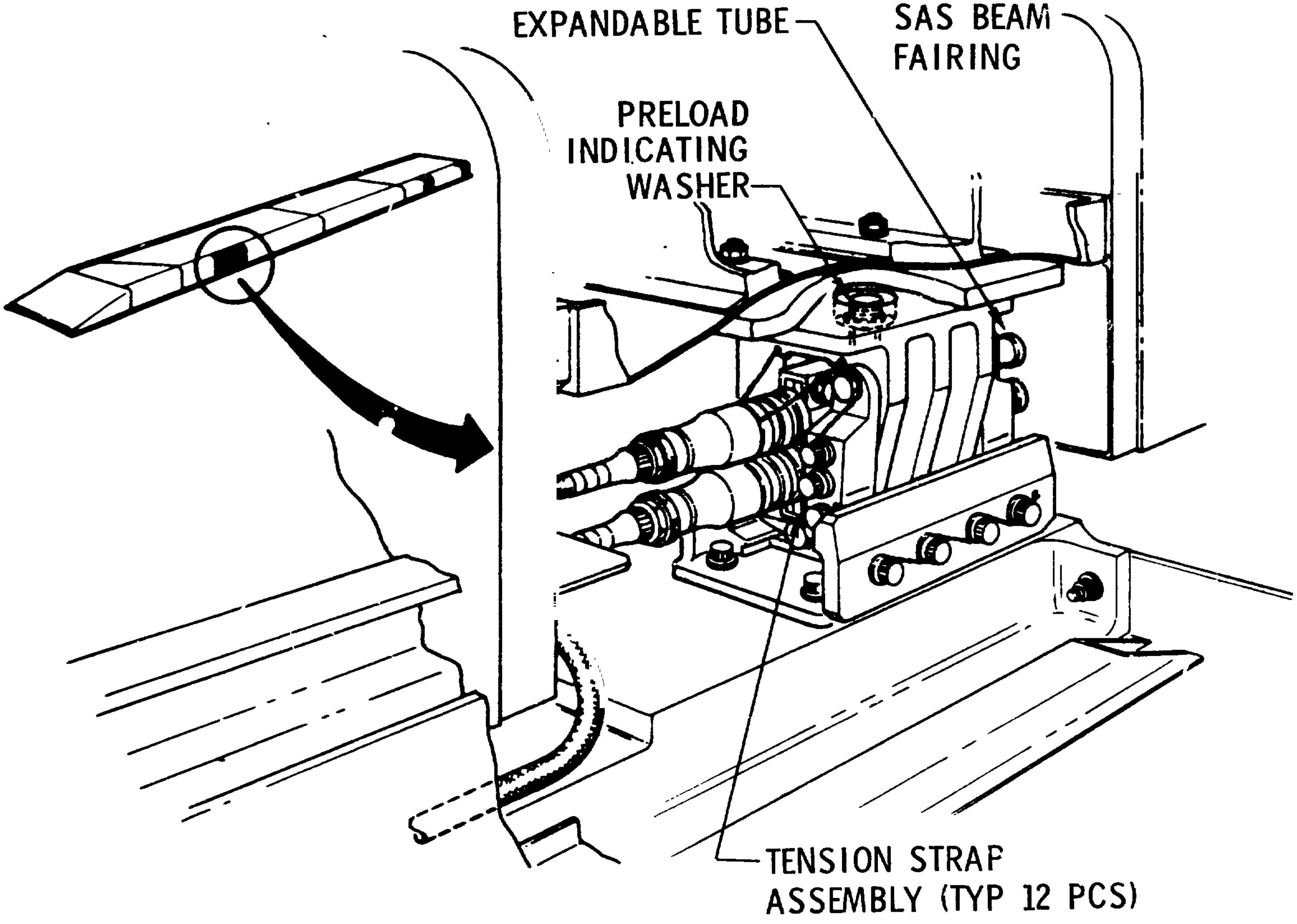


Skylab — Orbital Workshop SAS — Electrical Power

Figure 2.2.5.2-3

SKYLAB - ORBITAL WORKSHOP

SAS BEAM/FAIRING SKIRT ATTACH POINT

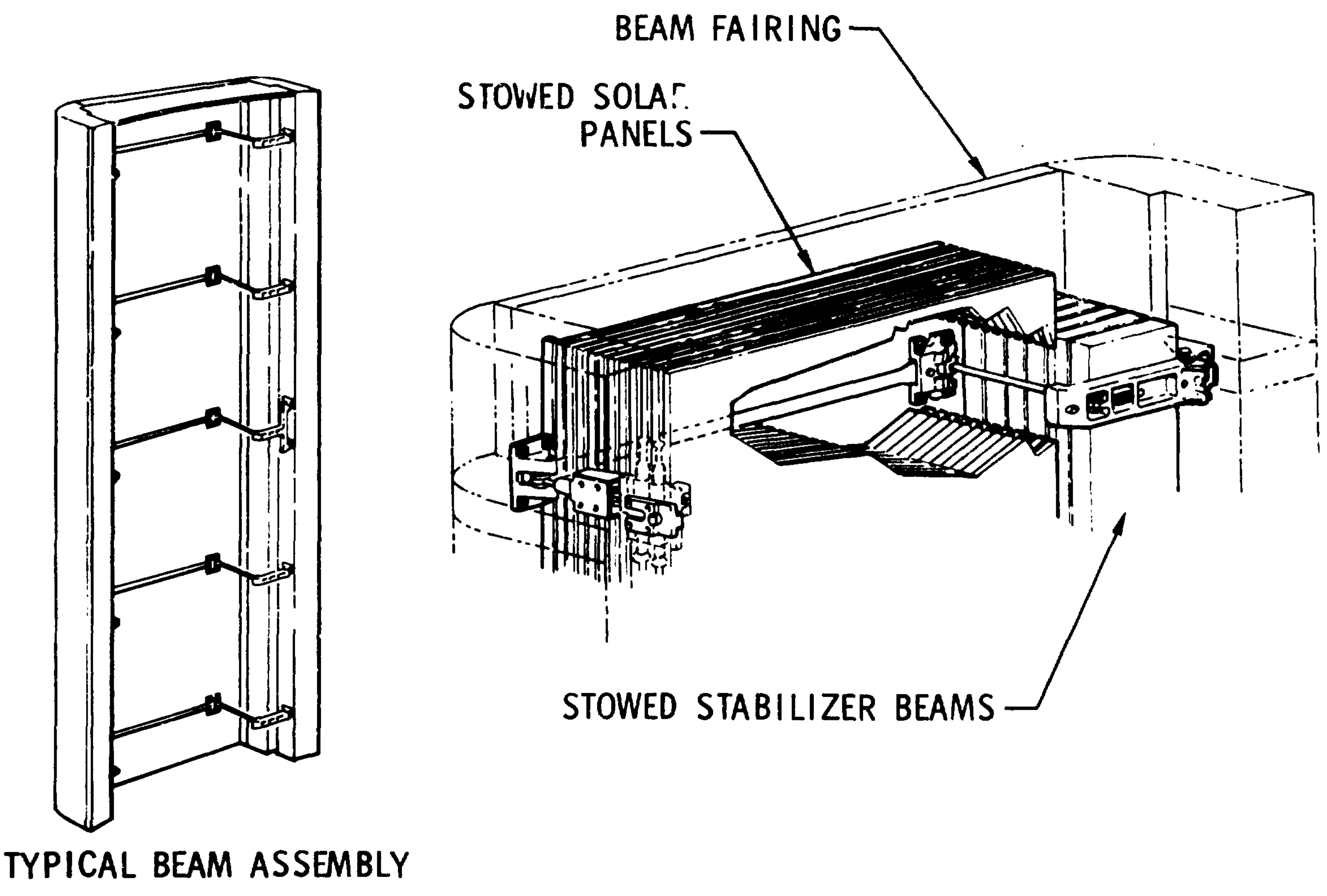


in the track to mate with the interface-hole pattern on the forward and aft skirts. Beam fairing deployment is actuated and controlled by a viscous damper driven by a compression spring about a skewed hinge axis. A latch is provided to lock the beam fairing in the deployed position and latching is verified by microswitches.

After the beam fairings have been deployed and are latched in the deployed position, the solar array panels are deployed by means of a damped mechanical system. The folded and stacked panels are stowed in the beam fairing cavity by means of mechanical latches which retain the hinged edges of the stacked panels. The latches at each edge are interconnected by a mechanical linkage to form an assembly whi . serves as a cinching mechanism for the panel stack. The elements of this system are shown on Figure 2.2.5.2-5.

Five cinching mechanisms are provided for each panel stack (or wing section), and each mechanism is held in the latched p si-tion by means of a frangible link (or tension strap). The panels in the stack are preloaded one against another by jackscrew adjustment provisions incorporated in the latches. This preload is carried in the links of the cinching mechanism such that when the tension strap is severed, the preload is relieved, springs rotate the mechanism and the latches release the wing sections to permit deployment. A redundant pair of explosively actuated expandable tubes installed in each wing extended the length of the beam fairing cavity and mate with the 15 tension straps which retain

SKYLAB - ORBITAL WORKSHOP
WING SECTION RETENTION AND RELEASE SYSTEM



the three wing sections. The hinged solar panels and stabilizing beams are released from their restrained position by the ordnance system. Springs throughout the system provide the energy to deploy the solar panels. The deployment rate is controlled by a viscous damper in each wing section. The deployed position of the panels is maintained by positive latches. A rotary potentiometer indicates the position of the panels during deployment.

The SAS vent system consists of one vent module on each of three sealed beam fairing compartments. The vent module is an acoustically actuated system designed to preclude beam fairing overpressurization during ascent and provide pressure relief during pre-launch nitrogen purge. System actuation and purge venting occur immediately prior to launch vehicle liftoff. The acoustic actuation device is triggered by the acoustic environment developed by the launch vehicle engines.

2.2.5.3 Testing

The Solar Array System Test Program consisted of development, qualification, and special testing of component level and assembly level hardware. Although the SAS for the OWS was a completely new design, all elements were qualified at the highest level of assembly wherever possible. Certain "common ordnance" devices used in the beam fairing and wing section release systems had been qualified in other programs.

Following identifies the development, qualification, and special tests performed for the SAS. Requirements and results are shown for each electrical and structural/mechanical component and assembly tested.

A. Development Tests

1/ Solar Panel (SA-13)

o Requirements - Evaluate the structural integrity of the panel being subjected to launch and boost dynamics of vibration, shock, acoustics and on-orbit thermal vacuum cycling. Evaluate electrical performance by exposure to simulated solar radiation of thermal cycles.

o Results - The structural integrity of the panel was satisfactory. Electrical performance was not degraded by exposure to the environments. Post test inspection demonstrated that the design changes implemented after earlier engineering model tests were effective. One open prayer tab was noted, and a small number of rear side open solder joints. The noted defects had no measurable effect on panel function. The test demonstrated the design feasibility and provided the confidence to proceed into production.

2/ SAS Wing Release Ordnance Expandable Tube and Link Assembly (SA-14)

o Requirements - Develop a specific expandable tube and tension strap or link for releasing the stowed solar array panels. Evaluate the performance of the ordnance device after being subjected to launch and boost vibration environments.

- o Results - Five specimens were used in the test. Three specimens were tested and design changes were required in the expandable tube fuse retention method and the dimensions of the frangible link. The last two specimens were tested with the design changes included and performance was satisfactory.

3/ Actuator Damper, Beam and Wing Section Deployment (SA-18)

- o Requirements - Evaluate structural and functional characteristics of actuator damper under extreme temperature and pressure ranges. Evaluate seals and damping materials.

- o Results - Structural integrity of design was proven. Seals in system leaked under temperature extremes and material was changed. Characteristics of actuator force and damping characteristics of fluid were determined.

4/ Actuator Damper, With Broken Spring (SA-20)

- o Requirements - Demonstrate capability of actuator damper to function with sufficient deployment driving force if actuator spring had a broken coil.

- o Results - Actuator damper demonstrated adequate margin to deploy beam fairing with one coil of the compression spring broken.

5/ Magnetic Latch, Vent Valve (SA-21)

- Requirements - Evaluate capability of a magnetic latch to function under acoustic driving force. Develop magnetic materials and forces required to meet design acoustic requirements.

- Results - Acoustic panel size and magnet force were determined. Change of magnet force with temperature was unresolved and left for development as part of vent module assembly. Latch mechanism capability was demonstrated.

6/ Vent Module (SA-22)

- Requirements - Evaluate vent module functional performance, and demonstrate the structural capability to withstand pre - and post - flight environments.

- Results - Development testing brought out design changes required. Magnet force was redesigned to compensate for temperature changes affecting force. Structure was changed to reduce restriction to air flow. Relief valve body material was changed to withstand vibration loads. Satisfactory completion of testing of critical functions of latch operation under acoustic loads.

7/ SAS Beam Fairing Release (SA-17)

- o Requirements - Develop the configuration of expandable tube and frangible tension strap for the beam fairing. Evaluate the performance of the frangible link and expandable tube after exposure to cyclic loading and worst case thermal conditions.

- o Results - Twelve specimens were used in the test. Results exceeded 10,000 cycles and showed a 100 percent margin on strap severance. A redesign was made to keep the tabs in the link from breaking loose. Five specimens of the redesign were fired satisfactorily.

8/ One-Third Wing Assembly (SA-2)

- o Requirements - Evaluate the ability of the wing section to deploy following exposure to liftoff and boost vibration, acoustic, and shock environments under predicted temperature extremes. The test specimen shall serve as a test bed for environmental testing of other test items - Solar Panel (SA-1), Wing Section Ordnance Release (SA-15), Actuator Damper (SA-19) and Vent Module (SA-23) and structural qualification testing of the deployed wing section for deployed loads.

o Results - Deployment capability successfully demonstrated following several developmental problems which became apparent during test and were corrected by redesign. Developmental problems included -

(1) Tang on cinch bar broke. Material change and increase in cross section required.

(2) Actuator-Damper rod broke. Piston rod redesign to distribute load.

(3) Stabilizer beam hinge fitting broke. Material change in fitting required.

(4) Cinch bar would not lock in open position against seal in low temperature deployment. Redesigned cinch bar with stronger deployment springs.

(5) Wire routing had areas of abrasion. Revised wiring installation at the stabilizer beam to solar panel interface. Added protective grommets at various points.

(6) Silicone rubber bumper stuck to aluminum panel under cold test conditions. Added teflon to bumper to solve problem.

9/ SAS Wing Release Ordnance System (SA-15)

- o Requirements - Evaluate the ordnance release system using the one-third wing assembly as a test bed. Evaluate firing the primary and back-up system after exposure to the launch and boost vibration, acoustic, and shock environments.

- o Results - The primary and back-up systems were operated with a programmed delay of 100 milliseconds between firings. All five frangible links separated in a satisfactory manner.

10. Beam Fairing Hinge Assembly (SA-16)

- o Requirements - Evaluate the capability and demonstrate the structural integrity of forward fairing structure, and hinges and latch to sustain limit and ultimate loads for launch, boost, staging, dynamic, thermal, beam fairing deployment and transient response from CSM docking.

- o Results - Evaluation of results of static equivalent of all load conditions indicated forward fairing, forward beam fairing structure, hinges, latch, and actuator damper satisfactorily withstood all predicted critical loads.

B. Qualification Tests

1/ Solar Panel (SA-1)

- Requirements - Demonstrate the solar panel will function within specification requirements and be structurally sound when subjected to vibration, acoustic and shock environments associated with liftoff and boost and thermal vacuum cycling simulating on-orbit conditions.

- Results - Panel functioned within specifications after all testing was completed. The structural integrity was maintained under test conditions. After 400 thermal cycles the number of open prayer tab solder joints on a single cell were exceeded. Analysis indicated this condition to be an isolated case. Nine-hundred additional thermal cycles were run on the SA-1 panel and 800 cycles were performed on another production panel in line item ST-18. The panel was successfully qualified.

2/ Power Panel (SA-3)

- Requirements - Demonstrate that the unit will function within specification limits after being subjected to the launch and ascent dynamic loads.

- Results - Exceeded allowable reverse leakage current in one diode. Requirement 10 μA at 400V; maximum leakage was 65 μA. Actual usage will allow milliamps leakage at 150V. Analysis concluded that it was a random failure caused by varnish on the substrate internal to the diode.

Experienced external surface defects on diode modules. Analyses concluded that cause was contamination in the form of tape, tape adhesive, and silicone in the region of the epoxy/heat sink interface. Cleaning and contamination control procedures were tightened, and a module rework process was developed to preclude recurrence of surface defects.

3/ Confined Detonating Fuse (CDF) Manifold Installation (SA-5)

- o Requirements - Demonstrate the ordnance components will function properly after being subjected to the launch, and boost vibration environments.

- o Results - All ordnance components functioned satisfactorily.

4/ Actuator Damper, Beam and Wing Section Deployment (SA-19)

- o Requirements - Demonstrate structural and functional integrity of beam fairing and wing section deployment actuator dampers (two configurations) under and following exposure to simulated critical environments including vibration, shock and temperature extremes.

- o Results - Actuators demonstrated capability to function properly under all environmental tests. Actuator was pressurized to ultimate and exhibited adequate factor of safety.

5/ Vent Module (SA-23)

- Requirements - Demonstrate functional capability and ability to withstand pre and post flight environments.

- Results - Functional capability of the operation of the relief valve, pendulum assembly, door release and opening mechanism was demonstrated. Flow coefficient and leak rate requirements were verified

6/ Cinch Bar Deployment (SA-26)

- Requirements - Demonstrate the capability of the cinch bar to deploy and latch after exposure to lift off and boost environments while operating under extreme cold temperature conditions.

- Results - Cinch bar tested in one-third beam fairing test bed operated satisfactorily and locked open under extreme temperature conditions following exposure to lift off and boost dynamic environments.

7/ Solar Array Wing Assembly (SA-4)

- Requirements

  a. Forward Fairing and Hinge - Demonstrate structural integrity of forward fairing and hinges when subjected to lift off and boost vibration and shock environments and combined loads from thermal stresses.

b. Beam Fairing - Demonstrate the capability of the beam fairing to deploy after exposure to lift off and boost vibration, shock and thermal environments. Deployments to be performed under the influence of lateral thermal gradients which increase the effective deployment energy. Actuator damper temperature to be controlled to evaluate damper performance under worse case conditions of maximum damping force and maximum damping load.

c. Wing Section - Demonstrate capability of wing section to deploy following exposure to lift off and boost vibration and shock environments, and under the influence of lateral thermal gradients which distort the beam.

d. Solar Panel - Demonstrate capability to function properly after exposure to lift off, boost and deployment vibration and shock environments.

o Results

a. Structural integrity was maintained. No deformation or bind was evident in hinges.

b. Structural integrity was maintained. Hardware qualified for functional performance included beam fairing actuator damper, latch, and ordnance release system.

Deployment of wing was made under worst case thermal deformation loads as well as simulated anomalies in the ordnance release system. Five of the ordnance tie-down fittings were released then the sixth fitting subsequently released. All tests were satisfactory.

c. Hardware qualified for functional performance were wing section retention and release (cinch bar) system, ordnance release, wing section actuator damper, wing section hinge deployment springs, and hinge latches. All items functioned satisfactorily.

d. Solar panel performance after environmental and deployment tests, showed no electrical degradation from the test environments. Wire harnesses from panels to umbilical showed no abrasion or wear.

C. Special Tests

1/ Sunlight Cell Test (ST-7)

- o Requirements - Establish values of current and temperature coefficients of a group of representative glassed cells using the solar simulator and verified using natural sunlight.
- o Results - The test demonstrated cell sunlight performance and its correlation with solar simulation performance. The test determined cell voltage temperature coefficients.

2/ Sunlight Panel System Test (ST-8)

- Requirements - Using two groups of representative flight panels determine electrical characteristics.

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

  b. Mismatch losses of modules.

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

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

  e. Mismatch losses of power groups.

  f. The basic design compatibility of the power source with the PCG.

- Results - Testing was performed outdoors in natural sunlight at ambient temperature and at a minimum sunlight intensity of 100 mW/cm^2 and, when analytically corrected, established the true performance of the OWS solar array. This test demonstrated panel module, Solar Array Group (SAG) and SAS sunlight performance and its compatibility with the airlock module power conditioning equipment.

3/ Solar Cell Module Shadow Test (ST-9)

- o Requirements - Study and evaluate cell failure mechanisms and module string configurations under changing shadow conditions.

- o Results - Module and cell testing was accomplished under solar simulation with various initial temperatures and shadows. Cell characteristics, the optimum module string arrangement to minimize cell failure as a result of shadowing, and affect of thermal cycling on interconnects and associated solder joints were determined.

4/ Solar Panel Thermal Cycle Test (ST-18)

- o Requirements - Perform thermal cycles in a vacuum to determine degradation of solar panel performance.

- o Results - One panel used in the solar panel qualification test was cycled an additional 900 cycles (1300 total) and a second panel was tested for 800 total cycles. Test results proved confidence in the solar panel capability to successfully complete the required number of orbital thermal cycles. Degradation rate data was accumulated and analytically combined with the results of the ST-9 test. The result was a predicted array performance degradation, from thermal cycling, 4 8 percent for the mission.

5/ Solar Cell Test (ST-29)

- o Requirements - Investigate, though x-ray and radiograph techniques, causes for separation of materials in SAS solar cells. Effects of material variables, type of solder, and solder schedule on solder wettability and joint strength will be studied.

- o Results

  a. A total of 212 solar cells were removed from production panels after each panel had been x-rayed. Cells and P-contact interconnects were subjected to pull and peel tests, and metallurgical analysis using Electron Microprobe analyzer, SEM, and metallograph on selected cells, interconnects, and solder joints.

  b. A total of 205 specially manufactured solar cells were tested to determine the cause of solder dewetting and low solder joint strength. Effects of such variables at Titanium thickness, silver thickness, solder thickness, deposition atmosphere, solder type, and solder schedule were investigated using radiography, metallography, SEM, electron microprobe, colorimetric chemical analysis, and pull strength tests.

Analysis of above test results and radiographs of all production panels concluded that the SAS could lose only 0.55 percent of its power output from P-contact solder joint failure over the mission.

Contacts having the lowest pull strength tend to fail in the titanium layer, while others generally failed in solder cohesion or in tensile strength of the Kovar interconnect itself. A normal cell, therefore, has adequate contact strength, but in rare cases, the cohesive strength of the titanium layer is deficient.

The reliability of solar cell contacts can be improved by cell manufacturing process modifications, particularly in the vacuum deposition phase.

Radiographic inspection of solar panels can provide useful information on relative thickness of the solder coating on solar cells.

6/ Vent Module Storage and Operational Test (ST-15)

- o Requirements - Verify capability to survive out-of-doors storage for extended time period and position modules to verify doors actuate when exposed to Apollo 16 launch acoustic environment.

- o Results - Two vent modules were placed so that Apollo 16 engine acoustics would be at the same levels as the modules would see on the OWS. The doors actuated at Apollo 16 engine start. Two units were placed outdoors in an atmosphere similar to launch site. After four months in atmosphere units were tested and door deployment mechanisms successfully demonstrated.

7/ Spring Loaded Magnetic Latch Test (ST-16)

- o Requirements - Demonstrate repeatability of magnetic latch to operate after extended period of time in the latched position.

- o Results - Fifty specimens were fabricated and tested at six week intervals in lots of six. No failures were encountered in all tests.

8/ Expandable Tube and Strap for Beam Fairing (ST-24)

- o Requirements - Test expandable tube and strap assembly at maximum temperature conditions to assess generation of loose tabs.

- o Results - First specimen fired generated loose tabs. Thermal tape was wrapped around strap and tabs were contained on the remainder of the specimen. The thermal tape was a flight configuration.

.2.5.4 Mission Results - Evaluation of SAS performance has been based on review of launch films and upon real time data from HOSC, user tapes, and MOPS data from NASA/MSFC.

A. Ground Purge and Venting - A GN_2 blanket purge was maintained on the solar panels from the time the wings were mated to the OWS in the VAB until the vent valves opened just prior to lift-off. Periodic checks of the relative humidity in the beam cavities were made to monitor effectiveness of the purge. The maximum readings recorded were seven (7) percent which was well below the maximum allowable requirement of fifty-five percent. Launch films were only focused on Wing No. 1. A review of the launch films revealed that all vent module valves on wing No. 1 were open as the vehicle started ascent. It is assumed that the vent module valves on wing No. 2 were also open as all vent valves operated in the same acoustic range. There was no instrumentation carried to monitor venting performance. Deduction from post-flight analysis was that the purge and venting system performed as required.

B. Launch and Ascent - At approximately 63 seconds into the Skylab 1 flight, the vehicle experienced structural failure of the OWS Meteoroid Shield. This failure unlatched and partially deployed SAS Wing 2 Beam Fairing, as evidenced by the fairing secured bi-level event measurement K7211-426 and indications of the light impingement on the solar cells verified by an increase in the Solar Array Group (SAG) voltages.

Following S-II cutoff at 589.172 seconds, all SAG voltages, with the exception of M104-524, SAG 4 voltage, exhibited an increase as SAS Wing 2, no longer restrained by the launch vehicle acceleration forces, started to deploy. The S-II retro-rocket exhaust plume impinging on SAS Wing 2 contributed to the loss of the wing causing it to rotate rapidly and tear off, thereby severing all electrical connections at approximately 593 seconds. At this time all SAG voltage measurements dropped to the level of PCG batteries, which indicated no further illumination of any solar panels, and all SAS current measurements dropped to zero. Subsequently, no valid data were received from any of the SAS Wing 2 temperature or position measurements.

SAS Wing 1 attempted to deploy at the nominal time but was constrained in a partially deployed configuration by remnants of the Meteoroid Shield. Wing section partial deployment in this configuration allowed sunlight to illuminate some solar cell modules and provide power approximately equivalent to one normally deployed module (1/240 of total SAS capability). Although insignificant in terms of supplying cluster loads, this output was utilized to allow some recharging of the AM batteries.

C. On-Orbit Deployment - Due to the loss of the OWS SAS Wing 2 at orbital insertion, and the entanglement of the meteoroid shield with Wing 1, deployment of the SAS was non-nominal. The separation commands, Electric Bridge Wire (EBW) units, and the ordnance systems functioned as designed. The command sequences and results are shown in the following EBW Data History. The SAS Wing 1 Beam Fairing ordnance was successfully detonated at the proper time by the preprogrammed primary command. The Beam Fairing left its secured position and partially deployed until it was constrained by the remnants of the meteoroid shield. The backup system EBW was charged and fired by ground command and operated nominally, but the backup system was ineffective in further deploying the restrained beam fairing. The SAS wing section EBW responded to the primary Charge and Reset commands, but was prevented from firing the ordnance for deployment by an interlock which is only satisfied by full deployment of both Beam Fairings. The backup system was charged and fired by ground command and the Wing Sections were observed to partially deploy until contact with the OWS tank wall was made.

EBW DATA HISTORY

PRIMARY SYSTEMS

	MEASUREMENT	TIME COMMAND ISSUED GMT	GET (SEC)	CMD SOURCE	REMARKS
M7061	SAS FAIRING				
	EBW FU 2 CHG	18:10:00	2400	IU S/S 9	SAS WING 1 FAIRING SECURED M7212 INDICATED MOVEMENT AT 18:10:06
	EBW FU 2 FIRE	18:10:05	2405	IU S/S 53	
	EBW FU 2 RST	18:10:10	2410	IU S/S 10	
M7067	SAS WINGS				
	EBW FU 2 CHG	18:22:00	3120	IU S/S 11	EBW DID NOT FIRE - INTERLOCKED WITH FAIRING
	EBW FU 2 FIRE	18:22:05	3125	IU S/S 51	

SECONDARY SYSTEMS

	MEASUREMENT	TIME COMMAND ISSUED GMT	GET (SEC)	CMD SOURCE	REMARKS
M7060	SAS FAIRING				
	EBW FU 1 CHG	19:08:22	5902	DCS-182	PRIMARY SYS. RELEASED FAIRING
	EBW FU 1 FIRE	19:08:42	5922	DCS-163	
	EBW FU 1 RST	19:09:10	5950	DCS-183	
M7066	SAS WINGS				
	EBW FU 1 CHG	19:20:56	6656	DCS-172	SAS WING 1 POSITION G7008 INDICATED MOVEMENT AT 19:23:28
	EBW FU 1 FIRE	19:23:26	6806	DCS-162	
	EBW FU 1 RST	19:24:01	6841	DCS-173	

In support of MSFC, activities were initiated at MDAC and TRW to devise methods to fully deploy Wing No. 1. Analysis of data indicated the wing was constrained with the Beam Fairing deployed approximately 6°. Thermal analysis predicted the fluid in both the beam fairing and wing section actuator dampers would be frozen. It was determined that if the astronauts could free the beam fairing from the meteoroid shield constraint that additional force would be required to break the actuator damper link to allow full deployment of the beam fairing. A series of tests were run at MDAC and TRW using two test specimens from the SAS development and qualification program.

The first tests were performed to determine the load required to "break" a frozen actuator damper which in turn would allow the beam fairing to rotate around the hinge line. The tests were performed utilizing an actuator damper qualification test specimen and a simulated SAS forward fairing attached to a plate simulating the OWS forward skirt with a stub section of the SAS beam fairing attached to the forward fairing through the main hinge components. A SAS beam deployment tripod, designed and built for this purpose, was attached to the specimen. The actuator damper was chilled to a frozen state and a load was applied to the tripod through a cable in the direction of the MDA. Failure occurred at a cable force of 102 lb, (454N) in the clevis fitting in the forward fairing to which the actuator damper was attached. Analysis confirmed the clevis was the structural weak point in the system; however, a bolt internal to the actuator damper was very marginal at the loads applied.

The full SAS qualification test wing was mounted in a deployment fixture at TRW and subsequent tests were made on this specimen to complement underwater testing and mockup testing which was conducted at MSFC.

The first series of tests on the qualification wing were performed to determine the parameters of deployment assuming (1) a partially deployed beam fairing, (2) an astronaut pull force on the tip of the beam fairing and (3) a frozen actuator damper. The load was applied at the free end of the beam fairing utilizing a simulated "shepard's hook." Significant findings from these tests were; a force of 10 to 20 lbs (44 to 90N) applied by the "hook" would in most cases fail the clevis; however, in some cases the internal bolt in the actuator damper would fail first. The greatest deployment energy occurred for the case when the bolt broke which allowed both the actuator spring force and the astronaut force to be applied to wing deployment. The latch-up forces were within the demonstrated structural capability limits, however, they were high enough to show the advisability of slowing the deployment with an external force.

Utilizing the qualification wing test set-up, a series of tests were run utilizing a washcloth squeezer bag as a source for applying the load on the beam fairing to break the actuator damper clevis. The first series of tests proved a squeezer bag placed between the beam fairing and the OWS tank wall when pressurized to approximately 5 psig ($34.5 kN/m^2$) with GN_2 could develop enough forces to break the clevis. Access for positioning the evacuated bag between the beam fairing and the OWS was minimal but appeared adequate. The next series of tests used the squeezer bag and was performed to demonstrate the capability of a back-up tether system to successfully stop the beam fairing swing from energy imparted into the beam fairing by the squeezer bag. A solid link was put in place of the clevis and actuator damper and tests were performed using various pressures in the squeezer bag to test the structural capability of the SAS. The purpose of the tests was to see how much load could be applied if the beam fairing was constrained by debris on the underneath side. Pressures were stabilized in the bag at different levels with no structural damage to the SAS. Tests with squeezer bag demonstrated a method to deploy the beam fairing using GN_2 to break the clevis and additional energy to break loose any restraining debris.

The next series of tests were run with the qualification specimen held at about 6° with different pieces of meteoroid shield constraining the beam fairing. The purpose of the tests was to determine the feasibility of breaking the meteoroid shield restraining angle by applying a load at the end of the beam fairing. Loads were applied up to 100 lbs (445N) with no failure occurring. The specimen was then used to test methods where the astronaut could go EVA and pry loose the restraining angle. Using a pry bar consisting of a section of fireman pole with a pinch bar attached at one end a man was suspended in a sling and pried on the angle. The sling simulated a zero-g effect. The angle was pried loose effectively.

The last series of tests using the qualification specimen were performed with a frozen actuator damper and a tether rope. The tests were performed to demonstrate the feasibility of using the astronaut to apply a lifting force on the tether to break the clevis. The method proved out was to attach an adjustable tether or nylon strap between the SAS forward vent module and the forward end of the SAS. A crewman properly tethered then positioned himself in a squatted position with the tether over his shoulder. The crewman then stood erect to create the load in the tether necessary to break the clevis. This method was proven to be successful. It was found in the testing a second crewman was needed to provide a counter force to the beam fairing if necessary, because the stability of the first crewman was poor immediately following the release of the clevis.

A series of tests were run at TRW to determine the deployment characteristics of the wing section actuator dampers under extreme cold conditions. The test specimen used was a qualification test actuator damper placed in a cold chamber. Test results showed that below -50°F (227°K) the actuator damper fluid viscosity would increase to a point to stop extension of the actuator. For nominal SAS deployment, the worst case design predicted temperature of the actuator damper was -16°F (246°K) and the damper had been qualified at -25°F (251°K).

A thermal analysis was made which predicted the wing section actuator dampers would be at approximately -50°F (227°K) or below at the time the beam fairing would be released and the fluid would cool down further since the SAS would no longer be adjacent to the warm OWS stage. The analysis showed a -45° pitch maneuver could be made to direct solar heating on the beam fairing top surface to warm the frozen wing section actuator dampers and allow wing section deployment.

On DOY 158 the astronauts went EVA to attempt to deploy SAS Wing No. 1. A bolt cutter was used to sever the angle restraining the beam fairing. A tether was tied to the SAS vent module and the astronaut stood erect under the tether applying a force to the beam fairing and breaking loose the actuator damper. The beam fairing deployed to the full open position in approximately 15 seconds. The wing sections partially deployed and then stopped due to the temperature of the actuator dampers. A -45° pitch maneuver was made allowing solar heat to warm the beam fairings. In approximately 5 hours the wing sections had deployed 100 percent.

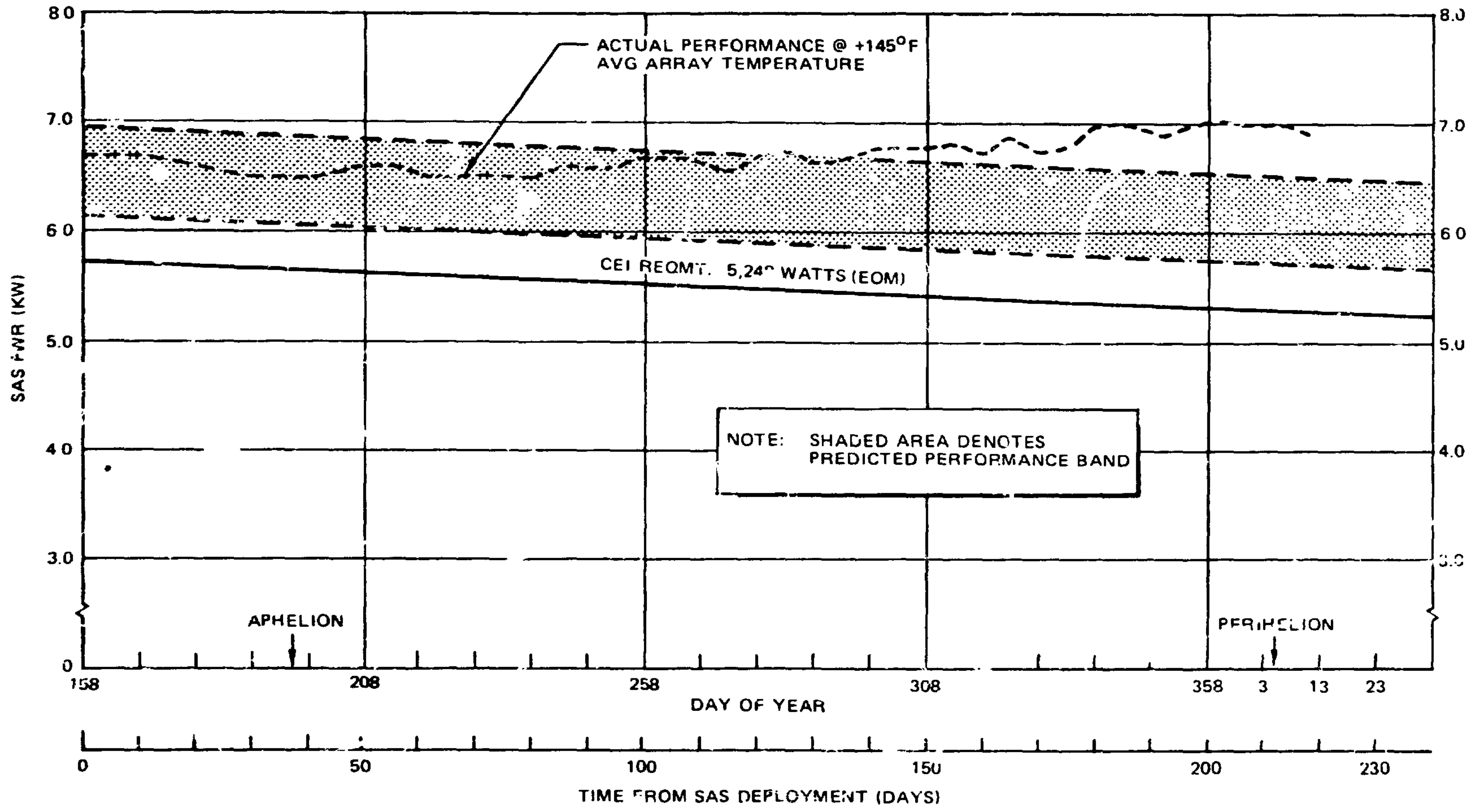
D. On-Orbit Performance

1/ Electrical - Full deployment of SAS Wing 1 beam fairing and its three (3) wing sections was completed on DOY 159 at approximately 00:30 GMT hours following 24 days of orbital storage in the partially deployed configuration. This resulted in full power generating capability on that wing or approximately 1/2 of the total design capability of the SAS.

The power was to be available at a voltage of between 51 volts and 125 volts at the AM/OWS interface. With the loss of Wing 2, the power required became not less than 5,248 watts total for Wing 1 only and 656 watts for each SAG at the end of mission. Predicted SAS performance degradation from all causes was 8.3 percent for the mission. This converts to a minimum available average of 5,723 watts total and 715 watts from each SAG at the beginning of the mission. The voltage requirement was not affected by the loss of Wing 2.

As shown on Figure 2.2.5.4-1, predicted Beginning of Mission (BOM) SAS performance ranged between a minimum of 6,120 watts and a maximum of 6,920 watts. Maximum and minimum average power output accounted for variations in beta angle and solar flux, and a performance degradation of 8.3 percent over the mission.

SAS performance was analyzed for sampled orbits beginning with 100 percent Wing 1 deployment on DOY 159. Array performance was plotted for an average array temperature +145°F (335°K) and shows an available average array power of between 6,500 watts and 7,050 watts. The increase in power over the period of the mission occurs for two reasons; (1) solar flux increased from a minimum (Aphelion) near the beginning of the mission, to a maximum (Perihelion) at approximately 1974 DOY 005, and (2) no measurable performance degradation has been detected. Solar Array Group (SAG) voltage and current data was evaluated for solar inertial orbits at beta angles from 0° to 73.5°.



OWS Solar Array Performance

FIGURE 2.2 .4-1

At low beta angles, the SAS sees the sun approximately 61 percent of the time, and since a large Depth of Discharge (DOD) on the PCG batteries occurs, the SAS operates at peak power for several minutes. At beta angles above 69.5°, continuous sunlight orbits take place, and battery charge/discharge cycles do not occur; hence, the system does not operate at peak power, and only small variations are seen in SAS voltage and current.

Figures 2.2.5.4-2 thru 2.2.5.4-16 show typical SAG voltage and current profiles for 1973 DOY's 159, 175, 339, and 1974 DOY 034. Data for DOY 175 is included to illustrate high beta, continuous sunlight, SAG characteristics; while DOY 339 shows voltage and current profiles during one orbit of peak power operation.

From analysis of DOY 159 and 034 data, it is seen that the voltages and currents for each of the groups are similar except where, (1) modules are shadowed, or (2) a low current reading exists. In solar inertial vehicle orientation, shadowing from the ATM solar array results in the loss of less than one module from SAG 5, less than two (2) modules from SAG 6, and one full (1) module from SAG 8. Only one or two cell strings are lost from SAG 5. For SAG 6, one module is always shadowed and up to two additional strings are shadowed on the second module. The variation in the number of strings shadowed is a result of small variations from true solar inertial vehicle orientation, and appears to verify the ±0.5 degree vehicle control accuracy.

SAG PERFORMANCE

SAG 1 & 2 (DOY 159, $\beta = 10^0$)

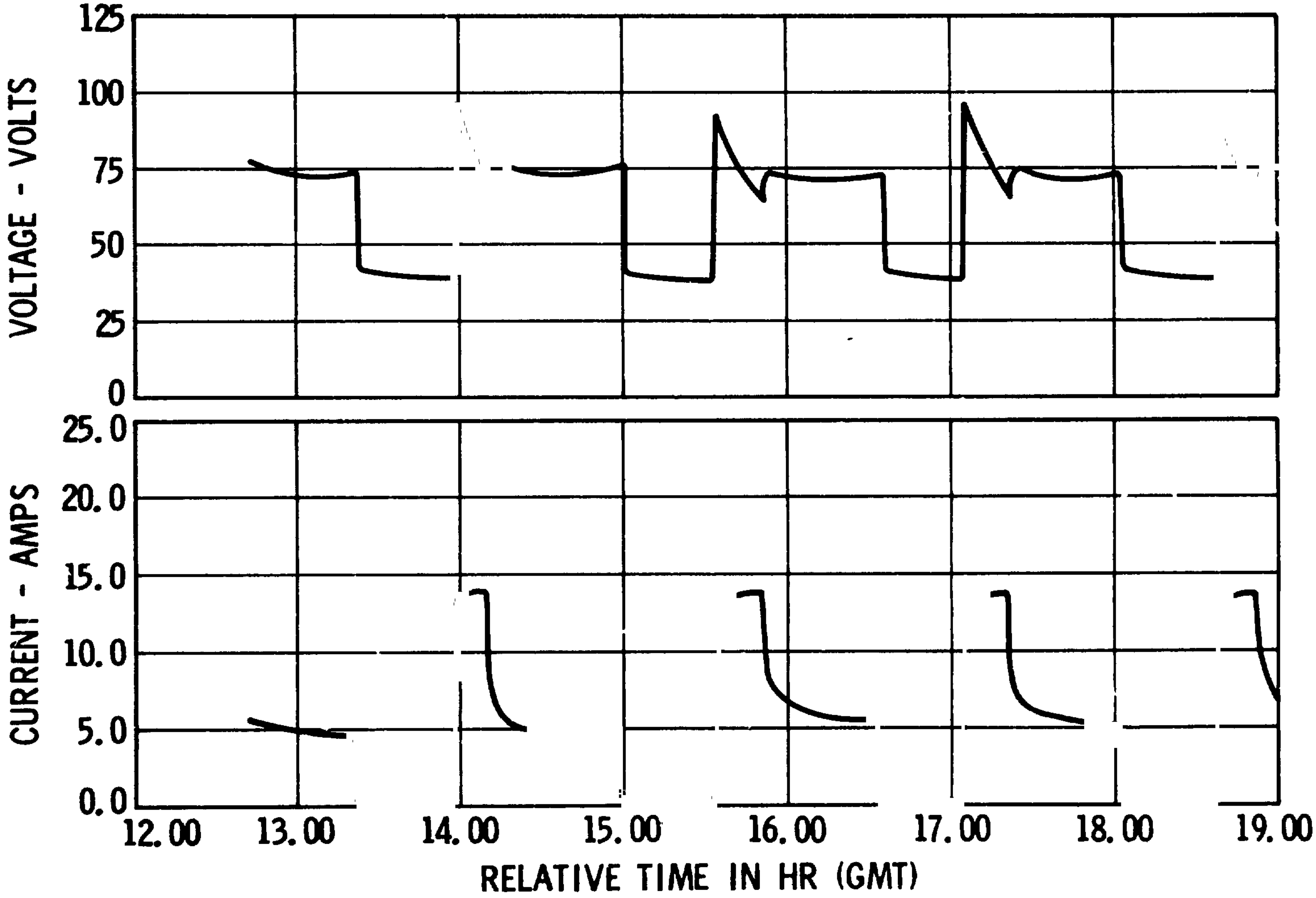
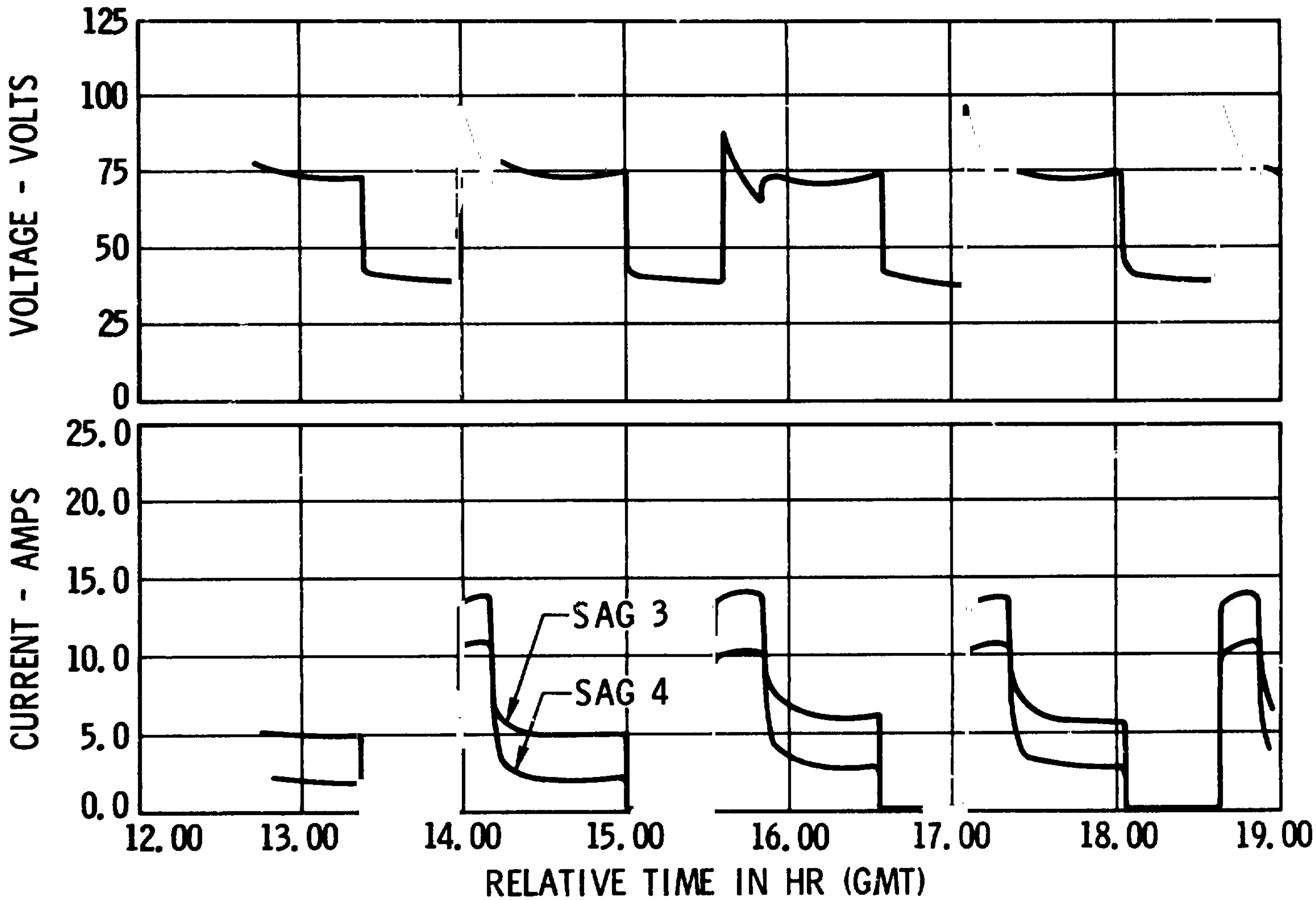


Figure 2.2.5.4-2

SAG PERFORMANCE

SAG 3 & 4 (DOY 159, $\beta = 10^0$)



SAG PERFORMANCE

SAG 5 & 6 (DOY 159, β = 10°)

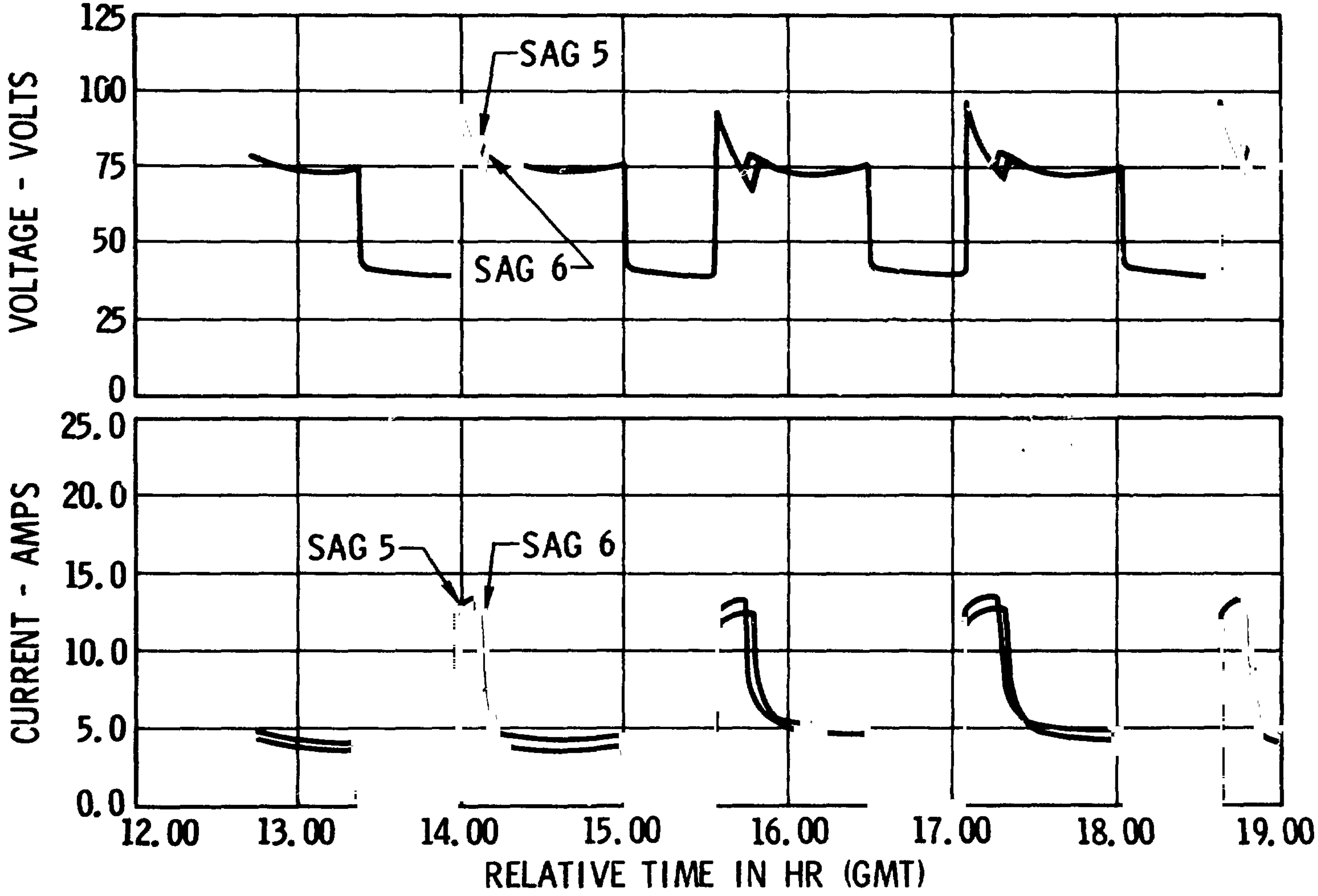


Figure 2.2.5.4-4

SAG PERFORMANCE SAG 7 & 8
(DOY 159, $\beta = 10^0$)

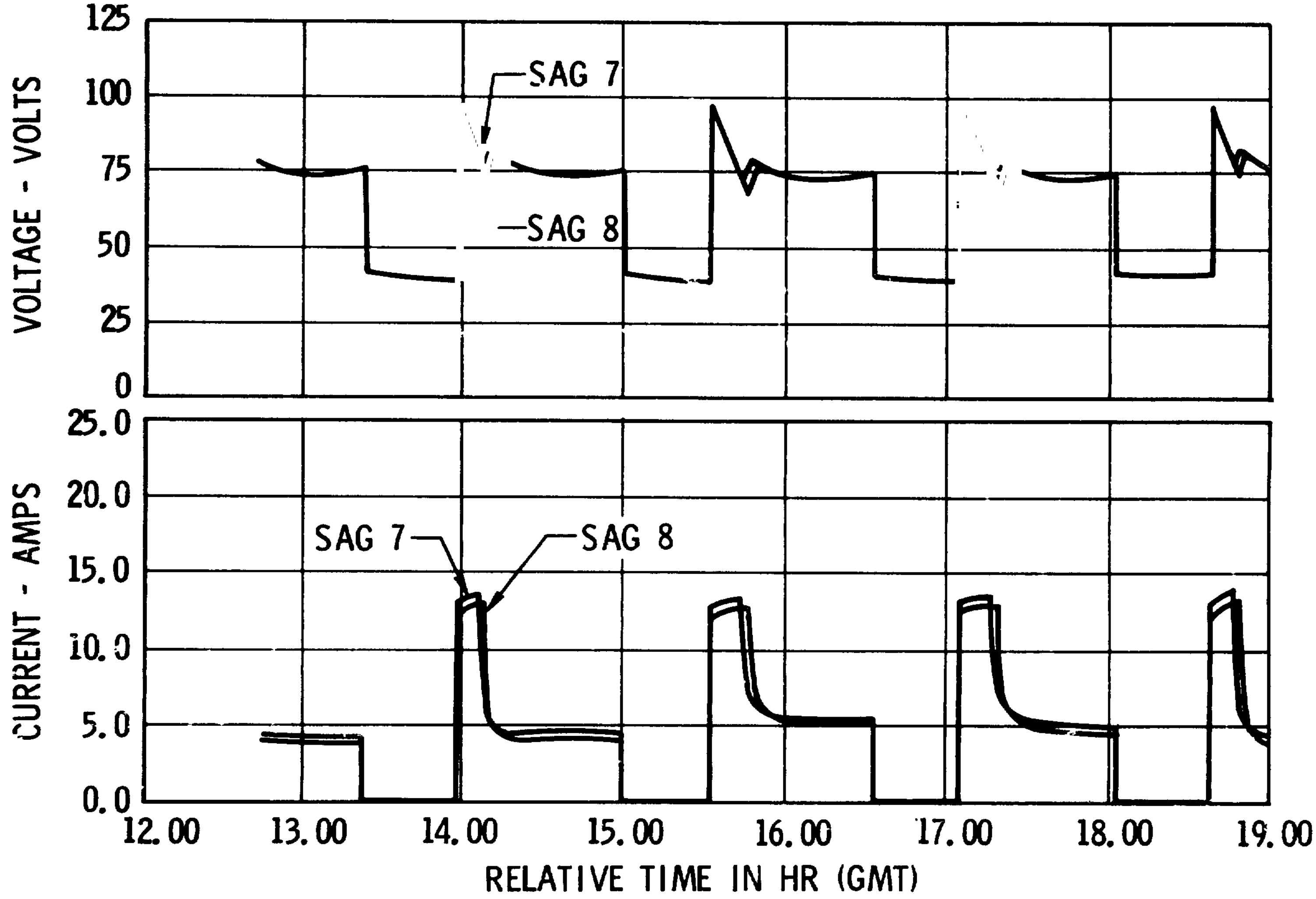


Figure 2.2.5.4-5

SAG PERFORMANCE

SAG 1 (DOY 175, β = +73.5^0)

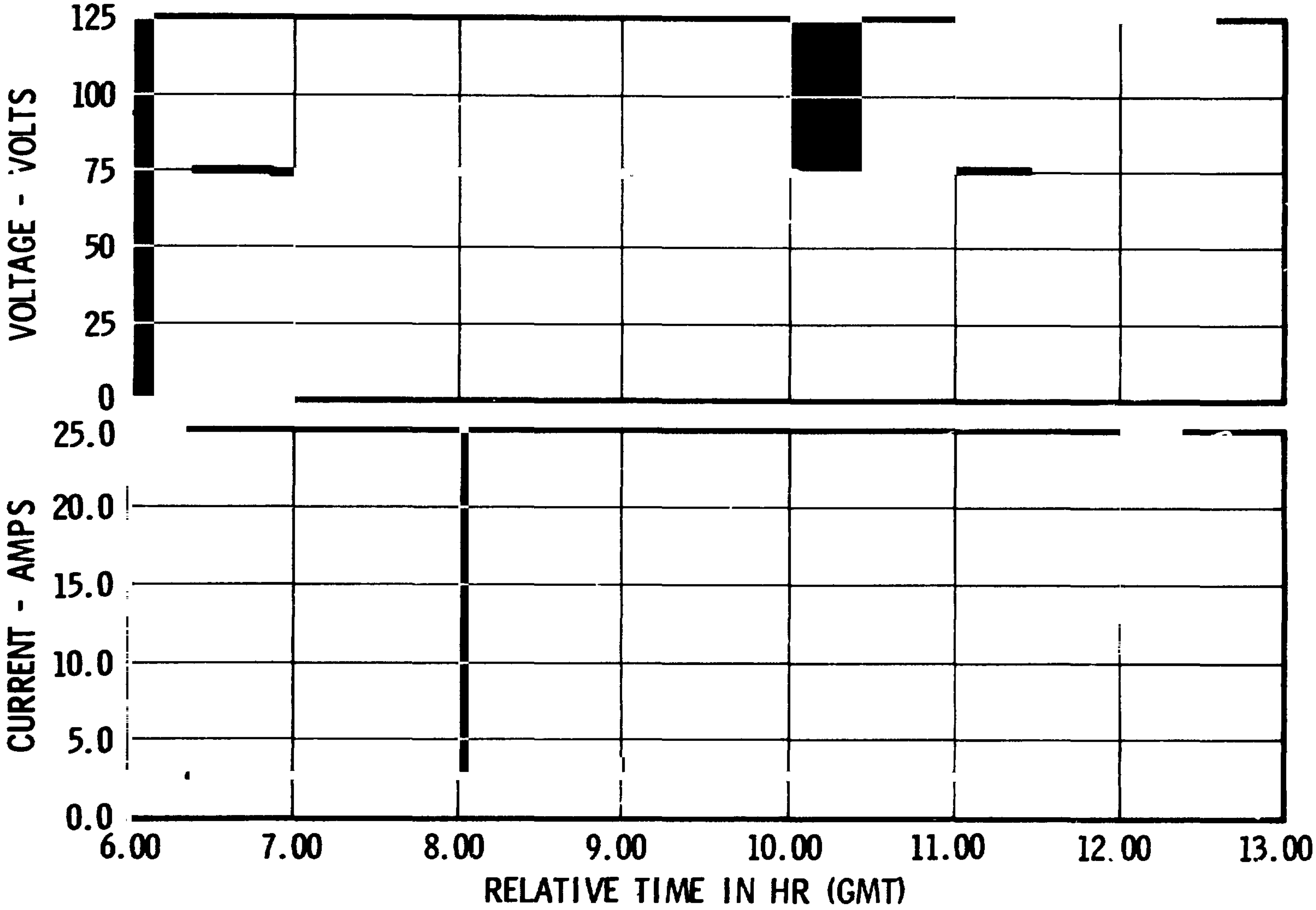
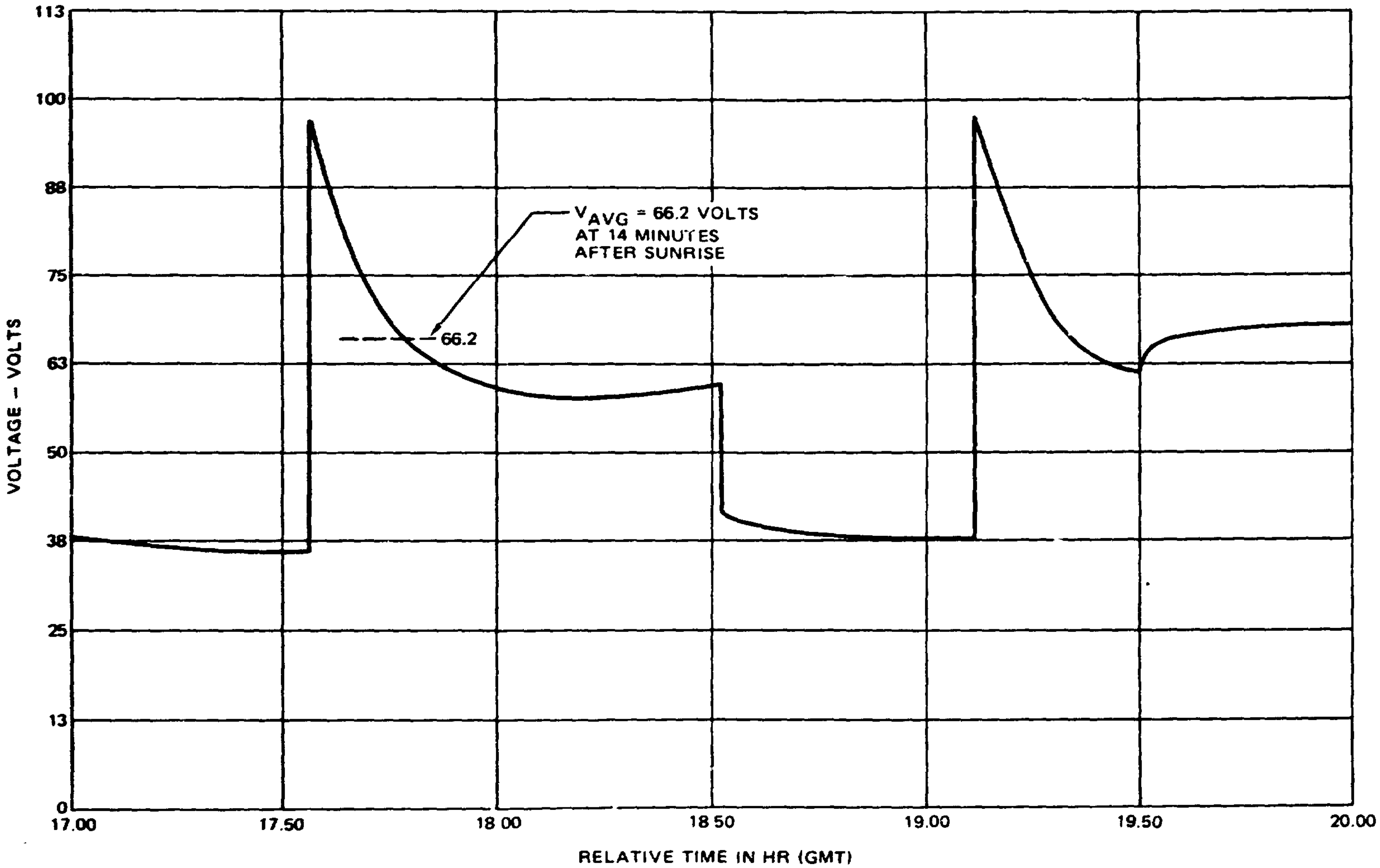
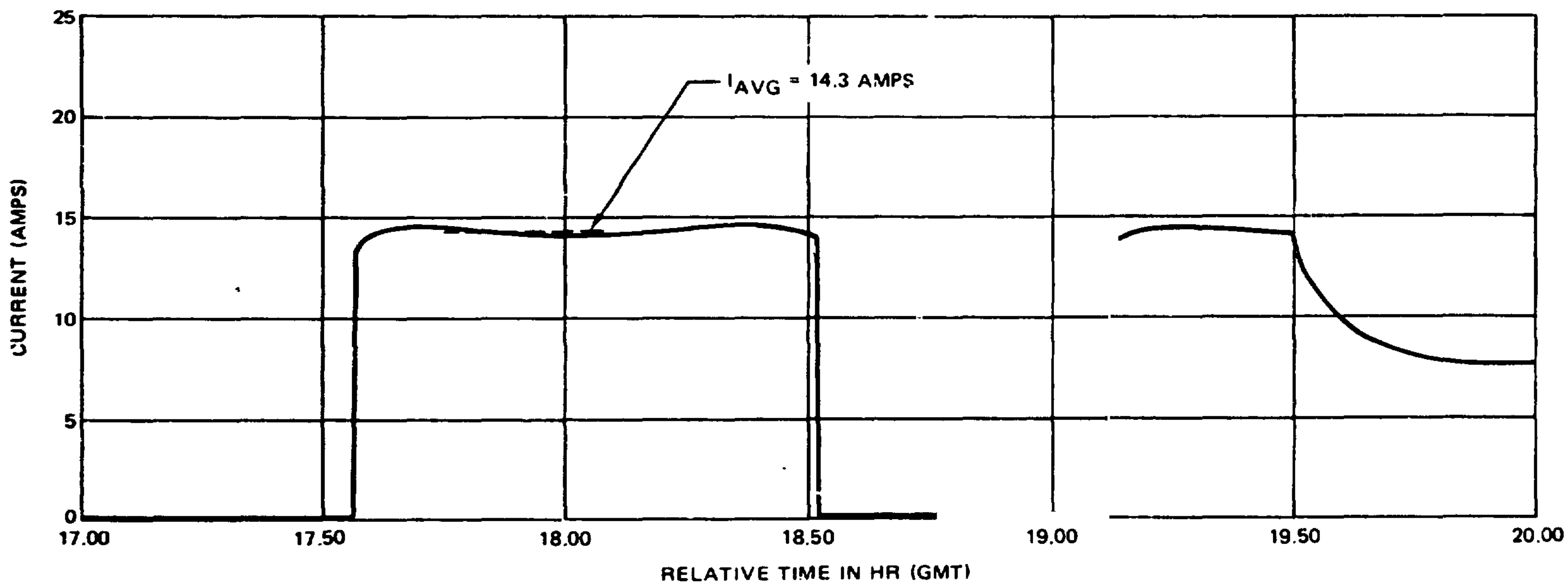


Figure 2.2.5.4-6



SAG 1 Voltage, DOY 339, Beta = -9^{o}



SAG 1 Current, DOY 339, Beta = -9°

Figure 2.2.5.4-8

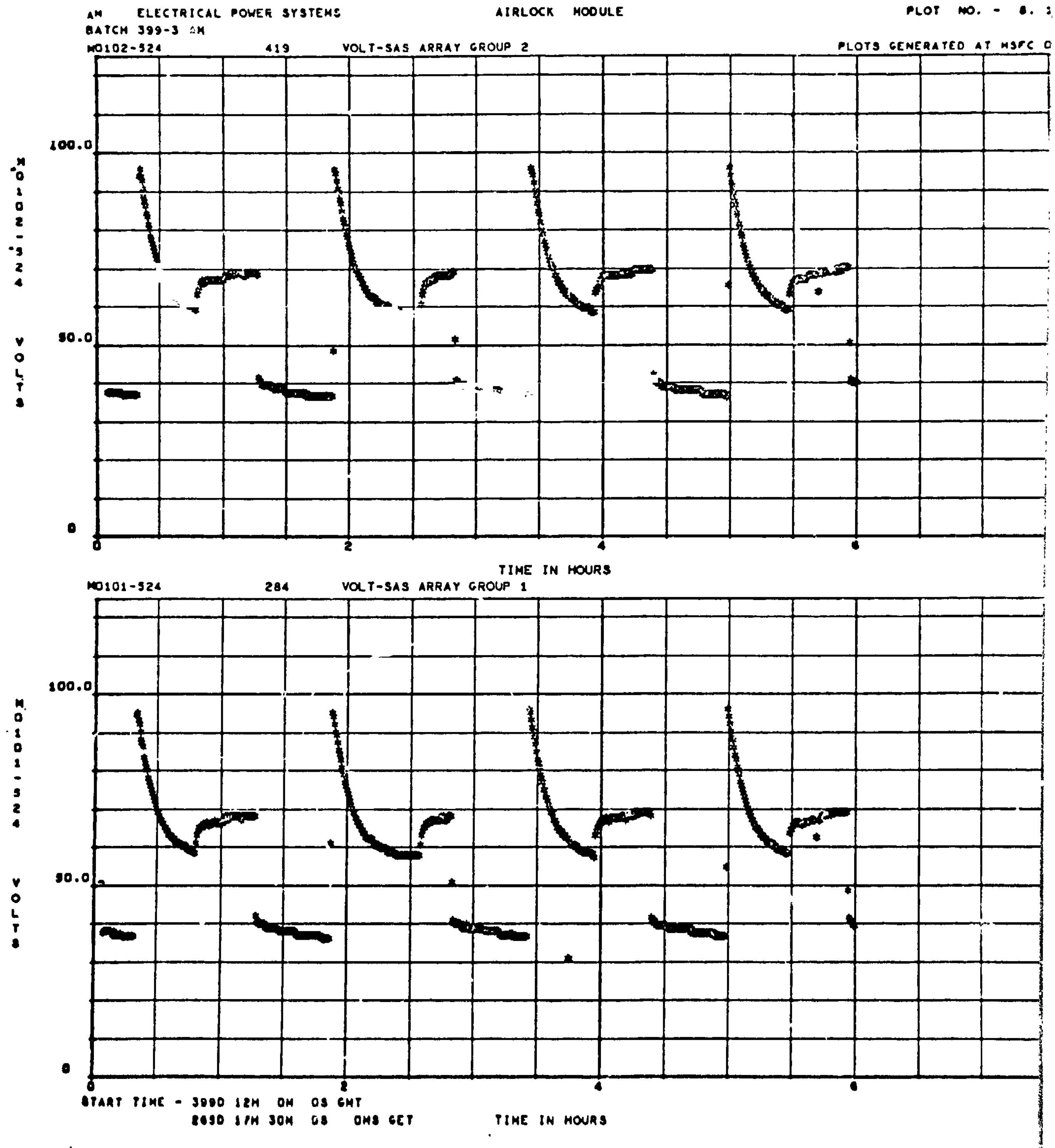


Figure 2.2.5.4-9. SAG's 1 AND 2 VOLTAGE DOY 034, BETA = 0°

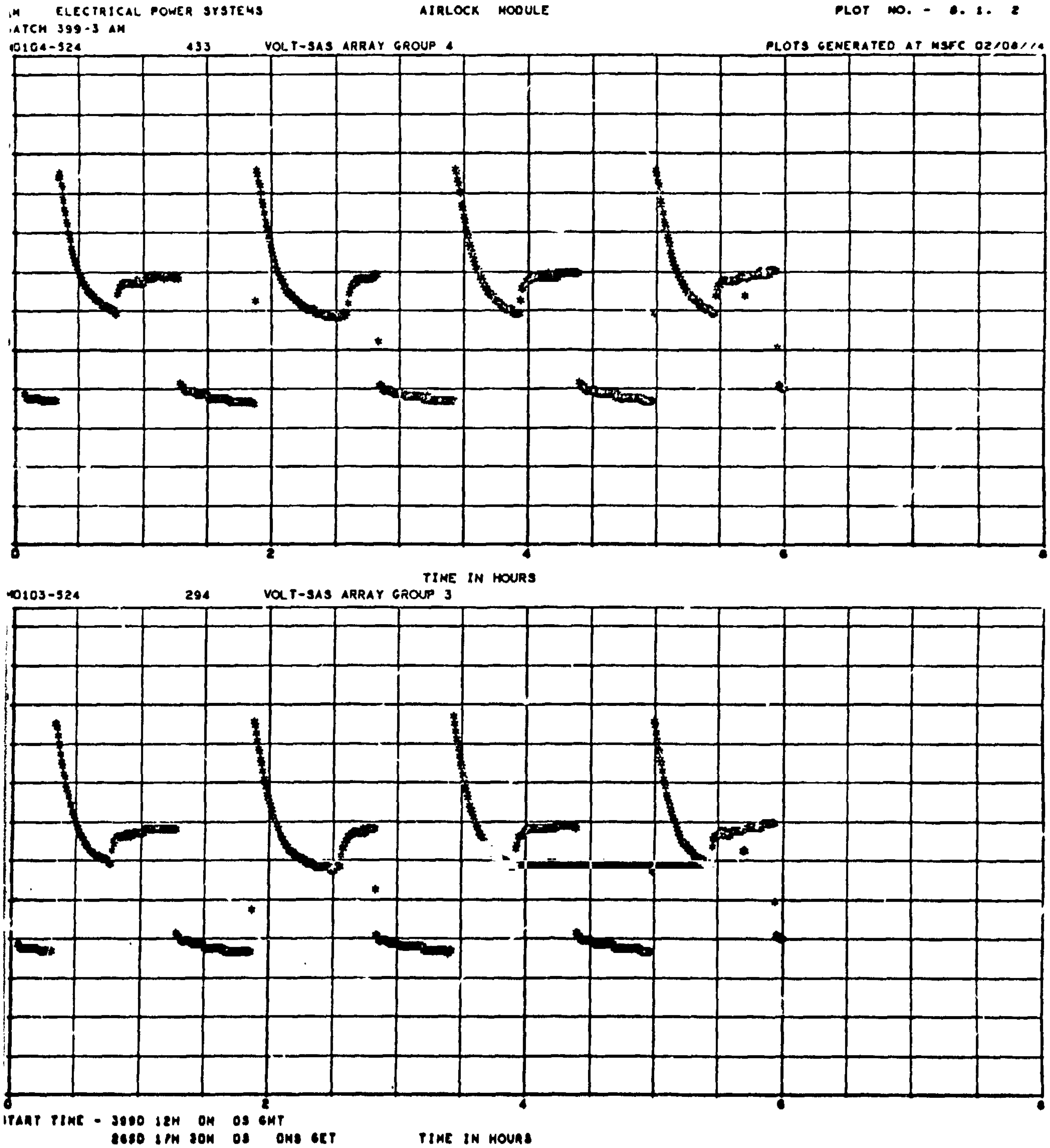


Figure 2.2.5.4-10. SAG's 3 AND 4 VOLTAGE DOY 034, BETA = 0°

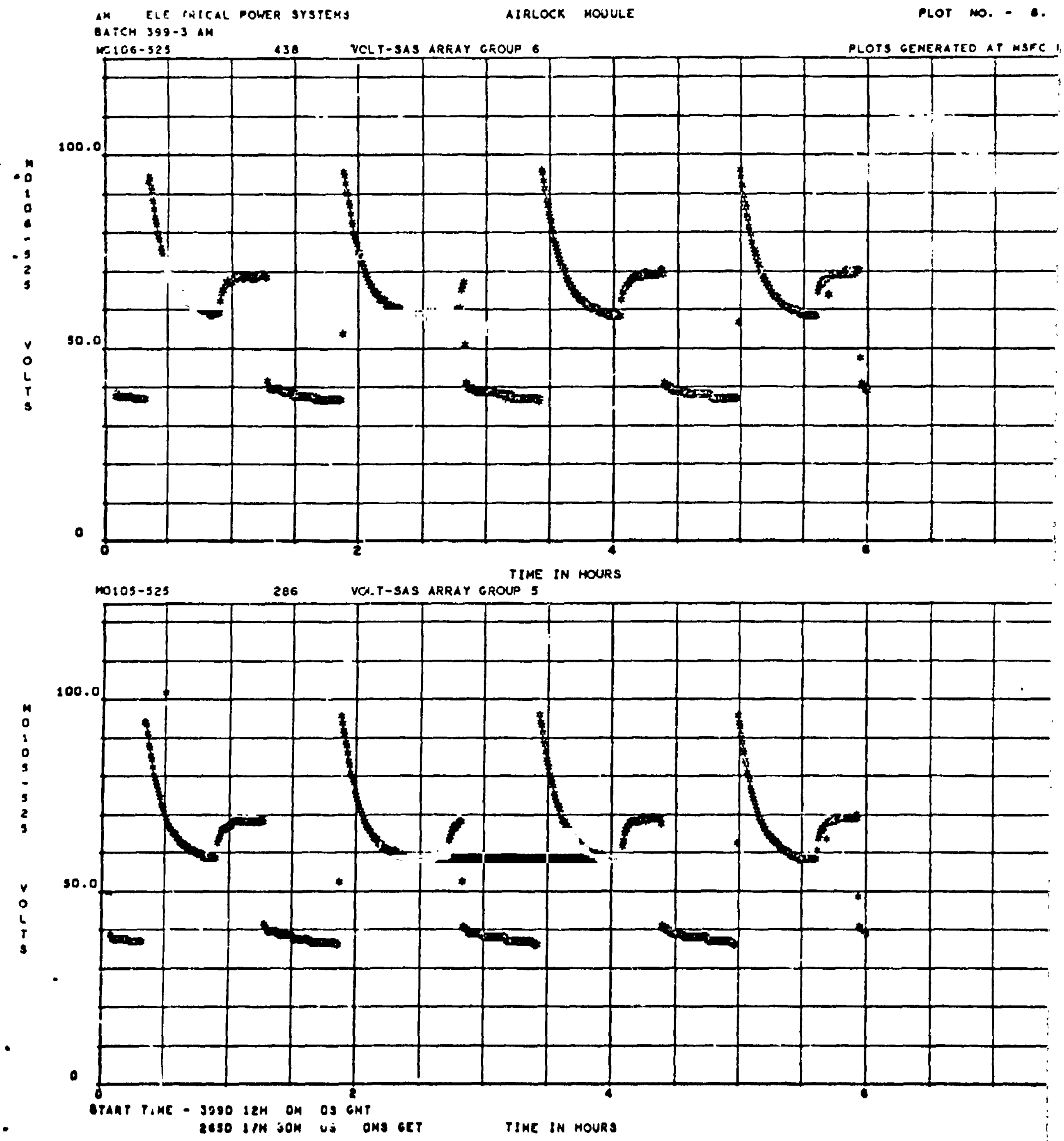


Figure 2.2.5.4-11. SAG's 5 AND 6 VOLTAGE DOY 034, BETA = 0°

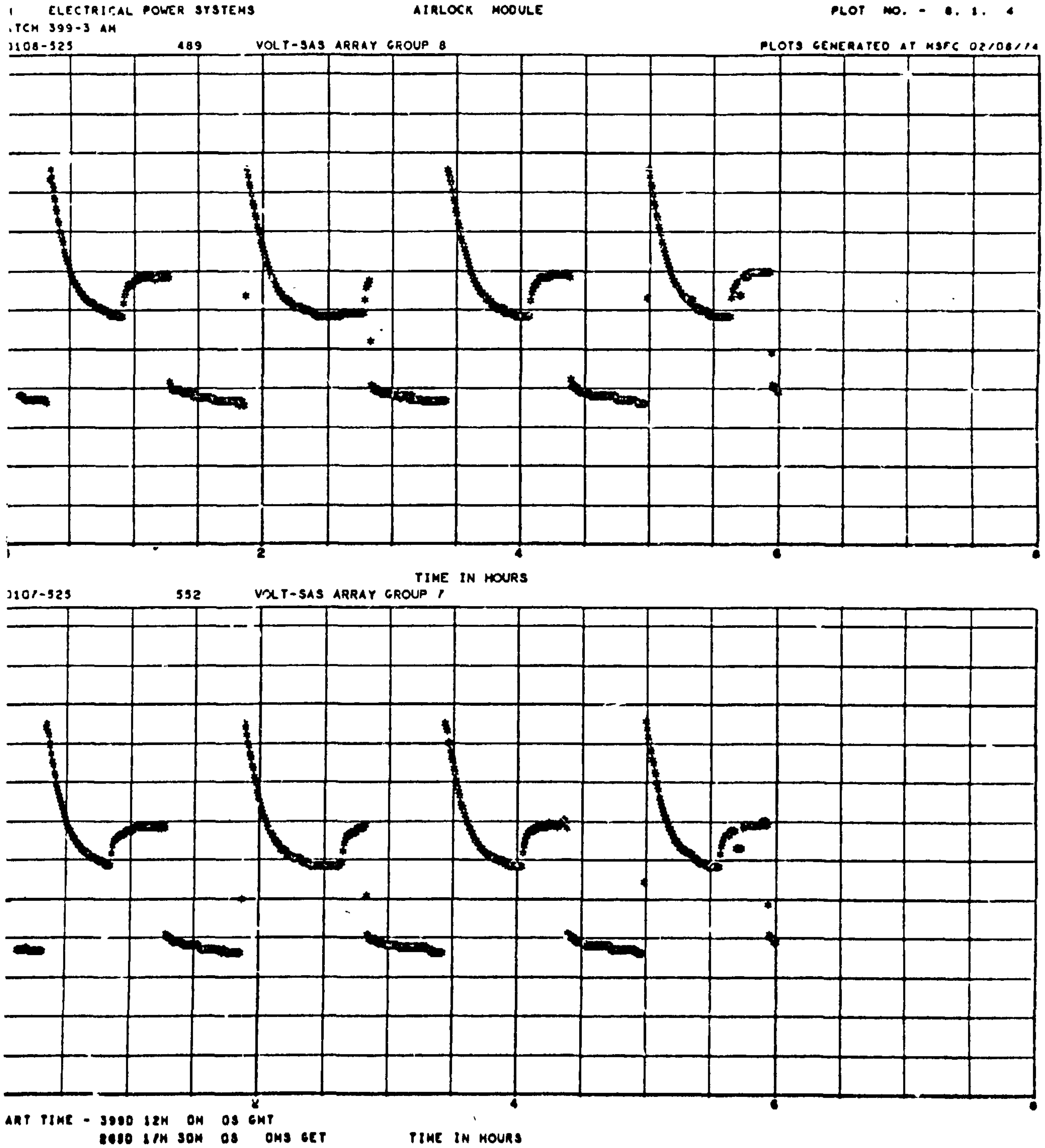


Figure 2.2.5.4-12. SAG's 7 AND 8 VOLTAGE DOY 034, BETA = 0°

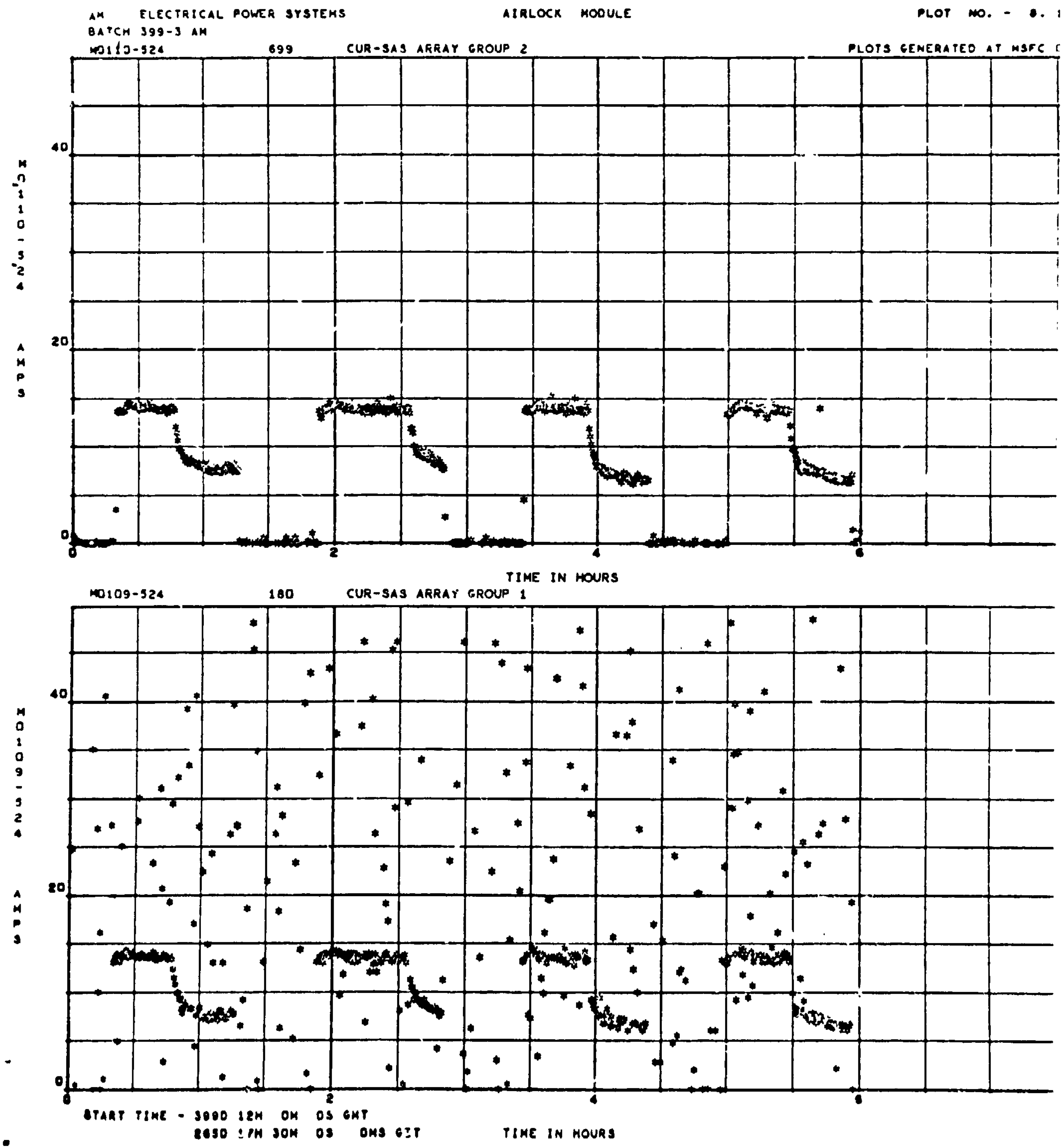


Figure 2.2.5.4-13. SAG's 1 AND 2 CURRENT DOY 034, BETA = 0°

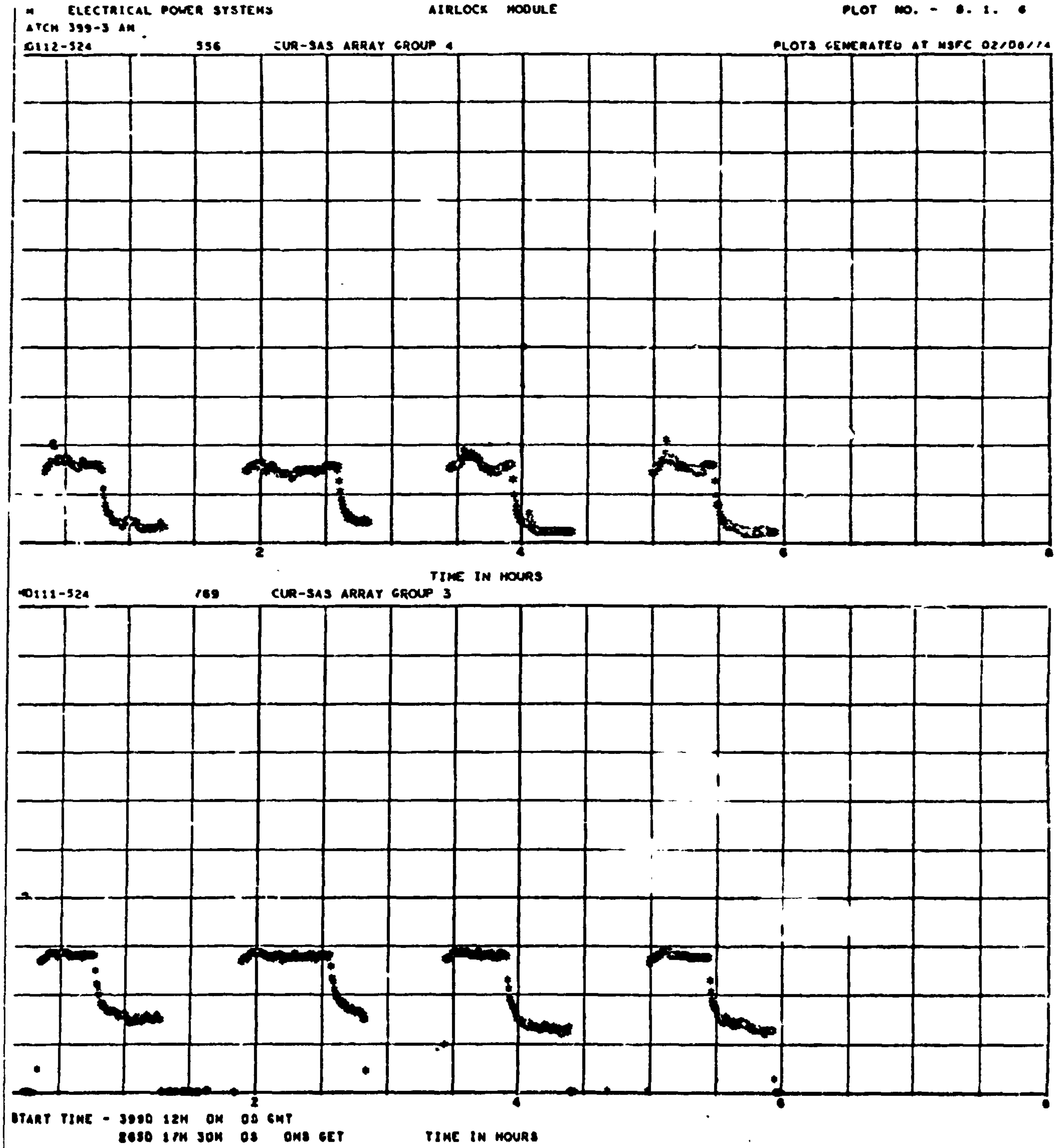


Figure 2.2.5.4-14. SAG's 3 AND 4 CURRENT DOY 034, BETA = 0°

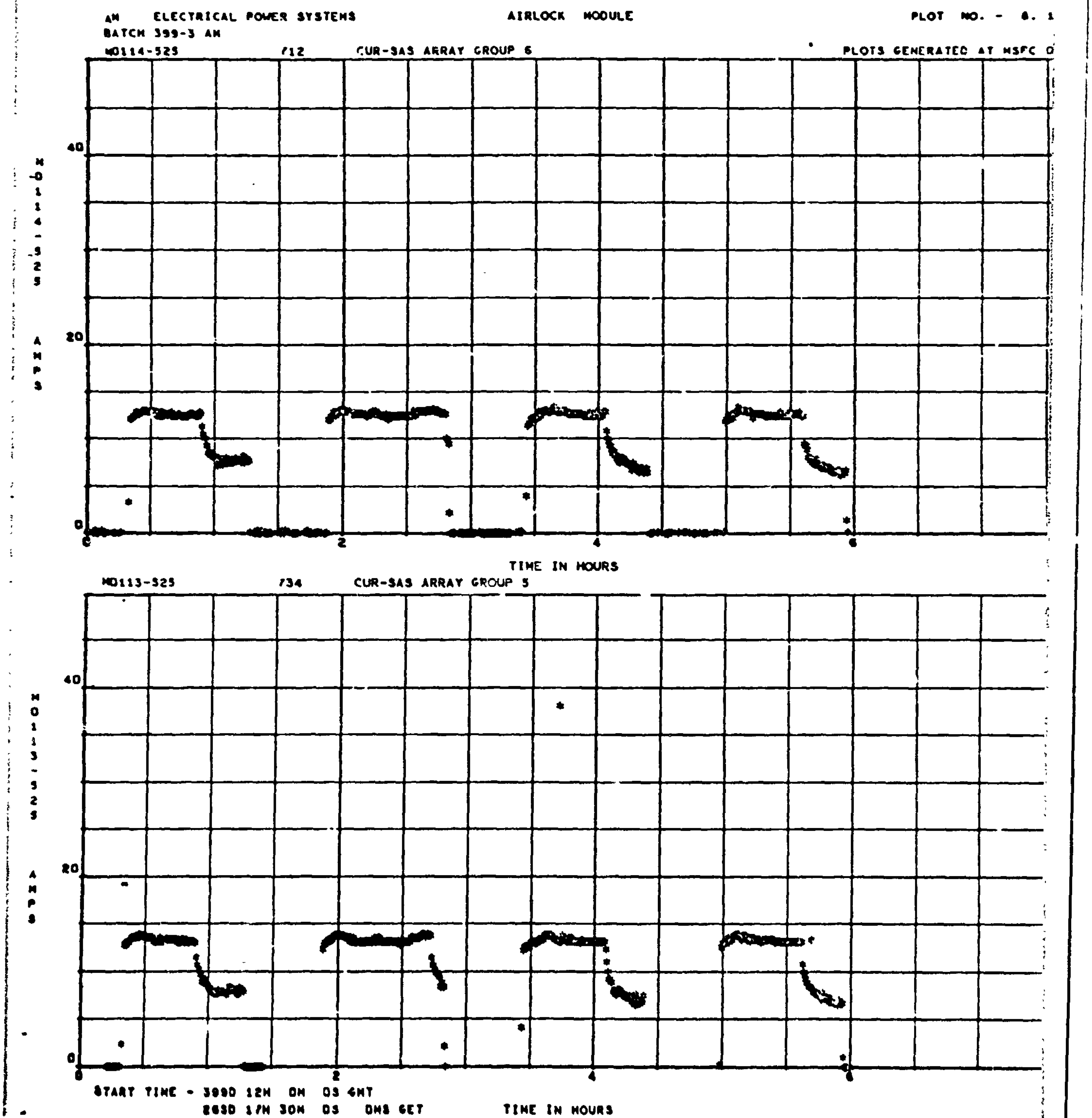


Figure 2.2.5.4-15. SAG's 5 AND 6 CURRENT DOY 034, BETA = 0°

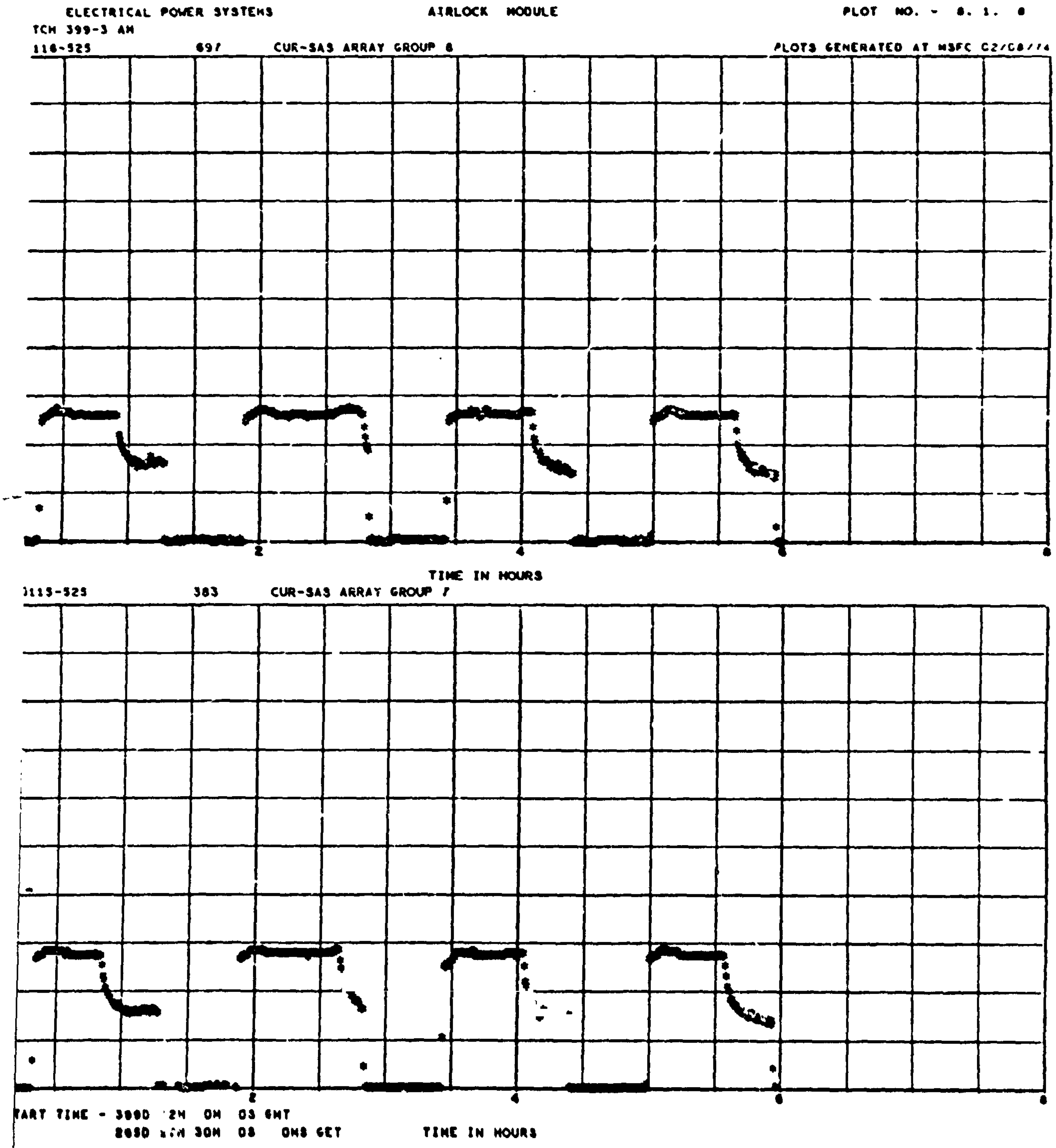


Figure 2.2.5.4-16. SAG's 7 AND 8 CURRENT DOY 034, BETA = 0°

The lower current on SAG 4 on Figure 2.2.5.4-3 is because of an anomaly in the current measurement. If the current for SAG 4 were as low as indicated, the battery of PCG 4 would take much longer to recharge than the other batteries. There has been no indication that Battery 4 has taken longer for recharge than any other battery supplied by a 15 module SAG.

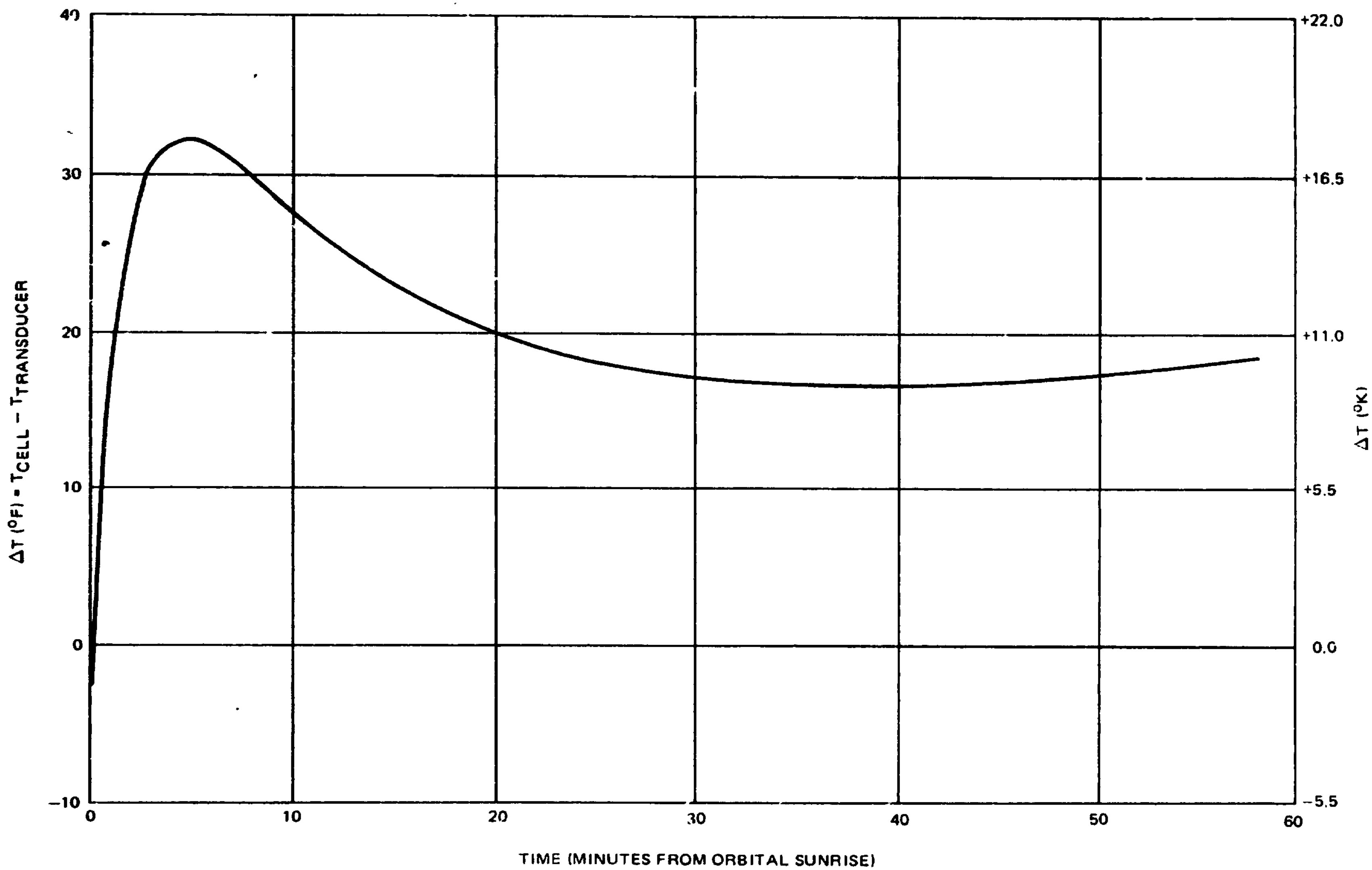
The events of an orbit can be followed on Figure 2.2.5.4-2. The data begins near the end of the sunlight portion of an orbit. As the solar array goes into shadow the current drops to zero and the voltage drops to the AM PCG battery voltage. During this period the batteries provide the power to the loads and their depth of discharge will depend upon the load and the duration of the shadowed portion of the orbit. When the arrays come into sunlight they are cold, and the voltages are at their peak values and decrease as the array warms up. The current is high because of the increased loads while the batteries are recharging. When the batteries reach voltage limit, the charge rate decreases resulting in a drop in the current and a rise in voltage. After the batteries are fully charged the current remains nearly constant at the lower values shown and the voltage continues to vary as a function of temperature with a slight rise in voltage prior to end of sunlight portion of the orbit corresponding to the small decrease in temperature that occurs.

One slice of the DOY 159 was analyzed in detail when all SAG's were operating near maximum power; that is, when the combination of battery charging and bus loads present the maximum demand and the operating point of the SAS is controlled by the PCG peak power tracker. The data slice was at 6.5 minutes after sunrise. At this time, the average transducer temperature was determined to be 21.8°F (267°K).

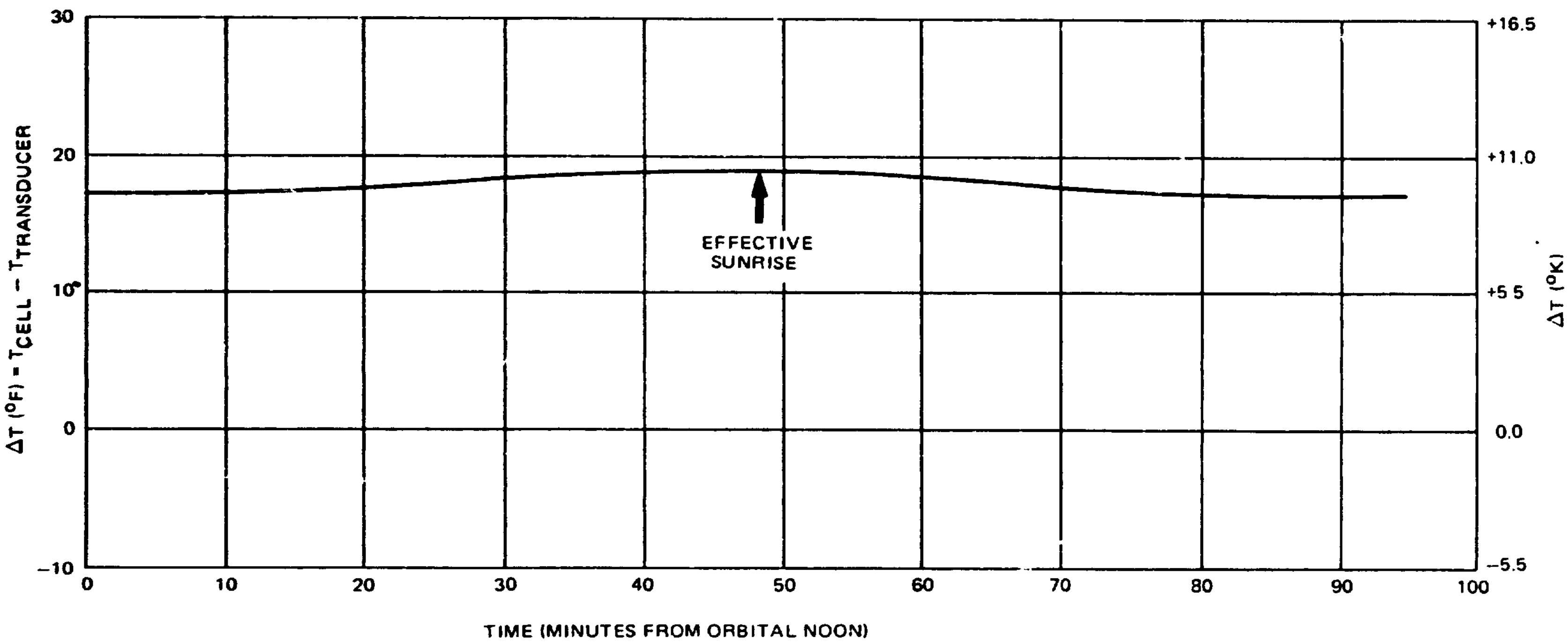
In order to determine average array temperature from the transducer data, a correction factor was derived based upon the solar panel thermal characteristics. The ΔT correction factor is a function of (1) time from sunrise, and (2) beta angle. Figures 2.2.5.4-17 and 2.2.5.4-18 are representative of how the ΔT factor varies nominally with time from sunrise at beta angles of 0° and 73.5°.

A ΔT correction factor for the DOY 159 data slice was determined to be +32°F (273°K), and when added to the average transducer temperature, an average array temperature of +53.8°F (285°K) was determined.

The voltage and current for each SAG was also determined at this time slice and plotted against SAG prediction cuves in Figures 2.2.5.4-19 thru 2.2.5.4-21. These figures represent the performance predictions for 15, 14, and 13 module SAGS. in all cases, except for SAG 4, the performance exceeded the predicted values. Analysis of PCG input and output power values and battery charge current measurements indicated normal PCG 4 operation, and that SAG 4 was producing

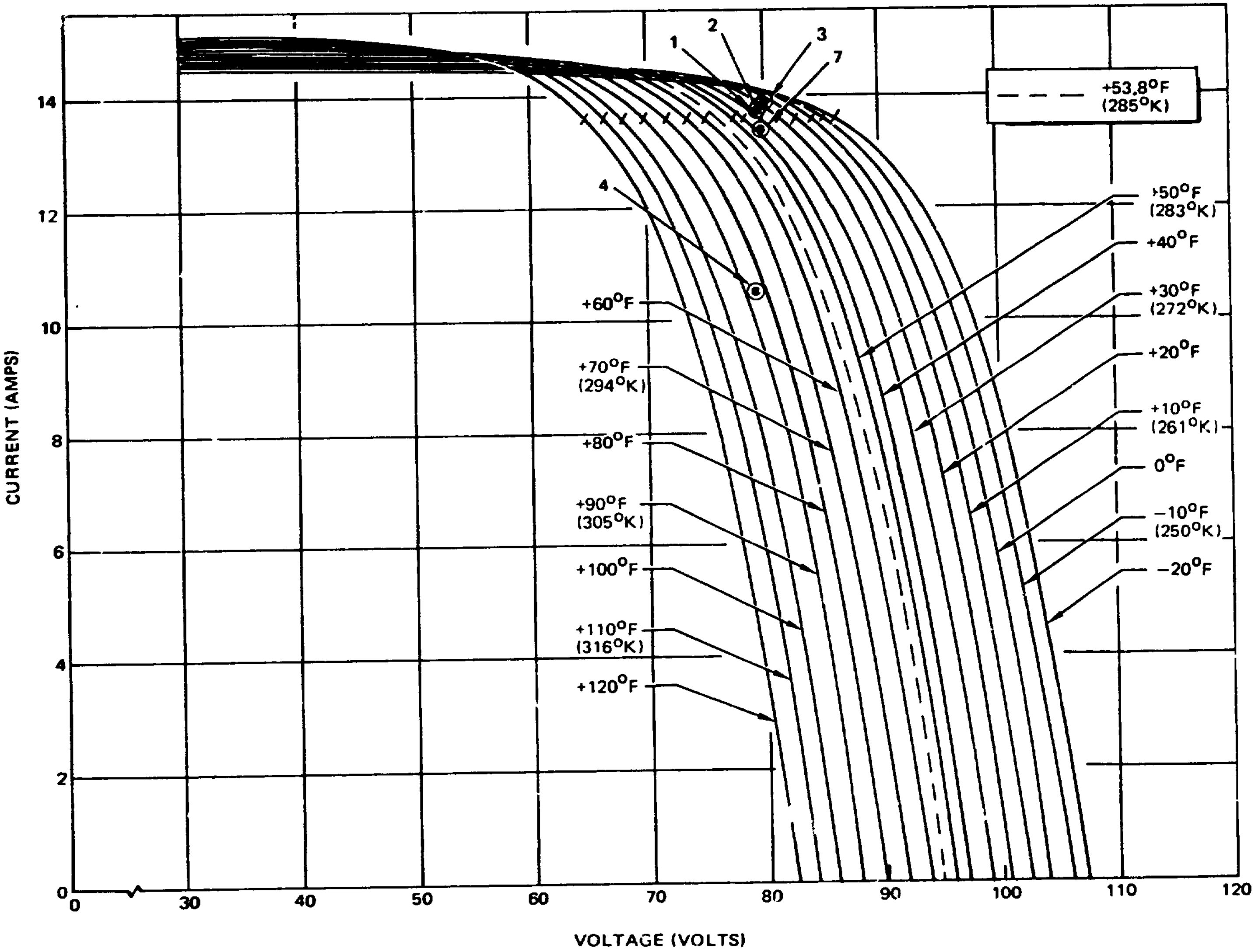


Solar Array/Temperature Transducer Temperature Differential (Beta = 0°)



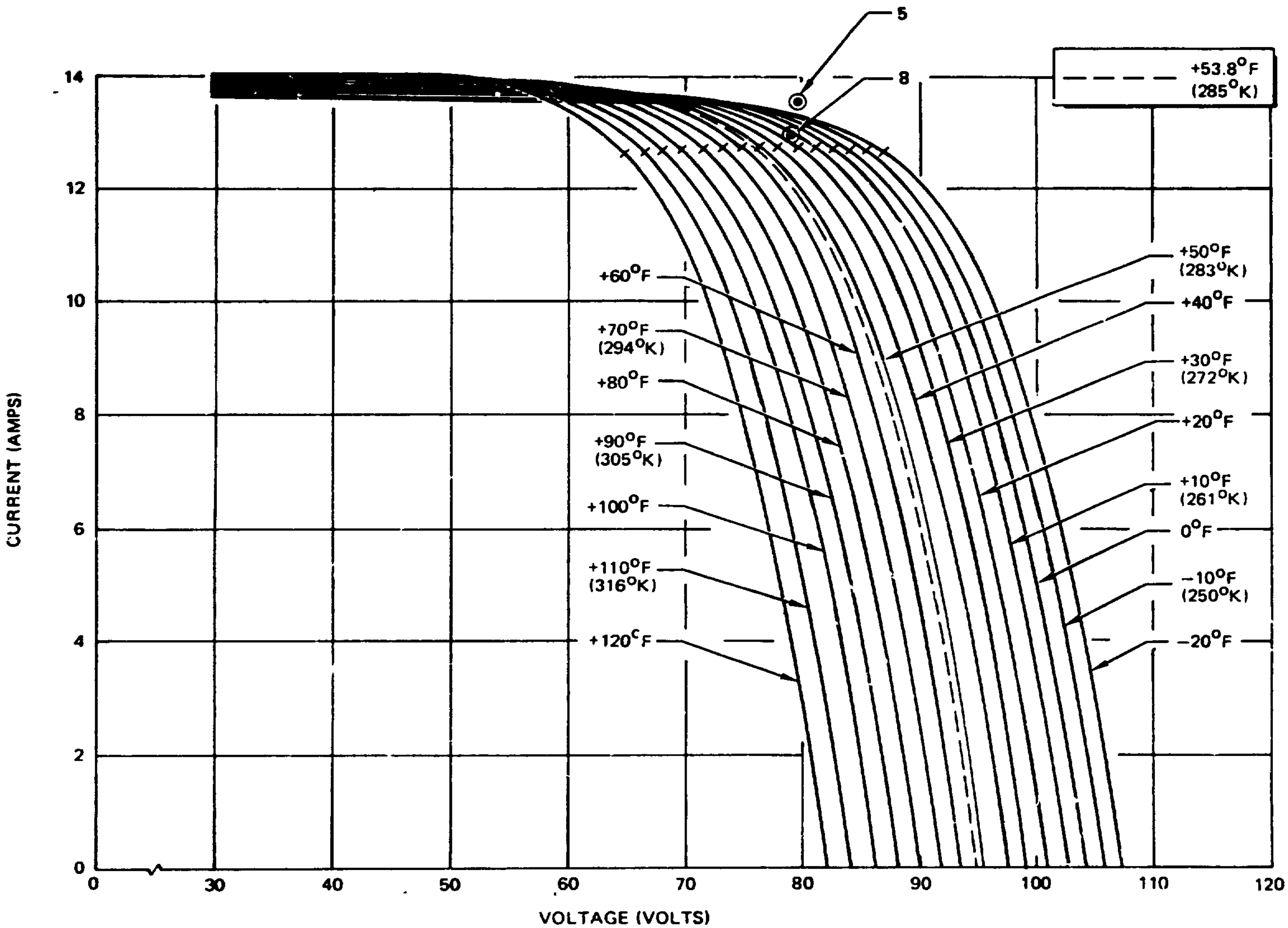
Solar Array/Temperature Transducer Temperature Differential (Beta = 73.5°)

Figure 2.2.5.4-18



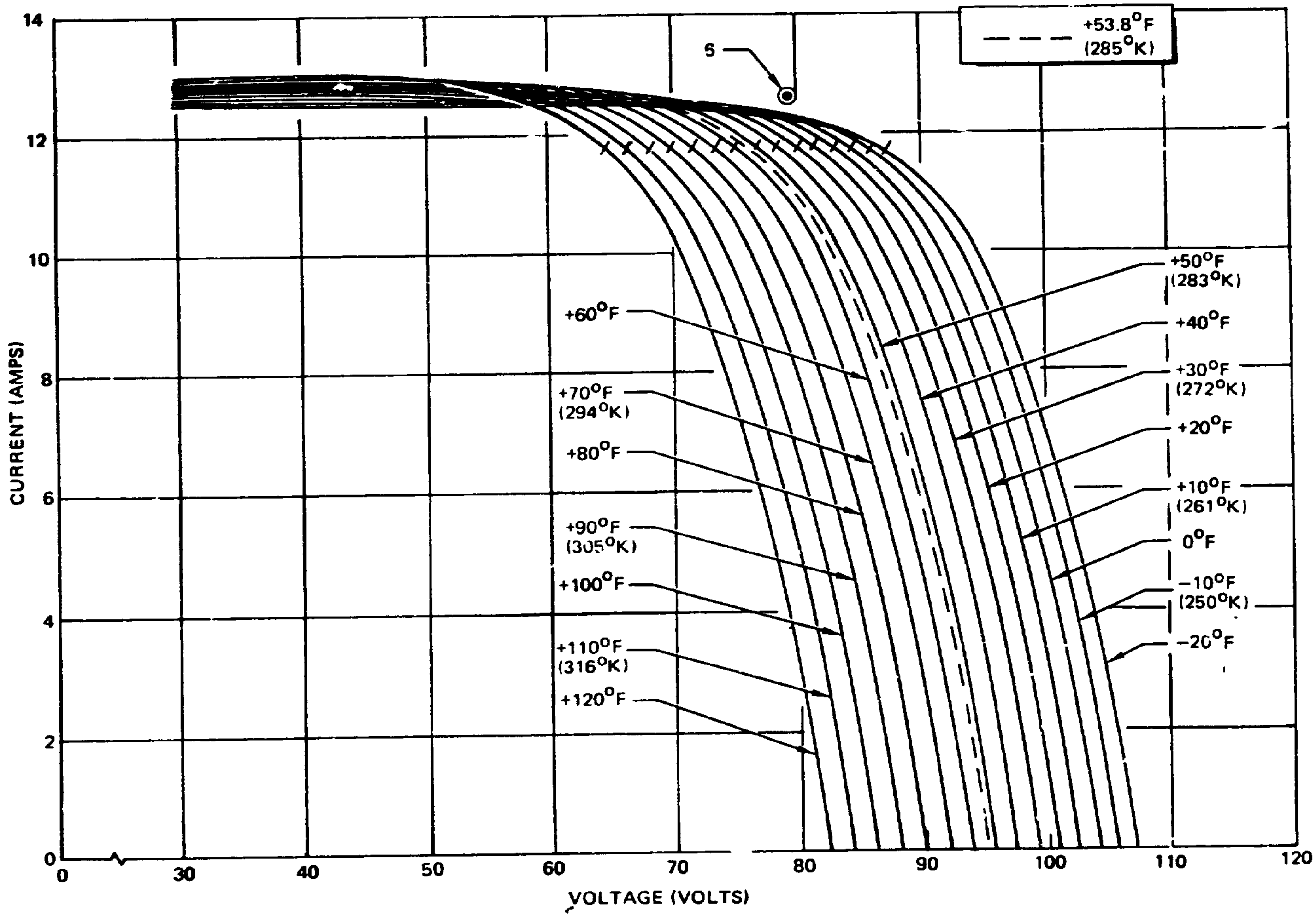
SAG Characteristics — 15 Modules DOY 159; SAGS 1, 2, 3, 4, and 7

Figure 2.2.5.4-19



SAG Characteristics – 14 Modules DOY 159; SAGS 5 and 8

Figure 2.2.5.4-20



SAG Characteristics — 13 Modules DOY 159; SAG 6

Figure 2.2.5.4-21

power comparable to the other SAG's having no shadowed modules. For purposes of SAS performance evaluation, SAG 4 current was assumed to be equal to the average of SAG's 1, 2 and 3 currents. Using this method of evaluation, it was concluded that SAG 4 current also exceeded the predicted value. Average array power, at 145°F (335°K), was determined to be 6,700 watts.

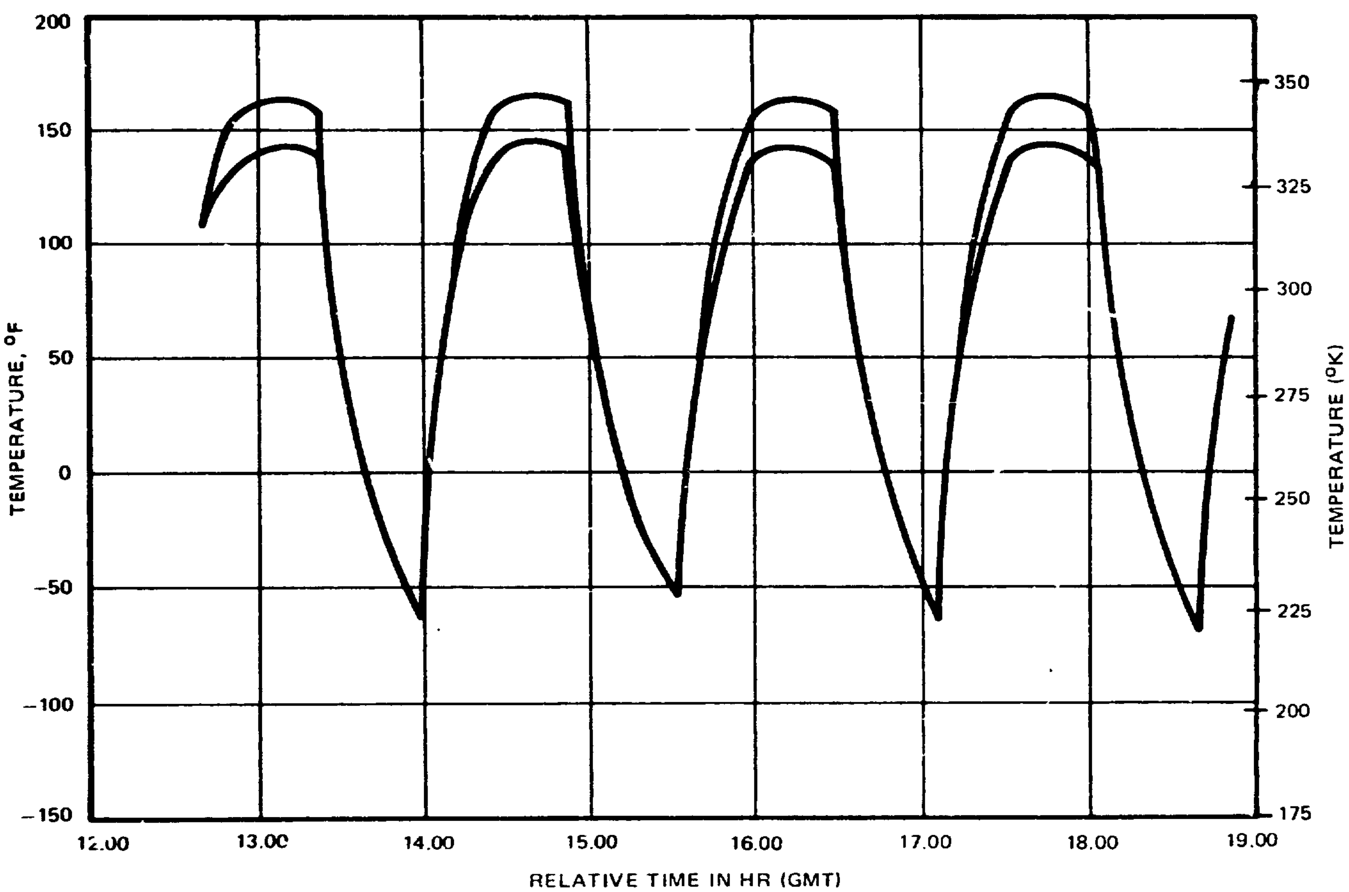
SAG 1 voltage and current profiles are shown on Figure 2.2.5.4-6, 73.5° beta orbit on DOY 175. SAG voltage was fairly constant at 75 volts and SAG current measured 2 to 3 amps. These values are consistent with the constant array temperature at high beta angles and the fact that the PCG batteries demand only trickle charge current. Figure 2.2.5.4-7 shows voltage and current performance for SAG 1 for DOY 258, beta angle = -37°.

Figures 2.2.5.4-7 and 2.2.5.4-8 show voltage and current performance for SAG 1 for DOY 339, beta angle = -9°. EREP No. 11 maneuver to Z-LV (Z-axis Local Vertical) was concluded at GMT 1634 on DOY 339. Battery Depth of Discharge (DOD) was great enough following the maneuver to cause all SAGS/PCGS to remain in the peak power tracking mode for one entire solar inertial orbit. Using MOPS data, array performance at about 5 minutes after sunrise was analyzed. The average temperature transducer measurement was +12.3°F (262°K), the ΔT correction factor was determined to be +32°F (273°K), and the resulting average array temperature was +44.3°F (280°K). Average SAS power was found to be 6970 watts at +145°F (335°K).

As a verification of the above method of determining average array power from instantaneous values of SAG voltage, current, and temperature, data from user tapes was analyzed for SAG 1. Voltage, current, and temperature plots (Figures 2.2.5.4-7, 2.2.5.4-8 and 2.2.5.4-22, respectively) were integrated and average values of each were determined. Using this technique the resulting average array power was found to be 6940 watts which correlates within less than 0.5 percent with the 6970 watts obtained using the instantaneous or single data slice method.

DOY 034 - Voltage and current performance characteristics for SAG's 1 thru 8 on DOY 034, beta 0°, are shown on Figures 2.2.5.4-9 thru 2.2.5.4-16. The characteristics are the same as those recorded on DOY 159, with the exception of time in peak power operation. Calculated average array performance, at +145°F (335°K), was 6895 watts.

2/ Thermal - With the loss of Wing 2, the operating temperature of the SAS is determined from the outputs of ten (10) temperature transducers on Wing 1, corrected as a function of beta angle and elapsed time since orbital sunrise. The solar panel transducer temperatures are cyclic with each orbit with the maximum and minimum temperatures dependent upon the beta angle of the orbit and the orbital thermal environment.



SAS Transducer Thermal Profile (DOY 159, Beta = 10°)

Figure 2.2.5.4-22

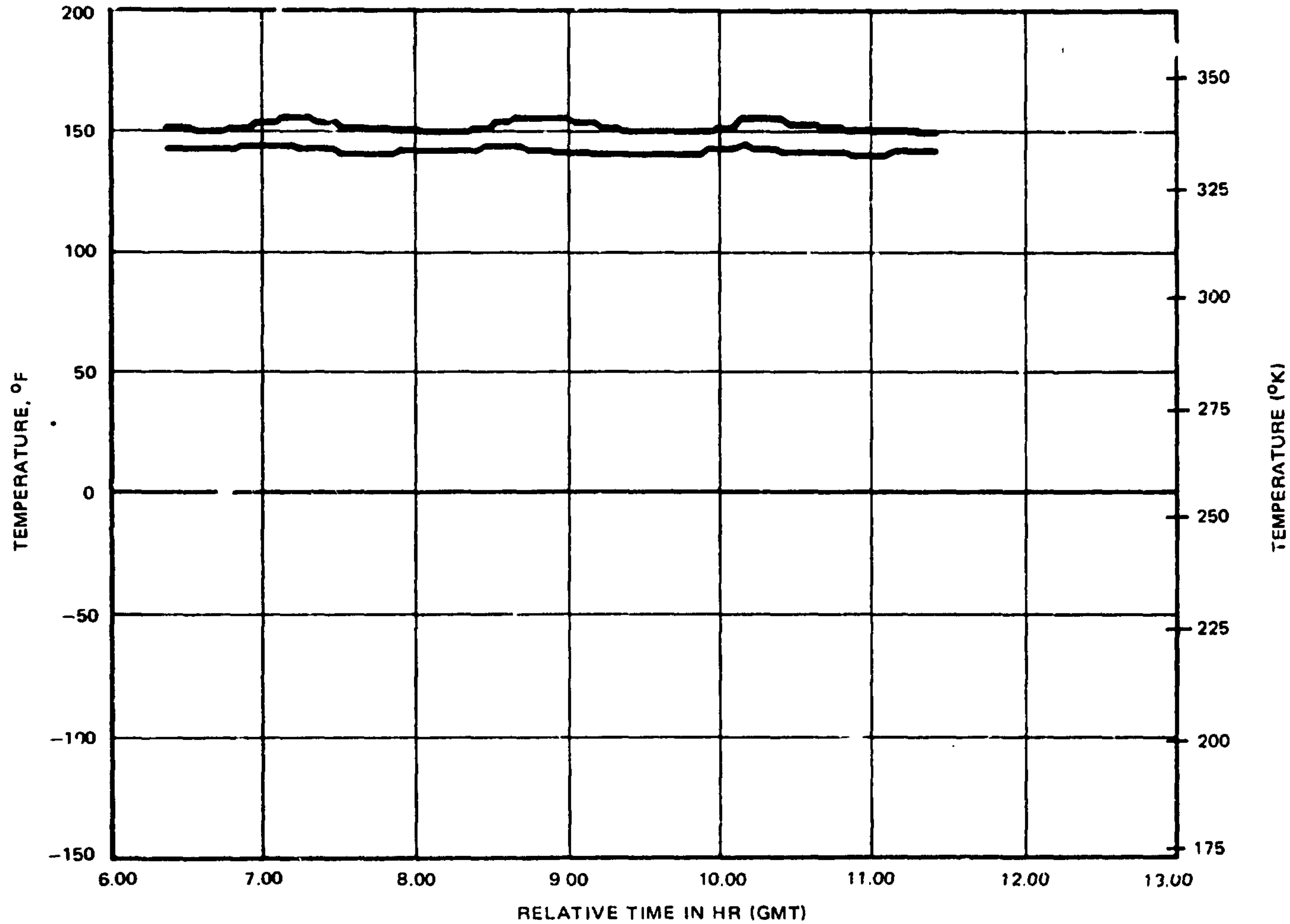
As the beta angle increases, time in the earth's shadow decreases and total sunlight orbits occur for beta angles above approximately 69.5°. Figures 2.2.5.4-22 thru 2.2.5.4-25 show typical SAS temperature transducer profiles for the following days of year.

FIGURE	2.2.5.4-22	2.2.5.4-23	2.2.5.4-24	2.2.5.4-25
DOY	159	175	339	034
BETA	10°	+73.5°	-9°	0°

Maximum and minimum temperatures of the 10 transducers are plotted.

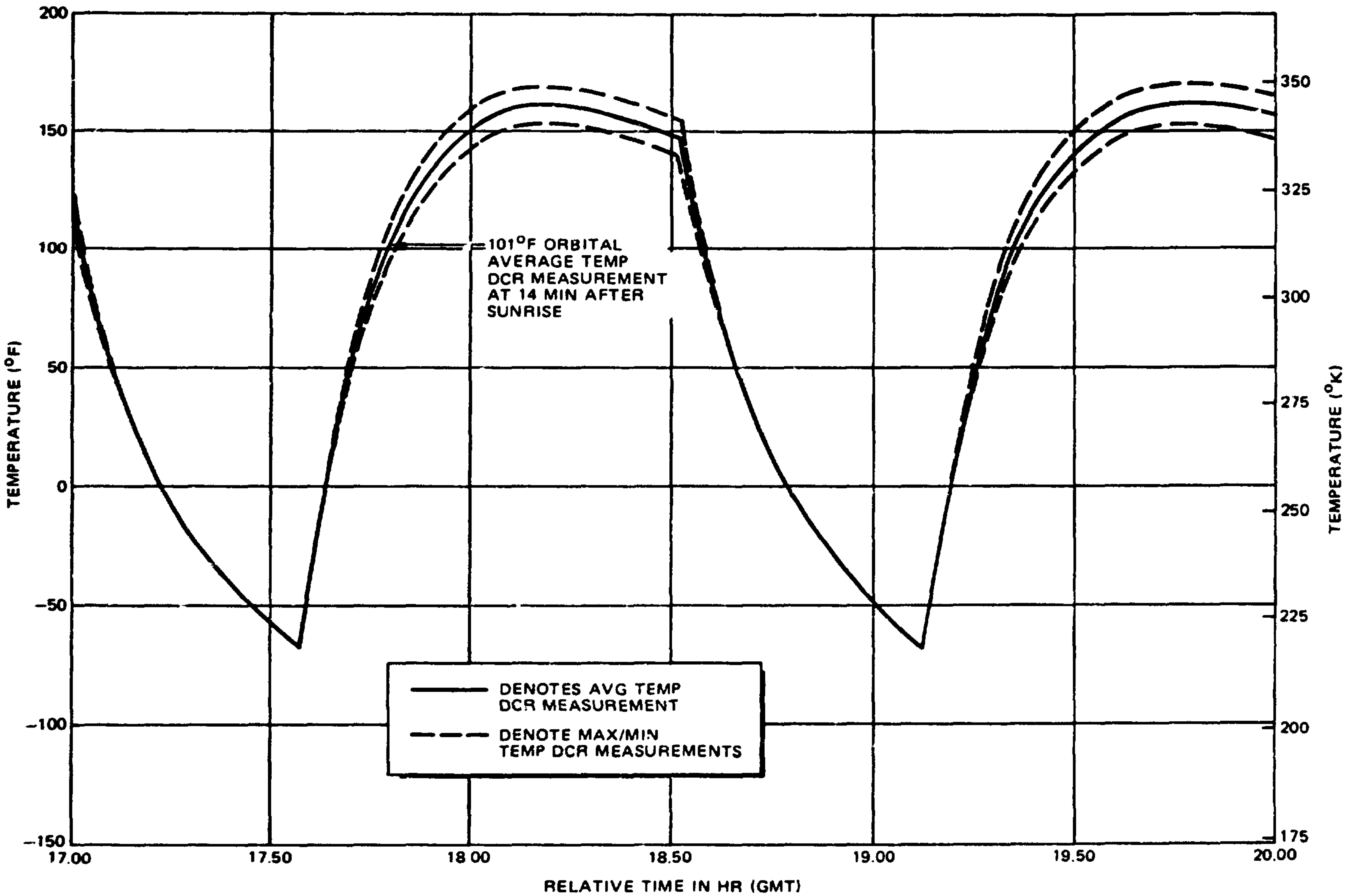
Comparison of actual temperature profiles with predicted profiles showed good correlation; however, two (2) differences do exist. These can be seen in Figure 2.2.5.4-26 for one orbit on DOY 216 at a beta angle of -2°. Differences are shown in the maximum temperature and the temperature gradients across the wing.

The lower predicted maximum temperature, occurring at or before orbital noon, was based on the assumption that the SAS would be operating at peak power continuously in sunlight. In reality, peak power operation ends when the batteries approach full charge, and this generally occurs in the first 15 minutes of sunlight in a solar inertial orbit. When operating below peak power, the array efficiency drops and self heating increases.

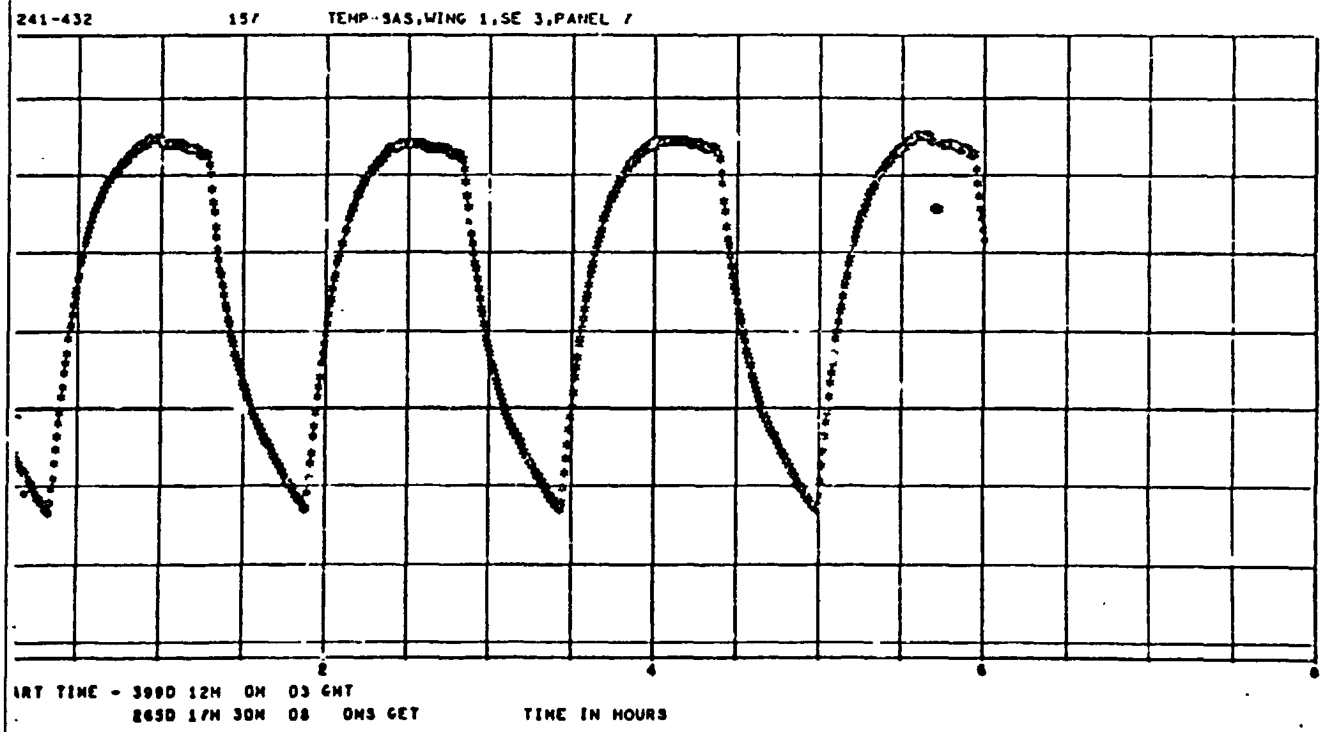


SAS Transducer — Thermal Profile (DOY 175, Beta = +73.5°)

Figure 2.2.5.4-23



SAS Transducer Thermal Profile (DOY 339, Beta = −9°)



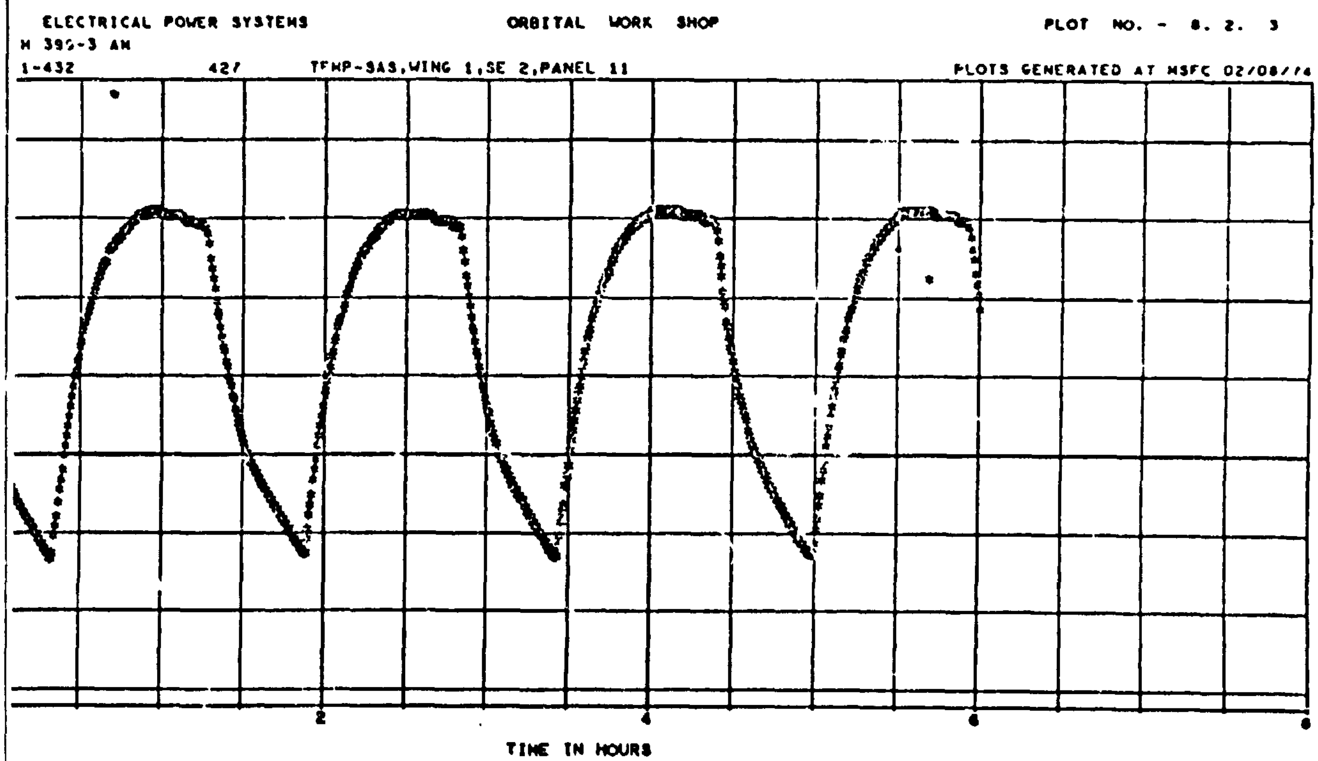
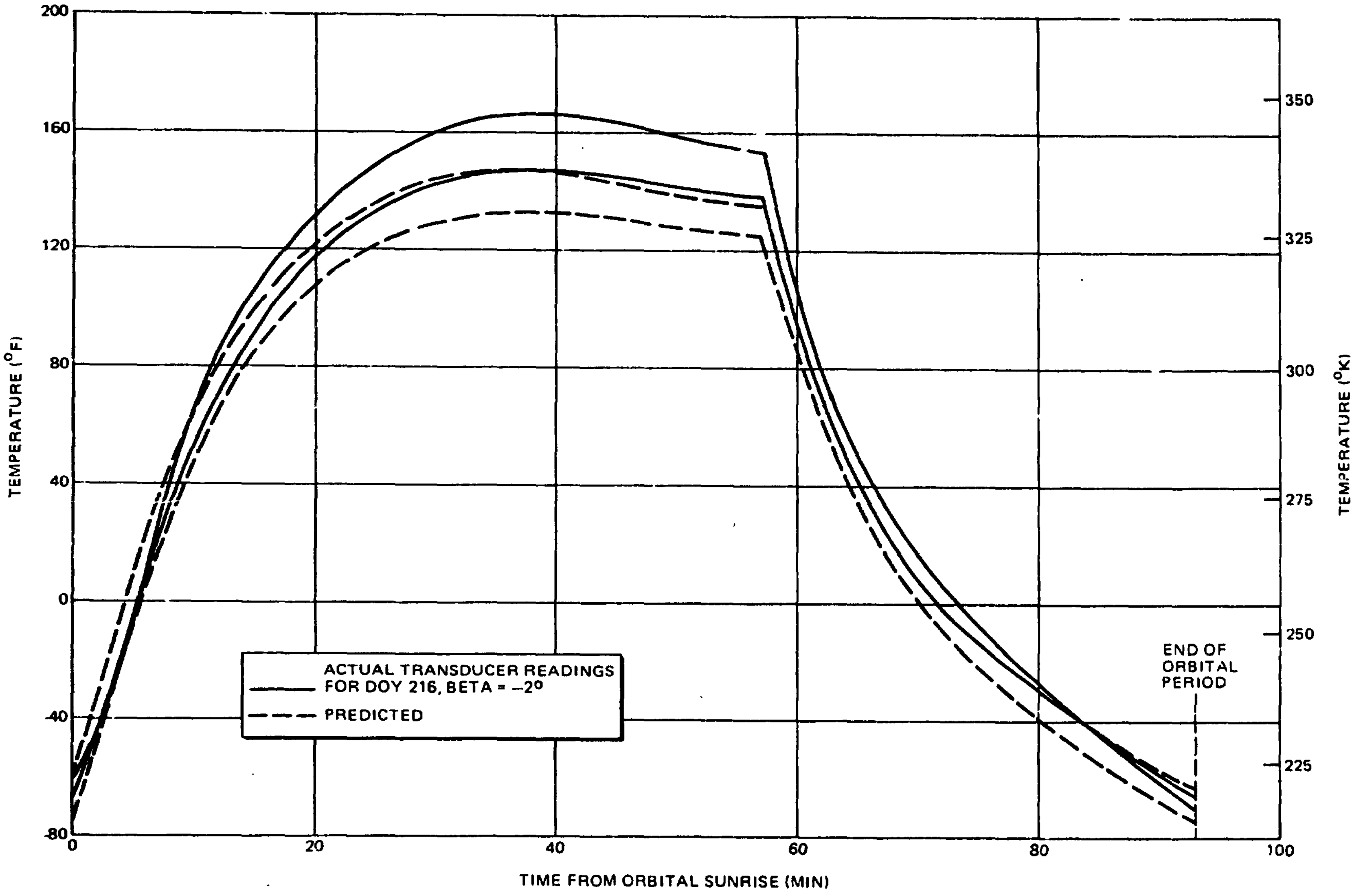


Figure 2.2.5.4-25 SAS TRANSDUCER THERMAL PROFILE (DOY 034, Beta = 0°)



Typical SAS Thermal Profile (Actual vs Predicted)

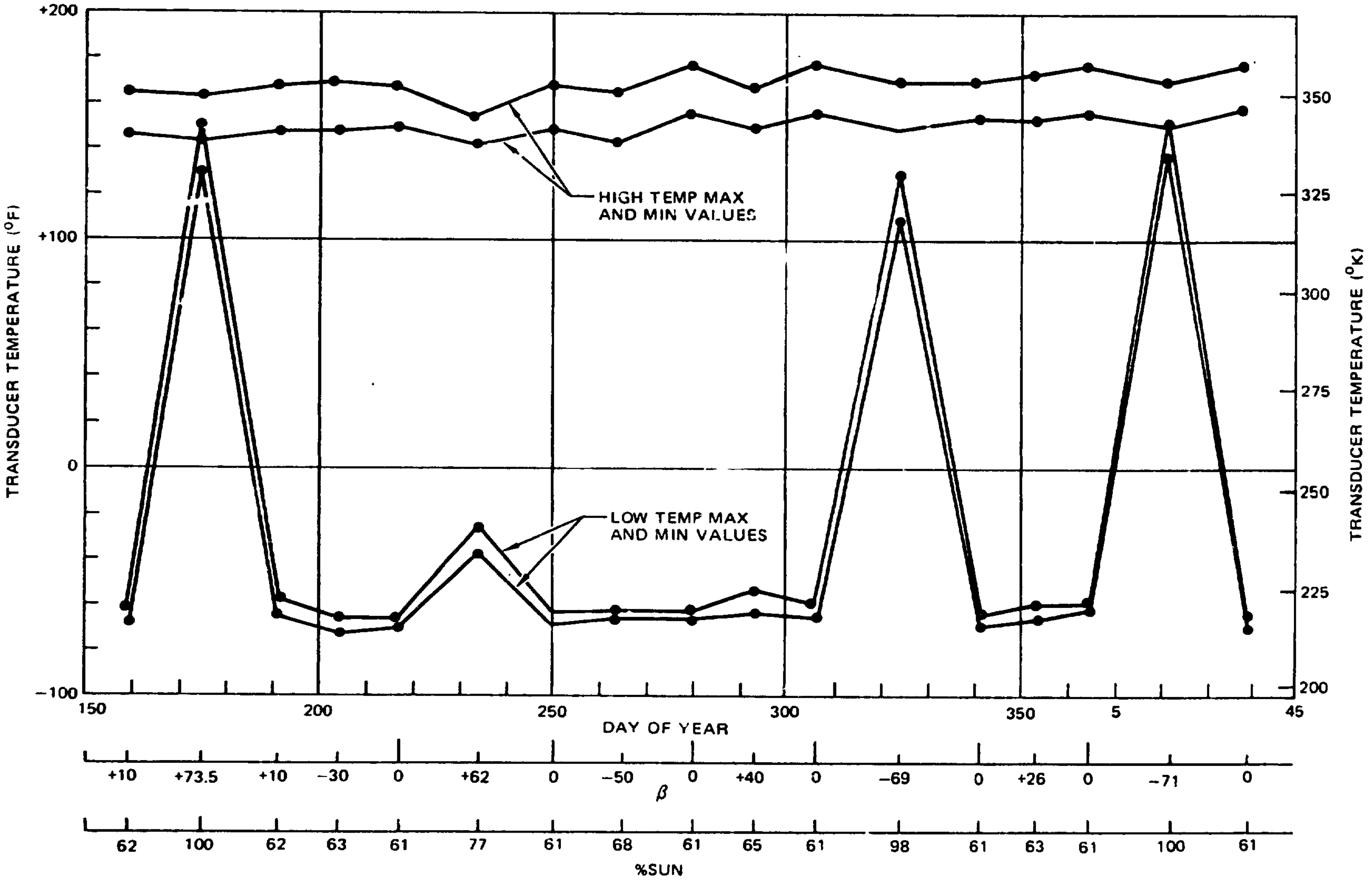
Figure 2.2.5.4.26.

The larger gradient of the actual temperature is a result of the loss of the meteoroid shield. The meteoroid shield in the vicinity of Wing 1 was painted black and had a low reflectivity. The loss of the shield exposed the high reflectivity gold surface and resulted in increased albedo reflection from the OWS tank, and in the area where the parasol did not shade the OWS tank, direct solar reflection from the tank to the SAS.

Figure 2.2.5.4-27 is a plot of temperature transducer measurement history, and shows high and low temperature maximum and minimum transducer readings at orbital noon and prior to sunrise. The trend toward slightly warmer temperatures at a given beta angle is attributed to increased solar intensity as the mission progressed; hence, it appears that no measureable degradation of solar panel thermal characteristics has taken place.

.2.5.5 Conclusions and Recommendations

A. Conclusions - The design requirement for the solar array system (SAS) was 10,496 watts at the end of the mission. One wing was lost during ascent, which cut the potential power source in half. Investigation and analysis of the Skylab ascent anomaly concluded that the loss of SAS Wing 2 and the failure to deploy Wing 1 on time was a direct result of the meteoroid shield failure. The



SAS Temperature Transducer Measurement History primary and back-up command sequences, the EBW electronic units, and associated instrumentation and interlock circuits functioned as designed. The deployment mechanisms in Wing 1 functioned to fully deploy the wing. It is concluded the purge and venting systems performed as designed.

EOM requirements of 5,248 watts minimum average power, and a voltage between 51 volts and 125 volts at the AM/OWS interface were fulfilled. Minimum average array power ranged between 6,500 watts and 7,050 watts at +145°F (335°K), with the variation being attributed to (1) measurement inaccuracies, (2) changes in solar flux which reached a maximum approximately 1974 DOY 005, and (3) the absence of any measureable performance degradation. Throughout the mission, SAG voltages remained between 51 volts (during peak power tracking) and 125 volts (at sunrise). SAG voltages typically ranged between 58 volts and 99 volts.

Predicted SAS performance degradation from all causes was 8.3 percent for the mission; the major contributor being thermal cycling effects, followed by charged particle and ultraviolet radiation.

It is concluded that the orbital environmental encountered by the SAS was very nominal, and in particular, the extremes of thermal environment were less severe than those assumed in pre-flight analyses and testing. Additionally, there was no measureable degradation of solar panel thermal control surfaces.

The power margin at the end of mission is also a result of some conservatism in original performance predictions.

- o The early program concern over the discrepancy between the AM power requirement and predicted array performance resulted in concentrated efforts to make the best possible use of available array area and to ensure providing a minimum of 51 volts at the AM/OWS interface.

- o Shadowing analyses considered 17 out of 240 modules would be shadowed for entire orbits (5° TACS control). In reality only 3 equivalent modules (of 120 Wing 1 modules) were shadowed during CMG control ($\pm 0.5°$).

- o Power calculations assumed 3-sigma maximum instantaneous values of heat flux for entire orbits. In actuality the effects of the random behavior of earth IR and albedo are not well known.

- o The assumption of an eight degree mis-orientation error existing continuously between the array and the sun was overly conservative.

B. Recommendations - The SAS design, manufacture and test program resulted in a SAS that performed equal to or in excess of all specification requirements. Some of the decisions made were influenced by schedule, test status, hardware production status, and the status of interfacing hardware. A review of major decisions and recommendations for any future production of solar arrays follows:

1/ Beam Fairing Assembly - The SAS design incorporated a structural memb r to function as both a beam to support the solar panels and a fairing to protect the solar cells and deployment mechanisms from ground environments as well as ascent thermal and aerodynamic forces. The dual purpose of the structure coupled the deflections of the fairing with the panel stack and the panel cinch bar supporting mechanism. The articulation requirement set the basic design of the structure. It is recommended that for future designs of large solar arrays the articulation requirement be carefully weighed in the initial design.

2/ Actuator-Dampers - The actuator dampers, used to both deploy and control the rate of deployment of the wings, used an orificed fluid for damping. The damping characteristics of the fluid were highly dependent on the thermal environment of the dampers. It is recommended that a type of activ thermal blanket be employed on designs of this type. In the case of Skylab, the wing deployment dampers were frozen before full deployment after being in orbit long after the design period. The astronaut was used to break the link connecting the damper rod allowing Wing 1 to fully deploy.

3/ Vent Modules - The requirement to maintain a purge atmosphere on the wings prior to lift-off was made late in the SAS development program. As the mating electrical interfaces were already designed and fabricated, a decision was made to design the vent valves to operate mechanically with no interface between the SAS/OWS structure. An acoustic actuated valve was designed and developed to provide the venting function. The disadvantages of this type of valve were the lack of capability to close the valve in the case of premature opening and the lack of an automatic talkback on valve position. The valve operated at lift-off and did not prematurely open. It is recommended the use of this type of valve be limited because of its inherent disadvantages.

4/ Solar Panel and Solar Cell Size - Among the most significant trade-offs made during the design phase were solar panel and solar cell sizes. It was desired to maximize the power obtained from the area available. The 2x4 cm solar cell size was selected and proved cost effective from a fabrication and assembly standpoint. Other sizes considered were 2x2 and 2x6 cm.

The solar panel [2x10 ft (0.61 x 3.05 m)] vs. the solar module [2x2-1/2 ft (0.61 x 0.76 m)] trade-off resulted in the decision to use the panel approach. The equivalent of four solar modules were contained in one solar panel, thereby optimizing the useful area. Although larger test chambers and fixturing was required in some instances, handling proved relatively simple; and after a short learning period, panel damage and required rework was infrequent. No panel replacement was required during or after final assembly and installation. In-place cell repair techniques were developed and applied satisfactorily.

As the cell and panel size tradeoffs were cost effective and did optimize power available it is recommended future designs use the panel large cell concept.

5/ Wire Harness Design - Round wire cable (RWC) vs. Flat Conductor Cable (FCC) was another major tradeoff. The decision to use RWC was made to avoid the costs in time and money associated with development of a space qualified connector for FCC, and to take advantage of the subcontractor's experience in RWC design. Few new processes and procedures were necessary, and fabrication, installation, and maintenance were straight forward.

Numerous deployment tests and on-orbit deployment supported the decision in favor of RWC. It is recommended future designs employ the RWC unless major flexing problems are identified early in the program.

6/ Electrical Interfaces - The decision to eliminate all connector interfaces between the solar module and the OWS power unit interface was based upon reliability and voltage drop considerations. While intermediate interfaces in the cabling may have facilitated production and assembly in some instances, system performance has supported the chosen approach. It is recommended this design concept be used on future arrays.

7/ Dark EI Testing - The development of the Dark EI test concept and equipment permitted the establishment of individual module characteristics in the absence of sunlight. These characteristics were then verified during assembly, integration, and test phases. The Dark EI test concept is recommended for implementation on future solar array programs when it is desired to verify array performance capability without the need for costly and time-consuming deployment and large area solar simulation.

8/ Sunlight Testing - On-orbit performance of the SAS has shown good correlation with the pulsed Xenon solar simulation tests performed on all panels during acceptance testing. Likewise, the sunlight tests performed under line items ST-7 and -8 correlated well with the simulator and orbital performance. It is recommended that future array performance verification rely upon proven solar simulation methods, and where array compatibility with power conditioning equipment is of concern, a solar array simulator be used to verify that interface.

9/ Instrumentation Changes - Utilize one solar cell on select solar panels to more accurately determine array temperature in sunlight. This will eliminate the uncertainty in the cell temperature determination caused by the ΔT between the temperature transducer and the solar cell. The ΔT changes rapidly as a function of time from sunrise and is strictly an analytical valve.

10/ Thermal Control Paint - The increased power (approximately 130 watts) did not justify the difficulties encountered in the application, maintenance, and repair of the Z-93 paint used on the rear of the solar panels. Its use in future applications of this type is not recommended.

11/ Ordnance Release Systems - The completely contained expandable tube ordnance system used for release of the beam fairing and panels provided a reliable, redundant release system. This completely contained system, developed several years earlier for releasing the meteoroid shield, was found readily adaptable for both the release of the stowed beam/fairing as well as release of the stowed panels. The systems, as developed for SAS, used expandable tubes of quite different lengths, demonstrating the versatility of the concept. The beam/fairing system required expandable tubes approximately one ft. (30.48 cm) long, while the wing section system required an expandable tube design of over thirty ft. (9.14m) in length. The Skylab I crew, in making its visit to the orbiting laboratory, had a unique opportunity to assess the damage that had occurred during the boost phase. Photographs verified proper ordnance function of the SAS systems. Further use of this type of gas-contained system on future space programs is recommended especially where equipment, such as that with optically critical surfaces, cannot tolerate the contamination produced by most ordnance systems.

12/ Overall Testing and Quality Control - Close attention was given to details of quality and workmanship during all levels of fabrication, assembly, and integration. No direct measure is available as to the value this attention contributed to the power output of the arrays. It is recommended future comparative testing be accomplished to determine the value on large arrays.

The test program was planned for development and qualification at a high level of assembly. As the test program progressed new tests had to be added to pick up detail components.

It is recommended on large complex arrays, the detail components be extensively development tested to preclude failure of large assembly tests.

2.2.5.6 Development History - During the design phase of the Wet Workshop the Solar Array Wing Assemblies were being designed by the NASA, MSFC for fabrication and checkout at the MSFC. At the decision point to convert from wet to dry workshop the SAS was partially designed and part of the development testing was completed. A decision was made by NASA to have MDAC take over the SAS design, development and fabrication as part of the wet to dry conversion in 1969.

At the time of turnover the plan was to finalize the MSFC design to meet the requirements for launch as a dry workshop. The requirement for articulation was deleted, but a decision was made to provide space in the design for incorporation at a future time for an articulation motor and sun sensors. At this time the CEI requirement for the SAS was, "...provide 11,200 watts at the S-IVB/fairing interface, at the beginning of mission, at 55°C (328°K), without shadowing."

The CEI requirement was evaluated and it was concluded that, (1) SAS power at the end of mission should be specified, (2) on-orbit degradation should be accounted for (approximately 6 percent), (3) shadowing by the ATM solar array and the OWS structure should be considered, (4) the 55°C (328°K) array temperature was too low, and should have been around 70°C (343°K), and (5) performance should be specified at the AM/OWS interface.

To meet the cluster requirement it was determined the SAS should provide a minimum average of 10,496 watts and a minimum of 51 volts at the AM/OWS interface.

The MSFC design was assessed and it was estimated that 8,719 watts would be available at the AM/OWS interface at the end of mission, at 70°C (343°K), with ATM shadowing. To meet the end of mission requirement and stay within the same design envelope the solar panel rather than the solar module concept was adopted. This concept allowed for more solar cells per available unit area and an overall reduction in system weight.

In November 1969 a make-or-buy decision by MDAC was made to subcontract the complete wing assemblies except for the ordnance release system. TRW, Inc. was selected as the sub-contractor and an award to TRW was made in March 1970 to build the wing assemblies in accordance with MDAC specification drawing 1B79083. The preliminary design drawings and all information generated by MSFC in design of the SAS were furnished to TRW to be used in the SAS design.

At the start of the TRW design the basic MSFC concept was adopted with a few exceptions. The flat conductor cable was replaced with round wire cable. This decision was made to avoid the costs in time and money associated with development and qualification of a space qualified flat conductor connector and to take advantage of TRW's experience in round wire cable. The solar cell layup was changed from a flat layout to an overlapping shingle type layout to provide for more solar cell area per panel. The wing section ordnance release system was defined as an expandable tube tension link system using the design developed for the meteoroid shield. The venting system for the beam/fairing had not been defined in the MSFC design and the original TRW concept was for vent holes on the sides of the torque boxes.

During the design and development phase TRW, MDAC and NASA worked together and developed a criteria document to control workmanship requirements in the solar cell soldering and layup process. The criteria upgraded the final configuration of the solar panels. During this phase TRW analysis showed the retention mechanism of the solar panels for the launch and boost phase would induce high torque moments with a large residual force in the bars during solar panel release on orbit. To solve this problem the design was changed to two small cinch bars connected through a tension length. During this same period, the supplier for the beam/fairing explosive bolt advised MDAC that the on-orbit contamination requirement could not be met. A decision was made to use the expandable tube concept. The design change required a complete new design of a yoke and tension fitting and redesign of the mating structure on the beam/fairing.

At the preliminary design review a venting system was still undefined. Between the preliminary design review and the critical design review a task team worked on a venting analysis and evolved a design concept of a three compartment beam/fairing with an aft facing fairing over a vent hole in each compartment. A spring loaded flapper was over the exit to preclude retrorocket plume from being ingested into the cavities. During the same period new docking loads and a requirement to be able to maneuver from solar inertial to a Z-local vertical attitude was added to the program. The structure and the panel to panel hinges had to be strengthened to handle the new loads.

The critical design review was held in January 1971. Approval of the venting system, ground purge system, and actuator/damper design were left open for completion of detail design and analysis. The requirement for maintaining relative humidity on solar cells at or below fifty percent was discussed, but no decision was reached as to the validity of the requirement. A research of available test data and experience in the solar array industry revealed no history on exposure of solar cells for long terms at relative humidities above sixty percent. A requirement was imposed to maintain the atmosphere around the solar cells below fifty-five percent relative humidity except for excursions to sixty percent not to last over eight hours. The relative humidity requirement forced a change in the ground purge from a high volume air to a blanket GN_2 purge. To accommodate the GN_2 purge required closing the vent ports and sealing the beam/fairing cavities to withstand a seventy knot wind on the launch pad. In parallel with the design to change the purge requirement, wind tunnel test results of the Skylab configuration showed a more severe venting profile on the SAS than had been incorporated in the design. To provide a minimum impact on the OWS the SAS beam/fairing was moving out so the aerodynamic excursions would not make contact between the beam/fairing and the OWS. The seal between the OWS and the beam/fairing had to be completely redesigned to bridge the large gap. A vent module was added incorporating an accoustic actuated vent valve.

During the completion of the stress analysis in May of 1971, the thermal excursions of the beam/fairing at the time of release were determined to be too large to clear the ordnance tie down fittings. Ramps and rollers were added to the ordnance fittings to ensure a clean separation at release. The force imparted to the beam/fairing by conversion of the thermal to mechanical energy in the rollers caused a design change in the supporting structure at the tie-down fittings and the viscosity of the actuator damper to be increased to absorb a portion of the energy.

All design changes were incorporated into the hardware prior to the start of qualification testing. The scope of the test program was continually increased to test all of the configurations of components and the worst case design conditions. The qualification testing of the SAS wing assembly was completed in July 1972 and the first flight wings were delivered in September 1972.

2.2.6 Electrical Power Distribution System

2.2.6.1 Design Requirements

A. General Requirements - The general requirements of the Orbital Workshop (OWS) Power Distribution System were that the OWS was to be considered as a load for the power which is distributed from the Airlock Module (AM). Therefore, no power is generated within the OWS Power Distribution System (i.e., the OWS Solar Array System is treated separately in Section 2.2.5).

The primary requirements for this system were to:

- o Distribute power (redundant where required)
- o Provide circuit protection of all distribution wiring
- o Limit voltage drop within system to prescribed levels
- o Provide control (switching) capability for the various loads within the OWS.

B. Detail Requirements

1/ Common Requirements

a. Materials, Parts and Processes - Material considerations shall be per Contract End Item (CEI) Specification CP2080J1C paragraph 3.3.3

b. Thermal - Touch (surface) Temperature - Material considerations/design limitations shall be per CEI Specification CP2080J1C, paragraph 3.1.2.1.6.3

Module/Subsystem Operational/Nonoperational Temperature limitations shall be per CEI Specification CP2080J1C, paragraph 3.3.1.1.2.1

c. Induced Loads - Module/subsystem shall be designed to withstand/operate within the environment defined in CEI Specification CP2080J1C, paragraph 3.3.1.1.2

d. Maintainability - Subsystem maintenance considerations shall be per CEI Specification CP2080J1C, paragraph 3.1.4

e. Useful Life - Module/component useful life consideration shall be per CEI Specification CP2080J1C, paragraph 3.1.6

f. Component Construction - Containers of electrical systems shall be hermetically sealed, purged, pressurized, or encapsulated, where necessary. If containers are pressurized, they shall be capable of maintaining a minimum of 2 psig (13.78 kN/m^2) of GN_2 for 24 hours under the specified environmental conditions. All switching devices shall be contained in hermetically sealed containers. Solenoids, transducers, squirrel-cage induction motors, and similar hardware having no circuit switching devices shall be hermetically sealed, purged, pressurized, or encapsulated with compatible material. Precautions against sparking or metal-to-metal contacts shall be taken for all devices that have moving parts.

Bused connector design requirements shall be as specified in MDAC Drawing 1B57771 and in accordance with the requirements of MSFC-PROC-186. All connectors, accepted to the previous design requirements, are interchangeable with those connectors manufactured to these new requirements. New part numbers shall not be assigned. Exceptions applicable to MSFC-PROC-186 are defined in CEI Specification CP2080J1C, paragraph 3.3.1.5.5.1.

Potting of electrical connections using epoxy resin compositions shall conform to MSFC-PROC-196, except that potting personnel shall be trained at the contractor's facilities, given qualification tests by the contractor, and issued a certification by NASA and the contractor.

All threaded electrical connections used for OWS equipment interconnecting wire harnesses, except vibration accelerometers and amplifier coax connectors, shall be lockwired.

g. Radiated/Conducted Interference - The subsystem shall be designed to minimize conducted and radiated interference, and shall not be susceptible to conducted and radiated interference. However, in no case shall this subsystem exceed the limits specified in MDAC-WD Drawings 7883816 and Design Memo SIW-40.

Line shielding shall be used only for suppressing undesireable interference. Except for coaxial cables, shields shall not be used as a functional current return. The shield of a coaxial cable and the outer shield of triaxial cable used for rf shielding shall be grounded to local vehicle structure at both ends and at every break in the cable. The television (T.V.) subsystem is an exception to the coax shield grounding requirement and is not grounded to the vehicle. For the remaining cases, only the signal source end of the shield shall be grounded to local vehicle structure. The shield may, however, be connected to a pin on the equipment connector for reference inside the equipment. Shielding shall not be used on power lines, which shall be routed and twisted together wherever possible. The cases of all electrical equipment shall be grounded in accordance with the requirements of the DAC Drawing 7883816. No electrical connections shall be made to the equipment cases from any return line. Case ground shall be terminated to a pin on a connector.

The subsystem components shall be capable of withstanding transient voltages of ±50 volts for 10 microseconds at a repetition rate of 10 cycles per second imposed at the power input and elevated by 28 vdc in addition to the requirements of paragraph 4.3.4.1.3 of MDAC-WD 7883817.

h. Lightning Protection - Bonding for protection against the effects of lightning shall be in accordance with MIL-B-5087 except for the requirements of paragraph 3.1.1.1.2. Tunnel cover segments shall be electrically bonded to adjacent segments using bonding straps as defined in MIL-B-5087. The covers shall be electrically bonded to the OWS at both ends and at intervals not exceeding 5 feet (1.5 meters).

i. Circuit Considerations - Conductor sizes shall be selected to limit the voltage drop from the Airlock Module (AM) OWS interface to the OWS equipment loads, to 1.5 vdc maximum.

The conductors shall be sized and electrically protected so that maximum wire temperature does not exceed 400°F (204°C) and the fuse current for wires is not exceeded. Where circuit protection controls multicircuits, with individual series circuit protection for each load, a fault on an individual circuit shall not result in a loss of capability to operate the remaining loads.

Electrical cables and wire harnesses for the exterior OWS equipment shall conform to ABMA-PD-E-53 and ABMA-PD-C-711 except as follows:

1. Lacing cord used on cables and wire harnesses shall conform to MIL-T-43435, Type I, Finish B, Size 3.

2. Wire bundles, harnesses, and cables may be spot tied in lieu of continuous lacing, as specified in paragraph 3.2.7 of ABMA-PD-E-53.

3. Delete the requirements for serving adjacent to branches, breakouts, and connectors on blackbox or panel interconnecting harnesses, as specified in paragraph 3.2.7 of ABMA-PD-E-53.

4. The high-voltage capability required for a 1,000 volt "hi-pot" test in paragraph 4.7.3.3 of ABMA-PD-C-711 shall be deleted.

5. Insulation resistance tests may be conducted within the temperature range of 69°F (20.6°C) to 95°F (35°C) in lieu of limits set forth in paragraph 4.7.3.2 of ABMA-PD-C-711.

All functions which cross an interface [the junctor of different contractor supplied/controlled end-items shall be controlled by an interface control document (ICD)]. The ICD shall contain all pertinent data pertaining to the interface function. All OWS related ICD's shall be as identified in MSFC document CM-023-003-24, "Skylab OWS Interface Control Documentation Contractual Index and Status Report".

The OWS wiring design shall provide the capability for post-mate verification of the AM to OWS electrical interface. Bused pins and test connectors shall be provided where functional operations will not provide the required verification.

Power to mission-critical loads shall be distributed by at least two positive isolated buses with separate connectors.

j. Circuit Isolation - All circuits shall be isolated from structure ground. Two-wire single point ground circuits shall be employed. The single point ground shall be in the AM or Command Service Module (CSM).

All wiring and equipment using different AM bus power shall be physically and electrically separated.

2/ AM/OWS Interface

a. Power Characteristics - The OWS shall receive 28 +2, -2.5 vdc from the AM at the OWS/AM interface. This voltage shall have the following characteristics:

1. Bus noise - The total alternating current (ac) component of the voltage shall not exceed 1.0 volts peak-to-peak for all frequencies from 20 Hz to 20 KHz.

2. Under Voltage - Voltage shall not fall below 25.5 vdc by more than 3 volts and shall return to the steady state voltage within one second.

3. Over voltage - Voltage shall not exceed 30 vdc by more than 3 volts and shall return to the steady state voltage within one second.

4. Transients - Transient voltage at the interfaces shall not exceed ±50 volts with a pulse width not greater than 10 microseconds.

5. Only DC power of the quality described above shall be available to any OWS load. Any requirement for a higher quality DC power or AC power shall be satisfied by equipment within the load.

6. All functions crossing the AM/OWS interface shall be as identified in ICD 40M35594.

3/ Internal Requirements

a. Internal (Habitation Area) Subsystems - The Power Distribution System shall provide via a centralized control panels power distribution to all internal OWS subsystems, such as:

1. Thermal control system
2. Internal lighting system
3. Experiment support system
4. Habitability support system
5. Communication system
6. Caution and Warning system
7. Urine dump heater system
8. Refrigeration system

9. Viewing window heater system

10. Utility outlets

11. Television system

b. Zero-Gravity (G) Equipment Connection/Disconnection - All OWS connectors that are to be demated in orbit shall be designed to preclude the occurrence of a hazardous condition caused by electrical arcing when connecting and disconnecting equipment and shall be designed for one-handed operation under zero-g conditions. Reference Figures 2.2.6.1-1 and 2.2.6.1-2.

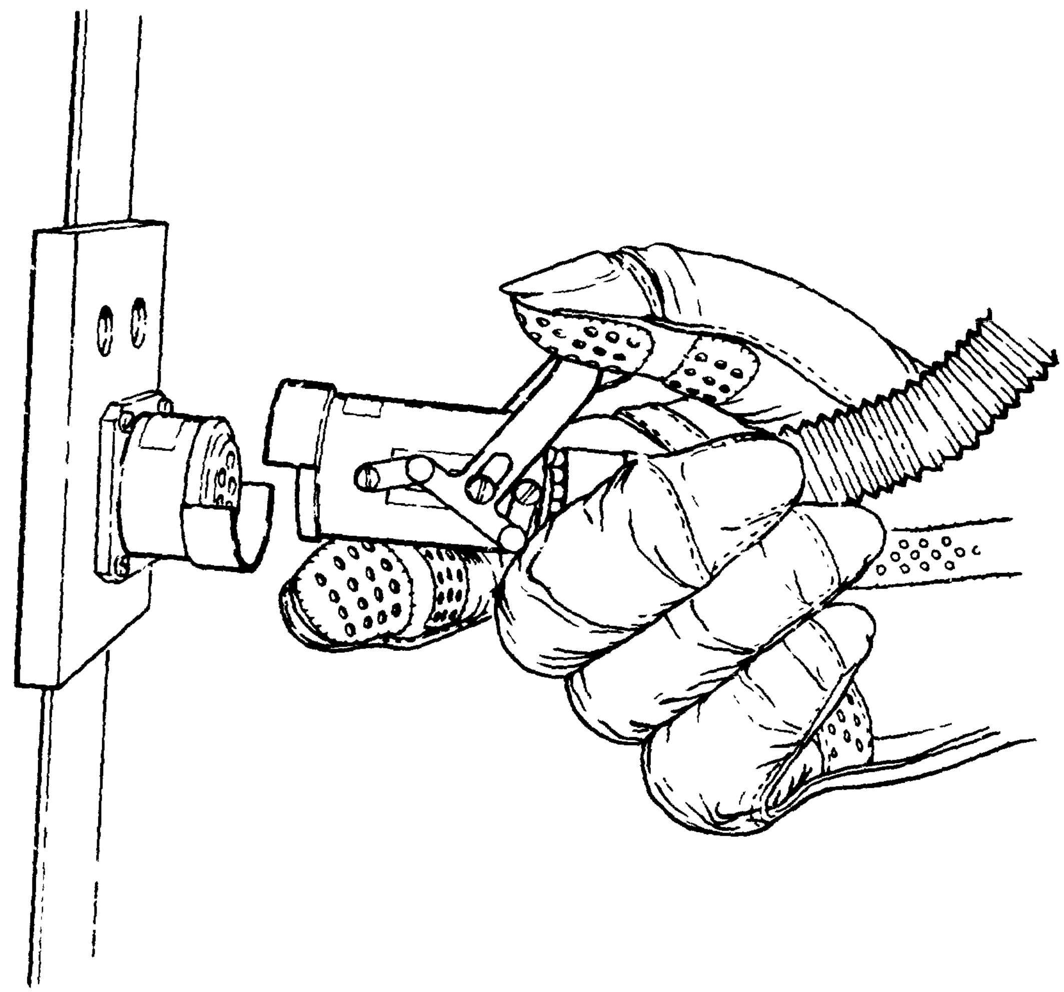
c. Wiring Installation/Protection - Wiring shall be installed from the interface to a power distribution panel, which shall be located in the experiment area.

All wires in the pressurized area shall be protected by circuit breakers. Circuit breakers shall be selected for their ability to provide the nominal current required, and to protect the minimum wire gage used in the event of inadvertent shorting.

Termination of internal wire harnesses for fans, lights, experiments, and communication equipment shall be determined on an individual basis, i.e., permanently mounted receptacles or pre-installed pigtails. The internal cables and wire harnesses shall be compatible with the OWS operation environments.

All harnesses shall be protected to prevent physical damage by the crew.

SKYLAB - ORBITAL WORKSHOP
ZERO G CONNECTOR - DISENGAGED



SKYLAB - ORBITAL WORKSHOP
ZERO G CONNECTOR - ENGAGED

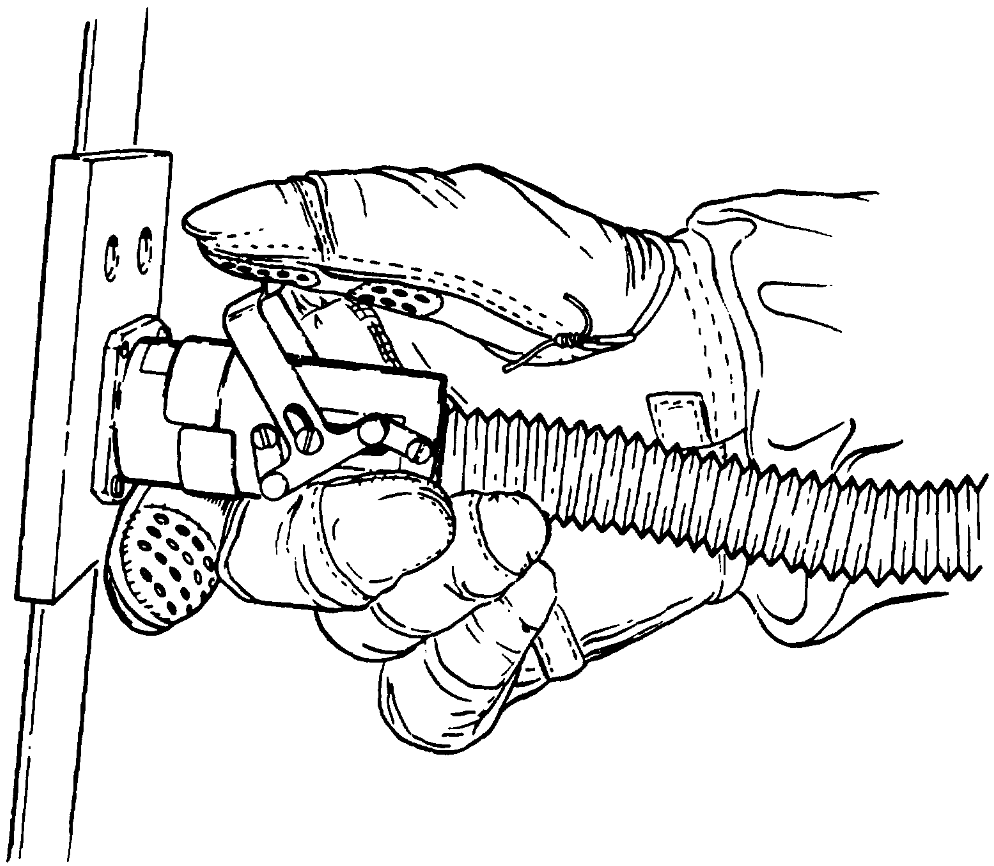


Figure 2.2.6.1-2

d. Extension Cables - Extension cables shall be provided to supply power to the portable OWS equipment. Quantities are as specified in I-SL-008, and three configurations shall be provided as follows:

1. 15 foot (4.672 meter) long utility cables with plugs (pin contacts) on one end and receptacles (socket contacts) on the other end.

2. 15 foot (4.672 meter) long high power cables with plugs (pin contacts) on one end and receptacles (socket contacts) on the other end.

3. One foot (.3048 meter) long high power adapter cables with plugs (pin contacts) on one end and plugs (socket contacts) on the other end.

e. Bus Kill Switches - The OWS power control and display console shall provide a master power switch to control power to each OWS bus. The AM shall also provide manual control capability and supply Digital Command System (DCS) commands to control (ON/OFF) OWS bus power.

4/ External Requirements

a. External Subsystem - Wiring shall be installed external to the pressurized compartment to supply power to the following subsystems:

1. Instrumentation System

2. Solar Array System (SAS)

3. Thruster Attitude Control System (TACS)

4. Meteoroid Shield System

5. Command System

6. Airlock Module Umbilical Requirements Support System

7. Habitation Area Pressure Control System

Each external subsystem shall be provided power from two separate power and return buses.

.2.6.2 System Description

A. General Description - The Workshop El ctrical Power Distribution System provides the means for distributing power from the AM to all loads within the OWS. In addition to power distribution from the internal OWS power buses, power is distributed from airlock power sources to allow operation of external subsystems such as TACS, instrumentation, etc. The OWS power distribution system accepts the AM power at the OWS/AM interface. This interface is called the "octagonal ring" and is located external to the airlock module.

For the internal systems, power is routed from the "octagonal ring" to hermetically-sealed "feedthroughs", which are mounted in the forward dome of the OWS. From the "feedthroughs", the power is routed to an electrical display and control console located within the experiment compartment of the workshop. This console (in conjunction with remote control panels) contains all necessary switches, circuit breakers, and indicators to allow crew control of the OWS electrical system.

Power for the external systems is routed from the "octagonal ring" to various bused connectors mounted on electrical equipment panels located in the forward and aft skirt of the OWS. The electrical equipment panels contain the necessary fuses and control modules for control and protection of the external systems.

B. System Details

1/ Common Details

a. Flammability - Material selections for the OWS Power Distribution components located within the habitable interior were govered by MSFC-SPEC-101. This is the specification for flammability, odor, and outgassing as modified by CEI CP2080J1C, paragraph 3.3.3.

b. Induced Loads - System components/modules/panels are selected/designed to withstand astronaut-induced loads as well as flight induced loads. The design is verified by the OWS Development and Qualification Test and/or analyses for every OWS panel, module, and component.

c. Maintainability - Each component part is designed to assure proper installation within the OWS. Circuit breaker and control and display panels and panel mounted modules are mounted in such a way as to expedite any rework, testing or removal and replacement of components mounted to these panels.

d. Component Construction - All switching devices are contained in environmentally sealed containers, as specified in the applicable electrical component Design Requirement Drawing (DRD). Other containers are hermetically sealed or encapsulated, where necessary, to protect parts contained in them and to satisfy the system design requirements.

The leakage rate for hermetically sealed containers does not exceed 1×10^{-8} standard cubic centimeters per second (SCC/S) of helium at a one atmosphere pressure differential. The leakage rate for environmentally sealed containers does not exceed 1×10^{-5} SCC/S of helium at 1 atmosphere pressure differential (101.3 kN/m^2).

All insulated conductors on the OWS are teflon covered nickel coated copper stranded with a 1,000 v rating. The wire gauges used are 12, 16, 20, and 22 single conductor, plus 20 and 22 gauge triple conductor shielded and jacketed. The conductor insulation material is TFE teflon. The jacket material is FEP teflon. The shield material is silver coated copper. The 16, 20, and 22 gauge conductor consists of 19 strand wire. The 12 gauge conductor is comprised of 37 strands of wire.

e. Radiated/Conducted Interference - The subsystem is designed to minimize conducted and radiated interference, and is not susceptible to conducted and radiated interference.

Each component part of this subsystem is designed to effect an electrical bond when installed in the OWS. The bonding techniques are in accordance with MDAC-WD 7883816 and Design Memo OWS 38, except that cadmium or zinc plated hardware are not used. Bonds are Classes H, L, and R for panels to the console and structure and Class S for other applications, as defined in MIL-B-5087.

f. Circuit Isolation - Wire harnesses carrying different bus power are physically and electrically isolated. The power control console is compartmented and enclosed to provide flammability and physical damage protection. 1,000 volt wire is used to provide additional protection against shorts and wire damage.

Hard anodize finish is used on the inside of the power control console to provide additional 500 volts minimum breakdown protection. Sufficient wire bundle string ties are used to prevent a loose wire from reaching structure ground. Wire harness design meets or exceeds all mechanical support criteria outlined in MIL-W-8160D.

Wiring internal to the OWS is routed through a closed-trough system for flammability and physical damage protection. The closed trough system consists of rigid troughs, flex troughs, interchange boxes, convoluted rubing, and connector boots. Barriers within these devices will cause a flame to self-extinguish. Reference Figures 2.2.6.2-1, 2.2.6.2-2 and 2.2.6.2-3.

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RIGID TROUGH

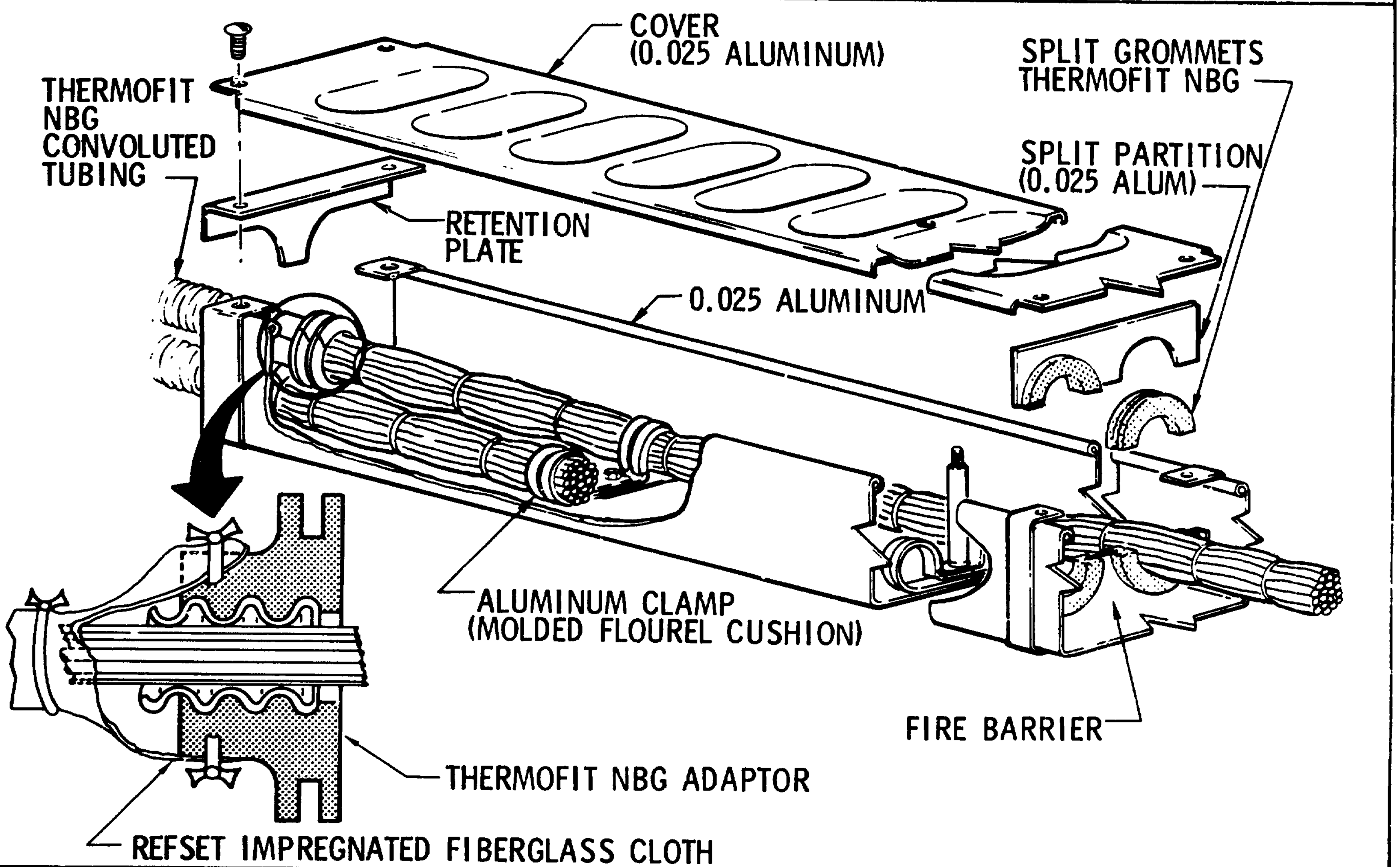

Figure 2.2.6.2-1

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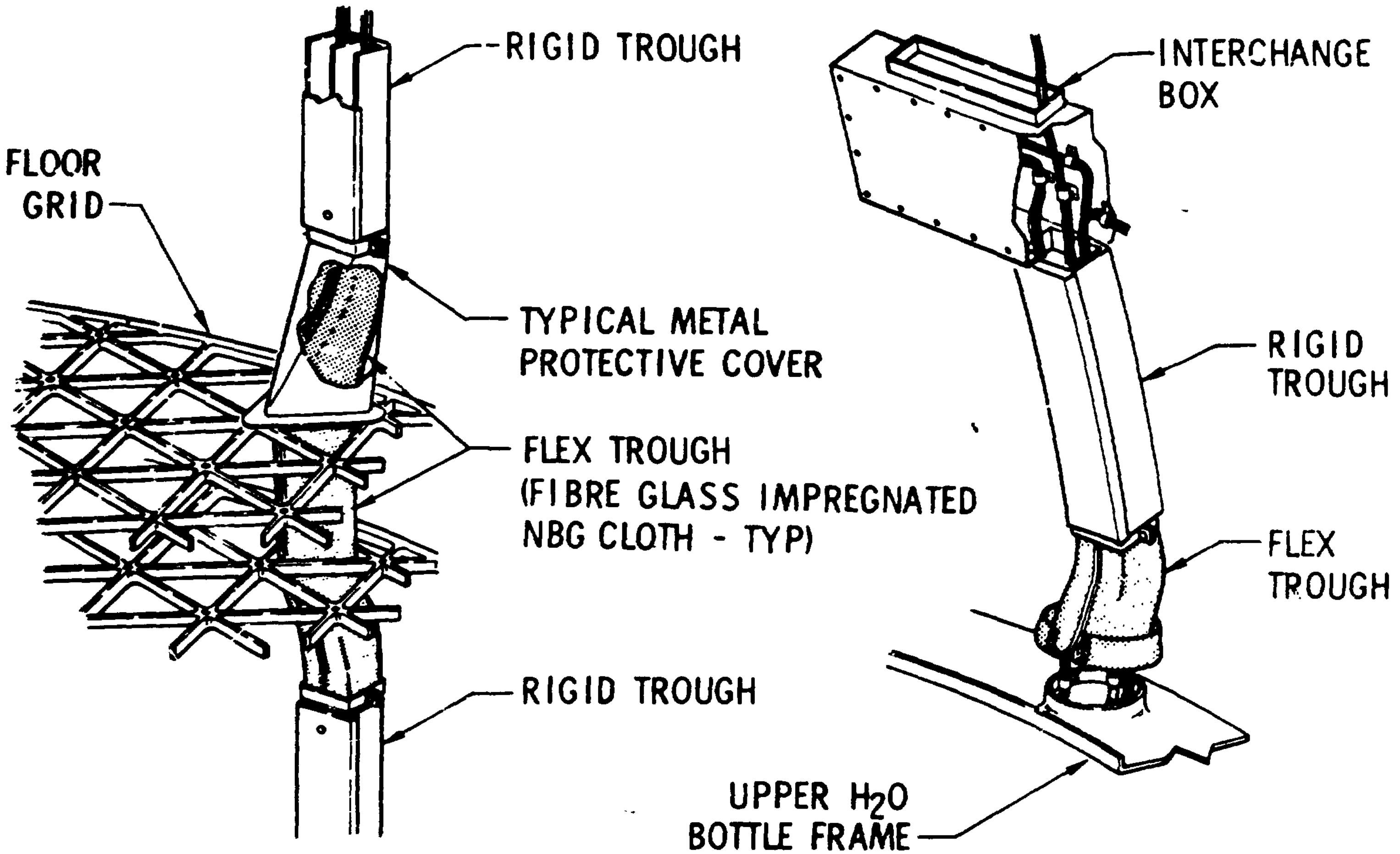
FLEX TROUGH USAGE (GENERAL CONCEPT)



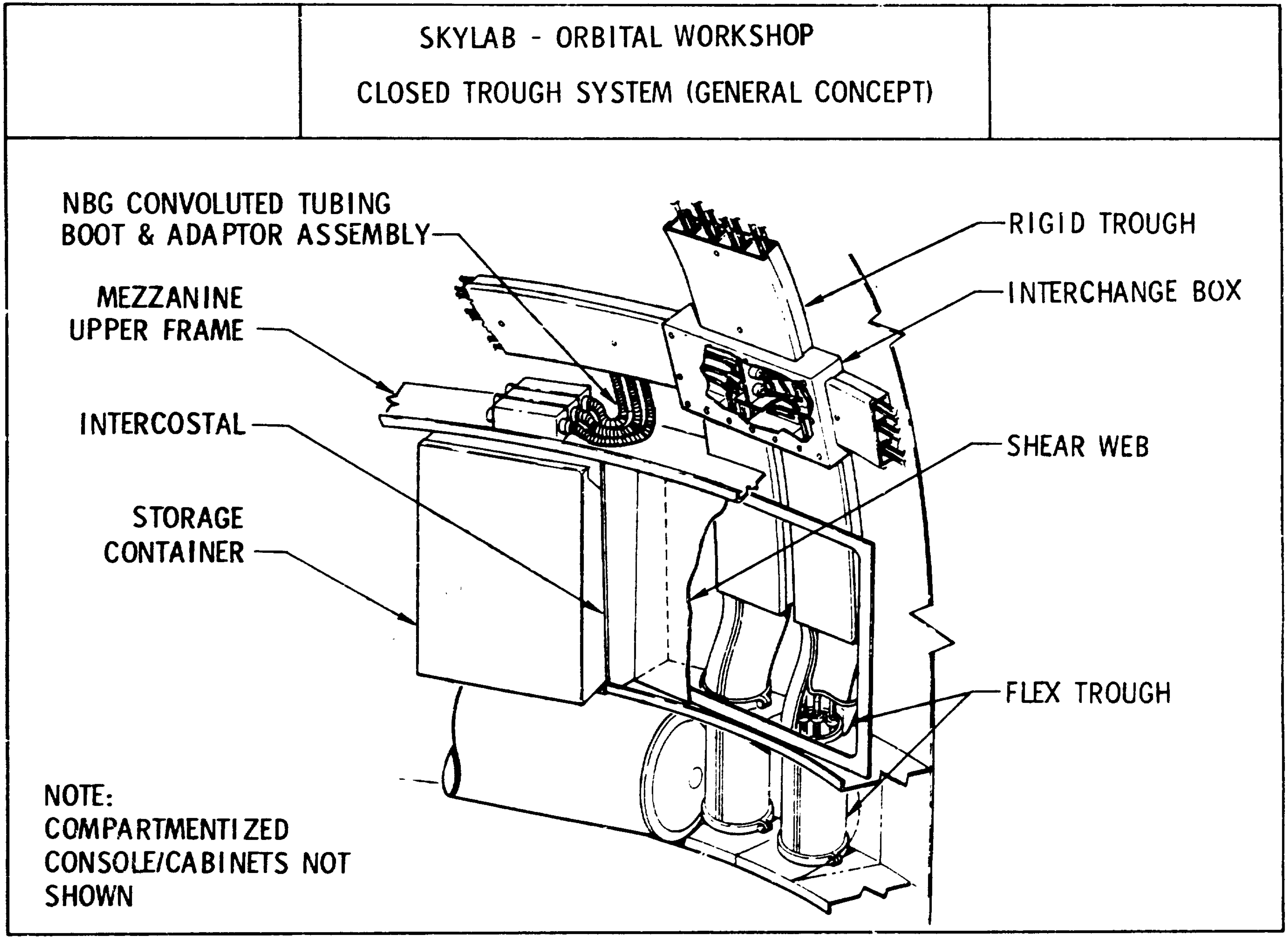


Figure 2.2.6.2-3

Designated connectors on the wire harness have tethers attached to prevent the mating of a connector to the wrong receptacle.

g. Circuit Considerations - The system is designed to provide a voltage between 24-30 vdc to all OWS end-items.

All subsystems are supplied power from two (2) power buses which are electrically and physically separated. All conductors are electrically and physically protected. In the event of a fault, the sizing of the circuit protection device limits the temperature of the conductor insulation to less than 400°F (204°C) and limits the current to a value which is less than the fusing current of that conductor. This protection is from the voltage source at the point of connection to the end-items.

The wiring in the OWS is categorized by function and installed with physical separation dictated by the category. The OWS subsystem wiring is categorized and installed per the following:

1. Category 1
   - (a) All power wiring
   - (b) Solenoid and relay coil wiring

2. Category 2

   (a) 0-5 v analog signals

   (b) Bi-level measurements

3. Category 3*--Low Level, 0-20 mv analog circuits

4. Category 4--RF coaxial lines (above 150 kHz)

5. Category 5*- Multiplexer wiring

   (a) Timing inputs and outputs

   (b) Power inputs and outputs

   (c) Analog outputs and return

   (d) Bi-level outputs

6. Category 6*--Audio signals for communications

7. Category 7--Speaker intercom interface circuit

8. Category8--3 phase, 400 Hz

9. Category 9--3 phase, 36 Hz

10. Minimum Edge Distance Separation for Wire Runs in inches (centimeter)

*Shielding required

Cat/Inches	1	2	3	4	5	6	7	8	9
1	0	3	6	3	3	4	3	6	3
2	3	0	4	3	3	3	3	12	3
3	6	4	0	5	5	4	4	12	6
4	3	3	5	0	3	3	3	12	3
5	3	3	5	3	0	4	3	12	3
6	4	3	4	3	4	0	3	12	4
7	3	3	4	3	3	3	0	12	3
8	6	12	12	12	12	12	12	0	6
9	3	3	6	3	3	4	3	6	0

3 inches = 7.62 centimeters
4 inches = 10.16 centimeters
5 inches = 12.7 centimeters
6 inches = 15.24 centimeters
12 inches = 30.48 centimeters

11. General Ground Rules

(a) Power and return routed together (twisted if at all possible and close to ground plane). Without exception, categories 8 and 9 wiring are twisted.

h. System Measurements - The measurements used to evaluate the OWS Power Distribution System are as follows:

1. Caution & Warning Indications

Caution & Warning Indications	Location
Reg Bus 1 (2) Low	(AM Panel (Pnl) 207)
Reg Bus 1 (2) High	(AM Pnl 207)
OWS Bus 1 (2) Low	(AM Pnl 207 & OWS Pnl 616)

2. Status Lights

	Location
OWS Bus 1 (2) On	(AM Pnl 206)
OWS Bus 1 (2) Off	(AM Pnl 206)
AM Bus 1 to Reg Bus 1 (2)	(AM Pnl 206)
AM Bus 2 to Reg Bus 2 (1)	(AM Pnl 206)

3. Meters

Reg Bus 1 (2) Voltage	(AM Pnl 206)
OWS Bus 1 (2) Voltage	(OWS Pnl 617)
Reg Bus 1 (2) Current	(AM Pnl 206)
OWS Bus 1 (2) Current	(AM Pnl 206 & OWS Pnl 617)

4. Telemetry Channels

M151	EPS Bus 1 Voltage
M152	EPS Bus 2 Voltage
M169	EPS Bus 1 Current
M170	EPS Bus 2 Current
M153	Reg Bus 1 Voltage
M154	Reg Bus 2 Voltage
M161	Reg Bus 1 Fine Voltage
M162	Reg Bus 2 Fine Voltage
M163	Reg Bus 1 Current
M164	Reg Bus 2 Current
M182	Reg 1 OWS 1 Tie
K183	Reg 2 OWS 2 Tie
M7002	OWS Bus 1 Voltage
M7003	OWS Bus 2 Voltage
M7004	OWS Bus 1 Current
M7005	OWS Bus 2 Current
M7400	OWS Bus 1 Voltage Umbilical (Umb)
M7401	OWS Bus 2 Voltage (Umb)
K177	AM 1 to Reg Sel
K178	AM 2 to Reg Sel
M155	AM Bus 1 Voltage
M156	AM Bus 2 Voltage
M159	AM Bus 1 Current
M160	AM Bus 2 Current
K323	Deploy Enable
K328	Deploy Arm
K179	Deploy Bus 1 ON/OFF
K180	Deploy Bus 2 ON/OFF
K194	Sequential Bus 1 ON/OFF
K195	Sequential Bus 2 ON/OFF
M167	Reg/Xfer 1 Current
M168	Reg/Xfer 2 Current

2/ AM/OWS Interface - The receptacle mechanical arrangement on the "octagonal ring" of the airlock module is designed to provide maximum signal category separation as well as maximum physical separation for redundant circuits. Wire harness routing from OWS components to the interface is routed from the forward skirt over the forward dome of the OWS to the AM/OWS interface while maintaining the separation requirements. The AM/OWS Electrical ICD is 40M35994.

3/ Internal Systems - The major elements of the internal distribution system consist of a main control and display console, and associated remote control panels. These system elements are designed and constructed to contain the necessary circuit breakers, switches, and displays to allow operation of all the internal subsystems.

The system receives its power from the AM by two (2) separate isolated buses, each of which is protected by nine parallel 12-ampere circuit breakers. Internal OWS end-items are then supplied power from these two (2) isolated buses. Each end-item is also protected by a circuit breaker. The ground return paths from end-items are bussed together with eight (8) terminal junction blocks and then routed to the AM for single point grounding.

The feeder circuit breaker panel (Panel No. 615) contains the 18 circuit breakers that feed AM power to OWS buses 1 and 2. The remaining circuit breaker panels contain the circuit breakers that control individual loads. The voltage and current measurements for OWS buses 1 and 2 are on Panel No. 617.

The display and control panels are preassembled, including all interconnections and interface wiring, prior to assembly to the equipment console in the OWS. Panels and components mounted on the console are designed and constructed in accordance with their applicable Design Requirement Drawings (DRD's). Circuit breakers, switches, and displays are mounted on panels in a systems oriented manner. MSFC-STD-267A is used as a guide for the astronaut-panel interface. Design features are standardized to the greatest extent feasible. Such features include but are not limited to:

a. Captive fasteners for attachment to the equipment console. Such fasteners are compatible with the inflight tool kit.

b. A means of maintaining the panel in an open position during zero-"G" environments.

c. A means to prevent i   ertent actuation of switching devices by an astronaut during zero-"G" environments.

All OWS control a d displays are designed to be compatible with astronaut   tion.

The controls and displays are arranged by function and subsystem conforming to a left-to-right, top-to-bottom progression. This convention is commensurate with the cultural traditions normally encountered in the NASA space programs. Horizontal progression is preferred to vertical progression.

Switches, circuit breakers, and other control devices are protected from inadvertent actuation. Methods used include partial recessing with barrier protection and full recessing.

Controls are placed to prevent damage or inadvertent actuation. Switches and circuit breakers that are toggle-lever actuated have wicket barriers. The spacing between barriers is not less than 1 inch (2.54 cm) nor greater than 1.125 inches (2.70 cm). Rotary control knobs are recessed, fully skirted, and not less than 2 inches (5.08 cm) in diameter.

Two (2) momentary toggle switches are provided on the power and display console to allow the crew to remotely control an AM relay network that can enable or disable either OWS bus.

Accessory cables are provided with a non current carrying small gauge wire cable that is slightly shorter than the current carrying wires to provide strain relief. The cables are fabricated with zero-"G" plugs/receptacles to facilitate connection/disconnection in a zero-"G" environment. High power accessory cables are color coded blue to prevent confusion between high power accessory and low power utility outlet cables.

Electrical outlets are provided at convenient locations throughout the forward compartment and crew compartment. Utility outlets capable of delivering 6 amperes are provided for additional lighting, cameras, area circulation fans, etc. They are divided into two (2) circuits and distributed to allow loads to be connected to either bus 1 or bus 2. Each utility outlet circuit wiring is protected by 6 amperes circuit breakers in the Control and Display panel. These outlets utilize the low power utility outlet cables.

High power accessory outlets capable of delivering 12 amperes are provided for photographic lights and vacuum cleaner. These outlets are divided into two (2) circuits and each circuit is protected with a 12 ampere circuit breaker in the same way as the utility outlets. These outlets utilize the high power accessory cables. Television outputs provide power and signal routing for the TV cameras. Scientific Airlock (SAL) outlets provide power for experiments (20 amperes) and signal routing for experiment instrumentation. The types of outlets (utility, high power, TV, SAL, and instrumentation) are not mutually interchangeable.

4/ External Systems - Power is distributed from AM Bus 1 and Bus 2 to the external OWS subsystems. Physical and electrical separation of the harnesses carrying different bus power is maintained. This power is routed directed from the "octagonal ring" down the OWS dome to the various forward and aft skirt panel bus modules. The power is then distributed to the various loads of the particular subsystem per the design requirements of that subsystem.

All wiring crossing the AM/OWS interface is protected by AM or OWS located circuit protection devices depending upon which side of the AM/OWS interface the power or signal originates. On the OWS side of the AM/OWS interface circuit protection is provided by fuses and current limiting resistors.

2.2.6.3 Testing

A. Testing Program - A testing program for the Power Distribution Subsystem and its component parts was conducted to verify that all of the CEI imposed and designer imposed requirements were satisfied by the subsystem hardware. Testing was conducted in three (3) distinct phases; development, qualification, and system tests. Development tests primarily consisted of component level testing as a part of the normal design evolution process and therefore are not elaborated on any further in this report. However, the attendant qualification and system level test performed on this subsystem are delinated below.

1/ Qualification Tests - Qualification test line items for the Power Distribution Subsystem were: ES-7, ES-11, ES-13, ES-14, ES-15 and CS-3. For each of these line items, individual Test Control Drawings (TCD's) and Detail Test Procedures (DTP's) provide the detail test requirements and procedures followed in conducting the qualification tests. The test results are documented in individual line item test reports. Table 2.2.6.3-1 provides a cross reference of line item number and components tested vs. TCD, DTP and test report.

In addition to the individual line item test reports identified in 2.2.6.3-1, the Test and Assessment Document (TAD) for Orbital Workshop 1 and the Backup Vehicle (MDC G0424) provides a cross reference of design requirements vs. method of verification, including rationale detailing how each OWS hardware item is qualified.

2/ System Tests-Huntington Beach - The following tests, as documented in Report MDAC G3069, were performed in the Vehicle Checkout Laboratory (VCL) at Huntington Beach.

a. Continuity Compatibility Procedure (1B66984) - Prior to the application of power to the OWS, the continuity compatibility test was conducted to ensure confidence in the OWS electrical system wiring. For the Power Distribution Subsystem, the test verified (continuity wise):

Table 2.2.6.3-1
QUALIFICATION TEST SUMMARY

LINE ITEM	COMPONENTS TESTED	TEST CONTROL DWG.	DETAIL TEST PROC.	TEST REPORT
CS-3	Voltage sensor	1T16838	1T45683	TM - DSV7-EE-R7028 (11-14-72)
	Junction module d.c. amplifier circuit breaker assemblies			
ES-7	Toggle switch assemblies	1T16070	1T45981	TM - DSV7-EE-R6931 (12-1-72)
	Meter assemblies Lamp assemblies Push Button switch assembly Rotary switch assembly Annunciator assembly Rheostat Diode Module			
ES-11	10 Amp Relay Module	1T16836	1T45845	TM - DSV7-EE-R6943 (4-11-72)
ES-13	30 Amp Relay Modules	1T19772	1T45872	TM - DSV7-EE-R6877
ES-14	Remote Control & Display Panel Waste Management Compartment (WMC)	1T19727	1T46080	TM - DSV7-EE-R6939
ES-15	Diode Modules	1T43617	1T46648	TM - DSV7-EE-R7053A (11-14-72)

- o Isolation between power buses and return buses.
- o Isolation between different power buses.
- o Isolation between different return buses.
- o Isolation between power buses and OWS structure.
- o Isolation between return buses and OWS structure.
- o Individual conductor resistance was within a specified limit.

b. Power Distribution Subsystem Test and Checkout Procedure (1B83585) - This test verified that the distribution of electrical power to the Orbital Workshop end-items is:

- o Adequate (voltage is within limits at rated loads).
- o Compatible with end-item (voltage polarity is correct).
- o Properly controlled and separated (thermostats, switches and circuit breakers correctly apply/interrupt power from the designated busses).

c. All Systems Test Countdown Procedure (AST), 1B85235 - This test verified the power distribution subsystem's compatibility with all of the OWS electrical subsystem Electromagnetic Interference (EMI) generation/susceptibility is within design requirements limits. The AST was the final demonstration, at Huntington Beach, of OWS flight readiness. This was a functional test with all OWS systems active in the required boost or orbital configuration within the limits of ground testing.

3/ Systems Tests - Kennedy Space Center (KSC) - The following tests, as documented in Memo A41-814-SWS-M-1, were performed at the Kennedy Space Center.

a. OWS/Instrument Unit (IU)/Saturn II (S-II) Continuity and Compatibility Checks (KO-1004) - This procedure verified the compatibility of the OWS electrical interface lines prior to the application of power and prior to mating with the airlock module (AM), Instrument Unit (IU), SII, and the Solar Array. This test is similar to the A3-VCL Continuity Compatibility Test.

b. AM/Multiple Docking Adapter (MDA)/OWS Electrical Interface Test (KS-0003) - Two (2) of the functions of this test were to verify, after mating with the AM, the power transfer capability across the AM/OWS interface and to function the OWS Power Distribution Control System. This section of the test is similar to the A3-VCL Power Distribution Test.

c. SWS Operations for S-V Overall Test (OAT) and SWS Mission Simulated/Flight Readiness Test (SIM/FRT) (KS-0009) - This test functionally verified the electromagnetic compatibility of the Power Distribution Subsystem with all of the Skylab electrical subsystems. It is similar to A3-VCL All Systems Test.

d. AM/MDA/OWS End-to-End System Test and Experiment Test (KS-0045) - This Checkout Procedure functioned all of the Skylab cluster electrical and mechanical systems and again verified compatibility of the Power Distribution Subsystem with each/all electrical subsystems.

B. Major Problems/Solutions

1/ Qualification Test Problems/Solutions

a. Problems - During the Qualification test program, several of three (3) different module configurations (meter, circuit breakers, and switch assemblies) did not meet the minimum insulation resistance requirement. The problem was determined to be associated with the bonding or adherence of the encapsulant to the metal housing.

b. Solution - Basically, the repair of the completed circuit breaker and switch assemblies consisted of cleaning the junction area of the encapsulant and housing assembly, removing some of the encapsulant at the junction area, filling in the voided area with adhesive compound, and then sealing with fiberglass tape and epoxy. The display light assemblies were also modified in the same manner even though no anomalies were noted during their qualification testing.

In order to obtain a good bond for new production items, a sand blast method was utilized on the bonding surface of the housing assembly. This process created a rough surface on the housing sufficient to facilitate a good adherence of the encapsulant to the housing.

The fix for the meter assemblies was to remove the encapsulant and matrix block from this assembly and then solder the spacecraft conductors (control and display panel wiring) directly to the solder terminals on the meter assembly. The environmental seal was then provided by a heat shrink tubing covering the soldered area.

2/ Huntington Beach - VCL Testing Problems/Solutions

a. Problems - During post-manufacturing checkout, the OWS megger test indicated an out-of-tolerance insulation resistance for several of the circuit breaker assemblies. Also noted during the megger test of OWS was an anomaly of one circuit breaker assembly bat handle to not remain in the closed position.

b. Solution - As a result of the two (2) above problems, all of the meter, switch, circuit breakers, and light assemblies, on the completed and installed control and display panels, were removed and replaced with the reworked/new configurated assemblies.

In addition to correcting the housing-to-encapsulant bonding problem, the circuit breaker manufacturer provided an additional inspection point on the assembly of the circuit breaker during/after the activation mechanism manufacturing step was performed. This inspection verified proper assembly of the actuation mechanism. When incorrectly assembled, this mechanism could cause the mechanical anomaly.

3/ KSC Testing Problems/Solutions - There were no anomalies associated with the checkout of the Power Distribution System at KSC.

4/ Waivers/Deviations - There were no waivers or deviations required for the Power Distribution Subsystem.

.2.6.4 Mission Results

The OWS Electrical Power Distribution System performance during the launch phase and on-orbit operations was satisfactory. All EPS launch Mission Rule requirements were satisfied throughout the countdown. OWS bus loads at liftoff were 500 watts (17.5 amperes at 28.6 vdc) on OWS Bus 1 and 486 watts (17.0 amperes at 28.6 vdc) on OWS Bus 2. The only OWS bus loads active or enabled from launch on Day of Year (DOY) 134 until SL-2 activation on DOY 146 were ten water tank heaters (5 on each bus), the primary and secondary refrigeration systems (disabled prior to liftoff and enabled immediately following orbital insertion), and the ion pump in the M171 Metabolic Analyzer. The bus loads at liftoff agreed with the nominal prediction for the case of all water tank heaters operating and the other loads as noted.

The loss of the Meteoroid Shield approximately 63 seconds after launch and the resultant loss of the OWS Solar Array System Wing 2 at approximately 593 seconds did not directly impact the Electrical Power Distribution System. No electrical wiring or components, other than those associated with the two affected systems, sustained any damage and no transients or perturbations of any kind were observed on the OWS buses at the time of the incidents. Activation of the Airlock electrical power system was delayed until full deployment of workshop solar array Wing 1 on DOY 158, because the partially deployed solar array could not supply a significant amount of power to the spacecraft load buses.

Following orbital insertion the OWS bus currents increased at Refrigeration System activation to 20.8 amperes on OWS Bus 1 and 18.0 amperes on OWS Bus 2 which represents the maximum load experienced in the unmanned phase. Subsequently, the combined action of the water tank heater element and the OWS thermal environment raised the water temperature so that individual water tank heater elements started to turn off at launch plus 24 minutes and all ten were off by launch plus 4 hours 47 minutes. Subsequently, the loads remained at approximately 3.0 amperes on OWS Bus 1 and 1.0 ampere on OWS Bus 2 at 28.5 vdc until SL-2 crew activation on DOY 146.

After all attempts to deploy the OWS SAS by on-board sequence and ground uplinked commands proved unsuccessful, the Apollo Telescope Mount (ATM)/AM transfer relays were closed to allow the ATM Electrical Power System (EPS) to supply all power to the cluster. This was accomplished approximately 2 hours after launch. Subsequently, the

AM Power Conditioning Group (PCG's) were commanded off to prevent further depletion of the AM batteries and the cluster electrical systems remained in this configuration pending attempts by the SL-2 crew to deploy OWS SAS Wing 1.

Launch of SL-2, the first manned vehicle, was delayed until DOY 145, 11 days after the Skylab 1 launch. This added 10 days to the launch to activation phase. Thermal problems which developed as a result of the loss of the meteoroid shield required that the vehicle be maneuvered out of the normal solar inertial pointing mode to reduce internal temperatures in the workshop and maintain the integrity of the coolant loops, refrigeration system, food supplies, and film in the storage lockers. Each departure from the solar inertial pointing mode resulted in a reduction in ATM power system capability; therefore, the requirement to manage power for the required electrical loads became critical.

Power management procedures were initiated to ensure that demands on the ATM electrical power system would not exceed its capability. Since OWS loads during this period were constant and minimal, the OWS electrical power distribution system was not a large factor in cluster power management until after the start of OWS activation on DOY 146. Although rigorous cluster power management techniques were required for this time period, the ATM power capability was sufficient to supply the minimum load requirements at the various vehicle attitudes.

The OWS bus voltage levels for this time period remained substantially above the 24.8 volts required to insure a minimum input voltage of 24 vdc at each end item. The minimum voltage observed on the OWS buses during the entire launch, boost and unmanned phase was 27.4 vdc on both OWS Bus 1 and Bus 2. This occured at approximately launch plus 5 hours during maneuvers out of solar inertial attitude to alleviate OWS thermal problems. Subsequently, the OWS bus voltage remained above the nominal 28 volt level at approximately 28.5 vdc.

The OWS meteoroid shield mishap resulted in delayed activation of OWS systems until DOY 146 and then the requirement for rigorous power management prevented full activation. Capabilities of the OWS power distribution and control and display systems were used extensively during this period to achieve near-normal operation. Full activation of all OWS systems was not accomplished until DOY 159 when successful deployment of OWS SAS Wing 1 by the crew allowed activation of the AM/OWS Electrical Power System. The additional solar array capability of approximately 7,000 watts from OWS SAS Wing 1 allowed full activation of the AM Power Conditioning Groups and activation of all SWS systems. Subsequent cluster power margins relaxed the power management task until CSM fuel cell shutdown when the CSM became an additional load on the cluster power system. Fuel cell shutdown due to depletion of the reactants occurred on SL-2 Mission Day 22 (DOY 168), SL-3 Mission Day 20 (DOY 228), and SL-4 Mission Day 20 (DOY-339).

Although required after fuel cell shutdown for low beta angle conditions (minimum solar array power) and EREP pass orbits, power management at these times was not nearly as rigorous as in the early part of SL-2 mission prior to SAS Wing 1 deployment.

A. Circuit Protection - All of the circuit protection devices contained within the OWS (i.e., isolation diodes, circuit breakers, and fuses) performed as expected. The sizing of these components allowed sufficient power to be applied to all end-items operated during the SL-2, SL-3, and SL-4 missions while providing the necessary vehicle wiring protection. There were no cases of vehicle wiring/component damage attributable to inadequate and/or faulty circuit protection.

B. Power Transmission - Distribution of electrical power within the OWS was satisfactorily accomplished in the following respects:

1/ All of the distribution control devices contained with the OWS (i.e., switches and circuit breakers) performed properly during the mission. Circuit Breaker/switch positions were not altered by SL-1 boost vibration or by SL-2, SL-3, or SL-4 CSM docking loads.

2/ All power circuitry was successfully operated without incurring any short circuits or discontinuities.

3/ No static discharges were encountered by the crew (i.e., the crew did not receive any electrical shocks during operation of the electrical equipment).

4/ No EMI problems were evidenced with relation to the OWS portion of the Power Distribution System. It was observed, however, that the Van Allen Belt Dosimeter (VABD) installed in the OWS was affected by transients on the AM bus when the AM was supplying power to the Command Service Module (CSM). It was subsequently determined that the VABD was susceptible to conducted interference generated by a heater circuit in the CSM. Although VABD data was degraded, it was recoverable.

5/ Voltage drop in the power feeders from the AM Regulator (Reg) buses to the OWS buses was well within the anticipated band as noted below:

- Actual Mission Data

	SL-2 DOY 162	SL-3 DOY 214	SL-4 DOY 343
REG BUS 1 VOLTAGE	28.89 v	29.13 v	28.37 v
OWS BUS 1 VOLTAGE	28.50 v	28.64 v	27.94 v
Δv =	0.39 v (@ 14.1 amps)	0.49 v (@ 19.75 amps)	0.43 (@ 27.6 amps)
REG BUS 2 VOLTAGE	28.90 v	29.14 v	28.37 v
OWS BUS 2 VOLTAGE	28.50 v	28.77 v	27.94 v
Δv =	0.40 v (@ 13.1 amps)	0.37 v (@ 10.29 amps)	0.43 v (@ 23.2 amps)

- KSC Test Data

Δv = 0.60 v @ 15 amps (both Bus 1 & Bus 2)

6/ Power was supplied to the OWS by the AM at levels sufficient to maintain the voltage to each OWS end-item between the required limits of 24 to 30 vdc. The observed range of voltage on OWS Bus 1 and 2 was 29.36 vdc maximum and 26.08 vdc minimum from SL-1 launch through the end of SL-4 mission. The 29.36 volt level occurred on SL-3 and the 26.08 volt level occurred during the storage period between SL-3 and SL-4. Since the wiring design maximum voltage drop from the OWS bus to an end-item is 0.8 vdc, the terminal voltage at all end-items remained well above the minimum 24.0 volts at this bus voltage setting. At the beginning of the SL-4 mission, on DOY 321, the AM Reg. bus voltages were readjusted to an Open Circuit Voltage (OCV) setting of approximately 29.3 vdc.

In addition to maintaining the proper voltage level at the end-item, the bus current levels were always maintained below the maximum limit of 94 amps per bus (94 amps being the maximum allowable bus current which can be handled without tripping the 9 parallel 12 amp feeder circuit breakers, allowing for unbalance of resistence between the feeder lines). The maximum currents observed on OWS bus 1 and bus 2 were during the SL-3 mission and were indicated as being 43.3 amps and 34.5 amps respectively.

7/ The circuit breaker/switch guards provided adequate protection against inadvertent crew operation of these devices.

8/ All controls and displays successfully withstood the launch environment.

9/ Legibility of control and display panel markings, under lighting conditions encountered during the SL-2 and SL-3 missions, was adequate.

10/ During SL-3 and SL-4 missions, power was distributed from high power accessory outlets in the OWS forward compartment to loads in the Multiple Docking Adapter (MDA) via two 15 foot utility cables connected in series.

C. Anomalies - The following OWS EPS anomalies were encountered during the SL-1/SL-2 mission: (none encountered during the SL-3 and SL-4 missions).

1/ Loss of OWS Solar Array Wing 2 - The OWS Solar Array Wing 2 was physically and electrically separated from the vehicle during SL-1 orbital insertion. This resulted in loss of approximately one-half of the OWS Solar Array System (SAS) power generation capability which, at the start of the SL-2 mission, amounts to approximately 7,000 watts. This reduction in power capability caused some flight plan modifications to accommodate the power management requirements associated with the overall cluster EPS (e.g., allowable night average battery depth of discharge), under low beta angle conditions, Earth Resource Experiment Package (EREP) passes, etc.

2/ Delayed Deployment of SAS Wing 1 - Due to a portion of the Meteoroid Shield being partially deformed over the SAS Wing 1 Beam Fairing during the SL-1 ascent phase, SAS Wing 1 did not fully deploy when commanded at T + 40 minutes. This condition, coupled with the complete loss of Wing resulted in the cluster power generation capability being cut virtually in half (i.e., the only source of power generation remaining was the ATM solar array). This condition remained until the crew manually deployed Wing 1 via Extra Vehicular Activity (EVA) on Mission Day 14 (24 days after SL-1 launch). The delayed deployment of SAS Wing 1 did not degrade the performance of the solar cells, which immediately started to generate power upon deployment.

3/ Below Nominal Solar Array Group (SAG) #4 Current Indication - Upon comparing SAG 4 current reading to the other 7 SAG current readings it was noted that it always indicated 3 to 6 amperes low. However, a check of SAG 4 performance has revealed that its power generating capability is equivalent to any of the other 7 SAG's. Therefore, the low current reading on SAG 4 has been attributed to a possible short to structure of the SAG 4 return wires, which would allow return current to bypass the Airlock Module current shunt while not degrading the performance in any way. The most likely area for this short is the point at which the SAS Wing 2 wire harness was severed. A short of this type does not impact the cluster electrical system because the positive leads are protected by isolation diodes in the SAS power modules.

4/ Internally - Mounted Components - Due to the loss of the Meteoroid Shield during the S1-1 boost phase, the predicted temperature profiles for the internally-mounted electrical components were no longer valid. The direct exposure of the vehicle skin to the sun's rays resulted in the internal temperatures exceeding the anticipated levels by a significant factor (internal component temperatures as high as +225°F, which is 107°C). Although these high temperatures actually exceeded the component qualification temperatures in many cases, the components were not thermally overstressed since their inherent design capability, based on temperature ratings at the piece-part level, would permit continuous operation at 257°F (125°C). The only exception to this statement is the thermal susceptibility evidenced by the anomalous operation of one fire sensor (located on the "hot" side of the vehicle) and the Duct #1 flow measurement (which is also located on the "hot" side of the vehicle).

5/ Externally-Mounted Components - From the thermal standpoint, loss of the Meteoroid Shield did not affect the temperature of equipment located in the forward or aft skirt areas except for a slight temperature rise (i.e., 10 to 15 degrees) on one aft skirt panel during vehicle attitude maneuvers which were performed to lower the internal temperature. In general, all skirt mounted components remained within their predicted temperature profiles.

6/ Caution and Warning Low Voltage Alarms - On DOY 153, Caution and Warning low voltage alarms were initiated simultaneously for OWS Bus 1 and Bus 2. Examination of the OWS bus voltage displays did not indicate that a low voltage condition actually existed. Subsequent investigation by the crew revealed that both of the Low Voltage Sense circuit breakers on Panel 614 were in the OPEN position. Further data evaluation confirmed that there were no bus voltage anomalies or Caution and Warning System anomalies that could account for a low voltage caution alarm being initiated. The most probable cause was attributed to the inadvertent opening of the Low Voltage Sense circuit breakers by the crew while intending to open the two immediately adjacent circuit breakers (i.e., the Display Power/Recorder Control circuit breakers). The crew subsequently reset both Low Voltage Sense circuit breakers, re-enabled the corresponding Caution and Warning System monitor circuits, and the system functioned normally. No further anomalies were noted during the remaining 20 days of manned operations.

.2.6.5 Conclusions and Recommendations

A. Conclusion - Performance of the OWS Power Distribution System, since the launch of Skylab 1, has been adequate. The subsystem has performed as designed and its operation during the mission has verified the data obtained in checkout/analysis to be very close to actual mission conditions (reference 2.2.6.4 - Mission Results).

B. Recommendations - In review of the various subsystem problems and crew comments obtained during the mission, the following modifications/improvements are presented for consideration.

1/ One-for-one ground control capability for every voltage sub-bus (enable/disable via Digital Command System).

2/ Voltage and current telemetry (T/M) parameters for every sub-bus.

3/ High resolution for all T/M current/voltage parameters (i.e., if range is 0-140a, provide a low and high range measurement).

4/ Provide multi-scale meter (range selection switch) for on-board voltage and current measurements.

5/ Provide local power ON/OFF control at all utility outlets. This was the subject of an ECP requested by the crew, but was too late for incorporation.

6/ Provide more utility (LO/HI) power) outlets.

7/ Provide circuit breakers that are not easily (inadvertently) activated/deactivated (improved toggle guards or different type toggles).

2.2.6.6 Development History - The final configuration of the Power Distribution and Control System was the culmination of many "in-house" and customer design review meetings.

The design concepts were presented at Electrical Subsystem design review meetings which were chaired by MSFC and co-chaired by MDAC representatives. After the design concepts and guidelines were firmly established, the design was finalized and presented for review at formal meetings for the NASA intercenters (MSFC and Johnson Spece Center). The intent of the meetings, which were identified as Preliminary Crew System Reviews (PCSR's), was for the Skylab crew members and/or their representatives to critique the design. Many of the crew member's requested design modifications were implemented, and the system design from that point in time was firmly established. The following synopsis identifies several of the design trade-offs conducted during the conceptual and requirement definition phase of the system design period.

A. Two Wire Single Point Ground - A "one wire" system utilizing the vehicle structure as the current return path was initially considered. This concept routed all end-item returns (except for instrumentation) via the shortest route to the vehicle structure or to grounding plates which in turn were electrically connected to vehicle structure.

   The two wire single point ground concept routed all end items back to the power source return and then connected the power source return to the vehicle structure at a single point.

Both concepts had been utilized on various spacecraft and booster stages. Features of both systems were identified and presented to NASA with the two wire single point ground being selected as the final design requirement.

B. Parallel Feeders (Stiff Bus) - The AM was baselined to provide power to the OWS.

A sub-bus concept was considered as the means for distributing this power. This design provided for the AM to supply the OWS with nine (9) 12 ampere rated/protected sub-buses from each of the AM regulator buses. The OWS would then distribute the sub-bus power to the OWS end-items. Each end-item would have individual circuit protection as well as the capability to be power (switched) from either regulator bus.

The parallel feeder concept connected all of the nine AM supplied 12 ampere protected feeders electrically together in the OWS to provide a "stiff bus" or one main bus for each of the AM regulator buses. The power was then to be distributed and protected in the same manner as the sub-bus concept.

Both concepts were presented and MSFC selected the "stiff bus as the final design requirement.

C. Parallel Conductors for the AM/OWS Power Feeders - One of the basic requirements imposed upon the OWS system was to limit the voltage drop (line loss) from the AM/OWS interface to any OWS end item to 1.5 (round trip).

This requirement, in addition to the space environment derating consideration, dictated the amount of copper required for any given load.

Sufficient copper could be provided by paralleling small gauge wires or by utilizing one large conductor.

A basic constraint upon the initial design (wet Workshop) was to use existing qualified hardware. The largest feedthru receptacle qualified for the "wet" Workshop environment was 12 gauge. Therefore, the parallel conductor concept was selected.

"Utilize existing qualified hardware" was still the theme when the OWS was converted from "wet" to a "dry" launch configuration. In order to comply with the basic 1.5 line loss limitation and existing qualified hardware, three (3) number 12 gauge parallel conductor was baselined for each feeder circuit (9 feeder circuits per "stiff" bus) and 36 parallel number 12 gauge conductors for the common return bus.

D. Power Distribution and Control Console - The Power Distribution and Control console for the "wet" Workshop consisted of two enclosed "drag-on" panels (one circuit breaker panel and one control and display panel).

The panels were to be stowed in the AM for the launch and would be installed on orbit, by the crew on the "wall" of the OWS.

The crew would then connect the pre-installed wire harness connectors to the panels.

The conversion from a "wet" to "dry" Workshop resulted in a complete redesign of the "wet" Power Distribution and Control Console. All of the system components could now be hard mounted within the OWS prior to launch.

A console was developed within which the system electronic modules, circuit breaker panels, and control and display panels would be installed. However, the wet to dry conversion also resulted in more systems, and more sophistication. The final number of console mounted panels were 5 circuit breaker panels and 2 control and display panels. The circuit breakers, switches, and display arrangement was finalized after the last PCSR meeting (mid-year 1971).

In addition to the console mounted panels, four (4) "remote" control and display panels were baselined. One each for the waste management compartment, wardroom, forward compartment and experiment compartment. The "remote" panels provide for local crew control of functions which would be cycled many times during the mission. By providing the controls in the area of usage, traffic to and from the power distribution and control console would be considerably reduced.

E. Cable Routing, Separation, Protection - The original OWS internal wire harness (W/H) installations concept was to route wiring in as many "hidden" areas as possible, i.e., install wire harness inside structural members, behind cabinets or experiments, or in any manner that would preclude the possibility of crew contact. Lightweight, protective covers were to be used in areas where it was impossible to "hide" the wiring. These covers would utilize the same pickup points as the clamps for attaching the wiring. The cable routing allowed for physical separation required to maintain EMI control.

After MSFC-SPEC-101A (flammability) was imposed as a CEI requirement, much effort was expended to determine materials and methods to meet the 101A requirements. The following highlights the development history.

1/ Investigation and evaluation of available materials and methods to meet flammability requirements. This effort included:

- Determining availability of new materials for connector sealing grommet, wire insulation, and clamp cushions;
- Determining the available materials for wrapping or enclosing the W/H's and attach clamps;
- Determining methods of protecting the W/H's if suitable insulation materials were unavailable;
- Determining affects of the above approaches on engineering deisgn, manufacturing operations and schedules.

2/ Selection of a design approach that combined the best of all elements. This resulted in an enclosed, compartmentized, metal trough for main routing paths and a new "state-of-the-art," material (Raychem NBG) in the form of convoluted tubings for localized breakouts to end-items.

3/ Redesign of all wire routing paths. This effort included:

- o Selecting routing paths that were more direct;
- o Gathering of as many W/H's in one trough as possible to minimize weight increase;
- o Sizing trough and trough compartments in order to standardize parts;
- o Sizing of convoluted tubing to standard parts.

4/ Redesign of the Electrical Power, Display, and Control Console (EPD&C) for the purpose of compartmentizing the wiring for flammability considerations.

5/ Several key factors led to the final selection of the trough and tubing design:

- o Unavailability of a qualifiable wire insulation and connector sealing material that would meet the stringent requirements of 101A.
- o Selection of the best alternate flammability protection method that minimized design effort while favoring manufacturing fabrication, installation, and maintenance effort;
- o Selection of a design that would fit within established design and manufacturing schedules.

The resulting flammability and physical protection resulted in a significant increase in design and manufacturing effort. However, two major advantages were achieved. One was better EMI control of the wire harnesses through the use of the continuous metallic barrier afforded by the compartmentized trough. Another, was the reduction in the number of routing paths and attach points that would be required in the tank wall insulation.

F. Utility Outlets - Extension Cables - The final number and loca- of the utility outlets was baselined as a function of the PCSR meetings. In general, they were located by anticipated/planned usage of the portable equipment (vacuum cleaner, fans, lights, cameras).

After the outlet locations were baselined, the length requirement of the extension cables was determined. The requirement to provide for vacuum cleaning and lighting coverage for the total volume within the OWS including the plenum area and still provide for ease of stowage resulted with the optimum length for each cable as being 15 feet.

G. Zero G Connectors - The basic design concept for the wet OWS was that all wire harnesses would be pre-installed and that all electronic equipment which could not withstand the liquid hydrogen cryogenic temperature environment would be "drag-in" or crew installed items. The "drag-in" concept coupled with a potential hazardous atmosphere dictated the use of a connector that provides:

- Ease of operation:

  Could be operated (connected/disconnected) with one gloved hand under zero-G conditions.

- Safe:

  Precluded hazardous condition due to arcing when connected/disconnected under load.

These two basic considerations resulted in several design concepts and proposals. Several companies submitted design concepts. One concept utilized a fixed pin on the receptacle to actuate a microswitch within the connector which then energized a relay which in turn completed the electrical circuits in the connector. The design that was finally selected was submitted by Bendix and the resulting connector was baselined for the wet workshop. A basic requirement for the conversion from "wet" to a "dry" OWS was to utilize all applicable "wet" hardware. Therefore, the "dry" OWS retained the "wet" zero-G connector for those end-items which would still require the crew to connect/disconnect.

2.2.7 Illumination System

2.2.7.1 Design Requirements

A. General Requirements - An illumination system was provided in the Orbital Workshop (OWS) for use during habitation periods. The interior lighting system shall be provided to allow for normal and emergency crew activities, and experimental operations.

- o General Illumination Lighting: General illumination lights were provided in the forward compartment and crew quarter compartments.

- o Initial Entry and Emergency Lighting: A low level lighting system was provided for use during initial entry operations and for emergency egress.

- o Auxiliary Lights: A supplemental illumination level of not less than 20 foot candles (215.3 lumens/square meter) at work surfaces shall be provided for crew operations requiring reading, writing, and experimental tasks.

B. Detail Requirements

1/ Common Electrical Requirements - Requirements imposed on the Illumination System such as flammability, contamination, grounding, bonding, etc., which are imposed on all electrical subsystems, are as stated in paragraph 2.2.6.

2/ General Illumination Lighting Requirements - An interior illumination system shall be provided in the OWS for use during habitation periods. The lighting system shall be provided to allow for normal, experimental operations and emergency crew activities in the forward compartment and crew quarter compartments.

a. Controls - The lights shall be capable of being controlled from either the light assembly or the power control panel. Any light which has more than one control switch, excluding the switch on the light assembly, shall be capable of ON-OFF control independent of the other switch positions. One light in the Waste Management compartment and sleep compartment shall be capable of being turned on from the doorway. The lights in the sleep compartment shall be located such that at least one light shall be capable of being turned on and off from any sleep restraint. A switch shall be provided on the light assembly to allow OFF-LOW-HIGH control of the light intensity. The LOW position shall simultaneously lower the light power consumption.

b. Illumination Levels - The lights shall provide the following average illumination levels:

Area	Foot Candle (Minimum)
1 - Sleep Compartment	4.5 (48.4 lumens/sq. meter)
2 - Wardroom	5.0 (53.8 lumens/sq. meter)
3 - Waste Management Compartment	9.0 (96.9 lumens/sq. meter)
4 - Work Experiment Compartment	5.5 (59.2 lumens/sq. meter)
5 - Forward Compartment	1.0 (10.8 lumens/sq. meter)

The foot candles specified for the forward compartment shall be an average illumination level 3 feet (0.9 meter) from the light source. In the crew quarters the illumination level is measured 3 feet (0.9 meter) from the ceiling with the experiments installed in the operating mode.

Brightness ratios shall not exceed:

1 - 10:1 between task areas and remote surfaces

2 - 20:1 between light source and immediately adjacent surfaces.

3 - 3:1 between task areas and immediate surroundings

c. Replacement - Light assembly design shall meet the following requirements for the purpose of replacing lights:

1 - one hand replacement under zero-gravity (g) conditions.

2 - utilize a pigtail type connection.

d. Life - The light assembly shall meet minimum life cycle requirements for one 28-day and two 56-day habitation periods over an eight (8) month mission span. The required levels for light assembly are 4,500 hours service life and 800 start cycles.

e. Operation - The light assembly shall provide standard cool white light as defined by coordinates on the chromaticity diagram in MIL-M-25050, and shall produce no noticeable flicker or undesirable audible noise during startup or operational mode. The maximum start time shall be two seconds where start time is defined from switch activation to lamp lighting.

f. Temperature Deviations - The OWS internal surface temperature variation to the touch temperature requirements of 55°F (12.8°C) to 105°F (40.6°C) will be as follows:

Equipment	Calculated Maximum Temperature (°F)
Interior Light Housing (assembly grid enclosing light)	123 (50.6°C)

3/ Initial Entry and Emergency Lighting Requirements - Initial entry and emergency lighting shall be provided in the OWS for use during initial entry operations and for emergency egress. The low level lighting system is required to aid the crewman in locating and recognizing controls, e.g., power distribution, panel handles, handrails and hatches.

a. Controls - These lights shall be electrically controlled from the AM via a circuit which shall bypass the OWS circuit breakers, control switches, and the switch on the light assenbly.

b. Ilumination Levels - The low level lighting system shall provide an average illumination of 0.5 foot candles (minimum) (5.4 lumens/square meter) in the crew quarters and forward compartment.

2.2.7.2 System Description

A. System Configuration - The OWS Illumination System configuration is comprised of the components listed in Table 2.2.7.2-1. The items not listed are the Power Distribution equipment such as cable harnesses, matrix blocks, electrical panels, etc. which have commonality in design with other system uses. The list includes the portable auxiliary lights which are powered with utility cables from outlets.

B. Functional Description

1/ General Illumination - The OWS contains 42 floodlights for internal illumination (Figure 2.2.7.2-1)--eighteen in the forward compartment with eight (8) lights on the forward dome and ten (10) lights around the upper walls, four (4) in the wardroom, three (3) in the Waste Management compartment (WMC), three (3) in the sleep compartment, and fourteen (14) in the experiment compartment. To identify the light's location for the dome and upper wall lights in the forward

Table 2.2.7.2-1

ILLUMINATION SYSTEM COMPONENTS

ITEM	PART NUMBER	QUANTITY
Housing Assembly, Interior Light	1B75486-1	42
Housing Assembly, Portable Light	1B77441-1	3
Floodlight, General Illumination	1B69364-501	
Installed in Interior Light Housing Assembly		42
Installed in Portable Light Housing Assembly		3
Available as Spares (Stowed)		6
Portable High Intensity Photo Lamp	95M10750-1	2

compartment, the floodlight number is marked on the housing hinged cover. For the crew quarters light installation the housing has marking numbers on the integral light switch plate and on the opposite end plates. These floodlight numbers correspond to the nomenclatures on the remote light switch panels 616 and 630 (Figures 2.2.7.2-2 and 2.2.7.2-3) and on the circuit breaker panel 613 (Figure 2.2.7.2-4). In addition, red stripe marking is used on the hinged cover for floodlights used for initial entry and emergency purposes.

The OWS general illumination lights are controlled from the remote light switches on Panel 616 and 630. The dome lights, upper wall lights, and experiment compartment lights may be turned on by combinations for each area through the lighting

SKYLAB - ORBITAL WORKSHOP
OWS FLOODLIGHT LOCATIONS AND MARKING

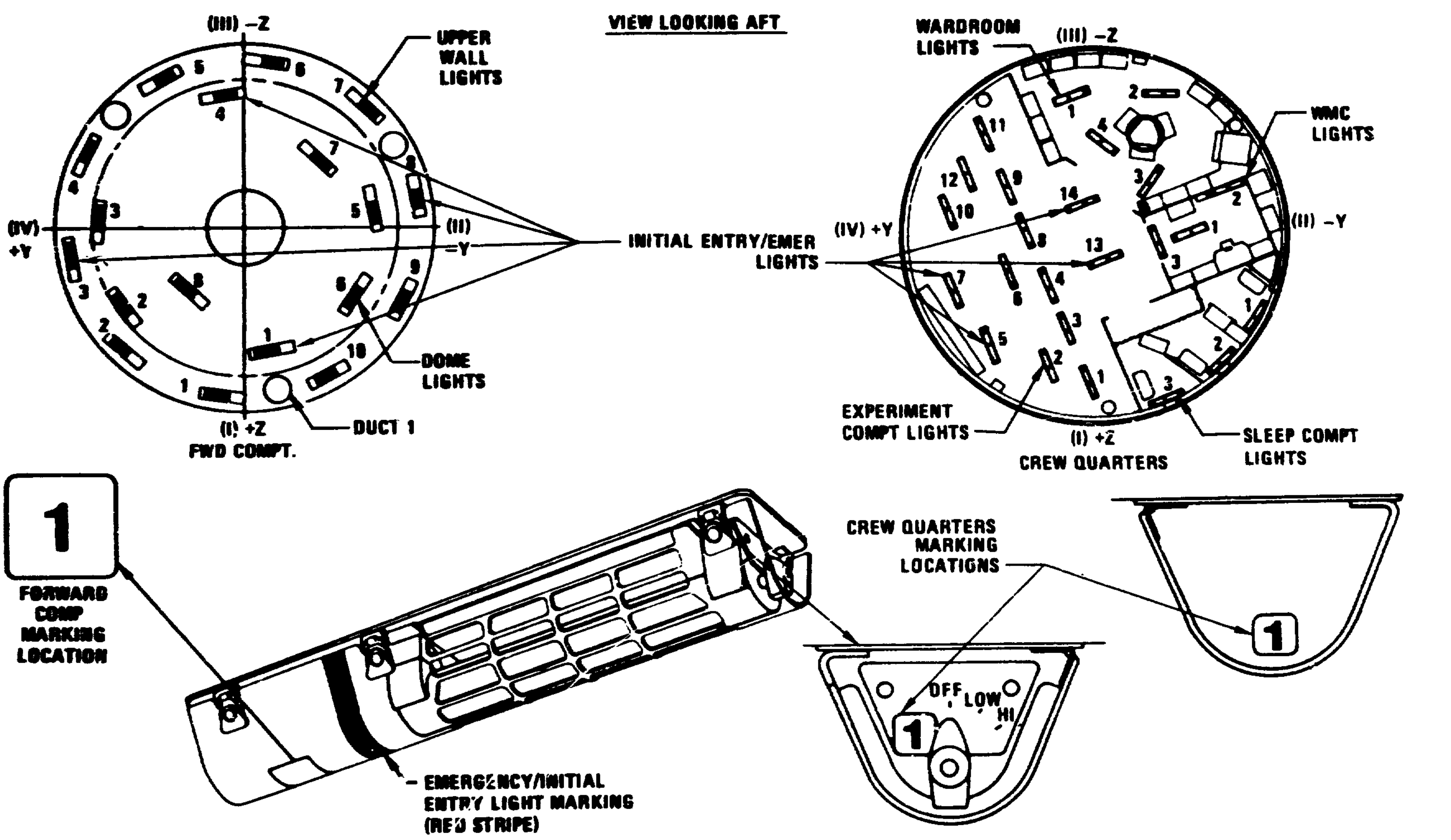
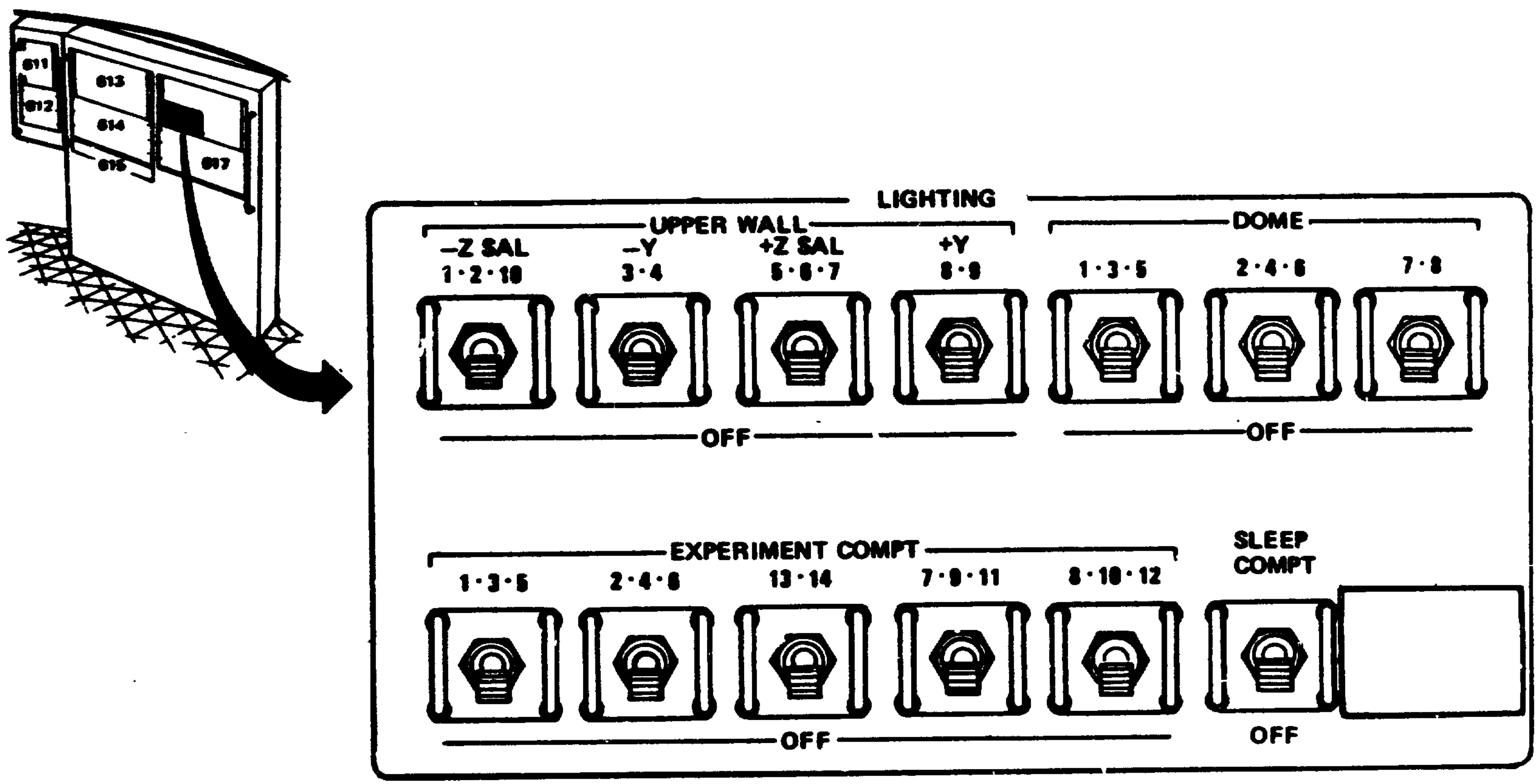


Figure 2.2.7.2-1

SKYLAB - ORBITAL WORKSHOP
REMOTE LIGHTING SWITCH PANEL 616



SKYLAB - ORBITAL WORKSHOP
REMOTE LIGHTING SWITCH PANEL 630

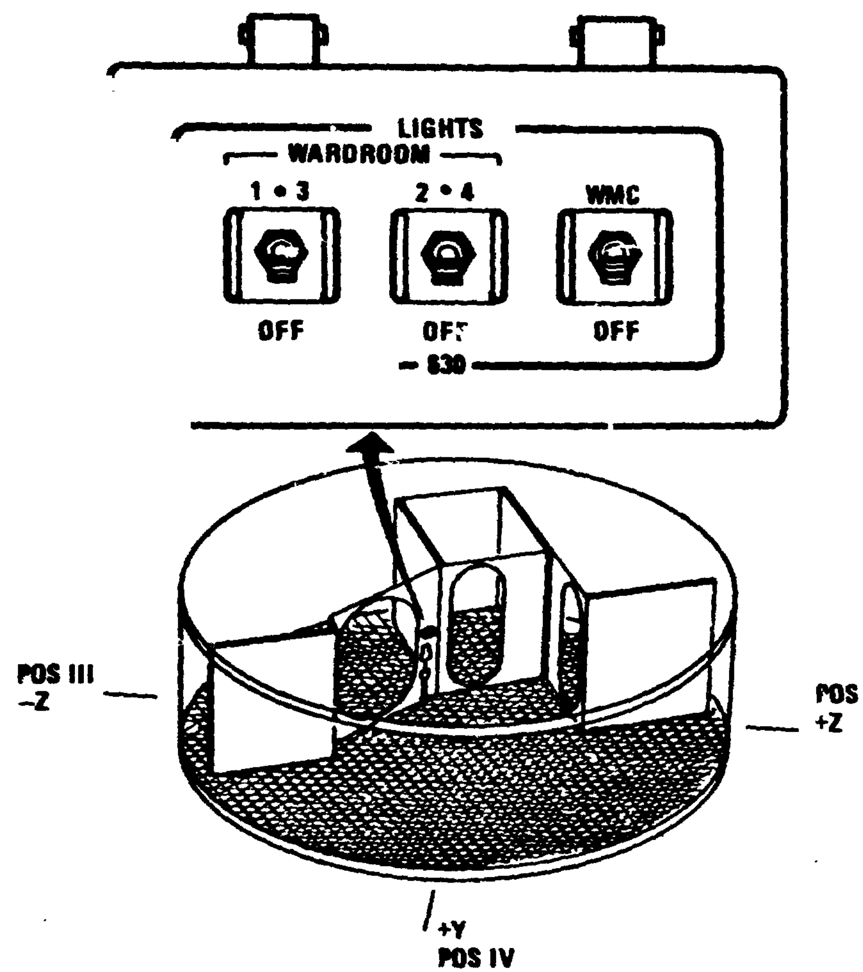
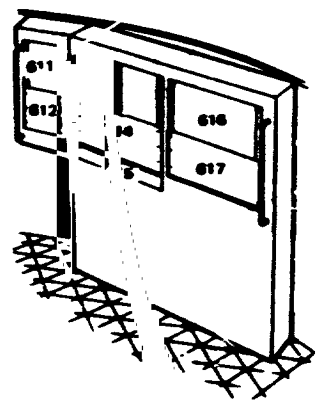
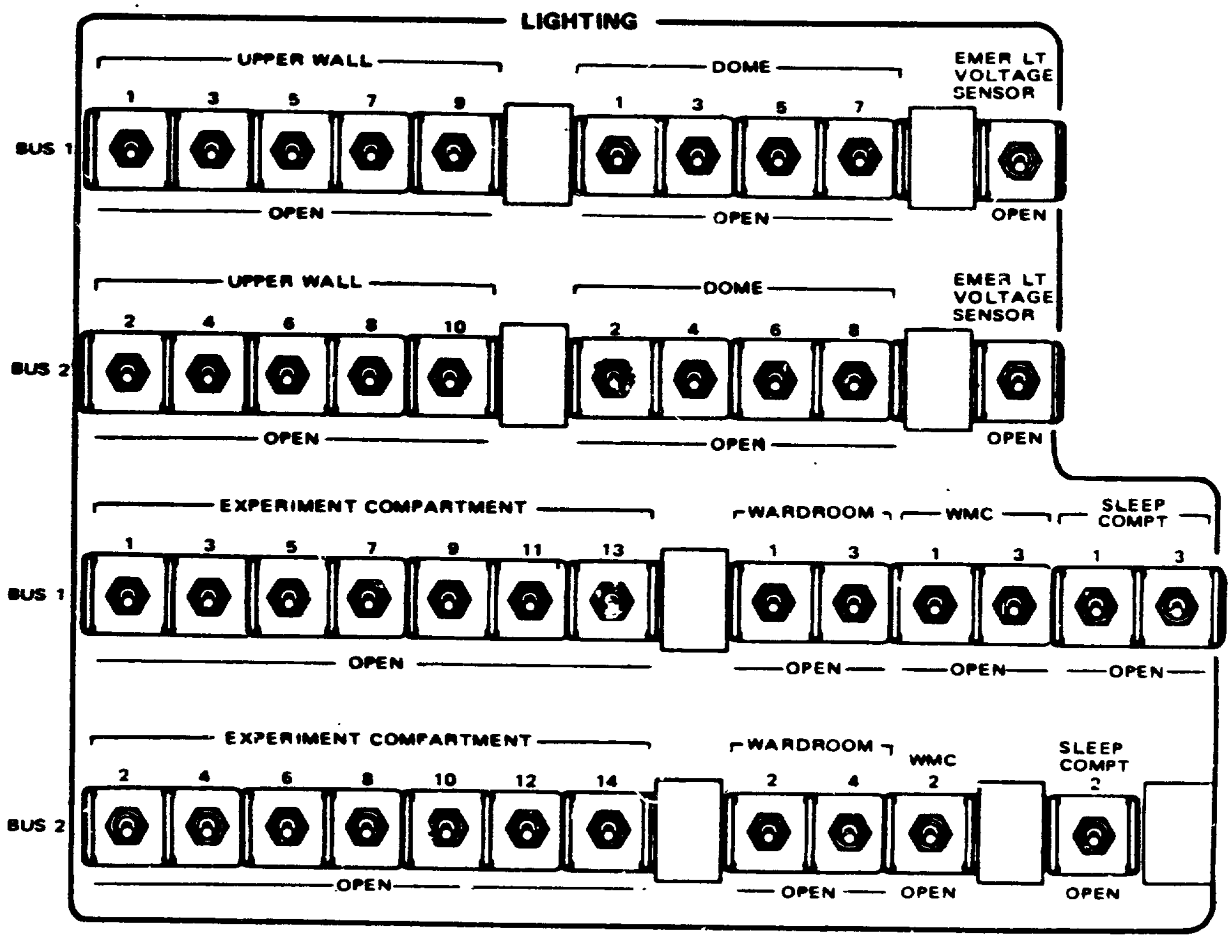


Figure 2.2.7.2-3

SKYLAB - ORBITAL WORKSHOP
CIRCUIT BREAKER PANEL -613 LIGHTING





dome switches, upper wall switches, and experiment compartment switches on Panel 616. In addition, Panel 616 provides simultaneous remote switch control of all sleep compartment lights through a single lighting sleep compartment switch. Panel 630, located on the experiment compartment partition between the wardroom and the WMC, provides remote control of the wardroom and WMC lights. The wardroom lights may be turned ON in pairs through the wardroom switches on Panel 630; all WMC lights may be turned ON simultaneously by the single WMC switch on Panel 630. The remote switches for the OWS lights will control their respective floodlights, providing the appropriate circuit breaker is closed and the floodlight's integral switch is set either on HI or LOW. Placing the integral light switch to OFF disables that floodlight from being controlled by any remote switch. The low position on the integral light switch provides for a low-intensity illumination of the OWS during power management periods as required.

2/ Redundancy - Lighting redundancy is provided in the OWS by powering approximately half of a given area's lights from OWS Bus #1 and half from OWS Bus #2. The even-numbered lights are powered from OWS Bus #2 and odd-numbered lights from OWS Bus #1.

3/ Initial Entry/Emergency Lighting - During OWS manned activation, or emergency, a light system is provided to control the following eight (8) floodlights: Dome 1, Dome 4, Upper Wall 3, Upper Wall 8, and Experiment Compartment 6, 7, 13 and 15 floodlights. These floodlights will illuminate, regardless of the position of their remote or integral light switch. However, the light intensity varies with the integral light switch positioning, i.e., low intensity at OFF or LOW mode and highest intensity at HIGH mode.

a. Initial Entry Lighting - Entry lighting is controlled by a single OWS entry (on-off) switch on the AM aft compartment panel 390. This switch controls the eight (8) OWS floodlights designated for initial entry and emergency. The entry switch supplies Airlock Module (AM) Electrical Power System (EPS) Buses #1 and #2 power directly to the entry lights where normal power source is disengaged. A relay interlock control prevents power sharing from the normal bus source while the EPS control power is present and powering the floodlight. After activating general lighting, the entry switch is turned off which removes the EPS power and restores the interlock for normal operation of the lights.

The crew uses the OWS entry lights during activation upon opening the OWS hatch, and during deactivation for the storage reconfiguration of the OWS internal lights.

b. Emergency Lighting - During normal operation, the lights in the OWS are assigned to buses so that a loss of a single distribution bus will not disable any more than half the lights in a given area. Illumination in this case is degraded, but adequate for crew operation to continue satisfactorily. If both buses that supply power to the lights within the OWS fail simultaneously, an emergency lighting network will automatically activate and supply EPS power to the floodlights designated as initial entry and emergency lighting.

The OWS buses 1 and 2 are continuously monitored for proper voltage level by the AM low voltage sensors in the emergency lighting network. If the voltage level for both OWS buses 1 and 2 decays below 23 vdc, the voltage sensors will activate the network to provide EPS buses 1 and 2 power to the designated emergency OWS floodlights. EPS power is applied directly and similarly as in the initial entry operation and illuminates the lights to either low or high intensity, depending on the integral switch position. The normal bus power source is automatically isolated by an interlock relay whenever EPS power is present and powering the emergency lights. When either failed bus increases above 23 vdc, the low voltage sensor deactivates the network and removes EPS power from all emergency lights, enabling the auto matic isolation interlock to return the floodlight power source back to the normal bus.

Eight (8) OWS floodlights are used as the emergency (or entry) lights with half on each bus system for redundancy. The emergency lights in the OWS dome and on the upper wall provide illumination of the OWS forward area and illuminate the translation route between the crew quarters and the AM aft compartment. The emergency lights in the experiment compartment provide general contingency illumination of crew quarters and illuminate the egress opening at the experiment compartment ceiling and the electrical control console.

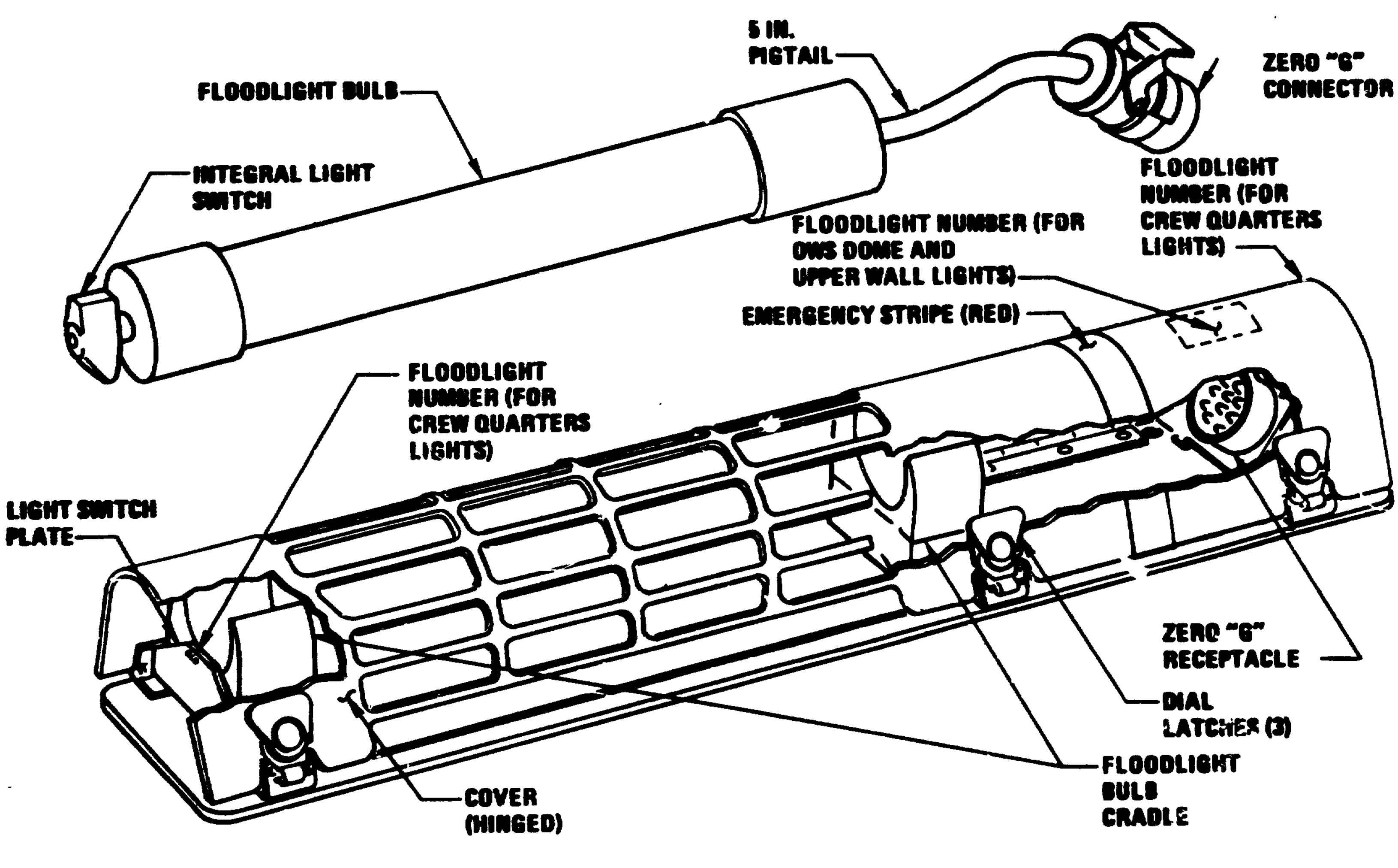
4/ High Intensity Light - Two portable high-intensity lights are provided for tasks requiring high illumination. Each high-intensity light contains four (4) permanently installed fluorescent lamps. The four (4) fluorescent lamps are separated for dual system control, with two (2) lamps assigned to system 1 and the remaining two (2) lamps assigned to system 2. Each system may be operated in one of two (2) illumination modes, high or low, through system switch controls mounted on the high intensity light. Either mode uses both lamps but each system's circuit is designed such that the low mode emits a two-lamp illumination with 40 watts power consumption while the high mode will emit a two-lamp illumination of 75 watts. A single power switch, mounted adjacent to the system control switches, provides power to operate system 1, system 2, or both. Over-temperature protection is provided in the event extravehicular activities require high-intensity lighting. If an overtemperature condition occurs, a thermostat will close and interrupt the power supply to the system 2 lamps, extinguishing the lamps. After the thermostat is allowed to cool to its open setting, the crewman may reapply power to the system 2 lamps by momentarily positioning the thermal protect switch to reset.

Each high intensity light contains a 12-inch (0.3 meter) pigtail for use at any high power accessory outlet. High power accessory utility cables provide additional extension capabilities.

5/ Construction

a. Floodlight - The floodlight housing has a protective hinged cover that permits access for bulb replacement (Figure 2.2.7.2-5). The replaceable bulb includes an integral hi-low-off switch and a pigtail with a zero-g connector. The bulb (Figure 2.2.7.2-6) is comprised of a fluorescent lamp and an electronic package. The lamp (Figure 2.2.7.2-7) is enclosed in a Lexan tube filled with Sylgard silicon resin. A chemically tempered glass tube surrounds the Lexan tube and is coated with translucent teflon to prevent fragmentation and migration of the glass in the event of breakage. The electronic package is enclosed and encapsulated in the aluminum tubular section of the bulb.

SKYLAB - ORBITAL WORKSHOP
FLOODLIGHT ASSEMBLY DETAIL



SKYLAB - ORBITAL WORKSHOP EXPLODED FLOODLIGHT ASSEMBLY

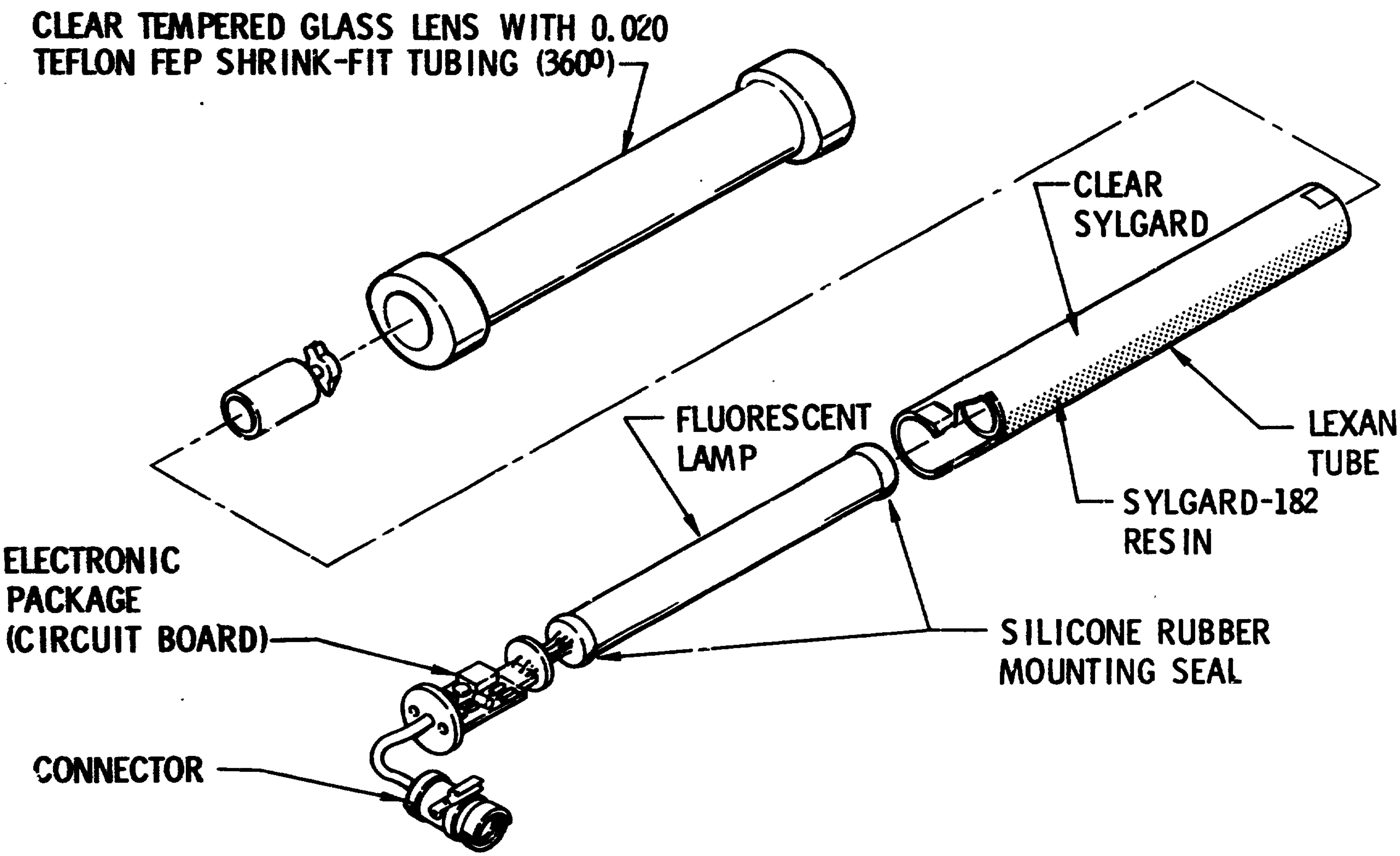


Figure 2.2.7.2-6

FLOODLIGHT CROSS SECTION

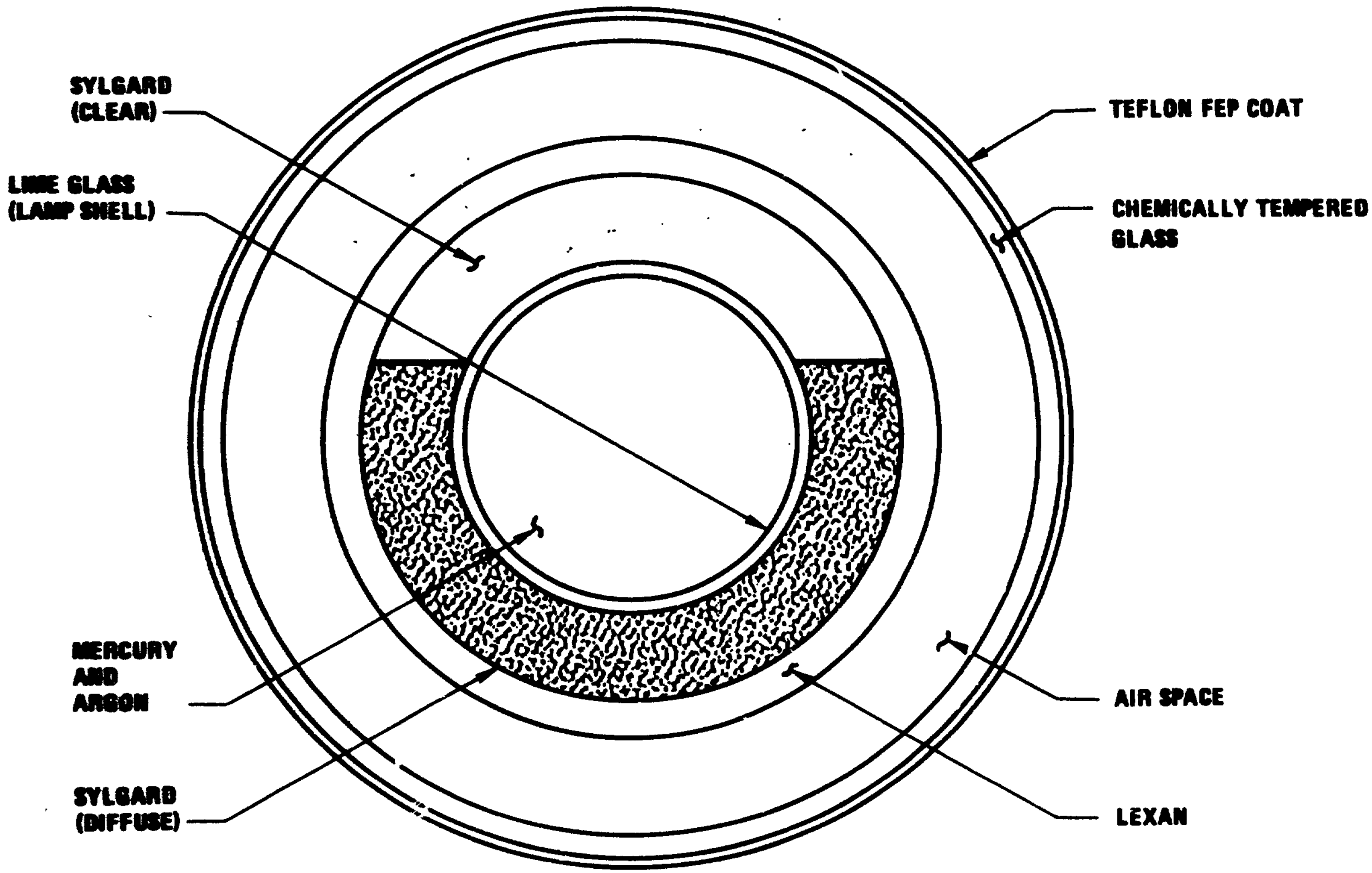


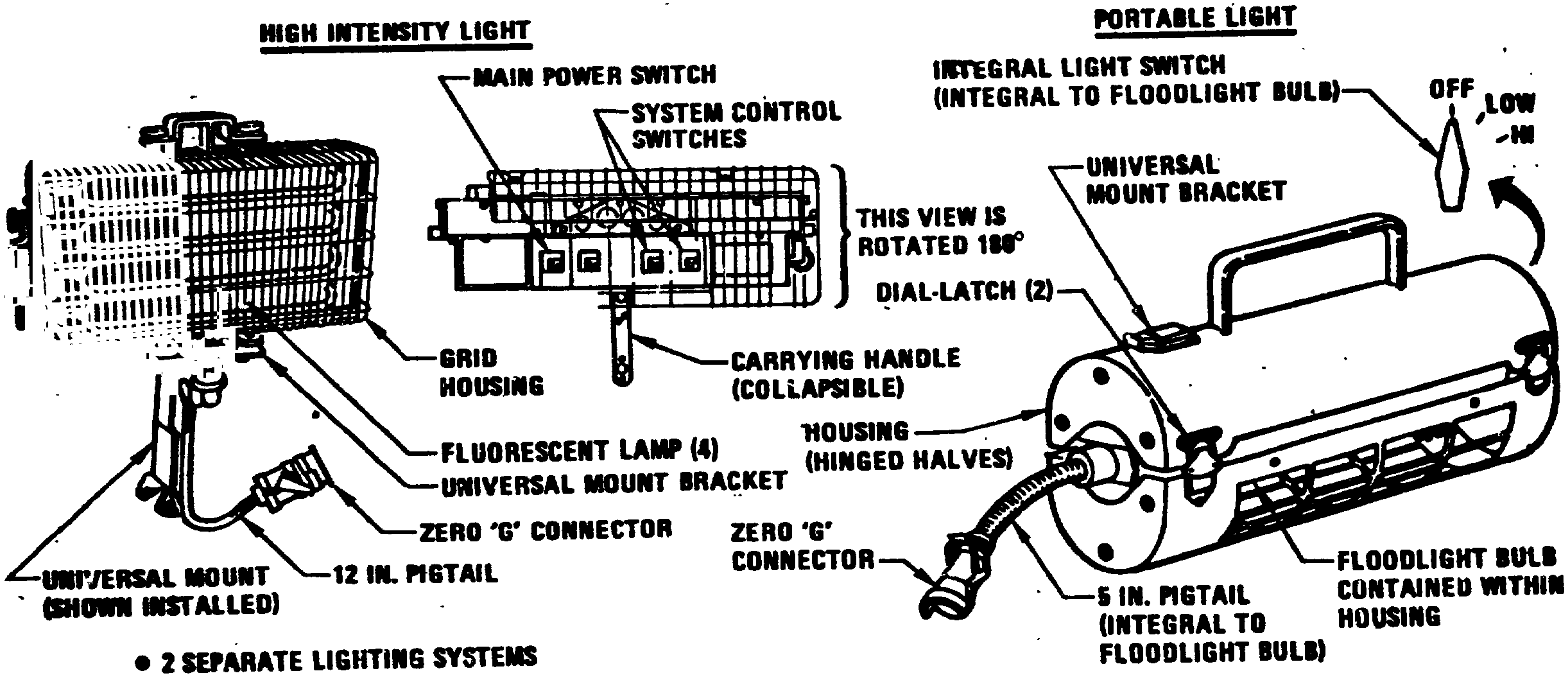
Figure 2.2.7.2-7

b. Portable Lights (Figure 2.2.7.2-8) - The portable light is a housing with a carrying handle and includes a floodlight bulb. The housing is hinged and secured with dial-latches to permit access to the floodlight bulb. The housing is also fitted with a universal mount bracket to permit utilizing the universal mount on a convenient structure.

c. High Intensity Lights (Figure 2.2.7.2-8) - The high intensity portable light contains four (4) permanently installed fluorescent lamps, protected by a grid housing. The grid housing is fitted with a collapsible carrying handle and a universal mount bracket to permit installation on a convenient structure.

6/ Utilization of Portable Lights - The portable lights (floodlights and high intensity) can be connected to any convenient utility outlet in the Saturn Workshop (SWS) for floodlight power. The 15-foot (4.5 meters) utility cables can be used as extensions to allow the portable lights to be used in remote locations of the SWS or for Extra Vehicular Activity (EVA).

SKYLAB - ORBITAL WORKSHOP
PORTABLE LIGHTING



HIGH INTENSITY LIGHT

- 2 SEPARATE LIGHTING SYSTEMS
- 4 PERMANENTLY INSTALLED FLUORESCENT LAMPS WITH 2 LAMPS/SYSTEM
- INTEGRAL SWITCH CONTROL HIGH-MODE 75 W AND LOW-MODE 40 W PER SYSTEM
- OVERTEMPERATURE PROTECTION PROVIDED (SYS 2)
- 2 STOWED
- POWERED FROM ANY HI-PWR ACCESSORY OUTLET

PORTABLE LIGHT

- 1 REPLACEABLE FLOODLIGHT BULB
- INTEGRAL LIGHT SWITCH CONTROL HI-12.5 W AND LOW-10.0 W
- 3 STOWED
- POWERED FROM ANY UTILITY OUTLET
- LAUNCHED WITH A FLOODLIGHT BULB INSTALLED

2.2.7.3 Testing

A. Test Programs

1/ Qualification Testing

a. Purpose - Qualification testing was performed on production light assemblies to demonstrate that design and production methods result in a product which fulfills the design requirement established for use.

b. The qualification testing of the general illumination light was done in two separate line items, IS-1 and IS-7. The second test, IS-7, was performed after a redesign/reconfiguration of the high-low switch circuitry of the lamp electronics. The line item tests validated the design requirements with regard to the following type stress or environment; vibration, acoustical noise, life cycles, high and low temperatures, humidity, and Radio Frequency Interference/Electromagnetic Interference (RFI/EMI). In addition, electrical characteristics and illumination levels (component) were verified by IS-1.

2/ Vehicle Checkout Laboratory/Kennedy Space Center (VCL/KSC) Integrated Testing

a. Purpose - The purpose of these tests were to assure that the distribution of light within the spacecraft is (1) adequate (illumination in terms of foot - candles) to meet the requirements defined in Contract End Item Specifications; (2) contrast ratios are correct and compatible with various assembly end items; and

(3) properly controlled switches and circuit breakers correctly apply/interrupt power from the designated power bus. The Test and Checkout Procedures served to correlate actual subsystem parameter measurements (illumination levels and contrast ratios and subsystem output) as they related to spacecraft display/controls under ambient and emergency/initial entry conditions.

b. Summary of Completion - The tests were performed per the requirements of Acceptance Test Procedure 1B83586 "A" Revision, Illumination Subsystem, OWS and KS-0045 AM Multiple Docking Adapter (MDA)/OWS end-to-end system test and experiment test. Completion of the tests verified the adequacy of the OWS Illumination Subsystem design to effectively control and provide illumination within the various areas of the spacecraft.

B. Test Anomalies and Solutions

1/ Qualification Testing

a. Line Item IS-1 - Five (5) general illumination lights were subjected to the environments as specified:

	S/N 005	Failure Analysis S/N 002	Failure Analysis S/N 057	Specimen #1 (Hardmount) S/N 059	Specimen #2 (Shockmount) S/N 004
Pre-Functional	X			X	X
Low Temperature (Non-Operational)	X			X	X
High Temperature (Non-Operational)	X			X	X
Vibration (Non-Operational)	Failure*	Failure*	Failure*	X	X
Acoustics (Non-Operational)				X	X
EMI				X	X
Humidity, Temperature, Life (Operational)				X	
Post-Functional				X	X
Vibration (Delta) (Non-Operational)					X
Shock (MDA) (Non-Operational)					X

*[These failures (see paragraph 3. and 4. below) and analysis resulted in the need for two additional specimens (S/N 059 and S/N004)]

1. The illumination levels in the high position were below the specified tolerances throughout the qualification tests for S/N 004, 005, and 059. This anomaly was traced to an error in the manufacture's production acceptance test equipment setup and procedure.

2. Low insulation resistance was observed with S/N 059. This failure was caused by electrical leakage through a moisture laden opening in the splice insulation sleeve to the switch and container case.

This opening resulted from repeated impact of the splice with the interior surface of the container. Investigation of the problem proved that this light was one of the exceptions and most lights (including all lights to be used in flight) were manufactured with epoxy bonding the splice anchored to the end of the container.

3. Floodlights S/N 002 and S/N 005 failed during the first few seconds of random vibration. The failure was caused by an unexpected amplification of the housing in the range of the resonant frequency of the lamp subassembly. The only installations of the floodlights in jeopardy from the housing amplification are those installed on the forward dome. These installations will be safely protected by the addition of a vibration isolator to each assembly.

4. The S/N 057 floodlight was broken in vibration during sine evaluation. The floodlight was installed in the housing which in turn was attached to the isolator system and bolted to the shaker head. At approximately 25 Hertz, the floodlight, housing and isolator assembly were thrown off the shaker head. The floodlight was broken by the severe reaction due to a vibration input at least double that specified. The loss of the assembly was due to the mounting bolts being too short and was holding by only a couple of threads.

5. Floodlights S/N 059 and S/N 004 failed to meet the requirements for broad band conducted interference and broad band radiated interference tests. These out-of-tolerance conditions have been deferred until All Systems Test on the Orbital Workshop to determine if the levels interfere with other subsystems. The conducted interference was out-of-tolerance as much as 29 db at 18 MHz when the lamp was switched from off to low. The radiated interference was out-of-tolerance as much as 50 db at 100 MHz when the lamp was switched from off to low. (Referer Paragraph B.1/b.3 below).

6. Pre and Post Tests - The Pre and Post tests performed on S/N 059 and 004 test specimens verified they had not degraded as a result of the applied environments. The test specimens were required to operate in the same mode during each environmental test as they are expected to function during the Skylab mission.

b. Line Item IS-7 - The test was started with test part 1B69364-501, S/N 070, but due to an incorrect installation of the light to the vibration test fixture, a structural failure occurred. The test was hence restarted with a new test specimen, 1B69364-501, S/N 034.

The specimen was subjected to the following environments to verify that the part would function within required specification limits.

Vibration (Hardmount and Softmount Configurations)

Life Cycles

Humidity

Pre and post tests were performed to verify that the unit had not degraded as a result of environmental exposure.

Sylvania EMI test data has been utilized in lieu of conducting EMI testing as originally defined by IS-7.

1. During the post C-axis (hardmount) power consumption test, a step increase was noticed in the light intensity after approximately one second. It was determined that the anomalies would not affect the operational characteristics of the light. The step increase in light intensity at turn-on corresponded to a degradation in start time but the time was still within the maximum requirement of two seconds.

2. Power consumption was measured once every 24 hours during life cycle testing and slightly exceeded the required limit of 12.5 watts at 28.0 vdc in High Mode operation--the first day. After 109 cycles were completed with the power consumption remaining out-of-tolerance, Failure Report F08511 was written.

The life cycling was continued in an effort to verify the validity of the high power consumption readings. Measurements were made immediately after turn-on and again 15 minutes later of which results indicated that consumption was in tolerance shortly after turn-on but out-of-tolerance after the 15 minute warm-up period.

After 460 cycles the specimen would not turn on completely with 24.0 vdc input and life cycling was terminated. A post test was performed in both the high and low modes during which turn-on time vs. input voltage data was taken, starting with 32.0 vdc and decreasing in increments of 0.2 volts until the light failed to turn on. From this data it was noted that a significant increase in start time occurs with input voltages below 29 vdc and long start times are damaging to the lamp filaments.

A fluorescope examination was also performed which indicated that all heating elements were intact.

Continuation of testing at this point was conducted under the direction of Failure Report F08511 to satisfy humidity environment requirements and newly defined mission life requirements, and to obtain start time vs. anticipated life data.

It was also determined that the cause of the excessive power consumption was due to heating effects of the lamp. The lamp was not in its proper usage configuration and hence had inadequate heat sinking.

It was also determined that the failure of S/N 034 to turn on after 460 cycles was caused by cycling with low (24 vdc) input voltage. The 24 vdc input used in life cycling was not representative of flight profile and thus new mission requirements were defined.

The humidity and life test were successfully completed thus satisfying mission requirements.

3. Conducted and radiated interference specifications were exceeded during EMI testing of the floodlight in Line Item IS-1, however, since no interference with other subsystems was experienced during All Systems Test on the Orbital Workshop, this condition has been considered acceptable.

2/ VCL/KSC Integrated Testing - No major discrepancies were noted during integrated/all systems light tests performed in the VCL and at KSC.

C. Waivers/Deviations - None.

2.2.7.4 Mission Results

The OWS Illumination System performance during the launch phase and on-orbit operations was satisfactory. All general illumination lights, portable lights, and high intensity portable lights survived the launch environment, the high temperature environment of the first twelve days of the SL-1 mission and the SL-2, SL-3, and SL-4 docking loads.

Rigorous power management techniques during the first thirteen days of the SL-2 mission prior to Solar Array (SAS) deployment required a greatly increased number of on/off switching cycles on the general illumination lights. Following SAS deployment, the system was operated normally and has exhibited no degradation or failures due to the additional start cycles. Each crew indicated that, with the exception of the early SL-2 period, the OWS general illumination lights were all turned on in the high mode and operated continuously during awake periods and all turned off during sleep periods. All OWS lights were turned off during Extra Vehicular Activity (EVA) to reduce OWS waste heat loads. There were no failures of general illumination lights in the OWS nor in the MDA which utilizes the same bulb/electronics.

The portable light performance was satisfactory. These lights were utilized per the crew checklists as required to supplement the general lighting for maintenance and repair operations. One light was installed on the floor of the SL-3 Commanders (CDR's) sleep compartment after the sleep restraint was inverted to achieve improved ventilation. There were no failures of OWS portable lights.

The high intensity portable lights were utilized only when specifically called for in the crew checklists. Performance of these lights was satisfactory and there were no failures.

Table 2.2.7.4-1 shows the actual and predicted light usage based on the following data:

A. Accumulated Running Time

1/ Time period to flight: Total accumulated time through KSC testing as recorded on the Quality Control records.

2/ SL-2, SL-3, SL-4 Estimated: Hours were computed on the basis of an average 16 hour work day, all lights on, and total occupancy of 172 days.

3/ End of Mission Margin: Design requirement (predicted life) of 4500 hours less total time accumulated through end of the SL-4 mission.

B. Accumulated Cycles

1/ Cycles prior to flight: Total accumulated cycles through KSC testing as recorded on the Quality Control records.

2/ SL-2, SL-3, SL-4 Estimated: Cycles were computed based on Astronaut usage information (i.e., lights were all turned on in the morning and off at night. This is equivalent to one cycle per day for 172 days average use).

Table 2.2.7.4-1

ILLUMINATION SYSTEM - OWS - USAGE

USAGE	BULB S/N	TIME ACCUMULATED PRIOR TO FLIGHT	TIME ACCUMULATED SL-2,3,4 ESTIMATE	TIME ACCUMULATED TOTAL TIME	TIME ACCUMULATED PREDICT. LIFE	TIME ACCUMULATED EOM MARGIN	CYCLES ACCUMULATED PRIOR TO FLIGHT	CYCLES ACCUMULATED SL-2,3,4 ESTIMATE	CYCLES ACCUMULATED TOTAL CYC.	CYCLES ACCUMULATED PREDICT. CYC.	CYCLES ACCUMULATED EOM MARGIN
1. DOME-1	041	93	2,752	2845	4,500	1655	42	172	214	800	586
2. DOME-2	017	354		3106		1394	45		217		583
3. DOME-3	108	324		3076		1424	60		232		568
4. DOME-4	086	387		3139		1361	64		236		564
5. DOME-5	040	331		3083		1417	53		225		575
6. DOME-6	117	345		3097		1403	58		230		570
7. DOME-7	124	322		3074		1426	57		229		571
8. DOME-8	047	356		3108		1392	56		228		572
9. UPPER WALL-1	113	322		3074		1426	58		230		570
10. UPPER WALL-2	087	357		3109		1391	56		228		572
11. UPPER WALL-3	053	89		2841		1659	53		225		575
12. UPPER WALL-4	089	349		3101		1399	55		227		573
13. UPPER WALL-5	044	332		3084		1416	53		225		575
14. UPPER WALL-6	125	81		2833		1667	22		194		606
15. UPPER WALL-7	043	321		3073		1427	65		237		563
16. UPPER WALL-8	097	383		3135		1365	61		233		567
17. UPPER WALL-9	045	380		3132		1368	56		228		572
18. UPPER WALL-10	094	349		3101		1399	55		227		573
19. EXP COMPT-1	090	332		3084		1416	56		228		572
20. EXP COMPT-2	095	357		3109		1391	56		228		572

Table 2.2.7.4-1

ILLUMINATION SYSTEM - OWS - USAGE (Continued)

USAGE	BULB S/N	TIME ACCUMULATED: PRIOR TO FLIGHT	TIME ACCUMULATED: SL-2,3,4 ESTIMATE	TIME ACCUMULATED: TOTAL TIME	TIME ACCUMULATED: PREDICT. LIFE	TIME ACCUMULATED: EOM MARGIN	CYCLES ACCUMULATED: PRICR TO FLIGHT	CYCLES ACCUMULATED: SL-2,3,4 ESTIMATE	CYCLES ACCUMULATED: TOTAL CYC.	CYCLES ACCUMULATED: PREDICT. CYC.	CYCLES ACCUMULATED: EOM MARGIN
21. EXP COMPT-3	093	372	2,752	3124	4,500	1376	38	172	210	800	590
22. EXP COMPT-4	072	356		3108		1392	56		228		572
23. EXP COMPT-5	100	333		3085		1415	56		228		572
24. EXP COMPT-6	084	362		3114		1386	62		234		566
25. EXP COMPT-7	083	388		3140		1360	64		236		564
26. EXP COMPT-8	023	282		3034		1466	38		210		590
27. EXP COMPT-9	079	328		3080		1420	55		227		573
28. EXP COMPT-10	092	356		3108		1392	56		228		572
29. EXP COMPT-11	055	333		3085		1415	70		242		558
30. EXP COMPT-12	080	356		3108		1392	56		228		572
31. EXP COMPT-13	156	172		2924		1576	47		219		581
32. EXP COMPT-14	071	364		3116		1384	63		235		565
33. SLEEP COMPT-1	064	173		2925		1575	58		230		570
34. SLEEP COMPT-2	085	362		3114		1386	60		232		568
35. SLEEP COMPT-3	067	336		3088		1412	58		230		570
36. WARDROOM-1	075	328		3080		1420	55		227		573
37. WARDROOM-2	036	352		3104		1396	52		224		576
38. WARDROOM-3	0[illegible]3	328		3080		1420	55		227		573
39. WARDROOM-4	026	352		3104		1396	43		215		585
40. WMC-1	120	091		2843		1657	33		205		595

Table 2.2.7.4-1

ILLUMINATION SYSTEM - OWS - USAGE (Continued)

USAGE	BULB S/N	TIME ACCUMULATED										
		PRIOR TO FLIGHT	SL-2,3,4 ESTIMATE	TOTAL TIME	PREDICT. LIFE	EOM MARGIN	PRIOR TO FLIGHT	SL-2,3,4 ESTIMATE	TOTAL CYC.	PREDICT. CYC.	EOM MARGIN
41. WMC-2	077	352	2,752	3104	4500	1396	55	172	227	800	573
42. WMC-3	009	323		3075		1425	50		222		578
43. PORTABLE LIGHT-1	013	012*					16*				
44. PORTABLE LIGHT-2	128	013					05				
45. PORTABLE LIGHT-3	123	012					30				
46. FLIGHT SPARE-1	127	003					33				
47. FLIGHT SPARE-2	131	003					33				
48. FLIGHT SPARE-3	133	003					45				
49. FLIGHT SPARE-4	135	013					51				
50. FLIGHT SPARE-5	020	012					29				
51. FLIGHT SPARE-6	048	012					31*				

*Estimated

3/ End of Mission Margin: Design requirement (predicted life) of 800 less total cycles accumulated through end of the SL-4 mission.

Actual usage of portable lights is based on experiment and/or housekeeping tasks and is insignificant. Flight spares would only be used in the event of a light failure.

2.2.7.5 Conclusions and Recommendations

A. Conclusions - The results of all three Skylab missions have shown that the OWS lighting systems are adequate and have met all design requirements specified in the OWS Contract End Item (CEI) Specification CP2080J1C.

B. Comments (Crew) and Recommendations

1/ Light Intensity (High vs. Low)

Comments - All General Purpose lights were used in the HIGH mode only. The difference between high and low modes was slight.

Recommendations - Future general lighting fixtures be limited to a single light level for simplification and cost reduction.

Special low level lights should be installed for emergency, night lights, etc.

2/ Detailed Work Illumination

Comments - Supplemental lighting was required for close work, i.e., item repair, shaving, reading, etc.

Recommendations

a. Specific area(s) should be designated as a repair/maintenance facility and provided with sufficient illumination for close detail work.

b. Provide additional lighting for personal hygiene such as a "make-up" type mirror with side lighting as opposed to overhead lights.

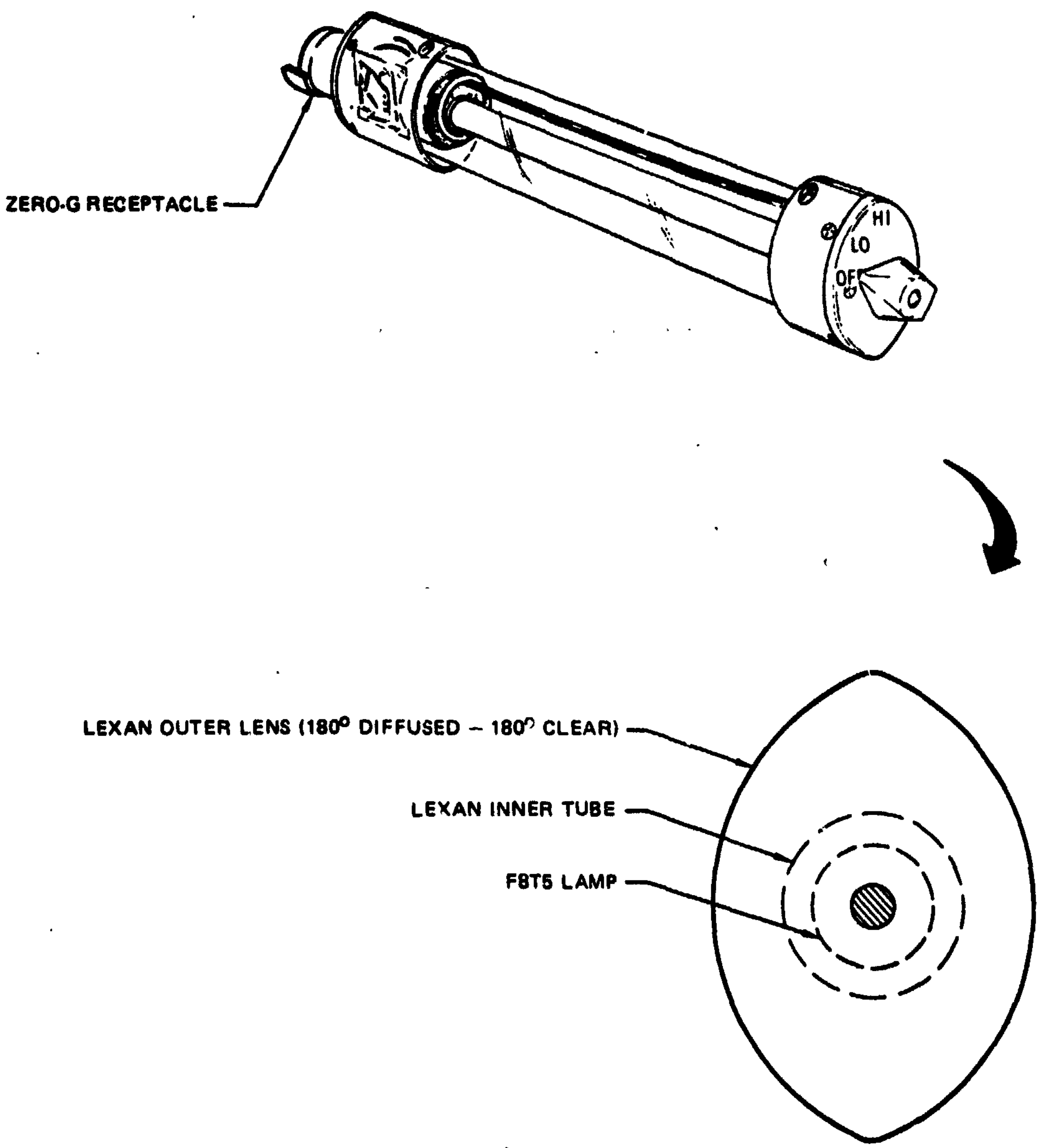
c. Provide higher illumination levels (higher intensity and/or additional lighting) in areas where reading and/or record keeping is performed, i.e., Wardroom, Sleep Compartments, and Experiment Area.

d. When body orientation tends to block lighting, such as the case when the waste management system was in use, added lighting should be provided.

2.2.7.6 Development History - The general illumination light originally planned for use on the OWS was a 15 inch (38.1 cm) floodlight with an F8T5 [8 watt, 10 inch (25.4 cm) length, 5/8 inch (1.6 cm) diameter] Sylvania lamp covered with a lexan inner tube and a lexan outer lens (180° diffused - 180° clear). (Reference Figure 2.2.7.6-1). This preliminary design concept was in force until December 12, 1969.

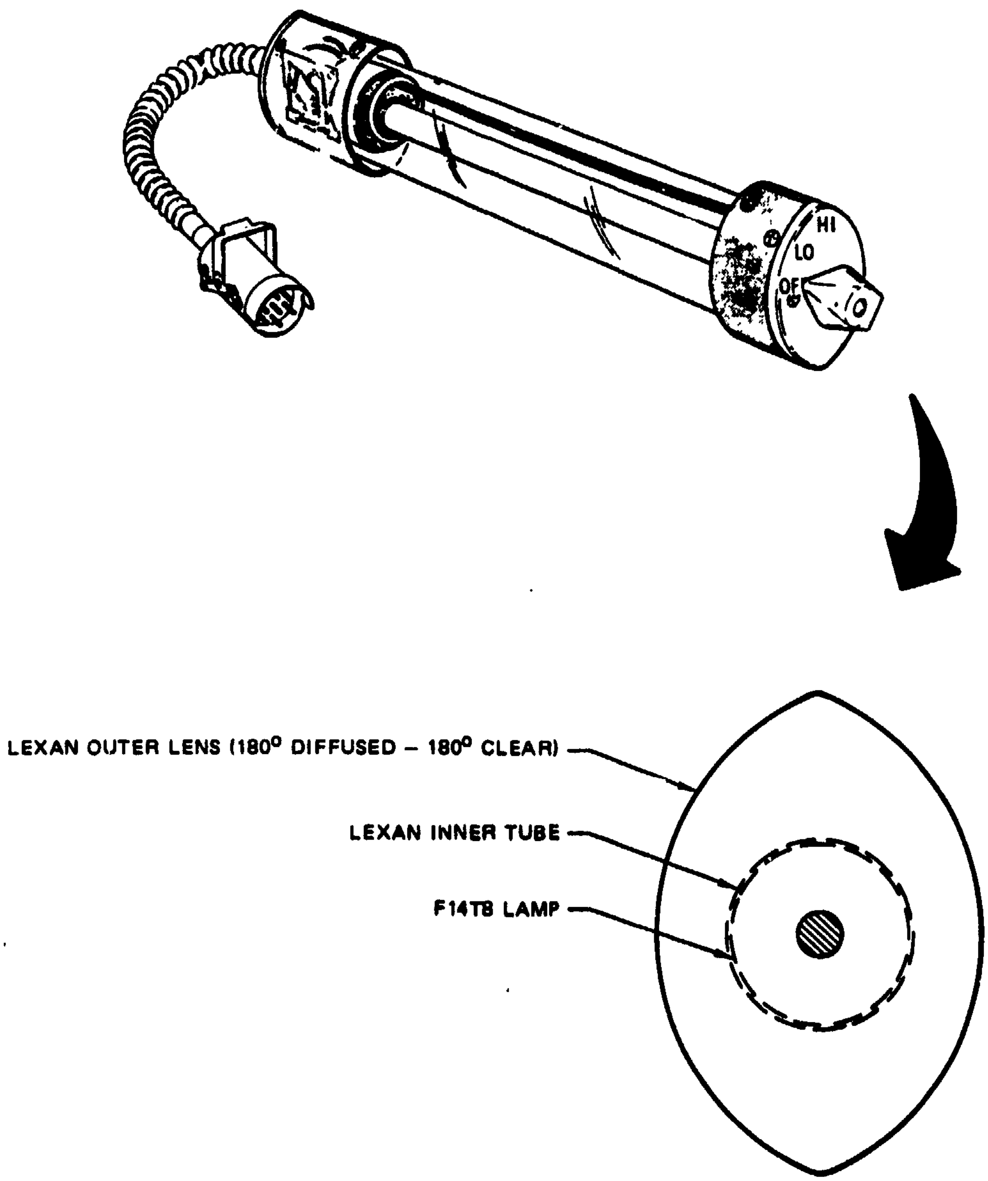
On December 12, 1969, a meeting was held with Sylvania to review the preliminary design of the floodlight. Sylvania presented the light output data for various combinations of input power, bulb size, and physical configuration. With the existing design concept, the lamp would only produce 62% of the required illumination output. Increasing the input power from 10 watts to 13 watts (maximum usable power for this lamp) would still only bring the light output to 69% of the required level. Therefore, it was proposed to (1) change the lamp from an F8T5 to an F14T8 [14 watt, 1 inch(2.54 cm) diameter 13 inch (33 cm) long] which would result in increased efficiency due to the larger capacity of the lamp, and (2) change the EMI screening to the housing, rather than on the floodlight, which would increase the light output an additional 4 to 10% (Reference Figure 2.2.7.6-2).

After performing a full assessment of the total cluster impact associated with the design changes proposed on December 12, 1969, it was established that additional detailed development testing was necessary at the system level. Therefore, an illumination pattern and intensity level test was conducted with a mock-up light. Utilizing the data derived from this testing, an analytical evaluation of the total interior light was performed.



FLOODLIGHT AS ORIGINALLY PROPOSED – IN FORCE UNTIL DECEMBER 12, 1969

Figure 2.2.7.6-1. Floodlight as Originally Proposed – In Force Until December 12,1969



FLOODLIGHT DESIGN IN FORCE FROM DECEMBER 12, 1969 UNTIL JANUARY 15, 1970

Figure 2.2.7.6-2. Pictorial History of 1B69364 Floodlight Design

It was determined that CEI Specification levels of illumination could be met with a floodlight producing 85% or more of the original intensity as specified in Source Control Drawing (SCD) 1B69364. Concurrently, Sylvania was proceeding with the investigation of floodlight design alternatives based on the following ground rules:

1/ The input power to the lamp would be 12.5 watts.

2/ EMI screening would not be used on the floodlight housing. EMI suppression will take place within the floodlight.

3/ Low operational temperature is +30°F (272°Kelvin)

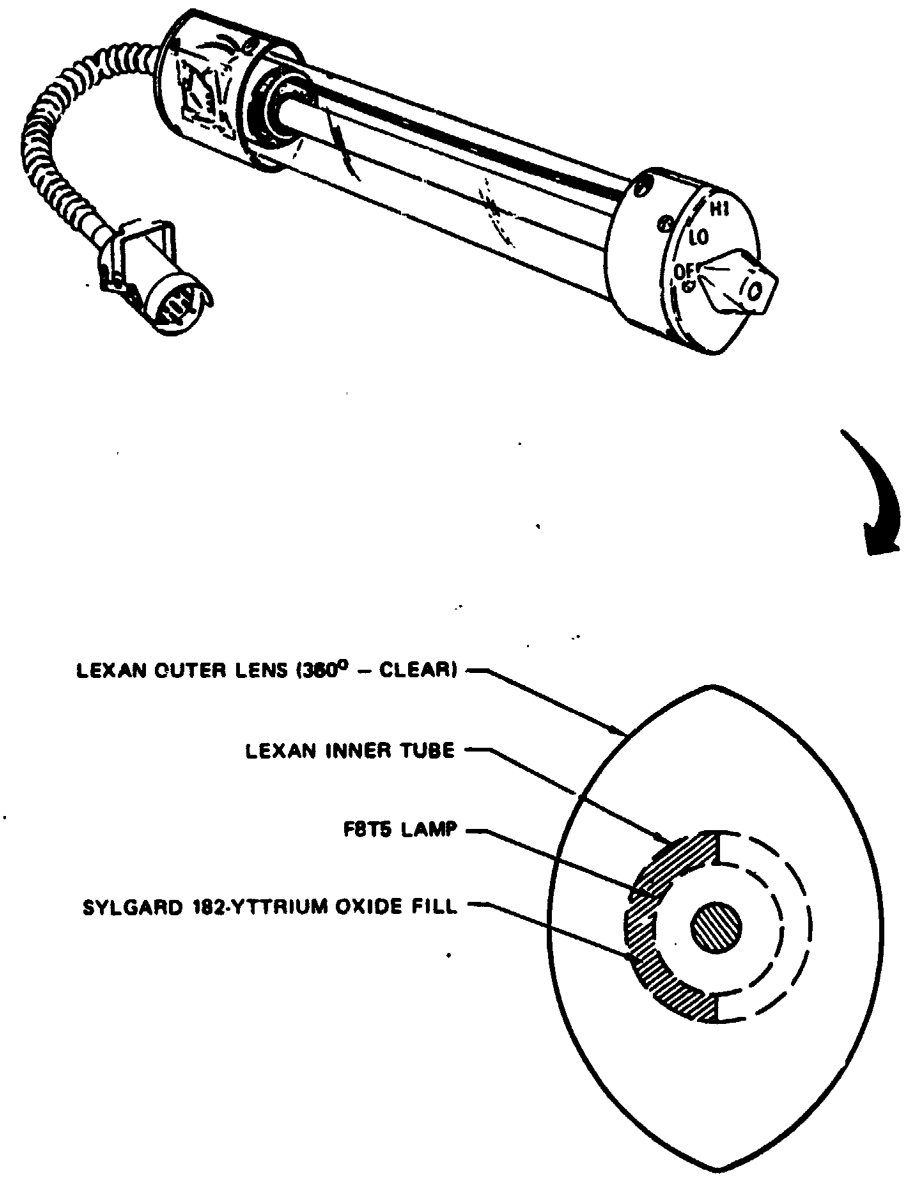
4/ Removal of the clear half of the outer lens of the floodlight was acceptable, although not desirable.

5/ A multiple lamp floodlight would not be considered due to the increased mercury content.

A meeting was held on January 15, 1970 to present the results of the above two efforts and to reach an agreement on a firm set of requirements for the design of the floodlight. During the meeting, Sylvania presented the results of recent investigations with an inner diffused floodlight. The inner diffused light has a half-circle fill of the inner Lexan tube with Sylgard 182 encapsulant resin. Yttrium oxide is mixed with the Sylgard, for light diffusion (see Figure 2.2.7.6-3). This configuration provided the following advantages:

1/ Light diffusion takes place within the inner Lexan tube rather than at the outer lens, producing a pattern almost identical to that defined in SCD 1B69364.

2/ Heat conduction through the Sylgard allowed cooler operation, and therefore increased efficiency.



FLOODLIGHT DESIGN IN FORCE FROM JANUARY 15, 1970 UNTIL FEBRUARY 13, 1970

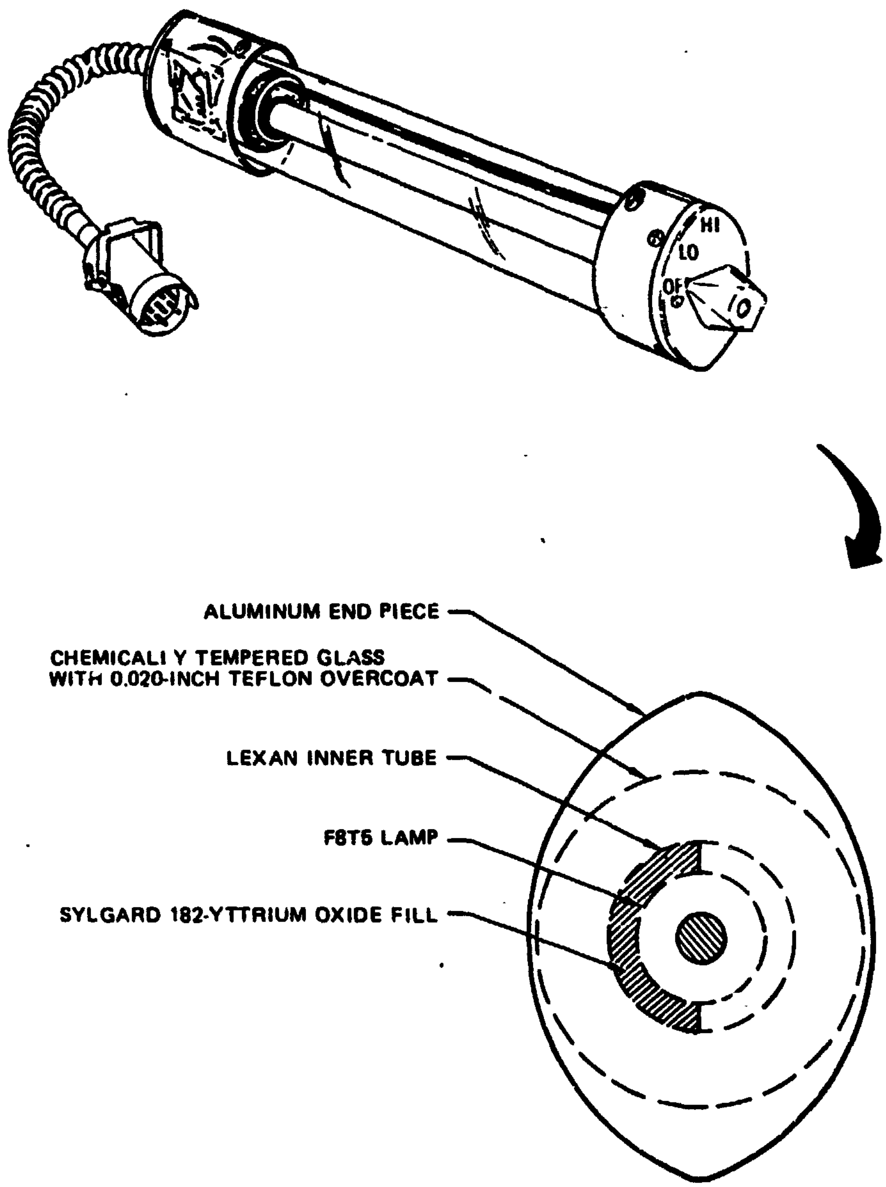
Figure 2.2.7.6-3.

3/ The Sylgard fill decreased the boundary layer losses in light transmission.

It was then agreed that the floodlight design presented by Sylvania offered the best solution to the problem. Revision -G of SCD 1B69364 was formally released on January 26, 1970, incorporating the agreed upon design and the addition of electrical bonding requirements.

The current configuration (Ref. Figure 2.2.7.6-4) was finalized with release of SCD 1B69364-H on February 13, 1970.

Minor modifications to the light control electronics have been made since the February 13, 1970 date; however, they did not affect the current basic floodlight.



FLOODLIGHT DESIGN IN FORCE SINCE FEBRUARY 13, 1970

Figure 2.2.7.6-4. Floodlight Design in Force Since February 13, 1970

2.2.8 Communication and Data Acquisition Systems

2.2.8.1 Communication System

A. Design Requirements

1/ General Requirements

a. The Orbital Workshop (OWS) audio system shall be a hardware system consisting of ten (10) Speaker Intercom Assemblies (SIA's), P/N 61A850003, which shall be provided as Government Furnished Property (GFP) for the OWS. The SIA's shall be communication stations distributed within the OWS as follows:

LOCATION	QUANTITY
Experiment Compartment	2
Waste Management Compartment (WMC)	1
Wardroom Compartment	1
Sleep Compartment	3
Forward Compartment	3

b. The OWS audio system shall operate as an integral part of the Skylab (SL) Orbital Assembly (OA) system defined in NASA Interface Control Document (ICD) 50M13136, Skylab Orbital Assembly Audio System Requirements.

2/ Detail Requirements

a. Power

1. The Airlock Module (AM) power buses provide dc power, through 5.4 amp circuit breakers, at the AM/OWS interface to provide intercom and voice recorder control power to each channel of the audio system SIA's. The AM power buses provide dc power, through 3.9 amp circuit breakers at the AM/OWS interface to provide Crew

Communication Umbilical (CCU) power to each channel of the audio system SIA's.

2. No subsystem loading will cause these limits to be exceeded.

3. The electrical power bus characteristics are defined in the electrical power distribution system paragraph 2.2.6.1.

b. Voice Requirements

1. The audio system shall be a two channel operating service, Channels A and B to each of the ten (10) OWS communication stations.

2. Each communication station in the OWS shall be provided with the capability to accommodate headset voice functions for duplex (simultaneous talk and listen) voice communications between crew members within the modules of the OA or between crew members in the OA and the Spaceflight Tracking and Data Network (STDN) on both Channels A and B.

3. Microphone voice functions shall be provided from the OWS communication stations to the AM/OWS interface for simplex (talk or listen) voice communication between crew members within the modules of the OA, or between crew members in the OA and the MSFC on both Channels A and B.

4. The OWS audio system shall provide for voice recording functions from each of the communication stations to the AM/OWS interface to control the voice tape recorders in the AM on both Channels A and B.

c. Caution and Warning (C&W)

1. The OWS audio system shall receive tones and indicator signals from the C&W system and route them to the communication stations and crewmen as required on Channels A and B.

2. Detailed requirements for the C&W and crew alert functions are contained in the ICD, 50M13148, Speaker Intercom Assembly to Multiple Docking Adapter (MDA) and OWS Interface.

d. Operational Biomedical Data

The OWS audio system shall route operational biomedical data from the CCU of the communication stations to the AM/OWS for insertion into the AM Pulse Code Modulation (PCM) data system, from up to two crewmen, on Channels A or B. Detailed requirements for the biomedical data functions are contained in the ICD.

e. Interfaces

The OWS audio system interfaces shall be defined by the following ICD's:

- 40M35594 - Orbital Workshop to Airlock Module Electrical Interface.
- 40M13148 - Speaker Intercom Assembly to MDA and OWS Interface.
- 50M13148 - Ancillary Equipment to Saturn Workshop Instrumentation and Communication Interface.
- 50M13136 - Skylab Orbital Assembly Audio System Requirements.

B. System Description

1/ General Description - The OWS communication system is designed as a functional part of the OA audio system and provides the following: (1) direct voice link between the OWS and the STDN via the Command Module (CM) S-Band; (2) biomedical data to the STDN through the AM PCM telemetry system; (3) intercommunication link between astronauts within the OWS; (4) audio and visual displays of warning tones generated by the C&W system; and (5) control for the operation of the voice and data recording system in the AM.

2/ System Details

a. Power

1. The utilization of SIA's having a potential of ten (10) stations active at the same time, created voltage drop difficulties with lines providing power to the SIA's. Therefore, parallel "ring" bus circuits with busing redundancy within the busing "ring" were designed, using heavier 12 gauge wires, to carry the heavier load currents. The circuits requiring the additional busing redundancy are the intercom power circuits, and the call command circuits of both communication channels.

2. See Figure 2.2.8.1-1 for the "ring" bus circuit concept.

b. Voice

1. The Channel A and Channel B functions are routed across the AM/OWS interface through feedthrough connectors into the habitation area and connected to each of the communication stations in a parallel "ringed" bus circuit (see Figure 2.2.8.1-1 for the "ring" bus circuit concept).

"RING" BUS CIRCUIT CONCEPT

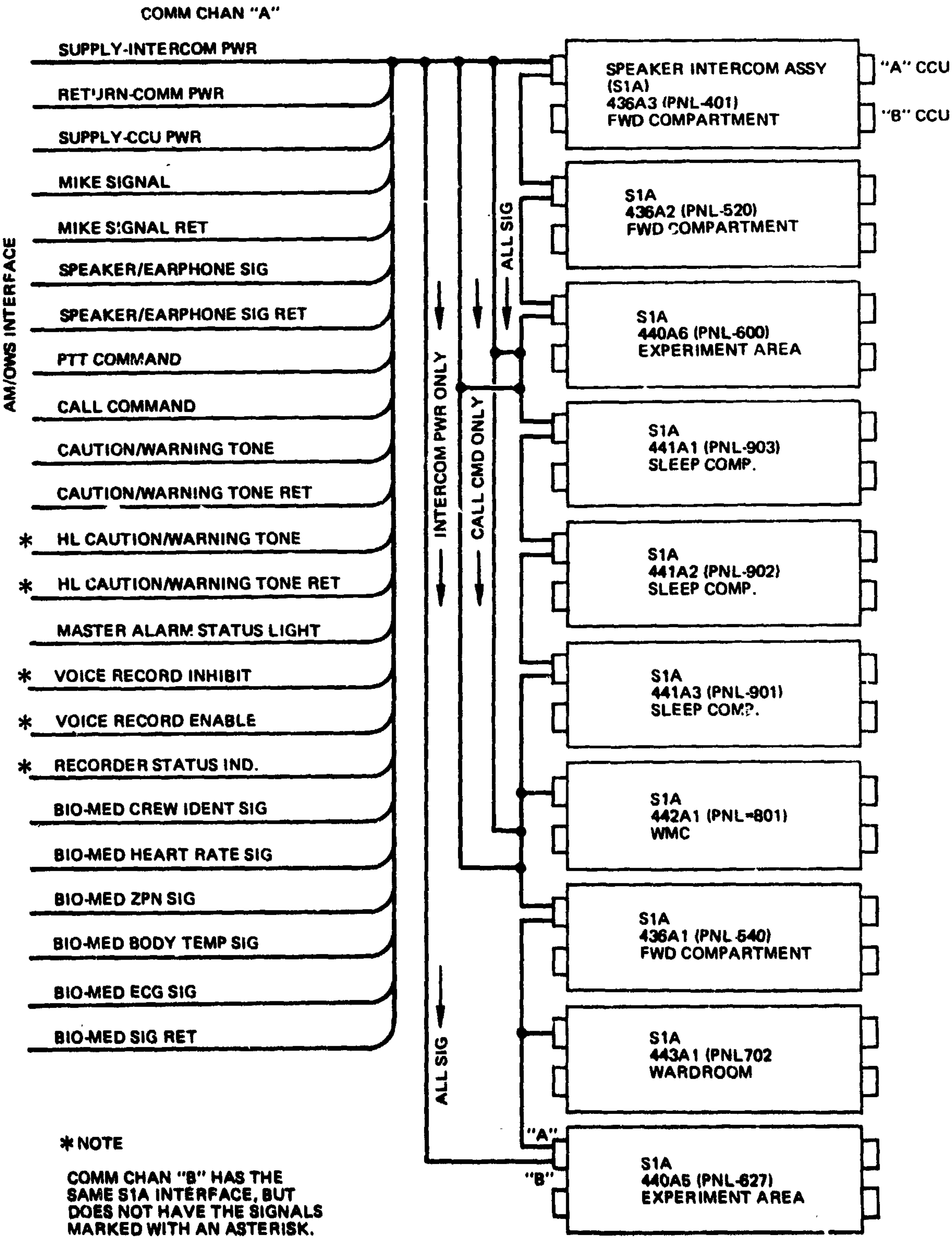


FIGURE 2.2.8.1-1

2. The capability is provided to operate the speaker/microphone of the SIA by selecting intercom (ICOM) listen, or transmit (XMIT) mode of operation. ICOM allows microphone outputs to the OA audio network and also enables the voice transmission to the Manned Space Flight Network (MSFN). The listen mode enables the SIA speaker. ICOM and XMIT control positions are momentary (see Figure 2.2.8.1-2).
3. A CCU power and mode selection switch provides for each communication channel CCU receptacle. The switch provides the capability of positively selecting OFF, ICOM/PTT, PTT, or SLEEP modes of operation for the CCU functions.
4. The voice RECORD switch enables or inhibits voice tape recording. Controls are momentary-contact; the enable (RECORD) switch activates the tape recorders in the AM, as required. The inhibit (OFF) position deactivates the tape recorders without interferring with AM PCM data storage when it has been enabled.
5. The green advisory light confirms successful voice recorder enable or inhibit selection by the voice RECORD switch as described in the previous paragraph. It indicates tape motion on the data (subframe 1) recorder, provided the voice recording has been enabled and a playback has not been enabled.
6. The SIA provides for a momentary "call" which performs the following functions: Connects together the microphone lines of both Channels A and B, overrides SLEEP

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY	SKYLAB - ORBITAL WORKSHOP COMMUNICATION BOX	CHART NO. SA-3511 DATE 4-27-72 SPEAKER

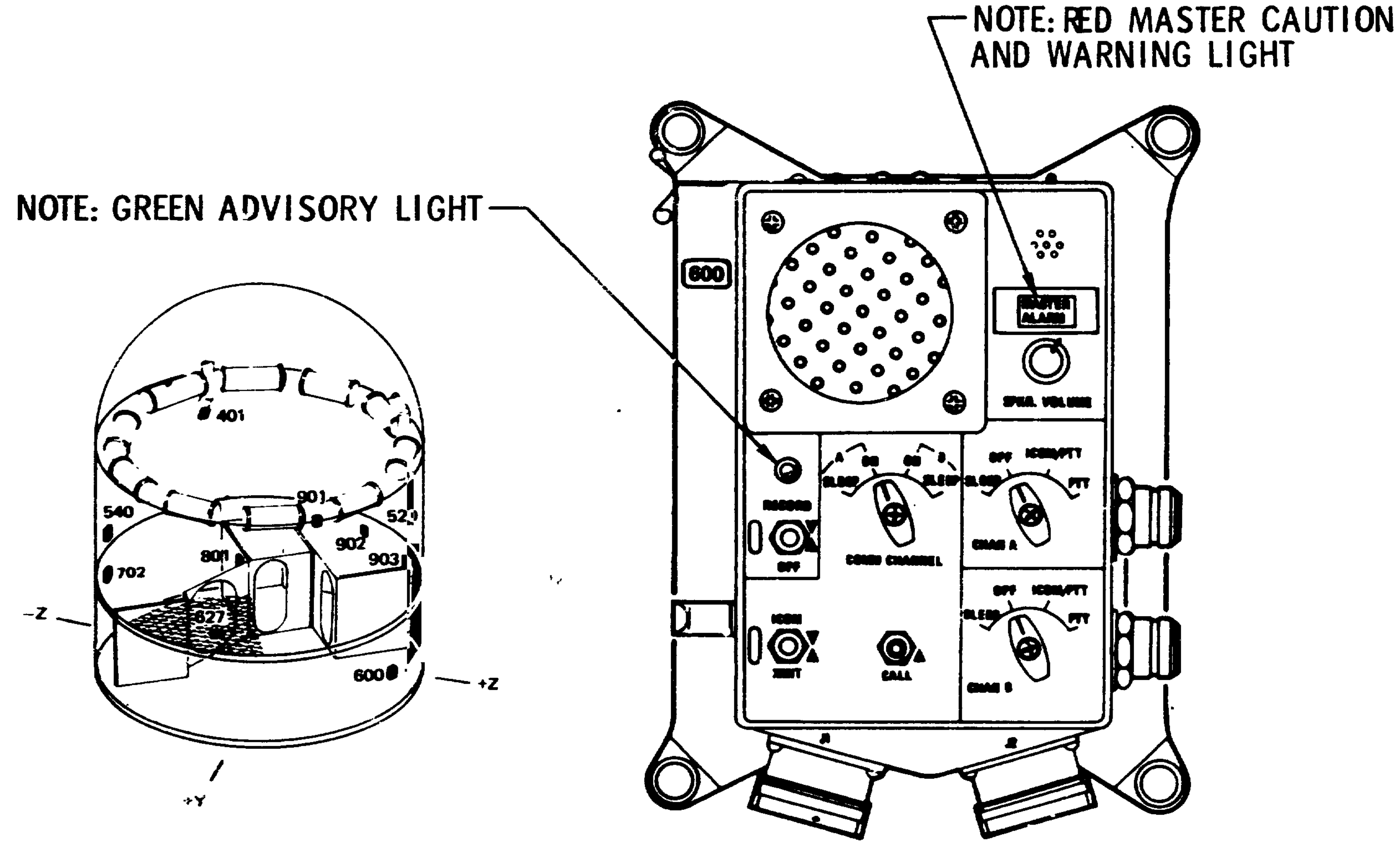


FIGURE 2.2.8.1-2

mode on all except calling stations, overrides SLEEP mode on all CCU except earphone and C&W circuits, enables ICOM for the speaker/microphone, and establishes ICOM/PTT for the CCU receptacles on the calling station.

c. Caution and Warning (C&W)

The AM provides C&W signals and ground commanded crew alerts to the OWS SIA's. The Master Alarm Status Light is activated and the C&W tones are generated at each of the SIA's.

d. Biomedical Data

The system transfers biomedical data from up to two crewmen on separate channels through the CCU's of the SIA.

C. Testing

1/ Testing Program

a. There were no OWS Test Plan, DAC-56697A, line items prepared by MDAC-W for development testing of components used in the communication system.

b. The SIA was provided as GFP for installation as part of the OWS communication system; consequently the SIA qualification tests were in accordance with MDAC-E document 061-063.22, Test Request for Qualification of Speaker Intercom Assembly.

c. The OWS communication system consisted of the SIA's and interconnecting cable harnesses; therefore, production testing involved verification of the cable harnesses. The SIA's were production tested by MDAC-E at the St. Louis facility.

d. Post manufacturing tests were performed at Huntington Beach which included subsystem and integrated system testing. These tests involved the utilization of equipment simulating the AM portion of the audio system. The OWS communication system was verified to be compatible with the audio system in the airlock. Tests contributing to the verification are listed in Table 2.2.8.1-1.

e. Testing at KSC consisted of post manufacturing subsystem retesting of any delta changes affecting Huntington Beach test results and integrated system testing at the module and cluster levels. Major testing related to the verification of the communication system is listed in Table 2.2.8.1-2.

2/ Major Problems and Solutions

a. There were no significant OWS communication system problems encountered during checkout of the system at MDAC-W (Huntington Beach).

b. Functional verification of the OWS communication system at KSC disclosed two (2) significant problems. Both problems required the removal of the SIA's from the spacecraft for design modifications. The first removal was to reduce the output level of the call potentiometer to minimize the possibility of acoustic feedback in the CALL mode. The second removal was due to the misalignment of the channel select knob on the SIA's which caused channel function indexing problems. The SIA's were reworked; reinstalled, and successfully retested according to Test KS-0045.

TABLE 2.2.8.1-1

HUNTINGTON BEACH POST-MANUFACTURING TESTS AFFECTING OWS COMMUNICATION SYSTEM

Procedure	Nomenclature	Tests
1B66984	Continuity compatibility	Assures confidence in OWS stage wiring
1B83587	Intercom subsystem	Verified the performance of the audio communication system by methods of dialogue and calibrated signals into the earphone and microphone lines. All functions associated with each of the 10 communication stations (SIA's); which included the warning tones, tape recorder controls, voice communication for each audio channel, as well as the CCU functions including biomed functions to telemetry; were verified.
1B83590	EMC setup and systems reverification	Demonstrated that the communication system met transient and margin of safety requirements of the EMC criteria.
1B93589	All system test - prep and securing	Preparation and securing of the OWS for all system test
1B93591	All system test - activation, orbital operations and deactivation	Simulated OWS test of systems after the insertion phase and during orbital operations.
1B93588	All system test - prelaunch, boost, and preactivation	Simulated OWS test of systems during prelaunch, boost and preactivation periods of the OWS.

TABLE 2.2.8.1-2

KSC TESTING OF THE OWS INTERCOM SUBSYSTEM

Procedure	Nomenclature	Tests
KS-0045	AM/MDA/OWS end-to-end system test and experiment test.	Verified the performance of the cluster audio system utilizing simulated CSM audio center. Verified that the OWS communication system operated compatibly with other module components of the system.
KS-0009	SWS Operations for SV CAT and SWS mission SIM/FRT	Integrated cluster level testing which functionally verified the compatibility of the OWS electrical power system, including the OWS communication system and ensure electromagnetic compatibility of these systems.

3/ Waivers and Deviations - There were no waivers or deviated-to-design specifications of the OWS communication system.

D. Mission Results - The OWS communication system, an extension of the OA audio system, has successfully supported the SL-1/SL-2, SL-3 and SL-4 missions. The OWS hardware has performed well and has enabled the astronauts to communicate among themselves and with the STDN team throughout the missions. The biomedical data, routed through the SIA's were of good quality and enabled the medical team to perform their functions.

Mission problems were limited to a malfunctioning SIA located at Position 540, and an acoustical feedback problem that is similar to that experienced during the Huntington Beach checkout. The anomalous SIA had a malfunctioning ICOM/XMIT switch which resulted in continuous "hot" microphone condition. This unit was replaced.

The acoustical feedback problem was attributed to the placement of the SIA's within the OWS to support the different experiments and crew tasks. The feedback problem was operationally controlled during SL-2 and SL-3 by either keeping the SIA speaker volume controls turned down or by activating the SIA's only when they were required.

This technique was unacceptable to the crew and for SL-4 JSC developed an external load that was used to load the microphone line and thus reduce its sensitivity. This, in turn, reduced the feedback problem. The astronauts stated that in the 5 psia

(34.5 kN/m^2) environment, they were able to maintain normal conversation without the aid of audio equipment, up to a distance of 5 to 8 feet.

E. Conclusions and Recommendations

1/ Conclusions - The ultimate criteria for success for the OWS communication system was to meet the objectives of the Skylab mission in support of the Saturn Workshop (SWS) cluster audio system operation. Therefore, it can be stated from the mission results that the overall performance of the OWS portion of the total communication system has been acceptable.

All audio equipment of the OWS communication system performed as expected during the mission with no failures except for the SIA located at Panel 540 which sustained a broken ICOM/XMIT switch. The SIA unit was replaced.

Based on crew debriefings, the OWS communication system provided adequate volume level and quality during mission operation; however, some audio feedback problems were encountered. The problem manifested itself as a nuisance to the crew and it is attributed primarily to the interaction between SIA's due to crew usage as well as the total gain characteristics of the cluster audio system. Both channels of the OWS communication system provided adequate intercommunication for activities within the OWS as well as uplink and downlink communications.

2/ Recommendations - Inasmuch as the OWS communication system performed satisfactorily throughout the Skylab mission, there are still areas where recommendations can be made to improve on system shortcomings or program deficiencies. They are delineated below.

a. The feedback problem encountered during the mission can be eliminated or minimized by reducing the number of SIA's in an acoustically reverberant enclosure such as the OWS to a minimum, and provide a battery operated personal transceiver-type intercom for each crewman for voice use which would be tied together with the cluster audio system.

b. The number of functions of the SIA should be reduced to primarily accommodate personal communication requirements (i.e., C&W).

c. Present SIA design contains a volume control in the SIA speaker circuit; a volume control in the microphone line would give the SIA greater attenuation selectivity and could be useful in reducing the feedback problem.

F. Development History - The "wet" OWS Communication System was initially defined as an extension of the Apollo Audio System, The design origginally allowed for 10 "drag-on" communication panels which would provide for two independent communication channels and connection of a "drag-in" portable microphone/speaker unit.

During the conversion from "wet" to a "dry" Workshop, the dry design concept combined the intercom microphone/speaker unit and the communication unit into one permanently installed module. Ten of the units (SIA's) was baselined for the OWS portion of the total orbital assembly (OA) communication system, and were to be designed/supplied by MDAC-E.

Two basic requirements of the wet workshop was to minimize weight and utilize existing hardware. Two wire harness designs were considered for the SIA system. Reference Figure 2.2.8.1-3.

One concept provided for a central distribution center. After routing the system function from the Command Service Module (CSM) through the AM to a central distribution area within the interior of the OWS, the communication functions were then to be independently routed to each SIA. This concept required development and qualification of a distribution center in addition to requiring an excessive amount of copper.

A second concept provided a "ring bus" function routing to the SIA's. A bused connector (three bused pins per function) would replace the central distribution and the functions would be "daisy chained" to the SIA's via the ring bus.

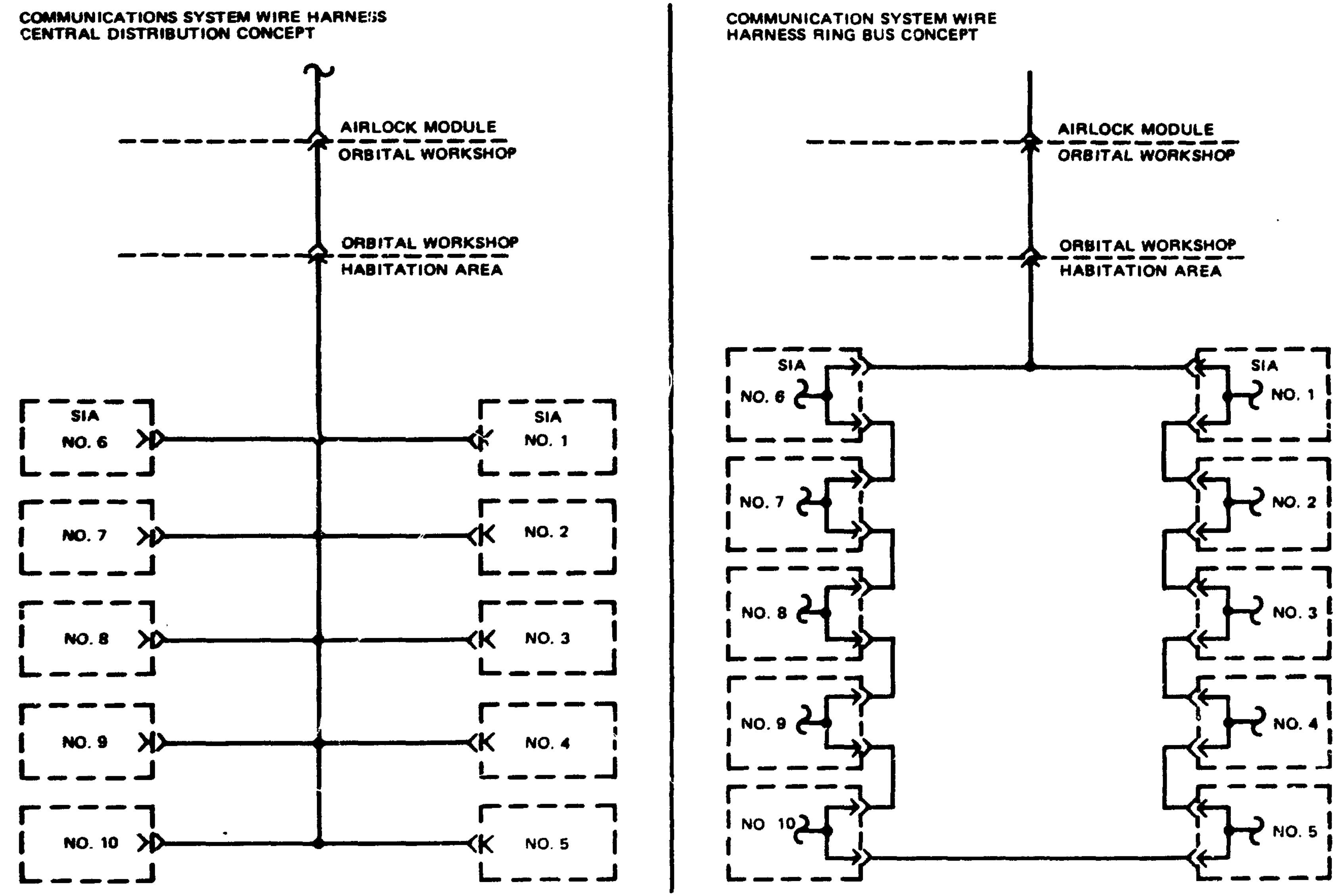


Figure 2.2.8.1-3: Communications System Wiring Concepts

A connector from an existing "family" of connectors could be utilized and the weight of the ring bus wire harnesses was less than the central distribution concept. The ring bus would not be as reliable as the central distribution system. However, two failures would be required before any given SIA would become non-functional.

The trade-off indicated the ring bus was the most cost effective of the concepts. The final ring bus configuration is shown in Figure 2.2.8.1-1.

2.2.8.2 Data Acquisition System (DAS)

A. Design Requirements

1/ General Requirements

a. Design Trade-Offs - During the changeover in design from "wet" to "dry," the criterion was to minimize system redesign. This fact, together with the "designed-in" limitations of the existing Gemini multiplexers (i.e., restrictions to flammability, outgassing and odor), prohibited installations within the OWS internal cavity and influenced the present design. The multiplexers and associated components were mounted on panels within the forward skirt. Thermal studies were performed to optimize instrumentation component installation for maintaining the required thermal environment while in the solar inertial mode. Skirt paint patterns and the various cluster attitudes were contributing factors. Component heaters and thermostatic switches were added to the mounting of the components whenever it was concluded that the components would be below their respective thermal requirements, while the cluster was operating outside the solar inertial mode.

Wire harness installations and transducer/signal conditioning multiplexer versus proximity considerations dictated the location of two multiplexers in the aft skirt area of the Orbital Workshop (OWS). However, due to the timing signals being affected by the increased long line capacitance, the multiplexers had to be located in the forward skirt.

Individual timing signal lines to each multiplexer, as initially considered, increased the number of wires significantly. The "ringed" bus circuits were then conceived and implemented. Signal redundancy was provided across the Airlock Module (AM)/OWS interface, through two separate connectors for each "ringed" bus circuit, to improve reliability.

b. Requirements

1. The Saturn Workshop (SWS) Pulse Code Modulation (PCM) Telemetry (TM) system consists of the programmers, interface box (I/B), tape recorders, and low-level and high-level multiplexers. The OWS portion of the PCM TM system shall consist of the low-level and high-level multiplexers. Detailed requirements for both the low-level and high-level multiplexers are defined in MDAC-E Drawing 52-85713, Appendix C1 and Appendix C2, Specification Control Drawing, MAC Model 133P, 195B, and 1003 Data Transmission System [including Change Notice Request (CNR) 68].
2. The OWS measurement program shall be defined in MDAC Drawing 1B68467.
3. Display panels shall be provided which shall allow the crew members to monitor the OWS environment and the status of OWS equipment. These display parameters shall be defined in MDAC Drawing 1B68467.

2/ Detail Requirements

a. Power

1. Two separate power buses in the AM shall provide

direct current (dc) power, through 9.3 ampere (amp) circuit breakers, at the AM/OWS interface to two (2) separate instrumentation system power buses in the OWS to excite transducers, signal conditioners, and 5 vdc excitation modules.

2. Two separate power buses in the AM shall provide dc power, through 9.3 amp circuit breakers, at the AM/OWS interface to two separate instrumentation heater buses in the OWS to provide power to the telemetry system component thermal elements.

3. Power characteristics shall be as defined in electrical Power Distribution System (PDS) paragraphs 2.2.6.1, 2.2.6.2, 2.2.6.3, and 2.2.6.5.

4. Grounding requirements shallbe as defined in electrical PDS paragraphs 2.2.6.1, 2.2.6.2, 2.2.6.3, and 2.2.6.5.

b. Telemetry System

1. Seven (7) low-level multiplexers, designated B, D, H, J, L, M, and Q are assigned to the OWS and are to operate electrically and logically as an integral part of the SWS PCM TM system.

2. Five (5) high-level multiplexers designated D, E, J, K, and T are assigned to the OWS stage and are to operate electrically and logically as an integral part of the SWS PCM TM system.

3. The maximum measurement capability of the OWS TM system multiplexers shall be as follows:

° 152 0-5v channels at 1.25 samples per second.

° 56 0-20mv channels at 1.25 samples per second.

- 168 0-20mv channels at 0.416 samples per second.
- 72 bi-level channels at 10 samples per second.
- 64 bi-level pulse channels at 10 samples per second.

4. Biomedical and experiment measurements shall be routed to the programmer/interface box or multiplexers in the AM across the AM/OWS interface from the Speaker Intercom Assembly (SIA) of the audio system, and from the Experiment Support System (ESS).
5. Measurement capability of OWS inputs directly to the programmer/interface box shall be as follows:
   - 5 0-5v channels at 320 samples per second.
   - 3 0-5v channels at 80 samples per second.
   - 1 0-5v channel at 40 samples per second.
   - 1 0-5v channel at 20 samples per second.
   - 4 0-5v channels at 10 samples per second.
   - 4 0-5v channels at 1.25 samples per second.
6. The OWS shall provide eight (8) command signal lines for AM tape recorder control functions from the experiment and forward compartments to the AM/OWS interface.
7. Time reference system signals from the AM shall be provided to the M509/T013 experiments in the OWS.
8. Hardline cabling from the AM/OWS interface to the OWS/Electrical Support Equipment (ESE) umbilical on the forward interface of the OWS shall be provided for ground checkout monitoring of the PCM data.

c. Measurement System

1. The telemetry measurement system shall consist of signal

conditioners and/or transducers necessary to convert physical and electrical parameters into electrical signals which meet the input requirements of the high-level and low-level multiplexers. Measurement parameters are defined by the Instrumentation Program and Components List (IP&CL), Orbital Workshop 1 and 2, 1B68467. The following parameters shall be monitored:

- Temperatures
- Pressures
- Vibrations
- Flows
- Positions
- Events
- Liquid Levels
- Volts, currents
- Radiation
- Experiments Parameters

2. The 5 vdc excitation modules shall be designed to meet the accuracy and regulation requirements of signal conditioners and potentiometer types of transducers of the telemetry measurement system. The output of the module is 5.000 $\pm$0.010 vdc over the operating input voltage range of 24 to 30 vdc with load currents of 0 to 200 milliamps.
3. OWS on-board display measurements shall be operationally independent of the OWS PCM data system. The OWS on-board display measurements shall be powered from either of the two OWS bus powers, OWS Bus 1 and OWS Bus 2, through

circuit breaker protected sub-buses (Sensor Power Buses 1 and 2). Measurement parameters are defined by 1B68467, IP&CL, Orbital Workshop 1 and 2.

4. The AM shall provide time reference signals to the digital clock for display in the OWS. The digital clock displays elapsed time in days, hours, minutes and seconds.

5. The OWS shall provide a low range habitation area pressure measurement to the AM and a Thruster Attitude Control System (TACS) supply pressure measurement to the Multiple Docking Adapter (MDA), across the AM/OWS, for displays.

6. The OWS measurement systems shall be provided with a Remote Automatic Calibration System (RACS) for ground checkout.

7. The Ground Support Equipment (GSE) measurements shall be operationally independent of the OWS PCM data system. The measurements shall be powered from the prelaunch instrumentation bus, 4D119 bus, and OWS Buses 1 and 2. These measurements are required for ground checkout and prelaunch countdown. Measurement parameters shall be defined by 1B68467, IP&CL, Orbital Workshop 1 and 2.

d. Telemetry Component Thermal Conditioning - The temperature environment of the OWS TM system components shall be maintained within their thermal qualification limits.

1. The Gemini multiplexer thermal environment shall be controlled with thermostatically controlled resistance-type heaters with set points at 35 $\pm 5°F$ (1.7 $\pm 2.8°C$)

for ON and 50 $\pm5^\circ$F (10 $\pm2.8^\circ$C) for OFF.

2. The instrumentation fuse modules shall be controlled with thermostatically controlled resistance-type heaters with set points at -20 $\pm5^\circ$F (-29 $\pm2.8^\circ$C) for ON and 0 $\pm5^\circ$F (-17.8 $\pm2.8^\circ$C) for OFF.

e. Data Acquisition System Accuracy - The OWS DAS accuracy is determined by the root-sum-square method of combining the independent 3 sigma errors of the various components and sources that comprise the subsystem and contribute to measurement errors. The OWS DAS identified by this document is designed or specified such that its combined root-sum-square accuracy, together with the total measurement system (including transducers, signal conditioning components, data system components in the AM, GSE data reduction hardwares and other factors), does not degrade the measurement performance beyond the requirements specified in the respective Measurement Requirement Drawings (MRD's) identified in accordance with Design Memorandum OWS-39A.

f. Interfaces - Requirements for the OWS DAS interfaces are defined in the following documents:

1. 40M35668 - Interface Control Drawing (ICD), Definition of OWS/ESE Electrical Interface Forward Umbilical Plate.
2. 40M35594 - ICD, OWS to AM Electrical Interface.
3. 40M30597 - ICD, S-IVB/Instrument Unit (IU) Electrical Interface.
4. 40M35651 - ICD, ESS/OWS Electrical Interface.

g. Radiation Monitoring

1. Van Allen Belt Dosimeter (VABD) - The OWS shall

be designed to support operation of a VABD GFP. The VABD shall provide direct measurement via telemetry of skin and depth dose rates in rads/hr of radiation that penetrates the OWS. The VABD shall be provided power from the OWS instrumentation bus. The VABD mounting assembly shall incorporate a protective guard for the skin sensor ion chamber.

2. Personal Radiation Dosimeter (PRD) - Six (6) stowage restraints shall be installed in the OWS to mount the PRD's (GFP). Three (3) restraints shall be located in the sleep compartment, two (2) restraints in the forward compartment, and the other in the experiment compartment.

3. Radiation Survey Meter (RSM) - A bracket (GFP) shall be provided to physically mount an RSM (GFP).

h. Common Electrical Requirements - Common requirements imposed on the OWS DAS such as flammability, contamination, bonding, etc., which are imposed on all electrical subsystems, are defined in paragraphs 2.2.6.

B. System Description

1/ General Description - The OWS DAS consists of the OWS portion of the SWS PCM TM system, OWS on-board displays, and ground checkout support measurements.

The SWS PCM TM system is a PCM/Frequency Modulation (FM) system which consists of a Radio Frequency (RF) transmitting system, a PCM system (including programmers, an interface box, high- and low-level multiplexers), a data recording system, a time reference system, and assorted measurement monitoring instrumentations. The PCM system is designed for a maximum capability of 18 high-level and 19 low-level multiplexers in addition to the measurement signals that are directly inserted into the programmer or Interface Box (I/B). The data from the PCM system is categorized as analog, bi-level, or bi-level pulse. They are formatted by the programmer in the AM and transmitted through the RF data link at 51.2 Kilobits Per Second (KBPS) or recorded on tape recorders in the AM at 5.12 KBPS and transmitted delayed time at 112.64 KBPS (22 times recorded speed).

As part of the overall SWS PCM TM system, the OWS PCM TM system provides for the transmission of real time and/or delayed time monitored data of OWS subsystem flight measurement parameters, crew biomedical data, and scientific experiment data to ground tracking stations of the Spaceflight Tracking and Data Network (STDN).

The OWS on board display parameters provide for crew participation in monitoring selected OWS subsystem parameters on a real time basis.

Selected parameters are hardwired through the OWS umbilical connectors for GSE monitoring during ground checkout. These measurements are inactive for flight.

2/ System Details

a. Power

1. The two separate instrumentation system power buses provid[illegible]itation to transducers, signal conditioners, and 5 vdc excitation modules (see Figure 2.2.8.2-1).
2. The two separate instrumentation heater buses provide power to the TM system component thermal elements (see Figure 2.2.8.2-2).

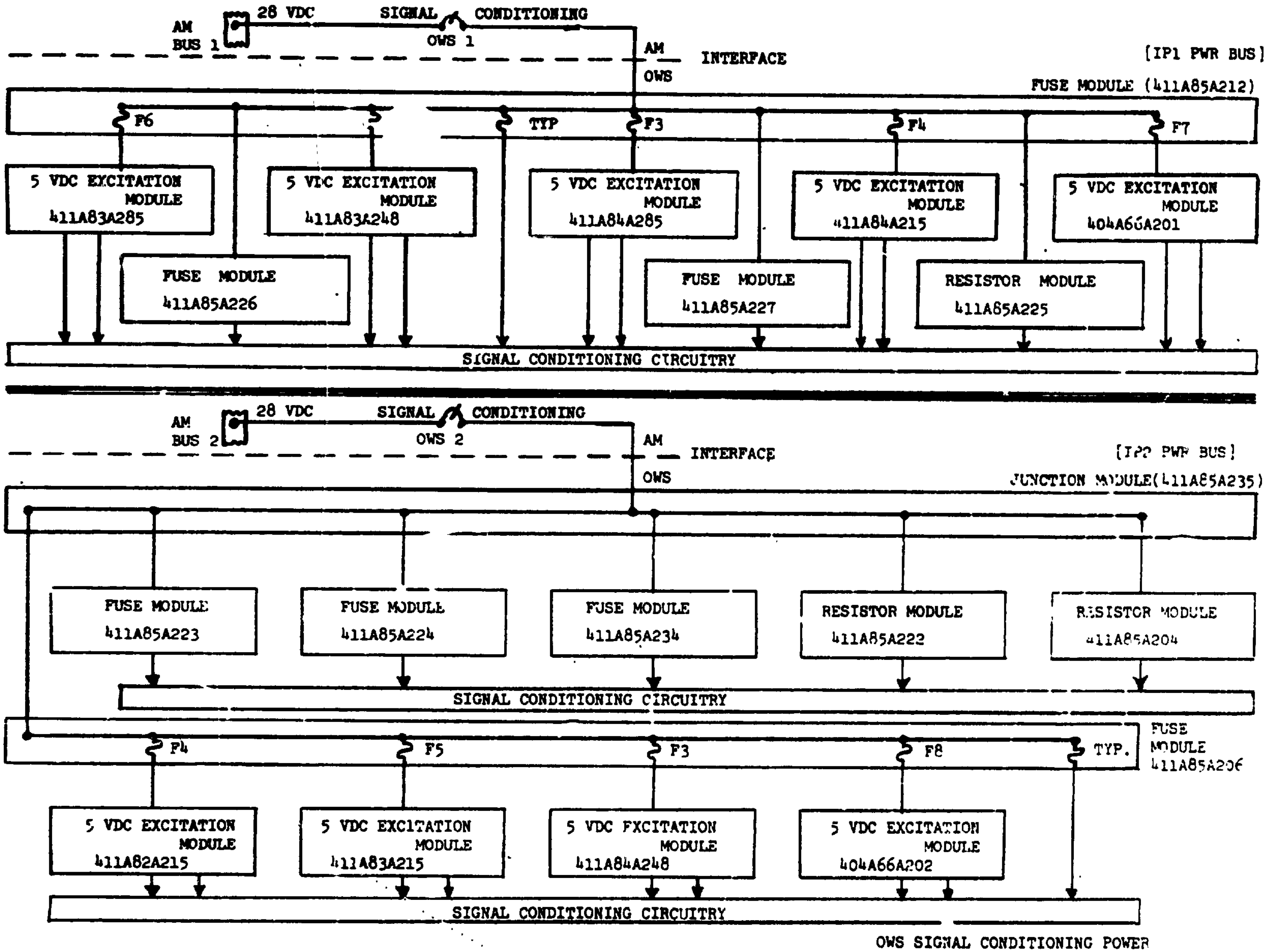
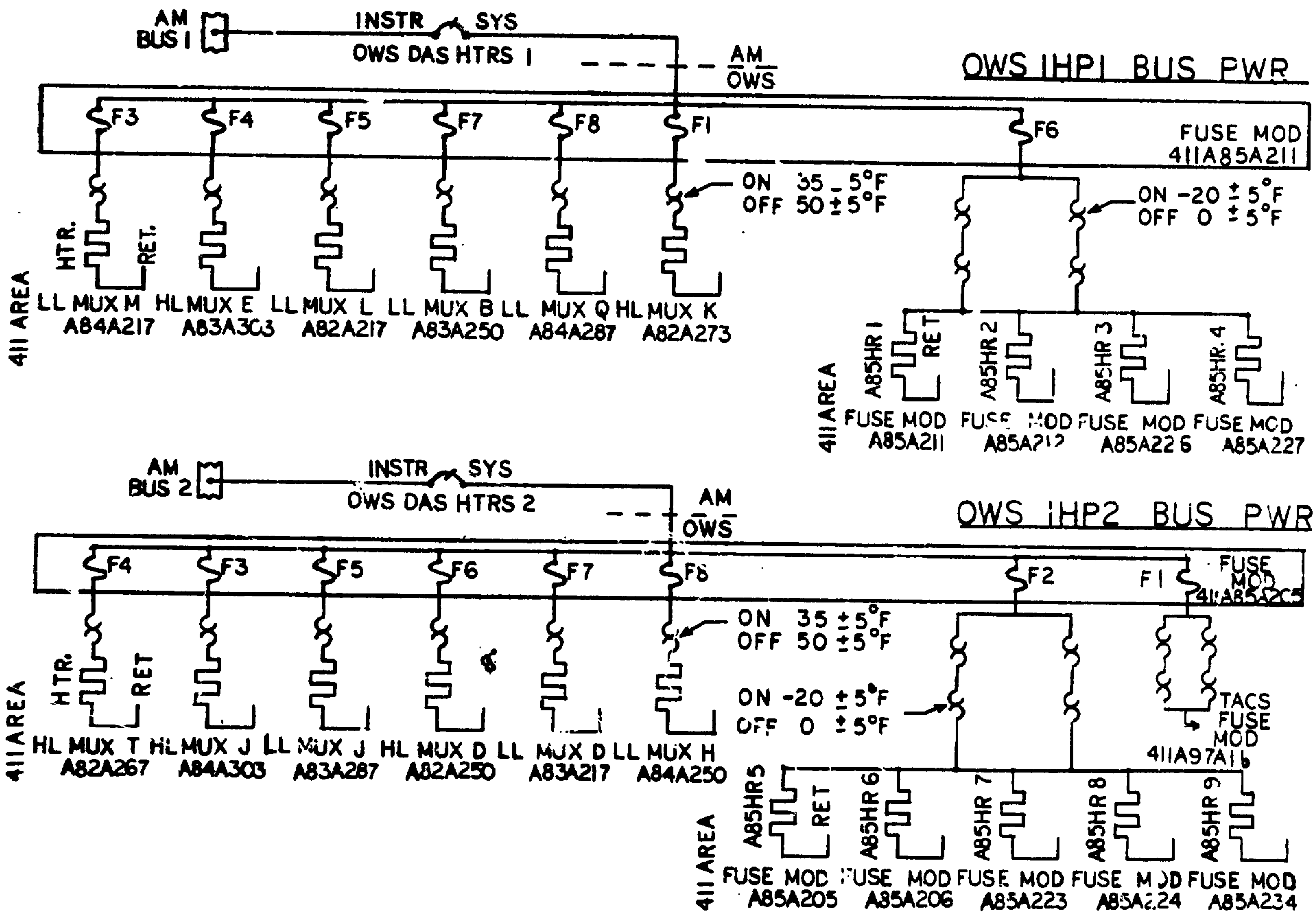


Figure 2.2.8.2-1

SA-3592



OWS DAS HEATER POWER

Figure 2.2.8-2

b. Telemetry System - The telemetry system multiplexers and the signal flow from transducers and signal conditioning are shown in Figure 2.2.8.2-3.

C. Testing

1/ Testing Program

a. The integrity of the OWS DAS hardwares and equipment was tested to assure operational success during the Skylab mission by the test programs defined in the OWS Test Plan, DAC-56697A.

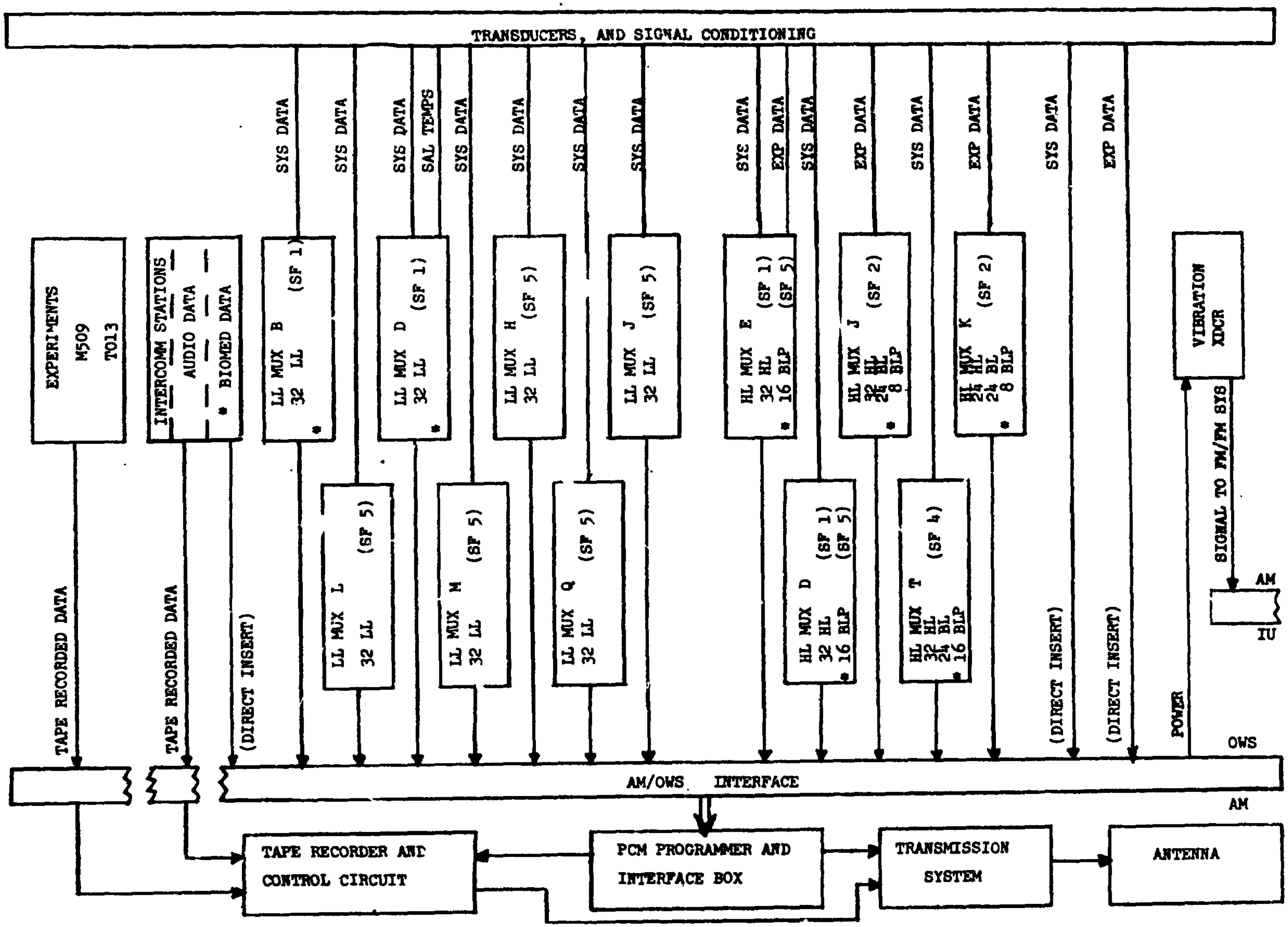
b. The primary objectives of testing was to ensure that the hardware and equipment furnished by MDAC-W fulfilled the objectives delineated in the NASA Mission Requirements Document I-MRD-001A and the requirements of OWS Contract End Item (CEI) Specification CP2080J1C.

c. Development testing was performed to optimize system or component configurations and identify potential areas of marginal design or performance. Hardware utilized during the test program was either prototype or preproduction configurations.

d. Qualification testing was performed to demonstrate that the design and production methods utilized in system manufacture provided a product that fulfilled the design requirements. Qualification tests performed on OWS DAS components are delineated in OWS Test Plan, DAC-56697A.

e. Production testing of MDAC-W fabricated or assembled items and supplier items were tested to product test requirements at either MDAC-W's Santa Monica or Huntington Beach facility, or the supplier's facility.

TELEMETRY SYSTEM SCHEMATIC



*RECORDABLE DATA(SF 1, SF 2, SF 3, SF 4)

f. Post-manufacturing tests were performed at Huntington Beach. They included subsystem and integrated system testing which assured the operation of the PCM system as well as its compatibility with other OWS systems. Huntington Beach testing which verified the OWS DAS subsystem are listed in Table 2.2.8.2-1.

g. Testing at KSC consisted of post-manufacturing subsystem retesting of any changes affecting Huntington Beach checkout test results, and integrated system testing at the module and cluster levels. All testings of the OWS were performed using the DAS. Major tests at KSC are listed in Table 2.2.8.2-2.

2/ Major Problems and Solutions - The OWS DAS underwent extensive testing, design qualification as well as operational, to ensure successful attainment of mission objectives. There were problems encountered and resolved at the various levels of testing (component to cluster). Significant test problems encountered and resolved are delineated in the following tables:

a. Table 2.2.8.2-3 identifies major qualification test problems and solutions.

b. Table 2.2.8.2-4 lists problems encountered during Huntington Beach post-manufacturing tests.

c. Table 2.2.8.2-5 identifies major KSC test problems and their resolutions.

3/ Waivers and Deviations - There were no waivers or deviations to design specifications of the OWS DAS. However, a waiver to the Test and Checkout Requirements, Specification and Criteria (TCRSC) Document, 1B83429, deleted the requirement to verify full

Table 2.2.8.2-1

HUNTINGTON BEACH POST-MANUFACTURING TESTS AFFECTING OWS DAS SUBSYSTEM

Procedure	Nomenclature	Tests
1B66984	Continuity-compatibility	Assures confidence in OWS stage wiring
1B83585	OWS electrical checkout preparation	Pretest - Post test preparation of DAS multiplexer ring buses and interface cable connections.
1B83584	Signal conditioning setup, acceptance test procedure	Verifies measurements that requires setups, ambient checkouts, and those that require special handling. Verification of 5 vdc excitation module.
1B83574	Power setup, IC scan, power turnoff	Verifies multiplexer reference channels.
1B83576	DAS calibration, OWS	Multiplexer verification for encoding and system synchronization.
1B83578	Data acquisition subsystem acceptance test procedure	Performs end-to-end verification of T/M measurement channels, umbilical measurements, display measurements utilizing RACS.
1B835[illegible]0	EMC setup and systems reverification	Verification of critical parameters of OWS to EMC criteria for transients and margin of safety in all systems testing.
1B93589	All system test prep, and securing	Preparation and securing of OWS for all system tests.
1B93591	All system test - activation orbital operations and deactivation	Simulated OWS tests of systems after the insertion phase and during orbital operation.
1B93588	All system test - prelaunch, boost and preactivation	Simulated OWS test of systems for during prelaunch, boost and preactivation period of the OWS.

Table 2.2.8.2-2

KSC TESTING OF THE OWS DAS SUBSYSTEM

Test Procedure	Nomenclature	Test
KO-3018	Meteoroid shield mechanical deployment test	Setup and verification of meteoroid shield telemetry measurements performed as part of testing.
KO-1001	OWS power up support	Accomplished power up and power down of OWS electrical power buses.
KS-0003	AM/MDA/OWS electrical interface test	Routed, clamped, and connected OWS/AM interface electrical harnesses. Verified proper operation of OWS instrumentation system in conjunction with AM PCM system.
KS-0045	AM/MDA/OWS end-to-end system test and experiment test.	End-to-end tests on measurements in conjunction with other system testing in cluster configuration.
KS-0004	SWS to IU interface test	Test verified OWS vibration measurement to IU for telemetry.
KS-0009	SWS operation for SV OAT and SWS mission SIM/FRT.	Simulated mission for functional verification of OWS systems in cluster.
KS-0007	CDDT and CD	Vehicle and ground electrical power support for simulated countdown and actual countdown and launch of AM/MDA/OWS.

Table 2.2.8.2-3

SIGNIFICANT DAS QUALIFICATION TEST PROBLEMS

Component	Problem	Solution
Air Flowmeter (1B78503)	1. The flowmeter shaft broke during qualification test vibration testing.	1. Vibration isolator system was designed and implemented for installation of flowmeter in the duct. Qualification test vibration retesting was successful.
	2. Corrosion on bearings and rust contamination were noted on flowmeter during humidity and life test.	2. Flowmeter gold plating was replaced with hard anodized surface on aluminum parts and bearings were lubricated. Humidity and life tests were completed after correction.
5 vdc Excitation Module (1B79121)	The qualification test unit failed to turn on and meet start-up conditions under high temperature testing condition.	Module was redesigned in the electronics problem area and retested successfully.

Table 2.2.8.2-4

SIGNIFICANT HUNTINGTON BEACH DAS SYSTEM TEST PROBLEMS

Component	Problem	Solutions
DAS Subsystem	During spacecraft testing of the data acquisition systems, per acceptance test procedure (ATP) 1B83578, measurements failed in responding to automatically programmed RACS commands to provide checkout verification levels.	The problem was extensively investigated in both software and hardware areas. All measurements responded to manually initiated RACS commands. During subsequent testing no random failures occurred. As the problem no longer occurred and all possible causes of failures modes were investigated with no explanations, the problem was classified as a phantom. It does not affect the flight performance of the measurements. Although installed for flight, the RACS is used for ground checkout only.

Table 2.2.8.2-5

SIGNIFICANT KSC DAS SUBSYSTEM TEST PROBLEMS

Test	Problem	Solution
KS-0003	During the integrated system test of the PCM system, noise spikes on the digital ground lines caused undesirable multiplexer resets.	Adding of 0.1 μF capacitor between digital ground and case ground of the multiplexer test connector reduced the noise spikes to acceptable levels and the malfunction was corrected.
KS-0008	During post test data analysis of KS-0008 tape recorder dump, loss of sync. was exhibited during the sub-frame 4 portion of the data dump.	Cause of loss of sync. was traced to lack of transitions in the S/F 4 data stream. This problem caused the ground station to have a data lock problem. Correction to the problem was made by adding 28 vdc signal inputs to 7 previously unused bi-level channels of the OWS high level "T" multiplexer. The addition of these 7 inputs provided the transitions to the S/F 4 data stream to correct the problem as verified by subsequent testing.
KS-0009	During visual inspection of the OWS, the multiplexer thermostats, P/N 1B75338, were found to be installed in reverse with the thermostat sensing surface installed away from the multiplexer surface.	Thermal analysis performed to determine the thermal response of the thermostats indicated a 1 degree difference in the temperature switching point of the thermostat as a result of the sensing element being installed away from the multiplexer case. Drawings were changed to permit the installation on OWS-1.

scale readings (100 ±2.4%) of the water level transducers after the completion of filling operations of the water system. This request was made in Devaition/Wavier Request No. MDAC-OWS-WR-33 and was attributed to a marginal operating condition of the transducer which did not warrant any redesign or rework. (Ref OWS DCR RID IC-5).

Several transducers experienced electromagnetic compatibility (EMC) out-of-tolerance conditions during vendor testing. They were 1B78503, Transducer, Flowmeter, Air Duct; 1B78870, Transducer, Pressure Absolute; 1B79315, Transducer Pressure; and 1B86638, Transducer Pressure. Although waivers were considered, the dispositions were deferred until after completion of the Huntington Beach EMC system test. Upon the completion of the Huntington Beach EMC testing the transducers were found to be acceptable under system performance and no waivers were generated.

D. Mission Results

1/ Performance During Launch and Flights - The OWS DAS has successfully supported the SL-1/SL-2, -3, and -4 missions. The telemetered data has enabled the ground recipients (ground controllers, experimenters, design groups, etc.), to perform their work as planned, whereas the on-board displays helped the crew to perform system monitoring while exercising the various equipment. A daily verification of the OWS DAS has demonstrated that the telemetered Instrumentation and Communication (I&C) measurements were performing well within the design limits (±1.5% for high-level and ±2.0% for low-level multiplexers). This is based primarily on the performance of low-level multiplexer reference measurements M7031 through M7044, high-level multiplexer reference measurements M7045, M7057, M7051, M7053, and M7054 and substantiation by the design technologies who continue to be satisfied with the performance of their telemetered measurements.

The 5 vdc excitation modules continue to function satisfactorily and provide proper excitation to signal conditioning modules and transducers as verified daily by the multiplexer reference channel measurements and by technologies evaluating measurements excited by the 5 vdc modules. The instrumentation thermal conditioning system, heater blankets, and thermostats, have provided the multiplexers and fuse modules with proper thermal environments as it can be verified indirectly by successful multiplexer operation and an uneventful power distribution history.

The on-board display measurements have successfully supported crew activities and aided the ground controllers in evaluating TM discrepancies. Ground personnel with the aid of the astronauts, have periodically verified the performance of the on-board displays and correlated the information with telemetry data whenever display data was made available.

Review of flight crew comments did not disclose any complaints in the area of adequacy of the on-board display measurements to monitor the OWS environment and the status of OWS equipment in flight. However, the crew of SL-3 did state that OWS Bus 1 and Bus 2 current measurements had too broad a range.

During crew debriefings, the astronauts stated that the OWS tape recorder control provisions were adequate and enabled them to control the AM tape recorders remotely while performing experiments in the OWS.

2/ System Anomalies - There have been several problems that have affected the system since liftoff. These problems include an anomalous low-level multiplexer, a reference level shift on a high level multiplexer, a number of measurements that were lost as a result of Meteoroid Shield (MS)/SAS wing structural failures, a set of measurements that were affected by the high temperatures in the OWS early in the mission, and a set of measurements that have exhibited noise interference.

a. DAS - L -level "B" multiplexer anomaly. Day of Year (DOY) 215:04:57:50 all of the measurement parameters processed by low-level "B" multiplexer were lost. Since that date all of the parameters have simultaneously randomly cycled on/off. Whenever the parameters are present the data is valid.

In investigating the observed anomaly the following analyses were performed: (a) a thermal analysis of the multiplexer including additional thermal testing at MDAC-E, (b) a detail analysis of the telemetered data, (c) a design analysis of the hardware involved, and (d) a correlation of multiplexer cycling vs. (1) crew activity, (2) position of the spacecraft, (3) and (4) time of day.

The MDAC-E tests and analysis concluded that the most probable cause of a multiplexer failure would be the non-redundant pulse steering diodes used on the counter module inputs. However, the concurrent analyses and data reviews concluded that the problem was not necessarily associated with the multiplexer but it could be an anomaly within the I/B. In order to isolate the malfunctioning components, MDAC-W recommended to have the flight controllers transfer the AM PCM system to

The secondary electronics. This would have isolated the anomaly to either the multiplexer or the AM I/B.

This was not accomplished during the SL-2 and SL-3 mission periods since the lost measurements had backups or related measurements that could be utilized in assessing flight system performance. However, during the SL-4, the AM PCM was switched to the secondary electronics and the multiplexer remained off indicating that the operational anomaly was in the OWS.

The multiplexer data continued to randomly cycle on/off and the source of the problem was not conclusively defined although the most probable cause of the problem is suspected to be the multiplexer.

b. Meteoroid Shield (MS) - Approximately 63 seconds into SL-1 flight the MS was lost which severed the instrumentation wire harnesses required by 9 analog and 3 bi-level MS measurements. However, loss of these measurements had no mission impact since these sensors were used to monitor the status of the lost shield.

c. Solar Array System (SAS) - Approximately 593 seconds into the SL-1 flight, the SAS Wing No. 2 structural failure occurred which severed the instrumentation harnesses required by 13 analog, and 2 bi-level measurements. Loss of these measurements had no mission impact since these sensors were used to monitor the status of the lost wing.

d. Thermal Control System (TCS)

1. F7005-436; Flow, Ventilation Control System (VCS), Duct 1,

(TM) - On DOY 147, between 0322 and 0344 Greenwich Mean Time (GMT) the measurement failed to provide any flow data. Consequently, MDAC-E Engineering performed a number of studies that included (a) a design analysis of the hardware, (b) a failure history of the part, and (c) a thermal analysis relating to the high temperatures experienced during the first two days of SL-1.

Studies (a) and (b) did not provide an explanation for the failure; however, a thermal analysis of the first ten days of the SL-1 mission revealed that the flow-meters were exposed to higher than designed thermal environments. This, plus the observed behavior of the measurement during the six (6) hours prior to the failure, indicated that the most probable cause of the malfunction was a random failure of the converter, initiated by the adverse thermal environments during the initial phase of SL-1.

Loss of this measurement had a minimal impact on the mission since there are on-board displays that can be used by the crew to verify flow status on Duct No. 1.

2. F7001-436; Flow, VCS Duct 2 - On DOY 228:1548 GMT the telemetry measurement for VCS Duct 2 flow showed a degradation while the on-board display measurement showed readings consistent with normal system operation.

Data reviewed since for SL-2 and SL-3 indicate a degradation of approximately ±5% compared to the Duct 2 on-board display equivalent.

During SL-4, the measurement showed increased erraticity after turn-on and turn-off of duct fans. On DOY 29, the measurement level dropped sharply to zero level and remained zero through the end of the mission. During these periods, the on-board display indicated Duct 2 flow to be normal.

During qualification testing, the transducer encountered flow degradation due to bearing contamination. Although the transducer was finally qualified using bearing lubricant in its life test, it is believed that this anomaly was caused by some type of bearing contamination.

A comparison of this data to qualification test data disclosed that during qualification testing there was a similar flow degradation as a function of time due to bearing contamination. It is believed that this anomaly was caused by some type of bearing contamination.

3. M7058-440, Current, TCS Duct Heater, indicates current to the heater elements when the heaters are off. Review of the mission data indicates that measurement M7058 increases/decreases at M7005 increases/decreases. This tracking phenomenon began on DOY 156, between 10:50 and 11:20 GMT.

A detailed analysis of the current sensor, thermal control assembly, the multiplexer and system harnesses was performed. The analysis was inconclusive since it was impossible to isolate the anomalous device without additional information. If the crew were to perf--- an

"OWS TCS Check" procedure (ref. SWS System Checklist), additional fault isolation information could be obtained by comparing the results with available data. However, this anomaly has no mission impact.

e. Pressure Control System (PCS)

1. D7125-422; Press Waste Management Compartment (WMC) H_2O Dump Line - On DOY 210, at approximately 13:45 GMT, the crew reported that the display measurement was off scale high. This measurement system consists of a sensor and a deflection type display meter.

   A failure mode analysis was performed on the meter and the sensor. The analysis revealed that the most probable cause of the failure was within the sensor. The failure was either a contamination of the particulate filter to the pressure sensing cavity or an electronic component degradation or failure affecting the circuit gain or zero level. Loss of this display measurement had a minimal impact on the mission.

2. D7112-436; PCS Habitation Area (HA) Low Range Sensor 2 (TM) - On DOY's 164, 173, and 187, the subject measurement exhibited level changes which differed when compared with OWS Measurement D7111 and AM/MDA Measurements D0218 and D0002. Investigation revealed that the observed shifts may have been due to a performance degradation of the transducer.

   Degradation of the measurement had a minimal impact on the mission, since the redundant measurement (D7111) was used to monitor the pressure of the HA.

f. Van Allen Belt Dosimeter (VABD) - P7001-440; VABD Skin Dose Rate - On DOY 165, at approximately 1750 GMT, the measurement exhibited cyclic excursions of approximately 10 seconds in duration and about 0 to 12 percent of full scale at a repetition rate of 20 seconds. The same anomaly was observed for Measurement P7002; VABD Depth Dose Rate. On DOY 165 the VABD was replaced by a spare unit. The spare also exhibited the same anomaly.

The anomalies appeared for the first time when the Command Service Module (CSM) was powered from the AM buses and returned to normal when the CSM was transferred from AM bus power to its own power again. The CSM Inertial Measuring Unit (IMU) heater cycles correspond exactly in time with the VABD data excursions. These anomalies were concluded to be caused by the Skylab and CSM generated electromagnetic interference (EMI).

Although the measurements were degraded, the dosimeters were responding to radiation and the data was considered usable.

g. High-level "J" Multiplexer Reference Channel - Starting with DOY 011 during the SL-4 mission, the high-level "J" multiplexer reference channel, M7053-411, was observed to go out-of-tolerance. The measurement level expected was 4.763 vdc to 4.901 vdc with 4.842 vdc as nominal and the out-of-tolerance observed was as high as 4.960 vdc.

Investigation and analysis was performed which indicate the most probable cause to be a signal return reference level shift of the measurement as a result of common mode voltage level changes at the low-level signal return bus. Extensive review of data has not revealed the contributing cause of the anomaly to a specific fault. However, the data indicates the following:

1. Other multiplexers, both high and low, and their data have not been affected by the anomaly.

2. There is no correlation between CWS and AM bus load changes versus measurement level changes which indicates the problem is not associated with major power components.

3. There is no correlation between DCS command or crew activity and the reference measurement level changes which indicates the same as Item 2 above as well as no RF interference.

4. Only two measurements on high-level "J" multiplexer, M7053-H/L "J" reference, and D7137-ESS ambient pressure, are affected by the ground reference shift. Other measurements on high-level "J" are not affected because the measurements do not receive transducer excitation from the 5 vdc excitation module or utilize the low-level signal return bus as does the affected measurements. Level shifts on D7137 are of the same magnitude as M7053 and, therefore, can be scaled utilizing correction equal to the percent change of the reference voltage.

5. The anomaly is not detrimental to the operation of the instrumentation components.

E. Conclusions and Recommendations

1/ Conclusions - The overall performance of the OWS DAS throughout the Skylab mission was acceptable. The OWS TM multiplexers and their assigned measurement parameters provided information to ground control and responsible system technologies for continued monitoring and evaluation of system performances. Display measurements which provided the astronauts with on-board real time monitoring of critical functions were adequate. The astronauts were able to assess system performance to a higher degree of confidence.

Despite the failure encountered by the low-level "B" multiplexer data, optimization of reliability through distribution of a system measurement to separate multiplexers avoided the total loss of data from any one particular system.

Components of the OWS DAS had acceptable performance over the Skylab mission periods.

2/ Recommendations - Although perfo[illegible]nce of the OWS DAS was acceptable throughout the Skylab mission, there are still areas where recommendations can be made to improved on system shortcomings or program deficiencies. They are delineated below.

a. The OWS DAS instrumentation panels located in the OWS forward skirt area should be provided with temperature measurements which measure the panel thermal environment. The failure associated with the low-level "B" multiplexer made it necessary to base thermal environment predictions for the multiplexers on analytical values rather than direct measured values. Since these instrumentation panels contain the major portion of the components of the data system, the actual measured temperature environment would provide a fundamental assessment of the actual thermal environments of the system's major components.

b. The OWS instrumentation and heater power buses should be instrumented for current monitoring. Many of the system analyses performed during the mission required such measurements. Load current changes are very significant analytical data in evaluating system performance or anomalies.

c. The design of the OWS DAS was basically the Gemini design which required that all multiplexers to be operating during the entire mission. Consequently, a large quantity of unnecessary data was produced. Future space missions similar to Skylab should incorporate a data management system so that measurements required only for boost, deployment and initial activation (i.e., Exploding Bridge-wire (EBW), position, events, etc.) would be deactivated after their usefulness. On-board data compression would be another method of implementing better data management. These approaches would reduce the quantity of data, speed up the data processing, enable better quality control of the data and allow for the data to be disseminated in a more timely manner.

d. One of the limitations of the DAS was the lack of continuous ground station coverage in order to provide continuous real time crew/ground communications and parameter monitoring. Several times during the mission, including manned periods, there was only one short station pass during an entire orbit (approximately 90 minutes). Although crew activities, such as EVA, etc., can be constrained and scheduled for orbits providing a greater ground station time; anomalies cannot. It is, therefore, recommended that any future Skylab type missions consider the possibility of continuous ground station coverage (e.g., via satellite relay, etc.).

e. The OWS DAS could increase its data acquisition versatility, especially within the OWS HA, by having remote interface panels with patching-type connections or connectors for accessing the unused multiplexer channels. The usefulness of this concept was made obvious by the addition of new equipment, work-around, and anomalies which made it necessary to accommodate additional data during the Skylab missions.

F. Development History - The OWS Data Acquisition System evolved from the requirement to provide real time and delayed time monitoring of subsystem flight parameters as well as biomedical and scientific experiment data to ground tracking stations of the Spaceflight Tracking and Data Network (STDN). Crew monitoring of basic subsystem functions with on-board displays was also defined as requirements.

Initial design of the Data Acquisition System was begun with the "wet" Saturn I Workshop (SIW). Early Workshop proposals were made to utilize the telemetry system (consisting of an RF system, Model 301 PCM Assembly, Model 270 multiplexers, and remote analog and digital submultiplexers) that existed on the Saturn IV-B booster. However, during trade-off studies it was decided that the telemetry system used on the Gemini program and proposed for the Airlock Module would also be used for the workshop. The telemetry system on the workshop was to be designed as an extension of the Airlock Module Gemini-used system with Gemini high level and low level multiplexers located remotely on Workshop for inflight data processing. The trade-off studies indicated that the Gemini used telemetry system had the advantages of much less power consumption, proven long duration use in Gemini missions, and was smaller and more versatile in sampling rates.

Only those components which can withstand the LH_2 cryogenic environment, such as cablings, connectors, distribution junctions, and temperature transducers were to be installed within the habitation area for lift-off.

Other electronic components were to be installed in the multiple docking adapter for crew "carry-in" into the habitation area after LH_2 tank passivation.

Subsequently, design changeover from a "wet" workshop to a "dry" workshop was made. One transition criterion was to minimize system redesign. This fact, together with the "designed-in" limitations (i.e., restrictions due to flammability, outgassing and odor) of the existing Gemini multiplexers, prohibited their installation within the OWS internal cavity. However, the design of other OWS instrumentation hardware (such as on-board displays, vibration transducers, habitational pressure transducers, and water level sensors), permitted their usage within the habitation area.

Individual timing signal lines to each Gemini multiplexer located on the OWS were initially considered but this would have significantly increased the number of wires crossing the Airlock Module/OWS interface. Hence, the "ringed" bus circuits were conceived and implemented. To increase the system reliability, signal redundancy is provided across the Airlock Module/OWS interface, through two separate connectors, for each "ringed" circuit.

Early design concepts were based on locating two multiplexers in the aft skirt area of the OWS. However, due to timing signals being affected by increased long line capacitance to the aft skirt area, all multiplexers were located in the forward skirt area.

They were not located in the habitation area for the same basic reason, in addition to not being qualified for flammability, outgassing and odor.

Thermal conditioning is provided for the OWS multiplexers and the fuse modules. Thermal conditioning consists of heating pads under the modules with power to the heaters being controlled by thermostats. In this manner, the component low temperature operating limits are not exceeded. Active thermal conditioning for panels (cold plates) were considered. However, the cost was considered prohibitive with respect to benefits derived.

Temperature bridge module excitation voltage source used on the S-IVB "mainline" program was considered in an effort to use proven hardware of other programs. However, the use of Gemini-type multiplexers restricted its use. Since the "mainline" S-IVB used temperature bridges, an excitation voltage of +20 vdc caused the bridge output signal to exceed the Gemini type low level multiplexer requirement of a maximum unbalanced common mode voltage limit of six volts. Therefore, the 5 vdc excitation module for temperature bridge excitation (used for other 5 vdc excitation measurements also) was designed and developed.

To minimize the total loss of telemetry data from a subsystem, the telemetry channelization of the subsystem is optimized for reliability. Measurements for each subsystem are distributed among the various multiplexers and related measurement parameters are assigned to separate multiplexers whenever possible. Also, for data reliability optimization, excitation voltages for measurements of each subsystem come from two separate power sources.

2.2.8.3 Command System

A. Design Requirements

1/ General Requirements - The Orbital Workshop (OWS) Command System shall provide for relaying Instrument Unit (IU) initiated commands to various Saturn Workshop (SWS) subsystems during the unmanned activation phase of the SWS mission profile. Backup control for these commands via the Airlock Module (AM) Digital Command System (DCS) shall also be provided.

2/ Detail Requirements - In addition to the common Electrical Power System (EPS) design requirements (Paragraph 2.2.6), the OWS Command System (which is comprised of the switch selector (sw/sel), the AM DCS, and the relays that control subsystems) shall comply with the following requirements:

a. Switch Selector Requirements

1. Commands for operation of the OWS switch selector shall be provided by the IU across the IU/OWS interface, and the verification of receipt of command by the OWS switch selector shall be returned to the IU at the IU/OWS interface.

2. The command requirements defined at the switch selector input terminals are presented in the following subparagraphs.

(a) The switch selector shall operate with stage select, register address, reset, and read command pulses of 18.3 to 32.0 vdc amplitude.

(b) The command pulse shall have the following durations:

COMMAND	PULSE WIDTH
Stage select	$14.5 ^{+3.5}_{-0}$ milliseconds
Register address	$14.5 ^{+3.5}_{-0}$ milliseconds
Reset	$12.5 ^{+2.5}_{-0}$ milliseconds
Read	$25.0 ^{+3.0}_{-0}$ milliseconds

(c) The switch selector dc input impedance shall be as follows:

COMMAND	SWITCH SELECTOR INPUT IMPEDANCE
Stage select	242 ± 5% ohms at 25°C
Register address	725 ± 5% ohms at 25°C
Reset	630 ± 5% ohms at 25°C
Read	210 ± 5% ohms at 25°C

The impedance values specified shall increase by a maximum 10 percent for each 25°C increase in ambient temperature.

3. The switch selector shall provide a maximum of 112 output channels. The selection of a particular channel shall be automatically determined from the 8 bit input register address, or its complement. The selected channel shall provide a pulse output within 7.0 milliseconds after receipt of a read command.

4. The voltage output shall not be less than 3.0 volts below the switch selector input power voltage of 24.0 to 30.0 vdc.

5. The pulse duration shall be 27.5 $^{+0.5}_{-2.5}$ milliseconds.

6. The switch selector shall provide eight (8) outputs for address verification. These lines shall convey the complement status of the address register within 20 milliseconds after receipt of a stage select command.

7. The switch selector shall provide a register test output. The output shall occur whenever the input register address contains all "ones", and shall be present within 7.0 milliseconds after, and for the duration of a read command.

8. The switch selector shall provide a zero-indicate test output. The output shall occur whenever the input register address contains all "zeros". A read command shall not be required for a zero indicate output.

C-4

9. The switch selector shall provide an output pulse proportional to the number of output channels switched on at any given time. The output pulse voltage shall be in accordance with the following tabulation:

NO. CHANNELS SIMULTANEOUSLY ON	SWITCH SELECTOR INPUT POWER VOLTAGE	MONITOR OUTPUT VOLTAGE
None	24-30 vdc	$0.2 ^{+0}_{-0.2}$ vdc
One	24-30 vdc	2.0 ± 0.4 v pulse
Two or more	24-26 vdc	$2.8 ^{+0.2}_{-0}$ v pulse
Two or more	26-30 vdc	$3.0 ^{+0.2}_{-0}$ v pulse

NOTE: Two or more channels switched on simultaneously represents an abnormal or malfunction condition.

10. With the exception of a stage select command, the switch selector shall internally reroute all power and commands received from the IU.

11. The eight (8) address verification lines shall be routed to the IU/OWS interface. The maximum voltage drop and loading shall not exceed 0.2 volts at 120 milliamps.

12. The switch selector output signals shall be monitored by the AM PCM Data Acquisition System.

13. The following list identifies the measurements that shall be used to evaluate the performance of the OWS switch selector.

K0005-602	Event-SW Sel Stage Select
K0006-603	Event-SW Sel Read Command
K0008-603	Event-SW Sel Register Verify
M7014-411	Volt-SW Sel Output Telemetry (T/M)

14. The switch selector Register Test shall be routed through the OWS forward umbilical for GSE monitoring.

b. Digital Command System Command and Control Requirements

1. Backup control of OWS Command System relays shall be provided by circuits in the OWS which are an extension of the AM DCS. AM DCS channel assignments shall be controlled by Interface Control Drawing (ICD) 50M16141, AM Digital Command System Radio Frequency Command List.

2. The command voltage levels at the AM/OWS interface shall be 25.5 to 30.0 vdc.

3. The command signal shall be a 200 $^{+48}_{-46}$ msec pulse from the AM DC controlled relays.

4. The AM DCS Radio Frequency (RF) signal shall be routed to Ground Support Equipment (GSE) through the OWS forward umbilical by means of a 50 ohm coaxial cable.

5. Cabling shall be provided between the AM/OWS and the OWS forward umbilical for control of the DCS RF path to either RF or hardline.

6. Cabling shall be provided between the AM/OWS and the forward umbilical to inhibit the application of power to the AM DCS.

c. Command System Load Characteristics

1. Maglatch and general purpose relays shall be provided to transfer the OWS Command System outputs to the subsystems being controlled.

2. The characteristics of the OWS Command System pulse outputs shall be as follows:

	AMPLITUDE	DURATION
SWITCH SELECTOR	21 to 30 vdc	25 to 28 milliseconds
AM DCS	21 to 30 vdc	154 to 248 milliseconds

3. The general purpose relay normally-open contacts shall be fully closed for a minimum of 20 milliseconds for a switch selector output and 149 milliseconds for an AM DCS command.

4. ATM and MDA command and control signals, switched and returned to the AM for control of Apollo Telescope Mount (ATM) and Multiple Docking Adapter (MDA) functions, shall have line resistance less than 250 milliohms.

B. System Description

1. General Description - The OWS Command System was designed to provide commands to various OWS subsystems and to control certain AM, ATM, and MDA functions. The design utilizes the Saturn - IVB (S-IVB) Switch Selector and, as in the S-IVB operation, receives command input logic across the IU/OWS interface from the Launch Vehicle Digital Adapter (LVDA) in the Instrument Unit (IU). General purpose and magnetic latching relays are utilized to load the command drives of the Switch Selector. The Airlock Module Digital Command System (DSC) is used to provide backup commands to the systems controlled by the OWS Switch Selector during the Unmanned Activation Phase and control other subsystems during other mission phases. The latter DCS capability, which is essentially the ground control of OWS systems, is discussed in more detail in the system description where it applies.

2/ Detail Description - The OWS Command System was designed as a functional part of the IU and AM Digital Command Systems and consists of one switch selector, maglatch and general purpose relays, diode modules, and interconnecting harnesses. The part numbers of the major components are as follows:

PART NO.	TITLE
1B65319	Switch Selector Assembly
1B77691	Relay Module, General Purpose
1B78535	Diode Module
1B79710	Relay Module, Magnetic Latch
1B79769	Relay Module, General Purpose

a. Switch Selector

1. The Switch Selector Government Furnished Property (GFP) consists of electromechanical components which decode digital flight sequence commands from the LVDA/LVDC and activate the proper stage circuits to execute the commands. It is provided redundant dc power via two separate buses from the AM through 3.9 ampere circuit breakers and diode isolation circuits.

2. The Switch Selector is designed to execute flight sequence commands selected by the 8-bit code or by its complement. The flight sequence commands are stored in the Launch Vehicle Digital Computer (LVDC) memory and are issued according to the flight program. The switch selector decodes the commands and activates, one at a time, 112 different pulse circuit outputs (27.5 msec nominal) which control mag-latch or general purpose relays in various subsystems.

3. During the Unmannded Activation Phase, the switch selector provided commands for the following operations:

   - Refrigeration System (RS) Radiator Protective Shield Jettison
   - Habitation Area Venting
   - Waste Tank Venting
   - Meteoroid Shield Deployment

- Solar Array System (SAS) Deployment
- Thruster Additude Control System (TACS) Control Transfer (IU to AM)
- Payload Shroud Jettison
- MDA Venting
- ATM Activation

4. To maintain power isolation between vehicle stages, the Switch Selector is divided into two (2) sections: The input section (relay circuits) of the Switch Selector receives its power from the IU; the output section (decoding circuitry and drivers) of the Switch Selector receives its power from the AM. The input and output are coupled together through a diode matrix. This matrix decodes the 8-bit input code and activates a Positive Negative Positive (PNP) output driver, thus producing a Switch Selector output.

5. The Switch Selector is connected to the IU through 22 lines:

Stage Select Lines	- 2
Read Command Lines	- 2
Reset (forced) Lines	- 2
Bit Register Output Lines	- 8
Verification Lines	- 8

In addition, there are 22 lines for IU + 28 vdc and 2 lines for signal return between the IU and the Switch Selector.

6. The wire pairs for stage select, read command, forced reset, IU + 28 vdc, and signal return are redundant. Only one of each pair is required for normal operation.

7. The output signals of the LVDA switch selector register, with the exception of the 8-bit command, are sampled at the Control Distributor in the IU and sent to IU Pulse Code Modulation (PCM) telemetry (T/M). The Switch Selector also provides outputs to telemetry.

8. The following list identifies the measurements that will be used to evaluate the performance of the OWS Switch Selector:

MEASUREMENT NO.	TIME
K0005-603	Event - Sw. Sel. Stage Select
K0006-603	Event - Sw. Sel. Read Command
K0008-603	Event - Sw. Sel. Register Verify
M7014-411	Voltage - Sw. Sel. Output T/M

The above noted measurements convey the following information:

(a) K0005-603: This measurement uses telemetry channels DP1A0-13G00-01 through -04 to identify which of the four (4) Skylab Switch Selectors have been addressed (i.e., the SIC Sw. Sel., the SII Sw. Sel., the IU Sw. Sel., or the OWS Sw. Sel).

(b) K0006-603: This measurement uses telemetry channels DP1A0-13G00-06 to identify when a read command has been sent to the Switch Selector. A Switch Selector pulse output is provided within 7.0 milliseconds after receipt of a read command.

(c) K0008-603: This measurement uses telemetry channels DP1A0-14G00-01 through-08 to identify which of the 112 Switch Selector channels has been selected.

(d) M7014-411: This measurement provides an output voltage which is proportional to the number of output channels switched on at any given time in accordance with the following tabulation:

NO. CHANNELS SIMULTANEOUSLY ON	SWITCH SELECTOR INPUT POWER VOLTAGE	MONITOR OUTPUT VOLTAGE
None	24-30 vdc	$0.2\,^{+0}_{-0.2}$ vdc
One	24-30 vdc	2.0 ± 0.4 v pulse
Two or more	24-26 vdc	$2.8\,^{+0.2}_{-0}$ v pulse
Two or more	26-30 vdc	$3.0\,^{+0.2}_{-0}$ v pulse

NOTE: Two or more channels switched on simultaneously represents an abnormal or malfunction condition.

b. Diode Modules - The Switch Selector is provided redundant power from AM buses #1 and #2 via two (2) separate diode modules to satisfy the physical isolation requirement between buses. The diodes used in the module (Part No. S1N1204A) will conduct an average current of 12 amperes and can stand a reverse voltage of 400 vdc, thus assuring electrical isolation of the 28 vdc buses.

c. Relay Modules - The relay modules used in the command system output circuitry were the 1B79710-1 10 ampere maglatch relay module and the 1B79769-1 10 ampere general purpose relay module. Test data on these modules verified that the relays will operate satisfactorily over the range of 21 to 33 vdc. Since the contact-release time of the general purpose relays was equal to/or greater than the pull-in time in all cases, the requirements (2.2.8.3A.2c) of being fully closed for 20 msec with a 25 msec duration switch selector command and 149 msec with a 154 msec duration command from the AM DCS were achieved.

C. Testing - The objectives of the test program were to (1) perform all tests necessary to verify flight readiness of the Command System hardware, and (2) demonstrate that the Command System design and components fulfill the requirements of the Contract End Item (CEI) Specification CP2080J1C.

1/ Qualification Tests - The qualification test line items (DAC-56697) associated with the Command System were CS-3, Structural Mounted Console Components, and ES-11, OWS Relay Modules.

Line item CS-3 tested the Junction Module Assembly, 1B79020-1 and -501. The module was subjected to high and low temperature testing, functional testing, and vibration testing. The module was qualified to the humidity requirements by line item ES-7. The qualification test units were identical to the flight modules; no command system hardware malfunctions or anomalies occurred. A detailed test definition is provided in Test Control Document 1T16838. The test results were published in technical memorandum TM-DSV-7-EE-R7028, dated 11-14-72.

Line Item ES-11 tested the following OWS relay modules which were used in the Command System:

PART NO.	PART NAME
1B79710-1	10-amp Maglatch Relay Module (bused)
1B77691-1	10-amp General Purpose Relay Module
1B79769-1	10-amp General Purpose Relay Module (bused)

Testing verified that all of the above relay modules, which were identical to the flight hardware, would satisfactorily survive high and low temperature cycles, vibration, and shock. A detailed test definition is provided in Test Control Document 1T16839. The test results were published in technical memorandum TM-DSV-7-EE-6943 dated 4-11-72.

The switch selector was provided to the OWS as GFP. Detailed qualification of this component for use on the OWS is provided by the following documents:

IBM Report 66-373-001

TM-DSV-4B-(SSL)-EE-R-554-3

MSFC 46M51488

IBM Report 66-544-068

IBM Report 373-66644-15

TM-DSV-4B-ENV-R-5574-2

2/ Vehicle Checkout Laboratory (VCL) Tests - Postmanufacturing tests performed in the VCL assured performance of the Command System prior to shipment of the OWS to Kennedy Space Center (KSC). System wiring and interfaces, switch selector operation, and the command capability via the DCS or umbilical were validated by the following tests.

a. 1B66984 Continuity - Compatibility

RESULTS: The majority of the problems were procedural. No command system problems identified.

b. 1B83574 Power Setup, IC Scan, Power Turnoff

RESULTS: Three hardware problems; none were Command System related.

c. 1B83580 Meteoroid Shield and SAS Exploding Bridge Wire (EBW) Subsystem

1B84786 Refrigeration System Activation, Operation and Securing

1B83589 Thermal Control and Ventilation

1B83582 TACS Checkout

1B86961 Refrigeration System Elect Preps

1E90960 Leak and Functional Checks - Pneumatic Control, Habitation Area and Waste Tank, OWS

RESULTS: Command System functions were required to exercise the above systems during the tests. No Command System problems were identified.

d. 1B83590 Electromagnetic Compatibility (EMC) Setup and Systems Verification

RESULTS: No Command System malfunctions occurred. In addition, the test indicated that the Command System did not generate EMI and was not susceptible to EMI.

e. 1B93589 All System Test Prep and Securing

1B93591 All System Test - Activation, Orbital Operations and Deactivation

1B93588 All System Test - Prelaunch, Boost and Preactivation

RESULTS: No Command System problems were identified during All System testing.

Detailed descriptions of all of the above tests and test results are documented in MDAC Report G3069, Report, Orbital Workshop Checkout, Vehicle Checkout Laboratory (VCL), dated November 1972.

3/ KSC Tests - During the subsystem and all-system testing at KSC the Command System was used extensively to exercise the OWS subsystems. The tests which were primarily associated with the OWS Command System operation were as follows:

KS-004 Saturn Workshop (SWS) to IU Interface Test - This test verified switch selector interfaces and operation of all channels except 108 and 109, radiator shield jettison, which were verified by deviation to KS-0008.

KS-0009 SWS Operations and Space Vehicle Overall Test Mission Simulation/Flight Readiness Test (Sim/FRT) - This test (a) verified IU/SWS interface compatibility in a simulated flight mode; (b) exercised Skylab-1 (SL-1) countdown and countup functions, and (c) demonstrated electromagnetic compatibility between the individual SWS systems.

KS-0045 SWS End-to-End Systems Test and Experiment Test - This test verified OWS control circuits, ordnance circuits, and other Command System interfaces.

No major problems or anomalies were identified during these tests and no waivers or deviations to either the hardware design or test requirements were required.

D. Mission Results - The OWS Command System successfully supported the boost and deployment phases of the SL-1 mission. The OWS installed hardware performed well as assessed by the performance of the OWS Switch Selector and the response of the subsystems commanded by it.

The predicted event times compared nominally with the actual event times as assessed by the response of the Switch Selector measurements. The only anomaly associated with the command system relates to the Switch Selector data reduced from the Apollo Range Instrumentation Aircraft (ARIA) which was approximately 60 seconds ahead of the predicted times. A subsystem response data review verified that the actual commands got to the end-items at predicted times. Further evaluations and data reviews indicated that the most probable source of the timing error is either in the code generator of the ARIA or in the data reduction area.

The CWS Switch Selector was inhibited at approximately 10 hours and 30 minutes into the flight of SL-1.

E. Conclusions and Recommendations - Indications are that the Command System provided acceptable performance throughout checkout, launch, boost and the unmanned activation portion of the Skylab mission. This conclusion is based on telemetry data and the fact that no subsystems controlled by the Command System experienced any malfunctions which could be attributed to the Command System.

The Command System design was not unique to the Skylab program. As mentioned previously, the design is the same as that used on the Saturn stages for several years and has exhibited high reliability. In addition, the ATM command and control system includes four (4) switch selectors which are required to operate the entire mission duration; no malfunctions or anomalies have been identified at this time.

Therefore, on future space programs where there is a requirement for programmed control it is recommended that this same design concept, switch selector control with DCS backup, be incorporated.

The DCS command capability has been used effectively for control of Skylab subsystems during both manned and unmanned portions of the Skylab mission. A recommendation for future space vehicle designs would be the incorporation of remote panels with patching-type connector capability which could provide an interface between the DCS and some subsystem requiring a capability which resulted from an anomaly or a re-evaluation of the requirements. This capability would increase the DCS command versatility and might have eliminated much of the new equipment and work-arounds which were required during the Skylab missions.

F. Development History - The initial concept for the Electrical Command System, during the change-over from a "wet" to a "dry" Workshop, was to have the IU Switch Selector issue commands directly to the OWS for the functions required for the first 7.5 hours of the mission (launch and orbit phase). The AM DCS would be utilized to provide backup or redundant commands for the IU DCS.

As more of the OWS command requirements were identified, it became evident that the existing IU Switch Selector did not have sufficient spare channels to accommodate the OWS functions. Therefore, the existing concept of the S-IVB booster control system, which utilized a GFP switch selector controlled/commanded by the IU Launch Vehicle Digital Computer, was retained for the "dry" OWS Electrical Command System. The AM DCS would still provide backup or redundant control.

The IU/S-IVB system had an extremely reliable flight history. The only modification incorporated for the OWS system was to provide redundant isolated AM power (power from AM 1 and AM 2 buses) to the switch selector in lieu of a single power source.

2.2.8.4 Television System (TV)

A. Design Requirements

1/ General Requirements

a. The Orbital Workshop (OWS) TV System shall be an integral part of the overall Skylab TV System. It shall include three (3) TV Input Stations and interconnection system cablings. The TV Input Stations shall be located as follows:

Location (General)	No. of Stations	View Requirements
Forward Compartment	1	View performance of experiments M509, T013, and T020.
Three feet forward of sleep compartment ceiling on forward compartment wall	1	View performance of experiments M509, T013, and T020
Ceiling of experiment compartment		View subject of bio-medical experiments

b. The TV Input Stations shall provide means of connecting the portable TV camera, defined in Interface Control Drawing (ICD) 50M16154, to the OWS video bus.

2/ Detail Requirements

a. Power

1. Power for the TV System shall be from OWS Buses 1 or 2 to each of the three (3) TV Input Stations.

2. Characteristic details of the power source for the TV Input Stations shall be defined in the Electrical Power Distribution System paragraphs 2.2.6.1, 2.2.6.2, 2.2.6.3, and 2.2.6.5.

b. System Provisions

1. The TV Input Stations, Part Number (P/N) 82000003800, shall be provided as Government Furnished Property (GFP) for installation in the OWS.

2. Each station shall have an ON/OFF power switch.

3. The video bus from the Airlock Module (AM)/OWS interface to the TV input stations shall be 93 ohms coaxial cables.

4. The OWS TV Input Stations shall be connected such that the activation of a TV Input Station shall connect the video signal bus line of the TV System to the activated station and disconnect the video signal bus line to TV Input Stations further removed from the AM/OWS interface.

c. Interfaces - The OWS TV System interfaces are defined by the folloiwng interface Control Documents:

o 40M35594 - Orbital Workshop to Airlock Module Electrical Interface

- o 50M13149 - TV Input Station to Airlock Module and Orbital Workshop Interface
- o 50M16154 - Portable Television Camera Assembly to Saturn Workshop
- o 50M16132 - Skylab Orbital Assembly Television System Requirements

d. Common Electrical Requirements - Requirements imposed on TV System such as flammability, contamination, grounding, bonding, etc. which are imposed on all electrical subsystems are defined in paragraph 2.2.6.

B. System Description

1/ General Description

a. The OWS TV System is an extension of the Skylab TV System. It provides accommodations for the transmission of real time television data from the OA to the manned Spaceflight Network (MSFN) when the Command Service Module (CSM) is docked to the Saturn Workshop (SWS). All TV transmissions are made through the CSM Unified Sideband (USB) data transmission link.

b. The OWS TV System consists of three (3) TV Input Stations and associated interconnecting cabling which accommodates the connection of the portable color TV camera equipment to a video bus to provide video coverage of crew activities, equipment operation, and experiments in the OWS.

2/ System Details

a. Power

1. The TV Input Stations in the forward dome and the experiment compartment are powered from OWS Bus 2 through 6 amp circuit breakers.

2. The TV Input Station in the forward compartment wall is powered from OWS Bus 1 through a 6 amp circuit breaker.

   o Refer to Figure 2.2.8.4 for circuit details.

b. System Provisions

1. Only one TV Input Station can be operating with a portable TV camera at any one time. The TV camera is an Apollo color camera with a 30 foot (9.144 meter) cable.

2. TV coverage will be provided for Workshop tour, system housekeeping and experiment operations.

3. Refer to Figure 2.2.8.4-1 for circuit details.

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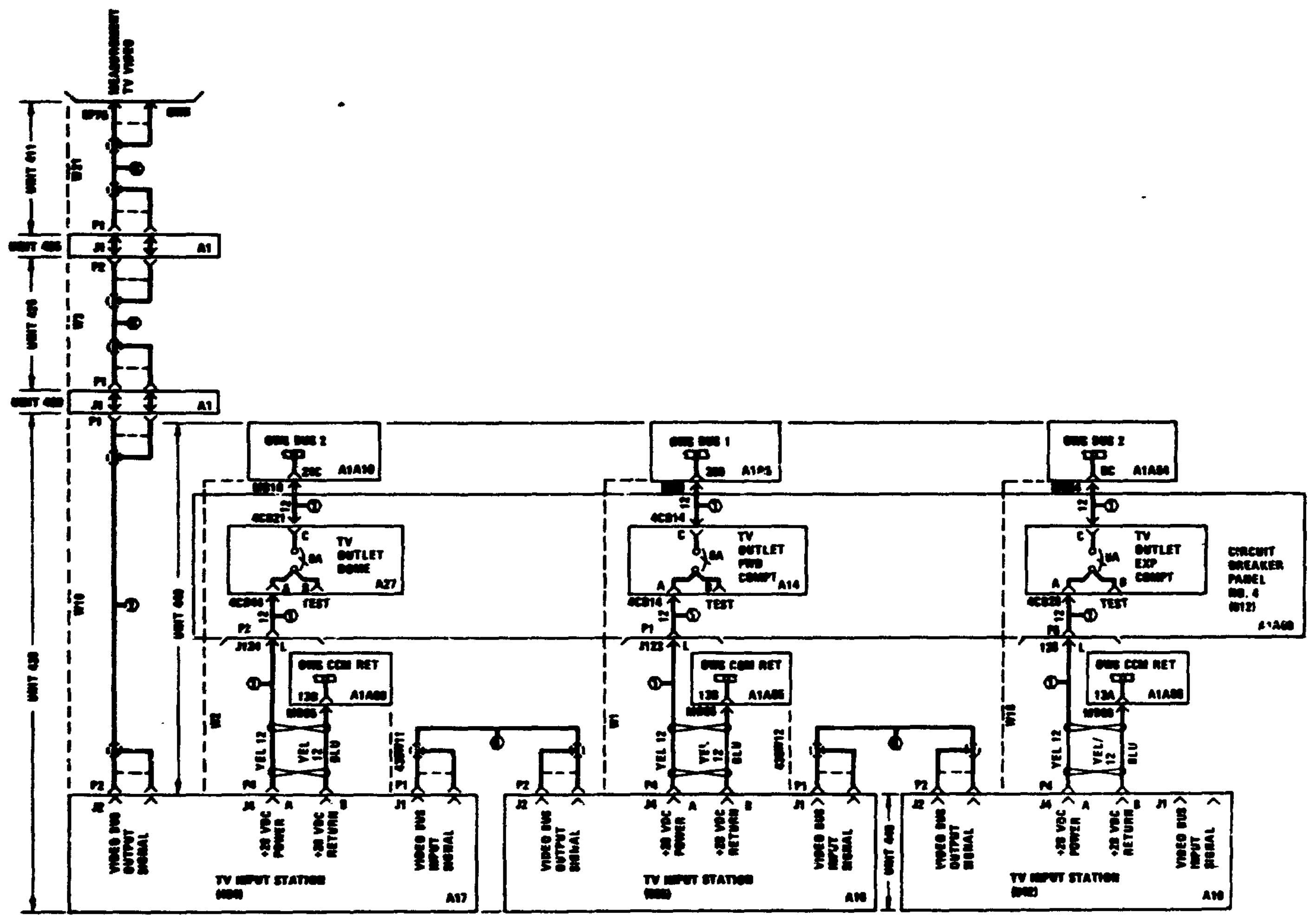


Figure 2.2.8.4-1

C. Testing

1/ Testing Program

a. There were no Orbital Workshop Test Plan, DAC-56697A, line items prepared by MDAC-W for development testing of components used in the TV System.

b. The TV Input Station is provided as GFP for installation as part of the OWS TV System. The TV Input Station was qualification tested by Martin-Marietta (MMC) - Denver and the results documented in MMC Environmental Laboratory Test Report No. 3278.

c. As the OWS TV System consists of the TV Input Stations and interconnecting cable harnesses, production testing involved verification of the cable harnesses. The TV Input Stations were production tested by MMC at Denver.

d. Post-manufacturing tests of the OWS subsystem were performed at Huntington Beach. They included subsystem as well as integrated system testing. These tests utilized Government Furnished Equipment (GFE) portable TV camera and monitor to accommodate video testing. The testing ensured that the OWS installed TV system would adequately support the operation of the total video system. Tests contributing to the verification are listed in Table 2.2.8.4-1.

Table 2.2.8.4-1

HUNTINGTON BEACH POSTMANUFACTURING TESTS AFFECTING OWS TV SYSTEM

Procedure	Nomenclature	Tests
1B66984	Continuity compatibility	Assures confidence in OWS stage wiring.
1B91066	TV system acceptance test procedure	Test performed video cabling conductor isolation and characteristic impedance checks, verified the performance of each TV input station, assured TV input station and TV camera interface, and assumed adequacy of scenes and illuminations of video transmission to the AM/OWS interface.
1B83590	EMC setup and systems reverification	Demonstrated that the TV system met transient and margin of safety reuirements of the EMC criteria.
1B93589	All system test - prep and securing	Preparation and securing of the OWS for all systems tests.
1B93591	All system test - activation orbital operations and deactivation	Simulated OWS test of systems after the insertion phase and during orbital operations
1B93588	All system test - prelaunch, boost, and preactivation	The all system test, as part of the test, assures the harmonious operation of the OWS TV system with the overall operation of the OWS stage systems. Adequacy of TV scenes in the OWS habitation area were assured.

e. Testing at Kennedy Space Center (KSC) consisted of a post-manufacturing subsystem retesting of any delta changes affecting Huntington Beach test results and integrated system testing at the module and cluster levels. Major testing accomplishing verification of the TV System are listed in Table 2.2.8.4-2.

2/ Major Problems and Solutions

a. There were no operational problems having any impact on test performance with the TV System hardwares installed in the OWS during checkout of the system at MDAC-W (Huntington Beach).

b. Functional verification of the OWS TV System was very successful at KSC. There were two problems related to OWS TV System hardware that were considered significant. One problem dealt with a DC bias difficulty on the TV Input station at P404 on the OWS dome. After the problem was isolated to a malfunctioning component, it was removed, replaced, and retested in accord with KS-0045. The other problem was the difficulty encountered when the 30 ft. (9.144 meters) TV camera cable would not lock on the P642 TV Input Station (TVIS) connector. The problem was attributed to a dimensional out-of-tolerance condition on the connector and it was corrected by placing a washer under the connector airlock housing. With the correction, the cable was mated to the TV Input Station and testing was completed by KS-0045.

Table 2.2.8.4-2

KSC TESTING OF THE OWS TV SYSTEM

Procedure	Nomenclature	Tests
KS-0045	AM/MDA/OWS end-to-end system test and experiment test.	Verified the performance of the cluster TV system. Verified that the OWS TV system operated compatibly with other module components of the system.
KS-0009	SWS operations for SV OAT and SWS mission SIM/FRT	Integrated cluster level testing which functionally verified the compatibility of the OWS electrical power system, including the OWS TV system, and ensure electromagnetic compatibility of these systems.

D. Mission Results - The OWS Television System, an extension of the Orbital Assembly Video System, has successfully supported the SL-1/2, SL-3 and SL-4 missions. The OWS installed hardware has performed well and enables the astronauts to provide the ground controllers, experimenters, design technologies, and the public viewers good video data of the crew activities and orbital assembly hardware status. The television input stations were strategically located in the OWS to support viewing of the different experiments and the astronauts were pleased with the locations. The local control of each TVIS gave the crew the mobility required while working in the OWS. The kinescope films that were viewed in assessing the picture quality verified that the lighting provisions were good throughout the OWS, but the picture quality did vary as a function of location/light level.

There were no mission problems associated with the OWS installed hardware and thus, it was not necessary for the crew to perform the TVIS replacement procedures.

E. Conclusions and Recommendations

1/ Conclusions - The OWS TV System accommodations consisting of the Television Input Stations (TVIS), and its associated wire harnesses, provided satisfactory performance in support of the Skylab Television System in transmitting video information during the manned Skylab missions as well as during the ground checkout activities. There were no major accommodation problems encountered by the OWS TV System during the mission and during checkout.

2/ Recommendations - Future design or redesign of the OWS TV System accommodations should take into consideration provisions to permit the astronauts to control the operation of the Video Tape Recorder (VTR) from each TVIS or the TV camera. During the Skylab missions the astronauts were required to activate the VTR in the MDA which was a major inconvenience when TV activities were being performed within the OWS.

F. Development History - The original OWS TV System design concept provided for only two TV outlets within the OWS. In addition, the TV Coaxial signal cable was to be routed by the crew through the AM/OWS hatch in lieu of being pre-installed with permanent feed-thru connectors.

In July of 1970, the TV system requirements were finalized and resulted in the present design. The final design provided for a permanent installation of a 93 ohm coaxial signal cable and three TVIS units. These design requirements were defined by MSFC upon their consideration of the total cluster system design and operation constraints.

2.2.9 Caution and Warning System

2.2.9.1 Design Requirements

A. General Requirements

1/ Caution and Warning (C&W) system for the Skylab (SL) shall monitor the performance of itself (voltage only) and other systems, including the Orbital Workshop (OWS) portion, and alert the crew to hazards or out-of-limit conditions. Parameter limits monitored shall be those which constitute crew hazards or could result in jeopardizing the crew, compromise primary mission objectives, or if not responded to in time, could result in loss of a system. These parameters shall be categorized as either EMERGENCY, WARNING, or CAUTION. Criticality and required crew response shall be used to determine the category of a parameter. Emergency, Warning, and Caution categories are 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. Requires immediate crew action.
- CAUTION - Any out of limit condition or malfunction of a cluster system that affects primary mission objectives or could result in loss of a cluster system if not responded to in time. Requires crew action (although not immediately).

2/ The number of monitored parameters must be consistent with effective monitoring. When any of the monitored parameters reach the predetermined out-of-tolerance level appropriate visual and acoustical signals will be activated.

B. Detail Requirements

1/ Common Electrical Requirements - Requirements imposed on the Caution and Warning System such as flammability, contamination, grounding, bonding, etc., which are imposed on all electrical subsystems are as stated in paragraph 2.2.6.

2/ Redundancy - The OWS portion of the cluster Caution and Warning System (C&W) shall be fully redundant and consist of a display panel, an emergency alarm and the wiring required to transmit the C&W information to/from the AM/OWS interface.

3/ Displays - The following C&W displays shall be provided in the OWS:

Title	Category
Cluster Low Pressure	Warning
OWS Bus 1 Low	Caution
OWS Bus 2 Low	Caution
Crew Alert	Warning
MDA/STS Fire	Emergency
AM Fire	Emergency
OWS Forward Fire	Emergency
OWS Crew Quarters Fire	Emergency
OWS Experiment Fire	Emergency

Title	Category
Rapid ΔP	Emergency
One Display Spare	Emergency
Two Display Spares	Caution and Warning

The displays shall be powered from the AM/OWS interface. The display lights shall be color-coded as follows:

a. Emergency - Aviation Red

b. Warning - Aviation Red

c. Caution - Aviation Yellow

4/ Bus Voltage - The OWS Bus voltage signals shall be provided by sense lines to the AM/OWS interface. The parameters sensed shall be OWS Bus 1 and OWS Bus 2. Redundant sense lines shall not be provided.

5/ Fire Detection Sensor Subsystem

a. Twelve (12) ultraviolet sensors Government Furnished Property (GFP) shall be installed in the OWS in the following areas:

• Sleep compartment	3
• Wardroom	2
• Waste Management compartment	1
• Experiment compartment	3
• Forward compartment	3

b. The sensors shall be powered from the AM/OWS interface. The signals resulting from contact closures in the three sensors in the Forward compartment shall be "or"ed and routed redundantly to the AM/OWS interface as the parameter "OWS Forward Fire." The outputs from the three sensors in the Experiment compartment will be "or"ed and routed redundantly to the AM/OWS interface as the parameter "OWS Experiment Fire." The outputs from the remaining six (6) sensors in the Wardroom, Sleep compartment and Waste Management compartment will be "or"ed and routed redundantly to the AM/OWS interface as the parameter "OWS Crew Quarters Fire."

c. Seven (7) sensor control panels (GFP) shall be installed. Each panel shall include test and inhibit switches and an annunciator for its associated sensor(s).

6/ Master Alarm Light - A master alarm light shall be provided on the OWS display panel. This red light (switch/indicator) shall be powered from the AM/OWS interface. When depressed, this light shall provide a contact closure returning AM power to the AM/OWS interface.

7/ Emergency Alarm

a. The emergency subsystem audible alarm shall be generated by an acoustical transducer (such as Klaxon horn, bell or similar device). One Klaxon assembly will be GFP and shall be controlled from the AM.

b. The acoustical alarm shall output a distinctive audible tone through redundant speakers. Each speaker shall produce a minimum output of 89 db measured one foot axially from the speaker cone with rated power.

8/ Verification - The verification requirements for the C&W system are as follows:

a. The C&W system shall have a capability to permit end-to-end checkout during ground testing.

b. The C&W system within the OWS shall be designed to remain in the on-orbit configuration from acceptance testing through launch; i.e., system integrity will be maintained.

c. The C&W system shall be capable of integrated checkout prior to launch.

d. The C&W system shall be designed to permit system testing by a crew member in flight. In the emergency subsystem, capability shall be provided to permit checkout from each transducer input through the electronics, to illuminate the applicable lights and trigger the acoustical devices.

9/ Isolation - The Caution and Warning system design shall satisfy the following isolation requirements:

a. The C&W subsystem and the emergency subsystem shall be separate and independent. An exception of this requirement will be at the AM/OWS interface where the two subsystems will use the same connectors, and the fire detection system wiring may be routed with other subsystem wiring. Failures in other systems shall not cause a malfunction in the C&W or emergency subsystems.

b. Isolation shall be included for all C&W systems sensors having multipurpose usage, i.e., also used by the instrumentation system. Use dual sensors (independent C&W sensors) for all parameters wherever practical.

c. There shall be no single-point failures in the C&W system. The redundancy within the C&W system shall be capable of inflight verification.

10/ Reliability - the design goal of the C&W system shall be as follows:

a. Components shall be selected such that the maximum allowable failure rate for the C&W system shall not exceed 1.145 failures per million hours of operation.

b. Failures which will trigger false alarms shall not exceed 2.289 failures per million hours of operation.

Analytical verification will be required to assess the design against the above failure rate goals.

2.2.9.2 System Description

A. General Description

1/ The Caution and Warning (C&W) system installed in Skylab provides the crew with visual displays and audible tones when selected parameters reach out-of-tolerance conditions. The parameters selected are those which could result in jeopardizing the crew, compromising primary mission objectives or if not responded to in time could result in the loss of a system. The monitored parameters are categorized as either Caution, Warning or Emergency parameters.

2/ The monitor electronics of the Caution and Warning System for the Skylab cluster is in the AM. The OWS contains selected redundant displays for crew observance while in the experiment compartment. A block diagram of the system is shown in Figure 2.2.9.2-1.

3/ Two independent subsystems are used; Caution and Warning subsystem for monitoring various system parameters, and an Emergency subsystem for detecting Fire or rapid loss of pressure.

4/ Each workshop Caution and Warning Subsystem is redundant within itself, with respect to displays, signals and sensors. Each switch has a redundant set of contacts, each display has redundant indicators - input and return, and each signal has a dual special C&W power source.

5/ The OWS Caution and Warning Subsystem panel is primarily a repeater station displaying the condition of selected cluster

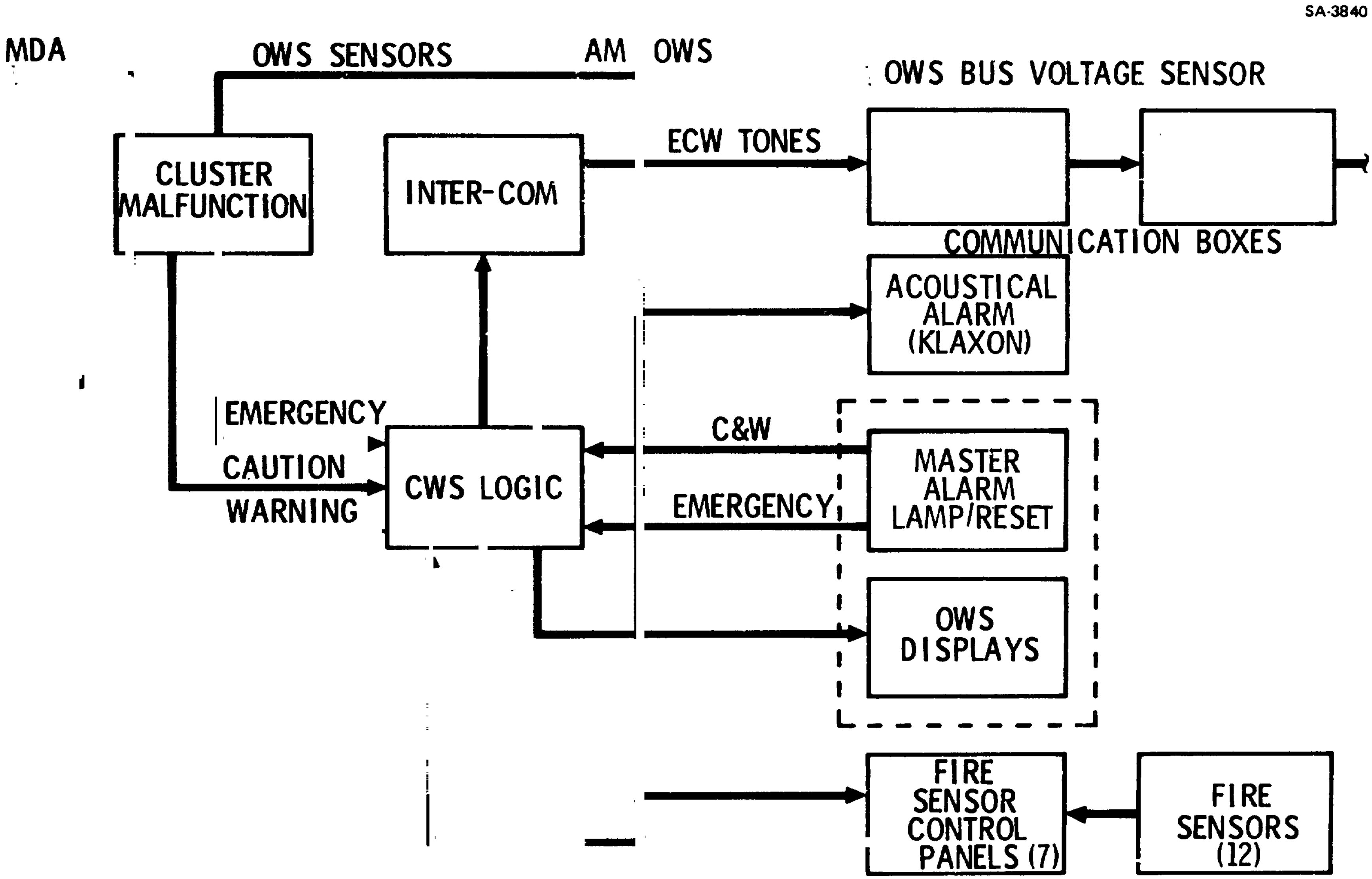


Figure 2.2.9.2-1. Fire Sensor Control Schematic

Figure 2.2.9.2-1

parameters. Six (6) emergency parameters, two (2) Caution parameters, and two (2) warning parameters are displayed. These are listed in Table 2.2.9.2-1.

B. System Details

1/ Common Electrical Design - Compliance to requirements imposed on all electrical subsystems such as contamination, flammability, bonding, grounding, etc., is as indicated in paragraph 2.2.6.

2/ AM Control - The control logic and a display panel for the C&W system are located in the AM.

3/ OWS Repeater Panel - A repeater panel, P616 shown in Figure 2.2.9.2-2 located in the OWS, contains displays of selected malfunctions, and a Master Alarm reset switch light.

4/ SIA's - Ten (10) Speaker Intercom Assemblies (SIA) in the OWS each contain a repeater MASTER ALARM light and reproduce an acoustical tone for Cautions and a different tone for Warnings.

5/ Emergency Alarm

a. There are two (2) Klaxon assemblies, one in the AM and the other in the OWS. Each Klaxon assembly contains redundant speakers that reproduce an acoustical tone for rapid loss of pressure and a different tone for fire. The Klaxon annunciates a siren for a fire and an interrupted buzzer for a rapid P.

b. Each Klaxon assembly speaker produces a minimum output of 89 db measured one ft. (.3048m) axially from the speaker cone with rated power. Audio output varies as the square of

Table 2.2.9.2-1
CAUTION AND WARNING SUBSYSTEM PANEL DISPLAYS

Parameter	Category*	Indicator Color
Rapid ΔP	Emergency	Red
MDA/STS Fire	Emergency	Red
AM AFT Fire	Emergency	Red
OWS FWD Fire	Emergency	Red
OWS EXP Fire	Emergency	Red
OWS Crew Qtrs Fire	Emergency	Red
Crew Alert	Warning	Red
Cluster Press Low	Warning	Red
OWS Bus 1	Caution	Yellow
OWS Bus 2	Caution	Yellow

ORBITAL WORKSHOP
CONTROL AND DISPLAY PANEL -616
CAUTION/WARNING SYSTEM

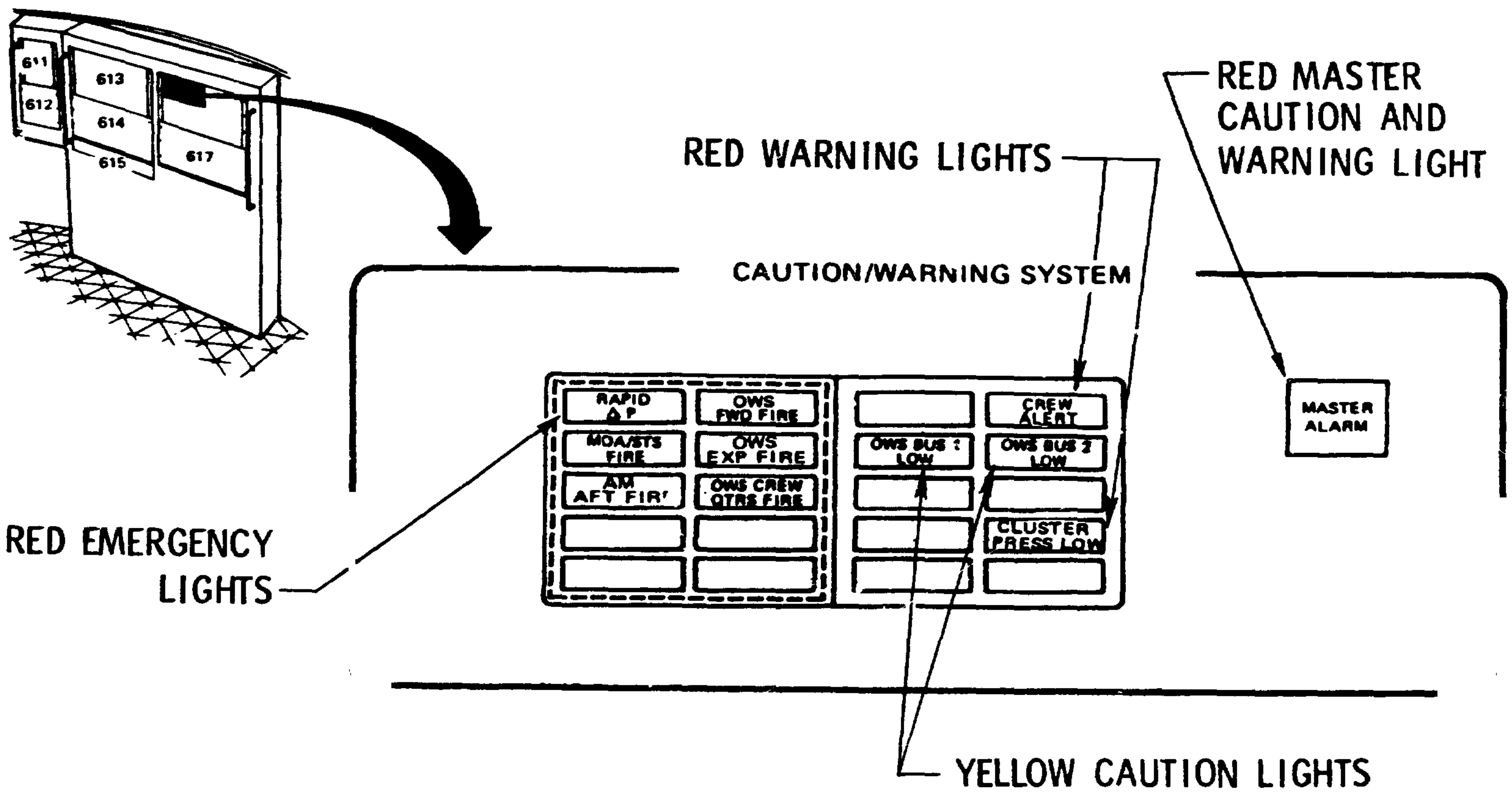


Figure 2.2.9.2-2

the distance from the source. Therefore, a decrease of 6 db is noticed each time the distance doubles. Additionally, a loss of approximately 5 db is incurred in going from 14.7 psia (101.3 kN/m^2) to 5 psia (34.5 kN/m^2).

6/ Fire Detection

a. Twelve fire sensors are located within the OWS, distributed per the previously stated requirements. The purpose of the fire sensor is to detect the presence of fire in the form of Ultra Violet (UV) rays in excess of predetermined level. A gain adjustment on each sensor allows for in-flight setting of the activation level. An internal UV source is activated when the common Fire Sensor Control Panels (FSCP) switch is positioned to test to establish proper operation of the sensors.

b. There are seven Fire Sensor Control Panels (FSCP) located within the OWS. Each FSCP can control one or two fire sensors as determined by the number of sensors used to provide coverage in an area. The panel has a switch for each sensor that can turn off the sensor or provide power from Bus 1 or Bus 2. Fire detector test and master alarm reset capability also exists at each fire sensor control panel.

c. The fire sensor circuits are designed to send redundant signals to AM C&W logic and illuminate fire locator lamps on the fire sensor control panel. The capability to switch any given sensor from one bus to the other is incorporated.

d. The 12 fire sensor and 7 fire sensor control panels are distributed as follows:

Forward Compartment Sensor	Control Panel	Measurement CWS OWS Forward Compartment Fire 1
Forward Compartment Sensor		
Forward Compartment Sensor	Control Panel	
Experiment Compartment Sensor	Control Panel	Measurement CWS OWS Experiment Compartment Fire 1
Experiment Compartment Sensor		
Experiment Compartment Sensor	Control Panel	
Sleep Compartment Sensor	Control Panel	Measurement CWS OWS Crew Quarters Fire 1
Sleep Compartment Sensor		
Sleep Compartment Sensor	Control Panel	
Waste Management		
Wardroom Sensor	Control Panel	
Wardroom Sensor		

7/ Voltage Sense Circuit Breakers - A circuit breaker for each OWS Bus labeled LOW VOLTAGE SENSE 1 and LOW VOLTAGE SENSE 2 is located in the C/W portion of Panel 613. The purpose of the circuit breakers is to allow isolation of the OWS 1 or 2 bus from the OWS bus low voltage sensor located in the AM.

8/ Master Alarm - The master alarm redundant circuit presents a contact closure to the AM when the master alarm reset switch is depressed (momentary). This command/signal is utilized to reset the alarm logic of the cluster C&W system.

9/ Verification - Tests of the Caution and Warning subsystem at the component, subsystem, and integrated vehicle level on the ground, and in-flight C&W subsystem tests, have established its compliance with the verification requirements.

2.2.9.3 Testing

A. Test Program

1/ The Caution and Warning subsystem did not have a development test program.

2/ Parts were qualified through test data taken from system components mounted in Qualification tests ES-6 and ES-7.

3/ Acceptance tests and an All Systems Test were performed at MDAC-W Huntington Beach to verify proper workshop C&W system functional operation.

4/ At KSC the Caution and Warning system was tested in detail as part of the integrated vehicle tests KS-0009 and KS-0045.

B. Major Problems and Solutions

1/ During tests at Huntington Beach, a calfax fastener roll pin fell out of a Fire Sensor Assembly S/N 037, while retorquing to flight requirements. The problem was attributed to a marginally high torque value. The torque value was reduced. All units were checked and reworked at Huntington Beach by the supplier.

2/ During KS-0045 testing of flight spare Fire Sensor Control Panel (FSCP), S/N 041, Sensor 1 and 2 lights did not illuminate during self test. Failure analysis revealed that the FSCP lamp assembly potting boost were improperly installed and were impeding the proper seating of the lamp assembly.

As a result all FSCP's were removed and sent to St. Louis for further testing and rework.

Upon completion of the rework, the FSCP's were returned and installed in their original locations. A successful retest was performed.

C. Waivers and Deviations - There are no waivers or deviations that exist against the OWS Caution and Warning System.

2.2.9.4 Mission Results - The OWS C&W System, an extension of the Orbital Assembly C&W System, has successfully supported the SL-1/2, SL-3 and SL-4 missions. The OWS installed hardware has performed satisfactorily and provided the astronauts continuous monitor and status of the emergency, warning, and caution parameters. The repeater C&W 616 panel in the OWS provided the crew with continuous remote C&W parameter status monitor and master alarm reset coverage. The twelve (12) fire sensors and the seven (7) fire sensor control panels, strategically located throughout the OWS, gave the crew confidence of safety and great mobility.

There were no hardware failures during the SL-1/2 and SL-3 flights. Mission problems were limited to the following: (a) a low voltage caution indication was experienced on Day of Year (DOY) 153 for OWS Buses 1 and 2. Results of an investigation into the problem revealed that the most probable cause of the anomaly was an inadvertent opening of the circuit breakers by a crewman, who at that time was cycling adjacent circuit breakers; and (b) the fire sensor in the OWS Sleep Compartment 2, initiated three (3) false alarms on DOY 146. Results of an investigation revealed the cause of the anomaly was the high temperature within the OWS. This was substantiated by special tests performed by MDAC-E which confirmed that the fire sensor sensitivity increased at high temperatures. The crew was appraised of the findings and were asked to turn the affected fire sensor off until the OWS internal temperatures decreased to acceptable levels. When temperatures were again normal, the sensor was activated and performed satisfactorily during the remainder of the mission.

2.2.9.5 Conclusions and Recommendations - The OWS Caution and Warning System design and installation has satisfactorily supported the Skylab missions. All design goals of the subsystem have been met.

The Caution and Warning hardware performed without failure during flight. False alarms which occurred during the mission were not caused by any C&W system hardware failure but were the result of other mission operations (e.g., inadvertent exposure of a fire sensor to ultraviolet light).

The OWS repeater panel and SIA portion of the Caution and Warning System gave the crew the desired mobility while providing the necessary monitoring function.

The Caution and Warning ground test program satisfactorily proved the adequacy of the Caution and Warning hardware. The hardware performed as expected. High temperatures early in the mission caused only temporary undesired operation from one fire sensor.

Crew comments during debriefings indicated satisfaction with the Caution and Warning System.

In-flight tests proved to be satisfactory. These tests were designed to test the system during activation of the OWS.

There are no recommendations or suggestions made to alter the Caution and Warning System or do anything differently should the opportunity present itself for redesign.

2.2.9.6 Development History - Initial design of the Emergency and Warning System called for a completely independent system located wholly within, and controlled from, the habitation area of the OWS.

In early 1970, by Change Order direction, the system was redesigned (Caution-Warning) into a redundant, repeater-type system. The OWS portion of the C&W would now input signals to, and receive command signals from, the AM C&W logic unit.

Subsequent to the change from an independent OWS system to the repeater-type system, the only changes to the system design have been to alter the criteria associated with the monitored parameters.

2.2.10 Experiment Accommodations System

2.2.10.1 Experiment Installation and Operation Provisions

A. Design Requirements

1/ The list of OWS experiments is shown in Table 2.2.10.1-1. The design requirements for the integration of this experiment hardware into the OWS were stated in electrical and mechanical Interface Control Drawings (ICD's). These ICD's covered design areas such as vibration criteria, acoustic criteria, thermal surface properties, electrical bonding, structural interface loads, scientific airlock (SAL) and experiment leakage, vacuum provisions, desiccated and filtered gas for SAL experiments, launch mounting dimensions, OWS airflow, nitrogen supply provisions, thermal environment, and electrical interface criteria. A list of these ICD's has been tabulated in Table 2.2.10.1-2. In those cases of experiment hardware where ICD's were not required by NASA, the related design requirements stated in the Cluster Requirements Specification were followed as the experiment interface

Table 2.2.10.1-1

OWS EXPERIMENTS

Exp. No.	Experiment Title
ESS	Experiment Support System
M071	Mineral Balance
M073	Bioassy of Body Fluids
M074	Specimen Mass Measurement
M092	Lower Body Negative Pressure
M093	Vectorcardiogram
M131	Human Vestibular Function
M133	Sleep Monitoring
M151	Time and Motion Study
M171	Metabolic Activity
M172	Body Mass Measurement
M487	Habitability/Crew Quarters
M509	Astronaut Maneuvering Equipment
M516	Crew Activities/Maintenance
S019	UV Stellar Astronomy
S020	X-Ray/UV Solar Photography
S063	UV Airglow Horizon Photography
S073	Gegenschein/Zodiacal Ligh-
S149	Particle Collection
S183	UV Panorama
S190B	Earth Terrain Camera
S228	Trans-Uranic Cosmic Rays
T002	Manual Navigation Sightings

Table 2.2.10.1-1

OWS EXPERIMENTS (Continued)

Exp. No.	Experiment Title
T003	Inflight Aerosol Analysis
T013	Crew/Vehicle Disturbances
T020	Foot Controlled Maneuvering Unit
T025	Coronagraph Contamination Measurement
T027	Contamination Measurement
ED31	Bacteria and Spores
ED32	In-Vitro Immunology
ED41	Motor Sensory Performance
ED52	Web Formation
ED61/62	Plant Growth/Plant Phototropism
ED63	Cytoplasmic Streaming
ED72	Capillary Studies
ED74	Mass Measurement
ED76	Neutron Analysis
ED78	Liquid Motion

Table 2.2.10.1-2

EXPERIMENT-RELATED ICD'S

ICD NUMBER	Title
13M07393	S149/T027, Mechanical Requirements
13M12041	M171, Metabolic Activity, Mechanical
13M12051	M092, Inflight LBNP, Mechanical
13M12071	M131, Human Vestibular Functions, Mechanical
13M12091	M074, Specimen Mass Measurements, Mechanical
13M12101	M172, Body Mass Measurements, Mechanical
13M12181	M509, Astronaut Maneuvering Equipment, Mechanical
13M12183	M509, Astronaut Maneuvering Equipment, I&C
13M12231	T003, Inflight Aerosol Analysis, Mechanical
13M12261	T020, Foot Control Maneuvering Unit, Mechanical
13M12301	T025, Coronagraph Contamination Measurement, Mechanical
13M12311	T027, ATM Contamination Measurement, Mechanical
13M12321	T013, Crew/Vehicle Disturbance, Mechanical
13M12341	ESS, Experiment Support System, Mechanical
13M12351	S149, Particle Collection, Mechanical
13M12353	T027/S073, ATM Contam Measurement and Gegenschein/Zodiacal Light/OWS I&C
13M12381	S019, UV Stellar Astronomy, Mechanical
13M12391	S020, UV/X-Ray Solar Photography, Mechanical
13M12401	S063, Airglow Horizon Photography, Mechanical
13M13512	M071/M073, Return Payload to CM, Mechanical
13M13514	M071/M073, Freezer to CM, Mechanical
13M13515	Camera and Photolight LOC/OWS Experiments, Mechanical
13M13516	Bio-Med Stowage Container/OWS, Mechanical

Table 2.2.10.1-2

EXPERIMENT-RELATED ICD'S (Continued)

ICD Number	Title
13M13519	Experiment and Operation Film/SWS Film Vault, Mechanical
13M13521	S183, UV Panorama/SWS, Mechanical
13M13532	M133, Sleep Monitoring Equipment/OWS, Mechanical
13M13535	T002, Manual Navigation Sightings, Mechanical
13M13540	Earth Terrain Camera to OWS, Mechanical
40M35606	T027/OWS, Electrical
40M35624	T013, Crew Vehicle Disturbance/OWS, Electrical
40M35640	M171, Metabolic Activity/OWS, Electrical
40M35641	M092, LBNP/OWS, Electrical
40M35642	M131, Human Vestibular Functions/OWS, Electrical
40M35643	M074, Specimen Mass Measurement/OWS, Electrical
40M35644	M172, Body Mass Measurement/OWS, Electrical
40M35645	M509, Astronaut Maneuvering Equipment/OWS, Electrical
40M35650	S063, Airglow Horizon/OWS, Electrical
40M35651	ESS/OWS, Electrical
40M35656	S149/T027, Particle Collection/ATM Contamination, Electrical
40M35684	S183, UV Panorama/OWS, Electrical
40M35686	M133, Sleep Monitoring/OWS, Electrical
40M35731	Earth Terrain Camera to OWS, Electrical
50M13132	ESS/SWS, I&C
50M16135	T013, Crew Vehicle Disturb/OWS, I&C
50M16142	S149/T027, Particle Collection/ATM Contam, I&C
50M16146	S183, UV Panorama/OWS, I&C
50M16151	M133, Sleep Monitoring/OWS, I&C

design criteria. The contamination and flammability design requirements were stated in the OWS End Item Specification (CP2080J1C).

2/ An OWS Experiments Accommodations Requirements Summary has been compiled in Table 2.2.10.1-3. This lists the experiment equipment, method of attachment, gas and vacuum requirements, and electrical requirements.

B. System Description

1/ The experiments subsystem consisted of the hardware accommodations needed to integrate the GFP experiment equipment into the OWS. These accommodations included structural attachments, electrical cabling, pressurization and plumbing provisions, and stowage restraints. The location of the experiment accommodations in the OWS have been shown in Figures 2.2.10.1-1 and 2.2.10.1-2.

2/ The structural attachments for experiment hardware included floor, wall and ceiling attachment hardware for the experiment stowage containers and other equipment, floor-to-ceiling shear panels for the ESS and M171 Metabolic Analyzer, wall brackets for the T013 Force Measurement Units, the SAL tripod support and the S183 Spectrograph restraint assembly. A typical stowage container attachment has been shown on Figure 2.2.10.1-3. The SAL tripod was designed to prevent static and dynamic loads imparted to the T027 Photometer canister to induce excessive moment loads at the SAL/OWS wall interface. The SAL tripod design and OWS location has been described in Figure 2.2.10.1-4. A floor-mounted

Table 2.2.10.1-3
OWS EXPERIMENT ACCOMMODATIONS REQUIREMENTS
SUMMARY

EXP NO.	TITLE	MAJOR EXPERIMENT EQUIPMENT INSTALLED IN OWS	EXPERIMENT EQUIPMENT LOCATION	METHOD OF ATTACHMENT	GAS AND FLUID RQMTS			POWER RQMTS	ELECTRICAL CONNECTOR	DATA SIGNAL REQUIREMENTS
					OXYGEN	VACUUM	NITROGEN			
ESS	EXPERIMENT SUPPORT SYSTEM	ESS CONSOLE	CREW QUARTERS EXP COMPT	FLOOR-TO-CEILING STRUCTURE	NONE	NONE	FROM OWS WATER PRS SYS	28 VDC (OWS)	TYPE NB PER 40M38500	PCM DATA; VOICE
M071	MINERAL BALANCE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
M073	BIOASSAY OF BODY FLUIDS	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
M074	SPECIMEN MASS MEASUREMENT	SMMD (FOOD) SMMD (WASTE)	WARDROOM HEAD	HARDMOUNT TO CABINET HARDMOUNT TO CABINET	NONE	NONE	NONE	28 VDC (OWS)	TYPE ZG PER 40M38500	VOICE RECORDING
M092	LOWER BODY NEGATIVE PRESSURE	LBNP DEVICE	CREW QUARTERS EXP COMPT FLOOR	BOLTED TO FLOOR	NONE	FROM OWS	NONE	FROM ESS	NONE	DATA FROM ESS TO AM VOICE RECORDING
		LEG VOLUME PLETHYSMOGRAPHS (2) BLOOD PRESSURE ASSEMBLY	STORED IN BIOMED CONT STORED IN BIOMED CONT	NONE NONE						
M093	VECTORCARDIOGRAM	HARNESS (2) ELECTRODE APPLICATION KIT	STORED IN BIOMED CONT STORED IN BIOMED CONT	NONE NONE	NONE	NONE	NONE	FROM ESS	NONE	DATA FROM ESS TO AM VOICE RECORDING
M131	HUMAN VESTIBULAR FUNCTION	ROTATING LITTER CHAIR AND MOTOR BASE CONTROL CONSOLE	CREW QUARTERS EXP COMPT FLOOR CREW QUARTERS EXP COMPT INT WALL	BOLTED TO FLOOR BOLTED TO WALL	NONE	NONE	NONE	28 VDC (OWS) TO CONTROL CONSOLE	NB TYPE PER 40M38500	DATA FROM ESS TO AM VOICE RECORDING
		EXPERIMENT STORAGE CONTAINER	CREW QUARTERS EXP COMPT INT WALL	BOLTED TO WALL						
M133	SLEEP MONITORING	PANEL ASSEMBLY	SLEEP COMPT (ON-ORBIT)	HARD MOUNTED FOR LAUNCH ON FLOOR	NONE	NONE	NONE	28 VDC (OWS)	TYPE ZG PER 40M38500	DATA INTERFACE WITH INTERCOM BOX
M151	TIME AND MOTION STUDY	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
M171	METABOLIC ACTIVITY	METABOLIC ANALYZER ERGOMETER	CREW QUARTERS EXP COMPT CREW QUARTERS EXP COMPT	FLOOR-TO-CEILING STRUCTURE BOLTED TO FLOOR	NONE	FROM OWS	FROM OWS WATER PRS SYS	FROM ESS	NONE	DATA FROM ESS TO AM VOICE RECORDING
M172	BODY MASS MEASUREMENT	BODY MASS MEAS DEVICE	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	NONE	NONE	28 VDC (OWS)	TYPE NB PER 40M38500	VOICE
M487	HABITABILITY/CREW QUARTERS	EQUIPMENT CONTAINER EXPERIMENT EQUIPMENT	WARDROOM LOCKER	COMPARTMENT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
M509	ASTRONAUT MANEUVERING EQUIPMENT	AUTO. STAB. MANEUV. UNIT ANTENNAS	FWD SECTION FLOOR FWD SECTION DOME AREA	BOLTED TO FLOOR ATTACHED TO WATER BOTTLE RING	NONE	NONE	FROM AM RECHARGE STATION	28 VDC (OWS)	NB TYPE PER 40M38500	PCM DATA; VOICE
		NITROGEN BOTTLE STOWAGE PALLET	FWD SECTION FLOOR	BOLTED TO FLOOR						
S019	UV STELLAR ASTRONOMY	OPTICAL CANISTER MIRROR SYSTEM FILM CANISTER	FWD SECTION FLOOR FWD SECTION FLOOR	BOLTED TO FLOOR BOLTED TO FLOOR	NONE	FROM SAL	NONE	NONE	NONE	VOICE
S020	X-RAY, UV SOLAR PHOTOGRAPHY	CANISTER ASSEMBLY	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	FROM SAL	NONE	NONE	NONE	VOICE
S063	UV AIRGLOW HORIZON PHOTOGRAPHY	EQUIPMENT ASSY CONTAINER EXPERIMENT EQUIPMENT	UPPER COMPARTMENT	BOLTED TO TOP OF FILM VAULT	NONE	NONE	NONE	NONE	TYPE ZG PER 40M38500	TIMING, VOICE

Table 2.2.10.1-3
OWS EXPERIMENT ACCOMMODATIONS REQUIREMENTS
SUMMARY (Continued)

EXP NO.	TITLE	MAJOR EXPERIMENT EQUIPMENT INSTALLED IN OWS	EXPERIMENT EQUIPMENT LOCATION	METHOD OF ATTACHMENT	GAS AND FLUID RQMTS OXYGEN	GAS AND FLUID RQMTS VACUUM	GAS AND FLUID RQMTS NITROGEN	POWER RQMTS	ELECTRICAL CONNECTOR	DATA SIGNAL REQUIREMENTS
S073	GEGENSCHEIN/ZODIACAL LIGHT	USES T027 PHOTOMETER UNIT	STORED IN T027	NONE	NONE	NONE	NONE	NONE	NONE	PCM DATA, VOICE
S149	PARTICLE COLLECTION	DETECTOR ASSEMBLY	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	NONE	NONE	NONE	NONE	PCM DATA, VOICE
S183	ULTRAVIOLET PANORAMA	SPECTROGRAPH SUPPORT PALLET	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	FROM SAL	NONE	28 VDC (OWS)	TYPE ZG PER 40M38500	PCM DATA, TIMING VOICE
S190B	EARTH TERRAIN CAMERA	CAMERA, STORAGE CONTAINER INVERTER, CABLING	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	FROM SAL	NONE	28 VDC (OWS)	TYPE NB PER 40M38500	VOICE
T002	MANUAL NAVIGATION	SEXTANT; WARDROOM HOOD STADIMETER	LOCKER W740	COMPARTMENT STOWAGE	NONE	NONE	NONE	NONE	NONE	VOICE
T003	INFLIGHT AEROSOL ANALYSIS	AEROSOL ANALYZER	CREW QUARTERS INTERIOR WALL	BOLTED TO WALL	NONE	NONE	NONE	NONE	NONE	VOICE
T013	CREW/VEHICLE DISTURBANCES	FORCE MEASUREMENT UNITS	FWD SECTION TANK WALL	CANTILEVER MOUNTING STRUCTURE	NONE	NONE	NONE	28 VDC (OWS)	TYPE NB(OWS) 40M38500	PCM DATA, TIMING
		LIMB CONTAINER DATA SYSTEM UNIT	FWD SECTION TANK WALL FWD SECTION TANK WALL	BONDED NUT PLACES BOLTED TO FLOOR						
T020	FOOT CONTROLLED MANEUVERING UNIT	FCMU	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	NONE	FROM M509	NONE	NONE	NONE
T025	CORONAGRAPH CONTAMINATION MEASUREMENT	CANISTER	FWD SECTION FLOOR	BOLTED TO WALL	NONE	NONE	NONE	NONE	NONE	NONE
T027	ATM CONTAMINATION MEASUREMENT	PHOTOMETER ASSEMBLY STORAGE CONTAINER	FWD SECTION FLOOR	BOLTED TO FLOOR	NONE	FROM SAL	NONE	28 VDC (OWS)	TYPE ZG PER 40M38500	PCM DATA; VOICE
		SAMPLE ARRAY SYSTEM CONTAINER SAMPLE ARRAY	FWD SECTION FLOOR	BOLTED TO FLOOR						
OTHER EQUIPMENT:										
	BIOMEDICAL STOWAGE	BIOMEDICAL STOWAGE CONT (2)	CREW QUARTERS COMPT	FLOOR-TO-CEILING STRUCTURE	NONE	NONE	NONE	NONE	NONE	NONE
S228	TRANS-URANIC COSMIC RAYS	DETECTOR ARRAY	CREW QUARTERS COMPT	FLOOR-TO-CEILING	NONE	NONE	NONE	NONE	NONE	NONE
ED31	BACTERIA AND SPORES	PETRI DISHES	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED32	IN-VITRO IMMUNOLOGY	DISHES AND SYRINGES	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED41	MOTOR SENSORY PERFORMANCE	MAZE PLATE	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	28 VDC	TYPE NB PER 40M38500	NONE
ED52	WEB FORMATION	SPIDER CAGE	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	28 VDC	TYPE ZG PER 40M38500	NONE
ED61/62	PLANT GROWTH/ PHOTOTROPISM	PLANT VIALS	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED63	CYTOPLASMIC STREAMING	PLANT VIALS	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED72	CAPILLARY STUDIES	CAP TUBES	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED74	MASS MEASUREMENT	SPRING PLATE	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED76	NEUTRON ANALYSIS	DEFECTOR PLATES	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE
ED78	LIQUID MOTION	PISTON VIAL	UPPER COMPT LOCKER	COMPT STOWAGE	NONE	NONE	NONE	NONE	NONE	NONE

CLUSTER
OWS
EXPERIMENT ACCOMMODATIONS
EXPERIMENT LOCATION

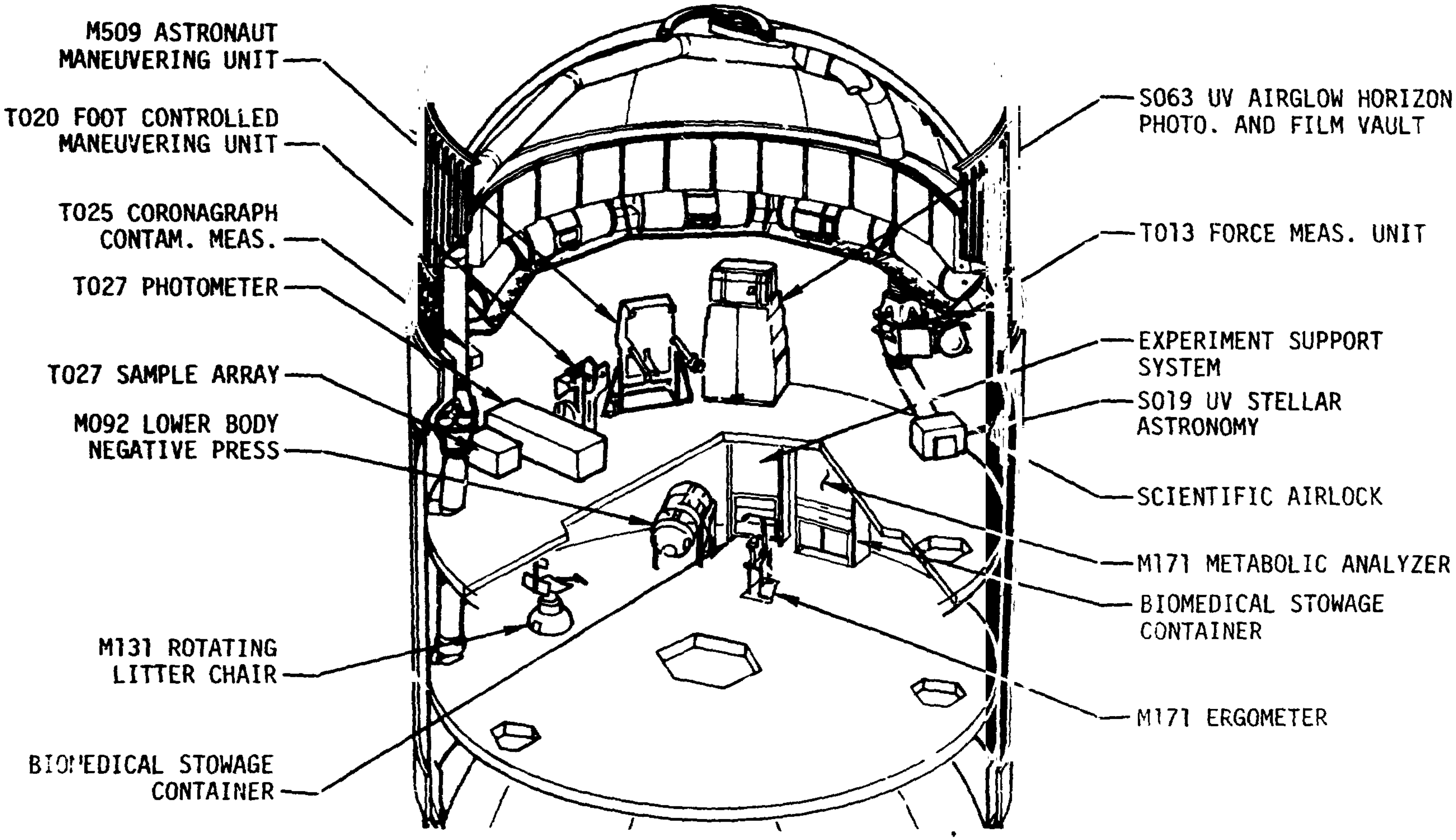


Figure 2.2.10.1-

CLUSTER
OWS
EXPERIMENT ACCOMMODATIONS
EXPERIMENT LOCATION

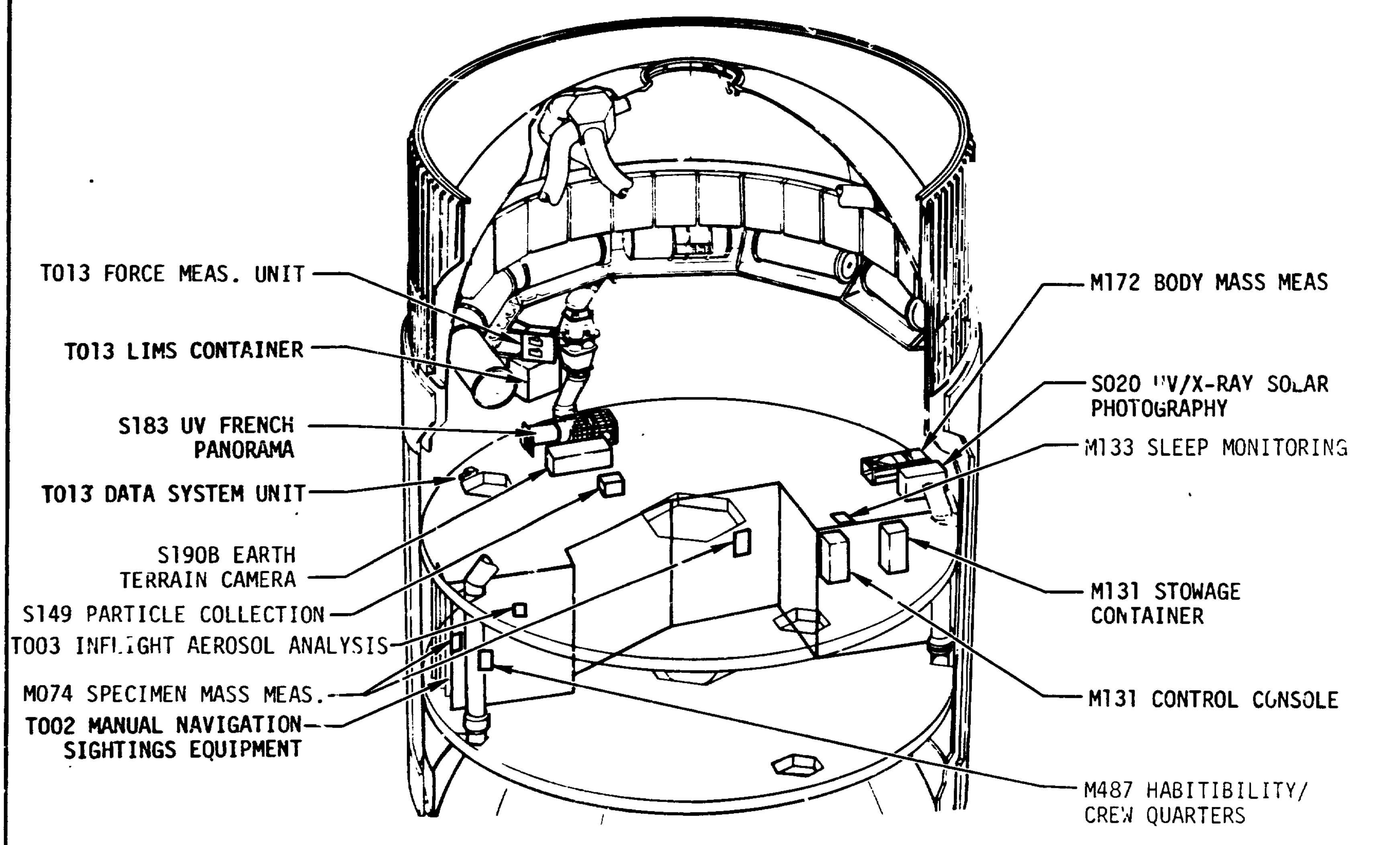


Figure 2.2.10.1-2

ORBITAL WORKSHOP
EXPERIMENT ACCOMMODATIONS
TYPICAL FLOOR MOUNTING PROVISIONS

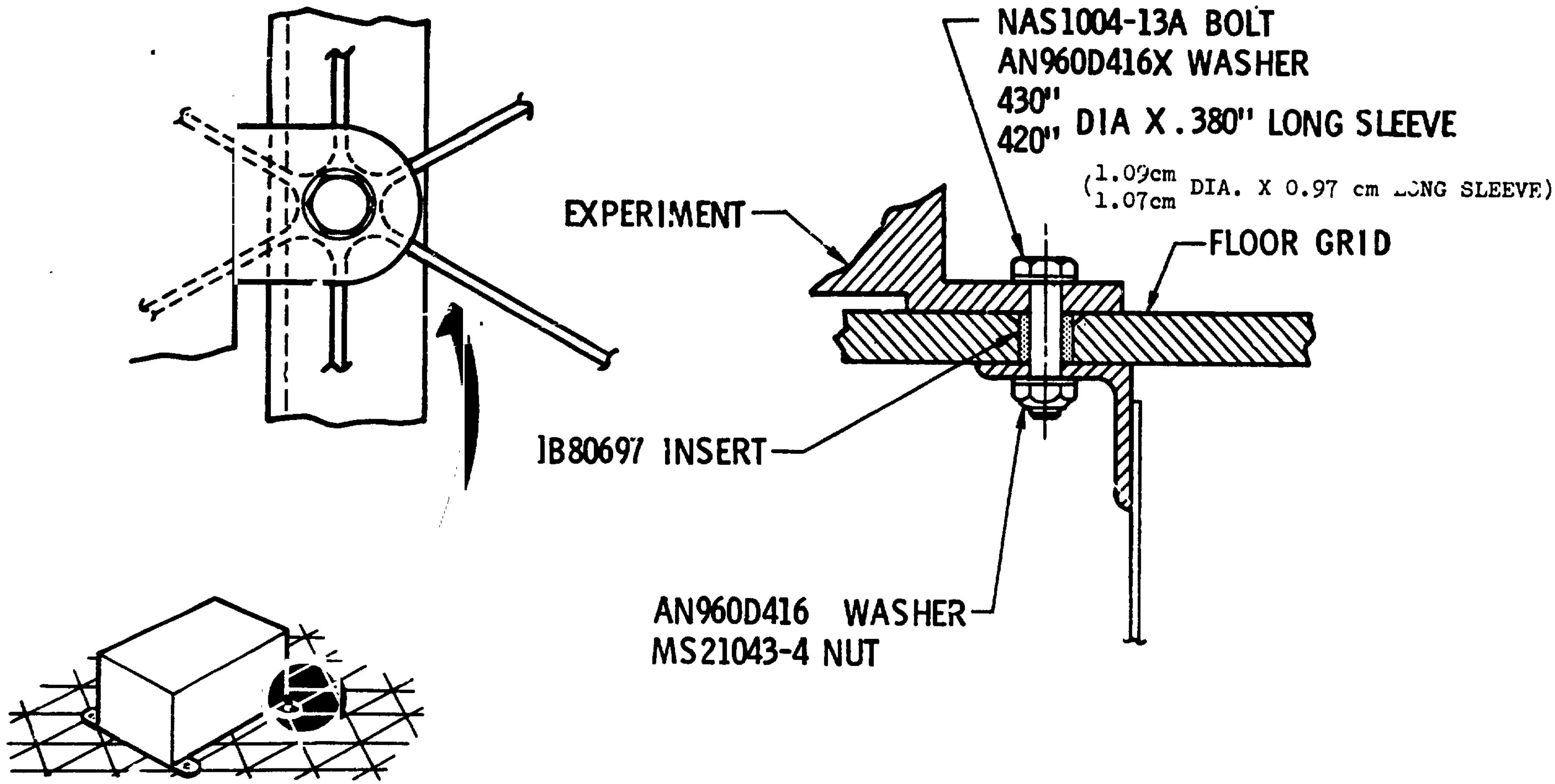
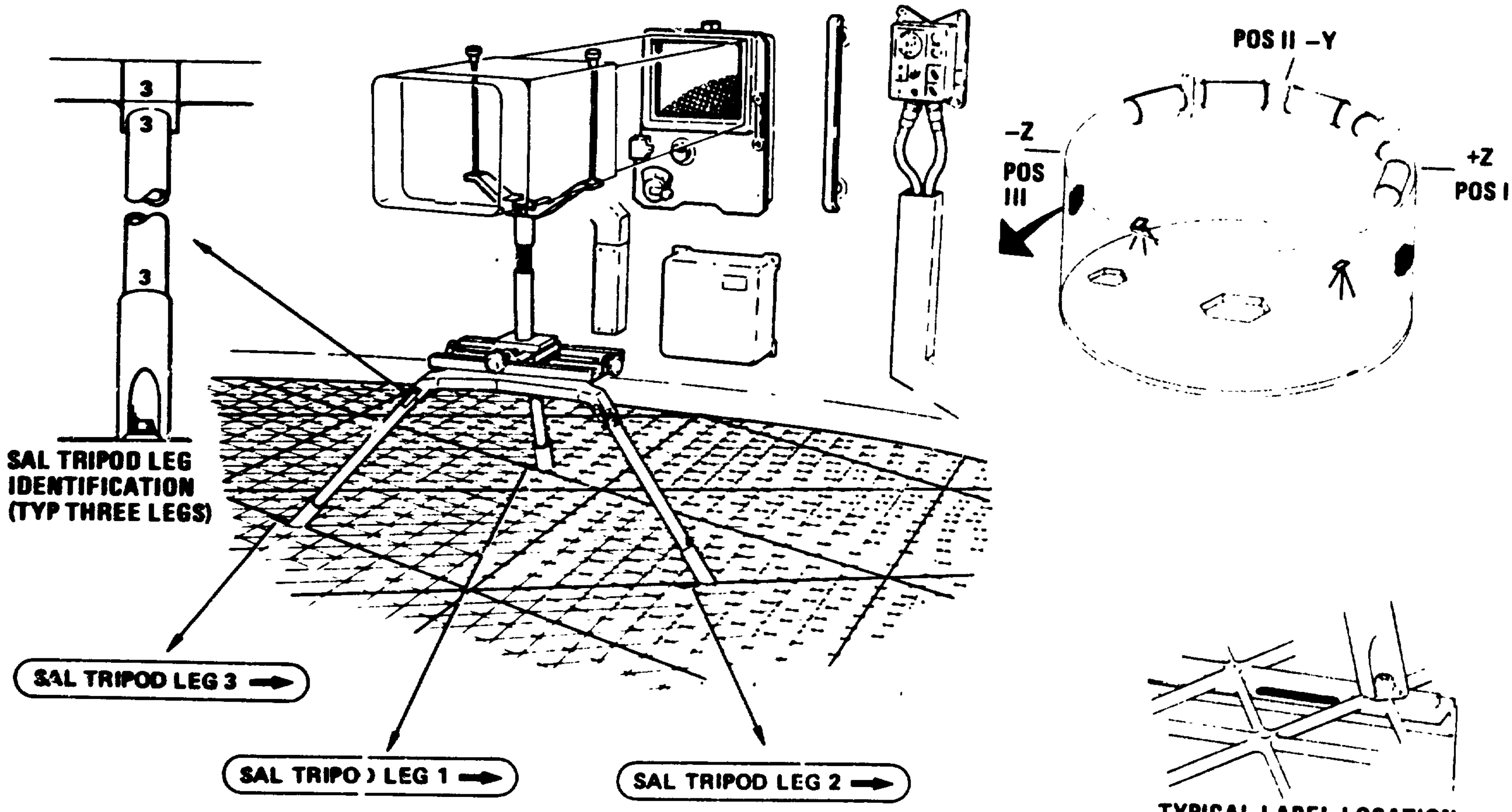


Figure 2.2.10.1-3



NOTE: -Z SAL FLOOR TO BE I ABELED
SIMILAR TO +Z SAL

Figure 2.2.10.1-4. SAL Tripod

Figure 2.2.10.1-4

S183 Spectrograph restraint assembly resembling a bumper pad was also installed for the same purpose.

3/ The electrical experiment accommodations consisted of power, telemetry and miscellaneous electrical provisions. The power distribution system was a two-wire, single point ground system which supplied experiment power from two completely separate supply buses. All power wiring supplying experiment equipment was protected with circuit breakers. Utility outlets with common receptacles were supplied for experiment use. The experiment telemetry data system used the OWS data acquisition system, supplied signals directly to the AM PCM interface box and utilized the OWS Communications System. OWS Multiplexers J and K were reserved for experiment data but for some experiments (M509, T013, M093, M131, T027/S073), high sample rate data was routed directly to the AM PCM interface box. There were also some miscellaneous electrical accommodations supplied for the OWS, including RF cables for M509 and T013, DCS commands for S149 and provisions for synchronizing the camera for S063.

4/ A nitrogen gas pressurization system was provided for the ESS and M171 Metabolic Analyzer, utilizing 1/4-in. (0.64 cm) OD stainless steel plumbing and a series of control panels to provide the required gas supply at the experiment interfaces. The plumbing was routed from the AM to OWS Panel 500 at the water bottle ring to Panel 620 in crew quarters compartment, as shown in Figures 2.2.10.1-5, 2.2.10.1-6, 2.2.10.1-7, and 2.2.10.1-8. All the plumbing had brazed connections except at the connectors to the ESS, Metabolic Analyzer, Panel 500 and Panel 620, where B-nut fittings were used.

5/ Vacuum provisions were supplied for the M171 Metabolic Analyzer (MA) and M092 Lower Body Negative Pressure Device (LNBPD). The system for the MA consisted of two vacuum lines, a one in. (2.54cm) line 8.5 ft. (2.55m) long between the MA and overboard penetration in OWS wall, and a 1/4 in. (0.64cm) line approximately 7 ft. (2.1m) long between the MA and LBNPD vacuum outlet line. The one in. (2.54cm) line was used primarily to pull the gas sample through the MA and vent it overboard while the other line was a relief vent line to vent MA methane overboard upon inadvertent failure of the MA calibration pressure regulator. The LBNPD vacuum system consisted of a 19 ft. (5.7m) length of one in. (2.54cm) line extending from the LBNPD to the OWS wall, with a hand valve included in this vacuum line to serve as an emergency shutoff should it be required. This vacuum system was used to depressurize the experiment and to provide the necessary pressure level for maintaining a constant negative pressure on the crewman during the experiment operation. These vacuum provisions have been pictured in Figure 2.2.10.1-9.

6/ The vacuum system described above was used in mission SL-1/SL-2 and SL-3. However, because M092 venting

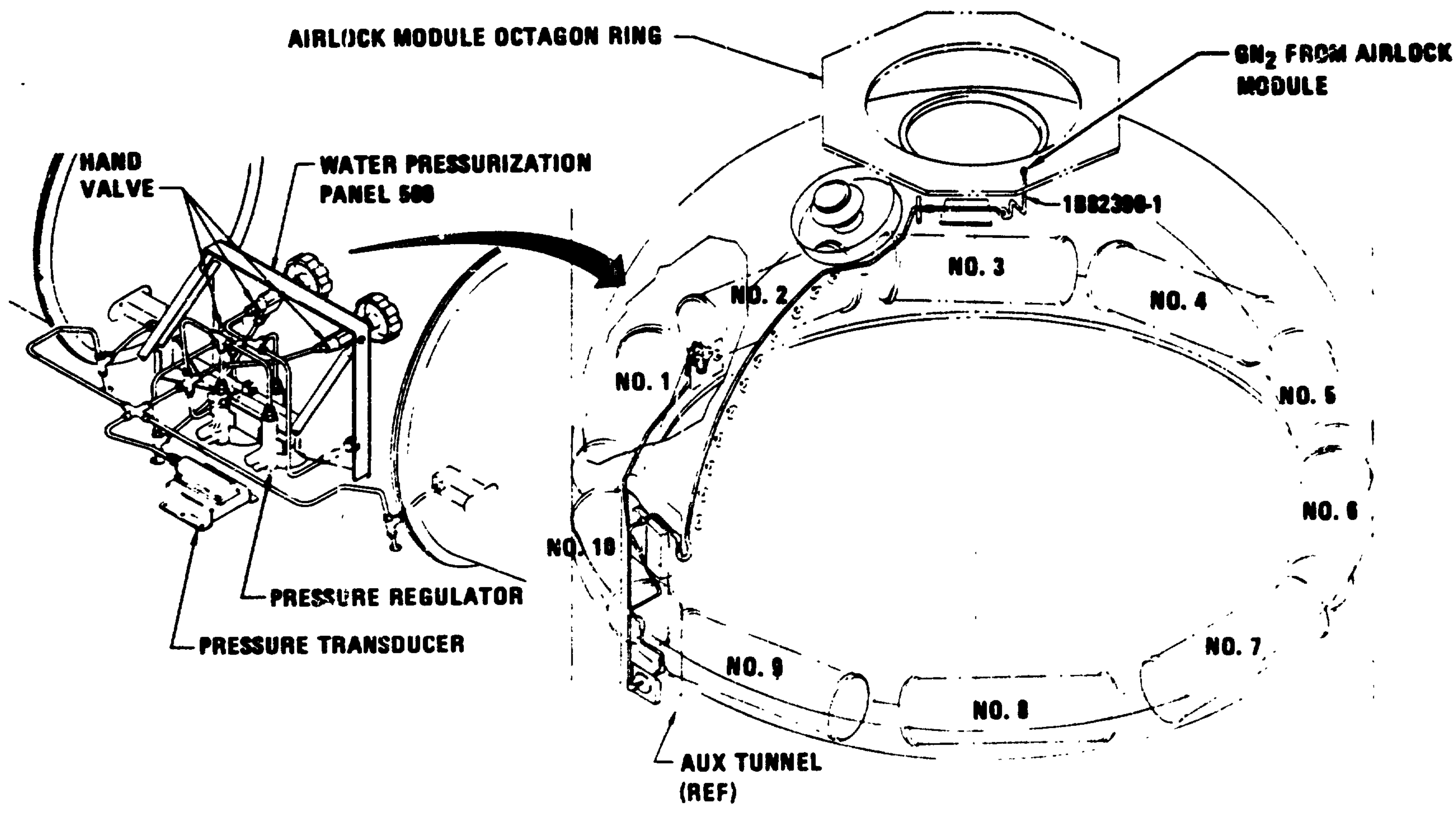


Figure 2.2.10.1-5 Water Pressurization Network

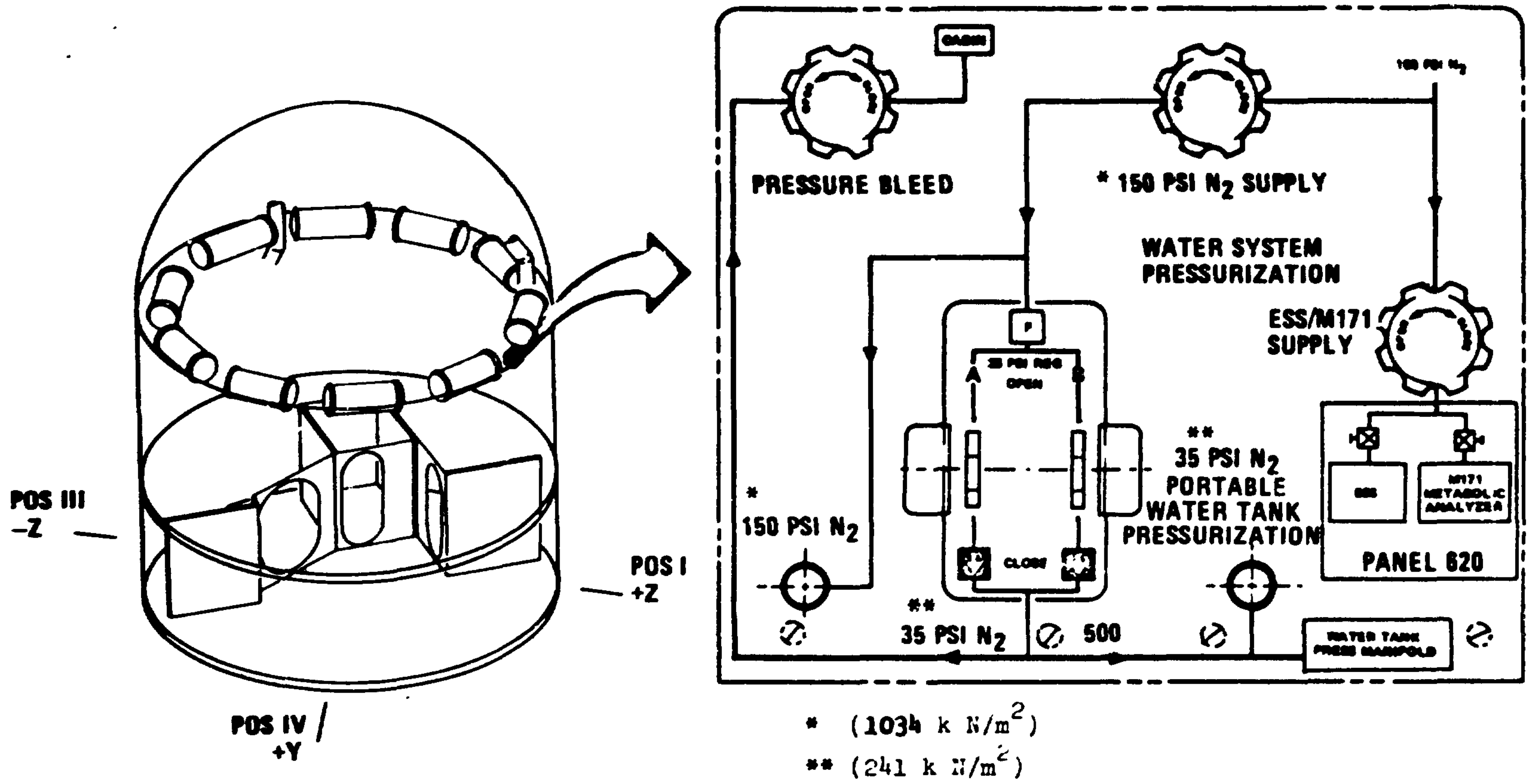


Figure 2.2.10.1-6 Water Pressurization Panel

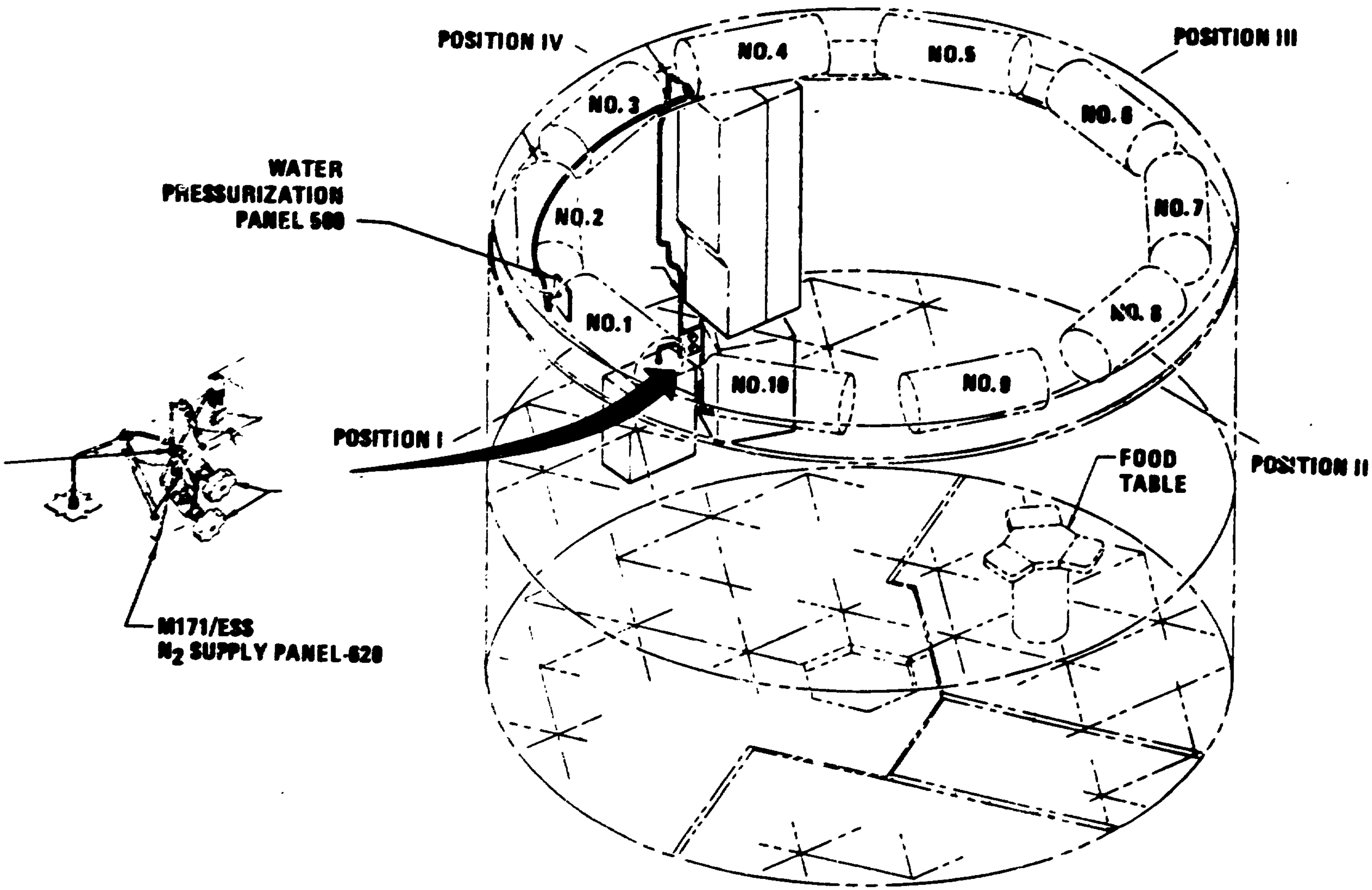
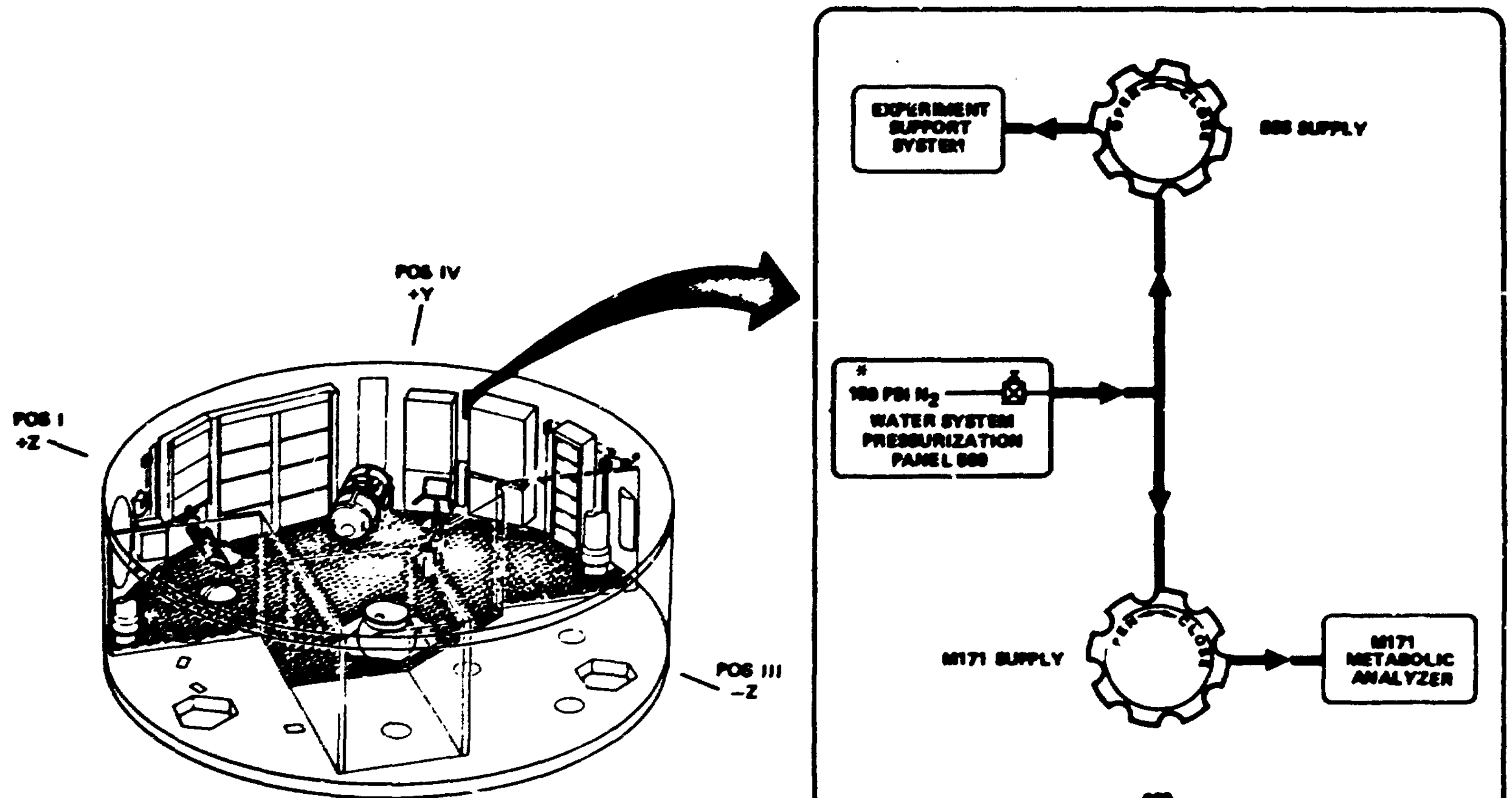


Figure No. 2.2.10.1-7 Water Pressurization Network



*(1034 k N/m^2)

Figure 2.2.10.1-8 ESS N_2 Supply Panel

CLUSTER
OWS
EXPERIMENT ACCOMMODATIONS
VACUUM SYSTEM - EXPERIMENTS

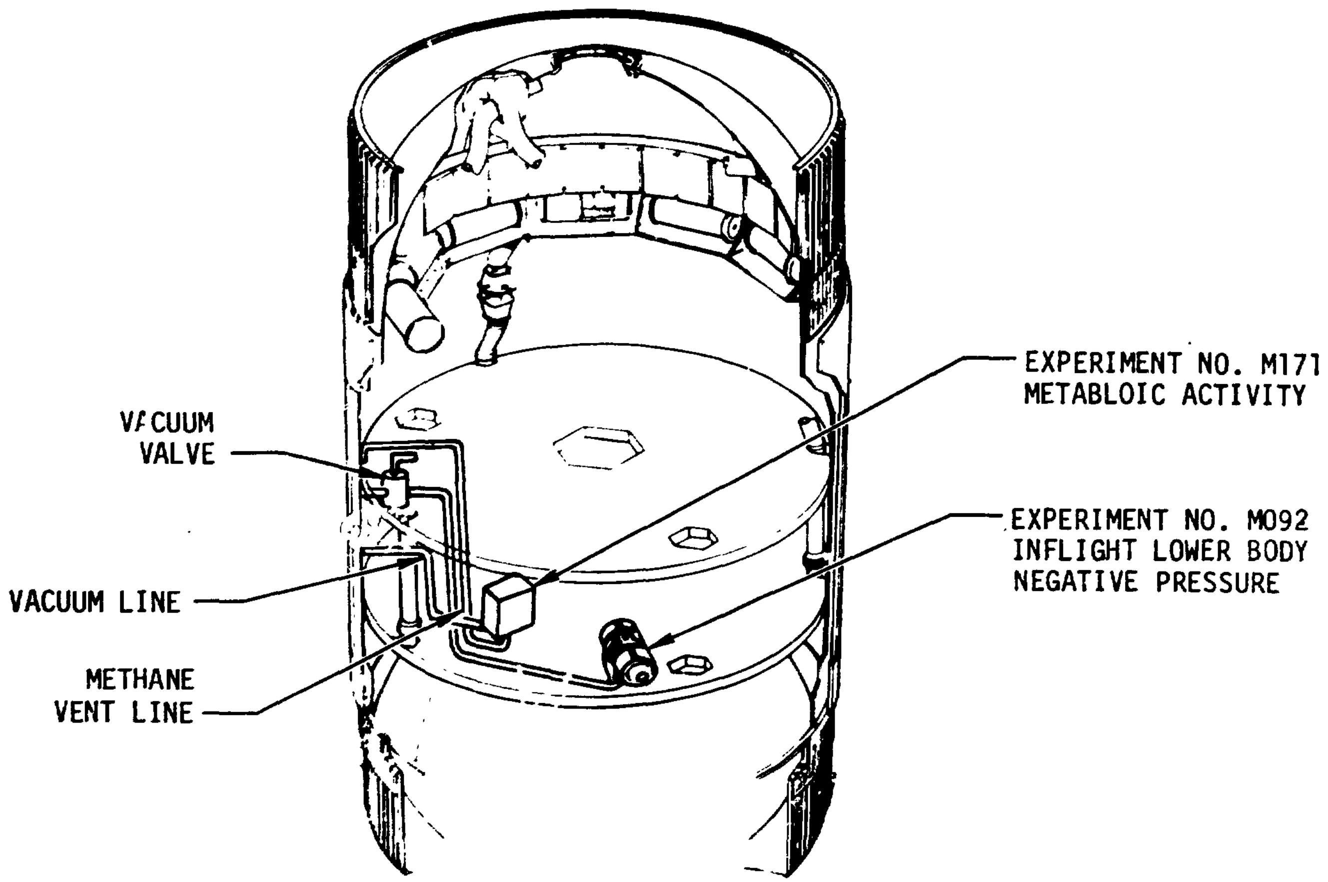


Figure 2.2.10.1-9

necessitated spacecraft vehicle attitude corrections, a redesigned system was developed for SL-4 and an adapter kit was flown on SL-4 for on-orbit installation. The new design approach was to vent the LBNPD into the OWS waste tank by closing the LBNPD vent valve at the OWS wall and connecting hoses between a port on the tee in the LBNPD vent line and the common bulkhead penetration which previously had the wardroom water dump probe installed in it. The two ports were interconnected by using three on-board hoses and two new adapters. A sketch of the new vacuum system was shown on Figure 2.2.10.1-10.

7/ The stowage provisions for experiment equipment was covered in Section 2.2.13 of this report.

C. Testing

1/ The experiment/OWS interface accommodations were verified through a series of subsystem tests and all-system tests at the Contractor facility and at KSC. Additional man/machine interface verifications were accomplished during Crew Compartment Fit and Function (CCFF) testing. No significant problems regarding OWS experiment accommodations were encountered during OWS testing but malfunctions occurred internal to the GFP experiment hardware. When these malfunctions occurred, the hardware was either repaired by Experiment Developer personnel at the test site or returned to the Experiment Developer's plant for rework. Retesting was then successfully accomplished.

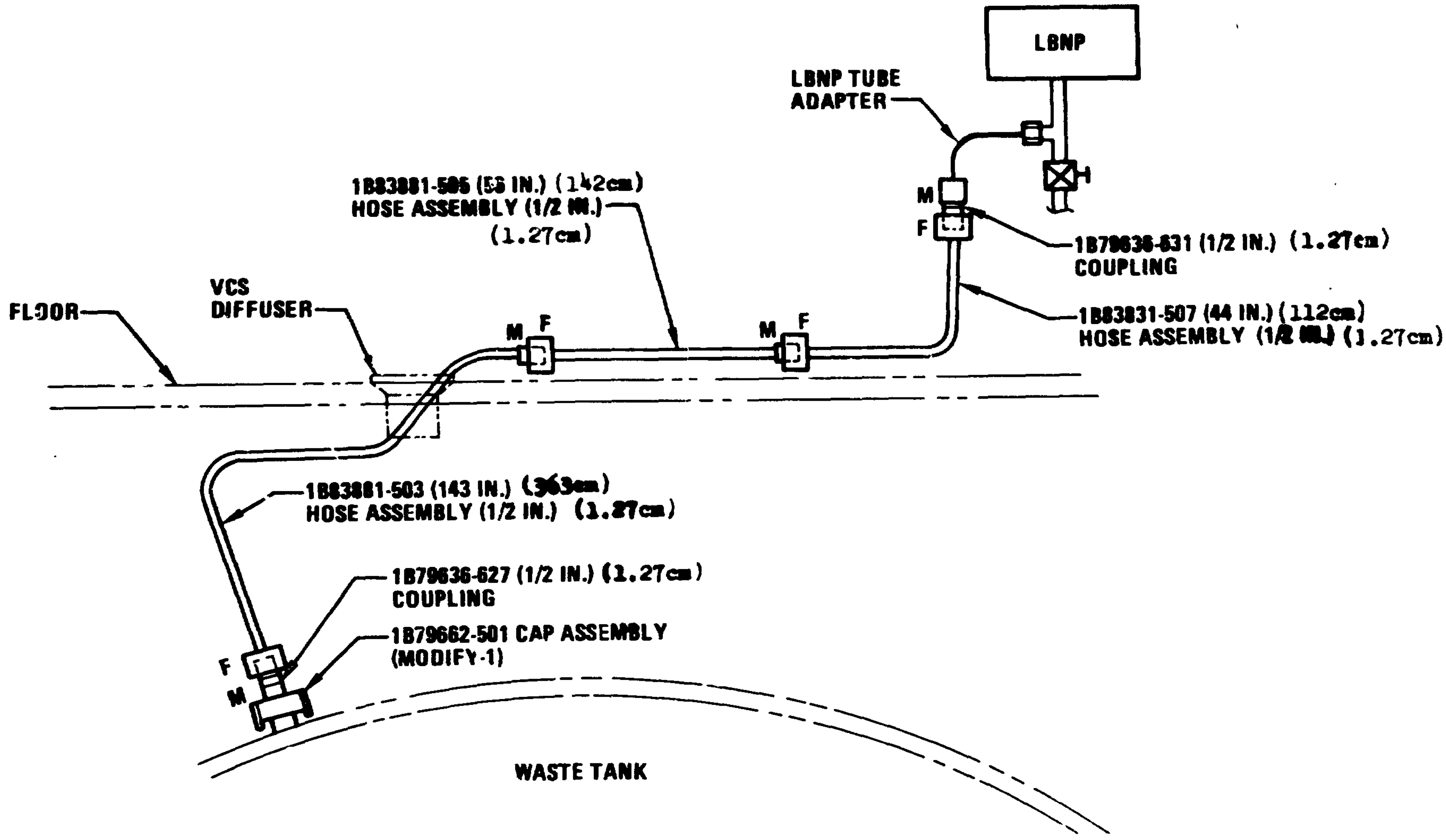


Figure 2.2.10.1-10. Redesigned LBNPD Vacuum System

Figure 2.2.10.1-10

2/ Receiving inspection of all GFP experiment hardware was performed at MDAC for visual damage, parts inventory, and adherence to OWS cleanliness requirements. The procedures used to perform these operations were listed in Table 2.2.10.1-4. One requirement for equipment in the OWS was that all breathing systems and pressurized systems must be certified to be free of mercury contamination per MDAC Mercury Contamination Control Plan 20 dated, October, 1971. All applicable hardware was either previously certified or a mercury contamination verification test performed at MDAC as part of the receiving inspection operations. Only minor discrepancies were noted during receiving inspection.

3/ Only four problems of any significance occurred during the installation of the OWS experiment accommodations hardware. They are as follows:

a. The support structure for the M171 MA did not meet the minimum ICD tolerance width dimension. After appropriate rework, the installation of the MA was successfully completed.

b. The mounting holes in the OWS structural bracket to support the T013 Force Measurement Unit No. 2 did not match up with matching mounting holes in the FMU. The holes in the FMU were reamed for proper alignment and the installation was successfully completed.

c. The M171 Ergometer forward mounting plate was out of flatness. After leveling shims were riveted to the mounting plate, a successful installation was completed.

Table 2.2.10.1-4

RECEIVING INSPECTION SUMMARY

Experiment	MDAC Procedure
T025	1C84141
M509	1C833970
M092	1C83993
M172	1C84006
M074	1C84008
S020	1C84053
S183	1C83999
T003	1C84004
T013	1C83971
T020	1C84031
T027	1C84078
BIOMED STOWAGE CONTAINERS	1C84062
M093	1C84080
M131	1C84073
M133	1C84081
M171	1C84098
ESS	1C84082
S019	1C84063
S063	1C84065
S149	1C84064
S190B	1C84196
T002	1C84222

d. During a mechanical fit check of the T025 stowage container, it was determined that one of the mounting holes in the container did not match up with the stud location of the OWS wall. After the flange hole was reamed out, a successful fit check was completed.

4/ VCL testing at MDAC consisted of experiment subsystem tests, CCTF tests, and all-systems test. In the experiment area, the purpose of these tests was to verify the experiment/OWS interface compatibility. No significant problems in OWS experiment accommodations were encountered during this testing. The procedures used in the VCL testing are listed in Table 2.2.10.1-5. A final report, MDAC Report G3069, OWS Checkout-VCL, was prepared to provide detailed information relative to test description, measurements, data evaluation and all experiment problems/anomalies, including crew comments. Each section of Report G3069 pertaining to a particular experiment was also listed in Table 2.2.10.1-5.

5/ Receiving inspection, subsystem and all-systems test for experiment/OWS interface compatibility were also performed at KSC. No significant problems regarding OWS experiment accommodations were encountered during this testing. KSC test procedures applicable to experiment accommodations are listed in Table 2.2.10.1-6.

6/ No waivers and deviations were required for any experiment accommodations, except for material flammability for M487 off-the-shelf experiment instruments procured under NASA direction.

Table 2.2.10.1-5

VCL EXPERIMENT TEST SUMMARY

Experiment	Checkout Procedure	Section of G3069
T003	1B86438	3.6.1
T013	1B84569	3.6.7
M074	1B84567	3.6.12
M172	1B84567	3.6.12
T027/S073	1B86432	3.6.6
S149	1B86432	3.6.6
S019	1B86428	3.6.3
S020	1B86430	3.6.2
M509	1B84565	3.6.4
T020	1B84565	3.6.4
S063	1B86442	3.6.13
M092	1B84568	3.6.5
M093	1B84568	3.6.5
M131	1B84568	3.6.5
M171	1B84568	3.6.5
ESS	1B84568	3.6.5
M151	1B86446	3.6.8
S183	1B86444	3.6.3
M133	1B84566	3.6.11
T002	1B91060	3.6.9
S190B	1B91058	3.6.10
T025	1B86439	N/A (Off-Module)
M487	1B86424	4.0
CCFF	1B86[illegible]4	4.0
All Systems Test	1B85235	5.0

Table 2.2.10.1-6

KSC TEST PROCEDURES APPLICABLE TO EXPERIMENT ACCOMMODATIONS

Test Procedure Number	Title
KO-19003	RECEIVING INSPECTION
KO-7000	LEAK TEST
KO-7001	INSTALLATION AND REMOVAL
KO-7002	MECHANICAL TEST
KO-7004	ON-MODULE PERIODIC
KE-7005	MEDICAL EXPERIMENTS OFF-MODULE
KE-7006	EXPERIMENTS OFF-MODULE PREPS
KE-7007	S019/S183 OFF-MODULE FUNCTIONAL
KE-7008	OFF-MODULE PERIODIC
KS-0009	SIMULATED FLIGHT
KS-0016	OWS CLOSEOUT
KS-0045	END-TO-END TEST
KS-7000	EXPERIMENT STOWAGE

D. Mission Results

1/ An experiment accomplishment summary was compiled in Table 2.2.10.1-7.

2/ On the three missions, the composite OWS experiment accomplishment percentage of planned versus actual was 87 percent. Flight planning rescheduling due to the loss of the meteoroid shield and the maneuver limitations due to gyro malfunctions resulted in the deletion of some experiment activities.

3/ OWS experiment accommodations anomalies which occurred on SL-1/SL-2 are listed below:

a. The crew was unable to obtain the proper calibration adjustment of -0.9K factor for the M487 Sound Level Meter. A -0.7K factor was obtained. The readings on the instrument is ± 2 db so the 0.2 db correction was not considered to present a problem.

b. The ways mechanism of the backup SAL tripod which was bolted to the adapter plate was drilled in a mirror image with the holes misaligned about two in. (5.08 cm). The SL-2 crew had to rotate the SAL tripod legs and had to realign the adapter under the T027 canister to accomplish the tripod installation. The tripod did perform its intended function although two of the tripod legs were bolted to open grid floor, instead of using the fixed nut-plate locations. The SL-3 crew transferred the backup tripod to the solar SAL where all the legs were successfully bolted into the fixed nutplates on the floor.

c. The crewmen stated that the SAL pressurization and re-pressurization times for experiment hardware

Table 2.2.10.1-7

SKYLAB EXPERIMENT ACCOMPLISHMENT SUMMARY

Type of Exper	Exper-iment	SL-1/SL-2			SL-3			SL-4		
		Planned	Actual	Percent Accomplished	Planned	Actual	Accomplished	Planned	Actual	Percent Accomplished
	M092	24	22	91	51	50	98	78	67	86
	M093	24	18	75	51	49	96	78	63	81
	M131	19	13	68	51	45	88	30	27	90
	M133	15	13	87	21	20	95	8	18	225
	M171	15	15	100	24	25	104	36	36	100
EREP	S190B	9	6	67	22	29	132	50	38	76
	M487	11	11	100	18	18	100	21	21	100
	M509	--	--	--	4	6	150	8	5	63
	M516	--	--	--	7	5	71	7	3	43
	S019	8	4	50	12	27	225	14	13	93
	S063	--	--	--	12	12	100	7	7	100
	S149	1	1	100	2	2	100	1	1	100
	S183	9	3	33	12	14	117	23	18	78
	S228	1	1	100	1	1	100	3	3	100
	T002	--	--	--	34	31	91	34	16	47
	T003	10	9	90	20	19	95	26	30	115
	T013	--	--	--	1	1	100	--	--	--
	T020	--	--	--	3	3	100	3	2	67
	S073	11	11	100	30	5	17	36	15	42
	S020	--	--	--	--	--	--	1	3	300
	S201	--	--	--	--	--	--	12	10	83
	TC25	--	--	--	--	--	--	1	1	100
	TC53	--	--	--	--	--	--	46	20	44
KOHOU-TEK	SC19K	--	--	--	--	--	--	20	13	65
	SC63K	--	--	--	--	--	--	22	14	64
	SC73K	--	--	--	--	--	--	0	1	--
	S183K	--	--	--	--	--	--	13	6	46
	S201K	--	--	--	--	--	--	15	14	93
	TC25K	--	--	--	--	--	--	2	2	100

Table 2-2.10.1-7

SKYLAB EXPERIMENT ACCOMPLISHMENT SUMMARY (Continued)

Type of Exper	Experiment	SL-1/SL-2			SL-3			SL-4		
		Planned	Actual	Percent Accomplished	Planned	Actual	Percent Accomplished	Planned	Actual	Percent Accomplished
	ED-31	2	2	100	--	--	--	2	2	100
	ED-32	--	--	--	1	1	100	--	--	--
	ED-41	--	--	--	--	--	--	3	3	100
	ED-52	--	--	--	3	3	100	--	--	--
	ED-61/62	--	--	--	--	--	--	2	2	100
	ED-63	--	--	--	3	1	33	3	2	67
	ED-72	--	--	--	--	--	--	3	1	33
	ED-74	--	--	--	4	4	100	--	--	--
	ED-76	2	2	100	0	0	0	2	2	100
	ED-78	--	--	--	1	0	0	--	--	--

installed in the SAL were greater than expected. They expected two minutes but the actual pressurization and depressurization times were five to eight minutes. MDAC analysis verified that the longer times were actually realistic and the flight plans were revised to allow more crew time for these operations.

d. The crew reported a bent bonding strap on the S149 stowage container. The strap was hand-bent back to its original shape without any damage to the strap.

e. The crew reported that the two Experiment Mode Select Switches on Panel 617 were loose. Using an allen wrench, the crew tightened the knobs on the switch and the switch operated properly after this operation.

4/ The only experiment accommodations anomaly reported on the SL-3 mission was the M092 propulsive vent problem previously described in Section 2.2.10.1.B.6/. The problem was alleviated by the SL-4 crew by rerouting the venting to the common bulkhead, using a penetration previously used by a urine dump probe.

5/ No additional experiment accommodation anomalies were reported during the SL-4 mission.

6/ The only test performed to support mission operations was a verification of the M092 vacuum line redesign hardware kit to be utilized on SL-4.

E. Conclusions and Recommendations

1/ The experiment accommodations subsystem performed per design requirements except for the few non-significant items mentioned above. Verification of compatibility of an interface, such as the backup SAL tripod, should be a basic groundrule for future programs.

F. Development History

1/ The initial program requirement was to provide mounting and system interface provisions (power, data, gas, and vacuum) for twenty-two experiments and a scientific airlock (On Position 1). Hardware for six additional experiments plus 11 student experiments and a second scientific airlock were subsequently added. Three of the original experiments were deleted and one of these three was later reinstated.

2/ As development of the experiments progressed, numerous modifications to OWS systems and hardware were required to support experiment requirements and redesign. This was especially evident in modifications to and special configurations of the mounting provisions required to attach the requirements to the OWS. Mounting locations and hardware were continuously changed to incorporate experiment additions, deletions, and volume requirements as well as flight crew interfaces. A tripod support assembly was provided to support the T027 Photometer canister at the scientific airlocks in order to protect the OWS wall integrity.

Vacuum and gas lines were modified in order to accommodate new hardware and safety requirements in the biomedical experiments. These were necessary in order to provide for the blood pressure measuring system and to provide for venting of methane from the metabolic analyzer.

Modifications to electrical connectors and wiring harness were required to incorporate power and instrumentation changes as well as connector relocations in the experiments.

3/ During the integrated test phase, minor modifications were required to accommodate incompatibilities in mounting and system interfaces.

10.2 Film Storage System

A. Design Requirements

1/ General Design Requirements - A film storage system (Film vault) with the following capabilities was to be provided:

- o Insure a maximum film temperature of 80°F (26.7°C) after film stowage.
- o Maintain relative humidity in vault of 45 ± 15 percent from film stowage until mission completion (including launch, unmanned and manned phases).
- o Provide radiation protection for the film.
- o Provide individual, removable film drawers for ease of film stowage and on-orbit film handling.
- c Dimensions of approximately 55 x 40 x 26 in. (139.7 x 101.6 x 66 cm).

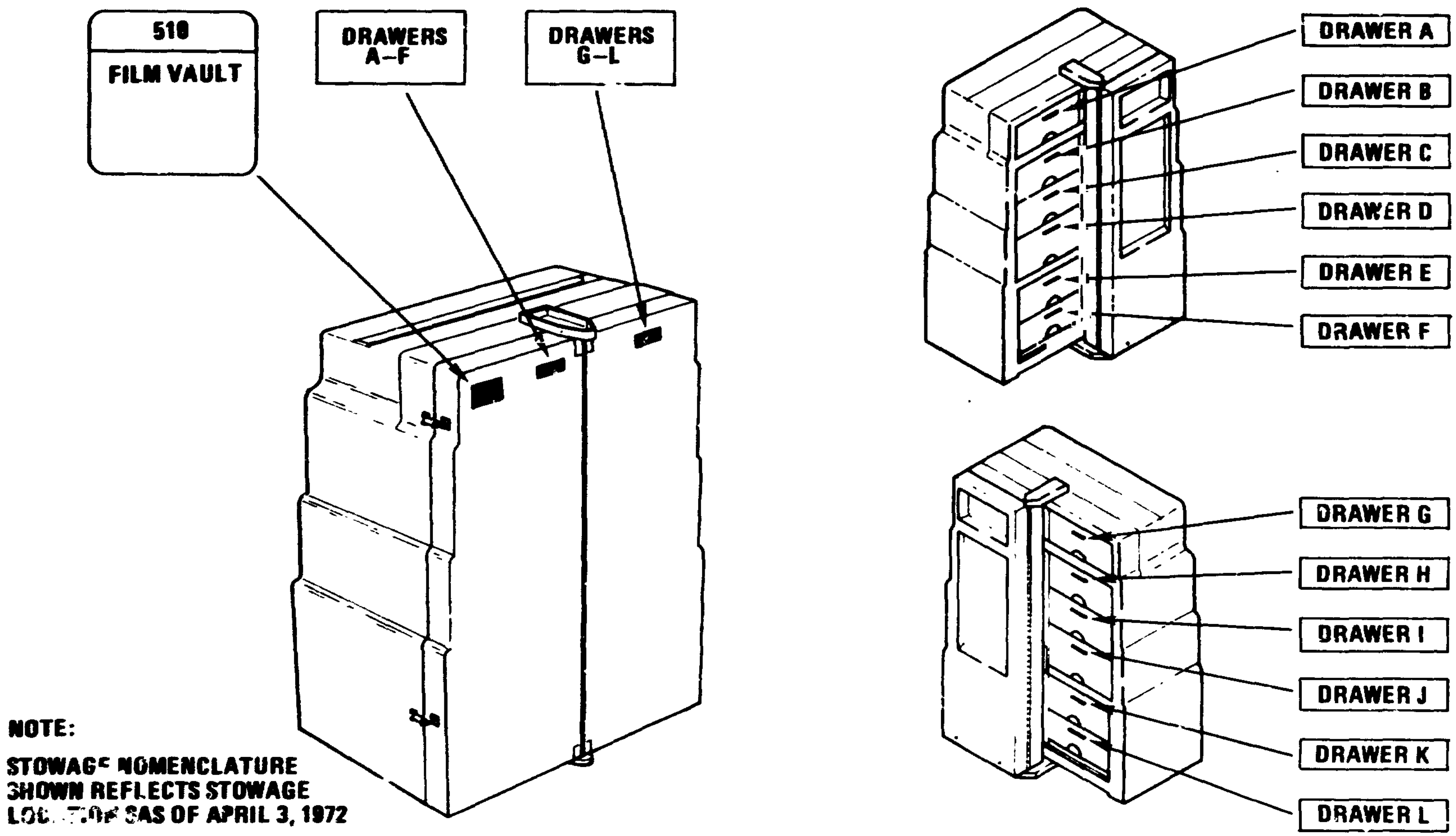
2/ Specific Design Requirements - The film vault was designed as a passive thermal and humidity control unit capable of maintaining the specified environment for the flight film. Humidity control (prior to OWS on-orbit activation) was maintained by the use of potassium-thiocynate salt pads.

Radiation protection for the film was to be obtained by using various wall thicknesses in the design and manufacture of the vault.

Special design considerations were required to insure that the materials used in the manufacture of the film vault were compatible with the film. Also, launch and flight induced loads were to be evaluated to insure that the vault design would protect the film through these environments.

B. System Description - The vault is a simple aluminum casting of four cells, each with a different wall thickness. Each cell wall thickness is commensurate with the degree of radiation protection required for the period of film stowage and its sensitivity. There are two doors, also of aluminum, vertically hinged at the center with thickness equal to the wall of each cell. These wall thicknesses are 0.25 in. (0.64 cm), 1.90 in. (4.8 cm), 2.90 in. (7.4 cm), and 3.40 in. (8.6 cm). The center hinge line of the doors is to reduce access volume required. Figures 2.2.10.2-1 through 2.2.10.2-3. The vault contains 12 drawers in two vertical columns of six. Each drawer is approximately 15 x 18 x 6-1/2 in. (38.1 x 45.7 x 16.5 cm) high. The heights of the drawers have been adjusted for special experiment packages to as much as 8 in. (20.3 cm) high. Access to the film containers is obtained by opening the vault drawer 180 degrees and sliding out one of the six drawers. Each drawer is mounted on a single, side mounted slide with a detent for both closed and open positions. In addition, each drawer may be released from the slide to permit bench loading of the film or serve as a travel container to the experiments during on-orbit usage. Within each drawer, individual film containers are restrained by on-orbit restraints, normally of machined teflon, which provides the ability to extract a single film container without handling other containers. All restraints within the drawers were designed for toolless removal and

SKYLAB - ORBITAL WORKSHOP
FILM VAULT



NOTE:
STOWAGE NOMENCLATURE SHOWN REFLECTS STOWAGE LOCATIONS AS OF APRIL 3, 1972

Figure 2.2.10.2-1

SKYLAB - ORBITAL WORKSHOP
FILM VAULT

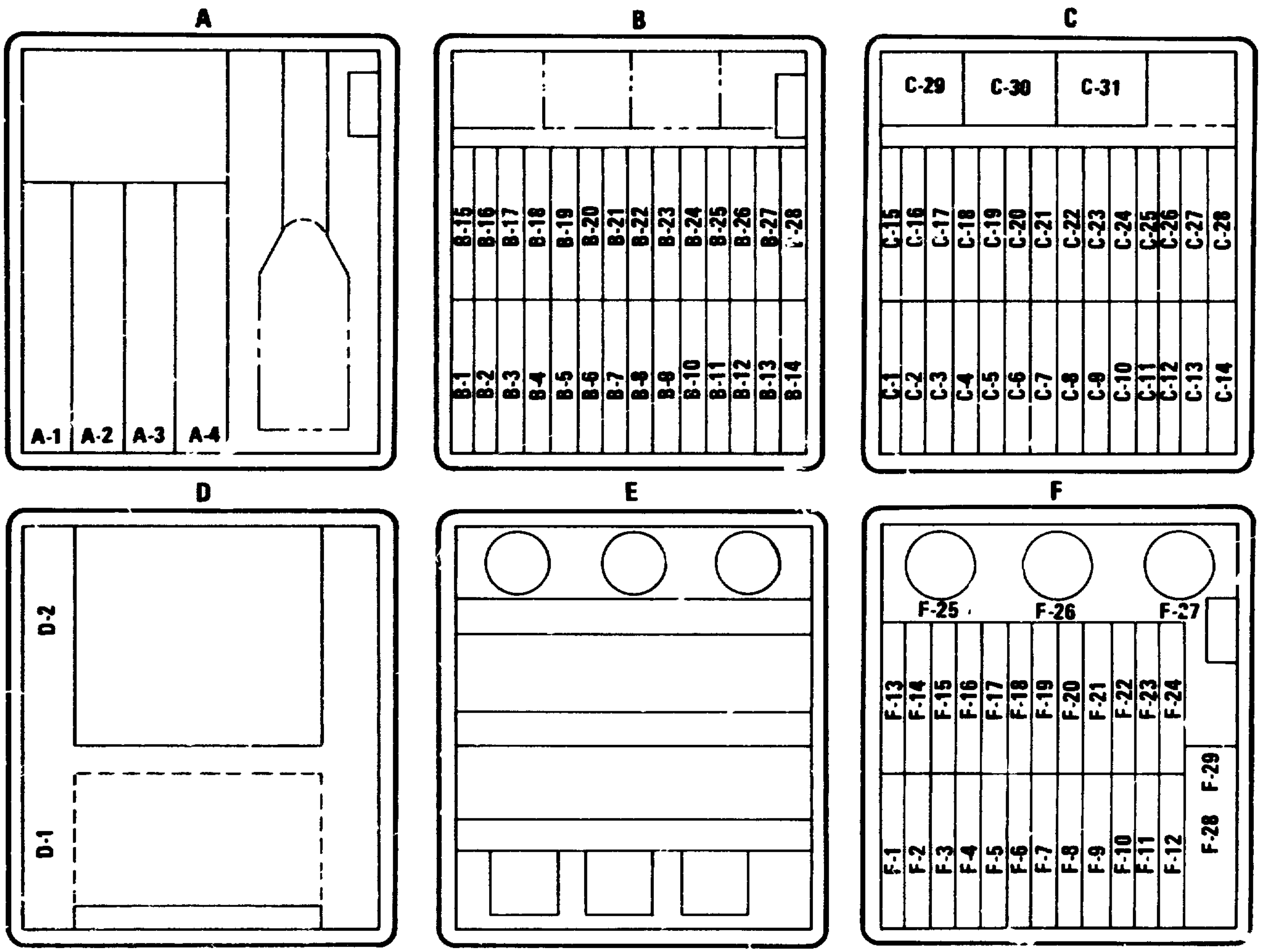


Figure 2.2.10.2-2

SKYLAB - ORBITAL WORKSHOP
FILM VAULT

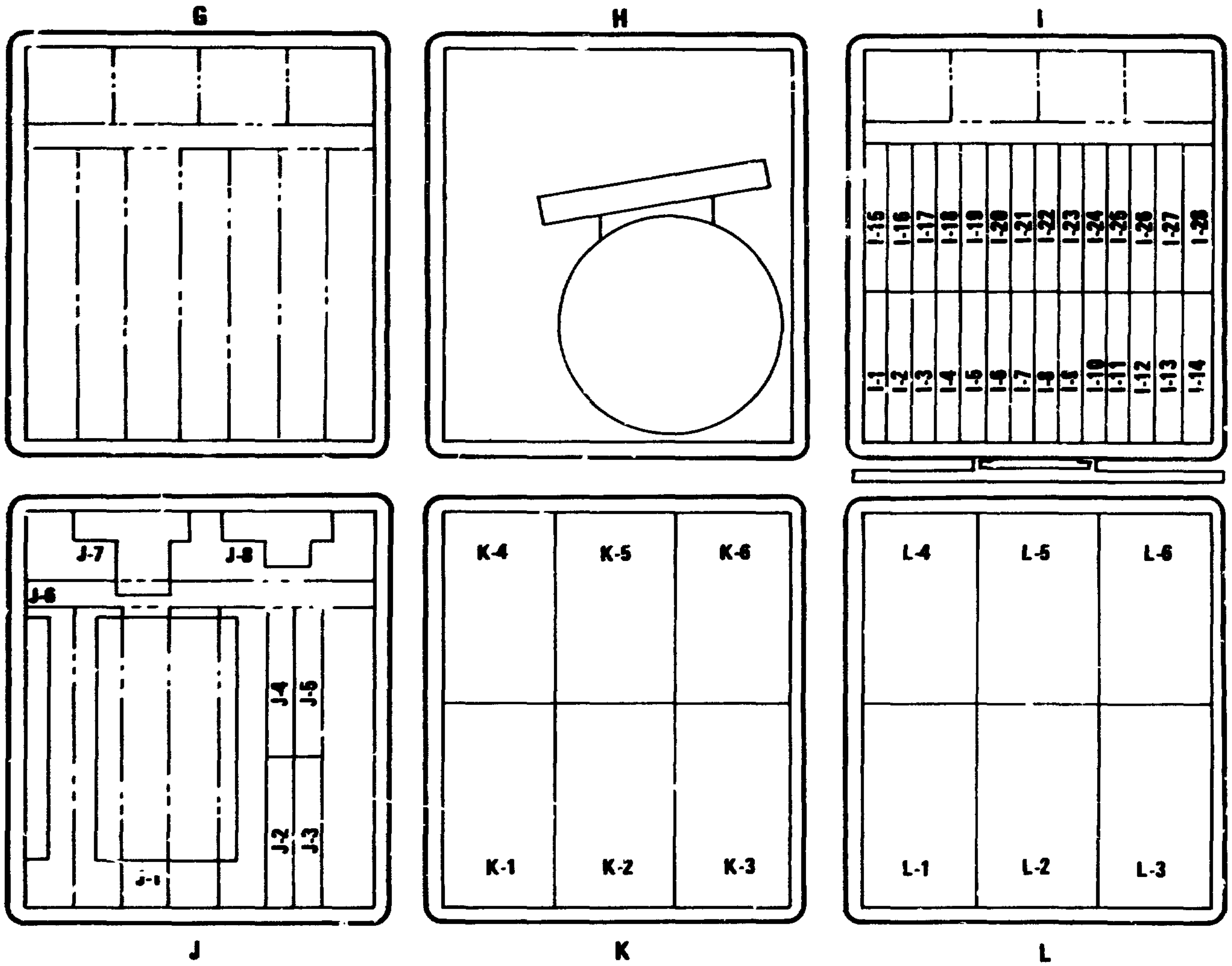


Figure 2.2.10.2-3

reconfiguration if necessary on-orbit. To accommodate launch loads, the film vault doors were bolted closed. The contents of each drawer were packed with corrugated cardboard to minimize vibration during boost.

There were no unique fabrication techniques used in the film vault. The size of the base casting [1,430 lbs (647 kg)] may be considered different, but it was definitely not unique. The doors were machined, the internal drawers were sheet metal, and the restraints within the drawers were machined teflon, as was the humidity control assembly.

Although the use of potassium-thiocynate salt pads for humidity control of film was not without precedent in space applications, the use of the fibrous teflon filter material (Zitex) to control the potentially poisonous solution was a new application. Within the humidity control assembly holders, each salt pad was sealed in a Zitex pouch. The Zitex allowed the water vapor from the salt pad to pass through with very little impedance, at the same time the Zitex retained the liquid solution. This new application resulted in a patent disclosure.

The materials selected for the film vault did not represent a contamination control problem to the rest of the OWS because they were picked for their inert qualities. The one exception was the potassium-thiocynate salt pads described in the previous paragraph. There was one slight contamination problem between the vault and the film, that is, under high humidity, high temperature, and long durations, it is possible for unfinished aluminum to contaminate or ruin film. However, the interior surface had been sealed, either with anodize, alodine, or plating, eliminating the potential source of free aluminum ions ruining the silver haloid emulsions.

C. Film Vault Testing

1/ Development Tests - There were four development tests, identified as CX7, WSTM-17, XC8, and XC11 that were associated with the film vault.

a. CX7 - Film Vault Humidity Control - This test established the humidity diffusion rate for the OWS Film Vault compared the theoretical diffusion rate that was used for designing the humidity control assembly and an actual expected rate demonstrated by the XC7 test fixture. In this test, the humidity diffusion opening with tolerances, i.e., the crack between the two doors, was simulated and the resultant, diffusion rate for the various tolerance conditions established. The results of this test showed excellent correlation between the theoretical calculation and the demonstrated diffusion rates and confirmed the design of the humidity control assemblies.

b. WSTM-17 - This test used the XC7 film vault humidity control test specimen to demonstrate that sealing the salt pads in Zitex did not adversely affect their ability to control humidity The Zitex encased salt pads controlled humidity and, therefore, allowed MDAC to seal the salt pads to control the potentially poisonous aqueous solution of potassium-thiocynate.

c. CX8 - This test demonstrated the compatibility of the materials used in the film vault with the five sensitive films to be stored in the vault. The materials for the film vault interior defined at the time all proved to be compatible with the five sensitive films. As a result of design reviews (CCSR) and potential material selection problems, it became necessary to run a second test.

d. CX11 - CX11 was the second materials compatibility test. None of the new materials presented a compatibility problem with the film.

2/ Special Tests (ST-23) - This special test qualified the film vault drawer contents to the expected vibration levels.

3/ Acceptance Test - The fit and function of the film vault was verified during stowage subsystem checkout at Huntington Beach and during film stowage at the Kennedy Space Center (KSC).

4/ Test Results - There were no waivers or deviations issued for the film vault during OWS tests.

D. Mission Results - The film vault adequately protected the majority of flight film despite the environment (excessive dry heat) encountered in the OWS interior until the crew deployed the thermal protection device. Only a few films that were extremely sensitive to heat deteriorated and were resupplied by the first crew. The humidity control assemblies performed successfully. These salt pads were recharged by the first crew and the returned films have not exhibited any humidity damage. Radiation damage on returned films for all missions was within expected limits.

The only anomaly associated with the film vault occurred in Drawer B, where some restraints were not being retained by the detent and were taped in place. Three other drawers with the same restraints performed satisfactorily.

The versatility of the film vault design was proven in that as mission planning required more and different film resupply requirements, the vault was reconfigured in orbit by the crew.

E. Conclusions and Recommendations   The OWS film vault, as used in conjunction with the Cluster Atmosphere Control System, was successful in providing temperature, humidity, and radiation protection to the over 600 lbs (272 kg) of film used for the Skylab experiments. Future programs which require protection of hardware from humidity and radiation could also successfully use the same approach of potassium-thiocynate salt pads and aluminum walls. The use of standard commercial fasteners such as a "dialatch" should be scrutinized carefully and tested thoroughly before use.

F. Development History - The film storage system began with two efforts. The first was to make accommodations, or scars, in the Workshop to accommodate a film vault and the second was to study and present to NASA a proposed design for the film vault. This resulted in a study that examined eleven different methods of film protection and selected an approach that included some eleven slabs of aluminum to be removed from the vault in order to spread out the concentrated launch loads associated with mass of the vault at the time. The initial requirements specified internal volumes and seven different protection levels specified as equivalent aluminum thickness of as thick as 7.8 inches (19.8 cm). The total vault at this time weighed 5,500 lbs (2,495 kgm). Subsequently the thickness requirements were changed to only three different thicknesses with a maximum being 3.4 inches (9.6 cm) of aluminum. Before the design was finished there was a fourth thickness added. The resulting vault weighed approximately 2,700 lbs (1225 kgm). Due to the decrease in weight, it became possible to launch the vault in one piece. About the time the vault design became reasonably firm, a requirement that had been deleted earlier because of potential complexity was re-imposed; the humidity had to be controlled between 40 and 60 percent R.H. A humidity control system was studied, proposed, and implemented into the vault design. The humidity control system involved using potassium thiocynate solution in dexter paper called salt pads. These pads act as an ambivalent desiccant; i.e., they take on water if the humidity is too high, and give up water if the humidity is too low.

A considerable effort was spent in designing an interior configuration that could be modified on-orbit without tools. The initial concept called for a series of armalon bags that would be attached to the drawers by velcro and would provide the packing control, in addition to cardboard for launch packing, to separate and maintain complete access to the individual film magazines stored in the vault. After review with the crew, it was determined that this was not acceptable and a system of m chined teflon film restraints was developed. These restraints could be inserted and removed without tools and when supplemented with cardboard would hold the contents satisfactorily during the vibration experienced during launch. During checkout of the vault, the interfaces between the machined teflon restraints and the sheet metal drawers were modified to conform with the specified tolerance so they could be interchangeable throughout the vault.

2.2.10.3 Solar Flare Notification System

A. Design Requirements - An audible alert was to be provided to the crew when a predetermined level of solar activity was present. This alert was to be audible throughout the OWS.

B. System Description - The alert signal is activated by a contact closure in the ATM and routed to the GFP supplied flare alert box located in the experiment compartment of the OWS. The power source of the signal is supplied from OWS power Bus 2 through the power distribution console (see Figure 2.2.10.3-1).

Contact closure and the subsequent flare alert signal is provided in the S054 X-Ray Spectrographic Telescope. A beryllium shielded sodium iodide crystal coupled to a photomultiplier monitors the x-ray emission from the sun and when a pre-set level is exceeded, indicating a flare activity initiates the flare alarm system. In addition to the flare alarm in the OWS, visual and audio indication is present in the AM/MDA.

C. Testing - The alert unit was tested at the OWS module level during post-manufacturing checkout at Huntington Beach and at the integrated level during the integrated test phase of the SWS cluster checkout at KSC. There were no waivers or deviations issued for the alert unit.

D. Mission Results - The alert unit in the OWS performed satisfactorily during the mission. There were no adverse crew comments regarding the alert signal.

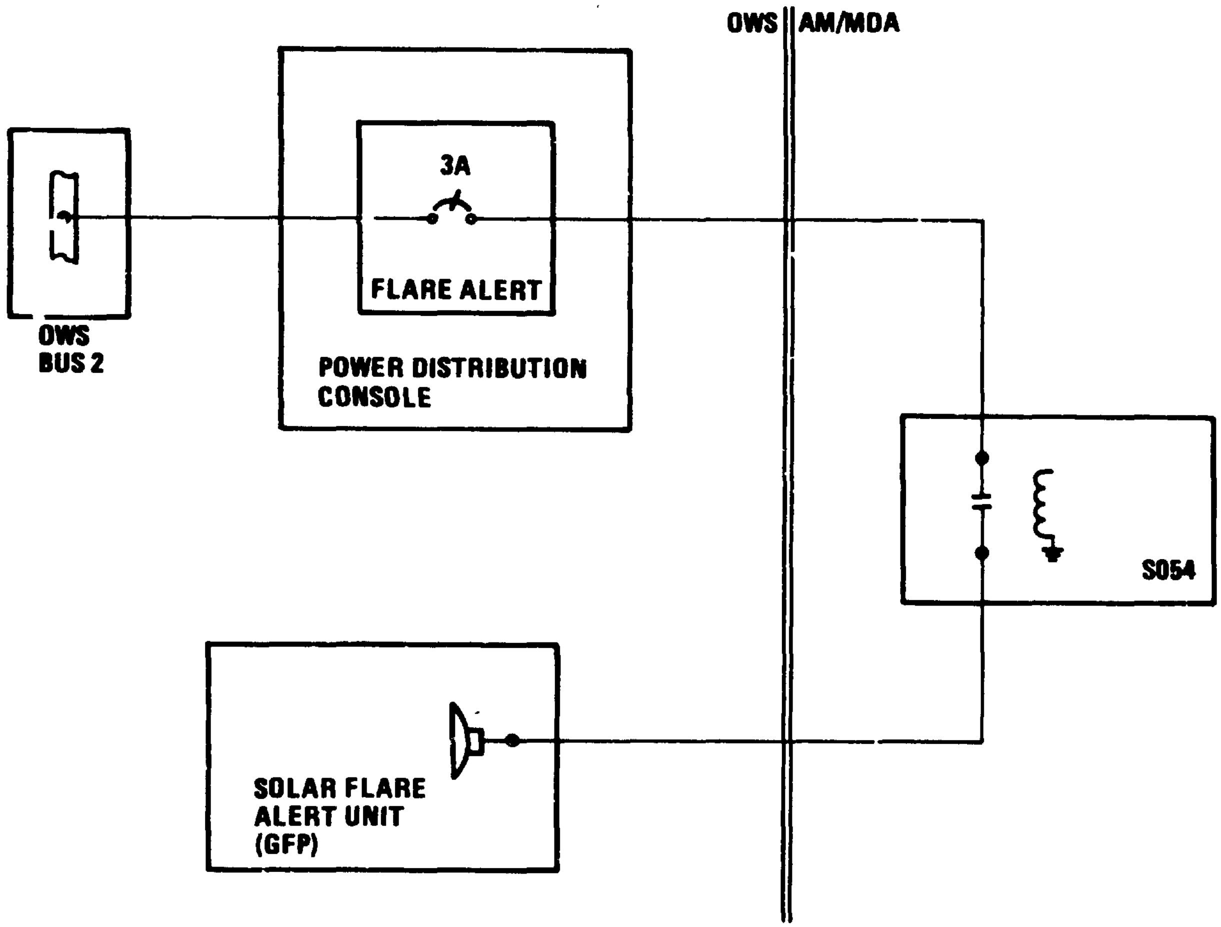


Figure 2.2.10.3-1. Solar Flare Notification System

The detector in the S054 experiment was capable of identifying the presence of a solar flare and initiating the flare alarm. However, this detector also triggered whenever the Skylab entered the radiation belt of the South Atlantic Anomaly (SAA). Instructions were provided to the crew to inhibit the detector prior to entering the SAA in order to prevent inadvertent alert indications.

E. Conclusions and Recommendations - The alert unit performed as required during ground checkout and mission operations.

F. Development History - The solar flare notification system as initially designed was flown with no modifications.

2.2.10.4 Scientific Airlocks

A. Design Requirements

1/ There were two Scientific Airlocks (SAL's) located in the OWS, one mounted on the solar side and one mounted on the anti-solar side of the spacecraft. Each experiment interfacing with the SAL was enclosed in a pressure vessel whose external flanges mated with and sealed against the inboard side of the SAL. The SAL itself was a pressure vessel sealed against the external environment by a translatable outer door. The inboard face had an opening which could be sealed by an experiment or removable plate. The outer door had to be sealed whenever an experiment or the plate was installed or removed, to isolate the OWS cabin from the external space environment. After installation, the pressure vessel became part of the SAL pressure vessel as a system and the outer door would then be opened and the experiment deployed outside the spacecraft. The internal pressure of the SAL was equalized to either the OWS cabin pressure or the external space environment by a vent (depressurization) valve. The SAL plates were stowed in a container near the SAL during boost.

2/ The two SAL's mounted to the habitation area tank walls were designed to withstand all the loads and environments associated with launch, boost, and orbital operations. During liftoff and boost, the SAL's were subjected to random vibration environments. In addition, the SAL outer door constituted an integral part of the tankage pressure seal. As such, it had to sustain a differential pressure starting with 11.3 psid (77.9 kN/m^2) (limit) at liftoff and increasing at about 120 seconds after liftoff to a maximum value of 26.0 psid (179.2 kN/m^2) (limit), which remained until orbital blowdown.

3/ On-orbit, the SAL was subjected to two different pressure conditions. The first condition existed with the outer door closed and with neither an experiment nor the plate installed. This case was identical to boost except that the limit pressure across the door was 6.0 psid (41.4 kN/m^2) maximum. The second condition existed with either the plate or an experiment installed on the SAL and the outer door open. In this case the entire SAL housing was subjected to a 6.0 psid (41.4 kN/m^2) "crush" differential pressure. In addition to pressure loading in orbit, the SAL was subjected to astronaut-applied loads in operating the outer door crank, in the installation or removal of experiments, or from physical contact of the astronaut's hand against the SAL structure. Furthermore, the SAL had to sustain any loads applied to an installed experiment and carried by the tankage wall. A summary of astronaut-applied loads was presented in Table 2.2.10.4-1.

Yield and ultimate factor of safety criteria along with the most critical load conditions were summarized in Figure 2.2.10.4-1.

Table 2.2.10.4-1

ASTRONAUT-INDUCED LIMIT LOADS ON SAL

STRUCTURE	TYPE OF LOAD	DESIGN LOAD (LB)	DIRECTION	COMMENTS
Experiment Locking and Release Handle	Concentrated at extreme tip	18.4 (81.8 N)	Any	Maximum load consistent with specific maximum operating torque of 75 in.-lb (847 N·cm) per 1B82363.
		50.0 (222 N)	Any	Maximum load that can be applied in the event the system jams. Malfunction condition.
Housing	Concentrated load applied by flat round surface with an area of 3 $\pm$ 1/4 in.^{2} (7.62 $\pm$ .64 cm^2)	125.0 (556 N)	Any	
SAL Structure with Experiment Installation	Concentrated load on 2 in. (5.08 cm) of member to be grasped. A personnel and equipment load distribution over a one square foot area.	250 (1113 N)	Any	Load applied anywhere on SAL experiment and support installation shall develop a limit bending moment to greater than 10,552 in-lb (119 kN·m) at the SAL/habitation area cylinder wall interface. Load shall be used only for design of support installation and habitation area cylinder wall at interface with SAL installation.

SKYLAB - ORBITAL WORKSHOP

SCIENTIFIC AIRLOCK (SAL)

DESIGN REQUIREMENTS SUMMARY

DESIGN CRITERIA

- STATIC OR QUASI-STATIC LOADS WHERE CAPABILITY IS VERIFIED BY TEST OR EXTENSIVE ANALYSIS
  - VEHICLE MANNED FACTOR OF SAFETY IS 1.40
  - VEHICLE UNMANNED FACTOR OF SAFETY IS 1.25
- YIELD FACTOR OF SAFETY IS 1.10
- MALFUNCTION FACTOR OF SAFETY (UNPLANNED EVENT, NOT CAUSING MISSION ABORT)
  - ULTIMATE FACTOR OF SAFETY IS 1.0
  - YIELD FACTOR OF SAFETY IS 1.0

CRITICAL DESIGN CONDITIONS

- MAXIMUM OPERATING DIFFERENTIAL PRESSURE (PRIOR TO BLOWDOWN)
- LIFTOFF RANDOM VIBRATION
- ASTRONAUT-APPLIED LOADS (NORMAL AND MALFUNCTION CONDITIONS)

Figure 2.2.10.4-1

4/ The airlock was originally designed to Project Apollo parameters, then reanalyzed for the more severe requirements of the OWS. No structural changes were required but some materials, components, and mechanisms were replaced, and several items were added.

The following considerations made design changes or operating changes necessary:

a. The loads and pressures were within the capabilities of the airlock as designed, but it was necessary to equalize pressure across the inboard cover during the launch-boost phases to prevent deformation.

b. The increased exposure to the external environment made thermal coatings necessary on both the solar and the anti-solar SAL.

c. The low temperatures on the anti-solar side made a desiccated repressurization system necessary. This system has been described in Section 2.2.10.5.

d. The requirement that certain experiments be electrically grounded and that the operating forces for locking experiments in place be minimized made redesign of the experiment latching mechanism mandatory.

e. Precise alignment of each airlock proved to be impossible because of the number of variables such as manufacturing tolerances, and deflections caused by gravity, pressure changes, and thermal stresses. Correction factors were calculated to ensure proper fit in the OWS.

f. Constraints were imposed by the interface requirements with the various experiments. Generally, the experimenters were required to conform to existing airlock configuration, but modifications were made in the experiment latching mechanism and the vacuum interface fitting to accommodate to experiment envelopes.

g. All materials were reviewed for compatibility with OWS requirements. Various plastic components and seals were replaced and paints removed to comply with offgassing and flammability specs.

B. System Description

1/ The overall system, installed per Stowage List 1B80701 and Installation Drawing 1B84513, consists of two SALs, two plate containers, two plates, two vacuum hoses, and two depressurization couplings, 1B90775-1. The components of the SAL system are composed of various aluminum alloys, corrosion-resistant steel alloys, glass, and fluorocarbon, butyl, and silicone rubbers.

2/ The two airlocks (1B83263-1 and -501) are identical except for thermal coatings. Figure 2.2.10.4-2 shows the basic airlock with vacuum fitting at the top, an experiment latching handle on the right hand side, a pressure gage at the center, and crank for opening the outer door at the lower left. The outer door waffle pattern was seen through the opening on the sealing surface on the inboard side of the airlock. An indicator mounted above the crank showed the door position relative to fully open and fully closed. A lock was provided to prevent accidental rotation of the crank. The valve on the left hand side of the airlock permitted venting the airlock cavity either overboard or to the cabin. Figure 2.2.10.4-2 shows the tank wall, the 1B79018 adapter fitting riveted to the wall, and seal plate V16-311203, which sealed the airlock to the tank wall. The experiment/plate latching mechanism was enclosed in the square tubular structure; roller dogs emerged through openings and engaged the flange of the experiment/plate, forcing the rubber seals on the flange against the airlock sealing surface.

3/ The vacuum hose 1B86940-1 was designed with one end attached to an experiment through a quick-disconnect fitting and the other end plugging into the vacuum fitting at the top of the airlock. This allowed for evacuation of the experiment, a film canister, or a stowage container.

C-6

SKYLAB - ORBITAL WORKSHOP
SCIENTIFIC AIRLOCK INSTALLATION

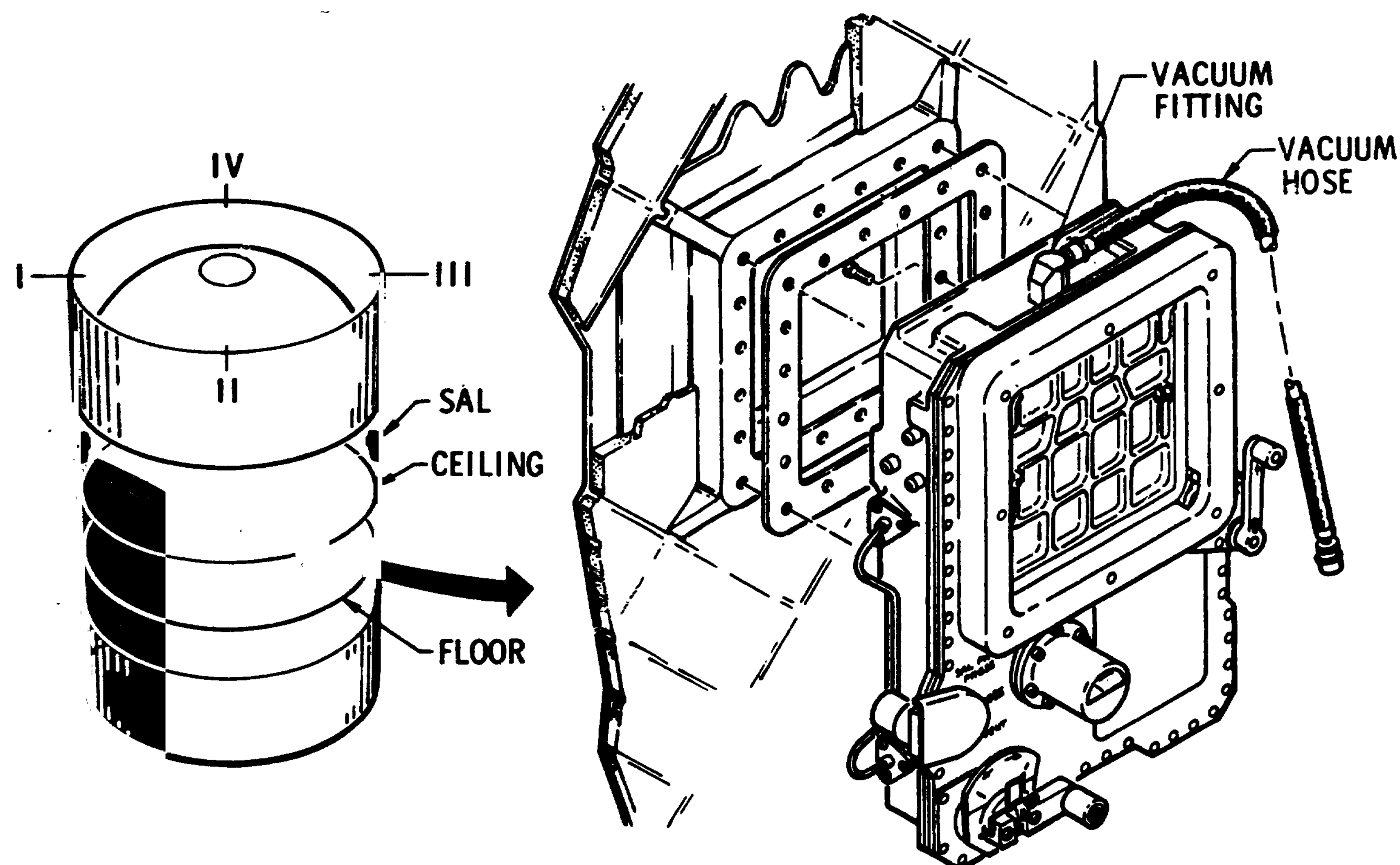


Figure 2.2.10.4-2

4/ The plates, 1B86327-1 (solar) and -501 (anti-solar), are installed in plate containers 1B83341-1 (see Figure 2.2.10.4-3). On-orbit, the launch restraint bolts were removed and the plate was installed in the airlock. It remained installed in the SAL at all times, except when an experiment was to be installed, at which time it was returned to the plate container and kept there until the experiment is removed.

5/ The depressurization coupling, 1B90775-1 was mounted on the side of each plate container. It mated with the male quick-disconnect on an experiment or film canister and was used to repressurize the container to cabin atmosphere.

6/ The airlocks and window containers are installed at Position Planes I and III, in the area from Station 445 to Station 490.

7/ The airlock interfaces with the tank wall through the 1B79018 adapter fitting which is installed on the tank wall per 1B79019 installation drawing.

C. Testing

1/ Phase 1 development testing consisted of the following:

- o Determine the load-deflection characteristics of a typical experiment flange seal, using a double Viton seal, a single Viton seal and a double Butyl seal.

ORBITAL WORKSHOP
SAL WINDOW CONTAINER

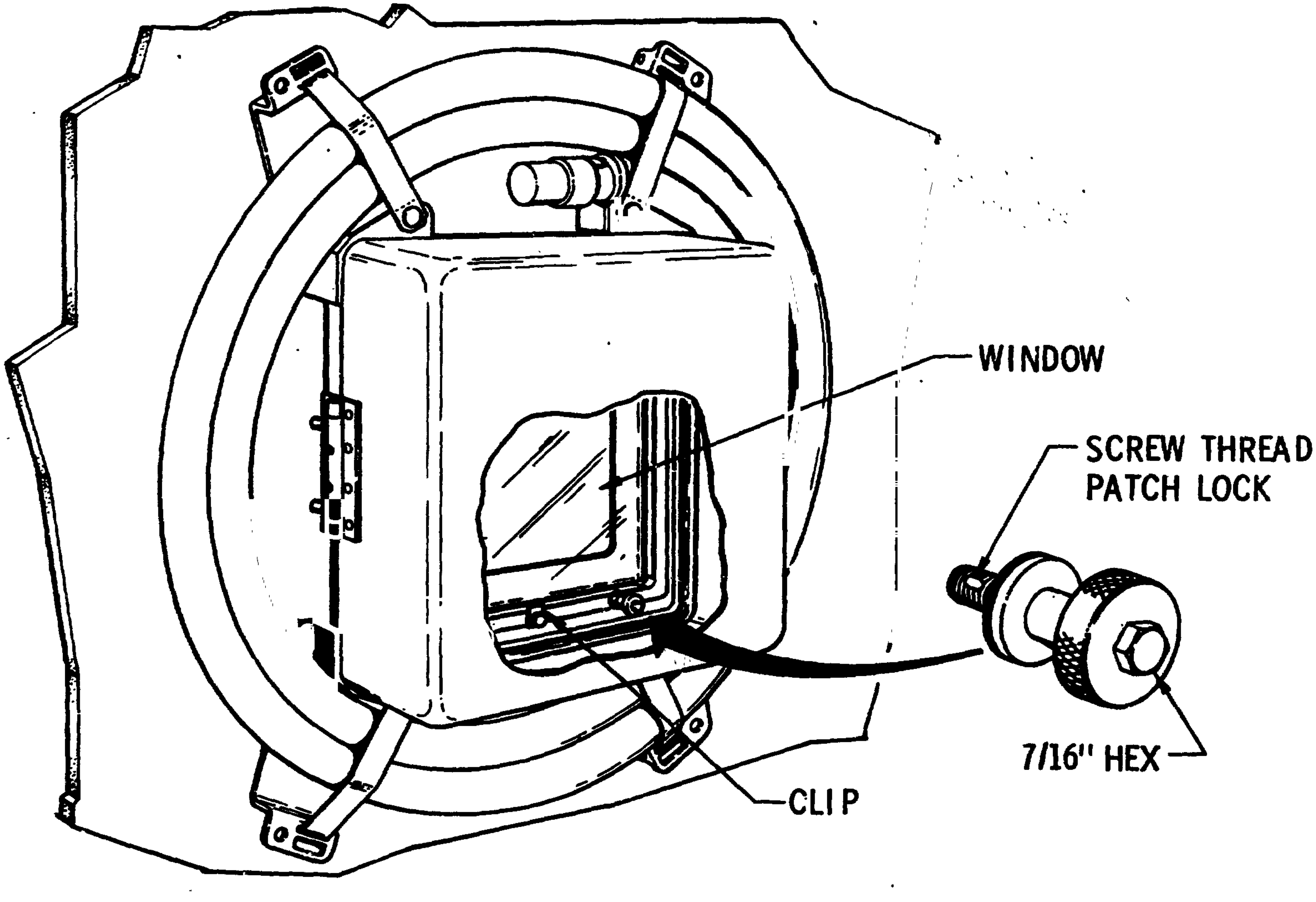


Figure 2.2.10.4-3

- o Determine SAL experiment latching force versus experiment flange seal deflection for Viton rubber and for Butyl rubber.

- o Determine from the available design data whether the latching mechanism, as designed by Rockwell International, could be made adequate for use with double Viton seals, and whether metal-to-metal contact for a good electrical bond could be achieved.

2/ Phase 1 development tests showed that obtaining a good leakage seal required very little force, but metal-to-metal contact between the experiment flange and the SAL could not be achieved by the existing roller method. Therefore, a program was instituted to provide a low friction type of experiment latching mechanism similar to that used on Experiment S019. The new mechanism was installed and tested as part of the Phase 2 development test program.

3/ It should be noted to clarify the test program that the original SAL design included a SAL window consisting of two glass panes in a frame separated by a cavity between the two glass panes in the window assembly pressurized to 14.7 psia (101.3 kN/m^2). However, during the Design Certification Review, MDAC was directed to replace the window with an aluminum plate using the same frame. The plate eliminated the possibility of viewing through the SAL but still provided redundancy on the outer door when experiments were not installed in the SAL. Since this change was introduced late in the program, the development testing was performed on the window configuration. No additional testing was required for the plates beyond production acceptance testing since the units were identical except for the plates replacing the glass panes. Therefore, during the test program, references have been made to "window" testing, even though the final design configuration consisted of plates instead.

4/ Phase 2 development testing consisted of the following:

- o Proof pressure tests at pressures which could occur during checkout, boost, and on-orbit.

- o Functional tests of the window latching mechanism, pressure control valve function, valve cover function, door opening and closing and indicator function, pressure gage function and accuracy, and hose coupling and uncoupling.

- o Leakage tests at ambient temperature, with 5 psi (34.5 kN/m^2) differential pressure at both atmospheric pressure and 5 psi (34.5 kN/m^2) absolute. This included component leakage where possible, and total leakage of the airlock-window-outer door combinations. A separate test of vacuum hose leakage was conducted.

- o Vibration test of the seal and the window and window container in the launch configuration per DAC-56620B.

- o Post-vibration functional and leakage test to determine any changes caused by launch forces.

- Thermal-vacuum tests, first simulating the effect of cyclic solar radiation on the SAL having solar thermal coatings. After this test was completed, the SAL was recoated with the anti-solar thermal coatings and re-tested in a simulated cyclic dark side environment.

- Tests were run with outer door open, and with outer door closed for each environment. Temperature measurements were made at various points on the tank wall, SAL, and window.

- In the experiment evacuation through SAL using the vacuum hose, one end of the hose was plugged into a 2.4-ft^3 (0.68 m^3) experiment filled with air at 5 psia (34.5 kN/m^2) and the other end into the SAL quick-disconnect. The SAL door was in the vent position at a 1×10^{-3} torr (0.133 N) vacuum.

- The endurance test consisted of operating the SAL through 1,000 pressurization-depressurization cycles at 5 psi (34.5 kN/m^2) differential pressure (14.7 to 9.7) (101.3 to 66.9 kN/m^2). This provided 1,000 cycles on the outer door crank, the experiment latching mechanism, the vent valve, and the pressure gage.

- Test leakage after 1,000 cycles were completed.

- For the cantilever beam test, loads of 0 to 125 lb (556 N) were applied at a moment arm of 60 in. (152.4 cm) at 5-psid (34.5 kN/m^2) differential pressure. Leakage was measured during test.

- For the yield pressure test, 9.9 psia (68.3 kN/m^2) were applied inside the SAL chamber. Leakage was tested at 5 psid (34.5 kN/m^2) afterward.

- For the ultimate pressure test, 32 psid (220 kN/m^2) were applied across the outer door, and 12 psid (82.7 kN/m^2) inside the SAL chamber and across the plate.

4/ The Phase 2 development tests showed several problem areas. In the vibration tests the following problems occurred.

- One screw in the airlock mechanism came out and its shim was broken.

- One mounting screw on the window container came out and another was loosened.

- One of the launch "retainers" for the window was broken and another was loosened.

- A thread insert loosened.

These problems were resolved in the following manner:

- The airlock mechanism was properly shimmed, and the screw reinstalled.

- The lugs on the window container were remachined to make the mounting surfaces parallel to the "patches" on the tank wall segment.

- A metal washer with a soft pad was designed to fit under each "retainer" so that the retainer could be torqued to higher values.

- The loosened thread insert was removed and another installed.

The SAL and window container were retested. After the window retainers were tightened to 60 in-lb (678 N·cm) torque, all components passed the vibration test without incident and were considered structurally adequate for launch.

In the proof and leak tests, the proof tests demonstrated that the scientific airlock could withstand all pressures and loads that it would be subjected to including a 125-lb (56.7 kg) astronaut load exerted (at a 60-in. (152.4 cm) moment arm) on an experiment mounted in the airlock without any significant leakage.

The viewing window survived pressures well in excess of any flight requirement.

The thermal-vacuum tests showed that the inside surfaces of the SAL would remain well within touch temperature limits during flight.

In the functional tests and endurance tests, examination prior to test showed that the experiment latching mechanism did not meet the electrical bonding requirement because the Belleville washers providing the sealing force had been assembled incorrectly. A representative of the manufacturer reassembled the unit properly so that it would exert enough force to produce metal-to-metal contact, and agreed to make sure that this was done on all future units.

During endurance testing, several problems appeared.

- The detent that holds the vent valve in position became sticky at approximately 72 cycles, and again at 104 cycles. At 740 cycles, the pin holding the detent cam on the valve stem sheared off. The pin was pushed back in, and the test continued to 1,000 cycles. (This was a failure of the detent, not of the valve.) When the test was complete, a small amount of oil was applied to the detent. The stickiness immediately disappeared, and the valve operated smoothly again. Disassembly showed that the problem was galling of stainless steel on stainless steel; this caused a burr to be thrown up which interfered with smooth operation. The flight parts have been lubricated to prevent recurrence of this phenomenon.

- Seven of the eight roller shafts on the experiment latching mechanism showed a tendency to work out of the pivot housing. This happened continually after about 500 cycles. By design, they were to be held in place by set screw friction. Although the set screws remained tight, they did not restrain the shafts sufficiently. This was not a serious problem, since the roller could be pushed back into place. The vendor agreed to eliminate the problem for the flight units by machining a depression in the roller shaft so that the set screw would engage it to produce a positive lock.

5/ The flight unit of the SAL is identical to the test unit except in the following details:

a. The "Micatex" paint on the exterior airlock surfaces and the markings were not on the test unit.

b. The vacuum hose stowage clips were not on the airlock, the hose stowage location was on the window container.

c. The windows on the flight unit include a shim designed to compensate for manufacturing tolerances and permit the proper seal preload.

6/ Qualification tests were not applicable. The SAL was previously flight qualified by Rockwell International testing.

7/ No waivers or deviations were required for the SAL.

D. Mission Results - There were no anomalies of the SAL reported during the three missions. During all crew debriefings, the Skylab crews stated that the SAL's performed flawlessly.

E. Conclusions and Recommendations - MDAC was successful in adapting a previously designed Apollo airlock to meet all the objectives of the Skylab Program. In regards to things to be done differently in future missions, the Skylab crew has recommended that two SAL's are not sufficient and consideration should be given to having more on any future spacecraft.

F. Development History

1/ The scientific airlocks were provided as GFP items to the OWS Program.

2/ Modifications were required to insure compatibility with the OWS and the experiments. All materials that were to be exposed to the habitation environment which did not meet type 1 flammability requirements of MSFC-SPEC-101A were replaced in order to protect the experiments. An indicator was provided to show outer door/closed position. Gauges and indicators were modified to provide protection from lens breakage.

The handle assembly of the experiment canister latching mechanism and the roller mechanism were redesigned to limit the force required to provide metal-to-metal contact of the faying surfaces. A common vacuum interface was provided for the venting of the experiments.

2.2.10.5 SAL Repressurization Subsystem

A. Design Requirements

1/ The SAL repressurization subsystem was designed to prevent condensation from forming on experiment hardware during their removal from the anti-solar side SAL. The repressurization subsystem also prevented contamination of certain experiments which had minute openings that could be clogged by foreign particles. On the anti-solar side SAL, the repressurization subsystem utilized dry gas and consisted of a desiccant canister, filter assembly, flex hoses, valve and tube assembly as shown in Figure 2.2.10.5-1. On the solar side, the subsystem consisted of a filter assembly, flex hoses, valve, and tube assembly as shown in Figure 2.2.10.5-2. Failure of any component did not preclude operation of the SAL's. Any part can be disconnected or bypassed.

2/ The repressurization subsystem was designed to withstand the random and sinusoidal vibration environments at liftoff and boost which are represented in Table 2.2.10.5-1.

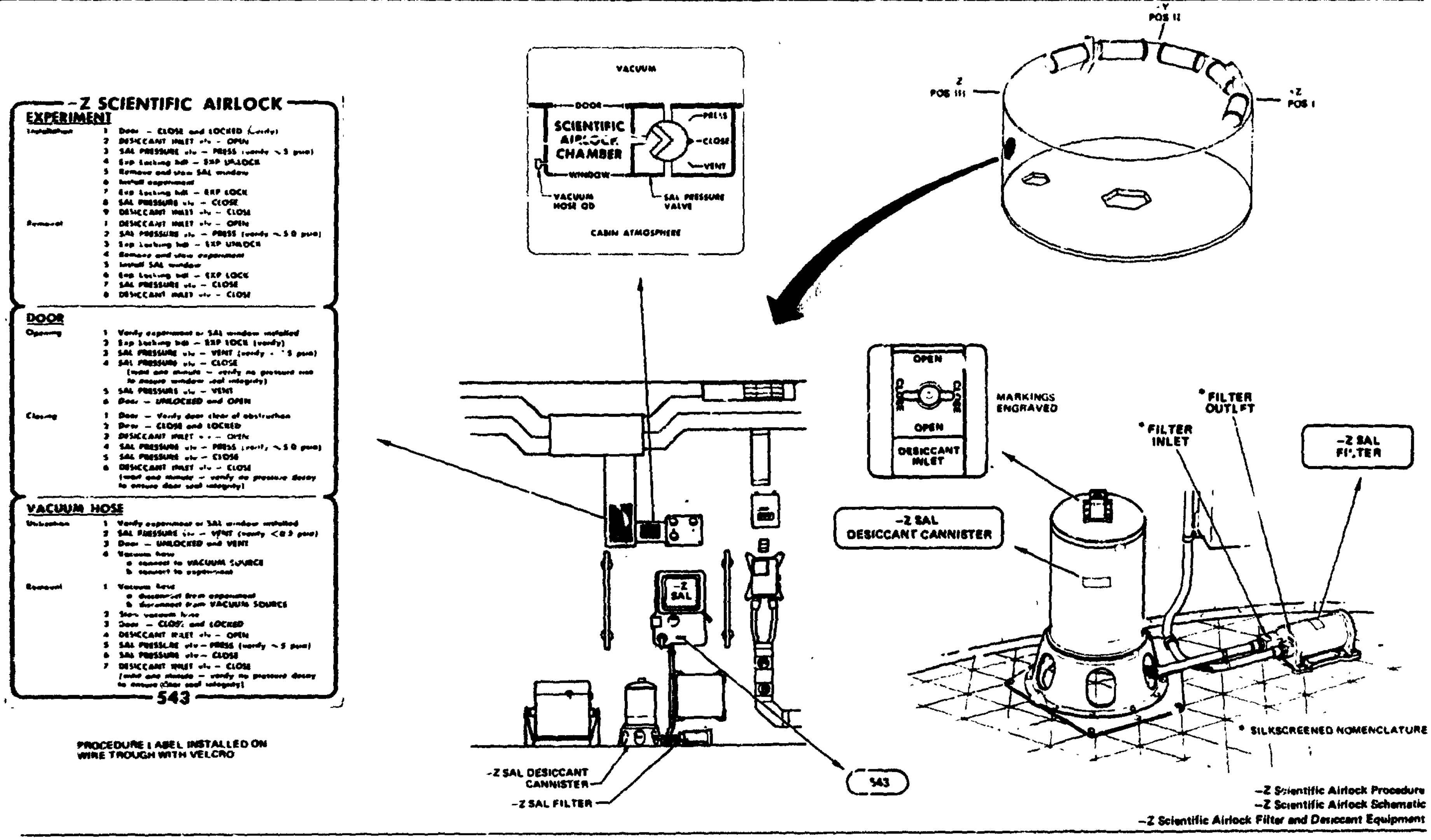


Figure 2.2.10.5-1

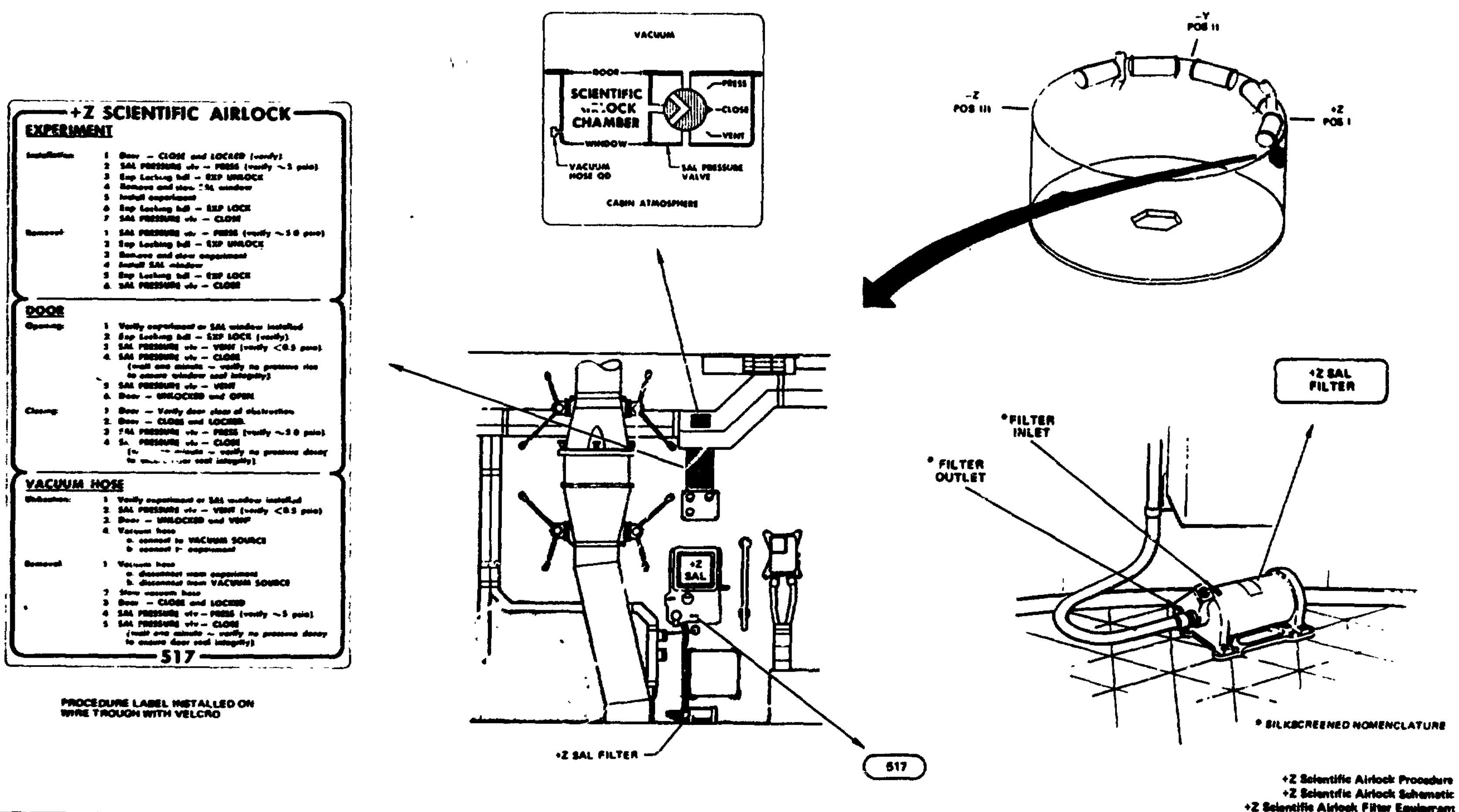


Figure 2.2.10.5-2

Table 2.2.10.5-1

RANDOM AND SINUSOIDAL VIBRATION LOAD FACTORS (LIMIT) AT LIFTOFF AND BOOST

Direction		
Thrust	Radial	Tangential
20 g's	20 g's	20 g's

During liftoff and boost, a crush-type differential pressure of 11.3 psid (77.9k N/m^2) (limit) occurred across the subsystem. The effects of this differential pressure were superimposed on vibration loads. The subsystem was also designed for a burst-type pressure differential of 14.3 psid (98.6k N/m^2) which occurred during the on-orbit blowdown period. No vibration occurred during this period.

An astronaut applied load of 125 lbs (56.7kg) (limit) was used for on-orbit conditions. The 125 lbs (56.7kg) was applied over a 3 in^2 ($19cm^2$) area.

Factors of safety used for design were:

- Random and sinusoidal vibrations only

  Ultimate factor of safety is 1.40

  Yield factor of safety is 1.10

- Interaction of random and sinusoidal vibrations and pressure

  Ultimate factor of safety is 1.40

  Yield factor of safety is 1.10

- Pressure only, for production acceptance

  Ultimate factor of safety is 2.50

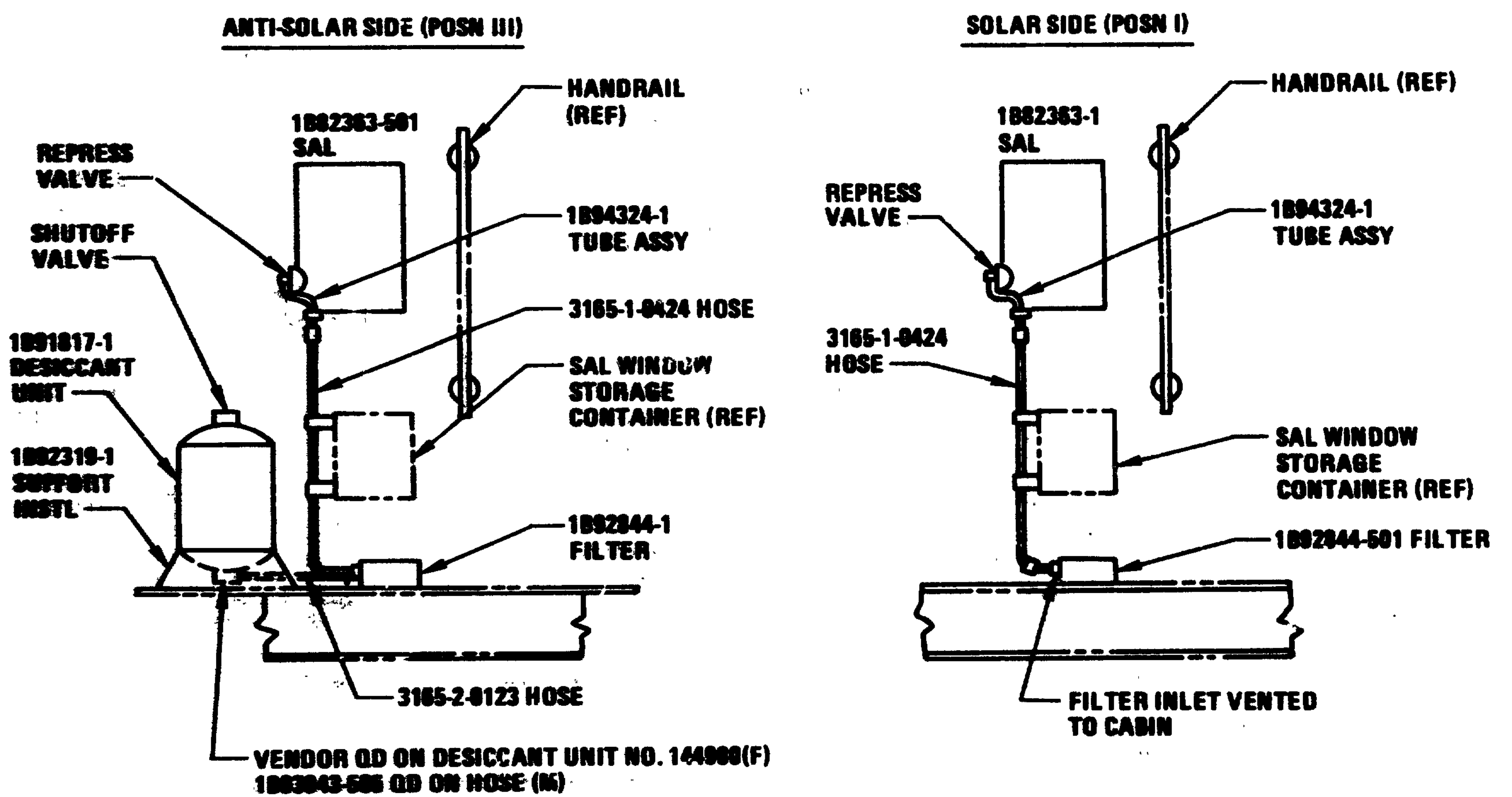
  Yield factor of safety is 1.65

3/ The main functions of the repressurization system were to desiccate the air entering the anti-solar SAL to minus 50°F (10°C) dewpoint or lower and to filter the air entering both anti-solar and solar SAL's to 3 microns absolute. The system was connected to the inlet port on the SAL repressurization valve. Mating parts were sized to permit interconnection so that the SAL could always be operated. For example, if the filter at the anti-solar SAL were plugged, the desiccant unit outlet hose could be connected to the filter outlet hose. This was strictly an emergency type operation. The inlet valve on the desiccant unit would be closed at all times when not in use. To minimize interference with astronaut accessibility to the SAL's, the filters were located under the SAL plate containers. Also, the desiccant units were mounted on the floor as close as possible to the habitation area tank wall to minimize any interference with crew movement.

Relative movement between the repressurization system mounted on the floor and the habitation area tank was accommodated by means of flex hoses.

B. System Description

1/ The anti-solar SAL repressurization subsystem consisted mainly of a desiccant unit (1B91817-1) and filter assembly (1B92844-1) which were connected by a convoluted CRES hose (3165-0123). A hose (3165-1-0424) lead from the filter outlet to a CRES tube assembly (1B94324-1), mounted on the SAL body, and the SAL repressurization valve. Refer to Figure 2.2.10.5-3.



NOTE: DESICCANT/FILTER SUBSYSTEM LAUNCHED IN OPERATING CONFIGURATION

NOTE: HOSE & FILTER WILL BE LAUNCHED IN OPERATING POSITION

Figure 2.2.10.5-3. SAL Repressurization Subsystems

Figure 2.2.10.5-3

The solar SAL repressurization subsystem consisted mainly of a filter assembly (1B92844-501) which was connected in a similar manner to the tube assembly (1B94324-1) and repressurization valve on the SAL body as shown in Figure 2.2.10.5-3. The outlet of each repressurization system connected to the inlet port on the SAL pressurization valve.

2/ The major components of the SAL repressurization system were as follows:

- Desiccant Unit (1B91817-1)

  The desiccant unit consisted of a cylindrical canister made of welded aluminum construction. The unit was filled with Linde 13X molecular sieve and was preloaded by a spring-loaded system to prevent channelling. Filters were located at the inlet and outlet to prevent particles from escaping. An inlet valve and an outlet quick-disconnect maintained the unit in an air-tight condition when not in use. The quick-disconnect would not be disconnected once it was installed.

- Filter Assembly (1B92844-1, -501)

  The filter consisted of a filtering element and a housing, both of which were made from stainless steel.

C. Testing

1/ This subsystem was tested under Line Item XC-9. The objective of the development test program was to verify that the desiccant unit and filter assembly were suitable for operation with the SAL experiments.

The test program was conducted as follows:

- Functional test of Specimen No. 1 at 5 psia (34.5K $N/_m2$) or 5 psid (34.5K $N/_m2$) to flow at 3 ft^3 (.085m^3) for each 100 cycles to show that the desiccant bed discharge would consistently have a ≤ minus 50°F (10°C) dewpoint. Functional test of the filter was performed. Dry bulb temperature shall be 65°F (18.3°C) to 80°F (25.7°C).

- Proof and burst tests of the canister would verify its structural capability to withstand OWS environment.
- Leakage test would verify that the desiccant unit leakage was within requirements.
- Vibration test would verify that the components were structurally sound and that the desiccant bed had not deteriorated.
- Flow versus pressure drop would be determined during the functional testing of the desiccant unit and the filter individually and the combined solar and anti-solar subsystems.
- Response time testing would determine whether the time to repressurize the SAL was satisfactory with either subsystem.
- Desiccant bed density would determine that the density remained uniform and that channelling had not occurred during cycling or vibration.

2/ There were no significant problems encountered during the SAL pressurization system test program.

3/ There were no waivers or deviations required for the system.

D. Mission Results

1/ During Mission SL-3, the SAL door was inadvertently left open for an extended period, with the SAL desiccant system hooked up. MDAC analysis resulted in the conclusion that this operation had no deleterious effects on the operation of the system. In addition, a vapor plume appeared at the wardroom window. Analysis of the formation of the plume concluded that it was the result of wardroom window vent plug leakage, and was not caused by any anomaly of the SAL desiccant system.

E. Conclusions and Recommendations - The SAL repressurization system has worked per specified performance throughout the three missions. It has performed its function of preventing condensation from forming on experiment hardware.

F. Development History - The SAL repressurization system was necessitated because those experimenters with hardware containing critical optical surfaces were concerned that the optics would become contaminated if the experiments were repressurized with OWS cabin atmosphere. It was determined that this contamination could be eliminated if either a long term experiment warmup period would be planned during each use or if a desiccant/filter system was used in line with the cabin atmosphere. Since the long term warmup period could not be tolerated by the flight planners, it was decided to incorporate a desiccant/filter system.

The system as initially designed was flown with no modifications.

APPROVAL

MSFC SKYLAB ORBITAL WORKSHOP

FINAL TECHNICAL REPORT

Orbital Workshop Project

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

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

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